Technical Report: Exploring Human Surrogate Characteristics

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Abstract. This report highlights some of the historical evolution of our research involving the characteristics that are essential for effective human-surrogate interactions. In this report, a consolidated glossary of terms related to human-surrogate interaction is described, following which an attempt at defining a consolidated space of surrogate characteristics is made. The rationale behind the space definition is to provide an easy way to categorize existing and future systems, and help identify areas in which the research community might focus its efforts.

1 Introduction

The notion of human *surrogates* has been explored in, among other places, literature, movies, computer games, and virtual reality. Research contributions from the disciplines of computer science, psychology, social science, and neuroscience help to shed light on how real human users/subjects perceive and interact with various forms of such surrogates. Today, applications of human surrogates include telepresence, military and medical training, education, and healthcare.

Though the manifestation of surrogates can range from *real humans* (e.g., standardized patients in medicine) to completely *virtual humans* (e.g., virtual patients) with computer-synthesized appearance and behavior, recent technological advances in computer graphics, robotics, and display technology are beginning to blur the line between real and virtual humans. Some researchers suggest that the advent of accurate visual portrayals of humans will soon allow the completely seamless blending of virtual and real elements and make them indistinguishable from each other [1].

Compared to real human surrogates, it is *virtual* (or *physical-virtual*) humans that we are particularly interested in. Figure 1 is intended to help illustrate the relationships between inhabiters (left), their surrogates (middle), and interacting human users/subjects (right). We use the term *virtual avatar* to indicate a surrogate with human-directed or autonomous behavior rendered on a conventional computer screen. We use the term *Physical-Virtual Avatar* (PVA) to indicate a surrogate with a physical manifestation, but virtual appearance and/or behavior. One example of a PVA is realized using cameras and digital projectors to map the appearance and motion of an inhabiter onto a life-sized animatronic human

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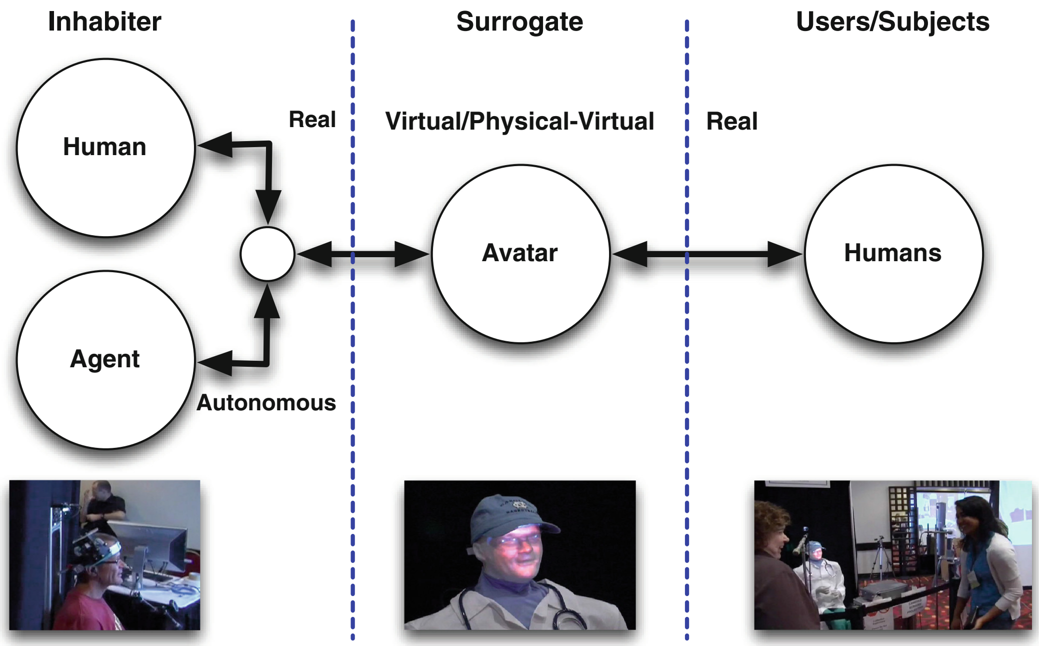


Fig. 1. The relationships between inhabiters (left), their surrogates (middle), and interacting human users/subjects (right).

