What Robots Need From Clothing

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ABSTRACT

Most robots are unclothed. However, we believe that robot clothes present an underutilized opportunity for the field of designing interactive systems. Clothes can help robots become better robots−−by helping them be useful in a new, wider array of contexts, or better adapt and function in the contexts they are already in. In this paper, we provide a foundation for a research area of robot clothing by speculating on its potential. We systematically present functional requirements of robot clothing, considerations, and parameters for robot clothing designers, as well as key reference cases of robots in clothes. We then discuss what robot clothes can do specifically for the field of designing interactive systems.

ACM Reference Format:
Natalie Friedman, Kari Love, Ray LC, Jenny Sabin, Guy Hoffman, and Wendy Ju. 2021. What Robots Need From Clothing. In *Designing Interactive Systems Conference 2021 (DIS '21), June 28-July 2, 2021, Virtual Event, USA.* ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3461778.3462045

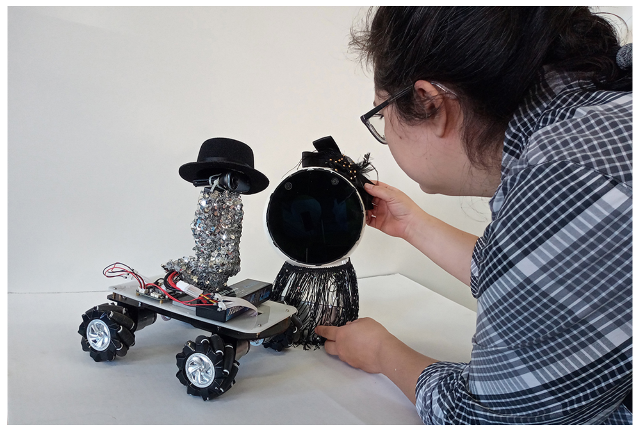

Figure 1: Clothing plays many roles for robots, and should be designed explicitly[1]

1 INTRODUCTION

Most robots are unclothed. This fact may not seem like a problem, since robots are usually not in a context where modesty or coverings are expected from them. However, while clothes might not be a necessity for robots, we believe clothing presents an opportunity in mediating technical challenges for robot interaction design. Clothing for robots provide flexibility for the deployment of interactive systems. Clothing can help robots better signal their function, enable them to handle dirty or dangerous tasks or to better interact with people.

By analyzing existing designs of clothing for robots, and extrapolating on examples contributed by designers, artists, soft roboticists, fashion designers, and HRI researchers, we offer a speculative analysis of robot clothing. We systematically present functional requirements of robot clothing, followed by considerations and parameters for robot clothing designers. We present several key reference cases and discuss what robot clothes can do specifically for human-robot interactions and the design of robots. The examples of robots wearing clothing are not intended to provide a systematic literature review, but instead to illustrate the utility of the framework. Finally, we examine how robot fashion can go wrong and outline future work for this emerging research area. This paper makes a speculative contribution, providing a theoretical framing, taxonomy, and key cases of robots in clothing to help define a new area in designing interactive robot systems.

1.1 What are robot clothes?

One key question we want to address at the outset is how we define robot clothing. We wish to contest the naive assumption that robot clothes should just be human clothes worn by robots. To make this point, we refer the reader to Figure 2: which dog is wearing pants? In an analysis of the popular internet "dog pants debate," Atlantic journalist Meyer [54] argues that, even though the dog on the right looks like it is wearing pants as a person would, for a dog to wear pants, all its legs should be covered, as seen on Figure 2 left. In a similar vein, we propose that robot clothing should avoid mere mimicry of human apparel, and instead be motivated by what robots need. For example, while people and robots are affected by humidity, robots do not sweat, so robot clothes might be made from different materials, with different venting requirements, than human clothes.

DIS '21, June 28-July 2, 2021, Virtual Event, USA

ACM ISBN 978-1-4503-8476-6/21/06…$15.00
https://doi.org/10.1145/3461778.3462045

[1]Photo credit: Kari Love

So, we argue that the question of what robot clothes *are* is integrally tied to what robots *need* from clothing. Robot clothing should analogously fulfill needs robots have, rather than just being human clothes on a robot. By working with a multi-disciplinary team of authors to brainstorm the potential utility of clothing to robots, we have developed the following early-stage model of what robot clothing can be. In short, robot clothing can help robots better be robots, by helping them adapt to context by being removable, operate in dirty or dangerous environments, and communicate their purpose to the people around them.

2 WHAT DO ROBOTS NEED FROM CLOTHES?

Clothes could have a lot to offer robots. The success of the design of an interactive robotic system depends on its ability to adapt, remain safe, and signal its intention and identity. We demonstrate that clothing can do this not only for humans, but also, for robots. In order to illustrate this, our authors are made up of human-robot interaction researchers, fashion and costume designers, material scientists, and social scientists. Together, we have drawn upon literature in robotics, fashion, semiotics, and material science to investigate the role clothing may have for robots. In this section, we present three uses for robot clothes 1) adapting to context, 2)protection, and 3) signaling.

2.1 Adapting to context

One of the goals for robots is to be general-purpose, able to adapt to a variety of uses and contexts. Robot clothing can help robots achieve that goal.

2.1.1 Interchangeability. Interchangeability is one of the defining features of robot clothing. Some robots, like Paro [76] or Furbies, have soft coverings, but these coverings are not clothing if they are integral to the robot.

