GENERAL DYNAMICS
Advanced Information Systems

NIAC
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Indirectly-Replicating NanoMachines: A Kinematic Cellular Automata Approach

NASA Institute for Advanced Concepts
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First Conference on Advanced Nanotechnology:
Research, Applications, and Policy

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Rationale

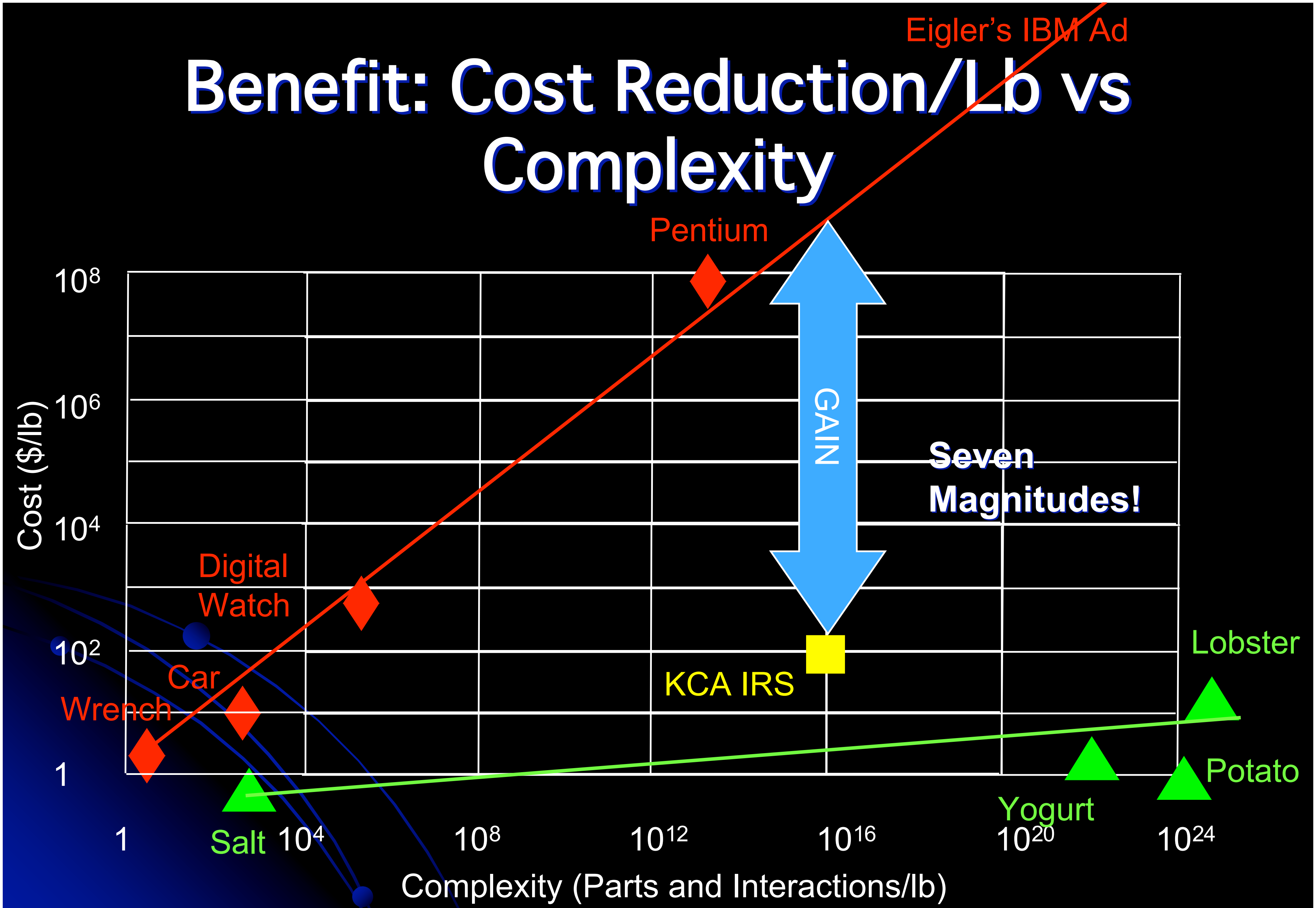
- Why Replication?
  - Revolutionary manufacturing process
  - Nanotechnology
  - Massive reduction in costs per pound
- Why Indirect Replication?
  - Easier to implement
  - Easier to control
- Why not Self-Assembly?
  - **Not “Genotype + Ribotype = Phenotype” (GRP)**
  - **No theory**
  - **Against the principles of sound design**

However, probably useful for simple input parts

Rationale: Why Kinematic Cellular Automata (KCA)?

