

# How People Naturally Describe Robot Behaviour

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## Abstract

Existing novice robot programming systems are complex, which ironically makes them unsuitable for novices. We have analysed 19 reports of robot projects to inform development of an ontology of critical concepts that end user robot programming environments must include. This is a first step to simpler end user robot programming systems.

## 1 Introduction

As robots become more pervasive in human environments, there will be a plethora of new task demands on them. As a result it will be necessary for end users to be able to program new tasks in the field, even when libraries and components are programmed in the factory. However, there is no well established ontology of robot behaviour on which to base such end user programming environments.

The most closely related works are ontologies designed to represent robotic systems [Schlenoff and Messina, 2005; Ros *et al.*, 2010; Paull *et al.*, 2012; Balakirsky *et al.*, 2012; Varadarajan and Vincze, 2012; Schlenoff *et al.*, 2012; Tenorth and Beetz, 2012], the most notable of which is a new IEEE working group formed to create the IEEE Standard Ontology for Robotics and Automation (SORA) [Schlenoff *et al.*, 2012]. SORA aims to represent every part of a robotic system; from low level devices, such as sensors and actuators; to the knowledge required for a robot to solve a problem, such as domain specific objects, like a mine object for a mine hunting robot [Paull *et al.*, 2012]. The problem with using these ontologies as the sole representation for end user programming systems is that they are not being explicitly designed for ease of understand by end users, which is what we aim to address.

The objective of this study is to develop an ontology suitable for end users, that can be used to describe robot

behaviour based on an analysis of healthcare robots. Our end goal is to create an end user robot programming environment, initially for healthcare professionals who do not have programming experience, and eventually for end users in other robot domains. However, a prerequisite to this is to understand how people naturally describe robot behaviour. This involves collecting peoples descriptions of healthcare robot behaviour and analysing them to uncover the key building blocks and relationships used in these descriptions.

There are two main options for collecting data where people describe healthcare robot behaviour: a case study based approach and a literature search. Given time and resource considerations, a case study based approach would only be able to gather data for a very small number of cases, meaning the results would only be applicable to the healthcare robots examined in the case study. This is not ideal as our goal is to create an end user robot programming system for the wider healthcare domain. Instead, a literature search approach was chosen as it can examine a larger variety of robots and the analysis of the data is likely to be more generalisable. The collection of sources describing healthcare robot behaviour is discussed in Section 2.

An approach based on grounded theory [Glaser and Strauss, 1967] was chosen to analyse the qualitative descriptions of robot behaviour found by the literature search. Grounded theory is a method widely used in social science research to discover theory from systematically collected data [Glaser and Strauss, 1967]. The researcher builds up a theory by iteratively identifying concepts and relationships that fit the underlying data. Eventually a conceptualisation of the data emerges. This allows us to create an ontology that is easy for end users to understand, because we can use the methodology to explicitly generate our theory from descriptions of robot behaviour that end users are expected to find comprehensible.

Grounded theory focusses on generation of theory, as

opposed to verification of theory [Glaser and Strauss, 1967]; because of this, we have focussed on generating our theory rather than verifying it at this stage. This doesn't mean that our theory is without evidence, in fact, Glaser and Strauss [1967] argue that theory based on data is hard to totally disprove because it is thoroughly connected to the data. It is likely to last even though it will certainly be refactored in the future [Glaser and Strauss, 1967]. The analysis of the qualitative data and the ontology it generated are discussed in Section 3.

Conclusions are presented in Section 4.

## 2 Literature Search

The design of a general robot programming system needs to be informed by many examples of robot behaviour. Fortunately, many research groups have applied robots to the healthcare domain, so there is much literature describing healthcare robots and their behaviour. This afforded us the opportunity to conduct a systematic literature search for articles describing healthcare robot behaviour. We expect this analysis to also reveal a significant amount of generic robot behaviour.

A systematic literature search is a formalised approach to searching literature [Kitchenham, 2004]. It focuses on a research question, inclusion and exclusion criteria to construct a search query, a corpus of work to search, and a process for quality assessment and data selection. Subsection 2.1 describes the systematic literature search methodology and subsection 2.2 presents the systematic literature search results.

### 2.1 Methodology

The methodology for systematically searching literature used in this study is based on guidelines provided by Wolfswinkel et al. [2011] and Kitchenham [2004]. The goal of our systematic literature search is to obtain descriptions of healthcare robot behaviour. The steps in the systematic literature search are discussed below.