Interchangeability introduces key benefits of clothing, like the possibility of washed coverings, or maintenance of sterility. Hence, interchangeable robot clothing might be a key feature of robots in a hospital or socially distanced setting. Similarly, robots used in food preparation environments might have aprons or smocks that can be cleaned for food safety.

2.1.2 Adapting to Tasks. Just as a robot can be outfitted with modular subsystems or a variety of end effectors to enable them to perform different tasks, so too, can a robot be outfitted with different coverings for different tasks.

A space robot, for example, might experience a few different environments, based on whether they are being deployed for extra-vehicular activity. Interchangeable robot clothes can help the robot make that transition so that only one robot needs to be brought onboard a space vehicle instead of two. Similarly, a firefighting robot may need a fireproof or a waterproof outfit, based on the particular emergency it is being deployed in.

2.1.3 Adapting to Social Context. Culture critic Cintra Wilson states that "style is [one's] visual interface with the rest of the world" [101]. Similarly, robot clothing can serve as a clarifying and functional interface between humans and robots.

Social context is defined by the "social interactions in any given environment" [29]. Robot clothing can signal the social context to which the robot belongs. This flexibility can signal the robot's function, and who should interact with it. For a robot, a bowtie might demonstrate its belonging in a formal social context, or that it is part of the service staff at a party or hotel. A soft robot, like Blossom, [88] might be suited for a playful or kid-friendly social context. In an emergency context, reflective gear, or bright colors (red stripes to represent a fire truck in [71]) can show that the robot has a professional task context, and should be left to perform its work. Using clothing appropriate to the social context makes the function of a robot clearer and more intuitive for people to interact with.

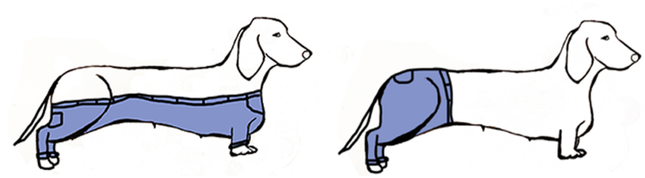

Figure 2: Thought experiment: If a dog wore pants, how would the dog wear them?[2]

Researchers have noted that hobbyists at home also design and dress up their Roombas [39] and make the patterns available online [75]. This can be viewed as owners dressing and customizing their robots to signify affiliation to themselves.

2.2 Protection

2.2.1 Durability. Clothing can enhance a robot's durability, protecting robots from hazardous environments, and enabling them to be exposed repeatedly to harsh environments. *The utility, or protection theory* says that clothes are for protecting the body from injury or from unpleasant features of the environment [23]. For people, clothing can be worn to protect from stabbings, bullets [82], ultraviolet radiation [22], and sunburns [27]. Uniforms also protect workers from fires, abrasions, or getting caught in equipment. Similarly, for robots, enveloping clothing could make the body more durable for the environment.

The need for protection also argues for earlier consideration of any fabric or clothing that might be put on a robot. If poorly designed, robot clothing can pose dangers. For example, fastening ties could get stuck in a door, or a mobile robot could trip on its own pants.

Robot clothing can make robots more durable, but for the safety of the human and the robot, designers must test the clothing's suitability in many environments.

2.2.2 Thermal protection. Clothes can help the robot be deployed in warm or cold conditions, so that screens, motors, or pneumatic elements are protected and can maintain function. Clothes should also be made thermally "comfortable" for the robot so that it is capable of the full range of their normal operations with any coverings applied.

2.2.3 Wire Modesty. In science fiction, robot nudity often involves having its wires exposed. In *Machines Like Me* [51], Ian McEwan writes, "and so it was a shock to enter the kitchen find [the robot] standing there naked by the table... one hand vaguely fiddling with the wire protruding from his umbilicus."

[2] Image credit: Natalie Friedman

The need for wire modesty–to cover up nudity–stems from the anthropomorphic priggishness, since robots do not get embarrassed about wires poking out of them. However, both humanoid and non-humanoid robots have pragmatic reasons to maintain a clean and covered aesthetic, because exposed wires present a real risk to function. Any wire that is pulled out or cut will remove power or signal to a subsystem, and that can be risky to the robot and any people or objects in the environment. Covering the wires can also signal to users what is acceptable to touch versus what is only appropriate for technicians to service. Hence, there is the non-anthropomorphic rationale, for both safety and aesthetics, that clothing should be used to protect the robot's "privates."

2.2.4 Robot ease. "Ease" is a term used in fashion to describe the amount of additional fabric needed to allow uninhibited movement [103]. When humans pick out clothing for themselves, they often touch the clothing, try it on to feel its flexibility, move around in it, lift their arms, and bend their legs. Robots need similar consideration of movement; to protect their function, robot clothes should be able to move in ways that do not constrain robot motion or block any of its functionality. In addition, robot clothing designers need to account for the experience of donning and doffing robot clothing; sometimes extra fasteners or ease is needed to make these transitions smoothly.

2.3 Signaling

While we argue against considering clothes as mere decoration, we also want to take seriously the role of coverings and decorations for the critical purpose of signaling.

2.3.1 Signaling Group Identity. Clothing can be used for the group identity [21] of a robot. Human and robot teammates have been studied in Nass and Reeves', "The Media Equation" in which group identity [15], defined as a marker indicating team membership, caused people to think they were more similar to the robot [69]. Group identity, within robotics, appears in branding, through brand colors or decal logos, and in religious settings through religious garb.

