An Architecture for Self-Replicating Lunar Factories

Gregory S. Chirikjian
Department of Mechanical Engineering
Johns Hopkins University

NIAC Phase 1 Award:
Oct 1, 2003- March 31, 2004

Background

- A device or organism is called self-replicating in a particular environment if it can assemble a functional copy of itself from a passive set of basic components in that environment
- Exactly what constitutes a basic set of components, and how much or how little structure must be present in the environment for a system to be convincingly self-replicating is subject to debate
- In the context of robotic implementations, the distinction between autonomous vs. directed self-replication is important, and human remote-control may be desirable over full autonomy

Related Research

Self-Replicating Automata:

J. von Neumann (1950); M. Arbib (1966); M. Sipper;
R. Laing (1975);

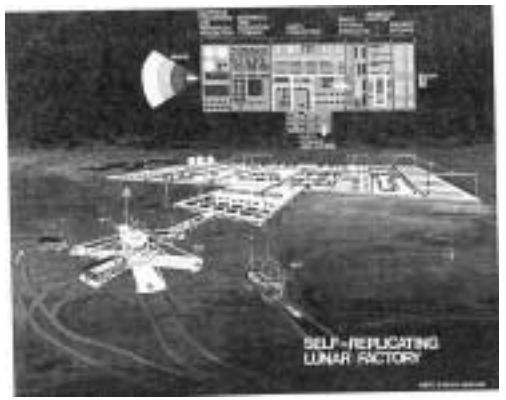
Self-Assembling Structures:

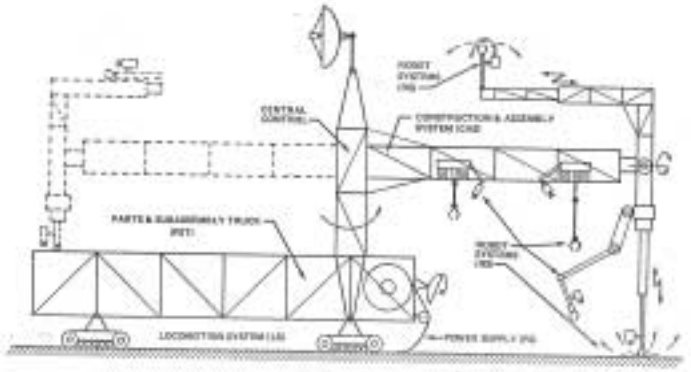
L. Penrose, H. Jacobsen (1959) ; J. Lohn; G. Whitesides et al (1995-present)

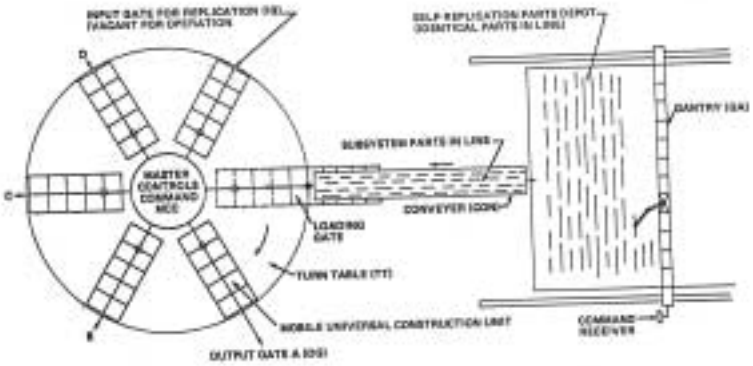
Self-Replicating Lunar Factories:

R. Freitas et al (1979-81); von Tiessenhausen and Darbro (1980); K.S. Lackner and C.H. Wendt (1995)

The Self-Replicating Lunary Factory Concepts circa 1980

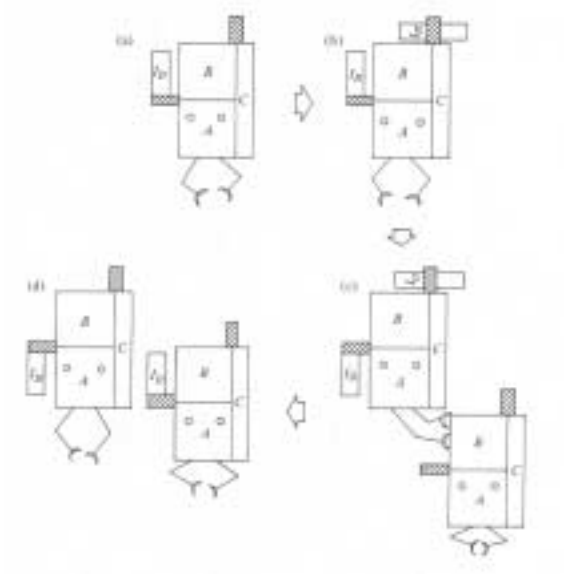






Reprinted with permission from R. Freitas

How do we go from concept to implementation ?



A ``fanciful'' conceptual SRR circa 1986 (reprinted with permission from M. Arbib)

vs.

A concrete architecture and system demo (Chirikjian, 2004-beyond)

Goals of Phase I

(1) Demonstrate in hardware that it is feasible for robotic systems to self-replicate from a set of basic parts;

