Robots as social mediators: coding for engineers

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***Abstract*— Coding can contribute to robot design by suggesting behavioural benchmarks. These, however, depend on the level of analysis. In illustration, semi-formalised rules are used to investigate child-robot *encounters*. By using behaviour-level codes, we extract information about how children use the robot. This leads to findings about longditudinal changes in how children evaluate its behaviours. Children, we find, use the robot as a social mediator– to prompt synchronized social events. By focusing on a *behavioural* level, coding can benefit designers of robots, software and sensors.**

I. Introduction

COMMUNICATION robots can be used for many purposes. Among these, as reported elsewhere, Kanda et al. [1] carried out a field trial of a robot in a primary school. In this setting, children were free to interact with the machine during recess between lessons. While the encounters were diverse [1] [2], early analysis led to interest in social events that occurred around the robot [3].

While opening up a many issues about human behaviour, this paper takes an engineer's perspective. Working bottom-up, we consider how coding-systems can be used to evaluate communication robots. Specifically, we aim to develop benchmarks for sustaining longditudinal interaction. Ideally these will be applicable to not just one robot but, suitably interpreted, as general design principles. By coding real-time social events, we find that robot behaviours are valued when they promote social opportunities.

II. Background

When Andy Clark realized that we were natural-born cyborgs, several matters fell into place [4]. He understood why losing a lap-top was like losing part of the brain, why we differ from other animals, and why it is hard to build intelligent robots. *Human* intelligence depends, to a large extent, on resources beyond the body. To interact with us, robots must both simulate mental functions and exploit our sensitivity to events beyond skin and skull. For the same reason, to understand human-robot encounters, we need fine description where, instead of assuming that we react predictably, we investigate what humans actually do. Code systems that do this can serve both in programming robots and designing sensor systems.

There are many difficulties in designing communication robots. First, empirical work shows that human-robot encounters often contradict models of human-human interaction [5]. Since we cannot make reliable predictions, we need descriptions of how behaviour changes in time. Second, what people say often fails to clarify events [6] [7]. While human action depends on taking an intentional stance, this clarifies neither real-time events nor how we use the complex patterns of the interaction order [8] [9]. Ideally models of human behaviour will be used to develop fine coding of human-robot encounters.

In practice engineers usually design robots with reference to putative individual functions. Many devices thus simulate mental competences [9] or elicit use of a 'social ''model' [10] [11]. Often they are defended by post-hoc psychological benchmarks [12] [13] [14]. Others reject synchronic models for ones that stress development and interaction [15]. These, it is hoped, may converge with functional and biological approaches [12]. Powers can be traced, as Asada et al. propose [15], to interactional history. Given co-evolutionary processes, functions can use a mutual relation between social interaction and biology. Generalizing, one can ask not only on how internal and external constraints shape development but also how they shape real-time events. Building on this, we illustrate what coding shows of how children use opportunities provided by a single robot.

Kanda et al. [1] [16] exemplify how empirical investigation can serve communication robotics. They report how a robot, 'Robovie', was both used in a museum and, at the same time, for making observations of how humans oriented to the machine [16]. These were subsequently used to update design. Rather than rely on what people said,

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TABLE I
REVISED VERSION OF KAHN ET AL.

Codes	Results	High level description	Comments on results
Exploration	More exploratory behaviour with AIBO (p=.013)	Child-at-the-centre (actor /feeler)	Children experience AIBO as more novel and, in spite of some apprehension are more prone to explore its affordances.
Apprehension	More apprehensive behaviour with AIBO (p=.000)		
Affection	No significant difference AIBO/ stuffed dog	Kind of engagement (positive/ negative)	While both elicit feelings, children are more likely to use the stuffed do to express negative feelings.
Mistreatment	Less mistreatment of AIBO (p= .000)		
Endow animation	Less endowment of animation to AIBO (p= .000)	Novel-object as mediator	Mediating means differ: if a dog is a novel object used to pretend, an AIBO seems to offer potential for co-action.
Attempt at reciprocity	More attempted reciprocity with		

changes were made on the basis of how they acted. Below, we too explore this space between intention and design by examining what children make of the opportunities found in Robovie's *behaviours*.

