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What do Collaborations with the Arts Have to Say About Human-Robot Interaction?

William D. Smart, Annamaria Pileggi, and Leila Takayama

This is a collection of papers presented at the workshop "What Do Collaborations with the Arts Have to Say About HRI", held at the 2010 Human-Robot Interaction Conference, in Osaka, Japan.

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What Do Collaborations with the Arts Have to Say About Human-Robot Interaction?

Papers from the 2010 HRI Workshop

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Disturbing, Fragile, Inexorable

Human-Robot Interactions from a Perspective of Artistic Practice

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***Abstract*—This paper discusses human-robot interaction through life cycle of the Inexorable, a mobile sculpture, as described by the artist in charge of the project. By investigating aspects of this particular process we hope to identify interesting intersection points for further investigations in HRI and the arts. In particular, we would like put emphasis on how the artist in this case reflects on aspects of companionship, the crafts of making, and the various contexts of exhibition.**

Keywords: Human-Robot Interaction, Artistic practice

I. INTRODUCTION *(HEADING 1)*

"The cart is standing still in the studio. It is a machine without power. What defines a robot, I wonder when I stumble into the immobile cart. Looking up the word robot in the National Encyclopedia I get intrigued by the information that a robot has anthropomorphic features, and that it often is a machine with warlike purposes. But this machine is not like that. It is a robot designed for its own sake, not for use, not for pleasure, not for destruction."

This paper takes as its starting point some of the design issues of developing robot technology for civil settings, from a user- and experience-oriented perspective [6]. Relevant questions then include how new technology may affect existing social practices, how the image of robots in popular media affect researchers and their designs, and the values that people in general associate with robotic technology. Our approach to exploring this broad field has included not only conventional studies of the use and development of research prototypes [1], but also use patterns of commercial products [5], reflection on robots in popular media [3], and robotic technologies explored on the art scene [2]. In this paper we delve deeper into the latter kind of exploration. A general motivation for this kind of study is that by welcoming perspectives of from outside of our own immediate research community, we hope to get a fuller view on what may constitute important design issues of our field, than if focusing solely on our own preconceptions of what a desired human-robot interaction may be like.

The data upon which this paper is based is the written documentation [in print] of a collaborative project run and orchestrated by artist Ulla West. The project was run by the artist as a collaborative effort together with a series of technicians from various fields, during a ten years time frame of 1999-2009. Importantly and in contrast to most research projects, the goal here was never expressed as developing an innovative piece of technology, but instead as an artefact that would work in a public artistic setting on a more conceptual level. The form and function of this artefact evolved out of available resources, a mix of ongoing ideas and collaborating partners. In parallel with this process, the artist was engaged in several other projects and she also lived, worked, travelled and had exhibitions in different countries.

Below we provide an overview of the project and the different exhibited forms and functions that the robot was given during this period. We end with a discussion concerning some of the reflections made by the artist herself concerning the process, and possible connections with more conventional HRI research, especially related to human-robot companionship, the crafts of making, and the context of public exhibition, respectively.

Figure 1. Ulla West equipping the robot with a video camera as a way of documenting the project.

II. Overview of The Project

The initial intention with the Inexorable was to create an artifact that would go its own way, in somewhat disturbing and inappropriate ways. As a general background for this, the artist mentions both her professional experiences of starting to work with different forms of interactive media in the late 1990's, as well as her more personal experiences of suddenly starting to encounter beggars on the streets of Stockholm:

"Every day on the way to and from the subway, bus or grocery store, I pass a street where there is a person who begs. Usually it is a man, sometimes a woman. One person at a time is standing there, never two together. Perhaps they have agreed with one another who should stand when and where in the neighborhood. The beggar is standing or sitting at the street that leads down towards the square and the underground station. The location is strategic, it is impossible to avoid the road without taking a detour around the entire block. [..] Daily I am reminded and I cannot help but compare the situation of beggars with my own situation as an artist.[..] Some of the phrases are repeated again and again as a mantra, others are more personally directed. Then I started to approach one beggar at a time with a microphone and a coin. I recorded their voices against that I gave away money. A deal. I changed from seeing these people as humiliated beggars, towards approaching them as peers who gave me phrases that I paid for. "

The first step towards developing this project into the form of a working robot began at an informal dinner that the artist had with one of her sons and some of his friends. At the dinner table they started talking about her ongoing ideas of making an interactive sculpture that would provoke a similar experience as her encounters with beggars on the street. Involved in the conversation was Isaac, who was just about to begin his final project for his engineering education in applied IT. A few weeks later the artist found herself visiting the university to present her idea as a draft examination assignment in cooperation with two students. The first version of the robot was presented by Isaac Skog and John Vettergren as their degree project in Electrical Engineering at KTH in 2003. In this first version of the Inexorable it was given a semi-human appearance with recorded voices of beggars as sound output.

While the students focused on getting the machinery to work, the artist concentrated on crafting a physical appearance, a costume for the moving beggar sculpture:

"By hand I constructed a shell around my own upper body, stitching together the padded parts of silk velvet. The sleeves were made from coated tubes. The head shape was built around on an old ice hockey helmet, with a window in front so that the mobility and accessibility of the heat sensor should not be disturbed. Bit by bit modelled after my own body, as jigsaw puzzle pieces in camo pattern, the cart became a body, a shape, a human figure. The costume is built into a corset which is also a kind of body armor. The costume was also inspired by knight armor, military uniforms and movie-theater costumes, and perhaps especcially the costumes of the characters in the starwar movies. […] The figure became androgynous, at once male and female. But this ambiguity turned out to become more negative than I had expected. Rather than both male and female, it became neither of them. I then decided to work on duality, ambivalence and contradictions. "

With a background in working with theatric costumes and various textile technologies, she put much effort into the crafts of printing and designing a graphic pattern for the textile of the costume. The first such pattern was designed as part of another theme project entitled Landescape. The pattern used on the costume was printed by hand in silk velvet, in the style of a military camouflage pattern, which as such is based on a kind of abstracted nature studies. When the Landescape project was later presented at Gallery Skarstedt in April 2005, the artist also presented video and prints based on a more general digital landscape pattern theme. Elaborating further on this costume in the context of a public presentation:

Figure 2. The original robot undressed and as presented at Gallery Skarstedt in 2004 (left), and dressed in its original costume moving among visitors at Kulturhuset (middle). The robot "gazing out" of the window, with close-up on the patterned costume (right).

"At a distance the robot looks lonely and sad in its shiny velvet suit. Like a cuddly toy it appeals to your emotions. If you approach it, it will do the same towards you, and with that bring some uncertainty. Soon it becomes evident that the suit is reminiscent of a soldier's uniform or a knightly armor. The military pattern becomes clear. The cuddly toy is not very cute. The robot, or whatever it is, keeps approaching, following, hooking on, and not giving up. Interest and curiosity transforms into dislike. "

"The comparison to a live person being difficult is close at hand. […] But the robot figure neither has the intellect or empathy, it is mechanical and continues its assertive hunt. Who would like to have anything to do with such a person? Who would be interested in such an art piece?"

It was also quickly decided to make changes to the voice output of the robot, as it was found that the sound was full of interference and the voices murky and inarticulate. One of the first improvements after the first presentation was to rerecord the phrases with a voice that would articulate better. The sayings of the beggars were recorded in a studio by actress Erica Braun, and then played back randomly with 10 second intervals whenever the robot stopped approaching something or someone. However, after a series of experiments in various contexts, it was decided to remove the voice device altogether:

The voice and phrases seemed to direct the activity in a way that delimited and diminished the experience. The robot became a one-dimensional beggar. Without the voice and words, the engine humming and buzzing, and the pursuit of following and escaping, the moving sculpture would become a more diverse experience.

Throughout the project, the robot was not only given different physical appearances, but also the ways that it interacted in its environment changed over time. Some of these changes were intentional, as e.g. the removal of the voice device above, but some changes in the interaction and movements were due to the physical circumstances the robot.

"In 2005, when the robot is shown at Kulturhuset in Stockholm, again in the costume of a beggar-knight-war invalid-cuddly toy-corset dressed androgyne, it keeps following selected visitors. As previously, the selection of whom to follow is random and arbitrary. The visitors encounter the robot when they come up the escalator to the 3rd floor of the stairwell, which is centrally located in middle of the building. When there is no visitor in the space, the escalator stops and the robot positions itself with its face directed towards a large window overlooking Sergels Torg, the glass stick statue and the tall buildings on the other side. It seems to gaze out over the city and the square. Under the window is a hot radiator. It is the heat from the radiator that determines the position of the robot."

After half a minute of standing still the robot starts to search for something new to stimulate its sensors. It picks up the heat from possible visitors or from the escalator. If nothing else is available, the robot returns to the heat from the radiator at the window. The escalator is set in motion when someone is on the way up or down. If the escalator is moving it radiates some heat, and the robot moves in that direction. When the robot is about 15 cm from the upward escalator, the sensors for the obstacle detection triggers and it moves away. But for the downward escalator, there is no barrier to be detected. Thus the robot continues uninterrupted towards the heat and falls inexorably down the stairs. Building a guard, a fence or a gate would be impossible given the visitors of Kulturhuset. Thus the sculpture requires constant care, as if it were a small child who is likely to fall and hurt itself."

Soon after this presentation, the robot is invited to move among the visitors at Stockholm Art Fair.

"It growls forward awkwardly in the crowd of booths and people. An empty circle of viewers is formed around the object that is driving through the crowd. After an intense hour it no longer moves forward, instead it turns in circular movements around its own axis, and after a while of such turning reaching a complete halt. It refuses. After some troubleshooting it turns out that a fuse has blown. The fuse is replaced and the movement returns to spinning around its own axis. Further analysis shows that dirt, dust, hair and various stuff has lashed into one of the two driving wheels and locked it. One wheel spins alone and the movement goes in circles. Rear-wheel number two is also well on its way to get stuck. This environment is too harsh for this simple unprotected technology. Revisions are needed if this robot should be able to cope with publicity on a large scale. The audience quickly loses interest in the artwork that is not working. "

The two separate accounts above of the workings of the robot in two subsequent exhibitions in different environments, illustrates how differently a robot like this can 'work' even though the programmed behaviors are the same. Especially the reflection on the robot as a fragile material is probably recognized for most people who have been involved with robotic technologies. However in HRI research, and perhaps especially in popular culture, robots are instead often described as strong, tough and potentially dangerous. Reflecting on the vulnerability of the technology as as part of the user experience, or as a part of the interaction design is interesting.

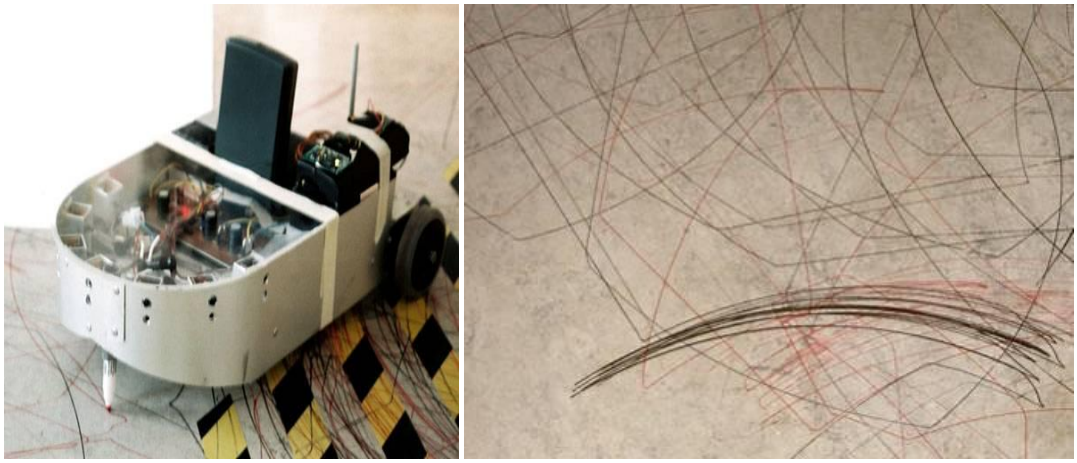

Figure 3. The robot at the Monster exhibition in 2005, drawing its path on the floor.

In this case, the apparent vulnerability of the robot (as it started to reach only two years of age), had direct consequences on the overall and continuing design process. After the above presentation the artist received an invitation to participate in a new larger exhibition and for that to work extensive efforts had to be placed into making the technology more stable, as well as more interesting for the audience. The exhibition was to be held at Gotland Art Museum during the fall 2005, under the name Monster. The exhibition should house several artists, designers and writers, whose different works were supposed to interconnect with one another. It was decided that the robot should move freely in the rooms of the museum, and also that it should leave traces behind on the floor, so that it draws its path in the room.

During six months prior to this exhibition a new technician, Göran Nordahl, was engaged in the project to help improving the machinery of the Inexorable. The costume was stripped off and the technology was instead displayed nakedly under a protective cover of plexi glass, this was to hinder dust and curious fingers to disrupt circuits and connections. The unit with the heat sensor was removed, a new circuit board was etched, and a telephone receiver, a speech synthesizer and speakers were added, to make it become a possible medium for reading out SMS text messages. Rather than a human-like figure it was thereby transformed into a small trolley that moved randomly in the room, avoiding obstacles, but no longer following people and other warm bodies.

"The robot draws its path. A pattern of red and black lines displays the path when the robot is presented. For each week that the exhibition is running, the floor is filled with a growing number of black and red lines that intersect one another in a jumble. Every other day, a black whiteboard pen draws the movements of the robot, every other day, a red pen. The choice of the pen has been preceded by tests with different types of pens. The floor must be possible to clean, to restore the state prior to the exhibition. For one hour each week, a white sheet measuring 70x100cm is placed in a designated spot on the floor, in the same place every day. As the robot passes over the paper surface a drawing is created that can be saved for later.

At 2 o'clock every afternoon, a little snap is heard from the trolley and a synthesized voice announces a verse through the small speakers of the robot. It is a haiku poem sent personally from my mobile phone to the exhibition visitors, or to no one in an empty showroom. The poem is read out at the moment, the sound is not recorded, and not saved for later. Anyone who wants to can send messages to the robot. All text messages are converted into sound and transmitted through the speakers into the room at the exhibition. However, the speech synthesis is designed for the English language and the sound conditions in the exhibition space are poor. The sounds that robot emits are therefore muddy and difficult to interpret. With much determination and effort I learn to interpret the sounds of these spoken text messages. To others, especially if sending messages in other languages than English, the words are conveyed opaquely and disappear into the void as passing noise. "

After a series if reflections concerning the cursory and temporal nature of the actions that the robot perform – and especially the lack of capacity of the robot to remember its own actions – it was decided to explore this dimension of the robotic material further. In 2006 the robot was further developed under the theme Resources at the Arkitecture school at the Royal Academy of Fine Art in Stockholm. The idea now was to read the robot's movements in a limited space, in a way that could be saved for later. In this part of the process the artist worked together with Ylva Fernaeus who was then in the final phase of her doctoral studies in human machine interaction. They attach a wireless RFID reader under the robot, which reads RFID tags glued on the floor in a tile system with 15 cm in between. Ylva programs a system so that each tag that the robot moves over is presented on a screen in the form of a checkered trail of pixels.

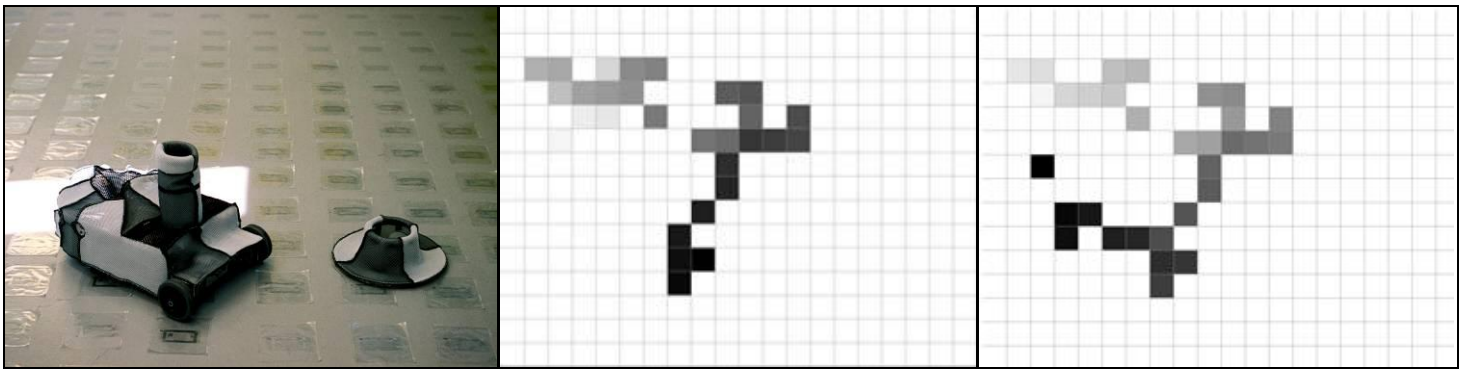

Figure 4. The robot as presented at the Resources exhibition in 2006. The cart moving on the tagged floor surface (left) and two screen dumps from the digital representation of the movements on the floor (right).

A textile product developer, Lisen Elmberg, who normally develops baby slings, is also involved in the project. Lisen is given free hands to design a suit that should not be a human form, but focusing on function and mobility. It should protect against bumps and debris, and meddlesome fingers. It should be light, airy and stable so that it can hold and carry a separate robotic device, a satellite that can be snapped on to and carried by the "mother" robot. The sensors and the movement of the main robot must not be disturbed. The choice of materials becomes a 3D net of polyester cut after the shape of the robot shell and its active components. Dressed up in its new suit, the robot looks like a toy, a small boat or some other kind of vehicle.

At the exhibition in summer of 2006 the robot/vehicle travels around at the same slow cautious speed as before, avoiding obstacles, but otherwise seemingly randomly. As a contrast, a small satellite robot is rolling around rapidly everywhere in a crashing progress, aggressive, thoughtless and erratic. The screen display shows the path. The path of the small satellite is not possible to read, it is only mettlesome and annoying or entertaining.

The robot is at a standstill since 2007, collecting dust. Ylva who periodically has worked on the robot project is now engaged in a research project, LIREC, which also deals with robots and robots characteristics. Together it is decided to disassemble the robot into its component parts, but before that the Inexorable is switched on for a last journey. Equipped with a black marker pen the robot gets to draw its last path during 60 minutes, on 51 sheets of paper, which are later to be used for the page spreads of the book on the project.

"It works slowly and shakily, reacts haphazardly. Sometimes it is completely quiet and then it makes a jerk and dances forward for a bit. After this last journey the robot is taken apart."

Upon reflecting on the many years that the project had been going on, the artist writes:

"During this time, my robot has been around almost like a family member, as something ongoing and evolving, impossible to comprehend completely. It has always been a topic of conversation."

III. Discussion

As a position paper for a workshop entitled *"What do collaborations with the arts have to say about HRI?"*, we would like to discuss the process as presented in this paper, and what potential aspects and intersections that could be relevant to bring up for the context of HRI. There are especially three aspects that we would like to bring to discussion, 1) the specific context of art performance, 2) the crafts of making, and 3) reflections on companion qualities.

A. The Specific Context of Art Performance

User- and experience-centred design (of which HRI could be considered a sub-section) touches upon a broad range of themes, including aesthetics, sustainable interaction, and contextual and cultural values. An important aspect in such work is to focus on how people are using and relating to technology in real world settings. In the cases explored here the 'contexts of use' have been art galleries, art fairs and exhibition halls.

When presenting the Inexorable in these kinds of settings this in itself may demand other forms of interpretations than if presented in other contexts. From a perspective of art theory it is for instance sometimes stated that the construction of the public rooms for art exhibitions, beginning with the 19th century museum projects, can be understood as a form of manifestation of the self image of the leading classes. This not only concerns representing the world in a certain way e.g. through the way motives are selected, depicted and displayed, but also to arrange spaces where societal relations are re-created. These rooms are thereby loaded with invisible restrictions, not only between objects and artefacts, but also between people and how they are meant to act and interact.

Drawing on this perspective, the Inexorable could be interpreted in terms of how everyday practices are experienced by individual citizens and about 'acceptable behaviour' in a society. From the project documentation, it is clear that the development of the Inexorable was grounded in the brief encounters with the homeless of a city, expressed in the form of a robot that does not pay respect to the codes of conduct that ties together the social web of everyday life. If the same artefact had been presented in other contexts, (e.g. educational,

entertainment, technology fair), interpretations at such a conceptual level would probably be less likely. Similarly, whenever robotic artefacts are being studied, be it in e.g. schools, work places, or more recently in theatrical settings, this naturally shapes the possible interpretations, judgements and uses that people are likely to make from them.

At the same time, when presenting something in environments like this, it also demands from the artist to stay open to interpretations that may go beyond the assumptions made beforehand. This echoes some of the reflections put forward also in recent work in interaction design [see e.g. 9]. What is happening with the moving sculpture in the enclosed gallery space is thereby a combination of the conditions, limitations and chances that may arise in the physical and social environment that it is put to act. With respect to this particular circumstance, the artist repeatedly questions her work as meaningful to this particular context (e.g. *"Who would be interested in such an art piece?"*).

Several research groups have implicitly expressed a vision of companion technology by performing e.g. comparative studies on how people act towards robots and how they interact with people and animals. This could be interpreted as robots supposedly having more in common with people and animals, than with other forms of existing technology (e.g. communication technology, physical tools, vehicles, electronic toys). Here rather than comparing the robot to a person or live animal, the context asks us to compare the robot to other objects that may displayed in artistic contexts, e.g. static and kinetic sculpture, video, dance and theatre. One aspect that HRI could potentially draw from staged artistic performances would therefore be to put further emphasis on use context as essential in understanding and approaching robotic artefacts.

1) The Crafts of Making

In the documentation of the project, we find several descriptions of how the surface appearance, as well as the behaviour of the robot is crafted, reflected on and changed over time. Small mistakes sometimes resulted in unpredictable effects, and failures turned out to be fruitful moments in the progress. Interestingly, these accounts are simple, straightforward and probably easily recognizable and understandable to anyone engaged in any process of giving physical form to these kinds of technical systems.

In a review of the Inexorable by Frans Josef Petersson (also printed in the documentation), the project is discussed in terms of textile crafts as a methodological approach. It is suggested that one may understand textile crafts not only as a set of techniques, but also as an approach that can be generalized and applied also to other practices. West's works in various media (photography, motion picture, digital media) could then be understood as founded on a set of practices that are specifically based on textile working models.

The relationship to textile crafting refers primarily to traditional work of the hand, to a semi-conscious, everyday making. Weaving, knitting, and crocheting are all time-consuming processes that may be integrated with the mundane sphere of everyday life, in a way that is rare in other forms of artistic practice. These kinds of crafts may be described as activities in which the practitioner must be sufficiently aware to have control over what one does, but at the same time must be sufficiently absent to avoid being bored by the slow progress. This could be perceived as practices where art and life run in parallel, without having to set itself against the idea that one must exceed the other.

Whether using crochet hooks or digital image software, or in this case electrical engineering and programming, the practice appears to be close to the half-conscious daydreaming, the aimless wandering – even if the overall approach is without doubt conscious and purposeful. This approach is different from the standard attitude of engineering and HRI, where the goals of the process are more explicitly defined. This refers directly to concepts often discussed in practice-oriented research and design theory, e.g. in Donals Schön's notion of 'reflective conversations with the material' [8], as well as in popular notions of DIY culture and Bricolage. As an area increasingly influenced by disciplines such as product- and interaction design, these kinds of reflections may become more relevant also in more conventional presentations of HRI research.

