HUMAN–ROBOT INTERACTION

Course Code: 23RIOE313 | Semester V | Credits: 3

MODULE 2: Design & Spatial Interaction

Syllabus topics covered: Design in HRI • Anthropomorphizing in HRI design • Design methods • Prototyping tools • Culture in HRI design • Use of space in human interaction • Spatial interaction for robots

Reference: Bartneck, Belpaeme, Eyssel, Kanda, Keijsers & Sabanović, "Human–Robot Interaction: An Introduction", Cambridge University Press, 2019 — Textbook sections 4.1–4.5, 5.1–5.2

1. Design in HRI

Turning "a pile of wires, motors, sensors, and microcontrollers" into a robot people actually want to interact with is the job of robot design — an iterative, interdisciplinary process.

1.1 Two ways of building a robot: inside-out vs outside-in

- **"Frankenstein approach" (inside-out)**: start from whatever technology/platform is available (e.g., a TurtleBot base), add sensors and actuators, then design a casing/appearance around it afterwards. Common, but suboptimal — it often ignores the human-centred context and use case.
- **"Outside-in" approach**: start from the interaction the robot is expected to have; let that determine its shape and behaviour, then fit the technology to it. Many commercial social robots are designed this way:
  - Honda's **ASIMO** was made smaller so it would not intimidate users.
  - **Pepper** was designed to interact with shop visitors and has a hinged waist so it can bow in greeting.
  - **Paro**'s design changed from a cat to a seal (so users wouldn't compare it to a real cat's behaviour) and had its wheels removed (its elderly users had limited mobility).

1.2 Robot morphology and form (4.1.1)

A recurring design debate is whether **form follows function** or vice versa — in HRI, form and function are inherently interconnected. Common robot forms available to designers:

- **Androids / humanoids** — closest to human appearance, but must live up to high behavioural expectations.
- **Zoomorphic robots** — shaped like familiar animals (cats, dogs) or familiar-but-not-interacted-with animals (dinosaurs, seals).
- **Minimalist robots** — explore the minimum needed to inspire social interaction (e.g., Muu, Keepon, or the extreme "Naked Invisible Guy" — just a pair of animated sandals on a box).
- **"Robjects"** — interactive robotic artifacts based on everyday objects rather than living creatures (a robotic ottoman, social trash cans, robotic toy boxes).

1.3 Affordances (4.1.2)

Originating in ecological psychology (Gibson) and adapted by Don Norman, an **affordance** is the perceivable relationship between an organism/user and its environment that enables certain actions (a chair affords sitting).

- A robot's **appearance** is itself an affordance: people assume capability matches looks — a humanlike robot is expected to act humanlike; eyes imply it can see; arms imply it can pick things up or shake hands.
- **Interaction modalities** are affordances too: if a robot speaks, people expect it to hold a conversation; if it shows facial expressions, people expect it to read theirs; a touchscreen implies touch-based interaction.
- Because robots are novel interaction partners, these design affordances are critical for signalling to people how to appropriately engage with them.

1.4 Design patterns (4.1.3)

Peter Kahn (inspired by Christopher Alexander's architectural design patterns) proposed **HRI design patterns** — reusable, abstract solutions to recurring interaction problems, which can be combined (e.g., a "didactic communication" pattern + a "motion" pattern → a robotic tour guide). Example patterns: "initial introduction," "in motion together." The key idea: design should focus on the **relationship** between humans and robots, not just the robot's individual characteristics.