III. THEORETICAL AND METHODOLOGICAL ISSUES

Although intelligent behaviour was regarded as action from the time of Aristotle until the 18th century, Descartes, Hume and other philosophers changed this view. Instead humans were seen as possessing internal systems that gave them cognitive powers. While Hegel and Marx rejected such views, internalism dominated psychology. Until recently informatics has usually drawn on the same models. Underplaying social dynamics and contingencies, interactions are modeled as sequences of output. Below, we deny that 'interactional' models are a suitable basis for evaluating human-robot interaction. This is because, in dealing with robots, humans rely less on inner competencies than on contingencies [17]. While sometimes goal-directed and sometimes reflex, much action *is* real-time coordination. For children, robots simply contribute variety to a familiar social world. Complex tasks, as Hutchins [18] shows, connect artifacts, information processing and social events. In Clark's terms, we are not information-processors, but, rather, natural-born cyborgs [4].

How can we investigate social behaviour? One standard method is to use coding or a 'more or less formalized set of rules for extracting information from the stream of behaviour' [19]. While many have used coding systems, they generally ask how, on average, humans interact with machines. In dealing with both non-verbal behaviour [20] and psychological benchmarks, coding has picked out an 'interactional level'. However, an engineer also needs to know about the quality of human actions. Instead of asking what children do and feel, we propose (micro) behavioural coding. Insofar as this is a new departure in human-robot interaction, we briefly contrast our approach with work on how children respond to novel objects[6] [21].

Interactional models are concerned with what, on average, happens during encounters. In the work of Kahn and colleagues, this view is applied to comparing encounters with Aibos and stuffed toy-dogs. For ease of understanding, **Table I** summarises one set of results [6]. Children are found, on average, to be more emotionally affected by the robot while, nonetheless making fewer overt affective displays. Equally, Aibos elicit significantly more attempts at reciprocity. As with all good coding, the results generalize by, for example, raising the question of why the (unfamiliar) Aibos promote less pretending but more exploratory action. While animation surely matters, engineers will nonetheless demand more details. They will want to know about individual differences, real-time events and if encounters change with familiarity. In short, while confirming the social potential of robots and the existence of reciprocation, interaction-level coding overlooks real-time. It is thus of limited value for developing software or sensors.

In seeking engineering benchmarks, we ask how children exploit the machine's (perceived) potential. Abandoning the 'interaction' level, we focus on micro-events that constitute reciprocation. We thus address several requirements. First, to function *socially,* robots must sustain human interest and thus influence social dynamics. Second, instead of focusing on averages, we ask how children act in the total situation. We therefore code –not reactions to the machine –but how children adjust to the setting. Third, we set the goal of understanding real-time events and, ideally, human decision-making. While these criteria could be used in many coding systems, our aim is only to establish that robot design needs behaviour-level coding. Accordingly, we draw on a system currently being used to update Robovie's design. In formalizing part of the behaviour stream, it traces how robot behaviours influence children. By addressing real-time and longditudinal change, it highlights what we call *co-action attempts*. Instead of regarding human behaviour as output from an inner-system, it is treated as using cyborg sensitivity to the world beyond the skin.

Coding began with a field trail of the robot's positive classroom effects. In subsequent work, emphasis was given to patterns in groups of children (e.g. male-female; indoor/outdoor) [22] However, when we asked if they actually formed relationships with the robot, no behavioural support could be found [3]. Investigation thus shifted to how co-action changed over the trial. Since Robovie makes what children see as contingent responses, they treat these –not as

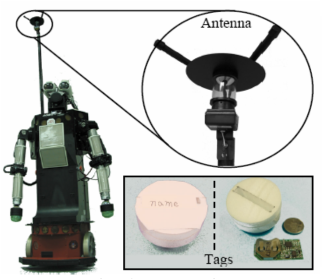

Fig. 1. Robovie and Wireless tags

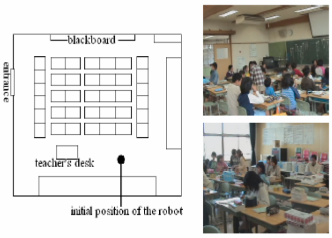

Fig. 2. Environment of the elementary school

stimuli –but as opportunities. Unlike most novel objects, Robovie's (perceived) unpredictability sets off complex social and emotional events.