(see left and middle of Fig. 1) [2]. The relationship patterns illustrated in Fig. 1 can be conceptually arranged or even "chained" to reflect different scenarios involving multiple inhabiters, surrogates, or users/subjects.

Getting started. Since at least October of 2012 we have been undertaking activities aimed at exploring the following primary questions:

- Can we define a space of characteristics that encompasses all currently known manifestations of human surrogates?
- How should the set of characteristics be chosen to provide a compromise between their generalization power and their utility towards distinguishing existing (and future) systems?
- How do the various dimensions of (or points in) said space affect human perceptions, their emotional responses, and interactions with human surrogates?

Our rationale was that satisfactory answers to these questions could offer a starting point for future research activities and potentially provide a set of application-specific recommendations. We continue the effort to explore the many factors that affect the responses of human users/subjects to various manifestations of human surrogates. In particular, one of our goals is to develop a comprehensive framework that identifies and classifies the main determinants for real humans' perceptions towards and interactions with human surrogates. A well-developed framework will prove invaluable in guiding future research directions while providing a clear structure to categorize previous contributions. We also hope to provide insights into the effectiveness of certain factors for applications employing human surrogates. This report describes a historical evolution of our research.

2 Terminology

Traditionally, two terms have been used to denote manifestations of human surrogates: avatars and agents. The distinction is based on the controlling entity, which could be either a human (avatar) or a computer algorithm (agent). The word **avatar**, in the context of computing, first appeared in the science fiction novel *Snow Crash* [3], in which avatars were introduced as virtual entities controlled by human users. More rigorously, [4] defines an avatar as "*a perceptible digital representation whose behaviors reflect those executed, typically in real time, by a specific human being*".

If a human surrogate is labeled as an **agent**, the common assumption is that its behavior is controlled by a computer program rather than a real human being. Analogous to the avatar definition, an agent is "*a perceptible digital representation whose behaviors reflect a computational algorithm designed to accomplish a specific goal or set of goals*" [4].

Since we do not want to restrict our investigation to either avatars or agents, we prefer to use the term **human surrogates** in our work. In the broadest sense, "surrogate" captures the fact that we are interested in human representations, while not being encumbered by traditional distinctions between digital and physical form as well as the nature of the agency. As elaborated in [1], our current generation might be the last one that can readily distinguish between real and virtual beings, so we believe that the generalizing terminology of surrogacy is appropriate.

A common metric of the human response to virtual environments is the feeling of "presence" or immersion that the users experience. **Presence** is a broad concept but is usually understood as the subjective experience of being in one place, even when one is physically somewhere else [5,6]. More relevant for our research interests are the concepts of co-presence and social presence, which are subsumed under the more general presence category. The feelings of co-presence and social presence that subjects experience when interacting with human surrogates are common metrics to evaluate what surrogate characteristics elicit physical and psychological responses. Due to their importance, these terms will be repeatedly used throughout the paper and we would like to provide basic definitions for them.

Co-presence was originally termed by [7] and denoted a state where "*people sensed that they were able to perceive others and that others were able to actively perceive them*". Reference [8] used the concept of co-presence in virtual environments to measure the psychological connection to and with another person. We would like to adopt this perspective and use the term to denote an acknowledgment by study participants that a human surrogate is perceived as a distinct, potentially intelligent, entity.

Social presence was first defined in relation to a medium by [9]: it is "*the degree of salience of the other person in a mediated communication and the consequent salience of their interpersonal interactions*". Reference [10] distinguishes social presence from co-presence by associating the first with the medium and the latter with the degree of psychological involvement. The authors of [11] propose an extension of the concept to Embodied Social Presence (ESP) which focuses on the embodied avatar as the center of activity in social interactions.

