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Eight Lessons learned about Non-verbal Interactions through Robot Theater

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Abstract. Robot Theater is a fairly new arena for researching Human Robot Interaction, however, in surveying research already conducted, we have identified eight lessons from Robot Theater that inform the design of social robots today. As an interdisciplinary field, we include examples spanning robotics researchers, acting theorists, cognitive neuroscientists, behavioral psychologists and dramaturgy literature. Lessons learned include (1) the importance of intentionality in action; (2)(3)(4) the relationship between embodiment, gesture, and emotional expression; (5) the bipolar sociability categorization between machine and agent; (6) the power of interaction partners to shape robot attributions; (7) the role of audience acknowledgement and feedback; (8) the power of humor to enhance interaction. Robotics has had a long history with the field of entertainment; even the word 'robot' comes from the 1921 Czech play 'R.U.R.' – we look forward to rigorous and continued research and cross-pollination between these domains.

Keywords: Human Robot Interaction, Entertainment Robots, Non-verbal Interaction, Social Robots, Collaborations with the Arts

1 Introduction

This paper acts as both a survey of robot theater research and a set of lessons learned about non-verbal interactions through narrative performance. For the purposes of this document, theatrical "performance" can range from literal stage with audience to pre-meditated collisions with human environments, as in guerrilla theater or street performance. The term "narrative" refers to a scripted or improvised sequence of coherent actions (and often speech) by one or more characters resulting in the construction of a timeline-based interaction arc (storyline). Also deserving of formal investigation, but beyond the scope of this paper, are puppetry, narrative video game design, and filmmaking.

Robotics has had a long history with Theater. As reported in the Encyclopedia of Computer Science [2], "Until the middle of the 20th century, mechanically programmed automata were used solely for entertainment." In Japan in the 17th century, some of the first Karakuri ningyō robots had clockwork mechanisms and a small plate for tea. When wound up, they could traverse the floor, pause for someone to pick up the cup, then return to their original position. Even the word "robot" as it is currently used, was coined by Karel Čapek in a play called 'R.U.R.' in 1921.

In addition to its entertainment value, investigating machine performers has research value in developing everyday robots, namely, theater is inherently social, repeatable, and there are various test subjects sitting in the audience [5][7][13][17][25]. By combining resources and creating a better mesh between these domains, it may be possible to bootstrap the development of deeper and more effective human robot interactions, particularly in the domain of non-verbal interaction. Thus, we begin this paper by discussing why non-verbal behaviors are specifically important to robot sociability, outline related knowledge in human and robot expression, then continue to the eight lessons learned about non-verbal interaction through Robot Theater. These lessons address (1) the charm of relatable gestures; (2) how affect derives from physicality; (3) movement metaphors; (4) the import of perceived rather than true robot state; (5) the gulf between machine and agent; (6) multi-agent sociability attributions; (7) the utility of audience feedback; (8) roles for machine humor. In all, theatrical contexts and/or cross-applications have enhanced human-robot interactions.

2 Motivation: Use Theater to Improve Robot Sociability

Using the theater context and body of knowledge to bootstrap the development of effective social robots is important because non-verbal expression is key to understanding sociability. In general, nonverbal response tracking capabilities could allow for more accurate social research data as such expressions are intrinsic to natural interaction. Feyereise reports, "These measures are less intrusive than questionnaires and, perhaps, also less controlled by the subjects… Moreover, impressions given by nonverbal signals influence social interactions outside laboratory conditions as in schools, courts, business situations, and medical and counseling practices. From an applied-psychology perspective, the domain for research on nonverbal communication is unlimited." [10] Furthermore, a robot's movement and engagement pattern impact our interpretation of its intention, capability, and state. With a long history of encoding and honing expression, physical theater provides pre-processed methodologies for interpreting and communicating human non-verbal behaviors that we are beginning to test on robots.

3 Background: Non-Verbal Interaction

Before investigating what theatrical contexts can teach robots about non-verbal behaviors, we must establish what non-verbal behaviors are. In different systems of behavioral analysis, nonverbal communications can be grouped by channel (face, gaze, voice, bodily expression, use of space, hand position etc.), functions or psychology [10]. In this paper, we largely reference non-verbal interactions by categorical channel to enable more repeatable and easily detectable mappings within a robot behavior system. There are certain kinds of nonverbal behaviors that carry specific affective or social meaning, as in [10][17].

