

1. Pre-linguistic communication and mind-reading system

Human beings have a distinctive ability to understand what is going on in others' minds. This ability, usually called "folk psychology," comprises a system of understanding others' intentions, which makes it possible for us to cooperate effectively. But how have we developed such an ability or mind-reading system? The most popular, though rough, answer is that it has been developed through the long history of evolution.

Language, obviously our most useful tool to communicate with each other, is also acquired through evolution. However, our ancestors, originally, did not have their own languages. We, as actual owners of highly organized languages, also read others' minds and communicate with each other by facial expressions, body language, and eyes directions in many situations without explicit use of language. That is, we deploy what might be called "primitive" parts of folk psychology for the purpose of communication.

The aim of our presentation is to show the basic functional structure of primitive folk psychology as a pre-linguistic tool. It is certainly not easy to explicate this dimension of mental function in an objective way because of its peculiar elusiveness. In order to cope with this inherent difficulty, we propose a "constructive approach" to human communication, which attempts to construct a computational model of the phenomena in question, and to implement it into artificial systems, such as computers and robots, and then, by examining the behaviors of those systems, to grasp the mechanism in the part of the human communication system. Assuming that there are relevant similarities between natural and artificial systems, experimenting and studying the behaviors of the latter can be expected to contribute much to the understanding of the former.

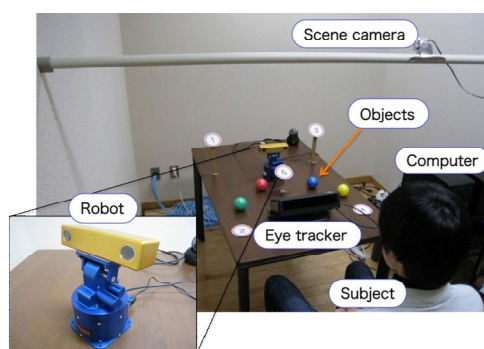
2. Making a robot with intentional agency

As an example of mind-reading function, we have selected "joint attention", one of the communicative behaviors found in infants, in which they follow their parents' eyes and try to look at things in the same direction as their parents. It is known that this kind of behavior shows up as a reflective one, but then develops gradually into the cognitive states where infants understand and share others' attention in terms of intentions (Tomasello, 1995). As suggested by many negative cases of people with autism (Barnbaum, 2008), joint attention constitutes a basis of social communication.

To share eyes direction with others is one thing, and merely to look at the same objects as others is another. The former state seems to require a kind of "nested structure" of intentions and understandings among us through which I understand that he/she understands that I intend to look at the object. In this regard, Tomasello suggests that infants become intentional agents before they can understand and share others' attention in terms of their intentions (Tomasello, 2000). We have constructed a computational model of this process of becoming intentional agents and implemented it into a robot. Through this model, we can see how that robot interacts with humans to share their intentions to see something (figure 1: An experimental setting of human-robot interaction).

We believe that our computational model makes primitive intentional agency of infants possible by some association mechanism comprising the following two functions: the one is to form a memory of connections between directions of others' eyes and gazed objects, and the other is to look for a target object according to the memory.

Robots with those mechanisms will try to look at the objects they remember unlike mere reflexive systems, which could choose an object at best among ones found only after they followed others' eyes directions. If we discriminate among 3 stages in this developmental process, our robot corresponds to the 3rd stage. This



(figure 1)

stage is a first level of joint attention in that subjects intend to look at an object they recall through some association mechanism when they notice their parents' eyes direction. If we briefly characterize the 1st and the 2nd stages here, the first is one where subjects look at objects through some reflexive mechanism, merely reacting to such external stimuli as sound or light, and the second where subjects look at objects in the same direction as their parents through another reflexive mechanism. We can verify that our robot attained a first level of joint attention by confirming that it had a chance of looking for an associated object in many directions in case of failure to find it in the humans' eyes directions. As we explain in the next section, infants have to pass through two more stages, the 4th and the 5th, in order to share others' intention in a full-fledged sense. But, regrettably enough, we have not succeeded in constructing robots in the 4th or the 5th stages yet, so we could only show a conceptual sketch of the mechanism of our future robots at this time.

3. From primitive intentional agency to understanding others' intentions

Our robot in the 3rd stage does not intend to understand humans' intentions to see something. It merely follows its own desire to look at some object independently of humans' intentions, although its desire is motivated by past associations of humans' eye-directions and objects found in those directions. In consequence, despite its appearances of sharing attention, our robot may look for an object in a different direction from that of humans because of mismatch of their intended object and its recalled one. We may call this level of joint attention "joint attention with primitive intentional agency".

We believe that it requires some inference mechanism for our robot to have the intention to understand humans' intentions. In the 4th stage, our robot can infer humans' intended objects (of course, not without any failure), using its inference mechanism which allows it to reach those objects from the past experiences of pairs of their eyes directions and objects found in those directions. In other words, our robot will intend to understand humans' intentions and to make their intended objects its own desired objects. This may be called "joint attention with understanding of others' intentions", because it will intend to share humans' intentions. In the final stage of joint attention, i.e. the 5th stage, our robot will want to know that humans understand that it intends to share their intentions to look at some object. This means that when it knows by some assessment mechanism that its desired object does not coincide with humans' intended object, it will correct its inference and change its desire in order to make the two objects coincide with each other. It is essentially the same process as infants accepting their parents' evaluative attitudes (affirmative or negative) and trying to follow their parents' suggestions. This level of "joint attention with shared intentions" can realize a kind of nested structure of intentions and understandings because, in successful cases, our robot will understand that humans understand that it intends to share their intentions.

The inference mechanism and the assessment mechanism in the 4th and 5th stages are essential in our project of making robots which can have joint attention with others. Although we are certain that those mechanisms are two fundamental functioning parts of our mind-reading system, we cannot foresee what kind of functions are required to be added to construct a full-fledged system. We are expecting to get this knowledge from making robots in the 3rd, 4th, and 5th stages through taking the "constructive approach". This approach, because of its methodological merit, could give some insight not only into the way our mind-reading system actually works, but also into a general form of mind-reading, which is instantiated in human beings contingently as a part of folk psychology.

References:

- Barnbaum, D. R. (2008) *The Ethics of Autism*, Indiana University Press.
- Tomasello, M. (1995) "Joint attention as social cognition," in C. Moore and P.J. Dunham eds. *Joint Attention: Its Origins and Role in Development*, Lawrence Erlbaum, pp. 103–130.
- Tomasello, M. (2000) *The cultural origins of human cognition*, Harvard University Press, Cambridge, pp.72–73.