OPERATIONAL CHARACTERISTICS OF A CONSTRUCTIVE MEMORY SYSTEM FOR DESIGN AGENTS

LIEW Pak-San and GERO John S.
Key Centre of Design Computing and Cognition, University of Sydney

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Abstract: This paper describes the operational characteristics of a constructive memory for a design agent that distinguishes it from a standard retrieval system. An architecture example pertaining to this behaviour of the system is also illustrated through a simulation of the memory system.

1 INTRODUCTION

Situatedness in designing involves taking account of both the external and internal environment of the designer as part of the design process. It requires the explicit consideration of the effects of the current external environment, the internal state of a design agent; and the interaction between the environment and the agent, on the behaviour of a design agent in performing a design task. Fundamental to this characteristic of designing is the notion of constructive memory (Gero 1998, 1999, 1999). By incorporating a constructive memory system into a software design agent, the behaviour of the agent can be made situated thus allowing it to operate within an environment that was not pre-programmed into the system. This paper describes the implementation of a constructive memory system and outlines the behaviour that set its behaviours apart from standard design memory retrieval systems. An application of these behaviours is illustrated in the redesign of walls.

2 THE PROCESS OF MEMORY CONSTRUCTION

Memory construction occurs whenever a design agent uses past experiences and knowledge within the current design environment in a situated manner. Associated memories are constructed and grounded according to the current interactions between the agent and the environment. This process is in contradistinction to memory as a retrieval process, where there is a “memory” stored that can be

retrieved directly and the retrieval has no effect on the "memory".

Within a constructive memory system, the very act of constructing a memory of an associated design experience affects that memory through its grounding in the interaction with the environment. Any information about the current design environment, the internal state of the agent and the interactions between the agent and the environment is used as cues in the construction process.

Figure 1 illustrates the memory construction process carried out by a design agent in performing a design task. Memories that define the actions to be performed are constructed from existing experiences and earlier memories of these experiences together with knowledge processed by the agent. This construction process is affected by the amount of learning that has taken place since the system has last obtained that experience and since it had constructed memories of that experience. The agent's knowledge determines what is extracted from the environment and the way in which the extracted information is structured. This knowledge, experiences and memories form part of the design situation and affect the kinds of memories that are constructed.

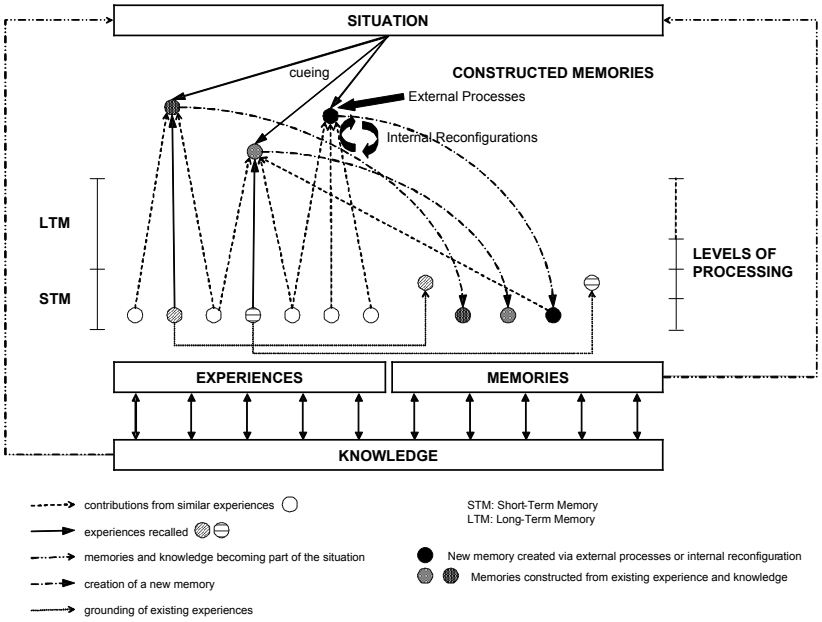

Figure 1 Memory construction process (based on Gero (1999a))

As the usage of a particular experience (memory) increases, its grounding increases and the memory trace representing this experience becomes more durable. This difference in durability is reflected in the level-of-processing within the memory system. The higher the level a memory resides, the more likely that memory will be used in the subsequent memory construction process. This effect models the process

of long-term learning within the system.

