INTELLIGENT AGENTS FOR CONCEPT INVENTION OF DESIGN FORMS

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Abstract. Concept invention refers to the act of discovering new concepts for the first time. Concept invention may require a new interpretation that motivates new mappings of the situation prior to the discovery of a new concept. This paper is concerned with developing intelligent design agents that would be capable of inventing creative concepts of design forms, shapes and compositions while involved in the design process. A new approach of exploiting the old notion of "*displacement of concepts*" with regard to concept invention in designing in the form of mobile design agents is adopted and utilised in developing the structure of intelligent mobile agent-based system.

1. Invention of Design Concepts

Design concepts are composed of rich sets of categorised abstractions of the mutual relationships between observations and actions. This research adopts the view that the process of designing is situated (Reffat and Gero, 2000) and design concepts are formed as consequences of the situatedness of design actions (Gero and Fujii, 2000). The process of designing is intertwined with discovery within and between design episodes whereby unintended consequences of design actions occur. Design actions are determined and executed in relation to: (a) some goals; (b) observations of the circumstances in which they were performed; and (c) internal state of the agent that performs the actions. A recent protocol design study has provided evidences that unexpected discoveries (inventions), play an important role in designing (Suwa, Gero and Purcell, 1999). New concepts emerge out of the interaction of old concepts and new situations. The old concept is not simply re-applied unchanged to a new instance. The new concept emerges in terms of situation within which the new instance is perceived.

The invention of new concepts involves discovery of the world; that is the development of a new way of looking at the world. The notion of displacement of concepts (Schön, 1963; Schön, 1967) is utilised as a process of inventing new concepts. Displacement is a metaphor for the process by which the extension of after-the-fact notion is affected. It means that new concepts include a type of new instance to the ordinary use. The displacement of concepts is different in kind from comparison, error, or the application of concepts to instances; and that is central in the formation of new concepts.

Concepts invention comes through the shift of old concepts to new situations. In this process, the old concept is not applied to a new situation, as a concept to an instance, but is taken as a symbol for the new situation. The new concept grows out of the making, elaboration and correction of the symbol. A number of phases are included in this process: transposition, interpretation and correction. These phases always occur in a specific context and situation. These are not discrete events following one another in a fixed order but aspects of the process often out of sequence and often inseparable. The difficulty with the process of considering new concepts in view of the old requires no changes in concepts. Comparison, and the correct or incorrect application of a concept to an instance have to do with the relation of concepts already formed, or the relations of concepts to situations stripped of their novelty. In this research, invented concepts are those that emerge for the first time for an agent whether they are new to its environment or not. They are new in themselves for this specific agent.

2. Invention and Creativity

Invention and creativity have diverse applications and have been studied by some scholars (Gordon 1961, Koestler 1964, Schön 1963). Perhaps the most striking example is provided by a case-study by Schön (1963) where a product development team was faced with the problem of figuring out why synthetic-fibre paintbrushes were not performing as well as natural fibre paintbrushes, and to improve their performance. The members of the team tried many ideas; for instance, they noticed that the natural fibres had frayed ends, and they tried to have synthetic fibres with frayed ends too but without success. The breakthrough came when one member of the team suggested that the paintbrush might work as a pump. This idea was initially considered quite shocking, for a paintbrush and a pump were thought to be very dissimilar. Yet, in trying to make sense of the analogy, a new ontology and structure for the paintbrush was created. In this new representation, the paint was sucked in the space between the fibres through capillary action, and when the fibres were pressed against the surface to be painted, the curve of the fibres caused a difference in pressure that pumped out the paint from the space between the fibres onto the surface to be painted. From this new ontology, when the synthetic-fibre and natural-fibre paintbrushes were compared, it was found that the synthetic fibres bent at a sharp angle against the surface, whereas the natural fibres formed a gradual curve. Thus, juxtaposition with pumping caused a new perspective to be created on the process of painting and paintbrush.

