The Uncanny Valley
Masahiro Mori
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Translated by Karl F. MacDorman and Takashi Minato

Valley of familiarity
There are mathematical functions of the form y = f(x) for which the value of y increases (or decreases) continuously with the value of x. For example, as the effort x increases, income y increases, or as a car's accelerator is pressed, the car moves faster. This kind of relationship is ubiquitous and easily understood. In fact, it covers most phenomena, so we might think that this function can represent all relations. That is why people are usually upset when faced with some phenomenon it cannot represent.

Climbing a mountain is an example of a function that does not increase continuously: a person's altitude y does not always increase as the distance from the summit decreases owing to the intervening hills and valleys. I have noticed that, as robots appear more humanlike, our sense of their familiarity increases until we come to a valley. I call this relation the "uncanny valley."

Recently there are many industrial robots, and as we know the robots do not have a face or legs, and just rotate or extend or contract their arms, and they bear no resemblance to human beings. Certainly the policy for designing these kinds of robots is based on functionality. From this standpoint, the robots must perform functions similar to those of human factory workers, but their appearance is not evaluated. If we plot these industrial robots on a graph of familiarity versus appearance, they lie near the origin (see Figure 1). So they bear little resemblance to a human being, and in general people do not find them to be familiar. But if the designer of a toy robot puts importance on a robot's appearance rather than its function, the robot will have a somewhat humanlike appearance with a face, two arms, two legs, and a torso. This design lets children enjoy a sense of familiarity with the humanoid toy. So the toy robot is approaching the top of the first peak.
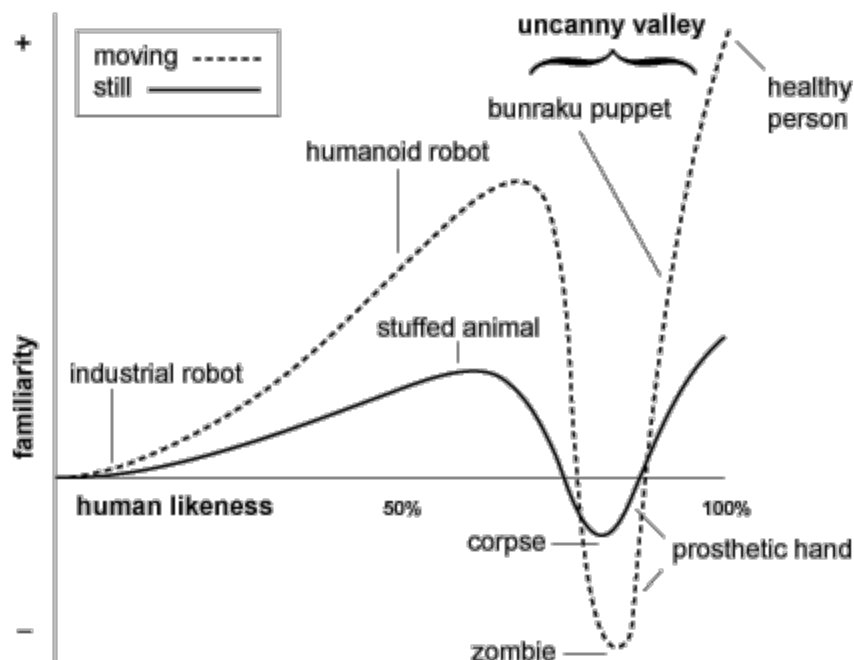
Fig. 1. [Note: This is a simplified version of the figure appearing in the *Energy* article. -Trans.]

Of course, human beings themselves lie at the final goal of robotics, which is why we make an effort to build humanlike robots. For example, a robot's arms may be composed of a metal cylinder with many bolts, but to achieve a more humanlike appearance, we paint over the metal in skin tones. These cosmetic efforts cause a resultant increase in our sense of the robot's familiarity. Some readers may have felt sympathy for handicapped people they have seen who attach a prosthetic arm or leg to replace a missing limb. But recently prosthetic hands have improved greatly, and we cannot distinguish them from real hands at a glance. Some prosthetic hands attempt to simulate veins, muscles, tendons, finger nails, and finger prints, and their color resembles human pigmentation. So maybe the prosthetic arm has achieved a degree of human verisimilitude on par with false teeth. But this kind of prosthetic hand is too real and when we notice it is prosthetic, we have a sense of strangeness. So if we shake the hand, we are surprised by the lack of soft tissue and cold temperature. In this case, there is no longer a sense of familiarity. It is uncanny. In mathematical terms, strangeness can be represented by negative familiarity, so the prosthetic hand is at the bottom of the valley. So in this case, the appearance is quite human like, but the familiarity is negative. This is the uncanny valley.

