Inclusive Symbolic Environments

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Abstract: Computer technology has only recently become advanced enough to solve the problems it creates with its own interface. One solution, *virtual reality* (VR), immediately raises fundamental issues in both semantics and epistemology. *Inclusive symbolic environments* effectively redefine the relationship between experience and representation, rendering the syntax-semantics barrier transparent. Reading, writing, and arithmetic are hidden from the computer interface, replaced by direct, non-symbolic environmental experience. *Inclusion*, the defining characteristic of virtual environments, is achieved through the integration of four component technologies: behavior transducers, inclusive computation, intentional psychology, and experiential design. The structure and function of VR systems reflect the mathematical necessity of *pervasion* of worlds, physical pervading digital pervading virtual. Pervasion permits novel semantic mappings which challenge the dominance of physical reality. *Physical semantics* is defined by the map between behavior and digital representation. *Virtual semantics* is defined by the map between digital representation and perceived behavior in the virtual environment. *Natural semantics* is achieved by eliminating our interaction with the intermediate digital syntax.

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1. INTRODUCTION

Broadly, virtual reality is that aspect of reality which people construct from information, a reality which is potentially orthogonal to the reality of mass. Physical reality is characterized by inertia, solidity and fullness. Virtual reality, in contrast, is characterized by potentia, fluidity and emptiness. Physical reality is built of mass while virtual reality is built of bits.

Within computer science, VR refers to interaction with computer generated spatial environments, environments constructed to include and immerse those who enter them. *VR affords non-symbolic experience within a symbolic environment.*

Since people evolve in a spatial environment, our knowledge skills are anchored to interactions within spatial environments. VR design techniques, such as scientific visualization, map digital information onto spatial concepts. When our senses are immersed in stimuli from the virtual world, our minds construct a closure to create the experience of inclusion. *Participant inclusion* is the defining characteristic of VR. (Participation within information is often called *immersion*.) Inclusion is measured by the degree of *presence* a participant experiences in a virtual environment.

We currently use computers as symbol processors, interacting with them through a layer of symbolic mediation. The computer user, just like the reader of books, must provide cognitive effort to convert the screen's representations into the user's meanings. VR systems, in contrast, seek to provide interface tools which support natural behavior as input and direct perceptual recognition of output. The idea is to access digital data in the form most easy for our comprehension; this generally implies using representations that look and feel like the thing they represent. A physical pendulum, for example, might be represented by an accurate three dimensional digital model of a pendulum which supports direct spatial interaction and dynamically behaves as would an actual pendulum.

To understand the deeper issues of experience in virtual environments, we must develop an infrastructure of component technologies to support "tricking the senses" into believing that representation is reality. The description of VR as techniques which *trick* the senses embodies a cultural value: somehow belief in digital experience is not as legitimate as belief in physical experience. The VR paradigm shift directly challenges this view. The human mind's ability to attribute equal credibility to Nature, television, words, dreams and computer-generated environments is a *feature*, not a bug. Quality virtual experiences, experiences that soothe rather than trick, that confirm rather than confuse, quality in the virtual world depends upon the integration of multiple perspectives and diverse component technologies.

2. COMPONENT TECHNOLOGIES

Computer-based VR consists of a suite of four interrelated technologies.

Behavior transducers (hardware interface devices) map physically natural behavior onto digital streams. *Natural behavior* in its simplest form is what two-year-olds do: point, grab, issue single word commands, look around, toddle around. Transducers work in both directions, from physical behavior to digital information (sensors) and from digital drivers to subjective experience (displays).

Inclusive computation (software infrastructure) provides tools for construction of, management of, and interaction with inclusive digital environments. Inclusive software techniques include pattern-matching, coordination languages, spatial parallelism, distributed resource management, autonomous processes, inconsistency maintenance, behavioral entities and active environments.