Invention and creativity are known under various garbs: Gordon (1961) calls it "*making the familiar strange*", Schön (1963) refers to it as *"displacement of concepts"*, and so on. But the basic idea is to juxtapose dissimilar concepts or objects so as to create new meanings and new perspectives through their synthesis. The underlying idea here is that if one recalls similar objects or concepts together, because they are already similar, their juxtaposition does not create any new meanings or perspective. However, putting dissimilar objects together forces one to reconsider the objects, and to stretch the imagination in order to find some meaningful connection. Whenever this process is successful, the resulting insights are often quite novel and striking. Famous poet Dylan Thomas, for example, described a similar mechanism that he claimed he used often while composing his poetry. The emphasis behind this mechanism is in moving away from similarity. This is a cognitively difficult task because our minds are full of associations which are not easy to ignore. Hence various techniques like emptying the mind, random juxtaposition, etc. are taught as techniques to enhance one's creativity.

Juxtaposition of dissimilar is difficult for us as human agents because we are constrained by the associations of our concept networks that we inherit and learn in our lifetime. So it requires a significant amount of cognitive effort to break away from these associations. On the contrary, computers do not have such conceptual associations. In fact, in artificial intelligence research a great deal of time and effort has been spent in modelling these conceptual associations. Semantic networks, frames, scripts etc. are formalisms developed to capture this associativity. So, it follows that it must be easier for the computers to break away from the conceptual association than it is for people.

3. Computational modelling of creativity and invention

Creativity might be modelled computationally by having multiple cognitive/perceptual layers with gradually increasing degrees of abstractions. For simplicity, we limit it to two layers here: the *perceptual layer* contains less abstract perceptual, imagery, and episodic data; and the *conceptual layer* contains the more abstract conceptual representations. This is shown in Figure 1. This requires both top-down and bottom-up mechanisms to work together and to connect the conceptual representations to the perceptual data. These inter-level connections are referred to as *interpretations* where the top-down mechanism is seen as *projection,* and the bottom-up mechanism as *accommodation.* Both the conceptual and perceptual layers should have their own autonomous structures. The structure of the conceptual layer reflects the conceptual associations; and the structure of the perceptual layer reflects prior perceptual experiences (episodes) with the objects. This requirement presupposes an autonomous memory for each layer where the associations or structures of the respective layers are stored. Also, there should be conventional interpretation relations between the two layers through which it is possible for concepts to evoke perception-like images of the corresponding objects in the perceptual layer, and for the images in the perceptual layers to activate their corresponding concepts in the conceptual layer. Conventional interpretations can be modelled as the default operations of the top-down and bottom-up operations of projection and accommodation. It should be emphasised that these inter-level activations are constrained by the autonomous structures of the respective memory modules. That is, when certain concepts evoke imagery in the perceptual layer, this imagery will be constrained by the prior perceptual experiences of the cognitive agent as reflected in the structure of the perceptual memory. A crucial final assumption is that the image created in the perceptual layer (evoked by the concepts in the conceptual layer) can sustain itself and can be made available for reinterpretation. It is important to point out that the empirical research on this issue is controversial (Indurkhya, 1998).

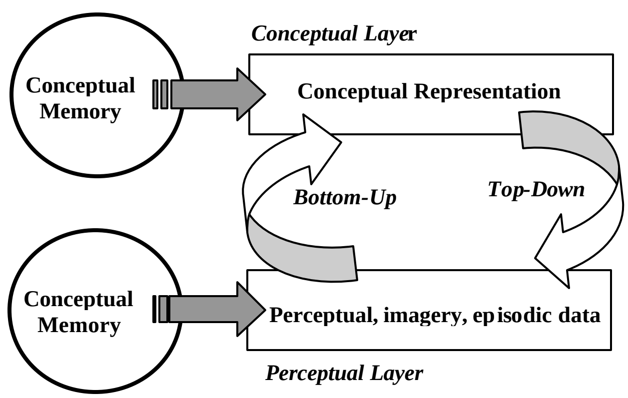

Figure 1. A two-layered architecture for modelling creativity (Indurkhya, 1998).

Computational modelling of the "displacement of concepts"

The notion of "*displacement of concepts*" or "*juxtaposition of dissimilar*" might lead to creative insights. It could be modelled computationally as shown graphically in Figure 2. It is assumed that one of the objects of juxtaposition is the focus of attention and referred to as the *topic*, for example the phenomenon of painting in Schön's example. However, it is also possible to have symmetric juxtapositions (as common in poetry and art) and this can be extended to cover this case as well.

