A FUNCTION – BEHAVIOUR – STRUCTURE VIEW OF SOCIAL SITUATED DESIGN AGENTS

JOHN S. GERO AND UDO KANNENGIESSER
University of Sydney
Australia
{john, udo}@arch.usyd.edu.au

Abstract. This paper proposes a comprehensive schema to represent an agent's social knowledge using the Function – Behaviour – Structure (FBS) schema. Although this schema has originally been developed to represent knowledge about design objects, it is sufficiently abstract to also describe knowledge about agents. This paper shows how such an FBS view can be useful to support the interaction of situated design agents.

1. Introduction

Providing better computer support for designers has been the ultimate goal of much design research. The emerging field of agents in artificial intelligence (AI) research has been seen as a promising technology to progress towards this goal. As a result, recent developments in computational design systems increasingly use agents to embody important aspects of human designing (Gero and Brazier 2002).

There has been a growing research interest in systems involving multiple agents that cooperatively perform a common design task. The fundamental advantage of the multi-agent system (MAS) approach can be seen in its modularity and its ability to work in complex environments. This is particularly useful in the design domain, which is a setting characterised by complex interactions of collaborating actors specialised in particular fields of expertise and often having conflicting interests. A number of design systems based on multiple cooperative agents have been developed (Campbell et al. 1998, Grecu and Brown 2000).

MAS's to be efficient have generally been recognised to require social abilities of its individual agents (Castelfranchi 1998). In particular, a social agent must have knowledge about the roles, the capabilities and eventually some of the knowledge of other agents. This does not mean

that the agent knows everything the other agent does; rather it is a form of "black-box" knowledge that enables the agent to carry out purposeful social interactions. What is needed is a comprehensive, formal representation schema for agents.

Agents that explicitly deal with internal representations are generally labelled cognitive. A large number of cognitive agents are based on the belief-desire-intention (BDI) model (Rao and Georgeff 1991), differentiating their internal state into formal representations of beliefs, desires and intentions. While the BDI model exclusively deals with cognitive states, it does not account for an agent's interactions with its environment. However, interactions play a fundamental role for situated design agents, and formally representing interactions is a condition for making situated design agents reason about other situated design agents.

In this paper we propose a comprehensive representation schema for social knowledge based on the abstract notions of function (F), behaviour (B) and structure (S). In particular, we show how a function-behaviour-structure (FBS) view has the power to support the interaction of situated design agents.

2. The FBS View of Situated Design

2.1. THE FBS SCHEMA: REPRESENTING DESIGN OBJECTS

Gero's (1990) FBS schema represents design knowledge in the form of the three abstract notions of function (F), behaviour (B) and structure (S) of a design object. These three notions are defined as follows:

1. The *function* (F) of a design object is defined as its teleology.
2. The *behaviour* (B) of a design object is defined as the attributes that are derived or expected from its structure.
3. The *structure* (S) of a design object is defined as its elements and their relationships.

The agent constructs connections between these notions through experience with the design object. Specifically, it ascribes function to behaviour and derives behaviour from structure. There is no direct connection between function and structure.

Generalized chunks of interconnected F, B and S, which are derived from sets of like design cases, are called design prototypes (Gero 1990). They enable the design agent to start designing with only incomplete information about the function, behaviour and structure of the object to be designed, as they readily provide additional representations of F, B and S.