Coding draws on with Cowley's experience with mother-infant interactions. It belongs in a tradition pioneered by Trevarthen, Murray and others who asked how a social partner influenced infant behaviour [23] [24]. In that work, rating was used to score infant, mother and interaction separately. This was done to address questions of how partners used the total situation to develop ways of behaving that shape relationships. Later, Cowley developed codes that show how cultural and health parameters influence infant development [25] [26]. Emphases, as with robots, falls on changing social dynamics. Finally, having carried out exploratory work, the project continued in Japan where the next stage took an engineer's perspective. We asked what the robot elicits at particular interactional moments.

IV. Methods

We conducted a two month field trial in an elementary school with the communication robot Robovie (**Fig. 1**)[20]. In this study we describe a coding system that deals with video data collected in the school.

Robovie is capable of simple expression that prompts human co-action by using various actuators and sensors. Its body is sufficiently articulated to produce communicative gestures. The sensory equipment consists of auditory, tactile, ultrasonic, and vision sensors. All the processing and motor control hardware is located inside the robot.

This robot has a software mechanism for performing one hundred interactive *behaviours*. These include the greeting, hugging, and exercising etc. that allow it to interact with a human rather as does a young child. All *behaviour*s were executed sequentially based on a rule that uses a sensory stimulus to select the next *behaviour*.

The experiment was carried in a fifth-grade class consisting of 37 students (10-11 years old, 18 male and 19 female). Over a two month period (32 experiment days), the children interacted freely with the robot (**Fig. 2**) during a 30-minute recess after lunch.

While detailed results are reported in [22], we summarise here. Over the whole period, interaction with the robot was

(a) First day **(b) *Behaviour* <Exercise>**

(c) *Behaviour* <PEEKABOO> **(d) *Behaviour* <SSP>**

Fig. 3. Scenes from the experiment

estimated[1] to average 64 minutes (SD=82 min.). While the robot caused much excitement in the first two weeks, interest then decreased until shortly before leaving. Examples of robot-child encounters are shown in **Figure 3**.

V. Procedure

The coding described aims to show why we favour work at the behavioural level. Not only can this capture social dynamics but, for engineers, is allows one to examines what effects *behaviours* elicit [2]. Given interest in different children, we coded what the 10 subjects who interacted most frequently with Robovie did in the 10 seconds following each instance of the 8 listed behaviours.

<HELLO>	The robot says "Hello" to children.
<TIRED>	The robot says "I'm tired" to children.
<ASK>	The robot asks "Am I cute?" to children.
<WHAT>	The robot asks "What shall we do?" to children.
<EXERCISE>	The robot says "I'm going to start exercise" and starts exercise. (**Fig. 3-(b)**)
<PEEKABOO>	The robot starts gesture and speech of peek-a-boo. (**Fig. 3-(c)**)
<HUG>	The robot says "Please hug me" and tries to hug children.
<SSP>	The robot says "let's play stone-scissors-paper" and starts the gesture. (**Fig. 3-(d)**)

The coders used what happened before each *behaviour* to consider whether or not it prompted attempts at co-action.

VI. Coding and Reliability

Given individual differences, attitudes, human-human interaction and creative use of the robot, our aim was to keep coding simple. Accordingly, for each instance in data from

[1] This estimate was made by the robot's person identification system.

[2] We coded the children's behaviour from when the robot started its *behaviour*, until 10 seconds after the *behaviour* ended.

