Modeling Creativity and Knowledge-Based Creative Design

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5 A Neuropsychologically-Based Approach to Creativity

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General features of creativity are discussed, aimed at providing a clear definition. In the view of general design theory, creativity is seen as a communication process aiming at consistency between different intensional and extensional representations of design. Basic concepts of classical neuropsychology and the functional structure of the brain are reviewed, emphasizing the self-controlling role of the mid-brain. Based on these, a model of creative behavior analogous to the brain model is presented. A key concept is called view, a restricted field of attention, or the momentary collection of objects and relations considered interesting in a situation. Drawbacks of traditional knowledge bases in implementing the model are pointed out, and their development towards creative behavior is discussed. The approach aims at deriving new connections and analogs between neuropsychology, general design theory and knowledge engineering, with special emphasis in the motivating forces of creativity.

5.1 What is creativity?

Creativity is usually understood as a person's ability to produce something new and unexpected. It is considered a desirable property and characteristic of intelligent human beings. It is involved in works of art and science, but may also appear in situations of everyday life. Essential in creativity is that something recognizable is produced, and that the result is novel.

But how and why this happens is often considered unknown, even mystical. Creativity is a concept hard to define. Some people totally deny the possibility of an exact definition, because it inevitably would be too specific and restrictive.

Intelligence and extensive training are considered necessary but not sufficient conditions for creativity. In addition, specific traits of creative people are a flexible, nondefensive openness to experience, an autonomy or independence of authorities, an ability to toy with conceptual ideas, and an aesthetic sensibility—the ability to judge and desire (Maher et al., 1989).

However, it may not be possible to define creativity exactly with a list of specific static attributes of a person, because so many different, even contrary properties may be associated to creativity. Instead, a clear definition can be based on the *processes* of mind recognized as creative behavior.

5.1.1 Process models of creativity

Indeed, creativity is nothing but the ability to perform creative processes. Such processes have through the ages been investigated and modeled both introspectively and by objective observations. Problem-solving is a common paradigm to describe creativity, and is useful in the context of design. Typically we can distinguish four phases in the process (Wallas, 1926):

1. *Preparation*, the collecting of facts related to the problem, and their analysis from different points of view—also trials to solve the problem,
2. *incubation*, subconscious organizing processes while the subject is not concentrating in the problem, but doing something else (e.g., while sleeping),
3. *illumination*, sudden appearance and recognition of the solution, and
4. *verification*, deepening and detailing the solution by comparing it against various constraints and requirements of the problem.

However, creativity is not only the solving of given external problems. Strong *internal motivation* is needed in order to start a creative process. A material reward can hardly compensate the gratification and satisfaction achieved from successful comprehension.

According to Freudian theories, creative activity is often explained as sublimation of other more primitive driving forces. From the psychoanalytical point of view the motivating force of creativity is a person's need to compensate for the feeling of imperfection. The person is building solutions to a loss (death of a close person, mother envy, phallic-narcissistic wound, etc.) by recreating the lost object in a transformed form. This behavior is learned in the childhood, when parts of the mother-child relationship are transferred to 'transitional objects.' From this perspective, imagination and animation with toys are the child's first creative attitude toward the environment (Hägglund, 1976).

In neuropsychological (psycho-physiological) terms a creative process can be understood as the autonomous (i.e. independent of immediate sensory stimulation) formation of new activation patterns in the brain, recombining already existing self-activating loops. Production of something new from existing prerequisites is not restricted to a 'creative personality,' but happens all the time. There are only different grades of its appearance: a housewife finding a new way to make food may be as creative as a novel writer giving us new insights into human lives. A child imagining the doll speaking is creative, as well as a drunken man seeing hallucinations (Hebb, 1958).

A biologist may generalize that creativity is an attribute of all life. It is the mind's morphogenetic tendency to build organized structures out of chaos, a feature not peculiar to humans but appearing even in lower animals (Sinnott, 1959).

5.1.2 Defining creativity

In this chapter the term *creativity* is understood mainly the same way as by Hebb and Sinnott: a creative process forms new patterns from previously existing patterns in the human mind. The patterns are conscious and strong enough to stimulate sensory areas of the brain, thus they are potentially externalizable. But even if not observable from outside, the patterns should at least be recognized by the creative individual him/herself.