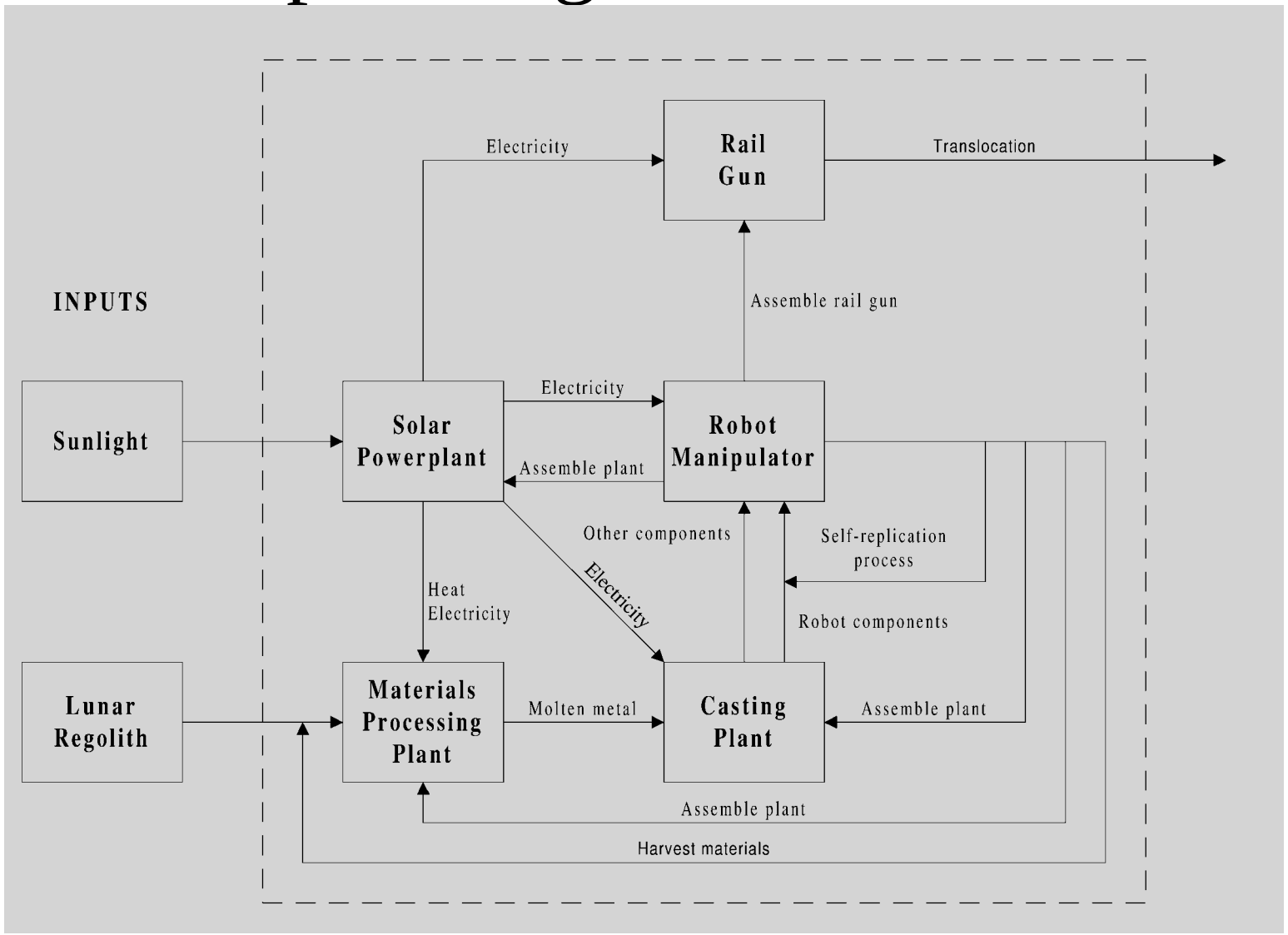
(2) Identify mechanical and computing elements which can be easily manufactured and assembled in situ;

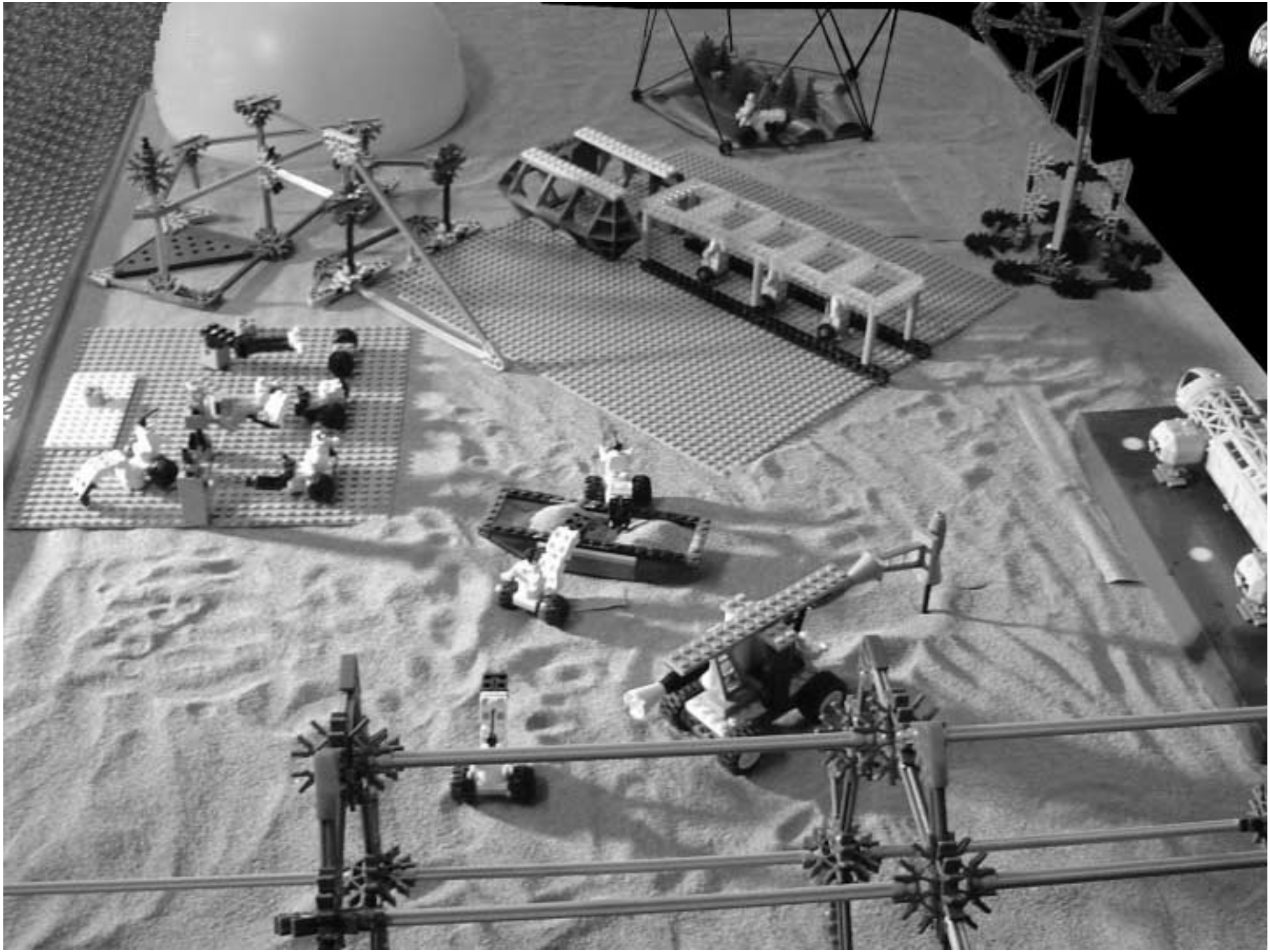
(3) Integrate previous concepts of ISRU and self-replicating lunar factories into a workable system architecture;

(4) Survey materials processing and energy production technologies and assess feasibility in absence of lunar water.

