What Other Movement Is There?

Rethinking Human-Robot Interaction through the Lens of Dance Performance

Kate Maguire-Rosier, Naoko Abe, and Fiona Andreallo

[The abject] is simply a frontier, a repulsive gift that the Other, having become alter ego, drops so that the "I" does not disappear in it but finds, in that sublime alienation, a forfeited existence.

—Julia Kristeva (1982:9)

Moving Beyond the Binaries

In mainstream Western imaginaries, the way robots move often represents violence, danger, and ultimately, abjection (Sone 2017). Think of the *Terminator* film, "Spot" robots "dancing with and alongside the [US] military" (Skybetter 2021), or consider the publicity campaign for the 2012 Paralympics—"Meet the Superhumans"—delivered by commercial TV Channel 4 in the UK (see Harrasser 2017). The athletes are explicitly positioned as "superhuman," largely thanks to the presence of prostheses, raising human performance above and beyond the normative range. Such a superhuman status gestures to and is contingent on the disproportionate exploitative and cheap laborious performance acts of digital manufacturing done in the Global South. This high-profile campaign starkly pointed to the absence of fellow disabled people who still do not—due to financial or other barriers—have access to even more basic technological aides.

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Crises of care, control, and identity all come to the fore as political stakes in discourse about "digital performance" (Dixon 2007) or Human-Robot Interaction (HRI). For example, during the forming of the US military-industrial complex, the term "high performance" became ubiquitous in describing technology such as guided missiles, prompting Jon McKenzie to declare his famous dictum "perform or else" (2001:102). Digital "smart" systems are already entangled within the lives of most humans; and yet, robots may seem external to us. They are simultaneously familiar, and foreign, us and other. As "us," they are able to help care for humans; but as "other" they also wield the power to destroy. Will they help? Will they kill? In the context is this study, can identifying other movement ambitions help rescue robots from this ubiquitous binarism?

In response to much contemporary robotic movement aiming for speed, efficiency, and precision, much contemporary dance sets forth a more tentative state of anxiety shaped by instability, stillness, and refusal (Lepecki 2006:1). Indeed, HRI influences human movement and vice versa. Rather than reproduce a still-capitalist world, exhausting bodies along racialized, classed, gendered, and ableist lines, how might movement interaction between humans and robots be democratized, reimagined, or redressed for the purpose of humanizing robots and unearthing different—careful, aesthetic, or enjoyable—ways of moving in the world together? Can HRI's value within human relationships shift? There is a dearth of knowledge about how to design robots, interact with them, and what role they should assume in everyday life (Dörrenbächer et al. 2022), thus the future of HRI design presents an urgent challenge.

Understanding the present and possible ways we move *with* robots (e.g., relatively passively slumped on a chair interacting with a chatbot on a website)—or *as* robots (e.g., an extra robotic arm to help chop the vegetables for dinner)—just might quell our anxieties about being exhausted by robots (and by extension AI), and lead to urgent insights about collaborating with robotic systems writ large.

Figure 1. (previous page) Marco Donnarumma in Alia: Zǔ tài *by Marco Donnarumma and Nunu Kong. The work premiered at Haus der Kulturen der Welt, Berlin, on 23 November 2018. (Photo courtesy of Underskin Photography)*

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Drawing on artistic perspectives can move the discourse beyond the mainstream, often neoliberal ideas underpinning current approaches to the design of human-robot interaction. Here we provide a sample survey of dance involving robots and propose a categorization system to probe the possibilities of HRI beyond concepts of anthropomorphic or utilitarian design. This system offers a dance performance analysis of the various human-robot interactions produced in the artworks. Through video recordings publicly available online, we observed a total of 25 live performance works, studied from 2019 to 2022. Our survey of live performance works stresses an artistic register for HRI design and opens up a discussion of what dance and movement might offer robot technology in our society.[1]

Social Robotics' Duet with Dance

Collaborating with artists, and particularly dancers, is of great value to social robotics (Hoffman and Ju 2014), a subfield of robotics that focuses on companion and assistive robots used in everyday life. Robot design can draw on the dancers' expertise in movement and bodily interaction. Dance allows us to design movement and interaction through bodily expression in a novel way, apart from and parallel to the classical approaches geared to speed and efficiency currently employed in social robotics. The artistic lens of dance performance impels us to explore the possibilities of robot movement beyond the question of efficiency and constitutes a novel approach itself in comparison to reigning dominant approaches in HRI (Abe 2022).

The examples we have identified are contemporary dance performance and research projects in which a dancer/group of dancers moves with robot(s) onstage and that have videos of the work available online and thus are accessible to the majority of readers. We define "dance" as bodily expression and an artform centering on physical activity by human and machine agents; "dancer" refers to a live human body executing aesthetic movement, that is, movement that is intentionally artful, skilled, technical, or conceptual (Brown 1994; Foster 1986).

