Book Review

Moshe Sipper
Department of Computer Science
Ben-Gurion University
P.O. Box 653
Beer-Sheva 84105
Israel
sipper@cs.bgu.ac.il

Kinematic Self-Replicating Machines. Robert A. Freitas, Jr., and Ralph C. Merkle. (2004 Landes Bioscience.) $150.00, xxi+341 pp.

Self-replication is the process by which an object or structure makes a copy of itself. Over the last century, research in artificial self-replication has progressed along two major tracks: (1) cellular or computational self-replication, which investigates the issue from a purely informational point of view [most notably using the cellular automata (CA) model], and (2) kinematic self-replication, which investigates self-replication in the context of physical machinery that can make copies of itself by using kinematic operations on physical matter, that is, movement of materials through physical space in the physical world. Both tracks were pioneered by John von Neumann in the late 1940s [2]. The book by Freitas and Merkle deals mainly with kinematic self-replication, although it also provides an excellent review of the informational track.

Perhaps the first thing that struck my mind as I opened this wonderful volume was the prodigious number of references: 3278. If this were the book's only virtue, it would still be worth owning. Happily, the book exhibits many other merits.

As I began the read, I was quite delighted to note that the authors had elected a not too formal style of writing, rendering the reading a joy rather than a pain. Aside from the clearly explained technical issues, the book contains numerous anecdotal sidelights, both within the text, and—most notably—in the footnotes. Caveat lector: Ignore the footnotes at your own peril. For example, Chapter 2 briefly biosketches von Neumann, with footnotes bringing forth various interesting discussions and quotations. Some footnotes even bring a smile to one's lips, no mean feat when indulging in such a serious subject. To cite one example, a footnote on p. 13: "An amusing example: 'In the reformatory at Caserta, Italy, as guards watched a movie, five youthful prisoners escaped. The movie the guards were watching was about guards who watched a movie while youthful prisoners escaped.' "

References, footnotes, and style aside, let's cut to the chase: the text itself. I would qualify it with three Cs: comprehensive, clear, and captivating. The authors begin in Chapter 1 with a basic introduction to the concepts involved in self-replicating machines, including a short historical survey of mechanical automata (such as Vaucansons's duck, built in 1739), common objections to machine self-replication, and the distinction between *reproduction* and *replication*. The latter issue, first raised by Sipper et al. [1], concerns the distinction between two terms that are often considered synonymous. Replication is an ontogenetic—that is, developmental—process, involving no genetic operators, resulting in an exact duplicate of the parent organism. Reproduction, on the other hand, is a phylogenetic—that is, evolutionary—process, involving genetic operators such as crossover and mutation, thereby giving rise to variety and ultimately to evolution. Replication, the main subject matter of this book, has the advantage of being safer due to the lack of evolution.

The second chapter reviews the classical theory of machine replication, the early history of which is largely the record of von Neumann's thinking on the matter. The chapter describes von Neumann's two major models: the CA-based self-replicator, and the kinematic one. It then goes on to mention several other works, both CA- and non-CA-based.

Chapter 3 is the first to delve into the book's main topic—kinematic self-replicators—concentrating on macro-scale machines, namely, ones that can be seen with the naked eye. From early works in the 1950s by Moore, Penrose, and Jacobson to the most recent works involving LEGO bricks and robotic ecologies, the chapter presents a wealth of information—to mention but a few examples: NASA's replicating lunar factory (1980), Lohn's electromechnical replicators (1998), and Bererton's self-repairing robots (2000–2004).

Chapter 4 thinks small, presenting micro-scale and molecular kinematic machine replicators. The first part delineates the many examples found in nature: self-assembling peptides, autocatalytic networks, ribosomes, prions, viroids, and more. The chapter then goes on to present the many efforts made at constructing (or at least designing) artificial micro-scale replicators, such as positional assembly using DNA, Drexler molecular assemblers, Merkle molecular assemblers, and the Zyvex nanomanipulator.

Chapter 5 discusses various issues in kinematic machine replication engineering, beginning with a presentation of several taxonomies of replicators. The most comprehensive of these is a taxonomy recently presented by the authors, who have identified 137 practical multivalued replicator design properties, which may be grouped into 12 primary design dimensions in four principal categories. The chapter continues with a discussion of several more issues: replication time and replicator mass, minimum and maximum size of kinematic replicators, the efficient replicator scaling conjecture, the fallacy of the substrate, closure theory and closure engineering, massively parallel manufacturing, simulation software, and a primer on the mathematics of self-replicating systems. The chapter ends with a treatment of two important issues regarding policy: replicators and artificial intelligence, and replicators and public safety.

Chapters 6 presents a discussion of motivation for molecular-scale machine replicator design, followed by two appendices: data for replication time and replicator mass, and design notes on some aspects of the Merkle-Freitas molecular assembler.

To be faithful to my job as reviewer I should, perhaps, endeavor to find a fault or two. Well, one such demerit would be the small fonts used throughout, necessary, I imagine, to pack all the dense information into a single volume, but tiresome at times. Also, I would have liked to have that prodigious reference list in alphabetical order.

Be that as it may, I think my conclusion will come as no surprise: I recommend this book wholeheartedly to anyone even remotely interested in the fascinating topic of self-replication. As of now, there is a definitive reference.

References

1. Sipper, M., Sanchez, E., Mange, D., Tomassini, M., Pérez-Uribe, A., & Stauffer, A. (1997). A phylogenetic, ontogenetic, and epigenetic view of bio-inspired hardware systems. *IEEE Transactions on Evolutionary Computation*, *1*(1), 83–97.

2. von Neumann, J. (1966). *Theory of self-reproducing automata*. Edited and completed by A. W. Burks. Urbana: University of Illinois Press.