2.3.2 Signaling Individual Identity. While clothes can signal group identity, robot clothes can also signal individual identity [21]. Whereas group identity is often signified through consistent forms of characters within the group, individual identity is often indicated through unique colors or styles. Because robots are mass-manufactured, robot owners often clothe robots to make their robot distinct from their group [75].

In industry, different outfits can also be used to signify the uniqueness and individuality of each robot. Hasumi Kazutaka, head of the SoftBank Robotics content marketing center explained, "At first, I thought it was crazy to have robots wearing clothes! But then I realized how important it is to distinguish between Peppers with identical faces." [5] In a potential future where we have several of the same robots in the same space, this differentiation through clothing will be valuable.

In popular media, we see depictions of outfits demonstrating group identity and individual identity. For example, in the film, *Power Rangers* the Power Rangers' suits have the same style and layout, signaling group identity, but different colors, signaling individual identity. This helps the viewer identify personalities within the group. Similarly, robot teams need outfits that both signal group and individual identity.

2.3.3 Signaling Role. The visual aesthetics of clothing can provide an observer with a narrative about the robot's role. A bartender robot might wear a bartending vest which signals that the bot bartends and belongs in a bar, which clarifies the formal service role. Robot clothes can also clarify the role of the robot in a religious setting as an intermediary [61]. For example, Pepper is dressed up as a Buddhist monk, but we do not see examples of Pepper dressed up as a deity, as that could be disrespectful in most religions.

2.3.4 Signaling Affordances and Action. Robot clothing can also highlight robot action and potential for action. Clothing can obscure or call attention to things that the robot is doing, based on whether knowledge of that action would benefit or detract from its current function. This can help people see what a robot is going to do, or how it can potentially be used. For example, vertical features in clothing–like stripes, or material changes–make it easier to see when a robot is rotating.

Clothing can also use affordances, which signal potential or intent for action [58]. A transforming robot that can stand or kneel, for example, might have clothing that has rubberized patches or treads where the robot would contact the ground; this affordance would make that potential for transformation more obvious. Because the robot's clothes are interchangeable (see Section 2.1.1), the clothes might need more overt affordances than the robot's main body, to signal changes of the robot in a specific function, task, or context. In costume design, complicated garments might have color-coded buttons that pair to matching colored button-holes to assure proper assembly; a robot's clothes might do the same if different attachments should be configured in different locations for different tasks.

People are very familiar with the affordances of clothing from their own experience: for example, a button indicates detachability, a zipper affords zipping, a buckle affords tightening, and stretching clothes afford flexibility. The use of human-clothing affordances might help signal to people how a robot's clothing functions. For example, there might be numerous coverings that could be used to protect a robot from rain, but people are familiar with rain hoods, so an analogous hood would do a better job of signaling to a person how it should be used.

3 DESIGN CONSIDERATIONS FOR ROBOT CLOTHES

What should robot interaction designers take into account if they are making clothes for robots? We review a number of design elements, taken from fashion theory - color, material, and silhouette [85], in addition to style and historical and cultural references [21]. While these design considerations have been used in fashion for humans, these design considerations also are seen in interaction design literature [47, 67]. We discuss these design elements in relationship to the framework from Section 2, to show how each consideration is functional for robots.

3.1 Materials

As mentioned previously, the physical needs of robots differ greatly from the needs that people have from clothing, and hence the materials used for robot clothing might be distinct from those used for human clothes.

3.1.1 Adapting to Context. The interchangeability of materials can support a robot's ability to be protected or signal when necessary. To make interchangeability possible, robot clothing must be assessed to allow for easy donning and doffing. Designers might consider using materials that are soft and flexible to facilitate change. Alternatively, hard materials might be attached more like plates or shields, but then need to be customized to the shape of the robot, and have appropriate fasteners. Materials on a robot can also signal adapting to context, by showing a current mode, which could show potential expected behaviors. For example, in HRI research, Pleo appears to go into "sleep mode" when a participant takes off a bracelet, and dresses Pleo in pajamas [25].

3.1.2 Protection. Materials for robot clothing can protect the robot when it is in dirty or dangerous places. Firefighter uniforms are a great example of how materials protect. Outer layers of uniforms are fireproof to 648°C, have venting, are waterproof, cut and abrasion-resistant, relatively lightweight, block harmful fluid (like battery acid), and insulated to maintain tolerable temperature. For visibility, they have stripes in fluorescent orange and reflective silver to be seen day and night; these stripes positioned horizontally in the front and vertically in the back so that the orientation of the wearer can be discerned from afar [30].

Similarly, robots might wear clothes that are fireproof, waterproof, lightweight, thick, reflective, and insulated so that they may be used in an emergency or dangerous scenarios, [50] while also signaling that the robot is prepared and belongs in the emergency scenario. When designers choose protective materials in clothing design for robots, each material must be tested on the robot to tolerate functioning in diverse extreme environments.

3.1.3 Signaling Role. The material chosen for clothing can signal a role. Some material associations come from human fashion: a robot wearing silk could signal a higher socio-economic class, whereas a robot clad in denim would be associated with working-class roles. Visible material qualities may signal role as well, with tougher and less permeable materials indicating suitability for manual work, and softer and more delicate materials indicating that a robot might be for recognition, social, or knowledge tasks.

3.1.4 Signaling Action. A benefit from using soft materials like fabric and elastics is that we can achieve a bigger and longer-lasting perception of motion, increasing the chance that a person will see it, magnifying the signaling effect of robot actions. The extra motion of loose materials and parts which continue moving after the body has stopped moving is called "follow through" in animation [36]. In puppetry, puppet designers use "motion materials," such as springs, feathers, rope, yarn, fringe, plastic tubing, metal chains, and wooden beads [41] to create "residual movement" to amplify and complement the movement from the puppeteer's hand [80].