Moreover, in order to realize a working interactive sculpture, the artist in charge of this project had to make use of a range of specialized skills that went beyond her own area of expertise. As designers and developers, they worked together to determine the conditions and premises for this sculpture, but were never able to completely predict its outcome. Parts of this uncertainty could be explained by the very nature of making artefacts that are active and interactive, and how these may be approached by people in different contexts. Similarly, applying user-centred approaches in HRI has previously been discussed as problematic, particularly as robots are difficult to study because of the complexity of resources needed to build them and the cost/sophistication of materials. It may therefore be difficult to get any informed sense of what human-robot interaction might be like in practice. Moreover, it seems users, as well as researchers, struggle to imagine what robots might do. Art practice may then work to broaden these visions (especially as these visions often have their roots in artistic practices to start with e.g. theatre and literature in conjunction with technical development).

However, an essential part of this difficulty of predicting the outcome in this case seems to be also the dependency on the skills of others in getting various aspects of the technology to work. This meant that essential parts of the design had to be left for others to shape. Thus, the resulting manifestations became the results of constant negotiations between disparate areas of technical knowledge. As a collaboration between an artist and technicians, this also illustrates an attempt to redefine relationship between art on the one hand, and everyday use and the so-called practical knowledge on the other, practices that do not necessarily accept a distinction between technology and art as separate knowledge and experience areas. Approaching robot making as an artistic craft or practical knowledge area could be given further

emphasis in HRI, where focus up till now has been dominated by more cognitively oriented studies.

B. Aspects of Human-Robot Companionship

In HRI, robots are often framed as potential social partners or companions as a metaphor for how they are envisioned to interact. Naturally, the Inexorable was in all its varying manifestations much simpler than most robots explored in research, but still it seems to at least partly generate a sense of empathy or relationship with people (e.g. *"almost like a family member"*). How this was created despite its very simple technology could be relevant to reflect further on.

A first explanation could be that as with most creative practices in which people invest much effort, this could be interpreted as a bond between the maker and its made artefact. This aspect has also been confirmed in recent HRI work were participants have built their own simplistic robots using Lego Mindstorms [4]. But there are also aspects of social relations at stake that goes beyond the interaction between the robot and its direct social environment. This is for instance shown in the artists' reflections on the different points of 'failure' in the process, e.g. how the robot worked as something or someone that is annoying and socially awkward.

Another possible interpretation could be based on how everyday life is dependent and constrained by technology in different forms. In a sense, and according to several theorists in media theory technology could even be described as that which sets the limits of what is possible to say and think at a certain point in time. This becomes relevant to us as robots of varying shapes, sizes and forms are getting deployed in different use contexts, ranging from autonomous consumer products such as vacuum cleaners to sophisticated interactive toys, industrial robots, service robots and interactive sculptural artworks. In this sense and in this setting, the 'companionship' between the robot and the human may then be understood in terms of providing the means for expressing and sharing a certain idea or concept. It is also in this sense that the work seem to have kept its long-term and ongoing status, e.g. as *"topic of conversation"*.

5. ACKNOWLEDGMENT

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Human interaction with flying cubic automata.

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***Abstract*—This paper discusses the qualitative results of an interdisciplinary art-science-technology project called SAILS, which consists in developing intelligent, geometric objects that hover and move in the air. From their first major performance in the Quebec Museum of Civilization to their last one in Moscow's Winzavod center for contemporary arts, several autonomous cube-shaped aerobots of the SAILS project have evolved under the artistic direction of its creator, artist and architect Nicolas Reeves, and following the technological developments implemented by engineer David St-Onge. The challenges met while developing and presenting various performances will be described, as well as the strategies that were used to select the behaviours and abilities to be implemented for the flying cubes. The SAILS project is an example of a situation where questions and needs required by the art realm have led to technological premieres.**

I. Introduction

From the time of their historical schism at the end of the Renaissance, the relationship between art and science has been described as either strongly collaborative, or strongly antagonistic [1]. An analogous situation prevails in the field of robotics engineering. Where robots are often viewed as pure mechanical devices, strictly dedicated to the implementation of tedious, difficult or repetitive tasks, and unable to convey any feeling or emotion, artists like Norman White ("Facing Out/Laying Low", 1977), Gilles Roussi ("Bons robots"), Stelarc ("Robot Arm") and many others have been using robots for more than 30 years for quite different purposes : instead of focusing on practical or material applications, they use them to ask new questions and to open research paths on technologies [2]. For instance, through the cybernetic engineering field, a lot of art work was created to explore the Artificial Intelligence and Human-Robot Interaction behaviours. Where most scientists seek to develop the robots abilities to relate and interact with humans, artists explore concepts such as identity, ontology, artificial emotions and social metaphors [3]. This exploration proves in turn extremely fruitful in shedding new lights on human-robot interaction processes. Since more than four years, the NXI Gestatio Design Lab, directed by Nicolas Reeves, works on developing autonomous cubic flying robots for artistic performances and exhibitions. This project, as well as many others, brings together engineers, scientists and artists in a unique collaborative work process.

The Tryphons (also referred to as T225c) are the latest aerobots developed within a research-creation program called SAILS (Self-Assembling Intelligent Lighter-than-Air Structures) [4]. It consists in a cubic polyurethane blimp surrounded by a cubic exoskeleton made from composite materials. Its overall size is 225cm, hence the acronym "T225c" (the small "c" stands for "composite"). The Tryphons predecessors were the prototype M180t and M170t "Mascarillon", whose edges were respectively 170cm and 180cm, and whose structure was made from basswood (the small "t" stands for "tilleul", the French word for basswood); and the M160c "Nestor". The Tryphons are larger and more robust in order to withstand the sometimes harsh circumstances of large public performances. Nicolas Reeves started to work more than 10 years ago on the concept of flying objects whose shape would be in strong contradiction with the idea of flying or hovering. Such objects constitute a paradox that becomes an architectural statement: they somewhat materialize the old mythical dream of an architecture freed from the law of gravity, an image that has pervaded the whole history of architecture, in many civilizations.

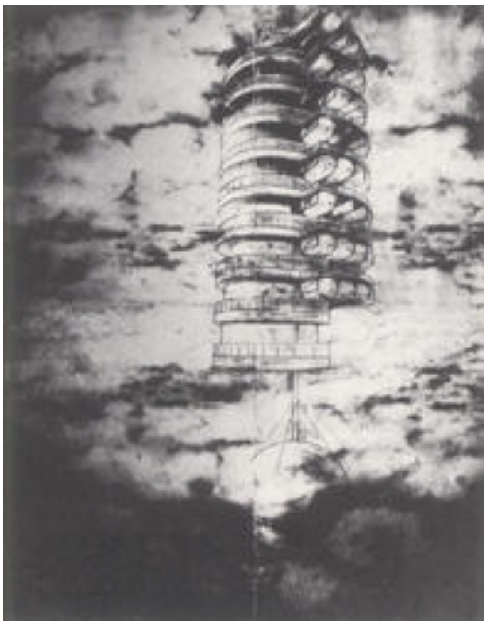

Fig. 1. Flying architectures : the historical and theoretical origin of the SAILS project

The evolution of the SAILS program faced the NXI Gestatio

team with a number of major challenges. The technological developments required to create such robots are important. Even if airship dynamics have been widely studied [5], and even considering the latest research on control of autonomous blimps, the literature on these topics provided no result that could be directly applied here [6]–[9]. The weight, size, structure geometry and motor location are unique to this application. The number of behaviours that can be implemented is virtually unlimited. However, the development of each new behaviour or interaction requests a good deal of time, materials and labour. In order to optimize the use of our resources and energies, we decided that the art performances to which we would be invited would determine the behaviours to be implemented; moreover, mock-up experiments with remote control, or even no control at all, would have to be made prior to any implementation, in order to validate the potential artistic interest of a planned behaviour. Public performances provided us with ideal opportunities to test our art hypothesis; but we also tested them during art residencies, where actors would join us for several days in our search for new behaviours and interaction possibilities.

After many acclaimed public performances in five different countries, the SAILS project proved to be one of the most successful stories of science-art-technology collaboration in the last years. This paper will cover five of these events, namely the Rom$^{<evo>}$ exhibition in the Quebec Museum of civilization, the CRIM conference in the Montreal Convention Centre, the Summer of Dance 2008 in the Grand Palais in Paris, the "Robofolies" festival in the Montreal Centre for Sciences and the ScienceArt Festival in Moscow Winzavod gallery.

Then, we will discuss an on-going research-creation project called "The Tryphons' eye", which consists in writing and implementing a full hybrid theatrical performance involving four actors interacting in real-time with four autonomous Tryphon aerobots.

II. ROM$^{<evo>}$

Rom$^{<evo>}$ [evolution of a dead memory] was the name of the first major interactive performance involving flying cubes. It took place in the Quebec Museum of Civilization in 2006. Its objectives were ambitious. They consisted in letting the cubes float randomly in a large closed room, programming them only to avoid obstacles, until a visitor was detected by motion sensors at the entrance of the room. This signal would tell the nearest aerobot to get as close as possible to the visitor, and to stabilize in front of him. An external, adaptive projection system would then map two eyes on the two visible faces of the cube; a voice coming from hidden speakers would try to start a discussion with the visitor. The eyes and voice were actually those of an actress who was hidden from the visitor, but could hear and see him through loudspeakers, microphones and video screens. The visitors had the impression of conversing with a strange flying machine endowed with a peculiar intelligence. In this context, the human-robot interaction was two-fold. First, the movements of the visitors triggered other movements on the cube. Second, though the voices and eyes were human, the vast majority of visitors thought they were actually talking with a computer and reacted as if they were. The actress had to simulate an artificial being whose knowledge was based on three sources: the information the visitors provided her, the inferences she could derive through logical extrapolations, and the conclusions of interpolations between the data she could gather. On the opening day, the aerobot would act as if it knew nothing; it would construct its knowledge along interactions and discussions with the visitors. This simulated human-robot interaction produced fascinating exchanges: one visitor tried to teach a poem to the aerobot; an old lady came several times, and stayed each time more than an hour and a half talking with it. Small kids were particularly attracted by it. This experiment proved totally successful, and encouraged us to develop an aerobot which could exchange with visitors through a completely artificial system, based on a voice-recognition program coupled with an artificial interlocutor - an updated version of Eliza or Racter. This development is one of our priority axis of research. It is a good example of the situation mentioned above: the amount of resources needed to develop such a system is actually important; the Rom$^{<evo>}$ experiment acted both as a mock-up and a benchmark test to validate the concept before engaging these resources.

Real Human-Robot Interactions were also planned during this performance. The actions of the robots were divided in three categories: random displacements with obstacles avoidance; approach of entering visitors; stabilization in front of a visitor for video projections of the actress' eyes on the faces of the cube. This was the first time that our control and stabilization algorithms were tried in a public performance situation. These actions corresponded to a set of ambitious technical objectives: to develop a completely new robot in a couple of months, and totally control its behaviours and displacements on the three states. What would already be an uneasy challenge for an engineering research laboratory had to be done in an art-dedicated space, without all the research infrastructure of technological labs. This, plus other specific circumstances of this public event, led the NXI Gestatio team to simplify the robots interactions and movements. The aerobots were instructed to stabilize on fixed spots, which was already quite difficult for them, since the calibration of the on-board mechatronic equipments, still in a prototype stage, was a challenge in itself. Then, each flying area has its own characteristics, depending on space configuration, convection movements, location of doors and windows, ventilation systems, nature of walls, and so on, so the aerobots' calibration must be adjusted to each place, by a process that typically requires several hours. Nevertheless, the event led to an almost surrealistic atmosphere of Human-Robot unique contact experience. The slight oscillations of the speaking cube when stabilizing were interpreted as hesitations: when a visitor was entering the room, the air flows created by his displacement and by the opening door required more power from the cubes ducted fans, and resulted in a supplementary reaction of the robot to a new

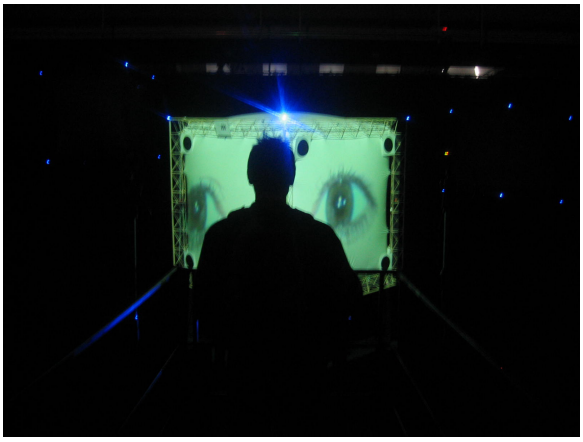

Fig. 2. A visitor discusses with a flying cube during the ROM$^{<evo>}$ event

human presence. In the same way, when many excited people were speaking in front of it, the flying cube seemed excited as well, since it had to adjust its position more frequently. This was both a consequence of the detection of the visitors by the cube (through the presence of the actress), and of the air movements they created. The ROM$^{<evo>}$ proved a very instructive event for us, not only because it allowed us to evaluate the potential of a robot endowed with artificial discussion possibilities, but also because it showed us a series of unexpected interactive behaviours that are now part of its basic interaction vocabulary.

III. CRIM & Summer of Dance

No direct interactions with people were planned for these events, which were seen only as opportunities to test future autonomous interactions in difficult circumstances, with large to very large audiences. The scenario for these performances was conceived so as to simulate aerobots that would try to mimic human movements, and to evaluate the audiences reactions to such behaviours. All displacements were made through assisted, partially automatic remote control. The CRIM event is a major conference that takes place each year in Montreals Convention Center, to which are invited all the principal representatives of the new technology realm (corporate, educational, administrative). Highlights of the Montreal technological scene are regularly invited to demonstrate the citys innovativeness and creativity. We were invited to show our work in 2007, by having our cubes fly and stabilize over the crowd during pauses, coffee breaks and lunchtimes, and we were allotted 30-minutes periods each day to demonstrate the potential of the cubes. Moreover, during lectures, two aerobots would stabilize on both sides of the scene, quietly surrounding the lecturer as if they were absorbed in a dreamy levitation. Stabilization was made through distance sensors.

An interesting incident occurred during a pause between two lectures : for reasons linked to the power of the ventilation system, one of the cubes escaped its prescribed position and began to move over the audience. The impact of this geometric object hovering over the heads was completely unexpected: people seemed both amazed and delighted. We then decided to create an improvised performance: one of us [N. Reeves] took a microphone and started walking between the tables, at the same time giving the audience technical details about the flying cube. Meanwhile, the cube was following him, as if attracted by its creator's voice, and constantly tried to stabilize about one meter over his head. This simulated behaviour - following a given person through sound or pattern detection - proved so successful on the artistic/theatrical point of view that it was also decided to give priority to its implementation. Voice recognition amidst an important audience is a task for which no clear methodology exists at the time being; following a person by pattern identification will be feasible in the next version of the SAILS aerobots, which should fly before the end of this year.

In the summer of 2008, the team was invited to fly three M225c "Tryphons" during the Summer of Dance in Paris. During this event, we managed to implement the first real autonomous stabilization in aggressive atmosphere with an absolute positioning system. The mechatronic had been completely changed prior to the event, in order to ensure proper stabilization over a dancing crowd within the gigantic space of the Grand Palais (length 150 meters, width 60 meters, height 45 meters). As it happens more than frequently in performance arts, the event was confirmed four months before its opening, which allowed us again an impossibly short development time. When in Paris, calibration times were particularly long -in such a huge space air currents develop that are almost equivalent to an outdoor situation, and the system only worked properly on the second night. The first performance was made through semi-autonomous remote control: the movements of the aerobots were partly induced by direct commands from the pilots, coupled with self-stabilization on the z rotation angle and collision detection. The Grand Palais space was a wonderful playground for the aerobots, but it led them to reach points that were almost out of view from the pilots, which justified the need for obstacle self-avoiding procedures. Our degree of control on the robots allowed us to make them act like dancers in the air, or even on the dance floor. Flying from the bar to the stage, close to the distant glass vault or nearly touching the floor, their movements were determined mainly by the reactions of the pilots to the music and the general energy of the crowd. The audience seemed to share the space with a different and new kind of dancer. It had to adapt to the presence of these huge moving objects, and to learn how to predict their movement so as to give them sufficient space to evolve. Once again, this situation, in which the cubes were almost dancing, led us to plan the design of rapid interaction procedures for the development of choreographic performances (see section VI below).

IV. Nestor & Véronique

The "Nestor and Véronique" event took place in the Montreal Center for Sciences, during an annual event called "Robofolies". It was our first completely interacting performance involving an actress and an autonomous cubic aerobot. The

Fig. 3. A Tryphon hovering in mid-air, in the gigantic space of the Grand Palais, in Paris

Fig. 4. The Nestor flying cube with his mistress, actress Véronique Daudelin: the ”Robofolies” event

performance was based on a simple scenario, in which the actress would tame an aerobot N160c ”Nestor”, by interacting with it through her movements and displacements, and with bright flashlights. An interesting phenomena occurred during the event, which lasted 14 days: since the actress had to adapt her movements to the slow pace of the aerobot, the performance progressively developed into a real choreography, just like if the particular behaviour of the aerobot had influenced the movements of the actress.

The event was quite successful; even children were able to interact with the robot and were amazed by it. From an engineering point of view, the most important aspect of the performance relied in the stability and precise repetition of the movements. Indeed if the actress - referred to as ”the mistress”, in this scenario - asked for a specific movement of the aerobot, she needed it to happen exactly as expected, otherwise the credibility of her control over the robot would be challenged. For this purpose, we first wrote a scenario for four preprogrammed movements, ensuring a high Interaction Situation Awareness for the robot [10]. In future developments, learning algorithms will be implemented, so that the robot will be able to send a request to the user when ambiguous situations occur ; but for this performance, Nestor was postponing its reaction until a clear interaction command was received.

Each movement was triggered by a different movement or displacement of the actress, and was fine-tuned to be as precise as possible; but there is no way to predict exactly the behaviour of a flying cube in every possible circumstances. After several representations, it appeared that unexpected movements from the cube could induce the actress to react on an improvised, almost choreographic way, which greatly enriched the performances, even if these emerging interactions were not a complete success every time. From these observations, we decided to add a fifth interaction sequence in which the cube was supposed to quit its stable position, fly to the center of the audience, and come back to its original place. The Nestor is equipped with small motors, so it happened that it drifted frequently during this sequence; this only added an anthropomorphic touch to its behaviour : small errors, which can be rectified in various ways, are more easily associated with humans than with machines.

Another element of successful human-robot interaction is to maintain a low Interaction Effort [10]. Since interactions were launched by distance and light sensors, the cube had to stabilize itself before listening to interaction signals, in order to discriminate environmental noises from these signals. A stable starting position also ensured that the movements could be executed without collisions with the walls. Stabilization times were variable, so the actress had sometimes to improvise while the cube was getting quiet and prepared. This added another unpredictable parameter which increased the living appearance of the object. To our knowledge, this performance was the first experiment involving a human interacting with an autonomous blimp stabilizing in the air.

V. Geometric Butterflies

This performance took place at the Winzavod center for Contemporary Arts in Moscow during the spring of 2009, as part of an event that was called ScienceArt Fest, the first ever science-art exhibition in Russia. ”Geometric Butterflies” was the first long lasting totally autonomous performance for the Tryphons. The aerobots were restrained within the flight area by walls on three sides; on the fourth side, they were reacting to the presence of the visitors. Dark blue, powerful spotlights were distributed around this area. The aerobots were instructed to run away from light; the name Geometric Butterflies derives from this behaviour : they reacted to light by moving far away from it, just as (inversed) moths; as this reaction pushes them back towards the center of the flight area, they avoid each other, which sends them back towards the periphery, and so on, creating unexpected and unpredictable orbits. When they got very close to each other, their collision detectors could briskly

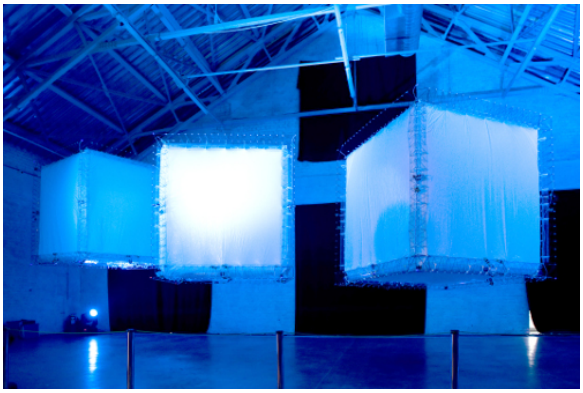

Fig. 5. Three Tryphons in Moscow during the ScienceArt Fest

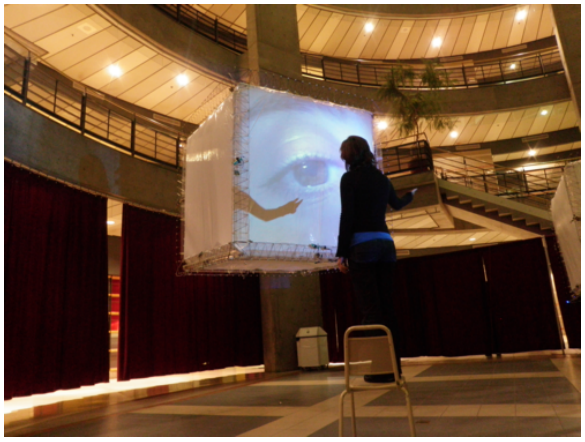

Fig. 6. Tryphons' eye workshop, Quebec city

expel one of them towards the audience, where it would react to the peoples' presence and movements. The sight of these huge objects approaching was rather impressive, so the visitors would quickly extend their arms, or position themselves so they could be easily sensed by the detectors.
Even when the Tryphons were in an almost stable position (in fact there were no perfectly stable position since at least one of the aerobot was always moving), the visitors tried to interact with them through the light of their cellphone, or with small pocket flashlights. At almost any time during the exhibition, one or several visitors were intrigued by the behaviour of the aerobots, and tried finding how to interact with them. This performance brought us to the conclusion that any future performance with the cubes, even theatrical, must take into account the presence of the audience, and benefit from it to develop new categories of interactions. This conclusion is taken into account in our on-going research, which is the object of the next section.

VI. Tryphons' eye

As mentioned above, during our previous performances and experiments, besides studying real-time interactions, we tried to simulate different kinds of behaviours, thus aiming to define those which carry the best potential for artistic purposes. The Tryphons' Eye project aims to integrate the most promising behaviours and interactions into an integrated research program which revolves around the writing, scenography and creation of a choreographic and theatrical performance that implies four actors and four Tryphon aerobots. As discussed in [11], interaction involving multi-robot and multi-user have not been extensively studied yet, so this artwork will explore an unknown area of the Human-Robot Interaction. This hybrid and interdisciplinary play will be based on a written scenario. The four actors will interact with the aerobots through movements, displacements, light and voice (sung notes, very short melodies). Several conclusions of previous experiments and performances will be exploited and put to work for this project; they will lead to the implementation of new behaviours for the cubes, and thus to new technological developments. Among them, the most important are the ability to follow an actor by voice or pattern recognition; the possibility to upload new set of behaviours on a cube by voice control (a short melody sung by an actor will completely change the cubes personality, reactivity and perceptive abilities); interactions with a number of people, such as the audience of a theatre; simulations and mimicry of human behaviour; and so on. As for all previous experiments, needs and requests coming from the art realm dictate the evolution of the on board technology and programming. This time however, intensive sessions are planned during which the actors are put in close contact with the cubes for several days, so as to become as familiar as possible with the potential and limits of the embedded technology, and be able to define and adjust their own set of needs for the play. Several theatre plays involving robots or automata have been written within the last years, but all of them use robots that are pre-programmed, and carefully controlled during the length of the play. "The Tryphons' eye" constitutes a premiere, since there will be real-time interaction between the robots and the actors, as if the cubes were actors themselves; and since the scenario will have to deal with the unpredictable events that unavoidably happen when dealing with objects in aerostatic equilibrium.