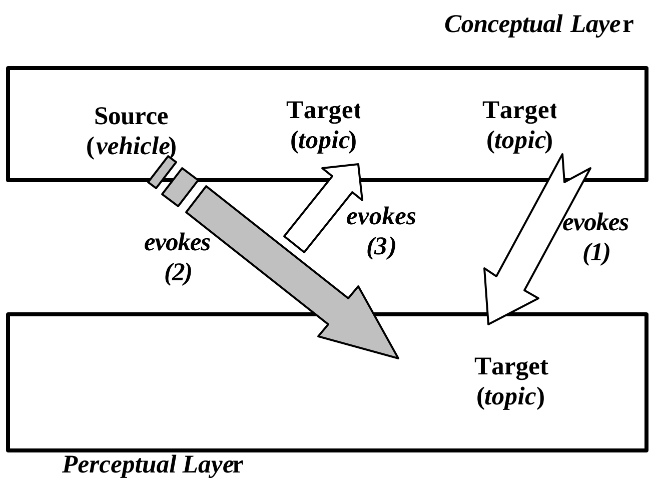

Figure 2. Creative insights by "*displacement of concepts*". The source concepts interact with the target image to create a new representation (with new features) of the target in the conceptual layer (Indurkhya, 1998).

As shown in Figure 2, both the *topic* and the *vehicle* concepts are activated in the conceptual layer. The *topic* concepts evoke the imagery of the associated objects, and the *vehicle* concepts are projected on this imagery in a top-down fashion. As a result a new set of concepts get activated for the *topic*, and constitutes a new perspective on it. Thus, the juxtaposition of dissimilar requires essentially modelling the top-down mechanism of projection. It is useful to point out that there are existing systems that do this kind of projection and can demonstrate 'creation' of features to some extent. For example, in a recent system to detect man-made objects in satellite imagery (Mandal, Murthy and Sankar 1996), if a certain part of the image is identified as an airport runway, conceptual features associated with the airport, like terminal buildings, car parking areas, etc. are projected onto the neighbouring parts of the image. Similarly, in a speech recognition system, if the topic of conversation is known or identified, related concepts are projected onto the sound pattern (Erman et al, 1980). There are also certain models specifically devoted to exploring this mechanism of creativity by juxtaposition. For example, Hofstadter (1995) have focused on simple but surprisingly rich domains such as letter strings and letter forms, and have implemented several systems to model how creative insights might be generated.

Taking this viewpoint, computers have a creative potential however humans have the ultimate determination in choosing what ways an object or situation is considered meaningful. But computers can explore this meaning space more thoroughly and provide perspectives that can lead to new insights.

4. Intelligent Agents for Concept Invention

Intelligent agents enjoy the following properties: autonomy, reactivity and pro-activeness whereby they do not simply act in response to their environment, they are able to exhibit goal-directed behaviour by taking the initiative (Wooldridge and Jennings, 1995). A general view of invention is as a search through a virtually infinite "problem space" of possible solutions whereas the challenge of an invention-agent is to reduce the size of, or find a route through, the problem space (Carlson and Gorman, 1992). For intelligent agents to be capable of inventing creative concepts they need to be mode shifters and adroit in any situation they encounter and ready to bridge boundaries by flexible casting or by following the thread of logic wherever it may lead in. They should have the capacity to convert old concepts to new ones by adroit abstraction, reasoning and the use of heuristics (Perkins, 1992).

This paper introduces a framework of multiple intelligent design agents that would have the capability of inventing new concepts of design forms. A new approach of exploiting the old notion of "*displacement of concepts*" with regard to concept invention in designing is adopted and utilised in developing the structure of intelligent design agents. The notion of displacement of concept is integrated within the framework through the mobility of each design agent. Each agent is considered as a concept invention agent (CIA) (Reffat, 2001). The structure of each CIA allows the agent to be a mobile agent. This requires equipping the agent with the capability of being a mode shifter in any situation it encounters based on its own perception and conception of the new situation without prior knowledge of such situation pre-coded into the gent's knowledge-base. The agent's capacity of viewing design environments differently and being adaptable to new environments allows transposition, interpretation and correction of concepts to occur and possibly leads the agent to invent new concepts. Such new concepts have a great potential in supporting design invention.

