7. Embodiment and appearance: robot bodies and human responses

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Abstract: Embodiment means AI inhabiting a physical body and thus having a given appearance. The appearance of robots is far from being neutral, but conditions the way humans perceive them and their capabilities. In particular, human-like appearance may elicit feelings of emotional state, consciousness and autonomy attribution, and induce empathy for the artificial being. Functionality has been up to now the guiding criterion for industrial, field, or medical robots. Now, as robots begin to spread in the services and domestic domains, with a higher degree of human-robot interaction (HRI) with non-professional users, other concepts such as trustworthiness arise. Several studies have been devoted to human acceptance and engagement based on the robot appearance and behavior. As soon as such robots become a consumer product, them being functional and trustworthy will not suffice: they also will need to be cute, beautiful, stylish, or adhere to the aesthetic standards of given collectives. Debates and fashions will unfold confronting machine-likeness and life (or human)-likeness, and regulations will have to be developed, concerning appearance issues related to deception, (particular) human replicas and image rights.

Keywords Robot embodiment and appearance, machine-like vs life-like, anthropomorphism, Human-Robot Interaction, deception

Summary: 7.1 Introduction: The bodies and faces of AI. 7.2 Robot appearance through history. 7.2.1 Fictional robots. 7.2.1.1 Metallic humanoids. 7.2.1.2 Undistinguishable from humans. 7.2.1.3 Other shapes. 7.2.2 Real robots. 7.2.2.1 Toys and protohumanoids. 7.2.2.2 Robot arms. 7.2.2.3 Mobile robots and autonomous vehicles. 7.2.2.4 Zoomorphic robots. 7.2.2.5 Humanoids. 7.3 Features of embodiment. 7.3.1 Static features. 7.3.1.1 Overall shape and size. 7.3.1.2 Faces. 7.3.1.3 Color. 7.3.1.4 Material. 7.3.2 Dynamic and relational features7.3.2.1 Mobility. 7.3.2.2 Proxemics. 7.3.2.3 Gestures and expressions. 7.3.2.4 Sound, voice. 7.4 Discussion: Appearance based acceptance and ethical concerns. 7.4.1 Acceptance and engagement. 7.4.2 Ethical risks. 7.5 Concluding remarks.

7.1 Introduction: The bodies and faces of AI

We have seen a lot of robots. In reality: in factories, laboratories, in fairs and congresses, in documentaries or the news, maybe also at home, in the humble embodiment of the robotic vacuum cleaner. But even more in fiction: in movies, comics, TV, in theaters and in art. Paraphrasing Joseph Engelberger[1], one of the fathers of industrial robotics, maybe we are unable to provide a precise definition of what actually a robot is, but we recognize one as soon as it appears in front of us, be it life or on the screen. Or maybe not, when it is an exact replica of a human, as the *replicants* in Blade Runner. How do we recognize them, what are their distinctive features? Is it just a matter of appearance, or do we need some hints provided by behavior? And how do artists, writers, engineers, designers, shape the robot's appearance? A necessary step to start to answer these questions is to review what has been done as for robot appearance up to now. To this end, Section 7.2 is devoted to a historical survey on robot appearance, both in the fictional and the real domain, intended to be representative rather than exhaustive.

[1] "I can't define a robot, but I know one when I see one." Engelberger's quote has been repeated once and again, without stating when he said this for the first time. See, for example, Zielinska (2016).

The claim exposed in this chapter is that AI's presence in the human society will experiment a qualitative change, if not an explosive boost, throughout robotic bodies. Up to now, interaction with AI programs occurred mainly via standard computer interfaces, e.g. in the use of Expert Systems[2] or in the training and usage of AI-based learning and classification algorithms by scientists. More recently, the general public has started to use AI apps such as ChatGPT, Grok, DeepSeek or Gemini on their PCs, tablets, or mobile phones. Siri and Alexa are even able to respond orally, thanks to synthetic voices. However, it is evident that the physical presence provided by a robotic embodiment will make a real difference on how the AI is perceived. In Section 7.3 the features of such embodiment will be analyzed.

Robot appearance has an obvious impact on human perception of robot capabilities, status, autonomy, relation to the user, and even (fictitious) mental states, emotions, and desires, as uncovered by studies using survey analysis tools. This impact may arrive to the extreme of conditioning or even threatening human dignity, liberty, and autonomy. These issues are addressed in Section 7.4. Finally, some concluding remarks are underlined in Section 7.5.

7.2 Robot appearance through history

7.2.1 Fictional robots

Robots are the most anthropomorphic under the machines. As machines, they are intended to relieve humans from manual work. But there is much more to the concept of robot. Robots are the heirs of the topic of the artificial human, which takes its roots in the soils of ancient mythology. Hephaestus, the god of blacksmiths and craftsmen, had created the Kourai Khryseai (Κουραι Χρυσεαι, golden maidens) according to Homer's Iliad, to assist him at home and at work. These and other automatons fruit of his artistry and skillfulness were not living beings, although "There is intelligence in their hearts, and there is speech in them and strength, and from the immortal gods they have learned how to do things."[3] There are many examples of the artificial human trope, which has two features to be stressed. The first one refers to circumventing the natural way, the way disposed by the gods, to create new humans, namely biological procreation. By making human-like creatures as artifacts, things made by skill, humans imitate and arrogate divine procedures, which is often viewed as hubris, excessive pride or arrogance, and has to be punished correspondingly. Compare for instance the myth of Pygmalion with Mary Shelley's Frankenstein[4]: the king of Cyprus and skilled sculptor Pygmalion carves an ivory statue so perfect he falls in love with, but it is Aphrodite, a goddess, who insufflates life in her, whereas Dr. Frankenstein pretends to be himself who animates, his creature, made from fragments of corpses, using electricity. In the first case there is no transgression and Pygmalion's new family lives happily forever, whereas in the second case, Dr. Frankenstein's hubris is punished with crime and despair. The second feature is about the figure of the other. For centuries, humans have populated their immediate surroundings and also distant (but at some point, accessible) fantastic realms with gods, spirits, angels, faeries, elves, demons, dwarfs, nymphs, or extra-terrestrial aliens, creatures that resemble humans but aren't, that are close enough we can understand each other, or at least their motivations, but at the same time are invested with the thrill of the strange, of the exotic. The artificial human is possibly the most realistic way to make this come true, to confront ourselves with our image in the mirror of the other.

7.2.1.1 Metallic humanoids

The first fictional robot (although it still does not receive this name) is a character of L. Frank Baum's novels, Tik-Tok (see Figure 1), appearing for the first time in *Ozma of Oz* (1907). The author was already renowned for his novel *The Wonderful Wizard of Oz* (1900), where another robot-like character appears, Tim Woodman, but who has rather to be considered a cyborg[5]. Turning back to Tik-Tok, his onomatopoeic name is a clear reference to the

[2] Sophisticated rule systems constructed and used by experts in a given field, able to provide answers, diagnostics, etc. by logical inference.

[3] Homer, Iliad 18. 416 ff (trans. Lattimore).

[4] Mary Wollstonecraft Shelley, *Frankenstein or The Modern Prometheus*, written in 1810 and published in 1818.

[5] Cyborgs integrate both biological and mechanical parts in the same being, usually they are humans with some parts of their bodies replaced by mechanical equivalents. Tim was originally a human woodman, who by successive accidents has gradually lost parts of his body, which have been replaced by tin parts.

clockworks that drive his actions and his thoughts. In this sense, Tik-Tok follows the tradition of the popular automata, self-moving devices that represent predominantly animals or humans performing diverse actions[6]. What makes him special and different from his ancestors is his autonomy, he is not condemned to execute always the same sequence of actions, but can decide what to do thanks to his clockwork of thought. Although information processing as sophisticated as human thought is practically impossible by mechanical ways such as a clockwork, it works as a metaphor[7]. This feature, a vaguely humanoid shape made out from metal, will become, and still is, the most iconic and recognizable representation of robots.