Creativity is largely identical to imagination, but not all imagination is creativity. Mednick (1962) distinguished creative thinking from original thinking by the imposition of requirements of usefulness. His definition (cited e.g., by Morris, 1982: p.333), that "creativity is the forming of associative elements into combinations which either meet specific requirements or are in some way useful," is especially suitable in design. Mednick admitted that usefulness is difficult to measure. In actual design situations it is hard to judge objectively the degree of novelty and practical value required to call a new product creative. They are a matter of cultural environment.

Instead of cultural novelty and usefulness, special emphasis in this chapter is given to the subjective motivation of creativity, that is to the requirement that a creative process should give the feeling of pleasure and gratification. The motivation for creative behavior is an explicit or subconscious problem, a dilemma or inconsistency, an initial displeasure that becomes rewarded and relieved when the problem is solved. From this point of view, creativity is not only the ability to solve problems, but includes the brain's homeostatic tendency to actively seek or autonomously produce problems, in order to get pleasure from solving them.

5.2 Design theory

In design we consciously aim at a useful concrete or abstract product. A design process typically starts with the analysis of the product's intended context. This analysis results in a heterogeneous set of loosely connected details and perhaps some insight into potential solutions.

The design problem is first structured and its solution is defined through its implicit properties. Without contradicting the context, a new construction should be made that will satisfy a given set of additional requirements. The requirements are *intentional*—their fullfillment can be tested and detected, but they don't yet directly devise a product. But what we actually want is an explicit solution, a unique *extensional* model or representation from which the product can be constructed (Takala, 1987b).

If the requirements and the context determine a unique solution, it may be derived algorithmically. Then 'designing' is simply the problem's transformation from intensional to extensional form. Such design automation can be performed by three alternative strategies or by any combination of these, depending on the formulation of the problem and the knowledge available about its solutions (Yoshikawa, 1981).

1. *Catalog model:* known standard solutions are stored in a database, from which they can be retrieved using the required properties as keys.
2. *Calculation model:* the basic form of the solution is known, but its dimensions or other explicit parameters have to be numerically calculated, based on mathematical formulas connecting them to the implicit properties.
3. *Production model:* inference rules are used to derive a solution logically from the requirements (much the same way as mathematical formulas are used in the calculation model, but in a more qualitative sense).

Often no algorithmic rules are known or the problem is underspecified, leaving space for free decisions and creativity. Then we have to search a solution by trial and error, generating and testing different proposals. Typically this is not done completely at random, but we have a paradigmatic solution, which is compared against a partial, gradually growing set of requirements, and modified if needed. This *paradigm model* describes design as the *convergent evolution* of solutions (Yoshikawa, 1981). Its gradual steps form the history of a design, which may branch and involve backtracking, but finally contains a path leading to the solution (Takala, 1987a). The end goal of design is that all the related facts, both the original requirements and the created constructions, are consistent.

5.2.1 Views to the design knowledge

The evolution is not often successful by straightforward derivation from one single direction only. Instead, the problem should be approached from various points of view. The designer's attention focuses to different aspects of the same problem, wandering around and slowly approaching it like a spiral (Zeisel, 1981).

The limited set of facts that are taken into account at a time, that is the focus of attention, will here be called a *view.* During a design process the focus is continuously fluctuating—the 'looking glass' is changing its size and location within the whole set of available knowledge (Figure 5.1). Within each view, partial solutions are constructed and tested against the respective facts.

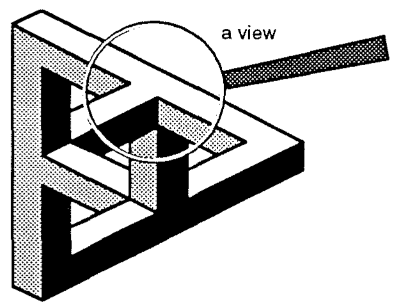


Figure 5.1. A geometrically consistent design when looked through a focused view, but globally a nonrealizable object (in the style of M. C. Escher).

The design is considered finished, when a sufficient number of views have been successfully handled this way without discrepancy (Takala and Silén, 1989). Larger design situations, that is architectural design of a building, are 'wicked problems.' They are so complex that there is no way to handle all relevant information within active views. This is why they cannot be completely designed before actually building the whole product.