In our research, human-robot interaction unfolds through dance or bodily, aesthetic movement. The terms "motion" and "movement" are used somewhat interchangeably in this study as a means of bridging descriptive ways of moving common in robotics (motion) to those in dance performance (movement). Motion and movement denote a state of action whereas the quality of movement refers to how a robot or human moves. Research on movement-based interaction as a communication tool covers nonverbal behaviors (e.g., displacement in space) (Mizumaru et al. 2019; Mavrogiannis et al. 2019); gestures (e.g., greeting gestures) (Salem et al. 2012; Calinon and Billard 2007); emotional "motion" (e.g., facial expressions, affective motion that produces emotion, feelings, or thoughts) (Thepsoonthorn et al. 2018; Burton et al. 2016); legible or predictable motion (Dragan et al. 2013, 2015). How might rethinking HRI through an artistic lens help us value movement expressions such as "kinesthetic stuttering" (Lepecki 2006:1), that is, movement characterized by muscle spasms and an example of disability aesthetics illustrating a condition of imperfection, instability, fragility, and ultimately, incapacity?

To date, motion design in social robotics has remained fixated on anthropomorphic or human imitation-based concepts. Roboticists have attempted to invest robots with human features so that the machine can act and move as if it has human agency. The motivation of anthropomorphizing robots comes from the idea that the robot's human-like behavior could make robots acceptable in human society and could enable easier communication with people (Sharma 2013; Shibata and Inooka 1998; Cross 2021). Affective or emotional movement by robots plays a functional role in establishing a meaningful and long-term relationship between humans and machines. Designing expressive robot motion inspired by or replicating human movement is certainly an important approach because it could help the viewer to understand the robot's intention (Bacula and LaViers 2020). The motivation of replicating human movement in the robot also guides roboticists toward

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understanding and synthesizing certain aspects of human functions with the goal of reproducing them through the use of mechanisms, sensors, actuators, and computers (Craig 2018). Moreover, as robots will presumably share space with humans, it is natural for roboticists to aim to generate anthropomorphic motion, imbuing humanoid robots with autonomy (Laumond 2016) so that a given robot is directly relatable to the human environment.

In addition to anthropomorphic- (or imitation-) based approaches, HRI research is rooted in the quest for usefulness, functionality, and efficiency. The same is also true of movement-based human-robot interaction where the efficiency of robot motion in favor of a user who is communicating or working with a robot is prioritized (Saunderson and Nejat 2019). The way robots move in space should be commensurate with the human environment, a human individual's movement, or the flow of people; while a robot's gestures should be legible for human users to ensure safety.

Human-robot dance performance produces innovative experiences and explores the possibility of movement beyond the laws of physics or limits of the human body (Unander-Scharin and Unander-Scharin 2016). Unlike the utilitarian motions of a workplace environment, motion in dance is useless beyond the task of the dance itself (Apostolos 1990), even if the dance serves a social or spiritual purpose. Furthermore, dancing with technology becomes a metaphor for understanding technology and our relationship with machines (Coeckelbergh 2020).

Deus ex Machina

Human-robot dance performance is a part of the lineage of what is called digital performance, which exists at the intersection of the live and the digital, and where artists incorporate digital technology such as computers in live performance contexts (Dixon 2007). We are particularly interested in human-machine performance because it contextualizes dance performance involving robots as part of a larger artistic canon and enables a richer examination of the myriad ways the relationships and interactions among humans (e.g. artist and audience) as well as technological objects are staged, designed, and presented.

The human body is central to live performance. Beginning in ancient Greek theatre, where a crane was used to lift actors onto the stage, the human/machine body has been recognized as a type of transformation (in the case of ancient Greek theatre convention—deus ex machina or "god from the machine"—of a human into God). Performing bodies are not only considered an expression of self and social community mediated by particular social and historical settings (Desmond 1997; Martin 1997); they also provide an analysis of nonverbal symbolic systems formative of lived experience and social contexts (Bull 1997).

Jennifer Parker-Starbuck (2011) refers to humans as perennially, natively entwined with technology by referring to a cyborgian fusion between flesh and machine as "subject technology" and using the image of a DNA spiral to highlight this inextricability. Moreover, she delineates the live presence of a human as a "process of technology" (10). For example, Australian performance artist Stelarc claims the body is a biological machine or might be understood as in fact, a biological robot. In his 2015 work *Propel: Body on Robot Arm* a huge orange robot arm propels Stelarc's body around the space, exploring the human body as machine.

As Parker-Starbuck explains, the abject is central to the cyborg (2011:11). Philosopher Julia Kristeva's notion of the abject (1982) is indeed central not only to the cyborg, a human-robot hybrid, but to any study of the relationship between a human body and technology. Parker-Starbuck draws a comparison between the cyborg and puppetry: "an abject body-abject technology meeting might be illustrated by a puppet on stage, both a forerunner and continuing colleague of the cyborg" (2011:42). Interestingly, in his 2015 work, Stelarc assumes the roles of both puppet and puppeteer in his abjected cyborg, producing enhanced motion as he moves with—or is forcibly moved by—a robot. Stelarc is already a cyborg without the robotic arm thrusting him about; his presence is uncanny because he appears human but sports a bionic ear (Stelarc 2015).

Stelarc is significant because he is an artist first and foremost, not an engineer. Three other works in our sample survey are authored by artists who similarly enact an intention stemming from

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aesthetic thinking rather than (only) roboticists' ambitions. Australia-based scholar and artist Mari Velonaki explores the emotions, feelings, and thoughts of audiences in her works *Fish-Bird* (2003; see Velonaki 2013a) and *Diamandini* (2012; see Velonaki 2013b). In *Fish-Bird*, two robotic wheelchairs communicate with each other and their audience through movement and written text. They produce intimate, written letters on slips of paper that they drop to the floor. Through movement and dialogue, failed intimate interaction is reflected by the parallel hopeless prospect that a fish and bird can never successfully be in love as they are two different species, though visitors were told "they couldn't be together due to technical difficulties" (Lim 2013). *Diamandini* is a robot, and also the title of another performance piece by Velonaki, who appears in the form of a white female-formed sculpture. The figure moves around the display space in a museum, interacting with visitors based on their body language, in a peaceful and harmonious manner.