The FBS schema of design knowledge has also been used to describe a set of processes that link F, B and S together as states of the developing design, known as the FBS framework (Gero 1990), Figure 1.
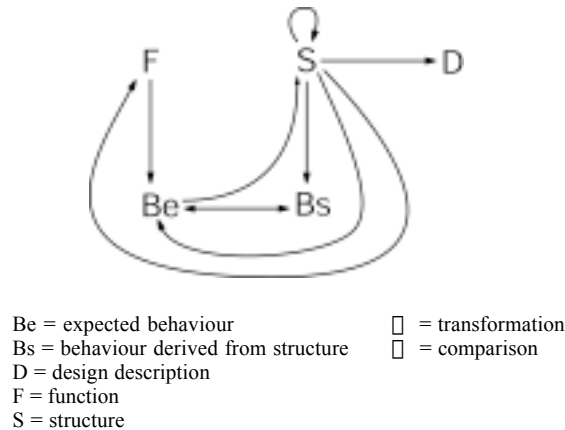
Be = expected behaviour   → = transformation
Bs = behaviour derived from structure   ↔ = comparison
D = design description
F = function
S = structure

Figure 1. The FBS framework after Gero (1990).

2.2. SITUATED CONSTRUCTION OF FBS SCHEMAS

The idea of situatedness can be traced back to the work of Dewey (1896) and Bartlett (1932) and has been introduced in design research (Gero 1998) to capture a range of phenomena observed in studies of designers, which traditional models of designing fail to address. Specifically, situatedness is used to account for the open environment in which designing by (human or computational) agents takes place. It is based on the view that "where you are when you do what you do matters", i.e. an agent does not simply react reflexively in its environment but uses its interpretation of its current environment and its knowledge to produce a response (Clancey 1997). Schön and Wiggins (1992) have identified designing as a process of "interaction of making and seeing". As a consequence the agent can be exposed to different environments (external as well as internal to the agent) and produce appropriate responses. The agent's knowledge is thus grounded in its interactions with the environment rather than encoded by a third party.

Situatedness also includes a concept known as constructive memory. It is best exemplified by a quote from Dewey via Clancey: "Sequences of acts are composed such that subsequent experiences categorize and hence give meaning to what was experienced before". The implication of this is that memory is not laid down and fixed at the time of the original sensate experience but is a function of what comes later as well. Memories can therefore be viewed as being constructed in response to a specific demand,

based on the original experience as well as the situation pertaining at the time of the demand for this memory. Each memory, after it has been constructed, is added to the agent's knowledge and is now available to be used later, when new demands require the construction of further memories. These new memories can be viewed as new interpretations of the agent's augmented knowledge.

To explicitly account for the situatedness of designing, the present authors have recently extended Gero's (1990) original FBS framework now forming the situated FBS framework (Gero and Kannengiesser 2002). A major feature of the situated FBS framework is the distinction between the agent's external and internal environment. This has made it possible to show the agent's interaction processes with and within the external world, which include interpretation, constructive memory and action. More generally, the situated FBS framework accounts for the construction of FBS schemas based on the individual experience of the agent. As a result, different agents having different experiences are likely to construct different FBS views of the same design (or design object), which explains the individual-based character of designing.

3. An FBS View of Social Situated Agents

3.1. AN FBS VIEW OF SOCIAL AGENTS

The FBS view is sufficiently general to provide a comprehensive set of formal representations not only for design objects but also for all objects in general, no matter if they are physical or imaginary. Even processes can be easily thought of as objects (this is what object-oriented software engineering does) and can similarly be represented in terms of F, B and S. The particular class of objects that this research is interested in comprises agents. Figure 2 shows how an agent can be represented using the FBS view.

