ACTION THEORY AND COGNITIVE PSYCHOLOGY IN INDUSTRIAL DESIGN: USER MODELS AND USER INTERFACES

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To my father Xinkai Li and my mother Shufen Lei.

CONTENTS

INTRODUCTION

1. User Models

As a kind of action, industrial design emerged at the very beginning of the Industrial Revolution. Its starting point was and still is the understanding of human nature, or the human model, or the user model. The model explains how people desire and how people behave. Such explanation was and is the foundation of industrial design. Up to now, there are two groups of user models in industrial design: the models based on behaviorism from the beginning of the 20th century, and the user models which include the action model (task models) based on action theory and the mental model based on cognitive psychology from 1970´s.

2. The Stimulus-Response Model

Behaviorism has studied and predicted successfully stimulus-response phenomena. Behaviorists describe the behavior of organism as a function of the states of environment (as stimuli). It is assumed that stimuli and responses can be described externally. Only observable and measurable behavior is taken as the study object because consciousness, mind, hope, emotion can only be understood through self-observation. Behaviorism especially concentrated on learned and unlearned association between situation (or stimulus) and reflex, reaction, i.e., organism was adapted to external demands or inner state of demands, upon which organism reacted with learned or unlearned behavioral ways (reaction chain). Behaviorism built the following conceptions about the human (Müller, 1989):

(1) behavior is seen as the result of a causal chain which is set up through current and past stimuli in the course;
(2) behavior is seen as dependent variable upon the factors which affect the organism from outside, and the behavior is determined completely through the environment;
(3) the organism has no dynamics of its own, but responds first to external affected force in a determined type.

This view in design builds such relationship between humans and artifacts that artifacts and the environment are the active side and humans are the passive side. Such stimulus-response (S-R) language of behavioral psychology was used as a description of human behavior (Figure 0-1). Physical aspect of human behavior was understood mainly as mechanical sensorimotor movement. People should respond rationally, correctly, skillfully and quickly without thinking. Designers´ concern was: "What does the operator have to perceive? What does he or she have to decide? What control operations must the person perform? Are equipment and system characteristics such that the human component can sense, discriminate, decide, and manipulate as required to accomplish system functions?" (Meister and Rabideau, 1965). The nervous system is conceived of as an inert switchboard with no power of initiating action and no spontaneity. (Ryan and Smith, 1954).

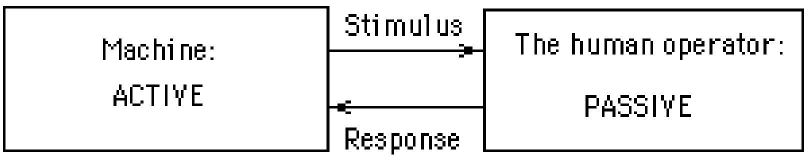

Figure 0-1: The relationship between the human and machine on behaviorism.

3. Action Theory and User Task Models

“Under action theory, we understand in general all those theories that have as their model human beings (themselves), as potentially reflexive (able to think of themselves as being in a situation) and as acting intentionally with reference to the environment" (Eckensberger and Silbereisen, 1980, p.24). Action theory was known originally as will psychology in Germany which was founded by Wilhelm Wundt (1832-1920). Will action was Wundt´s central subject, and he emphasized and distinguished between motivation and volition of human behavior (1894, 1907). Ernst Meumann (1862-1915), Wundt´s student, asserts:

> Der Wille ist nichts anderes als ein spezifischer Verlauf intellektueller Vorgänge, durch die sich unsere Zustimmung zu einem Ziele in Handlung umsetzt und mit denen das intellektuelle Seelenleben aus seiner reinen Innerlichkeit zur Einwirkung auf die Umgebung heraustritt. (Meumann, 1908, 1913)

In this direction, Narziß Ach (1871-1946), Oskar Külpe (1893), H. Münsterberg (1888), Hermann Ebbinghaus (1902), Otto Selz (1910), A. Hillgruber (1912), H. Düker (1931, 1957), Tolman (1932) and Lewin (1935) all conceived of such goal-directed action as the fundamental concept of psychology. In 1923 J. Lindworsky (1875-1939) collected the research achievement on will study in Germany in his book "Der Wille: Seine Erscheinung und seine Beherrschung." Since 1960, many researchers have again focused on the research of action theory. Action theory investigates the course of human action, including motivation, intention, plan, etc. Some psychologists create the user action models (or called task models) mainly in the field of the design of human-computer interface. Such models tell how humans act. However, industrial design lacks a systematical study on the user action toward or with various artifacts.

4. Cognitive Psychology and User Mental Models

In 1970´s cognitive psychology (and cognitive science) were founded in USA. Cognition refers "knowing" and "thinking." Cognition involves every mental processes and structures that can be described as an experience of knowing (or as mental information processing) as distinguished from other experiences or processes of consciousness such as feeling and willing. Cognitive psychology deals with human perception, learning, remembering, thinking (reasoning) about information, which relate to language, concept formation, planning etc., and also includes decision-making and problem-solving in the wide sense. "A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself, and the process of cognition is the actual (inductive) acting or behaving in this domain." (Maturana, 1970, p. 13). Recently, because of studying human mental work, many cognitivists consider humans as cognitive systems. For Maturana, "living systems are cognitive systems, and living, as a process, is a process of cognition." (Maturana, 1970b, p. 8). Cognitive psychology is to study the mind, and is concerned with the acquisition and use of knowledge, and with the mental structures and processes. Another related field is cognitive science. Cognitive science is a multi-disciplinary science, which embraces philosophy, anthropology, cognitive psychology, psychobiology, linguistics, and artificial intelligence, as means of understanding cognition. Cognitive science is interested in constructing computational models to enhance the knowledge of human cognition, and artificial intelligence. Cognitive psychology and science are currently emphasized in the fields of design because of the fact that the application of computers and information processing become more and more important, and design problems of human action to artifacts changes from the perceptual-motor performance into the cognitive aspect. Based on cognitive psychology, various user mental models in the human-computer interaction design are established. Such models tell how humans perceive, think, understand, communicate, and so on. Again, industrial design still needs various mental models for the design of various artifacts.

5. The Tradition of Rationality

Action theory and cognitive psychology provide a new view on the human in industrial design. Action theory provides the rationalistic models of human action. These action models describe the correct and successful way of action. Ideas about rationality also have significance for cognitive psychology. It starts with the assumption that humans perceive and think rationally, and that humans use language to communicate rationally. This way, cognitive psychology provides also correct and rationalistic way of perceptual and cognitive processes. Winograd and Flores (1986, p. 8) have labeled this tradition as the "rationalistic tradition." The rationalistic tradition means a narrow view focused on some aspects, which is not rational if viewed in a wider perspective. This rationalistic orientation is described by Winograd and Flores in a series of steps:

1. Characterize the situation in terms of identifiable objects with well-defined properties.
2. Find general rules that apply to situations in terms of those objects and properties.
3. Apply the rules logically to the situation of concern, drawing conclusions about what should be done.

Winograd and Flores assert that there is a close correlation between the rationalistic tradition and the approach of science. The scientific research frequently concentrates on finding and representing regularities and rules in observed phenomena by setting up models. The common way is to take observable phenomena as start points to outline systems with boundary conditions and to find variables in the systems with certain simplification. The final models can be used to explain the relationships among the variables in the systems and to predict. However, one should not forget in which way and on which view of point the models are built: (1) various models may be built on various philosophical backgrounds, on different observation perspectives; (2) simplification of variables and relationships make the theoretic models different from the real phenomena to certain extent; (2) the simplification and the boundary conditions limit the application of the models, (3) theories and methods which are applied to the models have also boundary conditions and prediction limitations. The rationalistic orientation just forget these.

Some of the rationalistic tradition appeared to lead to machine-centered, or artifact-centered design, as the contrast to human-centered design. Technical way of thinking, technical terms of machine-oriented model of human performance, reaction speed, reliability and accuracy are employed to describe operator´s behavior. The concept of effort was completely overlooked by many psychologists in industry. It was assumed that it could be completely solved by equating effort with the physical energy consumed in doing the work. Efficiency was either identified with output alone, or it was restricted to the concept of mechanical efficiency — the ratio of output to the physical energy used in doing the work (Ryan and Smith, 1954). The goal of this design emphasized the productivity and efficiency. Human operators in a machine system were regarded as a function component of input to machines with psychological and mechanical limitations. Designers had to allocate functions between the operator and the machine in such a way that those human limitations were not exceeded.

7. My goal and attempts

My view is human-centered design. My goal is to study methods for usability design. What I intend to do is to build theoretical methods of action analysis. Standing for users´ action, designers should view user´s action to artifacts as a psychological system. My approaches involve the followings:

- theories in industrial design. Based on action theory and cognitive psychology, one can understanding user´s action To understand human action. I will systematically study action theory and cognitive psychology, and apply these to artifacts, discover user´s needs and respond to the needs of users, rather than relying on mathematical analysis, on marketing research methods, and on what users say they do.
- To build the user model. The user model is the central point and starting point of industrial design. The user model consists of the mental model and the action model (or called the task model). I will systematically study the mental model on cognitive psychology, and the action model on action theory of psychology.
- Up to now, most of user models are mainly the rational models. That is, these models only describe the correct and successful courses of action. However, human action also has the irrational aspect. I will systematically study the rational and the irrational aspect of human action to artifacts.
- Action systems will be defined for every kind of user´s action to artifacts, and all elements in the action systems which influence users´ action will be investigated.
- For usability design, the user-artifact interface is the key concept. Various user-artifact interfaces will be established systematically.
- Felicity conditions for user´s action to artifacts and action guidances will be established.
- The concept of information will be studied.
- Users´ learning processing, errors in action, and their errors caused by design will be studied and employed for design.

8.Contents

Chapter 1 deals with the characteristics of main components of human action.
Chapter 2 introduces various types of action control in the practical sense.
Chapter 3 introduces the action system and action interfaces as the theoretic basis for usability design.
Chapter 4 discusses about several specific issues in industrial design.

9. Acknowledgement

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CHAPTER 1: MOTIVATION AND ACTION COMPONENTS

SECTION 1.1: USER´S ACTION

1.1.1. The Concept of Action

Human action is the basic concept and startpoint of usability design. Cranach et al (1980) define action as "goal-directed, conscious, planned and intended behavior of an actor." Shortly, action can be defined as goal-directed behavior, i.e. goal plus behavior. Action theory always emphasizes the term "goal" in human behavior. Human action in the sense of industrial design refers to users´ goal-directed behavior with artifacts or toward artifacts.

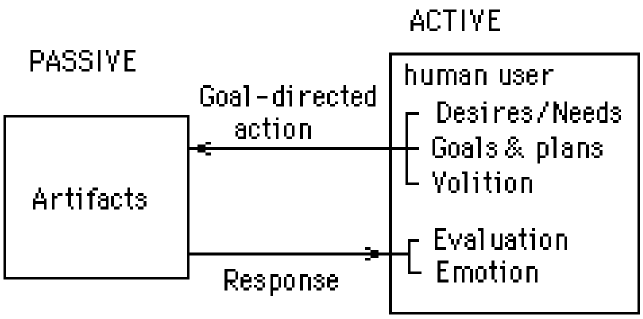


Figure 1.1-1: The relationship between object and user on action theory.

- An action starts from a motivational state. Artifacts which users need reflect cultural factors and social factors. From needs, values, desires and beliefs, users form motivations, which are concretized as goals.
- From these goals, clear action intentions are produced. Intentions direct users´ action with artifacts.
- Users´ action is executed on its action plans, ended with the evaluation of the action outcome, and causes a certain emotion (see Figure 1.1-1).
- An action may involves five aspects: perception, cognition, emotion, volition, and physical or motor performance (Figure 1.1-2). The five aspects affect the way of action, its features, and results.
- By learning, humans obtain various action abilities, knowledge or experiences in using artifacts.

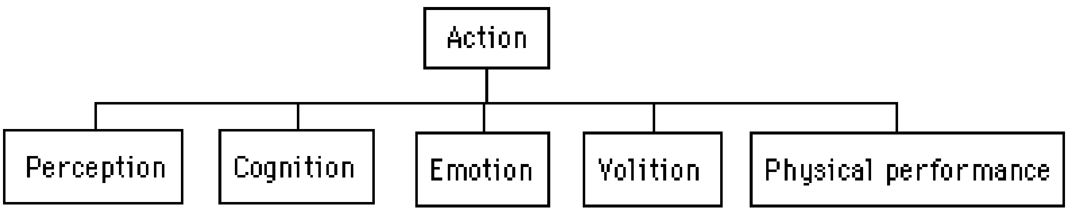


Figure 1.1-2: An action may involve five aspects.

1.1.2. Two Kinds of Behavior

Human action and machine behavior are different in nature. Their differences are shown as follows. There must be an transformation between human action and machine behavior through user interface. Such transformation determines usability of artifacts. For this purpose, the user model of action should be taken as the design model.

Human action	**Machine behavior**
- Directed by Intention	- Caused by human action
- Action can be changed suddenly	- Changeable only continuously from one state to another one
- Physiological and Psychological	- Mechanical and electronic, etc.
- Active, creative, flexible, and adaptable	- Passive and executive
- Human action pace	- High speed
- Approximate, illogical and emotional	- Accurate, logical and rational

- Individual difference	- Standardized
- Distractive and forgetful	- Executive, repeatable and routine
- Mental and physical load (stress, fatigue)	- Continual

SECTION 1.2: USER´S MOTIVATION

1.2.1. Motivation

Motivation is a comprehensive concept for various processes and effects in psychology. Kleinginna and Kleinginna (1981) unearthed 98 separate definitions of motivation, embracing diverse phenomena and theoretical orientations. For Heckhausen (1977), the objective of motivation is to find out for what goal an individual performs a determined behavior. Motivation refers to the latent motives which are activated by situational factors.

Figure 1.2-1: From motive to motivation.

For Parsons, et al. (1962, p. 111), Nuttin (1984), and Dörner (1985), motivation refers to a set of tendencies or dynamic orientation on the part of the organism to acquire certain goal objects, and motivation implies the dynamic and directional, selective and preferential aspect of behavior.

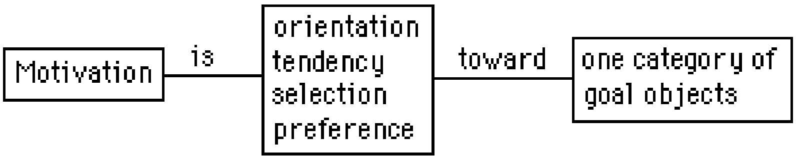


Figure 1.2-2: Motivation is the tendency toward goals.

For some other people, motivational psychology focuses on values, beliefs, preference and specific expectations. The structure of this configuration changes as a function of numerous internal and external factors. The motivation tendency which is not yet realized in action will increase by situational stimuli, while such motivation tendency which is just realized by actions will decrease with increasing duration of time. As its result, after a period of time a potential action tendency is stronger than the other one which is presently dominant and manifests, and will determine the change the action in favor of the potential tendency. The strongest tendency determines the goal-directed action.

1.2.2. Expectancy-Value Theory

Many motivation theories are based upon the expectancy-value theory (Lewin, 1938; Lewin, Dembo, Festinger, Sears, 1944; Feather, 1982, 1982b, 1987) which claims the proposition that behavior is a function of the person and the environment, and that the prediction of action should take expectations (subjective probabilities) and valences (attractiveness). The value consists of valences of goals. Positive or negative valences characterize the attractiveness of the goals. Valences are determined by attributes of the goal objects, by the person´s need state (Murray, 1938), and by values (Feather, 1982). A valence captures the subjective value of a goal and encompasses the specific emotions that will be experienced upon attaining that goal (Heckhausen & Kuhl, 1985, p. 135).

For Feather (1990, p. 151), the expectations involves "beliefs about whether a particular action can be performed to some required standard that defines a successful outcome, and beliefs about the various positive and negative consequences that may follow the outcome." Feather (1990, p. 161) assumes that the "expectations encompass both efficacy expectations and expectations that concern outcome-related consequence." "Efficacy expectancies refer to the "conviction that one can successfully execute the behavior required to produce the outcome (Bandura, 1977, p. 193). "An efficacy expectation can be seen as belonging to the same family of concepts that include perceived competence, person as 'origin,' perceived control, mastery, the concept of 'can,' and self-concept of ability." Heckhausen (1977, 1986) claims that individuals can influence outcome by ability or effort. However, many consequences of outcomes depend upon the responsiveness of the environment, and cannot be influenced directly by the individual.

Nuttin (1987, p. 314) introduces three types of expectation. (1) An anticipation or a prediction, which "is purely cognitive nature." This "type of expectation creates a certain perceptual alertness in the sense that the difference between what actually happens and the expected event tends to be noticed as a contrasting effect." (2) A more useful type of expectation "refers to a mixture of cognitive and motivational processes; it is the cognitively expressed form of a desire, as in concepts such as hope and interest." (3) The result of a more passive attitude by which a subject implicitly expects an event to occur the way is used to happen in the past.

Murray (1938) emphasizes that "the interrelatedness of the valence and the expectancy is essentially determined by stable person characteristics", i.e., by different motive. "The person´s motives determine how a situation is perceived and which incentive value situational features have." (p. 8). Under this concept, power motive, affiliation motive, aggression and achievement motive are studied.

1.2.3. Motive

McClelland (1985, p. 183) defines a motive as "a recurrent concern about a goal state that drives, orients, and selects behavior." For Atkinson (1957), "a motive is conceived as a disposition to strive for a certain kind of satisfaction, as a capacity for satisfaction in the attainment of a certain class of incentives. The names given to motives — such as achievement, affiliation, power — are really names of classes of incentives which produce essentially the same kind of experience or satisfaction: pride in accomplishment, or the sense of belonging and being warmly received by others, or the feeling of being in control and influential." For Heckhausen (1989) and Müller (1989, p.115ff), the term motive implies the activated needs, and is employed to outline the tendency to the content-categories of action goals in the abstract levels, which lead to a state of satisfaction and are presented in the form of relatively stable value dispositions. The concrete goals of activities are countless, whereas the content-categories are limited in number, although these categories are different in various cultures, in different individuals and in various periods of history. Motives include values and needs. Some authors developed motive classifications, for example, Murray´s classification on the relationship between the person and the environment, Maslow´s need theory (1970) and The Value Survey by Rokeach (1973).

1.2.4. Value

1.2.4.1. Concept of values

Feather (1990, p. 159) conceives values as "organized summaries of experience that capture the focal, abstracted qualities of past encounters, that have a normative or oughtness quality about them, and that function as criteria or frameworks against which present experience can tested. . . But they are not affectively neutral abstract structures. They are tied to our feelings and can function as general motives." For Feather (1990, p. 157), values are assumed to be seen as variables which help to structure thought across the life span, and play a key role in the choices that individuals make, in the plans that guide their behavior, in the way they justify their decisions, and in the way they structure their beliefs and attitudes. Feather claims that values are an integral part of the self-concept, and are better predictors which determine what the person will cognitively decide should be done, i.e., cognitive choices. Simply speaking, value are "the general beliefs of a certain kind that people hold" (Feather, 1987), or "standards or criteria held by people that effect the evaluative acts in which they are involved" (Rokeach, 1973; Williams, 1968). Such

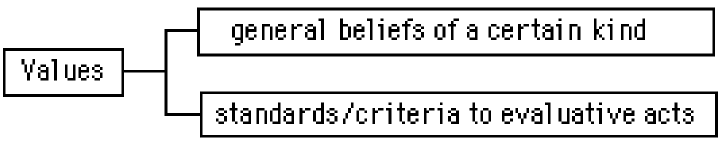


Figure 1.2-3: The concept of values.

standards have some persistence through time in organizing a system of action. It should be emphasized here that affective ("desirable"), cognitive ("conception"), and conative ("selection") elements are all essential to this notion

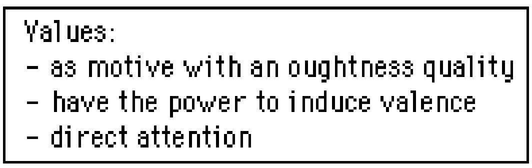


Figure 1.2-4: Values as motive.

of value. Rokeach (1979) conceived of values as cognitive representations of human needs, and of societal demands. They take the psychological form of prescriptive or prospective beliefs about the desirable means and ends of action. They are organized hierarchically to serve as standards or criteria that a socialized self employs to judge the efficacy of itself not only as a competent self but also as moral self. People employ values and standards as criteria for evaluation as "good," "bad," "must," and "ought." An individual has values, and also assigns values to specific objects, events and actions which are seen as attractive (i.e., positive valence) or aversive (i.e., negative valence) (Feather, 1990, p. 160). In the fields of design, the artifact-centered point of view is a type of values. The action-centered design is another kind of design values, and regards human values higher than the values of technology. Cultures have value standards, including cognitive (or understanding), appreciative (or aesthetical), and moral. These standards tend to be acquired by the actors living in these cultures, i.e., an actor tends to differentiate between the true and the false (i.e., cognitive), the beautiful and the ugly (i.e., appreciative), the good and the bad (i.e., moral), in ways prescribed by the culture.

1.2.4.2. Terminal and instrumental values

The Value Survey by Rokeach (1973) proposes 18 terminal values which relate to general goals, or end-state of existence, and 18 instrumental values which relate to ways of behaving modes of conduct. Terminal values will "influence the valence of specific outcomes, so that some outcomes are seen as more attractive or more aversive than others". Instrumental values will "influence the valence of specific instrumental behaviors or means to ends, so that some courses of action are seen as more attractive or aversive" (Parsons & Shils, 1962). People who have the same terminal value may have very alternative means of obtaining it. It may vary in their valence depending on the rank of the relevant instrumental values. According to Rockeach, the terminal values comprise "a comfortable life, an exciting life, a sense of accomplishment, a world of peace, a world of beauty, equality, freedom, happiness, inner harmony, mature love, national security, pleasure, salvation, self-respect, social recognition, true friendship and wisdom." The instrumental values consist of "ambitious, open-minded, capable, cheerful, clean, courageous, forgiving, helpful, honest, imaginative, independent, intellectual, logical, loving, obedient, polite, responsible, and self-controlled." Terminal and instrumental values are assumed to take highest positions in an individual´s belief system, to create one´s hierarchy of importance, and to guide one to satisfy his or her needs.

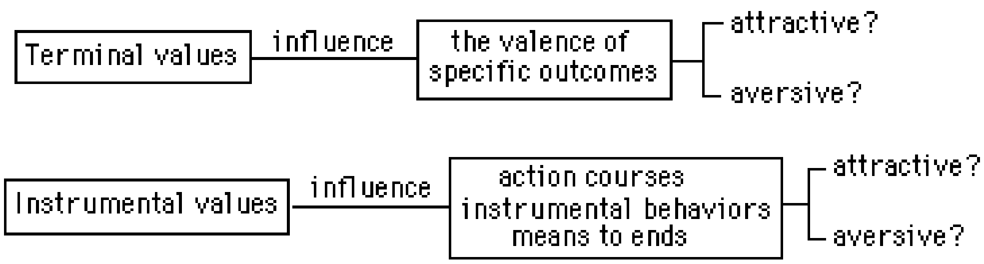


Figure 1.2-5: Terminal and instrumental values.

1.2.4.3. Users´ values

In industrial design, users´ instrumental values which are often met involve necessity, effectiveness, easy to use, simplicity, economy, efficiency, consistency, convenience, familiarity, reliability, adaptability, cooperativeness, flexibility, high benefit / cost ratio or high function/cost ratio, time-saving, action-saving, or activity-saving, task-saving. Users´ terminal values involve traditionalism, anti-traditionalism, social soundness etc, but the types of values and their priorities are also a function of several variables such as time, age, the generation of people, cultural group, gender, the occupation of job, etc. In the field of computers, consistency, easy to use, flexibility, natural way of action, adaptability, cooperativeness are currently main concerns of design.

1.2.4.4. Values of industrial design

Every designer has design values, such as consuming-centered design, cost-centered design, esthetic design and so on. One of the current issues about the values of design is that either technology serves humans or humans serve technology, either user-centered design or machine-centered one. It seems that most authors accept user-centered design. Terms such as "user-friendly" and "readiness-to-hand" reflect the concerns. However, in concrete design activities, rationalistic tradition, as a conventional way of thinking and understanding, still plays a role. The tradition is a pervasive, fundamental way of being, way of thinking, and way of understanding. It is unavoidable. Designers must be aware of its limitation. More and more designers have found the blindness and the limitation of functionalism. However, with the new technology come new blindness and even dangers. It is only emphasized that new technology (like computer) offers new ways of human action, but it may also introduce new problems. Many authors suppose that new theories should be needed to solve the new problems, but this is only a evolutional process. We can not suddenly escape from a tradition completely. For usability design, designers should study the features of human action in order to have artifacts fit users´ desires and needs. However, with this new attempt, maybe I also build a new blindness.

1.2.5. Needs

1.2.5.1. The concept of needs

According to Nuttin (1984), needs have two meanings. (1) Needs refer to "the dynamics of growth and development inherent in human being." (2) Needs are "to be conceived as a category of required relationships of the individual with his world" such as cognition and information processing interaction, interpersonal interaction and physical manipulation of objects. These behavioral needs are related to the various human organs of functioning or better functioning. Psychological concept of needs includes, for example, some form of deficit or urges.

1.2.5.2. Maslow´s model

Maslow´s need theory describes the general human needs in a hierarchy mode, which is derived from observation in the 1940´s and 1950´s about the development of personality and can be employed to understand user´s need structures. This needs hierarchy involves:

- The needs for physiological existence: hunger, thirst, sleep, etc. They are homeostatic and organic nature.
- Security (safety needs): Security and protection from pain, fear, anxiety and disorder. Needs for protecting dependence, order, legality and behavior regulation.
- Social and affiliating (needs for belongingness and love): the needs for love, tenderness, social connection and identification. Social communication is one of the major needs.
- Esteem and reputation: needs for achievement, validity and agreement.
- Autonomy and independence.
- Self-actualization needs: realization of self planned possibilities and abilities.

And other two higher forms of needs are not rigidly included

- Cognitive need and understand.
- Aesthetical needs.

When needs are satisfied at one level, the next is sought. The higher the needs are, the less urgent they are for the simple survival; the longer the satisfaction can be postponed, the easier it is for the needs to disappear on duration. Living on a higher needs level implies greater biological efficiency, longer life, less disease. Higher needs are less pressured subjectively. Satisfaction with higher needs creates more on the desirable and personal achievements. It should be emphasized that needs have two aspects: terminal aspect and instrumental aspect. Terminal aspects relate to the deficit, urges and functioning needs, for example, hunger. Instrumental aspects refer to the means satisfying the terminal needs, for example, the kind of food and the way of eating. The Maslow´s hierarchy of needs reflects the terminal needs. Individuals have limited terminal needs, but unlimited instrumental needs, from a single necessity of life to a systematical set, to self particularity or diversity, from "not so bad" to "need better and better", which means that there is no end of design for every, even very simple artifact. Understanding and realization of users´ action needs are one of the major goals of industrial design. Currently, human cognitive needs play a more and more important role in the industrial society because individuals need information and knowledge. The need to join reality and to comply with it is an important characteristic of cognitive development.

1.2.6. Beliefs and Desires

Chapman and Skinner (1985, p.204) claim the the development of action is influenced by the beliefs regarding to the efficacy of effort and other action causes. These beliefs influence the mobilization of effort in performance. Chapman and Skinner introduce the concept of the control beliefs. The control beliefs refer to the causal relationship between an actor and desired outcomes, and consist of the causality beliefs and the agency beliefs. The causality beliefs refer to those regarding to the relation between potential means and ends (what causes may lead to what outcomes). Agency beliefs refer to those regarding to the relation between the agent and potential means (“what agent is available to the person as agent“). Causality beliefs relate to causes, conditions (effort, personal attributes, environmental forces and chance), outcome valences, and the social domain of the action. Agency beliefs relate to the availability of the cause to the agent, and the modifiability of the availability over time. Chapman and Skinner (p.212) assert that “effort is a primary mediating factor in the relationship between control beliefs and performance.“

Some authors focus on naive psychological explanation of human intentional action of everyday life in terms of beliefs and desires. According to Wellman and Bartsch (1988), beliefs and desires are different kinds of mental states, and include both an attitude and a content. Beliefs are about some content which can be stated as a proposition (I believe that this model of car is the best). Desires can be expressed as propositional desires (I will buy a car). Actor´s beliefs consist of knowledge, convictions, suppositions, ideas, and opinions. Desires involve pro- and con-attitudes, such as wants, wishes, hopes, goals, aspirations and self-imposed obligations. Intentional action is "to have a desire and to engage in the act because you believe it will help satisfy your desire" (Wellman and Bartsch, 1988, p. 240). Perception tells the external objects, this way, one´s knowledge is obtained partly from perceptions, and then it can cause beliefs (p. 243-244). Basic emotions (e.g., love, like, enjoy, hate, dislike, and fear) and physiological states (e.g., hunger, thirst, and arousal) can cause desires (p. 243). Actions "are caused by and hence predictable from desires (e.g., wanted a car) and beliefs (e.g., believed that model was best); . . . perception often causes or informs beliefs (e.g., she´d seen a nice whole-wheat sandwich), . . . basic emotions (e.g., hate) and physiological states (e.g., hunger) ground one´s desires (e.g., she was hungry and wanted a sandwich); . . . actions result in real-world outcomes which produce psychological reactions (e.g., getting something you want tends to produce happiness or satisfaction, getting something you did not expect produces surprise)" (Wellman and Woolley, 1990, p. 246). This theory is called belief-desire reasoning by Wellman and Bartsch. Wellman and Woolley (1990) illustrate evidence for claim that young children (2-years old) understand action only in terms of simple desires. Simple desires cause their goal-directed actions and certain emotional reactions.

Cécora (1994) claims that "belief in economic and social progress ensuing from the Enlightenment and from developments in natural science and technology since the 18th century can be considered to be a principle social force or ideology in modern times, reaching its peak during industrialization in the 19th century."

What are origins of belief? Osherson, Smith, and Shafir (1986) claim that many beliefs are inherited from prior beliefs via various inferential links. It takes the form of "Premise 1, 2, . . . n; then conclusion." They propose "seven theories of the mechanism underlying belief-transmission via psychologically strong arguments" (p. 201). That is, (1) Enthymemes; (2) Reverse deduction; (3) Conditional plausibility; (4) Causal schemas; (5) Severe tests; (6) Logical form; (7) Similarity.

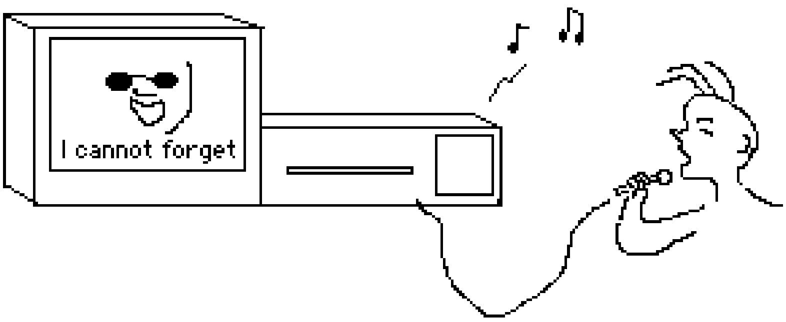


Figure 1.2-6: Kara-Ok.

1.2.7. Users´ Desires and Design

Emphasis on user´s desires, needs, and values will help designers find the real design objects and problems of design, or create new artifacts. For example, "Kara-Ok" is very popular in Asia. Its design idea came from the human needs in Asian cultures: people like singing, especially admire a certain singer star. But they may forget the musical notation, or words of a song. They would like to have a band accompaniment as stars do. From these desires and needs, designers combine television set and CD recorder into a unit, called Kara-Ok (see Figure 1.2-6). Words of a song and pictures are shown on the screen of the television set, the recorder plays the music, and the user sings with the microphone.

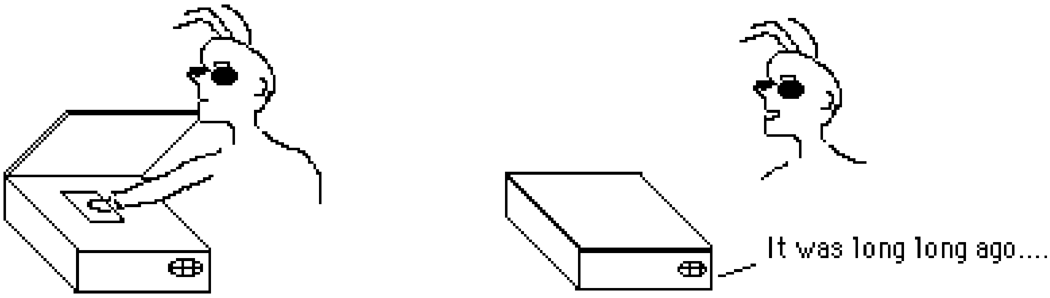
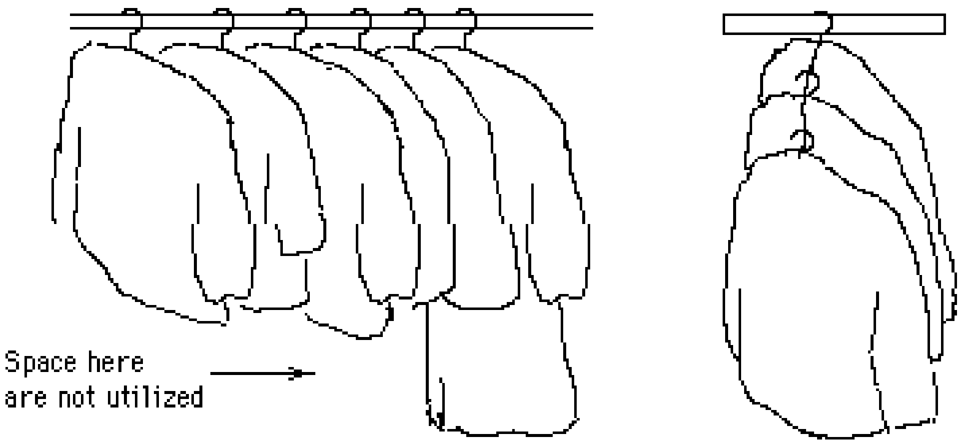


Figure 1.2-7: Reading scanner.

One can create for the blind the device to read books which is developed from the current scanner and some other techniques (Figure 1.2-7). Almost every housewife finds space limited for clothes hanging in the bedroom wardrobe, and the low part of the wardrobe is not always utilized (see Figure 1.2-8a). With the improved hanger accessory (see Figure 1.2-8b), this problem could be solved; and many housewives like this kind of commodity. This artifact is a new invention.



a. Some space in wardrobe is not utilized. b. Improved clothe-hanger

Figure 1.2-8: Users´ needs lead to a new invention.

SECTION 1.3: THE SELF-CONCEPT OF USERS AND ARTIFACT-HUMAN-AS-AN-ENTITY

1.3.1. The Concept of Self-Concept

Self-concept and self-knowledge are tied to individual values and needs. Self refers in an ontological sense to the essence of the individual person, and the inner core of personality system (Kuhn, 1964). In a functional sense authors stress the “agent“ or motivational aspects of the self construct, such as the motivated self and the emotional self (Offer & Offer, 1975). The self is the general force underlying an individual´s various activities. For some authors it is not easy to distinguish the self from concepts like personality (Fromm, 1968). In a phenomenal sense, self refers to this part of a person´s experience, including general self awareness, a sense of self, images of one´s own personality.

1.3.1.1. Self-concept

Self-concept refers to personal, process and situational aspects, and to the perception of self (Seiffge-Krenke, 1990, p.49ff). Self-concept is defined as a person´s view or mental representation of himself (Bosma and Jackson, 1990, p.33), or all self-related cognition or all attitudes concerning the individual himself (Mummendey, 1981, p.126). Identity is defined by Marcia (1980, p.126) as a self-structure: "an internal self-constructed, dynamic organization of drives, abilities, beliefs and individual history". A vital element of the development changes of an individual is the acquisition of new cognitive skills, which allow for a new relational definition of self. One begins to perceive aspects of his own self from the point of view of others. Self-concept is the foundation of personality: it represents thoughts and the way people perceive themselves. People are motivated to develop a positive self-image. People also strive to realize their inherent potential, a process, called self-actualization. Self-esteem is defined as the evaluative aspect of the self-concept. Self-actualisation emphasized man´s duty to realize what he essentially is. Self-actualisation labels the essentially uncompletable, continuous lifelong process of growth in which an individual´s authentic and essential potential self is realized, and also understood and accepted by that individual.

1.3.1.2. Representations of self-concept

Self-concept is active, and it exercises a function of directing behavior. The types of self representation are investigated by various points of view. There are central and peripheral self-concepts (Gergen, 1968), possible self-concept (real, expected, and frightened). Differences exist among the real, the ideal and the desired self. The discrepancy between the real and the ideal self may lead to depression, between the real and the desired self may lead to anxiety. Self-concept can also relate to the past, to the future or to the current. Anyway, people try to avoid the negative self-concept (Tesser & Campbell, 1984).

1.3.2. Effects of Self-Concept on Action

For Meyer (1987, p. 73-86), self-concept of ability often has effects on actor´s feeling, the expectation (failure or success) and way of action (e.g., to stop action or to maintain effort, to select tasks).

Mental information processing is influenced by the relation to the self in various manners (Kihlstrom & Cantor, 1984). There exists a increased ability in reception of the self-related stimuli. Stimuli which match the self-concept are processed efficiently, for example, self-relevant words, even self-related alphabetical letters (Bargh, 1982; Nuttin Jr., 1985). Self-relevant stimuli are remembered and recalled better than the comparable stimuli which are connected with the behaviors of the others (Markus, 1980; Nasby, 1985).

The second effect of the self relates to affect regulation, for example, protecting the self from negative feeling states. When people are not threatened, they tend to self-consistency and to self-promotion. Thus, negative feedback is so processed that its effect is reduced. (Greenwald, 1982)

A momentary motivation state can be also understood as a very concrete goal-setting which is characterized for a person in a given time point as his development. Such goal state of expected or frightened self-realization is called possible self by Markus and Nurius (Heckhausen, 1989). Possible self is the anticipated, highly specified state of the person himself. Every people has many such possible selves with himself. Possible self is a highly individualized category of motives for individual goals. The discrepancy between various self-concepts is to motivate the behavior in a certain direction. Schlenker (1985) describes this motivational function of self-concept as desired self. Here, the incentive feature of self-concept for directing action is emphasized.

Self-concept as motive is considered as individual variable which relates to success and failure. According to Kukla (1972) and Meyer (1973, 1976), the subjective success probability is dependent upon the self-concept of ability and the strength of the intended effort. If an actor believes that his/her ability can overcome the difficulty, the intended effort will be maximal, and vice versa. Buckert, Meyer and Schmalt (1979) assert that people with a self-concept of higher ability select more difficult tasks than people with a self-concept of lower ability. Maintenance of effort and persistence relates also to self-concept. People with lower ability of self-concept give up earlier.

Self-related cognition during task evaluation: Actor´s thinking and feeling during performance is also dependent upon the evaluation of the ability. Lower evaluation of ability, task-irrelevant, failure-oriented, ability-disturbed thinking will impair performance. For example, self-uncertainty can trigger anxiety of failure (Wine, 1982).

1.3.3. Self-Knowledge: The Ecological Self

Neisser (1988) distinguishes five types of self-specifying information, each establishing an aspect about the self: ecological self, interpersonal self, extended self, private self and conceptual self, in which the ecological self is related closely to industrial design. Neisser defines the ecological self as "the self as perceived with respect to the physical environment." "I can cause changes in the object and they are immediately perceptible, and this object whose movements and changes I can consistently control is part of me." If anything moves with the body, or is self-produced, it tends to be perceived as part of the self. For example, the car a person drives, or the pen a person uses can be seen as part of him or herself. "I fly to London" implies " I take airplane to London.""I write" means "The pen I use writes". In all these cases, in their imaginations, these artifacts are not perceived as the object, but just like part of the human self. The meaning of the objects is no possession or ownership but agency and coordination of movement, and the objects moving together with the user are perceived as a single coherent entity, an ecological unit. This is users´ fundamental need toward artifacts. This way, people can suppose artifact-user as an entity. It should be the final desire toward design. Many users can not verbally explain their needs toward the artifacts. However, when they use the products, they can immediately tell whether the products are adapted to them or not in the sense of ecological self. This intuitive feeling involves many past experiences, beliefs, needs, and standards. It means the natural way of interaction and effects.

Many artifacts are not only of use, but also more importantly, the spiritual and emotional sustenance for the self (user). Bicycles, cars, wrist-watches and furniture are more or less "emotionalized" in respect of human feeling. The colors and form are not only visual stimulus and geometrical effect, but also reflect certainly a kind of inner emotion and spirit, such as firmness, solemnness, simplicity, fineness, lifelikeness, fantasy, romance, creativeness, curiosity, and so on. Designers should find out this inner expressive power given by the artifacts in the design process. On the contrary, to some people, mechanical devices, machines and cars seem to be only pieces of metal, plastics when they do not operate. This feeling is also ecological self, which sees the difference of nature between a human being and artifacts.

1.3.4. Nature-Human-as-an-Entity, Artifact-User-as-an-Entity (Tian-Ren-He-Yi)

In Chinese Taoism, the concept of self means "Tian-Ren-He-Yi." "Tian" means sky, nature, the law of the nature, the environment. "Ren" is human being. "He" means "combine", and "Yi" means "as wholeness," "unity," "oneness," or "entity." "Nature-Human-as-an-Entity" is one of the fundamental points of view in various traditional philosophies of China. Old Chinese philosophers, such as Lao-zi (Lao-tze), Zhuang Zi (Chuang-tze) and the Taoist School (770-221 B.C.), the Confucian School, discussed this opinion in the whole Chinese history. The central concept in Taoism is Tao. The "Tao" is "way," the totality of everything that exists. Taoism suggests that reality can not be divided into object and subject and human being is only an element of Nature. The Nature and human being have characterized originally the same natural simplicity and harmony. Human being and the Nature have similar structure and similar "emotion," and they can feel each other, communicate with each other, and influence each other, or say, coupling or consensus (or inducing) between the Nature and the Human, called "Nature-Human-as-an-Entity" and "Nature-Human-Consensus." Human being should accompany well with the Nature, and friendly behave to the Nature. In Zhuang-zi, change of the universe is viewed as a great current. In this process of change, everything must follow its own nature. Similarly, "Taking no action is an action" means that a man should not attempt to replace the way of the Nature with the way of an individual, but support all things in their natural state. This and that, and possibility and impossibility mutually produce each other. All things are combined into an entity. A man of great knowledge will see Tao in all its unity. The ideal man will be a companion with Nature. In such philosophy, the relationship between the

Human and the Nature and between the Human and Artifacts are not viewed as a discrepancy, an opposite, or a competition, but as supplementary as an entity. The main points of Artifact-Human-as-an-Entity or Artifact-Human-Consensus relate to the following aspects:

- The highest human desire is a harmonic, simple, organic coupling of structures, or the consensual relationship between Humans and Artifacts or Environments;
- Such relationship may be represented as the mutual complement, the similarity, the adaptation, and the cooperation between artifacts and humans;
- This relationship relates, but not limited, to physiological and psychological characteristics, physical performance, perception, cognition, emotion, volition and feeling of humans.

The terminal effect of such relationship will be that (1) artifacts behave like an organic part of humans, or like expanding of human perception, cognition, volition, etc.; (2) users can naturally immerse in their actions, do not make errors caused by its design, will not be hurt by the artifact, will not be distracted with the artifact they use, do not have the feeling of “alienation," and will not destroy the environment and the nature. The key point of design is to discover the existence of the unity, to find the coupling and consensual relationship between the Human and the Artifact.

SECTION 1.4: USER´S INTENTION

1.4.1. Intentionality

In the book "Intentionality: An essay in the philosophy of mind," Searle (1983) claims:

> Intentionality is that property of many mental states and events by which they are directed at or about or of objects and states of affairs in the world. . . Intentionality is directedness. . . First, on my account only some, not all, mental states and events have intentionality. Beliefs, fears, hopes, and desires are intentional . . . if a state S is Intentional then there must be an answer to such questions as: What is S about? What is S of? What is it an S that? . . . Intending and intentions are just one form of Intentionality among others. . . (p.1)
>
> Here are a few examples of sates that can be Intentional states: belief, fear, hope, desire, love, hate, aversion, liking, disliking, doubting, wondering, whether, joy, elation, depression, anxiety, pride, remorse, sorrow, grief, guilt, rejoicing, irritation, puzzlement, acceptance, forgiveness, hostility, affection, expectation, anger, admiration, contempt, respect, indignation, intention, wishing, wanting, imagining, fantasy, aspiration, amusement, and disappointment. (p. 4)
>
> Every Intentional state consists of an Intentional content in a psychological mode. Where that content is a whole proposition and where there is a direction of fit, the Intentional content determines the conditions of satisfaction. Conditions of satisfaction are those conditions which, as determined by the Intentional content, must be obtain if the state is to be satisfied. (p. 12-13)

To find the user´s intentional content to artifacts and their conditions of satisfaction are the major concerns of designers. These issues will be discussed further in the following sections.

1.4.2. The Concept of Goal

Heckhausen and Kuhl (1985) defined goal as "the molar end-state whose attainment requires actions by the individual pursuing it." The molar end-states of one´s actions can be categorized in three levels:

- First-order level refers to an action. The end-states are the actions themselves, i.e., the interest in doing something continuously because it provides excitement.
- Second-order level refers to an action outcome with characteristics which are required and are inherently valuable.
- Third-level order refers to desirable consequences that may arise from an achieved outcome.

The processes at higher level presuppose the structuring of the lower levels. If desires are aimed at a third-order goal level, complex motivational processes that include lower-level variables are implied.

Schank and Abelson (1977, p. 102 - p. 112) investigated the knowledge of goal. People should understand what types of goals there are, how they interact with each other to formulate expectations, how to recognize a goal, and how to predict his or her future actions from that goal. For Schank and Abelson, the knowledge about goal involves: Goal origin, hierarchical structure of goals, change or substitution of goals, goal suspension, and multiple goals and their conflict, goals progression.

1.4.3. The Concept of Intention

For Kuhl et al (1991, p. 83), "intention is the symbolic representation of one´s current goal." Such abstract representations include information about goal states, relevant action plan, possible execution conditions and parameters such as its importance, urgency and competence (p. 83). Kuhl et al (1991, p. 16) asserted that fully developed intention has four components: (1) the context component which specifies when and where the intention is to be executed, (2) the subject component specifying the self as the agent of the intended action, (3) the action component specifying one or more action plans that can produce the intended results, and (4) the relational component which specifies the type of commitment, i.e., whether it is based on a wish (WANT), on some socially expected action (MUST), or on a full-fledged and self-generated decision (WILL).

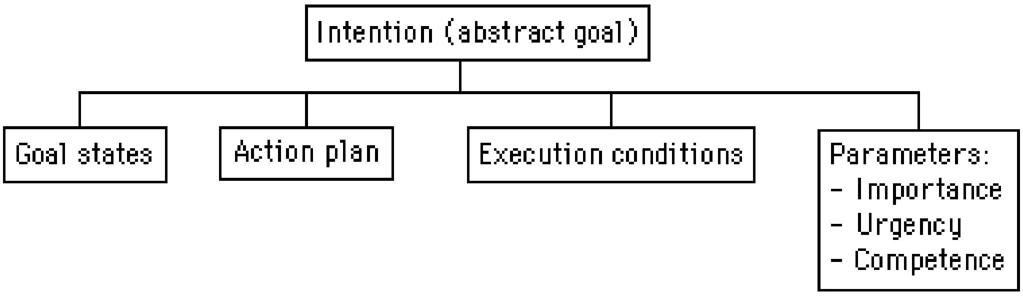


Figure 1.4-1: Intention on Kuhl (1991)

Norman (1984) defines intention as "the internal, mental characterization of the desired goal." "Intention is the internal specification of action responsible for the initiation and guidance of the resulting activity."

1.4.4. Prior Intention and Intention in Action

Searle (1983) distinguishes between prior intention and intention in action. Prior intention is "an explicit and conscious mental attitude leading straightforwardly to a real planning process which will elaborate an adequate plan of actions." Reason (1990, p. 7) claims that only the "major headings" are likely to be specified in the prior intention.

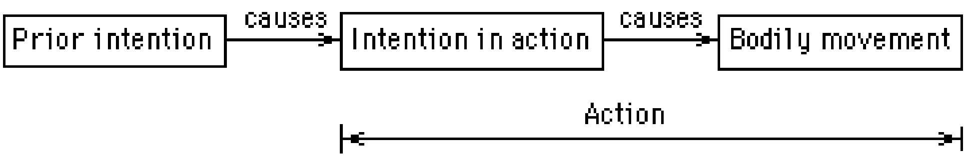


Figure 1.4-2: Prior intention, intention and action (After Searle, 1983, p. 94).

Intention in action is inherent to a spontaneous behavior. The prior intention causes action which includes the intention in action and the movement (Searle, 1983). The emphasis of intention, especially based on Searle´s model is mainly the feature of the industrial design in European countries.

Kuhl (1983) paid attention to the phenomenon that people often persist in a goal-directed action even in the face of comparatively more attractive, easily accessible behavioral alternatives. In this case, the will plays an important role in human action instead of intention.

1.4.5. From Desires to Intentions

The expectancy-value model was the most influential cognitive approach in psychology to explain action. However, it does not explain how wishes are transformed into intentions, why many wishes are not transformed into intentions, how intentions can be predicted, and what factors influence the intentions and actions. Many authors have investigated these issues further. For example, Heckhausen and Kuhl (1985) introduce a model from wishes to action, Icek Ajzen (1985) introduces the theory of reasoned behavior and planned behavior.

Heckhausen and Kuhl (1985) claim that the transition from desires to intentions requires a relevance check. They suggested five criteria for the transformation from the probability of a want to an intention:

- opportunity for achieving the desired goals (expectancy term),
- enough time for the goal pursuit,
- importance of goal to the person (value term),
- urgency for attaining the goal (value term),
- available means for attaining the goal (expectancy term)

or OTIUM for abbreviation. These five criteria can be involved into the value term (importance and urgency) or the expectancy term (opportunity, time and means). In their model, the processes from desires to action consist of two stages. The first step is to check the OTIUM to see what is possible and likely in the future and then to transform the relevant want into an intention. The second stage is to examine whether the criteria are present at a particular point of time. If they are, it facilitates action appropriate to the intention.

1.4.6. Reasoned Behavior and Planned Behavior

Many human behaviors in daily life can be considered under volitional control so that people can easily perform these behaviors if they are inclined to do so. This type of behavior is called reasoned behavior by Ajzen (1985). The theory of reasoned action is applied to these behaviors that are under volitional control. On the theory of reasoned behavior (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975), there are intentions competing with each other, and many factors influence the formation of an intention. Successful attainment of an intention is subject to the degree of control which an individual has over internal and external factors that may interfere with the execution of the intended action. The individual may change his or her mind after an intention has been constructed because of some difficulties or lack of self-confidence in abilities. However, predictive accuracy of this theory is decreased when behavior is influenced by the factors over which some individuals have only limited control. The theory of planned behavior is

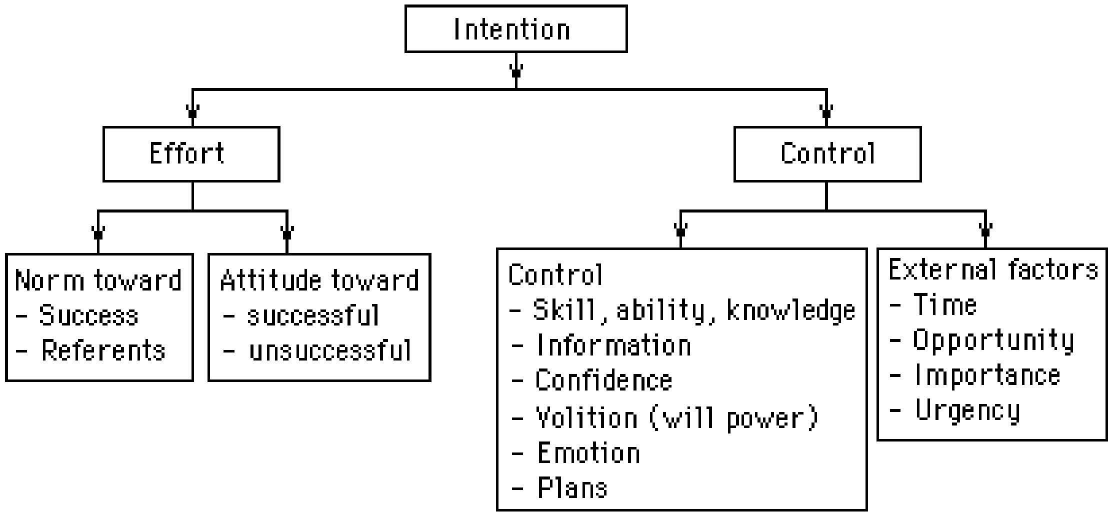


Figure 1.4-3: Planned behavior.

expected to expand this aspect. The theory of planned behavior summaries the important variables which influence the formation of intention, and emphasizes action plan. The success of an attempt to execute the behavioral plan depends upon:

- the effort or the strength of the attempt to perform a behavior, which is determined by the intention to perform it;
- person´s control over other internal and external factors, such as necessary information, skills, and ability, including possession of workable plan, will-power, time, opportunity, and so on.

Intention is the function of two variables:

- The subjective norm with regard to trying, which depends upon two factors:
  subjective norm concerning successful performance of the behavior,
  subjective probability of success attributed to the referents.
- Attitude toward trying, which is dependent upon two factors:
  the attitude toward successful behavioral attempt (effort),
  the attitude toward unsuccessful behavioral attempt.
  These two attitude are determined by
  - Salient beliefs about the consequences of a successful or unsuccessful behavior attempt,
  - Evaluations of these consequences.

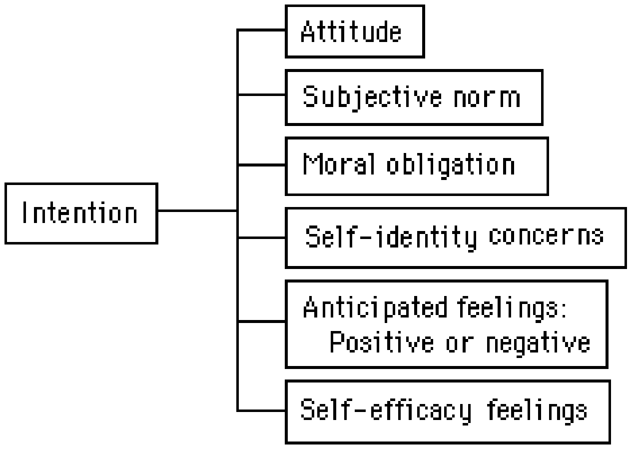


Figure 1.4-4: The determinations of intention.

From practical opinion, some other factors, including past experience, confidence in one´s subjective judgment of control, availability of a detailed plan of action and self-knowledge, are related with realistic perception of behavioral control. Past performance of a behavior has an influence on present behavior that is independent of behavioral intentions, attitudes, or subjective norms. Subjective perception of control may influence attempts to perform behavior. For example, optimistic or pessimistic view of one´s control will lead different attitude toward trying. On the other hand, these predictive models do not provide much information about the mental processes to the behavior.

Other authors claim that intentions may be determined not only by attitudes toward behaviors and subjective norms, but also by personal moral obligation (Schwartz and Tessler, 1972; Zucherman & Reis, 1978), self-identity concerns (Biddle, Bank & Slavinge, 1987; Charg, Piliavin & Callero, 1988), the anticipated positive/negative feelings associated with execution of the behavior (Triandis, 1977) and by a person´s self-efficacy feelings (Bandura, 1986).

1.4.7. Goal Intention and Implementation Intention

Heckhausen and Gollwitzer (1987, p. 356; Gollwitzer, 1990, p. 57) distinguish between goal intention and implementation intention (behavioral intention). Goal intentions specify what is to be achieved, and provide the individual with a commitment to this goal state. Forming a goal intention is preceded by contemplation on the valenceof the desired goal state, as determined by the probability of the desired goal state and the value of potential consequences.

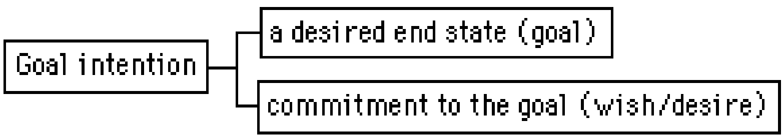


Figure 1.4-5: Goal intention

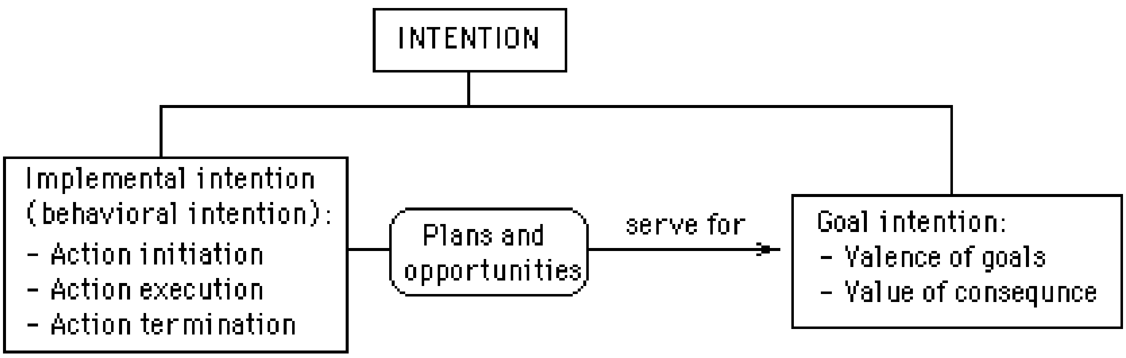


Figure 1.4-6: Goal intention and implementation intention

According to Gollwitzer (1990), formation of a goal intention can be represented as a decision such as "I intend to pursue x!" which terminates the deliberation when the actor is committed to achieving the goal. Deliberation of wishes and desires, decision making and commitment are important processes in formation of goal intentions. Many wishes and desires may conflict with each other because of the opposite values of the long-term and short-term consequences in terms of their attractiveness, because of their high desirability but low feasibility, or because of uncertainty about their feasibility or desirability. According to Marcia (1980), commitment refers to choice and one´s personal investment in this choice. Bosma (Gollwitzer, 1990) distinguished the content of the subject´s commitment, the strength of these commitment, and the amount of exploration involved in the process of reaching them. The commitment to a goal furthers the successful completion of goal pursuit once it has been initiated. People with weak commitment easily give up their pursuit for the intended goals. The amount of commitment (or volitional strength) associated with goal intentions mainly depends upon the desirability of the specified goal (attractiveness of the desire).

Figure 1.4-7: Implementation intention.

Heckhausen and Gollwitzer argue that solely goal intentions are not sufficient in realization of the wishes and desires effectively. People must know how to execution the action. For this purpose, people construct of an implementation intention (Vorsatz in German) with respect to when and how to act in the second phase of action (the pre-action phase), such as "I intend to initiate the action program P whenever the situational conditions are met." Such implementation intentions consist of initiation intentions, execution intentions and termination intentions. In serving a particular goal intention, the implementation intentions activate a general cognitive orientation to facilitate the initiation of action, and promote the successful attainment of the intended goal state by committing an individual to relevant opportunities to act, or to appropriate plans which deal with how to act. The implementation intentions may be generated in conjunction with goal intentions or at some later point of time, and draw one´s attention to opportunities to act when quick response is needed. Furthermore, forming implementation intention can speed up the initiation of action automatically without requiring much processing capacity even when the individual is heavily involved in performing a highly demanding task.

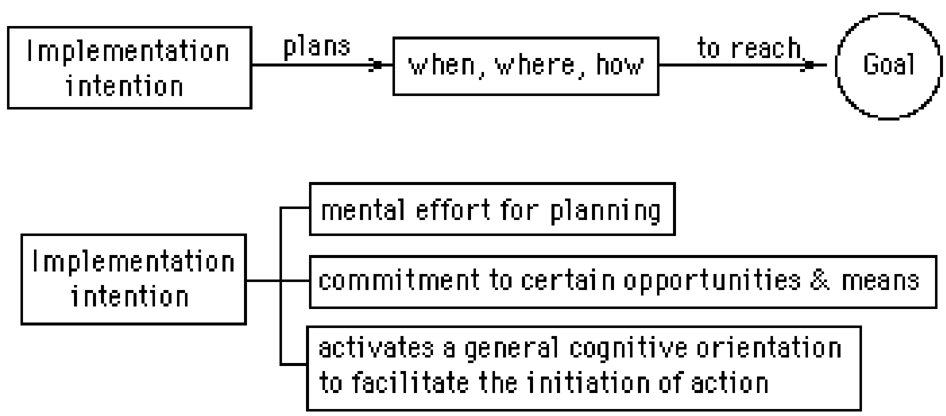


Figure 1.4-8: Implementation intention.

If a goal intention is supported with implementation intentions, its chances of realization increase. On the contrary, a goal intention without implementation intentions has rather low rates of completion. This is also observed by Kuhl (1982b): only focusing on goal intention will not guarantee progress to achieving the goal and if the individual is ready to stress "how" to achieve the goal, the goal achievement will be furthered.

However, the real processes of the intention formation are much more complicated. There may be some unforeseen factors during intention formation. Users do not always form a rational intention like this. Maybe, they have a glance at the artifact, think a short time about a desire and about one step of action, then start action without a careful plan. When they meet problems, they do by trial-and-error. In using artifacts, users have often clear goal intentions (I want to make coffee), but it is difficult for them to find implementation intentions from the artifacts (I don´t know how to use the coffee-maker). Maybe this is also one of the problems from machine-centered design.

SECTION 1.5: USER´S ABILITIES

1.5.1. What is Ability

Carroll (1993, p.3-7) argues that the traditional definition of ability is an ambiguous concept, and leads to contradictory and confusing conclusions from research studies on human abilities. The key point is what abilities exist exactly, how can be measured, how they are related to individual differences. He redefines the term ability.

> As used to describe an attribute of individuals, ability refers to the possible variations over individuals in the liminal levels of tasks difficulty (or in derived measurements based on such liminal levels) at which, on any given occasion in which all conditions appear favorable, individuals perform successfully on a defined class of tasks. (Carroll, 1993, p. 8)
>
> An ability can be regarded as a trait to the extent that it exhibits some degree of stability or permanence even over relatively long periods of time. (p. 7).

Because high intellectual ability is strongly valued by most people in Western cultures, Meyer (1987, p. 73-86) claims that self-perception of ability plays an important role in achievement-related feelings, motivation, the choice of tasks, effort and persistence. Self-perception of low ability leads to the expectation of future failure, and stops pursuing the task. Effort depends on estimation of ability and on perception of the difficulty in the task.