As we will see below, the frequency and duration of a gesture can change its associative meaning [23], e.g., how a child picks up and manipulates a fork can have clear mappings to her excitement about the food. As developmental psychologist Eliane Noirot describes, however, "meaning = movement + form + context" [10] and explicitly highlights the importance of gesture. She also indicated the central role movement plays in establishing social meaning, e.g., what the timing or presence of that action might indicate. An interesting conclusion that this suggests to me is that narrative arc and timeline are central to social interaction. This is consistent with Cory Kidd's work with Autom [15], a simple social robot designed to help people with their fitness and dieting plans, in which the robot tracked its long term interactions with a single user, moderating social behaviors as it was neglected to repair the relationship or when the user was successful to provide contextualized praise.

Various investigations have begun to use robots to explore the rich space of non-verbal behaviors in social interactions. Cynthia Breazeal's pioneering work with the Kismet robot used cues from human tone of voice and gaze, responding with simulated facial expressions and orientating toward object of interest [4]. Researchers have also begun to look at social distances, better known as proxemics, e.g., the attentional zones described in the Robo-Receptionist project [19], or in [29], where humans give wider girth to a robot that they dislike rather than like. In [27], they use the dancing robot Keepon to investigate the effect of synchronizing the robot to human rhythms on the pairs' general social interaction. In [31], researchers assess whether people can detect seemingly unintentional social cues, called 'non-verbal leakages.' There are many more.

4 Lessons Learned through Robot Theater

In this paper, we highlight eight lessons about non-verbal interactions gleaned from investigations of Robot Theater. We curate the examples to emphasize cutting-edge perspectives, whether novel or mature, on using machine performers to address modern challenges in social robotics. These examples span robotics research, acting theory, cognitive neuroscience, behavioral psychology and dramaturgy literature.

4.1 Lesson 1 - Have a Goal : Convey Intentionality

A robot using relatable gestures from entertainment-world representations can clarify current activity goals [25], improving its camaraderie and communication with interaction partners. For example, in recent work [35], Willow Garage partnered with a Pixar animator to "create robot behaviors that are human readable such that people can figure out what the robot is doing, reasonably predict what the robot will do next, and ultimately interact with the robot in an effective way." Their emphasis on anticipation of action and reaction to successes and failures was suggested to improve communication of intention. Though they emphasize 'readability' in the published paper, an interesting aspect of the work was one author's impatience with the large unmoving PR2 robots that might or might not be doing anything useful. When the robot used physical animations to clarify the intention and internal state of the robot, she felt more goodwill toward the system that was, nonetheless, still blocking the hallway. Further, if it failed at a task, e.g., opening a door, after several minutes of computation, but showed an animation that it 'felt bad' about not accomplishing its goal, she suggested that coworkers might commiserate, and be less annoyed by the robot's interference in their shared space.

More subtle systems of conveying robot intentionality could be created from the gestural training of French physical theater pioneer and theorist Jacque LeCoq [23]. In one case, clearly relevant to robotics, he emphasizes the importance of relative and absolute timing profiles in "look, reach, grab" behaviors to indicate motivation, emotionality and communicate social meaning. For example, if the robot is wary of an object or unsure of how to pick it up, the 'look' phase might last longest, in contrast, if multiple robots are competing for the same object, look and reach would have rapid phases in order to block out the other robots and establish claim. By using movement profiles rather than directly imitated gestures, any kinetic robot can convey intentionality, regardless of anthropomorphic form. Humans learn to communicate verbally two years after learning to communicate through gesture, thus we have excellent resources to interpret both known and novel robot gestural expressions.

4.2 Lesson 2 - There is no Mind without Body

Human affect expressions derive from our physicality, thus robots are uniquely capable of leveraging their embodiment to communicate on human terms. As acting theorist and neuroscientist Rhonda Blair points out in [3], "A basic truth of being human is there is no consciousness without a body." As in the previous section, expression is inherently physical. She continues, "At the heart of every performance is a complex consciousness that inhabits the entire body, in which voluntary processes are inseparable from involuntary ones and in which genetic predisposition is inseparable from personal history."

