The RUBI/QRIO Project: Origins, Principles, and First Steps

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***Abstract*— Computers are already powerful enough to sustain useful robots that interact and assist humans in every-day life. However progress requires a scientific shakedown in goals and methods not unlike the cognitive revolution that occurred 40 years ago. The document presents the origin and early steps of the RUBI/QRIO project, in which two humanoid robots, RUBI and QRIO, are being brought to an early childhood education center on a daily bases for a period of time of at least one year. The goal of the RUBI/QRIO project is to accelerate progress on everyday life interactive robots by addressing the problem at multiple levels, including the development of new scientific methods, formal approaches, and scientific agenda. The current focus of the project is on educational environments, exploring the ways in which this technology could be used to assist teachers and enrich the educational experiences of children. We describe the origins, philosophy and first steps of the project, which included immersion of the researchers in the Early Childhood Education Center at UCSD, development of a social robot prototype named RUBI, and daily field studies with RUBI and QRIO, a prototype humanoid developed by Sony.**

***Index Terms*— Interactive Resonance Between Robots and Humans, Architectures for Social Interaction, Non-verbal communication.**

I. Introduction

For the first time in history the development of robots[1] that interact with and assist humans in everyday life, has become a technological possibility [2, 6]. This paper argues that the computational power to address this problem is already available. The main obstacle for progress is the need for a new approach to the study of human nature that departs from the goals and methods of the cognitive sciences. While the development of general purpose digital computers fueled the cognitive revolution, the development of social robots needs to go hand by hand with a new approach to the scientific study of human nature.

This document presents the origin and early steps of the RUBI/QRIO project. One goal of this project is to accelerate progress in and explore the possibilities of interactive robots by addressing the problem at multiple levels, including the development of new scientific methods, formal approaches, and scientific agenda. The project focuses on education environments and the potential use of robots to assist teachers and enrich the educational material presented to children. As part of this project two humanoid prototypes, RUBI and QRIO, are being immersed at the Early Childhood Education Center at UCSD, on a daily basis, for a period of at least one year. In this paper we describe the origins, underlying philosophy and the first steps of this project, including construction of the RUBI prototype. At this point the project is on its early stages and thus this document is more a declaration of principles than a presentation of new empirical knowledge. For a paper documenting an experiment currently being conducted with QRIO under this project see Reference [14].

[1]We use the words "interactive robots", "social robots", and "communication robots" interchangeably to loosely refer to robots designed to interact with humans in a a social manner and assist them in everyday life activities.

II. On the Need for a New Science: Sex is Not Embodied Cognition

The development of social robots is revealing and making explicit aspects of human nature that have been ignored for the past 40 years. For example, social robots can trigger deep feelings and emotions and can touch the human heart in a manner that is completely missed by cognitivist [2] approaches. Indeed human behavior appears to be more reactive, more affective, and less deliberative than those approaches would suggest. The reactions produced by robots are fast and released by subtle stimulus dynamics. Their effect disappears when parameters in the robot behavior or the robot appearance are changed ever so slightly.

One of the key assumptions of the cognitive sciences is the belief that humans are fundamentally thinking creatures, and that human nature can best understood by focusing on cognition. Aspects of human nature like feeling, sensory processing, emotion, perception, or motor control are viewed as secondary, not particularly revealing of human nature, or non-scientific. Cognitivism is slowly recognizing the importance of non-cognitive processes however it typically portrays them as "modulating cognition", "energizing cognition" or, at best, "another form of cognition". This is reflected in concepts

[2]Cognitivism is the approach to the scientific study of human nature that replaced behaviorism in the 1970s. While behaviorism emphasized the functional study of the behavior of organisms, cognitivism emphasizes the study of cognition and the faculties of the mind. Key points in the history of cognitivism are the Darmouth conference in 1956, the infusion of funds by the Sloan foundation in the 1970s, and the founding of the Cognitive Science Society in 1979. An early alternative to the cognitive sciences was Wiener Norbert's "Cybernetics" which unfortunately never caught on in the social sciences.

like “Embodied Cognition” and “Hot Cognition” to refer to emotion. However one can argue, that cognitive attempts to capture non-cognitive aspects of human nature miss the point altogether. For example, one could view sex as “embodied cognition”. Love can also be seen as “a special mechanism that turns off some parts of your brains so that you don’t think about the consequences of your actions” [1]. There is some merit to these views but they are just the tip of an iceberg and do little justice to the function and nature of sexuality and love in human life. Something akin occurs when approaching social robots from a cognitive perspective. Progress in social robots will inevitably lead us to confront questions like the nature of love and its role in everyday life. Cognitivism is simply ill equipped to approach such questions in a useful manner.