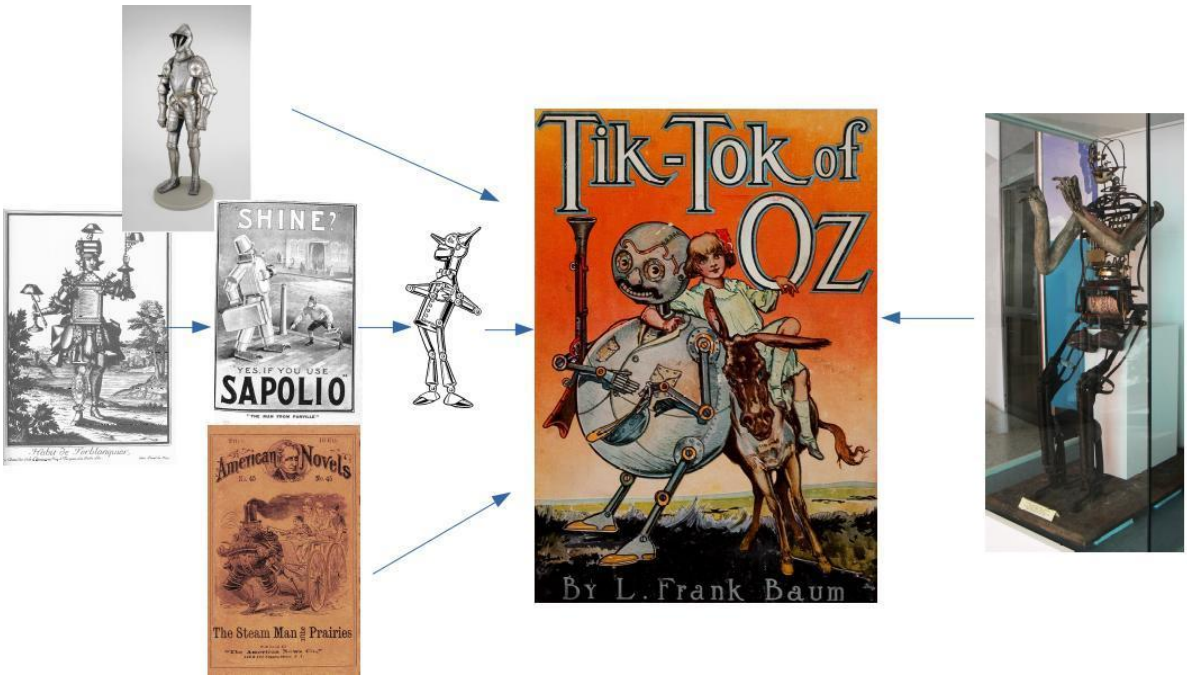

Figure 1. Metallic humanoid shapes preceding (a) the first fictional robot Tik-Tok[8]: (b) Armor of Emperor Ferdinand I, MET Museum[9], (c) Tinsmith by Nicolas de Larmessin (1695)[10], (d) tin-man in advertising (1899)[11], (e) Tim Woodman[12], (f) Steam Man of the Prairies, in the novel by Edward S. Ellis (1868)[13], which was an automaton, such as the real clockwork-based automata inspiring the inner functioning of Tik-Tok, as, for example, (g) the flute-player by Innocenzo Manzetti (1840)[14].

This depiction of robots is the one that better points at the mechanical, and thus artificial, nature of these beings. The term *mechanical* (or machine) *man* (human, person) makes this explicit: it was used the very same year that the

[6] The most well-known examples being Vaucanson's *Digesting Duck* or Jacquet-Droz's *Writer*, *Draughtsman*, and *Musician* of the XVIII century.

[7] Even nowadays it is not infrequent to use the image of gears inside a thought bubble to represent the thinking process.

[8] By John R. Neill - HA.com, Public Domain, https://commons.wikimedia.org/w/index.php?curid=146155889

[9] Photo by Kunz Lochner, CC0 1.0 in Wikimedia Commons.

[10] Recueil les costumes grotesques et les métiers de Nicolas de Larmessin, Public Domain, https://commons.wikimedia.org/w/index.php?curid=38131962

[11] https://citizendium.org/wiki/index.php?curid=14045

[12] By William Wallace Denslow, Public Domain, https://commons.wikimedia.org/w/index.php?curid=7274871

[13] By Unknown author - http://magazinehistory.blogspot.ru/2010/01/origins-of-american-science-fiction.html, Public Domain, https://commons.wikimedia.org/w/index.php?curid=27626733

[14] By Patafisik & Elena Tartaglione - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=14879258

word "robot" became popularized (1921), in a movie depicting tele-operated metallic robots, *L'uomo meccanico*, directed by André Deed[15], but also some years later (as the word robot had already gained international visibility), as the *Maschinenmensch* (the machine-human) in Fritz Lang's movie *Metropolis* (1928). The Chinese or Korean names for robot are also composed of *machine* and *human* or *person*.

Pop culture (in the form of mangas and animes, comics, pulp fiction covers and illustrations, movies…) contributed to the consolidation of typical metallic robot features and tropes:

- **Shape**. From the drawing-puppet shape of *Artificial human*, by Suihō Tagawa in 1929[16] or the spherical body of *Tanku Tankuro* (1934) by Gajō Sakamoto, to cylindrical bodies with articulated or corrugated pipe-type limbs (e.g. in Ōshiro Noboru's *Yukai na tetsu kôjo* (1941)[17]) and the complex shapes with spoilers and spikes of *mechas* and *transformers* (see below).
- **Face**. Expressionless (or with a frozen smile), round and fixed or slit-like eyes, medieval helmet-like, or simplified polyhedral face features. Sometimes reduced to a round cyclopic camera-screen-lamp-eye sweeping the environment in search of human victims.
- **Hands**. Dexterity of human-like hands is often sacrificed to simplified grippers with pointed fingers, overall more machine-like and threatening. Even worse: arms may be replaced by whipping mechanical tentacles.
- **Size**. The larger, the more menacing: the trope of the giant robot destroying a city, appeared first in an anti-American war propaganda manga, *The science warrior appears in New York* (1943), by Ryūichi Yokoyama[18]. This trope would become hugely popular, throughout pulp fiction magazines in the USA in the late 1930s to 1950s. Bad large robots also have the nasty habit of carrying young women away in their arms. Threatening robots may as well be just a little bit larger than humans, so the robot *Gort* from *The day the Earth stood still* (1951, directed by Robert Wise), the skeleton-like robots with red glowing eyes in the dark future world of the *Terminator* saga (1984-2003), or the armour-like Centurion Cylons of *Battlestar Galactica* (1978, 2004). There are two sub-genres of the giant robot trope:
    - ☒ *Mecha*. Enormous piloted robot, conceived both as a vehicle and as a weapon. Again this trope was born in Japan, with *Atomic Power Android* (1948), by Uno Kazumichi[19], and produced anime series such as *Mazinger Z* (1972) by Go Nagai, or *Neon Genesis Evangelion* (1995) by Hideaki Anno. They were piloted by the good guys, generally teenagers, and some of them transcended their mechanical nature to develop a kind of symbiotic connection to their young pilots.
    - ☒ *Transformers*. Robots that can modify their configuration to become apparently other machines such as cars, trucks or planes. The *Transformers* saga and franchise (with a homonymous 2007 movie directed by Michael Bay) is most representative, with the good blue-eyed *Autobots* and the malevolent red-eyed *Decepticons* using Earth as their current battleground.
- **Good fellows**. Metallic robots can be also good guys, which is reflected in their appearance: the permanently astonished expression and big round eyes of C-3PO from *Star Wars* (1977, by George Lucas), the frank smile and the warm glow of the round eyes of the gentle, considerate, and selfless alien robot in *The Iron Giant* (1999, by Brad Bird), or the puppet-like resemblance of featuring actor Robin Williams in the movie *Bicentennial Man* (1999, by Chris Columbus, based on a story by Isaac Asimov).
- **Gynoids or female robots**. Most outstanding is the *Maschinenmensch* in Fritz Lang's *Metropolis* (1928), with quite clear female facial and bodily features. Although gynoids appear more frequently as human

[15] This can be considered the first movie featuring a robot. In the previous serial *The Master Mystery* (1919) with Harry Houdini as the protagonist, there is a character, *The Automaton*, which is rather a cyborg, as it supposedly has a human brain, but it is discovered to be fake, a man in disguise.

[16] Maculotti (2015)

[17] Maculotti (2015)

[18] Frascella (2024)

[19] Graves (2020). The first piloted robot appears some years earlier, but it has the shape of an octopus: *Denki Dako* (The electric octopus, 1940).

replica, there are also some examples of clearly metallic gynoids, such as Aphrodite A, the companion of Mazinger Z, or the oversexualized female robots of the illustrator Hajime Sorayama.

- **Robots as human caricatures**. In animated movies, just as humanized animals, robots can be used to parody human society, as the bright color ones in the movie *Robots* (Blue Sky Studios, 2005), whose aspect reflects stereotypical human personalities. Bender, of the series *Futurama* (1999-2003, by Matt Groening) is another metallic humanoid whose aspect corresponds to its quite human cynical mood.

Nowadays, such robots are not entirely metallic anymore: new synthetic materials are used in their bodies, without replicating human appearance precisely. See, for example, the movie *I, robot* (2004, by Alex Proyas). Modern stock images display highly stylized robots, handsome androids and beautiful gynoids with harmonious facial treats, apparently made of some kind of synthetic material, predominantly white with some turquoise features such as the colors of the eyes. Agreeable to behold, while at the same time clearly displaying their artificial, mechanical nature.