1.5 Design principles in HRI (4.1.4)

- **Matching form and function**: a humanoid robot raises expectations of humanlike talk/thought/action; if this isn't needed for its purpose (e.g., cleaning), a less anthropomorphic design may be better. Appearance can also trigger stereotypes (e.g., people expecting a female robot to know more about dating, or a robot "made in China" to know more about Chinese tourist spots).
- **Underpromise and overdeliver**: raised expectations (from appearance or marketing as "intelligent"/"companion-like") that go unmet cause disappointment and negative evaluation. Fix: lower expectations — sometimes even avoid the word "robot," since it connotes advanced capability.
- **Interaction expands function**: people fill in the blanks of an open-ended design with their own values/beliefs — useful for robots with limited capability. Paro succeeds partly because it isn't compared to a real cat or dog (which would set unmeetable expectations).
- **Do not mix metaphors**: keep capabilities, behaviour, and appearance coordinated/holistic. A humanlike robot with skin on only part of its body, or an animal robot that lectures on mathematics, feels disturbing — related to the **uncanny valley** (see Section 2.2).

2. Anthropomorphizing in HRI Design

2.1 What is anthropomorphization?

Anthropomorphization is the attribution of human traits, emotions, or intentions to nonhuman entities (from Greek ánthrōpos = "human" + morphē = "form"). Everyday examples: "My computer hates me!"; naming your car. A special case is **pareidolia** — seeing humanlike features in random patterns (e.g., the famous 1976 Viking 1 "Face on Mars" photo, later shown by NASA's 2001 higher-resolution images to be just a natural rock formation).

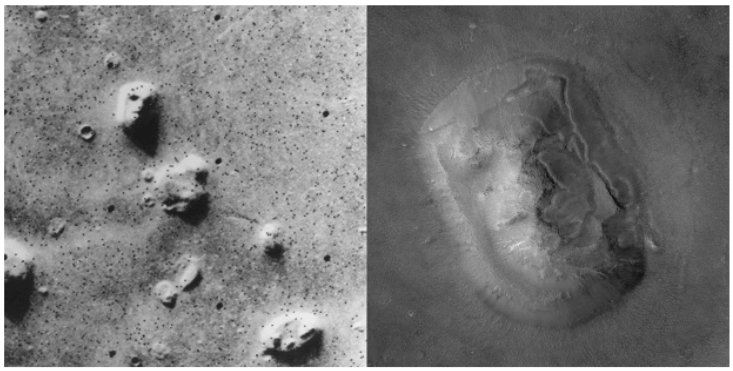


Figure 4.6 The face on Mars is an example of pareidolia. On the left is the photo from 1976, and on the right is the same structure photographed in 2001.

2.2 Attributing humanlike characteristics to robots (4.2.1)

Robot human-likeness ranges along a spectrum, from minimalist cues to near-exact human replicas:

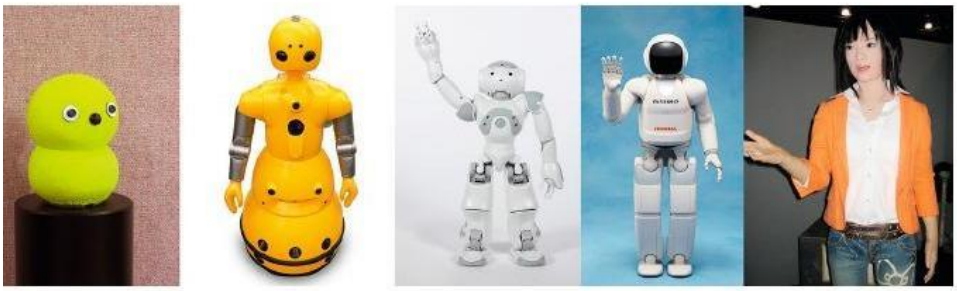


Figure 4.8 — People anthropomorphize all kinds of robots: from left to right, Keepon, Wakamaru, Nao, ASIMO, and Kokoro's Actroid android (Bartneck et al., 2024).

- **Android robots** (e.g., Geminoid, Kokoro) — designed to be as humanlike as possible, sometimes exact replicas of a specific living person.
- **Humanoid robots** (e.g., ASIMO, Nao) — a more abstract human-likeness: human body shape/proportions but often simplified features (ASIMO has a helmet-like head with no eyes; Nao has LED eyes but no mouth).
- **Nonhumanoid robots** can still be anthropomorphized — Keepon's two eyes and symmetric body, or Google's cartoon-like autonomous car prototype (wide headlights as "eyes," a button "nose").
- **Psychological anthropomorphism** (Epley et al., 2007) — attributing unobservable characteristics (emotions, intentions, mind) to a robot, going beyond just its appearance.