#### Research questions

The research question addressed by the literature search is:

1. What healthcare robots have been created to date and what behaviour do they exhibit?

The research question is concerned with finding as many healthcare robots and sources describing their behaviour as possible. The goal of this question is to obtain a broad collection of material describing healthcare robot behaviour that can be used in the analysis stage of the study (Section 3).

#### Inclusion and exclusion criteria

Healthcare robots were *included* if they discussed a robot that:

- Is physically embodied.
- Makes conscious decisions (in a limited sense).
- Treats or cares for a person to benefit their health.

Healthcare robots were *excluded* where:

- The “robot” is a virtual avatar.
- A human controls the higher level behaviour of the robot.
- The robot treats a person using invasive surgery.

Physical embodiment is a characteristic of robots that makes them unique compared with generic software systems, hence the requirement that the “robot” must be a real physical entity (ruling out virtual avatars).

The capabilities of existing robots may not meet users expectations because technology has not advanced enough yet. For example, a user might expect AIBO, a robot dog, to be able to sense touch all over its body. However, this technology hasnt been implemented in AIBO, let alone any robot dog. If we only included real robots in our systematic search our ontology would discount such natural expectations of users. To ensure that these natural expectations are represented in our ontology, our definition of robot also allows fake robots to be included. For instance, a robot could be a robot operated in a “wizard of oz” fashion (as is the case for most Autism robots) or even be a person acting like a robot for the purpose of discovering how people naturally interact with robots.

#### Search process

Several databases that are known to contain information related to healthcare robots were searched. These are: ACM Digital Library [ACM, 2012], IEEEExplore [IEEE, 2012], SpringerLink [Springer, 2012] and ScienceDirect [Elsevier, 2012].

The search terms were based on the inclusion and exclusion criteria defined earlier. The general structure of the query can be seen in Figure 1. The first part of the query contains several common synonyms for robot (humanoid and android). The second part of the query contains several synonyms for healthcare (care, treatment and words beginning with help).

Figure 1: General structure of database search terms.

```
(robot OR humanoid OR android) AND (care
OR treatment OR therapy OR healthcare OR
help*)
```

#### Quality assessment

Quality assessment was not important for this literature search. Even if a robotics project is poor quality, it does

not mean it cannot contribute to our understanding of how people describe robot behaviour. On the contrary, it is desirable to be able to describe the behaviour of any robot, regardless of whether it resulted in a high quality scientific study or not. The only quality requirement was to exclude articles that were solely abstracts, because they lack sufficient detail to be useful.

### Data selection

During the data selection stage: the list of healthcare robots was compiled and sources describing robot behaviour were selected. From an initial corpus of 761 articles, the following process was carried out to refine and extract data:

1. Duplicate articles were filtered.
2. The sample was refined based on titles and abstracts. During this process the articles were grouped into categories of similar types of robots so that whole groups could be discarded if necessary.
3. The sample was refined based on the full text. Here we looked for the main robot(s) the article discusses or whether the article discusses the requirements of healthcare robots. The categories formed in the previous step were iteratively refined as the full text of each article was read.
4. Backward citations. While refining the sample based on full text we looked for any relevant robots that were referenced in the text.
5. A free search was conducted using Google and Google Scholar to fill in any gaps in the initial search.

## 2.2 Results

The systematic literature search identified 163 healthcare robots. Some were not designed specifically for healthcare, however they have all been applied to healthcare or their creators envision them being applied to healthcare. Four distinct categories of healthcare robot emerged: healthcare robots for children; the elderly; hospital inpatients; and chronic disease sufferers.

Seventeen of these robots, represented by nineteen articles, were selected for analysis based on theoretical sampling, i.e. where cases are selected based on their ability to inform the problem [Glaser and Strauss, 1967]. The theoretical sampling approach proposes the researcher's informed intuition as a method of sampling. Our initial sample included articles that reported on all four categories of healthcare robots. New articles were selected on the basis that they described robots similar to those already analysed (a form of data triangulation). Eventually no new categories emerged, so articles describing robots with vastly different capabilities were selected to extend the analysis to new areas. The process