Cognitivism borrowed much of its cache from the development of general purpose computers, and thus, it is not coincidental for some of its major figures to dismiss the importance of special purpose systems:

> “*If the group at SRI hadn’t built Shakey, the first autonomous robot, we would have had more progress. Shakey should never have been built. There was a failure to recognize the deep problems in AI; for instance, those captured in Blocks World. The people building physical robots learned nothing.*” (Minsky, 1996, Reference [13]).

> ”*The worst fad has been these stupid little robots. Graduate students are wasting 3 years of their lives soldering and repairing robots, instead of making them smart.*” (Minsky, Wired Magazine, 5/13/2003)

Arguably, it is precisely these special purpose computers that are making us aware of the problems associated with operating in real-time in a highly uncertain but sensory rich environment. In such environment, timely sensory information, rather than symbolic inferences of the type favored in “Blocks World” problems is key to survival. As anybody that has tried meditation would attest, when deprived from real time sensory information the mind is *“like a drunken crazed money with St. Vitus’ Dance who has just been stung by a wasp”* [11]. Human behavior seems to be better described as a shallow “dance” of actions and reactions with the world, rather than an inferential turn-taking process, like machine-based chess-playing.

Besides a revolution in scientific agenda, progress in social robotics will also require a change in scientific methods. For the last 40 years the methods of the cognitive sciences have been instrumental in developing many heated debates: early attention vs. late attention, working memory vs. short term memory, serial vs. parallel processing, analogical vs. propositional representations, symbolic vs. sub-symbolic processing, modular vs. interactive architectures. These debates have turned out to be undecidable, contributed little to our understanding of human nature, and have had little impact on society at large. Indeed one can argue that one of the main accomplishments of cognitvism has been the discovery of the reasons why Google™should never have worked. Modern approaches and methods are needed that avoid scholastic debates and enable rapid scientific and technological progress.

III. Project’s Philosophy

A. Origins: Massive Lack of Knowledge

The origins of the RUBI/QRIO project date back to the first author’s involvement on an NSF project to develop computer tutors that teach children how to read (NSF IIS-0086107: Creating The Next Generation of Intelligent Animated Conversational Agents). The role of the first author on this project was to develop machine perception primitives (e.g., face detection, expression recognition) that could be used by the computer tutor to modulate its teaching behavior. During the course of that project we realized we could spend a great deal of time developing machine perception primitives that turned out to be not that useful for teaching. For example, to our surprise we found that the gross head movement of the children were probably more informative than facial expressions to assess the state of the student. We were also surprised at how little is known about the problem of real time social interaction, i.e., what cues are used by people to infer the internal states of other people in real time. Animators and artists ended up being one of the best sources of information, yet their knowledge about what makes the human heart “tick” was mostly intuitive and not properly formalized.

Another important event that helped originate the RUBI/QRIO project was the first author’s visit to ATR in the fall of 2002. During that time the first author became aware of the intense feelings social robots can trigger and of the dependency of these feelings on subtle and surprising cues, like the slow rocking back and forth of a robot’s body, or the high-frequency trembling of a robot’s eye. As part of that visit the first author brought Robovie-I, a communication robot designed by Hiroshi Ishiguro’s group [6] to a child-care center in Kyoto (see Figure 1). We were shocked at the intensity of the reactions and emotions caused by the robot in some of these children.

Most importantly, the RUBI/QRIO project has been possible thanks to a collaboration between the Machine Perception Laboratory at UCSD and Sony Intelligence Dynamics Laboratory, via a UC Discovery grant. In the course of this collaboration it became clear to us that progress in social robotics would require a body of knowledge about real-time social interaction that is currently missing in the scientific literature. SONY’s vision about personal robots and their experience with AIBO made possible to create a coalition of interests and perspectives that deviated significantly from the cognitivist agenda and methods.