7.2.1.2 Undistinguishable from humans

The other main representation of robots displays these artificial creatures as hardly distinguishable doubles of humans. This class of robots spans from the play that coined the term till the present day. Some variants on this figure include:

- **Physically undistinguishable**. So are the first robots called this way: the ones appearing in the play *R.U.R. (Rossum's Universal Robots)*, by the Czech writer Karel Čapek. It was represented for the first time on January 25th 1921, in the National Theatre of Prague[20]. The word "robot" refers to forced work in Czech, *robota* was the 6 months of work that serfs had to devote each year to their landlord in the past. That is, "robot" refers to human-like creatures, not pointing at their artificial nature, but stressing what they are intended for, to perform hard work. Robots are manufactured in the fictitious factory which gives the name to the play, and sold all over the world. Their body tissues and organs are made from a kind of artificial protoplasm, and assembled in the factory. Useless (for work) things such as emotions are left out, and this is the only feature that allows to distinguish them from humans, their faces void from expression, as they have no emotions to convey. The trope of artificial humans that are practically undistinguishable from real humans, but from their lack of emotions, was recovered much later in the characters of the *replicants* of Blade Runner (1982, by Ridley Scott) and Blade Runner 2049 (2017, by Denis Villeneuve).
- **Artificial interior revealed by damage**. This happens in the case of the severed head of the antagonist *Ash* in *Alien* (1979, by Ridley Scott) or by being bisected, as occurs to the loyal Bishop in *Aliens* (1986, by James Cameron). Partial skin removal has the same effect: facial skin damage in the model T-800 (Arnold Schwarzenegger) in *Terminator 2: Judgement day* (1991, by James Cameron) reveals its metallic skull underneath.
- **Artificial nature revealed by behavior**. The jerky, exaggerated movements of the transformed gynoid-Maria in *Metropolis*, while dancing, are an early example. Malfunction may be indicative as well, as occurs to Cherry 2000 in the homonymous movie of 1988, who suffers a short-circuit while having sex with its owner, or the strange behavior of the outdated *hubot* Odi, whose elderly owner keeps hidden, in the Swedish 2012 series *Äkta människor* (Real humans). In this series, as well as in the British adaptation *Humans* (2015) and other TV shows or movies, there are other subtle indicators of the non-biological nature of the androids, such as the absence of needs such as feeding or sleeping (replaced sometimes for energy-saving rest states, or battery charging times), the presence of data ports in discreet locations, the hidden activation/shutdown buttons (under the chin or the armpit), the unnatural display of emotions or the lack thereof, apparent absent-mindedness, clumsiness or, on the contrary, exaggerated effectiveness in performing tasks, not showing boredom or tiredness…

[20] Premieres all over the world marked the international success of the play: 1922, New York's Garrick Theatre (company Theatre Guild), 1923 St. Martin Theatre of London and Theater am Kurfürstendamm in Berlin, 1924 Théâtre Comédie des Champs-Élysées in Paris.

- **Human attitude towards robots**. Humans are allowed to treat robots in inhumane ways, just for entertainment, as happens in *Westworld* (1973, TV remake in 2016) where human customers can live adventures in the thematic park that include shooting at the android actors or having sex with them.
- **Multiplicity**. Occasionally, the only hint to the artificial nature of such humanoids is their multiplicity, that is, the presence of several identical individuals (as if they were cloned), which is the case for recognizing the most evolved cylons in *Battlestar Galactica* (2004).
- **Unnatural features in otherwise hyper-realistic human appearance**. For instance, the strange skin and eye-color of the character *Data* in *Star Trek: The next generation* (1987), the bright greens, blues and oranges, also in the eye-color of the synths in *Humans*, or the human hands and face on an otherwise clearly artificial body and head of the character Ava in the movie *Ex-Machina* (2014).

Human-like robots are recurrent character-tropes in science-fiction, especially in movies and TV-series, and not only because it is easier to use a human actor to play such roles. Human-likeness makes complex behaviors more credible and enables psychologically more intricate plots. It is also easier to play with the spectator's feelings, as it is easier to empathize with the robotic character. This becomes strikingly pungent in the case of child robots. Although not as widespread as their adult counterparts, robots embodying children shapes appear in robot fiction since the manga featuring the heroic *Astroboy*[21] by Osamu Tezuka (1952), the humoristic and irreverent *Arale* (from the anime *Dr. Slump*, 1980-84), or, with life actors, the characters Chip (*Not quite human*, 1987), David (*A.I. Artificial Intelligence*, 2001), Eva (*EVA*, 2011), or Ethan (*Extant*, 2014). The latter cases elicit protective feelings, maternal or paternal instincts that overlook the true artificial nature of the characters, conditioned by their helpless appearance. This goes to the extreme of feeling compassion for a robot that is being assembled before our very eyes, as in the short CG film *Kara* (2012, Quantic Dream, directed by David Cage).

7.2.1.3 Other shapes

Fiction has filled the popular imaginaries with many other non-humanoid shapes:

- **Vaguely humanoid**. Rosey/Rosie, of the animated TV series *The Jetsons* (1962) displaces on wheels, but has a recognizable head with eyes and mouth, and two arms. Even the shape of an elongated dome on a four-wheel platform applies to the "vaguely humanoid" category as soon as it is fitted with two articulated arms, and eyes and a mouth on top (see the robot *Jorge* in the Spanish comic *Dani Futuro* (1970, by Víctor Mora and Carlos Giménez). Similarly, the robot *Wall·E* from the homonymous movie (2008, Disney-Pixar) is far from being considered a humanoid, but its arms and its movable stereo-camera head provide human-like expressiveness to the character.
- **Zoomorphic**. They may appear in dog-like shape, as the robot dog *Sentro* (in a 1985 episode of *The Jetsons*), or as a cat, in *Doraemon* (1969), although the latter is hardly recognizable as such. Insect and spider-like robots are cybernetic reproductions of their fear-inspiring biological counterparts, so the acid-injecting robotic spiders in the movie *Runaway* (1984, by Michael Crichton), or the killer robots in the shape of underground bugs in *Screamers* (1995, by Christian Duguay).
- **Abstract geometric shapes**. *Dr. Who*'s evil foes the *Daleks* (1963)[22] transmit their menacing personality quite efficiently with their tank-like appearance. The robots Huey, Dewey and Louie, in *Silent Running* (1972, by Douglas Trumbull), resemble biped radiators, which does not make them less lovely. The crown of popularity, however, goes to R2-D2 from *Star Wars*, despite its dustbin shape. To a great extent, due to its reliability, but there are also a couple of traits of its appearance that contribute positively to its acceptance. One is its head movements, which it needs to position the camera and thus establish an eye-to-eye contact to the character it is interacting with (C-3PO most of the time). The other one is its repertoire of sounds which provide expressiveness and personality to the character.

7.2.2 Real robots

[21] Originally *Tetsuwan Atom* (Atom of the iron arm) (Nicora (2017))

[22] Although they are rather cyborgs, as they carry an organic alien being inside.

Real operative robots are already present in the world since the mid-1950s and first 1960s. They have been successfully applied to manufacturing and to exploration in human-hostile environments such as underwater or outer space. Except for very specific applications, vacuum-cleaning and swimming pool maintenance, they have not yet become a consumer product. Their shape is thus almost exclusively dictated by functionality criteria. Personal and social robots are called to change this.

7.2.2.1 Toys and protohumanoids

Wind-up robot toys are in fact simple automata, not really robots, but they recreate the metallic humanoid (Section 7.2.1.1). One of the first wind-up tin robot toys was manufactured by the Japanese company Kuramochi Shoten towards mid-1930s: the yellow robot Lilliput N.P. 5357, see Figure 2. These and other wind-up robot toys, and later the battery-powered robot toys, marked many childhood memories as the first contact to the figure of the robot.

Figure 2. Wind-up toy robots[23]. Lilliput N.P. 5357 appears in the center of the image.

Some decades before the first industrial robots, the real pioneers in the robotization of human work, popular mechanics gave form to devices that recreated the image of the metallic humanoid, capable of some movements, but still far from the autonomy robots are supposed to have. These devices were usually activated from the distance, could respond with previously registered answers, move their limbs, even sit down or stand up and make some steps, some of them even "smoked". The first ones were produced by the Westinghouse Electric and Manufacturing Company (USA) as a way of making publicity, starting with the very primitive Televox (1927) made of cardboard, to the evolved Elektro (1939), 2.1 m tall and exhibited at trade fairs. Other famous examples are Eric (1928) and its successor George (1930), with the letters RUR on the chest, constructed by William Richards and Allan Reffell (UK), Mr. Ohm Kilowatt (1933) by Earl Kent (USA), or Garco (1953) by Harvey G. Chapman Jr. from the Garrett Corp. (USA)[24].

7.2.2.2 Robot arms

The first industrial robot arm was patented in 1954 by the inventor George C. Devol, and two years later he met the entrepreneur Joseph Engelberger, who immediately recognized the possibilities of the machine. They founded the company Unimation, and in 1961 the first operative robot was installed in a factory[25].

Industrial machines in general, and robots in particular, displace their elements usually either along prismatic or linear joints, or around simple rotational joints. The latter type is shared with biological beings, e.g. human elbows, knees or finger joints. Along their history, industrial robots have been constructed using different combinations of linear and rotational joints. Nowadays, industrial robots are predominantly of the all-rotational-joints type (although

[23] Foto © Pablo Jiménez-Schlegl.

