The Art of Designing Robot Faces – Dimensions for Human-Robot Interaction

Mike Blow, Kerstin Dautenhahn, Andrew Appleby, Chrystopher L. Nehaniv, David Lee
Adaptive Systems Research Group
University of Hertfordshire
Hatfield, Hertfordshire AL10 9AB
United Kingdom
M.P.Blow@herts.ac.uk, K.Dautenhahn@herts.ac.uk

ABSTRACT
As robots enter everyday life and start to interact with ordinary people the question of their appearance becomes increasingly important. A user's perception of a robot can be strongly influenced by its facial appearance. Synthesizing relevant ideas from narrative art design, the psychology of face recognition, and recent HRI studies into robot faces, we discuss effects of the uncanny valley and the use of *iconicity* and its effect on the self/other perceptive divide, as well as *abstractness* and *realism*, classifying existing designs along these dimensions. The dimensions and issues of face design are illustrated in the design rationale, details of construction and intended uses of a new minimal expressive robot called KASPAR.

1. MOTIVATIONS
It is an exciting time in robotics. Personal service robots, so long the science fiction dream, are becoming reality and are for sale to general consumers. Currently their uses (and users) are limited, but capabilities are improving, costs are coming down and sales are growing. In addition robots are finding a new place in society as toys, artificial pets [29], security guards, teachers [18], tour guides [35] and in search and rescue [11]. They are finding use in areas as diverse as autism therapy [32, 33], space exploration [1] and research into cognition and biological systems [34].

1.1 RobotCub
One such research project that we are involved in at Hertfordshire is RobotCub, a 5-year multinational project to build a humanoid child-size robot for use in embodied cognitive development research [34]. The RobotCub consortium consists of 11 core partners from Europe with collaborators in America and Japan, and the institutions involved are each working on specific areas of the robot design, engineering, developmental psychology and human-robot interaction. The project software and hardware plans will be published under open-source licenses, with the aim of creating a community using a common platform for robotic and cognitive research.

1.2 Designing Robots for Users
Robots are becoming available in a wide variety of roles. A recent report by the UN Economic Commission for Europe and the International Federation of Robotics predicts that 4.1 million robots will be working in homes by the end of 2007 [36]. The implication is that, as they crawl, roll and walk out of the laboratory and into the 'real' world, that people in the real world will be using them - families, soldiers, nurses, teachers. These users will more than likely not have a background in engineering nor care about the intricacies of the control algorithm in their robot. To them it will be a tool in the same way as a DVD player or a PC. However robots differ significantly from most consumer electronics in two respects: (1) Robots are often designed (and expected) to use human communication modalities, for instance speech and hearing in place of LED displays and buttons. This is sometimes because these modalities are implied by the robots' anthropomorphic design and sometimes for practical reasons - robots are usually mobile and even a remote control may be of limited practical use. (2) Due to their embodiment, robots have the capability to supply rich feedback in many forms: anthropomorphic ones such as speech, gestures and body language and 'artificial' ones such as lights and music. Current consumer robots such as the Sony AIBO use a combination of both. Using real-time communication a robot can engage the user in active social interaction, and importantly even instigate interaction. In contrast, most consumer electronics are passive; that is, there is only interaction when instigated by a human, and that interaction is largely in one direction, from the human to the machine.

A user study of people's expectations of a robot companion indicated that a large proportion of the participants in the test were in favour of a robot companion, especially one that could communicate in a humanlike way [10]. Humanlike behaviour and appearance were less important. In terms of role robots were seen by the majority as suitable for personal assistant duties carrying out household tasks. Child care or friendship roles were seen as less suitable.

Human-human interaction studies are a good starting point for HRI research, but can only be treated as such. Robots

Human Robot Interaction '06 Salt Lake City, Utah USA

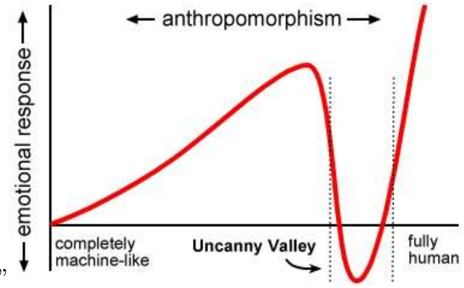

Figure 1: Mori's uncanny valley hypothesis.

are not people, and not all insights and results will remain valid for HRI scenarios. So given that the nature of the interaction between humans and robots is likely to be different from that between two humans, or between humans and most current consumer technology, there are many open questions. Most importantly for the general acceptance of robots, what appearance and modalities of communication are optimal for the majority of non-technical users? Will people find a machine with a human appearance or that interacts in a human-like manner engaging or frightening? If a face is humanoid, what level of realism is optimal? Are gestures useful? What role could timing [38] and the movement and timing of interactive behaviour (*kinesics* [31, 5]) play?

The remainder of this paper considers the design of robots, especially the face - arguably one of the most useful, yet communicatively riched and technologically difficult areas of a humanoid robot to design. Various designs are considered and compared and theories derived from the analysis of iconographic faces in narrative art are applied. Finally the HRI research robot KASPAR is introduced, whose design rationale illustrates the arguments presented.

