Semi-Autonomous Avatars

Phoebe Sengers
Media Arts Research Studies
GMD - German National Research
Center for Information Technology
Phoebe.Sengers@gmd.de

Simon Penny
Carnegie Mellon University
Department of Art and
Robotics Department
penny+@andrew.cmu.edu

Jeffrey Smith
Carnegie Mellon University
Robotics Department
jeffrey@cs.cmu.edu

Abstract

Avatars are generally thought of as a direct representation of a user in a virtual environment. But as the complexity of virtual environments increases and, with it, the scope and complexity of possible avatar behavior, it becomes more and more difficult to maintain a direct correlation between the user's wishes and the avatar's actions. Instead of this now inadequate notion of 'avatar-equals-user,' we propose that avatars can be fruitfully thought of as *semi-autonomous* agents, which have their own behaviors and intentionality, but are intimately tied to the user's actions. We describe two systems incorporating avatars with varying levels of autonomy: *Traces*, a Virtual Reality system in which a user's body movements spawn avatars which gradually become more autonomous, and the *Influencing Machine*, an installation in which the user does not directly control the avatar's actions, but instead influences them indirectly through a voodoo doll. The formulation of avatars as semi-autonomous agents opens a new and rich conceptual space in the design of virtual environments.

1 Introduction

Avatars are computational agents which represent users in virtual environments (VE's). Avatars range from simple programs that do little more than shuttle text between members of a text-based VE, to 3-D figures which move around graphical VEs in response to motion commands by the user, to complex agents which search the Web for the user and have autonomous decision-making capability. Generally, avatars, or 'user embodiments,' are thought to be like soul-less bodies for which the user acts as mind. Correspondence between the user's wishes and the avatar's actions is maintained using low-level commands like "walk forward 3 steps" or "pick up the box," or by using hardware sensors on the user's body which are translated into the corresponding movements for the avatar. In this way of thinking; the avatar is what we might call a *nonautonomous* agent; the avatar, fundamentally, is the user.

But as the complexity of virtual environments increases and, with it, the scope and complexity of possible avatar behavior, it becomes more difficult for the user to directly control all aspects of the avatar using simple low-level commands. In response, avatars have been built that allow the user to specify behavior at various levels, from "go north" to "find me an appropriate article" to "negotiate the release of hostages," while the avatar uses its own intelligence to fill in the details [Blumberg and Galyean, 1995, Perlin and Goldberg, 1996, Hayes-Roth and van Gent, 1997]. As these avatars become more independent, the idea that the avatar is just a simple extension of the user becomes problematic [Lanier, 1996, Wise, 1998]. In essence, the avatar is no longer a thought-free 'body,' but develops its own 'brain' that takes over some of the mental tasks needed to function in complex environments.

In this context, the currently dominant metaphor of "user = avatar" is no longer adequate to describe or innovatively solve problems that come up in designing avatars. In this paper, we propose that in the context of current trends in avatar research, avatars can be more fruitfully thought of as *semi-autonomous agents*. Avatars are thought of as agents like any other with their own behavior and intentionality, but with a particularly intimate relationship with the human user. This notion of avatar not only describes current avatar work more accurately, but also widens the conceptual space of possible avatars. Avatars can now appear on the full range of autonomy levels, from a fully passive traditional avatar to a fully active traditional agent. In this paper, we will describe our experience with two systems we have built, the Influencing Machine and Traces, which explore this range of avatar autonomy levels.

2 Fellow Travellers

Avatars may be talked about as though they are simple cyberspace extensions of the user; in the practice of building them, this idea quickly loses relevance. It is not possible to actually construct avatars for any period of time, especially those with complex behaviors, without realizing that it takes a great deal of engineering effort to engender the illusion that the avatar is identical to the user. As Bowers, O'Brien and Pycock argue, often a great deal of technical and social effort goes into having the avatar behave nonautonomously, i.e. as a direct and accurate representative of the user [Bowers *et al.*, 1996]. At the same time, several researchers have done innovative work that, rather than attempting to get rid of unwanted autonomy, uses that autonomy as a resource to create new, useful forms of the avatar-user relationship.