[24] These and other such devices are described and illustrated in https://cyberneticzoo.com/robot-time-line/

[25] https://en.wikipedia.org/wiki/Unimation

other types still have their application niche[26]), the so-called articulated robot arms, which are the most similar to the human arm. Significantly, different joints and parts are called shoulder, elbow, wrist, hand (or gripper), and fingers. The layout and appearance of industrial robot arms is dictated by functional considerations. Articulated robots are the best suited to avoid obstacles by surrounding them, and thus apt to work in cluttered environments. One of such characteristic design features is their color: being dangerous machines (isolated from human workers by performing their work inside caged robotic cells), they are predominantly painted with bright, jazzy colors such as the orange of ABB, Stäubli or KUKA robots, the yellow of FANUC, the red of Siasun (although you may find also white robots such as Kawasaki arms). Significantly, modern collaborative robots (*cobots*) that are to work close or even in contact to humans, besides having more rounded links to minimize the effects of possible impacts, are also painted in more soothing colors: for example, Universal combines gray and light blue, and an established robot company such as FANUC has opted for light green for one of its new cobot product lines.

Surgery robots are also robot arms, designed to perform minimally invasive surgery. Arms with grippers have been mounted on mobile platforms as well, used for example in exploration robots to collect samples. The design of all of these robots is exclusively based on functionality and efficiency criteria.

7.2.2.3 Mobile robots and autonomous vehicles

Robotic mobile platforms include the so-called field robots, that is, exploration, agriculture, mining, construction and maintenance robots, as well as industrial mobile robots used in transport and logistics, military robots, service and social robotics, experimental robots… The particular mobility solution adopted depends of course on the media and terrain the robot has to move: simple or omnidirectional wheels for buildings and cities, special rocker-bogie wheels, wheels-on-limb systems, caterpillar tracks, or legs for rough terrain, rotors, jets and wings for aerial locomotion, propellers, thrusts and fins for underwater displacements. They carry on board all the necessary devices to perform their duties, including arms, tools and measuring instruments, containers, sensors (simple ones but also cameras and whole computer vision systems), tethered or wireless communication with their operators, energy supply, etc. Most design solutions obey functional criteria, including in general their overall size and shape, but also specifics such as sealing for underwater systems, special radiation protections for extra-terrestrial applications, shielding in demining, etc.

Service and social robots design takes other criteria into account, beyond mere functionality, because these robots have to interact with people, in the most natural way for the non-expert user. Functional criteria may be interpreted in familiar, anthropomorphic terms. For example, putting a stereo camera on top of the robot can be a good idea to gain a better view, but can also be understood as the eyes of the head of the robot. These robots have different devices to facilitate interaction: cameras, visual displays –which can be touch-screens to enable bidirectional communication-, speakers and microphones for conversation, possibly a face and hands for gestural interaction… Friendly, cute designs are often sought to engage people for interaction (see Section 7.4.1).

7.2.2.4 Zoomorphic robots

The proto-robotic humanoid Elektro mentioned in Section 7.2.2.1 had a dog, Sparko (1940, also from Westinghouse), that accompanied it at exhibitions and trade fairs. The first real zoomorphic robots were not actually designed to imitate animals: the two units of *Machina Speculatrix* developed by William Grey Walter in 1948-49[27] were soon known as tortoises, due to their shape (their electromechanical components were protected by a dome-like shield) and the slowness of their motions. Many experimental robots inspired in biology have been created along the years, following a research line known as *biomimesis*. To cite some examples:

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[26] For example, there are large Cartesian robots (i.e., their three positioning joints are prismatic), so-called Gantry robots, for displacing heavy parts, and they are quite suited for this task due to the inherent rigidity of this configuration.

[27] They were plain tricycles with one drive and one steering motors, few sensors, and an analog computer, to demonstrate that few but highly connected neurons could exhibit complex behavior.

- Starting in 1993 the RoboTuna project in the MIT developed a fish-like AUV (autonomous underwater vehicle) which performed better, from the point of view of maneuverability and energy consumption, than other AUVs.
- In 1996 Prof. Toshio Fukuda at Nagoya University published a paper about the motion control of a brachiation robot, that is, which moved as an ape swinging from branch to branch[28].
- Sony produced from 1999 to 2006 its emblematic dog-like robot pet AIBO, actually a series with different models (including a lion cub), sold to tens of thousands of units around the world. Teams of AIBO robots have participated, as the standard platform, of different editions of the Robocup (robotic football).
- A hummingbird-like ornithopter[29] robot developed in 2019 at Purdue University allows for flying robots miniaturization that can't be achieved with drones due to fluid dynamics limitations.
- Rodney Brooks devised and even sold to different research institutes a small hexapod robot, where for instance the typical tripod gait of insects was implemented, as a platform for his behavior-based control architecture.
- Boston Dynamics, a spin-off company of the MIT, later acquired by Hyundai, developed the quadruped BigDog (2005), funded by the DARPA, and 2016 the smaller and more stylized Spot.
- The robot Paro sparked controversy for its use in homes for elderly people with dementia, in Japan. The robot reproduces a baby seal, covered with white fur and having a realistic face. The robot is caressed by the patients, who socialize talking about it as if it were alive. To which point there is willing suspension of disbelief or there is real deception is debated, although many researchers consider that the benefits outweigh the possible drawbacks[30].

7.2.2.5 Humanoids

A human-like torso robot, behind a counter in the reception of a hotel for example, can be considered a humanoid. Such torsos are suitable for exploring or working in hostile environments, tele-commanded by haptic feedback, as is the case of NASA's Robonaut-R2 (2010) for EVA[31] in outer space, or Stanford's OceanOne (2016), connected to an underwater vehicle (that is, being part of its body). However, we will focus on whole-body robots. The foremost difficulty encountered by humanoid robots is biped walking. The first such robots tried to keep static equilibrium, by maintaining the projection on the ground of their center of gravity within the polygon defined by their footprints at every moment. This resulted in a slow and quite unnatural walking pace. Ground reaction and zero moment point control allowed the Honda humanoid robot ASIMO, which resembles a small (1.30 m) astronaut, to walk and even to run up to 6 km/h. This robot was released in 2000, after decades (starting in the 1980s) of research in biped walking. Similar small cute humanoid robots have been developed since then, including QRIO by Sony (2003, credited as the first robot capable of running), Aldebaran Robotics (later SoftBank Robotics), Nao (2006), or SoftBank Robotics Pepper (2014, this one has no legs, but moves on a platform with omnidirectional wheels, its HRI abilities include emotion recognition and adjusting its behavior accordingly). The scientific research community has also developed their own humanoid platforms, such as the child-like (and sized) iCub (2009), by a consortium of European universities, and built by the Istituto Italiano di Tecnologia. This robot is a testing platform for the hypothesis of embodied cognition, which is about learning cognitive skills via interaction with the physical world, using the own limbs and senses.

Humanoid mobility has experimented a leap forward with the development and evolution of the robot Atlas of Boston Dynamics. Starting in 2013 as a hydraulic biped robot, displaying its inner mechanisms and circuits, early versions already showed its capabilities in walking rough terrain and climbing. The 2024 fully electric version is designed for its commercial use, with encased body and limbs, and besides its more natural walking and running capabilities, it is also able to perform jumps, side- and backflips, and to reconfigure itself beyond human

[28] Fukuda and Saito (1996).

[29] An aircraft that flies by flapping its wings.

[30] Calo et al (2011).

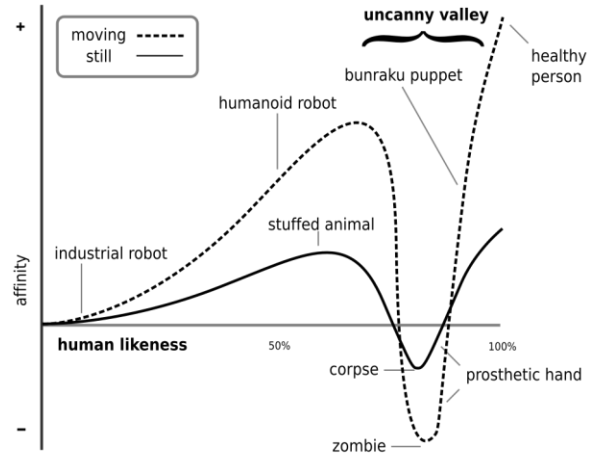
[31] Extra-vehicular activities, that is, work to be performed in the exterior of the spacecraft. To facilitate mobility, Robonaut can be furnished with climbing "legs", capable of anchoring on different parts of the spacecraft.

capabilities. The latest humanoid robots such as the Chinese Unitree G1 and H1, Qinglong, or Kuavo, or Optimus G2 of Tesla, exhibit impressive mobility skills as well. All of these robots, despite having a head, have empty faces.

In contrast, robots with realistic faces or even heads and neck, but clearly robotic bodies (or being just a torso), embody the concept of human-machine hybridization, sometimes in an unsettling manner. Examples include Albert HUBO (2005), one of the models of KAIST[32] series of humanoids HUBO, with an animatronics head in the likeness of Albert Einstein developed by Hanson Robotics, HRP-4C (nicknamed Miim), built by AIST[33] and presented in 2010, modelled after average Japanese girls, can sing and dance, or Sophia, who also owns her existence to Hanson Robotics, with a realistic face but a robotic skull, being activated in 2016 and the first robot to be granted legal personhood (in Saudi Arabia, 2017). Such robots are capable of a variated range of facial expressions. Sophia in particular is able as well to recognize faces, to maintain eye-to-eye contact while speaking, to understand natural language and respond accordingly, thanks to an AI program (but she does not actually understand or comprehend what she is saying). Engineered Arts' robot *Ameca* (2021) has realistic facial features but unnatural white color and neck and torso mechanics in display. It has an extraordinarily rich and human-like repertoire of facial expressions.