VII. Discussion

A number of relevant conclusions can be extracted from our observations of the last performances of the SAILS robots. The visitors' relations with the robots, as well as the actors relations with them, proved a valuable and meaningful source of information and knowledge for the design of Human-Robot Interaction procedures. In each performance, the visitors were seeking a contact with the robot, a reaction that they would have initiated. They may have wanted to experience their influence on what they saw as a large machine, or simply test its capacities; but more fundamentally, what could be gathered from our discussions with them revealed that they were attracted by the strange appearance of this slowly moving cubic organism, an attitude that is somewhat contradictory with the 'Uncanny Valley" hypothesis. It has also been observed that a slow moving cube was triggering more positive feelings; it

happened that some visitors who triggered accidentally a quick approaching movement from the aerobot were impressed, and even afraid when they realized that they had caused it. These reactions of visitors, or novices, proved extremely informative in setting a preliminary common ground [10] for optimizing Human-Robot communications.

Relationships with actors evolved in a different way, because their mandate was precisely to tame the aerobot, as if it were a big, unpredictable animal. After a little while, all the actors began to adapt their speed, the rhythm of their displacements and their general energy, to the specific pace of the aerobot. They adjusted their own movements so as to induce the cube to move smoothly, as precisely as possible, and to get the best level of control. Since the success and credibility of interactive procedures rely on the stability of the cubes, they looked for positions and ways of moving that could help the cube to stabilize, just as if they were unconsciously acting to enhance its interaction Situation Awareness. They also had to get acquainted with the unpredictable reactions of the cubes that were caused by the specific parameters of the flight environment. This may be a problem from an engineer's point of view, since the reproducibility and reliability of interactions are almost always essential for all technological applications. Things are different in art, and in particular for a theatrical play, since unpredictability may become a key ingredient in the definition of each cubes personality. As mentioned above, nearly precise (and slightly imprecise) interactions and movements may add to the poetic dimension of the cube, by facilitating their association with living organisms.

The Tryphons' Eye project has its own specific way of evolving in time, since it is not based on the integration of technology in an existing performance, but rather on the development of technological devices and method for precise performance needs. Since the objective is artistic, technological limitations can be bypassed by new approaches or new uses of existing technologies. As is often the case in Human-Robots Interaction, the scenario of interactions could first be developed by Human-Human simulations; however, while this technique suits the humanoid robots, no cubic 225 centimeters-edge floating robot can adequately be simulated by an actor. Remote-controlled performances are then crucial in defining the expected behaviour of the cubes, from which technological evolution can start to unroll. These observations lead to one of the main conclusions of this paper: endowing a robot with basic sensory and interaction aptitudes, and putting it in close contact with humans in a given context and an intentional frame, provides a wealth of observations and data that can be exploited for the design of optimal and adapted human-to-robot interactions.

This project, as well as several others from the NXI Gestatio Design Lab, brought together engineers, scientists and artists in a unique collaborative experience. As for all the labs projects, the process is launched by an art performance perspective, either coming from the author of the project (N. Reeves) or from external proposals by art organisms, centers or festivals. From the very beginning of the development, all team members are requested to participate in discussions and production meetings. The first steps consist in defining precisely the artistic needs, the visual atmosphere, the performance context and the desired interactions. Any detailed technical considerations are avoided during this phase, but the presence of the team engineers is mandatory so as to ensure their understanding of the final objectives. When the art project becomes more precise, the technical approach is discussed in order to adapt the different technologies available, or to implement new ones. In doing so, the artists need to actively participate in the discussion, ensuring that the available devices and methods will accurately fulfill their needs. Such an exchange is critical to ensure the success of the whole project, and requires active participation from everyone: the engineers need to be as open to the artist needs, just as the artists need to grasp clearly what the desired technologies will be.

> Artists should be hungry to know what researchers are doing and thinking, and scientists and technologists should be zealous to know of artistic experimentation. [3]

The Artist-Engineer collaboration needs a common ground to ensure its success.

VIII. Applications

Besides their major potential for theatrical and choreographic hybrid performances, the Tryphons and their predecessors constitute a full platform for research and experimentation in robotics, cybernetics, swarm intelligence, physics of flight and so on. Many applications have been considered, some of them having already been explored. The cubic shape of the aerobots adds to the general advantages of blimps (low energy consumption, low payload-to-weight ratio, high autonomy) an easier control on six degrees of freedom, and the possibility to assemble aerobots in flight for collective tasks. Indoor flocks of hovering robots equipped with cameras and infrared sensors can patrol a factory or a research center. They can detect intrusions, or collaborate in locating leaks in gas pipes and distribution networks, even high over the ground (as in [12] for other rescue missions). Security agents will only need to monitor their output signals on a main desk, or use them as external detectors. They can also be used to carry small equipments in areas that are either difficult to reach, or made inaccessible by radiations or toxic fumes; their available payload may be increased by assembling as many cubes as needed, and their flexibility could be enhanced by equipping them with small cranes. In this kind of application, they will overpower any fixed crane or wheeled equipment in terms of flexibility or efficiency.

In the same way, one or several flying cubes could collaborate in creating a hovering guide for visits in museums or exhibition halls; they could follow the visitors by through an appropriate setting of their sensing abilities. OLED screens on their faces could allow the display of various information and images. Indoor flying aerobots also provide an ideal benchmark and experimental platform for future outdoor applications. Outdoor

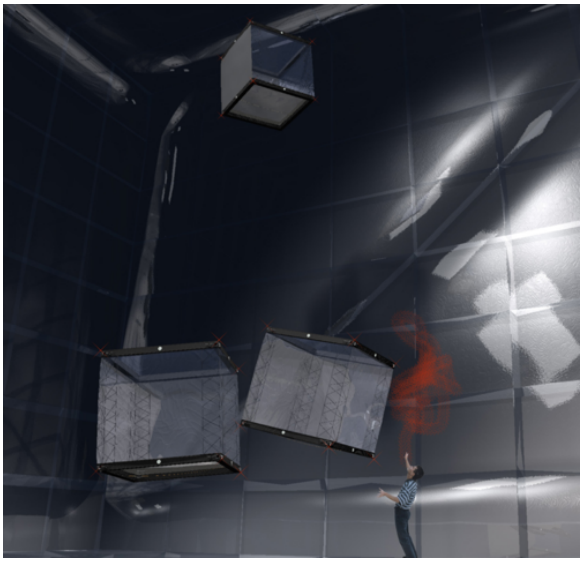

Fig. 7. Simulation of human-automata hybrid choreography

blimps could be instructed to hover around critical buildings, reaching places that would be otherwise difficult to control. The Tryphons are also particularly well-suited for education. They constitute a flexible, stable and easy-to-modify platform for studying and calibrating sensors, implementing interaction algorithms, and to explore exploring swarm-intelligence or any collective or collaborative processes. Since their their autonomy can reach more than six hours, they can be used for evolutionary algorithm research or human interaction testing, which typically requires long working times. Modifying the sensors configuration and number proves particularly easy on these blimps. All kinds of sensors (distance, light, cameras, microphones, altimeters, compasses, inclinometers, temperature, pressure, accelerometers...) can be installed.

Flying hovering shapes may also be of the greatest interest for architectural research. Many shapes can be imagined for such robots, benefiting from the developments made for the flying cubes. A properly designed set of shapes could permit using them for simple architectural mock-ups, and to quickly generates generating prototypes for evaluating various possibilities for a given architectural projectsuch robots, benefiting from the developments made for the flying cubes. A properly designed set of shapes could permit using them for simple architectural mock-ups, and to quickly generates generating prototypes for evaluating various possibilities for a given architectural project [13]. With a sufficient number of aerobots, evolutionary algorithms could even be used to let them generate an optimized structure from a set of basic design rules and conditions; an interface using control through voice, light, sound and displacements would allow an architect to easily modify and adjust such proposals by interfacing directly with the structure.

From its artistic origin [14], and throughout all the artistic development that surrounded its technological evolution, the Tryphon became a spokesman for science, for the widest audiences. It demonstrates how science and technology can collaborate to create fascinating and beautiful art objects and scenes. The slow oscillations of the flying cubes, their hesitations during interactions, make them look like big dreamy animals, when all these movements actually come from a sophisticated mechatronic equipment, and from complex behaviour algorithms. Their various sensors make them reactive to light, to the human voice, and to many other stimuli, which increases their resemblance with living organisms. This resemblance makes them a perfect platform for exploring human robots interaction in an artificial intelligence, or even artificial life context. As it can be seen, the potential of the flying cubes in art, architecture and design is limited only by the creativity of the artists using it.

IX. Conclusion

The observations made in some of the last performances of the SAILS robots project were presented in this paper. From those observations we extracted some relevant conclusions to be exploited in the further developments of the human interaction of these aerobots, with potential generalization to other robots. The artistic or human-contact approach to develop new interactions interfaces and behaviours has proved extremely fruitful. We then described various possible applications in many different fields for a cubic autonomous or semiautonomous flying robot interacting with humans. The number of these possibilities will grow even more with further art and architectural explorations.

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Human-Robot Interaction in a Media Art Environment

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***Abstract*—This paper presents observations on the nature of interdisciplinary collaboration drawn from a seven year collaboration between a media artist and a group of roboticists. During this period the team created a series of robotic projects that have provided platforms for investigations on human-robot interaction in both the robotics and interactive media arts domains. A case study of one of these robotic installations, "Fish-Bird", is also presented and discussed.**

Keywords-cross-disciplinary collaboration, interactive media art, human-robot interaction

I. INTRODUCTION

This paper presents observations on the nature of interdisciplinary collaboration drawn from a seven-year art-science collaboration between researcher/media artist Mari Velonaki and roboticists David Rye, Steve Scheding & Stefan Williams at the Australian Centre for Field Robotics (ACFR) at the University of Sydney. During this period the team created a series of interactive installations that have provided platforms for investigations on human-robot interaction in both the robotics and interactive media arts domains. These interactive installations have been experienced by thousands of participants around the world, and have provided valuable data and observation of how people can interact with robots in socially empowered spaces. A case study of one of these interactive installations, "Fish-Bird", is presented and discussed. In 2006 the Centre for Social Robotics was founded by Velonaki and Rye in recognition of the need for a center dedicated to the research and understanding of human-robot interactions that occur in socially empowered spaces.

II. COLLABORATION

Our collaboration began in 2002, when Mari Velonaki visited the Australian Centre for Field Robotics (ACFR) at The University of Sydney to discuss possible collaboration on her new project, "Fish-Bird". Although Velonaki had extensively utilized technology in her work, Fish-Bird was a very ambitious project as it required the design and construction of two autonomous robots—thus the need for high level collaboration with roboticists. The project was enthusiastically received by David Rye, Steve Scheding and Stefan Williams. The team was drawn together through our shared passion in the area of human-robot interaction. Another important starting point for us was our interest in the creation of novel human-machine interfaces.

From Velonaki's point of view, the interest was in the creation of haptic interfaces that promote explorations of new models of interaction between the participant and an interactive kinetic object. The opportunity to place a robot in a public space such as an art gallery or museum was both attractive and challenging to Rye, Scheding and Williams. Gallery spaces are open to the general public, and attract a wide variety of visitors—from children to the elderly—so in a technologically-driven interactive artwork the human-machine interface must be intuitive and robust to unexpected events.

Early in our collaboration we began to converse, exchange ideas and investigate mechanisms for cross-disciplinary research funding. In 2003 we received one of the first two Australian Research Council Grants to be awarded for art and science research. This ARC/Synapse grant supported the creation of our first major project "Fish-Bird" (2003-06), an interactive robotic installation.

A. Interactive Media Art and Robotics

Itsuo Sakane asserted [1] that "all arts can be called interactive in a deep sense, if one considers viewing and interpreting a work of art as a kind of participation". While all art is open to diverse interpretations, interactive art is unique in that the audience explicitly requires proof that the work functions. If the technological apparatus that supports a media artwork fails, the artwork also fails. As David Rokeby [2] has noted, the onus is on the artist to convince the audience that the interface is working.

Roboticists are distinguished from many other scientists since in addition to their theoretical contributions they often generate new knowledge by building and demonstrating complex physical systems. In this respect, an analogy and a commonality that both disciplines share is that their ideas must be materialized into a physical implementation that must function reliably

B. Concerns and Challenges

Regardless of the degree of affinity that may exist between media artists and roboticists, we believe that the following elements are essential to a successful collaboration.

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- Shared & Individual Goals. It is important for a group to identify through discourse a clear, common goal and to commit as a group to attaining that goal. Within the group, participants should have their own individual goals that are not necessarily shared by the whole group. For example, the performance of the tracking algorithms in the "Fish-Bird" system is of direct scientific interest to Stefan. For Mari, on the other hand, although tracking accuracy is important for the integrity of the system and therefore the smooth operation of the artwork, continued advancement of tracking algorithms is not her personal goal.
- Trust. Exchange of skills alone is not sufficient to keep people working together. Compatibility of personality and agreement on basic ethical and ideological positions are essential prerequisites for building trusting, long-term collaborations.

It was clear from the beginning of our collaboration that a concerted effort would need to be made to construct a "common language" or "shared vocabulary". Unencumbered dialogue within a collaborating group is essential in developing a shared language. Wide cultural gaps can exist between disciplines, and are perhaps inevitable because of differences in acculturation and education. In our experience, problems with language most commonly occur when an unfamiliar terminology causes misunderstanding. A shared language is in turn essential in building a shared vision and trusting relationships within the partnership. It is our position that trust is central to an effective, mature collaboration—what Mamykina et al. [3] term a "full partnership".

Interdisciplinary collaboration is intrinsically a high-risk, high-reward activity: the potential benefits flowing from an innovative, creative collaboration are large, but then so are the potential risks that an unsound collaboration may not succeed. Using case studies, Candy & Edmonds [4] have identified three models of successful collaboration between artists and technologists. In related work Mamykina et al. describe a number of requirements for successful collaboration: a shared language with which to communicate and exchange creative ideas, extensive discussion between the collaborators, the development of a common understanding of artistic intentions and vision and the sharing of complementary knowledge and expertise. Mamykina et al. conclude that

> "The importance of creating an emotional as well as physical environment that encourages creativity should not be underestimated. The atmosphere of trust, encouragement, and risk-free exploration as well as incentives for creative investigation is a necessary part of any creative culture.".

We are in complete agreement with these observations. Let us consider some of the factors that appear to influence the outcomes of art-science partnerships. Firstly, recognize that "artists" and "scientists" have many similarities; to succeed in their disciplines, both must work in creative and innovative ways. This creativity may be manifest in very different forms in the arts and in the sciences. Furthermore, many artists and scientists work in an intuitive manner. Both scientists and media artists utilize technology as tools, and depend on that technology to work.

Substantial differences may exist between artists and scientists as their career/life experiences are likely to be quite different. Differing acculturation will also explain the (expected) differences in the professional language of their chosen disciplines. The artist and the scientist could be expected to have different motivations even when working on a common project towards shared objectives.

In any project that involves art and technology a tension may exist between what is possible technologically—within the limits of available resources—and the technology that is needed to realize the artistic concept. A scientist can be tempted to push technological boundaries, just "because it can be done". An artist, however, is rather more concerned to see their original concept realized as envisaged. At the commencement of a new project the team will generally not have a complete understanding of either the artistic vision or the technological possibilities. Open, fluent dialogue is needed to promote mutual understanding and develop a shared vision.

For an artist, working in a laboratory or industrial environment can be alien at first. Many artists create their work through solitary practice in a studio environment, and are inspired or driven by internal factors that they may not wish to fully articulate and communicate to others at the first stage of the creation of an artwork. Working in a laboratory environment will initially involve interaction with many new people who are not necessarily involved with his/her project, in surroundings that are unlike a studio. The artist must find new ways of working in this environment. In full art-science partnerships, working methods will be very different to those where a technologist assists an artist: for example, where a programmer visits him/her at a studio for a few hours only to perform specified tasks.

C. A Definition of Collaboration

There is debate in the area of art-science partnerships as to what actually constitutes "collaboration". In our projects, we have chosen to adopt the following definition. Our definition is deliberately broad, but is also altruistic: collaboration requires that participants interact as equals, respecting each other's strengths and experiences, and should explicitly acknowledge the contributions of all involved. In shared decision-making, there should be no need for any party to compromise. In a full collaboration, there needs to be space—a generosity of spirit—for discussion, accommodation and contribution from various points of view. The process of accommodation is quite different from compromise. Development of trust can lead to fruitful relationships within a team, with space for accommodation without the need for personal or professional compromise. We believe that this is essential in an engaged collaborative partnership.

Furthermore, we argue that the ultimate success or failure of truly collaborative projects, such as those described in following sections, is best measured by the scholarship of the project outcomes. We define "scholarship" in terms of the following: knowledge of "best practice" in one's own discipline; the advancement of "best practice"; and the dissemination and uptake of the research outcomes by one's peers. Scholarship therefore also implies legitimacy within the

discipline of each collaborating partner. We believe that artistic merit should not be the sole metric by which collaborative projects between artists and scientists are judged. True interdisciplinary collaboration demands that the disciplines of all contributors acknowledge the work as a "scholarly contribution". That is, from the viewpoint of each discipline the work has "value", in making an original contribution to the field.

III. Case Study: The "Fish-Bird" Project

"Fish-Bird" (Fig. 1) is an interactive autokinetic artwork that investigates the dialogical possibilities between two robots, in the form of wheelchairs, that can communicate with each other and with their audience through the modalities of movement and written text. The chairs write intimate letters on the floor, impersonating two characters (Fish and Bird) who fall in love but cannot be together due to "technical" difficulties[1].

Figure 1. Fish-Bird: Circle B -- Movement C (2005).

Spectators entering the installation space disturb the intimacy of the two characters, yet create the strong potential (or need) for other dialogues to exist. The visitor can see the traces of previous conversations on the floor, and may become aware of the disturbance that s/he has caused. Dialogue occurs kinetically through the wheelchair's "perception" of the body language of the audience, and as the audience reacts to the "body language" of the wheelchairs. A common initial reaction of Fish and Bird to the unexpected disturbance would be to correspond on trivial subjects, such as the weather… Through emerging dialogue, the wheelchairs may become more "comfortable" with their observers, and start to reveal intimacies on the floor again.

The dialogical approach taken in this artwork both requires and fosters notions of trust and shared intimacy. It is intended that the technology created for the project is largely invisible to the audience. Going further than a willing suspension of disbelief, a lack of audience perception of the underlying technological apparatus focuses attention on the poetics and aesthetics of the artwork and promotes a deeper experimental and/or emotional involvement of the participant/viewer

A. *The Wheelchair*

The wheelchair was chosen as the dominant object of the installation for several reasons. A wheelchair is the ultimate kinetic object, since it self-subverts its role as a static object by having wheels. At the same time, a wheelchair is an object that suggests interaction – movement of the wheelchair needs either the effort of the person who sits in it, or of the one who assists by pushing it. A wheelchair inevitably suggests the presence or the absence of a person.

Furthermore, the wheelchair was chosen because of its relationship to the human – it is designed to almost perfectly frame and support the human body, to assist its user to achieve physical tasks that they may otherwise be unable to perform. In a similar manner, the Fish-Bird project utilizes the wheelchairs as vehicles for communication between the two characters (Fish and Bird) and their visitors. Finally, the wheelchair also possesses an aesthetic that is very different from the popular idea of a robot, as it is neither anthropomorphic nor "cute". Given that a wheelchair is a socially charged object, the interactive behavior and the scripting of how the chair should move was developed in consultation with wheelchair users. The participants are actively discouraged from sitting on the wheelchairs: if a participant sits on a wheelchair a sensor embedded in the seat upholstery pauses the entire system until the participant vacates the wheelchair.

B. *Interface*

Movement and text are ancient interfaces that people respond to regardless of their gender or ethnicity. In the Fish-Bird project, the robots use movement to convey awareness – for example, they turn to face a person entering the installation space. Changes of speed and direction are used to convey mood and intention. A robot indicates dissatisfaction or frustration during interaction with a human or robot participant by accelerating to a distant corner, where it remains facing the walls until its "mood" changes.

The manner in which the participants move in the space, their proximity to the robots, and the time spent with them determines the behavior of the robots towards them. In a way, human participants try to read the "body language" of the robots and the robots the body language of the participants. Fish-Bird has seven behavioral patterns based on the seven days of the week. For example, they seem to be more "happy" and "energetic" on a Friday and they tend to be more "lethargic" on a Monday. The way that the robots interact with a participant depends on six basic conditions: a) the day of the week; b) the state of the "relationship" between the robots; c) how they "feel" about themselves; d) how much time the participant spends in the installation space; e) his/her proximity to the robots and f) his/her "body language".

[1] The artwork was inspired by a contemporary Greek fairy tale about a fish and a bird who fall in love, but can't be together—one needs water, and the other air, to live. Nevertheless, they learn to coexist despite their differences.

Overt communication between the robots and human participants occurs through the medium of written text. Miniature thermal printers integrated with the wheel chairs to produce the "handwritten" text. A text phrase is assembled from digitized bitmaps of the glyphs in the chosen fonts, and printed sideways onto a slip of paper that is cut and released to fall to the floor of the exhibition space. Many of these slips of paper can be seen in Fig. 1. Each wheelchair "writes" in a cursive font that is selected to reflect its "personality". Different fonts also serve as a practical cue that assists the audience to identify existing text written by a particular character.

Each wheelchair writes in a cursive font that reflects its "personality". Different fonts also serve as a practical cue that assists the audience to identify existing text written by a particular character. The written messages are subdivided into two categories: personal messages communicated between the two robots, and messages written by a robot to a human participant. Personal messages are selected from fragments of love-letters offered by friends, from the poetry of Anna Akhmatova [5], and from text composed by Velonaki. The system also composes text (approx. 10%) in real time.

C. Realization

The robots and their audience are tracked in the installation space using a distributed data fusion system driven by four cameras mounted on the ceiling of the installation space, together with two scanning laser sensors that are concealed on the perimeter of the space. Movement of the wheelchairs and text generation is determined by a behavior module that executes on an installation control computer. The behavior module takes as its input instructions from a text script, processes the input using finite state machines (FSM) for both wheelchairs, coupled with a vector force field (VFF) path planning algorithm, and generates outputs in the form of velocity and turn rate instructions for the robots together with text phrases to be printed. Each state corresponds to a behavioral primitive, or action, such as "sleep", "talk", "gaze", "follow", and so on. Transitions between the various states are handled by the behavior module, and both the conditions that cause state transitions and the transition target states are specified by a scripting language. Some pre-planned motion sequences are executed under direct control. The motion instructions and text phrases are transmitted to the wheelchairs using Bluetooth wireless links, and robot internal states are returned via these links.

