Upending the Uncanny Valley

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Abstract

Although robotics researchers commonly contend that robots should not look too humanlike, many artforms have successfully depicted people and have come to be accepted as great and important works, with examples such as Rodin's Thinker, Mary Cassat's infants, and Disney's Abe Lincoln simulacrum. Extending this tradition to intelligent robotics, the authors have depicted late sci-fi writer Philip K Dick with an autonomous, intelligent android. In doing so, the authors aspire to bring robotic systems up to the level of great art, while using the technology as a mirror for examining human nature in social AI development and cognitive science experiments..

Uncanny can be good

This The myth that robots should not look or act very humanlike is a pernicious one in robotics research, one commonly known by the term "Uncanny Valley". Our research, however, furthers the tradition of human figurative depiction that reaches from classical Greek sculpture to "postmodern" contemporary art.

By advancing this tradition into the field of robotics with intelligent and highly expressive depictions of humans, we gain a powerful mirror that can help address the question of "what is human". While people do indeed appear to be more sensitive to the realistic human social countenance (vs. cartoonish depictions), this sensitivity can serve as a highly refined metric to assist in exploring human social cognition, in the pursuit of better cognitive science. And, if our engineered realistic robots do satisfy human's discriminating taste for verisimilitude, then we will have developed a powerful toolchest of principles for engineered non-realistic robots as well.

In this paper we will discuss the results of our recent human subject experiments, which strongly contravene the "Uncanny Valley" theory that humanlike robots are innately unlikable.

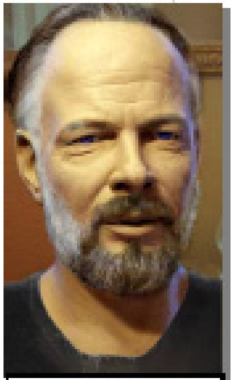


Figure 1
Hanson Robotics'
PKD-Android Hardware

We also demonstrate our latest robot that contradicts the Uncanny Valley—an android that portrays the late sci-fi writer Philip K Dick (PKD), the mind behind Blade Runner, VALIS, and other AI-inspired works. This robot incorporates numerous machine perception technologies and deep natural language processes, in an architecture that simulates the complete conversational persona of the man. This robot won first place in the 2005 AAAI Open Interaction competition. We acknowledge that there is still debate regarding whether robots can look human without being frightening. However, we think there is little to lose by making robots that look uncanny, and much to gain in our understanding of humans and human emulation.

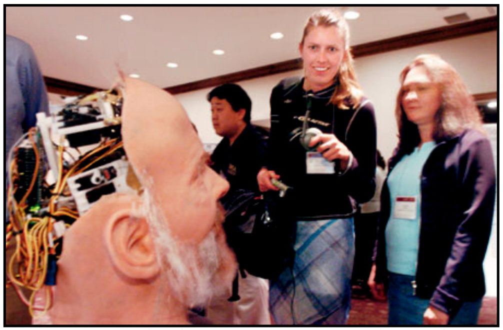


Figure 2. PKD android grabbing interest at AAAI '05. Photo from Pittsburgh Tribune, July 2005.

Background

Social robots use computer vision, conversational speech and animated gestures to socially engage people. These robots and their constituent technologies are evolving at a rapid pace, largely due to rapid advances in hardware performance. Given the U.N.-projected 7-fold expansion of robot markets between 2004 and 2007 [UNECE, 2004], one can anticipate that both performance and the prevalence of social robots will accelerate over time.

To date, most social robots have been designed to look not human, but animal-like (like the fantastic Leonardo of MIT [Breazeal et al, 2005]) or mechanistic (like the Robovie-series of the ATR [Fong, et al, 2003]) instead.

The robots of Fumio Hara and Hiroshi Ishiguro have been rare exceptions to this trend, attempting to emulate human faces as exactly as possible [Ishiguro, 2005]. These projects have generally used solid silicone elastomers and hydraulic or pneumatic actuators—staple technologies of movie/themepark special effects animatronics [Hanson et al, 2003]. In fact, the latest hardware of Ishiguro's robots, including the Repliee series (see figure 3), are made by the Japanese animatronics company Kokoro Dreams. But these technologies have problems, being heavy, power hungry (up to 3.7 kw [KokoroDreams website]), expensive, and tethered by big offboard compressors. Moreover, such materials don't fold, compress or otherwise move like flesh. These drawbacks limit these technologies and those of animatronics as well.