In another example, *Robocygne* (2012), created by Swedish choreographer Åsa Unander-Scharin and composer Carl Unander-Scharin, a robotic swan dances to Tchaikovsky's *Swan Lake* through programmed and choreographed zoomorphic movement (Unander-Scharin and Unander-Scharin 2016). Moving on a wheeled base, the work primarily focuses on the dance of the swan's neck and wings articulating small, subtle movements; the timing of the gestures; and the delicate presence of Tchiakovsky's score remixed as "an underlying shivering character" (Unander-Scharin and Unander-Scharin 2016:216). *Robocygne* as a live performance work expressed struggle and pain. For those watching the performance, the swan's unintentional and secondary movements generated what Unander-Scharin described as emotional effects. In Unander-Scharin and Unander-Scharin's words, these "emotional effects were not separated from the body [of the swan]—they were neither inside, behind, nor prior to movement," suggesting that the origin of the robot's apparent emotional expression in movement was perceived to be of the robot-body itself, the cyborgian human-animal-machine. Significantly, Velonaki and the work of Åsa and Carl Unander-Scharin offer examples of the potential of HRI, as artworks first and foremost, to play with human emotion.

A Survey of Dance Involving Robots

In our sample survey, Margo Apostolos was the first artist-engineer to explore robot motion explicitly as dance, or in her words, "robot choreography." Working in the early 1980s, she programmed robots to express curves and flow. In her early experiments, robotic arms (e.g., spine robots) were programmed to perform duets with a human counterpart (see Apostolos 1990). Apostolos's early artwork, including *Juxtaposition* (1986; see Apostolos 2007a) and *The Tempest* (1987; see Apostolos 2007b), inserted dance as an artform into what is now known as creative robotics, existing within a tradition of live/digital performance (Maguire-Rosier 2013).

While our definition of a "dancer" presumes a live human body, that is not to say that a robot cannot *function* as a dancer—if programmed to do so. All projects we observed incorporate a physically discrete robot that is separate from the dancer, though some robots are attached to the body of a dancer or are in the form of a kinetic sculpture.

The robot's motion is generally programmed using written software or teleoperation (the robot is conducted remotely by a person in real time). In most cases, the robot moves autonomously for the duration of the performance. The software is written to generate robot motion through control and planning algorithms so that the robot can independently move in space by adapting to its environment. In our review of the human-dance performance, for some of the works there was no available information on which motion generation system was employed. Therefore, we employ the definition of "robot" as an autonomous device, with varying degrees of intelligence, that is controlled by written software or teleoperation.

In considering the nature of the interaction between human dancer and robot and the intention underpinning the relationship between the two, we looked at the kinds of movement performed by robot and dancer; and the artistic or philosophical concepts guiding the artist's intention.

Our proposed classification system (box 1) might serve to inform future explorations of HRI, not only from social and technological perspectives, but also, moreover, from artistic perspectives.

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Box 1. Observed Artworks Featuring a Robot and a Human Dancer

The list specifies identified works in chronological order.

1. *Juxtaposition* (1986), by Margo Apostolos. A spine robot finds fluid, natural, human-like movement in dialogue with a human dancer. Giant arm-like robot structure gives the impression of controlled, nurturing, even caring and supportive motion. Robot: Spine robot.

2. *The Tempest* (1987), by Margo Apostolos. A robot finds curved, flowing motion to create a robot dancer that mimics the unpredictable movement of its human counterpart. Angularity of robot design reifies the sharp-edged, swift movement of its human partner. Robot: K2107 robot.

3. *Devolution* (2006), by Louis-Philippe Demers and Garry Stewart. Thirty physical robots and robotic systems are in conflict and in union with athletic Australian Dance Theatre performers who remain "subject to the instincts of the flesh" (see also Bollen 2009). Monstrous robotic platforms cocreate explosive movement with dancers that variously subjugates and lays subservient its fleshy environment. Robot type: Mechanomorphic, metallic industrial-like physical robots and robotic systems.

4. *Personal Space* (2007), by Margie Medlin and Gerald Thompson. This real-time duet between a robotic camera arm and dancer is part of the multimedia event and research project *The Quartet Project* (2004–2007), investigating the kinaesthetics of music. With a camera for an eye and movement that reciprocates and reverberates audiovisually across the live space and screen, the robotic platform is anthropomorphized and itself surveilled while the audience is positioned as though a meditative "third eye." Robot: Robotic arm with motion-sensor abilities and robot camera.

5. *Seraph* (2010), directed by Daniela Rus with New York dance company Pilobolus. Teleoperated drones fly above a dancer, both playing with speed, position, and the suggestion of nonhuman intelligence. Like a bird, the drones' movement is sprightly, sweeping, and at times sudden, enacting a lighthearted pet-human relationship replete with physical humour between its bare-chested primitive human male costar. Robot: Teleoperated quad-rotor flying robots.