Another form of learning is constructive in nature. In this mode of learning, new information is added into the memory system. There are two ways in which this can be done. In the first instance, new information is added through external designing reasoning processes such as analogy, combination, mutation and designing from first principles (Rosenman and Gero 1993) and reformulation processes (Gero 1998) that deal with re-parameterization and parameters expansions. In the second instance, the memory system reconfigures itself to produce new memories.

3 SYSTEM'S BEHAVIOUR

The behaviour of a constructive memory system within a situated environment has the following characteristics:

- memory operates as a dynamic process, it is not a static imprint to be stored in a specific location and retrieved for used later;
- the operations of the memory system are not predefined, they are influenced by the situatedness of designing;
- construction of memories do not rely on the exact matching between what the agent has in the memory system and the current designing environment; and
- memories that are constructed may not match the original experience exactly as it was first experienced, but change according to when, where and what the memory system is cued with.

The use of past design experiences entails a construction process where memory traces are recollected, reconfigured and combined or created through external processes according to the current design situation. Once the memory of a past experience has been constructed and serves its purpose in the current design session, the newly created memory is disassembled into a collection of memory traces and integrated gradually into the memory system.

The behaviour of the memory system is dependent on:

- the current external environment;
- the current internal state of the design agent; and
- the interactions between the agent and the external environment.

This dependency must be present whenever the design agent uses its past experiences while performing its current design task through the memory construction process so that the overall behaviour of the memory system is not predefined and its operations are based on the situatedness of designing.

3.1 Design and Implementation of the Memory System

Liew and Gero (Liew and Gero 2002) describe the design of a constructive memory system based on the notion of constructive memory in design (Gero 1998, 1999, 1999). The design is inspired by cognitive models of the human memory. In particular the following models of human memory are adopted:

- modal model of human memory system (Atkinson and Shiffrin 1968);
- multiple-component model of long-term memory (Baddeley 1999); and
- multiple-component workspace model of the human working memory (Logie 1995).

In developing the implementation model of the constructive memory system, various components are extracted from these models. The criteria for the selection of components are dictated by the operation of a constructive memory system as described previously. The aim of the implementation model is not to model the behaviours of the human memory, but to utilize the components from various cognitive models that provide the required characteristics.

The implementation of the constructive memory is based on a parallel distributed processing model of the medial temporal memory system by McClelland (McClelland 1995). The Interactive Activation and Competition (IAC) network (McClelland 1981) is used to implement this model.

In the current implementation, the system's knowledge of an individual design experience is represented as an instance node linked to a set of property nodes through excitatory connections. The connected property nodes represent the constituents of a design experience such as: action on the agent or on the environment; initial and final focused concepts; percept; initial and final expected percepts; initial and final exogenous sensory data and initial and final exogenous variables.

4 REPRESENTATIONS

The notions of a *design situation* and a *design experience* are based on the work on concept formation by a situated design agent (Gero and Fujii 2000). A design situation[1] models a particular state of interaction between a design agent and the environment at a particular point in time. It is a snapshot of all the variables that define the internal state of the agent and that part of the external state of the environment that the agent is interacting with. The expectation and interpretation of the agent may or may not be in agreement with each other. A design experience

[1] *A design situation is different from a situation in the context of this paper. A situation describes the conditions pertaining to a particular design session where a design agent is performing the act of designing.*

models the transition of state from one design situation to another in which the expectation must match the interpretation after the transition. The set of actions that facilitates this transition is also captured.

Symbolically, a design experience, E, is represented by a collection of constituent parts: E = {Vi, Si, P, Qi, Hi, A, Hf, Qf, Vf, Sf}, where A is the action performed on the agent or on the environment; H_i, the initial focused concept; H_f, the final focused concept; P, the percept; Q_f, the final expected percept; Q_i, the initial expected percept; S_f, the final exogenous sensory data; S_i, the initial exogenous sensory data; V_f, the final exogenous variable and V_i, the initial exogenous variable. Each of these components are described in more detail in (Liew and Gero 2002).