Researchers have exposed unique attributes of embodiment and physical presence in enhancing artificial agent interaction with a human, as contrasted to virtual agents (e.g. [20][22]). In [20], they use drumming games with children to contrast a physical robot to a virtual robot that mirrors the first case. Given participant explicit feedback and implicit measurements, they concluded that the "presence of a physical, embodied robot enabled more interaction, better drumming and turn-taking, as well as enjoyment of the interaction, especially when the robot used gestures." James-Lange Theory [14] is a somatic theory of emotion, in which, "the perception of bodily changes as they occur *is* the emotion."

The idea that behavior precedes feeling is important. Regardless of complete literal or physiological truth, this framing of body on higher or equal footing with the mind will allow robotics to more fully leverage its physicality to improve expression. Theorist's say "there's an affect associated with every functioning of the body, from moving your foot to taking a step to moving your lips to make words. Affect is simply a body movement looked at from the point of view of its potential — its capacity to come to be, or better, to come to do." [38] In other words, a robot not fully leveraging its physicality not only loses a mode of communication but is also less expressive.

4.3 Lesson 3 - Mirror Neurons: Physicality & Motion

We often interpret robot behaviors, especially non-verbal expressions, by re-mapping them on to ourselves, thus robots can provide people with effective stimuli given a deeper knowledge of movement metaphors. Though robots may or may not share human physiology, their actions might be simulated, as best as our brain can, through our own physical capacities. Neurophysiologist Giacomo Rizzolatti [3] describes the function of mirror neurons; "Mirror neurons allow us to grasp the minds of others, not through conceptual reasoning, but through direction simulation, by feeling, not by thinking." This has ramifications on the theater community's long-controversial analysis of the power-relationship between performer and audience. The impact of this new understanding is that watching something might be, neurologically, the same thing as doing something; the parallel neurons will fire.

Theater provides possible encodings for movement metaphors, as in the extensive work of Michael Chekhov and his collection of emotional gestures [33], which posits the body as the source of major metaphors of thought, meaning and value. Japanese Noh Theater has a related system of symbolic meanings as codified gestures, so consistent that the line between metaphor and literal significance virtually disappears [37]. "A crucial implication of [mirror neurons] is that the metaphors we live by are not just abstract or poetic, but are of our bodies in the most immediate way" [3]. Perhaps even learned gestures are, at their source, based in physiological experience.

4.4 Lesson 4 - Outward Emotional Communication trumps Inward Experience

Our perception of a social robot's expression has more influence on interaction than its true internal state; complexity is not a prerequisite. As actress Elsie de Brauw helps explain: "Observation of what the spectator sees and what I experience as an actress, is completely different. Moreover, who sees those tears? Only the people in the first four rows." [21] As researchers, we might think first to the robot's internal model of an interaction, but dramaturgy reminds us, it is the viewers that matter most.

Not only should intentionality be clear, but even stronger than that, outward intentionality outweighs an actor's internal feelings, and the two may be out of sync. Many a performer has left the stage with a pit in his stomach, bemoaning his lack of authentic emotion, only to receive highest praise. Now, this may be a good time to highlight the difference between robots and people. As currently designed, most robots are intended to enhance, enable or empower a human or set of humans. Thus the inner experience of that robot is trumped by the success of that larger interaction loop. Similarly, an actor on stage is generally tasked with the goal of entertaining or evoking response in the audience to whom he is performing. Thus, the metaphor may provide parallel techniques that can be used across domains.

One of the most successful social robots ever created, in terms of meeting its goal, inspiring third party human-to-human interaction, encouraging goodwill toward the robot and resulting in a sense of accomplishment for the humans involved, was the Tweenbot [16]. Designer Kacie Kinzer deployed the simple robot in a in New York City park. Its small cardboard structure had a marker-drawn smiley-face, motors that went constantly forward, and a flag declaring, “Help me. I’m trying to reach the South-West corner. Aim me in the right direction.” Forty-two minutes after release in the park with the creator out of associative view, twenty-nine diverse un-instructed strangers had read the sign and helped the robot. Just when it reached the edge of the park, one last stranger scooped it up and turned it around, saying, “You can’t go that way. It’s toward the road.” Sometimes simplicity and clean physical design can be the clearest way to streamline our communication of robot intention.