6. *Connected* (2011), by Gideon Obarzanek and Reuben Margolin with Chunky Move (see Chunky Move 2011). A kinetic sculpture designed by Reuben Margolin is manipulated by athletic dancers attached to it, replacing the usual automated hoists. The sculpture then extends the choreography externalizing movement from flesh to machine. Robot: Wooden, plastic, and steel kinetic sculpture suspended with fine strings.

7. *Human Interface* (2010), by Thomas Freundlich. Two human dancers and two industrial robots explore human and machine movement, whereby the robots can give the impression of living creatures. According to Freundlich (2012), the robotic platform enables more nuanced movement that encourages the perception of the movement as itself alive and "thinking." Robot: ABB robots with ABB SafeMove and RobotStudio.

8. *Machina* (2012), by Wayne McGregor, Kim Brandstrup, and Conrad Shawcross. Cast as "Diana," *the goddess of the hunt, moon, and nature*, a large machinic sculpture, capturing an uneasy and fearful relationship to technology in a nonnarrative dance work by the Royal Ballet, presented as a triple bill alongside *Trespass* and *Actaeon*. Robot: A computer controlled mechanical system with halogen light.

9. *Automaton* (2013), by Amy LaViers. Dancers explore the notion of "automatic style" and adopt a robot's way of moving and vice versa. The small, portable structure of the NAO robot is humble, unassuming, and contained, and it is easily cast as a nonthreatening, even docile body that welcomes and encourages movement learning. Resultant apparently "robotic" motion is thus open-hearted, attentive, and playful. Robot: NAO robot.

10. *ROBOT* (2013), by Blanca Li and Japanese performance art collective Maywa Denki. Seven humanoid robots perform alongside a company of dancers exploring notions of

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"us" and "them" and whether a machine can replace the living. Robots keep falling, only to get up again both with and without help. The short NAO robots are portrayed as cute and childlike but autonomous. Robot: NAO robot.

11. *Performative Body Mapping* (2014–2018), by Petra Gemeinboeck and Rob Saunders. Collaborating with dancers from Australian dance company De Quincey Co and their signature movement practice "Bodyweather," this experiment unearths subject-object encounters in human-machine relationships. Robot: Nonanthropomorphic, machine-like social robots with motion capture technology.

12. *Tribute to Madonna* (2015), by Robolounge and Hakim Ghorab. A video recording of a dramatized, stereotypical Spanish bullfight, where the bulls become demon-like robots. The robots move delicately at first then dynamically echoing the embodied drama of dancers in a full-length ballet. Robot: Robotic arm.

13. *Trespass* (2015), by Shobana Jeyasingh with King's College London's Interactive Architecture Lab and Department of Informatics. This work is predominantly about touch. It explores the fine line between unpredictability and control. The robotic sculpture pivots on itself round and round producing centrifugal force and a sense of animacy that appears to literally shape and influence a human dancer's movement, direction, line, and levels, ultimately enticing physical contact. Robot: Three-pronged Selective Compliance Assembly Robot Arm (SCARA).

14. *I/II/III/IIII* (2017, originally presented in 2007), by Kris Verdonck. Four dancers like the four swans in the quintessential quartet from *Swan Lake* are picked up in harnesses by a machine, which replaces the male dancers who would traditionally lift their female counterparts. The machine's movement complements and extends the ideal of ballet which is to be weightless. Robot: A hanging machine.

15. *HUANG YI & KUKA* (2017), by Huang Yi. A duet between a human dancer and a programmed industrial robot. The narrative stems from Huang Yi's childhood where his family's financial hardship led him to detach from all emotions and "be like a robot." The robot's movement harmonizes with Yi's. Robot: KUKA robot.

16. *Slave/Master* (2017), by Brooke Roberts-Islam and Moin Roberts-Islam (Brooke Roberts Innovation Agency) with London Contemporary Ballet Theatre. This work explores the borders around human-robot interaction, reversing the idea that robots influence humans. The piece aims to elicit sympathy from spectators rather than the traditional Western fear of them as an overbearing threat. The human size of these robots appears to create more democratic motion between their human partners. Robot: KUKA "cobots."

18. *Co(AI)xistence* (2017), by Justine Emard and Mirai Moriyama with Ikegami Lab and Ishiguro Lab. A dancer physically converses with a robot head animated by a form of primitive intelligence based on a neuronal system—an artificial life system programmed by Ikegami Lab (Tokyo University) with humanoid incarnation of the AI created by Ishiguro Lab (Osaka University). The robot appears to be watching attentively, and reacting by means of intricate facial movement, giving the impression of interpreting the dancer's movement. Robot: Custom-made humanoid robot with deep learning system.

19. *Alia: Zǔ tài* (2018; see fig. 1), by Marco Donnarumma and Nunu Kong. Accompanied by "biophysical music," three dancers and two robotic spines dance together with eerie, uncanny movement. The sinister movement seems to be determined by the dystopian cyborg characters, rather than the robotic systems themselves. Robot: Custom-made robotic prostheses with neural networks and learning algorithms.

20. *Våroffer* (2018), by ABB engineers and Fredrik "Benke" Rydman. A duet between an ABB 900kg industrial robot places a robot typically associated with danger in close proximity with a fragile, mortal human being. The movement is heavily influenced by the overwhelming presence and sheer force of the enormous robot and yet is gentle, and precise. The piece therefore conveys a strong sense of futurism, gesturing towards transhumanism. Robot: ABB 900kg industrial robot (IRB6620) with ABB SafeMove2.