Many design theories are based on a stereotypical hierarchical model of the design object or design process. However, each such model corresponds to one particular view only. No single hierarchy alone can describe all aspects of a design, but several crossing hierarchies are needed. For example, an architect has two complementary views to a room, one concerning its walls and another its enclosed space. They are not independent, and neither alone is sufficient for design.

In creative design the attention focusing, as described earlier, is essential. If all the requirements and all partial constructions made so far were taken into account at once, it would quickly lead to contradictions and a dead-end. Instead of convergent thinking, that is getting stuck in the first idea and following the most obvious logical reasoning straight-ahead, a creative mind applies divergent or lateral thinking, that is looks the problem from different points of view, "not digging the hole deeper but digging in a new place" (de Bono, 1967). In other words, creativity requires a "flat association hierarchy" Mednick (1962). Creativity enhancing techniques, like brainstorming and synectics, intentionally do this by leaving away critics for a moment, producing many partial solutions and new associations between seemingly unrelated things. Gradually the views are then enlarged, until they finally cover all the relevant facts (see Figure 5.5 also).

5.3 Communication and creative design

The paradigmatic solutions during design evolution are usually presented in models, drawings, or other external forms, which facilitate their communication both to other people and to the designer himself (autocommunication). It is important to note that such *an external representation is always ambiguous and metaphorical.* A house doesn't consist of the ink lines representing it in a drawing, nor of the pieces of paper in its scale model nor of words used to discuss it. A message, even if described with abstract concepts, has to be coded in a physical form, and the relevant information contained in a representation has to be interpreted, in order to be comprehended (Figure 5.2).

Understanding a new message is itself a creative process. During interpretation we make hypotheses about the meaning, which are then verified or changed as new information is attained. All the details have to be put

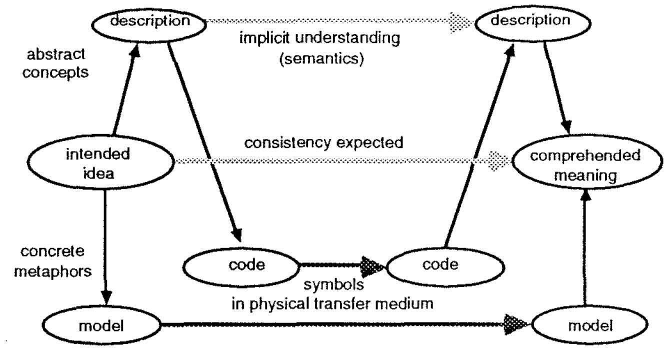


Figure 5.2. Model of metaphorical communication (Takala, 1989).

together into a coherent set. We are learning by *designing a mental model* of the world. However, in this process we also need to focus our attention to limited views, because a representation may contain too much information to be processed at once. This is especially true in auditory communication, speech, and music, where the sensory processing is strictly sequential, and memory has to be utilized to construct a holistic view.

In creative design the external models have an important communicative role. A representation may be interpreted not only in the obvious way, but it may stimulate various other associations and views also, which potentially lead to new solutions. This is why graphical sketching is so fruitful. Even an image totally unrelated to the problem at hand may give rise to innovative ideas. Particularly stimulating are incomplete and ambiguous messages, which can be understood in several alternative but logically consistent ways. Although exact communication is the act of understanding an ambiguous message in the intended way, creativity is the art of *misunderstanding in a meaningful way.*

In creative artistic design consistency within every view is even not always the goal. Surrealistic works are interesting and aesthetically pleasing for the reason that in most views they are consistent with the real world, but in some sense they are strikingly controversial. For example, if we scan Figure 5.1 with a looking glass, its small aperture gives a perfect image everywhere, but the geometric impossibility is only discovered when these are combined within a wider view. The discovery of such ambiguities is the essence of the art's appeal. Creative art is that which stimulates creative processes in its viewers!

5.4 Neuropsychological basis of thinking

In order to understand the mechanisms of mind and to find potential methods to simulate creativity, we have to take a look at the structural and functional physiology of the brain. This can be done at different levels of detail, ranging from individual cells and assemblies to functional areas of brain tissue, and finally to overall behavioral regulation. Thorough surveys are given by Kolb and Whishaw (1990) from the physiological point of view, and by Churchland (1986) with special emphasis on philosophy and computer science. A synthesis of these viewpoints may lead to a working computational model of human behavior, including creativity.