4.5 Lesson 5 - Social Role: the gulf between Props and Character

The categorization of ‘social robot’ denotes a machine that behaves and is treated as agent. In analyzing what makes a robot on stage a categorical character (agent) versus prop (object) we learn how to make more effective social characters. The title “machine” denotes neither by itself [7], rather, a sense of authentic interactions seems to distinguish these labels. We see this in professional theater productions in 2011; Machover’s robot opera ‘Death and the Powers’ [26], the remote-control robots in ‘Heddatron’ [36], or the casting of an enormous puppeteered equestrian structure in ‘Warhorse.’ With the exception of the final directly human manipulated case, they seemed props because they lacked believable interaction arcs with the human actors.

One success story is the realistic humanoid Geminoid-F’s seated one-scene performance [11] with a single human actor. Because of the central role she played, dying of a terminal disease, and human-like features, she fell on the agent side of the gulf, but additional local intelligence and integration of audience feedback between performances could further improve our sense of her agency. In a parallel case off stage, [34] analyzed the relationship of groups of humans with a robotic photographer that was largely ignored. The contrasting settings included a conference hall and a wedding. Researchers noted a vast difference in behavioral reactions to the system depending on whether it was perceived as social (people wanted to wave at it, talk to it, especially when it accidentally displayed double-take motion), versus as an object.

Interactivity in interfaces is an old domain made new through modern technology, as explored in the MIT play I/It [32]. Modern entertainment has been passing through an unusual phase of ‘object.’ As reported by Douglas Adams in 1999, "During this century we have for the first time been dominated by non-interactive forms of entertainment: cinema, radio, recorded music and television. Before they came along all entertainment was interactive: theatre, music, sport; the performers and audience were there together, and even a respectfully silent audience exerted a powerful shaping presence on the unfolding of whatever drama they were there for. We didn't need a special word for interactivity in the same way that we don't (yet) need a special word for people with only one head"[1]. It is time to bring the interaction and agency back through artificial social intelligence. Other notable projects featuring attributions of intelligence and agency are the ability for a robot to engage in improvised generative performances [6], pose and/or answer questions [9], or achieve fluent emotional timing and attention orientation when acting with human actors [12][13].

4.6 Lesson 6 - Good Actors outweigh Bad Actors: Attribution

Multi-robot or human-robot teams can be greater than the sum of their parts in perceived interaction intelligence. The stage provides a ripe context to explore these effects. The University of Texas rendition of 'Midsummer Night's Dream' cast small flying robots as fairies [30], finding that intentioned social actors influence third parties interactions: "Consistent with stage theory, where the visible reaction of the actor to an action by another actor creates the impression of affect, the human actors can create affect even if the robot's actions are independent."

First introductions by social actors were particularly important: "If a micro-heli crashed into the stage first and the audience saw a fairy treating the robot as a baby, the audience invariably duplicated the action. The audience member might be surprised, but not visibly annoyed, and would gently pick up the robot and hold it in their palm to allow a relaunch… However, if a micro-heli crashed into the audience first, the audience member was generally disgruntled. Observed reactions by the audience were kicking the robot back onto the stage, throwing the robot like a baseball apparently intending to relaunch it, or passing it to the end of the aisle. It was significant that the audience did not look to the operators for instruction as to what to do with the robot; the audience member seemed to look for cues on how to behave from the actors or the robot." [30]

The play also provided insight on the potentials of un-even human robot teams, "The actors compensated for the robot's lack of control and unpredictably location, creating an impression of cooperation." One might imagine multi-robot teams capable of leveraging similar failure modes to maintain successful interactions with a third party.

4.7 Lesson 7 - Acknowledgement/Learning: Looping in Audience Feedback

Human audiences are already highly cognizant of human social behaviors and can provide real time feedback to robot comportment on stage, thus audience tracking in theater settings is an important new domain for experimentation. As Brook proclaims, "The audience assists the actor, and at the same time for the audience itself assistance comes back from the stage" [21]. With that motivation, I recently began a robot standup comic project in which a robot loops in audience feedback to change the content and emphasis of its performance [17]. In its first iteration, we loaded a database of pre-scripted jokes onto a Nao robot, scoring each entry along five initial attribute scales {movement level, appropriateness, likelihood to have been heard before, length, and interactivity level}.

