COORDINATION OF MULTIPLE PATRONS IN VIRTUAL SPACE: PRELIMINARY NOTES

William Bricken
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Assume a software architecture for virtual reality within which each object/entity is organized into a sense-model-act system with its own (virtual) process resources. The model within an entity can be inhabited, that is, the computational cycle which maps sense input to action output can be under the interactive control of a user/patron.

What are the mathematical tools which coordinate actions of multiple patrons in virtual worlds? The problem is similar to that faced in the design of software architectures for intelligent distributed agents (Genesereth and Nilsson, Logical Foundations of Artificial Intelligence). Entities differ from agents in these ways:

(1) Entities can be fully connected while maintaining individual perspective (merged without resolving inconsistencies). Sharing information between automated entities is a matter of convenience.

(2) Entities inhabited by patrons do not require automation of knowledge. Some representation problems in world models can be interactively deferred to humans. Sharing information between patrons is a matter of negotiation and choice.

(3) The environment is computational. Some difficulties with modeling real world phenomena can be finessed in a virtual world. The environment, itself an entity, can be fully responsive.

Each entity is essentially a small symbolic system which maps input and state onto output and state. The symbolic framework can be functional, object-oriented, frame-based or rule-based; mapping eventually reduces to operations of pattern-matching and substitution. The internal organization of each entity consists of:

Input buffer	(fed by sensors)
Priorities	(rules for selecting input)
Disposition	(rules triggered by selected input)
Knowledge	(state collected by rules)
Output buffer	(actions generated by rules)

A set of priorities select an input item to compare to the trigger clauses in the set of disposition rules. When a particular rule is matched, the action it specifies is carried out. An action may be to store the input as knowledge or to cause an effector to generate an action external to the entity. Some rules may be contingent on stored knowledge to be triggered. Some rules may be independent of input, they form the internal processing disposition of the entity. Statistical classification and inference over knowledge are potential internal processing tools.   We are limiting the knowledge representation language of entities to first-order predicate calculus.

An entity becomes a virtual body when it is inhabited by a patron. The disposition within a virtual body defaults (partially or wholly) to the sensor/effector suite of the patron. For example, rather than controlling the viewpoint of a virtual robot by internal rules, viewpoint is controlled by the data stream generated by the head-tracking unit on the patron.

Each entity can construct a model of its environment by sensing and storing information or by directly incorporating knowledge of other entities. In contrast to robotic agents, sensory channels in virtual entities can be both objective (disconnected from environmental entities) and inclusive (directly sharing knowledge with environmental entities). Objectively, an entity with a viewpoint can sense the representation of other entities which fall within the range of that viewpoint. Inclusively, entities which share information boundaries can merge world models directly. Objective agents must communicate through links, simulating a physical environment. Inclusive entities can be informationally in contact, simulating a virtual database. Objective communication is broadcast, enforcing a sharp distinction between syntax, which is transmitted, and semantics, which is processed. Inclusive communication is like direct behavior, communication acts change mutual internal states without transmission. From another perspective, information processes in virtual environments are fully situated, requiring a new model of semantics (Brian Cantwell Smith, The Correspondence Continuum).

These two forms of information exchange can be represented by network and map models. Networks model broadcast information:

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[A]<--->[B]
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Entities A and B interact through the link between them. Each has a sensor at their local end of the link. Maps model shared information:

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[A][B]
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Here, the boundary,][, is a direct mutual contact. Although networks and maps are isomorphic representations for some purposes, in terms of virtual communication, they are different. Removing a broadcast channel, for example, leaves two isolated entities:

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[A]<--->[B]  ==>  [A]<    >[B]
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Removing a shared information boundary leaves one composite entity:

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[A][B]  ==>  [A   B]
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We are developing a calculus of information sharing which uses topological boundary models to regulate semantics and storage when information is exchanged virtually.