Fig. 1. A picture of the visit of Robovie to a child-care center in Kyoto during the Summer of 2002. The main result of that visit was our realization of our lack of preparation to the intensity of the reactions caused by social robots in children and how little is known about this issue.

B. *Focus on Non-Verbal Aspects of Human Nature*

While cognitive approaches focus on language and logic, the RUBI/QRIO project takes a more critical view about the role of words in human nature. We felt a healthy mistrust of words and language is particularly relevant to make progress in social robotics. It is just too easy and too tempting to fall in the trap of speech as a mean of communication, only to realize that such communication ends up being void of affect and meaning.

This was one of the reasons why we decided to focus RUBI/QRIO on the problem of interacting with 2 year old children. At this age children can speak and understand only about 50 words. Thus while speech is useful our focus needs to be on the affective, non-verbal aspects of human communication. These are at the heart of the social dynamics we want to study and the systems we want to develop.

C. *The Cathedral and the Bazaar*

Scientific progress is not unlike software development. Programs can be seen as well specified theories, and the problem of developing good theories is not unlike that of developing good software. Debugging methods are a critical part of the process. Indeed experiments can be seen as the basic debugging tool of scientists. Unfortunately the cognitive sciences have historically placed more emphasis on developing new flashy theories than on debugging them. For example, one of the most-cited papers in cognitive development is the 1977 report in *Science* that newborn infants can imitate facial expressions [7]. Almost 30 years later the scientific community is still split in half as to whether or not the phenomenon is real.

Inspired by the analogy between software development and science we felt it was important for the RUBI/QRIO project to adopt the "Bazaar" style approach that Linus Torvalds used so successfully when developing the the Linux operating system [10]. In particular we felt it was important to use the principles of "Early and Often Release" and the emphasis on "Listening to Your Customers".

Early and frequent releases are one of the most important innovations of the Linux development model. In our case this principle reminded us that we should not wait to have perfect robot hardware, perfect software, and a perfect scientific methodology before we start our experiments. Instead we decided to treat the RUBI/QRIO project as a fluid process subject to change and revision on a weekly basis. This focus on change forced us to find simple inexpensive solutions first, in recognition that little is known about the problems we are trying to solve. It also helped us design things with the understanding that they will need to be changed often.

Frequent change is an effective way to incorporate user feedback. Indeed Linus Torvalds emphasized seeing the users as co-developers or co-debuggers of the Linux operating system. With this idea in mind, we realized if we were to incorporate feedback in an effective manner, it was critical for us to move outside our laboratory, bring robots to every-day life environments (the "trenches"), and immerse ourselves in such environments for long periods of time, in the order of months or years.

In the RUBI/QRIO project we are bringing robots to UCSD's Early Childhood Education Center (ECEC), a child-care center for children from 1 year to Kindergarten level. The project started in September 2004 and during the first 6 months of the project the researchers spent an average of 10 hours a week volunteering at the Center. The goal was for the researchers to bond with the ECEC community, forming personal ties with the children, the parents, and the teachers.

While doing so we realized we were changing the ECEC community and the community was changing us. Aaron Cicourel, a senior sociologist and methodologist pointed out that these dynamics were of genuine scientific interest and deserved to be studied and documented. He then became part of a second tier of researchers in the RUBI/QRIO project working independently from the first tier. While the first research tier, led by the first author of this paper, focuses on making progress on the technical aspects of social robotics, the second tier, led by Aaron Cicourel, focuses on the social dynamics introduced by the immersion of the robots and robot researchers in the ECEC community.

IV. First Steps: Summary of the First 8 months

The first 6 months of the project were spent volunteering at the ECEC and developing RUBI (See Figure 2). This time was important to bond with the children, teachers, and parents, and to get a realistic sense of the environment where the robots will be operating. One of the consequences of this period is that 100 % of the families in Room 1, where the RUBI/QRIO project will reside, have agreed to participate, and consented to the scientific use of the audio-visual material produced in the project. This is remarkable considering the US culture is somewhat suspicious about robots, and the idea of mixing robots and infants is a bit out of the ordinary.