4.1 WHY USING MOBILE AGENTS?

First, an agent is viewed as a process that may migrate through a computer network in order to satisfy requests made by its clients. Agents implement a computational metaphor that is analogous to how most people conduct business in their daily lives. Mobile agents are defined as active objects or clusters of objects that have behaviour, state and location. Mobile agents are autonomous because once they are invoked they will autonomously decide which location they will visit and what instructions they will perform. This behaviour is either defined implicitly through the agent code (Gary, 1997) or alternatively specified by an -at runtime modifiable- itinerary (Wong et al, 1997). The employment of mobile agents has been particularly promising in application domain like information retrieval in widely distributed heterogeneous open environments (Baumann et al, 1999).

Mobility is an orthogonal property of agents. That is, all agents do not necessarily have to be mobile. An agent can just sit there and communicate with the surroundings by conventional means. These means include various forms of remote procedure calling and messaging. Our interest in mobile agents is not motivated by the technology per se, but rather with the benefits they provide for the creation of distributed systems and the possibility of employing the cognitive mechanisms of juxtaposition of dissimilar "*displacement of concepts*" computationally using mobile intelligent agents and the great potential of achieving a creative process for concept formation based on reinterpretation for creation.

4.2 MOBILE CONCEPT INVENTION AGENTS

A mobile CIA is an intelligent agent that can move or migrate from its initial environment to a new execution environment. An execution environment includes an external representation of a design composition and provides a medium for agents to communicate and reside in the environment. The actual immigration can be done primarily in two ways (Hohlfeld, 1998): either the entire thread context and the state of the agent is sent over, or only the state is sent over. The former approach is used by the most popular agent systems available, such as Voyager (ObjectSpace, homepage) and Aglets (IBM-Corporation, homepage). Aglets supports remote communication among agents. Voyager is essentially not an agent framework but rather an application server with agent support. However, agents are not only made up of states. The code that is used to run the agent must also be transferred to the new execution environment. A graphical representation of a migrant agent between two execution environments is shown in Figure 3. In this research the entire thread context and the state of the agent is sent over to its new environment in case of immigration but only the state of an agent is sent over while travelling or moving across environments. There is always an adaptation process involved for a mobile agent to reside in a new environment.

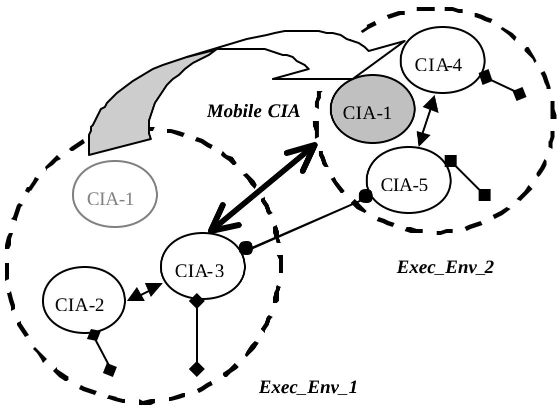

Figure 3. An illustration of a mobile, Concept-invention Agent (CIA), migrating from its initial execution environment to another environment.

4.3 MOBILE AGENT INTERACTION

The framework of a multiple mobile CIA system involves an investigation of autonomous, rational and flexible behaviour of mobile agents, their interaction and coordination in cooperative or competitive settings. It is very difficult and sometimes impossible to foresee all potential situations an agent could encounter and specify the agent's behaviour in advance. Domain knowledge and the ability to learn and act in relation to the situation encountered are necessary features of the proposed mobile agents within a multiple CIAs system. Mobile CIAs must have the capability to communicate with the surrounding world. Both direct and indirect types of communications are considered between mobile agents within an execution environment or remotely with other environments. Examples of possible types of communication among agents and execution environments are shown in Figure 4. Within this framework each agent is expected to modify its behaviour as the situation changes and to interact with other agents in its new environment and other agents in other environments remotely. The forms of interactions and co-operations within a multiple mobile CIAs system are to be assessed from the viewpoint of their role in achieving a displacement of concepts that supports design invention.