Figure 3. Hiroshi Ishiguro and the Repliee robot, 2005.

An important point here is that the robots of Ishiguro and Hara do attempt to look as perfectly real as possible, to dodge potential "uncanny valley" effects. To understand why, we must consider the theory.

As first posited by Masahiro Mori in the late 60's, the theory of the "uncanny valley" holds that cartoonish depictions of humans are appealing, as are perfectly realistic depictions, but in between there exists a "no man's land" that is inherently disturbing (see the leftmost graph of figure 5). Purportedly, Mori further contended that it was way too hard to make a robot realistic enough to be appealing, so should always be cartoonish [Reichardt, 1978].

Though never formally tested, this theory has an intuitive ring of truth to it, and so has resulted in a long-standing aversion to humanlike representations in robots.

Hara and Ishiguro are clearly bucking this trend by attempting the hard task of realism. Yet the valley still holds some sway, avoided as a no-man's land.

In figurative art, however, every level of abstraction and realism is tolerated and respected. Here, the uncanny is considered an interesting effect to be tackled, not skirted. A good example is the work of Ron Mueck, a sculptor who at one time worked in the Henson animatronics shop. His figures, while not animated, are extremely realistic in many aspects, but are distorted in others. The figures are much too large or small, overly expressive, or otherwise surreal.

Figure 4. "Mask" sculpture by Ron Mueck (not animated). Photo by Dan Feldman**.**

The effect can be unsettling indeed, but public reaction seems generally to be that of awe and wonder, not derision or rejection.

In figure 5, we point out that such alternate examples of depictions turn the intuitive logic of the uncanny valley theory upside down. Later in the paper we back up this conjecture with data from human subject surveys, and then we propose an alternative theory.

Yet, these things don't mean that realistic faces will be good for robotics. Truthfully, reasonable arguments persist against realism and near-realism in robots. The tasks are extremely difficult, as people seem to become more discriminating for realism. Realistic robots might turn people off, repelling them from robots in general, and perhaps exacerbating people's standing fear of robots. We may also risk creating unrealistic expectations of robots—if they look human, people might presume that the robots should be as smart as humans, and be disappointed with AI (once again) once they find the robots are not