1.5.2. What Are Cognitive Abilities?

Carroll describes cognitive abilities in his book "Human cognitive abilities" as follows:

> By using the adjective cognitive, however, I mean to limit the range of cognitive tasks to those that centrally involve mental functions not only in the understanding of the intended end results but also in the performance of the task, most particularly in the processing of mental information. That is, a cognitive task in one in which suitable processing of mental information in the major determinant of whether the task is successfully performed. . . I define a cognitive task, therefore, as any task in which correct or appropriate processing of mental information is critical to successful performance. Cognitive ability is any ability that concerns some class of cognitive tasks, so defined. (Carroll, 1993, p. 10)

Cattell (1971) incorporated Gf-Gc theory into a new and more general theory — the "triadic theory", which proposed that cognitive abilities fall into three types. "Capacities" are abilities reflecting "limits to brain action as a whole"; "provincial powers" are types of "local organization" for different sensory and motor modalities; and "agencies" are abilities to perform in different areas of cultural contents, acquired through the "investment" of fluid intelligence in learning. (Carroll, 1993, p. 62). Fifty years ago, design is worried about human physical abilities and load. Now, design is worried about human cognitive abilities and mental load.

1.5.3. The Structure of Human Ability Factors

Performing any action calls on whatever abilities it requires. All the human abilities are defined by certain tasks or tests. General intelligence (G) was common to all tasks requiring ability. It can be found in every task performance. G can be broken into Crystallized and Fluid intelligence. The recognized 38 types of cognitive ability factors (Carroll, 1993, pp. 75-77, in R. F. Dillon & R. R. Schmeck, Eds., Individual difference in cognition, Vol. 1. Orlando, FL: Academic Press) are listed briefly as follows:

Fluid Intelligence (Gf) "was defined by tests that were assumed to measure the biological capacity of the individual to acquire knowledge." (Brody, 1992, p. 19). It refers to the ability quickly to access knowledge in your memory. Gf reflects "basic abilities in reasoning and related higher mental processes," and Gf is "able to flow into many kinds of mental activities" (Carroll, 1993, p. 61). Gf can flow into many types of mental processes. Cattell (1963) argued that changes in the biological state of the organism influence Gf more than Gc (see below), and age-related changes in the brain lead to a decline in Gf. According to Carroll (1993, p. 74), Gf involves the following ability factors: Induction, Logical Reasoning, General Reasoning, Integrative Process, Judgment, and Planning.

Crystallized Intelligence (Gc) "was defined by tests that were assumed to measure the influence of schooling and acculturation" (Brody, 1992, p. 19). Gc is a kind of the end product of experiences of an individual, and reflects the extent to which the individual has been able to learn and profit from his/her culture through education and other experience, partly on the basis of level of fluid intelligence (Carroll, 1993, p. 61). According to this theory (Cattell, 1971), the bright and well-adjusted child who learns in a good school and is encouraged at home will invest most of the fluid ability in the crystallized skills of her culture. For Cattell, Gc does not decline with age. Based on Carroll

(1993, p. 75), Gc involves two classes of ability factors: Verbal Knowledge (Verbal Comprehension) and Numerical Facility.

General Visual Perception (Gv) factors involve: Spatial Orientation, Spatial Visualization, Speed of Closure (Gestalt Perception), Flexibility of Closure (Gestalt Flexibility), Spatial Scanning, Length Estimation, Verbal Closure, Perceptual Speed, Perceptual Alternations, and Figure Illusions.

General Auditory Perception factors involve: Auditory Integration, Auditory Resistance, Loudness, and Pitch Quality.

General Memory factors involve: Associative Memory, Memory Span, Visual Memory, and Musical Memory.

Fluency and Production factors involve: Association Fluency, Expressional Fluency, Ideational Fluency, Word Fluency, Flexibility of Use (Semantic Spontaneous Flexibility), Figural Flexibility, Naming Speed, Speed Fluency (Public Speaking), Speed of Association, Originality, Semantic Redefinition, and Sensitivity to Problems.

Speed factors (not otherwise classified) involve: Speed, and Speed of Judgment.

Selected Psychomotor factors involve: Aiming, Ambidexterity, Speed of Articulation, Finger Dexterity, Manual Dexterity, Psychomotor Coordination, Reaction Time, and Tapping.

Miscellaneous Affective-Cognitive factors involve: Attention, Carefulness, Persistence, and Perseveration.

1.5.4. How to Estimate the Demand for Abilities in Using Artifacts

One can not tell generally what kind of abilities are required by using a machine or a computer. The tasks of performance determine the demand for users´ abilities. Every tool or machine, every class of tasks and actions require certain concrete abilities of the users. Designer must take users´ abilities into account especially in design artifacts for skilled action. The goal of this analysis is to find users´ desired demand for abilities, either to reduce the demands of abilities and difficulties in using artifacts, or increase them for games for example. Ability analysis in design process is to determine the following five aspects:

- To analyze ability factors which are required by performance.
- To analyze the degree of difficulty of a task or an ability. Not all abilities have the equal degree of difficulty. Someabilities are very difficult for common people. Idea generation in using computers has the higher degree of difficulty than general reading abilities. Reasoning (e.g., 1.5 x 2.1) is generally more difficult than seeing or hearing (e.g. 3.15, which is equal to 1.5 x. 2.1). Artifacts should supply the action-adapted condition to give lower degree of difficulty to the users.
- Complexity of abilities refers to the number of ability factors involved in an action. Design processes should estimate what and how many ability factors of the users are required in using or operating artifacts.
- To analyze the loading of an ability. An ability (watching TV program) may be not difficult for most people, but watching TV programs for 20 hours is very difficult because of the high loading. Design should think of the application of the designed artifact: in what way or process will the artifact be applied. A seemingly simple tool may lead to heavy mental load or physical load by inadequate design.
- Speed and accuracy of performance are distinguishable aspects of performance. Human action itself in nature is not fast, not accurate compared with machines. Both high speed and high quality of accuracy may not be fulfilled by common users simultaneously.

Studying users´ abilities is its factor-analytic studies of the users in using artifacts. Psychological or educational tests may be beneficial for designers as reference. Influential methods of ability factors tests and analysis can be found in the following books: (1) Eductional Testing Service has developed "kits" of reference tests for factorial study, called ETS kits, "Manual and kit of reference tests for cognitive factors", issued in 1954, 1963, and 1976, by J. W. French, R. B. Ekstrom, H. H. Harman, and L. A. Price, Prinston, NJ: Educational Testing Service. (2) Guilford´s Laboratory has two publications which is considered out of data: "The nature of human intelligence" by J. P. Guilford, NY: McGraw-Hill, 1967; "The analysis of intelligence" by J. P. Guilford and R. Hoepfner, NY: McGraw-Hill, 1971. (3) "The IPAT

Culture Fair Intelligence Scales" by R. B. Cattell, and A. K. S. Cattell, Champaign, IL: Institute for Personality and Ability Test, 1957. "Abilities: Their structure, growth, and action" by R. B. Cattell, Boston: Houghton Mifflin, 1971. (4) "Human cognitive abilities: A survey of factor-analysit studies" by John B. Carroll, Cambridge, NY: Cambridge University Press, 1993. Ability is not an independent component of human action, but presents in the every component of action. The analysis and measurement should be in a real environment of user´s performance with the designed artifact. For most artifacts, design should reduce or avoid the demand for difficult ability factors of the users. For example, the demand for the degree of difficult should be reduced as less as possibly; simultaneously multiple factors should be avoided possibly, and performance loading should be reduced. Humans can obtain various abilities through learning and training.

SECTION 1.6: PERCEPTION

1.6.1. The Concept of Perception

"The term perception refers to the means by which information acquired from the environment via the sense organs is transformed into experiences of objects, events, sounds, tastes, etc." (Roth, 1986, p. 81). Perception and action are closely interwoven, and all actions are mediated by perception. The occurrence of events and our perception of them are almost simultaneous (von Hofsten, 1985, p. 80). The goal to study human perception is to understand the features of user´s perception, the perceptual abilities, and intentionality, and to provide users´ perception with the conditions of satisfaction, or to find recognition algorithms for artificial intelligence.

1.6.2. The Intentionality of Perception

Searle emphasizes that perception in goal-directed action "is an Intentional and causal transaction between mind and the world." (Searle, 1983, p. 49). "Visual perception, like belief, and unlike desires and intention, always has the mind-to-world direction of fit." (Searle, 1983, p. 42). The "direction of causation is world-to-mind" (p. 49). "Visual experiences, like beliefs and desires, are characteristically identified and described in terms of their Intentional content" which is propositional in form (Searle, 1983, p. 43, p. 45). The visual experience is directed at or of objects and state of affairs in the world just as other intentional states (belief and desire), and visual experience has conditions of satisfaction just as beliefs and desires (Searle, 1983, p. 39). He claims that

- Different beliefs cause different visual experiences with different conditions of satisfaction, even given the same optical stimuli.
- The same beliefs coexist with different visual experiences with different conditions of satisfaction even though the content of the experiences is inconsistent with the content of the beliefs and is overridden by the beliefs.
- The same beliefs plus different visual experiences yield the same conditions of satisfaction of the visual experiences. (Searle, 1983, p. 57).

Because of the intentionality, users´ perception is guided by expectation. Humans perceive the world selectively, extract only the intended information and neglect much more of it.

1.6.3. Perceptual Processes

There are mainly four kinds of theories that relate to understanding of users´ perception in industrial design.
Gestalt principles for human perceptual organization: Gestalt is the German word for form, shape or whole configuration. Gestalt psychologists, such as Kurt Koffka (1886-1941), Wolfgang Köhler (1887-1968), and Max Wertheimer (1880-1943), argue that human perception tends to group stimuli into pattern or figure-like qualities. The overall structure and the relationship between components play an important role in producing perceptual organization because the whole is different from the sum of its parts. Gestalt principles involve: (1) The rule of proximity: elements close together tend to be perceived as units. (2) Similarity: objects that look alike tend to be grouped together. The good configuration describes a general organizing tendency, including good continuation, common fate, closure and symmetry. (3) Good continuation: perceptual organization will tend to preserve smooth continuity rather than abrupt changes. A sharp turn seems not to be good continuative. (4) Common fate: elements which move in the same direction (parallel) are grouped together to form a coherent pattern. (5) Closure: more closed or complete figure is beneficial to perception. (6) Symmetry: priority in grouping is given to the more natural, balanced and symmetrical figure over the asymmetrical ones. (Schiffman, 1990, p. 292). (7) Symmetrical areas tend to be perceived as figures. Relative size, orientation, symmetry and surroundedness may all work together and dominate perception. (8) Prägnanz principle: "Of several geometrically possible organizations that one will actually occur which possesses the best, simplest and most stable shape" (Koffka, 1935). Gestalt principles of perception focus on aspects of the stimuli which influence human perception. Some cursor marks on the computer screen may be designed on this theory.

James J. Gibson (1904-1980) proposed the theory of the direct and ecological perception. He believed that prior knowledge and inferential processes are not necessary for perception in some situations. According to Gibson (1979), we use contextual information sufficiently, and the array of information in our sensory receptors is all we need to perceive. When we use cafe-machine, electric iron, or any other everyday things, we hope to perceive their user interfaces and operations directly, we do not hope to perceived insufficient information and then to infer where is the switch, how to switch on.

According to the theory of constructive perception, which is developed by Richard Gregory (1980) and Irvin Rock (1983), the perceiver uses perceived sensory information and other sources of information as the foundation of a cognitive understanding to construct perception. For example, when you see the sentence "My n_me is Li", you will think it over and know that it must be "My name is Li". The key point of constructive perception is that intelligence and thought will be required to combine sensory information with previous experience, for example, design of word puzzle. However, it means that if the sensory information is not enough for understanding, then users have to use their knowledge and inference. Of course, design for usability of artifacts should avoid this kind of problem.

David Marr (1982) proposed a model of visual perception, that is simulated by a computer program. According to Marr, the human brain processes the visual data in three steps to build the 3-D recepts. (1) According to the raw sensory data regarding change in light intensity from the retinas of the eyes, the human brain can map out a 2-D primal sketch of the sensory information, including edges of the boundaries between objects, contours of surfaces, and regions of similarity of areas. (2) The brain employs depth cues, including monocular cues (shading, texture gradients, relative size, interposition, linear perspective, aerial perspective, and location in the picture plane), binocular depth cues (binocular convergence, binocular disparity) and surface orientations, to convert the 2-D sketch into a 2 1/2-D sketch. (3) The 3-D model will be built by using the spatial relationship between the objects. These processes may be employed to understand the users´ "correct" or "rational" recognition processes of objects in everyday life. If designers do not provide sufficient information for light intensity, the boundaries between objects, depth cues, the spatial relationships, etc., or users lack such knowledge to recognize the depth cues and spatial relationships, or users do not pay attention to perceptual processes, then they will not perceive objects correctly. Such "irrational" perception occurs very often and leads to users´ errors of perception. The irrational perceptual factors must be involved in design process.

1.6.4. The Types of Perceptual Abilities

1.6.4.1. Human perceptual abilities in the traditional sense

Any kind of human ability is always defined in relation of a certain task. Carroll (1993, p. 8) defines a task "as any activity in which a person engages, given an appropriate setting, in order to achieve a specifiable class of objects, final results, or terminal states of affairs." In the traditional sense, human perception involves six basic forms of abilities or tasks: Detection, discrimination, recognition, identification, memory search, and visual search (with distracters). Detection and Recognition are major concern of designers. Recognition process involves comparing the representation of perceptual input to that stored in memory. There are three major determinants: (1) similarity of the perceptual input to a memory representation; (2) prior experience; (3) top-down processes involving expectation and the recognition context. (Glass, Holyoak and Santa, 1979, p. 63).

Based on the types of the perceptual abilities, the following design criteria are proposed (Sanders and McCormick, 1992, p. 102):

- Detectability (visibility): The quality of information that makes it possible to detect them differently from others.
- Identifiability: The attribute of stimuli that makes it possible to discriminate, or to identify them from others.
- Recognizability (readability): The attribute which makes it possible to recognize the information content or meaning in text, icon, or signal, i.e., the Gestalt principles.

These criteria are mainly focused on human physiological capacities, and are not enough for usability design.

1.6.4.2. Human visual perceptual abilities in the psychological view

Every sensory channel appears to have a temporary sensory memory: an iconic memory for visual channel, an echoic memory for auditory channel, and so tactual and olfactory memories. The iconic memory can hold about 7±2 chunks of information (5 to 9 items) which are shown only 50 ms., and they decay very rapidly. Their recall is down to 4 or 5 of the 12 items after 1 second (Sperling, 1960). And this information is disturbed very quickly by subsequent stimulation. That is, human perception is irrational.

In psychological tests, spatial ability is of more concern in respect to human visual abilities because in everyday life human interactions with artifacts emerge mostly in spatial relations: using tools, driving a car or reading text. Lohman (1979, pp. 126-127) defines spatial ability "as the ability to generate, retain, and manipulate abstract visual images. At the most basic level, spatial thinking requires the ability to encode, remember, transform, and match spatial stimuli. Factors like Closure Speed (i.e., speed of matching incomplete visual stimuli with their long term memory representations), Perceptual Speed (speed of matching visual stimuli), Visual Memory (short term memory for visual stimuli) and Kinesthetic (speed of making left-right discriminations) may represent individual differences in the speed or efficiency of these basic cognitive processes."

For Lohnman and Carroll (Carroll, 1993, p.304-363), the major ability factors of primitive visual abilities (the first-order factors), which show individual differences, can be discriminated from the following groups of tasks (Note: some of these abilities or tasks in psychological tests can be considered the difficult ones in using artifacts of everyday. One
can acquire them only through learning or training. These ability factors provide a reference for users´ action design).

- Visualization or called spatial visualization: This is the "ability in manipulating visual patterns" (Carroll, 1993, p. 362) This kind of tasks requires users to apprehend a spatial form, imaginary movements, or scene, to encode and to manipulate mentally spatial forms in imagination, or to transform the image of spatial patterns into another spatial arrangements. In Carroll´s analysis, more than 800 variables have salient loading on this factor. This ability requires understanding of mechanical movements and principles, and mechanical reasoning, spatial thinking, comprehend the interior structure, recognize how to combine them together, in many cases, with imaginative rotation demand (Carroll, 1993, p. 315-325). Many engineering, architectural and geometric problems involve this factor. Generally, mechanical tools and machines are visible, their shapes and principles are transparent. However, visualization of electronic instruments and computer-based artifacts sometimes cause problems.
- Spatial Relations: This type of tasks requires "speeded rotation or reflection," and represents "the ability to solve simple rotation problems quickly, by whatever means" (Lohman et al, 1987, p.267). It requires speed in manipulating relatively simple spatial forms, by mental rotation, transformation, or otherwise. This ability can be called spatial orientation. (Carroll, 1993, p.325-329)
- Closure Speed: This kind of tasks requires the ability to combine disconnected, vague patterns into a whole, to interpret words with incomplete letters, to unify an apparently disparate perceptual field into a single percept (French, 1951), to apprehend and identify a spatial form, without knowing in advance what the pattern is, when the pattern is disguised or obscured in some way. These tasks relate mainly to abilities of Gestalt principles perception (Carroll, 1993, p. 329-332). Obscuration of information increases obviously the difficulty to users.
- Flexibility of Closure: This kind of tasks relates to "Gestalt Flexibility" (French, 1951). It requires Two-Hand Coordination, to find hidden pictures in a snow scene, and to find simple figures embedded in the complex scene. The subject should "suppress the separate configuration for two hands and combine them into a single configuration" (French, 1951, p.212). This factor reflects "freedom of Gestaltbindung" and describes "flexibility in manipulating several more or less irrelevant or conflicting gestalts." (Thurstone, 1944, p.111)
- Perceptual Speed: These tasks require speed in finding a known visual pattern, or in accurately comparing one or more patterns, or in a visual field such that the patterns are not disguised or obscured.

There are some other factors which should be studied further according to Carroll:

- Serial Perceptual Integration: The ability to apprehend and identify a visual pattern when parts of the pattern are presented serially or successively at a high rate.
- Spatial Scanning: Speed in accurately following an indicated path through a visual pattern.
- Imagery: The ability in forming internal mental representations of visual patterns, and in using such representations in solving spatial problems.
- Length Estimation: The ability to make accurate estimates or comparisons of visual lengths or distance without using measuring instruments.
- Ecological Spatial Abilities: Lorenz and Neisser (1986) argue that there exist a series of variables which reflect ecological dimensions of spatial abilities, which are concerned to individual´s abilities to orient the self and to maintain a sense of direction. Three independent ecological dimensions are landmark memory, route knowledge and awareness of geographic directions.

1.6.5. Attention

"Everyone knows what attention is. It is the taking possession of the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others." (James, 1890, pp. 403-404). Attention refers to "selectivity of processing" (Eysenck and Keane, 1990, p. 97) and concentration (Reed, 1996, 50). Selectivity is necessary to keep users from becoming overloaded with too much information. Concentration means that more mental effort is required. Perception is directed by attention. Human action requires four types of attention: Selective attention, focused attention, divided attention, and sustained attention (pay attention over a long time, without rest, on detecting, monitoring or viligance). Attention is a single-minded, very limited mental resource that can be allocated to at most a few perceptual processes at a time. Only limited energy, only limited workplace, and only a single attention demons are available for one task or process. All information enters sensory memory, but only for very short time, and wait for further processing by attention. The limited capacity of attention can only process very limited sensory information. Then much information is lost. Providing too much information at the same time is useless. Performing two attention-demanding tasks is difficult. (Anderson, 1990, p. 52)

Study on attention relates to users´ selectivity and mental effort or load. The initial theories which have developed in the information-processing approach claim that there is bottleneck in selectivity, i.e., a stage at which only one message can be processed at a time. The key problem is where exists such bottleneck? Broadbent (1958) proposes filter theory. It specifies that the bottleneck occurs at the perception or pattern recognition stage, and attention works as a filter which precedes this stage. Treisman (1960) has modified the filter theory. She asserts that the filter attenuates the unattended message but important words or expected words could be recognized on the unattended channel in the thresholds which are low enough for the attenuated message. Deutsch and Deutsch (1963) suggest that the bottleneck should occur after perception and determines what is selected into memory. Norman (1968) further develops this theory, and argues that both the quality of the sensory information and importance determine what enters memory. Other authors suggest that there exist cognitive limitations in central processes such as thinking, retrieving, and acting. The additional central limitations prevent humans from selecting two manual responses at the same time. And the basic limitation is cognitive bottleneck, not motoric. These theories fail to agree on the location of the bottleneck. Perhaps, they supplement each other. In perception there exists limitation or bottleneck, for example, visual reaction time often increases with display set size in speed-up detection tasks, or, when humans try to perceive multiple objects in the same sensory modality. In cognitive processes there exist also limitations, for example, a central bottleneck prevents humans from selecting two responses at the same time. Then the effort is shifted to emphasis on capacity of attention. Capacity theory stresses that the amount of mental effort is concerned with how effort is allocated to different activities. Capacity theory supplements bottleneck theories, and proposes that the human ability should be limited if the action requires more mental effort than that is available.

Duncan (1996) argues that visual attention is a high-speed serial process, which deals with one object after another at the rates of a few dozen milliseconds for each item. Attention is a slowly evolving state, in which multiple brain systems settle together on the selected object. Of many brain systems responding to visual input, perceptual and motor, cortical and subcortical, many are competitive within each system. A gain in activation for one object means a loss to others. Attention itself is the product of such cooperative and competitive information integration process that takes place via bidirectional influences among systems interconnected brain regions. Design cannot reduce users´ attention by changing single factor of user interface. It means that designers should try to reduce such information competition, to provide limited visual objects which relates to users´ motivation and action, and to provide users with the easy way of logic thinking, deciding, retrieving, and acting. For example, for focused attention, design should reduce the unattended stimuli, and for divided attention, design should reduce the similarity of stimuli and task difficulty and employ user practiced action (habits). Design should employ automatic processes instead of controlled processes in man-machine interface design. Automatic processes mean the familiar, highly practiced tasks, low levels of cognitive processes or minimal analysis or synthesis. Automatic processes involve no conscious control, demand little effort, perform several operations simultaneously or in no particular sequential order, and relatively fast. That is, to find well-learned way of action or habitual way of action. In contrary, controlled processes refer to difficult tasks with many variable features, or unpracticed tasks. They require conscious control, perform sequentially, one step at a time, relatively slow, with intentional effort, and consume many attentional resources.

1.6.6. Perception in Human Goal-Directed Action

1.6.6.1. Perceptual intentionality

In human action, perception is mostly unconscious process of organization and interpretation of information. Perception is closely tied with most aspects of human action. Perception depends not only upon stimuli (information), but also upon human action desire, interest and attention which meet a specific selection from various external stimuli, and upon memory of prior knowledge and experience which are integrated with the sensory data. Expectation and anticipation all affect the attentional control and contents of perception. For example, perception of a table: If you want to design a table, what you perceive may be its structure, size, materials, color, and manufacturing. If you want to use a table for writing, you may perceive whether it is big enough and comfortable or not. It is always important to recognize users´ desires and intentions.

1.6.6.2. Features of human perception in everyday life

Perception is a prerequisite for human action. Based on sensory information (the layout, structures, forms, textures, materials, colors, the relation between the user and the environment), the user build a mental model or a representation of the perceived objects and the operation process. This mental model involves mainly an orientation, and action-related abstract or summary of information about an object, an event and action courses. Designers should take such user mental model as the design model. What should be perceived, when and how, are fundamental questions for designers. When you want to open a door, you may not perceive them as geometric lines, rectangles, but recognize as cues for opening, and for action: the round thing on the door is handle, and can be rotated for opening the door, the small slot under the door handle is the door lock, and the small round thing near the door may be button of door bell. You learn these by opening many doors, and obtain experience. You are unconscious how you open the door because all these processes have become habits. You pay little attention when opening the door. When you come at a door you have never seen, you recall the door models and the manners of opening in your memory. You expect or imagine on your experience that there should be these things on any door, and you want to find them at certain positions. You expect that these settings are similar and familiar with the knowledge of doors in yours mind, and expect to recognize them without effort. However, if a door is so designed that it is very difficult to find these settings on the door, you will lose your temper. That is why user´s perceptual habits or programs are important for designers. These programs (called schemata) of users´ perception determine the usability of artifacts to some extent. There exist differences of individual perceptual abilities, depending upon physiological differences, education, perceptual learning, experience, and the environmental condition.

1.6.6.3. Perceptual anticipation and expectation

Neisser (1976) emphasizes that mental schemata continuously predict and accommodate to events in the environment in a dynamic, interactive manner. To an extent, people tend to organize the sensory input on the basis of anticipations, expectation, and past experience (Schiffman, 1990, p. 310). "We cannot perceive unless we anticipate, but we must not see only what we anticipate" (Neisser, 1976, p. 43). "Perception itself depends on cognitive structures — anticipatory schemata — that actively direct perceptual exploration because they are prepared for certain types of information" (Neisser, 1976, p. 105). This way, perception results in a perceptual readiness to organize the visual input toward the desired state. In other words, the observer expects (or is set) to perceive a particular thing (Schiffman, 1990, p. 306). Expectation here is due to the prior experience as to what "should be there", and enables a meaningful interpretation and perception as to what "is there" (Coren, Porac and Theodor, 1986). Their effects are complicated. On a given detection trial, the task is to decide whether the sensory impression of observer´s own is due to the actual presence of the signal within a noise background, or from noise alone (from SN or N distribution). If the signal occurs in almost every trial, then the observer will come to expect a signal almost always, and the probability of false alarms will be higher than if no such expectation. In contrast, if the signal is rarely present, the result might be much more "no" responses when, in fact, the signal was present (Schiffman, 1990, p. 18). That is, experience can either aid or hinder recognition. It depends upon how well the current context matches your previous experience. Anticipation affects the response to the emotional event. The evidence is provided by experiments in which aversive stimuli (e.g., electric shock) are or are not preceded by a warning signal. 10-20% of subjects prefer unsignaled shocks (Averill and Rosenn, 1972) because advance warning is not always beneficial, and leads to anticipatory fear, and is stressful due to maintaining vigilance and preparatory coping efforts. (Frijda, 1987, p. 293). Therefore, designers must distinguish between the desired and undesired anticipation or expectation, and artifacts should offer relevant feedback in accordance to users´ action and expectation.

1.6.6.4. Perceptual learning

Perceptual learning is "an increase in the ability to extract information from the environment, as a result of experience and practice with stimulation coming from it“ (Gibson, 1969, p. 3). The major factor in perceptual skill seems to involve learning features specific to a particular stimulus that distinguishes it from other stimuli (Proctor and Dutta, 1995, p. 40-43). Well learned, experienced and highly practiced processes require little or no attention. It is called automatic processes. One can perceive objects automatically and do some other thing at the same time. Using everyday things is mostly automatic processes. Perception which requires attention is called controlled one. It must be controlled with consciousness and intentional effort.

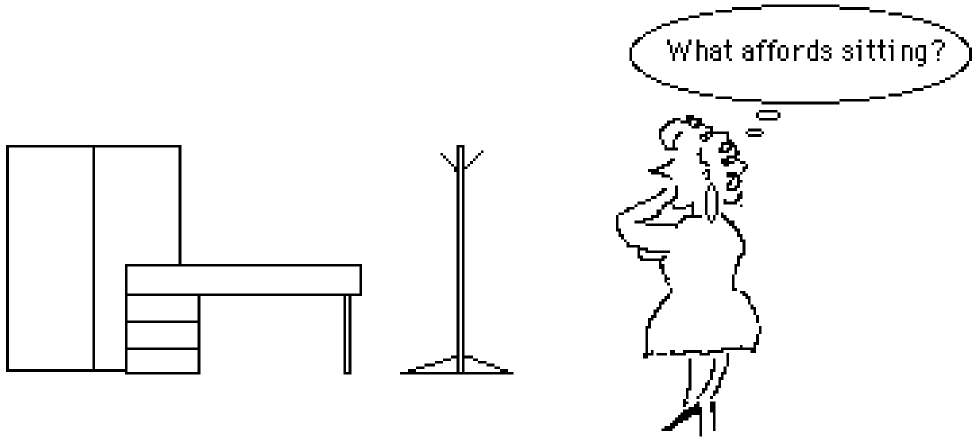


Figure 1.6-1: What one first perceives is the affordance of things.

1.6.7. Affordance

In using artifacts, what users first perceive is not the geometrical pattern, the depth and the color, but is what the environment offers them in relation to their action — affordance. People perceive different affordances on their own values and desires. For some people, a table affords sitting among other affordances, but for other people it does not afford sitting even they are very tired and there is no other things which can afford sitting. That depends upon users´ instrumental values. Things can afford wrong impression or illusion. Knives and hammers are constructed every simply. This is the first impression or perception of most people. They afford cutting and hammering — the second impression. Then, "I can use them to cut or hammer": wrong perceptual conclusion if you have never learned how to use them. Generally, people first perceive, then act, but it is not always the case by a knife and a hammer. Can you perceive with your eyes how much force should be exerted before hammering? Not always. You have to hammer first, then perceive, and modify your action. If you do not take care in an unusual situation, you would be hurt by it. Such artifacts provide the negative affordance and illusion for action. Many of these mistakes are caused by their design. Design for users´ perception is a big problem. Maybe, it should be written that "Knife (or hammer) can hurt your hand" on them.

1.6.8. Visual Illusion

When users are lack of perceptual knowledge, illusion may happen, for example, cues to space are lacking, distorted, illusion may result. Perceptual psychology has found a variety of visual illusions (Schiffman, 1990, p.375). The general theoretical emphasis is on the multiple determinants of illusions. Carroll (1993, pp.357-358) summarizes the findings of Coren et al on the basis of 221 observers to 45 illusion configurations as follows:

- Shape and direction illusions. "This grouping predominantly includes distortions in apparent shape, parallelism, and colinearity, which seem to arise in patterns with numerous intersecting line elements. . . . The Poggendorff, Wundt, and Zöllner illusions are characteristic of this class."
- Size contrast illusions. "This classification . . . represents those illusory distortions in which the apparent size of an element appears to be affected by the size of other elements that surround it, or form its context . . . The Delboeuf, Ebbinghaus, Jastrow, and Ponzo illusions are characteristic of the illusions on this factor."
- Overestimation illusion. "The illusions that show the highest loadings on this factor include all the apparently longer versions of the Müller-Lyer illusion, both parts of the Baldwin illusion, the apparently longer segment of the Oppel-Kundt illusion."
- Underestimation illusions. "Since it includes most of the apparently shorter segments of the Müller-Lyer illusion, the apparently shorter segment of the Oppel-Kundt, and the horizontal-vertical illusions, it seems to be a factor that is the complement to Factor III (the overestimation illusions), representing predominantly underestimation of linear extent."

- Frame of reference illusions. "We have tentatively identified this as a frame-of-reference factor. If this interpretation is correct, illusions like the rod-and-frame ought to fall into this classification. Further experimental investigation is clearly necessary to specify this grouping more clearly." (Coren et al., 1976, pp. 134-135).

For Schiffman (1990, p.403), two primary classes of illusion are proposed: optical-retinal components, and cognitive components.

- Optical-retinal components refer to the structural factors that help account for illusion effects, including subjective curvature, retinal blur, retinal interactions, and differential filtering of certain spatial frequencies.
- Cognitive components involve the perspective-constancy mechanism, attention and learning.

Industrial design distinguishes a desired illusion and a undesired one. Desired illusion may cause curiosity. Violating users´ habits or perceptual experiences can cause illusion in some cases. An example is a ball point pen shown in Figure 1.6-2. Four general ways to pull in/out the ball point are shown in Figure 1.6-2A. However, the ball pen B shows another mechanism. Many people looked at it for one or several minutes, and did not know how to pull in or out the ball point. The correct way is shown in this figure. Such design may be unconscious or conscious. What is the goal of its design?

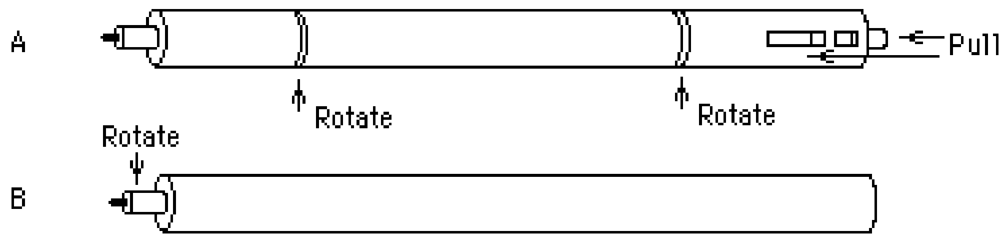


Figure 1.6-2: Ball pens.

1.6.9. Irrationality of Users´ Perception

Human Perception has a rational aspect in the perceptual processes. However, it has also a irrational aspect. (1) There is no standard affordance in perception because users have very different perceptual intentionality. (2) Information refers to the meaning that relates to user´s perceptual intentionality and action. Users perceive information from the layout, the structure, the form, the color, the texture, the material, and the relation among the user, the environment, and the artifacts, which relates to user´s goal and action. (3) Because of different learning and experience, users have different perceptual abilities. (4) Attention is a limited resource. There is a bottleneck in attention. Designers must find out where is the bottleneck, how many pieces of information users can perceive at a time without effort. (5) Sensory memory has the limitation (7±2 chunks). (6) There may exist perceptual illusions. (7) Users have different perceptual knowledge which depends upon learning.

SECTION 1.7: COGNITION

1.7.1. Cognition

Cognition refers "knowing" and "thinking," and involves every mental processes and structures that can be described as an experience of knowing (or as mental information processing), such as perception, learning, remembering, thinking (reasoning), which relate to language, concept formation, planning etc., and also include decision-making and problem-solving in the wide sense.

1.7.2. Memory Structures

1.7.2.1. Knowledge representations in human memory

How do people represent knowledge? According to Paivio (Anderson, 1990), there are two mental codes for representing knowledge. One code is for images or mental pictures, another is for words. Images are represented in a form analogous to the form we perceive. Some ideas are more easily represented in mental pictures, and others are represented in more symbolic forms (words). Symbolic representations are chosen to stand for something and does not perceptually resemble what it represents. This theory is known as dual-code hypothesis. Visuospatial information may be processed mainly in the right hemisphere and linguistic information may be processed mainly in the left hemisphere of right-handed people. Shepard and Metzler´s (1971) functional-equivalent hypothesis asserts that images are represented in a form which is functionally equivalent to percepts (perceived stimulus). Anderson and Bower (1973) propose the propositional hypothesis. They suggest that both image and words are represented in a propositional form. The proposition retains the underlying meaning of the images or the words without any perceptual features of either. Kosslyn (1994) suggested that images may involve both analogous and propositional forms of knowledge representation and both forms influence the mental representation and manipulation of images. Philip Johnson-Laird (1983, 1989) proposes a synthesis model, that is, mental representation may take three kinds of forms: propositions, mental models, or images. Propositions are fully abstracted representations of meaning. Mental models are spatial and temporally analogous to percepts. That can be viewed from any aspect, and is the generalized information of any category of objects (e.g., tables). Images are specific representations of concrete objects viewed from a particular angle. Some researchers assert that people may form imaginary maps by their physical interaction with their environment and by navigations through it even they have not seen the whole. Such internal maps are called cognitive maps, which may offer internal representations to simulate particular spatial features of the external environment (Rumelhart & Norman, 1988). Generally, it is suggested that knowledge may be represented in the form of proposition and images.

The features of human memory indicate that information representations in human memory are an abstraction or meaning, which is significant about an event, the meaning of a sentence (not the exact words and sentence), and the abstract representation that captures the meaning of a picture (not the exact visual details or spatial relations in a picture). It neglects other unimportant perceptual details. This is meaning-based representations, and is different from the perceptual-based representations. Human memory capacity seems much better for visual pictures than for words and sentences (Shepard, 1967). In Standing´s experiment, subjects can remember 73% of 10,000 pictures (Anderson, 1990, p. 114-118). That means, if design offers too much information, especially texts, to users, it is meaningless. What users need is the meaning which relates to their actions.

Imagery, especially visual imagery, is the mental representations of objects and events which are not currently being sensed by the sense organs. Mental imagery can represent things that do never exist or we have never seen. Imagery is subject to interference from percepts. Visual percepts may interfere with tasks involving manipulating visual imagery. Propositional code seem less likely to influence mental representation than imaginary ones

1.7.2.2. Two kinds of knowledge

Philosophers of classic epistemology, which studies the nature, origins and limits of human knowledge, distinguished between two kinds of knowledge structures, i.e., declarative knowledge and procedural knowledge. Declarative knowledge, called "knowing that", refers to factual information we know about objects, concepts, ideas, and events in the environment. Procedural knowledge, called "knowing how", is procedures or action courses which can be implemented.

1.7.2.3. Declarative and procedural learning

Learning is closely related with memory. For Johnson-Laird (1988, p. 129), learning "is normally a relatively permanent change that occurs when, as a result of experience, you become able to do something that could not do before, or able to do it better." In fact, it is difficult to define what learning is. In recent years, psychologists prefer to distinguish between two categories of learning: facts and procedures. Learning to use artifacts implies both the declarative and the procedural learning. According to Anderson and Fitts (Anderson, 1990), procedural learning, called skill acquisition, involves three stages: cognitive, associate, and autonomous stage (Section 2.7: Skilled action, artifacts and learning). Designers´ concern is how to guide learning process, and how to make learning easier.

1.7.2.4. Three kinds of memory

Broadbent (1958), Baddeley and Hitch (1974) propose that there are three distinct systems of memory: a set of sensory stores, a working memory and a long-term memory. Information which comes from sensory stores flows into the working memory for further processing, and well-learned knowledge is stored in the long-term memory. When you are now thinking about the well-learned information, then it comes from the long-term memory into the working memory. Information which is stored in long-term memory is only meaningful knowledge for humans. The short-term memory, or called temporary working memory, holds only the most recently activated portion of information from long-term memory for daily activities. Miller (1956) found that the capacity of the short-term memory appears to be 7 chunks ± 2 of information. Chunks consist of individual items which have been learned and stored as a group in the long-term memory, for example, such as strings, pictures, items of menu etc. The short-term memory is employed for control processes such as rehearsal, coding, decisions, and retrieval strategies. Information in the short-term memory will be lost within 20 to 30 seconds if it is not rehearsed. It is not because of memory decay, but of interference (Reed, 1996, 110).

1.7.2.5. Means of representing knowledge in memory

What are the means of representing both declarative and procedural knowledge in human memory?

- For declarative knowledge (which take the form of words, other symbols, propositions, or images), the basic unit of symbolic knowledge is the concept (e.g., TV set), which may be organized into schemas. Schema is an abstraction from individual instances to generalizations about a category. A schema has slots which specify values of the object on the attributes, such as TV functions, colored or black/white, channels, size, and power supply. "Schemas are designed to facilitate making inference about the concepts" (Anderson, 1990, p. 135). If we know that something is a TV set, we use the schema definition to infer that it consists of a screen, a switch of power supply, buttons of channels, and the antenna (Anderson, 1990, 133-143; Minsky, 1975; Bobrow and Winograd, 1977). There are two forms of schemata: frames and scripts. Minsky (1975), an AI researcher at MIT, proposes the term frame, which is a structure for representing a sequence of events used in stereotyped setting or situation (e.g., being in a office). Event schemata are called scripts by Schank and Abelson (1977). Scripts are used to describe stories or sequences of actions. An alternative model for representing declarative knowledge is a semantic network suggested first by Collins and Quillian (1969). The semantic network consists of nodes and connections. The nodes represent concepts. The connections between nodes are called labeled semantic relationships.
- For procedural knowledge representations, Newell and Simon (1972) propose the production system. A production is a generation and output of a procedure. Procedural knowledge can be represented in the form of sets of rules that govern a production.
- Anderson (1976) proposes ACT (Adaptive Control of Thought), ACT* and ACT-R theory. That is the integrative model for representing both declarative and nondeclarative knowledge. (Section 4.7)
- In 1980´s occurred the conncectionism model of knowledge representation, or called the parallel distributed processing (PDP) model. This model proposes that information is stored in the form of various patterns of connection strengths within a network. Such patterns of connections are distributed across the brain. Its information processing is through parallel processing of activated connections. (Section 4.7)

1.7.2.6. Are representations necessary?

On the other side, Winograd and Flores (1986. p.99), Heidegger and Maturana (1978) claim that biological cognitive systems do not operate by manipulating representations of an external world. Human cognition includes the use of representations, but is not based on representation. They claim that experts may manipulate representations as one part of successful activity, but it is fruitless to search for a full formalization of the pre-understanding that underlies all thought and action.

1.7.3. Thinking and Reasoning

Thinking implies mentally representing and manipulating actions, including desires, beliefs, motivation, and various action processes. Mayer (1991, p. 7) claims that the concept of thinking should involve three basic ideas:

> 1. Thinking is cognitive, but is inferred from behavior. It occurs internally, in the mind or cognitive system, and must be inferred indirectly. 2. Thinking is a process that involves some manipulation of or set of operations on knowledge in the cognitive system. 3. Thinking is directed and results in behavior that "solves" a problem or is directed toward solution. (Some types of thinking may not be directed, such as autistic thinking, daydreaming, or the fragmented thinking, etc.)

"Reasoning refers to the processes by which people evaluate and generate logical arguments. Logic is a subdiscipline of philosophy and mathematics that tries to formally specify what is means for an argument to be logically correct" (Anderson, 1990, p. 290). Design distinguishes between desired and undesired reasoning in artifacts. Undesired reasoning makes much more difficulties for mental load in user´s performance. The basic tasks of thinking are inductive and deductive reasoning.

1.7.3.1. Deductive reasoning

In deductive reasoning, the user is required to draw inference from premises or combinations of premises. "A world without deduction would be a world without science, technology, laws, social conventions and culture." (Johnson-Laird and Byrne, 1990). Deduction in using artifacts often occurs in the form of application and evaluation. There are several forms of deduction as follows.

Categorical syllogism tasks: A syllogism is normally any argument that consists of two premises and a conclusion. A kind of syllogism deals with the meaning of quantifiers such as all (universal quantifier), some (particular quantifier), not or no (negatives). A simpler and older kind of quantified deduction is called the categorical syllogism which can be found in Aristotle´s writing, for example, All X are Y, All Z are X, therefore All Z are Y. Examples include False Premises, Logical Reasoning, and Puzzles.

Linear syllogism task: In linear syllogism the premises state comparisons of entities in terms of attributes that can vary continuously. Operators are words or symbols (<, =, >). Examples involve Conditions, Reasoning, Syllogisms, and Symbol Manipulation. This kind of reasoning occurs frequently in computer programming.

Johnson-Laird (1983) and Byrne (Johnson-Laird and Byrne, 1990) have proposed the mental theory to explain deductive reasoning. People reason by constructing the model of the state of affairs which is based on the meaning of the premises and the experience or general knowledge. The model theory suggests that errors occur because people have a limited working memory; the more models users have to construct to reach a valid conclusion, the greater the likelihood that they will tend to make errors. Errors can arise as a function of difficulties at any of the stages; errors can arise if one or more possible models of the premises are neglected. Users´ difficulties in reasoning lie in that language may be ambiguous in its information, that words are often imprecise, and users may not find explicitly the correct meaning from the context. These factors may misguide valid reasoning. Such problems can be found in writing user´s manuals which lead to users´ difficulties in reasoning.

1.7.3.2. Induction

In Induction reasoning, one is required to inspect a set of instances and to induce a rule or a conclusion governing the instances, or a particular characteristics of the instances, such as a relation or a trend. Inductive tasks always involve at least one deductive step in arriving at a conclusion, classification, or other required response. Carroll (1993, p. 211-212) suggests six groups of inductive tasks in intelligence tests in which examples are Verbal Concept Formation, Rule Discovery, Seeing Trends and Series, Finding Similarities, Classification, Grouping, Inference and Mapping, and various Analogies. Most of these tasks can be found in the operation of computers.

1.7.3.3. Errors in reasoning

One of designer´s concerns is what, why and how users make errors in reasoning processing, from which one may find methods to deal with them.

- Novice programmers have difficulties in computer programming. Ebrahimi (1994) has investigated 80 novice programmers, and found that in Pascal the highest percentage of errors occur in the use of Logical IF, Input, and REPEAT...UNTIL loop, IF with "=" operator, Logical IF and DO...WHILE loop. In LISP are in the use of Logical IF, Compound IF and DO loop. The computers have their own ways of logical behaviors which are different humans for the same problems. He claims that the semantic misinterpretation of Language Constructs and misunderstanding of Plan Composition are the two major causes of errors.
- Braine´s natural deduction theory (1978) asserts the deductive reasoning is mediated by basic, abstract rules or schemata. The premises are comprehended and encoded into abstract schemata or rules by which inference can be drawn. There are three types of reasoning errors. Comprehension errors occur if the premises or conclusion are misconstructed. Heuristic inadequacy errors occur if the conclusion to reasoning problem fails to be reached because the strategies for coordinating numerous sets of reasoning schemata are inadequate (the problem is too difficult). Processing errors result from lapses of attention, or a failure to hold relevant information in working memory and slips in the application of schemata.
- Pragmatic reasoning schema theory (Cheng, Holyoak, Nisbett, and Oliver, 1986) claims that people use relatively abstract, context-specific schemata in solving the selection task. Errors in reasoning occur because of two sources. If situations cannot be mapped easily into pragmatic schemata, or because the inference generated by schemata since the rules in the schema do not always conform with those sanctioned by propositional logic.

1.7.4. Human Abilities in The Domain of Language

1.7.4.1. Human ability factors in language

According to Carroll (1993, pp. 145-195), human language ability factors involve Language Development, Verbal or Printed Language Comprehension, Lexical Knowledge, Reading Comprehension, Special Reading Comprehension, Reading Decoding, Reading Speed, Cloze Ability, Spelling Ability, Phonetic Coding, Grammatical Sensitivity, Foreign Language Aptitude, and Communication Ability, Listening Ability, Oral Production, Oral Style factors, Writing factors, and Foreign Language Proficiency. What I am interested in is the following three groups of abilities which relate to industrial design frequently.

1.7.4.2. Reading comprehension

For Carroll (1993, pp. 161-162), General Reading Skills involve "Letter-Word Identification, Passage Comprehension, and Word Attack, Reading-Decoding and Reading-Understanding, Similarities, and Information." When users read something, they is going to find and to understand goal-related information. They do not want to attack words, or to decode ciphered text. Easy writing makes easy reading. Only experienced people can write simple manuals.

1.7.4.3. Special reading comprehension

If reading comprehension is not easy, humans have to use special abilities to attack the text. Carroll (1993, p. 163-164), Spearritt, Spalding and Johnston (1977) and Frederiksen (1982) summarize the following special reading abilities which should be avoided in writing user manuals:

- Letter and Word Recognition.
- Word Sense / Phonics.
- Decoding Accuracy, which depends upon the understandability of a text.
- Pure Sentence Comprehension: Presumably, only children with very poor reading ability had difficulty responding.
- Semantic Context: short paragraphs are presented, each describing a situation that the child has to understand.
- Extrapolating a discourse representation: When the meaning of a text is not expressed directly, readers have to use this ability to extrapolate the meaning.
- Semantic integration of antecedents with a discourse representation: If the meaning of a text is not directly expressed, users have to guess it from its semantic context.
- Speed in applying context.

1.7.4.4. Reading decoding

The ability of reading decoding is independent from other skills in the domain of language ability. The word recognition skill can be divided into two processes: reading decoding accuracy, and a reading decoding speed, which are all independent from more general verbal comprehension, spelling, and reading speed factors. Word recognition or decoding involves the following specific skills (Frederiksen, 1978, 1982; Carroll, 1993, p.165):

- Grapheme Encoding, Letter Recognition.
- Multiletter Array Facilitation, Perception of Multiletter Units (e.g., sh, tion).
- Depth of Processing in Word Recognition.
- Phonemic Contrast, and Decoding.

1.7.5. Language as Action: Creation of Consensual Domain and Coupling

Traditionally, language is understood as a tool of communication and conveying information. According to Maturana, language is a kind of human social action. It is directed towards the creation of mutual orientation. In using language, people create a cooperative domain of interactions. "When two or more organisms interact recursively as structurally plastic systems, . . . the result is mutual ontogenic structural coupling. . . For an observer, the domain of interactions specified through such ontogenic structural coupling appears as a network of sequence of mutually triggering interlocked conducts. . . I shall call the domain of interlocked conducts . . . a consensual domain" (Maturana, 1978, p. 47). "The basic function of language as a system of orienting behavior is not the transmission of information or the description of an independent universe about which we can talk, but the creation of a consensual domain of behavior between linguistically interacting systems through the development of a cooperative domain of interactions." (Maturana, 1978, p. 50).

1.7.6. Meaning and Understanding: Creation of Commitment

Words have meaning. What does meaning mean? There are several theories of meaning. Concrete words mean what they refer to, and the meaning of a word is inherent in its image, the objects, the things, the people and so on. What does concept mean? The meaning of concept is the abstracted common information about a category of things. Componential theory claims the meaning of a word can be understood by disassembling the word into its meaning components, and these components are sufficient to define and to understand the concept of the word (Katz, 1972). Prototype theory claims that the meaning of a word is derived by listing its characteristic features, and they describe the typical model of the word (i.e., a prototype) (Rosch & Mervis, 1975). However, these theories deal only with the semantics. In fact, meaning of words relate to human action. Winograd and Flores claim that meaning is fundamentally social, and cannot be reduced to the meaning-giving activity of individual subjects. "Meaning is created by an active listening, in which the linguistic form triggers interpretation, rather than conveying information" (Winograd and Flores, 1986, p. 57). "Our ability to think and to give meaning to language is rooted in our participation on a society and a tradition" (Winograd and Flores, 1986, p. 61). Understanding something or a text does not mean to obtain information simply, but means to create commitment. Understanding a command of a computer means to perform those operations that the user intends to invoke in giving the command (Winograd and Flores, 1986, p. 123). By using a hammer or driving a car, there exists not such a question. However, by using computers, the central issue is the commitment created by interaction with computers in using language. The computer is passive, and can not enter into a commitment.

1.7.7. Idea Production

The ability to produce ideas is one of the important features of human cognition. "An idea can be expressed in a word, a phrase, a sentence, or in any verbal proposition, but it may be something expressed in a gesture, a figure, a drawing, or a particular action" and "musical phrase or composition" (Carroll, 1993, p. 394). He (p. 394-438) distinguishes Ideational Fluency, Naming Facility, Associational Fluency, Expressional Fluency, Word Fluency, Originality/Creativity, Figural Fluency, and Figural Flexibility, in which Naming Facility and Sensitivity to Problems are frequently required in using computers:

- Naming Facility (NA): This is the ability "in evoking and reporting an accepted name for a given thing, as cued by the thing itself or a picture of it, or in some other appropriate way." The types of tests involve Color-Naming, Form-Naming, Given First Name. Naming is a rather difficult task, for example, most colors are not named in the books of color spectrum, and so many people have the same names. Naming is frequently required by working with computers, to name a variable, a procedure, a program, a file, or a function key. Is it possible to create a naming mechanism in the computer? The demand for user´s naming abilities appears to involve several features: (1) Given the attributes, a corresponding object must be named. (2) Given the action, an agent must be named (Carroll, 1993, p. 411). (3) Given the function of a variable, a procedure, a program, an object must be named respectively. (4) Given the content of a file or a program, its title must be named.

- Sensitivity to Problems (SP): This is the ability of "success in thinking of, and reporting solutions to 'practical' problems, or new ways of using objects." Guilford asserts that this is "the ability to anticipate or be sensitive to the needs of or the consequences of a given situation in meaningful terms" (Carroll, 1993, p. 421).

1.7.8. Irrational Cognition

Human cognition have certain rational processes. Thinking, reasoning, reading and comprehension are defined as the rational mental behavior. A rational human should have the above standard cognitive abilities such as logical reasoning, and idea production. Up to now the design of human-computer interface depends up such rational mental model. However, human cognition has also the irrational aspect. (1) Humans have different cognitive preference. It is difficult for some people to understand concepts. It is hard for some people to understand procedures. (2) People understand different meanings from the same object. There exist no "standard" meaning, no "standard" understanding process. (3) Some people think pictorially, and other people think logically. (4) "A picture is better than hundred texts." It is easier for most people to find out related information in a picture than in texts. (5) People think in different speed. (6) Although some standard ways of reasoning are defined, most people do not think and reason in such a way. In everyday life, most people employ their experiences. (7) It is rather easy for most people to make errors if they employ the scientific logic.

When users interact with computers, they have their own way of cognitive behavior, called the normal way of irrational thinking, which includes some rational part, personal experience, emotional reaction, fantasy, imagination, autistic thinking, daydreaming, or the fragmented thinking, etc. Users have different backgrounds of education, knowledge, and experiences. They make errors in reasoning, in understanding, and in communication. Such a normal way of irrational thinking should be one of the bases of designing user-computer interface. That is, user-computer interface must have tolerance to users´ irrational way of thinking and reasoning, or must employ such irrational way of thinking.

SECTION 1.8: EMOTION

1.8.1. Concepts of Emotion

Emotion is another important aspect of human action. Many authors assume that emotion relates to evaluation processing and to certain forms of evaluation. Emotion is voluntary, and not easily controllable or changeable. It can either be an aspect of an action, or dominate action so as to become emotional action. In study on emotion, another class of terms are employed which are rather different from action theory. Various definitions of emotion suggest that emotion is mediated and regulated through neuronal and hormonal systems, and can involve four components. (1) Affective experiences and feeling state. (2) Cognitive information processing. (3) Motivational component, including desire, concern, action readiness and tendency. (4) Ways of motor and expressive behavior. The affective component is the central one. In various emotion theories, these components are represented in different ways, and there are very different understandings about the relation between emotion and cognition. Generally speaking, there are two categories of emotion theories: cognitive emotion theories and organism emotion theories.

1.8.2. The Classification of Emotion

Mees (1991, 1985), Ortony, Clore and Collins (1988) classified the concepts of the word "feeling" in spoken language into three classes of emotions (Laucken and Mees, 1995, p. 25-32) as follows. Mees assumes that all kinds of feeling imply a positive or negative evaluation.

Based on desires and goals, evaluation of events causes event-related emotions of "satisfaction or unsatisfaction."

The attributive emotions are related to the evaluation of DO/LET of the responsible subject in relation to norms (rules of the DO and the LET, social customs, and traditions, i.e., "should") and standards (quality criteria for performance). The attributive emotions imply the common evaluation elements of approved or unapproved DO/LET, and are dependent upon the type of the responsible subjects: the SELF, or the OTHER people.

The relational emotions are related with evaluation of PERSONS/OBJECTS (not with DO / LET) toward a VALUE (or belief), or toward PREFERENCE (like or dislike). Two types of relational emotions involve (1) admiration and despise (VALUE); (2) Attractive emotions (LIKE/DISLIKE).

1.8.3. Definition of Emotion and Emotion Processes

1.8.3.1. Definition of emotion

There are many theories on emotions. The following is mainly based on Frijda (1987). According to Frijda (1987, p.466), emotions are defined as "changes in readiness for action as such (we called these changes in activation), or changes in cognitive readiness (they have come under investigation as attentional arousal), or changes in readiness for modifying or establishing relationships with the environment (we called these action tendencies), or changes in readiness for specific concern-satisfying activities (we called these desires and enjoyment)." Basic emotions involve happiness, fear, sadness, surprise, anger, and disgust (Frijda, 1987, p. 85).

1.8.3.2. Concern: the alternative of action intention

Intention causes goal-directed action. What causes emotion? "Emotional action tendencies are felt as impulses, urges, and are states of readiness to achieve or maintain a given kind of relationship with the environment" (Frijda, 1987, p.75). Action tendencies are "the desired, to-be-achieved, to-be-maintained, or to-be-regained situation, they are not a true goal". They "are not an anticipated future state to be achieved, but one that should be obtain now." They are "concerns" (p. 80). Concern "is defined as a disposition to desire occurrence or nonoccurrence of a given kind of situation" (p. 335). Human concerns largely develop through experience, and are tied with specific environments, values and goals. Some concerns are linked to the general mode of functioning of the organism, and to the general observation of success of action (p. 467). Such concerns include cognitive assimilation, freedom for self-initiated action, and having experiences one is able to handle. (p. 335, p. 466). Concerns make themselves known only when actual conditions deviate from their satisfaction conditions to some extent, or when they signal a satisfaction condition that could obtain, as in acute desire or lust. (p.336).

1.8.3.3. The emotional process

The emotion process is shown in Figure 1.8-1. (1) The stimulus event is first perceived, and compared with the satisfaction conditions or sensitivities of subject´s concerns to evaluate the relevance. Mismatch between the satisfaction and perceived event results in four relevance signals (pleasure, pain, wonder or desire) indicating that action is called for. These signals claim attention to control the action. These signals initiate, maintain and terminate the action tendencies (Frijda, 1987, p. 77-78). (2) The stimulus situation is evaluated in regard to what the subject can do or cannot do. The context is evaluated for possibilities of coping and action. (3) Based on this information, urgency, difficulty and seriousness are evaluated, and combined in a signal of control precedence for dealing with the current event: interruption of the current action, or distraction when the action continues. From this information, action readiness change is generated. (4) The last step is to produce physiological change, and motor expression or overt action or cognitive action. (Frijda, 1987, pp.455-456). Emotional action tendencies can be conceived of as action programs in reflex-like, or stimulus-response fashion, such as the set of threat diminishing, of anger, or enjoying behaviors (Frijda, 1987, p. 75). These programs are linked to the mismatch signals under concern.

1.8.3.4. Output

Outputs of the emotional process include (1) overt behavior and physiological manifestations of action readiness change (physiological response affects behavior and behavior potential); (2) influence upon the flow of action control, control precedence; (3) emotional experience. Emotional experience consists of (1) awareness of situational meaning structure; (2) awareness of automatic arousal or dearousal; (3) awareness of state of action readiness as impulse and feedback from behavior; (4) perception of the horrible, the delightful or the enjoyable; and (5) awareness of control precedence or its complement; and (6) the response´s significance (Frijda, 1987, p. 463). In other words, the outputs of the emotional process is the largely experienced action readiness or unreadiness: impulse to flee, to strike or to embrace; lake of impulse, apathy, listlessness. (p. 469)

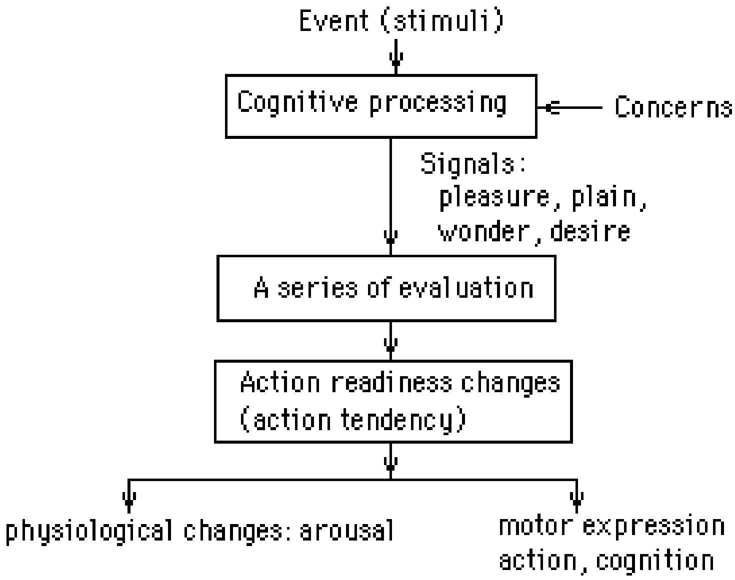


Figure 1.8-1: The emotion process (based on Frijda, 1987; simplified by Leshan Li).

1.8.4. Effects of Emotions on Human Goal-Directed Action

1.8.4.1. Goal change by emotion

In everyday life, emotion and feeling play an important role in drive of action. For example, Weiner (1986a, p.310) describes emotion as "prime motivers of most action," and emotion has a decisive mediation effect between situational conditions and individual action tendencies. The maximizing of positive affects (desire) or avoiding of the negative affects (undesired) are the highest regulative principle of behavior (Westermann and Heise, 1996, p. 290). Action goal will be so changed by strong activating an emotional state (intensity) that the current goal is neglected and substituted by the strong emotion. An emotional condition will lead to a goal alternative (Spies and Hesse, 1986), that is called an emotional interruption. Anderson formulates the following production rule:

"IF I suddenly feel extreme pain

Then set my goal to escape the pain." (Anderson, 1983, p. 163), (Westermann & Heise, 1996, p. 294).

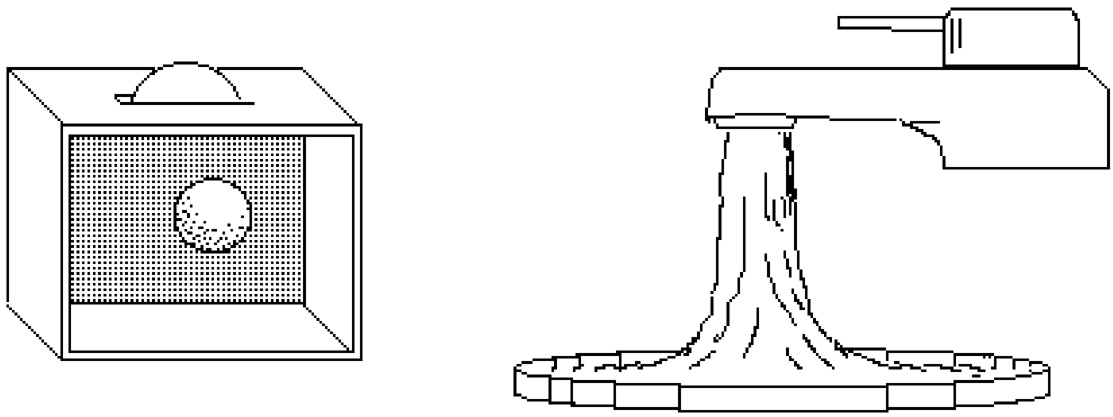
1.8.4.2. Irrationality of emotions in human goal-directed action (Frijda, 1987. p.118-121)
Emotions serve for concern satisfaction. Positive emotion can facilitate the execution of action. Generally, people act in a limited rationality, and they cannot reasonably do any more when they meet more difficulties, or more urgencies. Under over-excited emotions, they do much more, not based on reality, but on emotion, and cause behavioral disturbances, exhaustion and illnesses of adaption. Such irrationality is an important feature of emotional actions. "Emotion can cause some measure of belief in the efficacy of actions which will be believed in under other conditions," or called "emotion-instigated fantasy behavior." This kind of behavior produces "some satisfaction, and consists of imagined approach, avoidance, agonistic tendencies, and contributes to their action planning." (Frijda, 1987, p. 118). Such irrationality causes useless or dysfunctional actions: angry at unsolvable problems in the computer, irrational persisting in an action because emotional reaction is a last resource of user´s effort. The extreme irrational action is called state-oriented action by Kuhl (see Section 3.3 and 3.8).