I don't think a bunraku puppet is similar to human beings on close observation. Its realism in terms of size, skin, and so on, does not approach that of a prosthetic hand. But when we enjoy a puppet show in the theater, we are seated far from the puppets. Their absolute size is ignored, and their total appearance including eye and hand movements is close to that of human beings. So although the puppets' body is not humanlike, we can feel that they are humanlike owing to their movement. And from this evidence I think their familiarity is very high.

From the above maybe readers can understand the concept of the uncanny valley. So in the following I consider the relationship between movement and the uncanny valley.

The effects of movement
For creatures, including robots, movement is generally a sign of life. As shown in Figure 1, adding movement changes the shape of the uncanny valley by exaggerating the peaks and valley. For the industrial robot, the impact of movement is relatively slight because we see it as just a machine. If it stops moving, it just stops working. But if programmed properly to generate humanlike movements, we can enjoy some sense of familiarity. Humanlike movement requires similarity of velocity and acceleration. Conversely, if we add movement to a prosthetic hand, which is at the bottom of the uncanny valley, our sensation of strangeness grows quite large. Some readers may know that recent technology has enabled prosthetic fingers to move automatically. A commercially available prosthetic hand made with the highest technique was developed in Vienna. To explain how it works, the intention to move the forearm, even if missing, produces current in the arm muscles that can be detected by an electromyogram. So the prosthetic hand detects the current by means of electrodes and amplifies the signal to activates a small motor in the prosthetic arm to move the fingers. This hand can move in a way that causes some healthy people to feel uneasy. If you shook a woman's hand with this hand in a dark place, the woman must be shocked!

Since these effects are apparent for just a prosthetic arm, the strangeness will be magnified if we build an entire robot. You can imagine going to a work place where there are many mannequins: if a mannequin started to move, you might be shocked. This is a kind of horror.

In the World Expo held in Osaka this year, the robots displayed a more elaborate design. For example, one robot has 29 artificial muscles in the face to make humanlike facial expressions. According to the designer, laughing is a kind of sequence of face distortions, and the distortion

speed is an important factor. If we cut the speed in half, laughing looks unnatural. This illustrates how slight variations in movement can cause a robot, puppet, or prosthetic hand to tumble down into the uncanny valley.

Escape by design

We hope to design robots or prosthetic hands that will not fall into the uncanny valley. So I recommend designers take the first peak as the goal in building robots rather than the second. Although the second peak is higher, there is a far greater risk of falling into the uncanny valley. We predict that it is possible to produce a safe familiarity by a nonhumanlike design. So designers please consider this point. A good example is glasses. Glasses do not resemble the real eyeball, but this design is adequate and can make the eyes more charming. So we should follow this principle when we design prosthetic eyes. We can create an elegant prosthetic hand ? one that must be fashionable. Artist who makes statues of Buddhas created a model of a human hand that is made from wood. The fingers bend at their joints. The hand has no finger print, and it assumes the natural color of wood. But we feel it is beautiful and there is no sense of the uncanny. Maybe wooden hand can serve as a reference for future design.

The significance of the uncanny

In Figure 1, a healthy person is at the top of the second peak. And when we die, we fall into the trough of the uncanny valley. Our body becomes cold, our color changes, and movement ceases. Therefore, our impression of death can be explained by the movement from the second peak to the uncanny valley as shown by the dashed line in the figure. We might be happy this line is into the still valley of a corpse and that of not the living dead! I think this explains the mystery of the uncanny valley: Why do we humans have such a feeling of strangeness? Is this necessary? I have not yet considered it deeply, but it may be important to our self-preservation.

We must complete the map of the uncanny valley to know what is human or to establish the design methodology for creating familiar devices through robotics research.