Original Paper

Adaptive Behavior

Adaptive Behavior
2014, Vol. 22(6) 370–375

DOI: 10.1177/1059712314541299
adb.sagepub.com
SAGE

Takashi Gomi: a bridge builder in robotics

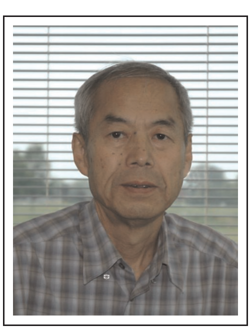
Inman Harvey

Abstract

Takashi Gomi's death in September 2013 has left an enormous gap in the lives of his family and friends. Here I pay tribute to his multiple roles in bridging many gaps – so uniquely and charismatically – in the field of robotics over several decades. He was a principal player in the development of autonomous and evolutionary robotics over this period. He called his approach Non-Cartesian robotics, others used different terms such as Behavior Based Robotics or Nouvelle AI for broadly similar ideas; what united them was a critical rejection of many of the classical robotic assumptions that have been loosely called GOFAI – Good Old-Fashioned AI.

1 Introduction

TG's official status was as founder and CEO of Applied AI Inc., a company based in Canada with strong Japanese connections. But his influence was far wider than that might imply, often behind the scenes, in arranging symposia and networking and facilitating contact between key members of different research groups and newcomers to the field. In particular, I can focus on four main gaps in robotics that he did so much to bridge: between Academia and Industry, between Japan and the West, between Philosophy and Applications, between Technology and Ethics. But first we should sketch the intellectual landscape that influenced him, and which he did so much to foster.



Takashi Gomi, 1940–2013

2 GOFAI and NEWFAI

From the 1950s to the 1980s, the computational metaphor for AI was just about the only game in town. The human brain was some sort of computer, it was held, running some unknown biological operating system. Since the same computation can be run on different operating systems, for instance a PC or a Mac, it was assumed that the details of the hardware (or wetware) of the brain were relatively unimportant. The problem of human cognition – and by extension, that of robot cognition that was intended to emulate humans – was to be considered primarily a software or computational problem.

Humans and robots have bodies, with sense organs and muscles, sensors and motors, of course. But these can, from a GOFAI perspective, be considered relatively minor details, merely as the input and output interfaces to where the real work is done in the computational brain. Thus the task of a robot, perhaps crossing a room avoiding obstacles in order to pick up an object, can be reduced to solving a succession of computational problems: given an instantaneous snapshot of the environment through its sensors, like a snapshot of a chessboard, what is the next move to be taken? Repeat until the goal is reached. GOFAI Cognition is the equivalent of solving a succession of chess problems.

Artificial neural networks, in their resurgence in the 1980s, seemed at first to present a possibly different model of what was going on in the brain. But they were soon conceptually incorporated into the same

Evolutionary and Adaptive Systems Group, University of Sussex, Brighton, UK

Corresponding author:
Inman Harvey, Evolutionary and Adaptive Systems Group, University of Sussex, Brighton, UK.
Email: inmanh@gmail.com

computational framework as 'just a different form of distributed computation'; often on the sensory input side of interpreting images into symbolic form that could then be fed into a program.

Brooks (1986) characterised this GOFAI approach as a sequential process SMPA: *Sensory* inputs get translated into an internal *Model*, on which computational reasoning comes up with a *Plan*, that then gets translated into *Action* through motor outputs. The side effects of such a mindset include: lack of situatedness, in that the planning works on a model abstracted from reality; a focus on abstract static problem solving, motion being seen as a succession of snapshots; a disembodied lack of attention to the dynamics of the body; and the computational breaking-down of tasks into separate subroutines, different boxes. Since most of the work was seen as being in the reasoning step between Model and Plan, much of this could be done relying on simulations of the environment. Once success was achieved in simulation, the job of transferring this to a real robot in a real noisy environment tended to be relegated to a mere implementational afterthought.

The results of such methods were often implementational failures that were slow, jerky and unreliable – and definitely unnatural. In the mid-1980s, a radical challenge to the GOFAI mindset arose, with Brooks at MIT being a major leader. Within his framework of Subsumption Architecture (SA) for achieving Behavior Based robotics, an approach aimed at real-time interactions within a real dynamic environment used a very different set of starting assumptions.