As illustrated, we can distinguish two kinds of structure (S) of an agent. One refers to those parts that are "visible" for the observer and typically includes the sensors and effectors of the agent. We denote this kind of structure as S^s ("static" structure). The other kind of structure refers to the internal representations that the agent is able to construct, which are commonly interpreted as its knowledge, beliefs or goals. These representations are normally hidden from the observer; however they can be inferred from generalised agent knowledge or from observations of the agent's actions, and/or they can be directly communicated by the agent. We denote this kind of structure as S^c ("constructed" structure).
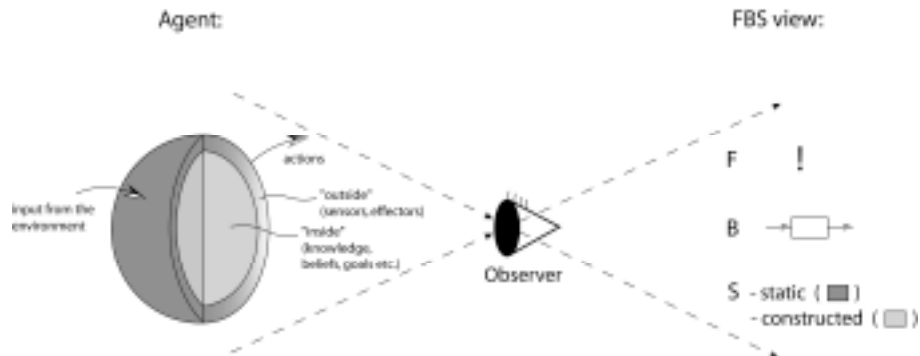
Figure 2. An FBS view of an agent.

An obvious interpretation of an agent's behaviour (B) is how the agent acts given a set of conditions (which are shown in Figure 2 as input from the environment). This corresponds to the notion of a "black-box" or "input-output" view of the agent.

The function (F) of an agent is the purpose that an observer ascribes to its behaviour and usually refers to the agent's social role.

The observer can also be identical to the agent, which corresponds to the agent (or observer) constructing an FBS view of itself. This allows the agent to reflect on its own purposes, behaviour and knowledge in order to better adapt future interactions with its (social) environment. Figure 3 shows a social agent (0) having an FBS view of itself as well as of every agent it interacts with (1 - 6).

In Figure 3, the FBS views of the other agents (1 - 6) are represented as nested in the FBS view of the agent (0) itself, since FBS views are clearly part of an agent's constructed knowledge and thus its structure S^c. As a general filter to access other agents' FBS views, we can use S^c to model social beliefs to an arbitrary order. For instance, $S^c_0 (S^c_1 (F^c_2))$ denotes agent 0's (first-order) belief about agent 1's view of agent 2's function, $S^c_0 (S^c_1 (S^c_0 (B_1)))$ denotes agent 0's (second-order) belief about agent 1's belief about agent 0's view of agent 1's behaviour, etc.

3.2. USING FBS VIEWS FOR SOCIAL SITUATED INTERACTION

We now want to examine how this FBS view is useful in supporting social interactions of situated design agents. Situatedness emphasizes that all internal representations are grounded in the agent's individual interactions. As a result, different agents are likely to construct different FBS views of the world. In designing this has often been seen as a benefit, as different views of the object to be designed significantly drive the design of novel (possibly innovative) products.
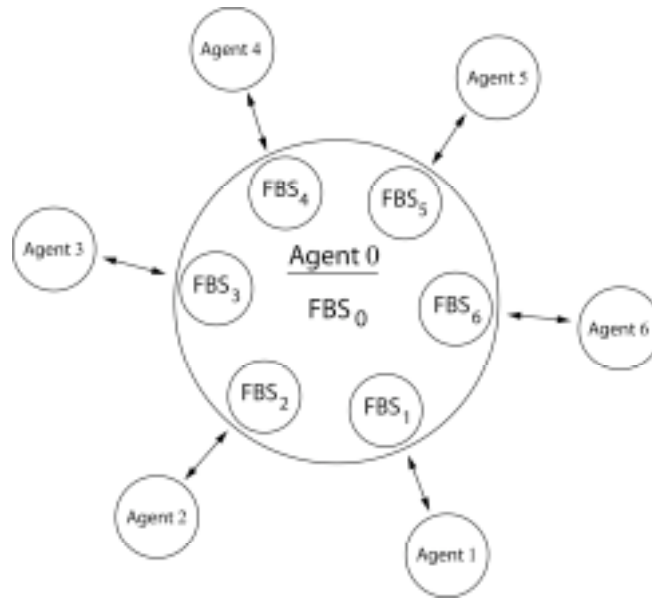
Figure 3. FBS views of a social agent.