Clothing materials with fringes, feathers, or pleats, can enable this "follow through" and "residual movement" on physical robots. The feather coverings of Tofu and Miso, for example, achieve a motion-magnifying effect through the use of feathers. Another animation principle which could inform material choice is "squash and stretch." [36]. Tofu and Miso, for example, use compressible foam surrounded by strips of material that bow when compressed so that the robots maintain volume as they compress or stretch; these accentuate the vertical motions of the robots with lateral movement. Robot clothes could enable such accentuation just for uses and contexts where attention to action is useful.

3.2 Form

Currently, clothing is added to a pre-existing robot to alter its perceived form. However, speculating on untapped opportunities, both the clothes and the robot could be expressly co-designed, to enable greater variations of forms for the same robot. Taking a co-design approach from puppetry, Puppeteer George Latshaw states that "the body can be the costume or the costume can be the body." This could also hold true for robot; changes to form by clothing can signal or change the robot's perceived and actual capabilities.

3.2.1 Adapting to Context. Clothing has the potential to change the silhouette or form of the robot–to give soft robots a hard shell, or to round a square robot's hard corners. Clothes can help a robot physically adapt, for example, when it needs to fit through a narrow or brambly passageway. They can also help the robot adapt their forms for social interaction. Robots which will be interacting with children, for example, invite enlarged, rounded forms that encourage comfortable physical interaction such as hugging [37, 72]. Robot clothing designers should also consider the population in the context. For example, assistive technology researchers found that children who were autistic preferred interaction with a robot without clothing or a face compared to a dressed robot with a face [73].

Robot designers also need to be cautious in making robot clothes that are too enveloping or form-fitting, because robots can overheat. To that end, clothing that can change form may benefit thermal management or protection. Robot clothes made of a shape-memory alloy (SMA) as used in Biologic [104] could curl away when the robot is overheating to enable venting.

3.2.2 Signaling Role. Robot clothes can also signal role through form, to help clarify the context that the robot belongs in. For instance, robots that perform care services for the elderly could wear profession-appropriate clothing in addition to a large lower frame to convey trust [87]. This type of clothing would present traditional healthcare forms, including appropriately long sleeves and lapel collars, indicating protection and cleanliness. The form of clothing can also have an effect on the height of a robot, which can change the dynamic between a robot and a person. HRI researchers studied the influence of height and leadership roles on persuasion and found that "when the system was shorter than the local and the operator was in a leadership role, the local found the operator to be less persuasive." [66] If a designer of robot clothes needs to prioritize persuasion, this finding can be leveraged.

3.2.3 Signaling Identity. Robot clothing form can also impart formal signals of gender. While robots have no innate gender, designers assign robots gender traits as a shortcut to accessing human assumptions, in which people socially categorize (cognitive process placing individuals into social groups [92]). This signaled gender can be flexible, such as Softbank's Pepper robot being dressed to present different genders interchangeably. Some forms borrow from human fashion norms, such as dresses vs. ties, while others evoke body morphology by using clothing to enhance or create gendered bodies. Shoulder pads can make wide shoulders for "men" and silhouettes from clothing form slim waists or breasts for "women." For a "woman" dancer robot, we see stereotype-based gender such as a pink shiny ballroom dancing robot with a voluminous skirt programmed only to follow [1]. Boston Dynamics' Atlas robot, while listed on the website as a research platform with the "power and balance to demonstrate human-level agility," [6] its form mimics a male infantry soldier, which adds to its characterization as a robotic super-soldier. While Atlas's form of an infantry soldier has been said to engender empathy [48], HRI researchers find that in order to create attachment with a robot, the robot form does not need to be lifelike (i.e., a Roomba) [91].

3.3 Color

Color is more easily modified in clothing than material or form, and so is an important consideration in robot clothing design.

3.3.1 Protection. Color can be used in robot clothing design to maintain safety and provide protection for the robot. Robots can be clad in dark clothes to enable stealth, or in bright colors to draw attention or notice, not only by people but also by environmental sensors, other robots or vehicles.

3.3.2 Signaling. In fashion, the color of clothes can affect both the way the wearer behaves and is perceived. More basic and primary colors are associated with younger demographics, while colors with lower value and saturation are usually associated with older demographics. A robot dressed in maroon, then, might invoke expectations of greater sophistication in vocabulary and recognition than a robot clad in bright red [98]. Since colors come into and out of fashion, robot clothes can be used as a timestamp for a time period.

Sometimes color can be used to offset the effect of other less modifiable features; Big Bird's bright yellow color, for example, helps signal his kid-like nature despite his great size. [86] The most clichéd–and quickest–way to give a robot a girl gender is to make it pink and add a bow. This said, it is important to consider the ways that signal sets expectations; a pink robot with a low voice and a serious job would be out of the ordinary for users, unfortunately.

The field of material science provides us with opportunities for robots to change their own clothing in response to temperature (Thermochromic materials [57]) or light (Photochromic materials [52]). These color-changing materials have been used for expression in art [55], jewelry [13], and even contact lenses [12].

3.4 Cultural and Historical References

In the preceding sections, some of the messages signalled by material, form, or color derives its meaning through reference to culture and history. There are interesting ways in which the cultural and historical references for robot clothes can have different referents than human clothes. For example, a steampunk robot can use copper, brass, feature steam valves, or gauges in a way that would not make sense on a human steampunk costume [94].