For a start, the SMPA sequence was discarded, and no longer was there the notion of reasoning on an internal model. The physical embodiment of a robot was not a mere implementational afterthought, but key from the beginning. Starting with simple individual behaviours, such as wall-avoidance, the robot designer should design a sensorimotor loop that generated the desired ongoing dynamics; for instance, in Braitenberg vehicle style (Braitenberg, 1984), a proximity sensor sensing a nearby wall on the right side directly promotes increased speed on the right wheel to turn away from that wall, and similarly for obstacles on the left – no model, no planning, but real-time reactive behaviour.

Building up from such simple situated and embodied behaviours is a challenge to the designer. SA is one set of design heuristics for building up more layers of behaviours on top of each other, such that each forms direct sensorimotor loops via the environment yet also interacts with other layers appropriately. Moving from merely reactive behaviour to the use of internal state, allowing for memory and temporally extended behaviours, is achievable through SA components with temporal properties called Augmented Finite-State Machines (AFSMs). If done properly, then multiple behaviours can give the observer the impression of smooth dynamic purposefulness; but if the observer attributes intelligence to this, it is an intelligence emergent in the behaviour rather than decomposable into some computational box in the brain.

To do this properly requires willingness to do multiple rounds of iterated prototyping with real robots in a real environment from the start. Debugging is driven by field tests. An incremental approach implies that the very simplest behaviours are designed first, and only when these are fully debugged is the next layer designed – and field testing starts again. This very much reflects an idealisation of how natural biological evolution has debugged evolving species over millions of generations. Evolutionary Robotics (ER) arose a few years after Brooks' initial revolutionary proposals, and very much in the same spirit; except that rather than relying on a human designer to craft successive incremental evolutionary steps, the human design role was to be largely limited to designing fitness tests for robots and artificial evolution was to do the incremental designing.

These new ideas – sometimes called NEWFAI – in the latter part of the 1980s and the early 1990s triggered a wave of enthusiasm in North America and Europe, with many research groups developing their own lines of research. Despite using different terms and having differing motivations, there was a common feeling that here was a fresh approach to understanding cognition in humans, animals and robots, with philosophical implications and with very practical consequences for the design of robots. In March 1993, Luc Steels organised a NATO-sponsored Advanced Study Institute 2-week workshop called 'The Biology and Technology of Intelligent Autonomous Agents' that brought together about 60 researchers active in such approaches. It was here, in a beautiful castle in the Trento region of the Dolomites of north-eastern Italy, that I first met Takashi Gomi and we immediately became friends.

We both took Rod Brooks' classes at the workshop teaching how to design SA in Behavior Language, and I learnt that TG had been, like me, an enthusiast for Brooks' ideas from their inception. TG ran an AI company in Canada and was keen to bring such robotic ideas into the mainstream. I also met properly for the first time Dario Floreano and Francesco Mondada at this workshop; I had been developing ER ideas at Sussex, and Floreano was working in similar areas in Italy and then EPFL in Switzerland. TG had immediately seen the commonalities in the philosophies underlying ER and the Brooksian approach, and he had already organised a first symposium on ER in Tokyo to follow very shortly after our Trento meeting; what was to be the first of eight such symposia. Though they kept the ER title, the subject matter was broader and covered all areas related to NEWFAI and robotics.

Even before he was explicitly influenced in robotics by the Brooksian revolution in the late 1980s, one can see recognisable concerns in consultancy work done by TG and his company (Gomi et al., 1988) for a municipal body, within a more conventional AI domain of building a knowledge-based system to aid the Transit System of buses to cope with expected and unexpected problems. He was concerned to move away from the conventional approach ‘where computer analysts or designers or software designers design what they consider to be ideal file and i/o formats, and impose them on the users, many of whom are application domain experts’. The alternative approach taken was to repeatedly build prototype systems and go back to test them against real world experience; this sounds like common sense, but it was resisted by many:

> Technologists within the government … basically understood what … a knowledge -based system was and how it was built. However, their comprehension of the process of repeated prototyping as an effective way to implement such a system was limited. The process was greatly different from the more conventional development process with which most technocrats in governments are familiar. A gap in conception inevitably started from there.

These observations translate directly to the gap between GOFAI and NEWFAI in robotics. The different starting assumptions as to how one approaches a project are sometimes so far apart that there is mutual incomprehension; the differences in technique show up in style as well as in content.