The definition of social presence exhibits a certain degree of overlap with co-presence, but we adopt the position of [11] that highlights the interactive component that allows human surrogates to actively influence and take part in social exchanges and thus be perceived as part of the social context. The surrogate can take cues from the environment, other surrogates, or human subjects and exert some level of influence on its surroundings.

We believe that both co-presence and social presence are valid measures of the quality of human-surrogate encounters.

3 Rationale

Virtual reality technology has been consistently used in training and educational scenarios over the last decade. The effectiveness of this technology has been the focus of researchers over several years, in order to better understand the underlying factors that influence the perceptions and interactions of the human users. Specifically, researchers have focused on several facets of the technology and the embedded surrogates, including the visual fidelity (appearance), auditory feedback, haptics (conveying force/touch information), physical manifestations (robots, 3D characters), intelligence of these systems, and so on. While several hypotheses of how human perceptions and emotional responses can be influenced have been tested during evaluation, there is no comprehensive space that encompasses all these findings.

From a purely academic perspective, a taxonomy is attractive for multiple reasons. A space of surrogate characteristics would provide an easy way for categorizing existing and future systems, while at the same time identifying regions that might merit further exploration. In addition, the variety of perspectives that have contributed to human surrogate research, e.g. psychological, technological, physiological, neurological, warrants an attempt to find generalizing principles.

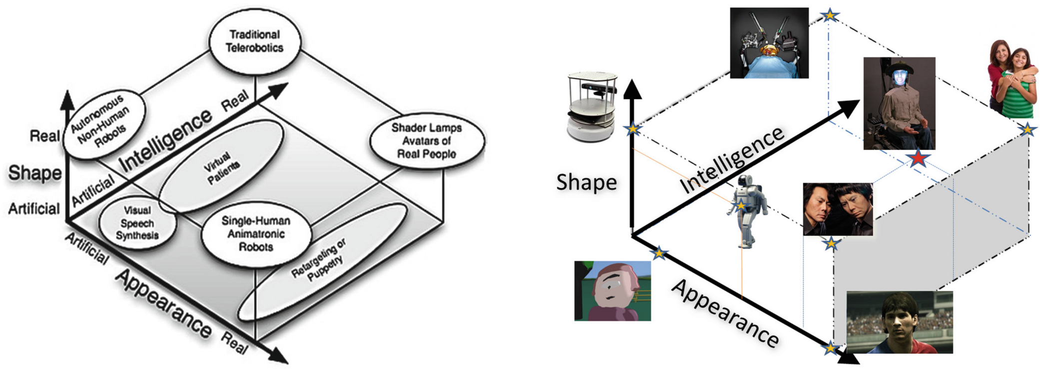
Although we hope that the resulting space can be constructed as application-agnostic as possible, an appropriately defined set of axes could assist choices of technology and surrogate characteristics in relation to application-specific training and interaction needs.

Additionally, we believe that the space will provide us with a better understanding of human-surrogate interactions from a psychological perspective, which in turn should translate to the ability to provide an effective means of interaction.

4 Defining the Space

Several attempts to classify existing work in this research area have been made previously. [12] proposed the Autonomy, Interaction, and Presence (AIP) cube to describe the components of virtual reality systems. Although not exactly a taxonomy of human surrogates, it is interesting that the author emphasizes the importance of agency, i.e. Autonomy, and interactive capacity, i.e. Interaction.

In the context of mixed-reality agents, a similar effort was undertaken by [13]. A 3D cube with the axes of Agency, Corporeal Presence, and Interactive Capacity



(a) Regions of existing human surrogate manifestations are highlighted through ellipses.

(b) Several instances of real systems can be placed in this 3D space. In addition, it allows us to place our own work on physical-virtual avatars.

Fig. 2. Historically, we envisioned the space of human surrogate characteristics as a 3D cube spanned by Appearance, Shape, and Intelligence. These are two early visualizations of this space defined in a top-down fashion.

mirrors some of our thinking, although the authors' choice of distinguishing characteristics is not sufficiently justified or grounded in existing literature. In addition, the authors concentrate on purely autonomous agents and combine attributes of body shape and appearance in the Corporeal Presence category.