2.3 The uncanny valley

Masahiro Mori (1970) proposed that as robots become more humanlike, likability/familiarity rises — until a point where they become almost-but-not-quite human, at which likability **drops sharply** (the "valley"), before rising again for a truly human likeness. This dip is amplified when the robot **moves**.

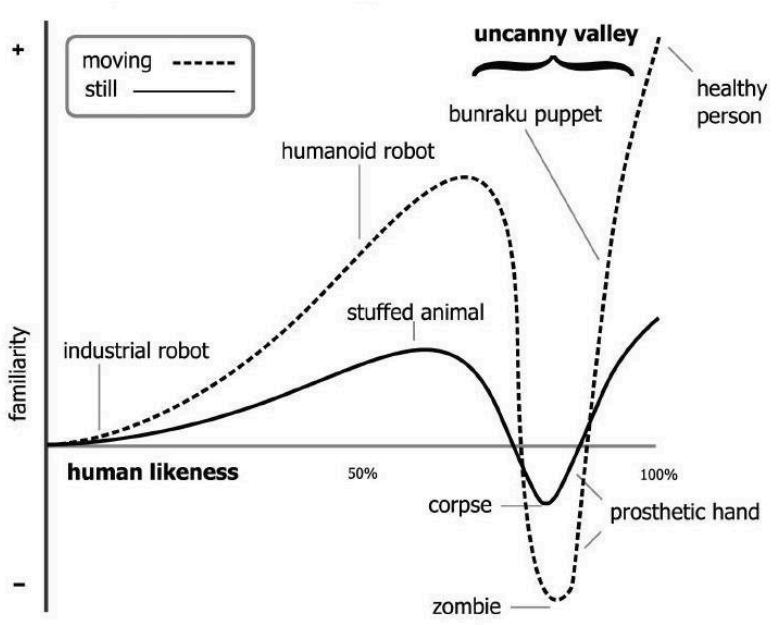


Figure 4.10 Mori's uncanny valley theory.

Figure 4.10 — Mori's uncanny valley theory: familiarity vs. human likeness (Bartneck et al., 2024).

- Mori's original term **shinwa-kan** (親和感) is hard to translate — rendered variously as likability, familiarity, or affinity; some researchers instead ask about a robot's "eeriness."

- **Caution**: Mori never empirically tested this idea — it is a hypothesis, not a proven law, and is often over-applied without proper justification. Anthropomorphism is multidimensional; reducing it to one axis (human-likeness) oversimplifies reality.
- One simple explanation for reduced likability in very humanlike robots: **complexity risk** — the more humanlike a robot, the more ways it can get some detail of appearance/behaviour wrong, and the more that mismatch stands out.

2.4 Designing humanlike appearance (4.2.2)

Robot designers treat human-likeness as a property of the robot; social scientists treat anthropomorphism as something a **person attributes** to the robot. Two levers designers use:

- **Appearance**: even minimal cues — two dots for eyes plus a nose/mouth — are often enough to suggest human-likeness. Adding more features (arms, legs) doesn't necessarily add much more anthropomorphic effect.
- **Behaviour**: Heider & Simmel (1944) showed people readily attribute social relationships and humanlike emotions to simple moving shapes (triangles/circles) — motion alone, without humanlike form, can convey character and intent (e.g., the animated short *The Dot and the Line*).
- **Reactive behaviour** (responding immediately to touch/sound, e.g., jolting when a door slams) and **contingency** (responding appropriately to context — briefly looking toward motion, sustaining gaze only if it's relevant, like a human waving) both increase anthropomorphization.
- The **more humanlike** a robot appears, the **more** people expect in terms of contingency, dialogue, and other humanlike features — raising the design bar.