Intentional psychology (interaction techniques and biological constraints) seeks to integrate information, cognition and behavior. It explores structured environments that incorporate expectation as well as action, that reflect imagination as well as formal specifications. It defines the interface between the digital world and ourselves: our sensations, our perceptions, our cognition and our intentions. Intentional psychology incorporates physiological models, performance metrics, situated learning, multiple intelligences, sensory cross-mapping, transfer effects, participant uniqueness, satisficing solutions, and choice-centered computation.

Experiential design (functionally aesthetic environments) seeks to unify inclusion and intention, to make the virtual world feel good. The central design issue is to create particular inclusive environments out of the infinite potentia, environments which are fun and functional for a participant. From the perspective of a participant, there is no interface, rather there is a world to create (M. Bricken, 1991). The conceptual tools for experiential design may include wands, embedded narrative, adaptive refinement, individual customization, interactive construction, multiple concurrent interpretations, artificial life, and personal, mezzo and public spaces.

Taxonomies of the component technologies and functionalities of VR systems have only recently begun to develop (Naimark, 1991; Zeltzer, 1992; Robinett, 1992), maturing interest in virtual environments from a pre-taxonomic phenomenon to an incipient science. Ellis (1991) identifies the central importance of the environment itself, deconstructing it into content, geometry and dynamics.

VR unifies a diversity of current computer research topics, providing a uniform metaphor and an integrating agenda. The physical interface devices of VR are similar to those of the teleoperation and telepresence communities. VR software incorporates real-time operating systems, sensor integration, artificial intelligence and adaptive control. VR worlds provide extended senses, traversal of scale (size-travel), synesthesia, fluid definition of self, super powers, hyper sensitivities and meta physics. VR requires innovative mathematical approaches, including visual programming languages, spatial representations of mathematical abstractions, imaginary logics, void-based axiomatics and experiential computation. The entirely new interface techniques and software methodologies cross many disciplines, creating new alignments between knowledge and activity.

VR provides the cornerstone of a new discipline: **Computer Humanities**.

3. THE STRUCTURE OF A VR SYSTEM

Virtual reality applications present the most difficult computational performance expectations to date. VR challenges us to synthesize and integrate our knowledge of sensors, databases, modeling, communications, interface, interactivity, autonomy, human physiology, and cognition -- and to do it in real-time.

The primary task of a VR system is to make computation transparent, to empower the participant with *natural interaction.* The technical challenge is to create mediation languages which enforce rigorous mathematical computation while supporting intuitive behavior. VR uses spatial interaction as a mediation tool. The prevalent textual interface of command lines and pull-down menus is replaced by physical behavior within an environment. Language is not excluded, since speech is a natural behavior. Tools are not excluded, since we handle physical tools with natural dexterity. The design goal for natural interaction is simply *direct access to meaning*, interaction not filtered by a layer of textual representation. This implies both eliminating the keyboard as an input device, and minimizing the use of text as output.

3.1. Functional Architecture

Figure 1 presents a functional architecture for a generic VR system. The architecture contains three subsystems: transducers, software tools and computing system. Arrows indicate the direction and type of dataflow. Participants and computer hardware are shaded with multiple boxes to indicate that the architecture supports any number of active participants and any number of hardware resources.

The ***behavior and sensory transducing subsystem*** (labeled participant, sensors and display) converts natural behavior into digital information and digital information into physical consequence. Sensors convert our actions into binary-encoded data, extending the physical body into the virtual environment with position tracking, voice recognition, gesture interfaces, keyboards and joysticks, midi instruments and bioactivity measurement devices. Displays provide sensory stimuli generated from digital models and tightly coupled to personal expectations, extending the virtual environment into the realm of experience with wide-angle stereo screens, surround projection shells, head-mounted displays, spatial sound generators, motion platforms, olfactory displays and tactile feedback devices.