Fig. 2. Constructing RUBI at the first author's Garage. Front from left to right: Kazuki Isaka, Bret Fortenberry. Back: Javier Movellan.

This time also helped shape the principles of the RUBI/QRIO project, as expressed in previous sections. It helped us realize how very little is known about the dynamics of real-life social interaction, how biased the cognitive approaches have been about this issue, and how important it was for us to focus on continuous change and continuous incorporation of feedback.

The volunteering period also had an effect on the design of the RUBI robot prototype. For example, prior to the volunteering we had planned to build a robot with a fixed smile, and leave the development of facial expressions for the future. During the volunteering period it became clear that facial expressions are a must. We also became aware about the importance of sensory features that one can easily disregard while working at a laboratory.

The volunteering period also helped focus on what we thought were the most important issues for which current robot technology could be useful in a child-care environment. We found the classroom goes through different moods in a regular manner: eating mood, dancing mood, playing mood, sleep time mood, waiting for the parents mood, crisis mood. The children seem to be experts at detecting these moods and the teachers seem to be experts at making the transitions between classroom moods as explicit and smooth as possible. We made the investigation of environment moods and the development of machine perception primitives to detect mood a top priority.

The volunteering period also helped shape the methodologies we will be using during the second part of the project. We decided to introduce 3 humanoid robots in the classroom: RUBI, QRIO, and a toy robot used for control purpuses. We decided it was important for the robots to be present every day. We settled on a daily observation period of 1/2 hour during which time children are allowed to move freely between three environments: (1) a room in which the robots are located; (2) An adjacent room with no robots; (3) An outdoors playground.

The first prototype of RUBI was introduced in Room 1 at ECEC on April 8, 2005. Since then we have had 11 daily sessions. For each session the room is set with 2 synchronized cameras, one providing a wide angle view of the room and the other hand-held by one of the researchers, that provides a view focused on the robot. The video of these sessions is coded on a daily basis by a team of 3 judges. We tried a variety of methods for coding these videos and found continuous audience response methods borrowed from marketing research [4, 9] to be particularly efficient. Every day 3 judges, one of them a certified expert in facial expression measurement, view the tapes and evaluate (from 1 to 5) the goodness of the interaction between children over the past 5 minutes. We found this method provided good inter-observer reliability (0.798 Pearson's Correlation Coefficient) and was sensitive to changes in the quality of the interaction between robots and children. The left side of Figure 3 displays the results on the first 9 days of interaction between the children and RUBI. Dots represent the scores given by 3 judges on 5 minute segments of video. The solid line represents the average of the three scorers. The graph shows a sustained change in the quality of the interaction after introduction of new interactive educational games on Day 6. Figure shows three images from periods of interaction with high goodness scores

One of our goals is to develop methods to perform probabilistic inference and sequential hypothesis testing on the data provided by the 3 judges on a daily basis.

V. Construction of the RUBI Prototype

RUBI's design was inspired on Hiroshi Ishiguro's Robovie-I humanoid [5, 6]. However, we found that the original Robovie-I design was frightening to children under 4 years of age and systematically changed RUBI's appearance until children found it non-threatening. Some of the modifications included shortening the body, making it more plump, including facial expressions, clothes, a touch-screen, and hair. Currently RUBI is a three foot tall, pleasantly plump robot with a head, two arms, and a touchscreen (See Figure 5, Left). It stands on four non-motorized rubber wheels for moving it easily from place to place. The external connections