However, different views and different knowledge are also known as an obstacle for smooth cooperation, especially in large design projects. How can we establish the commonalities (in terms of common knowledge and common language) necessary for successful agent interaction without curbing situatedness?

In contrast to non-situated approaches that pre-define the commonalities externally and then encode them into the agents, a situated approach is based on the ability of each individual agent to construct appropriate models of the agent(s) it interacts with. These models are then used to adapt the interaction to the respective agent. Common ground (Clark 1992) between communicating situated agents is the notion that affirms that all agents involved in the interaction have constructed appropriate models of each other to an extent sufficient for the purpose of the current interaction. Figure 4 depicts the pairs of (FBS) models that have to adequately match to establish the common ground between two agents.

"Satisficing" (Simon 1969) the construction of the FBS view according to the needs of the current interaction is an important feature of the common ground approach. It prevents the agents from trying to compute a "completely accurate" view of other agents, corresponding to recursively assessing common ground by constructing beliefs of infinitely increasing order (Clark and Marshall 1981). To summarise, we see

commonalities or common ground as *a posteriori* interpretations by an observer describing the successful interaction of agents that form adequate FBS views on the fly.
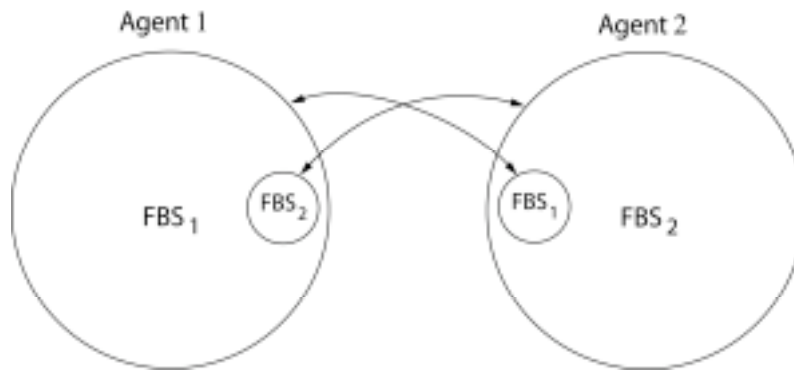

Figure 4. Pairs of matching FBS models that establish common ground.

An agent can generally use two sources of information to construct its FBS views. The first one is the agent's experience directly gained from observing or interacting with the agent that is to be modelled. The second one are generalisations over a set of experiences with other agents. Usually both sources of information are employed, with generalisations typically providing default assumptions when only incomplete information is available from direct experience. If an agent has only little experience from interacting with other agents, its generalisations are considerably biased by its own knowledge and its own view of the world. If this agent's knowledge differs from the other agents' knowledge, its FBS views may not be adequate to establish sufficient common ground. Over time, as the agent gains more experience through interaction, its FBS views become more accurate and its generalisations become modified accordingly.

Generalisation also helps to address the potential issue of how an agent can construct a model of every agent it interacts with without running into complexity problems for huge numbers of agents. By deriving large parts of the required agent models from generalised clusters of agent models, the amount of information to be handled by the agent remains manageable.

4. Conclusion

We have presented a formal representation schema for agents based on function, behaviour and structure, which is sufficiently comprehensive to capture all aspects of an agent. In contrast to other schemas such as BDI, the FBS model can explicitly deal with the interactions of the agent. It therefore succeeds in integrating situatedness and cognitive states of an agent into one framework. In particular, the FBS schema can be used by an agent to construct a view of its social environment.

Most importantly, a uniform and consistent framework such as the FBS schema helps an agent to generalise and thus to cope with increasing amounts of knowledge about other agents. This ability is an important condition for a social situated design agent to interact with other agents in a flexible and efficient way. It also allows the agent to engage in interactions with another agent even if its knowledge about that particular agent is not complete. We are currently implementing social situated design agents that use their FBS views to communicate with one another.

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