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21. *OUTPUT* (2018), by Catie Cuan. A solo dancer performs alongside her representation and movement captured and projected via the robot. Robot: ABB IRB 6700.

22. *Lucid* (2018), by Catie Cuan. A 7-minute duet with a robot. Sometimes movements of the robot and dancer synchronize. According to the work description, the dance is "inspired by the comprehension and transference of information gained through motion and touch" (Cuan 2018). The movement seems to be codetermined by both dancers but ultimately is organic in nature. Robot: NAO robot.

23. *Time to Compile* (2019), by Catie Cuan. This is a performance experiment exploring how robots are perceived by audiences. The work focuses audience attention on the perceived control of various robot agents. Robot: NAO robot.

24. *Merritt + Robot Dance* (2020), by Merritt Moore. A duet between a UR10 and a ballet dancer. The robot simulates the dancer's movement of upper body parts. This gives the impression of two actors performing identical movements. Like the virtuosic ballerina that is Moore's highly disciplined body, the robot (also highly disciplined through programming) similarly strives for elongated, effortless, and aesthetic lines and sinewy movement, altogether conveyed as visually "beautiful" according to the strict rubric of traditional Western classical ballet. Robot: UR10.

25. *The Pinoke Project* (2015–), by John McCormick, Kim Vincs, and Steph Hutchinson. Beginning in 2015, this performance project seeks to harness motion capture technology as a means of enhancing an entire performance space so that rather than animating screen avatars, a physical robot is animated, thus becoming a live performer, an artificially intelligent robot connected in a feedback loop to 3D projection. The NAO robot's animated movement casts the robot as a fellow human in the work. Robot: NAO robot.

Categorization of Artworks

On close observation of these artworks, we developed four categories: Motion Focus, Body Focus, Responsiveness Focus, and Uncategorizable. The first category is divided into three subcategories: Anthropomorphic Motion, Machine-like Motion, and Augmented Motion.

Categories and Descriptions:

1. Motion Focus
    a. Anthropomorphic Motion: human quality motion, flowings, organic, natural, curved lines.
    b. Machine-like Motion: precision control proximity and safety.
    c. Augmented Motion: Combined machine-like and anthropomorphic motion and creating new enhanced movement.
2. Body Focus: Robot device attached to human body extending the biological soma; or vice versa, a robot enhancing the live presence of human body.
3. Responsiveness Focus: Performing elements interacting with one another in a given work (e.g., human body, robot, sound, video projection).
4. Uncategorizable: Potential other focuses that have yet to be identified.

Motion Focus

Under the rubric Motion Focus we describe work that focuses principally on movement in space. The subcategories are determined by the discursive quality of the movement in each piece: anthropomorphic, machine-like, and augmented.

A. Anthropomorphic Motion: *HUANG YI & KUKA* (2016; see Yi 2017), created, performed, and programmed by Taiwanese dancer-choreographer Huang Yi, comprises duets between humans and a KUKA industrial robot. The KUKA robot's movement mimicks the lines, shapes, style, and even

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the live presence of a human body, specifically dancer Huang Yi's moving body. It moves through space, creating a sense of self-awareness by seeming to move, touch, look, and sense Yi's presence as if mirroring Yi. The robot partner is described by digital performance scholar Ya-Tin Lin as Huang Yi's "anthropomorphic double" (Lin 2016:1).

Anthropomorphic Motion accounts for more than half of the works we observed. It is characterized by conventionally humanlike qualities such as flowing, organic, smooth, and curved lines. Similarly, we observe anthropomorphic motion in Apostolos's *Juxtaposition* (1986) and *The Tempest* (1987); Daniela Rus and Pilobolus's *Seraph* (2010); Chunky Move's *Connected* (2011); Thomas Freundlich's *Human Interface* (2012); *Machina* by Wayne McGregor, Kim Brandstrup, and Conrad Shawcross (2012); Blanca Li's *ROBOT* (2013); *The Pinoke Project* by John McCormick, Kim Vincs, and Steph Hutchinson (n.d.); Petra Gemeinboeck and Rob Saunders's *Performative Body Mapping* (2015–2018; see Gemeinboeck 2017); *Slave/Master* by Brooke and Moin Roberts-Islam (2017); Catie Cuan's *Lucid* (2018); and Merritt Moore's *Merritt + Robot Dance* (2020).

B. Machine-like Motion: *Våroffer* (2018) is a duet with a two-meter-tall, 900-kilogram industrial robot. The piece was conceived by Swedish choreographer Fredrik "Benke" Rydman and ABB engineers. It uses ABB SafeMove2 software that allows the robot to sense where the dancer is at all times. The choreography here is meticulous and the human dancer must perform it precisely. In a word, the robot's movement is superhuman. The work explores controlled movement governed by a technical precision, which, executed by a 900-kilogram KUKA industrial robot, is intended and perceived as an impressive feat in machinic motion, especially in such close proximity to its human dance partner. The robot is programmed to respond to the dancer but significantly the work is not improvised. For extra safety, then, two technicians stand on either side of the stage ready to press stop if the dancer makes a mistake in the choreography, such as move in the wrong direction. There is thus a focus on machine-like movement here characterized by precision, control, proximity, and safety. In turn, from the machine-like quality of robot movement, we further identify a discursive quality in the robot's movement. We propose that the robot's movement is "supermachinic," referring to neoliberal, untenable, and potentially harmful objectives (e.g., precision, productivity, or efficiency).