1.8.5. Elicitation of Emotion
1.8.5.1. Unlearned emotional stimuli (Frijda, 1987. p. 271-277)
Emotions can be elicited by imagination and fantasies, and by one´s own actions. Some stimuli are considered unlearned emotional stimuli, for example, sudden (sharp rise time), intense stimuli: loud noise, light flashes, unexpected tactile stimuli. Unusual, unfamiliar stimuli generally tend to evoke curiosity, approach and exploratory behavior, or also tend to evoke apprehension or fear. Orienting response is elicited by novelty, unexpectedness and complexity. The same kinds of stimuli which evoke orienting and curiosity tend to evoke fear, apprehension or other distress if they are more intense, closer or in generally unfamiliar or unsafe context. Loss of orientation is seen as an innate source of distress. Loss of support is an fear stimulus. Fear can be understood as response to something that spells threat to some concern, joy as response to something that provides or promises some concern´s satisfaction. Fear is unlearned response to danger signals, even if it has to be learned what constitutes a danger signal. Mild panic is frequent in humans if losing back-front orientation in unfamiliar buildings (Katz, 1944). Distress or anxiety are evoked by internal or external conflict, by lack of congruence between expectations and events, by lack of control. Nonaggressive contact signs such as friendliness and smiling can be viewed a eliciting quietness.

1.8.5.2. Combined elicitation of events and concerns
For Frijda (1987, p. 271-282), most stimuli that elicit emotion are not innate, but as a result of previous experience or through cognitive activities. Emotion is elicited by constellations in which a stimulus event is relevant for one or more of the individual´s concern. Different emotions are evoked by different constellations, and not by different sorts of stimuli, nor by different sorts of concerns. What triggers grief is not only partner, but loss of a thing of importance. Partner, hope, desired position, and place of residence are among the things; attachments, life perspectives, self-esteem, and preference for a familiar environment are among the reasons for importance — that is, concerns which are related to values, needs, dispositions. Emotions result from match or mismatch between events and concerns. The major constellations on the elicitors of emotion are: loss, threat, challenge, frustration in its various overlapping meanings of blocking of goal directed activity, or of desired fulfillment, or decrease in expected reward (Yates 1962, Lawson 1965). Frijda (1987, p. 282-299) illustrates some concrete cases are as following:

- Thoughts, associations, and fantasies can be seen as stimuli, and can be proper elicitors of emotions. They also contribute to the impact of actual events.
- Expected or obtained outcome achievement can cause satisfaction. Nonachievement of an expected outcome causes disappointment. Lack of prospect for positive outcome achievement causes discouragement.
- Uncertainty whether or not an outcome will be achieved causes suspense.
- Recognition of fitness of objects to concerns cause enjoyment, including delight and pleasures, fascination, peacefulness, and pride. Recognition of unfitness as objects for concerns causes hatred, dislike, aversion.
- Imagination widens the scope of concerns for which a given event forms the substance of the significance of an emotional experience.
- Curiosity proper and fascination are considered as the concern of the desire and enjoyment types. Curiosity is orienting response toward occurrence of mismatch between stimuli and preexisting knowledge, experience and expectation. Figure 1.8-2 shows two examples of artifacts which cause curiosity.
- Sensation-seeking refers to the motivation to undertake risky activities, like dangerous sports or entertainment to obtain strong sensory or sensual experiences. It distinguishes four submotivations: (1) Thrill and adventure

seeking (mountain climbing, surfboard riding); (2) Experience seeking (liking new foods, unknown places); (3) disinhibition (dislike wild parties, drinking, sexual excitement); (4) Boredom susceptibility (dislike for predictable or boring situations). (Frijda, 1987, p. 348).



Money box: why does money disappear in the box? Water tap: from where does water come without pipe?

Figure 1.8-2: Design causes curiosity, fantasy, and imagination.

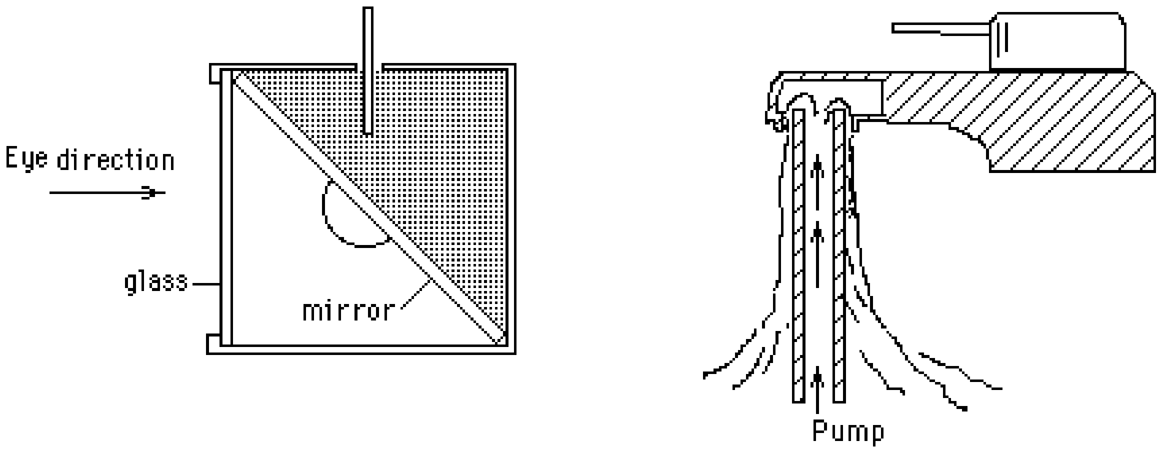


Figure 1.8-3: The answers to Figure 1.8-2.

SECTION 1.9: HUMAN MOTOR PERFORMANCE

1.9.1. Problems of Motor Control

Motor movements are the lowest level of the structure of an action. Typically, riding a bicycle, typing, and operating a keyboard involve mainly motor movements. It requires precise timing of movements, anticipation of motor requirements and consequences, the amount of force, direction, and duration of responses. Motor skill has a perceptual component. The study of motor skill relates to complex processes involved in controlling and coordinating movements. Industrial design distinguishes between the desired motor movement and the undesired motor movement. For example, some motor skills are required in assembly lines in factories, for eight hours a day, in high precise and speed. This is not human-centered design.

Figure 1.9-1: Simple digit keyboard in supermarkets: automatic motor skills can also cause great effort and difficulties.

Proctor & Dutta (1995, pp.100-130) suggest that three problems in motor control should be investigated:

- The degree of freedom: The degrees of freedom of the joints characterize the constraints on a movement. In general, the greater the degrees of freedom, the greater the complexity of the problem that must be solved by the motor system. The main ideas for design are (1) how to minimize the degree of freedom to simplify the movement; (2) to restrict the movements of some joints to construct rigid couplings between multiple degrees of freedom; it is called freezing of degrees of freedom. (Proctor and Dutta, 1995, p. 102-104).
- The sequential order: how sequences of movements are organized and timed.
- The perceptual-motor integration: The interrelations between perception and motor control is a key problem of motor dynamics: how does perception guide movement, and how does movement affect perception? Viviani and Mounoud (1990) found that moving a cursor to keep it in contact with a visually displayed target in two-dimensional space was more accurate when the target motion complied with the constraints that characterize the movements of organisms than it did not. A point moving on the screen can produce illusions of speed as a function of biological constraints. When its speed is varied according to biological constraints, the movement is perceived as having a uniform speed even though the actual speed of the point has varied by more than 200%. Conversely, if the point followed the same path at a constant speed, it is perceived as moving at a nonuniform speed (Viviani & Mounoud, 1992).

1.9.2. Motor Control

Motor control refers to the way that movements are executed, and are concerned with how the coordination and execution of motor acts are achieved and new motor skills acquired. There are two approaches to motor control: motor programming and dynamical approach. Motor programming approach emphasizes central control of movements. Dynamical approach emphasizes the mechanical properties of the body. For Lee (1977), the types of information necessary for guiding or controlling locomotor activities can be classified into three kinds:

- Exteroceptive: information about the layout of surface in the environment, and the position of objects or course of events. The important source of exteroceptive information is vision.

- Proprioceptive: information about the movement of body parts relative to one another, which is necessary for coordinated bodily actions, and is perceived through mechanical receptors in joints and within the vestibular system, but also through vision.
- Expproprioceptive: about the position of the body or parts of it relative to the environment. It is necessary for maintaining balance and guiding action through the world. Vision provides powerful information of this kind.

1.9.2.1. Motor programming

If feedback is integrated into the plan of action, the mode of control is called closed loop. Sensory feedback plays a role in the execution of slow movements. Lashley (1951) has noted that many rapid sequences of movements seem too fast for the feedback control. This mode of control is called open loop. Schmidt (1975) finds that unitary aimed movements can be made sufficiently fast so as to preclude the use of feedback. These findings suggest that the link between perception and action may be bypassed. Keele (1968) asserts that high-level plans or motor programs, which specify the muscle commands for particular actions, fulfill the role of guiding action. Schmidt (1975) asserts that these motor programs extend to entire classes of movement. To execute a particular movement from the class represented by a generalized motor program, values of its parameters or variables must be specified, for example, the force and duration of the strokes the muscle group to be used in signing your name.

Schema theory by Schmidt (1975) employs the view of the motor programming. According to Proctor and Dutta (1995, 109-110), when a class of movements is practiced, a recall schema specifies the initial parameter values in advance for generating the intended movement. A recognition schema serves as a referent of the fast movement against feedback. Discrepancy between the feedback and the recognition schema lead to learning and modification of the movement for slow positioning movement. Proctor and Dutta assert that four types of information contribute to the learning of the recall and recognition schemas, and are stored when a movement is executed with a generalized motor program: "Environmental conditions prior to the movement; parameter values assigned to the program; knowledge of the correctness of the outcome (essential to efficient learning); and sensory consequences of the movement." Schemas depend upon this information. "The schemas for a movement class will be learned better if a person performs a variety of movements within the class rather than just practices one specific movement in this class repeatedly." (p.110)

1.9.2.2. Dynamic approach

The dynamic approach emphasizes on coordinative structures between perception and movement. This coordinative structure is defined as “temporarily and flexibly assembled functional organization that is defined over a group of muscles and joints and that converts these components into task-specific coherent multiple-degree-of-freedom ensemble“ (Saltzman & Munhall, 1992, p.50; Proctor & Dutta, 1995, p.111). "Intrinsic dynamics" refer to the constraints which reflect the existing capacities a person brings to a new task. "Behavioral information" refers to the movement pattern to be performed in the task (Zanone & Kelso, 1992). If the behavioral information is consistent with the intrinsic dynamics, the tasks should be easy to perform. Otherwise, conflict between the both makes it difficult to perform the task.

Skill acquisition in the dynamic approach involves modification of the coordinative structure. This modification can occur through the actions of graph and dynamic parameter dynamics (Saltzman & Munhall, 1992). The parameter dynamics control the acquisition of the parameter values that are appropriate for the particular action classes. Graph dynamics are the processes that cause changes in the architecture of a system. Saltzman and Munhall (1992) suggest that acquisition of skill likely involves graph-dynamic processes that incorporate the state variables and parameters specifically associated with the tool. According to Zanone and Kelso (1992), the intrinsic dynamics of the action system serve as the general foundation of coordination on which learning of the specific control requirements for the task must be based. Intrinsic dynamics can influence the nature of learning in the manual coordination task.

1.9.3. Feedback

Feedback relates to action evaluation. Action evaluation is based on movement-related sensory information. Proctor and Dutta (1995, p. 115) introduce four categories of movement-related sensory information: (1) "Information available prior to the initiation of an action can influence the nature of the movement plan"; (2) "Information available during or after action is important for the acquisition of skills"; (3) "Intrinsic feedback is inherent in creating a response," and (4) "the extrinsic feedback can be provided to augment the intrinsic feedback." (p.115):

- Intrinsic feedback involves (1) vision; (2) proprioception from mechanoreceptors which provide information about movement, pressure and position; (3) the vestibular sense which respond to movement and changes in position of the head to maintain posture and balance. When motor performance becomes automatized and less reliant on feedback (more fluent and open loop), the actor reduces the use of sensory feedback. (Proctor and Dutta, 1995, 116).
- Extrinsic feedback is described as "knowledge of results" (KR) by Proctor and Dutta (1995, p.121). KR is "knowledge about the accuracy of performance after a response has been completed." "The more KR provided, the better learning will be." However, Winstein and Schmidt (1990) found that reduced frequency of KR enhanced motor skill learning, and that learning to perform a complex movement was at least as good when KR was provided at random 33% of the time as when it was provided on 100% of the learning trials. Another way is to provide a summary of performance at the end of a set of trials. KR feedback provided at task completion works well for tasks of single degree-of-freedom movements or scaling of a single general movement pattern (Newell, 1991). However, KR is less effective for the multiple degree-of-freedom tasks that are many behaviors in natural situations.
- Knowledge of performance (KP). KP relates kinetic feedback of the forces applied during performance, and kinematic feedback of the temporal and spatial properties of the movement (Proctor and Dutta, 1995, 123-126). KP can direct the actor´s attention toward those aspects which are critical to performance (Young & Schmidt, 1992). For this purpose, it is necessary to determine which performance information my be useful, and that the task criterion should specify what information the feedback must provide in order to be effective.

1.9.4 Human Psychomotor Abilities

According to Carroll (1993, p. 532-541), human psychomotor abilities involve the following :

- Static Strength: "This ability involves the degree of muscular force exerted against a fairly immovable or heavy external object in order to lift, push or pull that object. Force is exerted continuously up to the amount needed to move the object. This ability is general to different muscle group (e.g., hand, arm, back, shoulder, leg). This ability does not extend to prolonged exertion of physical force over time and is not concerned with the number of times the act is repeated." Mostly it refers to hand strength.
- Gross Body Equilibrium: "This is the ability to maintain the body in an upright position or to regain body balance especially in situations where equilibrium is threatened or temporarily lost. This ability involves only body balance; it does not extend to the balancing of objects."
- Choice Reaction Time: "This is ability to select and initiate the appropriate response relative to a given stimulus in the situation where two or more stimuli are possible, and where the appropriate response is selected from two or more alternatives. The ability is concerned with the speed with which the appropriate response can be initiated and does not extend to the speed with which the response is carried out. This ability is independent of mode of stimulus presentation (auditory or visual), and also of type of response required."
- Reaction Time: "This ability involves the speed with which a single motor response can be initiated after the onset of a single stimulus. It does not include the speed with which the response or movement is carried out. This ability is independent of the mode of stimulus presentation (auditory or visual), and also of the type of motor response required."
- Speed of Limb Movement: "This ability involves the speed with which discrete movements of the arms or legs can be made. This ability deals with the speed with which the movement can be carried out after it has been initiated; it is not concerned with the speed of initiation of the movement. In addition, the precision, accuracy, and coordination of the movement is not considered under this ability." Mostly it refers to hand movement speed.
- Wrist-finger Speed. "This ability is concerned with the speed with which discrete movements of the fingers, hands, and wrists can be made. The ability is not concerned with the speed of the initiation of the movement. It is only concerned with the speed with which the movement is carried out. This ability does not consider the question of the accuracy of the movement, nor does it depend on precise eye-hand coordination." For example, it can be thought as tapping, dotting, fine finger motor hand control, finger tapping, and manual speed.
- Multilimb Coordination: This is "the ability to coordinate the movements of two or more limbs (e.g., two legs, two hands, one leg and one hand). This ability does not apply to tasks in which trunk movements must be integrated with limb movements. It is most common to tasks where the body is at rest (e.g., seated or standing) while two or more limbs are in motion."
- Finger Dexterity: "This is the ability to make skillful, coordinated movements of the fingers where manipulations of objects may or may not be involved. This ability does not extend to manipulation of machine or equipment control mechanisms. Speed of movement is not involved in this ability."

- Manual Dexterity: "This is the ability to make skillful, coordinated movements of a hand, or a hand together with its arm. This ability is concerned with coordination of movement within the limb. It may involve manipulation of objects (e.g., blocks, pencils) but does not extend to machine or equipment controls (e.g., levers, dials)."
- Arm-hand Steadiness: "This is the ability to make precise, steady arm-hand positioning movements, where both strength and speed are minimized. It includes steadiness during movement as well as minimization of tremor and drift while maintaining a static arm position. This ability does not extend to the adjustment of equipment controls (e.g., levers, dials)."
- Control Precision: "This is the ability to make controlled muscular movements necessary to adjust or position a machine or equipment control mechanisms. The adjustments can be anticipatory motor movements in response to changes in the speed and/or direction of a moving object whose speed and direction are perfectly predicable." For example rotary pursuit task, complex coordination, two-hand pursuit, manual precision tasks."
- Aiming: "The ability to carry out quickly and precisely a series of movements requiring eye-hand coordination" or "the accurate positioning a pencil mark on paper." (Fleishman, 1972, p.87)
- Speed of Articulation: This factor is "to measure normal oral reading speed, the speed of performing fast articulation with the speech musculature, when a subject is asked to utter 'p-p-p- . . .' as fast as possible." (Carroll, 1993, p. 536).
- Speed of Writing. (Carroll, 1993, p. 536).

1.9.5. Simple Motor Movements
"Handbook of Perception and Human Performance" (Vol. II), edited by K. R. Boff / L. Kaufman / J. P. Thomas, 1986, New York: Wiley & Sons Publication, collects many studies about hand movements in various situation. I cite some information from this book as follows.

1.9.5.1. Irrationality: Speed and accuracy of simple movement
Simple movements to a target (e.g., moving s stylus a few inches to tap a small plate) vary substantially in time as a function of distance and precision. Movement time is on the order of 150 msec for a movement of 8 cm to a target of 2-cm width and about 500 msec for a 25-cm movement to a target of 0.25 cm (p. 30 - p. 12). Simple reaction time is on the order of 200 msec. Average simple reaction time varies with a number of factors, a primary one being stimulus modality. (Woodworth, 1938; Woodworth and Schlosberg, 1954; and Teichner, 1954). Simple reaction time to visual signals is about 180 msec under near optimum conditions. Auditory and tactile reaction time are on the order of 140 msec. Under less optimal conditions simple reaction time may slow by a couple hundred msec. Simple reaction time to tones increases to as much as 300-400 msec for tones near auditory threshold. Sound of 30-40 dB, which is rather low in intensity, is responded to in about 150 msec.

Likewise, simple visual reaction time is sensitive to intensity, flash duration, and size of stimulus. When a stimulus is very brief (e.g., 0.05 sec), small (e.g., 0.5 degree visual angle) and very dim (substantially less than 3 cd/square meter), simple reaction time may be slowed to as much as 500 msec. But for illumination of about 3 cd/square meter, which is near the threshold of cone vision and equivalent to candlelight reading, reaction time has improved to 200 msec even when the stimuli are brief in duration and small in size. (Another factor that influences simple reaction time is spatial frequency.) (p. 30 - p. 39)

1.9.5.2. Fitts´s Law of human motor movement (Movement Controlled by Visual Feedback)
The equation: $\mathbf{MT} = \mathbf{a} + \mathbf{b} \log_2 (2\mathbf{D}/\mathbf{W})$
is called the Fitts´s law. It describes movement time (**MT**) in the cases where movements are slow enough to be altered by visual feedback. **a** and **b** differ as a function for three situations involving linear hand and arm movement. Movement time for the arm is linearly related to the logarithm of the distance of movement **D** divided by the target width **W**(size). On Keele and Posner´s (1968) studies, it appears to take about 200-250 msec from the start of a movement to use visual feedback. A slightly larger estimate of 290 msec was derived by Beggs and Howarth (1970) in a similar study. Sometimes during the course of movement the target shifts. One might expect in that case also to find a minimum of 135 msec for adjusting movement. If early portion of the movement bringing the object´s limb close to a target is included, visually based correction time takes about 200-250 msec. But if only that time is examined is in which visual input is actually used, correction time is between 135-185 msec.

1.9.5.3. Movement time under water.

Kerr (1978) compared movement under water with that on land. Subjects alternatively tapped targets of widths varying from 2 to 15 mm over distances varying from 50 to 260 mm. Kerr separately analyzed slopes of the function, relating movement time (in msec) to distance and to width:

$$\mathbf{MT}\text{ (land)} = 34\text{ msec} + 111\text{ msec} \log_2 \mathbf{D} + 109 \log_2 (1/\mathbf{W})$$

$$\mathbf{MT}\text{(water)} = 145\text{ msec} + 155\text{ msec} \log_2 \mathbf{D} + 115 \log_2 (1/\mathbf{W})$$

1.9.5.4. Movements are not controlled by visual feedback

When movements are too fast for feedback-based correction, accuracy then is dependent on the speed chosen. Accuracy is expressed as a function of distance and time. They found accuracy to diminish both with shorter duration movements and increased distance, leading to the following formulation, called Schmidt´s law (1979):

$$\mathbf{We} = \mathbf{a} + \mathbf{b}\ (\mathbf{D}/\mathbf{MT})$$

where **a** and **b** are constants, **D** is distance, and **MT** is movement time. **We** is the standard deviation of end point dispersion and is known as effective target width. Faster movements are less accurate. The precise function of the trade-off is different from the Fitts´s law. At the root of the trade-off are variations in force: a faster movement over a fixed distance requires greater starting and stopping forces. Larger forces are less accurate. This equation provides a good description of accuracy for movements lasting 140-200 msec over distances up to 30 cm. It describes error both parallel and perpendicular to the line of travel, though constants a and b differ in those cases. Accuracy increases because with the slower movements visual feedback is used.

1.9.5.5. Movements under microscope

Other studies examined examined movements performed under a low-power stereoscopic microscope, a situation common to microscopic assembly work in industries such as electronics (Langolf, Chaffin, and Foulke, 1976). Often the hand moves a knob or level, which in turn moves a cursor into a target area. The Fitts´s law provides an apt description here as well, though slope and/or intercept are elevated sometimes to a very large degree. The Fitts´s law provides, therefore, a useful evaluation tool for assessing which transducers from human motion to machine motion are the best. Knight and Dagnall (1967) studied rotary movements of a knob. A pointer attached to the knob was aligned with a target. Jagacinski et al (1980) examined joystick movement produced movement of a scope-displayed cursor toward a scope target. With joystick control, position control is superior to velocity control. Remote manipulation is much slower yet, but different manipulators differ tremendously in their ease of operation. Performance with mouse was well described by the Fitts´s law, and the slope was about half of that with joystick. Cursor movement produced by stepping keys and character identification keys depended on the number of keypads, but in general such cursor manipulation is substantially slower (by a factor of 2 or 3) than mouse control.

1.9.5.6. Simultaneous target-directed movements

According to Kelso et al (1979), when two limbs move together, each to hit a separate target, movement time is influenced by a new constraint, coordination. When only a single hand moves, movement time is substantially longer for more precise movements over a longer distance. When both hands move together, the result is similar, provided that both hands move over the same distance and with the same precision. When the two hands move different distances, the hand covering the shorter route slows to nearly match the time of the hand covering the longer route. The latter is performed in more or less normal time. In each study, the hand moving the shorter distance did complete movement in slightly less time than the hand covering the longer distance. Nonetheless, the natural coordination appears to be one of near time locking of the two hands, even though in so doing, their velocities are quite different. Reaction time increased slightly for two-handed as compared to single-handed movements. In each of the Kelso et al (1979) study, reaction time increased by a slight additional amount when the two hands moved different distances.

A study by Marom (1981) further explored two aspects of the two-hand coordination problem. When the movements were symmetric, or nonsymmetric in direction, the shorter-distance movement slowed to nearly the same time as the longer-distance movement. One subject was a notable exception. The hand covering the short distance showed no tendency whatsoever to slow when paired with a long distance movement of the other hand. Instead, the two hands performed independently. Although Marom did find one subject with nearly independent control of the hands, the norm appears to be coordinated control. Apparently the natural coordination in discrete two-handed movements is for the hands to move in the same time, even when they move different distance.

CHAPTER 2: ACTION CONTROL AND ARTIFACTS

SECTION 2.1: THE RATIONAL ACTION MODEL — THE RUBICON MODEL

2.1.1. The Rubicon Model

Several authors introduce action models. I employ the rational action model created by Heckhausen (1987) and Gollwitzer (1990, 1991; Heckhausen & Gollwitzer, 1986, 1987), which is called the Rubicon model. The entire course of an action from desired impulse to realization of intended goals can be described as four phases (Figure 2.1-1): the predecisional, the preactional, the actional, and the postactional phase. These four phases are connected by three transition points: the decision-making to form an intention (Rubicon), the initiation of action, and disactivation of intention and termination of the action.

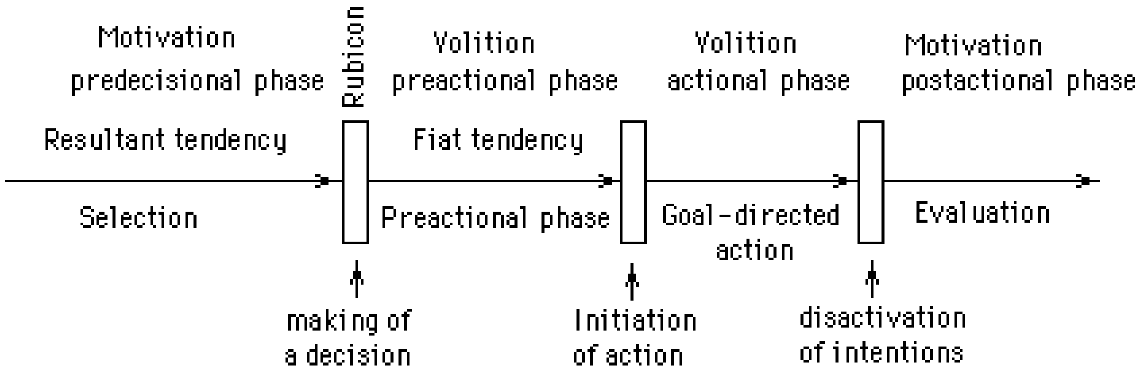


Figure 2.1-1: Four phases of goal-directed activity (after Gollwitzer, 1986).

2.1.2. Pre-Decisional Motivation: Desire and Deliberation

According to Heckhausen and Gollwitzer, an action begins from desiring and deliberating. Users´ wishes and desires are generated gradually during a long period of time, and may conflict with each other because of unreality, opposite attractiveness of long-term and short-term consequence. All these wishes and desires exist in the pre-decisional phase waiting for time, means, energy, priority setting and their initiation of action. People have to deliberate which of them they prefer to pursue. Desirability and feasibility are employed as criteria for the selection of goal intention. The desirability of the desired outcomes is determined by its expected values, which is derived by estimating the short-term and long-term consequences and by assessing the probability of these consequences after achieving the desired outcomes. For Heckhausen and Gollwitzer, these consequences comprise:

- positive or negative self-evaluation;
- positive or negative evaluation by significant other people;
- progress toward some important life goal, pleasant or unpleasant side
- incentives associated with the process of achieving the desired outcomes. effects (Heckhausen, 1977).

In respect to feasibility, users may consider whether or not:

- they can obtain the desired outcomes by their own actions;
- the respectively situational context facilitates their actions;
- time, means, or opportunities are sufficient for them to realize the desired outcomes.

During the pre-decisional motivation phase, only one decision is made. The more the people deliberates for a desire, the stronger it is. This is called a resultant tendency. If the resultant tendency reaches a certain threshold, the deliberation processing will be finished.

Actions are not only initiated through self-defined intentions, but also through habits or automatic actions. Some other actions are caused by higher-level intentions. They are related to the value dispositions, which are defined in the individual´s previous experiences. These values dispositions play the role as permanent intentions, which seek every opportunity for initiation. For these intentions there is no motivational phase.

2.1.3. Pre-Actional Volition: Planning

Even a desire is identified as the most desirable and easily feasible one (the highest preference), the fulfillment of such wish requires further a transformation of the desire into a goal intention. This transformation corresponds to a decision, and to a feeling of firmness to realize this desire. Then, the actor feels committed to achieving the goal. Only to this extent, the actor has constructed a goal intention. To describe this transition from the fluid state of deliberation to a firm sense of commitment, Heckhausen (1987) employs the metaphor of "Crossing the Rubicon," just as Julius Caesar started the civil war by crossing the Rubicon, and must then take the care to win, perhaps, so by transition from a desire to an intention. "Crossing the Rubicon" is to form a goal intention, and to provide the actor the commitment to the goal, "from a motivational state of mind to a volitional, implemental state of mind." (Gollwitzer, 1987, p. 358).

With the formation of goal intention, the actor comes into the pre-actional phase. The normal task in the pre-actional phase is to attempt to promote an effective planning. Generally, planning is necessary because (1) the goal intention can not be achieved in one single step; (2) the alternative actions must be first settled. For this purpose, the actor has to have a pause during action course. Planning and initiating of an action correspondent to the selected goal intention is the main problem that the volitional processes must solve.

Heckhausen and Gollwitzer claim that during the action pause, the actor with the feeling of self-commitment thinks over how to reach the goal in the best way, then when and where to begin the action, and how and how long is the action course. All the consideration is concentrated on implementation intentions. Implementation intentions (Vorsatz in German) consist of initiation intentions (Gelegenheitsvorsatz), execution intentions (Durchführungsvorsatz), and termination intentions (Desaktivierungsvorsatz). When various potential courses to implement a given goal intention conflict, and the individual can not determine how and when to start an action or what means to use, the implementation intentions are required for realization of the given goal intention. Its purpose is to formulate a specific action plan to promote the smooth initiation, execution and termination of the action.

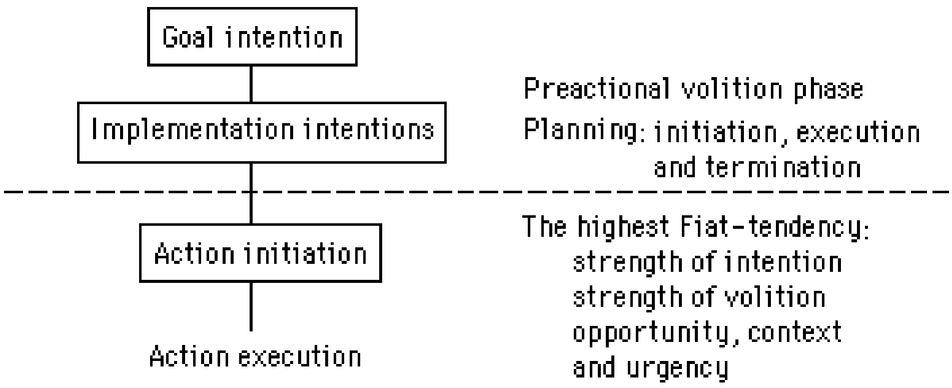


Figure 2.1-2: Preactional and actional phase.

If several stimuli which are connected with users´ different implementation intentions occur at the same time, they will lead to conflict between the implementation intentions. This situation is unfavorable for the user to operate the artifacts. It can lead to state orientation, and even worse, leads to danger. Therefore, the analysis of the intention conflict is an important task in design process. In principle, the design criteria for the analysis of the implementation intentions are as following:

- Artifacts should be so designed that users can find their goal intentions easily. If there are many goal intentions appearing on the artifact, designers must make the goal hierarchy very clear.
- Who wants to make a long operational plan to use telephone, pen, or camera? An action plan has to be employed only when there is no other way. Users must have rather strong volition and effort (mental load) to plan a complex action. It is better that the action plan or operational sequence can be easily seen and understood on the user interface. These operational steps should be smoothly connected with each other in a correct sequence;

- only one stimulus or signal from the artifact should be given and related with one implementation intention at one point of time. The design should not cause user´s potential implementation intentions which are not related with the goal intention;
- the operation of an artifact should be flexible so that after any disturbance to the prior action, the user can easily handle the emergent goal intention, and be reminded of the prior goal intention and operation.

Initiation of an action on an artifact may be troublesome in the following cases:

- if users must develop or prepare special demanded environments or accessory means;
- if it is difficult to recognize the critical opportunity in very short moment; and
- if competing goal intentions through signals and other feedbacks interfere with the current goal intentions.

2.1.4. Action Initiation and Actional Volition

In this phase a goal intention leads to the initiation of action. When does an intention lead to initiating its action? The term Fiat-Tendency is employed by Heckhausen and Gollwitzer to explain the action initiation. Every goal-intention has a different volition strength. The volitional strength is a positive function of the goal´s desirability and feasibility. Among the concurrently competing goal intentions, the one with the strongest volition — Fiat-Tendency — leads to the initiation of its related action. Gollwitzer (1987, p. 357, p. 366) asserts that the strength of the Fiat-Tendency depends upon (1) the strength of the goal intention, (2) its current volitional strength, (3) the favorable opportunity, (4) the situational context to realize the goal intention and (5) the priority, or one´s feeling of time urgency, the experience of failure, and so on. The volitional strength can vary:

- if an individual frequently ignores appropriate opportunities to initiate relevant actions, it may decrease over time;
- if an individual meets obstacles, the volitional strength may increase spontaneously at this very moment;
- if the situation may be more suited for smooth implementing one intention than other competing intentions.

Intentions can also conflict with each other if suddenly an opportunity falls into another action during an action. A possibility to initiate an unsettled intention draws attention to itself automatically, so that the execution course of the first action can be disturbed. In this situation a decision will be made for whether the first action should be interrupted in favor of the alternative action. The conditional disturbance to the action course may happen, especially when the emerged opportunity can not wait, or it behaves irregularly

Heckhausen claims that only one or two different actions at most can be executed at the same time until the intended outcomes and consequences of the action are achieved. Then this goal intention is disactivated. With the initiation of an action related to the goal-intention, the mental representation takes over the guidance of the action. Depending on the difficulties in acting, the goal can be represented at various abstract levels:

- at the lowest level are the intricacies of the action to be executed;
- at an intermediate level is the intended outcome; and
- at the highest level are the consequences that the outcome is expected to mediate.

At which level the goal is represented depends upon the concrete requirements. During the course of an action, the goal representation can be relocated at a higher level. If the current action meets difficulties, it requires strong attention in order to lead the action to an intermediate goal.

Heckhausen and Gollwitzer assert that the intensity and the endurance of an action is determined by the volition strength of the goal intention. The strength of volition is a variable, and its upper limit is determined by the resultant tendency of the motivation. The altitude of the actual volition strength (or the effort) depends upon the difficulty to be overcome. When the action consists of forthcoming goal, intermediate goal and feedback about the outcomes of its action, the versatile regulation of the effort and endurance distinguishes three factors which determine the volition strength or effort. These three factors are: the affective self-evaluation, the perceived self-efficacy (subjective expectation of outcome), and the new adaptation of the personal standards (Bandura, 1987). An individual exerts a stronger effort if he or she is left behind the goal, and has a high performance of his or her own self-efficacy; or if this person corrects a goal, he or she can also reach the goal with all the forces. The effort regulation is an important control process to guide the action. To the action control belongs the ability which protect the current actual intention from the competing intentions, but there are also other dangers of efficient impairment which is effected by the disturbance of dissatisfactorily disactivated intentions. One of these dangers is the over-effort to the greater obstacle. Because of the great effort (also called over-motivation), the efficiency of a action can impair.

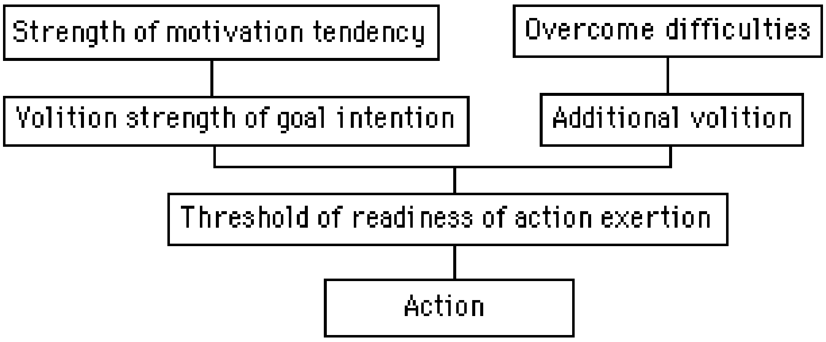


Figure 2.1-3: Volitions of intensity and the endurance of an action.

When users operate artifacts in this phase of action, they hope, of course, the operations are very easy. Strong effort and attention mean heavy mental load. That is, the action to the artifact should not require very strong volition or effort. Designers can take the following considerations as the analysis of the action control in design:

- It is better that the operation of artifact should correspond to users´ action imagination, action habits, sensorimotor habits, or easily become an automatic action.
- Design should try to reduce users´ effort in the action control of artifacts if the artifact is technically complicated.
- There are no more than two actions concurrent with each other during the whole operation. The actions should be successive in series, and try best not to arrange the control operation in parallel actions with two hands, or even with two feet.
- The course of action should be direct, simple, smooth and efficient from its beginning to the end.
- The pause time between two actions should be long enough for the user to think and to act, or the pause time could be controlled by the user.
- There should not be any ambiguity, obstacle or disturbance on the course of an action.
- Reduce the action difficulties, such as time urgency, action complexity, strong force, difficult operating position, complex technical knowledge and heavy training, in order to decrease the necessary attention and stress to the action control.
- Do not leave users any problem-solving processing in using artifacts.
- Many artifacts can be held with hand. Therefore, the analysis of hand-holding or hand motion is in common use.
- In many cases, not only one hand, or two hands but also other parts of human body must move to interact with artifacts (car driving). The analysis of body movement coordination is necessary in design process.

2.1.5. Post-Actional Motivation: Evaluation

The last phase of an action is the process for evaluation. The actor will evaluate whether the intended goal have been achieved or not, and whether the actual value of the goal striving matches its expected value or standard. This evaluation is related to the action outcome, and may be useful for further action. Users need information not only for the evaluation, but also for perceiving in which phase of an action the artifact works, and whether it is still running. For such evaluation and perception the artifact must be designed to provide the user with correct information, or feedback of an action. If the goal-intention has been reached with the action outcome, it can be available as successful. Thus it is disactivated. The individual would like then to turn to a new action, or stay for a short time in a comfortable feeling of the achieved goal state. If a goal is not or not completely reached, the person will examine where this problem occurs, then decide whether to pursue the goal-intention further or not, or to modify it, or to give it up. This examination may prove the motivational elaboration which originally led to the desired goal-intention, if it was incomplete, defective, or can not anticipate the essential aspects. In every case, the consequences are drawn in two respects: whether the goal can be pursued further or not, with which modification, which instructs from this experiences can be drawn for the future attempt.

2.1.6. The Irrational Aspect of Action

This model describes the correct and successful course of action, and called the rational model of action. In fact, users´ action to artifacts is not so direct, simple, or rational. Design needs further an irrational user model. Such model should involve the following consideration.

- There are two kinds of intention formation. One is that the rational model describes. The other is the intention driven by data, external information, and the environment. Emotion for the both intention formation plays a role. Users´ way of action formation depends also upon their knowledge, learning process and experience.
- In many cases, every step of action is a much more complicated process. Action planing is not always so correct and direct. It needs the trial-and-error process if users are not sure of how and when to do. This is processes of problem-solving. Various ways of problem-solving must be involved in an action course if there is any difficulty.
- Errors in an action course often happen. How to find and correct errors is part of an action.
- The mental load and the physical load can not be neglected. Effort which relates to volition and attention is another factor of an action.
- Any environmental condition influences users´ action.
- There are different ways of action control.

Such irrational aspect is one of my considerations. The same is that the user mental is also irrational because humans have limited perceptual abilities, limited cognitive abilities, and limited abilities in performance.

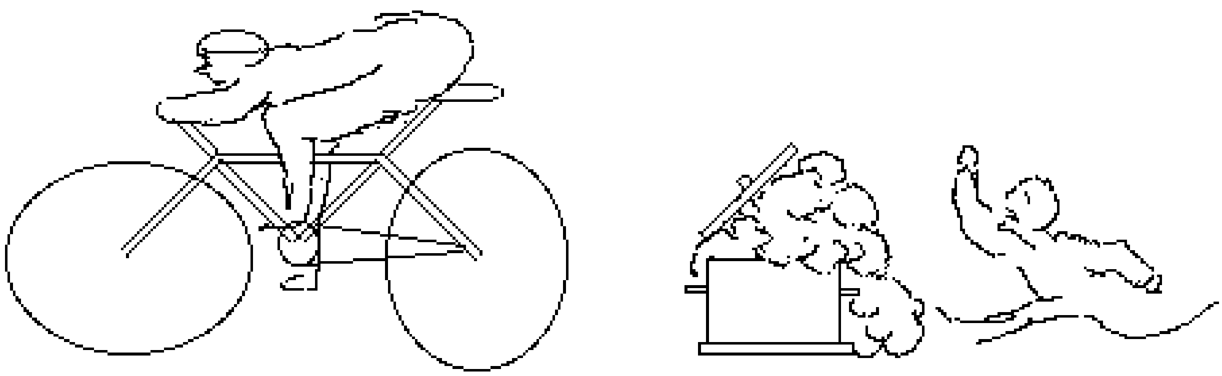
SECTION 2.2: VOLITIONAL ACTION CONTROL — COGNITIVE EFFORT

2.2.1. What Do Cognitive Efforts Mean?

What does the "effort" mean? Effort is the energy exerted by the agent in overcoming the resistance (Macmurray, 1962), and relates to difficulties in action, volition and attention. In Ach´s words (1935, p. 346):

> Die Schwierigkeit einer Tätigkeit ist das Motiv für eine stärkere Willensspannung bzw. Aufmerksamkeitskonzenztration in dem Sinn, daß mit der Schwierikeitssteigerung die Willensanspannung triebartig zunimmt. Bei der Auswirkung dieses Gesetzes handelt es sich also um eine unmittelbare Anpassung des Verhaltens an die gegebene Situation zum Zwecke der Erreichung des gesetzten Zieles oder der übernommenen Aufgabe. Die vorhandene Schwierigkeit, die dem Menschen bewußt wird, bewirkt dabei unmittelbar, d.h. ohne daß sich irgendwelche seelischen Prozesses, Übergänge o. dgl. einschieben müßten, eine Erhöhung der Willensanspannung, um trotz der Schwierigkeit das Ziel zu erreichen.

> The difficulty of an activity is the motive for a stronger volitional tension and concentration of attention in such sense that the volitional strength increases instinctively with the increase of difficulty. On the effect of this rule, it relates to a direct adaption of the behavior in the given situation for the purpose of reaching the settled goal or the accepted task. The existing difficulty which the people are conscious of generates directly — here without any psychological processes, transition, or the like — an increase of volitional tension to reach the goal in spite of the difficulty.



Desired effort (desired volition)　　　　Undesired effort

Figure 2.2-1: Desired and undesired effort

According to McDougall, "effort of attention is thus the essential form of all volition" (McDougall, 1908, 1946, p. 209), and "the essential achievement of the will, in short, when it is most 'voluntary', is to attend to a difficult object and hold it fast before the mind“ (James, 1905, p. 450). If the behavior is controlled by the actor himself/herself, not by the situation, the control of self requires a definite effort (Kanfer, 1977; Meichenbaum, 1979). Cognitive effort relates mainly to mental processing which requires self control. Now, the problem becomes what is volition? How to reduce user´s efforts in utilizing artifacts? Kuhl (1996, p. 678) defines volition as follows:

> Die Begriffe Volition und Wille bezeichnen eine Kategorie kooperierender psychischer Funktionen, welche bei Vorliegen von näher zu bestimmenden Realisierungsschwierigikeiten die zeitliche, räumliche, inhaltliche und stilistische Koordination einer großer Zahl einzelner Teilfunktionen innerhalb und zwischen verschiedenen Subsystemen und funktionen wie Wahrnehmung, Aufmerksamkeit, Kognition, Emotion, Motivation, Aktivierung ("Temperament") und Bewegungssteuerung (Motorik) aufgrund eines einheitlichen Steuerungsprinzips vermittelt, das wir als "Absicht" oder "Ziel" bezeichnen.

> The concept of volition and will indicates a category of cooperative psychic functions which, when there exists difficulties in realization of action, mediates the coordination among time, space, contents, and style of many individual subfunctions inside and between various sub-systems and subfunctions, such as perception, attention, cognition, emotion, motivation, activation (temperament) and movement control (motor) based on a coherent control principle which we define as "goal intention" or "goal."

Because there exist difficulties in action realization, the actor must control himself/herself (and action) with volition, thus, the actor experiences effort. Effort is directly connected with volition which depends upon the degree of difficulties of action realization. In automatic action the actor does not experience effort.

Kulka (1972) and Meyer (1973, 1976) develop another model of effort. The success probability of an actor depends upon the self-concept of ability, the perceived difficulties in the task, and the strength of the intended effort. The effort will be maximal if the actor can manage the difficulties based on estimation of his/her abilities. The effort will be minimal based on over-estimation or under-estimation of his/her abilities.

2.2.2. Volition

Volition is investigated under various points of view, and by different methods on various measurement levels. Weinert (1987) summarized four groups of applied will metaphors: volition as force (will impact, will vigor and universal driving force), volition as formal principle (control principle in decision-making, and regulation principle in action execution), volition as control authority which provides instinctive impulse toward desired goals, and volition as the decision-making which is characterized as crossing Rubicon. Two aspects in these metaphors are obvious: (1) volition as independent energy source, and (2) regulation or controlling function.

2.2.2.1. Desired and undesired volition and effort

Do you want to be challenged in playing games? Most people may answer "yes." Do you want to meet difficulties in opening a bottle of beer? The same people may answer "no." There exist desired and undesired difficulty, volition, attention and effort. This depends upon users´ action goal. When people use tools to do work for a goal, they desire to use easy tools. Tools are their mean, not goal. User-centered design emphasizes users´ action goal with artifacts. They desire to meet difficulties from some games, and they do not desire to meet difficulties from most everyday things at home and at work. Industrial design should distinguish between desired and undesired volition.

2.2.2.2. Sequential concepts of volition

In the Rubicon model, motivational processes are responsible for deliberation and selection of action desires. Volitional processes are responsible for planning and execution of action. Motivational state and volitional state follow each other in the action phases: after a motivational selection phase, the actor who has made decision to cross Rubicon comes into the volitional planning and execution phase, then again, a motivational evaluation phase. According to Heckhausen (1996, p. 820), various volitional processes play an important role in the following 15 processes:

- Store intention and recall it in an appropriate opportunity to realize it if there is intention competing.
- Formulate undertaking, initiation, execution or deactivation of the action.
- Initiate an action, and realize it.
- Select information.
- Control the expenditure on conscious representation and its processing.
- Protect against competing processes of motivation or volition.
- Regulate attention and feedback.
- Realize execution to anticipated critical points.
- Employ enough abilities of conscious processing for two activities at the same time.
- Compete because of the deviation of the action course, or because of the loss of momentum, partly through spontaneous and consciousness-obliged meta-volition.
- Return to the action course after the deviation or interruption.
- Catch feedback about the effects of the action.
- Deactivate the action after reaching the expected standards of action outcome.
- Evaluate the intention realization (look-back).
- Turn to a new action.

Almost in every step of action there exist more or less volitional control. Reducing users´ difficulties in action, especially making cognition easy, is one of the key points of the interface design.

2.2.2.3. Imperative concepts of volition

The imperative concept of volition emphasizes the command-liked assertion of a goal against the competing goals. For Kuhl, volitional processes can control the attention direction and behavior even when the behavior contradicts the actual desire and behavior supported by motivation, for example, an actor feels the weaker behavioral tendency but higher moral tendency. If the actual motivational action control can not reach the goal favorably, then volition may replace the motivation. Kuhl (1996, p. 684) claims that volition may coordinate many individual functions which mediate the anticipative adjustment or feedback-related regulations of every subfunctions, may mediate action control, and may facilitate the protection and maintenance of a current intention (even weak one) against the competing action tendencies. Kuhl (1987; 1996, p. 684) defines six mechanisms as strategies of volitional control which offer methods in user-interface design to reduce (or increase) user´s volition and efforts:

- **Motivation control**. When it is difficult to maintain the current motivation, recall and focus on the attractive stimulus and positive consequence to strengthen the motivation.
- **Attention control.** Attention should be concentrated selectively on the goal-related information (selective attention), especially when it is difficult to maintain the goal. Designed artifact should not provide redundant information.
- **Encoding control** facilitates selectively encoding information which is related to the current intention.
- **Emotion control** refers to the strengthening of emotions which facilitate the initiation, maintenance or termination of a difficult intention, i.e., to facilitate the protective function of volition by activating positive emotions, enhancing the motivational basis of the current intention, and by inhibiting negative emotional states.
- **Failure control**. Failure is controlled toward failure correction, and the emotion caused by the failure (disappointment, or anger) is employed toward mobilization of effort (energy).
- **Parsimony** of information processing (economic principle) means to recognize and catch the right moment to initiate an action, to coordinate every action step, and to optimize the decision-making process (to avoid too long process of decision-making). Whenever the user believes that further processing of information on potential action alternatives may impair the execution of the current intention, this processing should be stopped.

2.2.3. The Types of Action Control

Kuhl (1996, pp.670-678) has introduced the following types of action control based on the functions of volition:

2.2.3.1. Self-control: authoritarian will

This kind of action control defined by Kuhl has strong volition, and is strict self-management because sub-systems do not work cooperatively. A central coordination function must control all the subsystems to pursue long-term desires (and suppress the short-term desires), and work hard. The self- control is not automatic in nature. Kuhl introduces the features of self-control as follows:

- "I", as task-giver of will, take few of action instructions presented by others.
- It is goal-guided processing (top-down control).
- There may exists the long-term conflict which is caused by the suppressed factors.
- Strong volition control.
- Less duration of time, but great effort.

There must be a strong self-control if a goal must be reached (1) in a limited time, (2) by routine decision-making, or (3) if the actor is forced to do something because of the negative emotion or weak motivation. A prerequisite for the self-control is that all psychic sub-systems (e.g., perception, feeling, temperament, motion control) work under a strong regime. They work at least at a higher level of system organization in a hierarchical control system. Computer information processing can be seen as such control type.

Activation conditions of self-control are the difficulties in realization of action, for example, a time urgency, redundant decision making, or users are forced to do something. To reduce users´ effort in using artifacts is to avoid this type of action control by means of user-interface design.

2.2.3.2. Self-regulation: "democratic" type

The second type of action control by Kuhl is the loose, without tension, relaxed form of volition. Volition "listens to" sub-systems. It has the following features:

- Many processing units (perception, cognition, emotion, motivation, volition, motor movement, etc.) are coordinated cooperatively and harmonically.
- There exists fewer long-term conflict.

- Many participants lead to greater emotional support which favors the intentional goal.
- Less cost of time, energy and effort.
- Relatively late triggering of volitional support, and high latency.

If coping with a problem requires to develop a new behavioral pattern, and people can not rely on unreliable program; and if people have time and safety, this type of self-regulation is meaningful. It relates also to the situation in which many processing units should take part in the creative overcoming of new problems. Overcoming problems prefers to have a heterarchical organization, in which every unit can play a role. That is a parallel processing mostly. Self-regulation works toward a long-term point of view: (1) the various parts of our psyche work actively, (2) they are satisfied with duration of time without "complaint" or adverse feeling, and (3) action impulses must not be be held always under control.

2.2.3.3. Non-volitional type: self-organization (automatic control)
The third type of action control introduced by Kuhl is self-organization. There is not any central coordination function in it. The interaction of sub-systems and processing units organize their work by themselves. The examples are self-forgetful activities of high power, or voluntary attention to unexpected stimulus in the surrounding. Sub-cognitive instantiated needs and their cognitive-affective representation (motive) play an important role. The current needs influence the attention and action without demand for a central coordination function.

Activation conditions for self-organization involve that (1) no essential details of action control must be specified, (2) processing units can take care of action control without a "coordination center," (3) the control system provides proficient skills up to every detail of the reliable behavioral program through training. The central control function will be absolved if there is more and more practice up to that the processing can be organized by self. In this sense, users´ habitual motivations, habitual intentions, habitual ways of action and cognition, and automatic control are meaningful for user-interface design.

SECTION 2.3: THREE TYPES OF ACTION CONTROL

2.3.1. Three Types of Action Control

Kuhl, et al (1991) introduce three types of action control: the automatic (e.g., habitual behavior), the active controlled (e.g., action-orientation), and the passive (e.g., state-orientation) (Figure 2.3-1). These three kinds of action control can be converted from one to another. Automatic response is mediated by "privileged pathways" which associate stimuli with responses based upon prior learning. The controlled processes will be triggered if a novel, unpracticed or low-frequency response has to be performed while an incompatible well-practiced (automatic) response is simultaneously triggered by the stimulus; or if processing is sequential, slow, capacity-limited, and effortful; or if behavior is stimulus-independent and sensitive to arbitrary instructions or intentions. State-orientation is defined by Kuhl (1991a, p. 52) in terms of inability to escape the mode of control, where the initiation of intended behavior is difficult because of preoccupation (rumination) or of hesitation (through a monotonous activity) of a hypothetical supervisory control system. For example, it is hard to get rid of an unpleasant feeling after an unexpected failure for a long time, and it will forbid their abilities in action control. Thus the actor falls into the state-orientation, either in the past state, or in the current situation or in the future state. The actor ponders in a negative emotion, and does not know how to change this state by his/her action. One wants to do something, however, perseveration controls himself/herself. Some complex operations to a video recorder, for example, may lead the user to helplessness and the state-orientation.

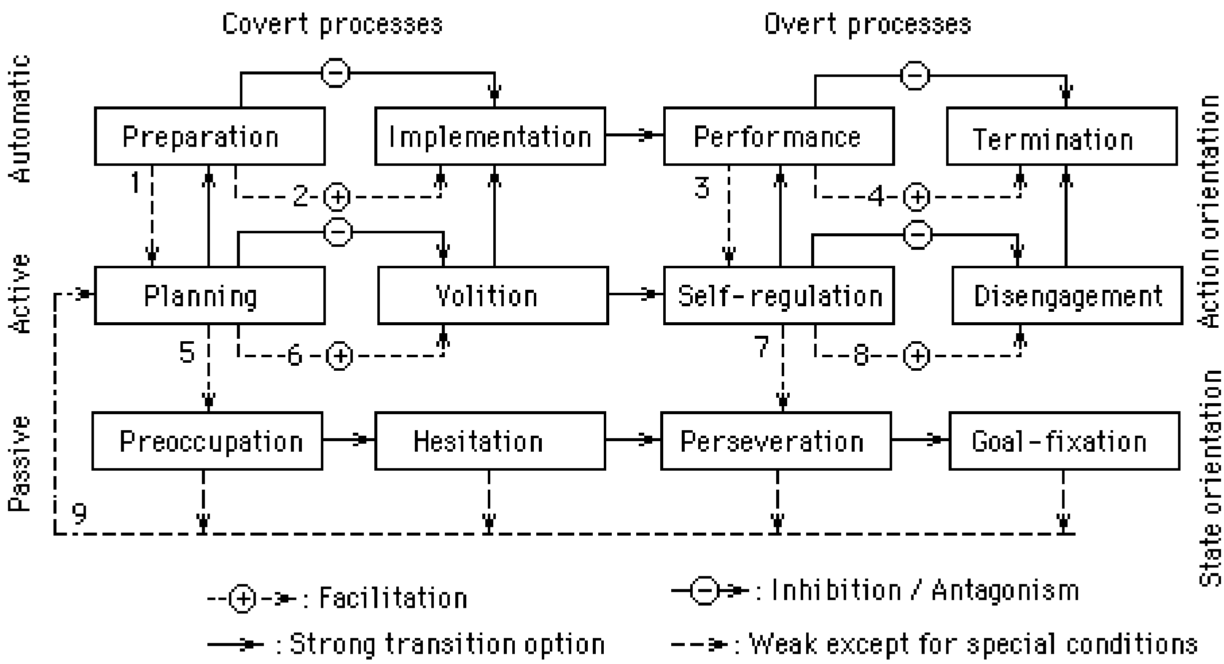


Figure 2.3-1: Four phases of action control (After Kuhl et al).

Automatic control mode is at the autonomous control level. The automatic mode and active control mode together refer to action orientation. The passive mode of control here refers to state-orientation. Kuhl, et al construct the model of the processes of action control. The model shows the temporal sequence of an action as four functions after the formation of an intention. The normal automatic action control has four functions: Preparation, Initiation of action, Performance, and Termination. The active action control: Planning (during preparation), Volition (during action initiation), Self-regulation (during performance), and Disengagement (during termination). The passive action control: Preoccupation, Hesitation, Perseveration, and Goal-fixation:

If a certain transition criterion in every phase is met, action control will proceed to the respective phase. Kuhl, et al defined nine types of transition criteria (Figure 2.3-1): Planning, Initiation, Self-regulation, Termination, Preoccupation, Volition, Perseveration, Disengagement, and the action-oriented mode (back from the state-oriented mode) which specify the conditions to initiate the next processing phase or a shift to a different processing level. Based upon these nine criteria, the control mode may be transited to the next phase at the same level, or to another level. For example, when the criterion for planning is met, the preparation phase in automatic mode will go to planning phase in the active mode. When the criterion for preoccupation is satisfied, the planning phase in the action oriented mode will change into the preoccupation in state orientation, etc. In the Figure 2.3-1 one can also find that some transitions are facilitated, while others are inhibited, as shown with the sign of '+', or '-', respectively.

2.3.2. Transition Criteria Rules for Automatic Control

Kuhl, et al introduce the criteria rules for automatic action control. The automatic mode of action control is usually the default mode, and is elicited by the current stimuli. For the automatic mode, designers should select user´s habitual pattern of action. Its four phases (functions) of action control can be described as following:

- Preparation refers to the selection of an adequate response and the specification of skill parameters, and their sequence scheduling. When the initiation criterion is met, the phase of preparation will proceed to the phase of implementation, or to the phase of planning if immediate initiation of action is impossible.
- Implementation (Initiation) refers to the fact that the access of an action schema is given to the motor system. When initiation criterion is satisfied, the preparation phase can proceed to implementation phase. Then action control goes to next phase, i. e., performance.
- Performance refers to the execution of an action, including the feedback and dynamic parameter specification processes that are necessary to adapt the action to a changing environment. Performance phase may go the phase of self-regulation if the criterion of self-regulation is met. Only when termination criterion is met, the action control will proceed to the final phase of termination.
- Termination comprises those processes (1) that check the outcome of the action against an internal representation of the goal state, and (2) that terminate the execution when certain criteria are satisfied (e.g., the goal is reached).

The implementation of these four phases may also be parallel or temporally overlapping.

2.3.3. Transition Criteria Rules for Active Action Control

Kuhl, et al propose the following criteria rule for active action control.

- Planning will be activated if the immediate initiation of an action is impossible or inadequate because of lack of stored skills for the intention, or lack of the selected behavior, or because of fear of failure. An action plan consists of the specific information about: (1) the present situation, (2) the future goal state desired, (3) action steps, and (4) conditions of these action step. In a complicated situation, planning process involves problem Planning will be activated if the immediate initiation of an action is impossible or inadequate because of lack of solving processes. Action will go to the next phase of volitional control if the criterion of volition is met. If the criterion of preoccupation is met, the action control will become state-orientation, the preoccupation phase.
- The second implemental phase is volition, which refers to the set of functions which mediate (1) the maintenance of goals against the competing action tendencies or external distractions, and (2) the disengagement from an unrealistic intention, or where the changed conditions require changes in the goal hierarchy (Kuhl, 1991, p. 72).
- The self-regulatory mechanisms can be understood as a set of strategies to resolve conflicts of intentions and to control the transition from cognition to action. An important prerequisite for developing self-regulatory mechanisms is the ability to distinguish self-generated intentions from externally caused behavior (Kuhl, 1991, p. 107). At the end of the third phase of self-regulation, its action control will go to the final disengagement phase if its criterion is met. It may also go to the perseveration phase in the state orientation mode if the criterion is met.
- Deliberate disengagement implies two possibilities: (1) disengagement as giving up is an avoidance strategy when negative expectations concerning the outcomes of actions, abilities, and resources outweigh the positive ones in situations with unsolved tasks and adverse action conditions; (2) Disengagement as an instrumental act is the strategy to engage other people´s help, then deliver the task to someone else. (Schönpflug, 1985)

2.3.4. Transition Criteria Rules for State Orientation

Kuhl, et al introduce four transition criteria which lead to the transition to state-oriented action. State-oriented mode is characterized by increased thresholds for automatic or controlled preparation, implementation, or performance. It encompasses: preoccupation, hesitation, perseveration (or distraction), and goal fixation. The preoccupation and hesitation are explained as a reduced ability to prepare, to initiate, and to maintain a new action even if its performance was intended, or is to disengage from an ongoing action even if the actor did not regard it as feasible any longer.

- Preoccupation emerges during the preparation phase. Preoccupation is an uncontrollable state of mind: very sensible to external stimuli and "focus inwards" . (Kuhl, 1996, p. 696). In the preoccupation the four components of an action plan are not completely included because of some dissociation between cognitive processing and the current generated intentions.
- Hesitation means that users feel helpless, and feels it difficult to initiate an action. Hesitation may occur during and after monotonous, routinized, or boring activities which are caused under the control of "use-it-or-lose-it" principle and chronic states of inactivity of volitional functions. Several situations may lead to hesitation: (1) to be sensitive to post-decisional, or to possibly information conflicting, or (2) lack of inhibition of rejected action alternatives. Hesitation leads to escaping and avoiding behavior. This problem relates to the prior frustration in this goal. (Kuhl, 1996, p. 696)
- Perseveration is a type of degeneration of self-regulatory maintenance of the goal after a plan has been initiated. A state-oriented individual is unable to terminate an ongoing action. For example, "even if you had never succeeded, you must keep trying forever."
- Goal-fixation implies that inability to be disengaged from past or future goals even if the individual had known that the execution was not possible at present. It manifests as ruminating, preoccupation and intrusive thinking about past failures. Impaired disengagement can be considered as a major determinant of preoccupation in the planning phase.

SECTION 2.4: THE PERCEPTUAL ACTION AND ARTIFACTS

2.4.1. The Perceptual Action and Perceptual Artifacts

The perceptual action is defined as any action in which the goal intention is to perceive, and in which perceptual abilities, perceptual skills, and correct processing of perceptual information is critical to successful performance. Of course, there exist also cognitive processes and physical performance in the perceptual action, but they are the mean-side. Many types of work seem to belong to perceptual action, such as X-ray diagnosis, astronomy observation, all kinds of direct observation in scientific experiments and so on. A perceptual action must not have a clear goal, but a desire, belief, or tendency, or direction to perceive something. There are two types of perceptual artifacts: (1) perceptual tools with which humans observe and perceive objects, such as balance, ruler, telescope, microscope, telephone, X-ray, radar, camera, TV telephone and so on; (2) perceptual objects which are the goals of human perception, such as books, multimedia, virtual reality, etc. The major issues of design for perceptual action is easy perception.

2.4.2. Problems of Visualization in Design: How to Perceive 0.1 Liters of Cafe

In a TV program, two persons competed to see who could perceive an exact amount of a mouthful of water. The winner could perceive with his mouth 20 grams, 18 g and 5 g of water, respectively. However, most people can not perceive so exactly things. That is human nature. Humans have very limited ability in perceiving physical quantities, and many problems in design can be found in this respects. Can you recognize 150° C of temperature with your eyes? Can you recognize 220 Volts of electricity with your hand? Can you differ between sugar and salt with eyes? Humans are not able to perceive well the physical and chemical quantities, such as distance, size, temperature, angle, and speed. However, some designed artifacts force users to perceive them with eyes. Human perceptual abilities involve many “irrational“ features. Human perceptual ability is not accurate, not very rapid, and has limitation of brightness and frequency. If designed objects force humans to perceive them, humans often make mistakes. Users´ perceptual needs are a very difficult problem in design. Visualization of artifacts implies to make things visibly perceivable, so that users can visibly perceive and visibly understand the information which relates to their action.