Hannes Vilhjálmsson's and Justine Cassell's pioneering system BodyChat, for example, uses autonomy in the form of body language to support interaction via avatars [Vilhjálmsson and Cassell, 1998]. That is, while the user is chatting with other people, their avatars autonomously display the kinds of physical signals humans unconsciously use to support communication, like using glances to show whether or not one is open to communication, raising eyebrows on emphasis words, and using gaze exchange to support turn-taking. These are behaviors which are essential for supporting communication, but of which humans are generally unaware and therefore would find difficult to directly control. While Vilhjálmsson and Cassell's avatar does have some semi-autonomous behavior, it is still a direct representative of the user — the avatar does what the user *would* do if s/he could. Interestingly, evaluation of their system [Cassell and Vilhjálmsson, 1999] suggested that users actually feel *more* in control of these avatars than ones where they had to directly control the avatar's body movements.

Avatars do not just behave; they also sense the virtual environment for the user. Michael Mateas has developed 'subjective avatars' for interactive fiction which behave nonautonomously, but have semi-autonomous sensing [Mateas, 1997] [Mateas, 1998]. These avatars are intended to help the user feel like a character in a story, by sensing the world in a way that reflects the character's perspective on events, drawing out details that matter to the character and describing them in terms of their impression on that character. The avatar is not simply a representative of the user, but also reflects an author-chosen character.

The work most similar to our work, particularly the Influencing Machine, is that of Johnson et. al. on Sympathetic Interfaces [Johnson *et al.*, 1999]. They face the problem of how to let a user control an agent which has its own autonomous behaviors. They built a plush toy in the shape of the agent, which the user can move in order to suggest behaviors to the agent; for example, moving the legs of the toy may cause the agent to run. The movements of the toy are interpreted according to the context in which the agent finds itself and which behaviors are now plausible. The agent thus has a great deal of latitude in interpreting the user 'commands,' and engages in fully autonomous behavior when the user does nothing. Interestingly, Johnson et. al. use the metaphor of the voodoo doll to describe this form of semi-controlling the agent, a motif that appears independently in our work below.

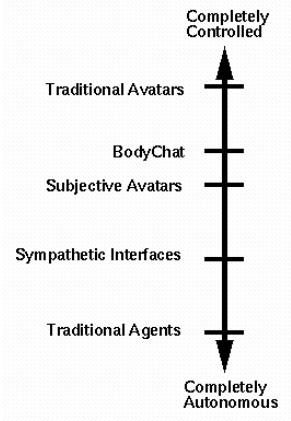

Figure 1: A range of semi-autonomous avatars.

In our work, we build on previous avatar work with different kinds of autonomy by suggesting they are not lone aberrations, but represent part of a continuum of kinds of avatars made possible by using the semi-autonomous avatars metaphor. Semi-autonomous avatars can be thought of as on a range of autonomy, from the traditional fully passive avatar to the traditional fully active agent (Figure 1). We begin to fill in this range, demonstrating several different kinds of avatars along that continuum. Here, we describe these avatars in the context of two systems: Traces, a VR system allowing full-body interaction, whose avatars start out closely coupled to user action but gradually become autonomous; and the Influencing Machine, an installation allowing users to interact with a largely autonomous avatar using a voodoo doll.