Finally, there are whole body realistic humanoids: the Actroid series (starting at 2003), developed by the Osaka University and built by the company Kokoro, have mostly a young female appearance, with a high realistic silicone skin. They can engage in conversation (at a basic level) with a human thanks to a speech recognition system and answering through speakers, while scaffolding the interaction with body language, including facial expressions, gestures, eye-to-eye contact, and modulating the voice pitch. However, their mobility is limited, being unable to walk (they are always seated or standing with support). Professor Hiroshi Ishiguro, co-creator of these robots, made a male model of himself, in 2006, called *Geminoid HI-1*, which through a motion capture interface is able to reproduce his body movements and facial expressions. Henrik Schärfe's tele-operated *Geminoid-DK* (2011, programmed to reproduce his characteristic shrugs and glances), or Professor Nadia Magnenat Thalmann's *Nadine* (2014) are two other robotic doubles of outstanding robotics researchers.

As for today, actual realistic robots are dwellers of the uncanny valley (see Figure 3). That is, their resemblance with the human is close enough to perceive the differences as unfit, out of place, creating an eerie perception. This is not the case with their fictional counterparts in movies and TV, as these are obviously played by human actors. Technology is not yet ripe enough to make them climb the right side of Mori's curve.



[32] Korea Advanced Institute of Science and Technology.

[33] National Institute of Advanced Industrial Science and Technology, Japan.

Figure 3. The uncanny valley effect, as hypothesized by Masahiro Mori in his 1970 book titled *Bukimi No Tani*, ("Uncanny Valley").[34] Observe the steeper shape for moving bodies. The "humanoid robot" indicated on the ascending part of the curve refers clearly to the non-realistic ones, but rather to the ASIMO, Nao, or Pepper type.

7.3 Features of embodiment

In this section we will make an exercise of abstraction and analyze the different features that define the appearance of a robot, and which criteria may guide the design decisions. We speak of physical appearance in a broad sense, so that we do not limit ourselves to a static photography of the robot image, but take also behavioral factors into consideration. That is, appearance is not only the set of physical features the robot has, but also what it does with them.

7.3.1 Static features

7.3.1.1 Overall shape and size

Robots are machines intended to face successfully variability in the task and in the environmental conditions. It is only natural that the human shape comes first to mind, as humans are good at it. But experience demonstrates that this is not always the best solution. A humanoid robot could certainly be able to sweep the floor with a broom or to manipulate the vacuum-cleaner. However, it is more efficient to robotize the vacuum cleaner itself. Simple dedicated robots to specific tasks do not require to even remotely resemble humans. Industrial robots are stripped to the basic essentials required from the human body to perform a task: an arm with a hand (or directly with a tool). However, functionality may at the end actually point at the humanoid form as the best design solution. Take the OceanOne robot for example: bimanual underwater manipulation is much more effective for recovering half-buried objects, and the process can be better observed with a stereo-camera and some kind of lighting at the front, so that we already have a head and two arms, i.e., a humanoid torso. Cost is also a driving force when it comes to shaping robots: simple, easy to maintain shapes will be preferred.

These criteria, functionality and cost, do also determine the size of the robot. In Section 7.2 we have witnessed robots as small as hummingbirds and as big as Gantry robots, but the range can potentially be much wider, from micro- and nanorobots to be injected into the bloodstream to perform very localized medical tasks, to giant construction robots. The size of a fixed industrial arm will depend on the required workspace, so that it can reach all the locations where it has to perform some action; a harvesting robot will have to be big enough to reach the fruit on a tree, or small enough to displace between the rows of vineyards.

For service, social, and personal robots, there are additional criteria at least as important as functionality and cost. At first place, there is safety. Robots interacting physically with humans have to be inherently safe. This is a control issue, but an adequate shape design is advisable as well. Such robots will avoid having pointy parts, sharp edges, access to gears or electrical loaded parts, smooth and rounded encasings will be preferred. The lighter and the smaller they are (as long as they can perform their tasks reliably), the better from the standpoint of safety. Trust and acceptance also play a very important role. A humanoid shape may contribute to acceptance in general, thanks to its familiarity: there is a head the user knows they can look at and speak to, there are arms expected to do things. Often a minimalist expression is more than enough, the "head" may be just the hemispherical top of a cylindrical shape, as in the case of R2-D2, if at least one camera or an "eye" is present. Acceptance, however, is not a unidimensional factor, a given robot shape, aspect and size may be perceived as being "cuter", but another appearance will be seen as "more competent". Personal preferences are also quite determinant on how particular robot appearances are valued. This has been confirmed by different studies, as commented in Section 7.4.1.

In a quite systematic and thorough study[35] on human perceptions and preferences about the image of social assistive robots (SARs), the authors dissect appearance into what they call visual qualities (VQ). These are then used to

[34] By Smurrayinchester - self-made, based on image by Masahiro Mori and Karl MacDorman at http://www.androidscience.com/theuncannyvalley/proceedings2005/uncannyvalley.html (archive), CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2041097

[35] Liberman-Pincu et al (2023)

construct a taxonomy that allows categorization of commercial SARs. Some of these VQs (color, material) are addressed later in this chapter, others are coincident with this section:

- morphology and abstraction level, which refers to anthropo- or zoomorphism, and has three categories, human-like, pet-like, and undefined, and the first two may display different degrees of abstraction;
- shape and structure refers to the (main) body, where structure distinguishes between a single unit or split units, and shape has four categories, namely A-shape, V-shape, hourglass and diamond;
- outline, either rounded, chamfered (with angles), or a combination of both;
- dimensions, what we have called size, and span from pet-size to human-size.

7.3.1.2 Faces

The association of cameras with eyes is straightforward, the more as they actually serve the same purpose. This is used by some robotic designers to provide some degree of anthropomorphism (or at least zoomorphism) to their creations. A stereo-camera couple, together with the mechanism to enable pan and tilt motions, constitute already a "head", as demonstrated by the fictional robots Wall·E or Number 5 from *Short Circuit* (1986, directed by John Badham). Nonetheless, a high percentage of social robots are designed explicitly having a face.

Robot faces are characterized by a geometric abstraction of the human face. This is evident in classical robot toys: a generally square or rectangular shape houses two circular, fixed-gaze eyes, a thin, horizontal rectangle as a mouth, prismatic or hemispherical noses, and small cylinders as ears (together with antennae). This basic conception has evolved in two opposite directions: towards increasingly abstract representations, and towards more realistic humanoid faces. In one extreme, the most minimalist expression reduces the face to the containing shape. This is the case of Honda's ASIMO, whose head may be interpreted as an astronaut helmet, or of modern humanoids, as mentioned in Section 7.2.2.5. The next step is to incorporate eyes, which in the case of the social on-table robot Jibo[36] consisted in a single white sphere projected on the black circular screen which was the face. This Spartan design was compensated by the mobility and shape-changing capability of this virtual sphere, which, together with the head and body movements, provided expressivity to the robot. Rendered faces are a good alternative to constructed faces if flexibility and non-static expressivity are sought: to display expressions on a screen is easier and cheaper than engineering and animating the mechanical counterparts of facial features. A meticulous study on rendered robot faces[37] surveys 157 faces on LCD screens on real robots, examining 76 attributes, including the features of the face (mouth, nose, eyebrows, cheeks/blush, hair, ears, eyelids, pupils, and irises), colors of these features and additional elements such as lips or eyelashes, size of the eyes, nose and cheek, feature and face shape and size, placement of these features in the face (discretized positions such as up, center, down), and possible animation of these features (e.g. blinking). Physical embodiment features are also taken into account (for instance, type, shape, size and position of the screen, additional features such as "ears", or robot embodiment type). The study provides statistics on these features, as well as an online survey on human perception on a selected set of such faces, which will be commented in Section 7.4.

Most constructed faces are static, or have limited eye mobility. Some earlier research robots such as Breazeal's Kismet[38], van Breemen et al iCat[39] or Diana and Thomasz's Simon[40] displayed mechanical movable eyes, eyelids, eyebrows, mouth, and/or ears, to express a limited range of simulated emotions devised to facilitate HRI. A great number of social robots present a childish or baby-like face configuration, mainly characterized by their big eyes, the rationale behind this appearance will be addressed in Section 7.4. This helps to maintain a gender-neutral characterization of the robot.

[36] The manufacturing company disappeared some years ago.