3.4.1 Signaling Time. By putting clothing on a robot, we inevitably date the robot. The choice of color, fonts, palettes, or silhouettes in the clothing can function to signal when that robot existed in time just the way that human fashions such as skinny ties, shoulder pads, wide lapels or hoop skirts do for people. These period markers

Figure 3: *(left)* Robotex protective covering for robotic arm on robot[3], *(right)* Robotex protective covering[4]

can be charming, but also unfavorable if it makes the robot look dated, something that perhaps a factory owner would not want. In this case, the interchangeability of clothes may be a boon; a robot manufacturer could send out new clothing with each firmware upgrade, to help signal which version of the robot we are looking at on the factory floor.

3.4.2 Signaling Culture. Other design considerations for robots come from invoking different cultural narratives. Robot clothing can be used to signal that a robot appropriately fits the group identity of a culture.

Designers need to be careful that they are aware of ideas or references they inadvertently trigger. For example, a robot with white vacuumed formed panels with black joints can inadvertently look like a stormtrooper from the popular Star Wars movie franchise–since these characters were the henchmen of the evil Empire, such an association would not be positive.

Roboticists might also consider the way that the references made by clothing can influence culture, diversity, and inclusion. For example, in 2009, Mattel came out with a line of Barbies, called "Barbie Fashionistas" which demonstrate the diversity of ability, human skin tones (35 tones), hairstyles (94 styles), and body types (9 bodies) [68]. A doll's race and clothing have been used more problematically; in the years between 1850 and 1940, Europe and the northern United States made Black racialized dolls [46, 49]. The clothing typed these dolls as domestic workers and laborers, which has been said to assist white children in perceiving Black people as inferior [49]. With the Fashionistas, all the diverse dolls had many options of clothing, and the Black, brown, and white Barbies could wear any of the clothing. Similarly, the clothes designed for robots can not only reference human clothing and culture but in fact be a step towards shaping and influencing culture.

3.5 Style

No discussion of clothes for robots would be complete without contemplation of style. "Stylish clothing" refers to distinctive dress, which draws attention, signaling identity and individuality, which in turn implies personality.

3.5.1 Signaling identity. Fashion designers are sometimes lazily critiqued for making unwearable clothes. Fashion, however, is often exploring new modes of what clothes can express. For example, fashion designer Alexander McQueen's "Savage Beauty" pieces immediately convey an exotic nature that suggests the wearer grew out of the wild. Marc Bohan's "Hyménée," is styled as an austere and minimalist form, suggesting a holy restrained persona. Outside of the realm of high-fashion, style in clothing is often about individual expression.

With people, personality traits like reliability and sociability have been found to be inferred from dressy or casual styles [62]. The style of clothing makes a strong first impression about traits such as the trustworthiness of the wearer [31]. However, the changeability of clothes gives the wearer a wide range of options over how they are perceived or wish to be perceived. Similarly, the style expressed in robot clothing says something not only about the robot (or its designer) , but also, the robot in a specific context.

3.5.2 Signaling individuality. HRI researchers have found that putting a rainbow wig and jester hat on a humanoid Baxter robot added to people's perceptions of the robot personality [79]. Similarly, the Henna Hotel in Sasebo, Nagasaki, Japan, makes a distinctive variant on their "irasshaimase" ("Welcome to the store") robot; their robot is dressed as a velociraptor wearing a receptionist's hat [40]. These cute adornments suggest the wider range of what designers can do to make their robots individual, expressive, and memorable.

Individual styling can also help people build personal relationships with their robots. Android sex robots, such as the Realbotix Harmony robots' [19], often arrive as a blank slate, so that their owners can select and install downloadable personality archetypes (including shy, jealous, or 'frigid') based on their own idealized and personalized girlfriend/boyfriend narratives. Similarly, these robots are designed to wear human clothing, but they typically arrive naked so that customers can style them from the first outfit. That is how important clothing styling is to the robot's identity.

4 REFERENCE CASES

To illustrate the variety of ways that robots can use clothes—for protection, adapting to context, and signaling—we have selected the following reference cases of robots with clothes, in a non-survey format.

4.1 Robotex

Robots can use protective robot clothing to provide durability and to protect the investment of the robot. One key example is the ARMATEX® SBN 13-602 ROBOTEX [50], which is a robot covering designed for extreme industrial environments. It is advertised as robot protective clothing made up of "high strength, aromatic polyamide woven fabric that is coated with a specialized and high-performance silicone elastomer." This material has abrasion resistance, thermal stability, ozone and UV resistance, thermal conductivity, fluid resistant. This multi-functional protective layer for a robot is flexible, which also means it can fit around many robots.

4.2 Relay

Relay the robot is a service robot that delivers toothbrushes, towels, and snacks to hotel guests [34]. Relay's short body (92" cm) is augmented with decals, sometimes in the form of a bow tie or hotel branding. Staff at hotels dress up their Relay robot to match their

Figure 4: Relay, a hotel service robot wearing decals, demonstrating branding, role and interchangeability[5]

branding through a logo or thematic colors. Relay's logo decals are an example of how "clothes" demonstrate group identity through branding and a service role through a bow tie decal.

The branded decals on Relay show the impact that personalization has on interactive systems. Personalization of clothing for robots can be functional in an interaction. For example, personalization has been found to cause people to treat an appliance robot as a member of the household and to strengthen bonds between the robot and owners over time [90]. In a longitudinal study, researchers also found that a personalized service robot enhanced rapport, improved cooperation, and engagement in service settings [42].