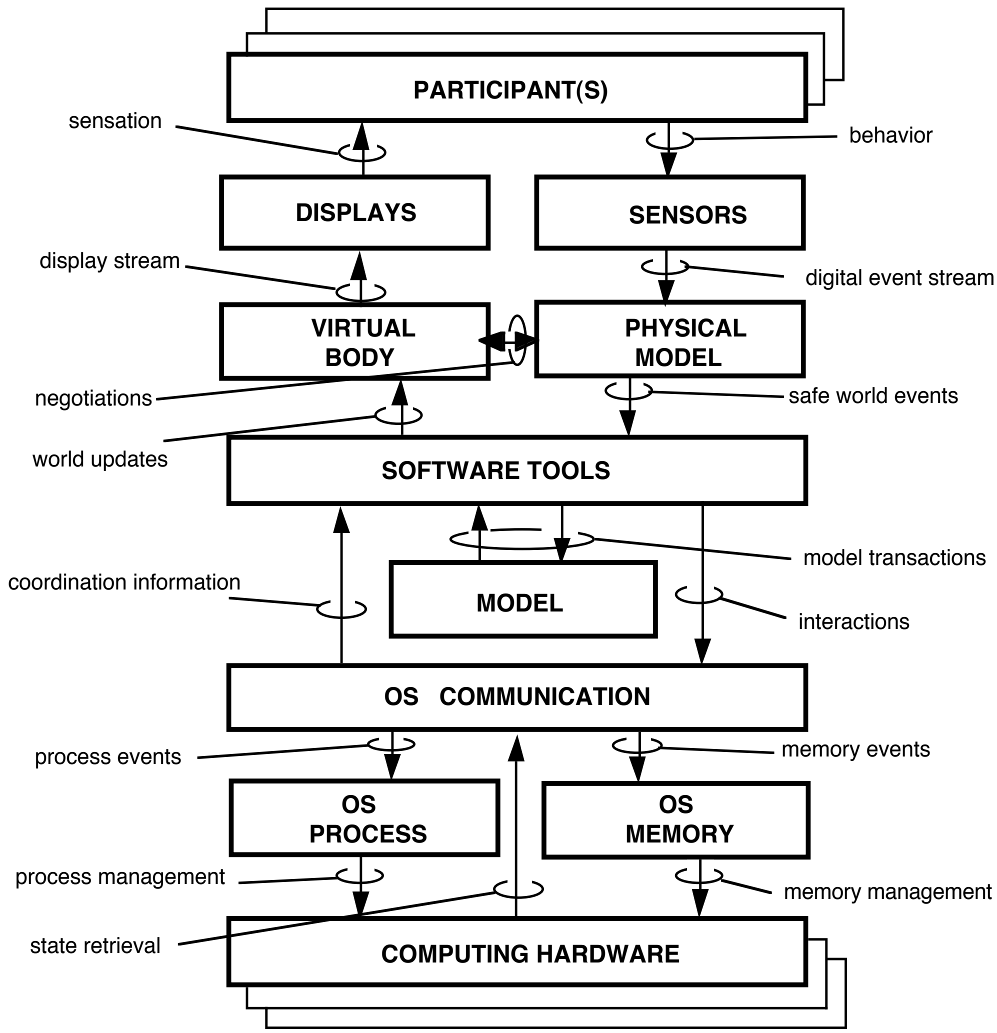

Figure 1. The Generic Functional Architecture of a VR System

The ***virtual toolkit subsystem*** (the physical model, virtual body, software tools and model) coordinates display and computational hardware, software functions and resources, and world models. It provides a wide range of software tools for construction of and interaction with digital environments, including movement and viewpoint control; object inhabitation; boundary integrity; editors of objects, spaces and abstractions; display, resource and time management; coordination of multiple concurrent participants; and history and statistics accumulation. The virtual body is tightly coupled to the physical model of the participant in order to enhance the sensation of presence. During runtime, the world model undergoes constant change due to parallel transactions, self-simplification, canonicalization, search-by-sort processes, process demons and function evaluations. The database is therefore better viewed as a turbulent fluid than as a stable crystal.

The ***computational subsystem*** (the operating system and hardware) customizes the VR software to a particular machine architecture. Since machine level architecture dictates computational capacity and operating system architecture dictates computational efficiency, this subsystem is particularly important for ensuring real-time performance, including update rates, complexity and size of worlds, and responsiveness to participant behavior.