5.4.1 Microlevel neural structures

The information processing in the brain takes place in a huge number of neural cells called *neurons*, which form a network tightly cross-coupled by synaptic interconnections. Each cell itself roughly behaves like a linear summation element, taking many inputs with different weights, and producing one output that is activated by some inputs and inhibited by others.

Although the nerves transmit information as digital pulses, the signals are of analog nature: the frequency of pulses corresponds to a continuous value, and the pulses are not synchronized. Perceptrons, digitally simulated cells without these properties, have strictly limited abilities in pattern recognition and learning (Minsky and Papert, 1969).

The topology of the network is formed in childhood and remains rather fixed thereafter. However, the synaptic connections (the summation weights for each cell) are still highly adaptive, facilitating learning. The connections have the tendency to reinforce when both connected cells are activated simultaneously, and to decay otherwise. This simple principle gives the network the ability to organize itself while working. Simulations of such neural processes, on the microlevel of individual cells, are called neurocomputers or *neural networks* (Kohonen, 1984; McClelland et al., 1986; IEEE, 1988).

Groups of tightly coupled neurons that can stimulate each other, may form feedback loops where activation is reverbarated and retained for some time. Hebb (1949, 1958) called these *neural assemblies* and used them to model brain functions on a higher level than single cells (see also Kolb and Whishaw, 1990: 527-530). They can act as mediating processes, making associations between nonsimultaneous stimuli. Except for simple reflectory learning, these loops are essential for any cognitive processes. According to Hebb, the three forms of cognitive learning are (Figure 5.3):

1. *Self-organization*, the formation and reinforcement of a feedback loop by repeating the same sensory stimulus,
2. *conditioning*, forming associations between loops when they are activated concurrently or closely sequential, and
3. *attaining knowledge*, forming connections between loops already formed by a set of stimuli and by several potential ways to react.

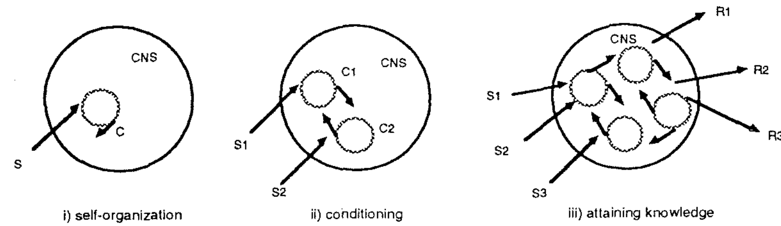


Figure 5.3. Hebb's three principles of learning with self-activating neural loops. CNS = Central Nervous System, S = Stimulus, R = Response, C = self-activating feedback loop.

The third type is considered closest to cognitive thinking, because it can be performed purely internally, without simultaneous appearance of the stimuli and the response reactions. Obviously it also corresponds to our definition of creativity: New patterns of activity are autonomously formed from existing ones.

5.4.2 Functional organization of brain

The brain as a whole is modeled by Luria (1973) with three main functional units (see also Kolb and Whishaw, 1990: 173–176, 183–202):

1. The 'input unit,' which obtains, processes and stores arriving sensory information,
2. the 'output unit' for programming, regulating and verifying the performance of mental plans and motoric movements of the body, and
3. the unit regulating tone or waking (the reticular activating system).

Information in the nervous system flows inwards from sensory organs through afferent nerves into the central nervous system (the spinal chord and the brain), and outwards through efferent nerves to the motoric organs (muscles). In the brain cortex these input and output channels are organized and interconnected by several hierarchical layers (three by Luria, more according to some others):

1. The primary projection areas, where each organ has a well-defined corresponding location, and where primitive features of senses are analyzed and topographically organized,

2. the gnostic and premotor areas, performing modally-specific synthesis of sensory functions and preparation of motor impulses, and

3. overlapping zones, enabling groups of several modal functions to work concertedly. This third 'supramodal' layer, performs integration of external stimuli, preparation of action programs and verification that actions are carried out.

Each of the main functional units has this layered structure, with modal specificity decreasing from the projection areas to the overlapping areas.

All three units have to work in close interaction for any perception to take place. A continuous optimal tone is required by the brain to work properly, and no spatial comprehension can be formed without proper correlation between sensory information and the body movements.