2. CONSIDERING DESIGN

2.1 The Extended Uncanny Valley

The effect of the aesthetic design of a robot is an area that has often been neglected, and only in visual science fiction media or recently with the advent of commercial household robots has it been paid much attention. A notable exception is the 'uncanny valley' proposed by Masahiro Mori in the late 1970's [25, 9]. Mori proposed that the acceptance of a humanoid robot increases as realism increases. However there comes a point where, as the robot approaches perfect realism, the effect becomes instead very disturbing and acceptance plunges, because the robot starts to look not quite human or at worst like a moving corpse (Fig. 1). In theory the realism of both appearance and movement can give rise to this effect, with movement evoking the stronger response, see [23, 22] for more recent work on the uncanny valley by MacDorman. MacDorman argues that the uncanny valley can be seen in a positive light as it implies people are applying a more stringent human model to evaluate an android (i.e. a realistic humanoid as distinct from one with a mechanistic appearance [15]), which is an indication that androids could be a valid tool in human psychology studies.

2.2 Managing Perceptions

DiSalvo *et al.* performed a study into how facial features and dimensions affect the perception of robot heads as human-like [12]. Factors that increased the perceived humanness of a robot head were a 'portrait' aspect ratio (i.e. the head is taller than it is wide), the presence of multiple facial features and specifically the presence of nose, mouth and eyelids. Heads with a landscape aspect ratio and minimal features were seen as robotic. They suggest that robot head design should balance three considerations: 'human-ness' (for intuitive social interaction), 'robot-ness' (to manage users' expectations of the robot's cognitive abilities) and 'product-ness' (so the user sees the robot as an appliance). The idea of designing a robot to be perceived as a consumer item is noteworthy for the fact that people's *a priori* knowledge of electronic devices can be utilised in avoiding the uncanny valley; the implication is that the robot is non-threatening and under the user's control. To fulfill their design criteria they present six suggestions: a robot should have a wide head, features that dominate the face, detailed eyes, four or more features, skin or some kind of covering and an organic, curved form.

It is interesting to note that these points seem to have been adopted in many of the consumer robots currently in development, which are often designed to be obviously 'product-like', appealing and engaging - the Sony QRIO, for instance, conforms to every one. A robot's appearance can affect the way it is perceived in other ways:

Role Suitability. Goetz et al. [14] introduced the 'matching hypothesis', i.e. that machine-like features are seen as more suitable for investigative and security (i.e. authoritarian) situations, whereas those with a human appearance are preferred for artistic, service and social roles.
Personality. Appearance has a great effect on the perceived personality and emotional capabilities of a robot. Some robots, especially those sold as toys or for use in the home, draw on the long history of doll design [3] and use abstracted or exaggerated infant-style features such as a round, symmetrical face and large eyes. This aesthetic evokes protective instincts in the user thus circumventing the uncanny valley. Woods, Dautenhahn and Schulz [37] conducted a study in which children were asked to rate robots in terms of several personality traits according to their appearance. The robots were classified as having machine, animal, animal-machine, human-machine and human appearance. Results indicated that the overall combination of physical attributes was important, with animal-like robots rated as happy, purely mechanistic robots rated as aggressive and angry, human-machine robots rated as friendly and human-like robots rated as aggressive. Interstingly this result supports the uncanny valley as human-machine robots were rated more positively than realistic human-like ones. The children were also asked to assign each robot a gender, and it was found that those perceived as female were often associated with positive personality traits.
Sensory and interaction capabilities. Users are likely to make an initial assessment of the robot's interaction capabilities based on appearance. An ultra-realistic humanoid with limited movement or interaction abilities is likely to disappoint; a simple-looking robot that turns out to have complex interactive behaviour will surpass expectations [8].

2.3 Consistency

The consistency of the design of a robot might also be a consideration in managing user perceptions. A robot with mismatched features, for example a realistic 'skin' covered head with exposed mechanical limbs, may appear more uncanny than one that is aesthetically harmonious.

2.4 Faces

Faces help humans to communicate, display (or betray) our emotions, elicit protective instincts, attract others, and give clues about our health. Several studies have been carried out into the attractiveness of human faces, suggesting that symmetry, youthfulness and skin condition [17] are all factors. Famously Langlois and Roggman [20] proposed that an average face - that is, a composite face made up of the arithmetic mean of several individuals' features - is fundamentally amd maximally attractive (although there are claims to the contrary, see [28]), and that attractiveness has a social effect on the way we judge and treat others [19].

Humans are extremely sensitive to the particular pattern of features that form a face. Neuroscientists have debated for decades the idea of 'grandmother cells' in the brain that fire only when a specific face is seen (or concept is recognised, see [30]). We cannot help but see faces in everything - rock formations, clouds, the front of a car, the windows and doors of a house. The famous 'vase/two faces' optical illusion plays on this anthropomorphic tendency. The Milanese artist Giuseppe Arcimboldo did likewise, forming whole portraits from fruit or flowers and producing work that is still life or portrait depending on which way up it is hung. Faces can be abstracted or simplified by a huge degree and still remain recognisable, a useful characteristic for comic and caricature artists - and robot designers. Minimal features or dimensional relationships are all that is required to suggest a face, and our brains 'fill in the gaps'.