TABLE II
BEHAVIOURS ELICITING CONVENTIONAL CO-ACTIONS

	Number of BEHAVIOURS	Number CCA	Numbe r SCCA
TOTAL %	1483 (100%)	464 (31%)	204 (14%)

TABLE III
NUMBER OF *BEHAVIOURS* ELICITING CCA

	Number of *Behaviours*	Number of CCA	Number of SCCA
<SSP>	199 (100%)	111 (55.8%)	68 (34.2%)
<HUG>	293 (100%)	148 (50.5%)	75 (25.6%)
<ASK>	77 (100%)	25 (32.5%)	12 (15.6%)
<PEEKABO O>	78 (100%)	23 (29.5%)	4 (5.1%)
<HELLO>	475 (100%)	106 (22.3%)	31 (6.5%)
<TIRED>	74 (100%)	15 (20.3%)	3 (4.1%)
<WHAT>	79 (100%)	12 (15.2%)	6 (7.6%)
<EXERCISE>	208 (100%)	24 (11.5%)	5 (2.4%)

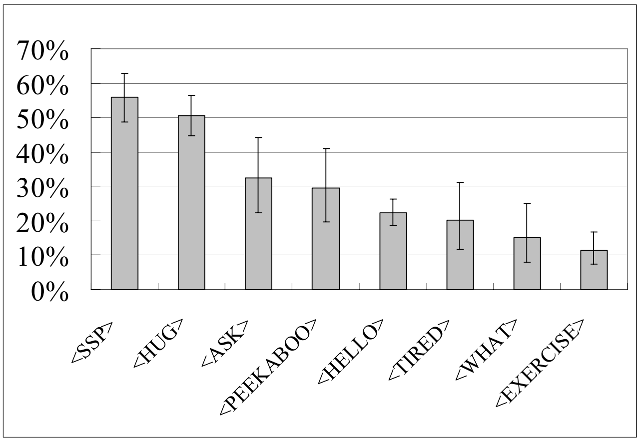

Fig. 4. Rate of *Behaviours* eliciting CCA

There was a significant relation found between *behaviour* and its rate of eliciting CCA (Chi test of independence, P<.001.)

Among these *Behaviours*, <SSP> had significantly higher rate of eliciting co-action than <ASK>, <PEEKABOO>, <HELLO>, <TIRED>, <WHAT> and <EXERCISE>. <HUG> also had a significantly higher rate than <PEEKABOO>, <HELLO>, <TIRED>, <WHAT> and <EXERCISE> (REGWQ test, P<.01.)

10 children, we asked the following questions.

(a) In these circumstances, did the *behaviour* afford co-action?

(b) Did it fit expectations for an interactional sequence?

(c) Was the reaction 'solo' or 'shared'?

The coder made judgments about timing, whether co-action conformed to design expectations and whether it was social. Accordingly, using synchrony, sequence and symmetry the coder made a yes/no decision. Since we are concerned with principles, we will discuss only conventional co-actions. These are sub-divided into those carried out alone (CCA) and those where more than one child is prompted to ‘shared’ co-action (SCCA).

Inter-rate reliability was compared for 205 randomly chosen robot *behaviours*. Coding was consistent for 158 *behaviors* (77%), giving a Kappa value of 0.54. This is within the acceptable range for such a study.

VII. RESULTS

In 10 subjects, we examined actions elicited by 1483 robot *behaviours*. **Table II** shows how many prompted either conventional co-action (CCA) or its shared counterpart (SCCA). It is striking that children only infrequently implement interactional sequences. Thus while the encounters can, of course, be described at the interactional level, our coding captures a lower level as is shown on **Table III** and **Figure 4**. Plainly, children act with a degree of freedom and, for this reason, we may be sure that analyses pick out changing dynamics.

Behaviours and elicited co-actions were tested for significant relations (Chi test of independence, X^2=186.339, DOF=7, P<.001). Among these, <SSP> and <HUG> elicited significantly higher rates of co-action than six and five other *behaviours respectively* (REGWQ test, P<.01, see **Fig. 4** for detail).

As noted, an engineering approach to communicative robotics asks whether a *behaviour* can elicit sustained (or increased) attempts at reciprocation. Accordingly, we divided the longitudinal data between the 16^{th} and 17^{th} days (of 32 days) [3]. This enabled us to compare and contrast the two periods to examine how many attempts at co-action were elicited by each of the *behaviours* in the different periods (**Table IV** and **Figure 5**).