2.5 Impact of context, culture, and personality

- Individual differences affect how much people anthropomorphize (Waytz et al., 2010); demographic/cultural background also shapes interpretation of a robot's social capabilities.
- **Just placing a robot in a social situation increases anthropomorphization.** Factory workers regularly anthropomorphized the collaborative robot **Baxter** — giving it hats/accessories and wanting it to chit-chat; office workers with a break-management robot gave it a name and wanted more social interactiveness.
- **Social modelling matters**: nursing-home residents were more likely to engage with **Paro** like a pet after seeing others do so first — anthropomorphic inferences can be shaped by watching others, not just by first impressions.

3. Design Methods

HRI design draws on methods from engineering, HCI, and industrial design. The overall process is typically **cyclical**:

> **The HRI design cycle**
>
> 1. Define the problem or question.
> 2. Build the interaction.
> 3. Test.
> 4. Analyze.
> 5. Repeat from step 2 until satisfied (or time/money run out).

3.1 Engineering design process (4.3.1)

- Start from a problem definition + requirements → consider possible solutions → rationally choose the one that best satisfies requirements, often via modelling/simulation.
- Works well for well-understood physical systems (e.g., aircraft), where simulation reliably predicts real-world performance.
- Much harder for HRI: simulating **social interaction** is very difficult, and engineers' intuitions about "friendly" design can be wrong — in one study, a robot programmed to be warm/personal (eye contact, using the child's name) taught prime numbers to children **worse** than an aloof version with the same content, showing designer assumptions can be firmly out of touch with classroom reality (Kennedy et al., 2015).
- Many HRI problems are **"wicked design problems"** (Buchanan, 1992) — changing, incomplete, interdependent, or indeterminate requirements that resist a clean linear "define → solve" process. The practical response is often to aim for a **satisficing** solution ("just good enough"), not the absolute optimum (Simon, 1996).

3.2 User-centered design (UCD) process (4.3.2)

UCD is "design processes in which end users influence how a design takes shape" (Abras et al., 2004) — not specific to HRI, but essential once robots move into open-ended, real-world spaces.

- Users can be involved via: needs/requirements analysis, commenting on design variations, and evaluating prototypes or the final product.
- Because many robot design decisions (torso colour, voice tone, etc.) have no "obvious" answer, designers build **prototypes** and run empirical evaluation studies to see what actually works — guided by the credo **"test early; test often"** (cost of change rises sharply later in the process).
- **Three types of stakeholders** to consider: **primary users** (main users, e.g., nurses/patients with a drug-delivery robot), **secondary users** (intermittent contact, e.g., passing hallway staff), and **tertiary users** (people affected by the robot's use even without direct interaction, e.g., workers whose jobs change).

3.3 Participatory design (4.3.3)

Participatory design goes further than UCD by involving users and stakeholders **from early on** in actual design decision-making — not just at the evaluation stage.

- Rooted in 1970s participatory design of workplace information systems; in HRI it has included community members co-developing environmental sensor behaviours, visually impaired users and roboticists co-designing guidance behaviours for a mobile robot, and even teenagers/children participating in HRI design.
- **Key challenge**: people have many preconceptions about robots but little technical knowledge (leading to unrealistic ideas), while designers often lack knowledge of users' day-to-day lived experience (e.g., eldercare) — successful projects (Lee et al., 2017; Winkle et al., 2018) focus on **mutual learning** between researchers and participants.

4. Prototyping Tools

Beyond cardboard/found-object prototypes, several kits make robot prototyping accessible to a wide range of skill and budget levels, enabling rapid, iterative design:

- **LEGO Mindstorms** (1998–2022) — one of the earliest kits; building bricks plus specialized bricks for programming/actuation; used for rapid HRI prototyping since the early 2000s.
- **Vex Robotics Design System** — widely used, including as the kit of choice for FIRST Robotics Competitions.
- **Little Bits** — plug-and-play electronic bricks (sensors, actuators) for quick interactive prototypes.