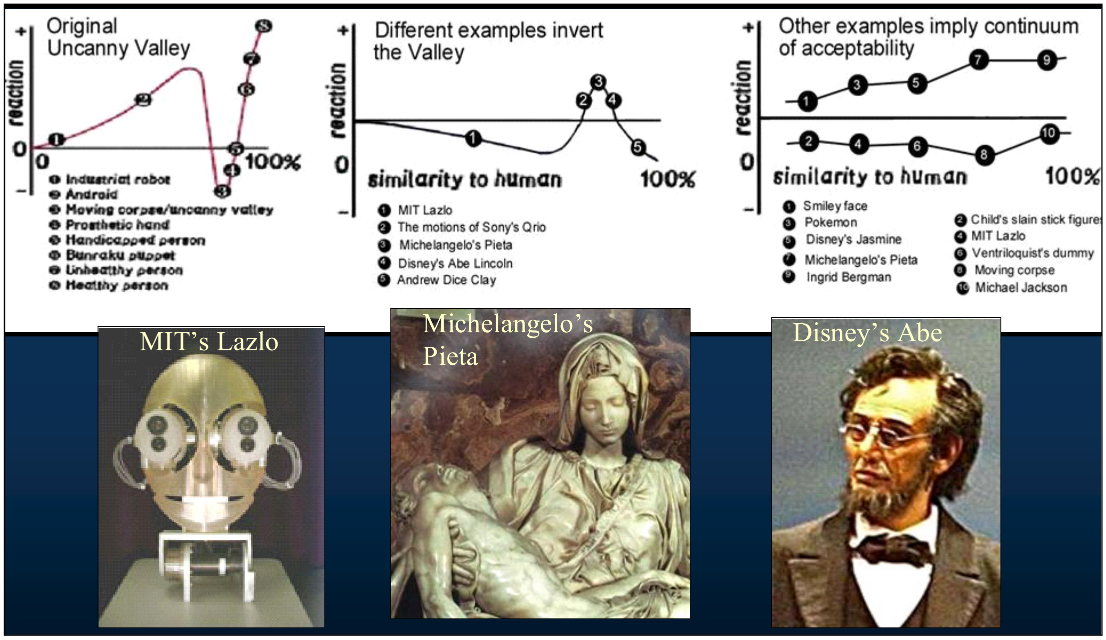


Figure 5. The uncanny valley theory, as Mori posited (on the left, image courtesy of [Bryant, 2002]), and with alternate examples chosen by the authors (center and right graphs)

On the other hand, realistic robots might do some good. They may serve as an excellent metric in the cognitive science of facial perception. They could help to explore/model human social intelligence. Also, such AI-driven robots might become a groundbreaking new art medium—the "film" or "marble" of the 21st century. After all, in art, the human face has proven an endlessly captivating subject, from prehistory to postmodernism. Thus, such faces may actually draw people *to* robotics rather than repel them; it remains to be seen. And finally, the resulting techniques may be applied to more abstract design modalities, just as realistic figure-drawing is the foundation of good cartooning. Certainly, realistic robots are enticing simply as an under-explored territory in robotics.

The robots of David Hanson (see figure 6) do not tiptoe around the uncanny valley, but dip in and out of the uncanny in attempt to chart the territory and its boundaries. It is in this spirit that the subject of Philip K Dick (PKD) was chosen, as PKD the writer himself fearlessly and ingeniously played with issues of the uncanny in his stories about androids and AI.

It should be quickly noted that the Hanson android hardware is also distinguished from that of other robots by its lightweight low-power characteristics, which enable the Hanson heads to be mounted on untethered biped bodies. To the best of the authors' knowledge, Hanson's is the only such expressive hardware to have been mounted on an untethered walking biped, as was achieved at the WIRED Nexfest, with the KAIST Hubo robot (see figure 7).

The key to this accomplishment is the nature of Hanson's patent pending Frubber materials, which are porous elastomers that stretch and compress much more like facial soft tissues than do materials classically used to emulate the face [Hanson and White, 2004]. In tests, Hanson's robots consume only 10watts, less than 1/370th the consumption of the Repliee robots. The Frubber materials also wrinkle, fold, and bunch into expressions that are more naturalistic that those achieved with conventional elastomers.

Figure 6. Hanson Robotics' facial expression hardware models demonstrating ranges of emotional affect.

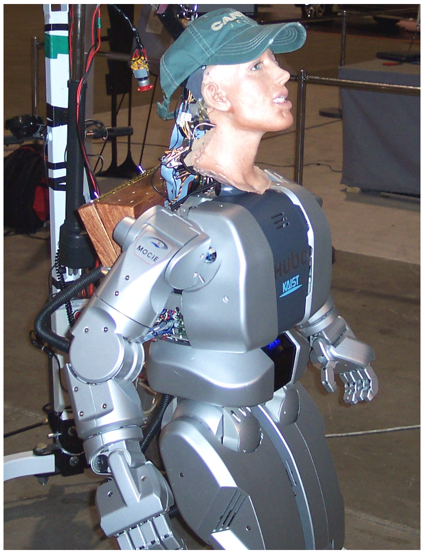


Figure 7. Hanson Robotics' EVA gesticulating atop the walking KAIST Hubo biped at WIRED Nextfest, 2005.

Mechanically, Hanson robot hardware actuates the skin along vectors corresponding to the natural muscle actions of the face, enabling animation control either in an intuitive manner or via systems like Ekman's FACS facial action coding system (see figure 8).

