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SITUATED DESIGN INTERPRETATION USING A CONFIGURATION OF ACTOR CAPABILITIES

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Abstract. A designer looking at a drawing sometimes notices things not originally intended. Conversely, not all implications of a design action are considered before each depiction action is taken. This paper describes an approach to understanding and reproducing this behaviour based on a situated interaction with an external representation.

1. Introduction

How is it possible for two designers looking at the same drawing to “see” different things? Also, how is it possible for a single designer to look at their drawing later and see things that they didn't intentionally put there? These are important aspects of conceptual designing. However, in order to build computational systems that will help us understand and produce this behaviour we need new approaches. This paper describes one such new approach.

As a human designer has a bounded capacity, they cannot consider all implications of a potential design action prior to taking it, and they cannot predict all of the effects of taking such an action. One way that human designers act creatively from within a bounded rationality was suggested by Schön. In his model, designing is a sequence of “move experiments”: a reflective conversation with the materials of a design situation (Schön 1992). Indeed, Goel (1994) found that only 1.3% of state transitions during design problem solving were generated by deductive inference, compared to 41% for non-design problems.

Designers do not deduce all of the possible effects of a design action over all design domains prior to taking it. Rather, they choose a likely action based on beliefs of one domain, with those beliefs learned through their own experiences. That action is then activated on an external representation of the design (a drawing, say) and the results observed across all of the domains of interest. This process is design as interaction, not design as planning and search. It takes advantage of perceptual behaviours that already exist in the designer, and it means that situated beliefs learned through prior interactions with the “real” world can be re-employed. It also keeps details of a design in the external representation and frees the designer to concentrate on the evolving interpretation.

We present here a model suited to this interactive conception of designing. Section 2 introduces the primary theories which underlie our model, those being situatedness, external representation and constructive memory. Section 3 then describes our model. Finally, section 4 concludes with implications of this work.

2. Situatedness and Designing

Our model is concerned with a situated model of designing. Situated agents have beliefs that are first person constructions, not third person encodings, and are grounded in and inseparable from environmental interaction. Representations may be symbolic or not, provided that the representations are grounded in the interactive experiences of the agent.

The importance of a situated model is twofold. The first is that we seek to understand designing by an autonomous design agent. The alternative of a model of designing not based on autonomy implies encoded knowledge, and such an alternative is clearly unsatisfactory for models of human designing. We also believe it to be unsatisfactory for artificially intelligent models of designing. It cannot be guaranteed whether such intelligence required to perform the design task existed within the model or whether it remained in the mind of the programmer who provided the encoding. Thus, we seek a model based on an autonomous agent, and if the beliefs of such an agent were acquired from interactive experiences with its environment then those beliefs must be situated. If such an agent is to design autonomously then it must apply its own previously learned beliefs to the process of designing, and if its beliefs were situated then so should be the application of those beliefs.

The second reason for desiring a situated model arises from findings that designers can associate a visuo-spatial feature with one concept at one time and with another at another time (Suwa et al. 1999). Sense-data are not simply a key with which to index a database of experiences. Rather, the mechanisms of perception are constructed according to the current situation and the expectations of the agent. Similarly, memory recall is a synthesizing process in which “what must have occurred” is reconstructed from a few fragments in working memory (Cherniak 1986). The effect of this is that the visual cues, which are perceived in

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the external representation, afford the selection of further design actions and that the perceptual processes involved are not fixed. Perception of these cues will vary with the beliefs of the agent and with the current situation. Thus, different designers may look at the same depiction and detect different visual cues, and the same designer may revisit a previous depiction and either detect new cues or revise their beliefs about the relative importance of different cues.

In the model to be presented, the mechanism for re-applying existing situated beliefs to a design task is for the design agent to interact with an external representation. Whilst external representations are an obvious memory aid and medium for memories to be shared (Zhang 1997), they have other advantages even for artificial agents. Take as an example the research into diagrammatic reasoning. With diagrammatic representations, topological and geometrical relations are necessarily preserved in their two or three dimensional real world embodiment (Lindsay 1995). They do not obey the same principles of compositionality as do logical sentences (Sloman 1995). They are not isomorphic with what they represent as the correspondence of parts, properties and relations are ambiguous. This provides a flexibility of interpretation that is useful in conceptual design.