- **Arduino** microcontroller — affordable, huge hobbyist community, open-source code/peripherals; more flexible but needs more technical know-how.
- **Raspberry Pi** single-board computer and affordable/portable **3D printers** — further widen access to HRI prototyping.
- **Smartphones as robot brains** — modern phones have ample compute plus built-in sensors (camera, mic, gyroscope, accelerometer) and actuators (screen, speaker, vibration motor). The **Robovie MR2** is an early example of a phone controlling all of a robot's functions — Hoffman calls this the **"dumb robot, smartphone"** approach to social robot design.

5. Culture in HRI Design

As an interdisciplinary **and** international field, HRI design pays close attention to cultural effects on how robots are designed and perceived. Culture — shared beliefs, values, practices, language, traditions — shapes both the choices designers make and how users interpret a design.

- Commonly cited (though contested) East–West contrasts: **animist beliefs** have been used to explain relative comfort with robots in Japan/Korea, while **human exceptionalism** has been suggested as a source of Western discomfort with humanoid/social robots.
- **Empirical cross-cultural findings** are more nuanced than the stereotypes suggest: a Dutch/Chinese/German/US/Japanese/Mexican comparison found **US** participants least negative and **Mexican** participants most negative toward robots — Japanese participants were **not** especially positive, contrary to popular assumption (Bartneck et al., 2005). A later study found **US and Japanese** attitudes were actually similar, suggesting history/religion (not just "East vs West") shape adoption willingness.
- Cross-country evaluations of **Paro** (Japan, UK, Sweden, Italy, South Korea, Brunei, US) found generally positive evaluations everywhere, but **different traits** were rated as most likable depending on country of origin.
- **Practical design implication**: robots communicating with culturally appropriate norms were found more persuasive in human–robot teamwork; user expectations for home robots differed between South Korea (**relation-oriented** view of home) and the US (**functionally-defined** view of home) — cultural considerations should inform design for both international and local deployments.

6. Use of Space in Human Interaction

Humans manage physical distance from others according to strong, often unconscious, social norms — the foundation for understanding how robots should manage space too.

6.1 Proxemics (5.1.1)

Proxemics — a term from cultural anthropology (Hall et al., 1968) — describes how people use space in relation to others, and how spatial positioning affects attitudes, behaviour, and interaction. Hall's four distance zones (for relatively unlimited space):

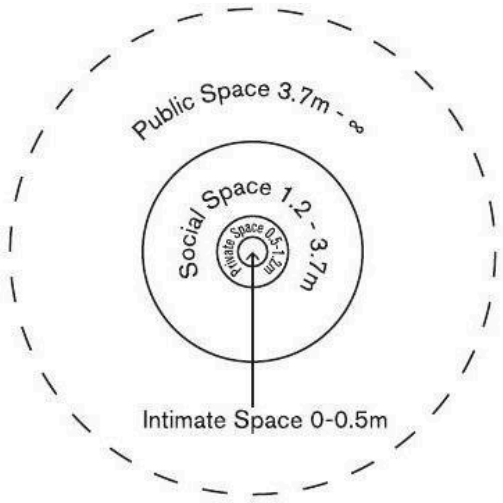


Figure 5.3 — Intimate, personal, social, and public distance zones, after Hall et al. (1968).

- **Intimate distance** (0–0.5 m) — reserved for close relationships or sharing private information.
- **Personal distance** (0.5–1.2 m) — together with intimate distance, makes up a person's "personal space."
- **Social distance** (1.2–4 m) — for acquaintances/colleagues.
- **Public distance** (4 m+) — impersonal settings, e.g., public speaking.
- **Cultural variation** is significant: "high-contact cultures" (e.g., South America) tolerate closer distance/touch; "low-contact cultures" (e.g., the US) can treat a stranger's touch as an intrusion.
- Proxemic norms can be **deliberately (and cautiously) breached** — e.g., gradually moving from personal to intimate distance to build closeness, or an interrogator "getting in a suspect's face" to intimidate. Meaning is highly **context-dependent**.
- **Orientation matters too**, not just distance: people seated next to each other tend to be more cooperative; people seated opposite each other, more competitive; conversational partners typically stand at an **angle** to each other (Cook, 1970).
- **COVID-19** forced a global, temporary renegotiation of proxemic norms (e.g., mandated 1.5 m/6 ft distancing), showing that proxemic comfort zones can shift with circumstance.