Reference [14] discusses a framework for classifying representations of humans (avatars) in physical and virtual space. The main discriminants discussed by the authors are Form Similarity (avatar resembles human) and Behavioral Similarity (avatar behaves like controlling human), but the singular focus on avatars does not allow the classification of computer-controlled agents.

We began to express our own thoughts on the subject in research funding proposals over the past several years, introducing a 3D classification cube with Intelligence, Shape, and Appearance axes. Our thoughts stemmed from a top-down choice of characteristics based on our a priori knowledge of humans and first-hand human surrogate research. Building upon these earlier developments, we were able to position our own work within the context of other systems and use the classification system to guide our research directions [15]. Please see Fig. 2a for a visualization of the resulting 3D space and highlighted regions that correspond to particular manifestations of human surrogates. Specific instances of existing surrogate systems are positioned in the same cube in Fig. 2b.

Each axis ranges from being artificial to real, with "real" referring to being "as close as possible" to a human and "artificial" occupying the other end of the spectrum. This, in particular, must not be confused on the intelligence axis, since "artificial intelligence" strives to achieve "human-like" intelligence. Virtual avatars (flat screen display) for instance could be made to appear like a particular human, exhibit artificial intelligence, but have no real shape (i.e. physical manifestation) associated with them. A typical example could be a football player in a computer game. Note that the intelligence of this avatar can tend towards the real when controlled by a real human playing the game. Similarly, the appearance can tend towards artificial if a human-player customizes his avatar to look cartoonish. Autonomous humanoid robots can be made to look similar to humans both in appearance and shape (depending on their degrees of freedom), but exhibit artificial intelligence. Tele-robotics on the other hand occupies one specific corner of the 3D space, since it is generally associated with human control—i.e. real intelligence. At the opposite corner lie Shader-lamp avatars [2] of real people since it is essentially tele-robotics combined with real appearance.

Specific examples of characteristics that would fit into each one of these axes include the following:

- **Appearance.** Virtual rendering/real video. Real video, but from a different time period or different user. Skin color/race. Auditory playback. Olfactory simulation.
- **Shape/Corporeal Presence.** Apparent physical structure/representation, e.g. humanoid vs. non-human mobile robot. Tactile feel of surrogate. Presentation medium, e.g. flat screen TV, projection screen. The term "corporeal presence" was termed by [13] and not only includes the external shape of the surrogate, but also its capacity to occupy a physical space, hence the term might be a bit more general than simply using "shape".
- **Intelligence/Agency.** In some publications this is also referred to as "Agency" in the sense of who the controlling entity (human, AI, some hybrid) is. This might also include the realism of the exhibited behavior, which [4] mentions as a significant dimension of realism.

5 Our Testbed and Surrogate System Instances

For several years, we have been working on developing a unified system for controlling *surrogates* in virtual environments. The system's architecture utilizes the Marionette Puppetry Paradigm. It is designed to support individualized experience creation in fields such as education, training and rehabilitation. The system has evolved over a period of six years with continuous refinements as a result of constant use and evaluation. It provides an integrated testbed for evaluating human surrogates for live-virtual training and is called AMITIES™ [16,17]. *Surrogates* in our virtual environments that can be controlled via AMITIES™ consist of various manifestations ranging from life-size 2D flat screen displays to fully robotic entities. Figure 3 shows the different surrogate instances in our lab and the space occupied by them in the hypothetical 3D cube of characteristics shown in Fig. 2 of this article. For example, visually simulated 2D surrogates via flat-panel displays have real intelligence (human-in-the-loop) and scale. They have virtual shape and appearance. A good instance of this manifestation and its effective use is described in Sect. 5.2 of this article. Similarly, all surrogate instances described henceforth can be tied back to the 3D space illustrated in Fig. 2 as well as comply with the illustration of human-surrogate relationships depicted in Fig. 1. In particular, one can envision each of these surrogates occupying the central band in Fig. 1, while an inhabiter (Real Intelligence) or an agent (Artificial Intelligence) controls their actions (left of the figure) when interacting with human subjects