Human infants seem to have a preference for faces, and it appears that even newborns possess an 'innate' ability to spot basic facial features, such as a pair of round blobs situated over a horizontal line which is characteristic of two eyes located above a mouth. It has been debated whether this is due to special face recognition capability or sensory-based preference based on preferences for general perceptual features and broad visual cues and properties of figures such as symmetry, rounded contours etc. which form the basis for learning to recognize faces [16]. The nature and development of face recognition in humans is still controversial. Interestingly, while the baby develops, its preference for certain perceptual features changes until a system develops that allows it to rapidly recognize familar human faces. Evidence suggests that exposure to faces in the first few years of life provides the necessary input to the developing face recognition system, e.g. [27]. The specific nature of the face stimuli during the first year of life appears to impact the development of the face processing system. While young infants (up to about 6 months of age) can discriminate among a variety of faces belonging to different species or races, children at around 9 months (and likewise adults) demonstrate a face-representation system that has become more restricted to familiar faces. The social environment, i.e. the 'kinds of faces' an infant is exposed to influences the child's preferences for certain faces and abilities to discriminate among them. Not only time of exposure, but also other factors, including emotional saliency, are likely to influence the tuning of the face recognition systems towards more precision [27].

In the context of humanoid faces the above discussion highlights why faces are such a crucial feature that people seek to identify. Humans are tuned towards faces, we can't help but recognizing them in various contexts, and what we recognize reflects what we are used to perceiving. Robot faces that mimic the prototypical dimensions of human faces are likely to stimulate the face processing system that we also apply to other people. One might thus speculate that a more 'generic'/iconic face of a robot affords more scope for people to identify with, since it allows them to project upon it face representations acquired during their lifetime. Note, this line of argument, based on biological and psychological studies of the ontogeny of face recognition and face processing, is consistent with work by Scott McCloud who derived his insights from comics design as described in the next section, and also influenced our choice of designing a minimally expressive robot head not aiming at mimicking the complexity of the human face entirely, cf. section 3.

2.5 Are Faces Useful?

Faces are the focal point of any humanoid robot, but most suffer from some, or all, of the following problems: they are hard to make look realistic, and even if they do the illusion is often shattered once they move; they are complex, requiring many degrees of freedom (DOFs); they are expensive to make and maintain, and they are arguably the part of the robot most likely to pull the rest into the uncanny valley. Furthermore it could be argued that the feedback provided by a face can be more cheaply presented using some other modality such as LEDs. So the question is: are faces worth the trouble? Quite apart from the fact that they are by definition part of a humanoid robot, there are several good reasons for their use:

1. Expressions are a universally-used feedback mechanism and are instantaneously understood by an interaction partner. A red LED could be used to represent happiness, but the association has to be learnt and processed, and the colour itself might come with cultural connotations (for instance red symbolises good fortune in China, but danger in the UK). A smile has a less ambiguous and more immediate emotive impact.
2. A face gives the user an understood focal point for interaction. A face *affords* interaction (cf. [26]).
3. A face can present visual cues to help the user understand the robot's capabilities, forming an unspoken social contract between human and machine [13]. A very mechanistic appearance may lead to confusion over communication modalities ("Do I *talk* to it? Will it understand me? How does it hear?"), whereas clearly-presented communicative features will encourage intuitive interaction. In addition the design of the face can give clues as to the ability level of the robot; a two-year old face implies two-year old cognitive and manipulative abilities [4].
4. Variable expressions can assist the robot in its role; for instance a face might allow a security robot to look friendly or intimidating as required, or allow a toy robot to look cute or express surprise in interaction games.

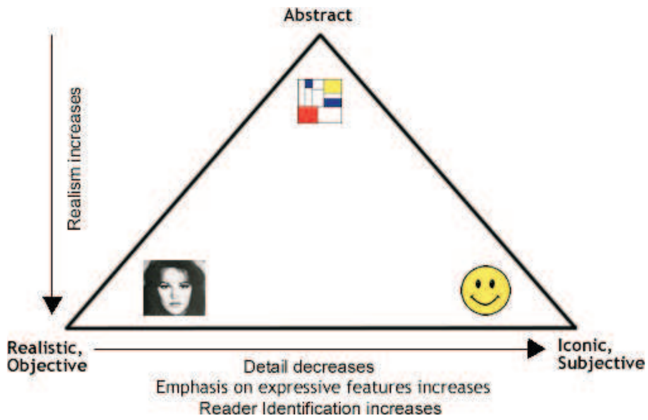

Figure 2: The design space of faces in comics and narrative art(modified from [24]).

2.6 The Design Space of Faces

Having established that faces can be useful, how should they look? Despite the enormous variety in real human faces, most people are intuitively aware when something looks unusual. Cartoons on the other hand, using merely representations of faces, can cover a far larger aesthetic range. In his book *Understanding Comics* [24], Scott McCloud introduces a triangular design space for cartoon faces (Fig. 2).

The left apex is *realistic*, i.e. a perfect representation of reality, for example a photograph, or realistic art such as that by Ingres. Travelling to the right faces become more *iconic*, that is, the details of the face are stripped away to emphasise the expressive features; emoticons such as **:)** are a perfect example in the 21st century zeitgeist. The simplification has two effects. Firstly it allows us to amplify the meaning of the face, and to concentrate on the message rather than the medium. Secondly the more *iconic* a face appears the more people it can represent. Dautenhahn points out that iconography can aid the believability of a cartoon character [8]. We are more likely to identify with Charlie Brown than we are with Marilyn Monroe, as a realistic or known face can only represent a limited set of people whereas the iconic representation has a much broader range - to the extent of allowing us to project some of ourselves onto the character. Towards the top apex representations become *abstract*, where the focus of attention moves from the meaning of the representation to the representation itself. Examples in art would be (to a degree) Picasso's cubist portraits or the art of Mondrian.