(5) Develop analytical models of proliferation of lunar factories

Our System Architecture for Self-Replicating Lunar Factories





Good News: We Can Concentrate on Robotics and Manufacturing

Others have made contributions to develop many of the subsystem concepts:

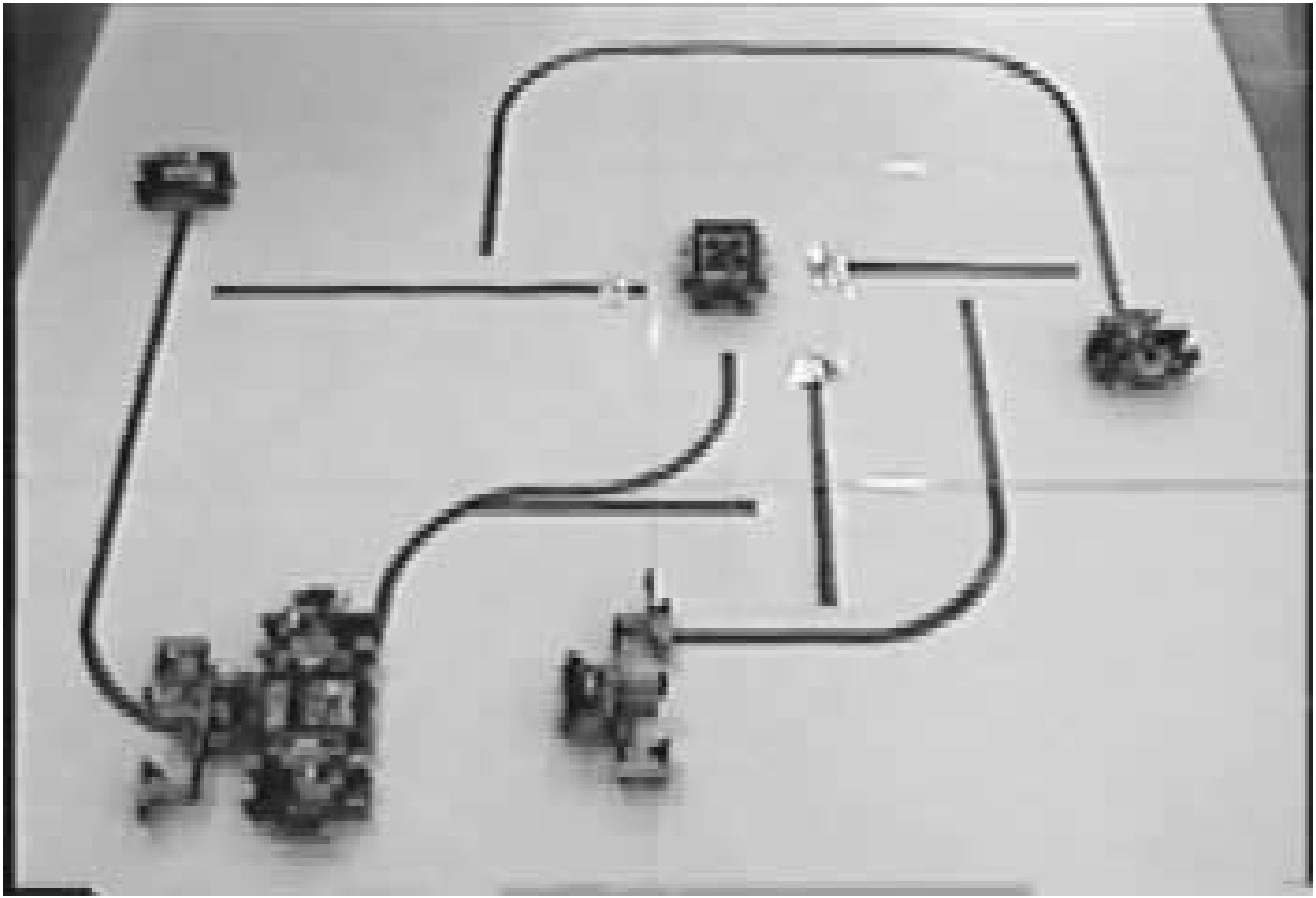
Solar Energy Production:
D. Criswell (1975 -present); P. Glaser (1975-present); G. Landis, A. Ignatiev (2000-2002)

Lunar Materials Processing and ISRU:
G. K. O'Neill (1975-1985); I. Bekey (1980); R. Zubrin (1995); et al

Electromagnetic Launchers:
E.F. Northrup (1937); A. C. Clark (1950):
G. K. O'Neill (1975-1985) ; H. Kolm (1977)

A Remote Controlled Design (Video)

A Fully Autonomous SRR (Video)



How to Make Computers and Actuators from Moon Dust ?

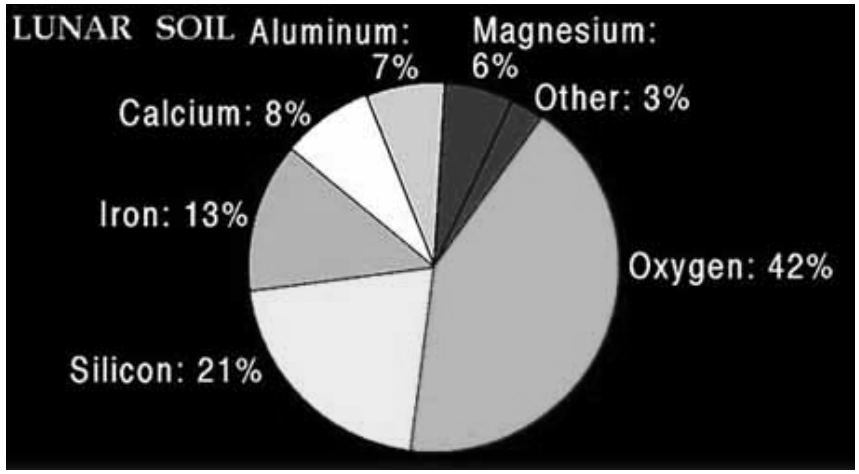
If we can separate insulating from conducting and ferrous from nonferrous materials then we can make coils and iron cores.