A total of six works are identified as expressing Machine-like Motion. One of these is Amy LaViers's *Automaton* (2013), which explores "automatic style" whereby dancers are tasked with the exercise of emulating an NAO robot's movements. Interestingly, Stewart's *Devolution* (2006) displays a *dual* focus, equally employing both anthropomorphic and machine-like motion. *Devolution* vividly and viscerally explores ways in which dancers move like, against, and with multiple robotic systems created by artist-engineer Louis Philippe Demers.

C. Augmented Motion: *I/II/III/IIII* (see fig. 2) was first presented in 2007, although the footage we saw is from 2017. In the collaboration between theatre director Kris Verdonck and choreographer Kim Amankwaa, a quartet of dancers is reminiscent of the four swans in Julius Reisinger's original *Swan Lake* ballet (1877; restaged by the better known Marius Petipa in 1895). The four dancers wear harnesses and are simultaneously picked up by a robotic machine, suspending and spinning them in space. These human-robot partnerships replace the female-male partnering of most classical ballet (although the four swans partner only each other). Traditionally male dancers lift their female counterparts, apparently freeing them from the confines of gravity. The work complements and extends the formal ideal of classical ballet, which is to be weightless, and in doing so, boasts a novel, augmented HRI.

Augmented Motion is therefore characterized by enhanced motion performed by both humans and robots working symbiotically. This synergistic combined human-machine motion is neither just machinic nor just anthropomorphic but both and more: the human and the robot bodies work together to produce unique movement.

Body Focus

Alia: Zu ˇ tài (2018) is a dance theatre piece conceived by artist-engineer Marco Donnarumma with choreography by Nunu Kong. The piece involves three dancers and two robotic spines (see fig. 1).

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On Donnarumma's website, the work is described as follows: "a woman nurses one of the spines, a primitive form of sensuality hidden behind an apparently everyday routine. The spine responds to her, caressing her with sinuous movements, wagging its limbs, moving as an eerie, alive piece of metal" (Donnarumma and Kong 2018). The spine is physically attached to the torso of Donnarumma, as if a robotic prosthesis, forming one body that is part machine, part flesh. Body Focus refers to work whose focus is on the biological human body, with the human body and machine body connected. Other works that amplify the living body include *Devolution*, which similarly features dancers connected to robotic prostheses; and *Personal Space* (2007), created by Margie Medlin and Gerald Thompson, where a robot camera scrutinizes its human dance partner, projecting its zoomed-in observations of her flesh through a live-feed on a screen directly behind her upstage.

Responsiveness Focus

Personal Space is a real-time duet between a robotic arm with a camera for an eye and a dancer. The robot, via motion capture sensors, responds to the dancer's movement in real time. The piece was part of *The Quartet Project* and the result of collaborative research between media and dance artist Margie Medlin and motion capture engineer Gerald Thompson. From Medlin's website:

> [The creators] investigated the kinesthetics of music: determining movements that produce sounds that in turn produce new choreographies. [They] aimed to present a versatile and flexible creative process for experimenting with cause and effect in multiple media; an insight into what it means to transform one medium or gesture into a completely different one; a redefinition of interaction through music and dance. (Medlin 2019)

Personal Space uses motion sensor capture to track the dancer's movements, which are then received by the robot as input into its own movement; communication channels seem to pass from one entity to another, from movement to sound, from sound to movement, from dancer to robot to live video feed. This duet appears to be performed to produce sound that, in turn, produces new movement—playing with ideas of cause and effect.

A focus on responsiveness refers to performances in which physically separate bodies onstage respond to each other, resulting in a feedback loop, or some form of communicative network. It is important to note that we are only considering "responsiveness" in terms of perceived performing elements (e.g., human bodies, robots, sound, video projection, etc.) responding to each other through movement in a given project.

Other pieces that fit into the Responsiveness Focus category include *The Dynamic Still*[2] by Elizabeth Jochum (2017), an improvised performance where the robot responds to human improvisation exercises; and *Co(AI)xistence*[3] by Justine Emard and Mirai Moriyama (2017), a video installation documenting a humanoid robot animated by an AI system responding to a dancer in dialogic interaction. In *The Dynamic Still*, the robot appears to react to human movement, as if by invitation: when the human twirls, the robot twirls in turn. In *Co(AI)xistence*, similarly, the robot appears to attune itself to the human movement by seeming to try to retain eye contact with the human, observing the human's prop (a torch) that is waved about, yet always returning to observing the human's face.

Uncategorizable

The final category covers works whose focus cannot be identified by the classifications above. "Uncategorizable" refers to work that we did not want to exclude from our sample survey because the works had an intriguing premise. At the same time we lack the necessary information to concretely classify them within our existing categories. Importantly, we wanted to retain this category partly to gesture to other realms of possibility for movement-based, human-robot interaction.

2. See https://sandromasai.net/2017/04/08/the-dynamic-still-dancing-with-a-robot/.
3. See https://www.youtube.com/watch?v=vcdUTEpSV1s.