3 Systems

3.1 Traces

Traces, conceptualized by Simon Penny and built by Penny, André Bernhard, Jamie Schulte, Phoebe Sengers and Jeffrey Smith, is an installation for the CAVE VR system [Cruz-Neira *et al.*, 1993]. The fundamental issue Traces deals with is the disembodiment that often

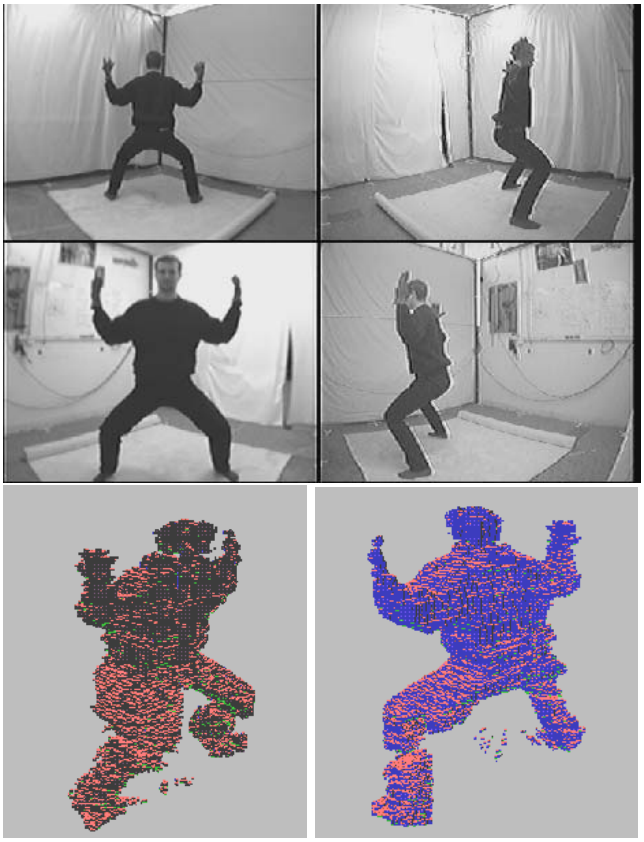

Figure 2: The vision system turns 4 camera images (top) into a 3-D body model of the user (bottom).

occurs in VR systems; just put on the headset and your body disappears [Penny, 1994]. When you look down at where your body should be, you see your avatar - and discover you are no more than a floating eye and hand. The CAVE system is an alternative VR display system that does not check the user's body at the door. The CAVE is not head-mounted; it is a small room you enter, onto whose walls 3-D images are projected. You have the illusion of a 3-D world surrounding you; yet when you look down, your body is still there. Your body is not, however, hooked into the system: the CAVE only senses the user's 3-D glasses and joystick, so that while you can see yourself, to CAVE applications you remain your bodyless avatar, a flying eye and hand.

Traces achieves user embodiment in the CAVE by installing a vision system in it [Penny *et al.*, 2000]. Four cameras in the corners of the CAVE watch the user, building a 3-D voxel body model of the user in real-time at 15 frames a second (Figure 2). These body models are used to generate 3-dimensional 'traces' of the user's movements, avatars of the user which surround him or her and with which s/he can interact. Traces is a fully implemented system as described and has been shown at Ars Electronica '99 in Linz, Austria. The next generation of Traces will be networked, so that users can

Figure 3: The Passive Trace of a user getting up from a backstand. The user model is displayed in black for reference; it is not displayed in the CAVE.

interact with each other's mediated trace-avatars.

3.1.1 Traces Avatars

The avatars in Traces start out very much like traditional avatars, passively following the user's movements. Over time, they gradually become more complex, going through three stages: the Passive Trace, the Active Trace, and the Behaving Trace. At each stage, the Trace-Avatar adds new levels of autonomy and new complexity to the avatar-user relationship.

Figure 4: The Active Trace develops according to CA rules.

During the Passive Trace phase, the avatar is simply a set of time-lapsed 3-dimensional images of the user's body movements, like a kind of 3-D stop photography (Figure 3). Over time, the images gradually fade and drift off into space. Internally, the Passive Trace is a 3-D voxel model; at each frame, the user's current body model as determined by the vision system is added to it, and older voxels are faded and removed.