2.7 Robot Faces in the Design Space

We can use this design space, and the accumulated knowledge of comics artists, to inform the appearance of our robots. Fig. 3 shows some robot faces and their (subjective) places on the design triangle. Most are 'real-life' robots although several fictional robots have been included, as functionality has no bearing on our classification in this context.

It is worthwhile to compare examples of robots near the extremes of the design space. Each extreme has advantages and disadvantages, and pragmatic design as ever will be an attempt to balance the two dependent on intended purpose:

Realistic Face (Extreme left). Repliee Q1. Lifesize android designed by Professor Hiroshi Ishiguro and the Intelligent Robotics University at Osaka University in collaboration with Kokoro Inc. Repliee Q1 has 41 degrees of freedom, air actuators and silicon skin with embedded sensors, and is used in human-robot interaction research. **Advantages:** Strong physical presence. Capable of subtle expressions and complex visual feedback. Rich interaction behaviour potential. **Disadvantages:** Very hard to avoid the uncanny valley. Expensive to build and maintain. Individual appearance makes the robot hard to identify with.
Iconic Face (Extreme right). Papero. Designed by NEC, the Papero is a small personal assistant robot currently in development. It has limited degrees of freedom and very limited facial features (although LEDs are used to provide feedback to the user, and the design cleverly uses the bottom curve of the face to imply a smile). Voice and visual detection features, networking abilities and control of household appliances make Papero suitable for the personal and educational robotics markets. **Advantages:** Simple and robust. Avoids the uncanny valley by being small and having a cute and non-threatening appearance. Large user-identification potential. **Disadvantages:** Limited range of expressions means less intuitive media must be used for interaction. Lack of complexity may lead to limited interaction and boredom for the user.
Abstract Face (Extreme top). Dalek. Fictional robots that first appeared in the BBC TV series Dr Who in 1963. **Advantages:** Avoids uncanny valley by becoming less human, distorting or replacing humanoid features. Strong physical presence. **Disadvantages:** Limited user-identification. Non-intuitive communication modalities. Potentially expensive and complex.

2.8 The Robot as an Extension of Self?

As one moves in the design space of the faces from realism towards iconicity, a human is more able to identify with the face, and the distinction between *other* and *self* becomes less and less pronounced. In theory then the less detailed a face becomes the more characters it can represent. In addition, the more *iconic* a face is the more we are able to project our own experiences and emotions on it. Why is this? McCloud argues that the mental image we have of our own face is a subjective, iconic one. In contrast, the way we see others around us is objective and fully *realistic*. Hence the iconic face can represent *us*, and the detailed face represents somebody else [24].

Could this idea be useful in robot design? Humans tend to extend their personal identity to include objects that they are using. Our senses seem to expand, incorporating these objects and making them part of our sensory apparatus. If we close our eyes and use a cane to find our way, we are aware of the end of the cane on the ground, not the end in our hand. If we are driving a car, we are aware of the tyres on the road, not our hands on the steering wheel. And if someone hits our car, we say "He hit me!" not "His car hit my car!". If a robot is to be designed to extend the user's abilities or carry out tasks on their behalf, iconic features may more easily allow the user to apply their identity to the robot. The robot may become, from the user's point of view, an extension of themselves. The obvious difference from the car examples is that the robot is not in contact