Table 1: Healthcare robots

| Category                  | Robot       | Reports Analysed                                                        |
|---------------------------|-------------|-------------------------------------------------------------------------|
| Children                  | AIBO        | [Robins <i>et al.</i> , 2005b]                                          |
|                           | Kaspar      | [Amirabdollahian <i>et al.</i> , 2011; Dautenhahn <i>et al.</i> , 2009] |
|                           | Keepon      | [Kozima <i>et al.</i> , 2007]                                           |
|                           | Nao         | [Shamsuddin <i>et al.</i> , 2012]                                       |
|                           | Zeno        | [Ranatunga <i>et al.</i> , 2011]                                        |
| Elderly                   | Robota      | [Robins <i>et al.</i> , 2005a]                                          |
|                           | ASIMO       | [Honda, n.d.; Sakagami <i>et al.</i> , 2002]                            |
|                           | Charlie     | [Jayawardena <i>et al.</i> , 2010]                                      |
|                           | COCO        | [Tran phuc <i>et al.</i> , 2011]                                        |
|                           | Huggable    | [Stiehl <i>et al.</i> , 2006]                                           |
| Inpatients                | Nabaztag    | [Klamer and Ben Allouch, 2010]                                          |
|                           | Paro        | [Wada <i>et al.</i> , 2005]                                             |
|                           | Twendy-One  | [Iwata and Sugano, 2009]                                                |
|                           | Actroid-F   | [Yoshikawa <i>et al.</i> , 2011]                                        |
|                           | Cody        | [Chen <i>et al.</i> , 2011]                                             |
| Chronic Disease Sufferers | RIBA        | [Mukai <i>et al.</i> , 2010]                                            |
|                           | HyperTether | [Endo <i>et al.</i> , 2009]                                             |

repeated. The selected robots are summarised in Table 1.

The children category comprises robots designed to treat or help children with various disorders. It has three subcategories, children with: Autism, Mild Mental Retardation and Severe Motor Impairment (based on Robins *et al.* [2010]). For example, Keepon, a simple, yet surprisingly expressive robot, was designed to encourage Autistic children to experiment with social interactions [Kozima *et al.*, 2007] (Figure 2a). Another example is Zeno, a robot with the same purpose as Keepon but it has a humanoid form [Ranatunga *et al.*, 2011] (Figure 2b).

The elderly care category is the largest. Examples include, Paro, a baby seal robot that acts as a surrogate pet for people suffering dementia [Wada *et al.*, 2005] (Figure 2c), and Twendy-One, a robot that can help Grandma prepare breakfast [Iwata and Sugano, 2009] (Figure 2d).

The hospital inpatients category comprises robots that assist patients in hospitals. For example, RIBA helps a nurse lift a patient from a bed into a wheelchair [Mukai *et al.*, 2011] (Figure 2e) whilst Actroid-F consoles a patient in a waiting room [Yoshikawa *et al.*, 2011] (Figure 2f).

The chronic disease sufferers category comprises robots that help sufferers of chronic disease when they are out of the hospital and back living their normal lives. For example, Hypertether is a robot that carries an oxygen bottle for a person undergoing at home oxygen



Figure 2: Example healthcare robots from the left, down: Keepon (a) [Product Joon, n.d.], Zeno (b) [Plastic Pals, 2011], Paro (c), Twendy-One (d) [Plastic Pals, 2010], RIBA (e) [House of Japan, 2011], Actroid-F (f) [DigInfoTv, 2011] and Hypertether (g) [Endo *et al.*, 2009].

therapy (typically someone suffering Chronic Obstructive Pulmonary Disease) [Endo *et al.*, 2009] (Figure 2g).

### 3 Data analysis

This section describes how we analysed the articles that describe healthcare robot behaviour found with the systematic literature search. The goal of this analysis is to discover how people naturally describe healthcare robot behaviour. Subsection 3.1 describes the data analysis methodology and subsection 3.2 discusses the results of the analysis.

#### 3.1 Methodology

The articles describing robot behaviour were analysed using a methodology based on grounded theory [Glaser and Strauss, 1967]. The steps involved in the data analysis are discussed below.

##### Research questions

The research questions addressed by the data analysis are:

1. What are the building blocks people use to describe robot behaviour?
2. How are those building blocks related to each other?

Research question 1 is concerned with finding the keywords people generally use when describing robot behaviour. The purpose of research question 2 is to uncover how those people typically assemble the keywords.

##### Analysis

The analysis followed this general pattern:

1. Sentences describing robot behaviour were extracted from the articles.
2. The sentences were open coded.
3. The codes were axial coded.