This gives some flavour of the intellectual context of robotics debates within which TG was placed, and in which I was to discover over the following years he was playing such a pivotal role, in Japan and North America and Europe. Gomi (1996) and Gomi (1998) provide an excellent introduction to the issues as he saw them. Other relevant background material includes Brooks (1991) and Arkin (1998) on Behavior-Based Robotics; Cliff, Harvey and Husbands (1993), Harvey et al. (1997), and Nolfi and Floreano (2004) on ER. In particular, TG was uniquely placed, both by personal circumstances and through the nature of his character, to forge links between different people and different worlds. He was a bridge builder par excellence.

3 Bridges between academia and industry

Your average unworldly academic might picture an industrialist as wearing a sharp suit, exploiting expense accounts and basing decisions on the bottom line of profit. Although TG was the founder and President of Applied AI Systems Inc. (AAI), started in 1983 in Canada and claimed to be the longest running speciality AI company in North America, and also CEO of their Tokyo offshoot AAI Japan, he certainly did not fit into that mould. He was very much a hands-on person, running operations often on a shoestring and optimism. The business keynote was more long-term survival in pursuing the principles he cherished, rather than profit, and we shall return to this theme in discussing ethics below.

In Tokyo, he had worked on R&D projects at the Institute of Systems Science at the end of the 1960s. Then after moving to Canada in 1971, he worked for 5 years on computing R&D projects at Bell-Northern Research, followed by similar positions at Atomic Energy of Canada and other corporations. So he had significant industrial experience before setting up his own business in 1983, and he had a wide range of contacts in both North America and Japan. His company collaborated with companies big and small, including Mitsubishi and NTT DoCoMo in Japan, and with government and municipal authorities in Canada and Japan on R&D projects. He acted as a main agent for many commercially produced intelligent mobile robots, particularly ones aimed at education and research. So his dealings with universities sometimes combined business with his research interests.

His freewheeling, often anarchic, style fitted in well with academics who often found it difficult to believe he was a businessman. A Takashi talk was bound to be startling, with far too many slides for the time allotted, random images illustrating gnomic observations, and often radical political observations that the audience was not expecting. Yet through such a stream of consciousness delivery, it was clear that he was an original with exciting ideas, with a well-developed and consistent world view, held sincerely and enthusiastically, that challenged many peoples’ assumptions.

Alongside his business, he found time to pursue strictly academic interests. He took a B.A. in Art History at Carleton University in 1986 – a topic rather distant from his original degree studies in Electrical and Electronic Engineering at Waseda University in the 1960s. Then in 1997 he obtained a D. Eng. in Complex Systems from Hokkaido University.

Since TG had entrees into both industrial and academic environments, he played a strong role in bringing these together. The ER symposia in Japan always brought in people from both industry and academia in the audience. On an individual level, several Japanese companies seconded interns to his company over the years, and he brought them with him on visits to universities and conferences. Conversely, many young researchers got their first jobs outside academia working for his company.

His business approach fitted in with his philosophy as a whole, and chimed with the approaches to robotics that he was promoting, in that his primary interest in academic ideas was in seeing them translated into real products that met real needs in the real world.

4 Bridges between Japan and the West

TG was born in Japan in 1940, and had tales of the hardship of surviving as a child there during and immediately after the war. In the 1960s, he came to reject some aspects of the Japanese culture he was then exposed to, and this prompted his move to Canada in

1971. There is a proverb that translates as 'the nail that sticks out gets hammered down', and Takashi was always going to be a nail that stuck out and refused to be hammered down. Though he fully embraced and appreciated his new homeland, though he had emigrated from and had some criticisms of Japan, there was much that he still loved of Japanese culture and he went back frequently. Indeed, at one period when setting up the Tokyo offshoot of AAI Japan, he was commuting almost weekly between Canada and Japan.

On a personal level, he introduced many western friends to some of the delights of Japanese rural culture, and of course to Japanese cuisine. I also recall a memorable stay in a large seaside hotel for the benefit of trade union members, with over a thousand guests sitting down together on tatami mats for dinner in their (and our) uniform yukata robes. More widely on the intellectual level, he acted as a major conduit bringing these new AI ideas from the west into Japan.