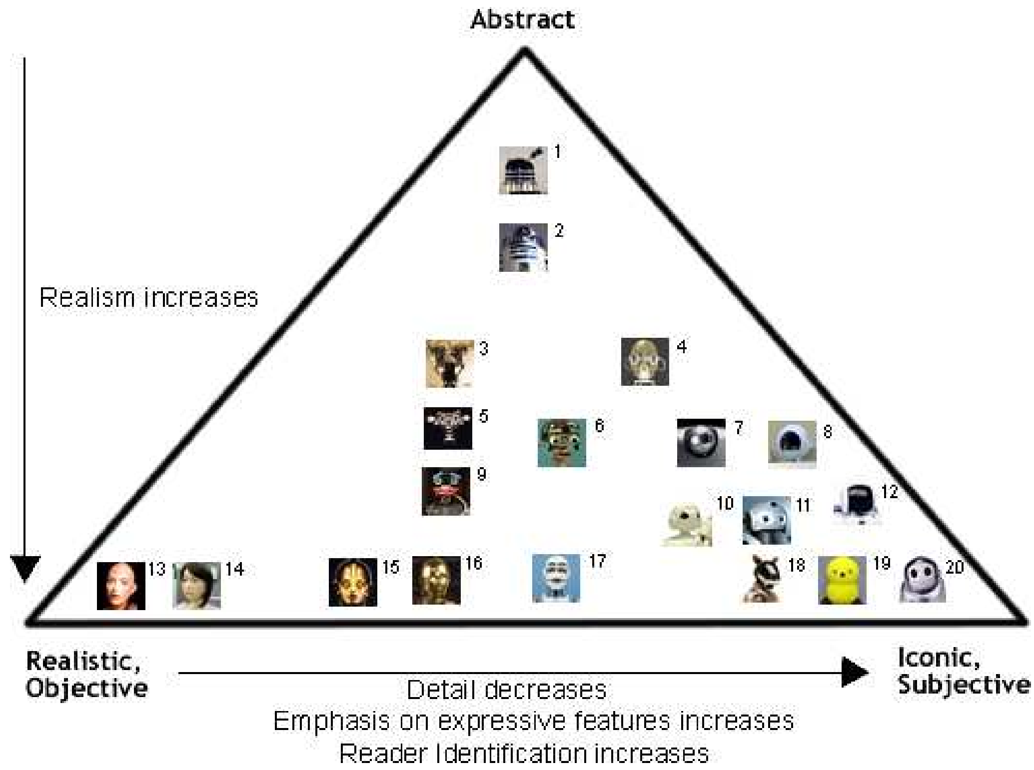

Figure 3: Robot faces mapped into McCloud's design space. 1. Dalek ((©the British Broadcasting Corporation/Terry Nation), 2. R2D2, fictional robot from *Star Wars* (©Lucas Film Ltd.), 3. DB (©ATR Institute Kyoto), 4. MIT Humanoid Face Project (©MIT), 5. Kismet (©MIT/Cynthia Breazeal), 6. Infanoid (©Hideki Kozima), 7. Nuvo companion robot (©ZMP Inc.), 8. HOAP-2 (©Fujitsu Automation), 9. Minerva tour-guide robot (©Carnegie Mellon University), 10. Toshiba partner robot (©Toshiba), 11. QRIO (©Sony), 12. ASIMO (©Honda), 13. K-Bot, extremely realistic 24 DOF head built by David Hanson (©Human Emulation Robotics), 14. Repliee-Q1 (©Osaka University/Kokoro Inc.), 15. False Maria, fictional robot from Fritz Lang's 1927 film *Metropolis*, 16. C3PO, fictional robot from *Star Wars* (©Lucas Film Ltd.), 17. WE-4R robot (©WASEDA University), 18. AIBO robotic dog (©Sony), 19. Keepon, minimal DOF HRI robot (©Hideki Kozima), 20. Papero household robot (©NEC)

with the user, or more specifically it is supplying no direct sensory feedback. It is an interesting question whether sensory feedback is a prereqisite for this extension of identity. Nevertheless, the effect can be manifest in less direct ways. When the user chooses to buy their new robot in a particular colour they are already making decisions based on their personal preferences. By choosing clothes, colours, voice type, interaction style and so on the user will extend their personality to include the robot. This effect is widely seen in computer games where players customise the characters they are playing, or even make a facsimile of themselves, to aid self-identification.

In contrast, realistic face designs will be seen objectively as 'someone else', and *abstract* designs often as 'some*thing* else'. In this case the interaction partner's identification with the robot will be discouraged due to the non-iconic nature of the design. Some robot roles (such as security guards) might benefit from reinforcing this perception.

3. KASPAR

Fig. 4 shows KASPAR (**K**inesics **A**nd **S**ynchronisation in **P**ersonal **A**ssistant **R**obotics). KASPAR is a child-sized robot which will act as a platform for HRI studies, using mainly expressions and gestures to communicate with a human interaction partner. The robot is a work-in-progress but when finished will comprise a static body with an 8 DOF head and two 6 DOF arms. Important features of KASPAR are:

1. Minimal design. Limited degrees of freedom and feedback options were purposefully chosen to reduce ambiguity in experiments, and in order to see what level of HRI can be achieved with minimal expressive and gestural capabilities.
2. Inclusion of eyelids, which are not often implemented on HRI robots (a notable exception is Mertz [2]), despite being identified as one of the main features contributing to the human-ness of a robot [12]. They will allow the investigation of the effect of blinking and eye narrowing in HRI scenarios.
3. Exclusion of eyebrows. Often a key expressive feature, animated eyebrows were not implemented as it was felt that any visible mechanism protruding through the skin would compromise the aesthetic consistency of the face, and as it became apparent that eyelids could at least partially fulfill their role. However KASPAR's face, which is a silicon-rubber resuscitation doll mask, does possess moulded eyebrows.
4. Non-discrete features. The facial features on many HRI robots are separate entities and do not interact, for instance the movement of the mouth has no effect on the eyes. Expressions produced this way are easily recognisable but can look unnatural, as human expressions tend to involve muscles over the whole face. As KASPAR's features are all part

Figure 4: KASPAR, HRI research robot.

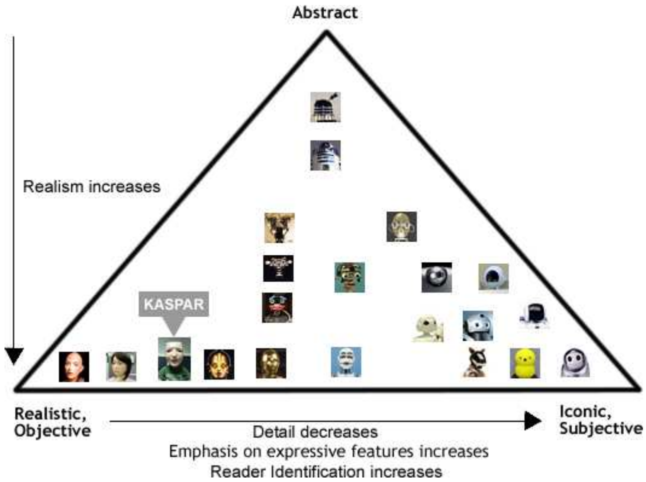

Figure 5: KASPAR on the design space of robots.

of the same rubber mask there is some interplay between them, which it is hoped will form more natural expressions and allow the user to forget the mechanics and concentrate on the meaning of the expressions.