[37] Kalegina et al (2018)

[38] Breazeal (2004)

[39] van Breemen et al (2005)

[40] Diana and Thomasz (2011)

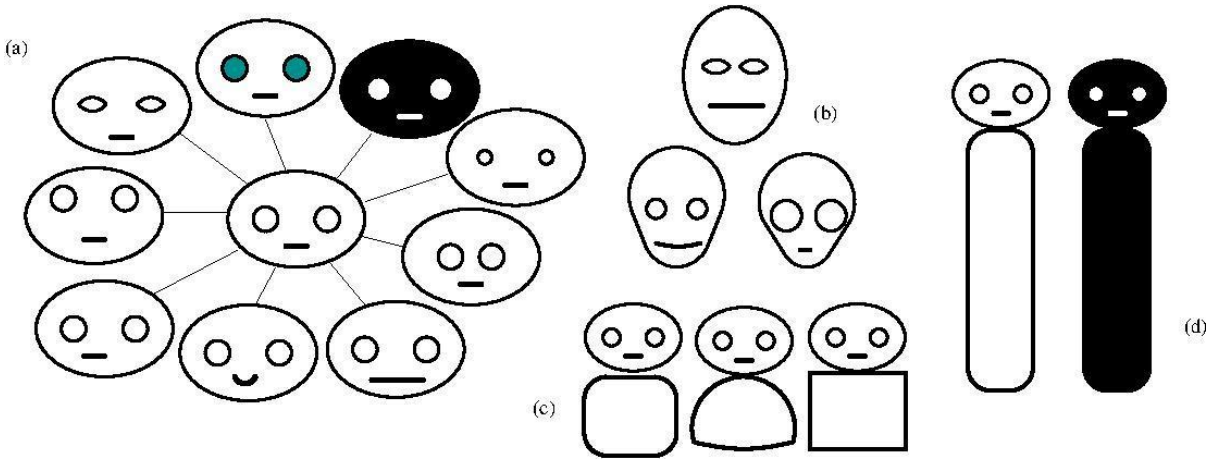


Figure 4. (a) Even a basic baby-like face design displays a high degree of variability, just playing with color, shape, size and position of eyes and mouth. (b) Elongated faces are not as cute, but may transmit a higher sense of competence. Small variations in facial features may significantly alter the perceived familiarity. (c) and (d) A face is not a standalone feature, but its relation to the body is quite important as well: A baby-face should be on a small body (c), whereas if on an elongated body it elicits confusion and uneasiness (d).

To complete this section, the other extreme as for human-likeness in the design of robot faces has to be stressed, although it was already mentioned in Section 7.2.2.5: highly realistic robot faces, with a complex actuation of the different face parts, with silicone skin modelled after real humans[41].

7.3.1.3 Color

We already saw in Section 7.2.2.2 the choice of flashy colors for industrial robots motivated by practical reasons. The different brands generally adhere to a specific color as part of their identifying trademark, although they can have alternative colors for different product lines. The color choice for field robots obeys in general functionality criteria as well: agricultural or exploration robots may be white or display flashy colors for easy localization on the field (unless they are precisely intended to not perturb wildlife), whereas for military robots, colors have to match camouflage measures. Medical robots are usually white to fit chromatically in sterile environments.

When it comes to social robots, color choice is once again conditioned by human perceptions and preferences. A simple image search on the internet with the keywords "social robot" reveals prevalence of white. Even in fiction: the robots in *I, Robot* (2004) are white (with some shades of grey) except for the dark metallic upper parts of the limbs[42], so is the efficient EVE in *Wall·E* (2008), and most of the robots on board of the human spaceship, or robot Baymax in *Big Hero 6* (2014), to name a few. Stock photos related to the search term "robots", implicitly humanoids and created from CGI, are all white as well. Some authors[43] view this as a projection of the robot developers' bias on race (and gender[44]) roles, which in the case of *service* robots is contradictory in terms. As a matter of fact, the shiny white color of robots is too unnatural to be ascribed to any human race, and rather stands for their artificial kind[45]. In the survey conducted by Liberman-Pincu et al[46] mentioned earlier, three color schemes are identified in commercial SARs: white with some areas of light grey and other light colors, white with different shades of blue, and dark colors such as dark grey, dark blue, or even black. Whereas the design value and arousal strength of color is undeniable, eliciting its semantic significance is not straightforward, nor is their acceptance by humans, as it depends on the objects to which it applies and on the cultural background of the human viewer.

[41] Prof. Ishiguro's *Geminoid*, modelled after him, even wears a wig made of the professor's own hair.

[42] Speaking of colors, these robots conveniently display a bright red spot in the middle of their chests when they turn evil.

[43] Paterson (2024).

[44] Can Nao, Pepper, iCub or others be really perceived as "feminine"?

[45] If more realistic robot companions were to be developed, they probably should reflect human diversity, although it is a widespread opinion among roboticists that too much realism should be avoided, we come to this later.

[46] Liberman-Pincu et al (2023)

Personal preference on a specific color may be determinant in product purchase, in the absence of primary factors such as color functionality (suitability for the function of the product) or color performance (the consumer infers that the product works better with a given color)[47].

7.3.1.4 Material

Structural materials are mainly aluminum alloys, steel, even titanium if the application justifies its use, and so are mechanical transmission elements (in the case of gears, also copper alloys such as brass or bronze, and thermoplastics). They are generally not visible from the outside, as neither are motors, proprioceptive sensors, electrical cables, etc. Most relevant, as for the robots' appearance, are the materials the casings are made of, as well as of elements (if present) such as limbs, locomotion parts (e.g. wheels), end effectors, heads… Casings of industrial robots are often made of metal, with a protective paint coat. In the case of SARs, more often different kinds of plastic or carbon fibre are employed. These materials, together with an appropriate surface treatment, provide the robot with its shiny, smooth but at the same time hard appearance. They are easy to clean, provide good protection as for environmental conditions, and are bad thermal conductors (as compared to metals) and non-conductive as for electricity, which makes robots safer for the user. Some applications will require the use of special materials: Kevlar is a good choice for extreme (cold and hot) temperatures, whereas the polymer ABS[48] is quite suitable for surgery robots for its resistance under demanding sterilization processes[49].

A further step in making robots intrinsically safe is to make use of soft materials. There is a lot of ongoing research in soft robotics, and in soft actuators in particular. As for the outer surface, materials such as fabrics are beginning to be used. Silicon rubber is employed in realistic humanoid robots, intending to emulate human skin. Synthetic skin made of rubber or other polymers can embed electrodes, change light transmission by reflection, or even act as a pressure changing semiconductor to provide sensing capabilities to the skin. Zoomorphism, on the other hand, has led to covering robotic pets such as the seal baby Paro with artificial fur.

Sustainability considerations will probably be a strong drive to employ recycled materials for the construction of robots, as well as biodegradable materials such as bioplastics.

7.3.2 Dynamic and relational features

These are robot behavior-related topics that have generated lots of research and publications, and will be treated here quite swiftly. As we refer to the appearance of the robot, only one direction in the interaction is considered, from the robot to the human. For example, as for gestures, we focus just on those that uses the robot to transmit some information to the human user, but human gesture recognition is completely left out.

7.3.2.1 Mobility

The way robots move betrays in most of the cases and most strikingly their mechanical nature. Wheels and tracks, rotors and helices provide kinetics that are unseen in nature. As for articulated limbs and body joints, earlier motion control produced uncoordinated, stilted, abrupt movements, that are replicated by humans in the popular robot style dance. Robot arms can move nowadays in a very smooth and natural-looking way, although they can also move with unnatural velocities and accelerations (too slow or too fast). We have already mentioned biomimetic movements in zoomorphic robots, as for example the tripod gait in hexapod robots, and even modern quadrupeds display a quite smooth trotting. Biped walking in humanoids is still far from being perfectly human-like. However, it should be stressed that seeming natural does not imply being the best solution from an efficiency standpoint, for example as for energy consumption. Robot bodies are different from their natural counterparts, weight distribution is not the same, and thus is neither the best way to put this body in motion.

[47] Yu et al (2017). They focus on these two primary factors, but mention also cultural color (e.g. the brides' white dresses) and other (such as fitting a color scheme in the home decoration) primary factors.

[48] acrylonitrile butadiene styrene

[49] Matthews (2019)

7.3.2.2 Proxemics

Proxemics is the study of the human use of space, in particular from the point of view of human-human interaction. Coined in the context of cultural anthropology, one of its most well-known findings is the definition of intimate, personal, social, and public spaces around a person (so-called *reaction bubbles*)[50]. The term has been borrowed by social robotics in the field of HRI to determine at which distance should the robot situate itself with respect to the user, depending on the type of interaction and the context. This distance should comply with the user's sense of easiness and comfort, facilitating communication and interaction without being intrusive. Research on human-robot proxemics focuses on the different aspects of the topic, both in static (with the person either standing or sitting) and in dynamic (or navigational) proxemics[51]. Employed criteria may alter the measured distances in the corresponding surveys, that is, appropriate distances may not be the same for perceived safety than for spatial comfort, expectation conformity, or general motion acceptance[52]. These distances obviously vary with the robot's general appearance and size. Humanoid robots intended to be realistic easily fall into the uncanny valley, eliciting larger appropriate distances, whereas robots equipped with a screen displaying a real human face have the contrary effect[53]. Distances do also vary depending on the approach direction, that is, if the robot is approaching from the front or from the sides or behind. A robot that has to avoid a person who is on its way to a goal destination has to take a larger detour if the person is exercising than if sitting. In the presence of several people, it has to avoid passing between two persons involved in a conversation, respecting social etiquette[54]. If the user is moving as well, proxemics deals not only with the distance the robot is accompanying the person, but also with their (application dependent) preferences regarding the robot to assume a leading or a following role.

