Robotic Science: Reproducibility and a One-time Nature in Science

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In general, people tend to focus on the practical applications of robotics research, such as sterilization robots to combat coronavirus, remote-controlled avatars for people with physical disabilities, surgical robots, and hospitality robots using Pepper, but this is only one aspect of robotics research. Also, the media often tends to focus on robots that mimic living things like humans and dogs, but simply replicating a living thing with materials and electronics put together by human hands does not mean we “understand” (or have understood) that living thing.

So what is robot research or research that uses robots (hereafter referred to as robotics science), and what is its purpose? And since it is conducted at universities, aside from applications and development, can we consider robotics science to be an “academic discipline?”

What is robotics science?

Robotics science is an integrative science that questions the mystery of humans and life and offers a new way of understanding all human- and life-related research through the methodology of constructivist science (described in more detail below). It includes biology, brain science, psychology, sociology, linguistics, complex systems science, and emergent systems theory.

The term “human” in this context is used in an extremely broad sense. It covers everything from a “human” as an organism to a “person” as an expression of society and culture, including the structure, function, and movement of the body; the structure, function, and behavior of the brain and nervous system; intellect and emotions; behavior; pathology; society and economics; philosophy; art; culture; and history. In addition, “life” includes evolution, emergence, adaptation, spontaneity, homeostasis, self-preservation, self-replication, and other life-like principles, as well as the nature of non-human and non-existent life-like entities (e.g., algorithms that behave like life and artificial life).

Importantly, having a way of framing and understanding problems that applies not only to machines but also to the behavior of living organisms seems to be an essential condition for robotics science. Perhaps we need not target living organisms. However, types of understanding and approaches that apply only to machines and that are arbitrarily and rigidly defined as closed systems cannot provide useful knowledge to those outside the field and can produce only limited and fixed knowledge. By including organisms that embrace complexity and diversity, we can ensure that we are not limited by such frameworks. In any case, robots are machines that operate (to some degree autonomously) in the real world, so they essentially have the same root as living beings. And, as mentioned above, it seems useful to pursue an understanding that spans both in order to continue generating new knowledge. In this sense, “humans and life” is an appropriate subject area.
However, we worry that the phrase “people and life” may be a meaningless definition because it represents such a broad field, while at the same time worrying that it may be too narrow because it

excludes non-living things (e.g., buildings and money). However, what clearly distinguishes robotics science from other academic fields is its approach, not its subject matter.

The constructivist approach is the most important feature

In the “Goals” section above, we wrote: “Use a constructivist approach to provide a new way of understanding all research related to humans and life.” This constructivist approach can be said to be the gateway to the new discipline of robotics science.

When considering scientific methods, one example is the analytical approach rooted in traditional elementary reductionism, but limitations have been pointed out in many cases. For example, Ilya Prigogine argues from a thermodynamic perspective that the essence of understanding the world lies in irreversibility and disorder, which are considered exceptions in classical science, while Murray Gell-Mann attempts to break out of the impasse of traditional knowledge from the perspective of complex systems science. In so-called “strongly correlated systems” or “adaptive emergent systems,” each element, such as life or brain function, interacts strongly with the other elements, and the resulting overall behavior changes the function of each element. When such systems are broken down into their parts, the behavior of both the whole system and the parts changes, meaning that they cannot be correctly understood using an analytical approach. Moreover, adaptive systems change the moment they are interacted with, i.e. when they are observed from the outside. In this case, a completely different kind of understanding is required, namely the constructivist approach. The analytic approach and this constructivist approach propose different ways of understanding, but neither is inferior to the other. Moreover, as we will briefly explain below, the constructivist approach incorporates the analytic approach and adds a perspective that considers the overall system.

The authors define the constructivist approach as follows. First, the evolutionary constructivist approach consists of identifying the most basic minimal units of robot intelligence (through the analytical and abduction methods), based on which a robot is constructed and deployed in an environment (emergent constructivism). We observe how well it performs intellectually, and determine what it cannot do (the outcome is a behavioral evaluation). We then add (or the robot autonomously acquires) the minimum necessary components to compensate for the missing capabilities (again emergent constructivism) and build the next level of robot. We repeat this process and gradually create a highly intelligent robot. Next, the developmental constructivist approach incorporates development over time into the emergent process in evolutionary constructivism, and we compare and evaluate the entire developmental process.