Virtual reality provides an empirical context for exploration of theories of cooperation between human groups and software configurations. Within an environment which has a visual semantics (such as architectural models and prototypes of instrument panels), patrons can interact directly with images rather than with textual representations. Digital databases can be updated automatically. Patrons can discuss and interact with models and with each other concurrently in virtual space. Inhabited entities must engage in broadcast communication, since humans cannot share minds. Automated entities can be informationally cooperative, although they may possess only partial models of the world. The issue is how to construct automated and inhabited entity collectives that maximize task-oriented productivity.

Coordination between patrons depends upon mutually consistent models of shared environments. Network-based research on intelligent agents has been developed for adversarial environments. Virtual worlds coordination theory extends broadcast models by including map-based cooperative models which permit complete communication with environmental entities while maintaining individual perspectives. Unlike objective reality, virtual spaces accommodate multiple concurrent realities, each associated with a different patron or perspective. I can perceive a green desk, for example, while you perceive the same desk to be brown. You may even not perceive my desk at all. We can each dwell in entirely different virtual environments, establishing communality only for those entities we explicitly wish to share.

Inconsistencies across patrons can be negotiated or managed. Negotiation can be sensory (sharing viewpoints), knowledge based (sharing memories), or rule based (sharing dispositions). Maintenance of contradiction in virtual worlds requires merging inconsistent knowledge without disabling action or inference.

We are developing an approach to inconsistency that uses a three-valued logic with an imaginary Boolean value, *j*.

$$(P \text{ and } (\text{not } P)) = j$$

The imaginary logical value is analogous to the imaginary numerical value *i*. It does not interact with two-valued deduction, permits a weaker form of inference in the presence of inconsistency, and allows lazy resolution of contradictions. This approach is equivalent to a hypothetical worlds approach, but splits at the variable level (bottom-up) rather than at the model level (top-down) (Nicholas Rescher, Many-valued Logic).

We are applying contradiction maintenance techniques to a broader project called televirtuality. The idea is to transmit virtual worlds over fiber optic telecommunications networks, to replace telephone and television with shared virtual realities. The conventional objective model calls for coordination of a single virtual space across multiple concurrent patrons. Contradiction maintenance reduces the transmission bandwidth and synchronization bottlenecks of objective approaches. The shift in perspective is analogous to moving from a knowledge database relying on accumulation of inferential assertions to a constraint database permitting any satisficing world configuration.

Another technique we are exploring is experiential mathematics, and in particular, visual programming. We are constructing formal maps from textual representations to virtual entities that are sensually accessible. For example, we have mapped textual logic onto stacked cubes. In contrast to iconic and representational visual programming languages, blocks world logic uses spatial position to embody logical semantics. Removal and rearrangement of blocks is axiomatized to hold computational semantics invariant. The evaluation of a configuration occurs visually as blocks join and tumble; the structure remaining has the value of the result of the computation. Programming bugs appear as anomalous configurations of blocks. Logics based on physical boundaries have pleasant properties; since they are many-to-one maps from textual logics, they simplify as well as concretize.

Visual programming is a component of a wider visualization project which includes the capabilities to transform, cluster, abstract and, in general, interact mathematically with data. The long-term goal is to construct an experiential environment which provides a non-textual yet formal interface to mathematical computation. The entity architecture permits, for example, data collection and analysis during a simulation experiment. We are designing SIMSTAT, an empirical analysis environment which provides statistical analysis integrated into experiential simulation. Using overlay display techniques which combine physical and virtual spaces, the scientist/patron will be able to enter into a virtual simulation running concurrently on top of a physical experiment. The virtual display is driven by data streams which may originate from mathematical models, from other entities within the simulation, or from the physical experiment itself. The history mechanism within each entity generates a stream of behavioral data which is linked to a statistical analysis package. Correlational analysis is achieved by linking two objects to a common clock which time-stamps their respective behaviors. The comparison of empirical and hypothesized results is displayed dynamically and interactively as data accumulates.

Naturally there are many active areas of research in distributed inference, negotiation of perspective, visual semantics and participatory simulation. Although we are exploring contributions to each (software entities, direct and broadcast communication, contradiction maintenance, experiential mathematics), we are primarily seeking to construct an empirical environment within which problems of coordinated action can be easily embodied and tested. Virtual reality is a workbench for mathematical models of multiple realities.