Generally, less co-action was elicited in the second part of the trial. Far from ‘responding’, humans seek to exploit opportunities by making co-action attempts. It is, of course, not surprising that interest in Robovie diminishes as behaviours become familiar. It is equally clear, however, that evaluations of behaviours change. Whereas in the case of <TIRED significantly less co-action occurs in the second period (**Table IV**), <SSP> and <ASK> show the opposite effect. To generalize from initial coding, we ranked *behaviours* from those most likely to elicit shared co-action to those where reactions were typically solo: 8. <SSP> 7. <HUG> 6. <WHAT> 5. <ASK> 4. <HELLO> 3.

[3] We excluded two days each from time-scale. These were the first day when crowding made coding difficult as well as one day when there were mechanical problems with interaction, **Fig.3-(a).**.

TABLE IV

CHANGES IN SOLO AND SHARED CONVENTIONAL RESPONSE

	Time 1		Time 2		Changes in rate (P value[1])
	Number of *Behaviours*	**Number of CCA**	**Number of *Behaviours***	**Number of CCA**	
<ASK>	32 (100%)	7 (21.9%)	45 (100%)	18 (40.0%)	0.138
<WHAT>	29 (100%)	6 (20.7%)	50 (100%)	6 (12.0%)	0.341
<HELLO>	244 (100%)	63 (25.8%)	231 (100%)	43 (18.6%)	0.062
<TIRED>	28 (100%)	10 (35.7%)	46 (100%)	5 (10.9%)	0.016 (*)
<SSP>	134 (100%)	72 (53.7%)	65 (100%)	39 (60.0%)	0.448
<HUG>	111 (100%)	63 (56.8%)	182 (100%)	85 (46.7%)	0.117
<EXERCISE>	125 (100%)	14 (11.2%)	83 (100%)	10 (12.0%)	0.829
<PEEKABOO>	45 (100%)	13 (28.9%)	33 (100%)	10 (30.3%)	1.000

1) Significant probabilities are calculated using the Fisher's exact test
(*) stands for P < .05.

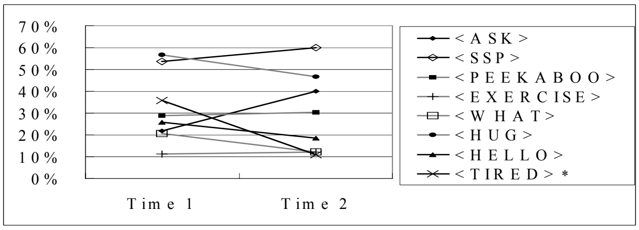

Fig. 5. Changes in conventional response

Behaviours elicited less CCA in the second term in general. There were significant decrease in <TIRED> (P<.05). However, in <SSP> and <ASK> it elicited more CCA in the second term of the trial.

TABLE V

CORRELATION BETWEEN INTEREST INDEX (II) AND RATE OF ELICITING CCA

	Spearman's correlation	Exact p
Time 1	r = 0.166667	0.703323
Time 2	r= 0.799641	0.0268353 **(P<.05)**

<EXERCISE> 2. <TIRED> 1. <PEEKABOO>. These results constitute what we call an interest index (II). Next, drawing on learning theory, we posit that affective reward will lead children to modify how they perceive robot behaviours. Since the robot itself gave no such rewards, this could only happen as action became part of the social flow. With this hypothesis in place, we then used the interest index (II) to examine whether co-action attempts showed any correlation between II ranking and CCA frequency. Results are shown on **Table V**.

In the first period, there is no association between II and CCA ranking. However, the second period features a positive correlation. This suggests that while the early scores are associated the value of a (novel) *behaviour*, co-action then shapes evaluations of the robot's behaviour. As expected, in the second period, co-action attempts were associated with highly ranked *behaviours*. From a design perspective, the coding shows that children attempt tend to favour behaviours that lead to human-human interaction.

VIII. DISCUSSION

Given the contingency of human behaviour, we sought to work between intention and design. Coding was designed to show how children behave in the total situation. Humans, we find, rarely behave as designers expect. Thus 69% of robot behaviours did *not* trigger conventional individual co-action (CCA). This, we suggest, is why design-relevant benchmarks must draw on behaviour-level coding. While interactional (and other) levels of analysis have many uses, they cannot show how robots become artifacts that serve many ends. For engineers, it matters that humans have a cyborg nature that prompts us to seek out novel effects. Thus, in developing benchmarks, we need to evaluate both real-time events and how robots affect social gatherings.