Perception is an active process including search for elements of information, their comparison, creation of hypotheses concerning the meaning of information, and verification of these hypotheses by comparison with the original elements. It is heavily dependent on the overlapping zones which, according to Luria, are located mainly in the frontal lobes of brain cortex. They are well-developed in humans, and are considered the place of higher mental processes. Actually the frontal lobes are found to facilitate divergent thinking, essential in creativity (Kolb and Whishaw, 1990: 474).

5.4.3 Role of the limbic system

Luria's third functional unit (tone regulation) is located in the limbic system and the reticular formation of midbrain and brain stem. These areas are phylogenetically very old, occupying the main part of lower vertebrates' brains. Their exact function is not yet clear, but we know at least that they strongly affect our emotions and general tone, including the homeostatic control of body temperature and other physiological processes.

Because of adaptation and habituation of sensory and other neural processes, no single form of behavior can maintain a constant activation, but there has to be a continuous fluctuation of activation from one area to another in the brain. The macrolevel activity never covers the whole cortex but continuously fluctuates from one place to another, corresponding to changing focuses of our thoughts and attentions, and being concentrated only temporarily during an intellectual activity (Luria, 1973: 98). This moving pattern of high level of coherent activity among cell ensembles can reasonably be called consciousness (John, 1976).

It seems evident that a mechanism focusing conscious attention to restricted views, a process similar to that described in the previous section, actually exists in the midbrain. Findings about the behavior of thalamus as a selective switchboard and reverbarating unit suggest it acts like a moving searchlight, paying attention to one thing at a time (Crick, 1984).

In the limbic system there are other areas, the excitation of which may cause ultimate pleasure or displeasure. They have a special role as the general controller and motivator of other activities. The behavior of any animal, including humans, acts towards getting the pleasure areas activated (Campbell, 1973). With this background, the limbic system's responsibility is to generate arousal and attention to new areas over and over again. It keeps on the activity to find potential new problems, and to feel satisfaction when a problem becomes solved. Its interaction with the frontal lobe and other associative areas selects which subjects we are interested in, and which arguments we consider relevant for reasoning, ultimately determining our values of life (Bergström, 1986).

It is important to note that the real neural system in itself has such a source of activity with a higher-level homeostatic control. Despite the intensive research done on artificial neural networks, such aspects seem to be totally neglected so far (Freeman, 1988). However, in order to simulate creativity we also have to model these motivation mechanisms of mind (Takala, 1987b).

5.5 A model of creativity

A model about how the brain works in a creative process is inevitably hypothetical and subject to speculation. Also, because of the brain's enormous complexity, it hardly ever can be exactly simulated with computers. Nevertheless, we can draw some analogs and conclusions about how computers can be developed towards more intelligent and creative behavior.

5.5.1 An associative network

First of all, we need a representation, that is data structures holding the knowledge of our design problem. The importance of adequate explicit representations in any form of artificial intelligence cannot be emphasized too much (Winston, 1984).

In our model the knowledge relevant for a situation is represented as a network, whose nodes stand for self-activating neural loops, and the lines stand for mutual activating or inhibiting associations between the loops. It is a network of entities (objects) and relationships, where one can build a coherent model of the world.

The four phases of a creative process, as described in the first section (Wallas, 1926), can be explained with the associative network model (Figure 5.4).

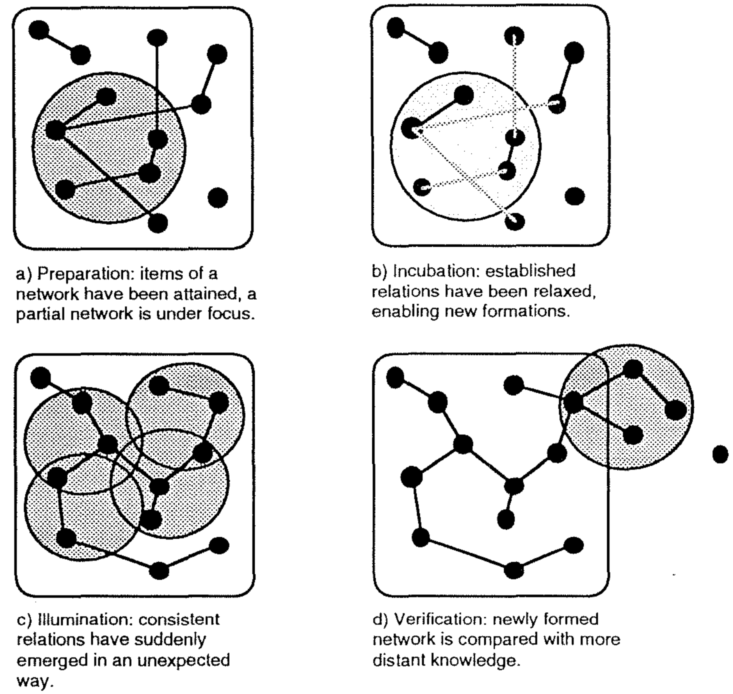
a) In the first phase, knowledge items relevant to the problem are formed. Some associations arise between them and other possible items. They are manipulated in small, possibly overlapping groups, corresponding to different views, but are not yet organized holistically.