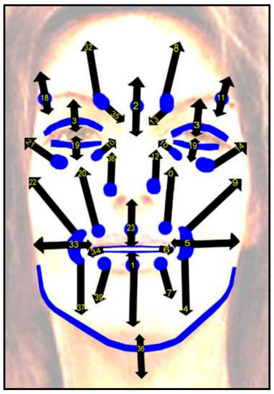


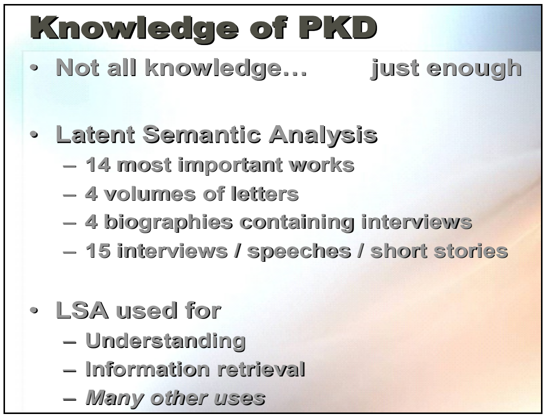
Figure 8. Facial action vectors of the EVA robot.

PKD-A Humanoid Intelligence Architecture

To make for an effective social robot, we must simulate the complete social responsivity of the human being. This requires the fusion of many systems elements including face detection and ID, speech recognition, natural language processing, speech synthesis, and an advanced motion control system for coordinating multiple competing motor control functions.

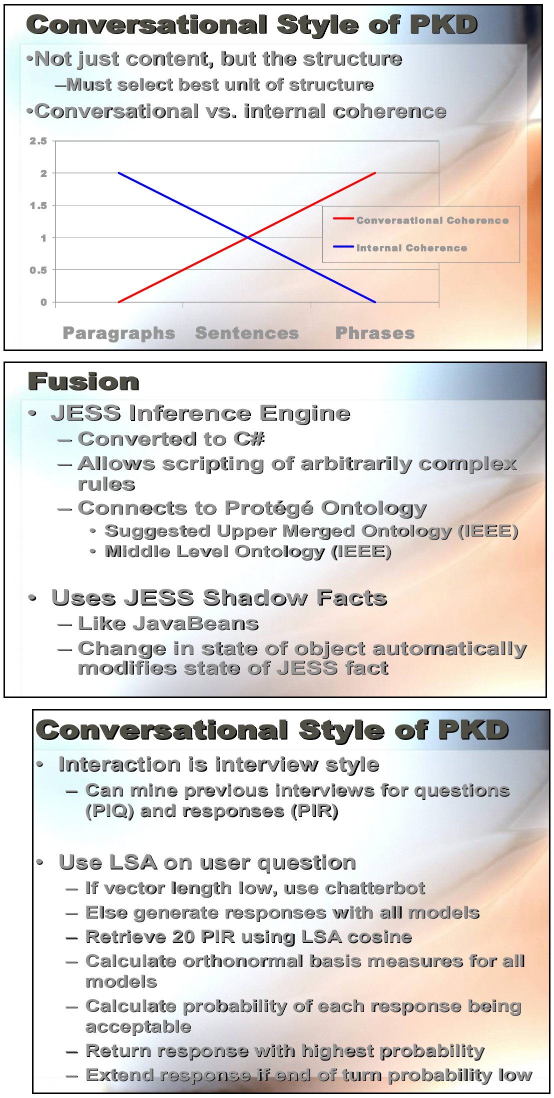
In a typical interaction scenario, face detection software will detect a person, and the robot will smile in greeting. The speaker independent speech recognition (provided by Multimodal Software) will accurately detect many thousand of words and phrases, and send this as text to the natural language processing core. The determined response will then drive the facial animation (running through a custom Maya plugin) in sync with a highly realistic synthesized voice provided by Acapela.

The natural language software uses an database constructed from the life of PKD, his works, and an enormous amount of common and literate knowledge. This ontology is expanded by an LSA corpus derived from several dozen volumes of PKD's own words, used to populate the database (see figure 9).