In the case of UAVs, proxemics extends to the vertical dimension[55]. Reaction bubbles are not circles (or ellipses) anymore, but hemispheres. Vertical proxemics is also important in the case of humanoid robots, as dominance-submission relations may be enforced by the relative face-to-face height. Confidence may be enhanced by a tall robot descending to the height of a smaller user (such as a child, for example).

The other way round, users may interpret given behaviors of the robot in human proxemics terms. For example, the experimental social robot Kismet had technical difficulties in focusing on the human face if the user came too close to its cameras (its "eyes"), which triggered withdrawing[56]. The user interpreted this response as they were invading the robot's personal space, and respected the established distance. Interpreting robot behavior in social human terms facilitates interaction for inexperienced users, but should be exploited with care to avoid deceptively humanizing the robot.

7.3.2.3 Gestures and expressions

Gestures and facial expressions belong to the strongest non-verbal communication channels. Even the motions of robots with a morphology so different from human's such as drones can be interpreted as gestures and have been used to convey information: facing the user (with the frontal camera) and salutation gestures such as waggling or nodding are to be interpreted as the robot acknowledging the user[57]. As for humanoid robots, the body attitude and the position of the limbs can be a rich source of conveying information to the user. Simple fin-like limbs can be used by a robot to indicate direction, more straightforwardly than any verbal message. Expressivity is obviously enhanced

[50] https://www.researchgate.net/figure/Halls-1966-proxemics-spaces-shown-as-reaction-bubbles-source-Wikimedia-Commons_fig32_322617164

[51] Repiso et al (2023)

[52] Neef et al (2023)

[53] Neef et al (2023)

[54] Samarakoon et al (2022)

[55] Jensen et al (2018)

[56] http://www.ai.mit.edu/projects/sociable/regulating-interaction.html

[57] Jensen et al (2018)

with the sophistication of the arms and hands, up to the point of enabling robots to communicate in sign language, or even tactile sign language for deafblind people[58].

Facial expressions can be quite useful, either by themselves or reinforcing verbal communication. A low battery charge status can be indicated with a tired expression, which is easily interpreted as the robot needing some rest (to recharge). The position of the eyes, lids and eyebrows, as well as of the mouth, can already express a wide range of internal states of the robot, which was confirmed by experimentation with the robots Kismet, iCat and Simon (see Section 7.3.1.2). Position and movements of the head do also contribute to facial expressions: sadness, for example, is much better expressed if not just the gaze, but also the whole head is lowered. In realistic humanoid robots, not just a richer expressivity and a more nuanced communication, but also more natural facial gestures are aimed by actuating more facial features. However, the risk of falling inside the uncanny valley is much higher than with static faces (and, as seen in Figure 3, this valley is deeper as well).

Once more, gestures and expressions should always be facilitators of human-robot communication, but in no case create the illusion of the robot having real feelings, emotions or conscience.

7.3.2.4 Sound, voice

Robots have electrical motors, mechanical transmissions, some have also pneumatic actuators: these devices produce characteristic sounds, that do not correspond to the silent activation of biological muscles. Natural bodies, on the other hand, produce their own sounds, for instance while breathing, that are absent in robots. The difference between these two soundscapes possibly will be reduced in the future by the development of soft actuators, but for now, this difference contributes to characterizing the robot's appearance not only visually, but also on the auditory plane.

In Latupeirissa et al[59], the semiotics of robot sounds along 15 movies (from the 1950s to 2021) is analyzed, in order to provide guidance to HRI designers. This analysis is conducted along the paradigmatic axis (examining types of sounds) and the syntagmatic axis (considering the events taking place around the sounds), and the relation between the two. The categories in the paradigmatic axis are mechanical sounds, created by the motion of the robot (further subdivided in lower-pitched sounds for larger movements or heavier robots, and higher-pitcher sounds accompanying smaller gestures such as finger or eyebrow movements), and synthetic sounds, created by analog or digital sound synthesizers (subdivided into simple and complex sounds[60]). The syntagmatic perspective provides the context or justification of the mechanical sounds as the robot's mechanical aspects (size[61], exposed mechanisms, construction quality[62]) or underlining its anthropomorphism (e.g., the sound accompanying blinking, although actually robots do not need to blink at all). As for the synthetic sounds, they are mainly devised to compensate for the lack of expressivity of the robots' faces (or to complement their limitations). The authors of the study categorize the circumstances that elicit such sounds as internal processes of the robot (learning, decision making, awareness of danger), as conversational cues (e.g. turn-taking), and as emotional expressions (e.g. lowering the pitch to express sadness). Along with this analysis, the authors propose ways to incorporate their findings into real robots.

The classical prosody of fictional robots was characterized from the very beginning; Baum's character Tik-Tok has a "monotonic, halting mode of speech: "Good morn-ing, lit-tle girl."”[63] With the development of the speech analyzer-synthesizer *vocoder*[64] in the 1930s for voice transmission in telecommunication, the means of producing a

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[58] The Tatum T1 Fingerspelling hand is such an example, https://tatumrobotics.com/home/about/

[59] Latupeirissa et al (2025)

[60] The characteristic sounds of Star wars' R2-D2 or Wall·E would belong to this latter subcategory, although they are not considered in Latupeirissa et al (2025), as they focus on humanoid robots with recognizable torso, arms and head.

[61] Lower pitched sounds for bigger robots.

[62] Older vs. newer models

[63] Wikipedia Tik-Tok (Oz) https://en.wikipedia.org/wiki/Tik-Tok_(Oz). Accessed: 25/04/2025

[64] From "voice encoder".

robotic sounding voice was obtained. For instance, in pop culture it has been used by the German electronic music band Kraftwerk for their song *Die Roboter*, from the album *Die Mensch-Maschine* (1978), and is a recurrent tool for voice distortion in pop music. Robots nowadays, however, are able to speak in a far more natural manner. Robot Ameca, for example, which sounds quite human-like, uses Amazon Polly Neural voices, a text-to-speech AI-based multilingual voice generator[65]. Voice is of utmost importance, as brilliantly illustrated by the movie *Her* (2013, Spike Jonze), and it is legitimate to wonder if a human-like voice might not add a layer to deception, to contribute to the attribution of humanity to the machine.

7.4 Discussion: Appearance based acceptance and ethical concerns

7.4.1 Acceptance and engagement

The first the robot has to accomplish is to be accepted by its human user. Its functionality in terms of usefulness and performance is clearly determinant, but the impression it causes through its appearance is quite important as well. This is especially relevant in social robotics. Acceptance is the premise for engagement (the user actually wants to start interacting with the robot), which is fueled by features such as perceived safety, likeability, trustworthiness, reliability (in the sense of performing consistently well), or transparency. Human user acceptance has centerd many research studies in HRI. The usual way to provide experimental evidence about how humans perceive a given robotic setting, or value a specific robot design, or consider a certain interaction is by performing a survey. They can be conducted online, where typically a higher number of participants can be reached, by confronting the participant with images or videos, or in person, in which case the participant can interact with a real robot[66]. At the end, the participant is asked to fill one or several questionnaires about the experience. As an example, the survey described in Liberman-Pincu et al[67] is fairly complete, as it includes a previous measurement of the participant's attitude towards robots and technology in general. This is performed via the Negative Attitudes towards Robots Scale (NARS)[68] and Technology Adoption Propensity (TAP)[69]. Then, they proceed to measure the participants' perception of the visual appearance of robot design via the popular Godspeed[70] semantic differential scales on anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety, and the Robotic Social Attributes Scale (RoSAS)[71], an 18-item questionnaire of 5-point Likert scales. Factor analysis of RoSAS unveils three central evaluation factors: warmth, competence, and discomfort. Liberman-Pincu et al adapt these questionnaires to evaluate the effects of individual VQs (body structure, outline and color, see Sections 7.3.1.1 and 7.3.1.3) on the participants' perception of the following robot characteristics: friendly, childish, innovative, threatening, old-fashioned, massive, elegant, medical, and gender. Valuability of these characteristics is application-dependent, which should be taken into account when designing a robot to enhance acceptance.

Humans tend to ascribe personality traits to artificial entities based just on appearance. In a survey conducted at the University of Hertfordshire[72] with four robot types (mechanical or humanoid, short or tall[73]), people who preferred a specific robot type, also valued different "personality" features: those who preferred the short humanoid type, for instance, perceived both humanoid robots as more extrovert and agreeable, whereas those who preferred the short

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[65] https://www.youtube.com/watch?v=wJyYMGswc1g

[66] As usual in such experiments, an informative sheet has to be provided to the participant, who has to express conformity in the informed consent form.