Explicit topological or metrical adjacency of related entities assists reasoning, and well practiced perceptual inference can sometimes make working with diagrammatic representations more efficient than deductive inference (Zhang 1997, Koedinger 1992). In any case, an autonomous agent would require (even if not designing) many of the perceptual behaviours which could be reapplied to design tasks. To see this, try the following test. Firstly, try to multiply 1984 by 6936 using internal reasoning only. Now try it with the assistance of a pencil and paper. Using a pencil and paper requires, in addition to perceptual processes which exist already, behaviours which are simple by comparison to the behaviours required to solve the problem internally.

Verstijnen et al.: 1998) found that CAD tools aimed at early phases of designing must support the processes of combining and restructuring. Current CAD tools employ vector representations in which each input is specified and stored as a concrete object. Consequently, tasks that combine objects are not easy and intuitive, and restructuring tasks are not supported. Their suggestion is to build “electronic sketch tablets” which leave input unspecified. This is the same idea as underlies the “electronic cocktail napkin” (Gross 1996). We agree, but make the added observation that what they describe is in effect a model of designing based on an interaction with an external representation.

3. A Situated Model of Designing

3.1 AN OVERVIEW OF OUR MODEL

We propose a design agent that interacts with an external representation that is itself a model of an evolving design. Concrete details of an evolving design reside in the external representation, but these are uninterpreted and mean nothing by themselves. Internal representations comprise a virtual world for the agent that is purely conceptual and exists only in the interpretations of the agent. Some part of a conceptual design solution, then, emerges from the interaction between the design agent and the evolving design.

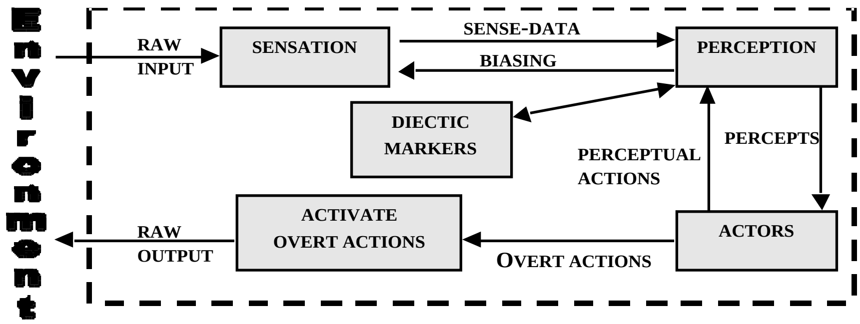

Figure 1. High level abstract model of the design agent

A high level view of the model is shown in Figure 1. For each sense, sensation performs a representation shift from the raw input into something more appropriate for learning and reasoning. Sensation is distributed and sense-data are uninterpreted by the agent, although it is biased by perception. An example is taking raw input as a set of pixels off a graphics card and producing as sense-data a set of detected edges, colours or motion.

Perception then interacts with a currently attended object via these sense-data so as to discover what it could be. The word "could" is deliberately chosen: for design interpretation we aim to find what a depicted object *could* be, which is not necessarily what it was intended to be at the time of original depiction. To achieve this we avoid the planning approach of explicitly searching a world model, and avoid the pattern matching approach of mapping sense-data to the closest stored object. In contrast, we wish to allow the agent to construct new interpretations rather than only matching previously described ones.

Perception in our model is action based and is organized on a hypothesise and test basis. With regard to shape perception, for example,

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the process would be that of scanning the focus of attention around perceived lines until a satisfactory interpretation was reached, be it of the originally localised object or of another more interesting object which was discovered along the way. Styled after work on active vision (see, for example, Ballard et al.: 1997)), our actions work on or at the current focus of attention and could be classified as:

1. *Overt*, or those actions which affect the external environment.
2. *Localisation*, or changing the focus of attention to a location with specific perceptual properties such as "vertical red line".
3. *Identification*, or actions which are used to perceptually discriminate between possible interpretations of whatever is at the current focus of attention.

To control actions, and therefore perception, our agent employs a set of "actors" that collectively interpret current sense-data obtained from the external representation during perception. This is shown in Figure 2. The aim is to maximize opportunities for the agent to discover something unexpected whilst still biasing perception by expectations. "Actors" are inspired by Minsky's *Society of Mind* agents (Minsky 1986), but we use the term "actor" (an entity which exhibits a behaviour (International Encyclopedia of Psychology 1996)) to avoid confusion with our design agent when using the word "agent". Tasks that actors perform are known as capabilities, and all capabilities adopted by actors concurrently operate on the same sense-data.