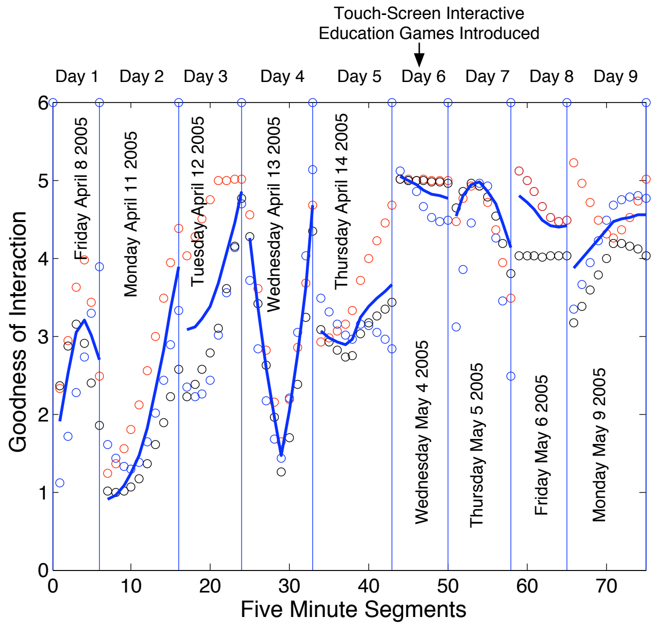

Fig. 3. *Each day 3 judges score the quality of the interaction between children and robots on 5 minute video segments. This figure displays the scores for the first 9 daily sessions. Dots represent scores (from 1 to 5) given by individual judges. The solid line is the average of the 3 judges score. The average inter-judge correlation is 0.798. Note the significant change in scores after introduction of educational software on RUBI's touchscreen on day 6.*

consist of a power cable, a wireless Ethernet adapter, a high-speed wired Ethernet, and a 900 Mhz Radio Modem. The high-speed wired Ethernet is used to connect RUBI to a computer cluster of 24 Power PC G5 CPUs. The body is a modified version of IKEA's ILEN TV bench. This bench is spacious enough to hold all of the RUBI's components, yet short enough to keep RUBI's appearance non-threatening to children.

A. Actuators

RUBI's head frame was borrowed from Hiroshi Ishiguro's group [5, 6]. It has 7 degrees of freedom (dof): Three of these are controlled by stepper motors driven by a Galil DMC-1832 PCI motor controller. The neck can move 54 degrees up and 30 degrees down from center position and 54 left and right of center. We set the maximum head speed to 60 degrees per second; faster motor control is possible but gives RUBI's motion an unnatural appearance. The remaining 4 dof are in the eyes, both of which have pan, tilt and zoom motors. The eyes are SONY EVI-G20 PTZ (Pan-Tilt-Zoom) cameras with horizontal range of ± 30 degrees and a vertical range of ± 15 degrees. Maximum speed on both horizontal and vertical axes is 150 degrees/sec. They are controlled via a 9600 bit/sec VISCA-protocol serial connection.

Fig. 4. *Images of periods with high Goodness of Interaction scores.* **Left:** *RUBI teaching materials targeted by the California Results Developmental Profile from the California Department of Education.* **Right:** *It is not unusual for children to express positive affect for RUBI and QRIO.*

Fig. 5. **Left**: The appearance of RUBI is in constant change based on feedback from children and teachers. Two of the early critics were Kai and Marina Movellan. **Right**: RUBI's sensors send information to a 24 G5 Power PC cluster. The cluster is being used for experiments for RUBI to discover object categories from interaction with the environment [3].

RUBI's face has four dof: two for the mouth, and one for each eyebrow. Though the system has limited movement, RUBI is capable of producing a variety of expressions (see Figure 6). In addition RUBI's hair is made of fiber-optics that can be lighted up with different colors to express emotional states. In order to add interactive touch and display scenarios, and for potential use in early education RUBI is outfitted with a 12 inch Elo Entuitive Touchmonitor.

Earlier versions of RUBI used 7-dof arms (See Figure 7). However due to safety concerns from the teachers at ECEC we decided to simplify the design in favor a very light and safe 1 dof arm. This was a good lesson for the development team to keep things simple and introduce complexity only after we listen carefully to the feedback from the children, teachers and parents. The goal is for them to become part of

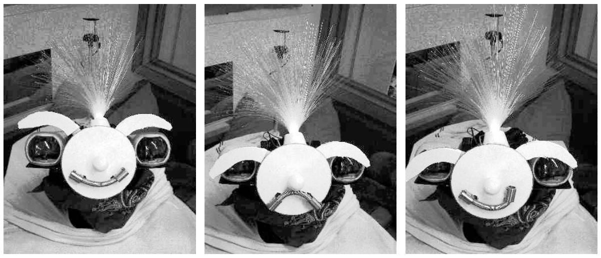

Fig. 6. Currently RUBI's facial expressions are controlled by 2 mouth servos, and 2 eyebrow servos. In addition she has fiber-optic hair which can take different colors to express emotion.

the development team.