Figure 2 illustrates an example of a design experience within the context of redesigning the walls of a room for additional functionalities. The goal of the agent is to modify the structure of the wall to satisfy additional requirement such as sound insulation. All the bare walls (P,e4,1,d) represented by the external structure in the environment (Vi,e4,1,1) are replaced by composite walls (P,e4,1,2) through the action (A,e4,1,1) performed by the agent to create a new external structure Vf,e4,1,2).

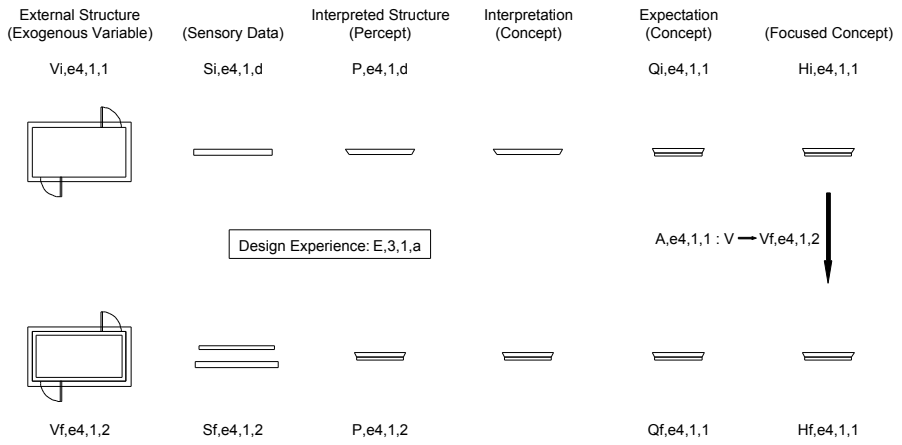

Figure 2 A sample design experience for redesigning walls

5 OPERATION OF THE MEMORY SYSTEM

A design agent starts off the redesign process with a set of design goals based on any new or additional performance requirements. These goals to be fulfilled are sequenced into an order according to the current design situation encountered by the agent.

For each goal selected, the associated focused concept (Hi,e4,1,1) is combined with the external structure, Vi,1,x,y (representing the existing design) to form a partial

design experience, E,1,x,y to be used as a cue into the memory system, Figure 3.

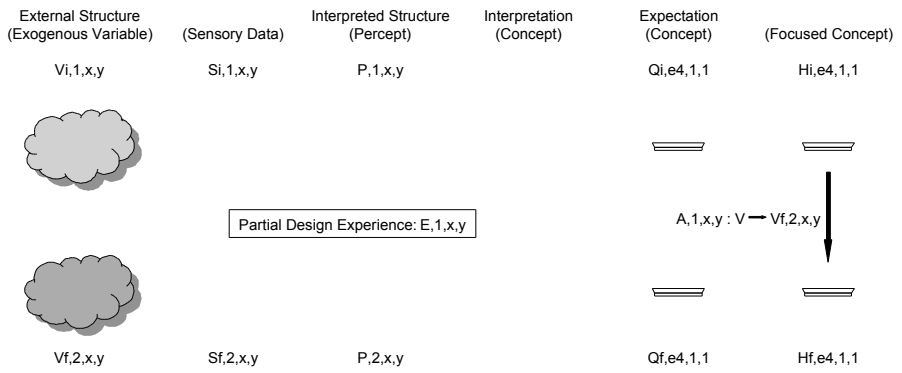

Figure 3 A partial design experience used to start off the memory construction process

The network is clamped by setting external input to nodes representing these constituents of the partial design experience and then cycled. The result of cycling the memory system according to this initial partial design experience is a set of related design experiences with different strengths based on the associations between memory traces captured implicitly within the network, Figure 4. The focused concepts from these experiences are alternative concepts that are related to the initial focused concept contained in the cue. If various alternatives are to be explored, each focused concept is processed sequentially. The other constituents of these experiences provide possible candidates for completing the initial partial design experience to form a complete memory.

There are various ways to complete the partial design experience, E,1,x,y since there are several options for filling each of the slots for the percept, initial expected percept, initial focused concept, action, final focused concept and final expected percept. However, most of these combinations are not applicable due to the inter-relations between the constituents of a design experience. For example, a focused concept is always associated with a particular expected percept if the former represents a design prototype and the latter represents an expected structure. Some of these heuristics are captured by the existing design experiences that are highlighted during the memory construction process. A pragmatic way to get the valid combinations is to consider the highlighted instance nodes and extract the valid combinations based on their configurations. Figure 5 illustrates a possible memory that can be constructed based on the constituents of a particular design experience, E,3,1,a, Figure 2, highlighted during memory construction.