4.3 Baymax

Baymax is an animated fictional robot in the Pixar movie *Big Hero 6* [3] inspired by a soft robot out of Chris Atkenson's Lab at Carnegie Mellon [77]. Baymax's inflatable housing makes this healthcare robot safe for patients to touch. This literal softness lends a soft visual touch [10] which makes the robot appear approachable and cuddly. In the story, his human owner, Hiro, builds Baymax a drab green first iteration carbon fiber suit in an attempt to transform the gentle robot into a fighting machine. The audience is intended to see the comedy of maintaining a rounded belly silhouette on fighting gear. In the scene when Hiro dresses Baymax, Baymax questions whether armor is appropriate for a healthcare robot stating, "This armor may undermine my non-threatening, huggable design."

When Hiro's initial suit design is insufficiently martial, a second candy apple red hero suit imparts Baymax with the classic V-shaped torso of a more traditional mecha fighting robot. The robot's programmed personality remains sweet and sometimes awkward, but he has become more physically powerful, and the visual language of Baymax's new outfit signals a new social role and group identity.

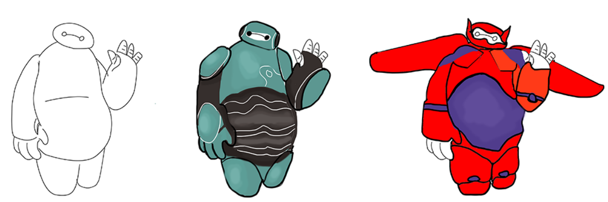

Figure 5: Baymax *(left)*, Baymax in first iteration of armour *(middle)*, Baymax in second iteration of armour *(right)*[6]

[3]Image source: Mid-Mountain Materials

[4]Image source: Gretchen Reimbold at Mid-Mountain Materials

[5]Image source: Savioke

4.4 Sophia

Sophia [84] (Figure 6) is an android technology demonstration robot designed by Hansen Robotics. While many feminine robots are designed as service robots [24, 65], Sophia is a feminine robot celebrity, intended to be deployed in fashion shows and high profile scripted speaking engagements. As befits her role, Sophia has been photographed in a wide variety of high-fashion clothes. Sophia's clothing is anthropomorphic and references high socioeconomic class through reference to human class markers.

Figure 6: Sophia dressed up on a Harper's Bazaar Arabia spread[7]

4.5 Blossom

Blossom is an open-source social handcrafted soft robot developed at Cornell University [88]. Blossom's exterior is hand-crocheted; this gives the robot a soft, homey, and personal character (Figure 7). The robot is designed with a craft audience in mind, with a public repository providing instructions to allow people to build Blossom's body and clothes at home [9]. The crocheted covers are easy to don and doff, with some designs including a button. There is a public repository, with dimensions for the outer shell, which makes the robot easy to design clothes for. Blossom's interchangeable clothing also allows a change in narrative for different characters, owners, and potentially different functions.

4.6 Pepper

SoftBank Robotics' mass-produced humanoid robot, Pepper (Figure 8), is designed to connect with people, assist them, and share knowledge with them [63]. Pepper has been clothed frequently enough that an online retail shop opened offering specialized clothing and accessories, like tunics with openings for Pepper's screen, or suction cup earrings [4]. The robot has also donned a face mask as a greeter to people quarantining for COVID-19 [53]. While primarily used in commercial environments, Pepper has taken on religious roles. While dressed as a Shinto shrine attendant at a convention in Japan, audience members spontaneously bowed down for blessings towards Pepper [16].

SoftBank's Pepper robot also has become an affordable substitute for a human Buddhist priest reading Sutras at funerals [7]. Since the role is ceremonial, the robot dons the traditional satin stole and clerical Japanese robes associated with the clerical role of the Buddhist priest. While some scholars argue that "Buddhist and Shinto ideas incline the Japanese to 'afford sanctity to robots,'" [35] it is hard to imagine Pepper would have sufficient gravitas for religious roles without the traditional robes that show affiliation, authority, and spirit.

5 WHAT ROBOT CLOTHES CAN DO FOR DESIGNING INTERACTIVE SYSTEMS

We believe the question of what robots should wear should be a domain area in the interactive system design community. Several areas of interaction design can be improved by designing clothing for robots: intentional selection of materials can support tactile human-robot interaction; attaching fabrics as appendages to robots can support legible motion; selecting material that exaggerates motion or that has bright colors can direct attention; and lastly, clothes can prompt observers to challenge their own biases about clothing in general. In this section, we talk about how robot clothing extends HCI and human robot interaction.

5.1 Tactile Human-robot Interaction

HRI researchers have studied how people respond to physical contact from robots [14, 20, 43, 105], as the possibility and need for safe contact is one of the ways that next-generation co-bots improve on the industrial caged robots of yesteryear [8]. The tactile qualities of robot clothing can help to mediate a tactile human-robot interaction – putting soft surfaces between the human and the robot, to soften contact or to encourage snuggling (as with the Paro [76]), to provide slick surfaces to prevent catching or dirtying (as with Robotex [50]), or even sharp poky surfaces to help signal areas to avoid touching (like the Urchin Bot [64]). In current day robots, these tactile surfaces are often the surface of the robot, but clothing could make surfaces be changeable for different contexts or users. The use of materials (see Section 3.1 can be used to increase the dynamic

Figure 7: Blossom is crocheted and has rubber bands inside of it to create a bounciness [9, 89][8]