6.2 Group spatial-interaction dynamics — F-formations (5.1.2)

Adam Kendon's **"facing formation" (F-formation)** describes how two or more people position themselves so their focus-of-attention spaces overlap and they have "equal, direct, and exclusive access" to a shared space.

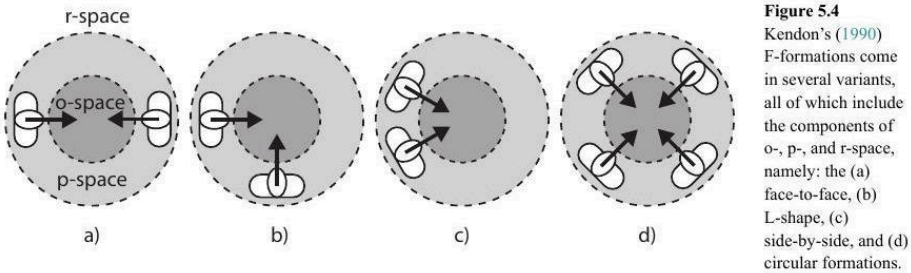


Figure 5.4 — Kendon's (1990) F-formation variants: (a) face-to-face, (b) L-shape, (c) side-by-side, and (d) circular formations, each showing o-space, p-space, and r-space.

- **o-space**: the inner, shared space the group faces/attends to.

- **p-space**: the space occupied by the participants themselves.
- **r-space**: the surrounding space beyond the group.
- Groups can adjust their formation to invite new members (opening the circle) or exclude them (tight-knit circle) — useful information for a robot deciding whether/how to approach a group in a public space.
- A robot navigating near people must also respect ongoing F-formations — e.g., it should **not walk between two people who are in conversation**, even if there is technically enough space (Pérez-Hurtado et al., 2016).

7. Spatial Interaction for Robots

Robots that share physical space with people must actively manage that space, or risk negative reactions, rejection, or withdrawal from users.

7.1 Social navigation — basic techniques (5.2.1)

- **Localization**: a robot must know where it is. Wheel odometry alone drifts/loses accuracy over time, so robots combine odometry with other sensors (LiDAR, camera) and a map of the environment — a process called **simultaneous localization and mapping (SLAM)**.
- **People detection/tracking**: short range via 2D/depth cameras (can report body-part locations — arms, legs, head); longer range via laser range finders (LiDAR); sometimes motion-capture markers (impractical outside the lab) or environment-mounted cameras.
- **Robot navigation** (moving through a crowded space) commonly uses the **dynamic window approach (DWA)** for short-term collision avoidance (computing a safe future velocity), and **path planning** for longer-range route computation. Crucially, path planners built purely for obstacle avoidance often produce **socially inappropriate** behaviour around people.
- Some systems make navigation more human-aware by using dialogue input to learn about places, or by building "cognitive maps" from a humanlike perspective so route instructions are easy for people to follow.

7.2 Socially appropriate positioning (5.2.2)

Basic obstacle-avoidance is not enough — treating people purely as "obstacles" produces behaviour humans find confrontational (e.g., a robot that waits until the last moment to yield in a corridor, instead of yielding early and clearly like humans do).