The public stereotype of robots is very different in Japan from the threatening Hollywood image of Terminator-style machines we are familiar with in the west. Astro Boy ('Mighty Atom') is a popular manga series adapted for television that conveys the basic assumption that robots exist to help people, and reflects similar public perceptions. Japan has far more industrial robots than any other country, and large companies also spend a lot of money developing robots primarily for advertising their excellence, e.g. Asimo for Honda, Qrio for Sony or the Toyota Partner Robots. But until relatively recently, and even more so in the 1990s, such robotics was overwhelmingly based on classical GOFAI principles. In the 1980s and 1990s, the challenge from NEWFAI came mostly from North America and Europe.

Interestingly, this position has somewhat reversed in recent years; nowadays many novel and revolutionary ideas in robotics come from Japanese researchers. Some part of this change can be attributed to TG's role in bringing the new wave of ideas to Japan. From 1993, he organised some eight symposia on ER, usually held in the fine Canadian Embassy building in Tokyo, to which many Japanese students and researchers came, from both academia and industry. Sponsorship for some of these came from major Japanese corporations. The speakers TG brought in, from key research groups across the world, often went on to give further talks elsewhere in Japan. Over the years, this cumulatively built up a network of international contacts, and many exchanges of researchers in both directions between Japanese institutions and their counterparts in Europe and North America.

5 Bridges between philosophy and applications

TG developed his philosophical framework for cognition very much in line with many others in the new wave of robotics. But this was not mere armchair philosophy – it was integrally a framework for action that was justified and made sense in the context of how physical robots were designed and applied in the real world.

Though discussed explicitly elsewhere, and further implied as lying behind all his work, the clearest summary of his views is in his robotics and autonomous systems paper (Gomi, 1996). This summarises the rationales behind SA, the behaviour-based approach pioneered by Brooks; the notion of Emergent Computation as a post-Newtonian science, along with related work by Steels and Pfeifer; and ER. He then draws all these together as examples of Non-Cartesian robotics, to be contrasted with the GOFAI products of typical Cartesian intelligent robots.

He notes a number of specific features, mostly negatives where the Non-Cartesian approach sees no (or little) need for what the GOFAI practitioner assumes is essential. No definitions and no models: a mobile robot may need to avoid an obstacle, but that does not mean the obstacle has to be defined and modelled somewhere. In consequence, no measurement and no computation: there is no need to calculate repeatedly the distance to an obstacle or the angle at which to turn away. No explicit planning: 'how far can we enforce what we believe is a "precise, exact system of events to take place" in a system which has to operate in the real world?' We can see in his earlier study cited above (Gomi et al., 1988) that analysis revealed that the human expert, who was impressively competent at managing a municipal transit system, did not act in such a fashion. No singularity, no central control: in Cartesian robots, when a control module breaks down, this typically leads to total failure of the robot, whereas in non-Cartesian robots, more typically the emergent behaviour from multiple parallel processes means that a loss of function in one merely reduces one functionality amongst many – graceful degradation. No hierarchy: though there may be an emergent hierarchy at the behavioural level in the eye of the observer, this need not be translated into a corresponding hierarchy at the mechanism level, within the control system.

This final point reflects the general positive message – 'Most of the *No*'s above can be replaced by *Emergent* in order to highlight the nature of Non-Cartesian robotics'. Though I personally am reluctant to use the term *emergence* because I feel it is often used vaguely and hence misunderstood, I can see exactly what is intended here. Where there are two very different levels of description of some phenomena – here the *behavioural* level, where an observer describes the behaviour of a person or robot in acting and responding to events in its world, and the *mechanism* level, where one analyses the components and control flow in the brain or control system – it is tempting to assume that the components and interactions of the second description must somehow mirror or have some clear correlation or correspondence with the components parts and interactions of the first description. That is the Cartesian assumption, and it is simply not necessary at all; the relationship between entities at the different levels of description need not be that of correspondence. When this is the case, they may be described as emergent; a term that needs these two levels of description to make sense. TG traces this notion of emergence to Heidegger, through Heidegger's discussion of the term *phenomenon* to its Greek roots – to show itself (Heidegger, 1962). TG explicitly follows Nagel (1961) in defining emergence 'in terms of the observation of properties of an object at a high-level, which are not predictable from the low-level properties of the same object'.

One strand of TG's research interests was in the possibility of, and the importance of, emotions in robots (Gomi & Ulvr, 1993; Gomi, Vardalas, & Ide, 1995). Here he clearly saw this as a further *emotional* level of description of behaviour, that was emergent in the same sense. Clearly, on this view, it makes no sense to try and locate emotions, or indeed motivations (or correlates of these), somewhere within the brain of a human or the mechanism of a robot control system.