[6]Image credit: Natalie Friedman
[7]Image credit: Harper's Bazaar Arabia
[8]Image credit: Michael Suguitan

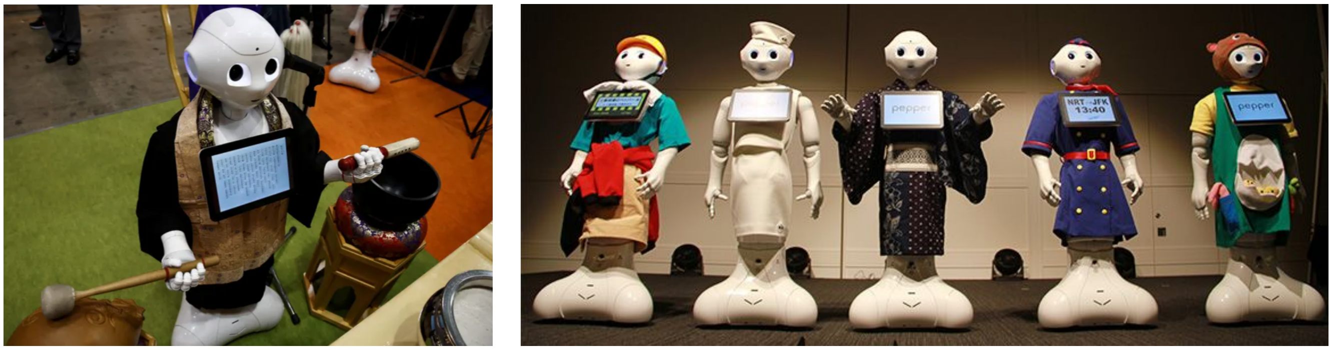

Figure 8: *(From left to right:)* Pepper, the robot dressed as a Buddhist Monk performing a funeral ceremony.[9] In the next image, Pepper is dressed as a construction worker, nurse, ryokan clerk, dressed in a kimono, airport concierge, and childcare assistant[10]

range of the tactile surfaces on robots that people touch, as is done in Hu et al.'s Texture-changing Robotic Skin, Goosebumps [32].

5.2 Legible Motion

The readability of robots in social spaces has an impact on the success of the interaction between the human and the robot. HRI researchers and designers have implemented animation principles into robot motion design [70, 93]. For example, a robot scratches its head after it cannot open the door, demonstrating thought. [93]

However, common robot housing materials (metals and plastic materials [100]) are not often ideally suited to make use of such animation principles. This is a missed opportunity since materials have a big impact on the way a robot's movement is read. We have seen a few soft robots which demonstrates this lifelike motion [59, 88, 102], but many everyday robots are rigid and do not provide the opportunity for displaying animation principles at their full potential (i.e., squashing or stretching).

Animation principles, mentioned in section 3.1.4 can be used to help designers select clothing materials and forms to support a legible human-robot interaction. Picture this: Before a robot begins to run, the fabric could sway back before the robot shoots forward (anticipation), indicating that humans should move to the side. The robot jumps forward, the fringe flies up (exaggeration). The robot stops, while the fringe continues moving (follow-through).

5.3 Robot clothes for In-situ Attention

HRI researchers are often concerned with directing human attention using deictic gaze or pointing [28, 78]. Motion, sound, and positioning are also effective ways to direct human attention [69, 81, 99]. Magicians are professionals at directing focus to portray magic. This is called "psychological misdirection," which means that magicians will use big gestures to distract until the observer views the trick (e.g., a dove appears) [38]. Affordances for such techniques can be used by robots to point toward or away from objects and actions. For example, a robot can use light-up gloves to draw attention to what they are doing with their hands, could use a swooshing cape to visually and auditorily draw attention to things people should look at, or as protection to physically and visually shield people from dangerous things.

Fashion designers are specialists in using color and form to obfuscate areas on the wearer (e.g., "opera shading" which uses dark panels on the sides, making a performer look slimmer). Bright colors on robot clothes can direct attention while a camouflage muted color might not. In costume design for dancers, we also see the use of the sound of coins or bells to make consequential sounds that direct attention to the wearer's motions [56, 96]. People might also perceive movement through the sound of fabric, which becomes louder when material cuts through the air, like the snap of a flamenco dancer's skirt. For robot clothing, designed intentional sounds could make the interaction more or less appealing [97].

5.4 Challenging Human Biases

One on-going issue in human-robot interaction is the dilemma of using human stereotypes when designing human-robot interaction [95]. HRI researchers such as Eyssel and Hegel [24] have argued that designers should develop gender-neutral or counter-stereotypical machines to counteract the stability of personal and cultural stereotypes. Similarly, novel ways that we dress robots can help to challenge human biased hierarchies.

We speculate that biases from human fashion, including gender, disability, age, race, culture, religion, socioeconomic roles could easily transfer to perceptions of robots and reinforce hierarchies. We expand on just two categories, socio-economic roles and gender roles, which are already supported by real-world robot examples.

5.4.1 Socioeconomic Roles. The socio-economic signals expressed in the construction and cladding of robots evoke strong cultural scripts. The HitchBOT (Figure 9), an unaccompanied robot designed to hitchhike across Canada, Germany, Netherlands, and the United States relying on the kindness of strangers [83], was constructed out of spare parts. Its construction could have unintentionally signaled that it was lower class. Some may have been willing to assist the robot for this reason, but its lower status may have contributed to its eventual mistreatment.