In addition to specifying a practical implementation architecture, the functional model in Figure 1 provides definition for the essential concepts of VR.

3.2. Presence

Presence is the impression of being within the virtual environment. It is the suspension of disbelief which permits us to share the digital manifestation of fantasy. It is a reunion with our physical body while visiting our imagination.

The traditional *user interface* is defined by the boundary between the physical participant and the system behavior transducers. In a conventional computer system, the behavior transducers are the monitor and the keyboard. They are conceptualized as specific tools. The user is an interrupt. In contrast, *participant inclusion* is defined by the boundary between the software model of the participant and the virtual environment. Ideally the transducers are invisible, the participant feels like a local, autonomous agent with a rendered form within an information environment.

An *interface* is a boundary which both separates and connects. Traditional interface separates us from direct experience while connecting us to a representation of information (the semantics-syntax barrier). Interface provides access to computation by first objectifying processes and then displaying the objective encodement. The keyboard connects us to a computational environment by separating concept from action, by sifting our intention through a symbolic filter.

The degree of presence achieved by the virtual world can be measured by the ease of the subjective shift on the part of the participant from attention to interface to attention to inclusion. For example, a standard mouse-driven cursor feels more like an extension of self than does a pull-down menu because the cursor is always active (it does not require a selection to activate), it is one-to-one with the movement of our hand, and it does not have textual mediation. The cursor has more presence. When we attach a force-feedback system to the cursor, so that we can feel the edges of windows, presence is significantly enhanced, the cursor feels more like a physical object.

Conventionally we speak of the "software interface" as if the locale of human-computer interaction were somehow within the software domain. The human interface, the boundary which both separates and connects us, is our skin. *Our bodies are our interface*. VR inclusion accepts the entirety of our bodily interface, internalizing interactivity within an environmental context.

The architectural diagram in Figure 2 is composed of three nested inclusions (physical, digital, virtual). The most external is physical reality, the participant's physical body at one edge of the architecture, the computational physical hardware at the other. All the other components of a VR system (software, language, virtual world) are contained within the physical. Physical reality *pervades* virtual reality. For example, we continue to experience physical gravity while flying in a virtual environment.

The apparent dominance of physical reality is dependent on how we situate our senses. That is to say, physical reality is dominant only until we close our eyes. Situated perception is strongly enhanced by media such as radio, cinema and television, which invite a refocusing into a virtual world. The objective view of reality was reinforced during the last century by print media which presents information in an objectified, external form. Immersive media undermine the dominance of the physical simply by providing a different *place* to situate perception.