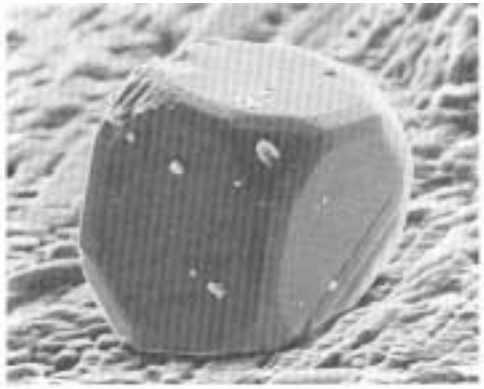
If we can make coils and cores, we can make electromagnets

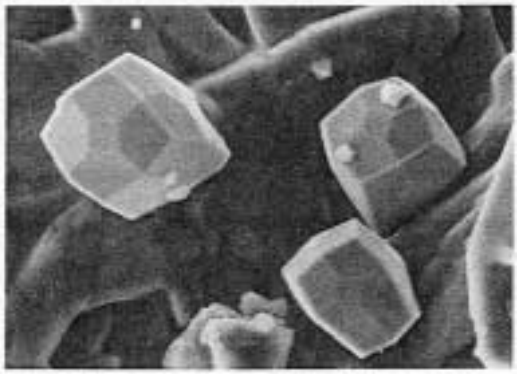
If we can make electromagnets, we can make relays and actuators

Lunar Sample Studies

Insulating oxides represent bulk of regolith with 0.1-1 percent metalic iron crystals

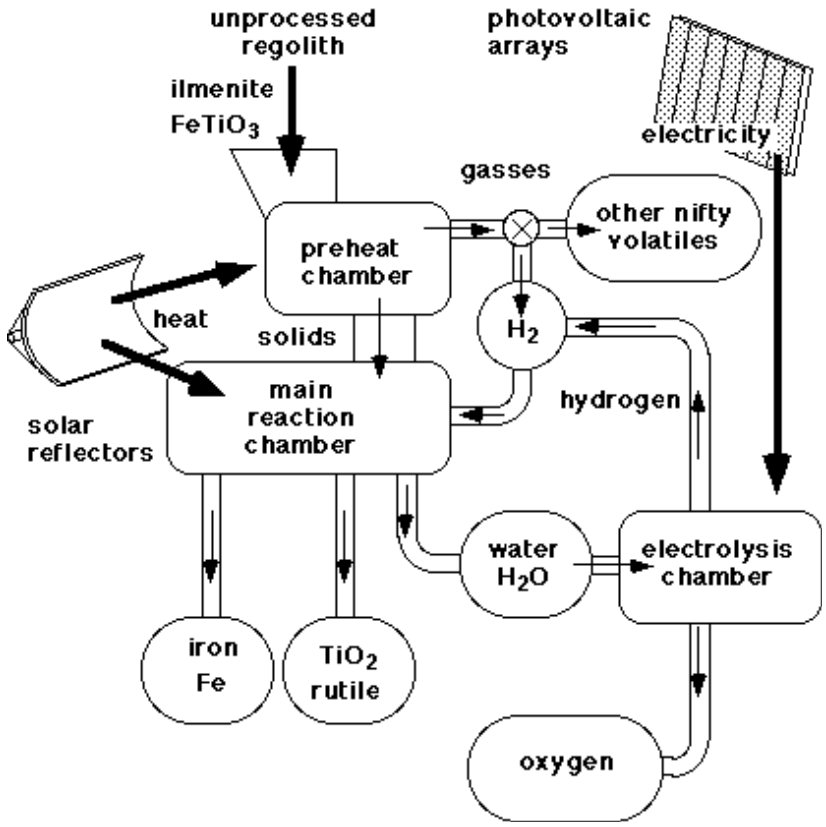






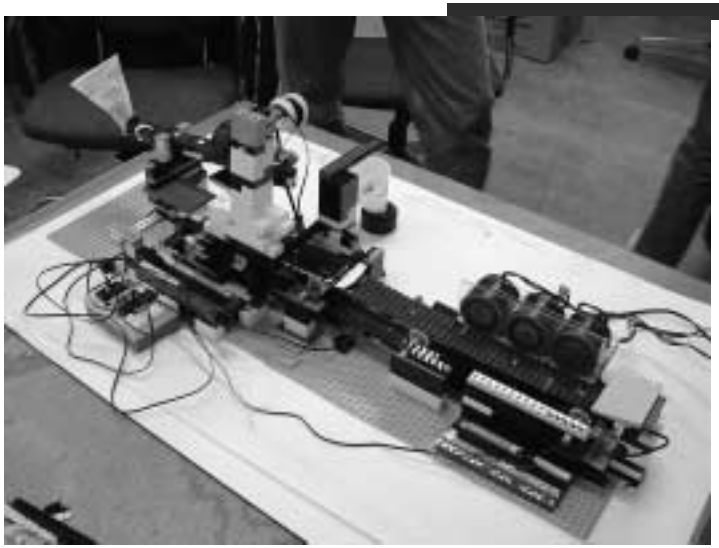
Reprinted from: (left) www.ssi.org and www.crystalinks.com/lunarmining.html; (right) Dr. J. Lindsay, with permission

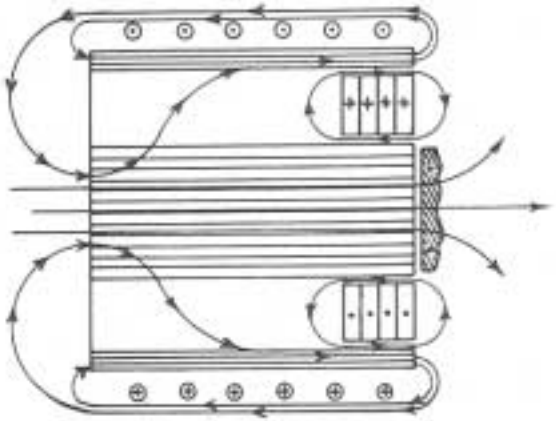
Lunar Materials Processing Strategies Proposed by Others