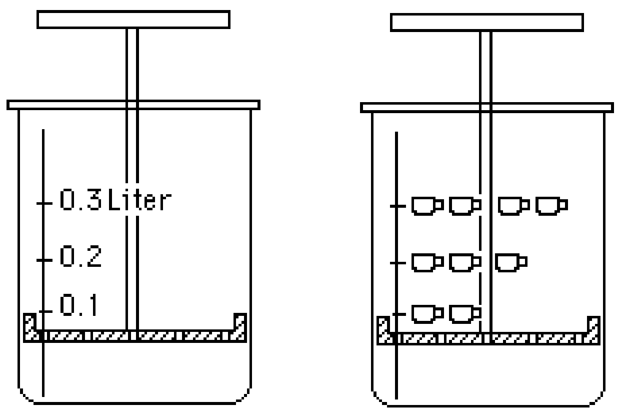


Figure 2.4-1: Cafe maker with different scales. Which is better for user´s perception?

Many problems in using are caused by perception-related design. When I say, "I want 0.1 liters of cafe", you may not know exactly how much it is. If I say, "three cups of cafe", you may understand immediately and exactly. Many cookbooks tell "3 gram salt," "3 milliliters of soy sauce." Maybe, in some cultural environments, people have such habits to weigh these things, but in other cultures, this way is not realistic. Either to provide scaled spoons, or to change these books. Human perceptual abilities and habits, in this sense, are a start point of design. Affordance of artifacts provided by design must match human perceptual motivation, and afford visualization. The first criterion of user-centered design is to see whether artifacts provide visualization or perceivability for potential users.

2.4.3. The User Perceptual Model (Prototype)

The user´s perceptual model or prototype is the knowledge about the user´s perception. This model comprises the users´ perceptual desires, goals, perceptual abilities, perceptual processes and sequence, perceptual habits, and expectations, and also comprises the cultural values, symbols, and role expectation. The user perceptual model is the basis of the design for perception-related artifacts. The goal of the user perceptual model is to find felicity conditions for easy perception. In design process, it is rather easy to think quickly that users have eyes, they can see everything, and there is no problem in user´s perception. Designers then concentrate on other aspects: function or form. In fact, to meet users´ perceptual intentionality is a every difficult task of design in many cases. In some analysis of user´s error in performance, the real problem comes from perception, but design improvement is tried toward to add more function for user´s performance. More often, design forces user´s perceptual processing to become a cognitive processing. When humans use tools to do something, they do not want to spend much time in perceiving and thinking how to use them, or even in solving problems in using. Perceive, then directly act, that is the common desire and expectation.

2.4.4. Adaptability of Information to User´s Perceptual Desires

2.4.4.1. Visualization of artifacts

Design should make things visible. What users want to perceive should not become cognitive process. Reducing the demand for user´s visual abilities involve the following considerations:

- Demand for multiple visual ability factors in a single task cause the complexity of user´s perception. To reduce the complexity of visual processing is to simplify the number of visual ability factors in any task.
- Many visual ability factors themselves are difficult for users, such as demand for speed, spatial thinking, and flexibility. Demand for difficult visual abilities of users should be possibly avoided.
- The loading of each visual task should be as low as possible. Some tasks do not require a difficult visual ability, but their execution leads to a heavy performance load to users. For example, watching a screen requires no difficult visual ability, but watching for eight hours without pause will lead to a big problem to the operator.

2.4.4.2. Easy perception: Adaptability to users´ perceptual intentionality

For some designers, users´ perceptive processing is a random sampling process. The designers do not know in many cases what and when users perceive, and how they perceive. A simplest way to solve this problem is to provide all information which the user needs at the same time. Users regard this kind of display as redundant and tedious one because it is not adapted to users´ action. Adaptability of information refers to that information provided by design must be adapted (1) to user´s goal, (2) to users´ desired perceptual abilities, and (3) to user´s action course. Such information is called ecological information: correct contents at right moment, at right location, and in the right form. It involves the following meanings:

- Stimuli which are designed for users´ perception must provide certain qualities to meet the lowest human perceptual abilities (Sanders and McCormick, 1992, p. 102). The criteria involve (1) Detectability (visibility): The quality of information that makes it possible to detect them differently from others; (2) Identifiability: The attribute of stimuli that makes it possible to discriminate, or to identify them from others; (3) Recognizability (readability): The attribute which makes it possible to recognize the meaning in text, icon, or signal, i.e., the Gestalt principles.
- Showing explicitly correct affordance of artifacts which corresponds to users´ values, needs and intentions, and ensure that users are able to perceive the affordances. For this purpose, information should have certain features: (1) Key feature: a particular feature of an object which elicits a perceptual response is called a key stimulus. The key stimulus simplifies the problem of recognition greatly (Bruce and Green, 1990, p. 177). (2) Certainty: information should have the definite meaning toward user´s action. (3) Completeness: information should be complete in regard to user´s goal and action, not more, not less. (4) Perceptual expectation: intention, perception and action construct a definite chain in user´s mental representation. Information should correspond to user´s desired expectation and imagination, to user´s experience, habits or knowledge, or it is easy to learn.
- Visual guidance: information should provide user´s with desired perceptual anticipation (signaled prior information, reminder of later to-be-emerged additional information, cue or warning). That is called visual guidance.
- There are several possible dynamic structure of information: (1) Sequential organization of information: it should be structured according to action course (action plan). (2) Information may be selected to display on users´ desire. (3) Continuity of information should be preserved in corresponding to action continuity, and can be accessed by the users.
- Economy: human attention is a bottle neck. Information should presented so as to reduce user´s mental processes and to satisfy direct perception process. Graphic information is generally better than text; picture synchronized

with the event is better than static one. Some designers prefer icons in computers. However, humans can recognize a limited number of icons.

2.4.4.3. Natural way of perception

In everyday life behavior, humans have learnt what, when, and how to perceive. Human perception proceed through multiple modalities, and accumulate many experiences, and perceive natural information. However, it is not enough because human perception has some limitation which is not satisfied by humans, for example the physical and chemical quantities. When humans look at something with telescope, they also want to know the distance. Both of the desired information and the desired way of perception are called the natural way of perception. The natural way of perception includes the following points:

- the desired amount of information, not more not less, for example, 7±2 chunks of information at every time;
- user-action-oriented information, no machine-oriented information;
- displayed in the desired place, at the desired time;
- corresponds to users´ knowledge, experiences, desired expectation and anticipation;
- in the desired sensory channel of perception;
- no difficulties in recognition of physical and chemical quantities, such as distance, height, temperature, etc.;
- less time for learning, and no difficulties in perceptual learning.

Recently, multimedia and virtual reality systems are some of main issues in computer design. Its goal is to offer a natural environment for human multiple modalities of perception and cognition.

2.4.5. Perception of Biological Motion for Design

Designers desire to know user´s body motion, for example, the motion episode of human head, body and arms at a car crash can become the basis for dynamic design. How can a designer perceive this information, or according to which principle is this sensory information organized? Gunnar Johansson (1973, 1975) first studied this problem in some experiments on simple body motion patterns, and introduced the concept of biological motion. Human motion such as walking, running, or dancing, and these complex pattern of movements determine the perception of the Gestalt-like locomotor acts. These bodily movements can be constructed from combination of pendulum-type motions that are specific for each type of action. When observed from the side, the upper arm swings around the shoulder, the lower arms around the upper arms, the hands around the low arms, the head around the neck. These complex patterns of motion are labeled with biological motion.

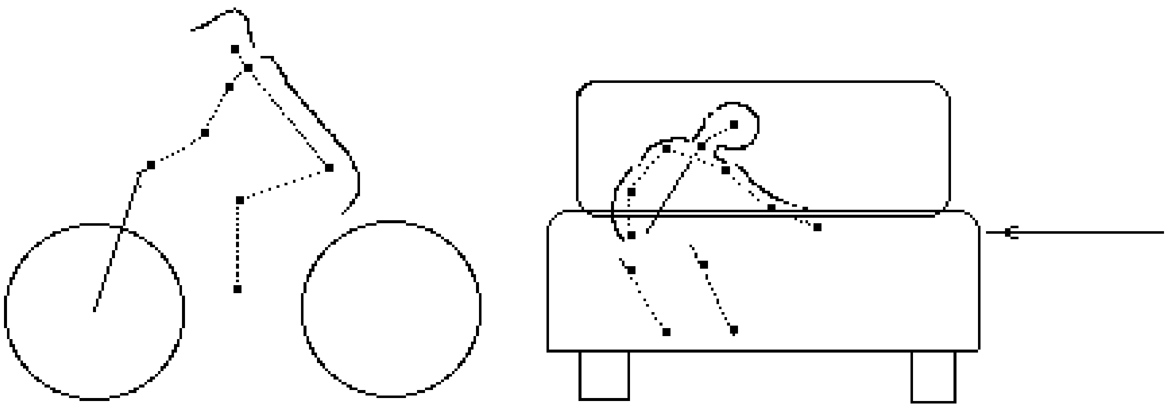


Figure 2.4-2: Biological motion.

He devised a method for direct studying the visual information for perceiving pure biological motion without any interference by the shape of the moving form. First, human movement was recorded on videotape, but was accomplished in complete darkness, and only spots of light placed at the main joints were visible: lights attached to the shoulders, elbows, wrists, hips, knees, and ankles form a total of 12 moving bright spots. The effect of the patterns of movement made by the joints, or the bright spots, determine uniformly the movement, which can not be established by any alternative impressions of movement. When the motion stops, the light configurations do not appear to represent a human form. This indicates that this pattern of movement determines the perception of the particular type of locomotor action.

Using point-light kinetic display to study gait perception can recognize one´s own walk or that of friends (Cutting and Kozlowski, 1977). By the perception of a male, his shoulder movement was greater than that of hip movement, and as female, her point-light configuration is the reverse (Barclay, Cutting, and Kozlowski, 1978). The pickup of biological motion is not difficult with camera or video camera. This method can be used to analyze the driver motion at car collision, riding a bicycle and so on. Similarly, designers may develop the method to analyze human hand motion, or hand-holding.

SECTION 2.5: THE COGNITIVE ACTION AND ARTIFACTS

2.5.1. The Concept of the Cognitive Action

I define the cognitive action as any action in which the goal is reached mainly through correct mental processing of information, while physical performance is the mean-side to the mental processes. Artifacts required for such cognitive action are called cognitive artifacts such as computer, computer-based artifacts, etc. There are differences between traditional tools and computers:

- The behavior of physical tools are often predictable. Humans can quite easily understand how to use the tools, then formulate action goals and implementation programs. What computers provide is a completely new way of behavior with which many people are not familiar. In using a computer, human actions are not uniquely determined by the user alone, but interlocked with the computer. User´s action can change the state of the computer, and the behavior of the computer can also obviously effect user´s intention and action. This interaction form a kind of behavior coupling. Learning to work with a computer is to create this action coupling: what should be done by me, what should be done by the computer, how and when.
- The affordance of physical tools are visible. Users can easily create action coupling with them: how to grasp a hammer and how to work with it correctly. The behavior of computers is frequently invisible and unpredictable. Such blindness is not formed only by menus, commands and mouse, but also by computer behavior. Visualization of computers is the first problem that users confront.
- Operating tools relies mainly upon physical skills. Operating computers mainly relies upon cognitive abilities, such as searching, naming and saving files. It needs often active thinking. The computer language is different from the natural language. Computers process the commands only according to their hardware structures of the commands. Users have to understand a computer language in the way of the computer behavior. "Why doesn´t the computer execute this command in this way?" "Why isn´t the result the same as my imagination?"
- The effects and responsibility in operating tools are obvious. Computer-based systems such as a management system imply transfer of power and responsibility, and may bring unanticipated effects. This system is created by experts in a certain situation. However, the structure of responsibility may be different in various administrations. With the computer system, some one may take more power, others less. When a problem occurs, should the computer system take the responsibility, or the operator?

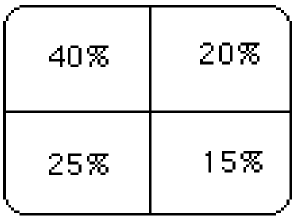


Figure 2.5-1: The relative ratios of the user´s visual focus expectation. (After M. J. Staufer, 1987)

2.5.2. The Features of the Cognitive Action and Artifacts

Computers are used for speech acts. They are linguistic tools, or the medium of communication. The main points of designing cognitive artifacts is to create a interlocked behavior between humans and computers, or a consensual domain as Maturana (1978) called. The consensual domain is generated in their interplay through structural coupling. This structural coupling is determined by the demands of an adequate organization of action. This organization of action is a network of processes through interactions and transformations by using language. That is, the cognitive artifacts and the user construct a structural coupling system. This kind of system provides new ways of human action. The action processes are mutually interlocked processes, which are determined by the features of the structure and coupling — the network of processes of transformations and interactions, not simply determined by users´ plan or imagination, or anticipation. Interacting systems engage in mutual structural coupling (Winograd and Flores, 1986, p. 75). Users are not able to reach their goals simply through their autonomic ways of action. They reach their goals through both the mental processes and the computer processes, and the coupling of the both. Commands of computer, as language, can not be understood as transmission of information, but as delivery of action and commitment to the user. User´s recognition of commitment, by understanding of the meaning of commands and operations of the computer, plays an important role in this interaction. Operation of computers is a kind of interlinked patterns of action.

2.5.3. Perception

Users perceive information mainly on the computer screen. How and what is the user-desired screen layout? One of the considerations is that information layout on the screen should relate to the primary attention focus on the screen. The major area of attention expectation is in the left upper quadrant, which takes 40% of observation time, the other distribution of attention is shown in Figure 2.5-1. Foley and Moray (1987) present a list of variables which plays a role in controlling dynamic visual attention:

- the rate at which the display varies: the greater the bandwidth, the more frequently is the display sampled;
- the value of the information: the more the information is worth, the more frequently the display is sampled;
- the cost of observation: the more costly an observation, the less frequently is the display sampled;
- forgetting; as time elapses since the last observation, the user becomes less certain of the value of the observed information even if it varies only slightly or not at all;
- the coupling between displays.

2.5.4. User Cognitive Models

The user model is the knowledge about the user cognition which is used by the human-computer interface designers, and relates to human interaction with computers. The approach to user modeling involves: for what purpose is the model needed, who will be modeled, what aspects of the user will be modeled, what relationships will be created between the computer and the user, and how will the user be modeled. Psychology can only offer the fundamental characteristics of human action. Every computer system must build the concrete user model of its own.

2.5.4.1. The user model of operating system

Donald A. Norman (1984) has developed the user model of action interacted with computers. This user model can be viewed as a user model of operating system. Norman claims that human interaction with a computer can be divided into four stages: Intention, Selection, Execution and Evaluation. First, the user has an intention. Computer commands often combine intentions with its action execution. Formation of the intention by users requires knowledge about the system and action plan. The intention stage can be supported by memory aids, by messages and interactions that take into account the intentions of the users. The second stage defined by Norman is the selection stage. Selection is to help translate the intention into one of the actual actions. The user must review the computer operations, and select those that seem to most satisfy the intentions. Design should have user knowledge about selection of an action sequence, such as how users decide upon, what command to invoke, or what files to use. The central question is how they know what is possible at any moment? Norman defines the third stage as the execution stage. It is also possible to provide considerable support: telling the user what actions are available and how to execute them. This is usually done with menus, abbreviated and restricted in content, serving primarily as reminders of the major actions available. The last stage defined by Norman is the evaluation stage. Evaluation requires feedback on whether the operation has been completed successfully or it has failed. Norman emphasizes that the user must know a number of things: what the previous state of the system was; what action was specified; what happened; how the results correspond to the intentions and expectations; and what alternatives are now possible. In the cases where the operation could not be performed properly either because it wasn´t properly specified or because some necessary precondition was not satisfied, the user will probably still maintain the same intention but needs to correct whatever was inappropriate about the previous attempt. It would be useful to provide the user with the information and tools necessary to do this with minimum disruption. Norman describes the sequence of stages like this:

Intention
Selection
Execution-Evaluation Cycles:
  Execute and Evaluate Action1
  Execute and Evaluate Action2 ...
Evaluation (of overall intention)

In reality, there are no well-defined and isolated stages of decision-making processes, and the humans are not exactly top-down processing mechanisms.

2.5.4.2. GOMS Model

Card, Moran and Newell (1983) introduce the GOMS model in the field of text editing. The GOMS model provides the dynamic description of task-oriented behavior (p. 146) in four terms: Goals, Operations, Methods and Selection

Rules. A goal is defined as a hierarchical symbolic structure (set of states). An operation represents an elementary act (perceptual, cognitive, or motor) applied to change the system or user state. A procedural method defines how to reach a state by means of a conditional action plan. A selection rule means how the user chooses among the methods achieving the similar goals.

2.5.4.3. The navigation model in using multimedia information system

Multimedia are defined by Väänänen (1993) as "the integration of a variety of natural human communication channels." "A multimedia environment is an information space in which the multimedia information units form a semantically defined collection, and around which the user can move using various navigation methods." Navigation means to move one´s point of view forward inside an environment (3D space). Väänänen (1993) describes the navigation processes as follows:

- An example of a vague goal is "I want to know something about churches in eastern Germany." The goal can also be just to explore the information environment.
- Developing an understanding 1.Definition of the goal. An example of a specific goal is "I want to find a hotel in Rostock which costs less than 50 DM per night." about the facilities offered by the system.
- Navigation (an iterative process)
  a. Moving around the information space using the navigation methods.
  b. Orientation and reorientation (Where am I? Where was I? Where can I go now?).
  c. Reaching the goal (finding interesting information and identifying it as interesting).

The system should ideally minimize the time spent on phase 2 of the interaction process, and allow selection and use of various intuitive navigation methods for performing the iterative steps of phase 3.

2.5.4.4. Other models

There are some other models. in 1981 Moran developed Command Language Grammar (CLG), and Reisner proposed a second model concentrated on the use of an action language. Kieras and Polson in 1985 developed Cognitive complexity theory (CCT) derived from the GOMS model, and introduced a rule-based production system. Payne and Green in 1986 developed task action grammar (TAG) model. In artificial intelligence, there are other user models.

Most of the models mentioned above are rational models. They are oriented toward the rational, correct and successful action. Users must have knowledge about the system and action plan. That is, learning machine-oriented knowledge (computer language and commands) is one of the important tasks for users.

2.5.5. User Behavior in Operating Computers

Wright and Lickorish (1994) have studied features of female novice users´ behavior in electronic shopping. The central interest concerns users´ choices among navigation options. This issue relates to learnability of the software, cognitive demands for remembering action goals, and navigation path (action plan). Learnability refers to how easy for users to learn the procedures. Cognitive demands for retrieval and decision processes are one important issue. On Wright and Lickorish, users will select procedures that result in the fewest additional demands for memory processes. Novice users at first select those procedures that are easier to remember, which must not be the fastest ones.

2.5.5.1. Memory for action goals

In a complex task of searching, users may forget their goals. The fixed sequence of subgoals serves as an indicator of action plan and can reduce the memory load. The absence of sequential constraints might make it more difficult to remember all the action goals. In this case, an indication of progress is provided as a spatial cue of the retrieval location. Wright and Lickorish introduce several computer-based memory aids to help users: (1) A Planner (navigation aid) can help remembering navigation goals; (2) Notebook enables information (prices of shopping list) to be recorded for later comparison; (3) Memory aid for rereading information (the shopping list). The experiment illustrates that users are likely to use several memory aids when they feel that their working memory is in danger of being overloaded. When the shopping task involves more four items, they use memory aids frequently. If the interface affords support for remembering future destinations (the next goal is constrained), then the memory load is reduced.

2.5.5.2. Way of navigation

On the screen, the same kind of products from different shops are displayed together for comparison. The experiment illustrates that the users prefer to collect the prices of all items in one shop rather than product by product as displayed.

It seems for them to enter a shop and to move around, then to enter another shop. Here, the way of navigation reflects the action habits of shopping. Wright and Lickorish assert that the users´ navigation choice is not determined by the length of the sequence of action (clicks), but cognitive complexity may have been a major determinant of navigation choice. These cognitive costs may contribute to (1) a large decision set (80 items) for the next destination; (2) index table of products filling the whole screen. Users do not select the shorter procedures of navigation of displaying prices (the fewer actions of clicks), but they select the procedure that requires less cognitive computation time.

2.5.6. Task-Action Mappings: The Structures of Editor Commands
A fundamental feature in using computer is mappings or associations. Lee, Foltz and Polson (1994) have studied this kind of cognitive action. For the authors, the association involves the following types of actions: (1) mapping between a user´s goal and the function of the computer, (2) mapping between the function and the the corresponding action of the user, (3) mapping between a menu item (or a button) and the function associated with that item or button. Learning and retention of these mappings are the prerequisite in using computers. Three factors determining the easy learning and retention of task-action mappings are mnemonics, regularity within a set of mappings, and consistency across different system contexts in mappings (Barnard and Grudin, 1988).

Barnard and Grudin "define mnemonics systems as some scheme that permits the user to use a straightforward rule such as choose the first letter or vowel deletion to derive the correct action sequence given knowledge of the proper task label." However, many task-action mappings are not able to follow this simple rule.

Regularity refers to the structure of commands (or tasks) which reflect the systematic relationship within a set of tasks. For example, operations such as insert, delete and copy are followed by a a character or a word, or composed by the first letter of the operation followed by the first letter of the object (e.g., DW stands for delete word). For the authors, regularity (and regular) means that the task is already preserved in the structure of the action sequence required to activate the functions, and "Irregular" refers to a set of task-action mappings that does not preserve the combinatorial operation-object structure. It is commonly found that the non-mnemonic, regular command set was easier to learn. Walker and Olson (Barnard & Grudin, 1988) designed a new set of commands for multimedia document called Diamand, which was both regular and mnemonic. Tasks were characterized on three dimensions: context (system, text editor, bit-mapped graphics editor, etc.), editing action, and editing object. The action sequence for a single command indicated context, action, and editing object. Consistency is one of the major concerns of design, and designers understand it very differently. Reisner has showed that if commands have simple generation rules, learning and mapping are facilitated. However, Lee, Foltz and Polson argue that well-learned task-action mappings may interfere with the acquisition of the new regular mappings, and contribute to higher error rates on the new application.

Their experiments show that Regular-Mnemonic task-action mappings (e.g., DW stands for Delete Word, DL for Delete Line) are easiest to remember. They can be learned in a single exposure to a small subset of task-action mappings). They would not be interfered with by knowledge of the mappings required by the previous version of the interface, or by inconsistent mappings used in other applications. The Irregular-Non-Mnemonic mappings (ctrl-Z for Delete Word, ctrl-P for Delete Line) are much harder to learn and to remember because of arbitrary associations. Arbitrary task-action mappings are a source of real difficulties.

2.5.7. Two Kinds of Interface Design Activities
Few authors have studied the behavior of computer designers. Inadequacy of human-computer interaction (HCI) design is not dependent upon designer´s motivation, but upon their ways of action, their declarative knowledge structures and cognitive models. Gillan, Breedin and Cooke (1992) use Pathfinder to investigate human factors experts and software development experts´ organization of declarative knowledge about the HCI. Pathfinder technique can be found in their paper. They use the following definition of a cognitive model: (1) a set of elemental concepts in a knowledge domain, including various input devices (mouse, keyboard, touch screen, trackball, function keys, etc.), advanced interface techniques (adaptive interfaces, speech recognition, auditory interface), graphical display elements (icons, cursor, windows, etc.), information display types, data manipulation (editing, searching, saving, entry, etc.), display coding (color coding, symbolic codes, highlighting, etc.), user-computer dialogue methods (interactive, direct manipulation, command language, keystrokes, natural language, etc.); (2) the relations among the elemental concepts; (3) the higher-level relations among groups of associated elements.

Gillan, Breedin and Cooke have found that the differences in understanding HCI and the user model between the two groups are not related to the concepts such as user´s action of manipulating data, the concepts of HCI software, and user´s knowledge. Both groups have similar dimensions concerned with advanced technology (display-related concepts), and the spatial nature of concepts (interaction-related concepts). Gillan, Breedin and Cooke claim that their differences lie in the cognitive models, and the organization of knowledge about HCI which are affected by their different experiences in interface design as follows:

- The declarative knowledge have illustrated the clear structures for the human factors experts, but the poorer agreement in classification and organization of the elemental concepts for software experts (lack of coherent structure).
- Human factors experts can focus on the user. Software development experts have to focus on three aspects of HCI design: technology, implementation and the user. Their cognitive model may compromise between the three kinds of knowledge. For example, human factors experts appear to link concepts of message area and icon to windows based on how they work for the user (user-oriented). Software development experts appear to link variety of concepts to windows based on implementation: graphics, highlighting, cursor, paging and scrolling. This may imply computer-orientation.
- Both groups have different ways of design. The primary work of the human factors experts frequently involves identifying the ways in which a system should display information to the user, and how the user should provide input into the system. Their work focuses on the interaction between the user and the computer. However, the software development experts focus to a greater extent on writing the code for a user interfaces design and
- integrating that code with the rest of the system.
- The overall structure of knowledge is different for the two groups of experts. Human factors experts use prototyping to develop the user interface, and the user interface management system is linked with prototyping. For software developers, the user interface management system is linked to application software, that is, they regard the user interface only as relation to the use of application software and aspects of program management.
- These two groups differ in the basic structure of the interaction concepts. For software development experts, editing and command language as well as command keystrokes serve as central concepts. They may conceive on rapid keystroke input of commands as an important bridge between the input hardware and user-system dialogues, and provide the user with help that is tailored to users´ specific task and needs or amount of expertise. For human factors experts, interaction with computers is a sequence of concepts, including menus, function keys, command keystrokes, command language, saving, editing, etc..
- These two groups classify all the elemental concepts into different dimensions. Human factors experts classify them into advance technology (e.g., icons and symbolic codes, cursor, windows, color coding, text, as well as printed manuals and hardcopy presentations, etc.), cognitive involvement, motor capability, experience, and spatial representation. Four of the five dimensions deal with user´s action: cognition, spatial abilities, motor abilities, and experience. For software development experts, all the concepts are classified into four dimensions. Only one is related to human action (spatial abilities), the other three dimensions were related to technology or implementation (the effort required to implement an interface element).

This study has revealed the fundamental differences between these groups of experts. Human factors experts are more oriented towards users, whereas software development experts are more oriented towards computers. User-oriented design appears to focus on the coupling between the user and the display of information. Their cognitive model can be embodied through (1) user´s cognition, (2) user´s motor abilities, (3) user´s experience, and (4) user´s spatial abilities.

2.5.8. Easy Cognition

Easy cognition is the major goal of designing cognitive artifacts. It involve the following considerations.

2.5.8.1. Visualization

Visualization of electronic instruments and computers means to make their behavior visible, understandable and predictable in light of user´s intention and cognition:

- Visibility refers to that the function of the instruments and the computer software, the input devices and input methods are transparent to users. Visible menu and on-line help are not enough. Operation sequence, procedures and their states, and the outcomes of user´s operation should be also visible. Everything that relates to user´s desire, intention and action should be visible.
- Understandability refers to make people easily understand the meaning of input/output devices, commands and methods, the meaning of their functions, and the commitment and the responsibility.

- Predictability refers to that the operation and the behavior of the machines are predictable in light of the user´s desire and expectation, the new version of software keeps the compatible operation with the old version.
- Text or graphics? Information (the content and the form) must fit their cognitive desire and abilities.

2.5.8.2. Consistent mapping

Many authors propose several criteria for design of human-computer interaction, for example, operation should be simple, flexible, consistent, and compatible. These criteria are frequently contradictory with each other. Here again, user´s intention and cognitive characteristics are emphasized. Consistency of operation is the key point in these criteria. Tero and Briggs (1994) summarize the various understandings of consistency as follows: (1) Similar tasks should be associated with similar actions. (2) The number of actions (e.g., typing, mouse movement) should be minimized. (3) A consistent interaction should present the user with fewer rules to learn. (4) Consistent interface language involves syntactic consistency, semantic consistency, and lexical consistency. Tero and Briggs claim that a high level of consistency is the command-action mappings which are internally consistent and also map onto the user´s prior expectations (familiar to the user). User´s experiences, or user´s world knowledge must be incorporated into the interface design. In a word, consistency means to create the coupling between the user and the computer in relation to the user´s intention, cognitive abilities, learning, cognitive processes and styles, and ways of action.

2.5.8.3. Learning and memory

User-centered design requires less machine-oriented learning and less memory. There must be a relatively stable minimal set of knowledge and of memory for users, less difficulties in reading and understanding, and easy action-operation mapping and action coordination.

2.5.8.4. Everyday logic

User-centered design should reduce machine-oriented scientific logic, employ everyday way of thinking and reasoning, offer convenience for natural way of thinking. That is heuristics, such as easy trial-and-error. Users must be allowed to try, to have a look, then to try again, and there must be lower demands for idea production, naming, problem-solving and decision-making.

SECTION 2.6: THE EXPRESSIVE ACTION AND ARTIFACTS

2.6.1. The Expressive Action

The expressive action refers to the action where expressive symbols have significance. According to Frijda (1987, p. 9-57) expressive actions "are evoked by events that the subject understands as aversive, desirable or exciting." They serve no obvious goals. Expressive actions "accompany the various emotions: happiness, fear, amusement, etc." Bühler (1934) in his "Ausdruckstheorie" (Jena, East Germany: Fischer) asserted that many (not all) expressions can be considered preparation for effective action or initial stages of such actions. Expressions of eagerness, desire, and reluctance are early actions of approach and withdrawing. Interactive expressions can be considered means of communication. What they communicate are behavioral intentions and requests for action. Their functional significance is (1) to establish, to maintain, to weaken, or to break some form of relationship or communication with the environment; (2) to express one´s emotion (happiness), or to give vent to one´s personal feeling (celebration of festival, birthday party, dancing party); (3) to influence the behavior of others; (4) to emphasize other goal-directed action (gestures). This is the general characteristics of expressive action. Four principles of expressions which are developed by Darwin (1872) and modified by Frijda (1987, p. 55-56) are supposed to explain the nature, form and occurrence of expressive action:

- The principle of relational activity. Some expressive action can be understood as relational activity that establishes, or weakens the physical and cognitive relations of the subject with the environment.
- The principle of interactive effectiveness. Some expressive action can be understood as action that aims at modifying the relation of the subject with the environment through influencing the behavior of others.
- The principle of activation. Some expressive action can be understood as the manifestation of behavior activation. Activation means intentional directedness: readiness for attention, striving, and responding.
- The principle of inhibition. Some expressive action can be understood as the result of inhibition of behavior. Some of this behavior results from inhibition of expressive behavior falling under the previous principles.

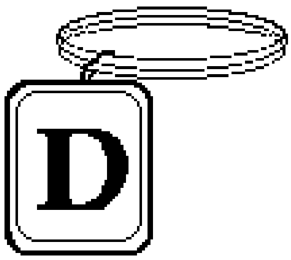


Figure 2.6-1: A tourist wants to find a ring of key which should be a sign of Germany.

2.6.2. Two Kinds of Expressive Artifacts

Pleasure, thankfulness, sympathy, anger, shame, irritation, love, sorrow and fear may (must not) cause the expressive motoring behavior on face, mood and body. This behavior can be intentional one, and controlled by emotion. People need appropriate artifacts for these expressive actions and activities. Two classes of expressive artifacts are related to human expressive actions. (1) Artifacts for direct expression. Such expression can be represented in many forms: celebration for some reasons, memorial, various parties, New Year, Carnival, and so on. People need many various artifacts for various expressions. Some design for these expressive artifacts only stay at esthetic aspects which seems to be designer´s preferences, and neglect user´s concerns and communicative purposes (potential intentions of communication). A tourist said that he wanted to buy a ring of keys which should be the sign of Germany (D), but he could not find it. (2) Artifacts for improvement of emotions. People need artifacts to improve their emotions, to enhance desired emotions, to improve negative emotions such as boring, grief, impatientness, or sadness. Many decorative artifacts are lack of user´s concern (intention), and purposeless. That may be why users cannot be moved by many decorative artifacts.

Many people see computer, camera, TV set, car not only as their application purposes, but also as emotional expression, or desire that these products do not elicit negative emotions. Users have emotional needs toward artifacts. In other words, artifacts present emotional aspect to users, not only in beautiful decoration things, but also in tools, machines and computers. Emotional aspect of artifacts or emotional artifacts should be part of designer´s consideration: what are user´s emotional expressive concerns, what factors of artifacts cause negative emotion of users? and how to avoid or improve user´s negative emotions in their using process.

Expressive action relates to culture (habits) and cultural semiotics. Cultural environment has powerful effects upon true emotional expression. Ekman (1972, 1973) investigated culturally defined "display rules", and distinguished four mechanisms: intensification, deintensification, neutralizing and masking. They concludes that culture defines not what emotional expressions to make, but when to make them, and how strongly. People in different cultural environments use different artifacts to express emotions. For expressive actions, cultural backgrounds provide very different artifacts to express happiness, friendship, or sadness. For example, when Japanese present a bottle of spirits and a leather belt, it means friendship.

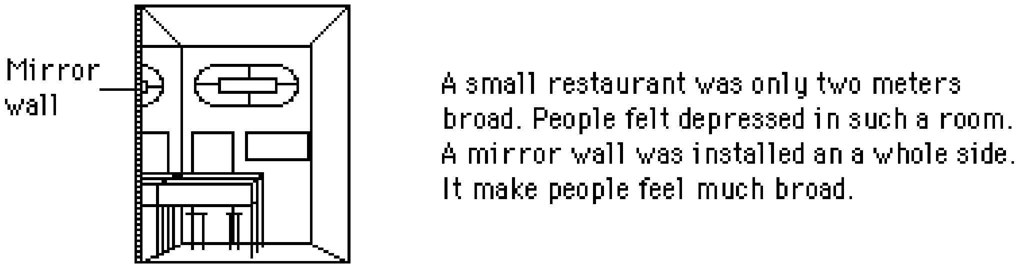


Figure 2.6-2: Design can improve users´ emotions in some cases.

SECTION 2.7: THE SKILLED ACTION, ARTIFACTS AND LEARNING

2.7.1. What Is the Skilled Action

What is skill? Skill is a type of procedural knowledge which has been automatized through practice for execution with economy of effort. The skilled action is fundamental not only to industrial environments, but also to everyday life; not only means manual operations, but also covers a wide range of mental processes. In the traditional sense, the skilled action refers to highly automatized psychomotor performance in speed and accuracy, such as playing football, riding a bicycle, handicraft, and so on. In the psychological sense, the skilled action involves all aspects of human action, including the skilled perceptual action, the skilled cognitive action (such as professional computer programming and data analysis), and the skilled perceptual motor action (e.g., typing). Of course, different skilled actions have different features and different requirements for the design.

2.7.2. The Desired and the Undesired Skilled Action

Designers must first distinguish between the desired and the undesired skilled action in performer´s view of point. Sport, traditional cultural craft may be desired skills for some people. Many skilled actions in everyday life and work are viewed by many performers as undesired. One of the reasons seems that such skills are directly related to the inadequately design tools, such as hand operations under microscope for eight hours, manual operations with improperly designed hammers, pliers, or the electric irons at assembly lines. Many hand-held tools belong to this category, which I define them as “dangerous tools." For example, in USA "chainsaws were cited as the cause of 20% of the logging injuries and generally credited with being the source of the greatest number of logging injuries in a 1985 BLS report," and "Injuries to the legs and ankles accounted for 47.8% of the chainsaw injuries in a study of Appalachian logging injuries" (Gleaves, Rummer and Smith, 1989, 283-298). Injury data of hand tools were involved in 5 to 10% of all compensable injuries (Sanders and McCormick, 1987, p. 302). The most common tools which causes injuries were knives, wrenches, and hammers. They are dangerous tools. Hand-held power tools, such as electric motor, pneumatic motor, hydraulic motor, are used for grinding, milling, drilling, etc. Their heavy mechanical vibration and noise cause so-called vibration-induced white finger, or vibration syndrome (Sanders and McCormick, 1987, p. 314). If the tools are designed to fit the features of human action, the performers do not need the old skills any more. Historically, the skills research was focused primarily on motor skill and performance (Weldford, 1976). Main problems in the design of manual tool involves (1) human limb which is located in the execution surface or interface of the tool or machine; (2) high demand for complex coordination, and accurate, precise timing of psychomotor performance; (3) high loading of performance duration with the tools; (4) high demand for human attention during action. Problems in the design of cognitive artifacts involve mainly high demand for the difficult and complex ability factors in cognitive processing with high loadings and with high duration of time. Other problems relate to high load in skill learning process.

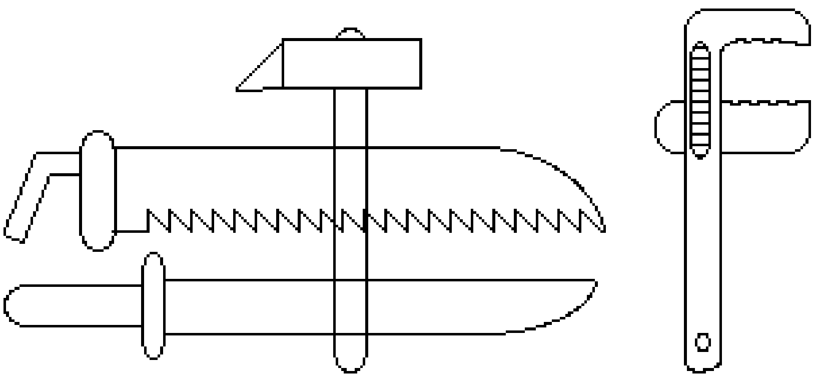


Figure 2.7-1: Knives, wrenches, hammers and saws cause most injuries.

2.7.3. Learning of Skill

Designers should know how to get users learn quickly and naturally to use artifacts, including the development of motor skills and cognitive skills, what factors influence learning, and how to improve these product-related factors.

Anderson (1982, 1983) developed a framework for the acquisition of cognitive skill based on Fitt´s three phases (Fitt and Posner, 1967; Anderson, 1983): the cognitive, the associative and the autonomous.

- Cognitive stage, or declarative stage: instructions and situational characteristics are encoded as set of facts. These facts must be rehearsed and retained in an active state in working memory to be used by general interpretive mechanisms. Learners develop a declarative encoding of the skill, and they commit to memory a set of facts relevant to the skill. In learning driving a car, you may memorize the location of gears and correct sequence of engaging the clutch and moving the stick shift. Learners rehearse these facts when they first perform the skill. They use these facts to guide their performance and problem-solving. They may have a general means-ends production as:

  IF the goal is to go in reverse
  AND IF the learner knows that moving the stick shift to the upper left will put the car into reverse
  THEN set the subgoal of moving the gear to the upper left

  Its general form is:

  IF the goal is to achieve a state X
  AND IF M is a method for achieving state X
  THEN set as a subgoal to apply M

  The learner must attend to outside cues, the instructions that are provided, and feedback about performance because of the heavy involvement of conscious cognitive processes early in learning. Fitts called this the cognitive phase. The knowledge acquired in the cognitive stage is quite inadequate for skilled performance.

- In the associative stage, errors in the initial understanding are gradually detected and decreased. The connections among the various elements required for successful performance are strengthened. The declarative knowledge is transformed into a procedural form. Procedural knowledge is the set of skills a person knows how to perform. In practices, procedures specify the task at hand, and the procedural knowledge governs the skilled performance. The learner does not require the active maintenance of declarative knowledge about how to do the task. For example, learner no longer has to sit for a few seconds trying to remember how to get to the second gear from the first. In some cases, both forms can coexist. In this stage, a successful procedure for performing the skill is worked out, and learners develop a special production for moving into reverse, rather than using means-ends production. In this stage, proceduralization gradually replaces the interpretive application with productions which perform the behavior directly. In this proceduralization process, there exists a composition process which combines a sequence of productions into a single production. Proceduralization and composition together are called knowledge compilation. This process corresponds to the automatization. The output of the associate state is a set of procedures specific to the domain:

  IF the goal is to go in reverse
  THEN set as subgoals

  1. To disengage the clutch
  2. To move the gear to the upper left
  3. To engage the clutch
  4. To push down on the gas.

- Autonomous stage. As the skill becomes more and more rapid and automated, the acquisition of skill comes into the. autonomous stage. Because facility in the skill increases, verbal mediation in the performance often disappears at this point. The skill — its speed and accuracy — improves gradually. The procedures come to apply more rapidly and more appropriately. When task performance has reached the autonomous phase, it is said to be automatic, no longer requiring conscious control. The increasing appropriateness of the procedure is called tuning (Rumelhart and Norman, 1978; Anderson, 1982). The tuning involves refinement of the procedures through processes of generalization (that broadens the range of applicability), discrimination (that narrows the rules to only appropriate situations), and strengthening (that weakens poorer rules and strengthens better rules). The process of tuning would result in the production that had additional tests for the appropriateness of this operation in IF conditions. For moving into reverse, it is only applicable to an ordinary three-speed gear:

  IF the goal is to go in reverse
  AND IF there is a three-speed standard transmission

  In this phase of skill development, the action is smooth, relatively effortless. According to Fitts, development of this automaticity may take months or years, and the automated task can be performed concurrently with other activities. Extensive practice is necessary to perform at the level of an expert.

2.7.4. What Abilities Are Required in User´s Learning

The goal of user´s learning is to acquire the performance to use artifacts. In psychological point of view, learning and memory are interrelated, and individuals have big differences in these processes. Carroll (1993, pp. 248-303) claims that five types of human ability factors relate to human abilities of learning and memory, each of which involve many factors (Carroll, 1993, pp. 302-303):

- There is a general learning ability: Fluid and Crystallized intelligence (p. 302). Fluid abilities reflect basic abilities in reasoning and related higher mental processes, and are able to flow into many kinds of mental activities. Fluid abilities decline with the increase of age. Crystallized abilities reflect the education or learning.
- There is evidence of factors of learning ability that are specific to particular kinds of learning situations (p. 302).
- Visual Memory: "The ability to form, in a study phase, a mental representation (or possible an image) of visual material that is presented, when the visual material is not readily encodable in some modality other than visual, and to use that representation in responding in a test phase by recognition or recall" (p. 302). Performance with artifacts may require various visual memory factors, such as Shape Memory, Building Memory, Map Memory, Memory of Relations, Memory for Pictures, Memory for Geometric Designs, and so on.
- Memory Span: "An ability indicated by the amount of material (verbal, numerical, or figural) that the individual can immediately recall, in its correct order, after one exposure to that material" (p. 302). "As Martin notes, the standard digit-span task is traditionally regarded as measure of short-term memory capacity, i.e., the number of items that can be held in immediate working memory" (Carroll, 1993, p. 262). Memory Span relates mainly the ability to recall the identities of the units presented and to recall the order of the units (p. 263). If the tasks illustrate various degree of difficulty, complexity and loadings for memory, humans have to employ extra abilities to maintain memory span. To maintain attention despite the difficulty, distractions, and feeling of boredom is to require high ability from users. (pp. 256-266)
- Associative Memory: "The ability to form arbitrary associations in stimulus material such that on testing, the individual can recall what stimulus is paired with another, or recognize, in a series of test stimuli, which stimuli were experienced in a study phase" (p. 302). The tasks require users´ ability to recall and recognize words, voices, colors, and figures, and to associate them in a new arrangement.
- Free Recall Memory: "Indicated by the fact that some individuals, after a study phase, are able to recall more (arbitrarily unrelated) material from the study phase than others, when the amount of material to be remembered exceeds the individual´s memory span." (p. 302).
- Meaningful Memory: "Indicated by the fact that some individuals, after a study phase, are able to recall (reproduce) or recognize more material from a study phase than others, when the material in the study phase has meaningful interrelations." (p. 302)

Note again: These abilities can also reflect the differences between individuals. Of course, every one must learn. Can design reduce the load of user´s learning and memory? Sure. Inadequate design may lead to more difficulty and higher demand for user´s abilities in learning process.

2.7.5. Felicity Conditions for Easy Learning

User´s learning is close related to user-interface design. Machine-centered design makes learning more difficult. There are some basic ideas to improve learning processing:

- Learning is a trial-and-error process in general. Artifacts should permit the trial-and-error performance if possible.
- Learning process should suit users´ action model, and provide mapping of action on operation. That is, to provide action-oriented affordance and visualization of performance.
- Learning process should suit users´ abilities of learning and make perceptual and cognitive processes naturally, i.e., less reasoning and less demand for cognitive complexity and speed.
- Machine-oriented concepts and principles must be interpreted in user-oriented actions, just as the direct manipulation interface of the Macintosh computer.
- Design can offer a number of ways to guide learning: (1) examples, (2) simulations, (3) direct procedural instructions, (4) tutorial dialogue.
- In the associative stage, the elimination of errors and coordination of goal-perception-motor performance are strengthened. Artifacts should provide memory mechanisms and possibilities of failure-driven learning to remind user´s errors and coordination of performances.
- Then users gradually replace this interpretive application with direct rules to perform action directly in the third stage. This is called proceduralization by Anderson (1983, p. 34). There exist the various degree of difficulty in proceduralization in using different artifacts. Main idea is to integrate machine-oriented operation primitives into users´ action steps.

- Feedback of action outcome is an important condition for learning process. There are several types of feedback: simultaneous feedback, feedback after an action, summary after a period of learning.
- Anticipation, prediction and mechanisms for error correctness are profitable for learning in general.

2.7.6. Design for the Human Skilled Action
Main issue for the skilled action which is most investigated is its training and practice. Design should distinguish their features of action, and find satisfactory conditions for user´s action.

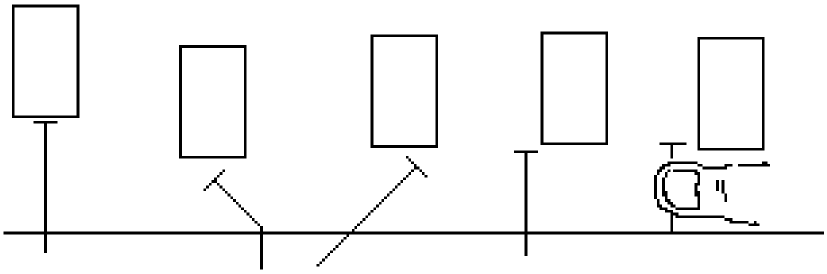


Figure 2.7-2: Uncertainty of hammering outcomes.

Uncertainty of action consequence is one of the problem in hammering. It is quite difficult to use a hammer to obtain a certain desired outcome (Figure 2.7-2). Such designer should be avoided.

Another problem is that human limb must be out of the execution surface or interface. Skilled action is sometimes very quick and without attention. Human fingers, limb which is located in the execution surface interface is easily to be hurt. Almost every one has such experience.

Skilled action requires quick perceptual processing. That is, information provided by design should be easily visible, understandable, goal-related, and perception-adapted. On the contrary, inadequate design makes perceptual processing become a cognitive processing so that one has to think, reason, calculate, or translate the information. Information, not only the content but also the form provided by design, should fit users´ action.

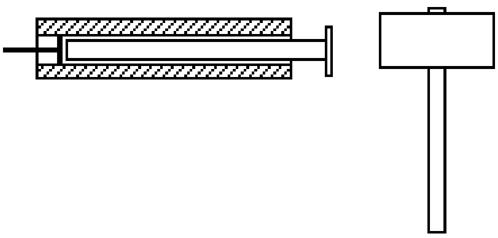


Figure 2.7-3: Another way of hammering

Overloaded information forces the actor to select a portion of it with selective attention, and selective attention deficit can reduce the efficiency of performance because of human limited processing of attention and memory capacity. Many factors can cause user´s attention deficits. Design-related attention deficit of the users may be as follows and should be avoided:
- Waiting for extra information without anticipation may cause divided-attention deficit. Skilled action required quick and random perception. Anticipation and expectation may play a role.
- Irrelevant, redundant, ambiguous information cause focused attention deficit. Information provided must be the relevant content, in the correct form, at the correct time, and at the correct position.

Simple knives, hammers and wrenches cause injuries in nature because they require strong attention for coordination of perception, cognition and performance.

Many skilled actions require precise and accurate timing of performance. There exists contradiction between accuracy and speed of human movement according to the Fitt´s Law (SECTION MOTOR PERFORMANCE). Demand for both high speed and high accuracy should be realized by tools and machines themselves.

Learning to drive a car may require 20 to 40 hours to reach the second stage of skill acquisition. It requires at least 100 hours of learning and practice to acquire the skill to program a computer (Anderson, 1982. 369). Expertise typically is acquired through intensive, deliberate practice in a particular domain, at least with 10 years for a expert level (Proctor and Dutta, 1995, p. 262). If designers develop new cars which requires a new kind of driving skills in every five years, can you imagine what will happen? What about computers? Skilled action requires consistent design.

Taping keypads is not difficult. However, performers can not maintain such a skilled action for a long time, say eight hours a day without pause. Such problem can only be found in user´s working situation.

The skilled action has very high requirement for its artifacts. The skilled action requires automaticity of psychomotor program, and fluent coordination of perception and physical performance. Any unnatural performance may lead to its interruption, errors, or danger. Artifact-Human-as-an-entity is users´ desires to the design. Such artifacts should provide the harmonic relationship between humans and the artifacts in all aspects. They must fit human organs, abilities, hand-holding and way of action. Each step in the action process must be smooth and continuous. Natural and smooth coordination is required between perception and performance, between all steps of action process, and between feedback and evaluation.

SECTION 2.8: ACTION ERRORS AND STATE-ORIENTATION

2.8.1. Humans Make Errors Always

The goal of this section is to summarize human errors, and to reduce human errors in using artifacts. Norman (1993, p. 131) writes some excellent words about human errors: "Human err, that is a fact of life. Another fact is that some situations seem as if they were designed to cause errors, especially when their design fails to take human abilities into account. Many situations seem designed as if to deliberately form a mismatch with human capabilities: (1) Human memory is well tuned to remember the substance and meaning of events, not the details; (2) Humans can essentially attend to only one conscious task at a time. We cannot maintain attention on a task for extended periods. Basically, we are sensitive to changes in the environment: We attend to changing events, not continual, ongoing ones. The same true for memory: We tend to remember novel and unexpected events better than regular, recurring ones; (3) Humans are pattern-recognition animals, matching things that appear similar to past events."

2.8.2. The Basic Types of Human Errors: Mistake, Slip and Lapse of Action

Reason (1990) claims that the term "error" has no meaning in relation to unintentional behavior. Reason defines error in a psychological way: "Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcomes, and when these failures cannot be attributed to the intervention of one change agency." There are three kinds of errors on Norman (1981) and Reason (1990, p. 9):

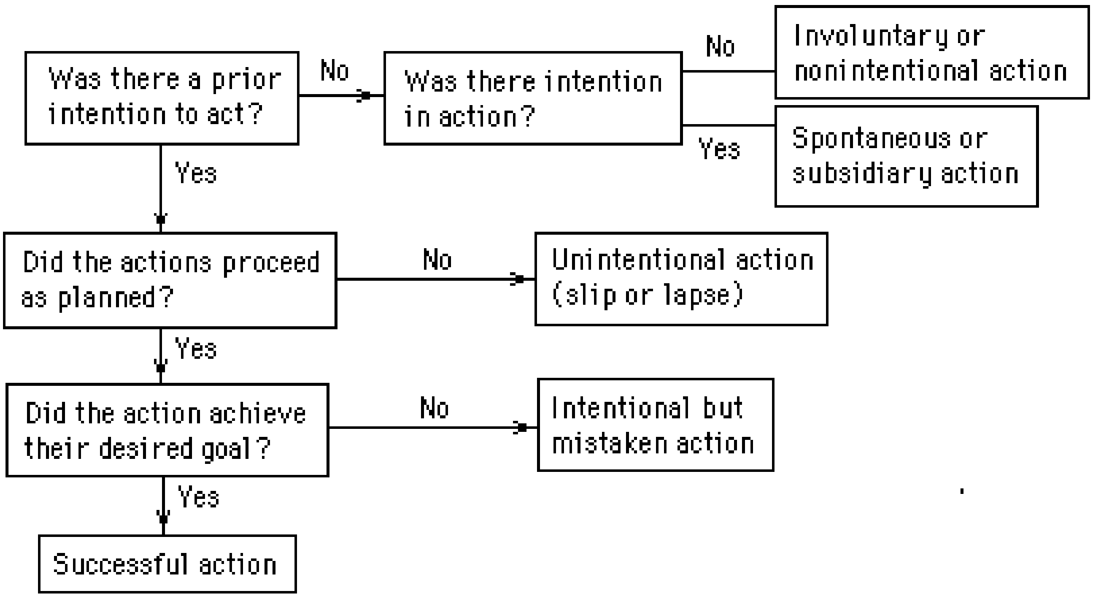


Figure 2.8-1: Three types of error related to three kinds of behavior (After Reason, 1990).

- If the intention is not appropriate, this is a mistake (Norman, 1983). Mistakes are defined by Reason as deficiencies or failures in the judgmental and/or inferential processes involved in the selection of an objective. Mistakes involve a mismatch between the prior intention and the intended consequences.
- Slips are the errors of execution, or actions-not-as-planned in execution stage: slips of the tongue, slips of the pen, slips of action. (Reason, 1990)
- The term lapse is reserved for more covert error forms, and largely involves failures of memory, that must not manifest in actual behavior and may only be apparent to the person who experiences them. (Reason, 1990)

Reason asserts that slips stem from the unintended activation of largely automatic routines (associated primarily with inappropriate attentive monitoring), and that mistakes arise from failures of the high-order cognitive processes involved in judging the available information, setting objectives and deciding upon the means to achieve them. Both slips and mistakes can take "strong-but-wrong" forms, where the erroneous behavior is more in keeping with past practice than the current circumstances demand. A necessary condition for the occurrence of a slip of action is the presence of attentive "capture" associated with either distraction or preoccupation, i.e., the limited attentive resource is not focused on the routine task in hand.

2.8.3. Failure Modes of the Skill-Based Behavior

According to Rasmussen´s model of human action in industry (i.e., skill-, rule-, knowledge-based behavior), Reason (1990) presents an integrated picture of the error mechanisms at these three levels of performance. Slips and lapses are seen as being mainly associated with monitoring failures in skilled behaviors. Errors that appear subsequently (rule-based and knowledge-based mistakes) are subsumed under the problem-solving failures. Generally, industrial design often meets the errors in skill-based action. For Reason, error modes at the skill-based level can be grouped into two categories: inattention and overattention.

2.8.3.1. Inattention

Inattention means to omit necessary checks. It consists of the following modes:
Double-capture slips: On Reason (1990), action slips occur when the limited attentive resource is claimed either by some internal preoccupation or by some external distracter at the time rather than by the currently intended pathway. Reason asserts that the necessary conditions for the slips involve: (1) the performance of some well-practised activity in familiar surroundings; (2) an intention to depart from habits; (3) a departure point beyond which the "strengths" of the associated action schemata are markedly different; and (4) failure to make an appropriate attentive check. A strong habit intrusion is the main cause. Example are: old habit intrusion because of a checking omission; strong habit capture during a moment of distraction; branching errors, in which an initial common action sequence leads to different outcomes, and the attentive check at the choice-point is omitted; unwanted reversion to an earlier play, etc.

Omissions associated with interruptions: In some cases, the failure to make an attentive check is compounded by some external event. For example, "I want to pick up my keys to go out when the phone rang. I answered it, then went out, and locked the door without taking my keys." There are several methods to solve the problem: (1) reminding them of the keys (e.g., the chain to tie the keys on the waist-belt); (2) provide action with restrictions if the conditions are not satisfied, that is, the door is not able to be locked without the key; or (3) new mechanisms of the lock which does not need the key (in application of face recognition, or recognition of finger print, etc).

Reduced intentionality: Because of time delay between the formulation of an intention and its execution, this intention might be forgotten and overlaid by other activities. This is a common class of slips and lapses. Many attempts of memory aid may be employed to remind people of their intentions.

Perceptual confusions: Perceptual confusions occur because of the similar affordance to other objects, to other plans, or to other action processing, which is at the expected location. For example, a fixed round object may suggest the action of rotation; two currently active plans, or two action elements within a single plan can become confused. When an attentive check is omitted, the control of action or perception is likely to be snatched by some contextually strong habit (action schema), or expected pattern (recognition schema).

2.8.3.2.Overattention

For Reason, overattention means to make an attentive check at an inappropriate point in an automatic action sequence. Overattention may also lead to slips. For example, if a skilled typist focuses on the movements of every finger, he or she will make more errors in typing. Overattention can cause action omissions, repetitions, and reversals. Like omitted checks, inappropriate monitoring is associated with attentive capture. Mistimed monitoring is most likely to occur immediately following a period of "absence" from the task in hand.

2.8.4. Norman´s Model of Action Errors

Norman (1981) has carried out a different classification of slips of action based on the action course:

- Slips that result from errors in the formation of the intention:
  *Errors in determination of goals, such as in decision making and problem-solving, and other related aspects;
  *Mode errors: erroneous classification of the situation;
  *Description errors: ambiguous or incomplete specification of the intention.

- Slips that result from faulty activation of schemata:
  *Unintentional activation: when schemata which are not part of a current action sequence become activated :
    - Capture errors: a sequence is similar to another more better learned sequence, the latter may capture control;
    - Data-driven activation: external events cause activation of schemata;
    - Associative activation: currently active schemata activate others with which they are associated.

  *Loss of activation: the activated schemata loses effectiveness to control behavior:
    - Forgetting an intention (but continuing with the action sequence);
    - Misordering the components of an action sequence;
    - Skipping steps in an action sequence;
    - Repeating steps in an action sequence.
- Slips that result from faulty triggering of active schemata:
  *False triggering: a properly activated schema is triggered at an inappropriate time:
    - Spoonerisms: reversal of event components;
    - Blends: combinations of components from two competing schemata;
    - Thoughts leading to actions: triggering of schemata meant only to be thought, not to govern action;
    - Premature triggering.

  *Failure to trigger: when an active schema never gets invoked because the action is preempted by competing schemata:
    - There was insufficient activation, either as a result of forgetting or because the initial level was too low;
    - There was failure of the trigger conditions to match, either because the triggering conditions were badly; specified or the match between occurring conditions and the required conditions was never sufficiently close.

2.8.5. Action Inability Caused by State-Orientation

Negative emotional states (such as anxiety, depression and anger of emotional reactions), unexpected events, surprise, fear of failure, loss of control, over-motivation, analytical focus on "why," and time pressure are likely to induce state orientation. Their cognition with these emotional reactions are concentrated on the past state (fear about the past accident), the present (fear of the present failure in using an artifact), or the future (fear to loss of control in action processing), rather than on the action alternatives to reduce the discrepancy between the present and the desired future states. Performance impairments are observed in state-oriented failure group. (Kuhl, 1985, p. 108)

Kuhl, Goschke and Kazén-Saad have investigated action slips caused by state-orientation. The following is abstracted from their book "A Theory of Self-Regulation: Personality, Assessment, and Experimental Analysis", Volume I: Theory and Volume II: Research (1991). State-orientation may exist in every phases of action course:

- During action preparation, there may exist excessive and uncontrollable preoccupation with unattainable goals. Uncontrollable cognition makes it difficult to synchronize all mental activities toward the current goal. They cannot stop thinking about the unpleasant experiences of failure. They have an increased tendency to keep on the intentions even if it is impossible to execute them. They have difficulty to initiate non-automatized actions (e.g., habits) in situations without specific external trigger stimuli. Preoccupation degenerates the analytical ability in self-regulation, such as in simulation, editing, planning or decision-making.
- Hesitation may occur during action initiation. State-oriented rumination (i.e., intrusive thinking about negative events and cognitive over-activeness) about unrealistic goals or past failures may interfere with the initiation of the novel action, and impair the enactment of realistic intentions. Initiation of novel and non-automatized actions becomes more strongly dependent upon situational trigger conditions (Norman & Shallice, 1986). Rumination causes also some action omission. Mild rumination results in internal over-awareness and inflexibility, i.e., an increased difficulty to switch actions from one to another.
- Perseveration may occur during execution of an action: Overmaintenance of unrealistic intentions impairs the implementation of realistic action plans. State-oriented people are especially afraid to commit action slips or to forget intentions. There is an increased tendency to forget the execution of non-automatized actions which are not triggered or specified by situational cues. They behave in passive simulation mode. They are not able to terminate a decision-making processing which requires action orientation;
- Goal-fixation during action termination: a big part of state-oriented people have difficulty in terminating a perseverating activity and in initiating a new one (too late). Upon the success in completing a task, the state oriented individual is less likely to deactivate intention-related information. They susceptible to action slips and failures of prospective memory.

2.8.6. Suggestions for Designers

It is generally said that the more practice, the less errors. It is not always. Machine-centered design naturally causes user´s error. Complicated perceptual and cognitive processing, high speed and accuracy, machine behavior, and heavy action load easily cause user´s errors. How to reduce user´s errors?

- Designers should take human errors as part of the user models;
- Designers should avoid various resources in using artifacts which may cause negative emotions;
- Provide various memory aids helps for users´ action;
- Provide cues and alarms for the possible errors in users´ action;
- The structure of the user-interface must offer restrictions to possible errors during using the artifact;
- If the user makes a failure, the artifact should not work, but show cues to remind the user of the failure, and give a chance to the user to correct the failure;
- Eliminate unnecessary users´ control of machine-centered functions.

CHAPTER 3: ACTION SYSTEMS

SECTION 3.1: ANALYSIS OF HUMAN ACTION IN DESIGN PROCESS

3.1.1. Values of Design Determine the Standards and Methods of Action Analysis
There exist technology-centered design, cost-centered design, consuming-centered design, anti-traditional design, user-centered design, etc. The values of design determine the goals, standards and methods of action analysis. For usability design, analysis of user´s action must be based on user´s intention and action.

3.1.2. Motion and Time Study (Barnes, 1963)
At the beginning of this century, Taylor introduced time study, Gilbreths and Barnes developed motion and time study. Their model of human action is called the "economic man." Their goals were to develop the efficient production system and the method to control workers with the lowest cost, to determine the least time required by a qualified and properly trained person working at a special task, and to assist in training in applying motion economic principles. They analyzed manual operations and defined 17 fundamental hand motions: Search, Select, Grasp, Transport Empty, Transport Loaded, Hold, Position, Pre-Position, Inspect, Assemble, Disassemble, Use, Unavoidable Delay, Avoidable Delay, Plan, and Rest for Overcoming Fatigue.

They analyzed work´s motion course in terms of operation charts or the left- and right- hand chart. This was a very simple and effective aid for analyzing an operation. On most kinds of work, this analyst could construct such a chart from observations of the operator at work. The principal purpose of such a chart was assist in finding a efficient way of performing the task in the shortest time. The most elaborate analysis is possible by means of full micromotion study. Barnes showed an example:

> Two symbols were used in marking operations. The small circle indicates a transportation, such as moving the hand to grasp an article, and the large circle denotes such actions as grasping, positioning, using, or releasing the article. In signing a letter with a fountain pen the left hand holds the paper while the right hand performs the various movements indicated in the Figure. The first step in making an operation is to draw a sketch of the work place, indicating the contents of the bins and the location of tools and materials. Then watch the operator and make a mental note of his motions, observing one hand at a time. Record the motions or elements for the left-hand, and then in a similar manner record the motions for the right-hand.