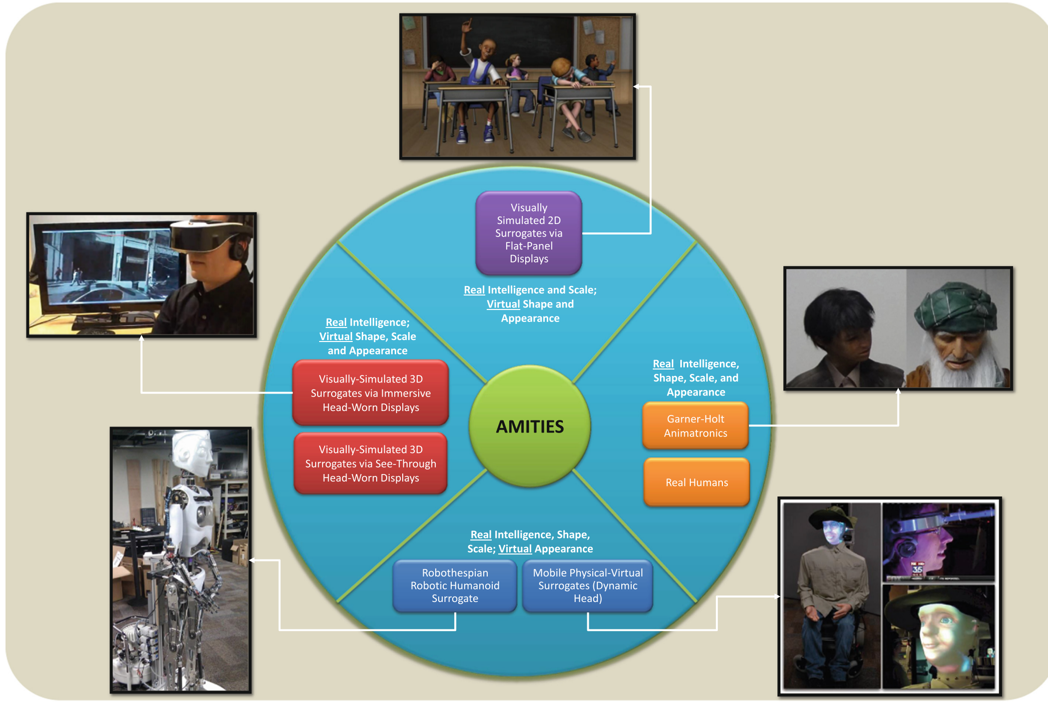


Fig. 3. The integrated testbed consisting of several manifestations of *surrogates* controlled by the unified AMITIES^{TM} architecture.

(right side of the figure). Use cases for each surrogate in our lab and the underlying framework used to drive them are described in the following sections.

5.1 AMITIES^{TM}

AMITIES^{TM} stands for *Avatar-Mediated Interactive Training and Individualized Experience System*. This is a framework to interactively control avatars in remote environments and serves as the central component that connects people controlling avatars (inhabiters), various manifestations of these avatars (surrogates) and people interacting with these avatars (participants). A multi-server-client architecture, based on a low-demand network protocol, connects the participant environment(s), the inhabiter station(s) and the avatars. A human-in-the-loop metaphor provides an interface for remote operation, with support for multiple inhabiters, multiple avatars, and multiple participant-observers.

Custom animation blending routines and a gesture-based interface provide inhabiters with an intuitive avatar control paradigm. This gesture control is enhanced by genres of program-controlled behaviors that can be triggered by events or inhabiter choices for individual or groups of avatars. This mixed (agency and gesture-based) control paradigm reduces the cognitive and physical loads on the inhabiter while supporting natural bi-directional conversation between participants and the virtual characters or avatar counterparts, including ones with physical manifestations, e.g., robotic surrogates. The associated system affords the delivery of personalized experiences that adapt to the actions and

Fig. 4. A screenshot of the surrogate student in the TLE TeachLivE^{TM} Lab environment

interactions of individual users, while staying true to each virtual character's personality and backstory.