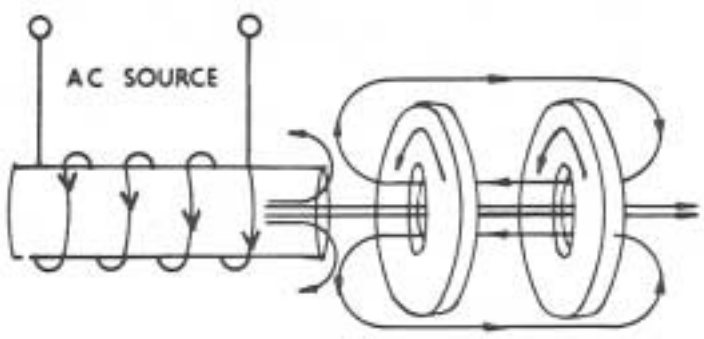


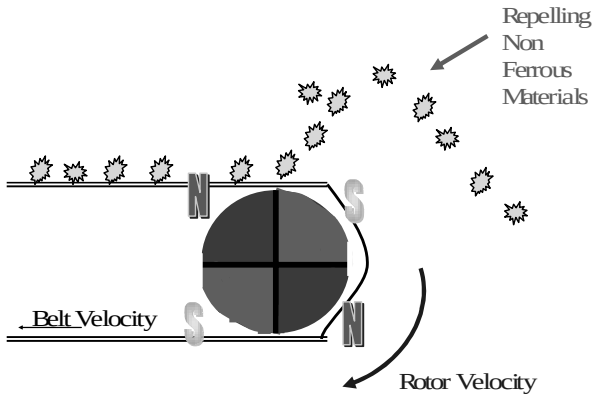
Project Artemis: www.asi.org

Our Minimalist Strategy for Lunar Materials Separation



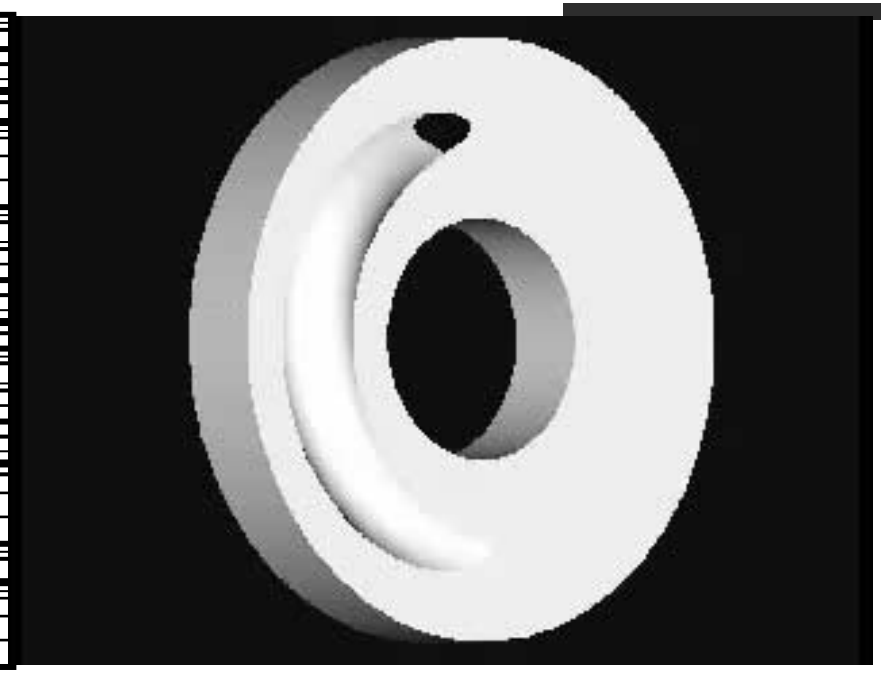






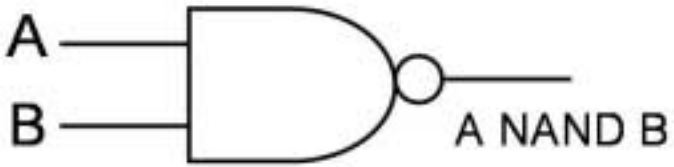
Lower left and upper right from: L.R. Crow, Design, Construction and Operating Principles of Electromagnets for Attracting Copper, Aluminum and Other Non-Ferrous Metals, 1951 (reprinted with permission of Benjamin Fleming)

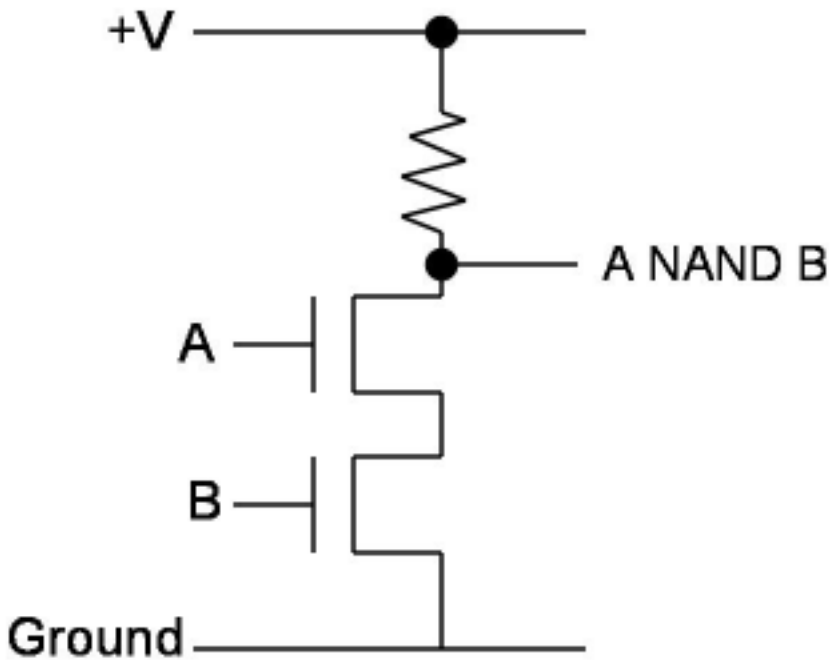
Demonstration of a Coil Made from Castings (Video)