For their purpose, Barnes proposed approaches for improving human motion:
- eliminate all unnecessary work;
- combine operations;
- change the sequence of operations to eliminate backtracking, to reduce transportation and handling, and to effect a smooth flow of work through the plant;
- simplify the unnecessary operations.

3.1.3. Study on Human Performance in Engineering Psychology
A primary goal of engineering psychology was to predict system performance. This was machine-centered approach. Human operator was viewed as the component of the machine system, and measured with the machine function. In order to realize the function of machines, performance of the human component must be predicted, and this was the objective of human performance models. The analysis of human performance was task-centered method. Human operator was analogized with information processor. Signal detection theory and information theory were employed to analyze human performance. Human attention was viewed as a time-sharing skill for a dual-task, and an ability for efficiency. The term of work load was used in order to avoid the task from exceeding human capacity and limitation. The technique of time-line analysis and task measures were employed primarily for human performance and workload prediction.

3.1.4. Action Syntax
Schank introduces the analysis of action syntax on semiotics. According to Schank (1979), conceptualization (action syntax) consists of an actor, (an animate PP), an ACT, an object, a direction or a recipient and an instrument (defined

as a conceptualization itself). A conceptualization can be an object and a value for an attribute of that object. It can relate in certain causality relations. The complete conceptual syntax is given below:

ACTORS perform ACTIONS
ACTIONS have OBJECTS
ACTIONS have INSTRUMENTS
ACTIONS may have RECIPIENTS
ACTIONS may have DIRECTIONS
OBJECTS can relate to other OBJECTS
 these relations are:
  POSSESSION
  LOCATION
  CONTAINMENT
OBJECTS can have ATTRIBUTES which have VALUES
ACTIONS can have ATTRIBUTES
CONCEPTUALIZATIONS can have TIMES
CONCEPTUALIZATIONS can have LOCATIONS

In general, the causal rules are:

- Action can result in state changes;
- States can enable actions, also can disable actions;
- States (or acts) can initiate mental states; and
- Mental states can be reasons for actions.

This method appears to be useful in analyzing the relationships and structures of actions.

3.1.5. The User Model

For usability design, the goal of action analysis is to build the human-centered user model. The user model should stands for the user. The user model involves the mental model and the task model (or called the action model). For this purpose, design should build the user-centered action system, and investigate various kinds of user´s actions to different artifacts, the environment and information, then establish the user-centered action interfaces. This is the main goal of this chapter.

SECTION 3.2: THE ACTION SYSTEM

3.2.1. The Concept of Action System

For usability design, the concept of action system is needed. A system S is built by a set of elements E = { E1, E2, E3, . . .} and a set of relations R = {R1, R2, . . .} between the elements. This way, the system consists of elements and relations: S = (E, R). For example, in a system there exist two elements E1 = {a} and E2 = {b, c}. The relation is a subsets of E1 x E2, including R1 = {(a, b)}, R2 = {(a, b), (a, c)}, R3 = {(a, c)}. The relation is all the connections between any variable of E1 and any variable of E2. In a car driving system, there may be three elements. E1 may be the driver {perception, cognition, emotion, volition, physical performance}, E2 is the car {every parts which is contacted with the driver´s activities}, E3 the environment {all the surfaces which relate to the driver and the car}. Designers may create various types of the relations between elements. For machine-centered design, the relations may be toward the machine-oriented behavior (e.g., humans as input behavior of the machine) and determined by the functions of machines. For action-oriented design, the designer´s task is to find the human-centered relations (the types of actions) and the felicity conditions for these relations.

3.2.2. The Elements of An Action System

An action system is the system in which humans can act based on their intention to the artifact and environment and realize their goals with satisfaction. An action system comprises the cultural and social background, the environment, the artifact, the user, the relations between them.

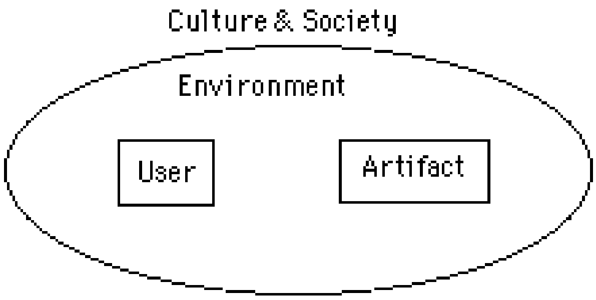


Figure 3.2-1: Action system.

- Human action always occurs in a certain cultural background. The effects of cultural and social factors on human action are embodied as values, norms and needs, as social relations, as ways of action, as ways of thinking and understanding, and as ways of responsibility and commitment.
- The environment is regarded as the external conditions for an action which are perceived by the user.

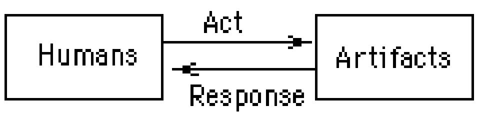


Figure 3.2-2: Action-response relationship.

- The user model involves the action model and the mental model. The rational action model describes the correct and successful course of action in the normal situation, and is constructed by its action intention, action plan and its selection, action execution, action evaluation and termination. Besides the rational aspect, the irrational action model includes also ways of users´ action in the real world, for example, in various abnormal, urgent situations and environments, users´ fatigue and errors, and so on.
- The rational mental model involves the theoretically perceptual and cognition processes. Besides the rational aspect, the irrational mental model should also describe ways of perception and cognition in everyday life, the influences of emotion, volition and ability factors and so on.

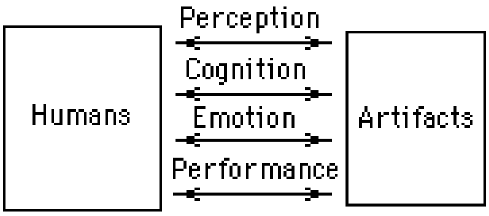


Figure 3.2-3: Man-machine system can be viewed as action system.

- All these aspects may have various even contradictory desires to artifacts. Designers should analyze them in a whole. Each factor plays a certain role in an action, and is not equally important. All these factors work together as an integration. In every kind of action, one factor may be the goal-side, and the other factors may work to match it. For example, in hammering, users´ goal is realized by physical hammering, and perception and cognition help it by collecting information, thinking and evaluation. For computers, users´ goal is mainly realized by cognitive processing. Physical performance is the mean-side.
- For usability design, the irrational models are more important than the rational models.
- One can classify the systems in various ways. For human-centered design, the systems may be classified into two groups. According to the type of users´ action, artifacts can be classified into perceptual systems, cognitive systems, expressive systems and systems of physical performances. According to Maslow´s needs hierarchy, artifacts can be classified into the system for USE (the use system), the system for WORK (the production system), the system for COMMUNICATION (the information system), the system for SUPERVISING (the supervisory system), etc.
- The basic attribution of the relations between humans and artifacts is that humans act actively for their goals. Artifacts respond to users´ action. They are the passive side or adaptive side to human actions.
- A scenario is regarded as the continuous (not discrete or typical) running of a action sequence or processing over time. A situation refers to a snapshot state of the action system at a certain moment of time. Designers should study the whole scenario of users´ action, not only the "typical situations." Designers should observe and investigate what users do to artifacts, rather than listening to what they say they do.
- Because of the significance, the cognitive component should be emphasized. The cognitive component comprises all the mental information processes. Motivation activates and directs human cognitive functions such as perception, thinking, memory, reasoning, etc. to discover everything useful in constructing an action path to the goal setting, and a link is mentally established among objects, acts and the goal. Cognition informs the user about what physical performance leads to which goal (Nuttin, 1987), what to do and how to do, the way of overcoming obstacles, and outcome standards, and control over the execution of actions (Lütkenhaus et al, 1987). The human cognitive system is complex, and generally works as a whole. It should not rigorously be divided into stages of cognitive processing.

3.2.3. Analysis of Action Systems

Analysis of an action systems refers to study the elements and the relations between the elements of the systems, and to analyze the action course and processes. The goal of the analysis is to find out users´ needs, desires, errors and to offer the felicity conditions to users´ action. The felicity condition is defined by Prof. van den Boom as any satisfactory or successful condition that easily makes an action take place. These conditions make it possible for users to do what they want to do with the artifact. From the felicity conditions the designer will find the important information and specifications about the artifact design. One of the main purpose in the design process is to seek for a method of constructing these felicity-conditions through action analysis. The objects of the analysis of action systems involves (1) the cultural and social factors, (2) the environment and various situations, (3) the elements in the system and relations among the elements, (4) action organization, ability factors, and processes, and (5) learning processes if necessary.

3.2.3.1. Analysis of culture and social factors

Cultural and social factors that influence human action to artifacts can be outlined as follows:

- Culture and society provide the systems of values, norms, standards, and expectations to actions which determine to some extent the needs and desires, way of action, way of perception, cognition and physical performance. For example, in some cultural societies individualism, competition and personal abilities are emphasized, the needs for artifacts appear to relate to efficiency and high speed, and in some cultural societies, simple and calm life, or life in a natural environment is emphasized, and so on.

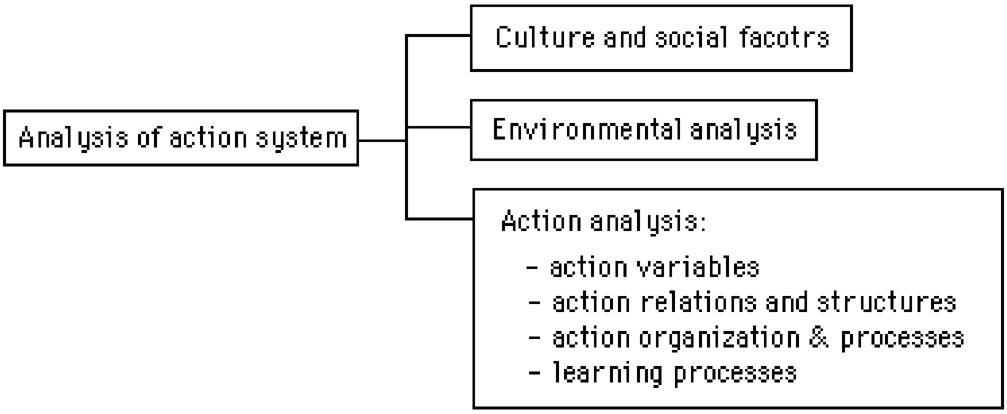


Figure 3.2-4: Analysis of an action system.

- Human actions are performed mostly in a social organization. For example, for an information system, the central core of the organization is the non-technology part of the action system, which consists of (1) the system of values and norms in this organization, (2) the structure of the organization and management and the role structure; and (3) the role expectation, way of individual action, and way of inter-personal communication through the system. All these variables construct the technical culture in this organization. Technical culture in the organization may be documented and partially programmed. (Gaines, 1988)
- What pervades the organization is rarely documented but communicated, called informal culture, which changes slowly. The informal culture is embodied as part of the structure and social processes of the organization. Effective information system must be consistent with organizational structure and processes, especially inter-personal communication where computer network should not violate the values, norms, role expectations, motivations and the conventions of the organization (Gaines, 1988).
- For this communication there is a work language (Andersen, 1990, p 55). Work language exists in every working environment to support the pre-understanding of the organization, the working process, the social relations, the role expectation, the responsibility and commitment in this work organization. Such work language reflects the technical culture (Gaines, 1988).
- People in this organization communicate and interact with each other partly through computers and communication protocols. The management structure of the organization controls its way of operation. The design problems on the standardization and communication protocols must be solved.
- There may exist various types of action in the information system, for example, navigation, supervisory control, tele-operation, multi-people communication, etc. Each of them requires its own user-interface, and its own way of interaction.

3.2.3.2. Environmental analysis

Human action with every artifact always exists in a certain environment. Human action and the artifact are conditioned and influenced by this environment, but human action may also change the environment. In the environmental analysis, designers should find out the following structures if they exist:

- the relations between the human and the environment, which are called the human-environment contact surfaces, including perceptual contact, cognitive coupling, emotional condition, and physical contact surfaces, etc.;
- the relations between the artifact and the environment, which are called the artifact-environment interfaces (e.g., the surfaces between the environment and the artifact for installation or contact); and
- the relations between the goal (e.g., working piece) and the environment are called the goal-environment interface.

Designers should discover environment-related felicity conditions for users´ actions, and environment-related conditions for users´ errors. The environmental analysis is not only related to the static characteristics of action, but also to the dynamic.

3.2.3.3. Action analysis

In the narrow sense, an action system consists of the actor, the artifact and the environment. Action analysis comprises the analysis of the action structures, the analysis of action organization and processes, the analysis of learning processes.

- Action structure refers to that of all the relations among the variables of the actor, the artifacts and the environment.
- Action organization and processes refers to the hierarchy of actions, the dynamic sequence of actions, and action processes.
- Learning processes relate to declarative and procedural processes of knowledge acquisition, the degree of difficulty in learning, and the time needed for learning.

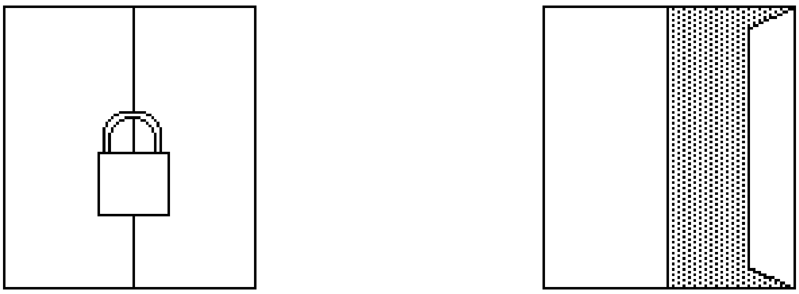
SECTION 3.3: THE ENVIRONMENT AND INFORMATION

3.3.1. Affordance

Users´ actions to artifacts always occur in an environment in the ecological way. The goal of studying the environment of users´ action is to what variables in the environment relate to what variables of user´s action (e.g., perception, cognition, emotion and physical performance), what properties in the environment will condition or deteriorate human action, and what can designers do to improve these conditions. According to Gibson´s (1979) ecological point of view, environment refers to the part that users perceive because of perceptual intentionality. The key issue is what is perceived by users. They perceive what the environment can afford them, the affordances:

> An important fact about the affordances of the environment is that they are in a sense objective, real, and physical, unlike values and meanings, which are often supposed to be subjective, phenomenal, and mental. But, actually, an affordance is neither an objective property nor a subjective property; or it is both if you like. An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer. (Gibson, 1979, p. 129)
>
> This is a radical hypothesis, for it implies the "values" and "meanings" of things in the environment can be directly perceived. (Gibson, 1979, p.127)

What exist in the environment and what the actor perceives are regarded as an entity, which is constructed by human action. Affordance is such natural unity or entity of the environment and perception. This insight stresses the relations between the environment and the actor.



"No one at home." "Come in, please."

Figure 3.3-1 Affordances.

Following these ideas, users´ perception assigns desires and meanings toward the environment. What humans first perceive is the needs which exist in the environment and objects. My pen affords writing, grasping, etc. However, Shakespearean´s pen, if it exists in any museum, affords exhibiting and evidence of history. The intention "it is worth seeing" leads me to see it. This is the perceptual values and needs. Both its existence and my action intention contribute to the affordance. When you see it, you would seldom perceive that “I can write with this pen." Maybe, you would also see a notice, it says, "Writing with the pen is forbidden!." Affordance is the perceived preference to your action goal, is the "complementary things" of your action, or completely speaking, the positive or negative affordance to my action. This is Yin-and-Yan nature of the relationship between the environment and the perception. The affordances to designers may be not the same as those to users. For user-centered design, designers must perceive in the same way as users do. This way, affordance is a bridge between designers and users.

3.3.2. Information from User´s Environment

What users perceive in the environment construct a perceptual environment, which is not same as the real one. What users perceive towards their perception intentionality is called information or stimulus. For Gibson (1979), an environment involves layout, media, substances, surfaces with textures, events and scenes:

- The arrangements of the surroundings and the ground is called their layout, for example, the layout of the floor. You feel the size, the arrangement and what you can be afforded by this room. To perceive a layout is not to find every concrete thing in the environment, but to detect your relative position relative to it, to detect an affordance which supports possible action tendency, direction, and offers aversion, or potential danger. When the user is moving, the related positions between these things are changing, the visible and the the invisible are changing, the layout is also changing.

- Media involve light, air, water, magnetic field, the contact surface between water and air etc. What you can see is mediated by light or media, must not be the direct object. Figure 3.3-2 shows an example, over the curved ware you can see a small bottle that does not exist there, and it exists inside it. It is an 3D image reflected by the internal quadratic surface. Media afford visibility, perceivability, or path for it. However, it may also provide "false" object illusion or distortion.
- Substances afford various meanings: rigid, cool, transparent, viscose, plastic; or graspable, movable, rotating, pushing, or supporting. To identify substance is to perceive what can be done with it for my (user) goal and action, what is it good or bad for, and its utility.

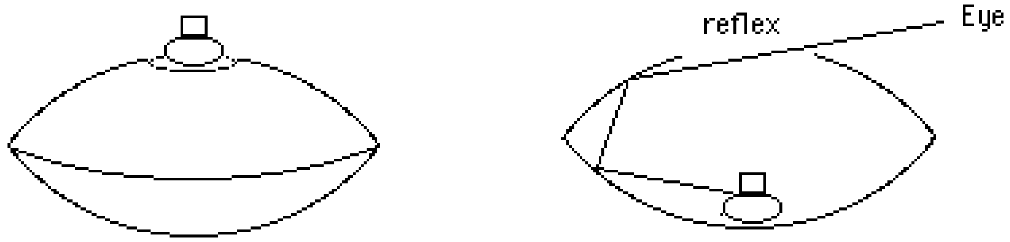


Figure 3.3-2: What you see is not the object but the image.

- The objects, other persons and animals afford various possibilities and influence for your action. Flexible objects afford bending. Round objects afford rotating. Plate objects afford sitting or placing. Users recognize the utility of objects or tools according to their forms in many cases. Different forms of levels, steering wheels and buttons afford various action possibilities. The edge and the corner of an object or layout can afford a convex or a concave angle, or afford reference for users. Form design is based upon such affordance in various contexts. What users desire is that the form of objects is tied with users perception intentionality as an entity, or a complement.
- The surface of a substance or an object has a characteristic texture, color, reflectance and layout. The Density and the slant of optical texture is important for human judgment. The ambient light is structured by the light reflected from surfaces so that these characteristics are specified if it is water specified by rippling, or wood, or metal.
- A point of user´s observation in the layout determines the visual window and direction of scanning, and what can be perceived. It is a stable point when the user does not move. When the user is moving, the point of observation is moving too, and the environment is also moving relatively to the user. This moving point of observation determines a path of observation, surfaces going out of sight or coming in sight at an edge. This way, the environment and the window of viewing are all changing.
- Events refer to the change, or a complete procedure, or a process in the environment which relates to user´s action, or asdisturbance. Such events may be a continuous change of a layout, surfaces, objects, colors, or positions. Such events may be reversible or nonreversible, or recurrent. Concurrent events must be studied by designers because of human limited ability of attention. For users, the causality of events are important. It affords knowing the effects of action and its cause. The continuity of the changes in the environment is important for perception and action.
- Scene of the environment refers to the spatial and contextual relationships of the objects in the environment at a certain point of time. It affords the temporal change of the environment, the intermediate outcome of action, or the urgency of action change.

3.3.3. Visual Information Perceived by Moving Persons.

Reality in the world is quite different from the information perceived by human perception. Gibson asserts that there is a distinction between (1) the kinds of visual processing which might be used to guide locomotion and manipulation of objects; and (2) the kinds of visual processing which might be involved in understanding the visual world in conceptual terms. Gibson (1966) introduces the concept of optic array: sunlight at any point of a surface will converge from all directions, the intensity of light and the mixture of wavelengths will vary from one solid angle to another, and this spatial pattern of light is optic array. The ambient optic array consists of invariant information about the world (e.g., horizon intersects an object at a particular height), in the form of higher-order variables. An observer´s task is to detect such invariant information by actively sampling the dynamic optic array, for example, the gradient of image size provided by the light reflected from textured surfaces receding away from an observer provides information as one cue for depth perception (Bruce and Green, 1990, p. 226) shown in Figure 3.3-3a.

For Gibson, the perception of objects should never be considered in isolation from the background texture. The important information about the layout of surface comes from a variety of gradients of information in the optic array, and gradients of texture, color, brightness, and disparity. (Bruce and Green, 1990, p. 224-239)

In everyday life, what humans perceive are mostly moving. Observer actively explores information from motion perspective to tell about their position and action. When an observer moves, the entire optic array is changing too. What the observer perceives is not the whole layout, shapes, surface but his action toward the world. Gibson addresses that this locomotion is always accompanied by optic flow in the optic array. This optic flow radiates out from the point at which the moving is aiming. The nature of optic flow pattern may be used to inform people of their actions, and is specific to a pilot and a car driver. Gibson claims that all event (objects translating, rotating, colliding or changing color, or disappearing) are accompanied by disturbances in the structure of the optic array. Texture elements which are covered by object motion are uncovered by motion in the reverse direction. This principle of reversible movements underlies the observer´s impression of the stable visual world, where even those surfaces momentarily hidden are still "perceived". Optic flow is a source of information about an observer´s surroundings.

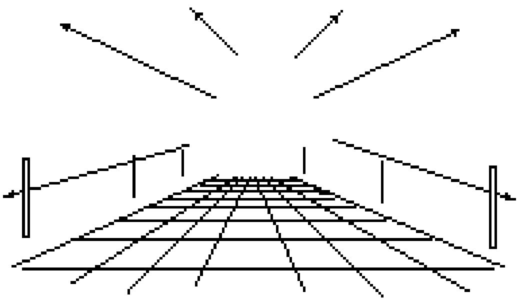


Figure 3.3-3a: Texture as cue of depth, and light flow. (After Gibson, 1979, p. 124)

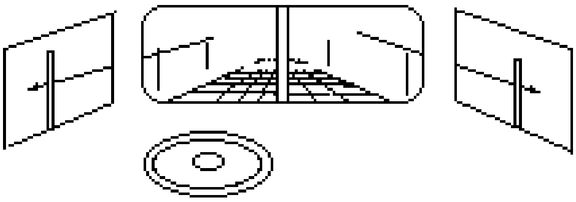
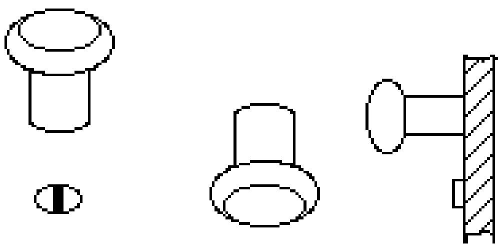
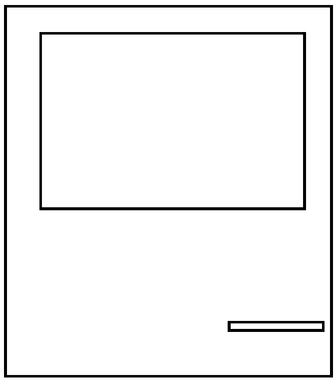


Figure 3.3-3b: What a driver sees in a car.





a.1. Child´s view a.2. Adult´s view b. User can not see the switches from the front side.

Figure 3.3-4: The real ecological view of perception.

Figure 3.3-4a shows two examples, the lock on the door can be seen only by children, but not by adults. The switches on the back side of a computer also can not be seen. This is what users have perceived in the real world.

3.3.4. The Irrational Perceptual Model

Human perceptual process has the rational mechanism. However, information the human perceives is closely dependent upon its environment, upon the individual intentions, and upon the relations between the observer and the environment. The best eye is worse than the worst scanner or camera. Not all the information provided by the designer can be perceived by the user. The environment affords various meanings to the observer. Observer´s location, direction and attention, media and the surface texture determine what users perceive in the environment. Information provided by the designer may not be perceived by the user as the same meaning. If users lack the perceptual knowledge or the designer does not provide sufficient information, users may not recognize the meaning, or may be led to illusion. Designers must keep such human irrational perceptual model for human interface design.

SECTION 3.4: **THE ACTION INTERFACE**

3.4.1. The Background of Man-Machine Interface

The concept of man-machine interface (MMI) was developed in engineering design from the 1940´s to the 1950´s. Its main objects were machines. Ergonomics (human factors) studied human physiological abilities (e.g., vision, hearing and performance) and measured the dimensions of human body that might be related to the operation of machines. Their emphasis of design was on human limitation of precision, accuracy, high speed, and multiple tasks, etc. Control theory and system theory were then introduced in MMI design. System components were identified in terms of inputs, outputs and transfer functions. The human operator was viewed as a component of the machine and simulated as certain technical parameters, and converted into a function of input. The relationship between humans and machines was "human follows machine." The man-machine interface consisted of individual controls, displays, and operation and maintenance procedures. In fact, human-interaction with artifacts is not limited only to such man-machine interface. For usability design, designers must find all the relationships between users and artifacts for the users´ action.

3.4.2. The Action Interface

I introduce the action interface instead of the man-machine interface. I define the action interface from two aspects. (1) The action interface in action system refers to all the surface, piping and coupling among the user, the artifact and the environment that are directly related with every aspect of human action, including intentions, perception, cognition, volition, emotion, and physical performance. (2) The action interface relates to all of the user´s action course. (3) The action interface may involve the following relations, and each of them may construct an interface or a surface:

- the relation between the human and the machine (the artifact), called human-machine interface;
- the relation between the human and the goal (e.g., the goal, the goal object, the working piece, goal state, etc.);
- the relation between the machine and the goal, called the execution interface;
- the relation between the goal and the environment;
- the relation between the human and the environment;
- the relation between the machine and the environment.

These relations may provide the necessary conditions or the limitations for human action. They are not equally important in various artifacts, in various action patterns, and in various cases. All these relationships mentioned above are integrated and coordinated by user´s action with the artifact. If and only if these surfaces, media and piping create the adaptive or coupling structure to human action, satisfy user´s action or interaction by offering felicity conditions and action guidance for the desired action pattern, action plan, and action evaluation, then the interface is called action interface, or action joint-face.

Thus, the goal for design of these interfaces is to join artifacts with humans as an organic entity or ecological wholeness. This is just the human highest desires to artifacts. Generally, user´s goal intention is rather easy to be found. Designers may be more concerned with the users´ implementation aspect of action (instrumental values, instrumental needs, implementation intention, and instrumental side of information).

3.4.3. Basic Structures between Humans and Artifacts

In order to find the relationships between users and artifacts, designers can classify human action types in various ways: (1) In industrial surroundings, human actions can be classified into skilled-based action, rule-based action, and knowledge-based action according to Rasmussen (1983). (2) According to Maslow´s needs hierarchy, one can find the following classification of human actions and artifacts, and the relationships between humans and artifacts:

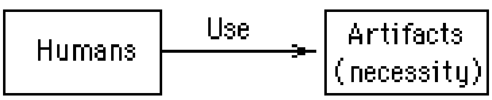


Figure 3.4-1: The Use relation.

Actions for physiological existence, security, protection, order, legality and behavior regulation, to avoid pain, fear, anxiety, tiredness and disorder. For this type of action, humans **use** the necessity-artifacts, or called the use system.

Humans must **work at** or **produce** things with tools, machines, etc. These are called tool-artifacts or the production system which are used for production-oriented actions.

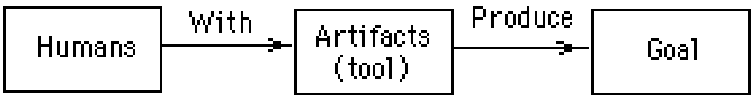


Figure 3.4-2: The 'produce-with' relationship.

Communication is a great category of human action. Communication refers to exchange information between dynamic systems. The process of communication is represented by the communication chain. Presented in various types of the sign systems, information is transformed by coding, emitted by a sender, transported through media, through a channel or media, is received and decoded by the recipient, then stored, and transformed for application. For the cognitive action, humans are mediated by the information system, which mainly refers computer-based artifacts. Humans may communicate with the system, and may communicate with other people through the system.

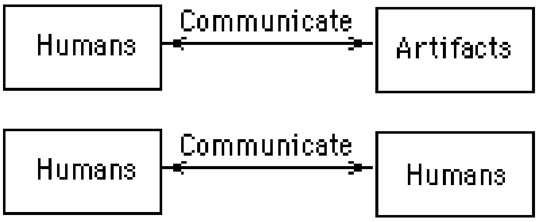


Figure 3.4-3: The COMMUNICATION relationships.

In this paper, the term information has two meanings. (1) In the field of computers, information refers to data, pictures and texts which users need from the computer system. (2) In the field of man-machine interfaces, information implies user´s perceptual objects of the external world. External information cannot be understood separately from human perception, cognition and action. Information the users perceive comes from two aspects: the environment and the man-machine interface. Information is the meaning (or relevance) of the events, the subjects, the signs, the sounds, the images, the color, the form, the texture of the surfaces and smell from the environment and from the man-machine interface which humans intend to perceive and to understand for their action. Information provided by design is called the artificial information. In the field of man-machine interface, industrial design is to offer the artificial information and action conditions on user-interfaces for user´s action. Study on information deals with how to design the artificial information in order to fit users´ perception, cognition and action. Its goal is to create the coupling between information and the user.

SECTION 3.5: USE ARTIFACTS

3.5.1. The Structures Which Exist for the Use

This type of action is that humans USE the artifacts. For example, people wear shoes, use wash-basin, use a bed, a chair, a room, a bicycle, a car, etc. The USE exists widely in everyday actions. There are two examples: shoe and wash-basin for the handicapped in Figure 3.5-1. Their main structures which exist for USE involve:

- relationships between the human and the artifact;
- relationships between the human and the environment; and
- relationships between the artifact and the environment.

The contact surface between the human and the artifact is called user-artifact interface; The surface between the artifact and the environment is called artifact-environment interface. The surface between the human and the environment is called human-environment interface. These three interfaces are together called action interface because user´s action relates to all these interfaces.

3.5.2. Users´ Desires for USE

The basic idea of action analysis is to find the relationships between the user and other elements of the action system, then to study the user´s desires towards these relationships. Designers can study them in two ways.

3.5.2.1. Users´ terminal values and needs

Humans wear clothes and feel warm, pretty, comfortable, status, feel it like a symbol, etc. People who have the same terminal needs (e.g., clothing) but the different terminal values (e.g., comfortable) and different instrumental values (e.g., clean) as well as different instrumental needs (e.g., rain-tight) will lead to different desires and intentions to clothing. That is, designers can distinguish users´ intentions on the basis of terminal and instrumental values and terminal and instrumental needs. Based on Maslow´s needs hierarchy, for example, the USE-relationship can be distinguished into the several (e.g., three) levels of terminal needs as follows:

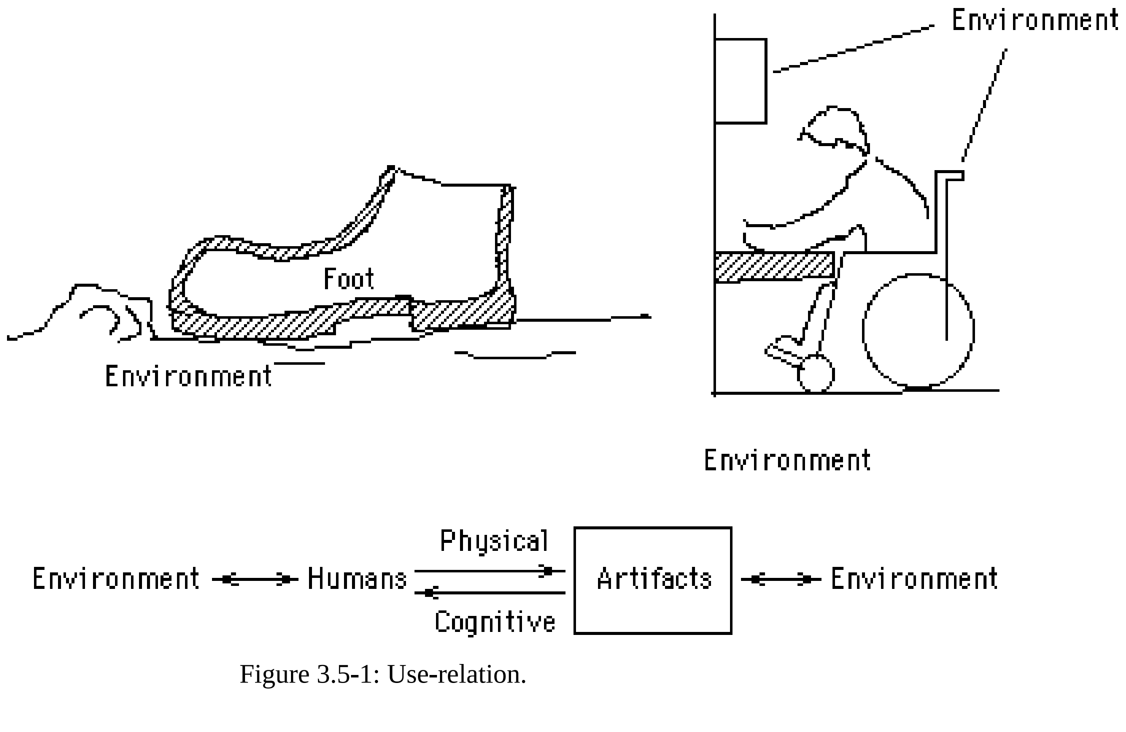


Figure 3.5-1: Use-relation.

- Necessity-orientation, or survival-orientation: It is for physiological and safety goals. Without the necessity people could not live. There is also necessity-orientation in work, in which main needs are only basic functions of the artifacts for work.
- Orientation to instrumental needs and values: For a same terminal need, individuals have very different instrumental needs and values. People may need artifacts for social-affiliation, time-saving, or action-saving.

People may need convenience, simplification, flexibility, or efficiency. This orientation is mainly toward realization of user´s instrumental intentions.

- Esteem-orientation, self-actualization-orientation, esthetic orientation. These are on a higher level, where needs for personality, emotion, status, dignity, spiritual and self-related are more concerned.

3.5.2.2. Users´ action needs

User´s action needs involve also the terminal aspect and the instrumental aspect. The terminal action needs depend upon the terminal values, and goal intentions. The instrumental action needs serve for the terminal action needs and depend upon the implementation intentions. The categories of terminal action needs are quite limited: perception, cognition, emotion and feeling, volition and physical performance. The instrumental action needs relate to ways of action, for example, how and when to perceive, to cognize and to perform, and are countless. Design for satisfying individual instrumental action needs is the main concern of designers.

3.5.3. Some Problems Caused by Design

People often feel that shoes do not fit their feet and action needs. This “feeling“ is very comprehensive. It does not only mean to fit the shape of the foot, but also the material, humidity, weight, temperature, and foot motion. It relates to the contact surface between the foot and the shoe, as well as that between the shoes and the environment, etc. For example, because the old can not always move their feet very high, the front sole of a shoe for the old should be made in an arc form to avoid falling down.

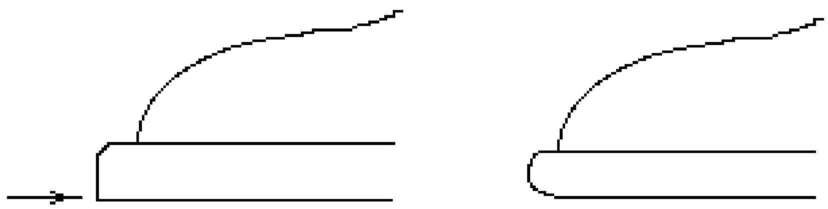
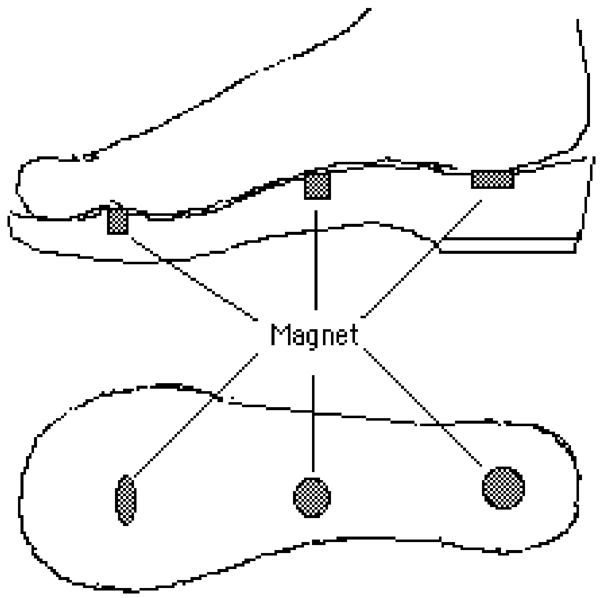


Figure 3.5-2: Shoe design for the old: the interface between artifact and environment.

Some people might think that their feet are cold because of the weak physiological circulation. The general solution to this problem is to make the shoes very thick with leather. However, these shoes are also very heavy. How to solve this problem? In 1994 Chinese traditional medicine found that appropriate magnets inserted into the shoes at some of the massage-acupoints could massage these acupoints. Such magnet-therapy may improve blood circulation of human brain and five kinds of the chronic diseases. (China Daily, June 28, 1996)



SECTION 3.6: WORK AND PRODUCE WITH ARTIFACTS

3.6.1. The Structure of WORK and PRODUCE

Humans WORK at objects or PRODUCE products with tools and machines. This type of user´s action is called the work or the production. Such type of artifacts are called the tool-artifacts.

In this action system there exist six relationships which may build some interfaces (Figure 3.6-1: Excavator):

- Human-artifact interface (i.e., man-machine interface): It consists not only of control, display, but also of the surface between the human and the artifact, such as the seat, the window, etc..
- Human-goal interface: Human may observe directly the goal, or may observe through window glass.
- Goal-artifact interface: This is execution interface.
- Goal-environment relationship.
- Human-environment interface: For example, the worker look backward through the reflex mirror, which is part of the tool-artifact.
- Artifact-environment interface: This surface offers the working conditions of the tool.

All these relationships contribute to the action interface for the perception, cognition, physical performance, and emotional feeling of the user.

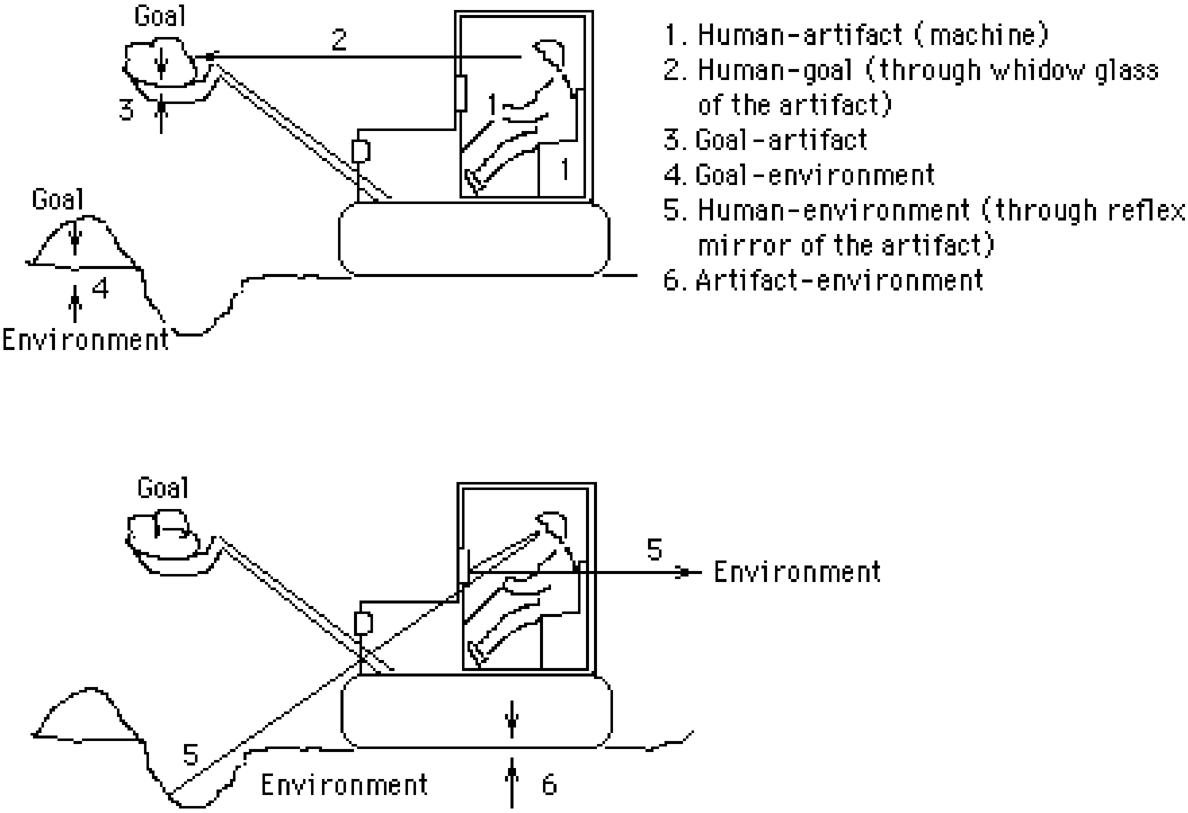


Figure 3.6-1: Six relationships between the human, the tool-artifact, and the environment.

Another example is hammering (Figure 4.6-2). In this case, two interfaces between the actor and the goal are heavily concerned: (1) The human hand and the hammer hand construct the human-artifact interface. On this interface, the humans not only act, but also perceive information which is internally transferred by the tool. This kind of sense is called the inner perception which is provided by the feedback inside the tool-artifact to the actors. (2) The execution interface, which is the contact surface between the hammer-head and the work piece. On this interface, the human action is executed. Furthermore, the actors perceive also through this interface with the eyes, ears, etc. This is called external perception. There is also environmental perception, i.e., actors perceive also information from the environment.

3.6.2. Analysis of Relations

One can analyze the relations in several ways. (1) Analyze the components of action: the perceptual, the cognitive, the volitional process and the physical performance. When one operates a hammer, he or she perceives the surrounding and the effect (e.g., the reaction force) through the contact surface between the hand and the hammer. This perception is inside the contact surface between the hand the hammer. The actor also perceives the consequence of the goal objects with the eyes, ears and so on, which are outside the hammer and the hand. Generally, human perception is multiple modalities. In the aspect of physical performance, a person normally holds the nail with one hand, and the hammer with the other hand. Notice that the left hand now is in the execution interface. The user wants to perceive the action-related events: the reaction force, the hammering location and direction, for example, "is the work piece too hard to hammer?" "I hammered vertically?" The person does not intend to concentrate on the tool-artifact "hammer," but has to. The inappropriate design of the hammer makes the user feel "the hammer-hand is too thick," or "too heavy." When the hammer fits completely into the action, he or she will feel that the hammer and the hand have become a organic wholeness. (2) Analyze the action course: the action goal, the initiation of action, the way of operation, the evaluation, etc.

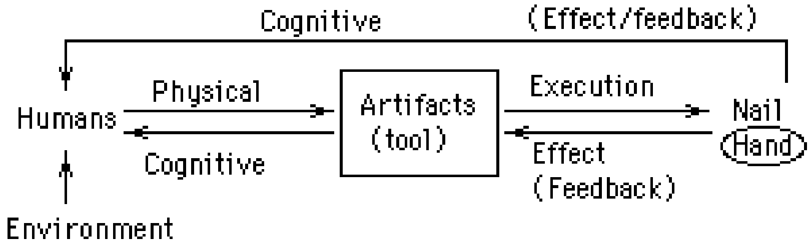


Figure 3.6-2: The relationship of production.

By 1867, five hundred different kinds of hammers had been developed in Birmingham, England (Petroski, 1992). However, up to now, everyone who has ever used a hammer has probably been hurt by it. If the plate or the wall is very hard, if the user is distracted, if the hammer is too heavy, if . . ., the user may hammer the left hand because it is at the execution interface. Such relationship is not appropriate for this action. Its design should avoid user´s hand at this interface. An appropriate design should be found to reduce or eliminate human attention and the error to fit the human action.

3.6.3. Perception, Cognition and Physical Performance

Human cognition is a comprehensive processes and cannot be easily simplified to only a single source or single display or the like. In the work relationship, human perceptual and cognitive processing is mainly through three resources: the inner, external and the environmental. The driver of a car looks at not only the meters, but also looks at the outside, the traffic lamps, the road, the weather, pedestrians in front of the car, and listens to radio about the traffic report, etc.

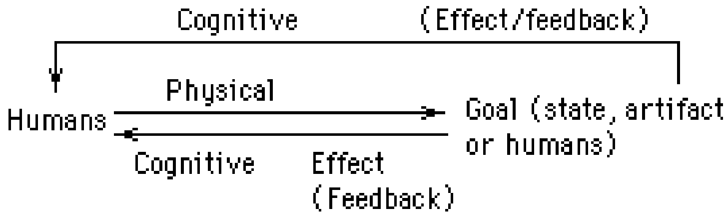


Figure 3.6-3: The goal of design for the relation of production is to minimize or eliminate the user consciousness of tool-artifacts.

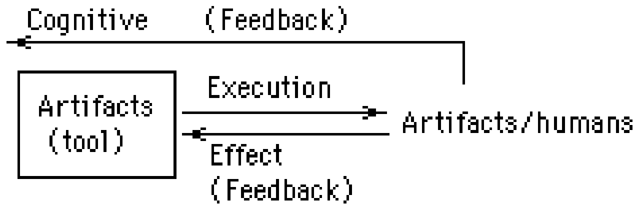


Figure 3.6-4: Automation: The goal of design for the relation of production is to eliminate the human-tool interface.

In such relationships, the goal-reaching is mainly through the physical side of action, and the perceptual or cognitive side is to assist it. It does not mean that the perceptual side is less important. As a matter of fact, the perceptual processing is often more concerned to guarantee the correct execution and evaluation of action. How to make user´s perception and performance as a natural unity is one of the key points of design concerns. Designers must study the coordination between users´ perception, cognition and performance.

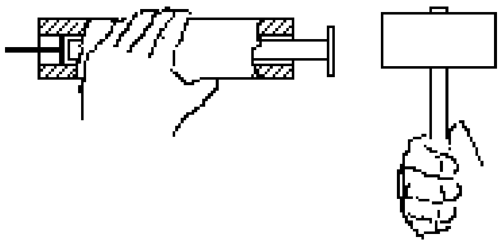


Figure 3.6-5: Separation of the hand from the execution surface.

3.6.4. The Main Goals of Design

The main problem in the design of such artifacts is that users´ hand has to insert into the execution interface. The possible solutions for this problem can be realized in several ways: (1) to separate users´ hand from the execution surface; (2) to eliminate the human-artifact interface, and the tool can independently work.

SECTION 3.7: INTERACTION WITH COMPUTERS

3.7.1. The Relationships between the User and the Computer
The concept of interaction refers to that users and computers influence each other, and through this mutual influence the properties of both sides can be changed. The interactive relationships encompass four aspects: the perceptual and the cognitive processing, physical performance and emotional reaction. The perceptual and cognitive side are the goal-side. The physical performance is the mean-side for the mental processing.

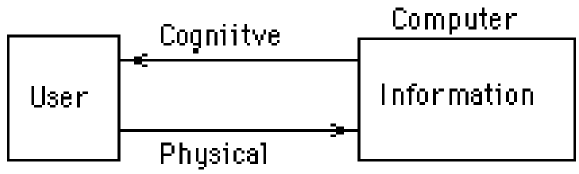


Figure 3.7-1: Interaction between the user and the computer for information.

3.7.2. The Concept of Information
Information systems consist of information carriers (media) and information sources. Information carriers in computer systems include signs, images, sounds, and colors. In the computer system, information refers to the meaning and relevance of events, signs, images and sounds. Information and users are an entity. In users´ view, a piece of information consists of two sides: the terminal aspect and the instrumental aspect.
The terminal side of information relates to recipient´s perceptual and cognitive desires (goals), that is, "who will use it?" "what to know? " On this view, information can be classified into affective information, cognitive information, and performance information.

- The instrumental side of information is its way of representation which relates to recipient´s perceptual and cognitive processing, that is, "how to perceive," "how to know," "how to think" and "how to understand the signs," which is determined by recipient´s implementation intentions, ways of perception and cognition, knowledge, experience and abilities. It relates to recipient´s understanding of meaning, and relates to recipient´s mental load. This relates to three aspects. (1) In what medium is information constructed: in graphics, signs, sounds, or in symbols? And how to represent the medium, that is, its font, style, format, color, context, etc.. (2) What are the regularity and the structure of information? For example, the syntax is employed in the linguistic representation. (3) When, where and how can the recipient perceive and cognize (feel, understand and interpret) it?
- Terminal side of information should be coupled with recipient´s goal intentions and the desired cognitive processes. Users are willing to concentrate on the terminal goal information and its desired processing.
- Instrumental information should be coupled with the implementation intentions (cognitive plan) and perceptual and cognitive habits. Users are not willing to be distracted with instrumental information.
- Information which exceeds users´ desires and cognitive abilities is called redundant information, which may be neither goal-related, nor appropriate to the cognitive processes. It may also be displayed at wrong point of time, or at wrong position.

3.7.3. The Coupling Model of Cognition and Information in Human-Computer Action Interface
Information cannot be understood separately from users´ action. Information should be analyzed in regard to the relations between human action (communication, perception and cognition) and computers. I understand communication and information in the cognitive and ecological sense. For this purpose, the concept of coupling should be introduced. A system S1 is coupled with a system S2 if the output border elements of S1 are available to the input border elements of S2, and every of both sets of border elements contains at least an element which is available to the element in the other system (Klaus, 1969, p. 305ff). Whether something is meaningful signs (information) or not depends upon the recipient´s intention and way of perception and cognition. If the meaning of signs can be coupled with the recipient´s intention and cognition, they are information for the recipient. If the information structure is coupled with the human intention, the perceptual and the cognitive structures and processes, it is called information coupling. The information coupling between humans and computers is one of the key issues for the usability design, and involves (1) how to find the meaning and the form of signs fit users´ intentions and cognition, respectively; (2)

how to design the output structures of computers (display-related) to correspond to the structures of human perception and cognition in the natural way; (3) how to design the inputs of computers to correspond to user´s action.

3.7.4. The Structure Coupling between Humans and Computers

On users´ desires, the human-computer interaction should consist of three structure couplings: 1. The human perception should be naturally coupled with desired information; 2. The cognition should be naturally coupled with information processing; 3. The physical movements should be naturally coupled with computer operations;

3.7.5. The Basic Features of Cognitive Action with Computers

3.7.5.1. The basic features of human-computer interaction

Human-computer interaction has mainly three characteristics:

- Display-based perception and cognition: all information has to be displayed, and to be seen only in the limited screen. This implies that the display should be the major location on which users´ cognition concentrates.
- Artificial information: much of information displayed on the screen is represented by numbers, text, icons, various signs and symbols. Humans have only limited abilities and capacities in processing such information. Such information is quite different from the natural information in everyday life.
- Skill-based physical operation: The keyboard and the mouse are major input devices. Users must learn the operations with them. Such instrumental side of action becomes sometimes rather difficult for some users.

3.7.5.2. The Relation model between users and computers

Computers make the relationships between humans and information, and between humans and their actions much more complicated.

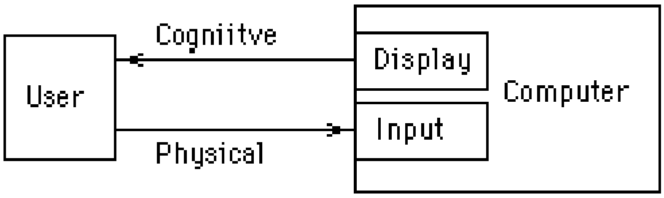


Figure 3.7-2: The basic relationships of the user to the display and to the input of computers.

- At the highest level there exist two kinds of relations: the relations between the user and the display, and the relations between the user and the input. The basic relationships here are cognition and physical performance. In other words, designers must be always concerned with user´s cognition and physical performance and their coordination.

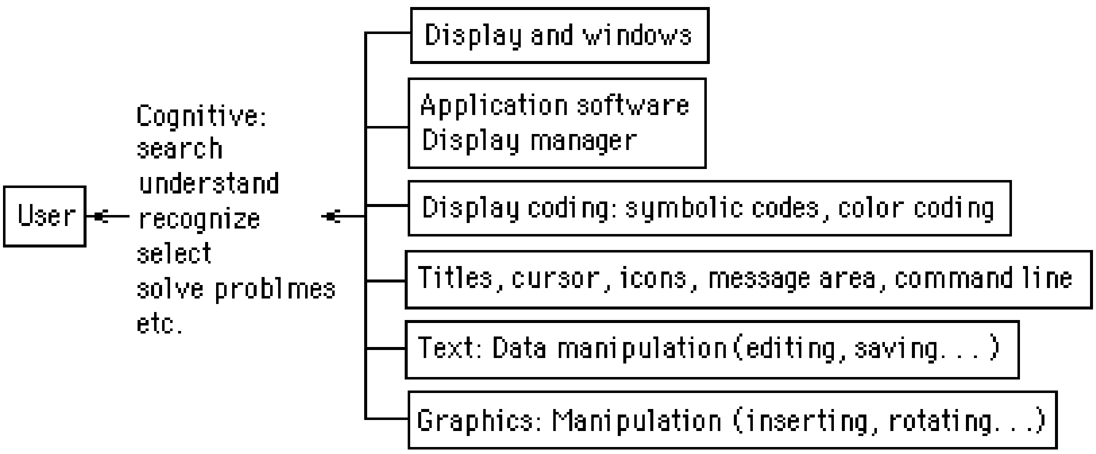


Figure 3.7-3: The cognitive relations of the user to the display.

- At the second level exist the relationships between the user and the display and between the user and the input. Display of information is a superordinate, central point. Under display of information there exist (1) display manager, application software, etc; (2) display coding (symbolic codes, color coding, highlighting, etc.; (3) text, graphics (inserting, rotating, mirroring, moving, zooming, grouping), and data manipulation (data entry, saving, editing, searching, and exiting). So many factors and processes relate to user´s cognition. They may create machine-oriented behavior, heavy mental load, difficulties in human cognition and interaction with computers, and distraction from user´s goals.

- The relationships of the user to the input consist of (1) various input devices (keyboard, mouse, function keys, speech recognition, touch screen, trackball, etc.); and (2) various dialogue methods (command keystrokes, interactive dialogue, command language, natural language, menu, etc.). User´s input is generally to assist the mental, cognitive action. Users concentrate on their cognition, and they are not willing to be distracted with the input devices and manipulation. Users need "natural" interactive devices. Easy perceptual-motor coordination and automation, reduction of unnecessary mental processing for machine-oriented input, and consistent mapping of user´s goals on computer execution are the central issues for input design.

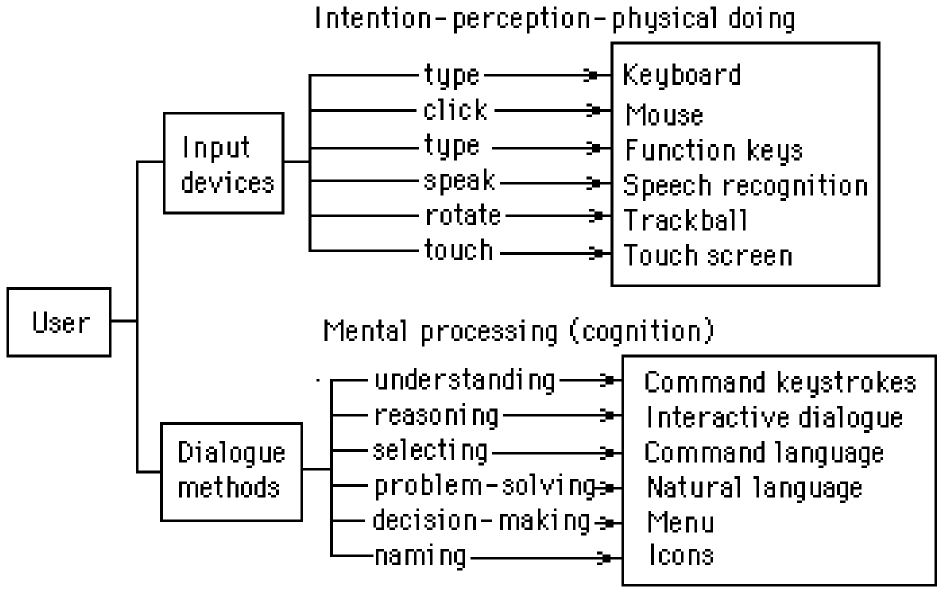


Figure 3.7-4: The relationships of the user to the input.

- At the third level is the relationships between the user and information, which has been studied above.

This is only a outline. The actual relationships are much more complicated. Many of these relationships are machine-oriented operations.

3.7.5.3. Problems

Humans understand the affordance of physical tools from their forms, structures, materials, colors, and behaviors. The affordance of physical tools are visible and predictable. Users can easily create action coupling with them: how to grasp a hammer and how to work with it correctly. The behavior of computers is frequently invisible and unpredictable. Such blindness is not formed only by menus, commands and mouse, but also by computer behavior. Visualization of computers is the first problem that users confront.

Computers are used for speech acts. They are linguistic tools, or the media of communication. Commands of computers, as language, can not only be understood as transmission of information, but as delivery of action and commitment to the user. User´s recognition of the commitment, by understanding of the meaning of commands and operations of the computer, plays an important role in this interaction. Today, learning to work with a computer means to to speak computer language. Computers refuse to speak the human language. Execution of the commands typed by the users is not in light of users´ understanding of the human natural language. Computers respond to the commands only according to their hardware structures of the commands. The computer language is not based upon the human natural language. Users have to understand a computer language in the way of the computer behavior. "Why doesn´t the computer execute this command in this way?" "Why isn´t the same result as my imagination?" Computers employ specific scientific ways of reasoning which are different from the common way of most people in everyday life, and the computer logic is difficult for most of people. Users dare to use only these commands which the users are able to understand. That is why some people hate computers. "Computer is inhuman."

The operations of computers are tedious and inflexible. The way of operation is inflexible. There are too many operations and tools in computers, but most of them are oriented to micro-operations. Users must understand, plan, organize, and convert them into human action, or called mappings. Mapping of human action into computer behavior is very difficult. There are too many tedious input/output, too many icons, especially keyboard, function keys, and their commands are very difficult to learn, to think, to reason, to remember, and to use. The operations make too heavy mental load for users, and users can not concentrate on their own tasks. If I was provided with 100 tools to make a photo, then I would never use them. The mapping does not imply sensorimotor performance, but thinking and reasoning, and to take commitment. Computers respond to every operation of the users, but take no commitment. Users must take commitment. To interact with the computer means to suit the behavior of the computer and to follow the computer. This way, users dare to use only the commands by which the users are able to take commitment, and to understand what the computer will do. That is why some people are afraid of computers.

Difficulties in sensory information may lead to over-attention, omission, perceptual speed, memory searching, and perceptual integration. Difficulties in syntactics of information may require decoding accuracy, and special skills for word attack. Difficulties in semantics of information may claim complicated reasoning, analysis of semantic context. Difficulties in pragmatics of information may require difficult problem-solving strategies. Difficulties in searching, naming, task planning, idea production and saving are the frequent operations in computers, searching a command, a file, naming a file, a variable, a function; or saving a file. These abilities are rather difficult for many people.

Computer-based systems such as a management system imply transfer of power and responsibility, and may bring unanticipated effects. Such system is created by experts in a certain situation. However, the structure of responsibility may be different in various administrations. With the computer system, some one may take more power, others less. When a problem occurs, who should take the responsibility, the computer or the operator?

Difficulties in complicated coordination among perception, cognition and motor skills make it difficult to learn and to form automatized behavior. Human cognition and its processes work generally as a continuous stream, and are organized in a natural sequence. However, computers divide them into the operations of various hardware devices (e.g., input and display) and software manipulations (e.g., commands, menu, signs, etc.). A cognitive stream becomes the discrete, tedious fragments of operations. Its result is that the user has to organize these discrete computer-oriented primitive operations into the cognitive stream and coordinate cognition and physical performance. These problems relate not only to the user interface design, but also to the organization of computers.

Computers are extremely rational, and do not allow users to make errors in thinking, in reasoning, and in operation. Users even do not know when, where, how, and what errors they have made, and how to avoid them.

3.7.6. The Irrational User Cognitive Model

All the user models up to now describe users´ rational operations with computers. Rational action is only part of human behavior. The other part is irrational one. Users may intend to act rationally, but they are not able always to do so.

Humans have intentions for action, but they sometimes may create irrational intentions or standards for action. They may create a wrong plan, wrong action course. Simply, they think wrong. Many unpredictable problems of such irrational intentions and plans of action will certainly occur. These are part of human action. Have designers considered to avoid these problems in user interface design?

Humans are forgetful during their action. They learnt the complete operations of driving car, or of controlling nuclear power plant. They passed the exams, then they got the licence. Three years later, a big accident happened. The reason is that "I forgot what I had learnt to deal with emergency." Forgetfulness should be an important issue to be studied by designers. Humans forget things everyday. They may forget their intentions, plans, information, action courses, etc.

Human speak language as action, but their language is often irrational. The spoken language does not correspond strictly to the grammar. The tune, the frequency band, the volume of everyone´s spoken language are not stable, and not the same as the electronic music instruments. Humans understand the meaning of words differently. They use different words for the same meaning. When I wanted to erase a word, I typed "erase," but the computer said "wrong." I typed "delete," and "cut," but all were wrong. I did not know which word I should type and lost my temper. The computer recognizes only "remove" as "delete." Is it possible that all these words can be used in the user interface for the same meaning?

"Thinking" is defined as a rational mental behavior. Thinking here implies mentally representing and manipulating goal-directed actions, including desires, beliefs, motivation, and various action processes. Thinking process involves some manipulation of operations on knowledge. Thinking leads to results in behavior that solves a problem. Although some "standard" ways of logic are defined, most people do not think and reason in such a rational way. In reality, there exist no standard way of thinking. Even a great mathematician, physician, or thinker may think irrationally. Users cannot interact with computers always rationally. Every one has his/her own way of thinking, which includes some rational part and irrational one, personal experience, emotional reaction, fantasy, imagination, autistic thinking, daydreaming, or the fragmented thinking, etc. Every one has different abilities in language, in reasoning, and in thinking. Theoretically, human action has a certain structure. Practically, human action is partly rational, and partly irrational. Humans do not have a "standard" plan, a "standard" course of action, and can not behave as a robot or a machine. Such is the normal way of thinking, and should be the basis of designing user-computer interface.

Humans have different cognitive abilities in reading, comprehension, planning, thinking, reasoning, and in problem-solving. Some abilities are quite difficult for some people, for example, scientific induction and deduction, idea-production, and naming. However, many difficult abilities are demanded by user-computer interface, such as Naming Facility, Associational Fluency, Expressional Fluency, Word Fluency, Originality/Creativity, Figural Fluency, and Figural Flexibility.