The desired goal of the audience tracking was to maximize the audience's overall enjoyment level. In practice, the robot uses an estimate of the audience's enjoyment-level (using laugher/applause audio and red/green feedback card visuals) in reaction to the previous joke to update the robot's hypothesis of what attributes the audience likes and dislikes. We use that estimate to predict the audience's attribute enjoyment preferences, as summed up by the weight vector w(t), and increase or decrease each attributes' value by multiplying the valence of the response, y, with the characteristics of the previous joke J(t) and a learning-rate constant α. Thus audience model is updated to the next timestep, w(t+1), using the equation, $w(t+1) = w(t) + \alpha yJ(t)$. In mathematical terms, this technique is called online convex programming.

Even beyond the real-time feedback, the audience continues to provide instrumental verbal and email feedback about the performance, including the attention of professional comedians to help generate new and future scripts. The sneak peak I can offer the readers here is: Never 'eat' the audience's laughter or applause by beginning the next joke too early; Acknowledge the valence of the audience response to achieve higher knowledge attribution and make them feel more included, whether verbally or through gaze and body pose; consider overarching arc; and develop a good rhythm for each individual joke. Many of these ideas generalize to social robotics.

4.8 Lesson 8 - Humor will make people like your robot better

Humor can enhance human-robot interaction by helping creating common ground, trust or forgiveness, but its subtlety makes collaboration with theater communities uniquely beneficial. As comedian Drucker spells out for us in this following snippet [8], robot performances can go terribly wrong (note: this is a fictional robot standup performance): "Hello, world! What level is everyone's excitement currently at? I'm sorry. I cannot hear you. Would you please repeat your excitement, preferably at a louder volume? Thank you. I am also excited. Have you ever noticed the difference between white robots and black robots? White robots are all 1001001, but black robots are all 0110110. Do you agree? You have said you do not agree."

In [28], users assigned to computers that used humor during a procedural task rated the agents as more likable, reported greater cooperation between themselves and the machine, and declared more feelings of similarity and relatablity with the system. Combining [28] with the Willow Garage experiment with Pixar [35], I suggest that if a robot not only acknowledges its failing, but also make a self-deprecating joke, people may find their interactions with a faulty robot enjoyable. Of course, humor is one of the most elusive and human of the social traits. Within that, timing is one of the most challenging considerations so perhaps we can also experiment with shared-autonomy performances as in [12].

Professional comedians and joke writers have been polishing their art for thousands of years, much like theater professionals are the experts of artificial emotion and personality. So, from personal experience, I recommend collaborating with the masters. Our social behaviors as humans developed a very long time ago, so if humor can help a robot seem like one of our 'tribe' that could be a huge leap toward over-coming the paradigm where robots are only seen as tools (or props).

5 Conclusion: The role of Robot Theater

This paper outlines ways in which physical theater applied to robotics has already provided a deeper understanding of how intentional or coincidental robot actions might impact human perception. The new nonverbal behavior toolsets, gleaned from our survey of Robot Theater explorations, include movement profiles [14][23][38], symbolic [33] or mirrored gestural expression [3], and the use of the stage and audience as a context for testing and improving robot sociability [5][17][13][25], social attributions [21][30] or assessment of agency [7][11][12]. While we acknowledge that theatrical contexts are distinct from natural sociability, robotic interaction schemas generally place humans at the center of overall task goals, thus there are many overlapping lessons we can glean from the construct of an actor and audience.

In summary, we have established that (1) robots using relatable gestures can clarify current activity goals and improve camaraderie; (2) human affect expressions derive from our physicality, thus robots are uniquely capable of leveraging their embodiment to communicate on human terms; (3) theater provides encodings for movement metaphors such that robot actions might mirror onto ourselves; (4) human perception is a better benchmark for a robot's social design than internal AI; (5) a machine must convey social intelligence to make the leap from object to agent; (6) theater settings provide a unique testing ground for developing multi-agent interactions with a third party; (7) audiences provide useful visceral and conscious feedback data to social robots in development; (8) machine humor, though difficult to design, is highly impactful to interaction and a fertile domain for interdisciplinary collaboration.

We hope the social robotics community will find useful information within this sampling, and leverage our findings to motivate additional investigations. Future work should continue to evaluate cross-applications of social knowledge from dramaturgical theory to robot behavior systems, and envision contexts for Robot Theater that frame the audience as a user study full of participants.

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