From Coils to Computing Elements

A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0



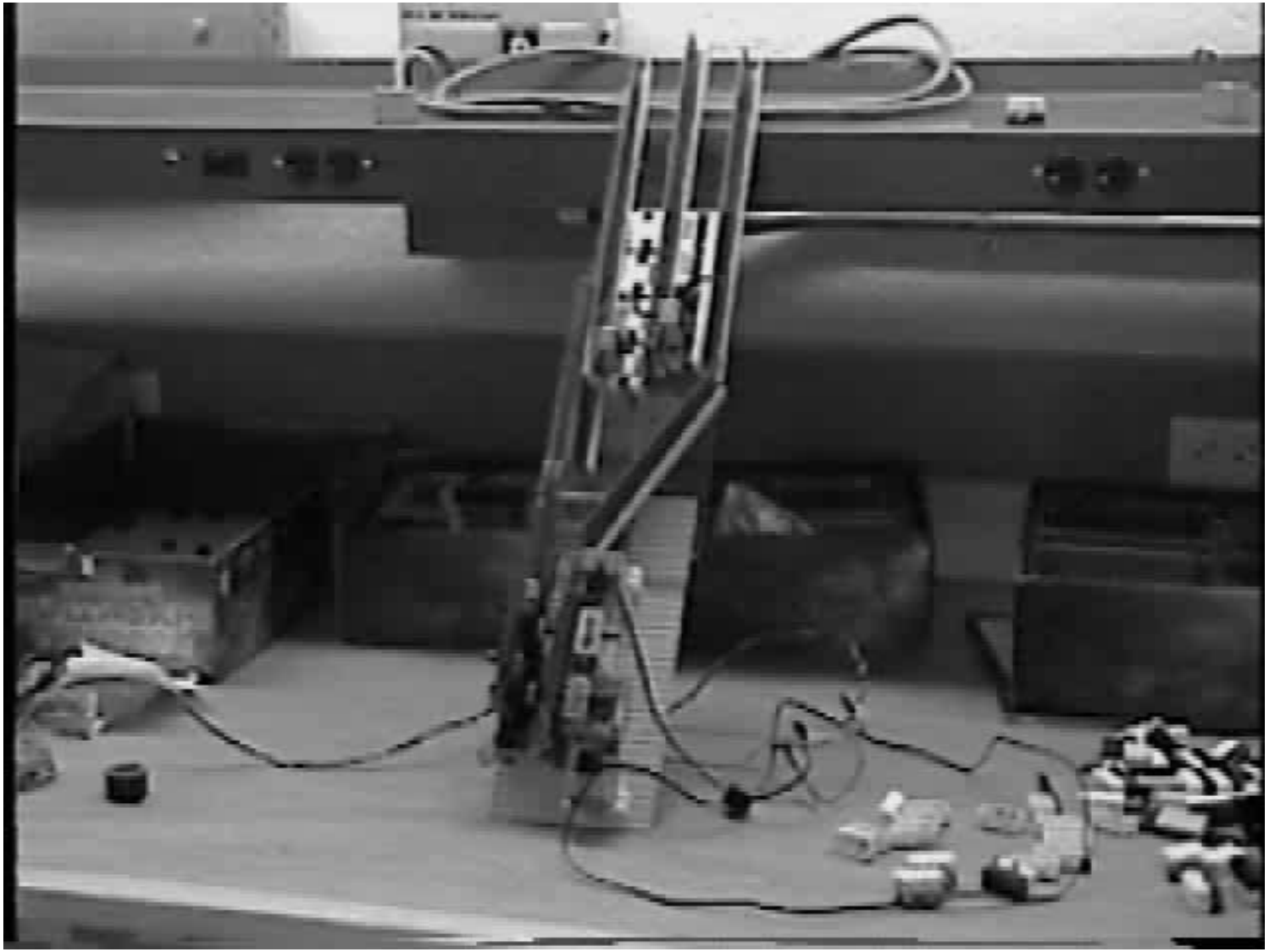


Computers that Copy Themselves

To make computers in situ from logic elements using a von Neumann Universal Constructor would require a very complicated code.

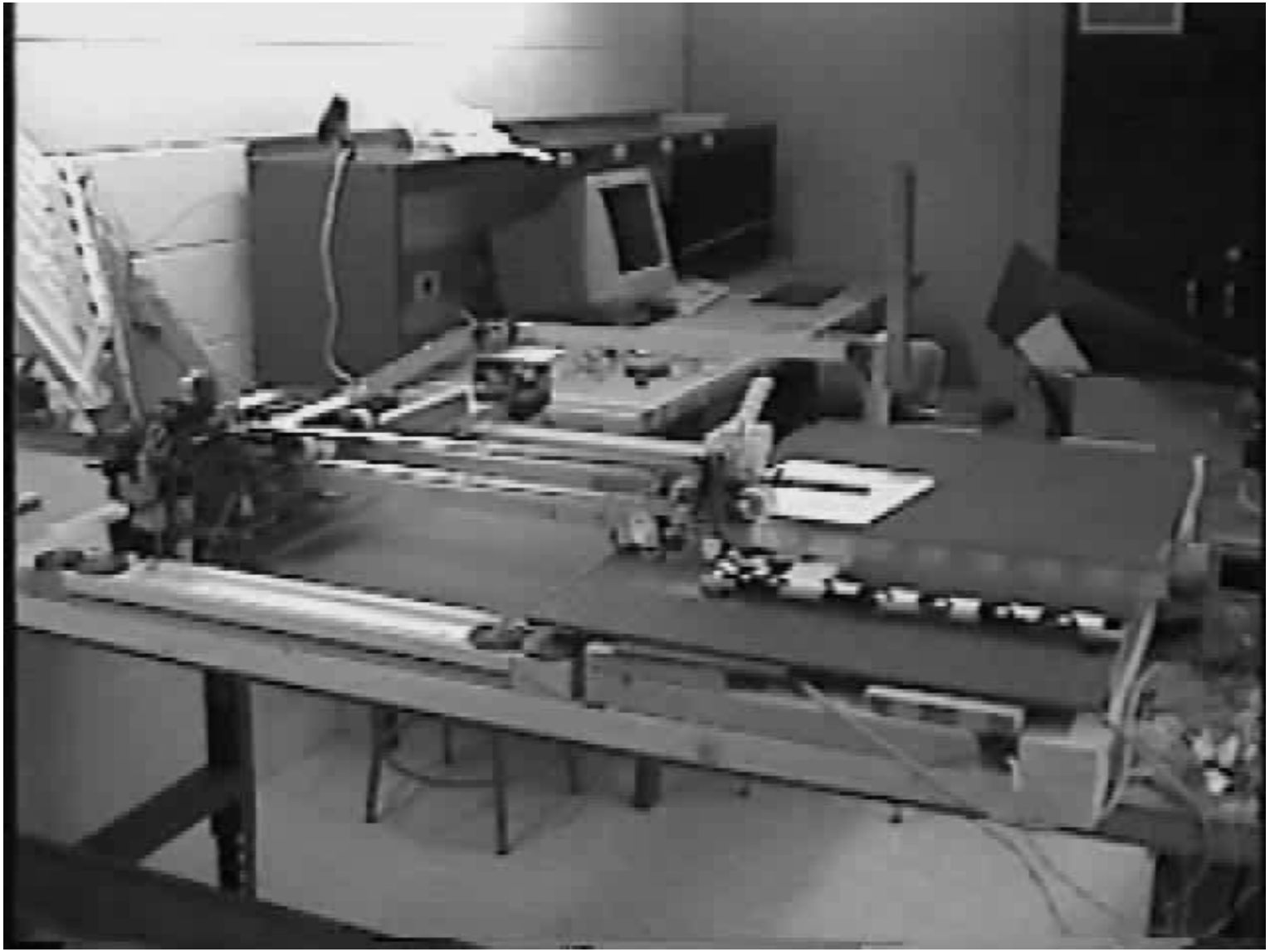
An alternative is Laing's paradigm of self-replication by self-inspection. We developed three prototypes to demonstrate this idea physically for the first time.