We consider that there are three base kinds of capability, derived from the three kinds of represented information (Whitehead & Ballard 1990). The first are peripheral capabilities: those that are spatially non-specific such as the presence or absence of "red" within the field of view. Another is local capabilities: intrinsic local features of a marked object such as a kind of shape at the current focus of attention. The third is relations between two objects, such as proximity and containment. Each base capability is also associated with an action that, if activated, would result in a further discrimination between possible interpretations.

The design synthesis model is as follows. The agent has prior beliefs, learned through experience, of how external artifacts behave. These are associations between behaviours and structure as perceived by the agent. Structure here is a configuration of actor capabilities. The agent believes that there is a "causal" link from perceived structure to these behaviours. Designing generates design alternatives, and the immediate goal of the design critic is to construct a configuration of agents which matches those of the required structure. After initial depiction actions on the external representation, a partial interpretation will lead to either more depiction actions or to a revision of the configuration. This in turn leads to a further revised interpretation. The external representation, the set of actors interpreting it and the partial interpretation all progress together until the current partial interpretation satisfies the design goals.

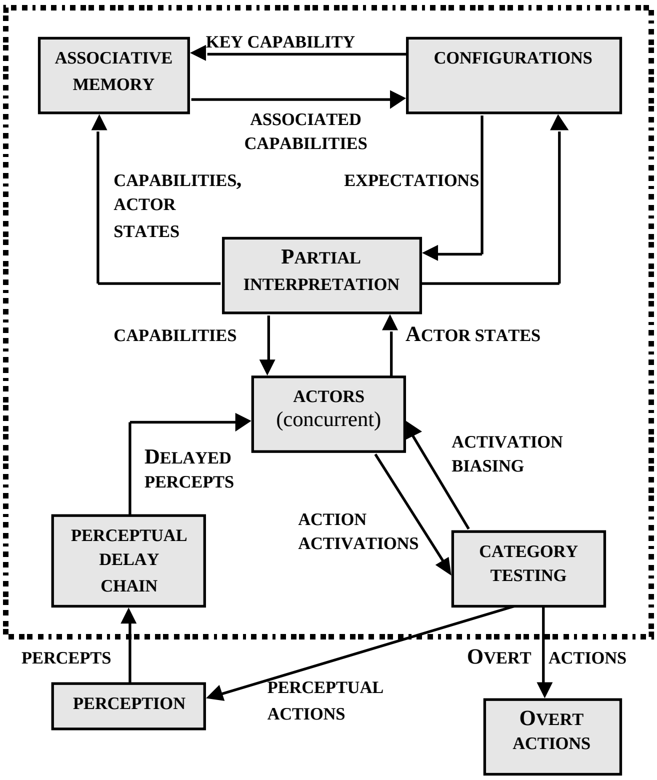

Figure 2. Expansion of "Actors" from Figure 1

In order to drive the construction of capabilities we need expectations, and these expectations should be based on beliefs and goals of the agent. The beliefs are concepts learned that are active (based on actor capabilities) and single step (based on remembering what capability is relevant in what context). It is an action model of the form in “such-and-such” a context then “such-and-such” an action is applicable.

The expectations we call a configuration. A configuration is a network of perceptual and overt capabilities and transitions between them. For example, we could abstractly represent a configuration as a Petri net, with each place representing one capability and a token representing a single capability required of or adopted by one actor. Transitions from one marking to another would then represent the idea that we expect “such-and-such to happen, and then such-and-such to happen”.

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Initially the design goals of the agent will be abstract. The process starts with design goals such as “would like such-and-such to be present” and “would like such-and-such to be not present”. Design goals are not a complete configuration but rather are a set of micro-configurations that need not be consistent and need not persist throughout the design process. These micro-configurations could be taken from different parts of already known configurations.

Aside from base capabilities we also require compound capabilities. These do not have actions of their own but instead have the effect of increasing the strength of the next capability it requires. They can be thought of as providing a degree of abstraction. Base capabilities are like biasing perception towards a preferred feature set; compound capabilities are like biasing towards an abstraction or a preferred ordering.

If our representation of concepts is based on capabilities then what we have is a map from one set of capabilities to another, where the sets may be current or immediately prior. The value stored for each capability in the partial interpretation is how well that capability is satisfied by the currently attended object. We represent this map as an associative memory and access is through a spreading activation (Collins 1975, Chen 1995). Nodes in the memory represent capabilities that are active immediately prior to and following an action, and node links represent the probability of co-occurrence of the nodes from the viewpoint of the agent in a manner similar to that of Chen. It provides for beliefs of sequence and of expectations of which capabilities will be useful next.