Fish and Bird have primitive "emotions" encoded by ternary logic states F_F, F_B, F_P, B_F, B_B and B_P that represent how each wheelchair "feels" about itself, about the other wheelchair, and about the participants in the space. A value of +1 represents a "positive feeling", 0 is neutral and –1 encodes a "negative feeling". The emotion states are used to shape the sources and sinks that generate the VFF and to select appropriate text output. Transitions of the FSMs are triggered by actions of people in the space, moderated by the emotional state vector.

D. Challenges

The exhibition of media art in a museum provides many significant challenges because of operating conditions. Once an interactive artwork is installed it is expected to operate without any intervention from the gallery: more than eight hours per day, seven days per week, for a duration of one to four months. During this time the artwork will be visited by thousands of people. These untrained members of the general public may find themselves interacting with a robotic system which must behave in "interesting" ways and function reliably.

During an exhibition it is the gallery attendants or security personnel who will be responsible for starting up and shutting down the interactive installation. It cannot be assumed that these personnel will have any special technical expertise so that the system must be designed to be very simple to shut down and start up.

Achieving sufficiently high reliability to operate successfully under these constraints is a significant challenge to contemporary robotics science.

Software that determines the behavior of a robotic is specialized, and it is quite unrealistic to expect an artist to work with a programming language in the same way as a computer programmer would. Instead, a state-based, non-blocking scripting language was devised for the Fish-Bird project to facilitate composition of system behaviors from behavioral primitives. That is, the language provides a high-level compositional interface to the robots. This procedural language allows complex interaction with audience participants to be encoded, and behaviors to be implemented without changing or rebuilding the code base of the system. By specifying the conditions that trigger state transitions of the robot's FSM, "stage directions" can be given to the robots, readily creating complex behavior patterns.

Many aspects of the Fish-Bird system design are strongly influenced by the desire to conceal the underlying technological apparatus. It should not be obvious to a spectator/participant how a wheelchair moves, promoting rapid engagement with the work and focusing attention on the form of interactive movement. As a consequence of this conceptual and ideological consideration, standard electrical wheelchairs could not form the basis of the autokinetic objects in the artwork. A wheelchair together with all associated electronics and software were custom-designed for the project.

Because the wheelchairs were specified to operate for up to ten hours per day a large volume was required for on-board batteries. Approximately two thirds of the volume under the seat of a wheelchair is filled with battery packs, and the design of hardware and software for power conservation was relatively important. Most of the system sensors are mounted off-board, minimizing the on-board power storage requirements. This decision also allowed a much wider variety of sensors to be used for tracking human and robot participants in the installation space.

E. Observations

To date, the "Fish-Bird" robots have been exhibited in five countries (Australia, Austria, China, Denmark and USA) and have interacted with more than 75,000 people. Tracking information and dialogues during these interactions have been logged to a hard disk, resulting in many gigabytes of experimental data. These data have been supplemented with interviews with people after they have interacted with the Fish-Bird robots, as well as personal observations.

One of our findings is that people in all five countries reported that they were attracted to the robots not because of the way that they looked, but because of the way that they behaved.

The first cue for engagement, from the participants' point of view, was commonly the realization that the wheelchairs/robots were responding to them in real time, rather than moving in a repetitive automatic manner. For example, as soon as a visitor enters the installation space the wheelchairs turn to "face" him/her. We classify this first stage of engagement as the state of "Interest".

The second stage of engagement is that of "Exploration" – the viewer becomes a participant by moving with and sharing the same physical space with the wheelchairs/robots. This physical engagement creates the opportunity for many interesting dialogues to emerge between the participants and the robots. In this stage we observe physical experimentation by the participants in their efforts to interact with the robots. For example, making sounds such as clapping their hands or talking with a variety of different intonations to attract the attention of the robots. The participants also experiment with physical proximity to the wheelchairs and manner of movement, changes of body stance, hand and arm gestures.

The third stage of engagement is that of "Emotional Involvement" – the participant discovers that the wheelchairs are capable of communicating with him/her via written text. S/he discovers that the wheelchairs release small pieces of paper that contain personal messages in a "handwritten" manner. The content of these messages—stories of unrequited love, comments about the weather, requests to set the wheelchairs free—trigger the participant's emotional response. Of the 163 participants whom we have interviewed, 160 stated that they felt empathy for Fish and Bird caused by the messages that they received from the robots. All participants chose to take their messages with them when leaving the installation space, as a memento of their encounter with Fish and Bird.

Even in the early stages of the project when the robots' behaviors were relatively primitive, participants tended to interpret some of the robots' actions in terms of their own prior experience with people or animals. People would talk to them, pat them and ask them questions like: "Are you afraid of me?" or "Do you like me?". They often think that the robots are capable of more than they actually are.

Children in general have been gentle with Fish and Bird. They tended to pat them, and even kissed the robots to encourage them to print more messages.

Figure 2. "Fish-Bird" interacting with children, NSW Parliament House.

CONCLUDING COMMENTS

This paper has shown through example that it is possible for artists and roboticists to work productively together in a way that advances understanding of human-robot interaction. Successful collaboration requires the development of a shared vision within a cross-disciplinary research team, and it is important to cultivate trust and a shared understanding of language so that this shared vision may be realized.

As the technological capability of robots increases, and interactions between humans and robots become more complex, it is important for researchers to consider the potential for an emotional connection that may exist between a human and a robot.

To this end, we are currently working on a new project that aims to create a wheeled humanoid robot. It is a five-year project that aims to investigate intimate human-robot interactions in order to develop an understanding of the physicality that is possible and acceptable between a human and a robot. The project seeks to answer the key question: Can emotionally-driven human-to-human physical interactions serve as models for analogous interactions between humans and robots?

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Expressive, Interactive Robots: Tools, Techniques, and Insights Based on Collaborations

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***Abstract*—In our experience, a robot designer, behavior architect, and animator must work closely together to create an interactive robot with expressive, dynamic behavior. This paper describes lessons learned from these collaborations, as well as a set of tools and techniques developed to help facilitate the collaboration. The guiding principles of these tools and techniques are to allow each collaborator maximum flexibility with their role and shield them from distracting complexities, while facilitating the integration of their efforts, propagating important constraints to all parties, and minimizing redundant or automatable tasks. We focus on three areas: (1) how the animator shares their creations with the behavior architect, (2) how the behavior architect integrates artistic content into dynamic behavior, and (3) how that behavior is performed on the physical robot.**

I. Introduction

Creating a robot to expressively interact with humans poses a novel set of challenges: designing a physical robot capable of compelling motion; animating expressive physical motion for that complex interactive robot; and combining this expressive motion with the robot's functional control to produce interactive behavior.

In an entertainment or motivational context, providing a compelling interaction through expressive behavior may be part of a robot's primary function. Even in purely utilitarian contexts, the robot's ability to express hidden states to a human partner can facilitate the interaction. For example, a robot learning from a human may benefit from more accurate, faster feedback about its errors if the human can readily interpret the robot's intentions.

Traditional motion control approaches fall into two extremes. *Functional* approaches, such as Inverse Kinematics (IK), provide accurate, dynamic solutions but have no mechanism to create natural looking, expressive motion. *Scripted* solutions, as used in animatronics, can be used to create lifelike motion by replaying animations, but they make it difficult to interact or vary performance (as well as often requiring the animation author to learn an ad-hoc tool specific to that robot). Our strategy is to work with skilled human animators, who provide the expressivity of the robot, while providing mechanisms to enable dynamic, responsive behavior.

In combining these approaches, we must embrace the reality that experts with different backgrounds must collaborate to make expressive, human-interactive robots possible. Like animatronic robots, they need to move in a reactive and lifelike manner, employing gestures and nonverbal behavior fit for human interaction. But due to their existence in real-world environments, they must also relate to their environment and interact functionally with the world around them. This paper describes our own method for breaking down this process among experts, and the lessons we have learned about how to allow them to best work together to produce a compelling, expressive system.

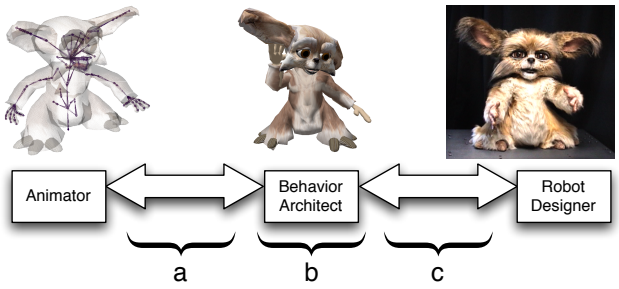

Fig. 1. Experts from three fields collaborate to produce an interactive robot with expressive behavior. This paper covers lessons learned and tools developed from our experiences with these collaborations, focusing on the parts shown: *a)* interface between animator and behavior architect, *b)* mechanisms to produce dynamic behavior using animated content, and *c)* the interface between behavior architect and physical robot.

The roles we will describe here are the animator, behavior architect, and designer of the physical robot. Our motivation is to enable each of these collaborators to have the most flexibility in their work and to limit the constraints placed on them to ones that productively define the capabilities of the system. We want the animator to be able to use the tool they are most familiar with. We want the behavior architect to have access to any mechanisms helpful for creating dynamic, interactive behavior. We want the designer of the physical robot to employ any complex mechanisms that are necessary, free of worry that complicated mechanisms will frustrate the animator or behavior architect. The goal is not to hide the limitations of the robotic system from the other collaborators - quite the opposite, we believe making these limits as visible as possible will aid the creation of the best, usable content.

We do, however, seek to shield each from complexities of implementation and control that would complicate their work without benefit. This interaction is pictured in figure 1.

Across all of the mechanisms, we have a consistent set of goals:

- *Best Tool/Technique for the Job*: Allow each collaborator to employ whatever tools/techniques they need. Excellent animation tools exist, and we should be able to leverage these tools and the artist's familiarity with them. The behavior architect should be provided with the best mechanisms possible to mix, blend, and combine animations to get the behavior they want. The robot designer should build the robot without constraining their creativity based on a certain control structure.
- *Playback Consistency*: The correlation between the robot motion as viewed in the animation authoring tools, the tools used by the behavior architect, and the performance on the actual robot should be clear and predictable.
- *Manage complexity*: Each collaborator should have access to as many useful constraints, data, and meta-information as possible, but not be burdened with arbitrary complexities.
- *Safety*: Animation/behaviors should be safe when played out on the robot. The authoring tools and—more critically—the execution systems should take into account the robot's physical limits: self-collision, joint limits, cable limits, workspace collision, and safe velocity and acceleration bounds.
- *Scalability*: Provide scalability (both in allowing high degrees-of-freedom robots, and in the capability to transfer the system between robots) by automating processes and facilitating the sharing of information/data among collaborators.

Covering our approaches to these requirements brings us through sections III to V, where we follow, step by step, the progression the animated content takes on the way to the robot: starting with the animation tool, making its way into the behavior engine to be re-mixed and blended, then finally off to be transformed into data necessary for the physical robot.

The system we will describe here is not the only way to accomplish these goals, and there is always room for improvement (see section VI). However, we feel we have assembled a set of tools/techniques that hits an important "sweet spot", greatly advancing possible collaboration between people in these three roles.

In section III, we describe the interface between the animator and behavior architect, which is designed to eliminate any redundant setup work, allow them to share an intuitive view of the joints of the robot, and allow the animator to prototype/author animations while also providing appropriate behavioral hints.

In section IV, we describe the tools available to the behavior architect which relate to authoring motor behaviors through combining animation data in different ways.

In section V, we describe the interface between the behavior architect and the physical robot, which is designed to abstract complex linkages, real-time concerns, and calibration issues away from the day to day work of the behavior architect.

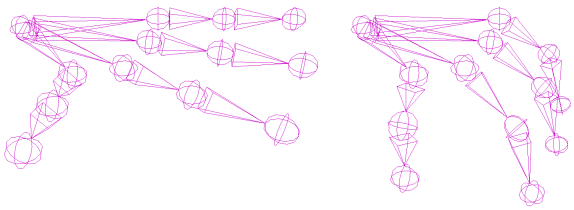

Fig. 2. In order to achieve an evenly bending finger, the model contains multiple joints linked down the center of the finger. These joints bend simultaneously causing the finger to curve.

II. Physical Platform

While these collaboration techniques were first attempted with a 13 Degree of Freedom (DoF) robot called "Public Anemone" [1], the first robot to push the development of much of the automation and abstraction was the much more complicated 65 DoF Leonardo [2]. These tools have also been used in robotic projects such as Aida, Aur [3], the Huggable project [4], the Operabots project, and Nexi.

III. Connecting Animator to Behavior Designer

In this section, we describe insights and techniques based on our work collaborating with animators to create expressive yet interactive behavior for robots. At the minimum, it is necessary to share 3D models and animations between the animator and the behavior architect. However, we have found that sharing additional information such as simplified DoF abstractions, joint constraints, and meta information about the animations enhances the collaboration, without increasing our commitment to a particular animation software package.

A. Abstract File Formats

To create a clean interface to any authoring tool a professional animator might want to use, we created file formats for representing 3D models and animations. The only restriction on authoring tools that can be integrated into our pipeline is that they provide plug-in capability to access and export the 3D models and animations. This provides the flexibility to switch to new authoring tools as they become available. Currently, such plug-ins have been written for Maya and 3D Studio Max.

B. Abstracting DoFs from Skeleton

We use the "skeleton" modeling technique, where a robot is represented as a hierarchical skeleton of joints connected by bones, with the visible surfaces of the 3D bot driven by the motion of these underlying joints. Because of the way skeleton modeling functions, an animator might be forced to model certain DoFs in a fairly complicated way, e.g. figure 2 and 3. These methods both use multiple joints in the animation tool to model what the animator and behavior architect would prefer to think of as a single DoF. Luckily, the animation tools

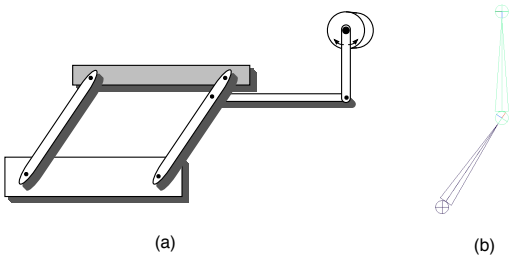

Fig. 3. (a) In a four-bar linkage the effector (shaded) stays parallel through its motion. (b) This is approximated in the 3D authoring environment by using two joints, where the child joint is programmed to compensate for the rotation of the parent.

all include mechanisms for the animator to make an interface to move those joints as a single element.

Unfortunately, this wouldn't help our behavior architect, because whatever interface is added in the animation tool to facilitate this process won't exist in the raw 3D model exported to the behavior engine, and so any procedural moving of the DoF in question would involve keeping track of all its component parts.

We want the same simplified controls the animator created in the authoring tool to become available for manipulation of degrees of freedom programatically by the behavior architect. Since the animator has already done the work of defining these controls, instead of having our behavior architect redefine them we can export this information from the animation authoring tool.

There are many different ways the animator might accomplish tying multiple joints into one scalar control. We wish to remain agnostic to the specifics of the animation tool and to the method used by the animator to tie the joints' motions together. So, instead of attempting to process and export the animator's custom interfaces directly, we resort to using a "calibration animation."

C. Calibration Animation

It is important for the animator's model to include the correct axes of rotation and joint limits for the joints of the robot. The animation authoring tools tend to have a good UI for manipulating these joint parameters, so we use the animator's 3D model of the robot as the canonical repository of this information. Keeping the animator's model as the canonical repository of this information ensures that the animator has access to all the known information about joint restrictions, decreasing the chance of creating animations that will not run correctly on the robot.

However, these parameters are also required for the operation of the behavior engine (and we wish to avoid error-prone manual replication of information). In an effort to stay agnostic towards any specific authoring tools, our architecture uses a calibration animation to obtain specific attributes about the robot's configuration instead of deeply inspecting the 3D model within the animation tool. The authoring tool simply outputs an animation where every DoF is moved individually

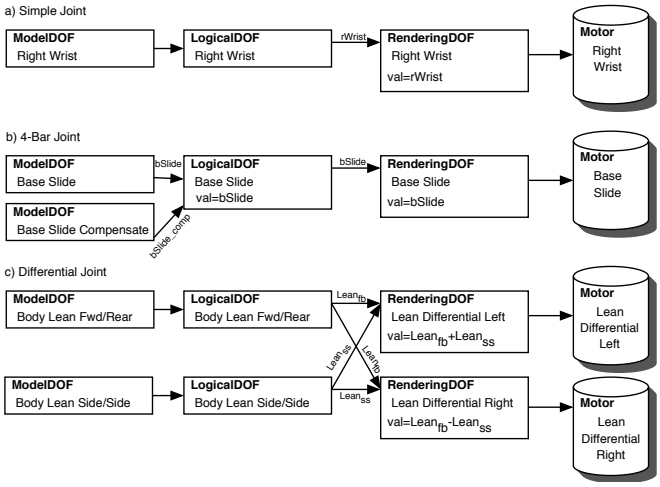

Fig. 4. `LogicalDoF`s interface between the—sometimes unintuitive—3D model of a degree of freedom and the—also possibly unintuitive—mechanical linkage that moves that DoF, providing a simple scalar value controlling a "logical" degree of freedom.

to its limits (which for some could represent movement of multiple model joints, if the animator has set up a complex DoF as described in the previous section). Our system reads this calibration animation and uses the motion contained within to define the joint axes and joint limits, as well as to discover which joints are tied together as one DoF (and in those cases, figure out the mapping of how they are correlated).

D. Logical DoF Representation

Once the behavior system is able to pull DoF information out of the calibration animation, it can store all this information in a *LogicalDoF*. The role of the *LogicalDoF* is to store all the relevant information that the animation tool had about the DoF (including limits, axes, and any DoF simplification controls added by the animator to abstract multiple joints as one DoF), and present it as an intuitive interface to the behavior architect. In this way, instead of being faced with potentially messy joint setups necessitated by skeleton modeling, the behavior architect is presented with a similar interface to the one the animator had created for themselves: a single scalar value per DoF. This process is shown in the left-hand-side of figure 4 (the right hand side will be covered in section V).

E. Animating Joint Priorities

Our robots frequently have to perform multiple different motions at the same time: for example, a robot might be running an animation that extends its right arm for a handshake while maintaining eye-contact with a person. In this example, one part of the robot is controlled via animation while the other is controlled using functional control with sensor feedback. In many cases these situations are handled by the blending systems in section IV without intervention of the animator.

However, we find that since our robots are employing a procedural orient behavior at almost all times, it can be helpful

to provide the animator a mechanism to specify when certain joints normally overridden for orienting the robot are required for the expressive purpose of the animation.

For example, if an animation includes an "eye roll", it is imperative that at that moment the animation have full control over the eyes (the robot must momentary cease any eye orientation behavior it is performing). To address this need, we provide a mechanism for the animator to specify the importance of certain DoFs to the success of the gesture. This mechanism is implemented as a set of special, invisible joints whose value, instead of indicating a rotation or translation, indicates the animation's desire for full control over a particular DoF. This implementation allows the animator to vary the ownership of a DoF over the duration of an animation, so the joint is only seized for the short time it is required. Also, this strategy means that the ownership data will be automatically included in any exported animation file without any authoring tool modifications.

IV. Tools For the Behavior Architect

The role of the behavior architect, as it fits into the structure we are proposing here, is to create the system which will drive the real-time behavior of the robot. This could take many forms, with varying levels of autonomy, but here we're focusing in particular on how the work of the animator can be used to create expressive behavior for the robot, while allowing for the flexibility of control required for an interactive robot. This section covers the common types of motion we have had our robots perform, and the tools we provide the architect to accomplish these motions utilizing the animations from the animator. Many of these techniques were developed for graphical characters, and are adapted from [5].

A. Kinds of Motion

We have found that a robot interacting with a human counterpart needs to be able to move in four distinct ways:

1) Gestural: First, a robot is expected to express its internal state through understandable social gestures and communicate ideas in verbal and non-verbal ways. This calls for a system that enables an animator to author natural looking *gestures* and behaviors to be played out on the robot. These motions are typically iconic gestures like thumbs-up, shoulder shrug, nod, and eye-roll.

2) Functional: As a physically embodied agent, the robot needs to be able to engage in *functional* motion relating to objects in the robot's workspace and human counterparts. Touching and manipulating objects and gaze fixation are examples of such motion.

3) Procedural Expressive: A third motion requirement may be called *procedural expressive* motion. These are motions that are mostly expressive in their function, i.e. not related to an external object, but are too variable to be authored as complete fixed gestures. An intermittent blink behavior, an ear twitch in response to a new sound, and an overall body posture indicating an emotional state are some examples of procedural expressive motion.

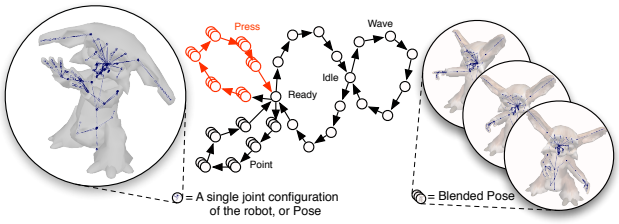

Fig. 5. Posegraph representation of imported animation data. Each node either represents a single pose of the robot, or a set of example poses that can be blended together at runtime based on input parameters.

4) Parameterized Gestures: Finally, *parameterized gestures* are required when an action may be performed in a number of ways, and it is desirable to form a continuous, parameterized space of actions rather than rely on choosing amongst a few discrete examples. We have used this method, for example, to create a continuous space of pointing gestures which allow the robot to point to an arbitrary location while maintaining the expressiveness of the original, discrete set of hand animated motions.

B. Realizing these Kinds of Motion

This section covers mechanisms to produce each type of the above motions individually. However, to create interesting behaviors, several motions may need to occur simultaneously which will be explained in the next section.

Our basic representation for positioning the robot is through a posegraph [6] (figure 5). In this graph, each node represents a pose of the robot, and the (directed) edges represent allowable transitions between poses. An animation, then, is loaded into this representation as a series of connected poses.

Gestures can be performed by simply traversing the appropriate series of poses in the posegraph. The connections between an animation and the rest of the posegraph are accomplished manually - this gives the behavior architect control of what transitions between animations are allowed based on their appropriateness to the behavior of the creature.

Parameterized gestures are created by authoring multiple versions of the same gesture, and blending them together based on a set of parameters provided in real-time (in the manner of verb/adverb actions [7]). This blending happens within the nodes of the posegraph. These blended nodes, instead of representing a single static pose, each contain multiple poses that define a blend space. Whenever a blended node is traversed, external parameters indicate a position in this blend space, and the node reads these parameters to produce the resulting blended pose.

Functional motion can be determined by direct IK calculations given the kinematics of the robot and the goals of the action. This often results in undesirably robotic motion, so to realize a functional goal (such as touching an object) we combine the IK calculation with *parameterized gestures*. These gestures are used to get as close as possible to a goal condition, then IK can take over to fulfill the goal with minimal

disruption to the expressive behavior of the robot.

Procedural expressive motion, while it describes different motion scenarios than the above categories, can be implemented as special cases of the above techniques. Many situations in this category can be described as a need to blend immediately between two static poses, for example, a blinking eye, or a slight "perk up" in response to an audio signal. These cases can be seen as a trivial case of *parameterized gestures*, where the change in parameter controls the motion and the example animations themselves contain no motion. For example, a blend parameter might control the blend space from example animation "eyes open" to example animation "eye closed", allowing for procedural blinking.