Self-Replication by Self-Inspection 1 (Video)



Self-Replication by Self-Inspection 2 (Video)

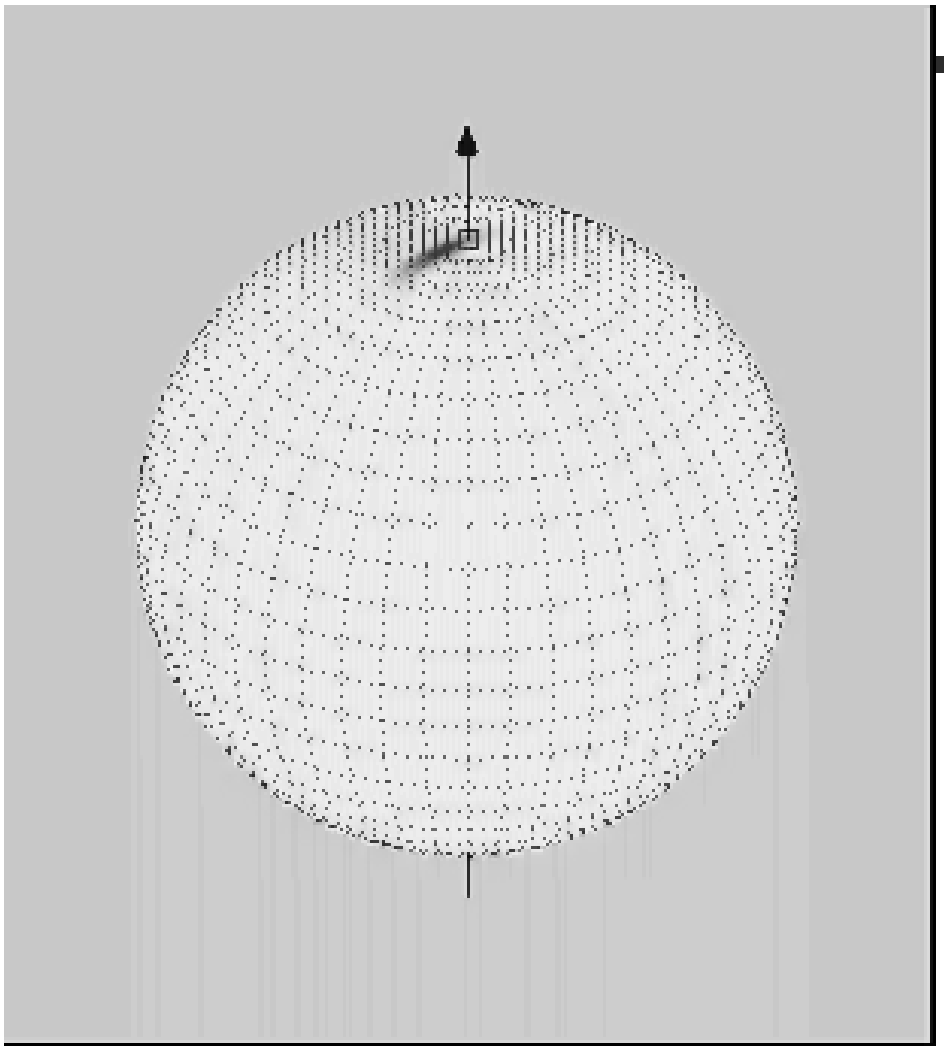
Self-Replication by Self-Inspection 3 (Video)



Discussion of Phase I Prototypes

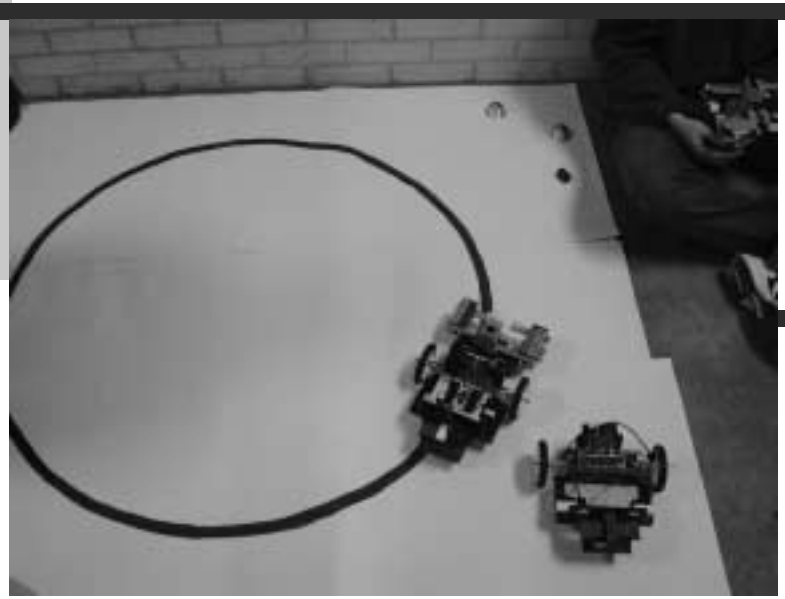
- These ``toy'' models are an inexpensive way to explore principles of robotic self-replication at several levels
- By making self-replication the topic of my course with 25+ students each Spring, opportunities for massively parallel prototype development exist.
- Robotic assembly of subsystems to form an exact replica of the robot is the first step.
- Developing autonomous SRRs that function in less structured environments (and act on a more elemental set of parts) is a challenging task for Phase II.

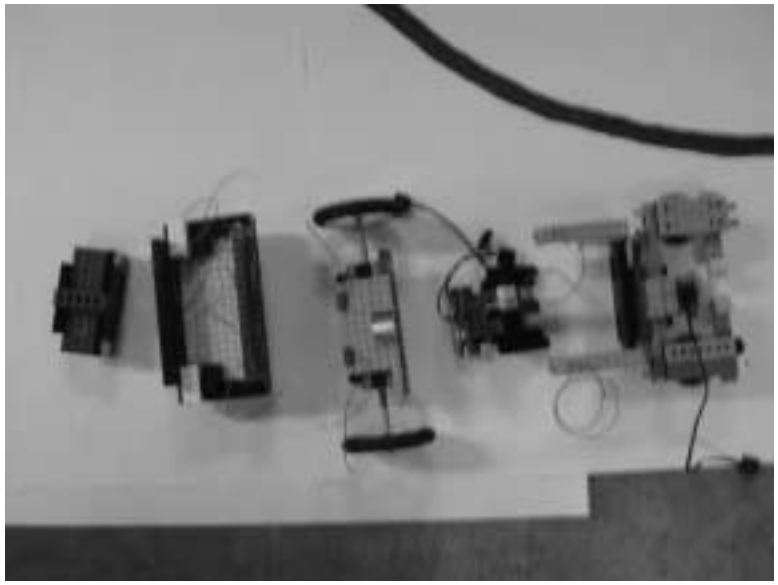
Initial Computer Model of Proliferation of Lunar Factories (Video Simulation)