The focused concept (Hi,e4,1,1) represents a design prototype (Gero 1990) that the agent is currently using. The function, behaviour and structure (FBS) information from this prototype are extracted via conception to form the expectation, Qi,e4,1,1 according to the current focused concept.

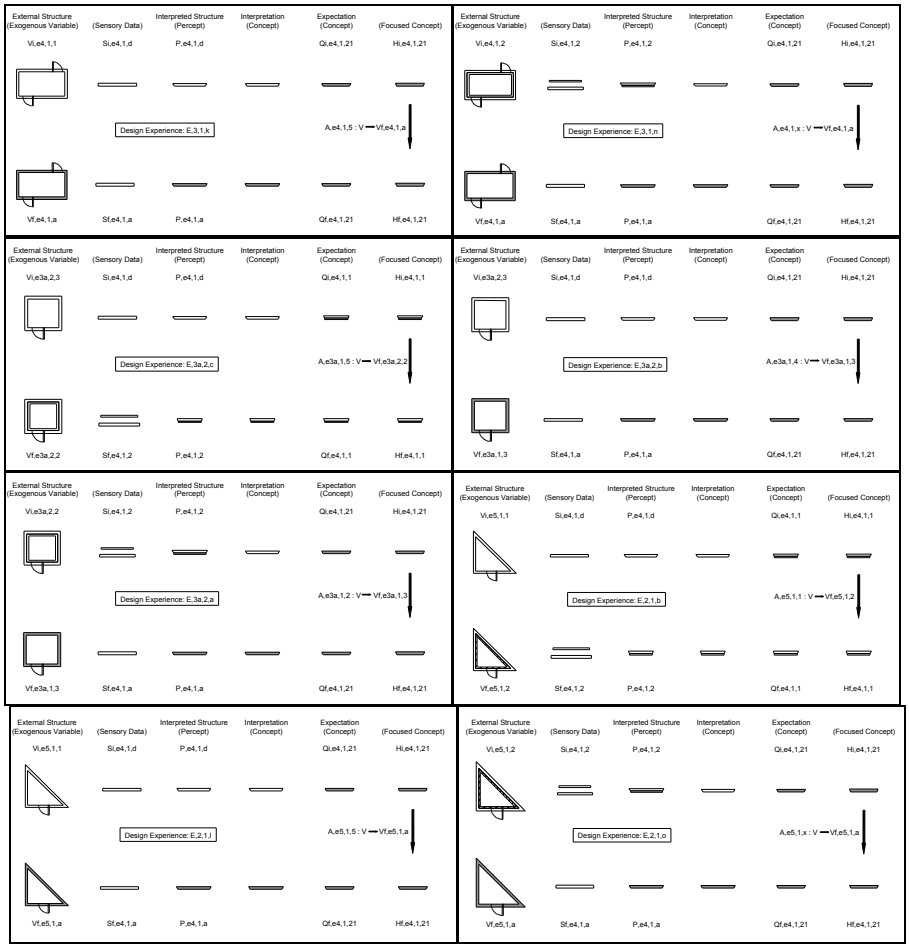

Figure 4 Similar design experiences that are highlighted during memory construction

The FBS information from the focused concept is also used in perception to bias the sensation process and structure the exogenous sensory data (Si,e4,1,d or Si,e4,1,2). The functional information (F) dictates which part of the environment will be focused upon and sensed into the agent. Only parts with the same function as that of the focused concept are extracted from the environment. The sensory data is configured into a complete assembly to form the percept (P,e4,1,d or P,e4,1,2) during perception. An interpretation is created by from this percept by embedding the functional, behavioural and structural information about the entities from an external database of design prototypes. This interpretation is compared to the expectation, Qi,e4,1,1 created from the FBS information of the focused concept in terms of the required behaviour dictated by the current design requirement. The required behaviour may appear as an additional required behaviour variable or as a common behaviour variable with a desirable value. The outcome of the comparison dictates

whether there is a performance difference between the agent's expectation and the interpretation of the environment. A higher performance can either appear as the present of desirable behaviour variables (in this case) or as desirable values of behaviour variables common to both the expectation and interpretation. This disagreement forms the basis for effecting the action, A,1,x,y to the environment to change Vi,1,x,y to Vf,2,x,y.