C. Combining Simultaneous Motions

The above section covered each category of desired motions individually. In general, however, the robot's behavior will call for executing a number of motions simultaneously. We have found that there are several ways in which we find ourselves routinely combining different motor behaviors.

1) Multiple Gestures: In a simple posegraph, the robot has one "play-head" which represents its current position as it traverses the graph. This can be limiting, because the robot may well wish to perform two gestures (parameterized or simple) simultaneously on different body parts (e.g., nodding while pointing). For this reason, we allow multiple "play-heads" to simultaneously traverse the posegraph. However, each gesture, or path through the graph, will have an associated set of preferences over what joints it requires. This allows the robot to play two compatible gestures simultaneously, and prevents it from initiating a gesture which requires joints that are currently in use. The set of required joints can be specified manually, however usually it can be assumed to be the set of joints that move during that animation.

2) Postural Overlay: As opposed to the gestures above, a postural overlay is an animation (or blended space of animations) which is designed to be applied to the DoFs of the robot all the time, even when gestures are happening. The posture often is used to reflect the emotional state of the robot. Just as with "multiple gestures" blending, a new "play-head" is required which will play this overlay animation at the same time as gestures or other activity is taking place. However, instead of taking full control over specific DoFs, the overlay is designed to be applied with a very light weight to all the DoFs of the robot, thereby slightly changing any gesture the robot performs. This is done by simply blending the postural animation with the gesture, using a very light blend weight. Gestures also have the option of locking out this postural overlay for specific joints, if their absolute position is critical (e.g., when reaching for an object, ancestors of the robot's hand must maintain their exact position).

3) Idle Overlay: An idle overlay can give the creature an appearance of life even when it is not actively executing a gesture. This type of overlay keeps track of which joints have not been claimed by any active gestures, and applies the current pose from an idle animation to those joints. We typically use an idle animation which simulates gentle breathing motions.

4) Procedural Overlay: Finally, any desired procedural overlay can be applied. One type of procedural overlay is the IK system for fine control of the robot's hand position. However, our most used procedural overlay is the orient system which the robot uses to look at a target. This system determines which joints it currently has access to based on the preference set of the current gestures, and then uses the joints it can access to orient the eyes and body as best it can towards the target. Because the robot is constantly looking around, we provide a special channel here to give the animator direct control over this behavior (section III). This allows the animator to control this important aspect of the animation's performance; instead of animating just the position of the eyes, they can also animate the transitions between procedural and animated content for them.

D. Types of Blending

There is an important distinction between additive and weighted-average blending, we have found it is important to provide both as options to the behavior architect. Weighted average blending is useful for combining multiple animations into a resulting animation that has aspects of all of the inputs, where each joint position will lie somewhere between the example positions.

Additive blending, on the other hand, is useful for offsetting animations so they are fully performed but from a new starting position. This is particularly useful to apply to the torso and neck areas of the look-at behavior of the robot. For example, when performing a nod and looking at a person, using additive blending the robot will perform the full nod in its current orientation. In a weighted average blend system, it would have to either fully center itself to perform the full nod (turn look-at off), or do a blend and get something halfway between a centered nod and an unmoving "look to the right" pose (a half-height nod oriented half-way to target).

V. Connection to Physical Robot

Just as section III discussed 3D model implementation issues that produce unnecessary complications, the physical mechanisms of the robot can also give rise to certain complexities that could burden the behavior architect or the animator. In this section, we describe some of the requirements of controlling a physical robot, and how we use the interface between the behavior system and the robot to model these complexities and shield the behavior architect and animator from needing to consider them in their daily work. This means that the robot designer need not be constrained by the preferred tools of the other collaborators, nor are the other collaborators inconvenienced by the complexities introduced by the robot designer.

A. Model / Motor Discrepancies

The most common DoF is a single motor controlling a single rotation, mirroring the simple representation in the

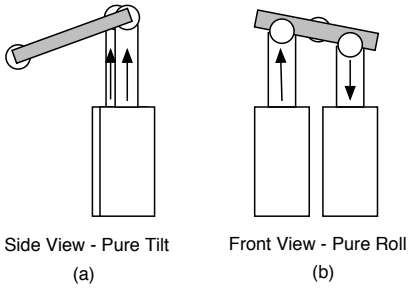

Fig. 6. A differential linkage prohibits mapping a single motor to a single DoF's movement. Both motors need to move in symmetry to achieve tilt motion (a) and in anti-symmetry to roll (b).

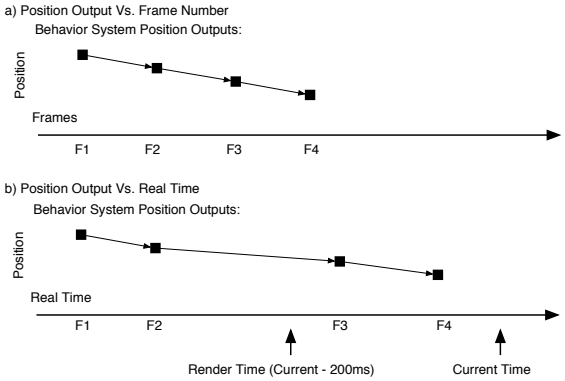

Fig. 7. A) shows the position output of a DoF from the behavior system plotted against frame number. We can see that there the DoF has a constant velocity B) shows the position output of a DoF from the behavior system plotted against real world time. We can see that although the DoF has constant velocity with respect to frame number, the real DoF velocity changes when there are fluctuations in duration of a frame.

behavior generation system. However, other linkages are more complicated.

There are many interesting linkages that occur throughout the robots discussed here, but a good example is a differential linkage (Fig. 6), which is often used to control two DoFs in a torso or neck where movement both forward/back and side-to-side is required. As shown in the figure, the *LogicalDoF*s of forward/back and side-to-side do not map cleanly onto individual motors - each direction requires motion from both of the motors. Explicitly representing the motors of the differential is not useful, and is somewhat confusing, for both the animator and the behavior architect. For this reason, we have the *RenderingDoFs* on the right hand side of figure 4. Each physical motor has a corresponding *RenderingDoF*, and its job is to acquire and transform data from one or more *LogicalDoFs* into the form needed by that motor.

Thus, in the behavior system, the data is represented in its most intuitive "logical" format, with one *LogicalDoF* for each of the logical degrees of freedom of the robot. The *RenderingDoF*s serve as the mechanism to transform the data into the format used by the actual motors of the robot. These complete the three stage system from figure 4, where each stage serves to abstract unnecessary complexities away from the collaborators.

B. Real-time Control

Updating the target position for a motor must happen at a regular, high frequency to produce smooth motion. Updating as slow as 30hz, a reasonable update rate for computer graphics, can introduce visible and audible jittering in a motor's performance. However, it is undesirable to insist on a precise, 60hz or greater update from the behavior engine. Depending on the interaction, it may have a large amount of processing to do, which could put a cap on its maximum frame-rate. Further, without a real-time operating system there is no guarantee that the updates will come at precise intervals.

We address this problem with a "Motor Rendering" layer that buffers data from the behavior engine. This layer introduces a 200 ms delay with its buffer, but it allows the data to be read at whatever frame-rate the motors require by upsampling with spline interpolation.

An additional problem we face with our system is based on an internal assumption that the time between each update is precisely 1/30th of a second. Using virtual-time in the system greatly simplifies certain calculations (as well as aiding in debugging), but it can introduce velocity discontinuities if the updates happen somewhat irregularly on a taxed computer (figure 7). To allow the behavior architect to continue to work in this simplified virtual-time, but to preserve joint velocities, we introduce the *timewarp renderer*.

The *timewarp renderer* takes in position samples from the behavior engine and places them in the interpolation buffer (just as described above). However, instead of placing them in the buffer at the current time, it places them at even 1/30th of a second intervals (despite the fact that they arrive irregularly). Then, by the time the read head travels through that buffer pulling out upsampled data for the motors, the behavior engine's samples are neatly arranged as if they came in at precisely 1/30th of a second intervals, and constant velocities are preserved.

The timewarp renderer must perform one more critical step: keep the read head from catching up to the write head (underbuffer), or falling too far behind (overflow), as would happen if the average speed of the behavior engine changes from the declared 30hz. This can be achieved by applying a scaling factor to the $\Delta real - time$ value used to advance the read-head between reads. This factor can be used to keep the buffer close to a desired size, but care should be taken to keep this value well filtered - if it changes too quickly, it creates the same velocity discontinuities we are trying to prevent.

C. Model/Robot Calibration

We have found it crucial to maintain an animated model that is as true to the physical incorporation of the robot as possible, in *structure*, *dimension*, and *movement*. While this seems obvious, we stress that in order to bridge the inherent differences between the virtual model and the robot, we have gone to great lengths to create a feasible mapping between the

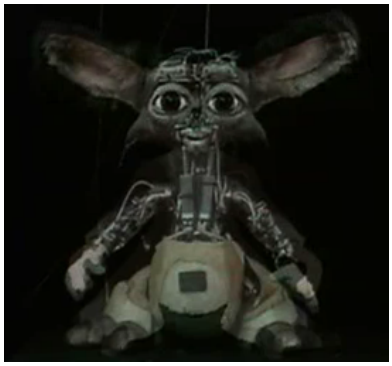

Fig. 8. Transparent rendering of 3D model of robot overlayed on live video feed. Useful for calibration.

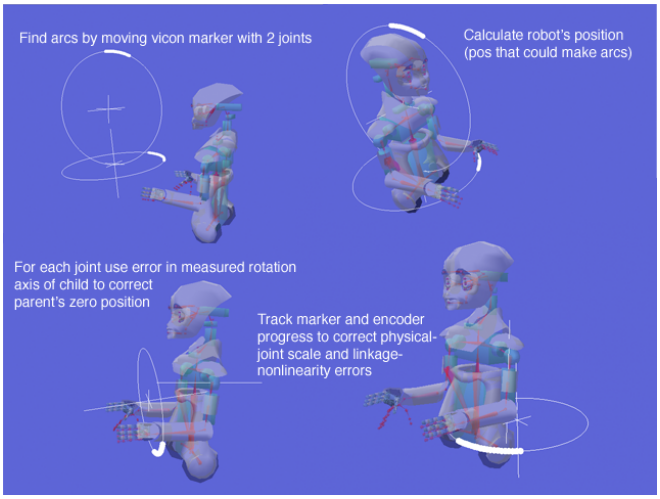

Fig. 9. Joint mappings and zeros calibrated by optically tracking a single marker.

euclidean joints representing the virtual model and the various physical controls that drive the robot.

In the past, we have found that a poorly matching model results in a severely hampered workflow, due to the misrepresentation in software of the actual result of the robot's physical motion. This violated not only the *playback consistency* authoring requirement but also affected safety calculations, as it was hard to evaluate from the virtual models when the robot would self-collide or reach other physical limits. In addition, a poorly calibrated model results in a highly iterative authoring process, requiring manual adjustment of uncalibrated animations until the desired physical result is reached. This also imposes unnecessary wear and tear on the robot.

The minimal parameters needed for calibration are offset (offset from zero position in the 3D model to the zero position on the physical robot's encoder) and scale (encoder ticks per radian). For complex linkages, the relation of radians traversed at the end effector to encoder ticks traveled on the rotation sensor may be nonlinear - in this case, a linear scale may not be sufficient. For many joints, a combination of calculation (eg. known encoder/gearbox parameters) and observation (visually lining up zero positions) may be enough. However, this can be become tiresome for a robot with many DoFs, or it may not provide the necessary accuracy.

1) Video Calibration: For joints that cannot be clearly described in terms of radians (e.g., a paddle that moves skin on a robot's cheek), visual scale and offset calibration are required. One technique that can facilitate this process is a video overlay (see figure 8). In this strategy, the camera parameters of the virtual camera are aligned with those of a real camera, and the two images are overlaid using transparency. This allows for straightforward tuning of calibration parameters with less reliance on subjective assessments.

2) Motion Capture based Calibration: For joints that can be clearly described in terms of rotation, optical motion capture can be used to automatically calibrate offset and scale (or a more complicated non-linear relation, represented as an interpolated map of example correspondence points). To minimize requirements on the physical robot, our technique requires a single trackable marker to be placed on an effector, and no access is required at pivots or joint axes. (See figure 9).

First, the two joints closest to the model's hierarchical root are used to precisely calculate the position of the physical robot (allowing the 3D model to be aligned for the next steps). This can be done by rotating these two joints through their range, with a marker mounted somewhere on their descendants. This will create two arcs that will define a single valid position for the robot.

For each joint that needs calibration, rotating the joint through its range will cause the marker, mounted on the final end effector, to traverse through a set of points. Those points will define a circle, and if each point is recorded along with the encoder reading at that time, the radians traversed can be matched against encoder ticks traveled, and these can generate an encoders-to-radians scale, or even a non-linear mapping useful for that joint's calibration.

Further, the line passing through the center of the circle (perpendicular to its plane) is the axis of rotation for that joint. The difference between this observed axis and the expected axis (calculated from the 3D model) indicates the zero offset necessary to correct the zero position of the joint's parent (assuming grandparents and further ancestors are already calibrated)

D. Flexibility

Robots and their behaviors in the context of HRI research can often be a moving target. As projects evolve requirements can change, hardware failures can occur, and mechanisms can be redesigned. We have found that maintaining an abstraction layer between the representation of the robot model used in the behavior system, and the mechanism for rendering motion data out to the physical robot through *RenderingDoF*s can be quite useful. Calibration, joint interdependencies, and non-linear linkages all are handled here, and thus many changes to the physical structure of the robot will not affect the behavior engine or animator. Of course, if there are significant changes

that actually change the morphology, they will need to be carried all the way through so that each collaborator has a correct kinematic model.

E. Safety

Experimental robots actively used for research are subject to damage through standard wear-and-tear as well as unsafe usage. Also, the possibility of causing such damage can slow development, as users of the robot will have to be cautious about every new change. Therefore, integrating a safety layer protecting the robot from harm not only will save time and money in robot repair but also allow the animator and behavior architect to work faster and more freely.

We currently do not have a foolproof system to prevent all kinds of damage to the robot, and this is definitely an area where we could benefit from more work to achieve our safety goals outlined in section I. However, we do employ a number of heuristics that help keep the robot safe.

1) Simulator: The first line of defense is the correspondence between the 3D model and the physical robot. This allows the animator and the behavior architect to prototype new animations and behaviors before ever sending them to the robot.

2) Constrained Generation: In some cases, the mechanism we use for *parameterized gestures* can provide a measure of safety. As opposed to IK solutions that might have unpredictable results when given incorrect input, if we are generating motions by blending within a set of example animations which define a continuous, safe space of gestures, no incorrect input can generate damaging output. For example, if we are generating a pointing motion by blending example pointing animations, flawed target parameters can at most generate extreme pointing examples, but will not be able to cause self-collision.

3) Output Sanity Check: Although we do not yet check for possible self-collisions, we do check individual joint limits, and at the lowest level each joint is prevented from moving past the extremes of its safe range. Finally, any accelerations that are out of the acceptable range can signal a fault, and thus halt the robot.

4) Self Report Watchdog: This is a high-level watchdog system, designed to detect errors that aren't caught by other, more specific checks. Each joint is queried for its current target position, as well as its current measured position (via a potentiometer or encoder). If a joint's measured position deviates from the target by more than the allowed latency and noise parameters permit, it may have encountered a hardware problem or experienced a collision. This system will generate an error message, and, depending on the configuration, disable that joint or the entire robot.

VI. Discussion and Future Work

In this paper we have explained a system that was iteratively designed through many years of collaborations with artists and engineers to control at least seven different robots of different levels of interactivity and physical complexity. Our system strives to empower each participant of the collaboration as much as possible by allowing them freedom, making them aware of important constraints, and shielding them from unnecessary complexities.

We have found these techniques and tools to be quite useful, and though many have seen use across a variety of robots, new challenges arise with every new project and there is always room for improvement.

Safety is an important feature for a system that enables non-roboticists to author content to be played out on delicate, one of a kind robotic platforms. Our system has several levels of checking for safety while executing animations and performing functional control of the robot but there is certainly more to be done in this area. For example, we currently don't check for self-collisions on a model level.

Full confidence in a comprehensive safety system would allow for very fast iteration and development, with less time spent double-checking new content and procedures.

Another area for improvement is for better preview tools for the animator. We currently integrate joint limits into the model, but integrating velocity and acceleration limits would eliminate another possible source of error. Even better would be to provide a preview tool that incorporated physics, so the animator could quickly view a very realistic rendition of how an animation would affect the robot.

Finally, we would like to see the animator gain the ability to, early in the authoring process, view how their animations will be later blended together (as in section IV). Each animation is currently viewed independently in the authoring tool, yet they will be combined in different ways during the robot's behavior - it might be interesting, for example, for an animator developing a postural overlay animation to be able to watch it affect existing gestures as they author it.

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Automated Caricature of Robot Expressions in Socially Assistive Human-Robot Interaction

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***Abstract*—Children with autism spectrum disorder suffer from a deficit that prevents them from observing, interpreting, and learning social cues. Clinical studies in social skills training have proposed methods, such as exaggeration, to enhance autism intervention strategies. Socially assistive robotics is an area of human-robot interaction that has the potential to improve social activity. Inspired by several principles of animation, such as *staging*, *exaggeration*, *anticipation*, and *secondary action*, we propose the use of caricaturized behaviors for a robot providing social skills training for children with autism.**

Keywords-Human-robot interaction, socially assistive robotics, autism, caricature, exaggeration, expression, animation.

I. INTRODUCTION

Children with autism spectrum disorder (ASD) suffer from a social deficit that prevents them from observing, interpreting, and learning nonverbal behavioral cues present in a "typical" social interaction. The face and body posture often express emotion or engagement. Eye gaze, head orientation, and other pointing gestures are often used to establish joint attention or communicate intent. These cues are sometimes subtle and, for children with ASD, often go unnoticed. However, clinical studies in social skills training have proposed methods, such as exaggeration, to enhance autism intervention strategies [1].

Socially assistive robotics is an area of human-robot interaction that has the potential to improve social activity [2]. Preliminary work in the Interaction Lab has shown that repetition and persistence of a communicative gesture influence the perceptions of a typically developed participant in an interactive game-playing scenario [3]. We follow up on this observation and apply principles of animation to caricaturize expressive behaviors in an interactive robot within the context of social skills intervention for children with autism.

II. BACKGROUND

In their eight laws of aesthetic experience, Ramachandran and Hirstein (1999) discuss the neuropsychological peak shift principle with regard to caricature in art. The peak shift principle states that an animal will exhibit a stronger response to an exaggerated version of a stimulus, rather than the stimulus upon which it has been trained or is most familiar. The animal learns to identify the stimulus based on distinguishing ("isolating") features, such as shape or proportions [4]. The amplification of a feature creates a starker contrast with other stimuli, making identification more conclusively unique. This amplification is what is most prevalent in caricature.

Brennan (1985) developed an automated method to produce digitized caricatures by "exaggerating the difference from the mean" (EDFM), amplifying proportions of a human face that exceed the norm [5]. Mo, Lewis, and Neumann (2004) noted that all facial features were treated the same in terms of how they were scaled, and extended the EDFM approach to incorporate the variance of each expressive feature [6]. However, unlike facial expressions, there are no well-defined universal or average "kinesic displays" (i.e., nonverbal behaviors pertaining to the body) and, thus, no standards that provide grounds for behaviors to be amplified [7].

The Transporters is an animated series designed to improve emotion recognition in children with autism [8]. Each of the characters is illustrated as a mode of transportation (e.g., a car, a train, etc.) that is bound by the corresponding medium of travel (e.g., a road, a train track, etc.); this systematizes the possible behaviors that the character might exhibit. A human face is digitally superimposed onto each character, providing a means for emotional expression. The emotion is spoken repeatedly (in context) and the facial expression is exaggerated for emphasis in correlation. Researchers have concluded that most of the children that watched the series daily developed face-based emotion recognition capabilities comparable to that of typically developed children in a variety of scenarios [9]. However, expressive and communicative behaviors of the body still remain to be addressed.

III. APPROACH AND METHODS

We take inspiration from several principles of animation in the caricature of social interaction behaviors of robots [10]. Initially, we aim to address *staging*, *exaggeration*, *anticipation*, and *secondary action*, and their respective implications with regard to socially assistive robotics.

A. Staging

This principle is the first that we must consider, for it aims to provide some grounding for robot gestures in subsequent operations. Staging—specifically, of the character—is the

process of presenting a communicative act in as clear a way as possible by attempting to minimize or eliminate conflicting signals [10]. This involves isolating the features that uniquely identify the content of the expression [4, 7]. Caricaturing in animation highlights such features, providing preliminary building blocks for a clear kinesic display [10, 7]. For example, posture can be parameterized to communicate comfort or confidence [10].

B. *Exaggeration*

The principle of exaggeration is at the heart of caricature. It involves amplifying the distinct features that identify the kinesic display in order to make the content of the behavior more convincing [10]. Using the feature parameterizations isolated during the staging process, we can apply techniques, such as in [5] and [6], to produce exaggerated expressions. We then exploit the peak shift principle [4], and hypothesize that a child with autism will be more capable of interpreting the content communicated in the expressive behavior.

C. *Anticipation*

Anticipation suggests that a clear sequence of events is required to adequately communicate an idea or action [10]. Specifically, anticipatory action often indicates or emphasizes the intent of the character [7]. Staging and exaggeration provide insights pertaining to the dynamics of a communicative act, which we utilize to automatically generate motion paths for both micro- and macro-expressions that precede it. We hypothesize that consistent anticipatory actions will provide a child with ASD a better understanding of the intent of his or her social partner.

D. *Secondary action*

The principle of secondary action provides the most complexity that we are currently considering within the context of autism therapy. It involves the use of redundant signals in an expression to better communicate an idea [10]. Birdwhistell (1970) suggests that most kinesic actions include redundancy and that these signals play a key role in social interaction [7]; however, such signals must be isolated into distinct parts for proper staging, and subsequent exaggeration and anticipation, to occur [4, 10]. We suspect that secondary action has potential with high-functioning children with ASD (particularly, those who have participated in [8] and [9]), but might be overwhelming for children that are far in the autism spectrum.

IV. Robot Platform

The gesture system is being implemented on the Sparky Minimatronic™ robot figure available in the Interaction Lab at the University of Southern California, courtesy of Walt Disney Imagineering Research & Development (http://robotics.usc.edu/interaction/?l=Laboratory:Facilities#humanoid). Sparky uses two servo controllers and 18 R/C servo motors for supermarionation: 4 for each arm, 2 for each leg, 2 for the neck, 1 for the mouth, 1 for the eyes, 1 for the eyelids, and 1 for the spine. The puppet-like structure of this robot allows it to be lightweight and highly dexterous; its movements are fluid and natural. Of particular interest is its articulated spine, which allows us to manipulate Sparky's posture. The robot utilizes an off-board sensor network that includes color cameras, lasers, Nintendo Wiimotes™, and a desktop computer interface. Sparky is currently being used as a conversational tabletop agent, interacting verbally and nonverbally with a user.

V. Experimental Design

We are currently in the process of designing and implementing experiments that test these techniques and hypotheses within the context of a social skills intervention with children with autism. We will first validate, with typically developed children, the expressive behaviors that utilize the isolated features determined during the staging process, and, subsequently, their exaggerated, anticipatory, and secondary counterparts. We will then conduct a comparable study with autism populations to determine the impact of each of the techniques.

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A Place for Fictional Robots in HRI Research?