TG also found inspiration in Gibson's (1979) notion of *affordances*, that can be thought of as yet a further level of description, similarly emergent. Examples of affordances could include 'open space for unhindered motion', or 'handle available for grasping', or 'shelter from observation'; in other words, these are descriptions of what may be available – for a human, animal or robot – for it to meet its needs, if it has the competence to recognise and act on them. Whereas a Cartesian approach tends to conceive the world in terms of physical objects that may be measured and modelled, this non-Cartesian approach focuses on such affordances as the organising principles for designing behavioural competences. A Gibsonian term that has confused many is that of 'direct perception' of such affordances; for the roboticist, this can be seen as a heuristic to focus design on the issues at the level of description that matters.

Such philosophical issues engaged TG, and he was very ready to discuss and expand upon them. But these are all grounded in reality and only make sense when applied to real robots in the real world. He was suspicious of simulations as frequently failing to recognise where the hard problems lie (Gomi & Ide, 1998); though he supplied Webots robot simulation software for educational purposes. Above all he dealt with physical robots, and built many himself and within his company. This extended to carrying excess amounts of robot baggage in suitcases all over the world – he claimed this helped him discover what embodiment really meant!

The imperative for multiple rounds of prototyping involved in developing any robot behaviours or competences meant that theory was subservient to hard hands-on experience. All his writings mix theory and philosophy with practical examples, usually with robots he has been directly involved with. His consistency and integrity shone through in this as with other issues – it came so naturally to him to bridge the gap between philosophy and applications that he could not do otherwise. Furthermore, his ideals extended to the decisions as to just what type of applications his company should focus on, as we shall see in the next section.

6 Bridges between ethics and technology

It is an unfortunate fact that much of the funding for robot R&D comes from military sources. In the USA, even much non-military research is funded via this route, since it is more acceptable for politicians to allocate public money for 'defence' related purposes than for e.g. welfare purposes. TG abhorred this, and went further. In Gomi (1998), he labelled as *dark* those applications that he believed did not advance the welfare of society in the long run. 'They are: defense related applications, resource mining and distribution, applications that encourage the current trend of mass-production/mass-consumption/mass-disposal, and others that accelerate the destruction of the environment'.

Avoiding such applications could limit the commercial possibilities for many AI companies, but he saw *non-dark* possibilities. He saw space exploration as one such, but in his business he explicitly aimed at *3D* tasks – Drudgery, Dirty and Dangerous – with a strong orientation towards welfare applications. One long running such project AAI undertook was the development of an intelligent wheelchair (Gomi & Griffith, 1998; Gomi, 2007). Other robotic aids for the aged, including a robot bed, were longer-term goals; these attract much support in Japan, which demographically is an aging society.

Since this aging demographic is disproportionally in the countryside, it turns out that the majority of rural workers in Japan are what would be considered beyond retirement age in most countries – yet they have hard physical labour to do in the field. So one such *3D* project was to develop semi-autonomous robots that could follow these workers and carry the heavy cabbages to the edge of the field. Others included the development of an intelligent camera that could monitor hillsides above roads or houses for landslides or their precursors; and similar automatic detection of fly-tipping.

Much of this R&D was supported by government and local government in Japan and Canada. The business side supplying robots dealt primarily with universities and research centres, and he was generous with his time and support. Nobody who dealt with him could doubt the integrity of his commitment to 'robots for the betterment of society in the true and unselfish sense of the words, and business for the same purpose' (Gomi, 1998). He approved of others who acted similarly; in his preface to one ER Symposium proceedings (Gomi,

1998) he praised Francesco Mondada for placing ideals above monetary accountability in running K-team, a robotics business with which AAI had much common cause.

7 His legacy

I am sure that those who worked directly for Takashi Gomi found him a hard taskmaster. But this would be tempered with the realisation that whatever he asked of others, he would do far more himself. His character and integrity, his generosity of spirit and indeed his charm, inspired much loyalty and admiration amongst his friends and colleagues. Ann Griffith, his Vice President, was a stalwart and irreplaceable support for decades.