Knowledge of PKD

- Not all knowledge… just enough
- Latent Semantic Analysis
  - 14 most important works
  - 4 volumes of letters
  - 4 biographies containing interviews
  - 15 interviews / speeches / short stories
- LSA used for
  - Understanding
  - Information retrieval
  - *Many other uses*



Conversational Style of PKD

- Not just content, but the structure
  - Must select best unit of structure
- Conversational vs. internal coherence

Fusion

- JESS Inference Engine
  - Converted to C#
  - Allows scripting of arbitrarily complex rules
  - Connects to Protégé Ontology
    - Suggested Upper Merged Ontology (IEEE)
    - Middle Level Ontology (IEEE)
- Uses JESS Shadow Facts
  - Like JavaBeans
  - Change in state of object automatically modifies state of JESS fact

Conversational Style of PKD

- Interaction is interview style
  - Can mine previous interviews for questions (PIQ) and responses (PIR)
- Use LSA on user question
  - If vector length low, use chatterbot
  - Else generate responses with all models
  - Retrieve 20 PIR using LSA cosine
  - Calculate orthonormal basis measures for all models
  - Calculate probability of each response being acceptable
  - Return response with highest probability
  - Extend response if end of turn probability low

Figure 9. PKD conversational systems.

A set of flexible rules based on a similar statistical and linguistic parsing determines the robot's response to conversational and environmental stimuli. Conversational Style of the PKD robot is determined by a statistical parsing of PKD's own, as parsed by latent semantic indexing and assembled by latent semantic analysis (LSA).

Through the cameras in its eyes, the robot perceives faces and facial expressions, using a combined application of Intel Open CV libraries and the Nevenvision Axiom facial feature tracker.

As faces come into proximity of PKD's Cameras a sequence of face recognition Algorithms are executed to determine exactly who's face is in the image. When PKD encounters new faces he simply remembers them to use in future comparisons.

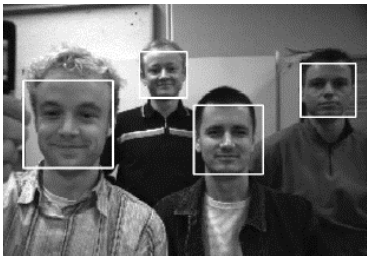


Figure 10. Facial detec`tion with Intel Open CV.

Additionally, Cognitec's FaceVacs software enables the robot to identify people known to PKD (family, friends, celebrities, etc). The data from the vision and language software are fused into several categories of models, which drive dynamically blended animations to affect eye contact with people.

Animation Systems

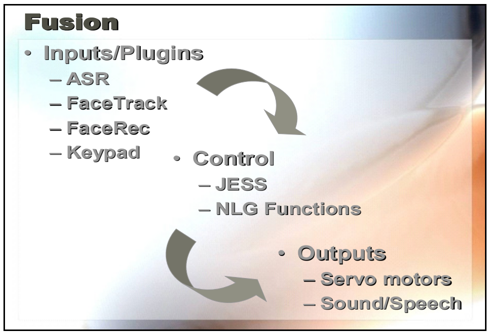
The interface of the AI and animation systems brings challenges new to animation, as such animations need to be contextualized in a conversation, be triggered by perceptions of people and the environment, or be controlled by internal motives or decisions.

Additionally, multiple animation streams and performance-based motions like locomotion and eye-contact, need to be coordinated and blended. With previous work done in this area, the tools need to be refined, usable, and extensible.

For the PKD android we considered that Maya could be used for several purposes: first, as an animation interface, second, as a motion control layer to be driven by our AI systems, and third, as a method for modeling and managing a 3D world view for enhancing the AI of the robot. Fourth and fifth uses would be as a visualization/debugging tool, and for enabling development of AI and animation for robots without the physical hardware being present.

As an animation interface, we found Maya quite promising. As a motion control layer however, unfortunately Maya's standard SDK appears to limit the interactive playback, so that realtime animation assembly and simultaneous playback can not be handled with Maya. We are seeking to resolve this with Alias/Wavefront, the manufacturer of Maya.