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***Abstract*— Fictional representations of robots can be extremely useful to the field of HRI, but are often understudied because HRI researchers are not familiar with empirical methodologies for evaluating art and fiction. We propose that content analysis is a viable methodology for empirically evaluating fictional robots, and we report data from a content analysis conducted on robot characters in 12 popular American films.**

Keywords- human-robot interaction; science fiction; robot capabilities; methodology

I. INTRODUCTION

Throughout centuries people have used art to question, critique, and comprehend issues that are fundamental to humankind. Artists and creators of art often present their audiences with a message that can be extended far beyond the context of the artistic work itself. In other words, art is often made with the intention to *affect* people.

Even when there is no specific intention to affect, art often influences thinking and behavior. Research across several disciplines has documented ways in which art, specifically film and television, can affect viewers' reasoning and behavior. For instance, fictional television shows have been found to contribute to children's learning of gender role stereotypes [1]. Similarly, a link between violent behavior and children's viewing of violent television shows, films, and video games has been established [2,3]. Additionally, studies have shown a relationship between seeing tobacco use in film and willingness to try smoking [4,5].

Art can be an especially powerful tool when it treats a subject that is not readily accessible to viewers. Many times, fictional representations of a theme or event provide access to people that otherwise have no experience with the topic. For instance, young viewers often build an understanding of historical events based on what they view in fictional films [6]. Similarly, inmates entering prison for the first time have been found to use events portrayed in television fiction to anticipate what will happen in an environment previously unknown to them [7]. Because most Americans have not ever interacted with a real robot, it is likely that their understanding of robots and their expectations about robots' capabilities are at least in part based on what they know about fictional robots. Thus, it is probable that robots such as The Terminator, Johnny 5, and Wall-E contribute in some way to Americans' understanding of robots and robotic technologies.

HRI researchers can benefit from an awareness of how fictional robots and their interactions with humans are represented in the arts. Understanding the capabilities of fictional robots can provide researchers with information about people's expectations of real robots. However, the inclusion of science fiction as a legitimate data source in HRI research does not come without challenges. Analyses of science fiction films and novels are predominantly qualitative, and there is very little cross-disciplinary communication between HRI researchers and film studies and cultural studies scholars. For instance, well-known cultural studies articles like Haraway's "Manifesto for Cyborgs" [8] get little exposure in the HRI community due to differences in the values of the two research traditions. One step towards incorporating the arts into the HRI research is to strive for better communication between researchers of HRI and cultural studies.

However, we also propose that HRI researchers can conduct their own research on HRI in the arts. By employing empirical methods, such as content analysis, researchers can collect quantitative data from science fiction sources. Content analysis, when performed correctly, can provide objective, reliable, quantitative results [9]. To illustrate how fruitful this methodology can be for HRI researchers, we report some results obtained from conducting a content analysis on 12 science fiction films with robots as main characters.

II. FICTIONAL ROBOTS IN FILM: AN EXPLORATORY CONTENT ANALYSIS

The purpose of this content analysis was to evaluate the cognitive and social capabilities that fictional robots portray. The content analysis was intended to be exploratory and therefore no specific predictions were made.

A. Method

The content analysis was limited to live-action (non-animated), feature-length American films. To objectively identify movies for the analysis, we first searched the Internet Movie Database (www.imdb.com) for all films tagged with the keyword 'robot.' After eliminating foreign films, animated movies, shorts, films made before 1950, and movies that did not have a robot character central to the plot, the remaining 68 films were reduced to 50 by eliminating 18 movies with the lowest IMDb user rating scores.

The second step in the process was to administrate an online survey to determine which films were most often watched and remembered. More than 250 people responded to the survey, and 12 films were selected based on the responses. The films were: *Star Wars* (1977), *Alien* (1979), *Blade Runner* (1982), *The Terminator* (1984), *Short Circuit* (1986), *RoboCop* (1987), *Star Trek: First Contact* (1996), *The Matrix* (1999), *AI* (2001), *I, Robot* (2004), *The Stepford Wives* (2004), *Transformers* (2007). Robot characters that appeared in a film for 20 minutes or more were considered main characters. A total of 25 main robot characters were analyzed.

Sixteen coding categories were determined by consulting the table of contents of introductory cognitive and social psychology textbooks. (See Table 1.) Each film was coded independently by two authors to determine whether the fictional robot characters exhibited each of the 16 cognitive and social features. Discrepancies were discussed by the authors until a consensus was reached.

TABLE I. SIXTEEN FEATURES CODED IN THE CONTENT ANALYSIS

Cognitive Features	Social Features
Learning	Social Cognition/Attribution
Episodic Memory	Self-Knowledge/Introspection
Visual Perception	Conformity
Spatial Cognition	Group Processes
Language Comprehension	Close Relationships
Language Production	Prosocial Behavior
Categories	Aggression
Problem Solving	Prejudice

B. Preliminary Results and Discussion

Several features were exhibited by 100% of the robot characters: visual perception, spatial cognition, language comprehension, and language production. Furthermore, 24 of the 25 fictional robots showed behavior that indicated they were members of a group (group processes). Aggression was also a feature that a majority of the robot characters portrayed (88%). Among the least frequent capabilities exhibited were: learning (40% of the characters), prejudice (44%), and conformity (52%).

These results suggest that fictional robot characters in popular American films reliably exhibit several human-like cognitive and social capabilities. There is likely a practical explanation for this trend: these features are necessary for basic communication and interaction. Without cognitive functions such as language and vision, a robot would not be able to exhibit behavior interesting enough to contribute to the narrative structure of the film. However, regardless of the reason, the fact that most fictional robots in Hollywood films have these capabilities may have a strong impact on viewers. As has been done in other fields, we are currently trying to link the results obtained from this content analysis to viewers' mental representations and behaviors. Specifically, we are in the process of analyzing the relationship between science fiction film viewership and people's expectations about the capabilities of a real robot.

C. Extending Content Analysis to HRI: Some Issues

We dealt with several challenges in tailoring the content analysis methodology to HRI research. For example, using behavior as evidence of underlying psychological capabilities can yield misleading results, as characters that appear for very little time offer less codeable behavior. Additionally, as social and cognitive competencies often overlap, it was impossible to make a coding system that specified one-to-one mappings between a particular behavior and a single psychological capability.

III. CONCLUSIONS

In this paper we argued that HRI researchers can benefit from understanding how robots and their interactions with humans are portrayed in fictional media. Studies in several domains have shown that fictional films can have a profound effect on viewers' thinking and behavior, and it is likely that representations of fictional robots contribute to the general public's expectations about real robots and their capabilities. We have utilized content analysis methodology to empirically study how robots are commonly portrayed in film. However, this type of content analysis can also be easily extended to science fiction writing, plays, television, and video games. Programmatic research that includes empirical analyses of how robots are portrayed in the arts and entertainment in combination with human-subjects experiments will likely provide insights that are not available from traditional HRI laboratory research methods alone.

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Machine Performers:

Neither Agentic nor Automatic

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***Abstract*—*Machine performers* could constitute an investigation of cultural codes of the theatre audience in order to look at a broader understanding of the machine itself. This paper investigates the perception of the robotic agent in the following four areas: the historical lineage of the uncanny valley, artificial intelligence (AI), anthropomorphism, causality and animacy. These four areas will be looked upon from the perspective of "body versus action" in an alternate way than science.**

Keywords — Robotic Art, Theatre, Embodiment, Artfificial Intelligence, Entertainment robotics.

I. INTRODUCTION

Artistic languages and scientific concerns might revolve on very different orbits. While the HRI community strives to define functional models and theories grounded in the physical reality of the robotic agent, art and in particular Theatre, are more concerned about staging the unreal.

Theatre theorist Horakova entitled a paper: "Robots between Fictions and Facts"[1] and the seminal book from Reichardt is entitled: "Robots: Fact, Fiction and Prediction"[2]. Peformance Theory and Art Theory have embraced, in their own terms, oblique analysis of the Uncanny Valley, of the roles and representations of the Robot and of the living/non-living dichotomy manifested by the Robotic Media. The very paradox of the embodied object[1], the art robot, might be real in its incarnation of mechanics and control, but its perception departs from its sole capabilities of acting in the real world[3].

Machine or mechanical performers have been around for centuries. This development has been furthered by the current advents in the digital age conveyed by virtual characters on the silver screen, and the recent presence of unsurpassed humanoids [4] and geminoids [5]. This paper will put forward some communalities and differences between HRI and Theatre via the analysis of *Machine Performers* supported with case studies. Both fields have to deal with liveliness, presence (physical), embodiment, perception and identification, empathy and finally, bringing realism to the unreal.

In order to unfold the investigation of *machine performers*, the analysis is broken down into the inter-related constituents of a robot: its body (representation), its movements or behaviors (body in action) and its context (environment at large, from the stage to culture). Over the last twenty years, the author has been focusing this research on experimental robotics, which can relate these robots constituents to human perception in the following four areas: the historical lineage of the uncanny valley, artificial intelligence (AI), anthropomorphism, causality and animacy. These four areas will be looked upon from the perspective of "body versus action" in a different way than science. Mostly in the fields of Human-Machine Interfaces (HCI), Psychology, Artificial Intelligence and Engineering, the scientists do not consider the potentials from the context of Art and Theatre. On a practical as well as a theoretical level, this paper will present an overview of these topics and then pose a number of questions about of how these could be reformulated for a trans-disciplinary investigation between HRI and the Performing Arts. The cumulative analysis is synthesized in Table 1.

II. FROM THE GODS TO THE UNCANNY VALLEY

A. *The Social Robot: a history of human representations.*

Through the history of machines, the role of theatricality can be traced in order to augment the viewer's reception of the *machine performer*. The aim is to also establish that the artistic renderings of the machines during certain periods can reflect the current social concerns and the current understanding of the human body.

Perhaps some answers can be found in the history of representations, models and simulations of the living body, by means of mechanical objects. This history is more than two millennia old. The media theorist David Tomas writes about modifications of the human-machine relationship as a "machine-based history of western body" [6]. Tomas often refers to the Cybernetics discourse, particularly to Norbert Wiener's writing on a history of mirroring the human body with machines. Wiener traced the parallel histories of machines and human bodies, when he presented a history of automata that was divided into four stages [7]. These histories generated four models of the human body. Firstly, a mythic Golemic age that referred to the body as a malleable, magical, clay figure. Secondly, the age of clocks (17th and 18th centuries) where the body was seen as a clockwork mechanism. Thirdly, he considered that the age of steam (19th century) transferred the body into descartain scenario; a "glorified heat engine" which burnt combustible fuel instead of the glycerin from human muscles. Finally the last stage, Weiner identified the age of

[1] The subtitle refers to the monographic work Neither Bachelor Nor Brides about the hybrid machines of Rebecca Horn

communication and control (the age of cybernetics); an age marked by a shift from power engineering into information and communication engineering; from "economy of energy" into the economy based on "the accurate reproduction of signal" that understands the body as an electronic system.

After Alan Turing's pioneering works, robotic art and artificial intelligence emerged from the assumptions established by Cybernetics. The appearance of robotic art in the midst of the 1960's cybernetic discourse is connected with an anti-mimetic shift in the history of humanlike-machines. As Tomas argues: "The cybernetic automaton's mirroring of the human body was not established on the basis of conventional mimicry, as in the case of androids and their internal parts, so much as on a common understanding of the similarities that existed between the control mechanisms and communicational organizations of machine systems and living organisms"[6]. However, robotic art has very broad roots and a rich cultural history. This history references modern science-fiction as much as artificial creatures (either real or imaginary); from ancient artificial maidservant to mediaeval Golems to Homunculus of Renaissance to androids of the Enlightenment. Contemporary robotic art brings a new aesthetic dimension that prefers modeling of behavior over a representative form or a mimetic static object.

The Uncanny Valley conjecture then follows this long lineage of mechanical relationships, and it symbolizes the current state-of-the-art in technology alongside the cultural anxiety of transferred agencies [8, 9].

B. Theatricality

Machines are regarded as distinct entities from us. As much as we consider ourselves distinct from nature, machines are a physical rendering of abstractions and can also act as a tool for the comprehension of ourselves within the structure of the world [10]. It is significant that outcomes of this effort, embodied in different robots/machines, are typically exploited by theatrical means [11, 12] . This history is driven by the ongoing quest for a true genesis and the deeper understanding of the inner self in the environment.

The paradox of the robot can be found in the ambiguous status of artificial human-like (androids) creatures and their existence. This paradox is not only present in the case of fictitious artificial creatures but also in the case of the 'real' mechanical puppet or android. As performance and puppet theorist Mark Sussman argues, thaumaturgical strategies often intensify this trick during robots public performances. Sussman began from the assumption that:

> "Certain pre-technological performances (…) can give us some insight into the tense metaphoric operations and interconnections of faith and scepticism, or belief and disbelief, in the staging of new technologies (…)".

In his analysis of the staging of the Chess Player automaton by Wolfgang von Kempelen (1762), Sussman came to the following conclusion:

> "The automatic thinking machine that concealed, in reality, a human person, can be seen as a model for how a spectator might reify, and deify, the hidden power at work in a new form of intelligent machinery".

Sussman suggests that this visual proof is a demonstration of the level of control at a distance and that the transmission of human intelligence into inanimate body of the object extends the context of androids/automatons staging in general. But also, it demystifies and reenchants the performing object itself.

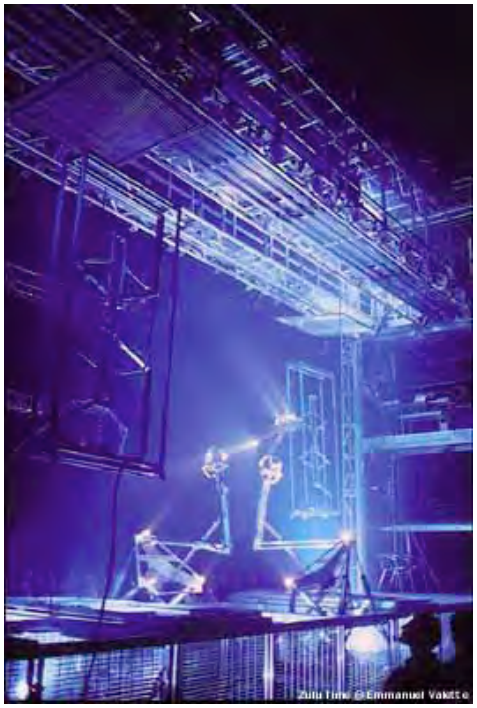

Figure 1. Le Proces(Kafka).

The machine performers depicted in Figure 1 are the main protagonists of the robotic performance adaptation of *Le Procès,* a novel by Franz Kafka (Kafka 1925,[13]). These robots are deliberately part zoomorphic (an arm, a hand) and part mechanomorphic (the lower body is a simulation platform structure). Utilizing existing mechanisms to construct life-like objects brings us back to the paradox of the *quasi-living* objects of the robot history. The signs of the machine design comprise both inert and living connotations about the performing objects. In parallel to human performers, we can ask, whether and how are these robot performers able to carry an alternate set of sign-systems of their bodies (shape, material) and their behaviors (actions/acting).

C. The Uncanny Valley: at the crossroad of Art and Science

In recent artificial intelligence discourses, social robots have attempted to embrace the human form endowing it with friendly appearances and behaviors as a privileged mode of intercommunication [14]. This addiction to the mimicry of humanoid form in the appearance of robots connects them with a long history that has been written in myths, legends and even in real experiments.

Figure 2. AreaV5. 60 pairs of eyes gazing at the audience.

This addiction includes in itself two challenging motives: the dream to create an artificial human being and the need to create helpers for ourselves. On the one hand, this is seen as an attempt to imitate a 'Creator', to make a creature in our own image or even to discover the secret of life. On the other hand, it may be an entirely practical ambition to make optimal or perfect servants of man. This second motif is often connected with utopian projections of an ideally ordered social system.

A specific issue has arisen about the increase in realism, both in virtual and physical agents. This research has led to a controversy about the acceptance of those agents by humans. Within this conjuncture, the Uncanny Valley was already described 30 years ago by roboticist Mori [15] and it has recently resurfaced and it lies at the centre of discussions, namely in the field of social robotics. Mori proposed a thesis that would create an asymptotical burden in the development of human-like robots. Mori posited that, as realism of a robot increased, dips or discontinuities in the relationship between affinity and realism would occur. First there would an increase in affinity but as the robot would approach a nearly human state, there would be a dramatic decrease in acceptance. Mori plotted his assertions as an apparent mathematical two-dimensional graph (see Figure 3). This displayed a strong dip - "the Uncanny Valley" - when the robot is a "near human" entity, and then slowly ascended towards affinity when the robot is a perfect replica of the healthy human body and its behavior.

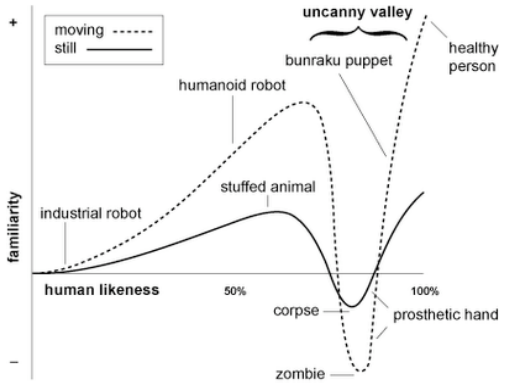

Figure 3. The Uncanny Valley graph [15].

Research into the Uncanny Valley shifts our perception of the abilities of the mechanical performers both in artificial intelligence and in other cultural environments. In both settings, it forces the beholder of the robot to continuously draw lines between human and non-human traits. However, experimental theatre directors are also exploring this line, one that extends the notion of the fourth wall[2]. This is because one of the main aims of staging is to make the real out of the unreal. The uncanny Valley does not affect strongly the abilities of mechanical performers on the stage and in other cultural environments but it does shift our perception and empathy. The value lies in a breach of *suspension of disbelief* on the part of the audience; the moment where the agency of the machine performer is replaced by its sole automation.

What is the next step in the lineage? Would the supposed Uncanny Valley, the asymptotical burden in acceptation of the human-like robot, carry on to the *machine performers* on the stage? By bringing the robot onto the stage and away from the laboratory, how do shifts in perception affect the Uncanny Valley of the future?

By linking the Uncanny Valley to the experimental theatre stage, will anthropomorphism and anthropopathy play a major role in the perception of the non-human performer? Certainly, they both refer to the attribution of a human form, human characteristics, or human behavior to non-human things such as robots, computers and animals. However, anthropomorphism goes beyond the simple morphology of the perceived agent. For instance, the interaction designer Carl DiSalvo states that four categories of anthropomorphism can deal with what aspect of the human form is actually being imitated: the structural anthropomorphic, the gestural anthropomorphic, the anthropomorphic from the character and form of the aware anthropomorphic state [16].

By playing role between the agentic and the automatic, the robotic performer can explore some of the disturbing ambiguities associated with the machine's uncanny lack of agency. The Uncanny Valley might lie where the perception start oscillating between the function (automatic) and the intention (agentic). In other words, the valley is where the perception oscillates between the inert/mechanical and the quasi-life qualities of the robot. In other words, shifting the anthropomorphism to level beyond morphology: what is seen as a pure functional entity and what has strong apparent autonomy and intentions?

The term uncanny, functions in both scientific and aesthetic significance. In the scientific view (AI discourse) the uncanny is seen as pseudo-natural perception without cultural codification. The task of the artistic and aesthetic level should

[2] In a proscenium theatre, the term fourth wall refers to the imaginary invisible wall between the stage (universe of the play) and the audience. It was made explicit by Denis Diderot and spread in nineteenth century theatre with the advent of theatrical realism.

be, to clarify cultural backgrounds of the robot-perception. The Uncanny Valley idea also chimes with Freud's writing, the narcissism of minor differences, where feuds between communities of adjoining territories ridicule each other's. This territory is also depicted by Steve Dixon notion of 'metallic camp' [17]. Dixon argues that 'robotic movement mimics and exaggerates but never achieves the human, just as camp movement mimics and exaggerates, but never achieves womanhood', and that camp is an essential factor in anthropomorphic and zoomorphic robot performance.

Following Derrida's strategic valorization of the suppressed supplementary term of any binary, the dichotomy of the human versus the non-human lies in the grey area between these two realities. The place where the 'credibility gap' or the 'Uncanny Valley' occurs is not at the point furthest from the truth, but at the point closest to it. As observed by kinetic artist Kirbey, when a kinetic artwork is almost credible, it lacks credibility.

The interactive environment Area V5 (figure 2) deals with the Uncanny experience of the gaze of 60 pairs of disembodied eyes. It is a direct artistic comment on the role of the gaze in Social Robotics[18]. The design of the space and the unsettling embodiment from the sliced skulls was deliberately chosen to breach affinity. Audiences perceive the robots as both representative of the living and the non-living. The observed viewer experiences[3] lead to conclude that they voluntary engage in and out the suspension of disbelief (or the valley) without disengaging from the environment.

III. Artificial Intelligence and Embodiment.

The role of the body in relation to the comprehension of human intelligence is now at the forefront of scientific research in many of the fields like psychology and neurobiology. This section brings along top-down and bottom-up approaches in Artificial Intelligence with the focus on the implication towards *machine performers*. The Cartesian and orderly juxtaposition of the brain, the body and its interaction with the environment will be challenged in the hopes to construct a new perspective of implementing behaviors into machine performers (embodied agent).

A. The turn of the embodiment.

In the Dartmouth Artificial Intelligence Project Proposal of 1956, the community convened under the assumption that "...every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it". This idea dominated until the mid-1980s as a challenging approach. Recently the interest has increased in the notion of "embodiment" claiming that intelligent behavior is not only a matter of computation, but it requires a body, a complete organism that interacts with the real world. As a consequence, many researchers have shifted their attention away from the central brain (the computer) towards embodiment (the robots). This is seen by many AI theorists as a transfer from a top-down towards bottom-up approach [19, 20]. The far-reaching and often surprising implications of embodiment have often been used in relation to a literal meaning that intelligence actually requires a body. However there are deeper and more important consequences, concerned with the interaction of the brain, the body and the environment. Intelligence is not an "all-or-nothing" phenomena, but an incremental and interdependent gradual set of attributes that have emerged through the process of evolution [20]. Often the results of embodied AI start from models of physical agent behaviors without a complete base. For example, in "Stumpy" (figure 4), a robot that explores natural gaits and locomotion, the behavioral model was "outsourced" into a physical construction, where the apparent jumping actions emerge from the interaction of the agent within the physical world [21]. This was made with minimal computational efforts and representational models.

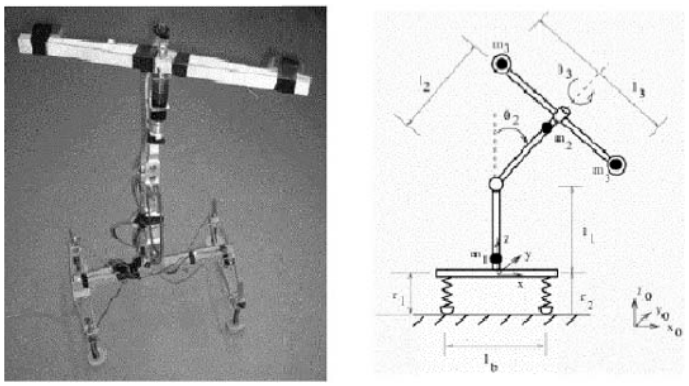

Figure 4. Photograph and Schematic of Stumpy (courtesy AI Lab U. of Zurich)

B. Acting without thinking/modelling.

As Rolf Pfeifer in his book " How the Body Shapes the Way We Think" suggests, AI should continue to focus on non hierarchical links between the brain (the computer) and the body as an eloquent distribution of muscular control mechanisms and cognition. He suggests that walking and the manipulation of objects reveal themselves to be a combination of the materials (tissues, bones, flexibility, sensors) and the system of distributed processing between system between the body and the brain.