The first stage of the analysis involved reading the articles found in the systematic literature search and extracting sentences that discussed robot behaviour.

In the next stage, we open coded the sentences that discussed robot behaviour [Strauss, 1987]. Open coding is where a word, line or sentence is conceptually summarised by a keyword. As more and more data is coded, a bigger picture emerges that is grounded in the source data. This was accomplished by grouping sentences with similar meanings together and representing them with a single code. This is an iterative process of constant refinement that continues until the codes and supporting data make sense. A snapshot of the open coding process is shown in Figure 3. Open coding provided much of the basis for our understanding of the building blocks people use when describing robot behaviour.

The last stage involved axially coding the data [Strauss, 1987]. Axial coding is where relationships are



Figure 3: A snapshot of the open coding process

formed between the codes that were created during the open coding stage. This was done by iteratively regrouping the codes given to each group of sentences to form categories, subcategories and other types of relationships. A snapshot of the axial coding process is shown in Figure 4. This provided the basis for our understanding of how to organise the building blocks people use when describing robot behaviour.

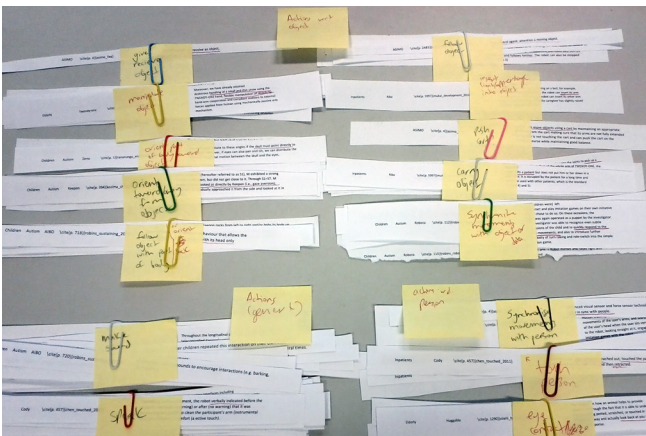


Figure 4: A snapshot of the axial coding process

Over and under generalisation had to be considered during this process. We focused on analysing uniquely robotic behaviours as opposed to those that could be produced by a generic software system. For instance, a robot copying a persons movements was considered uniquely robotic, however, a robot measuring blood pressure and displaying a video was not. This is neatly summarised by the following analogy: imagine you are programming the ‘core behaviour’ for a person - what critical concepts and relationships would you need to program them?

## 3.2 Results

Three important categories emerged from the qualitative analysis of the data: *Object*, *Robot* and *Person*. The following subsections describe these categories in more detail.

### Objects

*Object* is the most general category that encompasses all other categories in a hierarchical fashion. An *Object* has several properties which are inherited by all of its subtypes, these are: velocity, acceleration, orientation and size. Examples of *Objects* and their hierarchical relationships are illustrated in Figure 5. The two most important types of *Object* are *Robot* and *Person*, which are explained in the next two subsections.

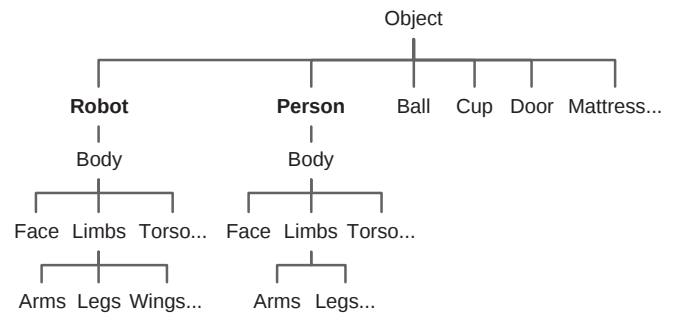


Figure 5: Example objects and their hierarchical relationships

### Robot

A *Robot* is a special type of *Object* that represents the robot for which we are describing the behaviour. A *Robot* has the ability to perform *Actions* and *Sense* the world. The robots *Actions* and *Senses* are relationships that either involve itself, *Objects* or *People*. *Actions* and *Senses* are relationships, not categories. *Actions* and *Senses* are illustrated in Tables 2 and 3, their instances are grouped according the *Objects* involved in each relationship. Examples of *Actions* and *Senses* are given in the next subsection, along with supporting data.