In addition to its avatar control paradigm, AMITIES^{TM} provides processes for character and scenario development, testing and refinement. It also has integrated capabilities for session recording and event tagging, along with automated tools for reflection and after-action review.

5.2 TLE TeachLivE^{TM} Lab

The TLE TeachLivE^{TM} Lab [18,19] is an Avatar-Mediated Interactive Simulator that is currently being used by over 55 universities and four School Districts across the US to assist in Teacher Skills Training and Rehearsal. This Virtual-Reality based simulation is used by teachers, both pre-service and in-service, to learn or improve their teaching skills through the processes of rehearsal and reflection.

The TLE TeachLivE^{TM} Lab includes a set of pedagogies, subject matter content and processes, seamlessly integrated to create an environment for teacher preparation. The technological affordances of the system allow teachers to be physically immersed in a virtual classroom consisting of several students that exhibit a wide variety of appearances, cultural backgrounds, behaviors and personalities commonly observed in specific age groups. The environment delivers an avatar-based simulation intended to enhance teacher development in targeted skills at any level (middle school/high school etc.). In fact, studies have shown that a single discrete behavior, e.g., asking high-order questions, can be improved in just four 10-min sessions in the simulated classroom. Moreover, this improvement continues at an even faster pace once the teacher returns to her or his classroom. Teachers have the opportunity to experiment with new teaching ideas in the lab without presenting any danger to the learning of real students in a classroom. Moreover, if a teacher has a bad session, he or she can re-enter the virtual classroom to teach the same students the same concepts or skills. Beyond training technical teaching skills, the system helps teachers identify issues such as recondite biases, so they can develop practices that mitigate the influence of these biases in their teaching practices.

AMITIES™ supports the users' needs for realism and the researchers' needs for quantitative and qualitative data. The integrated after-action review system provides objective quantitative data such as time that avatars talk versus time that a user talks, and subjective tagging ability so events such as the type of dialogue can be noted and subsequently reviewed by researchers (data analysis), coaches (debriefing) and users (reflection).

The TLE TeachLivE™ Lab has been used for teacher preparation since 2009, with over 10,000 teachers having run-through the system in academic year 2013-14. It is estimated that each of these teachers interacts with nearly 50 students resulting in an effective outreach of nearly 500,000 students. The surrogates used in the TLE TeachLivE™ Lab are an example of real intelligence and scale; virtual shape and appearance.

5.3 Physical-Virtual Avatar

The Physical-Virtual Avatar (PVA) was conceived and developed at the University of North Carolina at Chapel Hill in 2008–2009 by Greg Welch, Henry Fuchs, and others [2] and has since been replicated at both the University of Central Florida and Nanyang Technological University. This surrogate has a face-shaped display surface mounted on a pan-tilt-unit, stereo microphones, a speaker, and three wide-angle HD cameras to capture the environment in front of the avatar (each camera maps directly to one of the three large-screen displays in the inhabiter station). The pan-tilt-unit is programmed using a closed-loop velocity controller to match the current pose of the tracked inhabiter's head while live imagery from the inhabiter is projected on the display surface. This gives the inhabiter the ability to interact with multiple people through a physical 3D presence at the remote location.

The entire surrogate-side system is mounted on a motorized cart, and powered by an on-board battery. Video from the three cameras as well as the inhabiter's face imagery can be streamed over the wireless network. In addition, the PVA can operate in a "synthetic mode" where its appearance can be changed to reflect any virtual character on the fly. The wireless mode of operation of this unit allows inhabiters to control the motorized cart and freely navigate in the remote environment. AMITIES™ is used to control the PVA in its "synthetic" mode. It allows inhabiters to jump between various manifestations during interaction - for instance, an inhabiter can choose to inhabit a character in the TLE TeachLivE ™ Lab at one instant and immediately switch to inhabit the PVA