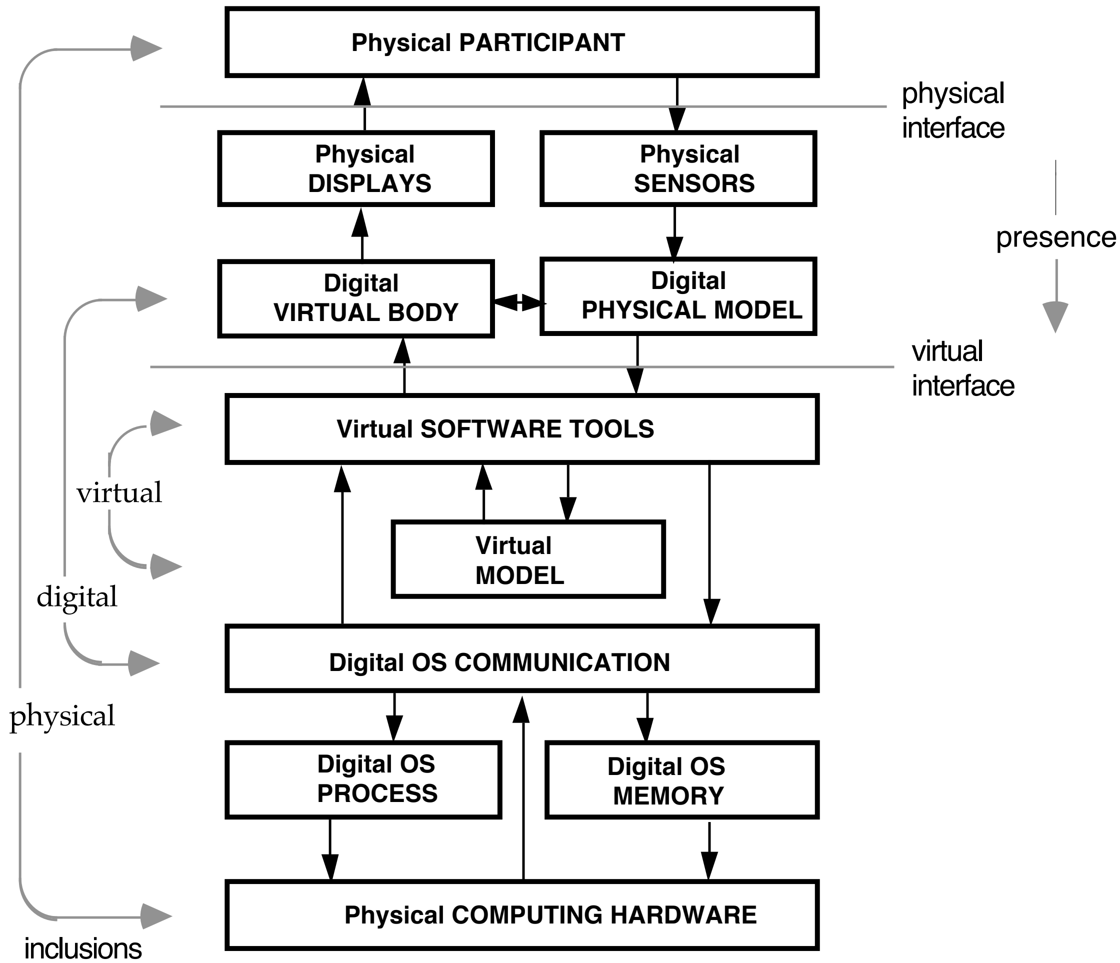

Figure 2: Presence and Inclusion

One layer in from the physical edges of the architecture are the software computational systems. A participant interfaces with behavior transducers which generate digital streams. The hardware interfaces with systems software which implements digital computations. Software, the *digital reality*, is contained within physical reality, and in turn, pervades virtual reality.

The innermost components of the architecture, the virtual world tools and model, form the virtual reality itself. (To be manifest, VR also requires a participant.) Virtual software tools differ from programming software tools in that the virtual tools provide a non-symbolic look-and-feel. Virtual reality seamlessly mixes a computational model of the participant with an anthropomorphized model of information. In order to achieve this mixing, both physical and digital must pervade the virtual.

Humans have the ability to focus attention on physicality, using our bodies, and on virtuality, using our minds. In the VR architecture, the participant can focus on the physical/digital interface (watching the physical display) and on the digital/virtual interface (watching the virtual world). Although the digital is necessary for both focal points, VR systems make digital mediation transparent by placing the physical in direct correspondence with the virtual.

As an analogy, consider a visit to an orbiting space station. We leave the physically familiar Earth, transit through a domain which is not conducive to human inhabitation (empty space), to arrive at an artificial domain (the space station) which is similar enough to Earth to permit inhabitation. Although the space station exists in empty space, it still supports a limited subset of natural behavior. In this analogy the Earth is, of course, physical reality. Empty space is digital reality, the space station is virtual reality. A virtual environment operating system functions to provide an inhabitable zone in the depths of symbolic space. Like the space station, virtual reality is pervaded by essentially alien territory, by binary encodings transacted as voltage potentials through microscopic gates. Early space stations on the digital frontier were spartan, the natural behavior of early infonauts (i.e. programmers) was limited to interpretation of punch cards and hex dumps. Tomorrow's digital space stations will provide human comfort by shielding us completely from the emptiness of syntactic forms.