b) In the next phase attention is moved away from the problem's network. Then the general activity in the loops is reduced, and the established associations are not continuously reinforced, but become subject to decay and change. Such a situation models the relaxation of constraints, typical in this phase of creative work. Because of the neural network's inherent tendency to organize itself (due to more or less random activation), new associations are automatically formed. However, because of mutual inhibition, not every such network is stable and most such trials soon decay. Contradicting knowledge items tend to compensate each other.

c) Whenever a potentially stable network starts to form, it grows very rapidly due to lack of inhibition, and the corresponding view widens. Almost simultaneous mutual activation is so strong that it starts to activate other brain areas, and suddenly comes to consciousness. This is felt as the moment of discovery.

d) After the sudden illumination, attention will be focused onto the problem again, and the new network will be related and compared, part by part, to other existing knowledge in the network. If no serious conflicts are encountered, the solution will be established and considered verified.

The overall behavior of the model is like assembling a jigsaw puzzle. Some pieces are first found to fit together and to form partial images, but a breakthrough happens only after finding some key pieces connecting them. The rest is then just to mechanically fill in the remaining pieces.



a) Preparation: items of a network have been attained, a partial network is under focus.

b) Incubation: established relations have been relaxed, enabling new formations.

c) Illumination: consistent relations have suddenly emerged in an unexpected way.

d) Verification: newly formed network is compared with more distant knowledge.

Figure 5.4. The four phases of creative process, performed on an associative network. The points stand for knowledge items (objects) and lines for relations between them. Circles are the moving foci of attention. Crossing lines symbolically represent contradictions.

5.5.2 Implications for knowledge engineering

The basic representational idea of objects and relations is similar to that in traditional knowledge bases; the objects can be understood as facts or frames, and the relations as inference rules or reference slots, respectively.

In traditional knowledge bases and expert systems all facts are considered of equal importance, available for inference all the time. Monotonic logic is applied, which restricts every assertion, whether proved by backward reasoning or generated by forward reasoning, to be within the transitive closure of original knowledge. Therefore the whole set of facts is forced to be consistent. Even a single contradiction would make anything logically inferrable with monotonic deductive logic.

In design, however, inconsistencies are a rule rather than an exception. Contrary tentative design alternatives are often kept open before final decisions. And even within one alternative discrepancies between representations may appear (e.g., a dimension may be calculated from other related measures in various ways with slightly different results; calculated results may also differ from preset nominal values). Also, the 'reasoning' in neural systems is concurrent and typically not logical. Even if we may afterwards explain and defend our findings with careful sequential inferencing, the solutions have usually not been reached that way. The order in which facts are considered is nondetermininstic, facilitating chance. Also the 'facts' handled in neural systems are not logical truth values, but continuously-valued signals with variable strength, reinforced by active usage. This means that traditional logic programming is not a sufficient tool for implementing a creative system.

The difference between logical and creative, or vertical and lateral thinking respectively, can be explained with the movement of views (Figure 5.5). It is the same as between monotonic and nonmonotonic reasoning. The former happens with a gradually increasing view where nothing once accepted cannot be discarded anymore, whereas the latter is realized by the focus of attention spontaneously jumping from place to place. This allows some facts to hold in one view and to be contradicted in another (although each view alone is consistent), as required by design practice.

