

MODELING CHALLENGES

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There are four major technical challenges facing the commercialization of Virtual Reality that are receiving little attention:

Constructing Cybernetic Hardware --

the development of interaction devices which integrate display and sensing into a participation loop.

Engineering the Virtual Body --

the integration of display and sensing signals with modeling software that is responsive to participants in real-time.

Assembling Software Tools --

the development of software interaction tools such as construction kits, dynamic interaction languages, virtual hand-held devices, and database navigation aids.

Evaluating Human Performance --

the identification of participant behavior associated with successful VR experiences, including measurement of physiological response, interaction effectiveness, learning transfer, cognitive load, and participant satisfaction.

INNOVATIONS IN DISTRIBUTED MODELLING

Foremost, VR is for multiple participants. Since each participant is within his or her own computational environment, the assumption of a shared communal environment is not necessary. Rather than assuming that we all are included in the same environment (a dictate of physical reality), assume that we are each in a unique environment. Studies of situated action conclude that each person has a unique world view [Suchman, Putman, Bricken]. Uniqueness in VR means that each participant has a unique world. All worlds are conceptually, but not visually, superimposed. Communality is negotiated between participants, they agree to maintain common images. Potential techniques for establishing common environments include:

-- The White Room, a standardized physical environment shared by all participants.

-- Enter all participants into a standardized virtual environment that is initialized at the beginning of the shared virtual experience. Permit inconsistency across virtual environments and standardize the display of shared objects through negotiation of a communal perspective on those objects.

-- Place all participants at the same viewpoint.

-- Use imaginary logical values to partition inconsistent domains and propagate contradictions as permissible structures.

Spatial Logic

We have been working with spatial expression of logical constants and connectives, and have identified a many-to-one map from logic expressed as lexicographic strings to logic expressed as networks of connectivity. Thus, we are able to map program control structure onto networks of entities distributed in space. All transformation rules for these networks can be implemented asynchronously. Thus it is possible to structure the connectivity between individuals distributed in space to have logical semantics. Each individual could represent a Boolean function; when the function is evaluated, the value can be propagated to others by asynchronously changing the local connectivity of that individual.

Contradiction Maintenance

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), participants can interact directly with images rather than with textual representations. Digital databases can be updated automatically. Inhabited entities must engage in broadcast communication, since humans cannot share minds. Automated entities can be informationally cooperative, although they must 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 participants 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 participant 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. [Kauffman, Varela]

Inconsistencies across participants 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 based on 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]. Semantically, it is equivalent to Kleene 3-valued logic.

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.

A THEORY OF COMMUNICATION

An entity becomes a virtual body when it is inhabited by a participant. The disposition within a virtual body defaults (partially or wholly) to the sensor/effector suite of the participant. 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 participant.

Each entity constructs 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 exploratory (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 information 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. The transmission model of information which characterizes the telephone is replaced by a common space model which characterizes shared participation in an environment.

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

$$[A] \langle \text{---} \rangle [B]$$

Entities A and B interact through the link between them. Each has a sensor at their local end of the link. Maps permit shared information:

$$[A][B]$$

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:

$$[A] \langle \text{---} \rangle [B] \quad \implies \quad [A] \langle \quad \rangle [B]$$

Removing a shared information boundary leaves one composite entity:

$$[A][B] \quad \implies \quad [A B]$$

We are developing a calculus of information sharing which uses topological boundary models to regulate the semantics and storage when information is exchanged virtually.

Sample Scenario

Consider a "Towering Inferno" scenario. The scenario is one in which a group of firefighters are tasked with controlling an out-of-control fire in a high-rise office building. The firefighters have access to building plans, but they do not know the state of locked doors, and access to parts of the building are being dynamically changed by the progress of the fire. Some routes may be blocked by debris, some by excessive heat, and some by smoke. As well, remote communication to the outside of the building will be blocked from locations deep within the interior. The task in this scenario is to use

prior global knowledge, and real-time, dynamic local knowledge to map the state of the fire, and to put it out. The scenario emphasizes distributed heterogeneous communication and computation, distributed, local, asynchronous problem solving, innovative support for task members (generalized dynamic maps, sensory augmentation in a life threatening environment, local personal communication, and dynamic, rapidly changing environments), and sensor/activator interface (infrared display, chemical and toxic composition of the environment, dynamic maps).