In the meantime, we have developed our own animation playback software, which plays and blends comma separated value (.csv) animation files developed using animation software called Visual Servo Automation (VSA). This software also blends visemes (speech related mouth motions), synchronizes these with tts speech synthesis, and controls head-pose to affect eye-contact, as the robot sees faces using the Intel Open CV Haar Face Detect computer vision. The robot's motions are not bad, but will be improved with a better motion control layer, and better animation authoring tools. We are considering open alternatives such as Open GL and Blender, which are promising because the source code is available to adapt as needed.



Fusion

- Inputs/Plugins
  - ASR
  - FaceTrack
  - FaceRec
  - Keypad
- Control
  - JESS
  - NLG Functions
- Outputs
  - Servo motors
  - Sound/Speech

Figure 11. PKD System flow.

The animation and conversational systems then all need to be grounded in a theatrical space that

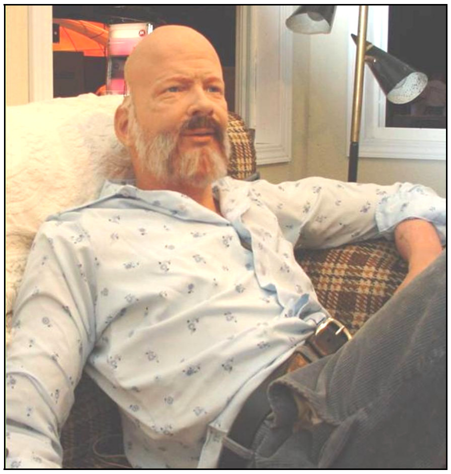


Figure 12: PKD android acting in its setting

Open Architecture for Humanoid Intelligence (HI)

We feel that for realistic robots to be appealing to people, they must attain some level of integrated social responsivity and aesthetic refinement. To facilitate this, many groups and individuals can coordinate and integrate their work in software component and systems technology. We have started a developer's network that has some of the PKD source code as built by Andrew Olney posted, at www.human-robot.org. Other similar group initiatives exist, and we link to some, and encourage others to notify us of their existence. Let's avoid redundant innovation.

Our intention is to host an open source development project on source forge where developers from all over the world can start contributing to the efforts of making software more intelligent and interactive. The architecture initiative is a core system that represents the brain of the android. The core will function as the reasoning engine, thought processor, memory (long, mid, short), and facts repository. These functionalities will be available to developers through a well defined API so that new system components can be integrated as they become relevant.

Along with a core system we want to provide the open source community with a 3D real time rendering engine to portray the android on a computer screen. This way a developer can write software components, integrate new technology, and watch it operate on their screen.

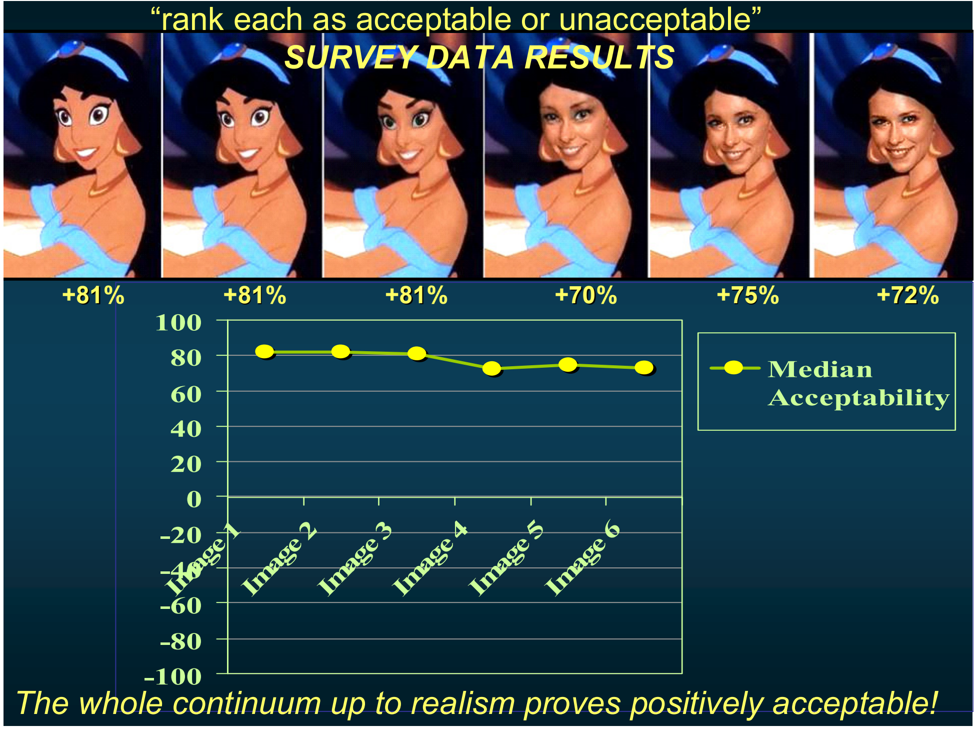
By working in larger groups, we can develop both better robots, and better tools for designing and building robots and their personalities. As the robots evolve, new aesthetic derivations will provide new waves of challenges to the old uncanny valley theory.