He was a workaholic who imposed impossible demands upon himself; not least his continuous travelling habits, with impractical schedules and improbable numbers of bags. The illness he developed in later years required him to eat little and often over 24 hours; so at all times of the day and night he was to be found phoning across the world and taking notes. However, on those rare occasions when he could be persuaded to slow down, he appreciated tranquillity. When he stayed with me in an old town in Sussex, he delighted in walking the streets, buying old books and rubbish in charity shops; or visiting a ruined church hidden in the hills. On a last visit Dario Floreano and I made to him in Canada, we found him initially very ill in the Emergency ward of the local hospital, where he was a regular visitor; but after we had left him there, we discovered a few hours later that he had discharged himself against doctor's advice and taken hospital transport some 25 km to meet up with us at a pub – typical Takashi to ignore anybody who said something was not possible. We then spent some time with him and his family at their lakeside retreat, and saw how he appreciated the serenity, such a contrast to his frenetic business life.

Many people will have such personal memories of a unique character. But here I have tried to pay tribute to his very significant influence, often behind the scenes, on robotics communities across the world, in particular those who shared elements of his philosophical vision as to the way robots should be designed and built, and his social vision of what robots can be used for. There are so many individuals who have been introduced to new ideas and new people, at conferences or through internships, whose direction has been influenced by him. For those of us who believe NEWFAI (or Non-Cartesian robotics to use TG's phrase) is an exciting and fundamental shift at the turn of the new millennium in our view of cognition and our attitude to robots, it is reassuring that the field attracted people of the calibre of Takashi Gomi. He was above all a good person, and he has left a lasting effect on the several communities with which he interacted, and helped to bring together through his bridge building.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors

References

Arkin, R. C. (1998). *Behavior-based robotics*. Cambridge, MA: MIT Press.

Braitenberg, V. (1984). *Vehicles: Experiments in synthetic psychology*. Cambridge, MA: MIT Press.

Brooks, R. A. (1986). A robust layered control system for a mobile robot. *IEEE Journal of Robotics and Automation, RA-2*(April), 91–122.

Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence 47*(1–3), 139–159.

Cliff, D., Harvey, I., & Husbands, P. (1993). Explorations in Evolutionary Robotics. *Adaptive Behavior*, *2*(1), 71–104.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Erlbaum.

Gomi, T. (1996). Non-Cartesian robotics. *Robotics and Autonomous Systems*, *18*, 169–184.

Gomi, T. (1998). Practical applications of Behavior-based Robotics: The first five years. In: *Proceedings of the 24 Annual Conference of the IEEE Industrial Electronics Society (IECON'98)*, August, Aachen, Germany.

Gomi, T. (2007). Intelligent wheelchair: Lessons learned from a decade of development. In: *Second International Conference on Technology and Aging*, Toronto, Canada, June.

Gomi, T., & Griffith, A. (1998). *Developing intelligent wheelchairs for the handicapped. Lecture Notes in AI: Assistive Technology and Artificial Intelligence* (Vol. 1458). Berlin: Springer.

Gomi, T., Griffith, A., Oppacher, U., Stanley, R., & Tuan, P. (1988). Development of a knowledge-based dispatch management system for a municipal transit centre. In: *Proceedings of IEEE AI'88* (pp. 496–501), Hitachi City, Japan, 25–27 May.

Gomi, T., & Ide, K. (1998). Evolution of gaits of a legged robot. In:*IEEE World Congress on Computational Intelligence (WVVI'98)*, May, Alaska.

Gomi, T., & Ulvr, J. (1993). Artificial emotions as emergent phenomena. *Presented at Robot and Human Communication Conference (RO-MAN'93)*, Tokyo, Japan, 3–5 November.

Gomi, T., Vardalas, J., & Ide, K. (1995). Elements of artificial emotion. Presented at *Robot and Human Communication Conference (RO-MAN'95)*, Tokyo, Japan, July 1995.

Harvey, I., Husbands, P., Cliff, D., Thompson, A., & Jakobi, N. (1997). Evolutionary robotics: The Sussex approach. *Robotics and Autonomous Systems*, *20*, 205–224.

Heidegger, M. (1962). *Being and Time* (pp. 29–30). New York:, Harper & Row.

Nagel, E. (1961). *The structure of science: problems in the logic of scientific explanation*. London: Routledge and Kegan Paul.

Nolfi, S., & Floreano, D. (2004). *Evolutionary Robotics: The biology, intelligence and technology of self-organizing machines*. Cambridge, MA: MIT Press.