- **Preferred interaction distance**: most people prefer a robot to keep **personal or social distance** (echoing human proxemics norms), though individual preference varies (Walters et al., 2005; Hüttenrauch et al., 2006).
- **Body orientation** can itself change a group's F-formation — and moving the robot's **whole body** (not just its head) is more effective at this than head movement alone (Kuzuoka et al., 2010).
- **Following behaviour**: when a robot follows a person from behind, following the **same trajectory** as the user (rather than cutting directly to their current position) is perceived as more natural (Gockley et al., 2007); side-by-side navigation requires the robot to **anticipate** the user's future motion.
- **Perceived vs. computed safety differ**: robots need to keep enough distance to avoid entering a person's intimate zone even when a shorter path is technically "safe" and collision-free; path planners increasingly incorporate comfort factors (e.g., whether people are sitting/standing, avoiding surprising someone from behind an obstacle).
- Even a robot **arm** operating near a person (e.g., handing over an object) should respect socially appropriate distance for its trajectory — this can be less energy-efficient, but leads to a more positive user evaluation.

7.3 Spatial dynamics of initiating HRI (5.2.3)

Every interaction must be initiated by someone — approaching, orienting toward a person, hovering nearby. Initiating interaction has psychological effects: it signals interest, triggers reward-related brain activity in the initiator, and is associated (both for humans and by their peers' perceptions) with assertiveness and personal control.

- Robots must be carefully designed to initiate appropriately — e.g., respecting personal space of people already waiting in a queue, and switching from purely functional to socially-aware navigation once people are detected nearby.
- **Context/task matters**: front approach is preferred when a robot is trying to start a **conversation**, but front approach is **less preferred** (and fails more often) when a robot is **delivering an object** to someone.
- If a **person** approaches the robot, the robot must respond at the right moment — failing to do so can feel unnatural/awkward and discourage the user from initiating again in future.
- **Self-driving car example**: early Google self-driving cars drove technically "optimal" trajectories per the highway code but startled other road users by cutting them off; only once **politeness** was explicitly added as an optimization criterion did their driving become socially acceptable.

7.4 Informing users of a robot's intent (5.2.4)

- A robot's **motion trajectory** itself can communicate intent — e.g., slowly passing near a visitor signals availability for interaction; cleaning robots/drones with few other expressive options can use trajectory alone to communicate intent.
- **Legibility** in handovers: when a robot hands an object to a person, users prefer motions that clearly convey the robot's **goal/intention**, even if a more energy-efficient motion exists but is harder to interpret.
- **Spatial perspective-taking**: to interpret ambiguous references like "give me that object" (when several objects are present), a robot needs to reason about the space the way the person perceives it — using cues like gaze direction, body orientation, and task context; robots typically rely on geometric models tracking what is visible/reachable to each party.

Exam-style pointers for Module 2

• Explain "inside-out" (Frankenstein) vs. "outside-in" robot design, with an example robot for each philosophy.

• Define affordance and give a robot design example of an appearance-based and a modality-based affordance.

• State Mori's uncanny valley hypothesis and note that it was never empirically tested by Mori himself.

• Compare the engineering design process, user-centered design (UCD), and participatory design — what changes is when and how deeply users are involved.

• Name at least three HRI prototyping tools (e.g., LEGO Mindstorms, Arduino, Raspberry Pi) and what each is best suited for.

• Know Hall's four proxemic distance zones (intimate/personal/social/public) with approximate ranges.

• Describe Kendon's F-formation and its three spatial components: o-space, p-space, r-space.

• Explain why treating humans as simple "obstacles" in robot navigation produces socially inappropriate behaviour, with an example (e.g., the corridor-yielding case).

Source: Bartneck, C., Belpaeme, T., Eyssel, F., Kanda, T., Keijsers, M., & Sabanović, S. (2019/2024). Human–Robot Interaction: An Introduction. Cambridge University Press — Chapter 4 "Design" and Chapter 5 "Spatial Interaction" (sections 4.1–4.5, 5.1–5.2). Figures reproduced from the same source, © Bartneck, Belpaeime, Eyssel, Kanda, Keijsers, and Sabanovic 2024, for personal educational use.