3.1 Design Motivations and Rationale

Part of Hertfordshire's input in the early stages of the RobotCub project was to suggest design motivations that would help produce a useful platform for HRI studies, and which also formed the basis of the design rationale for KASPAR. These were that there should be consistency of appearance and complexity between the head, body and hands to aid natural interaction, and also between the appearance and the capabilities of the robot to govern the user's expectations. It was also suggested that minimal expressive features should be included and that they should be used to create the impression of autonomy by (for example) allowing joint attention or expressing emotional state.

The design rationale behind KASPAR is, as far as possible, minimal and biologically-inspired. By keeping the complexity and DOFs down we aim to reduce building and maintainance costs while still creating a robot capable of a wide range of behaviours. The goal in this case is not perfect realism, but optimal realism for rich interaction. Some of the mechanical design of KASPAR has been inspired by human physiology, especially in the neck and mouth mechanisms.

3.2 Face Design

The face design echoes the overall rationale, in that it aims to approximate the appearance and movements of the human face without venturing into ultra-realism. Fig. 5 shows the approximate position of KASPAR on the design space of robot faces. The decision to position the face somewhat in the iconic direction was made with a two-fold purpose. We have seen that emphasis on the features used for communication allows the robot to present facial feedback clearly, by allowing the interaction partner to focus on the message more than the medium. Furthermore a reduction in detail de-personalises the face and allows us to project our own ideas on it and make it, at least partially, what we want it to be. These are both potentially desirable features for a robot in HRI scenarios. Note, however, that the emphasis on the communicative features is achieved not by using discrete, exaggerated versions (which is the case with robots such as Feelix [7] and Kismet [6]), but by reducing the distracting effect of other details of the face. KASPAR's expressions are not as unambiguously defined as those of Kismet or Feelix, but initial observations indicate that surprisingly subtle changes in expression can be effective if the transition between them is observed.

It was decided that the robot should look more biological than mechanical, so some form of skin was necessary. A resuscitation doll mask was found to be ideal, providing an appropriate level of aesthetic consistency and detail. KASPAR's skin is only fixed at the ears and nose, and allows the face to be pulled into some fairly natural-looking expressions (Fig. 7) as the actuation of the mask in one place tends to slightly deform other areas; for instance, a smile also pushes up the cheeks and narrows the eyes. In humans this is typically considered an 'honest' smile compared to one which moves only the mouth [5].

3.3 Design Specifics

Requirements and Strategy. KASPAR's design was informed by initial studies of existing robot heads and by the application of ideas from McCloud's design space. The design requirements were: (1) Minimal design, yet expressive enough for HRI, (2) capacity to display *autonomy*, (3) capacity to display *undirected* and *directed attention*. (4) iconicity, (5) capacity to accept "projected" expressions with change of view angle (a requirement that was inspired by this ability in traditional Japanese noh masks [21]), and (6) human-like appearance. To produce an economical and effective design, the following points were followed: (1) produce a head design that achieves the desired functionality without excessive over-engineering, avoiding increased weight and costs, (2) use 'off the shelf' components and materials where possible, (3) reduce the need for parts that require skilled machining to a minimum, and (4) for each degree of freedom, create a compact mechanism.

Body. KASPAR's body is a fibreglass child mannequin torso, which is hollow and provides ample space for internal mechanisms. The head was removed and the robotic replacement attached using multiple mounting points. The mannequin body has the advantage of being preformed and tough, and will allow the future fitting of robotic arms.
Head. Sheet metal was used as the prime construction material, as it is cheap, strong, lightweight and very easy to work as long as high accuracy is not required. The head was based on three longitudinally positioned sheets of aluminium alloy, which maximised the mounting possibilities for the actuating servos whilst giving least restriction for the operating links. Each degree of freedom was then developed in turn.
Neck Mechanism. A solution was required that made the best use of the limited space, and produced close to natural movements of the head in three degrees of freedom (yaw, pitch and tilt). The yaw movement is controlled using a shaft connected to a servo housed within the mannequin body. The pitch and tilt movements are created by placing the head on a universal joint in the spine position and using two servo-operated pushrods at the front to control movement. This helps create a realistic action by using a single pivot (the universal joint) for both axes.
Mouth Mechanism The mouth mechanism has two degrees of freedom: one for the lower edge of the lips and one that moves both outer edges of the lips simultaneously. The inside of the mask was strategically cut away to aid flexibility and a compact system of levers built to maximise the mechanical advantage between the servos and the lips. The resulting movements are transmitted to the skin via bonded links, and allow the mouth to open or close, and curve up or down by operating the two axes in opposition. There is also movement in the horizontal axis, creating a motion where the lips are pulled up and back to simulate a smile.
Eye and Eyelid Mechanisms. To provide sensory apparatus for the head, ultra-miniature video cameras are incorporated within spherical 32mm Delrin 'eyeballs', mounted on a pan/tilt mechanism that moves both eyes in unison. The mechanism was matched to eye sockets cut in the rubber mask and attached to the metal head structure. Eyelids are formed of plastic quarter-spheres and controlled by a mechanism that produces a controlled open-close movement of both eyelids simultaneously.
Actuation. Radio-control servos are used to actuate the head and face. During development an RC system was used to test each degree of freedom manually to rapidly evaluate the effectiveness of design ideas. The use of servos means the option to perform 'wizard of oz' experiments is available as required. Servos tend to be noisy, and although the ideal would be silent operation it was decided that a certain amount of noise would be acceptable. If noise becomes an issue, it will be reduced by siting the servos as deeply as possible inside the head or mannequin structures, and by using sound insulating materials. Metal rods are used to transmit servo movement to the required part of the face or head. These vary in strength and thickness from wire to 3mm threaded links with spherical bearings at each end. Metal rods can be shaped to fit around existing structures, without affecting the way they perform - making them very adaptable to modification. They take up relatively little space and can be set up to either increase or decrease the mechanical advantage between the servo and the connected part. Non-linearity of movement can occur, but can be overcome in software if necessary.
Sensors. In addition to CMOS cameras in the eyes, microswitches will be incorporated in the hands to provide simple tactile feedback and microphones added to the head.