During the Active Trace, the shape of the avatar is no longer completely dependent on the user's movements. The voxels that make up the trace are still generated by the user's movements, but instead of simply fading passively, they use a cellular automata algorithm to determine the color, transparency and persistence of trace voxels. The trace no longer passively fades away, but generates structures of varying stability in places where the user has been (Figure 4). The trace begins to feel lively; it sparkles and changes shape in unexpected ways.

During the Behaving Trace, the body movements of the user throw off agents, as though the user is shaking off water droplets (Figure 5). At first, these agents simply fly off the user; then, they exhibit their own behavior, following the user or exploring the CAVE (Figure 6). Agents have articulated bodies ("chinese dragons") which consist of a sequence of spheres, each of which follows the sphere before it. The agent's behaviors are written in a custom-made particle behavior language based strongly on Craig Reynolds's steering behaviors [Reynolds, 1999]. Agents can sense each other and the user's body location, including the user's head, hands, stomach, and feet (these are heuristically determined from the body model); sensors are shared among agents for efficiency.

At this stage, the avatar has become highly autonomous, engaging in autonomous behaviors and not necessarily following the user. At the same time, the avatar is not completely autonomous: it is still generated by and connected to user movements. Because the agents flock together, they feel like a coherent entity in the environment, as a distributed Behaving Trace rather than as a bunch of unrelated creatures. Subjectively, people often seem to feel a close connection to the Behaving Trace; they especially want to dance with it. Identification of the user with the Behaving Trace as a kind of half-alien self is enhanced by the gradual steps through which the user went to get to this stage; following Penny's theory of the auto-pedagogical interface, users are gradually

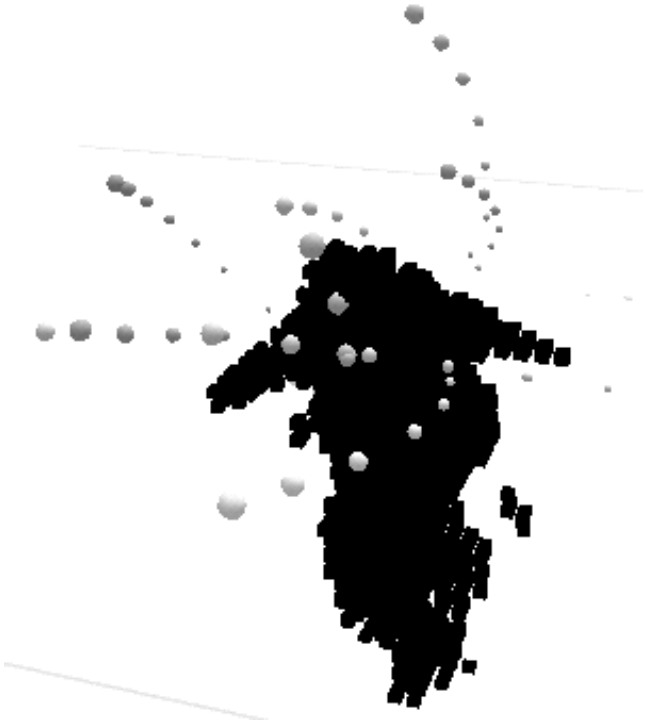

Figure 5: For the Behaving Trace, agents are spawned from the user's movements.

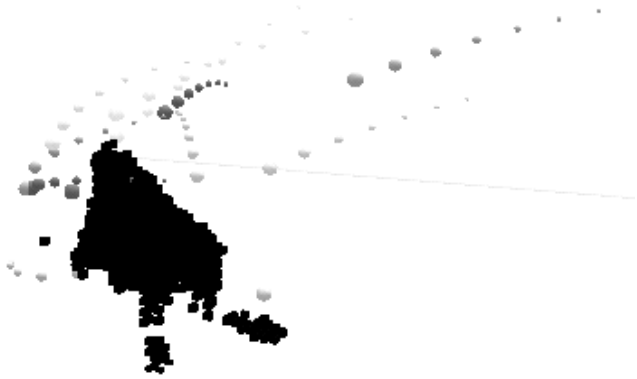

Figure 6: The agents that form the Behaving Trace have their own behaviors. Here they are following the user.