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Figure 2. I/II/III/IIII*, a collaboration between theatre director Kris Verdonck and choreographer Kim Awankwaa. A Two Dogs Company. Performers include Natascha Dejong, Kim Amankwaa, Helena Volkov, and Sophia Dinkel. The work premiered at Vooruit, Ghent on 16 November 2007. (Photo by Alwin Poiana; courtesy of A Two Dogs Company)*

For example, there is minimal information on the project *Trespass* (2015), a collaboration among choreographer Shobana Jeyasingh, the Interactive Architecture Lab from the Bartlett School of Architecture and the Department of Informatics, and the Cultural Institute at King's College London. A revolving kinetic sculpture pivots on an axis, its rectangular mechanism spinning above a dancer crouching down. The sculpture is composed of three modules extending like stairs stacked on top of one another. Yet, each module pivots back on itself, forming multiple points of rotation. Two dancers twirl on their own axes too, as if to echo the motion of the turning centerpiece (Jeyasingh 2015). From watching the video, we can discern a focus on touch in this work, and even Responsiveness Focus, but we have otherwise been unable to understand what responds to what and therefore, cannot confidently categorize this piece.

We also list Catie Cuan's *OUTPUT* (2019; see Cuan et al. 2019) and *Time to Compile* (2018) as "Uncategorizable." *OUTPUT* focuses on the mediation and representation of a dancer's image through the robot, where—perhaps similar to *Personal Space*—her emotional expression is lost and transformed through reprocessing. *Time to Compile* directs spectators towards the perception of control by different types of robot actors (NAO robot vs a virtual avatar).

A Framework for Dance with Robots

Together these categories offer a framework for understanding the dances reviewed in our study.

Classification of Artworks by Categories

Note that the artworks overlap with multiple categories.

1. Motion Focus
    a. Anthropomorphic Motion: *Juxtaposition*, *The Tempest*, *Devolution*, *Personal Space*, *Seraph*, *Connected*, *Human Interface*, *Machina*, *ROBOT*, *HUANG YI & KUKA*, *Slave/Master*, *Performative Body Mapping*, *The Pinoke Project*, *Lucid*, *Merritt + Robot Dance*
    b. Machine-like Motion: *Tribute to Madonna*, *Devolution*, *Automaton*, *Vâroffer*
    c. Augmented Motion: *I/II/III/IIII*
2. Body Focus: *Devolution*, *Personal Space*, *Alia: Zǔ tài*
3. Responsiveness Focus: *Personal Space*, *The Dynamic Still*, *Co(AI)xistence*
4. Uncategorizable: *Trespass*, *OUTPUT*, *Time to Compile*

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Overlap of the Categories

The vast majority of performances fit into the Motion Focus category within which there were very clearly variegated types of movement. Some artworks are classified under several categories. Arguably, these works are the most interesting as they take a more expansive, fluid approach to exploring qualities of HRI interaction.

The focus of *Devolution* is on movement as well as the body. Its focus on movement spills across two categories: anthropomorphic and machine-like movement. This tendency is illustrated in the scenes with dancers moving alongside the 30 large robot structures that appear to be fellow dancers onstage, although of a different species such as insect-like robots, towering sculptures, beaming lights, or cylindric disembodied wormlike spines hanging from the ceiling. The types of movement between robot and human dancers vary from zoomorphic to anthropomorphic. Yet, the machine-like movement of the 30 robots dominates over the 10 humans: the robots perform the role of "machine"—loud metallic noises, domineering visual aesthetics, and machine-like motion—while the dancers express the idea of humans-as-machine, executing highly athletic steps that supersede the focus on anthropomorphic motion. One scene focuses on the human body, similar to the robotic spine in *Alia: Zŭ tài*, with the robot taking on the role of a parasite body. *Devolution* falls under multiple categories because its many robots and robotic systems are presented onstage with a rich variety of types of physical activity, roles, and perceived intentions.

Personal Space also fits into more than one category of focus: Anthropomorphic Motion, Body Focus, and Responsiveness Focus. There is an emphasis on the human body, as the robot mirrors the human and films close-ups of the flesh of its human partner (projected via a live feed to a screen upstage). In addition, there is a clear emphasis on human motion as the robot appears to be copying the human dancer's movements. On the other hand, a strong element of Responsiveness Focus can be discerned among all elements onstage.

Precisely Anthropomorphic?

A Conflation of Movement Qualities

In terms of Motion Focus, there is an important remark to be made about its subcategories: Anthropomorphic and Machine-like Motion. In performing anthropomorphic motion, the dancers and robots create movement that appears to be derived from the biological body such as human- or animal-like motion. While a robot may be carrying out fluid, organic, curved movement reminiscent of human embodiment, there may be an intention underpinning this movement to enhance the machinic mobility of the robot body performing more subtly or more precisely "natural" movement. This intentionality may be unclear and thus confusing, conflating the two subcategories.

For example, this seems to be the case in *Vâroffer*, in which the industrial robot performs with precise movement qualities that give the impression of human gesture. Similarly, works such as Apostolos's *Juxtaposition* and *The Tempest*, Medlin's *Personal Space*, Chunky Move's *Connected*, the Royal Ballet's *Machina*, Li's *ROBOT*, Yi's *HUANG YI & KUKA*, Brooke's *Slave/Master*, and Gemeinboeck and Saunders's *Performative Body Mapping* all demonstrate anthropomorphic movement, mimicking the motion of organic, flawed life forms.