On the other hand, many robots are costly, and clothing made of expensive materials or featuring expensive brands could exacerbate socioeconomic differences. Robot clothes do not need to be "costly displays [that] reinforce social status" [11]. For example, in some

[9] Image credit: Reuters
[10] Image credit: Softbank

private schools, uniforms are used to emphasize common group identity and to minimize socioeconomic differences within the school; so too could robot 'uniforms' help to emphasize commonality over class through material.

Figure 9: HitchBOT, before[11] and after[12] mistreatment

5.4.2 Gender Roles. Robot design can replicate and reinforce problematic social norms, stereotypes, and expectations producing a "perverse fantasy of what femininity looks like" as Jenkins describes [45]. In existing feminine robots, we see a reinforcement of roles of service ("Marhu -M", a pink apron clad Korean maid robot or the fictional "Rosie the Robot" maid from the *Jetsons*) and seduction, (numerous real world sex robots or the fictional "Fembots" from the movie, *Austin Powers*). In contrast, robots with male voices often embody "smart" roles, like the library robot in *Robot & Frank* [74]. Research in HRI shows that such stereotypes shape people's interactions and assessment of social robots. [33, 44, 95]

Robot clothes have the potential to expand our relationships with identities both within and outside of gendered constructs. For example, Baymax and the Robear use a soft inflated shape and associations with friendly toys to communicate their nursing role without resorting to outdated gendered signifiers. While the first iteration maid robot Marhu-M [2] relied on a pink apron for signaling, the 2nd iteration Marhu-Z went with an ungendered design. We advocate for a future in which robot clothes more frequently challenge traditional gendered roles and influence fashion for humans.

6 ROBOT FASHION GONE WRONG

What is a "wardrobe malfunction" for a robot? And how does it differ from a "wardrobe malfunction" from a human? Potentially, the wrong robot clothes could interfere with robot functionality, be dangerous to a person, signal more capabilities than it actually has, and like humans, could violate norms. Below, we elaborate on these possibilities.

6.0.1 Physical Interference. As mentioned above, the wrong material could be too heavy, not have enough stretch or ease, which could limit the motion or functionality of a robot. Robot clothing might also be ill-fitting. For example, a loose shirt might sag, exposing wires. This "wardrobe malfunction" might make bystanders uncomfortable or put them in danger. For this reason, we recommend that any materials draped on the robot should be tested while the robot is in motion, in multiple environments.

6.0.2 Mis-signaling. Fancy robot clothing might signal that the robot wearing the clothing has sophisticated capabilities. Sophia, for example, wears a professional-looking blazer in interviews. However, Sophia's limited ability to understand and generate original speech belies her fancy dress.

Ill-considered outfits can also inadvertently signal associations not intended by robot designers. Hawaiian shirts, for example, used to be a marker of "casual Friday" office attire, but more recently are affiliated with the extremist 'Boogaloo Boys.' [26]

6.0.3 Wrong clothes for the situation. A service robot wearing the wrong clothing to a ceremony might be offensive to the guests it serves. For example a robot's festive attire for a wedding reception might be wholly inappropriate for a funeral reception, and cause additional stress or other negative consequences. To generalize, dressing robots for social situations requires sensitivity and cultural knowledge.

6.0.4 Cultural appropriation. While robot clothing might make use of cultural and historical references, designers and roboticists must be careful not to appropriate culture. Cultural appropriation is defined as "the adoption or exploitation of another culture by a more dominant culture" [60]. For example, the dominant white culture in the west has used American Indian headdresses as casual fashion. This exemplifies a dominant group taking a piece of American Indian culture that they find attractive, and reusing it and misrepresenting it. In designing clothing for robots which intend to reflect a culture, it is important that designers fully understand the repercussions of misrepresenting another culture and make efforts to avoid cultural appropriation, through inclusive design.

7 CONCLUSION

While designing robot clothing does have risks (i.e., cultural appropriation, safety), it offers opportunities for signaling, protection, and adaptability which can lead to better robots and better human-robot interaction. Designers should consider how to use robot clothing, while continuously testing durability and social perception. We also suggest that designers should not only be mindful to avoid the reproduction of biased human hierarchies. Through inclusive design, there could be an opportunity to challenge existing biases [17, 18]. Clothing for robots provides a way to learn about the way humans interact with machines, and with each other in many contexts.

As we look to the future, we speculate that the topic of robot fashion design will call on DIS researchers to extend their reach into topics such as material science, color theory, cross-cultural studies, animation, fashion, costumery, and puppeteering. By learning from these areas, we hope to both improve first impressions of interactive systems and expand the range of possible robot functionalities.

ACKNOWLEDGMENTS

We would like to thank Alexandra Bremers, Dr. Denise Green, and AJ Parry for their assistance with this paper. Thanks to those who assisted us with gaining image reproduction permissions, including

[11] Image credit: Michael Barker
[12] Image credit: Rebecca Tennenbaum, *http://rebeccatennenbaum.com*

Laura Kell at Harper's Bazaar, Jennifer Pats at Savioke, Gretchen Reinbold at Mid-Mountain Materials, Javier Ruiz at Reuters, Michael Suguitan at Cornell University, Vincent Samuel at Softbank Robotics, and Rebecca Tennenbaum. Stacey Dryer, Naomi Fitter, Natalie Freed, Mikail Gkinis, Dylan Glas, Hiroshi Ishiguro, Jacqueline Kory, Kohei Ogawa, Leila Takayama, and Kevin Weatherwax also have our appreciation for providing valuable discussion and insight into their own use of clothing and textiles in their robotics work.

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