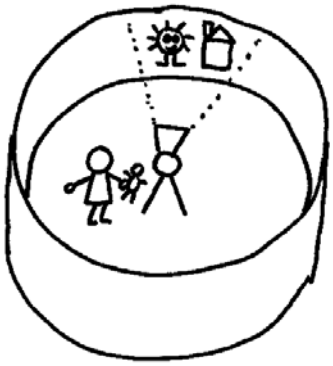

Figure 7: The set-up for the Influencing Machine.

trained to understand more and more complex relationships with their avatar.

3.2 Influencing Machine

The introduction of highly autonomous avatars quickly introduces the question of appropriate user control. It is easy to understand how users control avatars which are completely passive; the user simply hands out commands. But what happens when the avatar is meant to be somewhat autonomous? Phoebe Sengers's Influencing Machine explores the question of how the user's and semi-autonomous avatar's wishes can be meaningfully combined.

The Influencing Machine bases its style of avatar-user relationship on the metaphor of the Influencing Machine, a paranoid delusion first described by Victor Tausk [Tausk, 1992] and extensively described by Bruno Bettelheim in his case study of Joey, a boy who believed he was mechanical [Bettelheim, 1972]. People suffering from the Influencing Machine delusion feel that they are being controlled by a machine which projects hallucinations, produces or removes thoughts, feelings, and physical sensations, and changes one's bodily composition.

This Influencing Machine is a projection of part of a person's sense of self; i.e. their sense of self is split into two parts which share control of the person. In this way, the Influencing Machine is a model of what it is like to have shared control between two entities, a concept which maps to the user-avatar relationship. It is easy to imagine that an avatar could experience the user as a kind of influencing machine, who is not accessible to the avatar but causes changes to the avatar's actions, body, and perhaps even thoughts. In the Influencing Machine system, the user does not directly control but indirectly influences the avatar's behavior, acting as the Influencing Machine for the avatar.

The Influencing Machine installation (Figure 7) works as follows: the user enters a (physical) room, onto whose

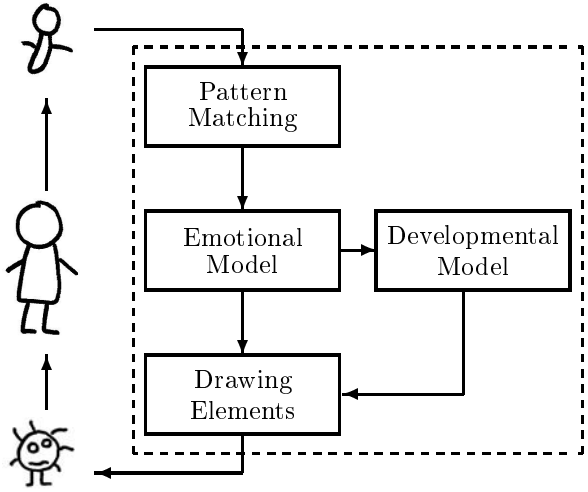

Figure 8: Structure of avatar architecture

walls are projected expressive, child-like drawings, which are being done by the computer in real-time. In the center of the room lies a voodoo doll. By touching the voodoo doll in different areas, the user affects the emotions and developmental state of the avatar, which in turn changes the style and content of the drawings. The avatar itself is not seen; the user experiences it through its expression in drawings. Over the course of the interaction, the avatar ages from 9 months, when it merely scribbles, to about 5 years, when the content of the drawings starts to become highly representational.

3.2.1 Architecture

The architecture of the system (Figure 8) consists of the following parts: (1) a *pattern-matcher*, which receives as input touch-information from the voodoo doll and uses pattern-matching rules to generate influences to the avatar's emotions; (2) an *emotional model* which uses these influences to update the avatar's emotional state, passing on changes to the drawing style; (3) a *developmental model* which uses changes in emotions to update the avatar's developmental state and sends the current pictorial elements to the drawer and (4) the *drawing system* which generates the actual, real-time drawings based on the current emotional style and pictorial elements. These drawings are then observed by the user, who touches the voodoo doll in response, and the process begins again.