On a deeper level, how does a hand grab a glass or an object? In this case, the sole capacity of the anatomy and morphology of the forearm and the hand enables them to adapt to all different shapes. Currently, the perpetual paradox of AI is very much at stake: being highly contested between simulation and modelisation, the grasping hand demonstrates that this kind of intelligence does not reside in the intelligence of the brain, neither of all the memorized forms of glasses, nor even from the cognitive level of the object "glass".

"Outsourcing" behavioral and emotional models into physical constructions is along the line of the creative process of Kinetic Art. Apparent actions emerge from the interaction of the agent within the physical world with minimal computational efforts and representational models. Can machine performers behaviors and emotions be implemented without a complete computational model?

[3] Empirical and qualitative observations were made in the museum by the author (personal archive).

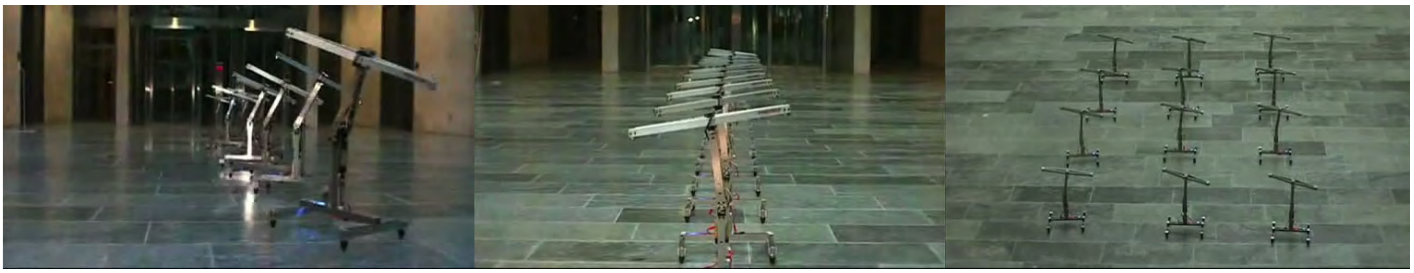

Figure 5. The Tiller Girls as 12 Autonoumous Stumpies.

Machine performers can express emotions due to their intrinsic materials and the very complex dynamics of their structure in motion. Such paradigm is similar to the psychophysical relation found in theatre acting methods where behavior and emotions are inherently physically grounded. For instance, the walking table of figure 6 manages to navigate even under a deliberate poor gait. The behaviour is a collaboration of the unstable equilibrium of the construction and the staging. The introduction of a latent failure in the gait not only creates a poetic moment but also gives a supplementary spark of life to the object, as it is similarly proposed for social robots. Acting methods also propose opposite stances to be taken by actors: presence or absence. The presence calls upon the performer's experience to dwell into his/her experience to deliver the character, absence requires an abnegation of the self to produce a pure rendering of the directors' directives and scripts. The beggar of figure 6 had no experience of misery neither of being poor. Its shape was a square box (symbol of a chest) that could rock over a hinge (body language of imploring). The beggar performer lean towards absence while the table is rooted more in presence via the physicality of its shape. This situation gravitates around the *cheap design* paradigm[20] where an ecological niche is being exploited thru an *ecological balance* among morphology, sensing, control and finally dramaturgy.

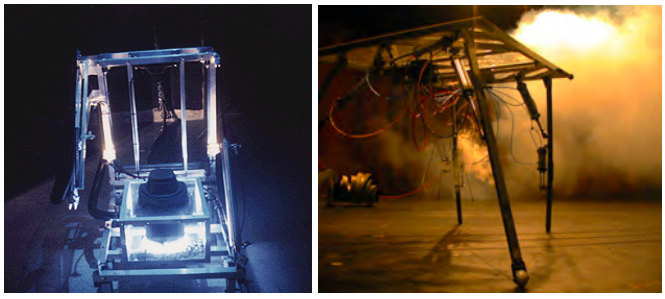

Figure 6. A begging machine (left) and a limping table (right)

The above situation is far from the mechanomorphic attempts of traditional robots from the top-down cybernetic wave. Perhaps the concept of embodiment inside of the theatre environment is underestimated by AI researchers where the relation between basic human movement and robotic movement can be compared simultaneously not only on a literal level but also on a metaphorical level. Being situated, theses agents can also empower intangible contributions from the cultural context, the suspension of disbelief and the attribution of intention towards any outside physical objects acting upon the world. From the audience standpoint, where our perception departs from the simple function (mechanical or programmed) towards the intention or emotions (self motivated complex agent)? Perhaps this collaboration will help to derive a form of the bottom-up "synthetic methodologies" [20] for the *machine performers* on the stage.

C. *Performative vs Interpretive.*

Performers in the traditional performing arts such as music, dance and theatre are generally thought to have both technical skills and interpretive skills, where the latter skills are regarded as specific human skills. Auslander highlights the 'grey' area between these with examples from the performing arts such as the practiced routines of orchestral musicians, and the famous early 20th-century Tiller Girls' (figure 7) synchronized chorus-line dance, in which human performers are 'called upon to exercise their technical skills but not their interpretive skills[9].

> "Auslander exposes indeterminacies in this binary thinking in the traditional performing arts. In contrast, Auslander draws upon performance theorist Michael Kirby's notion of 'nonmatrixed performing', in which a performer does not feign or present any role and is simply being himself or herself, carrying out tasks, to assert that robot performances can indeed be placed within the continuum of performance art. Auslander discusses examples of performance art in which there is no difference in overall artistic intention whether tasks are carried out by human performer or robot performer, and where the actions of a human or a robot can be regarded equally as art performances (p. 98)." [8]

The robotic Tiller Girls (figure 5) are empowering the AI embodiment while exploring what would happen if the physical world were shifted from the lab onto of the stage.

Figure 7. The Tiller Girls .

IV. Between the Agentic and the Automatic:

As the movement of the machine is one of the most prominent factors for the perception of its agency, this section

investigates the human intrinsic mechanisms of perception of motion and the attribution of causality (from the audience experience standpoint).

A. Perception of Causality and Animacy

The perception of Animacy, Causality and Motion was an important field of research uncovered by Psychology and Neuro-Biology, which began in the 1900s by Albert Michotte [22]. At the time, scientific evidences were being accumulated about very simple displays (visual cues) and how they give rise to surprisingly high-level percepts.

The awareness of those fields were expanded by the Heider and Simmel [23] through the method of testing animated perceptual experiments with different audiences. In Michotte's concept of "functional relations" wherein one perceives properties in visual cues that are found in an objective environment, he posits that one can not locate judgment in neither the actual events nor in their retinal reception. Heider and Simmel proved that the functional relations are primarily perceptual but that the interpretations are highly personalized and individual (see Figure 3).

Clearly animacy cannot be separated from the concepts of embodiment nor from the bodies of primal mechanism. The results tend to show that the perception of animacy and causality are innately connected in the human. Perhaps as Scholl and Tremoulet both posit, the pathways of animacy and causal modular processing could be dissociated from high-level cognitive judgments (2000).

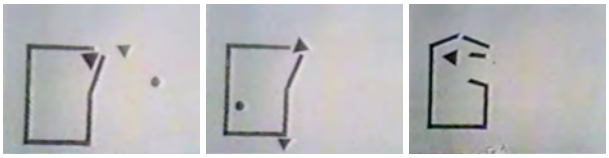

Figure 8. Various frames from a sequence of visual display (Heider and Simmel 1944) where participants anthropomorphizes through individual narratives.

B. Animacy for the stage.

This research into causality and animacy could prove to be very valuable for designer of *machine performers* in the future. Only by gaining a deeper understanding into how primal and visceral human perception functions, can artists invent more fictional and more factual arrays of movement for the *machine performers* on the stage. Therefore, studies into causality and animacy will also extend the understanding of the agentic (intentional) and the automatic (functional) forms of robots on the stage. The main question is: at what point does a machine performer graduate from an automata into an agent?

The movement (or perceptible change of state) of an object can be seen in part as its objective nature, while its perception can be its subjective counterpart. Consequently, a rather abstract inert shape can become fluid, organic and eventually anthropomorphic, by the sole means of contextualization and movement. In figure 9, a simple motor mounted on springs creates a rich range of chaotic movement, staging this object in a cage anthropomorphises its essence resulting with the viewers perceiving it as an untamed miserable entity in La Cour des Miracles[13, 24]. Without an immense degree of computation, the behaviour is carried out by a juxtaposition of this social mise-en-scène and the inherent complex dynamic characteristics of the structure.

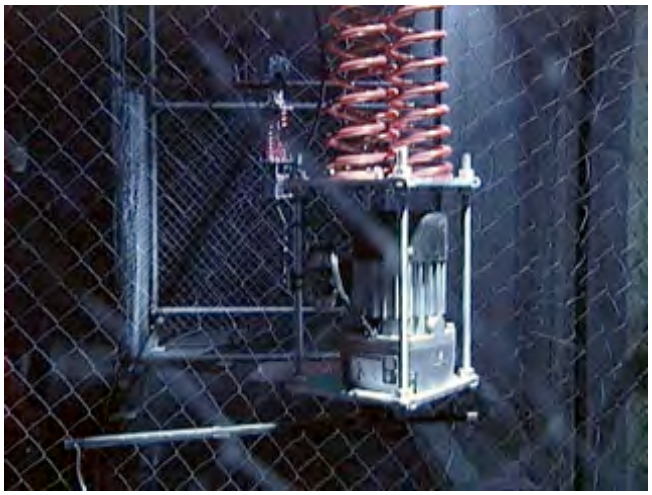

Figure 9. Untamed Machine in La Cour des Miracles

Movement is seen as a sign of life and in order to fully understand causality of motion and perception, further research has to be considered when designing the robotic agent. How does our understanding of animacy affect our prediction and our assignment of "judgments" to the movements? When a human acts and when a human observes the same action performed by machines, how do they relate and respond? Like the mirror neurons[4], machines are often built to mimic our behavior as though the viewers were carrying the actions themselves. The author suggests that performing machines feel conspecific for the viewers and this aspect is part of their major appeal for humans. Can a social relation between machines be based on our understanding of animacy and how can adaptation to the theatre stage change their relations to each other? How does social interactions between machines on stage translate into social interactions of the audience? For example, will the audience feel excluded, indifferent or fascinated? One of the contributions from the Theater would be to formulate a new way of gathering information from the above questions.

C. Point Light Animation.

Animacy and causality are important aspects to explore in relation to the emotional reaction of the audience. Point Light Animation technique (PLA)[5] investigates the isolation of movement from other visual cues such as the morphology. Surprising results from these experiences demonstrate that we are able to identify action with a very reduced set of information as well as basic emotional reactions. Does the Uncanny Valley dip resonate within the agentic vs. automatic qualities of *machine performers under the PLA*? How can *machine performers* be built to explore these questions?

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[4] Psychologist Susan Blackmore attempts to constitute memetics as a science by discussing its empirical and analytic potential

[5] Psychologist Gunnar Johansson (1973) devised an experiment, the Point Light animation (PL animation), to study the information carried by biological movements.

V. Anthropomorphism and Theatre: the realism of the unreal

Anthropomorphism within the history of machines, design of objects and theatre semiotics includes a broad array of abstract and representative mimicries of human behavior. From the beginnings of Greek automata to biomechanics, the enhancement via anthropomorphism has played a major perceptual role. The anthropomorphic character inside its context of arts is an important factor to consider.

Anthropomorphism entails attributing humanlike emotional states, behavioral characteristics, or humanlike forms to nonhuman agents. In 6th century B.C., Xenophanes was the first to use "anthropomorphism" when describing the similarities between religious agents and their believers (Lesher 1992). As Dennett (1987) also confirms, the audience often attributed intentions to mechanical characters or agents in relation to their predominant belief systems.

The close association between the performing machine's visual image and the human image raises difficult questions not only for artistic practices but also for scientific disciplines. According to Cary Wolfe (Wolfe 2003) anthropocentrism or specieism both reflect the priority of visual reception into the human sensorium and only performances that engage other senses can be considered truly posthumanist. Wolfe suggests that our senses should be extended into a broader range not necessarily confined to the human bodily sensorium.

Today, this attribution raises questions about the level of anthropomorphism needed in robots [25]. It also raises discussions in relation to the act of projecting intentions on performing machines and question if this is an inevitable reflex or not (Duffy 2005). When comparing attributions in the field of AI to staged robots, the fictional potentials of the stage and the robots in this environment, have always and always will allow the audience to have more associative attributes rather than literal ones. Normally a literal interpretation by the audience is related to the goal oriented bottom-up approach of AI (Pfeifer 2007) however, complex behavior could emerge from robot morphologies that bear no direct resemblance to zoomorphic entities. This does allow for more free association by the audience.

The author suggests that the definition of anthropomorphism by behavioral scientist Nicholas Epley is more suitable for performing machines. He defines it as a process of inference about unobservable characteristics of a nonhuman agent, rather than descriptive reports of a nonhuman agent's observable or imagined behavior [26]. Similarly, as American historian Lewis Mummford writes, the machine is a mythical construction. A machine is not only a complex tool but also a social apparatus. It is not only constituted of material pieces but also of immaterial elements, of a mentality and of a belief in a goal or an effect [27].

In relation to these shifting definitions of anthropomorphism, *machine performers* and puppets share the essential characteristics of being inert entities that are "animated" and "brought to life" in the front of an audience. When Steve Tellis (1992) writes about puppet anthropomorphism, he suggests that the verisimilitude in mimicking human behavior often creates a superficial sense of realism. He further suggests that the illusion of life is better supported from movements exclusive to the puppets morphology. A comparable argument can also be raised in relation to sculptural movement. In the "Morphology of Movement", kinetic artist George Rickey traces the history of verisimilitude in art and argues that when the artists attempts to abstract and stylize form from reality, they are often more successful [28]. He further suggests that awkwardness and failure to achieve verisimilitude permitted objects to evolve into an artwork. In his terms, kinetic art cannot be served by a direct imitation of nature but by recognition of it laws, awareness of its analogies and a response to the vast repertory of its movement through the environment. Therefore, the interpretation of robots as performers, or staged robots, involves an act of *suspension of disbelief* as a first and constitutive condition of theatrical reality**.** The puppet as the machine performer take on their metaphorical connotations because they inherently provokes the process of double-vision, creating doubt as to their ontological status: "What is the nature of its being?"

By sharing these ontological[6] interrogations [29, 30] raised by puppet theorists and by exploring the paradox of the quasi-living, machine performers force to define a set of new ontological states that could become guidelines, in artistic and scientific domains, for both researchers and educationalists in the future.

Kinetic art, usually mechanomorphic, feeds on continuous transformation and participation of the viewer. Shapes of figure 10 were created by a set of discrete manipulators [] where theses geometries are asked to perform to an audience. Beyond the aesthetic of the hypnotic organic movements of these machines, audiences readily address the intent. This weak or shifting anthropomorphism is here an advantage as it frees the "sign from the signified". It enables a multiplicity of readings from a simple starting shape: an array of cubes.

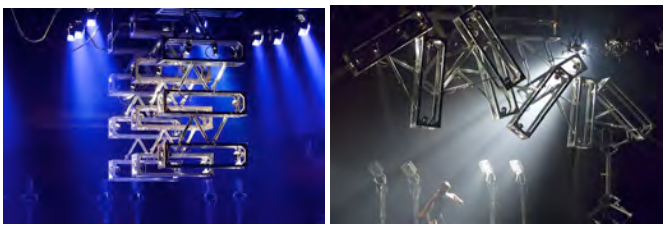

Figure 10. The Deus Ex Machina character in Devolution. Mechanomorphic (left) and Zoomorphic in motion (right).

VI. Conclusion

Since the concept of environment in AI is limited to the physical world, it does not include the social and the aesthetic potentials. Therefore, by combining AI with Theatre, new question will be raised about how a presentation of an

[6] As regarded by the field of Artificial Life, an ontology defines how the world in which the agent lives is constructed, how this world is perceived by the agent and how the agent may act upon this world.

experiment from an AI lab can differ from a theatre presentation of the same machine. Researchers from these disciplines operate from different perspectives; art can become the "new" experimental environment for science because it the world does not only consists of physical attributes but also of intangible realities. Hence, *machine performers* could constitute an investigation of cultural codes of the audience in order to look at a broader understanding of the machine itself. Perhaps the, theatre directors would start to attribute the character of the actor to the character of the machine or as performance theorist Erika Fischer-Lichte says: from the "state of being" towards the "state of becoming"[31] .

ACKNOWLEDGMENT

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TABLE I. MULTIPLE ONTOLOGIES OF THE MACHINE PERFORMERS.

Theatre / Semiotics	History	AI	Uncanny Valley	Anthropomorphism	Animacy and Causality
Body / Embodiment	Understanding of internal mechanisms	Outsourcing of intelligence	Quest for the "perfect double"	Starting from the body. The predisposition into the capabilities of the agent from its shape	Subtracting the body from the shape
Action Performance (performative actions) / Stage Co-presence of audience	Using theatricality	Implementation of natural actions	The uncanny effect of verisimilitude of movements	Cognitive dissonance in non-anthropomorphic agents. The predisposition into the capabilities of the agent from its movements	Passage from pure movement to judgment, i.e., automatic to the agentic
Context Specification of the situation	Utopian Social Concerns Imitation and the Fake Staging Realism	Context is included in intelligence	Japanese glorify their machines as westerner express anxiety.Theatre stage is outside normal lab contexts.	Belief systems of today The predisposition into the capabilities of the agent from its context	Isolated in experiments the field but in our case, we shift it to the theatre stage
Subject/Object Agentic/Automatic	From combined fragments of history	Life as it could be? Simulation.	Dividing line of the human and non-human	Belief systems shifting interpretation of the object	Function vs. Intention vs. Aesthetics

A Midsummer Night's Dream (with Flying Robots)

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***Abstract*— Seven flying robot "fairies" joined human actors in the Texas A&M production of William Shakespeare's *A Midsummer Night's Dream*. The production was a collaboration between the departments of Computer Science and Engineering, Electrical and Computer Engineering, and Theater Arts. The production used two types of unmanned aerial vehicles, an AirRobot 100-b quadrotor platform about the size of a large pizza pan, and six E-flite Blade MCX palm-sized toy helicopters as alter egos for fairies in the play; the robots did not replace any actors, instead they were paired with them. TThe observations from the four weeks of practice and eight performances contribute a taxonomy and methods for creating affect exchanges between robots and untrained human groups, discussion of the importance of improvisation within robot theater, and insights into how untrained human groups form expectations about robots. The taxonomy captures that apparent affect can be created without explicit affective behaviors by the robot, but requires talented actors to convey the situation or express reactions. The audience's response to robot crashes was a function of whether they had the opportunity to observe how the actors reacted to robot crashes on stage, suggesting that pre-existing expectations must be taken into account in the design of autonomy. These contributions are expected to inform design strategies for increasing public engagement with robot platforms through affect, and shows the value of arts-based approaches to public encounters with robots both for generating design strategies and for evaluation.**

I. Introduction

Seven flying robot "fairies" joined human actors in the Texas A&M production of William Shakespeare's *A Midsummer Night's Dream*. The November 2009 production grew out of a January 2009 meeting between members of the Computer Science and Engineering (Murphy) and Performing Arts (Casey, Hopper, and Morris) departments to discuss how to expose roboticists to the principles in creating believable agents.

The theater arts offer many advantages for studying human-robot interaction in public encounters. Theater has an experience base of creating believable agency and predicting how "untrained" observers (the audience) will interpret agents' intent, but this base is not codified in a form suitable for computational systems. It is a domain where success is defined by large numbers of the general population observing agents (attendance) and by the believability of the agents (as measured by reviews and audience feedback) working together in a shared space. [1] argue that the theater is a suitable test domain for social robots because the interaction is bounded by the script, the environment is constrained and can be engineered to support robots, and the robots must be convincing and compelling.

The introduction of the robots, one pizza-sized AirRobot 100-b Quad-rotor and six E-flite palm-sized toy helicopters, did not alter the play and were not limited to a single scene (as with the recent production of *Phantom of the Opera* [2]). The robots did not subsume any roles, yet the integration of the robots into the narrative of the play made the robots more than props, in contrast to the robotic technology used in *Cymbeline* [3, 4]. More importantly, the robots were inserted into an existing play written about humans rather than a play written specifically for robots (cf., [5]) or about human-robot interaction. By being supporting elements in a "human" play, the robots provide insights into believable human-robot interaction.

The plot of *A Midsummer Night's Dream* can be summarized as follows. In the days leading up to the marriage of Duke Theseus of Athens and Queen Hippolyta of the Amazons, lovestruck Athenian teenagers Lysander and Hermia run away together through the Athens forest pursued by Demetrius, who loves Hermia, and Demetrius is pursued by Helena, who loves him. Meanwhile, a blue-collar community theatre troupe meets in the same forest to rehearse the play they are performing in honor of the wedding of Theseus and Hippolyta. Unfortunately for all, this forest is ruled by an arguing Fairy King and Queen. The Fairy King decides to get back at his queen by placing a magic spell on her, and, after encountering the teenagers and workers in his forest, he decides to have some fun placing magic spells on most of them, too. When the spells are finally released by the Fairy King, harmony and love are restored to all and the wedding and play happen as planned. The director (Hopper) began envisioning the forest as a fairy "otherworld" where human fairies shape-shift into robot fairies, costumes incorporate high-tech elements (LEDs, light ribbons, fiber optic fibers, metallic jewelry), and fairy movements generate evocative sounds, similar to the sound shifts in the humming of a light saber in Star Wars.

The concept of using small unmanned aerial systems as fairies was a part of the production from its inception. When the production officially began in the Fall semester, the three lead engineering professors (Murphy and Shell from Computer Science and Engineering and Zourntos from Electrical and Computer Engineering) attended all the production meetings. The professors, operators, and robots participated in all development and dress rehearsals. The choice of robot platforms, the decision for teleoperation, the behaviors and staging, and

all aspects were collaborative. As a result, the production provides a solid foundation for understanding how robots can generate believable agency.

The play ran for eight performances and one preview over two weeks and was entirely sold-out during the second week. The presence of robots in the play was not advertised, though the announcement for the local newspaper did mention robots would be involved. In general, the audience was the typical theater-goer and were not disproportionately technophiles. Thus the audiences represented "untrained observers" who had little or no knowledge of, or previous interaction with, robots and were there to see a Shakespearean play. The audience reaction to the play was outstanding as evidenced by the sold-out shows, the review in the university newspaper praised the production and seamless incorporation of the robots, and the production was covered by WIRED and other online news outlets which circulated video clips.

II. PREVIOUS AND RELATED WORK

The staging of *A Midsummer Night's Dream* appears to be the first integration of mobile robots, either ground or aerial, into a complete production of an existing play. The inclusion of robots was motivated by an intent to explore affect in non-anthropomorphic robots versus portraying socio-political themes or demonstrating improvements to humanoid robots. The production also differs in the conclusions about the role of improvisation. As with many of the robot theater systems surveyed, the aerial vehicles in *A Midsummer Night's Dream* were operated by humans.