3.7.7. The Design of Interfaces

3.7.7.1. Direct manipulation

Direct manipulation refers to that users can directly operate the objects on the screen with the mouse or other devices. They do not need to type the commands on the keyboard. The objects are continuously represented on the screen. Physical actions or presses of labeled buttons are employed instead of syntax, and reaction of the objects on the screen are visible. The popular example is the direct-manipulation interface of Macintosh computers in stead of DOS commands. Such direct manipulation reduces novice´s learning load. It is easy to retain. Error messages are rarely needed. Users can see directly the effects of their actions. However the programming is difficult and it require graphic display. Direct manipulation has been widely employed in text editor, data management, air-traffic control, video games, remote manipulation, and some programming. Virtual reality is the further development of such idea.

3.7.7.2. The adaptive human-computer interface

The adaptive interface means that the interface should be adapted to user´s action, mainly cognitive action. The goal is to make the users more independent of the designer, and to make the system fit a specific kind of users (Oppermann, 1994, p. 455-472). There are two ways for this purpose: (1) The interface is in a form which enables the user to modify if the user is unsatisfied with it. (2) Dynamic adaptation is made by the system itself with artificial intelligence. This kind of adaption is realized by machine learning with respect to the individual behavior. An adaptive interface should have a knowledge base which consists of user models, the interaction, the task/domain (problem area and goals), and the system characteristics (Croft, 1984; Rissland, 1984). The user cognitive models are the most important, and may involve perceptual and cognitive abilities, reasoning and planing strategies, and cognitive styles. Adaptive systems consist of three parts: an afferential, an inferential, and an efferential components (Oppermann, 1994, p. 458). More information can be found in R. Oppermann (Ed, 1994): Adaptive User Support. Hillsdale, NJ: Lawrence Erlbaum.

3.7.7.3. Cognitive coupling: joint cognitive systems

Some authors have accepted an ecological view in designing human-computer interface. They emphasize the cognitive relationship between humans and computers. The goal is to exploit the natural coordination between humans and computers by using artificial intelligence. Hollnagel and Wooods (1983) proposed Joint Cognitive Systems. The human and the computer are considered as a joint system. It is assumed that performance can be enhanced by improving the cognitive coupling. Dalal and Kasper (1994) use cognitive coupling to describe the relationship between the human cognitive behavior and that of computers. In human-computer interaction, the user or the computer each undergoes a process of cognitive coupling due to the cognitive behaviors generated by the other. This mutual process leads to interlocked patterns of behavior. These cognitive behaviors comprise goals, problem-solving strategies, knowledge, and cognitive style. Cognitive coupling is a multi-dimensional two-way relation which consists of : (1) a number of primary dimensions, including goals, problem-solving strategies, knowledge and cognitive style; (2) secondary dimensions representing the interactions of primary dimensions with other attributes. The state of coupling refers to the extent to which the system´s characteristics are consistent with the actual characteristics of the user. Dalal and Kasper propose two kinds of coupling: similar cognitive coupling and complementary cognitive coupling. Similar cognitive coupling is more desirable and effective in the design of decision aids. Cognitive style has great impact in activities of decision-making. There are two problem types: analysis-inducing vs. heuristic-inducing. These two types of problems induce two different human cognitive style: analytic vs. heuristic. The heuristic problem induces intuition and heuristics (The Group Embedded Figures Test developed by Witkin et al in 1971 is used to assess the cognitive style). Two types of aids for decision-making are analytic and heuristic with artificial intelligence.

3.7.8. Natural Way of Cognition

It is generally noticed that human cognition in real life proceeds through multiple modalities and coordination of multiple perceptual, cognitive and physical processes. Such natural way of cognition is the final goal of computer design, and users should not be abstracted with machine-oriented cognitive processes. The natural way of cognition should have the following features: (1) The human-computer interface does not need the operation manual. (2) There must exist the minimal set of knowledge about computer interface which is stable over time, i.e., minimal concepts and minimal steps of the procedure. Users will not have difficulties in understanding them. (3) All the knowledge and operations are oriented to users´ tasks. (4) Everyday logic, everyday concepts, and everyday reasoning are employed instead of scientific logic. Users can learn it in trial-and-error. (5) Computers follow users. The computer can be adapted to users´ operation, and give action-oriented help. (6) There exist memory assistant and easy error-correcting function. (5) Natural input/output devices are provided. There is no (or less) action-operation mapping. Users will not be abstracted with tools and operations. (7) Users may change their goals and action courses anywhen and anywhere. The operation must be flexible. (8) Users can predict events during operations. (9) Computers provide the desired context and desired information. (10) To provide natural coordination of various action aspects. (11) Terminal side of information must suit users´ desires, not more not less. Instrumental information must make it easy for users to perceive and to know what they want to, to think and to understand the meaning, and easy to member it.

Natural way of cognition needs (1) natural interactive devices; (2) natural context and natural information for natural understanding; (3) natural way of action. Up to now, four primary tasks in virtual reality are recognized, including (Pimentel and Teixeria, 1993, p. 73):

- navigation: moving your view in the 3D environment;
- selection: picking an object in the 3D world for further action;
- interaction: moving, deforming or scaling the selected object;
- command: the way of controlling the simulation.

For this purpose, many devices are developed. Wide Eye head-mounted display (HMD) with 3D sound can display 3D reality. Dermal electrodes contained in the eye glass frame track eye movements by measuring muscle electrical movements. Tactile simulation (e.g., the Teletact-I was the first device of tactile feedback for a virtual context) may be employed to make human feel the surface of virtual objects. Motion platforms are used as flight simulators. Wired clothing devices and wired gloves are designed as tracking devices to recognize the position, orientation or gesture of body or hand (e.g., DataGlove of VPL Research Inc). Force balls are used to measure the multiple forces or torques applied to the ball-shaped device. 3D mice (ultrasonic, electromagnetic or gyroscopic tracking sensor) are used as tracking of 6 degrees of freedom of spatial position (x, y, z), and orientation (roll, pitch, yaw). Single-handed KAT (keyboard-alternative technology) are developed.

SECTION 3.8: ACTION ORGANIZATION AND PLAN

3.8.1. Two-Step Regulation of Action

Designers should understand how users organize action. Dörner (1985) introduces the model of two-step action organization (see Figure 3.8-1.). After the actor has selected the strongest motivation as the intention, two levels of regulation of action are developed: the level of automatic action and the level of heuristic processes.

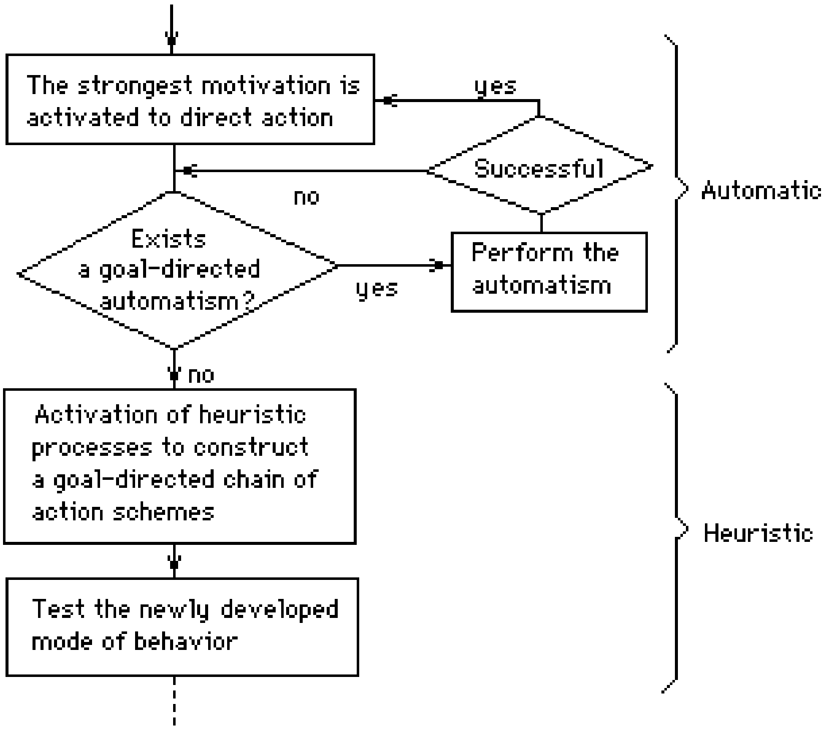


Figure 3.8-1. Two step organization of the structure of human action (After Dörner, 1985).

On the automatic level, the regulation of action searches the memory for a way to lead from the current start situation toward one of the goal situation. This memory can be seen as a network of action scheme. If the given situation and one of the goal situations are located at the beginning and end of a chain in the network of action schemes respectively, the corresponding chain will be activated. Otherwise the control of action goes into the heuristic processes which produce a chain of action schemes toward the goal. Heuristic processes involve "trial and error," "gradual analysis," and "sudden reorganization" (Durkin, 1937). Dörner asserts that thinking plays an important role in the control of action. The motivation provides a goal for thinking. Perception supplies information for thinking toward one direction. While thinking, one may also learn. Major phases of thinking are goal analysis, accumulation of information, action planning and self-regulation. Emotional processes are important because it can guide the course of thinking. Emotions depend upon the success or failure of action control, and, to high extent, upon the image that a person has of oneself, and on his or her confidence in the ability to overcome difficulties. Stress, time pressure, or overload of information may activate the feeling that one will lose control. Sequential-analysis thinking will disappear completely in the moment of anger or fear, and giving over to a primitive holistic reaction.

3.8.2. TOTE Model

Miller et al (1970) suggest that elementary unit of behavior should be the Test-Operate-Test-Exit unit (TOTE) as shown in Figure 3.8-2. The TOTE model consists of two phases: test and operation. The arrows show the directions of energy (neural impulses), information (knowledge of result), and control (the order of the "instructions"). Action is initiated by an "incongruity" between the state of the organism and the state that is testing for, and the action persists until the incongruity (i.e., the proximal stimulus) is eliminated. Thus there is feedback from the result of the action to the testing phase. The test phase can be regarded as any process for determining that the operational phase is appropriate. The TOTE represents the basic pattern of action plans.

For Miller et al, the TOTE unit can be integrated into the hierarchical structure of action. In the example of hammering a nail, the operational components of TOTE units may themselves be also other TOTE units. It has two nodes: hammer "Lifting" and hammer "Striking." The Hammering continues until the head of the nail is tested to be "flush" with the surface of the work. The sequence of events to run off in this order is expected to be: test nail (head sticks up), test hammer (hammer is down.), lift hammer, test hammer (hammer is up), test hammer (hammer is up), strike nail, test hammer, (hammer is down), test nail (head is up), test hammer, etc., until the test of the nail reveals that its head is flush with the surface of the work, at which point control can be transferred elsewhere. The operational phase of the TOTE can be expanded into a list of other TOTE units. The operational phase may be quite various and complex, and the tests are conceived to be relatively fixed. According to Nuttin (1984), constructing a standard or goal is the dynamic starting point of an action. In his opinion, constructing the Standard (S) should be the first phase. The Standard (S) triggers the Operational phase (O) of the behavioral process. When the Standard (S) is attained, it controls the Exit phase (E). Without the motivational phase Standard (S), the concrete behavioral process itself does not exit.

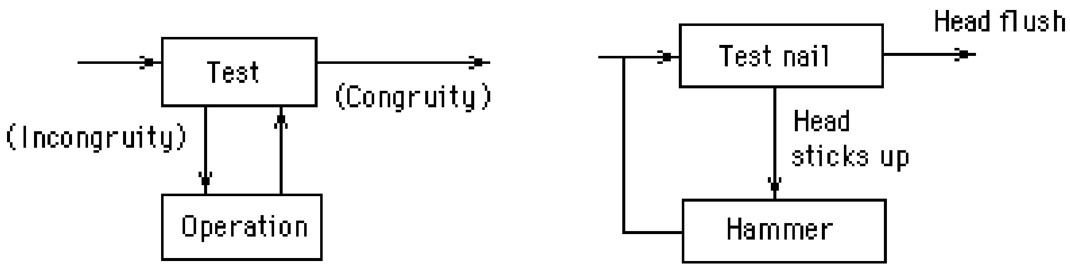


Figure 3.8-2: The TOTE unit (After Miller).

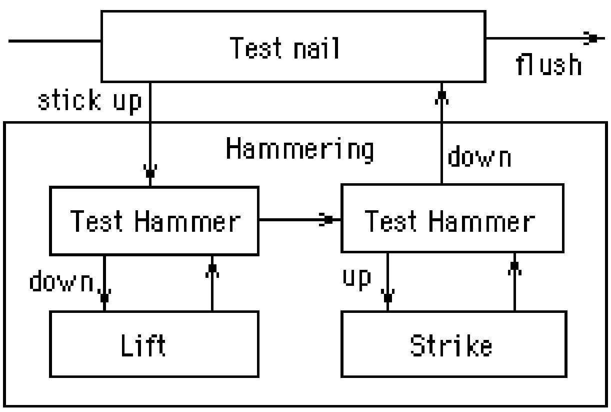


Figure 3.8-3: The hierarchical structure of TOTE units (After Miller).

3.8.3. Five Levels of Action Components

A complete action consists of five levels of components: (1) at the lowest level is the basic motion of muscles which is the smallest unit; (2) at the second level is a complete sensorimotor unit, called a movement, which is often automatized by learning; (3) an operation is a basic component of an action, which is the interface between humans and machines with sub-goal; (4) an action is an complete unit of goal-directed behavior; (5) an activity is a sequence of actions which is determined by a complicated goal. Felicity conditions must be considered at every level of them.

3.8.4. Schema Theories

In 1970´s schema theories were employed in analyzing action. Bartlett (Reason, 1990) defines a schema as "an active organization of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response. That is, whenever there is any order or regularity of behavior, a particular response is possible only because it is related to other similar responses which have been serially organized, yet which operate, not simply as individual members coming one after another, but as a unitary mass." Bartlett claims that schemata were unconscious mental structures, they composed of old knowledge or experiences, and long-term memory comprised active knowledge structure rather than passive images. This process leads to certain predictable biases.

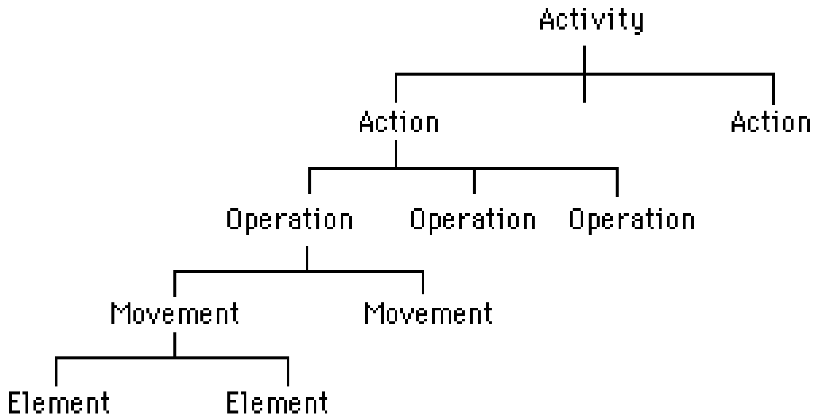


Figure 3.8-4: The structure of activity.

Minsky (1975) was mainly concerned with perception and with the way schemata guide the encoding and storage of information. In his conception, common visual environment, for example, rooms are represented internally by a structure, called "frame." Each frame contains "nodes" for standard features, such as walls, floors, ceilings, windows. The informational “slots“ are used for storing the particular items or variables related to a certain kind of room. The regularities of the word, and the routine dealings with them are represented internally as schemata. The price users pay for this largely automatic processing of information is that perceptions, memories, thoughts and actions have a tendency to err in the direction of the familiar and the expected.

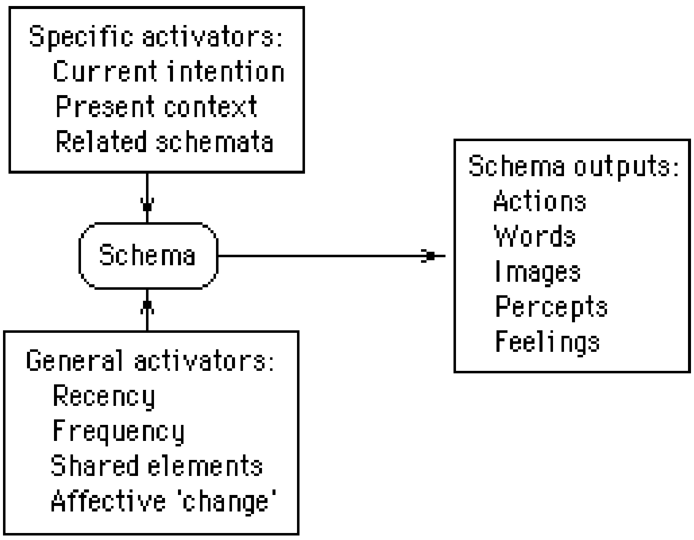


Figure 3.8-5: Schema and activators (After Reason, 1990, p. 99).

Schemata are currently viewed as higher-order generic cognitive structures that underlie all aspects of human knowledge and skills, such as words, images, feelings and actions. Their encoding and representational functions include lending structure to perceptual experience and determining what information will be encoded into or retrieved from memory. Their inferential and interpretative functions allow us to supply missing data within sensory or recalled information. The schematic control mode can process familiar information rapidly, in parallel and without conscious effort. However, this mode is relatively ineffective in the face of change (Reason, 1990, p. 51 - p. 52). Fitting the data to the wrong schema can cause systematic errors. (Reason, 1990, p. 35 - p. 36)

It should be emphasized that there are no limits to the number of schemata, or to the duration of their retention. Performance in any sphere of mental activity is achieved by activating right schemata in the right order at the right time. Reason (1990, p. 99-100) asserts that schemata require a certain threshold level of activation, i.e., specific and general activators (Figure 3.8-5). Specific activators are related directly to the current intention, and activate a given schema into play at a particular time. Practiced people have a brief description of action plan. For example, "Go to the kitchen to make some tea." However, a novel must develop rather detailed plan description. Such plans are context-dependent (Bobrow and Norman, 1975). Reason (1990, p. 100) claims that in general activations, frequency of prior use is probably the most influential. The more often a schema is used, the less it requires intentional activation. Quite often, contextual clueing is needed to trigger it, particularly in very familiar environments.

Schmidt studied human motor behavior on schema theory. When an individual makes a response of a type for which he or she has a schema already developed, this person begins with two inputs to the schema: the desired outcome for the movement, and the initial conditions. When the individual makes a movement that attempts to satisfy some goal, four things are to be stored (Schmidt, 1975, p. 235):

- The initial conditions consist of the information received from various receptors prior to the response, such as proprioceptive information about the positions of the limbs and body in space, as well as the visual and auditory information about the state of the environment. After the movement, the initial conditions are stored.
- Before the movement, the response specifications (parameters) for motor program must be specified, such as speed and force. After the movement, these specifications are stored along with other information received.
- After the movement, the response-produced sensory information is stored, which consists of the actual feedback stimuli received from the eyes, ears, and proprioceptors.
- The success of the response in relation to the outcome originally intended is also stored after the movement. Without any feedback information, the individual does not have outcome information to store.

After a number of such movement has been made, the individual abstracts the information about the relationship among these four sources of information. The strength of such relationship increases with each successive movement of the same general type, and increased accuracy of feedback information from the response outcome.

3.8.5. Plan

3.8.5.1. The concept of plan

A plan here refers to an action plan. An action plan is a concrete description of an action course, a set of instructions that can guide the action, or a collection of alternative sequences of the action, or a rough sketch of implementation intentions for an action course. Kuhl (1987, p. 355) claims that successful execution of an intention is dependent on the following aspects (Kuhl, 1987, p. 355):

- whether the action plan is sufficiently constructed;
- whether the individual focuses his or her attention on this plan in an action orientation;
- the smooth implementation of an activated plan is dependent on whether the individual is in command of self-regulatory skills.

3.8.5.2. The plan of using artifacts

Learned experiences, environmental and situational factors play an important roles in planning. In everyday life in using artifacts, people learn and build up an internal representation, a model of the world, a schema, a cognitive map or image. All of them are the accumulated and organized knowledge, and past experiences about himself or herself and the world. The "experience" or the "knowledge" here mainly relate to using artifacts: the facts about the artifact, the procedure of using. They are the basis of the plan of action.

The planning phase can not be separated from the execution phase in reality. A plan must not be completed before initiating the action. There must be a general notion of a goal and general idea about the plan. The outcomes of acts should be fed back, allowing adjustment of the plan. In some cases, an user can only find out one step ahead. Expert-users may plan their actions in another way. That is style of planning. This style belongs to cognitive style: analytic or heuristic.

The appropriate design should provides users with information for planning in the desired formats. After a prior step of execution, a new clue or a response is present to tell the user whether the execution is correct or not, what the next step should be executed, and if the goal is reached or not. Such plan needs fewer decision-making, less effort, and less central processing capacity. Designers should not neglect users´ habits in using artifacts and expert-user´s behaviors. Especially, expert behavior needs ten-year practicing. If the basic structure of action plan for car-driving was changed every three years, who would become expert-driver? Some of computer software are greatly changed in new updated versions, which interrupt the consistency of user´s action and plan to the old versions. Who can become expert-user?

3.8.5.3. The criteria for rational plans

For Rawls (1971, p. 416-417), the best plans are determined by the principle of deliberative rationality. This principle characterizes that if all the various courses of an action are opened to the actor, and their consequences can be foreseen and realized in imagination, the actor will desire and seek the future good. For Baron (1985), the best plan would be without providing a rule for finding it. Inadequate design makes it difficult to plan an action course in using artifacts.

3.8.5.4. Anticipation

Anticipation and representation are prerequisites for action. Stadler and Wehner (1985) point out that anticipation consists of perceptive and operative one. Perceptive anticipation time (0.7 to 1.0 sec) refers to the transmission of information from the machine to the sensory organs of the user. Operative anticipation time (0.3 to 0.5 sec) refers to the transmission of information from the user to the machine, and perceptive anticipative time is always greater than operative anticipation time. Anticipation is closely related to the plans. Stadler and Wehner introduce five levels of anticipation:

- Subsensor level: Anticipation at this level deals with unconscious processes on the neuromuscular level, such as pre-motor time (8 ± 2 msec) and central preprogramming of movements.
- Sensorimotor level: This is the lowest level of regulation where stereotypic and automatic movement sequences are organized without conscious attention.
- Perceptive level: Anticipation at this level serves as a link between the task (the anticipated goals), the accompanying images, and the execution of the action according to the plan.

All these three levels deal with sensory or perceptive processes.

- Level of secondary images (representation, imagination): Anticipation at this level is presented in the form of fantasy and operations within schemata. Fantasy is also based on anticipation of the external world, abstracted from current needs, and anticipates future satisfaction with these needs. Imagination can be classified as trial thinking. Based on reality, experiences, and images of potential alteration of this reality, fantasy and imaginative processes are abstracted by the person from the effect and plans. When a person develops concrete plans without the opportunity to obtain perceptive information on the goal object, anticipatory phenomena in the sense of operating with schemata occur.
- The level of abstract thinking is the highest level. It is abstracted from the current reality, but does not refer to past experiences and is not based on concrete idea. This is where logical inconsistencies are tested and abstract heuristics are generated. These heuristics help in developing concrete goals and plans and in using feedback in the action process.

SECTION 3.9: ACTION GUIDANCE

3.9.1. Motion and Time Design

In motion and time design, Barnes (1963) has introduced the following criteria:

- Create alternative action plans based on various user´s behavioral intentions and habits;
- Eliminate all unnecessary action, activity or task;
- Combine operations of machine or elements of human action or by making some changes in method to combine operations or actions, which may lead to the design of new artifact;
- Change the irrational sequence of action in order to find a smooth flow of actions;
- Simplify the actions. To do this is to ask the questions:
  *Where is the action done? Why is it done there? Could it be done somewhere else more economically?
  *When is the action done? Why should it be done then? Would it be better to do it at some other time?
  *What is the goal of the action? what is done? Why should it be done? What would happen if it were not done? Is every part of the action or detail necessary?
  *Who is the user? Who could do it better? Can changes be made to allow a person with less skill and training to use this object?
  *How is the action done? Why is it done this way?

3.9.2. Fundamental Considerations of Action Design

Accuracy, efficiency, durability, stability, repeatability, reliability etc. are all the machine-oriented standards. For these purposes, correct operation relies upon training. For usability design, artifacts should be adapted to user´s action, offer felicity conditions and action guidance for users. These are some fundamental considerations of design:

- Berstein (1967) has pointed out that humans must first be able to maintain equilibrium of body and a stable orientation relative to the artifact and the surroundings. Postural disequilibrium of body will lead to motor disturbance. Single motion can not be defined in isolation, but in coordination which needs a certain interval of time. Maintaining posture is usually accomplished through small, but continuous, compensatory adjustments. For such adjustment the vestibule and visual systems require information from environment about small changes in position and orientation.
- Coordination of action sequence: Each of sub-action and operation, according to van den Boom, must be provided with four conditions: (1) well defined start; (2) well defined end; (3) feedback; and (4) less demand for attention. The goal of these conditions is to create a smooth sequence for action. The feedback at the end of a sub-action represents "inter-punctuation of action, and offers information for starting the next sub-action. The functions of artifacts must correspond to these condition.
- Timing coordination of action components: Precise timing is one of the conditions to maintain the smoothness, rhythm of the action and successful performance. Action components (perception, cognition and physical performance), anticipation, prediction, and information about the progression should be delicately timed each other. (von Hofsten, 1985, p. 87-92)
- Simplicity is a criterion of design. Employ easy ability factor: easy motor performance, easy perceptual-motor coordination, easy perception, easy cognition, easy goal-action-task-operation mapping, easy learning, easy installation and repairing. Find short, simply action course, no problem-solving, and less plan. Accept users´ habits, experiences, imagination and anticipation.
- Flexibility is another criterion of design. Users may change their intentions and action plans, etc. This change will lead to the change of perception, cognition and physical performance. Designers should study such potential changes of users thoroughly. An action may have the heuristic component. Unforeseen environmental change may lead to the change of action. Designers should systematically study users´ action in the real world. After any disturbance to the prior course of actions, the user can easily handle the emergent goal intention, then easily come back to the prior action from the interrupt point, or the user can start an action again from the beginning. Design for flexibility does not mean to provide many action selections to the user. Many action selections often increase user´s mental load.

3.9.3. Goal-Guidance:

Designers must offer action guidance in artifacts. Action guidance consists of goal-guidance, preparation-guidance, plan-guidance, implementation-guidance, performance-guidance, and termination-guidance. For manufacturing, installing, and repairing of artifacts, designers should also provide corresponding felicity conditions and action guidance.

In motivational phase, users may have several potential intentions. Goal-guidance is employed to help users select an appropriate goal and make decision. Reason (1990, p. 71) asserted that because of a type of delay, the intention probably will become overlaid by other demands. For example, (1) detached intentions ("I intended to close the window. I closed the cupboard door instead"), (2) environmental capture ("I went into my bedroom intending to fetch a book. I took off my rings, looked in the mirror and came out again — without the book."), and (3) multiple sidesteps ("I intended to go to the cupboard under the stairs to turn off the immersion heater. I dried my hands to turn off the switch, but went to the larder instead. After that, I wandered into the living room, looked at the table, went back to the kitchen, and then I remembered my original intention.").

Goal-guidance may be realized by several possibilities:
- Cue of an appropriate goal intention is to remind the user of selecting a goal intention and make decision for it.
- Reduce unrelated information which may distract user´s intention.
- Reduce preparation work.
- Reduce the possibility of formation of several intentions.
- Simplify and eliminate goal-unrelated operation (machine-oriented operation).

An example of goal-guidance is the numbers on the telephone dial, in which goal-guidance and operation guidance are united.

3.9.4. Plan-Guidance

Plan-guidance refers to make the action course transparent to users. Hacker (1985) claims that plans can be distinguished by three levels of consciousness: (1) Unconscious programs for elementary patterns; (2) sometimes conscious action schemata; (3) conscious plans, meta-plans, and strategies. Kuhl (1987) points out that an action plan contains specific information about (1) the present situation, (2) the future goal, (3) action steps, and (4) action conditions. Users may plan during the preparation phase or during action execution.
- The action plan must be aimed at user´s smooth and correct sequence, and easily perceived on the user interface.
- Plan-guidance consists of both the physical Do-side and the cognitive Know-side: "what to do," "when," "where," and "how " to do should be clearly, and continuously marked, not ambiguous.
- Text or picture? Picture is normally better than text.
- "Machine follows user" or "function follows action." Machine-centered operational procedure should not be delivered to users, but executed in the background.
- There exist several kinds of action guidance: (1) An action flow chart of the whole sequence. (2) Stepwise cues: After a step of execution, a cue for the next step is shown for the users. The pause time between two steps should be long enough for the user to think and to select the next step; or the pause time can be controlled by the user.
- Wrong action will not work, but can cause alarm. If no water is in a cafe-maker, the heater should not work.
- Only one stimulus from the artifact should be given and related to one behavioral intention at a time.
- As users like, simple schemata of action and common motor skills should be employed. There should not exist two or more actions concurrent with each other. The action should be successive in series, not in parallel with a different course of two hands or even with two feet.
- Reduce the difficulties in physical and cognitive side, such as action complexity, strong force, difficult operating position, time urgency, complex technical knowledge, strong attention and stress to the action control.
- At the end of every action there should occur a related feedback to users for evaluation and deactivation of the action.

3.9.5. Preparation Guidance

Before execution of an action, users may do some preparation in two aspects: action preparation and material preparation. For action preparation, the user may focus more on the cognitive aspect, thinks about the goal intention, looks for the selection of familiar scenarios for action. The user may plan the action in advance and prefer the automatized skills (Kuhl et al, 1991), and select adequate action schema and concrete parameters for the relevant skills and their sequence. Inappropriate design will make the user´s cognition complex. Thus, experiential action becomes uncertain trial-and-error behavior, and simple preparation of action turns into problem-solving one, causing needless mental effort, taking needless time (Norman, 1993, p. 16 - p. 26). Such preparation can be provided by the following design consideration:

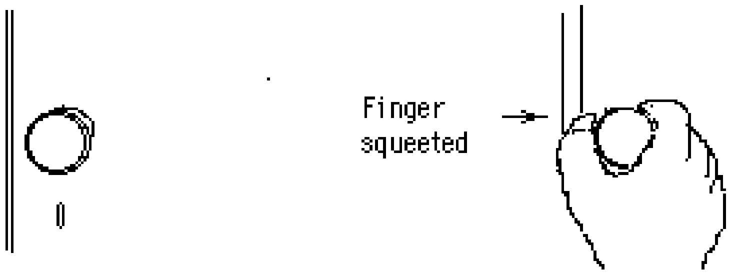


Figure 3.9-1: Door knob I: How to open it? The lock is under the knob, and it is not easy for human eyes to see the lock. Sometimes, finger got squeezed.

- Provide the user with appropriate conditions for cognition based upon users´ desires, intentions, abilities, and experience. The round "door knob I" may make some people not know in which direction of rotation to open the door because there are three possibilities: clockwise or counterclockwise for opening, and the third one: the knob is only for holding (can not be rotated). It is also possible that human fingers are located in the execution interface: in the gap between the door and door frame, so that sometimes fingers could get squeezed in such a door. Users have to try to solve these problems of preparation, including cognitive and physical aspects.

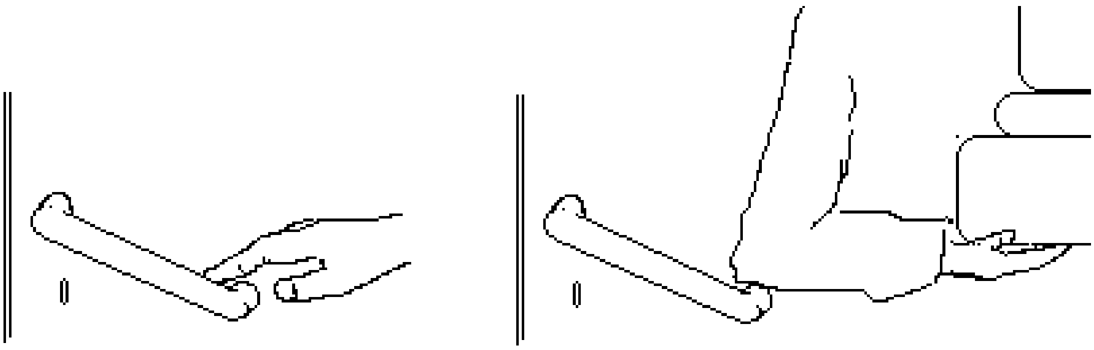


Figure 3.9-2: Door handle II provides direction guidance, preparation guidance for action. It is also easy for children to open the door.

- Select the common habits and motor skills for using artifacts. For example, the simple action schemata as Grasp, Rotate, Push, Pull, etc. The door handle II shows a cue for action Press. It corresponds to common cognition and motor skill for door opening. Also, human fingers are separated from the execution interface.

Material preparation can be distinguished between goal-directed and artifact-centered ones. When using a washing machine, the user must put some detergent and clothes into the machine, plug in the machine, etc. These activities are related to the goal-directed action. In some cases, the user must first install the parts into the whole. In some other cases, say, camera, the user may set the distance, the aperture and the flash. The preparation for non-experts is not desired. The preparation guidance can be provided in the following:

- Desired or undesired preparation must be distinguished. Designers should reduce or simplify the artifact-centered preparation, including the cognitive and physical aspect. For example, an automatic camera for non-experts, once the user pushes the button, the protection cover of object lens opens automatically, the distance and the aperture are automatically set at the same time. Preparation work and installation of accessories should be reduced.
- Remind the user of preparation. For example, there are some cues on the copy machine, such as “no-paper.“ The user must know the correct and complete preparation in appropriate way before using the artifact.

- The artifact will not work if the preparation (i.e., set up) is not correct or complete.
- The artifact should not generate side-effect, damage or danger if the preparation is not correct.

3.9.6. Performance-Guidance

3.9.6.1. Initiation-guidance

This guidance, such as “switch on,“ is always found important by users. However, artifact-centered design makes its position uneasy to be found. Some cameras have “ON/OFF“ switch for batteries, and have also button for the shutter. People may press the shutter, but forget to turn on the switch. The following suggestions may be useful for initiation-guidance:

- Designers must distinguish between the desired and undesired initiation guidance of users.
- The artifact should suggest the start and the end of action which must be easily found by the user.
- Unique initiation condition should be provided. Reduce or eliminate the preparation action which may be misunderstood as the initiation condition by the user.

3.9.6.2. Direction-guidance

Action direction is important for many actions. The conic slope around the lock-hole is to guide key insertion. Without such slope or the slope is too, people will feel it difficult to insert the key into the lock. Also, the slope surface at the edge of the slot for calling-card makes it easy to insert the card. The airport usually provides several aids to guide runway direction. All runways are numbered with compass directions. Each runway has a special light: two light bars located on the side of the runway along the touch-down region that help the pilot to the correct glide slope and direction. For hammering, the left hand holds the nail for direction guidance, but it is at the execution interface. If one uses a pair of tweezers to guide action, the hand is isolated from the execution interface. The idea is useful for the design of many tools and machines which are operated by the hand.

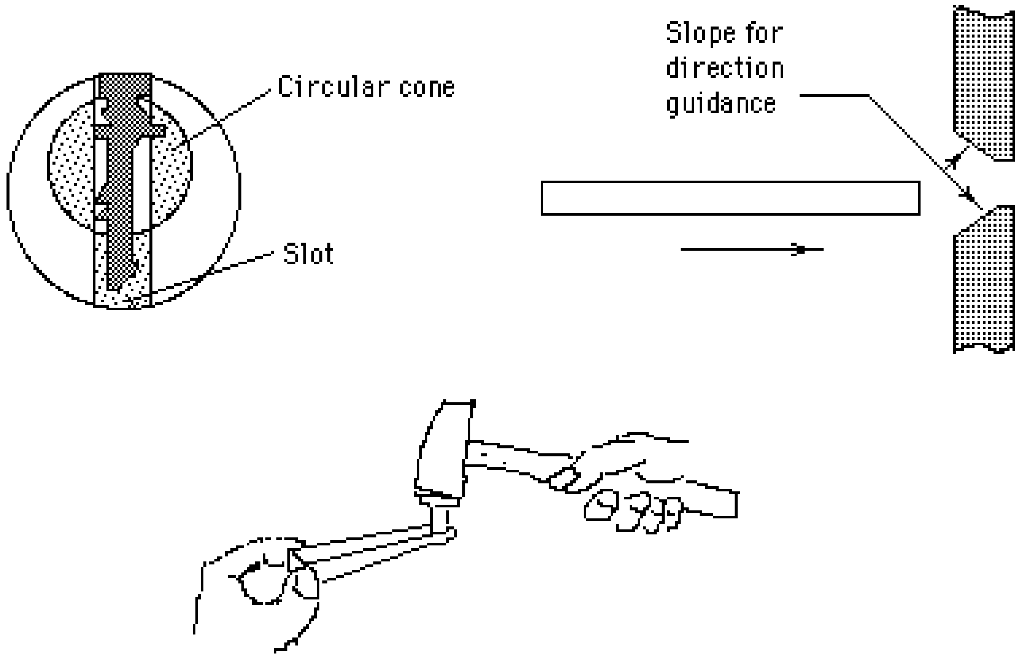


Figure 3.9-3: Direction guidance for action.

3.9.6.3. Selection-guidance

Many artifacts provide users with this kind of action guidance; for example, on washing machines. It is a very usual way to help users for use, designers believe. Selection is different from plan. Selection guidance has no suggestion about how and when to do. There are several suggestions in design of selection guidance:

- Designers must distinguish between desired and undesired selection.

- Selection guidance should be oriented to user´s implementation intentions, not to the machine-centered parameters. The latter should be automatically performed by the machine itself in background according to the user´s action.
- Many selections will lead to undesired processing of decision-making of the selection. Designers should delete those selections that are not often employed by the users.
- Selection has no guarantee of correct action plan. If users takes an inappropriate selection, then troubles, errors even damages could be caused. Careful design of selection-guidance should be combined with action plan guidance.

3.9.7. Rule-Guidance and Knowledge-Guidance
Traffic signs can be seen as a kind of rule-guidance for action. The arrow-signs on the streets pointed to the right side and straight forward means that if one wants to turn the direction of the car, then he or she can drive only to the right, but never to the left. However, the driver can also drive straight forward. Rule-based action is dominant in tackling familiar problems in which solutions are governed by stored rules of IF-THEN type. These rules are mainly machine-oriented and obtained from prior experiences. The goal oriented RB action belongs also to manual control behavior, but aims mainly at procedural oriented tasks of supervisory control behavior, including monitoring, interpreting, planning, fault management and intervention.

At the KBB level, problem solver has exhausted their stock of stored routines for problem solving. They have to work "on-line," to use slow, sequential, laborious and resource-limited conscious processing. This process is to set local goals, to initiate actions and to achieve them, observing the extent to which the actions are successful and then modifying them to minimize the discrepancy between the present position and the desired state. It is, in essence, error-driven and feedback type. The rule-guidance and knowledge-guidance are very new to industrial design.

3.9.8. **Termination-Guidance: Evaluation and Termination**
After the execution of the action, the user will evaluate whether the desired outcome of the action has been achieved or not, and whether the actual value matches the expected value or standard. This evaluation may be useful for future deliberation, the future goal and planning. Here, the feedback is the key issue.
- Feedback information must fit users´ intentions and perceptual abilities. Human perception is not sensible of accurate physical parameters, such as size, temperature, volume, grade, weight, etc. These parameters should controlled by machines themselves.
- Feedback of any type in the phase of termination must exactly correspond to users´ evaluation intention. This intention can be distinguished between several types. (1) Goal-state: feedback should provide the goal-state-related information only. (2) OK or NOT OK: This is the two-level evaluation. Do not provide other kinds of information.
- Do not provide redundant information. Only one action can be evaluated at a time.

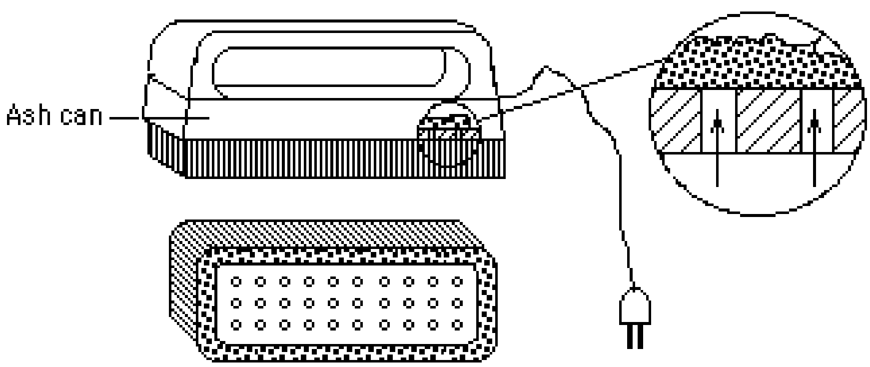


Figure 3.9-4: Brush with a small ash can (After Firma Harald Bockstatt, Germany).

As termination, the user has to do some other work, such as cleaning, packing, etc. These are not the desired actions. Design should reduce these additional actions. For example, after cleaning with a brush, one has to collect rubbish from the ground. A new brush with an ash can collects dust automatically.

3.9.9. Cognitive Guidance

Cognitive guidance refers to that for users´ mental aspect: perception, understanding, reasoning, memory, decision making, and problem-solving. Norman (1993, p. 16 - p. 26) points out that human cognitive processing is a multidimensional, involving all of the senses. Although parts of the cognitive system are separated out for special attention, each part can only be understood properly in its place in the functioning of the whole. There are many modes of cognition. Two of them are particularly relevant: experiential cognition and reflective cognition.

For Norman, The experiential mode of performance is one of the perceptual processing, called pattern-driven or event-driven processing. The experiential mode is a kind of expert behavior, perceives and responds to events automatically, efficiently and effortlessly, without the need for reflection. The human perceptual system is well suited for the experiential mode, such as our expert driving. Experiential mode plays important roles in the routine aspects where the perceptual recognition can lead to a well-learned, pattern-driven response without deep reflection or planning. The patterns of information are perceived, assimilated and the appropriate responses generated without apparent effort or delay. Experiential thought is essential to skilled behavior. It appears to flow naturally, but training and years of experience may be required to make it possible. What is called "experiential," or "reactive" is to emphasize the subjective aspect and the automatic nature of the reactions. On Norman, the reflective mode refers to that of comparison and contrast, of reconsideration, of planning, of concepts, and of decision making. Reflection is learned and greatly aided by systematic procedures and methods. This mode leads to new ideas, novel responses. It is slow and laborious. Reflection is best done in quiet environment. Rich, dynamic, continually present environments can interfere with reflection: these environments lead one toward the experiential mode, driving the cognition by the perceptions of event-driven processing, thereby not leaving sufficient mental resources for the concentration required for reflection. In terms of cognitive science, reflective cognition is conceptually driven, top-down processing.

Norman suggests that tools for experiential cognition should make available a wide range of sensory stimulation, with enough information provided to minimize logical deduction. Tools for reflection must support the exploration of ideas. They must make it easy to compare, to evaluate and to explore alternatives. They should not restrict behavior to the experiential mode. If tools are designed inappropriately, various dangers may arise, as Norman has pointed out:

- Tools for experiential mode behavior that require reflection: These tools turn simple tasks into problem-solving ones, causing needless mental effort, taking needless time. Consider the lapse of attention from driving when attempting to change the station with a typical automobile radio.
- Tools for reflection that do not support comparisons, exploration, and problem solving: In many cases, people have be able to look over the situation and compare alternative course of action. Many electronic decision aids tend to restrict the availability of information to small segments visible on the relatively limited display. This makes it difficult to integrate disparate sources of information, difficult to explore and to make comparisons.
- Experiencing when one should be reflecting. When similar events move rapidly but situation changes, experiential cognition may not be flexible enough to change appropriately.
- Reflecting when one should be experiencing. Too much reflection will see every point of view, consider every possible alternatives, but never decide and act.

CHAPTER 4: CASE STUDIES

SECTION 4.1: PROBLEM-SOLVING IN USER´S ACTION

4.1.1. The Concept of Problem

Based on Dörner (1987, p.10), problems in using artifacts may be defined as following. When a user sets a goal to do something by using an artifact, he/she meets an undesired state which does not correspond to his/her goals and the desired action results, or there exists an obstacle that obstructs the user from transforming the undesired state into desired one, then, it becomes a problem of the user. Users are not the intended problem-solvers for these obstacles, but they have to solve these problems in many cases. Designers should be the intended problem-solvers for using artifacts. Designers should investigate:

- What strategies do users take to solve problems in using or operating artifacts? — These can become some cues for design processes to reduce the degree of difficulty in using.
- What obstacles in using artifacts may be caused by inadequate design? — Designers can improve them later.
- What methods may designers take to solve problems in design processes? — From these methods designers can find more experiences.

4.1.2. General Problem-Solving Methods: Algorithm and Heuristic

It seems that all cognitive activities are fundamentally problem solving in nature. The term operator refers to an action that will transform the problem state into another problem state. The solution of the overall problem is a sequence of these known operators. The key to solving problems in many cases is to represent them in a way that the needed operators can apply. There are two basic ways of problem-solving: algorithm and heuristics. Algorithms are procedures which guarantee to work out the solution to a problem. If there exists no obvious algorithm to solve a problem, heuristics must be employed. Heuristics imply searching and finding. Strategies of heuristics are only rules of thumb or experiences that are often employed in searching and finding, but do not guarantee to find out a solution. On occasion, it can be wrong. The methods of problem-solving in the following are all heuristics.

4.1.3. The Difference-Reduction Method

For example, a painter is drawing a portrait to a model. The goal is to draw the portrait which is similar to this model. How does he/she draw? The main method is to draw a approximate structure firstly; to find the differences between the sketch and the model; then to reduce these differences in order to reach similarity. When users use the first time a camera, they read its manual, look at the pictures on this manual, find the differences between the camera and the corresponding picture, then eliminate the differences. This is the difference-reduction method, and is often employed by novice users. Anderson (1990, pp. 228-232) explains that the difference-reduction method for problem-solving is to choose operators that reduce the difference between the current state and the goal state. Human problem solvers are often governed by similarity: "Which state is more similar or closer to my end goal? Then, I choose operators that transform the problem state into a state that resembles the goal state more closely than the initial state." This technique relies on evaluation of the similarity between the current state and the goal state. However, the sequence is important. Different sequence will get different reduction to the final goal. Using sequence as a measure of similarity leads to more effective problem-solving based on difference reduction. This method is employed particularly in unfamiliar domains. However, it does not work in some situations, or even leads to failure.

4.1.4. Trial-and-Error Method

I was taking photo with my camera. I had pressed the shutter release, but nothing happened. What was wrong? The film had gone to the end? I looked at the number: 21. This trial was wrong. I changed two new batteries. It did not work, too. Again, error. What should I try again? . . . 20 minutes later, I found that I had not switched on the power supply. I must first switch on this power supply, then I can press down the shutter release to take photo.

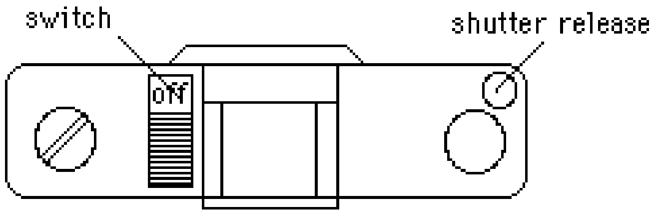


Figure 4.1-1: Camera with a battery switch.

This is trial-and-error method of problem-solving. Users do not know exactly where a problem exists, then they try what they guessed. When they find this trial wrong, then change to another one and try again. This is the general way to find problems not only in using artifacts, but also in repairing, in testing and in research if one is not sure where the problem is. When one tries, a reaction is expected for evaluation and for a new goal setting. Artifacts should provide such reactions of trial. However, wrong design causes also some unnecessary problem-solving, just as this example above. There are several trial-and-error methods which are combined with other methods of problem-solving.

4.1.5. Means-Ends Method

I have just bought a new TV set. I want to install it at home. What is the difference between what I have and what I intend? An antenna, its plug and wire, a cable wire, a socket and a plug of the power supply. I set three sub-goals: (1) to buy these accessories; (2) to find proper tools; and (3) to install them. I must find a solution for each problem. The first sub-goal is to buy all these things: What is the difference? I need a automobile to take them back. My automobile won´t work. What is needed to make it work? Gasoline. Where can I get gasoline? Gas station. There I get gasoline, but I don´t take money in my pocket. Where can I get money. Bank. . . This method of problem-solving is called the means-ends method. The structure of means-end analysis is organized as a series of subordinated goals. Each time the discrepancy is gradually reduced by selecting operators, the problem becomes a little easier to be solved. On Newell and Simon (1972), the heuristic works like this:" I want to act from A to B, but I do not know how. What is the difference between what I have and what I want? The difference is D. How can I reduce D? Operator T will reduce D, but I do not see how to apply it. Transform A so that operator T will apply to it. Now apply operator T and get a new object A´. The new problem is to act from A´ to B, but I do not know how to act from A´ to B." And so the means-ends analysis proceeds further. The means-end analysis is a step-by-step strategy, and it is to see only one step ahead.

This method has been extensively studied by Newell and Simon (Newell & Simon, 1972, p. 22) in a computer simulation program of human problem solving, called the General Problem Solver (GPS). The human does not wander around randomly in the problem space, rather in a goal-directed search through it. At each step, GPS lists the differences between the present state and the goal state, looks for the difference that has the highest priority, goes through a list giving the connections between the differences and the operators which can reduce them, and selects the appropriate operators. If the conditions required for applying the operator are not met and a specific goal can not be satisfied directly, a subgoal of having these conditions met will be created by GPS. There are general steps applied in means-ends analysis (Eysenck, 1984):

- Try to find if there is any way to convert the currently given state into the desired end-state. If not,
- Transform state A into state B. In this case, the problem is currently in one state but one would like to change it into some other state. Compare the two states; if they are different, one must attempt to specify what the discrepancy is.
- Reduce this discrepancy between state A and state B. The task here is to find an operator that is appropriate for this discrepancy, and that can be applied to state A.
- Apply operator to state A. What happens here is that the operator is compared to state A. If they match, then one can apply the operator and produce state B. Otherwise return to the subgoal.
- Then try the first step again, and search again for a way to decrease the discrepancy, etc.

Really, some people behave like this way: only see one step ahead. When you bought a cafe maker or a car, you do not desire to solve many problems like these. Some differences will be more difficult to affect than others. They may introduce new differences and difficulties. The number of subgoals that have to be considered before a move can be made corresponds to the level of difficulty of a problem state (Greeno,1978). Is it possible for designers to solve some of these problems? Obviously, yes. If designers imagine all the real situations of user´s behavior in this way, they can design much better.

4.1.6. The Working-Backward Method

This method is to work back from the goal. The key to working backward is to decompose the initial goal into a set of subgoals that imply solutions of the original goal. Thus, the solver can focus on solving each of the subgoals independently. This method can be useful to find proofs in mathematics (Anderson, 1990, pp. 238-239). In everyday life, people also employ this method to solve problems. For example, I want to go from Braunschweig to Stuttgart in Germany by train. Firstly, I find out on a map where Stuttgart is. From Stuttgart I look back, through Hannover, to Braunschweig, and I find that I should take a train from Braunschweig to Hannover, then change to another train to Stuttgart. When solving one of the subgoals prevents solution of another subgoal (the subgoals prove not to be independent), this method runs into difficulty.

4.1.7. Problem-Solving by Analogy

Problem solving by analogy is to use the structures of the solution to one problem to guide the solution to another problem (Anderson, 1990, pp. 239-242). For example, a desk lamp was not bright when I switched it on. That means the electric current could not flow through this path: maybe this lamp or the fuse was broken, or anywhere the contact point was broken. Thus, I checked all the contact points. In the same way, if the lamp in a car is not bright, I can employ this method to check it. Further, if a TV set does not work when I switch it on, I can try the same way: to see if its plug and fuse is in order or not. This way, users´ experience is important for design. This method is often employed by students in solving exercises in a mathematics text.

4.1.8. Production System (Anderson, 1990, pp. 242-244)

Anderson (1990) claims that the knowledge-based problem solving can be formalized as production systems. Production systems consist of a set of production, which are rules for solving a problem. A typical production for problem-solving consists of a goal, some application tests, and an action for achieving the goal under particular conditions. It is useful in representing problem-solving knowledge. Anderson illustrates an example:

```
IF the goal is to drive a standard transmission car        /* Conditions
     and the car is in first gear
     and the car is going more than 10 miles an hour
THEN shift the car into second gear.                        /* Action
```

Certain tests (under IF conditions) determine if the rule is applicable to the goal. If these conditions are met, the rule will apply, and the action (under THEN) will be performed. However, if the rules and knowledge of driving cars are changing completely every three years, what will happen?

4.1.9. The General Problem Solver (GPS)

Frequently, problem solving is described in terms of searching a problem space, which consists of various states of the problem. The solution to the problem is achieved through a search process of operators, and an appropriate path through a state space. In some cases, problems are usually poorly formulated and ill defined, at least initially. It should be clarified at the start in order to obtain a clear and unambiguous statement of the real problem. The basic steps of the general problem-solving method proposed by Newell and Simon (Newell & Simon, 1972, p. 22) are following: (1) Problem-finding: Finding a problem which is worth solving from ill-defined one to well-defined one. Abstract or define the problem clearly, and generate a range of feasible approaches for this problem. Finding an appropriate problem to solve is often far more difficult than solving this problem. (2) Work out a detail solution for the abstract formulation of the problem. (3) Apply the solution as a plan in the original problem. (4) Execute this plan to solve the original problem. It is a top-down strategy. This method is the major principle for some planning methods.

4.1.10. Hierarchical Planning Method (Sacerdoti, 1974, 1977)

Since the 1970´s, the representation of goal-directed action with computers has been one of the important aspect in artificial intelligence. For Sacerdoti, the types of knowledge consist of domain knowledge and plan knowledge. Domain knowledge refers to, for example, the task domain, individual actions, and the interrelationships among these actions. Plan knowledge, for example, consists of (1) the ranked collection of alternative sequences of individual actions that the problem solver has under consideration for achieving a given goal state, (2) the characteristics of the purpose of each action within an overall plan, (3) a measure of the cost or difficulty of each action. Problem-solving can be considered as a searching process through a space of possible world models for a solution state, or through plan to satisfy the external imposed criterion (problem). The process of problem-solving refers to a development of constraints that gradually restrict the originally large space of possible world models to the solution space which includes only available solutions. Sacerdoti developed the software NOAH (Net of Organized Action Hierarchies) to provides a framework for storing expertise about the actions for a particular task domain. Sacerdoti describes the algorithm for the planning process as follows:

Step1: Expand the most detailed plan in the procedural net. This will have the effect on producing a new and more detailed plan.

Step2: Criticize the new plan, performing any necessary reordering or elimination of redundant operations.

Step3: Go to step (1).

Here the term criticize is concerned with checking decisions. This system integrates problem-solving with execution monitoring. In the NOAH, planning follows a top-down, breadth-first search path.

4.1.11. The Opportunistic Planning Model (OPM)

On the contrast to the hierarchical model, Hayes-Roth and Hayes-Roth (1979) proposed another type of the planning activity. It is described as that "people´s planning activity is largely opportunistic. That is, at each point in the process, the planner´s current decisions and observations suggest various opportunities for plan development." (Hayes-Roth & Hayes-Roth, p. 276) It means that the human solves problems not purely in a top-down or bottom-up manner. Instead, it is on all levels almost simultaneously. There are sets of condition-action rules in this system. A plan is incrementally accumulated, and rarely produced in a systematic manner. It is assumed in the OPM that people make tentative decisions without fitting each other into integrated plan. But this new decision is related to some subject of previous decisions, and then plan grows up incrementally. OPM model employs the heterarchical plan structure instead of hierarchical structure of planning.

4.1.12. **The Goal-Directed Action of Problem Solver** (Rouse, 1985)

There are also many other models of human problem-solving behavior and strategy models for a wide range of tasks. A common feature of these models is the extensive use of rule-based strategies, as opposed to algorithmic optimization, and in a few cases, with a mixture of probabilistic or fuzzy choices or transitions among modes. In order to describe multiple modes of problem-solving, various dichotomies have been suggested, such as pattern recognition vs. heuristics, intuition vs. analysis, remembering vs. solving, retrieval vs. search, and symptomatic vs. topographic strategies. A common characteristic of the modes such as heuristic, analytical, or topographic, etc. is that the human must go beyond the surface feature of the problem.

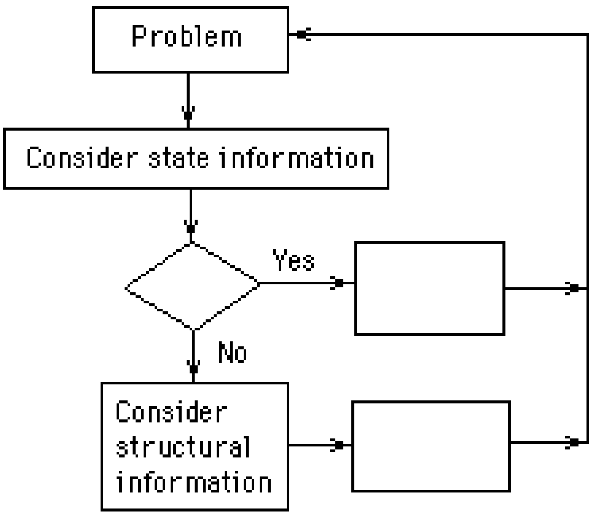


Figure 4.1-2: Model of problem-solving process (After Rouse, 1985).

As the impact of automation has come to be increasingly important, more and more control loops are automatically controlled without manual operation, and the operator´s manual activities will increasingly substituted by problem-solving activities, and becomes more of monitor and supervisor of automation. That is, the operator´s role and goal-directed activity is problem solver, or mental activity instead of hand-holding or physical action. The traditional concept of user-interface is changing toward information interface or communication interface. The major tasks of industrial design should also change. This is an important tendency of design development.

Table 4.1-1. Decisions and responses for problem-solving (After Rouse, 1985)

Level \ Process	Decision	State-oriented Response	Structure-oriented Response
1. Recognition and Classification	Frame Familiar?	Invoke Frame	Use Analogy and/or Basic Principles
2. Planning	Script Available?	Invoke Script	Formulate Plan
3. Execution and Monitoring	Pattern Familiar?	Apply Appropriate S-Rule	Apply Appropriate T-Rule

Rouse introduces a model for capturing the whole of problem-solving on system failure as shown in Figure 4.1-2. The problem-solving is described in terms of detection, diagnosis, and compensation. He proposes human preference for pattern recognition, e.g., the human must go beyond the system state and consider the system structure.

In the investigation on human problem-solving in aircraft, ships, and process plants, Rouse claims that problem-solving in the model of human behavior occurs on three general levels: (1) Recognition and classification (detecting a problem-solving situation), and assigning it to a category; (2) Planning; and (3) Execution and monitoring. It is the actual process of problem-solving.

In Table 4.1-1, Rouse describes the operator´s goal-directed action or the basic mechanism applied to the three levels of problem-solving. (1) At the first level, the operator is to identify the context and category of a problem. If the operator finds the state information to match a familiar frame (Minsky, 1975), problem-solving will proceed on that basis. If the frame is not familiar, structural information might provide clues to an analogy, or employ basic principles of, for example, scientific method. (2) The second level is planning. Based on the state information, the operator may conclude that the problem-solving situation is familiar, and appropriate script (Schank & Abelson, 1977) or standard procedure can be employed. If no script is available, the operator must use structural information to plan in term of generating alternatives, imagining outcomes and valuing outcomes. (3) At lowest level is actual problem-solving. Scripts or plans are executed and monitored for success. The familiar pattern of state information may allow him to use context-specific symptomatic rules (S-rules) that map directly from observation to action. Otherwise, structural information may allow him to use topographic rules (T-rules) to search the structure of the problem. All the responses invoke the same mechanism as shown in Figure 4.1-2 recursively until actions are produced and the problem is solved. In this model only a single mechanism is recursively involved for all aspects of problem-solving.

There is no "standard" way of users´ problem-solving. Most users do not employ scientific logic to solve the problems in using artifacts. They often use the heuristic way or trial-and-error. When they meet problems in artifacts, they will have a look, and try, and look at it again, and try again. They may press a key which leads to deletion of a file unconsciously, or to other unforeseen catastrophes if designed products only allow the correct operations and do not tolerate trial-and-error. In order to reduce or avoid such design problems, designers must understand users´ way of problem-solving.

SECTION 4.2: THE IRRATIONAL USER MODEL AND USER´S LEARNING

4.2.1. Who Is User?

For usability of artifacts, designers must focus on users´ action: Who is the user? How does the user use artifacts? What is user´s desires and performance with the artifact? These questions seem to be very simple, but not always. Designers should observe the user´s action exactly. An incomplete concept of users in design process causes many problems. For example, without consideration of the users in manufacturing processes, a rather simple artifact is so designed that its manufacturing processes are quite difficult. Without the concept of the users in the repair activity, the repair and maintenance of products are often troublesome. Designers should distinguish the various users´ goals and actions in using, in manufacturing, in transportation, in installation, in repair and maintenance, in storage, in packaging and unpacking, and design appropriate action interfaces for them. This is often the forgotten problem in design process. For example, it is difficult to clean some artifacts (Figure 4.2-1), or to repair (Figure 4.2-2). The users are different in several categories, for example, children, the young, women, the old, or the handicapped, etc. Their intentions and action features to the same artifact are quite different.

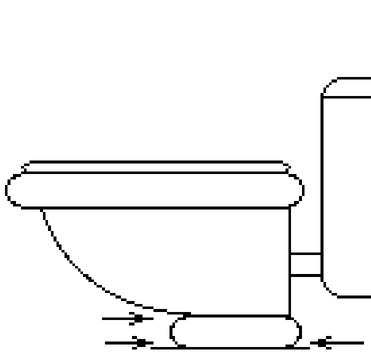


Figure 4.2-1: This form may be beautiful but the locations of the arrows pointed to are very difficult to clean.

4.2.2. The Rational User Models

For usability design, designers must find everything about users´ action to the designed product. This knowledge is called the user models. The user models involve mainly the mental model and the action model. The mental model consists of users´ mental processes: perception, cognition, physical performance. Users´ emotion plays very complicated role in his/her action to artifacts. The action model describes the action course, the operating procedure, their knowledge about the operation and their learning processes. The action model should also involve user-entity relations, including the user, other related people, the operated artifact, and the environment. The theoretical basis for users´ action model is action theory. Up to now, psychologists have created many user models in the field of human-computer interface. These models are oriented to correct and successful action, and called rational models.