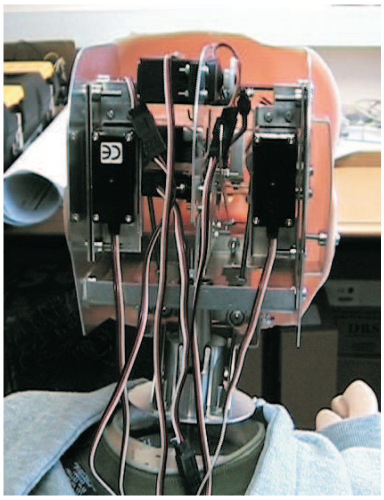

Figure 6: Internal view of the head showing servo actuators and neck mechanism.

Figure 7: Some of KASPAR's expressions: (left-right) happiness, displeasure, surprise.

3.4 Potential Uses

KASPAR can be used to study a variety of research issues relevant to HRI such as interaction dynamics, gesture creation and recognition, joint attention, communication through imitation and the use of expressions. The addition of arms will allow a range of interaction games to be played.

3.5 Conclusions

The field of HRI contains much unexplored territory, and predictions of how people and robots will interact are hard to make from knowledge of existing human-human or human-machine interactions. However it is clear that robot design affects users' perceptions in significant ways. In this paper we focused on design issues of robot faces integrating finding from psychological studies, work on narrative art design, and recent HRI studies. Consideration of these design issues strongly influenced our creation of a minimally expressive humanoid face, part of the robot KASPAR. Dimensions of face design were discussed with aims to help researchers and designers understand and exploit some ideas synthesizing those of artists, roboticists, and psychologists that pertaining to human perception of robot faces in HRI.

4. ACKNOWLEDGMENTS

The work described in this paper was conducted within the EU Integrated Project RobotCub ("Robotic Open-architecture Technology for Cognition, Understanding, and Behaviours") and was funded by the European Commission through Unit E5 (Cognition) of FP6-IST under Contract FP6-004370.

5. REFERENCES

[1] R. Ambrose, H. Aldridge, R. Askew, R. Burridge, W. Bluethmann, M. Diftler, C. Lovchik, D. Magruder, and F. Rehnmark. Robonaut: NASA's space humanoid. *IEEE Intelligent Systems*, 15:5763, 2000.

[2] L. Aryananda and J. Weber. Mertz: A quest for a robust and scalable active vision humanoid head robot. In *Proc. IEEE-RAS/RSJ Intl. Conf. Humanoid Robots*, 2004.

[3] A. Billard. Robota: Clever toy and educational tool. *Robotics and Autonomous Systems*, 42:259–269, 2003.

[4] A. Billard. Challenges in designing the body and the mind of an interactive robot. In *Proc. AISB05, Symposium on Robot Companions: Hard Problems and Open Challenges*, pages 16–17, 2005.

[5] R. L. Birdwhistell. *Kinesics and Context*. University of Pennsylvania Press, Philadelphia, 1970.

[6] C. L. Breazeal. *Designing Sociable Robots*. MIT Press, 2002.

[7] L. Cañamero and J. Fredslund. I show you how I like you - Can you read it in my face? *IEEE Trans. Systems, Man & Cybernetics, Part A*, 31(5):454–459, 2001.

[8] K. Dautenhahn. Design spaces and niche spaces of believable social robots. In *Proc. IEEE Intl. Workshop Robot and Human Interactive Communication*, 2002.

[9] K. Dautenhahn. Socially intelligent agents in human primate culture. In S. Payr and R. Trappl, editors, *Agent Culture: Human-Agent Interaction in a Multicultural World*, pages 45–71. Lawrence Erlbaum Associates, 2004.

[10] K. Dautenhahn, S. Woods, C. Kaouri, M. Walters, K. L. Koay, and I. Werry. What is a robot companion - friend, assistant or butler? In *Proc. IEEE IROS*, 2005.

[11] A. Davids. Urban search and rescue robots: From tragedy to technology. In *Proc. IEEE Ro-Man*, 2004.

[12] C. DiSalvo, F. Gemperle, J. Forlizzi, and S. Kiesler. All robots are not created equal: The design and perception of humanoid robot heads. In *Proc. Designing Interactive Systems*, pages 321–326, 2002.