The value of a particular behaviour typically depends on the total situation. This is because, once a child has expectations of the robot, its role gradually becomes that of a social mediator. Our coding thus gives an outcome that can be formulated as a benchmark.

> A communication robot should prompt context sensitive co-action attempts.

Humans are typically less interested in the conventional value of behaviour that what it can be used to do in the total situation. This concern form 'quality' is, in our data, associated with the value of <SSP> and <HUG> (see below). Coding must therefore be sensitive to how people act, the setting, and previous encounters between partners. Ultimately, it will identify many parameters that influence real-time human decisions. Our system must thus be extended to non-conventional responses, human-human co-action and, crucially, events in other time-scales.

In making a start at showing how coding can contribute to engineering goals, we find that, as natural-born cyborgs, children seek opportunities that emerge from the robot's actions. Indeed, it is this which makes clear that they want Robovie to act as a social mediator. It also helps explain why, in exploiting the robot's behaviours, they use a number of contingencies (and, above all, who else is present). Over time, therefore, they develop expectations that allow them to use the robot with each other.

Turning to specific results, these children give especially high value to <SSP> and <HUG>. While this may be for idiosyncratic reasons, it is something that can be further investigated. Speculatively, it may be due to the 'symbolic' value of hugging and the chance of 'winning' thrown up by <SSP>. In pursuing such issues, it will be of value to clarify why most other behaviours elicit diminishing returns. This might be pursued by using the Interest Index to gain insight into how the children use the robot in affective signalling. It is thus of importance to understand Robovie's social potential and, specifically, expectations associated with a social mediator. After all, for the children, it is this role which makes Robovie a valuable prompt to co-action.

IX. Software and Design

We have shown that social dynamics influence what happens between children and a single robot. This is because children are natural-born cyborgs who, while processing information, value co-actions that arise in the total situation. With this in mind, we argue for coding the real-time effects that influence human sociality or what Hegel [27] and, echoing him, Marx [28] called *mediated activity*.[4]

In designing software, engineers need to recognize that behaviours will be evaluated –not only for what they mean – but also against contingencies. Designers, therefore, must not overplay what humans are expected to do. In addition, weight must be given to the quality of behaviour and novelty should be recognized as no more important than social potential. In a classroom, at least, the most valued behaviours influence the group. This, of course, has implications for Robovie. Indeed, while the matter needs to be pursued, there may be an advantage in programming behaviours that elicit both a degree of competition and shared affect. Further, in contrast to previous practice, it comes to seem less important that behaviour be matched to interactional types. In software development, the focus can shift from stereotyped moves to evocative activity (including speech).

Children value conventional co-actions that can be shared. This may be of importance in developing sensor systems which pick up on 'responding to the robot together'. Not only might this be done by using acoustic measures but it might also use symmetry, synchrony and sequence. Indeed, in shifting emphasis to what children do with opportunities, we may design robots that mimic our cyborg-nature. Like children, such machines would use what others do as the basis for co-action attempts. Further, if especially if coupled with social learning, the outcomes would not only be novel but, in all likelihood, would elicit striking social outcomes. Indeed, a failing of today's robots is that, when children attempt co-action, there is no reciprocation. While this is well-known, our coding suggests that non-reciprocation has unexpected social effects. In co-action attempts, a child's beliefs and values imbue a robot's *behaviours* with shared values. Gradually, these influence the total situation and, if positive outcomes ensue, they come to be increasingly valued. By thinking of robots as social mediators, we can turn to the design challenge of getting them to reciprocate. Eventually, they may prompt children to develop reasonable expectations about the social potential of friendly machines.

[4] Hegel's comment that the cunning of reason (as opposed to its power) depends, primarily on mediated activity as well as Marx's use of the idea is Mind and Society (p. 54) [29]. In seeing the robot as a prompt to human use of culturally-based contingencies, we are closer to a material version of Hegel than we are to how the idea is used in Vygotskyan tradition..

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