### Robots Actions

A *Robot* has a number of *Actions* that involve itself and *Objects*, three examples are its ability to: move toward an object, orient toward an object and orient a body part toward an object. Robins *et al.* [2005b, p. 718] describe an experiment where AIBO is able to walk toward or away from a person (this could apply to any *Object*), e.g. AIBO is seen “walking towards the person or away from the person”. AIBO is also able to orient itself toward an object, e.g. AIBO responds via “orientation toward the interaction partner” [Robins *et al.*, 2005b, p. 721]. Lastly, Nao can orient a part of its body toward an object, e.g. “The humanoid robot NAO

Table 2: Robot Actions

| Category        | Actions                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Object          | Move (speed(walking, running, km/hr), forwards/backwards, left/right, toward/away from object, to a place or location).<br>Give or receive <i>object</i> .<br>Orient body part toward or away from <i>object</i> .<br>Orient toward or away from <i>object</i> .<br>Follow <i>object</i> .<br>Follow <i>object</i> with body part.<br>Insert body part into <i>object</i> .<br>Push <i>object</i> .<br>Carry <i>object</i> .<br>Synchronise movement with <i>object</i> . |
| Robot Specific  | Make sound.<br>Speak (accent).<br>Change colour of light emitting diode.<br>Move body.                                                                                                                                                                                                                                                                                                                                                                                    |
| Person Specific | Synchronise movement with <i>person</i> .<br>Touch <i>person</i> .<br>Make eye contact with <i>person</i> .<br>Guide a <i>person</i> .                                                                                                                                                                                                                                                                                                                                    |

shall turn its head right, left and then back to facing the child” [Shamsuddin *et al.*, 2012, p. 191].

The three most important *Actions* a *Robot* has that only involve itself, are its ability to: make sound, speak and move its body. Keepon was described as making sound, e.g. “Keepon could only respond to [the child] by bobbing up and down with the ‘pop, pop, pop’ sound” [Kozima *et al.*, 2007, p. 398]. Cody is able to speak, e.g. by saying “I am going to rub your arm. I am going to clean you. The doctor will be with you shortly” [Chen *et al.*, 2011, p. 460]. Lastly, Coco is able to move its body parts, e.g. “[sic] responded by flapping its wings” [Tran phuc *et al.*, 2011, p. 1092].

A *Robot* also has some *Actions* that involve *People* but no other types of *Object*, these are its ability to: synchronise movements with a person and make eye contact with a person. Robota can synchronise movements with other people, e.g. “Robota can copy upward movements of the user’s arms, and sideways movements of the user’s head” [Robins *et al.*, 2005a, p. 111]. Zeno is able to make eye contact with people, e.g. “[Zeno] will be capable of identifying, tracking and maintaining eye contact with the subject” [Ranatunga *et al.*, 2011, p. 1].

### Robots Sensing Ability

A *Robot* can *Sense* a number of things about *Objects*. For instance, it can sense the properties of objects (this applies equally to itself), e.g. Huggable can obtain its orientation with respect to the world: “inertial measurement unit in the body which allows for the Huggable to know how it is being held” [Stiehl *et al.*, 2006, p. 1291]. Another example of sensing is where a robot senses the position of an object relative to itself, e.g. “N often sat

Table 3: Robot Senses

| Category        | Senses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Object          | <i>Objects</i> velocity.<br><i>Objects</i> acceleration.<br><i>Objects</i> orientation.<br><i>Objects</i> size.<br>Associate <i>object</i> with touch.<br>Pattern that occurs over time.<br>Number of <i>objects</i> .<br>Relative position of an <i>object</i> .<br>Distance to an <i>object</i> .<br>Inside or outside an <i>object</i> .                                                                                                                                                             |
| Robot Specific  | Own emotional state and desires.<br>Sound.<br>Touch: pressure, temperature, force, sliding distance.<br>Light.<br>Beat/rhythm.                                                                                                                                                                                                                                                                                                                                                                          |
| Person Specific | <i>Persons</i> name.<br>Where <i>persons</i> attention lies.<br>Object of joint attention between <i>person</i> and itself.<br>Where <i>persons</i> gaze lies.<br><i>Persons</i> body gestures (kinesics).<br>Identify <i>person</i> .<br><i>Persons</i> emotions.<br>Is <i>person</i> copying me?<br><i>Persons</i> speech: verbal command, keyword spotting, continuous.<br><i>Persons</i> actions.<br>Social rhythm between <i>person</i> and itself.<br>When <i>person</i> is answering a question. |

in front of Keepon” [Kozima *et al.*, 2007, p. 395].