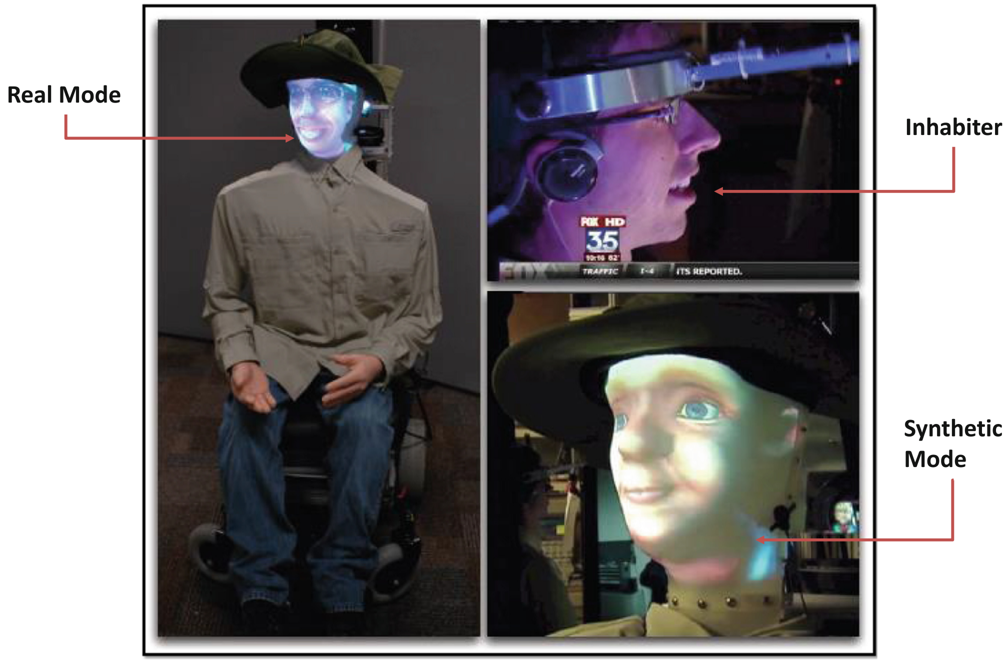


Fig. 5. The Physical-Virtual Avatar can operate in "real" or "synthetic" modes when inhabited.

at the next instant. The PVA is an example of real intelligence, scale and shape with virtual appearance.

5.4 Robothespian

The Robothespian is a humanoid robot developed by Engineered Arts, UK. It consists of a hybrid actuation system with pneumatic fluidic muscles and electric actuation. This surrogate has a total of 24 independently controllable degrees of freedom. As previously mentioned, the AMITIES^{TM} paradigm has been developed to support inhabiting of robotic avatars including the Robothespian. This instantiation uses a master-slave relationship, where a virtual surrogate on a display screen is controlled by the inhabiter. This virtual surrogate behaves as a master and the Robothespian behaves as a slave by mimicking the master as closely as possible (both in space and time).

The Robothespian features a rear-projected head and supports appearance changing in real-time. Inhabiters can switch between virtual surrogate masters and the Robothespian's facial imagery will change to reflect this switch. In addition, each master surrogate can have very specific behaviors. The Robothespian is opaque to this behavioral uniqueness of each master and simply follows commands given to it by a specific master. This architecture allows different behaviors of the Robothespian to be associated with the same inhabiter's intent, simply by switching the master controlling it. For instance, culturally varying gestures such as "Hello" can be programmed into three different masters. Each time a master is chosen by an inhabiter, the culturally appropriate version of