The agent adapts to its environment by learning both base capabilities and associations (compound capabilities are constructed on demand directly from a configuration). As capabilities map from a space of the last N percepts (with N small) to actions, these can be learned through reinforcement and error correction. That is, capabilities that get used often generate new capabilities, unused capabilities get forgotten, and errors in expectations get corrected. Thus, the capabilities that an agent most often expects and most often activates are a function of its past experiences. Associations are similarly experience dependent as they are based on co-occurrences of capability activations immediately prior to and following an action.

3.2 BUT WHY THIS MODEL?

To review, the agent starts with a small configuration representing initial design goals that may or may not be feasible. We look up the associative memory with the set of capabilities in the configuration, and those capabilities that activate above some threshold are adopted by actors. Each actor interprets current sense-data according to its adopted capability and competes to take the next action, be it perceptual or overt. After some depictions and interactions, an evolving partial interpretation results as a marking on the current configuration. The design critic evaluates the current marking and uses the associative memory to suggest changes to the configuration. These changes in configuration result in changes to the actors, which in turn result in changes in interpretation and depictions, and so on until the agent is satisfied with the current partial interpretation.

Our answer to the question "how is it possible for two designers looking at the same drawing to see different things" is "because the model is interactive and situated". Learning in a situated model such as ours is fundamental, and is based upon interaction with a designer's environment just as the design process is. In the model, therefore, knowledge therefore is not encoded. If the beliefs of a designer reflect how capabilities and associations between them have adapted to their environment, and if the beliefs of a designer are what guide design decisions, then design decisions will vary according to the experiences of the designer. Different designers, even if originally clones, can have different capabilities and associations. Therefore, those designers can generate different expectations and construct different perceptual mechanisms in response to the same sense-data and the same initial design goals. As capabilities with strong associations to expected capabilities can be run by actors, but those which are expected are more strongly biased, we have a model which provides for both serendipity in discovering unexpected things whilst still biasing perception by expectations.

Further, as perception is adaptive and is concentrated around a focus of attention, then the mechanisms of perception will be constructed according to what is expected and what the immediate goals are. This does not provide for determinism in interpreting sense-data from the same depictions at different times. Expectations will drive the construction of the mechanisms of perception but this does not guarantee that an object that was depicted previously will be interpreted in the same way. For designing this lack of determinism is useful as it enables the emergence of new interpretations and provides a mechanism for helping to explain creativity through perceptual interactivity. Thus, the same designer may revisit a previous depiction and "see" something not intended.

We agree with Thomas (1999) that "no end-product of perception, no inner picture or description is ever created". Instead, perception is an ongoing interactive process of environmental exploration. This applies to designing as much as to other perceptually based activities. The capacity for *seeing as* (Schön 1992) - for constructing different interpretations of the same image at different times and under different

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circumstances - is argued by Thomas to be the link between mental imagery and creative imagination.

Finally, consider the building of a virtual design studio aimed at conceptual designing which takes account of our model. We wish an environment where depicted objects remain uninterpreted. On a sketchpad this means a trail of ink across paper; electronically it means a trail of pixels across a raster. Both contrast with CAD packages which commit depicted objects to concrete interpretations. Now, the beliefs of the agent are situated and learned through interaction, and the same perceptual mechanisms are employed whilst designing. If the designer usually interacts with a 3D environment then designing may be assisted by facilitating the more direct reuse of existing capabilities. That is, by "sketching" in 3D, with the designer leaving a trail of voxels through an initially transparent 3D "raster".

4. Conclusions

In the model presented the mechanisms of perception and the interpretation of percepts are both constructed on the fly according to both (i) expectations based on situated beliefs and on design goals, and (ii) sense-data at the current focus of attention. We take advantage of the design as a depiction on an external representation, with opportunities for emergence resulting from such an interpretation model and as a mechanism for reusing prior situated beliefs and perceptual behaviours. Basing perception on a set of concurrent and independent actors enables construction of the mechanisms of perception as a function of design goals and expectations whilst not precluding the bottom-up discoveries which are essential if emergence is to occur.

Thus, our model explains how designers can reapply situated beliefs to design tasks, how different designers can look at the same drawing but "see" it differently, and how the same designer can revisit an older drawing and "see" it differently than they intended. We believe that this model can help lead to a further understanding of how and why designers take design actions, and of which tasks designers should find easy and which not. Such an understanding may allow for a better understanding of interactions with CAD tools and, eventually, to the construction of better CAD tools and to better artificial agents.

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