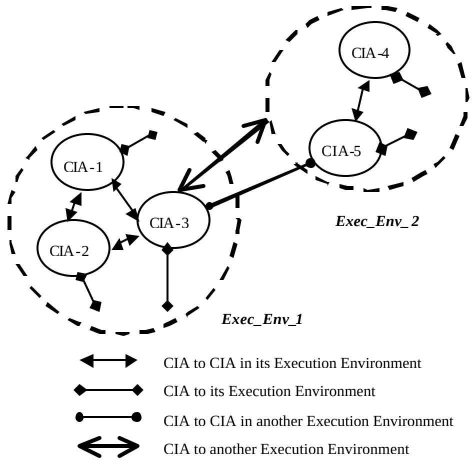

Figure 4. Various types of communications among CIAs within and outside its execution environment.

4.4 CONCEPT GENERATION

To generate creative design concepts, it is best to come up with a high number of concepts at the beginning of a design process without worrying too much about feasibility. Afterwards one can narrow down and select the concept to pursue. It is also essential to be able to communicate the design concepts effectively. In conceptual design the process of concept generation of design forms commences by establishing structural relationships and searching for regularities and combining them into concept variants. The concept generation and clustering algorithm utilised in the mobile CIAs agent–based system is beyond the scope of this paper. However it is utilising a Robust Competitive Agglomeration (RCA) algorithm (Frigui and Krishnapuram, 1999) that starts with a large number of clusters to reduce the sensitivity to initialisation, and determines the actual number of clusters by a process of competitive agglomeration. Noise immunity is achieved by incorporating concepts from robust statistics into the algorithm. RCA assigns two different sets of weights for each data point: the first set of constrained weights represents degrees of sharing, and is used to create a competitive environment and to generate a fuzzy partition of the data set. The second set corresponds to robust weights, and is used to obtain robust estimates of the cluster prototypes.

5. Intelligent agents for concept invention of design forms

In architectural designing, as in many other design disciplines, creating design forms is an important design activity. Through forms and shapes designers express ideas and represent elements of design, abstract concepts and construct situations. The formation and discovery of relationships among parts of a design form are fundamental tasks in designing. The abstraction and explicitness of these relationships in a recognised drawing can therefore lead to a closer and better understanding of shape semantics. These semantics may play a crucial role in developing new ideas if designers pursue them further.

Here is an illustration of a single concept-invention agent (CIA) in the domain of designing shape compositions. This CIA is pre-programmed to have a set of sensors with which it detects its encountered environment. This set of sensors incorporates the recognition of square, rectangle and triangular shapes as shown in Figure 5(a). When the CIA encounters an environment that includes an external representation of a shape composition as shown in Figure 6(a) it generates an infinite maximal line representation of this external representation as shown in Figure 6(b). The infinite maximal line representation is generated by extending the line segments in the external representation to the boundary of a selected frame. The CIA develops a set of representations from the infinite maximal line representation using its initial sensors as shown in Figures 6(c) and (d). The infinite maximal line representation provides a platform for new invented concepts to be discovered by the CIA such as the set of shapes shown in Figure 5(b). The CIA uses its discovered concepts as new sensors to perceive the environment, eg. external representation. Figures 6(e) to (h) show different set of representations using the new sensors.

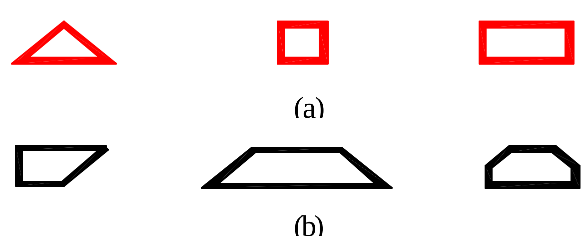

Figure 5. (a) Initial sensors available to a CIA and (b) invented concepts by a CIA and used as new sensors to detect various environments.