[13] A. Edsinger and U.-M. O'Reilly. Designing a humanoid robot face to fulfill social contracts. In *Proc. 9th IEEE Ro-Man*, 2000.

[14] J. Goetz, S. Kiesler, and A. Powers. Matching robot appearance and behaviour to tasks to improve human-robot cooperation. In *Proc. IEEE Ro-Man*, 2003.

[15] H. Ishiguro. Android science: Toward a new cross-disciplinary framework. In *Proc. XXVII Ann. Meeting of the Cognitive Science Society*, 2005.

[16] M. J. Johnson and J. Morton. *Biology and Cognitive Development: The Case of Face Recognition*. Blackwell, 1991.

[17] B. C. Jones, A. C. Little, D. M. Burt, and D. I. Perrett. When facial attractiveness is only skin deep. *Perception*, 33(5):569 – 576, 2004.

[18] T. Kanda and H. Ishiguro. Communication robots for elementary schools. In *Proc. AISB'05 Symposium Robot Companions: Hard Problems and Open Challenges in Robot-Human Interaction*, pages 54–63, April 2005.

[19] J. Langlois, L. Kalakanis, A. Rubenstein, A. Larson, M. Hallam, and M. Smoot. Maxims or myths of beauty? A meta-analytic and theoretical review. *Psychological Bulletin*, 126:390–423, 2000.

[20] J. Langlois and L. Roggman. Attractive faces are only average. *Psychological Science*, 1:115–121, 1990.

[21] M. Lyons, R. Campbell, A. Plante, M. Coleman, M. Kamachi, and S. Akamatsu. The noh mask effect: Vertical viewpoint dependence of facial expression perception. *Proc. Royal Soc. London*, 267:2239–2245, 2000.

[22] K. F. MacDorman. Androids as an experimental apparatus: Why is there an uncanny valley and can we exploit it? In *CogSci-2005 Workshop: Toward Social Mechanisms of Android Science*, pages 106–118, 2005.

[23] K. F. MacDorman, T. Minato, M. Shimada, S. Itakura, S. Cowley, and H. Ishiguro. Assessing human likeness by eye contact in an android testbed. In *Proc. XXVII Ann. Meeting of the Cognitive Science Society*, 2005.

[24] S. McCloud. *Understanding Comics: The Invisible Art*. Harper Collins Publishers, Inc., 1993.

[25] M. Mori. *The Buddha in the Robot*. C. E. Tuttle, 1982.

[26] D. Norman. *The Design of Everyday Things*. Doubleday, 1990.

[27] O. Pascalis, L. S. Scott, D. J. Kelly, R. W. Shannon, E. Nicholson, M. Coleman, and C. A. Nelson. Plasticity of face processing in infancy. *PNAS*, 102(14):5297–5300, 2005.

[28] D. Perrett, K. May, and S. Yoshikawa. Attractive characteristics of female faces: preference for non-average shape. *Nature*, 368:239–242, 1994.

[29] J. Pransky. AIBO - the No. 1 selling service robot. *Industrial Robot*, 28(1):24–26, 2001.

[30] R. Q. Quiroga, L. Reddy, G. Kreiman, C. Koch, and I. Fried. Invariant visual representation by single neurons in the human brain. *Nature*, 435:1102–1107, 2005.

[31] B. Robins, K. Dautenhahn, C. L. Nehaniv, N. A. Mirza, D. François, and L. Olsson. Sustaining interaction dynamics and engagement in dyadic child-robot interaction kinesics: Lessons learnt from an exploratory study. In *Proc. 14th IEEE Ro-Man*, 2005.

[32] B. Robins, K. Dautenhahn, R. te Boekhorst, and A. Billard. Effects of repeated exposure to a humanoid robot on children with autism. In *Proc. Universal Access and Assistive Technology (CWUAAT)*, pages 225–236, 2004.

[33] B. Robins, P. Dickerson, P. Stribling, and K. Dautenhahn. Robot-mediated joint attention in children with autism: A case study in robot-human interaction. *Interaction Studies*, 5(2):161–198, 2004.

[34] G. Sandini, G. Metta, and D. Vernon. Robotcub: An open framework for research in embodied cognition. In *Proc. IEEE-RAS/RSJ Intl. Conf. Humanoid Robots*, 2004.

[35] S. Thrun, M. Bennewitz, W. Burgard, A. Cremers, F. Dellaert, D. Fox, D. Haehnel, C. Rosenberg, N. Roy, J. Schulte, and D. Schulz. Minerva: A second generation mobile tour-guide robot. In *Proc. IEEE Intl. Conf. Robotics and Automation (ICRA'99)*, 1999.

[36] United Nations Economic Commission for Europe. World Robotics 2004 - Statistics, Market Analysis, Forecasts, Case Studies and Profitability of Robot Investment, 2004. Summary at `http://www.unece.org/press/pr2004/04stat\_p01e.pdf`.

[37] S. Woods, K. Dautenhahn, and J. Schulz. The design space of robots: Investigating children's views. In *Proc. IEEE Ro-Man*, 2004.

[38] M. Yamamoto and T. Watanabe. Time lag effects of utterance to communicative actions on robot-human greeting interaction. In *Proc. IEEE Intl. Workshop Robot and Human Interactive Communication*, 2003.