[67] Liberman-Pincu et al (2023)

[68] Nomura et al (2006): NARS subdivides its 14 statements into three groups, namely "negative attitudes toward situations of interaction with robots," "negative attitudes toward the social influence of robots," and "negative attitudes toward emotions in interaction with robots".

[69] Ratchford and Barnhart (2012): based on a 14-item index combining assessments of consumers' positive and negative attitudes towards technology, TAP measures their propensity to adopt new technologies.

[70] Bartneck et al (2009)

[71] Carpinella et al (2017)

[72] Walters et al (2009)

[73] The mechanical ones had just a camera on top of a frame, whereas the humanoid ones had a "head" and two arms on the same frame. The tall ones were still smaller than an adult human.

mechanical one rated it for being relaxed and contended (low neurotism)[74]. The same study concluded that the taller (humanoid) robot was seen as more conscientious. Gender-coded robots elicit a different personality attribution and emotional response depending on the gender of the user. Diverse studies differ in whether a positive attitude is provoked by same-gender or opposite-gender coded robots which probably depends on the context and the particular embodiment of the robots, beyond gender attributes, but these studies are coincident in that a difference in attitudes exists. In Forgas-Coll et al[75], a survey following a reduced version of the Almert model[76], gender was coded into the robot's rendered face (comic-like eyes, with eyelashes in the case of female-coded, and accompanied by a moustache in male-coded face) and voice (higher and lower pitch), and the results showed that women saw the female-coded robot as an element of social influence and the male-coded robot as nothing more than a useful instrument, whereas men viewed a male-coded robot as serving for entertainment, although difficult to handle.

Focusing on faces, a study by Chen and Jia[77] revealed the effects of the so-called baby-schema[78] on the participants' perception of cuteness and trustworthiness of social robots. Baby-like faces (big eyes on a wide face, big forehead, relatively small nose and mouth) elicit feelings of protection, of innocence and thus of trustworthiness. A set of 100 homogenized images of real social robot heads (both with constructed and with rendered faces) were presented to the participants, who had to score them according to having a baby face, trustworthiness, cuteness, and perceived emotion (i.e., the robot face displaying a positive or negative emotion). The study and statistical analysis afterwards revealed a positive correlation between these factors. Performing further experiments on a reduced set of 5 robots, modifying eye size (as the most outstanding feature of the baby-schema), confirmed the relation between baby-face, cuteness and trustworthiness, although it also uncovered that this is not a universal recipe, but depends on the particular embodiment (robot type), being even counterproductive (lower cuteness and trustworthiness) in some case.

The surveys conducted for the original RoSAS study[79] revealed that a female and human-like appearance was perceived to be warmer and more competent, whereas a male and machine-like robot rated higher for discomfort. This rises two questions: on the one hand, assigning a gender to robots entails the risk of perpetuating or reinforcing conventional gender roles. On the other hand, resorting to more human-like appearances in order to prompt the perception of higher competence may enhance acceptance, but at the expense of a higher risk of deception. The perception of competence of a robot should result basically from the interaction and the efficacy in completing the assigned tasks, i.e., from the robot's behavior. However, also the robot's appearance can contribute to such a perception, predisposing favorably the user without necessarily adopting a high degree of anthropomorphism, by playing with the size, overall shape, styling, etc. One should be also aware about the existence of conflicting factors in acceptance: small, baby-face robots may trigger trustworthiness but rate worse in the perception of competence. At the end, although the surveys may unveil general tendencies in users' preferences as for robot design, acceptance is also heavily determined by the intended use of the robot (application and context of use), and by the personal preferences of the users. As for the latter, they may be conditioned by attitudes towards technology, cultural environment, and even gender[80], as already stated.

7.4.2 Ethical risks

Acceptance may evolve in long-term interactions towards stronger feelings of sympathy, empathy, even friendship and love. These feelings are deceiving, as they are unidirectional. Not deceiving *per se* (one could for example be very attached to an object for its sentimental load), but for the implicit assumption of correspondence, which is

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[74] But those who preferred the tall mechanoid considered it as being more extrovert too!

[75] Forgas-Coll et al (2023)

[76] In this model, intention of use depends directly from perceived usefulness, perceived ease of use, perceived enjoyment, and social influence, and indirectly from perceived adaptability and perceived sociability.

[77] Chen and Jia (2023)

[78] The baby-schema effect was proposed by the well-known etologist Konrad Lorenz who considered it to being an innate mechanism in humans and other animals (https://en.wikipedia.org/wiki/Cuteness).

[79] Carpinella et al (2017)

[80] For instance, in Liberman-Pincu et al (2023), differences in preferences about VQs for robot design were found correlated to NARS score and gender of the participants.

fueled by anthropomorphism. In the long term, appearance may lose the novelty appeal, but if the interaction is satisfactory or even pleasant for the user, this will be compensated by familiarity. This may even condition the following choice of a new robot, if the previous one has to be substituted. Even sentiments of grief may arise in such cases.

Standardized expressions of beauty may possibly shape the appearance of future humanoid robots, which may have as a consequence a lower appreciation of the aesthetic diversity of humans. The nuances and variability introduced by genetics may become unnoticed as factors of attraction, reducing instead human appreciation of beauty to a few conventional aesthetic icons. People aesthetically educated in robotic beauty will possibly lose sensibility in enjoying the sight of a human face.

More ethically compromising are the risks associated to loss of liberty and autonomy, or of privacy, motivated by an excessive attachment to robots, linked to their appearance. Humans are easily manipulated by appearance and may without hesitation delegate decisions to competent-looking robots. A baby-scheme robot evokes trustworthiness, as we have seen, and this may be used by a third party –be it the manufacturer of the robot, another user, or a hacker- to exploit gullibility or credulity to their own benefit. A pet-like robot may be easily allowed to access the private or intimate spheres of its owner, putting privacy at risk. And as with any consumer appliance, but possibly at a higher degree, the appearance of a robot may overshadow its actual performance, and condition its acquisition by the user irrespectively of their real needs.

Further development and expansion of social robots will spark new concerns and debates related to their appearance. Gender role perpetuation, degrading depiction of given social groups, wear-out or obsolescence of perfectly functional units due to changing fashion, are some of the possible social and environmental problems that a robotized society will face. Moreover, as soon as technology is advanced enough, impersonation of actual people by robots looking the same may become a real threat. Popular icons may exploit their image by allowing robotic replicas of themselves to be manufactured and marketed (and charging for this), or maybe such replicas will be created illegally or without consent[81]. New forms of crime and of security threats may arise related to robotic impersonation.

In the same way that nowadays manufacturers of cars have certain stylistic freedom for their models, but have to adhere to security and functional specifications, also legal constraints for the appearance of service and social robots will be developed sooner or later. Safety-by-design will be a guideline that will pose limits to the size and general configuration of the robots. There will be restrictions as well in regard to personal tuning of the robots by their owners. Some robot appearance related conflicts can be anticipated and the corresponding legal measures adopted in time, but there will also be room for the unexpected and the unforeseen that will have to be confronted by law-makers and society once the problem is there.

7.5 Concluding remarks

Although adhering to a limited set of prototypical appearances (metallic or machine-like, humanoid, zoomorphic…), robots in fiction and in the real world can display a practically infinite range of specific looks. This chapter has not only shown this overwhelming variety along the short history of robotics, but has dissected as well the different constituents of robot appearance, both static and dynamic, that allow, by shaping and combination, achieve such a variability. Playing smartly with the nuances of the different features, plus clever marketing and publicity, can render irresistible robot companions, that may lead towards deception and frustration of the human owners if their actual performance does not meet the expectations.

Appearance of competence may pave the way to delegate decisions on the robot, which can be detrimental in the user's autonomy. If appearance does not meet actual performance, the results of such decision delegation can be catastrophic, but even if the robot is able to effectively look for the interests of the user, in the long run there is a clear risk of losing the capacity of taking the own decisions. Although this is rather a behavioral issue, the appearance and gestural clues of the robot should always point at its role as a tool, in the best case as an informed counselor that is able to present different options to the user, who has to take the ultimate decision.

[81] If, by then, popular icons are still human.

Falling in love with objects is certainly not a new issue under the sun, but at least no correspondence in feelings is expected from them. Humanlike robots, however, may be deceiving in this sense. In human-human relationships deceptions do also exist, manipulative partners that use feelings to constrain their lover's liberty and autonomy, but in some sense, even if holding a position of power, they are exposed too, even if to a small extent. This does not happen in human-robot relations, where a third party may profit from excessive engagement, without any personal risk. Cute personal robotic companions which appear in the need of care may help some people to feel useful and to develop healthy routines, but the danger exists of creating a relationship of dependence, which is based on a mock-up. There is no biological being whose survival and well-being depends on the user's care, but the user's liberty of action may be coerced by this farce, feelings of guilt may arise if the user decides to interrupt caring for the robot (or simply cannot continue doing it for any reason). Cuteness in robot appearance may be designed to exacerbate such feelings, even more than with living pets. Thus, bounds on design should be envisioned so as such appliances remain on the side of fair play.

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