A *Robot* can sense things that are exclusive to itself, including: its emotional state and touch. Coco, the parrot robot, is explicitly described as having emotions, e.g. “Coco is his own man and sometimes does not listen to what he is told. You can change his mood by treating him well, though” [Tran phuc *et al.*, 2011, p. 1091]. Touch is one of the most common senses among the robots analysed, e.g. Huggable has a “full body ‘sensitive skin’ for relational affective touch” [Stiehl *et al.*, 2006, p. 1290].

A *Robot* can also sense things specific to a *Person*, including: a person’s eye contact and whether a person is copying its motion. The ability to sense eye contact was especially important for Autism robots, e.g. “[Keepon] produces a positive emotional response ... in response to any meaningful action (e.g. eye contact, touch, or vocalization)” [Kozima *et al.*, 2007, p. 391]. In Autism therapy, the child mimicking the robot is seen as positive so one can expect an Autism robot to be able to sense that, e.g. “some [children] mimicked [Keepon’s] emotive expressions by rocking and bobbing their own bodies” [Kozima *et al.*, 2007, p. 392].

Table 4: Control structures

| Control Structures                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------|
| Command.                                                                                                              |
| Abstract a set of commands into one command.                                                                          |
| Repeat command.                                                                                                       |
| Execute command if condition is true.                                                                                 |
| Execute commands simultaneously.                                                                                      |
| Randomise execution of a command.                                                                                     |
| Execute commands in sequence.                                                                                         |
| Constrain an action: keep below value, keep between values, distribute action between two values, spatial constraint. |
| Execute command until.                                                                                                |
| When $\rightarrow$ do.                                                                                                |

### Actions and Senses are Commands

*Control Structures* are what orchestrate the robot's senses and actions at a local level (Table 4). All of the robots *Actions* and *Senses* are *Commands* that can be manipulated with various *Control Structures*. The most common *Control Structure* is the when  $\rightarrow$  do command, which means, when the robot senses something it should perform a particular action, e.g. when Huggable is "being petted, scratched, or touched in another affectionate way [it looks] back at you" [Stiehl *et al.*, 2006, p. 1290]. Multiple commands can be executed at the same time, e.g. "Nao will play another children song; 'Itsy Bitsy Spider' together with the hand movement act" [Shamsuddin *et al.*, 2012, p. 191]. Commands can be executed in sequence too, e.g. "Nao shall turn its head to the right, left and then back to facing the child" [Shamsuddin *et al.*, 2012, p. 191]. Lastly, commands can be executed randomly, e.g. "Random function: Coco spontaneously interacts with the owner by saying random sentences..." [Tran phuc *et al.*, 2011, p. 1091].

### Person

*Person* is the main *Object* that a *Robot* interacts with. Hence, a *Robot* has many specialised actions for interacting with a *Person*. The main property of a *Person* is its name. There are several special types of *Person* that a *Robot* needs to be able to distinguish between (when it is identifying a *Person*). These are the patient, the patient's biological caregivers and the patient's professional caregivers. For instance, Keepon can perform actions with respect to both the patient (the child) and the professional caregiver (the therapist), e.g. "[Keepon alternates] its gaze between a child's face, the caregiver's face, and sometimes a nearby toy" [Kozima *et al.*, 2007, p. 391]. In the experiments with Keepon the experimenters made the observation that "During this play, N often looked referentially and smiled at her mother and therapist" [Kozima *et al.*, 2007, p. 395] so it is likely important that an Autism robot can distinguish this too.

## 4 Conclusion

We have developed an ontology grounded in real healthcare robot data that can be used to describe robot behaviour. While only a sample of the available literature has been analysed, we are confident that the selection process used means that the sample is an excellent representation of the field. The ontology developed from this literature has several implications for end user robot programming systems.

At the very least, our ontology helps inform designers of end user robot programming languages what level of complexity is appropriate for novice robot programmers. We contend that our ontology provides explicit guidance on the critical concepts and relationships needed in an end user robot programming environment designed for healthcare professionals. The wider field of robotics has significant similarities to the robots the ontology is grounded in, so the ontology will have good applicability to robots used in contexts other than healthcare.

Our ontology is a first step towards simpler end user robot programming systems. It is our intention to implement the current ontology and analyse more robots to expand the results. The implementation will be used as a basis for developing several end user robot programming systems targeted at healthcare professionals.

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