A kind of nonmonotonic reasoning may be achieved using certainty factors associated with facts and rules. Actually such a knowledge base would effectively do the same as the 'connectionistic' neural network described by Rumelhart et al. (1986), later elaborated for creative design by Coyne et al. (1990). Parallel forward reasoning, using additive certainty factors, corresponds to iteratively multiplying the vector of cell activities by the network's connectivity (autocorrelation) matrix. The possible stable states of the network are then the eigenvectors of the matrix (although slightly complicated by the thresholding after summation of cell inputs). Rumelhart et al. (1986) did not analyze the situation that thoroughly, but recognized that the stable states maximize a 'non-energy' function, and that these local maxima are reached by 'hill-climbing' (i.e., optimization by the gradient method). Sejnowski and Hinton (1987) modified the system by 'heating' it with random noise, and then letting slow 'annealing' to statistically reach the global optimum.

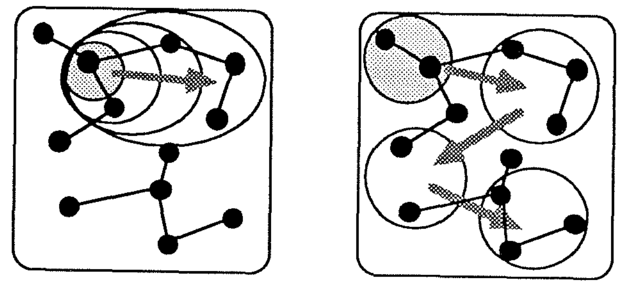


Figure 5.5. The difference between strictly logical and creative thinking, illustrated with movement of views within a knowledge base.

What happens in our model within one view during the incubation phase is actually the same relaxation process as described earlier, although with the minor difference that not only cell activities but also their association strengths may vary (they are not assumed to be direct synaptic connections but mediated by other active cells).

However, a fundamental difference from usual knowledge engineering and connectionistic neural networks is that here we have a dynamically partitioned knowledge base. Each view is the selection of knowledge considered interesting. At any moment during design, only a small portion of all facts is considered and made consistent, but there always remains a possibility for contradictions with the rest of facts. The whole knowledge base may never become consistent, as actually happens with 'wicked problems.'

We also need a mechanism controlling the changes of the focus of attention. In the brain such mechanisms are on one hand the pleasure areas, determining if we enjoy a state or wish to move into another. Where to move, on the other hand, is directed by the associative areas of cortex, coordinated by the frontal lobes. They generate free associations, not necessarily following the most logical reasoning routes.

In the computer model this mechanism could be based on time-dependent feedback from a consistency detector, which continuously measures the currently active view's coherence. It would keep us in an inconsistent view, trying to solve its problem. However, if no progress is made for some time, the view will automatically be changed, that is some knowledge may be dropped and new items added, or a totally new focus may emerge.

The basic idea is that a view is stable only as long as it is enjoyable. The interest is sustained within the view as long as there are inconsistencies being resolved, but ceases when full coherence is achieved. The system would widen the view whenever consistency is reached—the faster the easier consistency is found—but ultimately, if everything became rigidly consistent, the system would disturb itself by randomly corrupting any facts, producing new motivating problems for itself. It would have a homeostatic tendency to always be active (Takala, 1987b).

5.6 Conclusions

In this chapter, a system has been sketched, which might have creative behavior. It is an associative network of knowledge, combining features from both the neural network models and the functional neuropsychological models of brain. A classical process model of creativity has been demonstrated within this model.

A fundamental concept in the system is a view—a dynamic partition of the knowledge base, containing those objects and relations that are considered relevant at a moment. It allows the knowledge base to contain partial design solutions, which during a design process are not yet consistent with each other.

The control strategy for the views is based on a consistency detector, which corresponds to the pleasure areas of brain. It keeps the system continuously active, solving problems given from outside or generated by itself. Creativity is understood as the system's inherent tendency to solve problems and to enjoy that.

The goal has been to research, how creativity could be developed within a computer system, and which basic mechanisms are needed for this. An active, creative system could serve as a more intelligent apprentice for a human designer than the current logical knowledge bases. However, still much reasearch is needed in order to make the approach practical.

A simple experimental system with the features described earlier may be constructed using hypermedia techniques. A generalized product model, consisting of objects (simple facts) and associative relations (activating or inhibiting) between them, is a network where the designer can freely move and make new constructions. The hypermedia environment makes it easy to incorporate any types of representations and to utilize the designer's associative and creative capabilities through the interactive user interface.

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