Prototype of the first three systems, which compose the avatar's 'brain,' are running and will be described here. The fourth system, the Affective Renderer, is an on-going research project.

The **pattern matcher** takes as input sensations from the voodoo doll. The voodoo doll's body is divided into 4 zones, which represent the head (intellect),

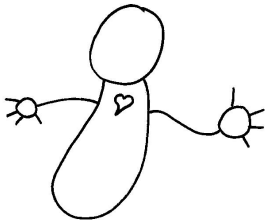

Figure 9: Schematic of the voodoo doll showing the zones of the body: head, hands, body, heart.

hands (exploratory), body (physical), and heart (emotional) (Figure 9). The pattern matcher looks for particular patterns of activity in each zone, matching them to emotional influences, in ways that make sense for the avatar's personality and developmental state. For example, a pattern-matching rule could be "if the heart is touched ten times in a row, increase the feeling of being smothered by 2."

The **emotional model** for the avatar is based on the depth-psychological literature on analysis of children's drawings (e.g. [Strauss, 1988] [Richter, 1987]). This literature uses radically different emotions from those which have been common in AI emotional architectures (e.g. [Bates *et al.*, 1992] [Neal Reilly, 1996] [Cañamero, 1997] [Elliott, 1994]); rather than happy, angry, sad, the literature discusses emotions like sense of flow, feeling of physicality, rigidity, or contentment. While highly meaningful in the context of children's drawings, these emotions are neither clearly defined nor orthogonal to one another (for example, 'rigidity' is almost the opposite of 'flow'). The avatar's emotional model is therefore a minimum-commitment model, consisting of emotions which have a simple label and value, connected into a spreading activation network allowing them to reinforce or inhibit one another.

The avatar's **developmental model** is again based on the literature on children's drawings. This literature tends to describe the gradual complexification of children's drawings in terms of an accumulation of pictorial elements which appear in a particular order and are triggered by certain emotional states. For example, if a child draws a human figure surrounded by a circle, this means a kind of protection ("house") that the child is seeking or feels. Using these analyses of children's drawings, we can construct a directed graph of developmental states, their associated pictorial elements, and their emotional triggers (e.g. Figure 10).

This is the representation used for development in the Influencing Machine system. Nodes of the graph represent the agent's state, and contain pictorial elements. Links represent triggers where the agent moves from one state to another. An agent can be in multiple states simultaneously (e.g., 'drawing human figures with arms but no bodies' and 'drawing houses around

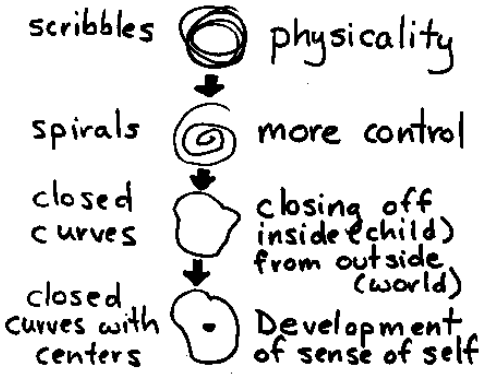

Figure 10: Developmental graphs capture the developmental states of the avatar and their corresponding pictorial elements.

human figures'). An agent changes state when a trigger occurs, typically because of changes to the emotional state. For example, the 'rule' above can be implemented by triggering entry to the house-drawing state when the agent is in the previous state and security has been above 4 for 30 seconds. The output of the developmental model is pictorial elements which are used by the affective renderer to generate the current drawing.