What is the one-time nature of events versus reproducibility?

While the traditional scientific approach is based on the reproducibility of the object (or hypothesis) as “being,” the constructivist approach is based on “generation” and accepts the one-time nature of events. In this respect, the constructivist approach is not a mere expedient, but is related to the foundations of science. Mathematical physicist Izumi Ojima argues that in the formation of nature, although “generation” comes first and “existence” (e.g., the state of a system at a particular time) appears as a result, humans usually think that we can first describe only “existence” (e.g., position), and then use it to define “generation” (change in position). In other words, he points out that there is an epistemological difficulty in describing “generation” directly at all, a difficulty in which traditional science is trapped and from which some at the forefront of modern physics are demanding and trying to escape. Moreover, the possibility of falsifiability is a fundamental condition of science, as proposed by the philosopher of science Karl Popper, which of course presupposes reproducibility. However, considering that it is not an extreme argument to say that having exactly the same conditions and the same environment on a time axis that runs in only one direction is an impossibility in principle, it can be argued that the foundations of (traditional) science rest on an extremely weak assumption.

The constructivist approach tackles these difficulties of describing “generation” and “reproducibility.” In other words, if traditional science (i.e. elementary reductionism) assumes reproducibility and focuses on the fact that any phenomenon can be explained by a single law, science based on constructivist methodology instead avoids reproducibility (an impossibility in the extreme case) and focuses on how a single law (in this case a robot) can generate a complex (one-time) phenomenon. Given the success that the constructivist approach has had in robotics science, the foundations of which are being laid, it is not an exaggeration to say that robotics based on the constructivist approach is a technological advancement of complex adaptive systems science and opens up a new scientific paradigm.

A new way of sharing research

Moreover, an even more radical prediction emerges when we consider the foundation of science, namely the sharing of knowledge. In the world of the constructivist approach, one-time events are accepted over reproducibility, or in other words, in the understanding of “generation,” the logic of change itself is the object and changes as a result of observation. In statistics, the fundamental logic is buried in the noise (how many experiments were conducted and how many of them were successful), so we must rely on an explanation of the process of each observation and change that varies with each observer and each observation experiment. This is in contrast to the analytical scientific method, which explains phenomena by deriving laws and theories so that we can share personal experiences, so to speak. This is not accepted in traditional science, but if we look around in academia, it is similar to the ethnographic approach in cultural anthropology or the work of seeing universal truths in literature through exploration by novelists.
First of all, the difficulty of expressing things and events in language is an ongoing struggle, and one could argue that the only real way to share knowledge is to let the other person experience it. If this is the case, it is logical to assume that “installations” - which have become commonplace since the 1970s and are considered to be method of expression in contemporary art, along with painting, sculpture, video, and photography - could become a method used by science (and, by extension, academia). The format of academic papers and conferences would be left behind, and work would be shared as participatory installations, with participants also committed to generating knowledge.

Robotic science opens the door to learning

As critic Hideo Kobayashi astutely pointed out, modern science can be described as a science of measurement. It develops without considering things that cannot be measured, and although it resulted in mankind landing on the moon, it is a distorted kind of development because it does not deal with things like tradition, values, and spirituality. (In retrospect, these things that science does not deal with are fundamental and essential to humanity and life.) However, robotics science deals with one-time events and individuality as a science (constructivist approach), so it can be said that it goes one step further than the traditional definition of science. A science that embraces narratives.

This is the unique essence of the approach and perspective of robotics science, a discipline that spans all fields that tackle the mysteries of humanity and life.

We began this article by questioning whether robot research or research that uses robots is an "academic discipline," but this was a new suggestion about the roots of this traditional approach to science. This article is based on the article "What is Robotics Science" published exactly 10 years ago and has been adapted to the current situation. Compared to that time, one could say that robotics has established itself as a solid field with the launch of the journal Nature Robotics and the recent rise of artificial intelligence. However, this means that it is now on the same footing as other academic fields, and it still requires tireless efforts and research by researchers in the field to update the state of science and, by extension, of learning, as discussed above, in other words to be accepted by all as a new science.

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