B. Sensors and Machine Perception

RUBI's 3 vision sensors consist of a pair of SONY EVI-G20 color cameras which are its 'eyes' and third input, a low-resolution stationary omni-directional color camera which acts as RUBI's peripheral vision. All three of these cameras are routed through a quad-camera video splitter that combines the each video frame into a single 640x480 image. That single image is then captured via a BT848 video capture card running at 29.97 Hz (see Figure 8).

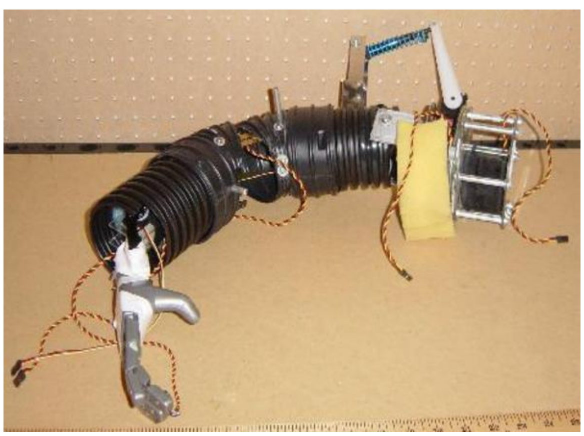

Fig. 7. RUBI's original 7 dof arm design was rejected by the teachers for safety concerns. The current arm uses a 1 dof design which is very flexible and robust. After having spend many hours developing this arm, it was a valuable lesson for us to have it rejected. It taught us the importance of starting with very simple designs that are safe and durable.

RUBI is currently equipped with real time face detection, eye detection, eye-blink detection, and expression recognition. These systems were developed at UCSD's Machine Perception Laboratory (MPLab) for the past 5 years. All of these components, except for the facial expression recognition module, are part of the MPT Library available at the MPLab's Web Site. One of the goals of the RUBI project is to evaluate the accuracy and value of these systems in social robots.

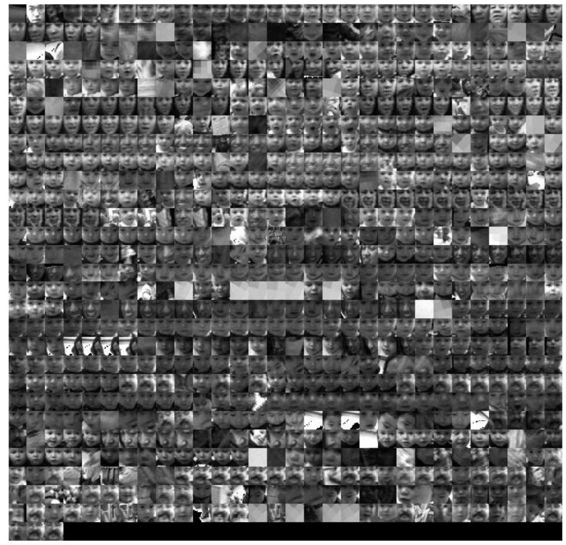

Fig. 8. A collage of faces automatically detected by RUBI during a 1/2 hour daily session at ECEC.

RUBI's auditory system uses an AcousticMagic Voice-Tracker 8 microphone array. Currently the 12 inch touch-screen is the only source of tactile information.

C. Computer Systems

RUBI is powered by 5 computer systems and by an off-site cluster of 24 G5 Power PC CPUs. The on-board systems take care of real-time interaction. The off-board system is used for experiments on self-supervised learning of the environment. Of the on-site system, two of these are dual-processor 2.8 GHz Intel P4 Xeon PCs with 512MB RAM running the Red Hat Linux 7.3 operating system. One Xeon PC currently handles the face-detection and color-detection on both eye cameras, the peripheral vision camera processing, the expression detection, and the head motor control. The other Xeon PC handles speech detection, external interactions, and any long term decision interactions that will be added. The third computer is a 1.8 GHz Intel P4 with 512MB RAM running the Windows XP operating system. This computer is used to control the interactions of the touch screen monitor. In addition RUBI uses two Microchip 18F8520 PICmicro micro-controllers. The first is the Master processor which handles radio communications, generates most of the motor control output signals, and oversees the general operations of the Robot Controller. The second micro-controller handles fast reactive behaviors.