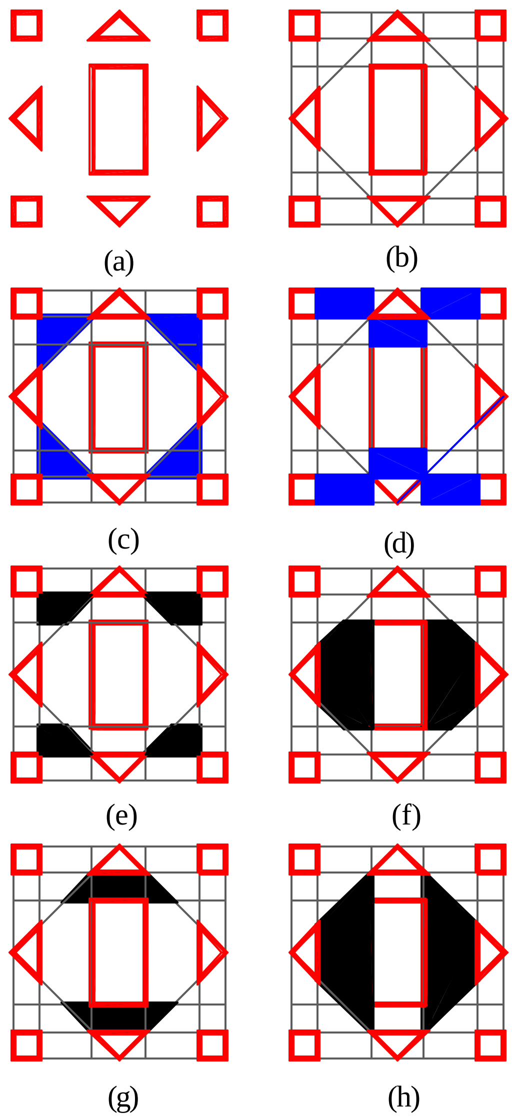

Figure 6. (A) An external representation available in the design environment, (b) an infinite maximal line representation of the external representation, (c) and (d) two representations developed by a CIA using its initial sensors, and (e) to (h) four representations developed using discovered concepts as new sensors.

6. A Brief on the Implementation of Mobile Concept Invention Agents

This section provides a brief of an undergoing implementation of mobile concept invention agents of design forms and shapes. Mobile agents are defined as an encapsulation of code, data and execution context that is able to migrate autonomously and purposefully within various execution environments (hosts) within a computer network. The fundamental ideas of Java-based agent system have been devised in the scope of Mobile CIAs. We are building on the MOLE (Baumann et al, 1999) agent-based system that is mainly based on the concepts of agents and places. Places provide the environment for executing local and visiting agents. An agent system consists of a number of places, being the home of various services. Agents are active entities that may move from place to place to meet other agents and access the places' services. In this model, agents are multi-threaded entities, whose state and code is transferred to the new place when agent migration takes place. Each agent is identified by a globally unique agent identifier. An agent's identifier is generated by the system at agent creation time. It is dependent of the agent current place and it does not get changed when the agent moves to a new place. A place is entirely located at a single node of the underlying network, but multiple places may be implemented at a given node.

Considering inter-agent interaction, there are three types of communications: mobile agent/service agent interaction; mobile agent/mobile agent interaction; and anonymous agent group interaction. In the MOLE agent-based system message passing is session oriented which means that agents wanting to communicate need to establish a session before they can exchange information.

7. Discussion

This paper introduced a conceptual framework of multiple concept invention agents to provide the capability of autonomous and cooperative agents in order to create new design forms. Since the implementation prototype is not yet completed, so it is early at this stage to conclude on the functionality and performance of the proposed mobile CIAs agent-based system. The future work consists of four areas. First is the implementation in terms of performance and robustness; second is observing efficiency of the concept invention process and the usefulness of the proposed Robust Competitive Agglomeration (RCA) algorithm; third is to test the role of various communication types and migration places on the discovery of new concepts; and finally is to evaluate the innovation and creativity of invented concepts based on their newness and uniqueness for the required task.

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