Ground robots have participated in portions of *The Phantom of the Opera* but not the complete play [2]. Robotic technology such as a large printer was used in a recent production of Shakespeare's *Cymbeline* but actual mobile robots do not appear to have present [3, 4]. As such, *A Midsummer Night's Dream* is the first use of robots alongside with human actors in a play that is part of the theater canon. The staging of *A Midsummer Night's Dream* is also usual in that the inclusion of robots was not widely advertised or used to attract the audience; publicity about the robots came from a review of the play by the student newspaper [6] followed by national press [7] after the play ended. Thus the audience for the performances were primarily "normal" theatergoers expecting a play by Shakespeare.

Since the 1990's, ground robots have been used in plays written for robots (e.g., [5]) or for improvisational theater (e.g., [8]). [8] and later [1] compare the challenges of using robots in a scripted play versus improvisation, with [8] arguing that improvisational drama is superior in terms of audience satisfaction and understanding dramatic structure for human-robot interaction. The experience with *A Midsummer Night's Dream* provides a counterpoint to [8] and [1]; a play performance by robots requires understanding the context of a particular evening's performance, changes in lines, pacing with respect to the particular audience, changes in lighting speed, failures of technological elements, etc. Improvisation occurs even in a scripted play performed by only human actors, as it is not an entirely predictable sequence of events. The inclusion of robots led to minor improvisations within the context of the play to compensate for variations in robot behavior and crashes, illustrating how the inclusion of robots is richer than mere playback of fixed patterns. Likewise Sec. IV describes the audience reaction which clearly found the staging to be satisfying as a performance of a Shakespeare play.

The motivation for incorporating robots or writing a play specifically for robots generally falls into three categories: to explore socio-political themes in accepting robots into society (which are too numerous to cite here, but begin with Karel Čapek's R.U.R.), affect and expressiveness of robots [2, 9, 10, 11], experimental aesthetics [12, 13, 14, 9, 10, 15, 16], or some combination. The majority of productions exploring affect and expressiveness of robots have concentrated on improving the physical expressiveness of humanoid robots [2, 9, 11], on creating the sensing needed for awareness [2, 11], or computational structures [17, 9, 10, 18]. The production of *A Midsummer Night's Dream* was motivated by the desire to understand affect and expressiveness of non-humanoid robots, using commercially available robots designed for flight stability with limited degrees of freedom.

The robots used in *A Midsummer Night's Dream* were controlled by human operators, placing this within the puppetry category defined by [19] and [20]. However, this distinction is not significant for this article as the purpose of the reported research is to better understand affect and expressiveness as the first step towards capturing it with autonomous behaviors. Of the robotic performance systems, only [1, 2, 11] appear to use fully autonomous robot actors, while [14] had the audiences and actors interact essentially through teleoperation, [9, 10, 16] support both autonomous and teleoperation, while [15] and [21] captures human performers' movements and translate them into robot or avatar actions.

III. IMPROVISATION

The micro-helis were not always at the right place at the right time, occasionally crashed, and sometimes fewer than six were flown during a scene. The micro-helis were surprisingly fragile, were sensitive to air flow from the ventilation system, and the costumes impacted the control. Operator expertise and availability also varied. In general, the larger number of micro-helis that flew, the more effective their contribution to a particular scene; that is, the number of agents increased comprehension of intent. Fortunately, through the noteworthy adaptability of the human actors, crashes did not distract from play and further engaged the audience.

There were two opportunities for improvisation to a crash or errant behavior depending on whether the micro-heli was over the stage or over the audience. If the crash struck an actor or became entangled in a costume or wig, the nearest human fairy might extract the micro-heli and mime scolding it. See Fig. 1 for a particularly elegant response during a dance scene. If the micro-heli simply crashed to the stage, a human fairy would usually pick it up with exaggerated gentleness, and stroke or coo over it as it is were a bruised bird or child, then hold it up

Fig. 1. A dancing fairy carries off a crashed micro-heli by improvizing a one-handed cartwheel, robot in hand.

to let the operator attempt to relaunch and resume hovering. If the operator did not spin up the rotors or if it were the second crash in a row (the operator presumed a mechanical failure and would not attempt flight again for fear of distracting from the play), the human fairy would just cuddle the robot as she continue her role.

The most interesting variations were when a micro-heli crashed into the audience or drifted over the audience prior to landing. 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. The operator would turn off the LED to signal that it wasn't going to fly and the audience member would either spontaneously pass the micro-heli to the end of the row or a human fairy or the stage manager would retrieve the robot at the end of the scene. 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 itself.

Particularly during Act 4.1 where Mustardseed and her robot mock Bottom, the micro-heli had a tendency to drift over the audience, although this sometimes happened in Acts 2.2 and 3.1 (see Fig. 2). In order to maintain the fast tempo of the staging, the actor would improvise getting the robot back rather than wait for the operator to try to move the robot back to position. She might reach over the audience or even climb on seats. If the micro-heli had drifted too far, the operator would land in the audience and Mustardseed would gesture for the micro-heli to be returned to her. Mustardseed reacted as if this was all the audience's fault; she mimed scolding the audience and implied that they were trying to steal the micro-heli. In general when a micro-heli drifted over the audience, the audience did not appear to pay attention to it and instead focused on the action on stage. However, there was one exception when a audience member appeared to intend to humorously swat the micro-heli away but the disrupted airflow caused a crash and much embarrassment on the part of the audience member.

IV. Audience and Actor Reactions to Interaction

The audience reaction to the use of flying robots was overwhelmingly positive and their unintended interactions with the robots are described in Sec. III, while the reaction of the actors changed from wariness to positive over time. The one review of the play was by the university student paper, The Battalion, which clearly viewed the robots as one aspect of the play that accentuated the acting and dancing [6] rather than the major distinguishing point seen in other uses of robot in theater [2, 3, 4]. An interesting point is that the reviewer interpreted the micro-heli crashes as due to lost communications, rather than mechanical failure, environmental variability, or operator error.

The robots did not distract the audience from the play as evidenced by the lack of attention paid the robots or operators. No more than four audience members at any performance were observed to follow the Quad-Rotor's exits, despite close proximity to a loud device creating a large air current. As noted in Sec. III, the audience generally ignored the micro-helis when they flew overhead. Consistent with puppetry, starting with Japanese Bunraku which originated in the 17th century and had 3 to 4 puppeteers visibly operating a puppet [20] and continuing through the recent productions of Disney's *The Lion King* and the musical *Avenue Q* where puppeteers are visible, the audience treated robot operators as invisible even though they were in view.

Observations of the actors, statements from the "talk back" sessions after select performances, and a follow up interview with one of the human fairies suggest that the actors had expectations of the robots based on the movies (especially the Terminator) and consumer products (much more hardened and safe). The actors had expected humanoid robots and also that the robots might take over roles normally given humans. Initially the actors treated the micro-helis roughly and perhaps being non-science majors did not show an understanding of "naive physics" of flight and continually surprised the robot operators with how the robots were launched. The actors also appeared to be oblivious to the safety hazards associated with the Quad-Rotor. Although it was extremely unlikely that an injury could result, the dancers were often on eye level with the rotors as the robot descending the aisle to the stage. The robot operators gave an official safety and care briefing, creating two analogies that persisted and were mentioned by the actors in their interviews for The Battalion: one was to think of the Quad-Rotor as a "giant flying weed wacker of death" and the other was to think of the micro-helis as robot babies [6]. The metaphors produced the desired effect of a more safety

Fig. 2. Mustardseed launches her micro-heli fairy and together they mock Bottom. In ending the scene, the micro-heli flys over the audience. Mustardseed improvises by clamouring over the audience and casting them with a look of scorn for stealing her baby fairy, much to their amusement.

conscious culture. Finally, the actors were at first annoyed at the robots, not the operators, by the limited expressiveness and frequency of crashes. The actors playing the fairies then realized the opportunity for improvisation and to expand their roles. One actor commented that the unpredictability of the robots kept the actors on their toes and not to lapse into inattentiveness. The peer reaction to the "coolness" of having robots in the play also seemed to facilitate the shift from wariness to enthusiasm.

V. Lessons from the Theater about Affect

The production of *A Midsummer Night's Dream* forwarded an understanding of how affect, an important component of believability in agents, is created. The results are synthesized into a preliminary taxonomy for generating affect. A major surprise was the importance of improvisation and its necessity for even a highly scripted play; the necessity and contribution of improvisation had been eschewed in the literature.

A. Preliminary Taxonomy for Generating Affect

A goal of the collaborative production was to codify the behaviors would lead to untrained observers perceiving the desired affect and intent. Towards this goal, three categories of how robots can generate affect were identified. The first two categories, *apparent affect from animacy* and *apparent affect from actor reaction*, require that the robot be proximate to the action and only loosely coupled; in essence, the robots do not have to have or execute affective expressions because the overall action or the response of the actors is sufficient to create the perception of affect. Only in the third category, *affect from explicit affective expressions*, does the robot begin to explicitly contribute to the perception of affect. The three categories are ordered by increasing robot affective complexity: animacy and reaction require less behavioral subtlety from the robot than the explicit affective expression. A weakness of the taxonomy is that it categorizes the effort required by robots to generate affect, rather than organizing the audience's understanding of the affect based on the contribution of mechanisms (proximity, synchronization, mirroring, sounds, etc.). Even without a detailed model of the audience's understanding of affect, important distinctions of degree or kind of affect may alter which taxonomic categories are applicable. Apparent affect by actor reaction was the dominant mechanism in the play; in all but one case, the actors led the action and their reaction created the affect. While robot capabilities or operator skill may limit expressions of affect to the first category or first-and-second categories, the experience is that this need not imply a hard limit on the expressiveness of the robot. Within the first two categories a lack of complexity in the individual robot is compensated for by other agents: the observed robot-actor relationship and interaction is the expressive element, rather than the robot itself. When generating affect the robot should be considered a socially situated agent within a broader ecology of agents, the scene, and staging.

Apparent affect from animacy (the Heider-Simmel effect). Consistent with the seminal Heider and Simmel study that showed observers assign affect and interpret intent based on motion [22], the audience perceived affect and group coordination even though the robot motions where independent of the actors' motions. As seen in the Prologue and Act 2.1 and 5.1, the connection between the actors and robots was through accidental *proximity* and *loosely coupled synchronization*. For example, in the Prologue, the goal for each robot operator was simply to get their robot over the dancers and, if the mechanical control and environmental conditions permitted, to rotate their robot to the beat of the music. The apparent affect was perceived more strongly when there were more robots, possibly because the probability of a favorable synchronization confirming an intent was increased (e.g., "that robot is moving to the beat; oh, all the robots are excited by the music…" or "those two robots are above the action, they all must be watching the action").

Apparent affect from actor reaction. 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. This type of apparent affect occurred in Acts 2.2, 3.1, and the first part of 4.1, where the micro-helis swarmed overhead and then landed in the human fairies' hand, creating an impression of baby fairies. Unlike the Prologue and Acts 2.1 and 5.1, there was explicit interaction between the actors and robots but the human was expected to compensate for deficiencies in the robot. For example, the lead fairy cued the robots to descend and then all fairies attempted to gracefully catch the robots. The actors compensated for the robot's lack of control and unpredictably location, creating an impression of cooperation. Rather than the robots or their operators keeping up with "their" mother fairy, the mother fairies were expected to keep up and compensate for the robots.

The robot's contribution to the generation of affect in this case was *proximity* and a more *tightly coupled interaction* (i.e., descend on cue) but the responsibility for the perception of affect relied on the skill of the actors, very precise stage directions, and an awareness on their part of the situation, and their ability to improvise.

It is interesting to note that the audience learned how to interpret the robot agent's actions based on the actor's reactions; as described in Sec. III, the response of an audience member to a robot crash depended on whether they had witnessed an actor responding to a crash.

Affect from explicit affective expressions. In this category, the robot initiates and performs some, if not all, of the direct cues to create affect, with a much lessened dependency on the reaction of the actors. In some sense, this is where a robot can deliberately project affect and intent. Only one scene in the play had a robot attempt to create affect using explicit affective expressions. In that act where Mustardseed mocks Bottom, a robot baby fairy is launched by a mischievous Mustardseed, it then moves away from Mustardseed to follow behind Bottom while making a set of mocking (up/down, roll/yaw) motions and "sneaky" noises like Snidely the Dog (the sound was not added for technical reasons), then spins to communicate enjoyment of the prank. Note that in theory, the interpretation of affect in this category would depend more on what the robot actually does independently of the actors. However, this was only weakly demonstrated in *A Midsummer Night's Dream*; the success of the act depended on the actor who non-verbally conveyed mischievousness before and during launching her robot baby and that impression was transferred and attached to the robot. It should be emphasized that the actor was chosen for her ability to set up the affective nature of the scene, and other actors in the production would not have been as successful as she.

B. The Importance of Improvisation within Robot Theater

Perhaps the most surprising aspect uncovered while creating the taxonomy was the degree of improvisation required of the human actors. As described in Sec. IV, the effectiveness of the improvisational actor-robot interaction in communicating affect was undeniable. Improvisation is both necessary for both the pragmatics of staging a production with robots and for an enjoyable play, but the robot does not have to be the improvising party.

The use of improvisation runs counter to [1], which postulated that improvising would be the hardest case of interaction for robot and human actors and thus should be attempted last. Instead, the experiences with *A Midsummer Night's Dream* show that improvisation is required both implicitly (to compensate for timing, actor variations, etc.) and explicitly (to compensate for technological failures, such as the crashes in Sec. III). Furthermore, the taxonomy shows that it can be simpler to produce believable characters with improvisation than without, as creating apparent affect from animacy and actor reaction is less complex for a robot than explicit generation of affect. Therefore, improvisation should be expected to be incorporated into any human-robot theater production both from necessity and from simplicity.

The clear audience acceptance of robots as an enhancement to *A Midsummer Night's Dream* and their clear enjoyment of the play contradict [8] who argue for robots in fully improvisation drama saying that "Having robots perform a pre-scripted, complex play (say, Hamlet) would be an obviously unsatisfying experience." This can be interpreted in a less extreme "do away with scripts" fashion as a fear of the loss of dynamic coordination and timing between actors. However, the lessons learned from *A Midsummer Night's Dream* was that while such timing is critical for an enjoyable play, the robot does not necessarily have to be responsible for it. Affect can be generated with unsynchronized timing (apparent affect from animacy) and from the human actor (apparent affect from actor reaction). Certainly having autonomous robots which can observe and respond appropriately is a goal, but in terms of the goal of this article, *A Midsummer Night's Dream* shows that the robot may not have to explicitly generate or be responsible for affect production.

C. How Untrained Human Groups Form Expectations

The observations of the actors during pre-production and the audience suggests that people base how they will interact with robots from watching others. The actors started off with expectations formed by movies and TV and previous interactions with hardened consumer goods which were supplanted by experience. The audience started off with similar expectations but as seen in Sec. III revised them with what they saw the actors do. This appears to be an extension of the concept of "social proof" forwarded by [23]. This suggests that first encounters between the public and a robot(s) must be managed so that the correct expectations are formed or reinforced.

VI. Conclusions

In conclusion, the successful production of *A Midsummer Night's Dream* with humans and robots provides insight into creating believable agents. Seven non-anthropomorphic aerial vehicles with only a few degrees of freedom to provide expressiveness were able to amplify the emotional content of the play.

The experience produced a preliminary taxonomy of how robots can generate affect. Affect can be generated with no explicit behaviors as a consequence of the assignment of causality to animate objects (apparent affect from animacy). It can also be generated without explicit affective behaviors through the response or context setting by the actors (apparent affect from actor reaction). As the third level of complexity, the robot itself can explicitly contribute to the perception of affect (affect from explicit affective expressions). Lessons learned for creating apparent affect include having robots in close proximity to humans, multiple robots do not have be tightly coordinated or synchronized to generate affect, and having more robots increases the understanding of intent when robots are performing in parallel to humans (i.e., humans aren't providing direct cues). There remains the question of whether affect production in the theater, which is surreal, will hold for real world public encounters with robots.

The production also illustrates the importance of improvisation to be a workable and desirable means for interacting with robots. Such improvisation is necessary to overcome the natural behavioral variability in theater and also the results of control error, noise, and uncertainty. While *A Midsummer Night's Dream* relied on the human actors to be the improvisational agent, it is expected that improvisation will be a fundamental component of believable agency and not an optional, advanced case.

Future work is expected to continue to refine the ideas put forth in this article, especially addressing how the audience perceives for affect (versus how a robot can generate affect). Plans for another human-robot production are underway and a new play with key roles for robots has been proposed.

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A Miniature Robot Musical Using Roboid Studio

Kindergarten Education by Robot Arts

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***Abstract*—This paper introduces a miniature robot musical for early childhood education. We adapted a story 'three little pigs' to a more educational script, and developed a hardware system composed of four robot actors, a dozen of mini-robots for the chorus, and various devices for a stage effect. We also developed a software system to control all robots, devices, dialogues, and music in sync. Our miniature system is very effective to educate early childhood in a kindergarten.**

Keywords-robot musical; roboid studio; synchronization

I. INTRODUCTION

The focus of advanced industry such as computer games and cellular phones has significantly shifted over the past decade from hardware-centered to software-centered development. Then, it is currently moving to a contents-centered market. It is instructive to note that the user's repetitive exposure to the same service contents can lead to the decrease of interest and results in a demand on new services. Thus, to seize the commercial opportunity and have a social impact, the diversity of service contents is the key to success in the market. The same trend can be observed in robot industry, and we refer to the contents for a robot especially as robot contents [1, 2].

Early attempts to comply with this request for a robot have tried to change and adopt the conventional multimedia contents to a robot. These activities typically involve laborious, time-consuming and tedious efforts even though they can be carried out by specially trained experts. Moreover, these are not effective and attractive since it is the characteristic of the contents that their form is changed according to the devices containing the contents. Thus, it is desired to produce robot contents in a different style so as to show the distinct features of robots.

As an alternative there have been many trials to develop a robot theater or a robot musical [3, 4]. However, in spite of successful results of robot technology, our attempt to create a competitive and useful application to early childhood education is faced with actual problems or imperative issues:

- The existing robot theater systems are very huge and the robot actors are far from the audiences. Thus, it is difficult to actively utilize the system in a kindergarten and an elementary school for interactive education.
- Opposed to a single conventional robot, one of the primary problems of multiple robots' performance is to encounter the difficulty in control. The motion of each robot should be synchronized with other robots. To cope with this requirement, the communication protocol has to ensure multiple sensor and effector data can be delivered at the same time.
- A robot musical is composed of various elements such as robot actors, devices for a stage effect, dialogues, and music. This requests multimedia data as well as the motion data of robots should be incorporated into robot contents and they should be controlled in sync.
- It is not effective and attractive that a robot musical system performs only one story. The system should be easy to produce various play scripts. Thus, a common software framework is critical to diversify robot contents and to reduce the development cost by avoiding repetitive work from scratch and sharing the developed robot contents.

In this paper, we introduce our miniature robot musical system which adapts a well-known story 'three little pigs' to more interesting and instructive script for educational purpose. Given the above problems and issues, we present a software framework, Roboid Studio, as a solution. The framework includes a communication protocol for synchronous control of many devices and multimedia data as well as various tools for composing robot contents very easily.

II. HARDWARE SYSTEM

Out hardware system is composed of three pig robots and a wolf robot as main actors, a dozen of mini-robots for the chorus, a main controller for handling various devices, stage devices and limit switches for the global movement of robot actors, and lighting devices with pan/tilt mechanism for a stage effect, as shown in Fig. 1. The view size to the audiences is 1m × 1m, and the whole size of the system is 2m × 1.5m × 1.5m which is bigger than the view size to hide robot actors according to the story. Three pig robots can move their two arms and a mouth, and change 6 eye-expressions and a dual-colored LED. A wolf robot can move its 4 legs and a mouth. The global movement of these main actors on a stage is controlled by chains and limit switches. According to the story, two miniature houses can fly

off to the top of a stage by a wire mechanism, and the robot chorus comes down from the top of a stage to sing a song together with main actors. Fig. 2 shows the implementation of our hardware system.

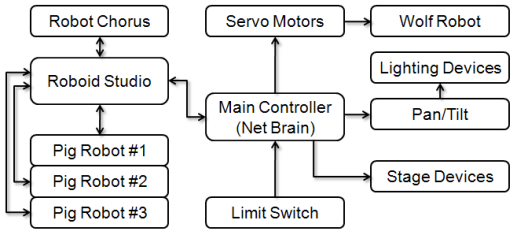

Figure 1. Overall hardware structure

Figure 2. Miniature robot musical system

III. SOFTWARE SYSTEM

The Roboid Studio is a software platform based on the Eclipse adopting OSGi framework to develop robotics applications for all kinds of robots. It includes support programs, easy-to-use graphical tools, code libraries, a modeling language, a script language, execute semantics, a communication protocol, and functional software components [5]. The configuration of the system and the interface, as shown in Fig. 3, have been developed through HCI work involving design principles and iterative design practices.

The crucial concept, simulacra, has been introduced to the Roboid Studio, which is a mirror image or snapshot representing the current status of all devices in each robot [2]. Even if two systems are physically separated, they can share the simulacrum of the other through a network, and a device map protocol makes up for the difference at every 20msec to maintain the perfect copy of the status. Thus, we can access a remote robot as it were in a local system. A core bundle of the software platform manages the life-cycle of each component in runtime. While the contents are playing, the core bundle executes software components at every 20msec and updates the corresponding simulacrum.

The Timeline Motion Editor, as shown in Fig. 3, is a graphical tool to create static contents for various robots, which aims to synchronize multimedia data and the motion of add devices in robots. With the Timeline Motion Editor we can sequence the motions of robots on different tracks and adjust the timing of each motion easily and accurately by simple click and drag operation of a mouse. The audio data are segmented into 960 bytes of data corresponding to 20msec and the motion data between adjacent key frames are obtained by linear interpolation, so that a set of audio and motion data can be sent to a robot at every 20msec.

Opposed to the Timeline Motion Editor, the Contents Composer enables the robot to dynamically respond to the user's behavior such as touch and voice. It enriches the robot contents by arranging motion clips created by the Timeline Motion Editor and embedding other contents clips composed by the Contents Composer in sequence or concurrence. Motion clips and contents clips can be connected with various logical, control, functional or conditional blocks to control the process flow in the contents. In addition, to create graphical interfaces and to augment robot contents, we can also use JavaScript codes in the Contents Composer.

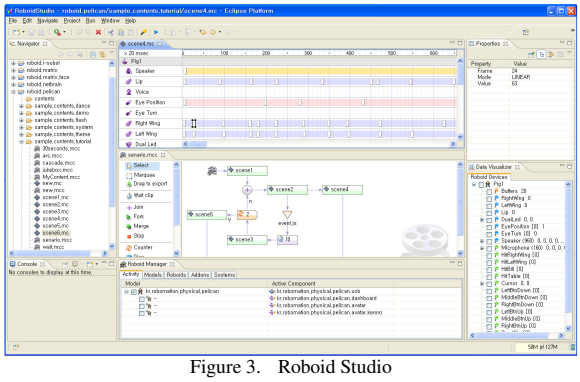

Figure 3. Roboid Studio

IV. CONCLUSION

The communication between human and robots is one of promising technology desired to realize in the near future. The contents of communication are robot contents and the communication method is robot media while communication itself is objective. Miniature robots as robot media and a robot musical as robot contents are expected to play an important role in the market of early childhood education.

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