The Influencing Machine avatar is relatively highly autonomous. The avatar is largely independent in what it does; as with Johnson et. al. 's "voodoo doll" avatars [Johnson *et al.*, 1999], the 'avatariness' of the agent is based on the fact that the user is in a deeply intimate relationship with the avatar, intervening in its mental processes. The user is not out of control, but has a mediated form of control: using the voodoo doll, the user can influence the emotions, which in turn changes the developmental state, which changes the drawings the user sees.

Rather than exploring a physical environment with the avatar, the user explores a drawing-generation process which changes over time. Their interaction gives him, not a sense of a physical environment, but a sense of the way in which the avatar thinks and feels. In this sense, the Influencing Machine interface can be thought of as a way of exploring the *psychic space* of the avatar.

4 Discussion: Ranges of Autonomy

Each of the avatars discussed here — the Passive Trace, the Active Trace, the Behaving Trace, and the Influencing Machine — has a different level of autonomy, resulting in a different level of identification with the human user. These varying autonomy levels start to fill in the range of possible levels between complete nonautonomy and complete autonomy (Figure 11). At one extreme, semi-autonomous avatars become fully passive avatars in the traditional sense; at the other, they become com-

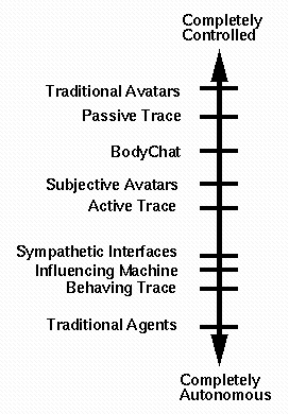

Figure 11: Traces and the Influencing Machine begin to fill in the range of semi-autonomy.

pletely autonomous like traditional agents. The dividing line between avatar and agent is now blurred; indeed, must be blurred in order to understand the partially controlled agents which are gradually becoming a standard avatar practice.

In addition, we believe the concept of avatar as semi-autonomous of the user is important from a critical perspective. The idea of avatar as simple extension of the user has worried several critics [Lanier, 1996] [Doyle, 1997] [Edwards, 1997], because, as J. MacGregor Wise points out [Wise, 1998], the unrecognized disjunction between avatar and user makes it difficult for both researchers and users to develop a critical understanding of the possibilities and constraints imposed by the interface. For example, while promising the user full engagement, avatars are frequently only able to do a small part of what the user wants, and, for more complex avatars such as information-gathering programs on the Web, may confound the user by acting on idiosyncratic, unstated interpretations of the user's commands. By presenting the agent as semi-autonomous, it is easier for users to develop critical distance and understand the limits of their avatar's ability to accurately represent them.

In the semi-autonomous avatar paradigm, rather than being identical to the user, an avatar must be thought of as the part of the system which is intimately connected to the user. In this way, the line between system, avatar, and interface also becomes blurred; the avatar becomes the interface, the point at which the computational system and the user make contact. In our experience, avatar design is interface design and must occur in concert with a host of design decisions about the entire system.

At the same time, there are limits to the usefulness of the range-of-autonomy concept. Subjective avatars do not differ from BodyChat, for example, only in that they are more autonomous; they are autonomous in a different way, with respect to perception rather than action. In this respect, it may be helpful for avatar designers to think about the different axes along which avatars can be more or less autonomous.

More generally, we believe that the necessary fundamental progress in avatar research can be made, not simply by expanding the number of options along a single dimension, but by rethinking the metaphors underlying the avatar-user relationship. Viljhálmsson and Cassell work with the metaphor of avatar-as-body; Mateas speaks of his avatars as being a kind of "magic glasses" which alter perception; Johnson et. al. build on the metaphor of the voodoo doll; Traces uses stop-shutter photography (among others); the Influencing Machine design is based on Tausk's description of the Influencing Machine delusion. In each of these cases, a metaphor that makes explicit the nonidentity of avatar and user becomes the basis for a new technology. We suggest that thinking of avatars as semi-autonomous opens a space for new metaphors for the avatar-user relationship that move beyond simple identity, metaphors which can lay the groundwork for a new generation of avatar technology.

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