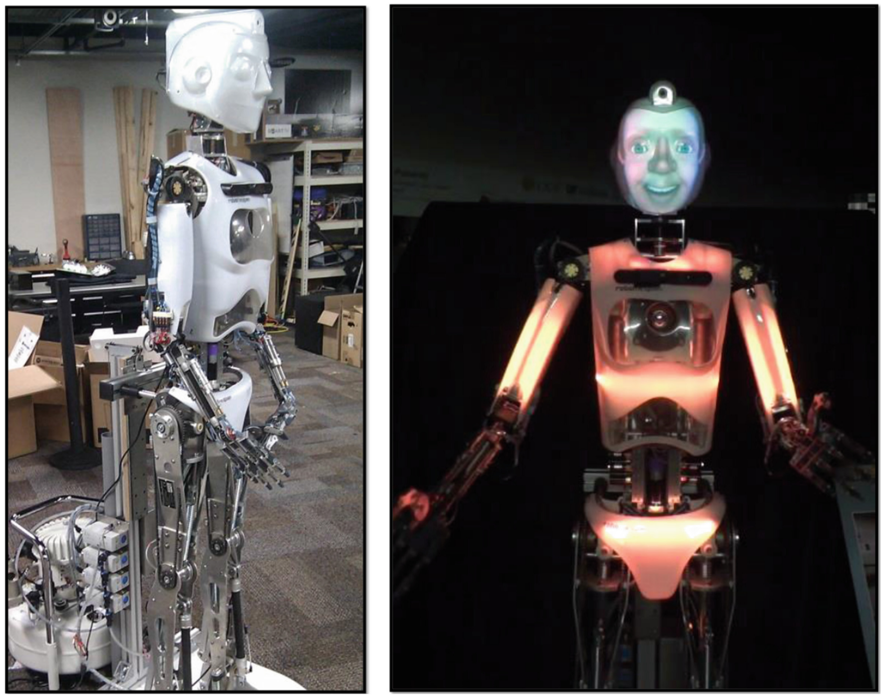


Fig. 6. The Robothespian Humanoid Robot is one of our surrogates that can change appearance and physically gesture while interacting with people in the environment.

"Hello" is faithfully reproduced at the Robothespian's end. The Robothespian is another example of a surrogate with real intelligence, scale and shape and having virtual appearance.

5.5 Animatronics

Three animatronic humans (fully pneumatic) complete our collection of human surrogates used for live-virtual training. They are manufactured by Garner-Holt Productions. Two of these animatronic figures are young boys while the third is an older man. The old man has more degrees of freedom than the young boys. The appearance of these animatronics is very realistic since they have customized rubber/synthetic skin on them to represent the middle-eastern culture. While this is an advantage to explore the effect of "realism" in surrogates, there is the drawback that changing appearance becomes much harder (unlike projected systems featured in most of our other surrogates). The motion of the animatronic figures is also quite realistic. The level of control on different joints depends on whether the actuators support binary operation (on/off) or position-based responses. We are currently adapting these animatronics to be driven by the AMITIES^{TM} paradigm. The animatronics (when driven using AMITIES) are an example of real intelligence, shape, scale and appearance since they resemble a real human very closely in all aspects.

Fig. 7. The Young Boy (left) and the Old Man (right) are two of our three very realistic-looking animatronic surrogates.

6 Conclusion and Future Work

We believe that this document begins laying the foundation for developing a comprehensive framework that identifies and classifies the main determinants for real humans' perceptions towards and interactions with human surrogates.

We began this year with a plan for exploring a "space" of surrogate characteristics. Through an extensive literature review and bottom-up categorization, we distinguished a number of fine-grained characteristics that appear to be strongly correlated with the quality of human-surrogate interaction. In addition to this bottom-up approach, we also posited a substantially smaller set of high-level characteristics in a top-down fashion: appearance, shape/corporeal presence, and intelligence/agency. These were conceived through our prior knowledge of humans and previous research results with which we were already familiar. Future work in this area includes consolidating the characteristics from both top-down and bottom-up approaches.

While this initial "space" exploration was useful, we are most excited now about developing a broader framework that will expand the original "space" exploration to include psychological, environmental, and other aspects that affect real humans' perceptions towards and interactions with human surrogates. Our original "space" of surrogate characteristics could conceptually be contained within the "Surrogate" section of that framework.

Such a framework will keep evolving, as will our database of relevant work (publications, studies, etc.), and both will guide the development of a research roadmap that describes future research directions for exploring interesting aspects of the framework. From a practitioner's perspective, we hope that our work will also be a tool to provide application-specific recommendations of which characteristics are most pertinent to meet individual training and interaction needs.

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