Tihamer Toth-Fejel
Veridian Systems Division, Inc.

Modeling Kinematic Cellular Automata: An Approach to Self –replication

Veridian Systems Division proposes to design a useful Self-Replicating System (SRS). As shown by NASA's summer study *Advanced Automation for Space Missions*[1], and other smaller studies[2], the development of dynamically reconfigurable SRSs that implement Universal Constructors[3] (UC) can revolutionize future space missions. For example, a self-replicating lunar factory could build solar cells and other manufactured tools with which to explore and develop the Moon with exponential growth.[4] But despite the fact that these studies showed the tremendous power of machine self-replication, there have been no serious attempts to further the field.[5] However, two recent small efforts have resulted in some success. We propose to build upon one of those successes by designing a system of Kinematic Cellular Automata (KCA) cells that are configured as a limited implementation of a Universal Constructor.

The trivial self-replication is easy, but the final goal of autotrophic[6] self-replication is certain to be extremely difficult. So there is a huge unexplored area between theses two extremes, and we believe that an iterative approach of gradually moving complexity out of the environment and into the cell is the best chance at characterizing it.

Macro-scaled self-replication may be cumbersome and impractical, but with the advent of nanotechnology, "self-replication is widely viewed as the key to an entirely new industrial era that may one day replace modern microelectronic systems."[7] Also, self-replicating nanotechnology would reduce the price of complex manufactured goods to that of agricultural products.[8] But first we need to understand self-replication.

[1] Robert A. Freitas, Jr. and William P. Gilbreath (Eds.), *Advanced Automation for Space Missions*, NASA CP-2255, 1982, http://www.islandone.org/MMSG/aasm/

[2] Georg Von Tiesenhausen and Wesley A Darbro, "Self-Replicating Systems - A Systems Engineering Approach", NASA TM-78304, July 1980; Robert J. Coppinger, "The Drexlerian Terraformation of Mars: A New Ark for Humanity", The Assembler, V4 N1, Q1 1996, http://www.islandone.org/MMSG/9601-news.html; and Gregory Chirikjian, Yu Zhou, and Jackrit Suthakorn, Self-Replicating Robots for Lunar Development, ASME & IEEE Transactions on Mechatronics in the Special Issue of Self-Reconfiguration Robots, V7 N4, Dec 2002, http://custer.me.jhu.edu/jackritweb/SRR-Mechatronics-Paper.pdf

[3] John von Neumann's first model for self-replication appeared in "The General and Logical Theory of Automata", *Cerebral Mechanisms in Behavior - The Hixon Symposium*, L. A. Jeffress, ed., John Wiley & Sons, N.Y., 1951. See also his posthumously published *Theory of Self-Reproducing Automata*. Edited and completed by A. W. Burks. University of Illinois Press, 1966.

[4] Robert A. Freitas Jr., "Terraforming Mars and Venus Using Machine Self-Replicating Systems (SRS)", Journal of the British Interplanetary Society 36:139-142 (1985), http://www.rfreitas.com/Astro/TerraformSRS1983.htm

[5] The only exceptions are: 1. the A-life (Artificial Life) work on mathematical cellular automata models (which rarely addresses physical self-replication), 2. the preliminary work at the CMU Robotics Lab (personal email, Trey Smith trey@ri.cmu.edu, 16 May 2000), and 3. the two projects described later in this proposal (by Matt Moses at University of New Mexico, and by Gregory Chirikjian and Jackrit Suthakorn at John Hopkins University).

[6] *autotrophic* - Capable of utilizing simple molecules as the main source of raw materials and of obtaining energy for metabolic processes from the oxidation of inorganic elements (chemotrophic) or from radiant energy (phototrophic).

[7] John Markoff, "I.B.M. Makes Breakthrough in Memory for Computers", *New York Times*, http://www.nytimes.com/library/tech/yr/mo/biztech/articles/17blue.html

[8] K. Eric Drexler, "Engines of Creation: The Coming Era of Nanotechnology", 1986, http://www.foresight.org/EOC/

Given such potential, it is incredible that half a century after John Von Neumann's seminal work, and 23 years after NASA's follow-on project, we do not have a single useful SRS, and little idea of the answer to the question:

How do we quantify the difficulty of implementing machine self-replication for universal constructors?