D. Behavior System

The current behavior architecture is production systems based [6]: The interactions are driven by scripts called

Modules, which currently include face tracking, dancing, peek-a-boo, external toys and teaching. Each Module receives sensory inputs from perception and feedback from the actuators. Depending on the current states of the system and the current module, RUBI follows a set rules to make a decision on timing, control and the target behavior. One of the goals of the RUBI/QRIO project is to develop a new architecture for social interaction based on probabilistic principles. A primitive version of this architecture is described in [8].

VI. Conclusions

We described the scientific philosophy and goals of the RUBI/QRIO project. The project starts with the acknowledgment that progress in social robotics will require a revolution in scientific agenda and methodology. Part of this revolution will include abandoning the cognitive paradigm as we know it, immersing researchers and robots into every-day life environments for long periods of time, and focusing on continuous debugging of theories, software and hardware. We describe the first steps of the RUBI/QRIO project, which included immersion of the researchers in the Early Childhood Education Center at UCSD, and development of a social robot prototype named RUBI. For the next year we will be testing RUBI and QRIO on a daily basis, making modifications in close contact with our customers: the children, teachers and parents of the center. Our long-term goal is to accelerate progress in interactive robotics. Our current focus is on education environments, exploring the potential use of this technology to assist teachers and enrich the educational experiences provided to children. Within a 1 year period we will evaluate the successes and failures of the project and modify the principles it is based on accordingly.

VII. Acknowledgments

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References

[1] BBC-3. Interview with marving minsky, 2004. URL `http://web.media.mit.edu/ minsky`.

[2] C. Breazeal. *Designing Sociable Robots*. MIT Press, Cambridge, MA, 2002.

[3] Ian Fasel and J. R. Movellan. Learning radon-nykodim derivatives for automatic discovery of object categories. In *Submitted to Neural Information Processing Systems 2005*, Vancouver, Under Review.

[4] I. Fenwick and M. D. Rice. Reliability of continuous measurement copy-testing methods. *Journal of Advertising Research*, 1991.

[5] H. Ishiguro, T. Ono, M. Imai, and T. Kanda. Tdevelopment of an interactive humanoid robor "robovie" – an interdisciplinary approach. In R. A. Jarvis and A. Zelinsky, editors, *Robotics Research*, pages 179–191. Springer, 2003.

[6] Takayuki Kanda, Hiroshi Ishiguro, Tetsuo Ono, Michita Imai, and Ryohei Nakatsu. Development and evaluation of an interactive humanoid robot "robovie.

[7] A. N. Meltzoff and M. K. Moore. Imitation of facial and manual gestures by human neonates. *Science*, 198: 75–78, 1977.

[8] J. R. Movellan. An infomax controller for real time detection of contingency. In *Proceedings of the International Conference on Development and Learning (ICDL05)*, Osaka, Japan, 2005.

[9] M. Polsfuss and M. Hess. Liking through moment-to-moment evaluation: Identifying key selling segments in advertisement. *Advances in consumer research*, 18: 540–544, 1991.

[10] Eric Steven Raymond. *The Cathedral and the Bazaar*. O'Reilly, Cambridge, MA, 2001.

[11] Huston Smith. *The World Religions*. HarperCollins, New York, 1991.

[12] Huston Smith and Phillip Novak. *Buddhism*. HarperCollins, San Francisco, 2003.

[13] David Stork. Scientist on the set: an interview with Marvin Minsky. In David Stork, editor, *HAL's Legacy: 2001's computer as a dream and reality*. MIT Press, Cambridge, 1996.

[14] Fumihide Tanaka, Bret Fortenberry, Kazuki Aisaka, and Javier R. Movellan. Plans for developing real-time dance interaction between qrio and toddlers in a classroom environment. In *Proceedings of the International Conference on Development and Learning (ICDL05)*, Osaka, Japan, 2005.