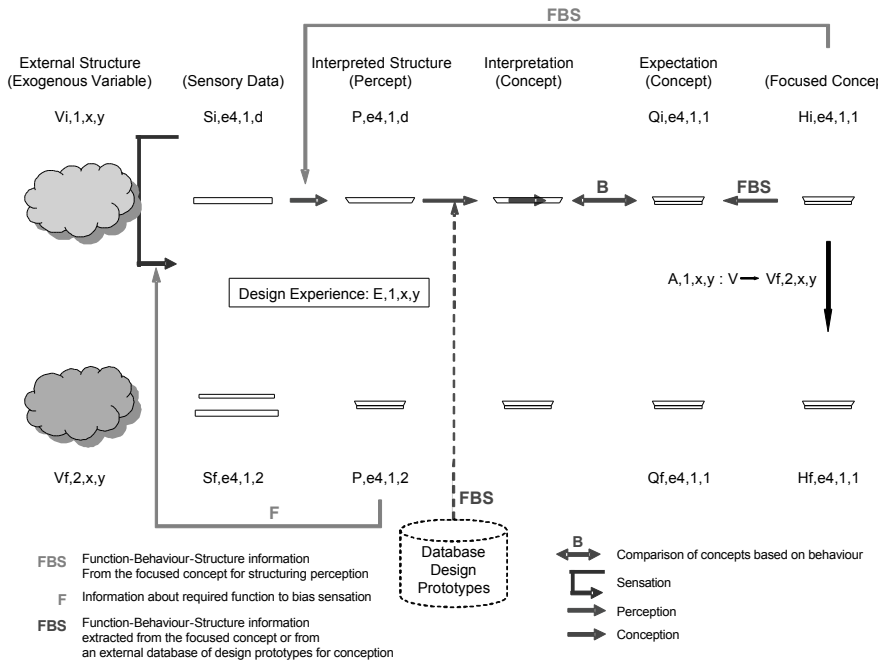

Figure 5 A constructed memory that provide alternative interpretations of the external structure presented to the agent

Note that the sensation and perception processes are required to extract the sensory data and percept from the environment to from a complete design experience.

If another alternative experience is considered, the process described here is repeated according to the new constituents provided by that experience.

5.1 Interpretation of Results

The memory construction process provides information (based on past experiences) for the following:

- alternative focused concepts that are associated with the current focused concept;
- alternative expected percepts based on the focused concepts together with

their associated feature detectors and structuring procedures to manipulate sensory data during sensation; and

- alternative actions to operate on the design artefact to fulfil the design requirements so that the agent's expectation and interpretation can be matched.

An important behaviour of the constructive memory system is the triggering of associated concepts (Hi,e4,1,21 in this case). The original focused concept, Hi,e4,1,1, triggers the activation of other focused concepts and effectively forms a cluster of associated concepts. The same phenomenon is observed in the list of exogenous variables that are highlighted. The list of external structures (Vi,e4,1,1, Vi,e4,1,2, Vi,e3a,2,3, Vi,e3a,2,2, Vi,e5,1,1, and Vi,e5,1,2) that are activated forms another cluster of similar artefacts based on the current focused concept and its associated design requirements. This is the differentiating factor that sets the memory system apart from a pure database retrieval system: memories are constructed according to the cue sent into the system *and* its associations with the contents of the memory system. Clusters of memory constituents are formed on the fly as a result of the cue into the system. These results of the memory construction process cannot be obtained from a simple query into a SQL database based on set theory.

6 CONCLUSION

The operational characteristics of the memory system implemented described in this paper is based on the theory of constructive memory in design. Essentially what is constructed by the system is a collection of candidate (partial) design experiences for the current situation based on the information the agent has. The constructed experiences provide alternative information for what to do in terms of how the sensory data of the design artefact is to be structured and what action is to be performed on the artefact based on the requirements of the selected design prototype or related design prototype highlighted by the memory system. These memory traces are still subjected to verification by the agent through its interaction with the environment before they are incorporated into the memory system as new experiences. This act of memory construction is situated as it varies according to when, where and what the memory system is cued with.

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