4.2.3. The Irrational User Models

However, humans are irrational. Human action involves both the rational part and the irrational one. The irrational mental models comprise the following aspects. (1) Human perception is irrational. For example, human eyes are irrational. Humans have limited perception abilities, such as the limited vision angle, the limited focus spot, and the limited sensory memory. The best eye is worse than the worst camera, and that not all of information provided by the designer can be perceived by the user. If users lack knowledge to perceive depth cues and spatial relationships, or if the designers do not provide sufficient depth cues and spatial relationships, and if the light intensity is not what the designers demand for the artifact, then it is very difficult for users to perceive and build 3D relationships of the object. (2) Humans have different perceptual experiences. They perceive difference affordances. In some cases these is no standard perceptual affordance. (3) Attention is a very limited resource, with limited energy, with limited capacity, works for a very short time. However, almost all the processes in perception and cognition need attention. It is difficult for humans to concentrate on a single object for a long time, say 10 minutes. They are easily tired and abstracted. The abstracting resources may cause unforeseen difficulties and accidents for users´ action. (4) Human cognitive processes are irrational. Humans have very different cognitive abilities, which cause many difficulties in communication or understanding processing. In everyday life and in using artifacts, there exist not any single "standard" or "rational" way of thinking, no standard way of understanding meaning. Generally, humans do not think logically, but according to their experiences, their feelings, their intuition, imagination, even illusion. (5) They are forgetful. Human memory is irrational. It is easy for them to forget their intentions, their plans, action courses, operations, and information. (6) Heuristic or trial-and-error, not scientific logic, is often employed to solve problems. (7) Cognitive process is very complicated. There is no standard way of cognitive process in using artifacts. Users have different abilities of cognition. Some abilities, such as idea production, are rather difficult for some people.

The irrational action model involves the following aspects. (1) Humans and machines have different way of behavior. Human action is led by intention. If intention changes, then its action also changes, no matter what is the current state of action. However, machine behavior is state-changing. Its behavior must change from the current state to the possibly next state. (2) Human hand motion is irrational. They often make action slips. (3) Different conditions of the environment may lead to different way of action and psychic states. Various psychic states influence also human action in various ways. Kuhl et al create the model to describe such processes. (4) Humans make errors. They may make errors in intention formation, in action initiation, in action planning, and in action termination, in every action phase even if they have learned the operation very well. (5) The operation of computers or car-driving for a short time is different from for a long time. Operation and driving for a long time will cause fatigue, unforeseen way of action, and even accidents. (6) Abnormal conditions and states will cause unforeseen way of users´ action, such as in the dark, in high temperature, in noise, etc. (7) In urgent situation, in time pressure, or emergency, users´ behavior is different from the normal way. There is no standard user model for general design. Designers should build the concrete user model for their design object in detail.

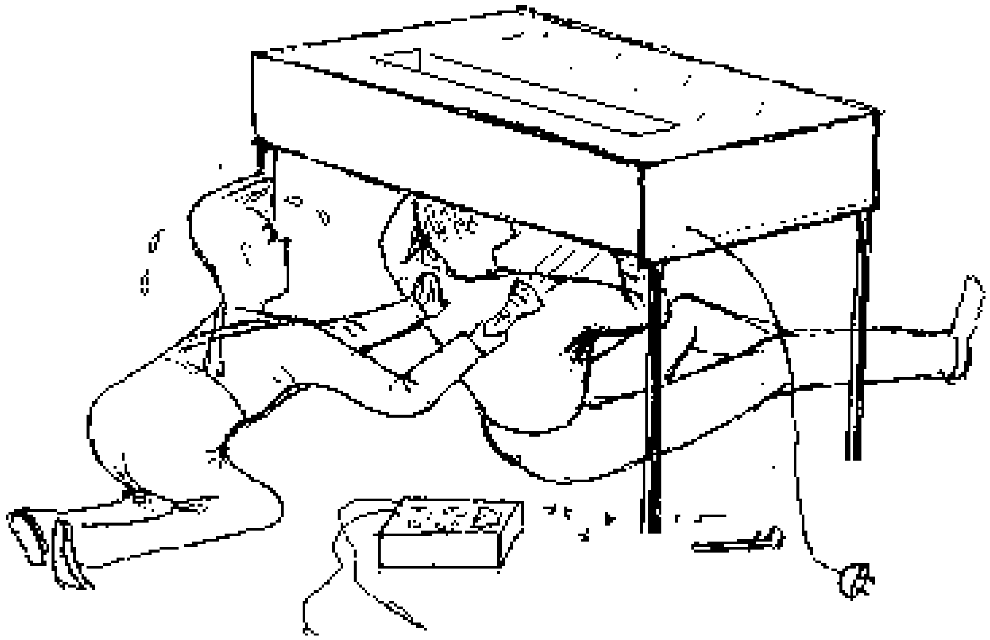


Figure 4.2-2: It is difficult to repair this work-table because it does not allow to be turned over.

4.2.4. Types of Users

4.2.4.1. The novice user and the average user

Various users are distinguished in regard to learning processing and experiences. Novice users may refer to who have no experience or have not learned how to use the artifact, or refer to who stay between the first stage and the third stage of the learning process. Computers spread more and more into various fields. The "experts" in their own fields may be novices in other fields. The technical culture in these fields (the technical way of behavior) should be taken into account. The expert users in any field refer to who have experiences in using the artifact more than ten years. Average users refer to who have finished the third stage of learning but do not have experience for ten years. The average users may not use computers professionally or naturally. They may have difficulties in problem-solving.

4.2.4.2. The accidental user

The accidental user refers to the users who have to use the human-computer interface because there is no other way, for example, to find a book on the computer of a library, or to get money from an automatic machine. The particular issue for design of such HCI is to consider how every people can perform in the HCI. The designers should consider the following issues:

- The user is not motivated to use the human-computer interface for many reasons, maybe they have had bad experience, or they fear computers, or they do not know how the computer works and so on. If the human-computer interface can encourage users, if it is user-friendly, if it is easy to use, then they may change their way to computers.
- They have not learnt how to type. They do not have the computer knowledge. Its design must avoid typing and the computer knowledge.
- The users may misinterpret the command, the output and information. The reason is simply that the users do not know the same things that designers know, and that users do not think in the same way. The designer must take the accidental user model as designer model.
- The user´s response is not recognizable to the system, or say, the system is not so flexible as the user´s way of behavior. The user interface must offer the easy way for the users to recognize and modify their way of behavior.
- If the system behaves in an unexpected way, then the user will not know how to respond. The user may lose orientation in the task. The interface must offer the human way of behavior in everyday life for the users.

4.2.4.3. The expert user

The experts users may have at least ten years experience in general in any cognitive or physical skills in any domain (Simen and Chase, 1973). However, it is not always the case. In the domain of computers, evidences show that a few very young people have become the expert users. On the contrary, it does not mean that every 10-year-experienced individual always becomes an expert. The expert users must possess the following characteristics. (1) They can use not only one tool very proficiently, but also the same domain of various different ones, and then can easily integrate new information in this domain. They know every details of the performance, the relationships between the human performance and the behavior of the artifact because they can readily perceive meaningful patterns and events in their domain. They can evaluate the performance on this product compared with that of various other products in this domain. In many cases, they know some special history about this domain and the unique tricks of using and improving the artifact. They have superior short-term and long-term memory and encoding domain information into larger chunks (Proctor and Dutta, 1995, p. 242-243). (2) Often, they spend much more time in using an artifact than its designers. Many basic components of the skills have become automatized. They can recognize effortlessly meaning of information at a deeper, more principled level, which is the sorting ability. They spend more time in problem-solving thinking, in forming the conscious users´ mental model (Proctor and Dutta, 1995, p.242-243). In other words, they think over the problem not only on the Self, but on the view of users, recognizing not only their own but also common feature of users´ action. They can explain the reasonability or unreasonability of the performance, based on human features of action or emotion, for example, how may they perform generally, what are their habits, why do a problem belong to its design, to the manufacturing, or to its user, how to improve its design, how to avoid such problems in using. The improved brush in SECTION: USER´S ERRORS CAUSED BY DESIGN, was designed by a 80-year-old decorator painter who was not designer. (3) Evidences make clear that their suggestions for design improvement are different from those of professional designers. The expert users appear to tend to solve problems in a simplified way. They have found some unique tricks. Designers seem to tend to solve problems in the direction of increasing the reliability or the control functions with more parts.

4.2.5. Action-Operation Mapping

In the user model, action-operation mapping is one of the key problems which designers should solve. Humans pay attention naturally to goal intention, outcome, evaluation and new goal-setting. In fact, during action there exist two chains of action-operation mapping which the implementation intention must care: (1) the mapping of action sequence on the sequence of machine-oriented operations; (2) coordination between perception and motions. It is difficult for humans to divide attention, perception, cognition into two or more directions at the same time for different intentions. Traditionally, the problem of mapping is solved in three ways:

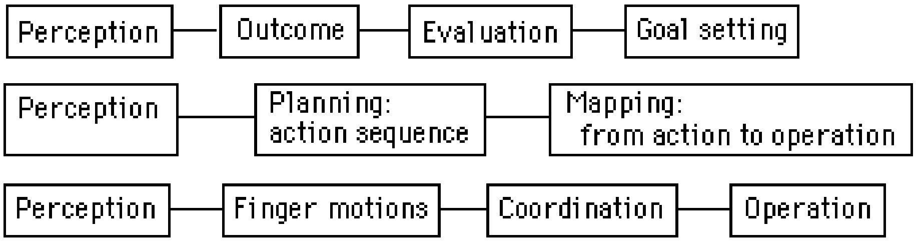


Figure: 4.2-3: Action-operation mappings.

- Users need only to perceive on the implementation object (the button of the electric bell, Figure 4.2-4), and must not care the goal object (the bell). It is the easiest way for the accidental users to operate the artifacts.
- The goal object (the text written on a piece of paper) and the implementation object (a pen) exist in the same angle of users´ view, and the outcome is the imitation of its action (the action and the outcome are united), and can be seed at the same time. This way, humans can naturally concentrate on the goal object (text).

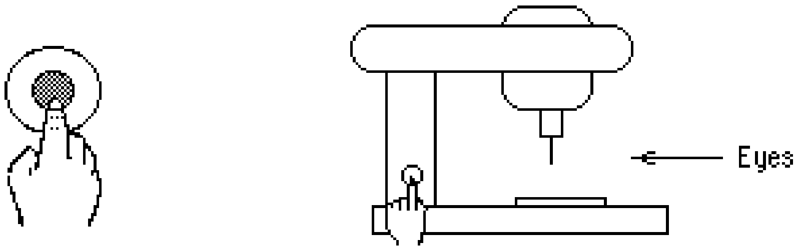


Figure 4.2-4: Action-operation mapping.

- The goal object and the operation are not in the same angle of view (Figure 4.2-4). Users should only concentrate on the goal object (the working piece). For this purpose, the operation should be realized either by easy hand or foot motor motions (click the mouse, or push the button), or should be easily automatized through learning or by unconscious motor performance. The operation of computers appears to be executed in this way. If you observe novice learn to operate a computer with the mouse, you will find that the novices can concentrate either on the mouse (organizing finger motions), or on the screen (detect the cursor, figure out an action plan), and only after learning, they can concentrate on their goal intentions and coordination the cursor and the mouse operation.

Design of artifacts implies also design of ways of learning. Designers must take user´s learning processing into account consciously. The goal is to make learning easy. Main issues include:
- What are the differences of the various ways of learning.
- What should be learned and should not be learned by users: The minimal, goal-related, necessary knowledge.
- How can designers make the user´s learning processing easier?

4.2.6. Specific Issues about Leaning
4.2.6.1. Five levels of learning
Users´ learning relates to five aspects in order to become a skilled performer:
- Fundamental ability factors of perceptual skills, cognitive skills, motor skills, and learning abilities.
- Action-related learning refers to acquire the skills of action processing, for example, formation of goals, attention, anticipation, planning and acting, evaluating and terminating action.
- Task-related learning relates to organization of the task.
- Tool-related learning refers to the tool-oriented domain knowledge (concepts, principles, functions) and procedures.
- Goal-action-task-operation mapping is to transform user´s intentions into an action sequence into computer-oriented tasks, and into operations.

Goal-action-task-operation mapping is the central problem in interaction with computers. Three of the five levels of users´ learning directly relate to the tools. Designers must think of how to simplify user´s learning processing, and reduce the interference of the tools with user´s action.

4.2.6.2. Easy to learn

Easy to learn is a common criterion of design proposed by most authors. Ease to learn relates to two aspects: what to learn, and how to learn. It implies:

- Users´ prior knowledge and education.
- Less machine-centered knowledge: fewer concepts, principles, and procedures.
- Easy understanding and less memory: For this purpose, there should be various kinds of mechanisms "finder," for example, pathfinder, finder of concepts, finder of procedures, finder of files, not so many icons and machine functions, etc.
- Easy mapping, or direct goal-operation mapping, and consistent mapping: Operations of computers, computer-oriented plans and selection of rules should directly be combined with or correspond to user´s action goals and plans.
- Lower demand for ability factors: No difficult ability factors such as logic inference, no heavy loading, lower speed, no multiple factors coordination, etc.
- Less attention, and no divided attention demand: that is, for example, to employ simply hand motion.
- Error detection by computers, avoidance of errors and easy correction. Gade et al (1981) have found that menu-operation decreased 30% of input errors compared to other input methods.
- Shorter procedures and fewer preparation for initiation and termination.
- Adaption to human learning processing: Trial-and-error, on-line help, examples, procedure-guidance instead of abstract explanation and manuals.
- Possibility of self-learning, less dependence upon the trainer or the manuals.

4.2.6.3. Flexibility of learning and operation

Flexibility of learning and operation poses another challenge to the structure of knowledge which is provided by the designers:

- Users´ behavior of using artifacts is frequently in an opportunistic way. Users may not have much time to learn and practice, and may forget what they have learned. Users themselves may accidentally change their intentions or plans. Human thinking sometimes is not logical, do not proceed in an orderly way and step by step. They suddenly think of another goal and procedure or problem. They desire to learn easily and quickly. However, knowledge is generally a hierarchical structure. Without understanding the basic concepts and procedures, one may not understand the advanced knowledge. Is it possible to offer an opportunistic structure of knowledge? That is, users can directly understand or quickly find what they want without systematic learning. For example, terms, the definition of icons, the examples and the common procedures in relation to applications and novices can be organized in on-line documentation, or as appendix in the book.
- During a goal-directed action, unexpected events may occur. Users must have possibility to handle the unexpected events. After this processing, the users may want to return to the interrupted point but forget where it was, or to go back to the beginning, or to go to the end. There exist many possibilities.

For these purposes, the topological structure of action paths must be studied by the designers.

4.2.6.4. Time Needed for learning basic knowledge

Bösser (1987, p.111, p. 114-115) has listed the basic hours for training:

- Basic principle of data processing: 100 hours
- Programming in BASIC: 100 hours
- Text-processing: 80 hours
- Introduction to CAD: 85 hours. 3 - 4 weeks for 2D system. 8 - 9 weeks for 3D system and 3 - 4 weeks for job training. (p. 119)
- Text-editor: 3 - 10 hours at least (p. 115)
- Typing: 30 - 50 hours (p. 115).

SECTION 4.3: USER´S ERRORS CAUSED BY DESIGN

4.3.1. Standards: Two Types of Errors

Electric iron is used almost in every family. In the past forty years, the design of electric iron has improved much. It can spurt water vapor. It can press various materials in different heat power. However, if one is not careful when pressing, it can also burn the clothes, then he or she says "I make error." Many housewives have such experience. How to estimate human error? It depends upon values and standards. In the artifact-centered standards, human action should fit the tools and machines. If humans can not fit the characteristics of the tools, then human errors may occur during action. For this reason, users need much more learning and training, acquire precise machine-centered sensorimotor skills, pay more attention to the action and act exactly, logically, and quickly. However, If designers take the human action-oriented standards, they may view some of these errors in another way. Designers must distinguish between two kinds of error: errors which are caused by the design and artifacts, and errors which are caused by the nature of human action. In this section, some errors caused by design and artifacts are described.

4.3.2. Problems in Action Preparation

Some design makes the preparation of action difficult. For example, the video cassette recorder has a function to program a recording for a TV program within the next 24 hours. There are four steps for its preparation. If you want to record a TV program broadcast from 10:30 to 11:00,

- Select the program channel to be recorded.
- Press the OTR On (+) or (-) Button to set the OTR starting time to 10:30.
- Press the OTR Off (+) or (-) Button to set the OTR ending time to 11:00. This Button must be pressed within 8 seconds to select the OTR ending time, otherwise the selected staring time will be canceled.
- The VTR will automatically switch off, when the OTR is completed. To turn the VTR on again, press the VTR On/Off Switch.

There are another eight items which relate to when it "does not work," what to "make sure," "if you want to ...," what is "possible," etc. OTR stands for One-Touch Timer Recording. Can you understand this explanation? Such skill is machine-oriented, and special training is needed for its operation. In my questionnaire, 80% of women over 40 years old cannot operate this function. Many designers believed that this preparation procedure was too complicated for everyday life.

4.3.3. False Perceptual Anticipation Caused by Design

When perceiving, people may have imagination or anticipation which relates to their experiences. Wrong design may cause users´ wrong anticipation. For example, in the Figure 4.3-1, when you enter the building door A, you will find immediately a door D on the right side, it is easy for you to imagine and anticipate that the door D should lead to the stairs because you can see the stairs just behind the door glass. However, the D is not a door. It is only a fixed window. The correct way to the stairs is to go through the door B and C, then stairs. Almost every one who first entered this building made this mistake.

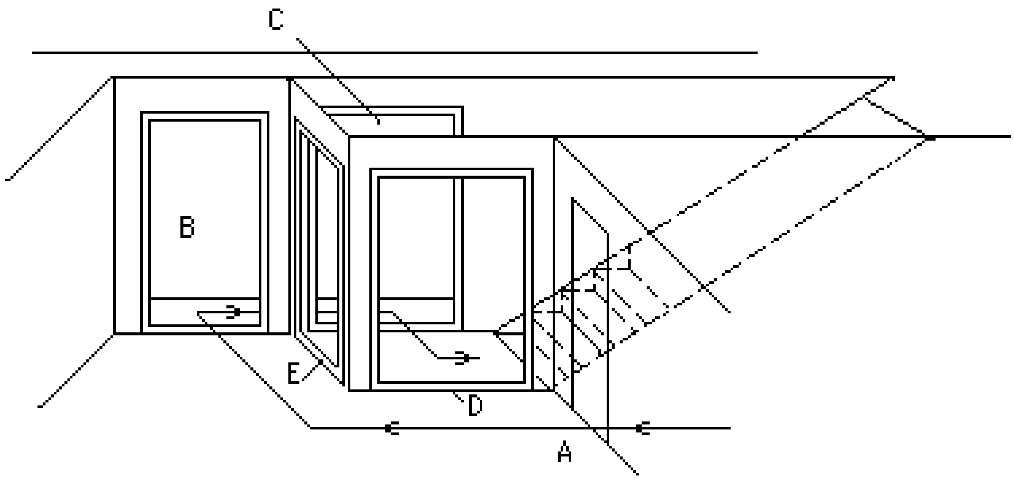


Figure 4.3-1: Design provides false perception.

4.3.4. Machine-Centered Design

Machine-centered design emphasizes machine-oriented functions. Humans, unlike machines, are not good at exact positioning, and cannot move so rapid and exactly as machines. The more rapid the action is, the less accurate the action is. Human action is not good at moving as geometric patterns, such as line, rectangle, circle, etc. Furthermore, human hand-holding can not control the dynamic of mechanic tools very well. For example, the electric handed drill used at home seemingly satisfies the human need: drilling, but in fact, not. The action of drilling can be analyzed in detail:

- Before initiating drilling, the user intends to press firmly the work pieces with the left hand. This way then this hand is located near the drilling bit (in the execution interface), and there exists certainly possibility to hurt this hand. How to find a way for the user to fix the work pieces which is not held with the hand, and to release human hand from the execution interface?
- During initiation of action, the drilling bit slips on the surface around because the material is rather hard, Human limited force could not hold firmly the drilling origin, or any other reasons. The user desires to position the drilling origin fixedly. How to position the bit fixedly, but not with the hand directly?

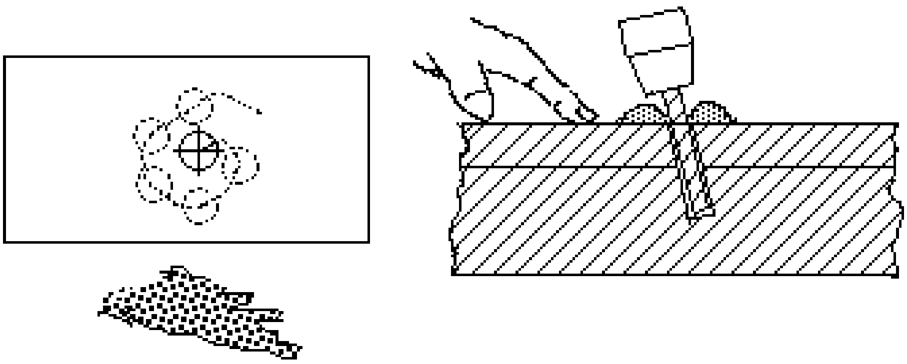


Figure 4.3-2: Human errors caused by inappropriate design: Humans are not good at positioning.

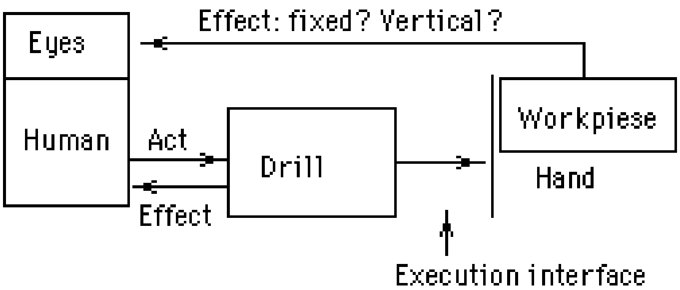


Figure 4.3-3: Human perception is not sensitive to physical parameters.

- During the execution, the user hopes to drill vertically. For this purpose, the user must pay attention to the direction of drilling, meanwhile pull the drill forwards with strong force. However, it is difficult for the user to do such two things exactly at the same time. One often finds it difficult to drill vertically, even if there is appropriate feedback information for the drilling orientation. How can one keep the correct direction of drilling? Another problem: When one drills on ceiling, the dust will fall on his or her face. The user hopes that the dust could be automatically collected.
- After the execution, the user must clean the drilling dust on the surrounding. For this sake, the user has to prepare cleaning tools to clean the ground, the work pieces, etc. These are extra or additional actions. How can designers reduce these additional action?

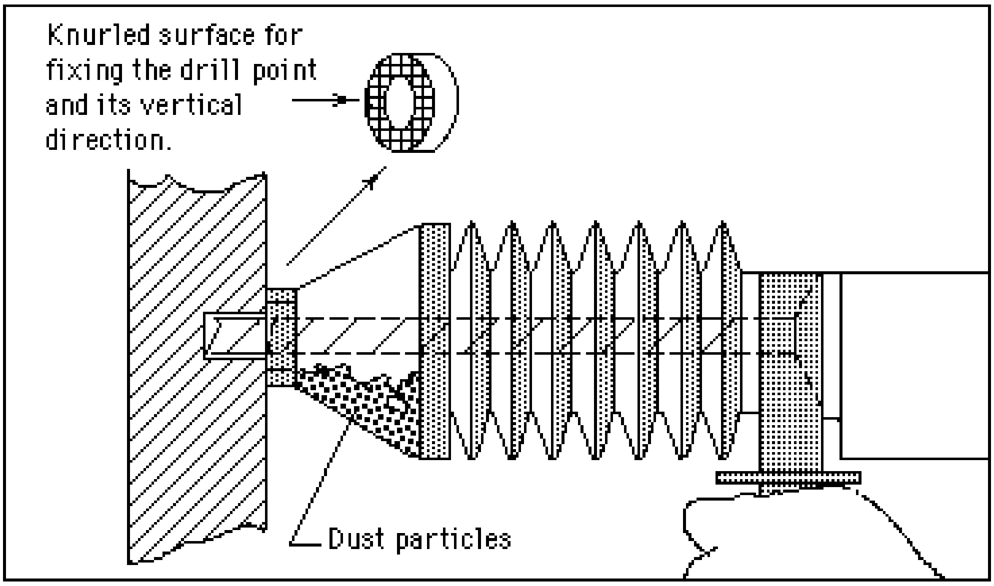


Figure 4.3-4: An accessory of drill protector changes the tool-centered design into human action-oriented one. (After M. Paulawitz, MPK, Germany).

Figure 4.3-4 shows an example of its new design. This accessory — drill protector, or drill holder — can provide fixedly adjustment of position, accurate drilling through depth, keep human hands away from the execution interface, protect the wallpaper, carpet, and human hands, as well as collecting drilled dust.

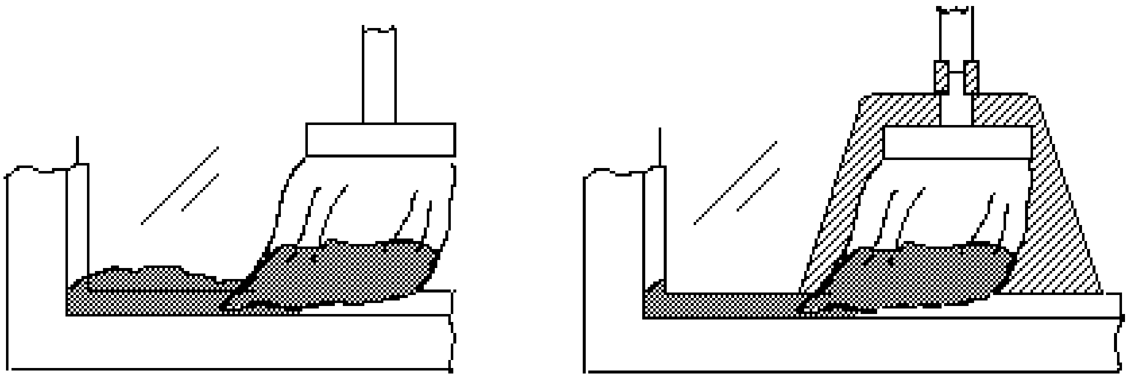


Figure 4.3-5: Paining window.

Human action is not good at accuracy and exactness. When people whitewash a window frame, they could hardly exactly paint it without whitewashing the window glass, even they are very careful, works at a very slow speed. For this accuracy, they must acquire very good sensorimotor skill. However, if its design is improved as shown in Figure 4.3-5 with a plate behind the brush, the accuracy can be reduced, and the user will feel it easy to whitewash.

Humans are not good at moving in geometric patterns, such as drawing straight and parallel lines. Generally, people use a T-square as reference, and move a set square along this T-square to draw parallel lines. In such action, people must pay attention to both the T-square and the set square while holding the both for different actions of each hand. New design of the ruler can simplify human attention and action (Figure 4.3-6). Two wheels which are knurled in full rectangular textures in this ruler can rotate on paper firmly and in parallel. This way, this ruler can keep moving in parallel direction.

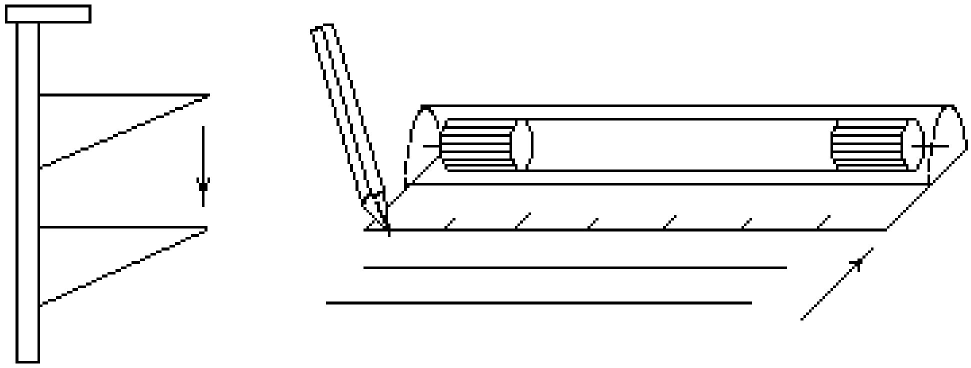


Figure 4.3-6: Old way of drawing parallel lines and the new ruler for it.

Action-oriented design must reduce the demands for accuracy and complexity of action, reduce the requirement of the new complicated sensorimotor skills, reduce the additional activities, simplify preparation and termination, reduce user´s attention to the tool, and avoid the user´s errors which are caused by the design.

4.3.5. Incorrect Feedback Information for User´s Perception and Cognition

Humans evaluate the effect of action by their perception and mental processing. To my knowledge, most design errors in everyday things relate to user´s perception and cognition. Human perception can not exactly perceive physical parameters, such as temperature, size, and time. It can not perceive and process several pieces of information at the same time, etc. For these physical parameters, humans may evaluate the action effects indirectly by using their experiences, by measurement, but can also make errors if the design is not appropriate.

During actions, users focus on their goal-directed action, say, press clothes. They are not, and should not be distracted with the state of the tool (the electric iron). It is necessary to provide appropriate feedback with the user for evaluation. In some cases, the feedback information does not fit human perceptive ability. For example, when people press clothes with an electric iron, he or she wants to know how hot the iron is. But how could humans know that the temperature is about 100°C? Human eye is not sensible of temperature. To feel with the hand?

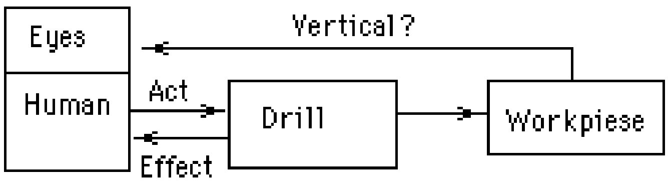


Figure 4.3-7: How can one perceive the exact direction in the angle of 1°?

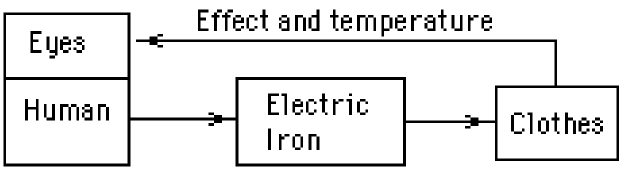


Figure 4.3-8: Human eye is not sensitive to temperature.

In order to avoid burning clothes with the electric iron, the users must have much more training, develop skills and experiences, and pay more attention to the tools when they are using it. To prevent this problem, a new kind of the electric iron is manufactured completely with plastics. In this plastic-iron, electric heater is not to heat the plastic, but to heat water, and hot water heats the bottom plate for pressing, and also water vapor is spurted to the clothes which are pressed. Such plastic-iron can not be heated to be more than 100° C and can not burn the clothes. This way, the user will not be distracted to the tool state.

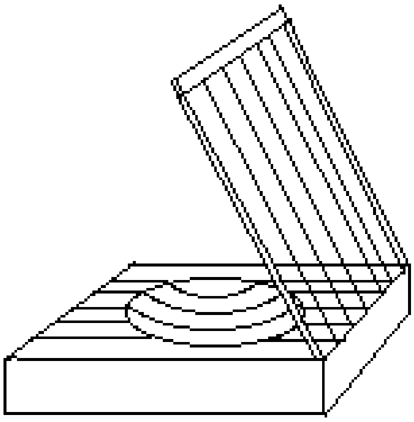


Figure 4.3-9: inadequate design will increase more activities from the user.

4.3.6. Additional Activities

Users´ final goal intention is to use artifacts, not to serve for them. My brother told me a story. He found a egg-slicer very attractive, and bought it without any hesitation. "Of course, I need it," he thought. Then, he found that he used it only once every year—for New Year dinner—only about one minute, but after use, it is very difficult to clean the very narrow slots of the slicer. He thought over and over, found an idea and another tool: a needle. He spent another two minutes on cleaning it. Since then, he has never used it again. The slicer serves him one minute, but he serves the slicer over ten minutes. Other example, to open a lock, one needs a key. For several keys, one needs a leather key-bag. To hold this bag on the trousers, one needs a metal chain. The final goal is to open locks, however, one has to find several additional artifacts to guarantee it.

Many artifacts require additional tools and additional action for preparation, operation, termination (disassembly, packing, and cleaning), storage, maintenance and repair. A housewife buys a washing machine in order to clean the washing machine? No, the final goal is to use it to wash clothes. She has to do other additional activities to maintain it in a good order, but she is not willing to do so. Such additional activities could be eliminated or automatically realized. But how? These needs and desires are not often considered by its designers.

4.3.7. From Machine-Centered Design to Human-Centered Design

Intention, perception, action, and evaluation— this is a forward chained processing. Machine-centered design interferes with this processing. Humans have to interrupt this consistent mapping processing, and to pay attention to serve for the machine. To prevent this problem, design must avoid machine-centered perception, cognition, physical operation and input. The structure of the action interface should be adapted, for example, to users´ hand-holding, become the expansion of humans, and compensate user´s actions so that the user feels that it behaves like part of the hand, eye, or human mental processes. To reduce or to eliminate the inconsistency between human actions and the operations of machines is one of the important problems in design.

4.3.8. Novice Designers

Bruno Sacco, as Styling Manager of Passenger and Commercial Vehicles, Daimler-Benz AG, has analyzed the behavioral difference between designers and engineers (Sacco, 1979) as follows. Technologists are extremely objective. They proceed step by step, and the next step is not made until the previous step is firmly finished. Their actions are characterized by method, and do not readily go off at a tangent. Most technologists are very disciplined. They often consider esthetics as that "what is technically correct is also beautiful." On the other hand, when industrial designers have just left the school, they do not integrate well into the overall working process. They prefer to set their own tasks and fly off at a tangent. They question everything. This critical, perhaps heretical attitude toward the tradition may be the characteristic of their own. The situation occurs especially when they are looking for the best form for expressing a certain function, the function itself is seldom improved. Sacco emphasizes that in automobile design, one of the goal intentions — the optimal spatial conditions for driver and passengers — must be created, meanwhile the vehicle weight, dimensions and air resistance must be kept as small as possible because of the consideration about the raw materials and primary energy source. In addition, precaution has to be taken to increase the safety of the occupants of the vehicle. Notice here: all these criteria are based on user´s goal intentions and long-term intentions. These are the guideline of technical design, or function design. All these requirements, which are contradictory to each other, must be weighted during the difficult balance performed in design process. The result is obviously a compromise. Whether it is a good compromise depends not only on the technologists but also on the industrial designers. Sacco claims that "form follows function" does not correctly sum up the spirit of the philosophy of industrial design in their company. What the users first need is good functioning and reliability before esthetic expectations. Good cooperation between both engineers and industrial designers is only possible if each member of professional group acknowledges the capabilities and the achievements of the other professional group. This process must be even taken to the point of a mutual recognition of the equal value of their tasks. On the basis of an equality that is felt to be self-evident, technologists and industrial designers can cooperate in harmony and the greatest challenges can be taken up. In concrete design process of C 111/III, the special boundary conditions play a successful role.

SECTION 4.4: PROBLEM-SOLVING IN INTUITIVE DESIGN

4.4.1. The Intuitive Design Process

Traditionally, industrial designers work intuitively. They investigate briefly, scan the evidence, ruminate upon implications and sketch ideas without exercising much conscious control over the activity of design. Eastman (1970) analyzed intuitive design as a problem-solving task to study their concept formation and problem-solving. Intuitive design means the procedures that designers have implicitly derived from their own design experience through case studies in school or from professional experience. In Eastman´s study, the human thinking is described as information-processing model. Memory is interpreted as allowing independent recall of past inputs and recall of past intermediate processing state. Human thinking is a result of information being brought together from the environment and memory in unique sequence. The processing of information by designer often depends upon some means for representing information or the designer´s ability of representing. There is a clear correspondence between the types of constraints considered by the designer and the types of design representation used: words, numbers, flow diagrams, plans, sections, and perspectives.

In an example, the designer to be investigated by Eastman is creative one and has seven year professional experiences. His design task is to remodel a bathroom because of buyers´ several comments for it: "that sink wastes space,"and "I was hopping to find a more luxurious bath". During the observation of his design activity, Eastman has found the following:

- The first step of design activity is determination of the information used, its sequence of use, and the operations applied at each state to produce a new state. Several groups of information are useful. (1) Design units, such as counter, toilet, bathtub, mirror, sinks, towel racks, etc. (2) Desired relationships between the units and the desired attributes of the units (constraints), and there are four given constraints: more luxurious bath, total design concept, wasting space and cost = existing + $50; and 14 retrieved information such as "look small," "functions okay," large mirror needed, adequate use space for fixture, no exposed bathtub corners and so on. (3) The plan made on a design to fulfill the relationships, i.e., "remove current unit," "rotate designated unit 90°," "extend unit around corner," "align horizontal edges," "locate along wall," etc. Cues to the source of each piece of information may be designer´s memory, his perception of the current design, information from client, or deductions from other information.
- The processing at any moment is influenced by prior processing, by the information available for the current problem, and by the operations available for operating current information. Eastman shows these influences as a flowchart in a Problem Behavior Graph (PBG).
- Designers begin design by developing a clear definition of the problem, formation of a goal, and generating operational rules for testing design alternatives.
- The pieces of information that are received are related during processing to produce a new information state. Each of such transformation requires one of four types of operations. (1) Logical, including all arithmetic and verbal logic. (2) Corroboration and possible expansion of information from one source by gaining similar information from another source. (3) Application of a manipulation or constraint to the current information state, producing a new form alternative or a test result. (4) Inductive association of a series of manipulations with a constraint.
- The point of view of esthetics is changeable. It has no unique standard or method. The sequence of this process is often not fixed and depends upon the designer.
- Eastman defines the determinant of a processing sequence as a strategy. It seems that previous experience, the limits of short-term memory, and the organizational structure of memory are strong influences on strategies. Two design strategies are involved: (1) Some design units are treated in a trial-and-error process, a sequence is taken from the top-down, then replaced in the reverse sequence (first with counter, toilet, tub; then reverse of these tub, toilet, and counter). These process is something like a breadth-first search in artificial intelligence. Then next unit is located. (2) The strategy for dealing with all other units of the design involves search heuristics to locate the mirror, medicine cabinet and towel racks. Another type of operations could be systematized as: "remove the first designated unit," "rotate previous unit 90°", if still unsatisfactory, "move it along the same wall to another corner", then repeat these operations on other walls. If all manipulations fail, the next unit is tried. If the design passes all constraints tests while the unit is in a given location, the prior unit is manipulated. The problem-definition process is mixed with a generate-and-test sequence.

- The strategy for retrieval constraints "imagining yourself functioning in the space," which is emphasized by action theory, has not been elicited from the designer.

Eastman concludes that intuitive design method in many cases is likely to remain entirely adequate, such as in jewelry, much interior and most furniture design. However, in some areas where it is becoming less and less possible to depend entirely on intuitive design. Design of automobile, computer, robot, instruments, and complex building of hospital involves a large number of interacting variables and requires so many detailed problem solutions that the designers cannot trust their intuition to tell which is the best.

4.4.2. The Role of Graphic Activity in Design Process

Rusch (1970) analyzed intuitive problem-solving process in another way. When faced with the problems where the designers have had no previous experience in strategy, the designer can no longer rely on simulation from trial-and-error behavior. One must draw inferences about the outcomes of future actions on this part. These inferences can be categorized into relational inferences and process inferences. In the former a judgment is made concerning the consequences of some possible new configuration of the problem elements. In the latter the consequences of a series of possible actions are considered. In both situations, because of the limited capacity of the mind, the amount of information carried by the judgments will be small. Rusch asserts that, in order to solve a problem by inference, the inferences must be made incrementally, and each increment must be checked before passing to the next.

For Rusch, the designer creates with forms through sketches, and the creation itself is both a form and a collection of forms. What is called "leveling" and "sharpening" are in wide use in solving of design problems, but not generally understood by designers. Wülf (Rusch, 1970) presented subjects with a series of simple line drawings and asks them later to remember and redraw them. He found that changes made in the reproduction fell into two categories. Either the figures are strengthened by accentuating certain characteristics of the form (sharpening), or the figures are strengthened by suppressing certain features (leveling). If the change is such as to approximate more and more some well-known structure, it is called normalizing.

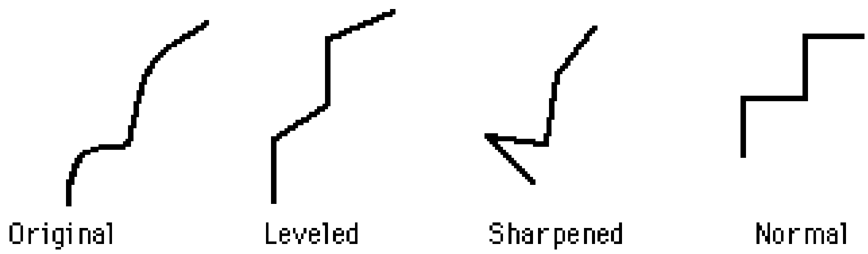


Figure 4.4-1: Gestalt principles of leveling, sharpening, and normalizing of graphic material (After Rush).

Rusch claims that leveling and sharpening do affect the solution and in rather unexpected manner in design process. As overlay after overlay of tracing, paper is placed on the drawing broad, forms are altered to give greater differentiation and a better resolution of the functional requirements of the problem. If the effort is for clarity, then the processes operative have to be leveling, sharpening and normalization.

Rusch selected Picasso´s eleven lithographic bulls created in December 1945 through January 1946, and analyzed the head of the bull of eight lithographs, which contain 228 graphic elements. Of course, the graphic activity represents only a small part of the information which enters the design process. A symbol, usually verbal, reasoning or logical activity continuously challenges each step for functional correctness. Rusch claims that the entire process can be represented as an interplay between rational and graphic activity. Leveling and sharpening is incremental by nature and forces the corresponding rational activity to be incremental as well. Reorganizations act to upset this pattern, but their occurrence is beneficial whenever they speed the problem-solver toward solution. When previous experience is not available to the designer, the designer must fall back on an incremental method.

Rusch has found out that continuity, clarity and relevance can be viewed as tendencies of artistic behavior peculiar to the type of problem presented. The first tendency is for the artist to make continuous or non-continuous decisions, i.e., he "knows" when he puts his pencil to paper whether he is going to modify the form, or change it completely. To the observer the change appears to be incremental, but in leveling and sharpening the artist makes a change which he thinks will preserve the continuity of the form. The second tendency is clarity, that is, the artist tends to work strongly toward clarifying the form. This tendency toward Prägnanz (pregnancy) is what leads the artists and creates the discomfort that causes him to want to work on. Finally, there is the tendency to drive toward some long-range goal, and changes are compared with its long-term direction or relevance.

The leveling and sharpening operates principally as a clarifying agent which leads the artist as a problem-solver toward stronger forms. As a result, its stimulus to short-term motivation is probably great. In contrast, reorganization seems to operate primarily as an agent of long-term direction. It acts to direct the incremental activity toward the long-term goal, starting the problem-solver over again in a new "location."

SECTION 4.5: SKILL, RULE, AND KNOWLEDGE IN THE INDUSTRIAL FIELD

4.5.1. Rasmussen´s Model of Goal-Directed Behaviors in Industrial Field

Jens Rasmussen (1983) introduces three types of goal-directed behavior in industrial fields in his paper "Skill, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models".

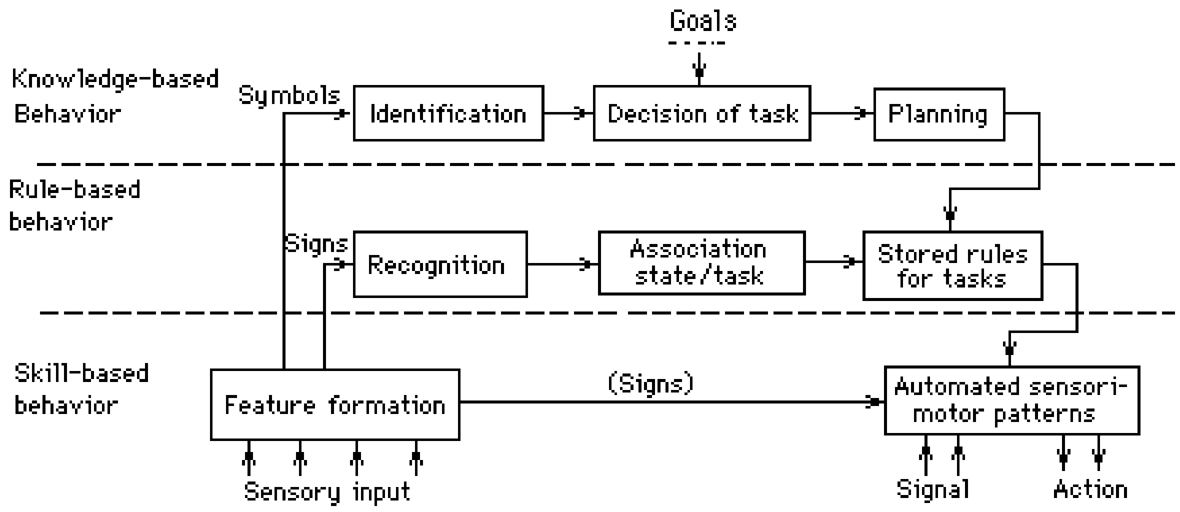


Figure 4.5-1: Simplified illustration of three levels of performance of skilled human operators (After Rasmussen).

Rasmussen claims that in a familiar situation human action will not be goal-controlled; rather oriented toward the goal and controlled by a set of rules which have been previously proven. In unfamiliar situations, human action may be goal-controlled by feedback control calling for accurate and slow time-space coordination. In more complex and rapid sequences, the sensory equipment is too slow for direct feedback correction, and adaption is based on means for selection and regeneration of successful patterns of behavior for use in subsequent situations, i.e., on an internal dynamic world model. Typically, the attempts to reach the goal are not performed in reality, but internally as a problem-solving exercise. The successful sequence is selected from experiments with an internal representation and behavior of the environment. Basically, meaningful interaction with an environment depends upon the existence of a set of invariable constraints in the relationships among events in the environment as well as between human actions and their effects. For Rasmussen, human goal-directed action must be based on an internal representation of these constraints. According to different manners of representing the constraints in the behavior of a deterministic environment or system, Rasmussen introduces three levels of performance emerge (see Figure 4.5-1). This model plays an important role in engineering design and artificial intelligence.

4.5.2. Skill-Based Behavior (SBB)

Rasmussen defines the skill-based behavior as smooth and automated sensorimotor performance without conscious attention or control during actions and as highly integrated patterns of behavior. Skill-based behavior is nearly effortless. Only occasionally is skilled-based performance based on simple feedback control, when motor output is a response to the observation of an error representing the discrepancy between the actual state and the intended state, and when the control signal is derived at a specific point in time. In real life this model is used only for slow, very accurate movements, such as assembly tasks or drawing. Rasmussen claims that sensory input is probably not used to control movements directly but to update and align dynamic internal map of the environment. Because the total performance is smooth and integrated, sensory input is not selected for controlling movement directly, but only directed towards the aspects of the environment needed subconsciously to update and orient the internal map. The performer "looks" rather than "sees." For example, bicycle riding, the higher level control may take the form of conscious intention to "modulate" the skill in general terms, such as "Be careful now, the road is slippery." In general, human activities can be considered as a sequence of such skilled activities with actual occasion. The flexibility of skilled performance is due to the ability to compose the sets suited for specific purposes from the large automated subroutines. According to Proctor (Proctor and Dutta, 1995, p. 17), the dynamic nature of work and other task environments guarantees that not many skills will be completely automatized. New skills must be acquired and often must be integrated with existing skills. Novel situations may be encountered, so that automatic responses are no longer appropriate.

4.5.3. Rule-Based Behavior (RBB)

At the next level, Rasmussen calls it the rule-based behavior. Behavior in a familiar situation is controlled by a stored rule or procedure. The rules are derived empirically during previous occasions, from other person´s know-how as instructions, or it may be prepared on occasion by conscious problem-solving and planning. The key point here is that performance is structured by "feeding control" through a stored rule. The control is goal-directed in the sense that the rule or control is selected from previous successful experiences. In real life, the goal of rule-based behavior will only be reached after long sequence of acts, and direct feedback correction. Feedback correction during performance will require functional understanding and analysis of the current response of the environment, which may be considered an independent concurrent activity at the next higher level (knowledge-based). Rasmussen claims that the difference between SBB and RBB performance is not quite distinct, and much depends on the level of training and the attention of the person. The SB performance rolls along without the person´s conscious attention, and the person will be unable to describe how he or she controls and what information the performance is based on. The higher level rule based coordination is generally based on explicit know-how, and the rules used can be reported by the person. The goal oriented RBB aims mainly at procedural oriented tasks of supervisory control behavior, including monitoring, interpreting, planning, fault management and intervention.

4.5.4. Knowledge-Based behavior (KBB)

Rasmussen claims that under unfamiliar situations, no know-how or rules for control are available, the control of performance must move to a higher level, where performance is called knowledge-based behavior. In this case, the goal is explicitly formulated, based on an analysis of the environment and the overall goals of the person. Various plans are considered, and their effects are tested against the goal, physically by trial-and-error, or conceptually by means of understanding the functional properties of the environment and prediction of the effects of the plan. Then a useful plan is developed and selected. At this level of functional reasoning, the internal structure of the system is explicitly represented by a "mental model" which may take several different forms. KBB is conscious, analytic, limited in speed, and mainly deals with apparent problems in decision making. The term KBB could be understood as discovery behavior or problem-solving behavior. Fault management and planning lead to the goal of KBB. It requires not only knowledge of the tasks, but also creativity and intelligence of the operator. The knowledge-based behavior in a new development is based on Fuzzy Set theory. This allows one to represent the operator´s knowledge in a way which is readily compatible with the linguistic forms used by operators when describing how they perform tasks; for example, the model of navigator´s behavior.

4.5.5. Three Types of Information

Further, Rasmussen asserts that three types of information which relate to the three types of behaviors respectively. For the control of perceptual-motor system at the SB level the sensed information is perceived as signals. Rasmussen defines signals as sensory data representing time-space variables from a dynamic spatial configuration in the environment, which can be processed by the organism as continuous variables. These signals have no "meaning" except as direct physical time-space data for direct perception. Rasmussen claims that at the RB level, the information is typically perceived as signs. Signs indicate a state and certain features in the environment, and relate to certain conventions for acts. Signs cannot be processed directly, they serve to activate stored patterns of behavior. Signs refer to situations or proper action by convention or prior experience. They do not refer to concepts or represent functional properties of the environment. Signs are generally labeled by names of states or situations in the environment, or person´s goals and tasks. Signs can only be used to select or modify the rules controlling the sequencing of skilled subroutines. They can not be used for functional reasoning, to generate new rules, or to predict the response of an environment to unfamiliar disturbances. Rasmussen asserts that, to be useful for causal functional reasoning in predicting or explaining unfamiliar behavior of the environment, information must be perceived as symbols. Symbols are abstract constructs related to and defined by a formal structure of relations and processes — which by conventions can be related to features of the external world. While signs refer to percepts and rules for action, symbols refer to concepts tied to functional properties and can be used for reasoning and computation by means of a suitable representation of such properties. Signs are part of the physical world of being, and have external reference to states of and actions upon the environment, but symbols are part of the human world of meaning, and defined by and refer to the internal conceptual representation which is basis for reasoning and planning. Rasmussen asserts that the distinction between the perception of information as signals-signs-symbols is generally dependent upon the goal intentions and expectations of the perceiver, not upon the form in which the information is presented.

4.5.6. The Failure Modes of SBB, RBB, and KBB (Reason, 1990, p. 57 - p. 96)

4.5.6.1. Error types: slips, lapses and mistakes

Reason (1990) distinguishes two categories of error. (1) At the SBB level slips and lapses are caused by execution failures or storage failures from the unintended activation of largely automatic procedural routines, and associated primarily with inappropriate attentional monitoring such as wrong selection. (2) Mistakes occur at the level of intention formation, and are likely to be more complex than slips and lapses. Mistakes arise from failures of the high-order cognitive processes involved in judging the available information, setting objectives and deciding upon the means to achieve them, the action does not run as planned, or the action plan is inadequate to achieve its desired outcome. He distinguishes between RBB mistakes and KBB mistakes. Performance at both the SB and RB levels is characterized by feed-forward control of stored knowledge structures (motor programs, schemata, rules). Control mode at the KBB level is primarily through feedback: to modify action to minimize the discrepancy between the current position and the desired state. It is error-driven.

4.5.6.2. Failure modes at the SBB level

Reason asserts that a necessary condition for a slip is the presence of attentional "capture" associated with either distraction or preoccupation, and the limited attentional resource is not focused on the routine task in hand. The failure modes at the SBB level are grouped by Reason into two. (1) Inattention toward a number of possible states, omitting to perform the necessary attentional monitoring at critical nodes, particularly when the current intention is to deviate from common practice; for example, double-capture slips, omission following interruptions, reduced intentionality, perceptual confusions, and interference errors. (2) Overattention, when making an attentional check at an inappropriate moment. Errors are mostly attributed to monitoring failures. Failure to bring the conscious workspace "into the loop" at these critical points generally causes actions to run by default along the most frequently traveled route when the current intention is otherwise. Slips and lapses also arise from overattention: when a high-level inquiry is made as to the progress of an ongoing action sequence, and the current position is assessed as either being further along or not as far as it actually is.

4.5.6.3. Mistakes at the RBB level

Reason claims that mistakes at the RBB and KBB levels are associated with problem-solving. RBB mistakes are divided into two categories: (1) those associated with the misapplication of good rules (i.e., rules of proven worth). Strong-but-wrong rules are applied because the rule was reliable in the past, but does not fit now, it is exceptions to general rules; countersigns (that indicate that the more general rule is inapplicable) may be missed in a mass of incoming information or explained away, more general rules will be stronger than more specific ones. (2) Those due to the application of bad rules. Bad rules can arise from encoding difficulties or from deficiencies in the action component such as wrong rules, inelegant or clumsy rules and inadvisable rules.

4.5.6.4. Mistakes at the KBB level

According to Reason, KBB mistakes have their roots in two aspects of human cognition: bounded rationality and the fact that knowledge relevant to the problem space is nearly always incomplete and often inaccurate; such as selecting the wrong features of the problem space, insensitive to the absence of relevant elements, confirmation bias, overconfidence, biased reviewing of plan construction, illusory correlation, halo effects, and problems with causality, with complexity and with diagnosis in everyday life.

4.5.7. Models of Human Performance in Man-Machine Systems

Stassen et al (1988) introduce models of fussy action control. Models based on fuzzy set theory can represent the operator´s knowledge. Information from the environmental data is sent to fuzzy decision making to generate the desired goal. The fuzzy prediction estimates the future dynamic state of the system. All the data are transferred to fuzzy control of the system. On the other hand, modeling operator´s creativity and intelligence can borrow technology of artificial intelligence (AI) and expert system. AI may change the future of the human supervisory tasks.

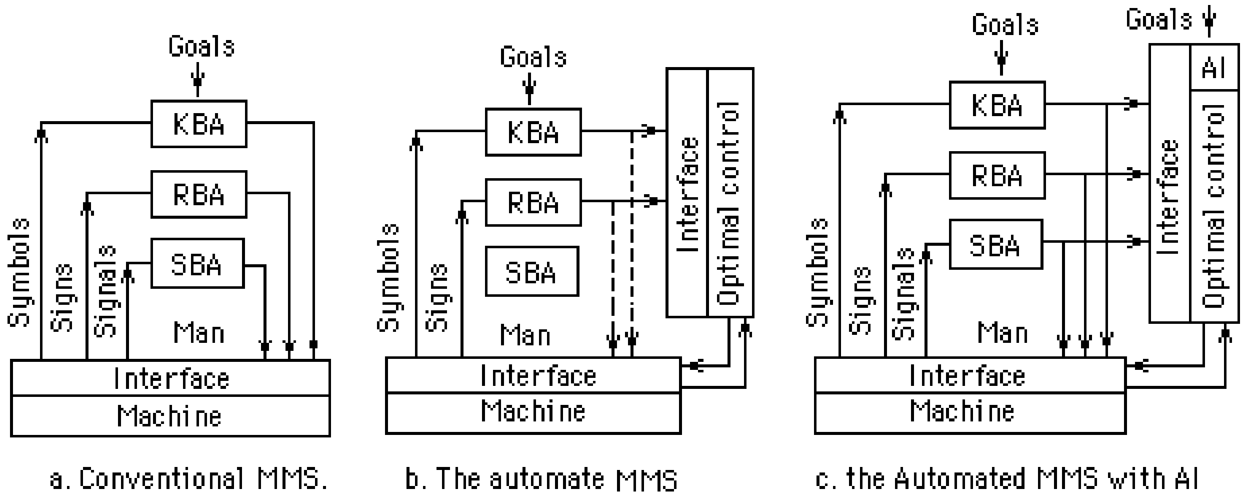


Figure 4.5-2: Models of goal-directed activity in MMS (After Winter).

Winter (Stassen et al,1988) demonstrated the development of man-machine system as shown in Figure 4.5-2. The operator is a direct controller in traditional man-machine system in Figure 4.5-2a and Figure 4.5-2b. This operator acts as a supervisor in the automated man-machine system. In Figure 4.5-2c, artificial intelligence (AI) devices are added in order to take over decision-making processes of the supervisor in automated plant because the AI development will promote the automation of man-machine system and its interface in the future.

SECTION 4.6: CULTURAL AND SOCIAL FACTORS OF INDUSTRIAL DESIGN

4.6.1. Culture

The cultural and social factors that influence human action to artifacts are very complicated, and should be studied as a specific project. My goal here is to attempt to find the way to analyze cultural and social factors that influence design of artifacts. However, this goal is still too big. What I can do here is to outline my basic consideration. What I emphasize is the cultural differences, not the similarities, of ways of action and artifact.

There are various definitions of culture because of different goals. On my goal, culture is the concerns which keep a society surviving, being stable and developing. These concerns are mainly reflected through ways of actions of this society. Huntington (Cécora, 1994) enumerates eight cultures, including Western (Western and Central Europe and North America), Slavic Orthodox, Confucian, Japanese, Islamic (Arabic, Turkish and Malayan), Hindu, Latin America, and possibly African cultures. In his view, their interactions will probably determine the future of mankind. For my purpose, the wisdom of life (philosophy), ways of action and life, and their relations to the tools people use in various cultural contexts are major issues for usability design of artifacts:

- Culture offers desires, beliefs, ideas, directions, values, norms for human actions and artifacts which are first represented in philosophy. Philosophy implies "the wisdom of life" in Greek words. This wisdom determines the reason of thinking, the reason of action. The wisdom may be expressed in various symbols (Parson, et al, 1962, p. 21), including cognitive symbols (beliefs and ideas), expressive symbols of feelings (appreciations: admirable, beautiful or ugly), evaluative symbols (justice, power or achievement: valuable, rational, good or bad).
- Ways of action, ways of expression, ways of life, and ways of work are reflected in values, norms, responsibilities, obligations. I distinguish theoretically among rational action, no-action, instinct action, and post-modern action.
- The tools reflect social beliefs, values and the way of human actions, and are produced by the technological system to cope with the environment. (These tools are defined as "artifacts" in the most part of the book as the objects of industrial design. In the wide sense, artifacts comprise all the things which are man-made.)

Philosophy, way of action and tools are mainly represented in the society, social structures, social networks, custom and tradition, and admirable patterns of action.

4.6.2. The Philosophy of Life and Action

4.6.2.1. The rational action (reason)

Since Kant, reason (Vernunft) is the concept for human ability to account mutually for all principles, evidences and constructions which precede and condition all communication, understanding, sensory perception (the theoretical reason), and all orientations of action (the practical reason). For Kant, the validity of action imagination must all be based on the Leistung (achievement) of reason itself alone if the reason can not be based on a traditional way of imagination and beliefs (Meyers Neues Lexikon, vol. 8, p. 321, 1981). Reason has become the philosophical idea and expectation towards action of folks in industrialized countries. People emphasize to "think over" rather than a spontaneous and instinct behavior. This philosophical foundation creates the concept of autonomy. Autonomous action emphasizes independent and active thinking and action, and self-responsibility. For autonomous action, abilities and intelligence are admired by the society. Belief in science and technology ensures developments in economic and social progress. People emphasize "do-it-yourself," and manufacture all the artifacts that relate to any independent, efficient actions. Such ideology has become the tradition in industrialized countries, and are reflected in everyday life. Girl students in the Department of Art buy a machine at home and manufacture ornaments and jewels. Women repair bicycles by themselves. Skills of home decoration, skills of woodworking and mechanical skills have become the tradition and habits for everyday life. People are often proud of decoration made by themselves at home. All these abilities and skills are related to working with tools. Various mechanical tools have become part of necessities of everyday life. In such industrialized societies, it is not strange that the function and quality of tools are naturally emphasized as evaluative standards. Simon evaluate rationality in the following way:

1. Rationality requires a complete knowledge and anticipation of the consequences that will follow on each choice. In fact, knowledge of consequences is always fragmentary.
2. Since these consequences lie in the future, imagination must supply the lack of experienced feeling in attaching value to them. But values can be only imperfectly anticipated.

3. Rationality requires a choice among all possible alternative behaviors. In actual behavior, only a very few of all these possible alternatives ever come to mind. (Simon, 1976, pp. 79ff).

4.6.2.2. No-action

Taoism claims that the wisdom of life should lie in the unity of the universe. "No action is an action." It stresses spiritual freedom, naturalness and simplicity. The ideal action should be tranquil and in this natural way. In this tradition, people act in the way of supporting all things in their natural state, and do not compete with them. People need necessary things for everyday life, but do not need so many tools and extravagant things. This transcendental ideal is typically reflected in Chinese traditional art. Of course, in current reality, one can seldom see the pure Taoism in common people. This tradition also builds the basic beliefs and evaluative standards to artifacts, such as simplicity, harmony, fineness and exquisiteness.

4.6.2.3. Post-Modernism

Post-modern cultural values emphasize spontaneity, self-expression, and immaterial goals. Change in the industrialized world is far harder to grasp, harder to conceptualize. One tends to use familiar images because we have no model of the future. Post-modernism represents the change of values and attitudes. How can we view the values and attitudes? Cécora (1994) claims that (1) religious tradition and ideology play an important role in value orientation; (2) one of the principles of immaterial community support is the elimination of cognitive dissonance. Differentiated values can be classified according to Hollander into theoretical values (the pursuit of truth), practical values (emphasis of utility and economic efficiency), esthetic values (emphasis of form, harmony and symmetry), social values (humanistic orientation, etc.), power values (seeking political and economic power and influence), and religious values (transcendent orientation). Franz and Herbert claim four types of differentiated value systems: conservatives, the resigned (passive, weak value profiles), realists, and idealists. The central issues of values and attitudes lie in what is understood as happiness, well-being and satisfaction. (Cécora,1994)

Veenhoven (1988) defines happiness (life-satisfaction) as "the degree to which people judge the overall quality of their life as a whole favorably." It emphasizes:

- sharper social awareness and perception,
- increased active social and political involvement and participation,
- improved quality of social contacts,
- positive effects on health,
- (in a positive sense) less discontentment with the status quo.