Human-Centered Robot Interaction

It is curious to note that in the works with a body focus—namely *Devolution*, *Personal Space*, and *Alia: Zŭ tài*—the presence of the live performer(s) was enhanced by the robot performer(s). This observation endorses digital performance theory that asserts that the live presence of digital elements onstage heightens the liveness of its human counterparts (Giesekam 2007; Lavender 2006; Maguire-Rosier 2013 and 2016). In response to the concerns of our particular study, this observation in turn indicates that dance performance privileges human-centered robot interaction. This insight alone is a valuable departure point for the future of dancing with robots.

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Super-Machinic Disguised as Anthropomorphic

Our primary contributions rest on the creation of an incomplete survey of the human-robot dance performances and a pilot framework. Although the survey is not a comprehensive inventory, it provides an overview of some existing artworks with details such as robot type, date, and authorship. These contributions and their attendant insights, we hope, advance research on human-robot dance performance not only in social robotics but also in dance practice and performance theory.

Our classification process reveals that, in dance contexts, an anthropomorphic movement focus is dominant in HRI. This is not surprising if the artworks seek to maximize the expressiveness of a robot's movement in the performance; expressive movement relies on the movement of biological systems and particularly human movement (Venture and Kulić 2019).

Analysis of robot-human dance performance also finds a new descriptor for conceiving of robot motion: super-machinic. This critical term warns of the transhumanism explored in Regan Brashear's documentary *Fixed: The Science/Fiction of Human Enhancement* (2014). Brashear's analysis derives from Kristeva's critical theory of abjection, that is, human horror of a threatened breakdown of meaning caused by the loss of distinction between subject and object, self and other. "Super-machinic" finds its ambition in Jaspir Puar's idea of "debility," or the capacity of incapacity (see Puar 2017); and a retort to biopolitical ideals of production, speed, and the "myth of autonomy" (Kittay 2011). Our review demonstrates that much, but not all, movement-based HRI risks (re)producing super-machinic surrealities. We suggest *Våroffer* typifies super-machinic motion. "Super-machinic" underscores and provokes the motivation for this study: to find other ways of moving beyond unsustainable neoliberal motivations.

From our work with these 25 artworks, we suspect there are other categories yet to be found by artists working with robots and further areas of inquiry: How does the expertise of human dancers intervene in the interaction with a robot, that is, disrupt how a robot might be impelled to move alongside humans? How might the athleticism of dancers and the aesthetics of dance impact on or generate human-robot interaction in the context of live performance? How might HRI avoid the super-machinic? These questions could lead to determining other types of categorizations. Besides human-robot interaction, what might a focus on other aspects of the artworks (sound, staging, technical capacities of the type of robot, etc.) tell us about robots, dance, or relationships between humans and technology, self in relation to others?

Unfinished Business

We've analyzed these human-robot performance artworks only from social science and humanities perspectives. In our first stage of research, technical aspects of a given robot were not required since our primary focus was to examine how artworks featuring a dancer and a robot are presented. A review of technical information about robots, such as ascertaining the degree of autonomy or intelligence, might lead to other categories of motion, to the discovery of new forms of human movement, and to better understanding of the engineering challenges in dancer-robot collaborations.

We were also limited by not having experienced the performances live and only experiencing them through archival videos and performance documentation, in conjunction with complementary artist and/or engineer explanatory notes, attendant media coverage, and corresponding research. We tried to describe the possible influence of the robotic platform on the motion type, but did not take into account the technical or commercial availability of various robots, which would also have determined the choice of which "dance partner" the artists used. Cost of the technology is also a consideration. For example, the NAO robot is $10,000–$15,000; UR10, $25,000–$35,000; ABB IRB 6700, $33,000–$50,000; and KUKA robot, $10,000–$16,000.

Our study's initial aim was to extend the current dominant approaches of HRI design based on anthropomorphic and efficiency-centered concepts in social robotics, and in creative robotics as an exciting space of enquiry. What we arrived at, as we moved in this direction, was a honeycombed

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framework representing dance with robots dominated by anthropomorphic movement, at times expressing a super-machinic character.

How might dance contribute to human-robot interaction? What other ways of moving are there? To attempt to answer these questions, our research established a porous framework for the analysis of human-robot motion-based interaction appearing in dance-robot contemporary artworks across three main categories: Motion Focus, Body Focus, and Responsiveness Focus. This framework offers an overview of human-robot interaction in dance. Our term "super-machinic"—in the shadow of the superhuman—critically describes HRI design that coopts human-centered anthropomorphic qualities in service to neoliberal objectives. This critical term speaks back to how—and to what ends—HRI motion is being authored, produced, and perceived in the lingering moment of late capitalism.

Human-robot interaction and relationships forged in the artworks are multiple and complex. These artworks seek to reconfigure and reconstruct such interaction and to produce new experiences resulting from innovative types of interaction. Human-robot dance performance ultimately provides a provocation for the field of human-robot interaction, and an invitation to redefine motion and interaction in everyday life, extending theoretical and practical enquiries of robots in social and creative robotics. Significantly, how might a human-robot duet exploring Siebers's notion of "disability aesthetics" (2010) probe future experimental iterations of HRI? How might one such iteration exploring expressions of "care aesthetics" (Thompson 2022) respond to a world of exhausted bodies in search of rest and loving support?

What *other* movement is there?

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