Another way to view the architecture of a VR system is in terms of meaning, of semantics (Figure 3). A VR system combines two mappings, from physical to digital and from digital to virtual. When a participant points a physical finger, for example, the digital database registers an encoding of pointing. *Physical semantics* is defined by the map between behavior and digital representation. Next, the "pointing" digit stream can be defined to fly the participant's perspective in the virtual environment. *Virtual semantics* is defined by the map between digital representation and perceived behavioral effect in the virtual environment. Finally, *natural semantics* is achieved by eliminating our interaction with the intermediate digital syntax. In the example, physical pointing is felt to “cause” virtual flying.

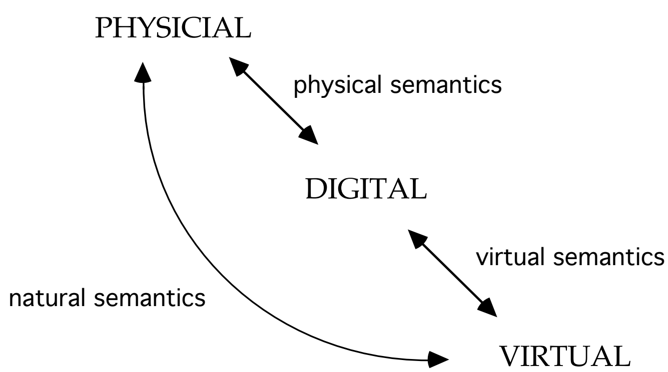

Figure 3: Types of Semantics

By creating a closed loop between physical behavior and virtual effect, the concepts of digital input and output are essentially eliminated from perception. When natural physical behavior results in natural virtual consequences, without apparent digital mediation, we achieve presence in a new kind of reality, virtual reality. When I knock over my glass, its contents spill. The linkage is direct, natural and non-symbolic. When I type into my keyboard, I must translate thoughts and feelings through the narrow channel of letters and words. The innovative aspect of VR is to provide, for the first time, natural semantics within a symbolic environment. I can literally spill the image of water from the representation of a glass, and I can do so by the same sweep of my hand.

Natural semantics affords a surprising transformation. By passing through digital syntax twice, we can finesse the constraints of physical reality. Crossing *twice* is a mathematical necessity (Spencer-Brown, 1969; W. Bricken, 1991). Through presence, we can map physical sensations onto imaginary capacities. We can point to fly. Double-crossing the semantics/syntax barrier allows us to *experience imagination.*

Natural semantics can be very different from physical semantics because the virtual body can be any digital form and can enact any codable functionality. The virtual world is a *physical simulation* only when it is severely constrained. We add collision detection constraints to simulate solidity; we add inertial constraints to simulate Newtonian motion. The virtual world itself, without constraint, is one of potential. Indeed, this is the motivation for visiting VR: although pervaded by both the physical and the digital, the virtual is *larger in possibility* than both. (A thing that is larger than its container is the essence of an imaginary configuration, exactly the properties one might expect from the virtual.)

4. CONCLUSION

VR design is inherently a multidisciplinary process and requires expertise in many different areas. Successful VR applications are manifested by the cooperative effort of system programmers implementing and abstracting performance bottlenecks, designers creating involving objects and terrains, dynamics experts implementing realistic behaviors, authors composing story lines, psychological researchers focusing on perceptual understanding, systems architects building automated and reliable infrastructures, and visionaries encouraging the whole process.

Now that the infrastructure of virtual worlds (behavior transducers and coordination software) is better understood, the more significant questions of the design and construction of *psychologically appropriate* virtual/synthetic experiences will see more attention.

The idea of a natural semantics that can render representation irrelevant (at least to the interface) deeply impacts the intellectual bases of our culture by questioning the nature of knowledge and representation and by providing a route to unify the humanities and the sciences. The formal theory of VR requires a reconciliation of digital representation with human experience, a reconstruction of the idea of meaning.

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