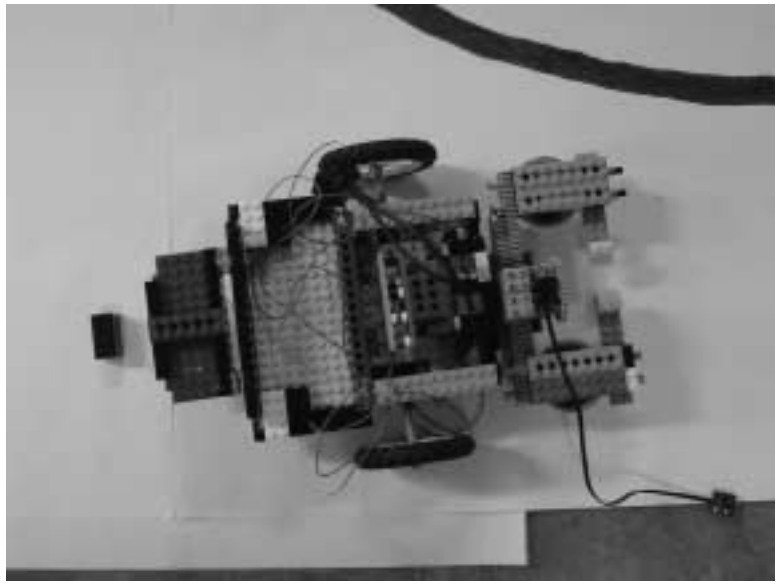


Summary of Phase I

- In this presentation we provided descriptions of concrete self-replicating robotic system designs that were implemented in LEGO Mindstorm kits by our students.
- We performed a survey and feasibility study of in-situ materials processing, energy production and electromagnetic propulsion devices.
- We also developed a minimalist strategy for ISRU and designed and built functional prototypes that illustrate materials separation and a concrete strategy for coil production in situ
- The study of self-replicating robots (SSRs) is an interesting research area of potentially high impact which has not been extensively pursued in recent years.
- SRRs are an essential subsystem in making self-replicating lunar factories (and hence large-scale ISRU) feasible



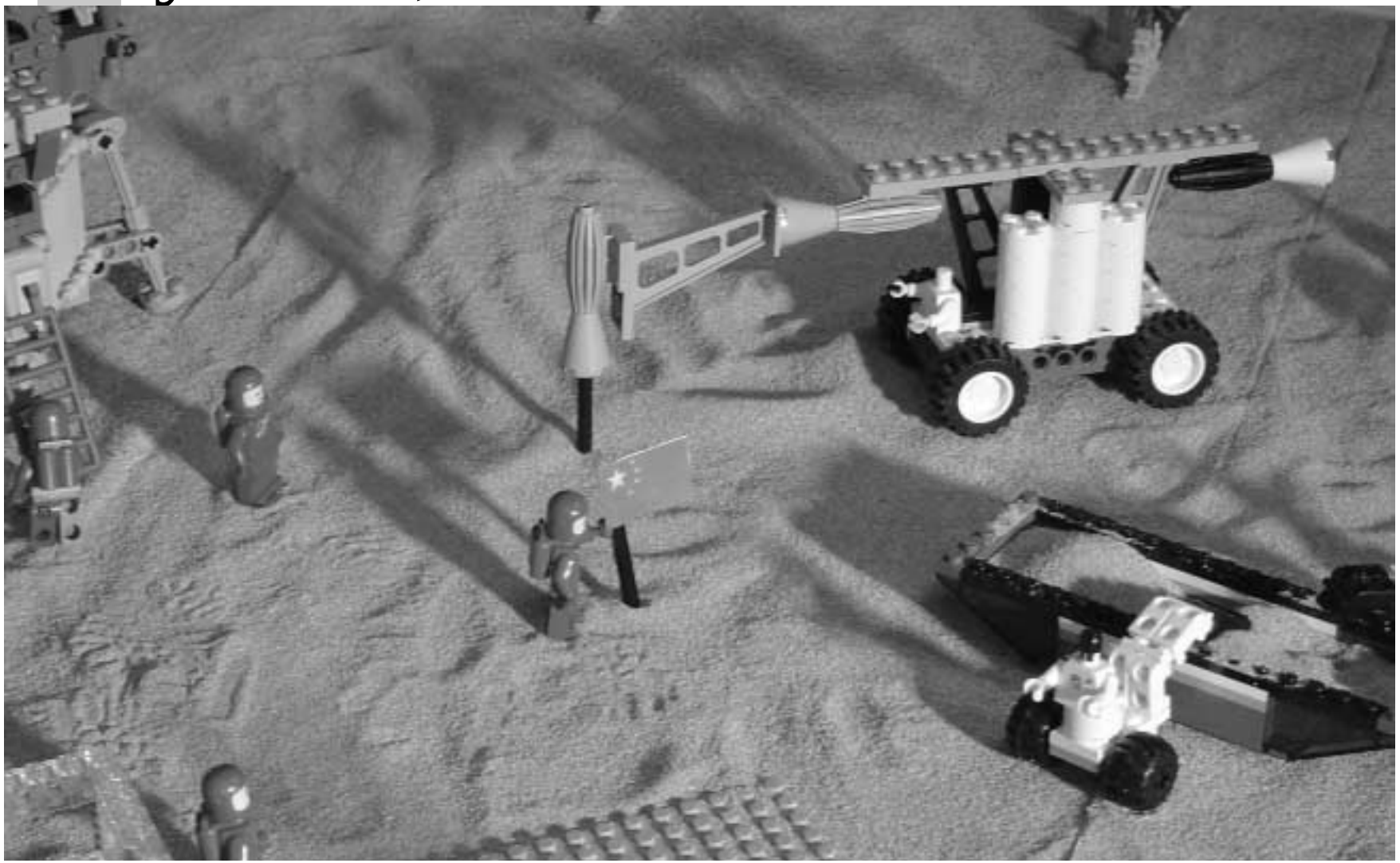




Phase II Objectives

- Build a scale model of a self-replicating factory which produces plastic parts, assembles those parts into subsystems, and assembles the subsystems into a fully functional replica of the model factory.
- Demonstrate materials separation technologies and robotic construction of coils from lunar simulant.
- Analyze minimalist energy generation and storage technologies (radiometers, flywheels)
- Integrate these ideas with new NASA objectives.

Acknowledgements

- The three conference papers that resulted from this work were written by graduate students Whitney Hastings, Jin Seob Kim and Jackrit Suthakorn
- Movies and pictures were edited by graduate students Y. Liu and G. Kaloutsakis
- Prototypes developed by 25+ undergraduates
- Initial concepts explored prior to phase I under a RIACS Summer Visit (thanks to Dr. Serdar Uckin)

We Should Develop Self-Replicating Systems, or Someone Else Will