Satisfaction is related to perceived human needs. For Chamberlain (Cécora, 1994), "satisfaction" is based on cognitive evaluation of life in general, and "happiness" is an emotional factor, and strongly oriented to sentiments of short duration of everyday experience. "Satisfaction" is a product of the perceived discrepancy between aspiration and achievement. The term subjective well-being (SWB) is used more than objective well-being as information on contextual opportunities and constraints for explaining human behavior, and SWB can not be used as a reliable tool for policy-making, knowledge of values and attitudes. Cécora (1994, p. 22) claims the following factors influence SWB:

- the perceived comparative social status of the respondent relative to his/her peer groups,
- readily available information affecting judgment of opportunities and of the respondent´s own relative status,
- expectations based on the individual´s estimation of his own entitlements/merits,
- aspirations based on the past "peak experiences " (the best and the worst); the best one raising expectations or aspirations and diminishing pleasure derived from lesser positive experiences,
- respondents´ needs vary as a function of the individual´s attained level-of-satisfaction,
- in particular, the recency of events/changes in the factors above.

Cécora claims that satisfaction is greatest if there is no discrepancy between what one has and

- what one wants,
- what other (peers) have,
- what one has had in the past,
- what one needs,
- what one observes,
- what seems possible in the future.

Cécora (p.24) points out that human action is a function of social structure, and that frequency of interaction, common interests, and proximity of social actors are important contextual features affecting values and attitudes. Postmaterialist values are presented such as personal ideals and social goals, like education, self-fulfillment, leisure and democracy, and are oriented to community of belongingness, self-expression, and quality of life such as private-orientation (Italian and Russian), public-orientation (American and English), and intermediate between these two (German and French).

4.6.3. Ways of Action

The effect of culture on human action can be analyzed from two aspects: (1) Social norms, standards, obligations, responsibilities as tradition and custom influence the ways of perception, cognition, emotion, volition, and the way of physical performance. (2) The expectation and constraints towards action which are determined by social structures. The second aspect can also be analyzed as norms, standards and so on in a certain social structure.

4.6.3.1. Perception

Because of the differences of cultural traditions, perceptual desire, anticipation and perceived meaning may be different. Figure 4.6-1 illustrates the Arabic traditional windows. One inside the room can see outside through the window, but one outside the room is not able to see inside through the window. This way realizes human perceptual desires which are determined by cultural tradition. Figure 4.6-2 is the sign "TU" for Technical University of Braunschweig, Germany, which is designed in 1995. This sign is abbreviation of T(echnical) U (niversity). However, every Chinese has recognized it as a Chinese word "Yuan," which means "first", "primary", or "Yuan Dynasty" (in 1271-1368) of the Chinese history.

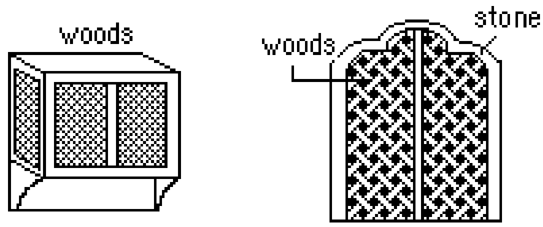


Figure 4.6-1: Arabic traditional windows.

Figure 4.6-2: The sign of Technical University of Braunschweig, Germany.

4.6.3.2. Cognition

Because of cultural differences, cognition may be very different in the following aspects. (1) Emphasis on different cognitive desires: orientations of values (technology orientation, human relation orientation or naturalness orientation) may lead to the different directions of thinking. Orientation towards science and technology appears to emphasize technical innovation and utility of tools, and production, transportation and communication. (2) Logic and inference of deduction and induction are emphasized in industrialized societies. The traditional way of thinking in China is called "Wu." It is only represented as assertions and conclusions. It is neither deduction nor induction, maybe includes both, throw out distracting thoughts and preoccupation (prejudice and logic), concentrate on the natural coupling and consensus, make human perception and cognition dissolved into the environment or object, create the connection between the self and the objective reality, and feel in such way that the object behaves. (3) Cognitive standards (beliefs and ideas), expressive standards (happiness, like and dislike), evaluative standards (quality or simplicity), appreciative standards (esthetics) and moral standards (justice, or power, or achievement) may be different. (4)

Different signs: languages, icons and symbols may be different. (5) Emphasis on different cognitive tendencies: towards understanding and explanation, or pragmatics orientation.

4.6.3.3. Motor behavior

In various cultures, there may exist different understandings of "natural" and "unnatural" motor behavior and the meaning of hand and shoulder gestures. Because of different orientation of values, people have different needs for motor skills, the strength of force, speed, rhythm and the motor pattern may be different. For example, chopsticks or knife and spoon lead to different hand motor skills. German bicycles employ the foot brake.

4.6.3.4. Admirable action pattern

Admirable action patterns in different cultural traditions are different. In traditional Japanese culture, the spirit of the soldier was admirable, and swords were the symbol of the admirable action pattern. In traditional Chinese culture, the four treasures of the study (writing brush, ink stick, ink slab and paper) were the symbol of the admirable action pattern.

4.6.3.5. Ability

Desired abilities in various cultures appear to be different because of the values, desires and traditions. For different needs of technologies, there exist mainly three types of ability orientation: emphasis on bodily physical abilities, on utility of mechanical tools, or on mental abilities. One can classify the abilities in the social sense: either emphasis on social abilities or emphasis on individual abilities of living. For the different desired abilities, people need different artifacts.

4.6.4. Social Factors Affecting Human Actions and Artifacts

4.6.4.1. Social factors of design

Social system is another factor that must be considered by designers. A society is a relation system which connects individuals with each other in regular ways. Any social system is made up of mutually overlapping social structures or institutions. Each structure or institution is constituted by a number of complementary social positions. Smelser (1973, p. 4) defines social structure as identifiable patterns of roles that are organized primarily around the fulfillment of some social function and activity. Social structures are ways of operating, and are mechanisms for organizing production, consumption, and survival in ways consistent with, or generative of, prevailing ideologies. The structure is the composition, arrangement and balance of components or units. Social structure consists of the parts of social life and the manner in which they are arranged (Cave & Chesler, 1974). The set of behaviors which ego is expected to perform by virtue of his or her position is called a social role. A role is thus a series of appropriate and expected ways of behaving relative to certain objects, called role expectations (Tolman, 1962, p. 349). Social action is the multiple and complex interaction. According to Parsons, et al (1962, p. 221), all social systems have the following structure:

- Certain relatively general patterns of categorization of their units, and of both individual actors and collectivity;
- Pattern of role orientation;
- The types of the division of labor;
- The system of social stratification, which is the reward system integrated about the allocation of prestige and produces extremely far-reaching functional consequences;
- The specifically integrative structures of collectivity, which include the modes of organization, regulation of the power system and ways in orientation to a paramount focus of values. It is here that differentiated role with integrative functions on behalf of the social system as a whole will be found.

In addition, communication structures — the way in which information (including attitudes and opinions) is transmitted — are a key to understand human social behavior (Cécora, 1994, p. 53).

Cécora (1994, p. 54ff) claims that social networks — being significantly in direct contact with many others — is an instrument in study of human relationships. Networks consist of members and links between them. For Cécora (p. 57), a feature of social relationships in modern industrialized society might be that individuals mostly prefer balance in interaction / exchange (balanced exchange imply higher degree of autonomy and less obligation), and often subconsciously suppress perception of information about unbalance. The links may be differentiated as contents of relationships (sentimental bonds, norms for role behaviors, obligations, beliefs of members, exchange and communication processes), intimacy of relationships, directedness of relation, frequency of interaction, intensity of relationships, role multiplicity of relationships, and durability of relationships. The structure of networks are differentiated as number of links per member, overall density of links, dispersion of members, homogeneity of members, anchorage, dominant source of relationship, distance of paths, network range. Such approach can be applied in analysis of family life and household. Michalos (Cécora, 1994, p. 180) claims that it is important for all members of society to access easily the place of work, public and commercial facilities, to have good relations with neighbors, and good environmental conditions.

4.6.4.2. Social relationships between humans and artifacts

Using artifacts is a social behavior, and appears to create relationships between users and artifacts, or between individual and society through artifacts.

Blumenthal (1995, p.1) claims that social relationships are an integral part of the motivation for using artifact, and of human-artifact interaction itself. He asserts that social relationships determine the way in which humans perceive, assess, use and learn an artifact. Social relationships and social structures are prerequisite for using artifacts. On the other side, artifacts influence also change of social relationships and structures.

- Blumenthal (1995, p.13) asserts that human-artifact interaction is a process of forming a social relationship, and learning to use a computer-based artifact may form social relationships with computer-based artifacts. Driving a car is not only a skill, but is to create a kind of relationship with the car and with the society or a type of activity in the society. In some countries, a car is a necessity of everyday life, and people may be isolated partly from the society if they have no cars, cannot go to work and cannot go shopping. In some countries, cars are the symbol of the social status. This way, using artifacts emphasizes not only usability of the artifact, but also the individual association, independence or connection with the artifact and with the society.
- The bus means the fundamental vehicle for most members in some societies, but means the circle of pupils and the old people in some other societies. Artifacts mediate the norms, the circles and the ways of action between individuals and the the society. This way, social relationships are an integral part of human-artifact interaction itself (Blumenthal, 1995, p.1).
- Driving a car in Germany is different from that in other countries. Not only the traffic regulations, but also the way of behavior, the custom of driving and parking are not the same. Driving a car, or using artifacts means to interpret and select the artifacts and the way of action in such social environment, and accept the social relationships, rules,conditions and constraints which relate to the interaction with the artifacts.
- With the mobile telephone, the structure of human activities or tasks are changed. Artifacts may change the way that humans think about their tasks, the organization of tasks and the social relationships.
- These social factors must be accounted in design process. The question for designers is whether the artifacts designed can satisfy these social needs or not.

4.6.4.3. The types of social action

Social interaction is often opportunistic, multi-action, and with various relationships. For most individual actions of everyday, people do not need plan in the familiar surroundings. Often, an action is interrupted by another (when I go to the bank, I meet a friend of mine and talk with him), or, several actions are interlocked together (I search information in the internet, and write a mail at the same time), or, change of sequence and plan is flexible because the situation requires.

Social structure, role expectation, social network of relationships, and social context affect human action. The affect is mainly reflected as social desires and constraints to the way of life, to the way of work, to the condition of living and working, and to the norms of social behaviors. I illustrate three types of social action as examples of showing how to define social system for human action to artifacts for design process.

- Way of work: For Gaines (1988), the central core of an organization is value system, the management structure (formal culture) and operation (technical culture) and inter-personal communication and behavior (informal culture). A working organization may consist of the goals, work conditions, ordering and work distribution, work plan and coordination, communication, and work management (control and supervision, reporting and problem-solving). These factors and structures determine the characteristics of way of work.
- Way of behavior in the public surroundings, such as in the street, the bank, the railway station, the bus station, the public telephone, etc. Such behavior is mainly independent and rule-oriented behavior. Such public ways of behavior pose the problem of specific needs which are called the public users. For the public users no training is possible. Various ways of behavior may occur.

- Way of life is defined by Rutkevich and Glezerman et al "as the system of activities characteristic of people living under certain life conditions" (Takala, 1984, p. 44ff). For Takala, way of life is related to material and non-material conditions, social relations, needs and activities of men. The scope of way of life comprises (1) realistic pattern of family activity (including daily routines and important issues); (2) hierarchy of activities; (3) the parents´ awareness of parenthood (including their goals, expectations, rules and procedures); (4) relationships among life conditions, family activity, and parental goals (Takala, 1984, p. 45); (5) habits. Takala emphasizes that activity structure is revealed by the use of time, and that work condition of parents relates to family interaction.

Furthermore, institutional life (schooling), life in apartment groups, single life, etc. can also be accounted as types of social action. The real meaning of the types of social action is to find the environmental conditions and factors of using artifacts.

4.6.5. Design in Real Life: Influences of Social Factors on Design

For Blumenthal (1995, p. 6), the design of an artifact is the design of social interaction between the user and his/her environment and between the user and the artifact. On Vygotsky (1981), the role that artifacts play in mediating activity is the result of social interaction. Blumenthal (p. 6) asserts that the relationships that users form with artifacts when they learn to use them go far beyond the notions of skill acquisition, that is, designers force users to think like their designs, and to accept the organizational structures underlying their designs as an integral part of the users´ psychological make-up. Social relationships and their boundary conditions are critical for design. Designers are used to viewing the designed artifact and the user as a system. It is partly wrong because this way has separated humans from the real life. Cultural and social factors must be accounted. Imagine: How many artifacts an individual has to use everyday? How many keys do you take in your pocket? How many numbers must you remember in your brain? How many stuffs do you take for your work? How many name cards are there in your wallet? How many addresses must you remember? How many things must you do after work at home? How can you find your way in a foreign country? Then, can you tell what else you need? Maybe, you have had most artifacts you need, but you need time, you need communication with your family, you need leisure. That is, you need "no action." In such a sense, a good designer is to give time and action space to humans by designing artifacts, i.e., time saving, or space saving. Designers can find human needs only in the real life as a whole.

SECTION 4.7: SCHEMA THEORY VERSUS CONNECTIONISM

4.7.1. Schema Theory

It seems plausible that knowledge is represented by sentence-like propositions. Its fundamental idea is that cognition involves the manipulation of symbols, and symbols can be stored in and retrieved from memory, and these symbols can be transformed by using rules. The rules which specify how symbols can be constructed are called syntax. Logic systems, such as propositional logic, deductive and inductive logic, consist of procedures for manipulating symbols. For example, Newell and Simon offer a way to construct the semantics of computational systems: a computer is a physical symbol system consisting of symbols, expressions and processes which operate on expressions. They claim that the internal semantics is the major advance over formal symbol systems, called the symbolic paradigm. For understanding cognition, symbolic paradigm has played an important role in 1960s and 1970s. Schema theory is from the symbolic tradition. In the article "A framework for representing knowledge", Minsky wrote on the computer modeling of pattern recognition in the field of computer vision. In "Notes on a schema for stories", Rumelhart in 1975 wrote on the interpretation of stories. Schmidt (1975) wrote "A schema theory of discrete motor skill learning". By the end of 1970, the symbolic approach has become the core of cognitive science. (Reason, 1990)

Bartlett (Reason, 1990) defines a schema as "an active organization of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response. That is, whenever there is any order or regularity of behavior, a particular response is possible only because it is related to other similar responses which have been serially organized, yet which operate, not simply as individual members coming one after another, but as a unitary mass." Bartlett suggested that schemata were unconscious mental structures, they composed of old knowledge or experiences, and long-term memory comprised active knowledge structure rather than passive images. Rumelhart defined schemata as "data structures for representing generic concept stored in memory" (Reason, 1990). Schemata have hierarchical feature. Higher-level schemata have lower-level ones as subparts. Variants of the schema notion include frame-slot by Minsky in 1975, scripts by Abelson in 1976, plans by Neisser in 1976, prototypes by Cantor and Mischel in 1977, and personae by Nisbett and Ross in 1980. (Reason, 1990)

Schemata were viewed as higher-order generic cognitive structures that underlie all aspects of human knowledge and skills, such as words, images, feelings and actions. Their encoding and representational functions include lending structure to perceptual experience and determining what information will be encoded into or retrieved from memory. Their inferential and interpretative functions allow us to supply missing data within sensory or recalled information. The schematic control mode can process familiar information rapidly, in parallel and without conscious effort. However, Fitting the data to the wrong schema can cause systematic errors. (Reason, 1990, p. 35 - p. 36)

The symbolic theories have several roots. (1) Philosophical roots in knowledge: There exist mainly two categories of knowledge: Empiricism and rationalism. In empiricism, knowledge must be obtained by and strongly rely on sensory experience. Rationalism claims that reasoning by using ideas is critical based on sensory experience. All knowledge is represented by symbols. (2) Philosophical roots in logic: using logic systems comprises procedures for manipulating symbols. There exist deductive logic and inductive logic. Deductive logic can be employed to evaluate whether a proposition is true or false, and to prove the relations between premises and any propositions are true or false. Inductive logic is to build formal rules. By using the logic, humans obtain knowledge. All these must employ symbols and rules. Thinking can be represented by logical manipulation of symbols. (3) Linguistic theory: Human cognition can be viewed as symbolic manipulation by using language, called information processing. Human knowledge can be represented by using language-style rules. (Bechtel and Abrahamsen, 1991, p. 12-13, p. 66-69).

Anderson (1983, p. 37) criticizes schema theory. "One serious question about schema theories is how one gets any action from them." Schema theory "blurs the procedural-declarative distinction and leaves unexplained all the contrasts between procedural and declarative knowledge" (p. 38-39). "Schemata are more declarative in character" (p. 39). "A second major problem with schemata. . . is that the units of knowledge tend to be too large, thus forcing the system into modes of behavior that are too limited." (p. 39). Another problem is that "the size of schemata also makes it difficult to construct effective theories about their acquisition. Technically, it is difficult to construct learning mechanisms that can deal with the full range of schema complexity. Empirically, it is transparent that learning is gradual and does not proceed in schema-sized jumps" (p. 39). Bechtel and Abrahamsen (1991, p. 17) claim that "Rule systems, as they became more adequate, also became more complex, diverse, and ad hoc. The desire for parsimony, which earlier had characterized behaviorism. . . a number of investigators began to confront the limitations of symbolic modes. While initially the task of writing rule systems capable of accounting for human behavior seemed were hampered by their 'brittleness,' inflexibility, difficulty, learning from experience, inadequate generalization, domain specificity, and inefficiencies due to serial search through large systems. Human cognition, which the rule systems were supposed to be modeling, seemed to be relatively free of such limitation." It "provides a poor medium for modeling learning or pattern recognition." (p. 261)

4.7.2. ACT* Theory

From 1968 on, Anderson was engaged in a issue of the categorical structure in free recall. From this work, he and Bower developed a complete model of the structure of human memory with computer simulation. The central structure was a propositional network representation. From the memory system, he came to a more general cognitive system and complex models of human cognition. From 1973 to 1976 he developed the ACT system (ACT stands for Adaptive Control of Thought) which was a synthesis of the memory system and a production system. A "production" is a rule. The production system was an interpreter of a propositional network. It was possible to "program" production sets that modeled various tasks, for example, mathematical problem solving. He spent the next four years making this ACT system address language acquisition. He reorganized the theory, "including changes in the spreading activation mechanisms, a theory of production pattern matching, augmentations to the architecture to handle goals, and additions to the production-learning mechanisms." (Anderson, 1983, preface p.ix). The new version is called ACT*. This "theory concerns higher-level cognition or thought" (p.ix). A central issue is the control of cognition — "what gives thought its direction, and what controls the transition from thought to thought." "A major concern for me has been to understand the principles behind the control of thought in a way that exposes the adaptive function these principles. Ultimately, understanding adaptive function brings us to issues of human evolution" (p.ix). His start point was "a belief in the unity of human cognition, that is, that all the higher cognitive processes, such as memory, language, problem solving, imagery, deduction, and induction, are different manifestations of the same underlying system." (p.1) ACT* is a general production system, and a unitary theory of mind. "All higher-level cognitive functions can be explained by one set of principles." "In ACT* the same core system if given one set of experiences develops a linguistic facility, if given another set of experiences develops a geometry facility, and if given another set of experiences develops a programming facility" (p.3). The basic idea of production system is that "underlying human cognition is a set of condition-action pairs called productions. The condition specifies some data patterns, and if elements matching these patterns are in working memory, then the production can apply. The action specifies what to do in that state. The basic action is to add new data elements to working memory."

Anderson introduces three representation types of knowledge: "a temporal string, which encodes the order of a set of items; a spatial image, which encodes spatial configuration; and an abstract proposition, which encodes meaning." (p. 45). In later years Anderson found "that nonpropositional representation could work well in a production system framework." "It was not its form or notation that was important. . . Rather, the important issue was what could or could not be done easily with a representation" (p. 45). The Production systems have the following characteristics:

- Production systems are made up of a large number of productions or rules in "IF . . . THEN" form.
- If information comes from the environment to working memory, and it matches the IF-part of the rule in long-term memory, the THEN-part will be triggered as a consequence and executed.
- If some information in working memory matches the IF-part of many rules, there may be other conflict-resolution rules which select one of these matches as being better than the others.

In 1993, Anderson, M. Matessa, and S. Douglass developed ACT-R theory to include a theory of visual attention and pattern recognition. Production rules can direct attention to primitive visual features in the visual array. When attention is focused on a region, features in that region can be synthesized into declarative chunks. This model is extended to complex problem-solving (equation solving). Anderson´s ACT* system has made explicit use of network in addition to rules, and is "nontraditional rule system" (Bechtel and Abrahamsen, 1991, p. 18).

4.7.3. Connectionism

"It has been argued that there are no rules in the brain, only a system of parallel interaction among connected neurons involving excitation and inhibition." "It is argued that the apparent rulelike quality of human behavior is an illusion, that humans do not truly possess rules any more than a bouncing ball possesses rules that guide its behavior"

(Anderson, 1983, p. 35). This point of view is proposed by connectionism. Connectionism represents a challenge to the symbolic theories. Connectionists encode knowledge without explicitly employing propositions, and does not construe cognition as involving symbol manipulation. Its basic idea is that there is a network of elementary units (neuron-like, nodes). These units are connected to each other. Each of them has some degree of activation. Active units excite or inhibit other units. This network, which is supplied with inputs, spreads excitations and inhibitions among its units until a stable state is achieved (in some types of network). This conception is inspired by the knowledge of nervous system (Bechtel and Abrahamsen, 1991, p. 23). Connectionism is concerned with ways of connecting neural elements together to process higher-level cognition. The connectionism focuses on causal processes by which units excite and inhibit each other and does not provide stored symbols and rules. Connectionist networks are dynamical systems which are described by mathematical equations. There are various models such as connectionist networks, neural networks, or parallel distributed processing (PDP) models (McClelland, Rumelhart, and Hinton, 1986; Quinlan, 1991). By the late 1970s, the development of computers offered possibilities of constructing multi-layered networks. Connectionist networks have some features (Eysenck and Keane, 1990):

- A network consists of elementary or neuron-like units or nodes, which are connected together so that a single unit has many links to other units.
- Units affect other units by exciting or inhibiting them.
- The units takes the weighted sum of all input links, and produce a single output to another unit if the weighted sum exceeds some threshold value.
- The network as a whole is characterized by the properties of the units which make it up, by the way they are connected together, and by the algorithms or rules used to change the strength of connections among units.
- Networks can have different structures or layers; they can have a layer of input units, intermediate layers (of so-called "hidden units"), and a layer of output units.
- A representation of a concept can be stored in a distributed manner by a pattern of activation throughout the network.
- The same network can store many different patterns in this way without them necessarily interfering with each other if they are sufficiently distinct.
- Mathematical equations determine an activation value for each unit as each point of time.
- One algorithm or rule used in network to permit learning to occur is known as backward propagation of errors (BackProp).

Many connectionist models have learning mechanisms for modifying the weights assigned to the connections between units, and different specific learning rules are used. "The model can be made to learn the behavior with which the cognitive scientist is concerned." (Eysenck and Keane, 1990, 22). For a connectionist system, learning does not imply to add or modify propositions, but to change connection weights between the units. There are two connectionist models of learning. (1) The Hebbian rule: Donald Hebb (Bechtel and Abrahamsen, 1991, p. 48) suggests that learning should mean to strengthen the connections between two neurons. The strength of the connection can be changed in proportion to the product of activations of the connected units. The Hebbian learning describes this function. (2) The delta rule: the discrepancy between the desired output pattern and an actual output pattern is utilized to improve its weights during the training phase. This is an error correction procedure and is regarded as a prototypical example of supervised learning (p. 72-74).

Holyoak and Thagard (Bechtel and Abrahamsen, 1991, 263) "suggest that it may be useful to employ connectionist designs in memory modules so as to be able to utilize content addressable memory, but to perform various computations upon the contents retrieved from memory in a symbolic manner."

SECTION 4.8: VIRTUAL REALITY

4.8.1. Natural Way of Action and Virtual Reality

For usability design, the central issue is how to get users immerse in their action. The term immersion implies that users are able to act on their goals and in their natural ways of action. Natural way of action refers to (1) natural information in natural language. (2) natural way of perception and attention, (3) natural way of cognition, (4) natural way of motor performance, (5) natural way of learning. The goal is natural interaction with computers. They are not willing to be distracted with tools and undesired information. For this purpose, people attempt to find ways of natural input, natural information, natural perception and cognition and natural interaction. These ideas lead to the emergence of virtual reality. The term virtual reality is widely used and it may mean different things. Pimentel and Teixeira (1993, p. 66) define virtual reality as "an immersive experience in which participants wear tracked, head-mounted displays, view stereoscopic images, listen to 3D sounds, and are free to explore and interact within a 3D world." In March, 1989, the first PC-based virtual-reality system was demonstrated by the Autodesk. VPL Research became the first company to focus on development of products of virtual reality.

4.8.2. Natural Visual Information: Head-Mounted Display (HMD)

A large portion of mental information processing is dedicated to processing visual input. Most of processing occurs without conscious effort in real life from shape, form, color and depth information. Many virtual environments are attempting to follow these innate capacities, to make visual immersion. The degree of visual immersion depends upon many factors, including interactivity, fast update rate, high image complexity, 3D sound, high resolution, stereoscopic, large field of view, eye tracking and head tracking (Pimentel and Teixeira, 1993, p. 106). Head-mounted displays (HMD) are attempting to satisfy these needs. HMD is a set of goggles or a helmet with tiny monitors in front of each eye that generate images. They are made of miniature CRTs, fiber-optic cables, or LCD. Depth information appears to be crucial. Friedhoff claims that several depth cues help eye establish the relationship of objects in a scene: Linear perspective, occlusion (Objects in foreground occlude, or obscure in the background), shadows, detail perspective (you see less and less detail with increasing distance), aerial perspective (haze washes out distant objects), and motion parallax. Other factors include texture, stereopsis (both eyes cooperate to identify depth). Several parameters control how images are displayed in a VR system (Pimentel and Teixeira, 1993, p. 118-119):

- Convergence: When separate left and right eye images fuse into a single image, convergence is achieved.
- Parallax: Parallax represents the distance between the left and right eyes of the viewer in the VR.
- View angle.
- Resolution: Most HMD use LCD displays with less than 400x300 pixel resolution.

4.8.3. Natural Sound and Speech Technique

Sound can be generated by various ways. The most popular method is to use the MIDI (musical instrument digital interface). Sounds are first digitally sampled from analog to digital form, then multiple outputs can be generated using a sequencer (Pimentel and Teixeira, p.120-121). VR uses 3D sound. Several factors control the ability of how sounds are received and processed by the brain (p.122):

- Interaural time difference: Human ear can distinguish difference of 70 microseconds with 1 inch resolution.
- Interaural amplitude difference (sound pressure, loudness).
- Frequency difference: Much of higher frequencies are impaired as sounds bend around the head because these sounds are more directional.
- Head-related transfer functions (HRTFs): Outer ear gathers sounds and also reinforces certain sounds in frequencies. HRTFs are a summed measure of the outer ear´s response to different frequencies of sound. HRTFs are the most complex to model. All these factors help locate the direction of a sound.

Speech technologies have aspects: discrete-word recognition, continuous-speech recognition, speech store and forward, and speech generation (speech synthesis). IBM In 1997 developed ViaVioce and ViaVoive Gold of continuous-speech recognition system, which are called the most important input devices after the keyboard and the mouse. With such devices, users can talk naturally to computers.

4.8.4. Natural Tactile Devices

VR systems simulate and generate tactile and force-feedback signals. Haptic or tactile output devices are devices which make users feel a felt-covered surface, cloth-covered surface, virtual sofa surface, or any virtual surface. Tactile feedback represents the pressure acting on human skin, and is realized by a two-glove system, one has force-sensitive resistors (FSRs) for measuring tactile force (e.g., Teletact I force-feedback glove of ARRC/Airmuscle Ltd, England), and the other has air pockets for displaying force. Force-feedback is the force acting on the muscles, joints and tendons. It make feeling of the weight of virtual objects or squeezing a virtual ball (a hard golf ball or a soft rubber ball) (p.125-126).

4.8.5. Natural Interaction Devices

Human action mainly can be discomposed into natural speaking, eye movements, hand-wrist movements, and body movements. The natural human movements can be represented as 6 degrees of freedom: movements are measured in spatial position (X, Y, Z) and rotations measured in roll (X axis), pitch (Y axis), and yaw (Z axis). Natural input devices to computers should be able to detect these natural human movements of spatial position and orientation. Detecting an object´s position and orientation is called tracking technology. Either electromechanical, ultrasonic, mechanical, inertial, or fiber-optic sensors are employed as natural interaction (input) devices. Wands are the simplest VR device. They are only a 6DOF sensor with several switches. It is easy to use them in public demonstrations of VR. Gloves (e.g., DataGlove of VPL Research Inc) that are wired with sensors can be connected to a computer system for gesture recognition. The fiber-optic loops measure the amount of bend or flex of a body joint, or of muscle tension. The 6 DOF position/orientation sensor keeps track of the the hand in the virtual space. Wired clothing (e.g., DataSuit of VPL Research Inc) is designed for measuring the bend angles of various body joints such as fingers, wrists and elbows. Users can communicate with computers through gestures of their hands. (p. 128-129). Force balls measure the amount of force applied to them. 6 DOF mice are employed for either ultrasonic, electromagnetic or gyroscopic tracking in the virtual world. Biological input sensors are called biosensors. Biosensors are a new technology of neural interface. They use dermal electrodes to detect particular muscle activities. They can detect and measure muscle electrical activity and brain electrical activity and recognize voice commands. Dermal electrodes contained in the eye glass frame can measure muscle electrical activity and track eye movements. Electrical signals have many measurable qualities such as intensity and spectral characteristics. Energy can also be measured from a multitude of motor units. Then these signals are interpreted by software to control electronic devices. There exist many types of devices for interaction such as Private Eye (by Reflection Technology), CrystalEyes LCD flicker glasses (by StereoGraphics), Teletact Commander force-feedback hand grip (by ARRC/Airmuscle Ltd.), CyberGlove (by Virtual Technologies), Flying Mouse (by SimGraphics), and so on.

The devices such as head-tracking, wands, and wired gloves can detect position and orientation of an object at any moment. This way, the computer can track these movements in real time and remains synchronized to one´s actions. Several parameters determine this effects (Pimentel and Teixeira, 1993, p. 136):

- Lag: lag is the delay between sensor movement and the resulting signals being processed for final use. If lags are above 50 milliseconds, it will affect human performance.
- Update rate: Update rate is the speed at which measurements are made. Most sensors support al least 60 updates per second.
- Accuracy: Accuracy in tracking effectiveness is the accuracy of position and orientation information. This varies with distance from the source, or drifts over time. Translational values vary from about 0.01 to 0.25 inch. Rotational values vary from 0.1 to 1.0 degree.
- Range: The range is the maximum distance between the source and sensor while retaining specific accuracy. It ranges from a three- to eight-foot cube surrounding the source to an entire room.
- Interference: Interference means sensitivity to environmental conditions such as the magnetic, electrical, optical, inertial or acoustic linkage, and radiation from display monitors. Problems can also occur if more than a single sensor is employed in close proximity.

4.8.6. VR System

A VR system consists of four components. (1) Effectors, such as head-mounted display, wired gloves, force ball, etc., allow users to experience flying, moving, grasping virtual objects in a virtual world. (2) Reality engine refers to the computer system (e.g., graphic board, sound source and 3D sound processor, I/O ports for glove input, position and orientation tracker) and external hardware (e.g., sound synthesizing equipment). (3) Application is software, for example, of car driving, of tennis playing, etc. (4) Geometry refers the representation of the physical attributes of objects such as shape, color, placement, etc. Currently virtual reality systems are made of a stereoscopic HMD, wired-glove sensors, and a computer to allow uses to manipulate the virtual environment.

4.8.7. Applications and Advantages of VR

Virtual environments not only offer the natural ways of action, but also create fantasies, and new possibilities in presenting information. Virtual reality systems have been applied in many fields. In sport, wearing Eyephones (by VPL), users can pedal the stationary bicycle which is connected with sensors through a virtual landscape. The users can also steer the handle bars in the virtual world. If pedaled fast enough, they would fly above the virtual horizon. Simulated airports and virtual sky can be used to train pilots. In education, virtual reality will play a more and more important role. Many scientific theories are based on ideal conditions which are seldom seen in the real world. Students understand them mainly on their logic reasoning and fantasies. With VR, students can perceive the molecular structure from any size, distance and color. Abstract ideas and processes for which there is no physical models can also be created in VR. ScienceSpace or NewtonWorld is realized where there exist no gravity and no frictional forces (Dede, Salzman and Loftin, 1996, p. 87-106). In surgical procedures, doctors use video cameras and fiber-optic cables to view patients´ body. VR have been applied in medicine, in business, in shopping and in many fields. VR has illustrated many advantages. (1) The goal of VR is to realize the fundamental relationships between humans and tools: Humans are active, tools are passive, and tools follow humans. This way, humans can act in their natural ways of action. (2) Users can immerse and concentrate on their own thinking and action, and they are not distracted with tools. (3) VR can illustrate the environments which do not exist but humans desire to see. (4) VR can illustrate human imagination and fantasy. (5) VR can display telepresence, another form of VR, such as robotic control of exploration work at NASA Ames.

SECTION 4.9: THE APPLICATIONS OF ACTION THEORY IN DESIGN

From the 1980´s, action theory is applied for usability design in many fields, including engineering, architecture, interface software, artificial intelligence, robot, automated sequential production systems, planning, etc. Their approaches introduce many new concepts, thoughts and methodologies for design. Since then, the fundamental design thoughts transcend the concept of "form follows function." The basic goal of industrial designers is to satisfy human values, needs, and intentions, to find demandability (desirability), feasibility and usability of design objects, and to realize artifacts join human as an entity. From this point of view, designers can find out more essential relationships between users and artifacts. Usability design relates not only to human-artifact interface, but also to the internal structure of artifacts. These approaches really have improved some defects in previous designs, and solved some problems in various design projects. I collect some examples, mainly of engineering and computer software, which may be useful for industrial designers.

Example 1: Tendencies conflict

Christoper Alexander and Barry Poyner (Alexander and Poyner, 1970) assert that the design begins with "user needs," i.e., performance specification, design goals, design criteria by engineering, user requirements. Designers must define its goals, requirements or needs in detail, which are employed as a checklist for evaluation before starting to design a building. The term "need" has a variety of meanings because its concept is not well defined. They suggest to replace the idea of need by the idea of what people are trying to do, called a tendency, which is an operational version of a need. But one might infer the existence of other tendencies. Under certain conditions, tendencies conflict. In a proper designed chair, this tendency conflict does not occur. But in buildings and cities the conflicts can be much more complicated. However, the design principle is the same, provided that all the tendencies can operate freely and are not brought into conflict with other tendencies. Since the tendencies in conflict may often be hidden, it is a difficult process to state the problem.

About value problem, Alexander and Poyner believe that all values can be replaced by one basic value: everything desirable in life can be described in terms of freedom of people´s underlying tendencies. Anything undesirable in life — whether social, economic, or psychological — can always be described as an unresolved conflict between underlying tendencies. The environment (building) design should give free rein to all tendencies. Conflicts between people´s tendencies must be eliminated.

They define a relation as a geometrical arrangement that prevents a conflict. The primary purpose of design is to predict and identify the conflicts of tendencies, invent a new relation that prevents the conflicts and combine these relations to form a cohesive whole. The authors analyzed in detail the five relations from the design of a supermarket:

- Check-out counters are <u>near</u> the exit doors.
- The stack of baskets and trolleys is <u>inside</u> the entrance and directly <u>in front</u> of it.
- Meat and dairy refrigerators are <u>at the back</u> of the store, and all other goods on display are <u>between</u> these refrigerators and the check-out counters.
- The display shelving has a <u>tapering</u> cross section, narrow at the top and wider at the bottom.
- The store is glass-fronted, with aisles running from <u>front to back at right angles</u> to the street.

These relations have become widely copied and typical of supermarkets because each of them can prevent some specific conflicts. The key point to invent a relation that prevents the conflict is the following:

tendencies are never inherently in conflict. They are brought into conflict only by the conditions under which they occur. In order to solve the conflict, designers must invent an arrangement where these conditions do not exist.

The authors take building as an example, analyze human action tendencies, and claim that the features that cause and prevent individual conflicts are geometrical relationships. Where a public path turns the corner of a building, people often collide. There are two tendencies: (1) people are trying to see anyone who are going toward them some distance ahead, so that they can avoid bumping into them without slowing down, and (2) when going round a corner, people try to take the shortest path. At the blind corner the first tendency makes people walk well clear of the corner, the second makes them hug the corner. At a blind corner the tendencies conflict. In this example, the corner is solid and square, and the ground is unobstructed around the corner. To eliminate the conflict, designers must get rid of one or more of these features. If designers make the corner transparent, people will be able to see far enough ahead through it. If designers round the corner with a gradual curve, people will be able to see around the corner. If designers place a low obstruction at the corner, like a flower tub, people will have to walk around it and see each other over it.

Example 2: Planning behavior of aircraft pilot
In the 1980´s, planning became increasingly central functions for the human operator as automation replaces more and more of the manual tasks in man-machine system. In 1983, Gunnar Johannsen and William B. Rouse (Johannsen and Rouse, 1983) presented a methodology for studying planning behavior of aircraft pilot. In the investigation and experiments of the planning process of aircraft pilots on HFB-320 Hansa Jet simulator at the Forschungsinstitut für Anthropotechnik (FAT) in Germany, three flight situations were studied by using the flight scenarios: normal, abnormal, and emergency. There were five measures for evaluation: depth of planning and time line, criticality, probability of increased difficulty, workload, and performance. They distinguish the dichotomy between event-driven and time-driven planning. Event-driven planning refers to updating a script or creating a new script. Time-driven planning involves monitoring the execution of a script. Because the aircraft domain is dynamic and uncertain, its planning is driven by both the urgency of time and unanticipated events, which are very different from the planning for restaurants. Therefore, both hierarchical, time-driven following of scripts, and opportunistic (heterarchical), event-driven planning are useful for describing human planning behavior in complicated dynamic environments. From a methodological point of view, the in-flight questionnaire techniques as well as pro- and post-experiment questionnaires provide various insights into human planning behavior. It could not be obtained by the traditional measures of workload and performance.

Example 3: The intention communication in advisory interaction
This is an example of computer software design. Giboin (1988) introduces some new ideas to improve advice-giving system. He argues that the success of an advisory interaction depends to some extent on the mode of appropriate intention communication between user and advisor. In his study, an intention means a set of hierarchically organized goals and plans whose function is to govern activities. Goals are various level representations of states to be achieved during an activity. The activities related with user and advisor in this system include (1) computing activities: Users interact with computer to tell it to do the tasks such as editing, formatting or compiling; (2) advisory activities: Users interact with the advisor about a computing activities that has been suspended because they do not know how to use. For example, they wants to use FIND command to implement the sub-function "FIND THE FILES TO BE REMOVED," and ask the advisor how to do it. Users and advisor set goals to achieve them with some plans. The model of this advisory interaction is a simplest form of advising about computer utilizing.

The author begins from the analysis of the situation. The situation involves the participating of two persons. A person seeks some advice on a specific topic about computer using, called the advice-seeker or the user. Another person gives this advice, called advice-giver or the advisor. This situation is considered as a complex one because various kinds of participants´ knowledge are interacted each other (see Figure 4.8-1).

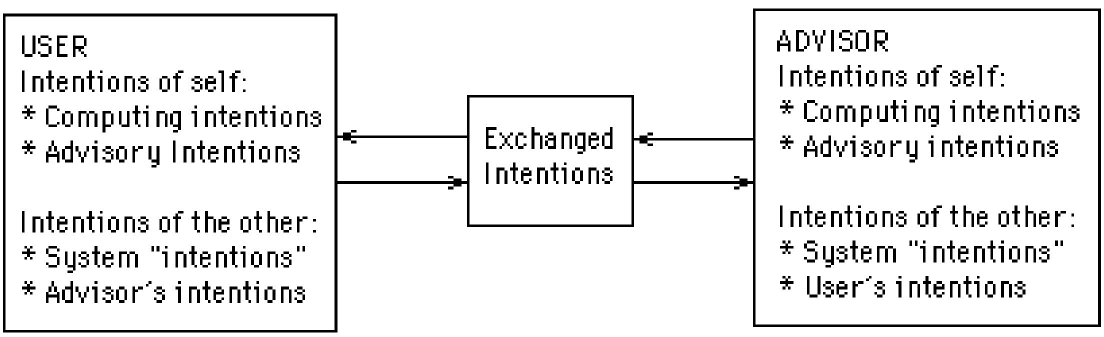


Figure 4.9-1. The model of advisory interaction.

In the model of advisory interaction, the user and the advisor are engaged in an advisory activity. They interact with various knowledge about intentions. From the user´s view, Giboin distinguished intentions of self from that of the other (advisor or system). In the latter case, goals refer to program functions, e.g., REMOVE FILES. Plans refer to the way in which programs achieve the functions, e.g., to use the FIND command with script.

The intention, or goal hierarchy is shown in Table 4.8-1, which reflects the states to be achieved by the user and the advisor during an activity. Goals can be terminal or non-terminal. Terminal goals are those that can be directly achieved, or immediately executed. Non-terminal goals must be achieved by calling on plans. The user´s goal is, for example, to seek advice about how to implement the function "FIND FILES TO BE REMOVED" with the FIND command.

Plans are at various levels of procedures for achieving goals. For example, the user´s advisory plan is "ASK AN ADVISOR FOR ADVICE," which is related to the goal quoted above. Procedures can be defined as sets of sequenced sub-goals. There are higher-level plans and lower-level ones. Lower-level plans fulfill the intermediate goals proposed by higher-level plans.

Cycles of advisory activity. The manipulation of intention is an aspect of performing an activity. From each participant´s point of view, the manipulation of intention results in embedded cycles of advisory activity. Each activity cycle consists of four steps:

- get a goal;
- get a plan;
- execute the plan;
- evaluate the goal.

Table 4.9-1: A hierarchy of user´s goals

Level 1	Level 2	Level 3
Seeking advice	Forming the request	Starting a "snag"
		Converting the snag into a request
	Communicating the request	Presenting the request
		Clarifying the request
	Assisting the advisor to form answer	Detecting a need for further information
		Giving the information
	Understanding the answer	Detecting the answer
		Evaluating the answer
		Asking for clarification

Cycles of advisory interaction. From the point of view of both participants, manipulation of intention leads to cycles of advisory interaction, which comprises also four steps:

- form/detect a request;
- communicate/understand the request;
- assist advisor with forming the answer;
- understand/communicate the answer.

In some literatures, it is often claimed that the success of advisory interaction depends upon that the advisor takes user´s intentions into account. On the contrary, Giboin suggests that the success is related to the mode of appropriate intention communication between user and advisor.

Example 4: Goal-directed activity in design processes of supervision and control
One of the major problems in industry is the insufficient control in complex processes, which often cause doubt, anxiety in the operations and event disasters. These problems have been investigated widely from two aspects: technical factor and human factor (ergonomics). In these studies the relationships between the human and machine

should be stable, but in reality, the human activity is always changing from time to time, from person to person. Therefore, designers should analyze the "real work" in the real conditions of system operation. Wisner et al (1988) assert that this goal can be realized, based on the course of action as the main object of work analysis and on the design of future probable activity as the focal point of the study of ergonomics intervention at the design level.

1. The course of action is defined by Wisner et al as the conscious (partly at least) intentional, planned, and socially controlled (or directed) behavior that is significant for the operator in the working environment. Studying the course of action implies attempt to find its determinants. It consists of three types of descriptions:
- the intrinsic description of the dynamics of the action course,
- the description of the dynamics of the technic-organizational system and process, and
- the description of the dynamics of the operator´s state.

The goal of these descriptions is assumed to obtain information about the instability of human activity. The emphasis is focused on the intrinsic description of the dynamics of the action course. It defines the dynamic relations among three sub-objects: significance for the action, cognition for the action, and manifest action. In order to find information about the course of action in a given situation, designers should employ two methods for work analysis:
- detailed observation of all behaviors,
- systematic verbalization collected from operators according to the defined rules.

2. For Wisner et al, study of the future activity in the design process is aimed at anticipating the main characteristics of the operator´s real activity to integrate them in the design of work facilities. Analysis of the action course is involved in every stage of design process as follows:
- In programming stage: Definition of detailed targets for the prime contractor. Designers should find out reference situations liable to reveal determinants of the future activity linked to: the characteristics of the future population, future raw materials, future products or sub-products, future machines, methods of processes, relations upstream and downstream with customers, etc., future energy sources, the geographical and climatic environment and industrial environment. From these analysis, designers can abstract the determinants of operator´s action course, especially the critical periods in the operation, and find ergonomic design principles.
- In design stage: Designers can define the general specifications, and anticipate empirically the future activity, which may take different forms. In some cases, this work can proceed through experiments according to two principles: (1) by using the information collected in reference situation above, designers can establish current experimental situations. (2) By the employment of prototype of the future equipment, designers analyze the course of action of operators in these situations. If there is no prototype equipment available for analysis of the future situations, then questionnaire can be employed. Designers ask them to describe, on drawings or the model of the future installation, the activity they would use in certain typical action situations, which are found in the reference situations, and then organize this work and evaluate the operating methods described. The main issues which should be considered include: structure of the course of action, the human physiological and psychological properties, and the characteristics of materials and equipment identified. In the previous analysis, some characteristics of the future situations cannot be presented in the experimental situations. Prediction contains some uncertainty. Therefore, designers must reserve possibilities in modifying the design by iteration. It should be also noted that laboratory experiments are different from the real environments.
- In the implementation period the working situation is constituted in real world. The problems caused in its design process can only be remedied through instruction and training. The investigation on the course of action in this stage is used for the modification of new design in the future.
- In the operating stage the complete study of the course of action is implemented in the real working situations. The evaluation is particularly important for the situation where severe local conditions lead to a certain deterioration of the machine. Its result is useful for the evaluation of the design methods.

3. In summary, the authors emphasize that the analysis of the course of action, and the empirical prediction of the future activity should be integrated in the structure of design process. This approach requires the designers, ergonomists and technologists to co-operate together with the goal of defining the concepts, the methods, and the characteristics of the human operation in real situations.

Example 5: Human-Computer Interface

Gaines (1988) asserts that human-computer interface presents four major problems in the specification, development and evaluation of computer-based systems:

- The rapid change in the computer technology, forms of interaction and systems designs.
- Inadequate psychological models of users in the field of computer technology. There is still a major gap between psychological and cognitive science theories on people and their behavior in practice.
- Inadequate systemic models of computer-based systems. The flexibility of computing technology makes it very difficult to employ previous engineering foundations that sufficiently capture critical issues in practical situations.
- Inadequate interaction models of the human operator and computer-based system coupled together. Even when psychological and systemic models are restricted to the domain of human-computer interaction, the residual flexibility and complexity make it difficult to generate adequate models. Empirical studies encompass too narrow a range of systems. Guidelines from experience are superficial and may fail to generalize to new situations.

It is now well known that computer design is not only based on computer technology, but also on user psychology. The system specification, development, the man-machine interface and evaluation should be also analyzed in terms of the requirements of non-specialist users and the goal-directed activity of users. One of the most important problem of system theory is the analysis of the relation between behavior and structure: given the structure of a system in one direction, to derive its behavior. In the other direction, given the behavior of a system, to derive its structure. In the study of physical systems, mathematical techniques have been developed for moving in both directions with causal models (Gaines, 1977; Klir, 1985). However, users´ activity or action are essentially different from those of the physical world and cannot be involved in causal models.

The author claims that in analyzing user-computer interaction it is important to establish the critical characteristics of a person and those of a computer. The "laws" that govern human behavior are largely motivations embedded in the society and propagated through its values which are the kern of the culture. Human beings create their future through acts of choice that are led by their forward-looking intentions. Physical systems unroll their future through acts of necessity that are determined by their previous states. From this point of view, in user-computer interaction people deal with phenomena of the life-world which are essentially different from those of the physical world and from a behaviorist psychological model of people. The user´s mental models may be influenced by their impressions of the designer´s intentions. The system designers may be seen as behaving through the computer to anticipate the future behavior of users.

In order to understand and overcome these problems, the author has developed a fundamental model — an analysis of the key features of a computer system in terms of the following six layers.

- Cultural layer is the top level. The overall computer system originates in terms of purpose and structure as part of the culture. The culture takes the genetic "virtual machine" and socializes it to have intentions and knowledge that conform with the purpose of a society.
- The the next level is intentionality layer. The activities generated from this structure and purpose lead to goal intentions which cause anticipatory activity. This anticipatory activity is carried out by generating goals and acquire knowledge or models of the world.
- At knowledge layer, the activities generated through anticipation lead to actions and actors, communications and communicators of the anticipatory system. This knowledge layer captures the internal processes supporting the modeling and control activities of an anticipatory system.
- At action layer, the activities generated through action and communication have to be transmitted to some external medium. This layer captures the internal processes supporting the interfacing of an anticipatory system to the world.
- Expression layer. The activities generated through transmission have to be expressed in such a way as to have the desired effect in the world. Expression layer captures the internal processes supporting the encoding of actions and communications.
- At the lowest level, the activities generated through expression exist physically in the external world. This physical layer captures the external effects of the activities of an anticipatory system.

CONCLUSIONS

1. User Models
User models are the foundation and starting point of design. For every project, designers must build its user model. User models involve two aspects: the mental model and the action model (task model). The mental model is mainly based upon cognitive psychology, and the action model is based upon action theory. Up to now, most of user models are rational models. That is, these models tell only the rational, correct, and successful processes of action.

1.1. The rational mental model
The mental model describes users´ processes of perception, cognition, emotion, and physical motion. Users´ perception is the intentional one which is mainly represented as perceptual expectation and anticipation. By perceptual learning, human perception and the perceived environment becomes an ecological entity. Human perception mainly includes direct perception and various recognitions. Human cognition deals with thinking, understanding, reasoning, language processing, problem-solving, idea production, and various cognitive processes. Motor performance is the physical side of human action, and always connected with human perception. Volition relates to human action control. There are three types of action control: self-control (willful), self-regulation ("democratic"), self-organization (automatic control) and from 15 mental processes which lead to great cognitive efforts in human action.

1.2. The rational action model (task model)
The rational action model describes users´ correct way of action in four phases: Motivation formation, intention selection, action initiation and execution, and evaluation and termination.

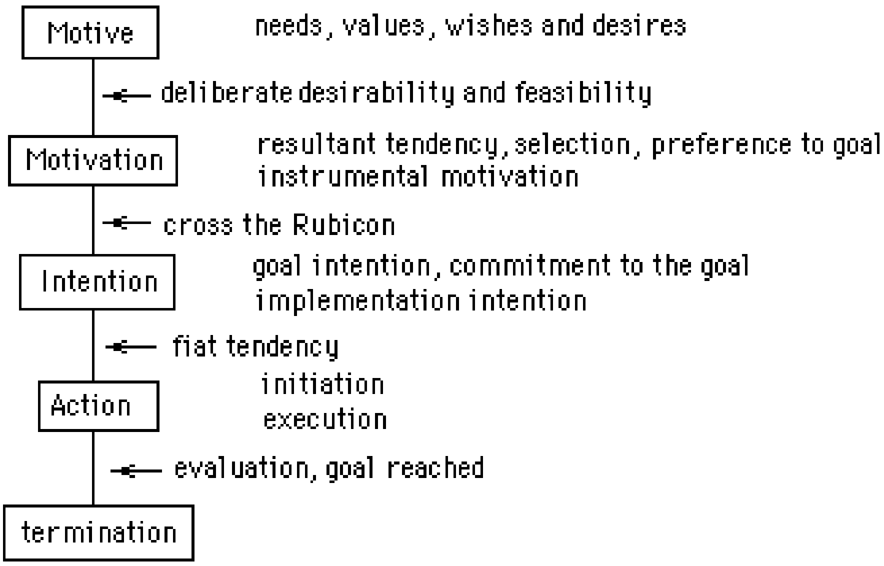


Figure C-1: The course of action.

1.3. The irrational mental model
In fact, human action involves both the rational aspect and the irrational one. The irrational user model comprises also the irrational mental model and the irrational task model. The irrational mental model includes the following aspects:

- Humans have limited abilities in perceptual processes. (1) Humans have different perceptual intentionality and experiences. They perceive difference affordances. (2) Humans can not perceive accurately physical quantities such as the size, the angle, the speed, the distance, the temperature and the volume. (3) Human perception may lead to illusion, including shape and direction illusion, size contrast illusion, overestimation and underestimation illusion if users lack perceptual knowledge, or designers have not provided sufficient visual information to users. (4) Human attention is very limited resources. Humans are easily tired and abstracted. Human perception is a difficult issue in design process. Many problems of usability design relate to it. (5) Human perception depends upon the environment and the external conditions.

- Human cognitive processes have limited rationality. (1) There exist not any "standard" or "rational" way of logic thinking. Generally, humans do not think logically, but they may think according to their experiences, their feelings, their intuition, imagination, even illusion. (2) Human memory is limited. They are forgetful. (3) Users often employ the heuristic or trial-and-error, not scientific logic, to solve problems in using artifacts. (4) Some cognitive abilities, such as idea production and naming, are rather difficult for many users. (5) The meaning of information may be understood differently. (6) People have different abilities to acquire knowledge. Concepts are difficult for some people, and procedures are different for other people.
- Human hand motion is irrational. It can not reach both of the high speed and high accuracy. They often make action slips and errors.
- Emotion is mainly produced by evaluation of action. Irrationality of emotion in human action can not be ignored in design process. Darwin and Frijda introduce four principles of expressions. Enjoyment, pride, curiosity, fantasy, imagination lead to positive emotion, but others lead to negative emotion.

Different conditions may lead to different way of action and psychic states. Various psychic states influence also human action in various ways. Kuhl et al create the model to describe such processes.

1.4. The irrational action model

The irrational action model involves the following aspects:

- Many unforeseen factors and conditions may influence human action course, so that human action is not always executed successfully. It may fail, or may cause accidents or catastrophes.
- Humans make errors in intention formation, in planing and selection of action alternatives, in execution and in evaluation of action. They also may make unconsciously action slips.
- Humans do not always act after careful planing even they thought that they had planed thoroughly. They often think about one or two steps ahead, then act.
- Abnormal conditions and states will cause unforeseen way of action, such as in the dark, in high temperature, in noise, etc. Operation of computers and car-driving for a long time will cause fatigue, unforeseen way of action, and even accidents. In an urgent situation, in time pressure, or in emergency, users´ action is different from the normal way of it.
- Humans and machines have different ways of behavior. Humans can not always consciously behave like the way of machine behavior.

There is no standard or universal user models for general design. Designers should build the concrete user models for their design objects in detail.

2. Usability

2.1. What is usability

Usability of artifacts is defined as the degree in which users are satisfied with using the artifacts. Usability design is to study users´ needs and the properties of human action, and to make artifacts fit human action. Many factors contribute to usability design:

- Cultural philosophy (wisdom of life), values, norms and traditions influence the opinion of usability and its criteria. For this reason, designers should regard potential users as cultural users.
- Social conditions, social relationships and social structure are another factor which determine way of human action to artifacts. For this reason, designers should regard humans as social users.
- Human ideas, including users´ motives, motivations, intentions, expectations and imaginations, are the third factor which determines the usability of artifacts. Their values, desires and intention involve two aspects: the terminal side and the implementation side. Most of current criteria of usability are mainly related to the latter aspect. Implementation desires may be effectiveness, efficiency, or flexibility, but also may be others, such as habits (traditional ways of behavior), anti-tradition, etc.
- Humans interact with artifacts by means of actions. An action consists of perception, cognition, volition, emotion and physical performance.
- Users´ knowledge of artifacts implies their experience, including declarative and procedural knowledge in using the artifacts. Usability means to fit users´ level of knowledge and learning processing.
- The environment provides information for human action.
- These factors are mostly presented on the artifacts, their functions, structures and user-interfaces directly.

2.2. Assessment of Usability

Usability should be evaluated by users´ action in the real world. Design criteria for usability generally involve the following aspects. (1) Cultural tradition and social environment. (2) Users´ intentions, including goal intentions and implementation intentions. (3) Users´ knowledge about the artifact, including users´ habits, declarative and procedural knowledge. (4) Demands for abilities factors, including difficulty degree of the ability, ability loading, complexity of abilities, speed and accuracy. (5) Users´ action processes and execution. (6) Representation of information. (7) Learnability, including learning period of time and easy self-learning. (8) Low error rate or difficulty rate.

3. Information Theory

Information cannot be understood separately from human perception, cognition and action. Information is the meaning of the subjects of the external world which humans desire to perceive. Information provided by design is called the artificial information. Information theory deals with how to design the artificial information in order to fit users´ perception, cognition and action. Its goal is to create the coupling between information and users, which relates to the following issues.

3.1. The structure of the artificial information

In the ecological view, the structure of a piece of information consists of two sides: the terminal side and the instrumental side. The terminal side of information refers to user´s perceptual intentionality. The instrumental side of information refers to the carrier (medium) of information and the way of transmission which relates to the way of perception.

The terminal side of the artificial information includes the followings. (1) The domain of information: the machine-oriented or the user-oriented. (2) The goal of information: which should relates to the goal of user´s perception, cognition and action. (3) The state-perceiving information shows the direction, the position, the current state, the distance, the temperature, and the quantity. Humans are not good at perceiving such state information. Design should offer appropriate ways for users to perceive such information. (4) The performance information deals with the mapping of human action on the operation of machines. Such information includes various conditions for action initiation, action plan, action selection, action evaluation and action termination. (5) The cognitive and communicative information deals with inquiry, telling, exchange, and understanding of meanings.

The instrumental side of the artificial information deals with the carriers of information, its regularity, its structure, and the way of transmission and perception. (1) For the artificial information there are various carriers, including the signal, the sign, the symbol, the color, the sound, the smell, the picture, the icon and so on. (2) All the carriers and the quantity of the artificial information must fit users´ perceptual processes and features. (3) Information should fit the feature of attention. (4) Information should correspond to users´ cognitive knowledge, perceptual experiences, desired expectation and anticipation. (5) The way of information display involves the serial, the parallel, the continual, and the selective.

3.2. Criteria of information design

The criteria of the terminal side of information involve the followings. (1) Information should be adapted to user´s cognitive goals and cognitive abilities. (2) Information should be complete. (3) The meaning of information should be understandable. (4) Information should be economical.

The criteria of the instrumental side of information involve the followings. (1) Information should fit user´s desired channel of perception. (2) The media of information should fit user´s desired abilities of perception and cognition. (3) Information should be directly perceivable. (4) Information should fit user´s prediction, anticipation, perceptual course and desired processes. That is, information should be displayed at the right time, at the right place, at the right direction, and in right carriers, so that users can easily perceive what they want.

4. The Action System

Machine-centered design regards humans as the input factor of machine functions. This model of design is centered in function of machines, and requires that humans should act as machines. That is, (1) users must concentrate on behavior of machine; (2) users must act highly accurately, rationally and stably; (3) no action error is permitted; (4) the user´s thinking must be logic. Such design emphasizes training, i.e., designing users to fit the machine.

An action system is the system in which users can act based on their intentions to the artifact and environment to realize their goals with satisfaction in a natural way. Based upon this natural relationship, the user, the artifact, the environment can be viewed as an action system. Action systems can be classified into the use system, the production system, the information system, and the supervisory system. The action system emphasizes that the machine should fit and follow users´ intentions and actions. For usability design, users´ action analysis is an important step of the design process. The goal of the action analysis is to find out the properties of users´ action and felicity-conditions. The action analysis involves the following aspects: cultural and social factors, the environment and the situation of action, action structure and organization, and learning processing.

5. Action Interface

5.1. The concept of action interface

The interface or the contact surface which relates to users´ action to artifacts are called the action interface or action joint-face only when the interface satisfies users´ action with their intended felicity-conditions. The interface involves four elements: the human, the artifact, the environment, and the goal (or the goal object). One of the tasks in the interface design is to find the type of users´ action toward artifacts and the action relationship between users and artifacts. User-artifact interface involves the following relations: (1) the relation between the human and the artifact (machines), (2) the relation between the human and the environment, (3) the relation between the human and the goal object, (4) the relation between the artifact and the environment, (5) the relation between the goal object and the artifact, and (6) the relation between the goal object and the environment. One can also classify these relations into perceptual interface, cognitive interface (information interface), performance interface.

5.2. The goal of interface design

Usability design can be distinguished between two levels: At the first level, the goal is to offer easy action to users, and to change partly machine-centered design into user-oriented one, that is, to make the operation easy. At the second level, the goal is to offer the natural way of action. The natural way mean that users are able to act in the way that they want to. This way, users can immerse in their action, and to realize Artifact-Human-as-an-Entity.

5.2.2.1. Easy way of action

The criteria include:

- Easy perception and less attention. For easy perception, design should offer (1) proper amount of information (7±2 chunks), (2) easy detectability and recognizability, (3) visualization of artifacts, (4) desired affordance, (5) visual guidance, and (6) economy of perceptual processing (less attention).
- Easy cognition and less effort. Design for easy cognition means (1) to make the behavior of artifacts (i.e., computers) visible, (2) to find consistent mapping of human action on computer operation, (3) to offer understandable and rememberable meaning of information, (4) to employ everyday logic, and heuristic way of problem-solving, (5) to make memory easily.
- Easy use (physical performance). For easy use, direct perception, perceptual-motor coordination and easy learning is main objects of design. Direct manipulation is one of the examples.

Easy perception and easy cognition relate to the environmental information, users´ intentions and abilities. That is to provide goal-directed information in the intuitive form (intuitive graphics, a limited number of icons and signs, for example) and with less demands for cognitive abilities.

For easy way of user´s action, design should offer action guidance. The goal of action guidance is to provide felicity conditions to users´ action toward artifacts. Users´ action guidance involves: (1) goal-guidance (or intention-guidance); (2) reparation-guidance; (3) plan-guidance; (4) implementation-guidance: which refers to initiation-guidance, direction-guidance, selection-guidance, rule- and knowledge-guidance; and (5) termination-guidance.

5.2.2.2. Natural way of action

The criteria of design involve:

- The natural context, the natural language and natural information.
- Natural ways of perception and the natural way of attention. For natural way of perception, every of perceptual senses (multiple modalities) and every of perceptual desires should be coupled with information in the natural way of coordination, and coupled with the ability desired by users.

- Natural ways of cognition, including every mental processes, imagination, fantasy, anticipation and prediction. Design should offer natural and multiple relations between desired mental processes and information. That is, (1) to provide natural (desired) and multiple way of reading, understanding, thinking and memory which has been learned by users in their real life; (3) to keep users immersing in action reality, not distracted with any undesired signs, information and physical performance; and (4) to provide natural way of learning processing.
- Natural ways of physical performance (natural way of use). Designers should employ human action habits, and offer the natural input and interaction devices which can automatically track human hand and body movements, and offer reality, natural environment and"natural information which humans have been used to in their real life.

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