New Data that Challenges the Uncanny Valley Theory

Because the Uncanny Valley has never been studied with real people we sought to put the theory to the test with human subjects. To make this happen, we conducted two web-surveys. The first showed videos of two Hanson robots, animated to simulate humanlike facial expressions, and asked what people thought of the images (see figure 13). The second survey showed a continuum of humanoid depictions, shifting from cartoonish to realistic over six frames (see figure 14).

Figure 13. Test 1. Left: video 1, Eva emoting; right: video 2, robotic pirate gesturing.

In the results of the first test, **73%** found both robots appealing, **0.0%** said that human-looking robots disturb them, and **85%** said the robots look lively, not dead. This was in spite of numerous unrealistic features (head on a stick, no back of head, etc).


“rank each as acceptable or unacceptable”

SURVEY DATA RESULTS

The whole continuum up to realism proves positively acceptable!

Figure 14: Results of test 2.

The results of the second test, clearly showed that viewers found the whole continuum positively acceptable. The reaction never dipped into the negative region, thus showed no sign of the repulsion that defined the “valley” of Mori’s uncanny valley. There does not appear to be an inherent valley.

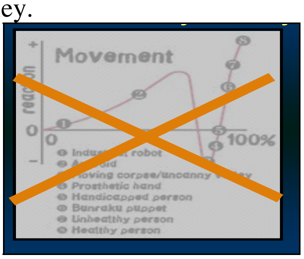


Figure 15: A new theory is called for.

So if people are indeed more sensitive to realistic depictions, but there is no “valley”, then the theory needs a new name and a new framework.

We suggest that any level of realism or can be socially engaging if one designs the aesthetic well. This, in effect, represents a bridge of good aesthetic, which inspires us to name the revised theory the “Path of Engagement” (POE).

This POE theory has someinteresting ramifications.

If people are indeed more sensitive to realistic faces, this may imply that realistic faces transmit a rich, high-bandwidth stream of data. Conversation diverts attention from watching for danger, so a face that behaves strangely or in an unhealthy manner may trigger survival or fear reflexes. Alternately, it may trigger “surreal” (dreamlike) feelings, rather than fear. Thus, people may find the robot strange but not frightening. As no “valley” is inherent; anthropomorphic depictions can be either disturbing or appealing at every level of abstraction or realism. People simply get more sensitive with increasing levels of realism.

In future work it will be important to push the science of the art (exploring the neuro-cognitive basis of social aesthetics), and the art of the science (art as a black-box problem solver for problems of social intelligence). In any case, the science, art and technology of social robots will benefit from the removal of the artificial proscription of the Uncanny Valley. We need to explore the valley to find the Path of Engagement.

Conclusion

We feel that for realistic robots to be appealing to people, robots must attain some level of integrated social responsivity and aesthetic refinement. An integration framework of AI, mechanical engineering and art is needed to achieve this objective. This quest is in its infancy, but as the discipline emerges, we contend that realistically depicted humanlike robotics will serve as an unparalleled tool for investigating human social perception and cognition. In our experiments, our robots have demonstrated clearly that realistic robots can be appealing. We conclude that rendering the social human in all possible detail can help us to better understand social intelligence, both scientifically and artistically.

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