- Combines Von Neumann’s two designs
- Hierarchical, standard Turing Equivalent
- Indirect replication
- Increased flexibility
- Decreased complexity
- Large system work envelope
- More capabilities than smart dust
- Both macro and nano scale

Benefit: Cost Reduction/Lb vs Complexity

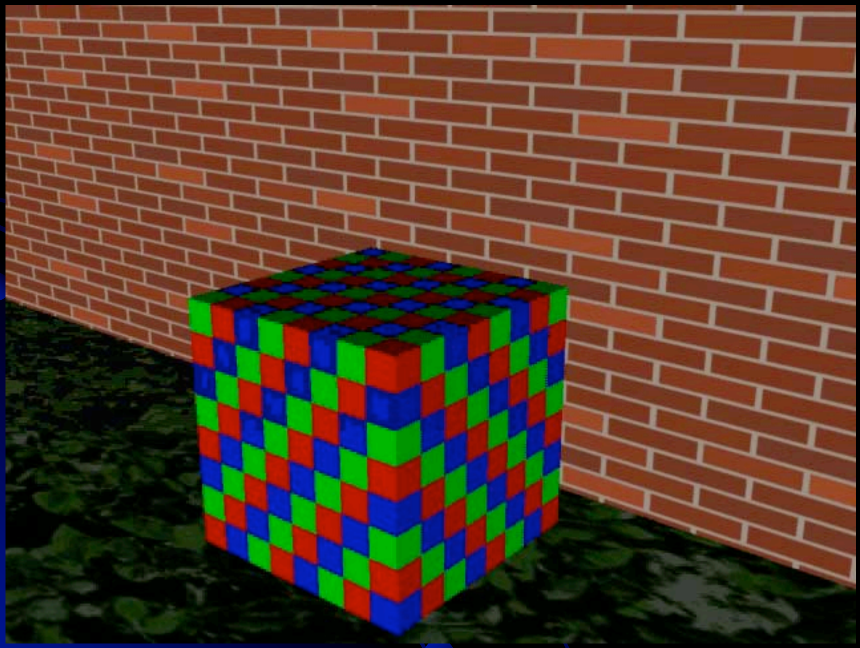


Traditional Top Down Manufacturing vs Bottom-up Molecular Replication

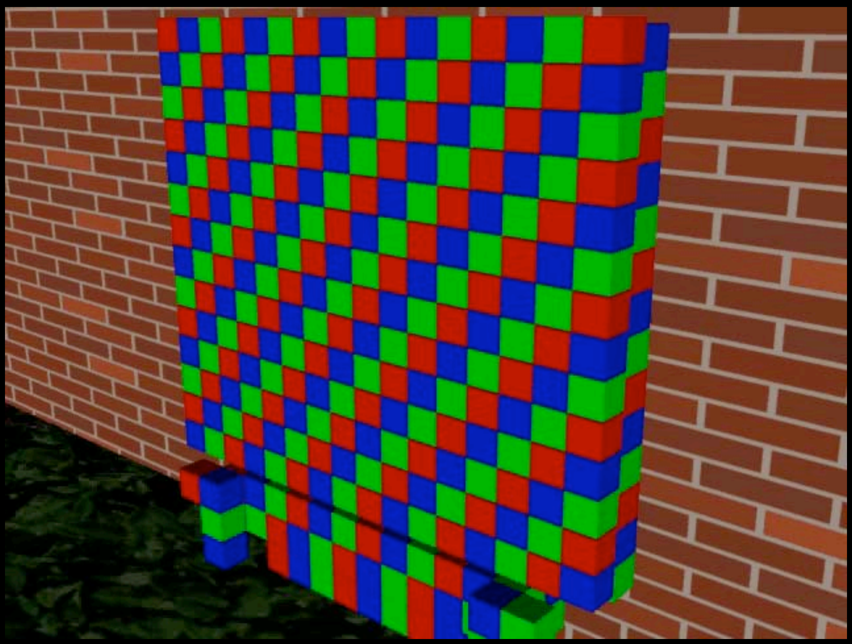
Benefit: Programmable Materials

Simple identical modules

- Flow Mode
- Pixelated Mode
- Logic Processing Mode



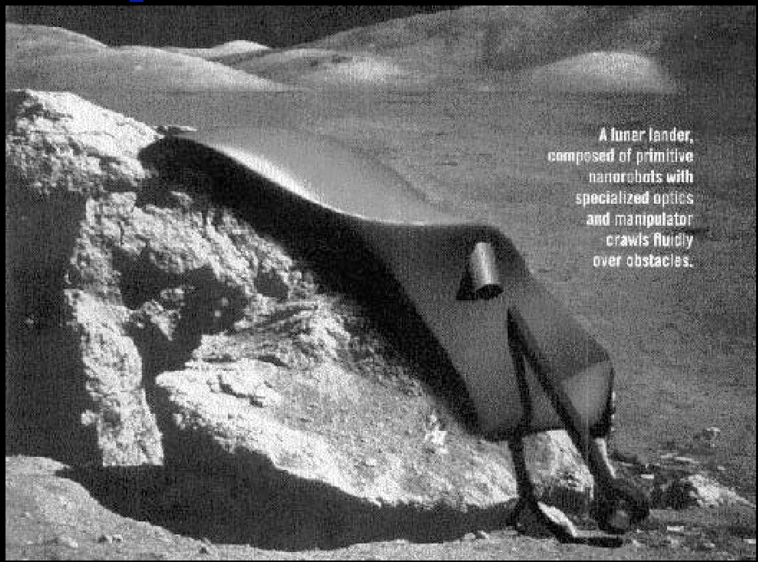
Flow Mode



Pixelated Mode

Application: Space

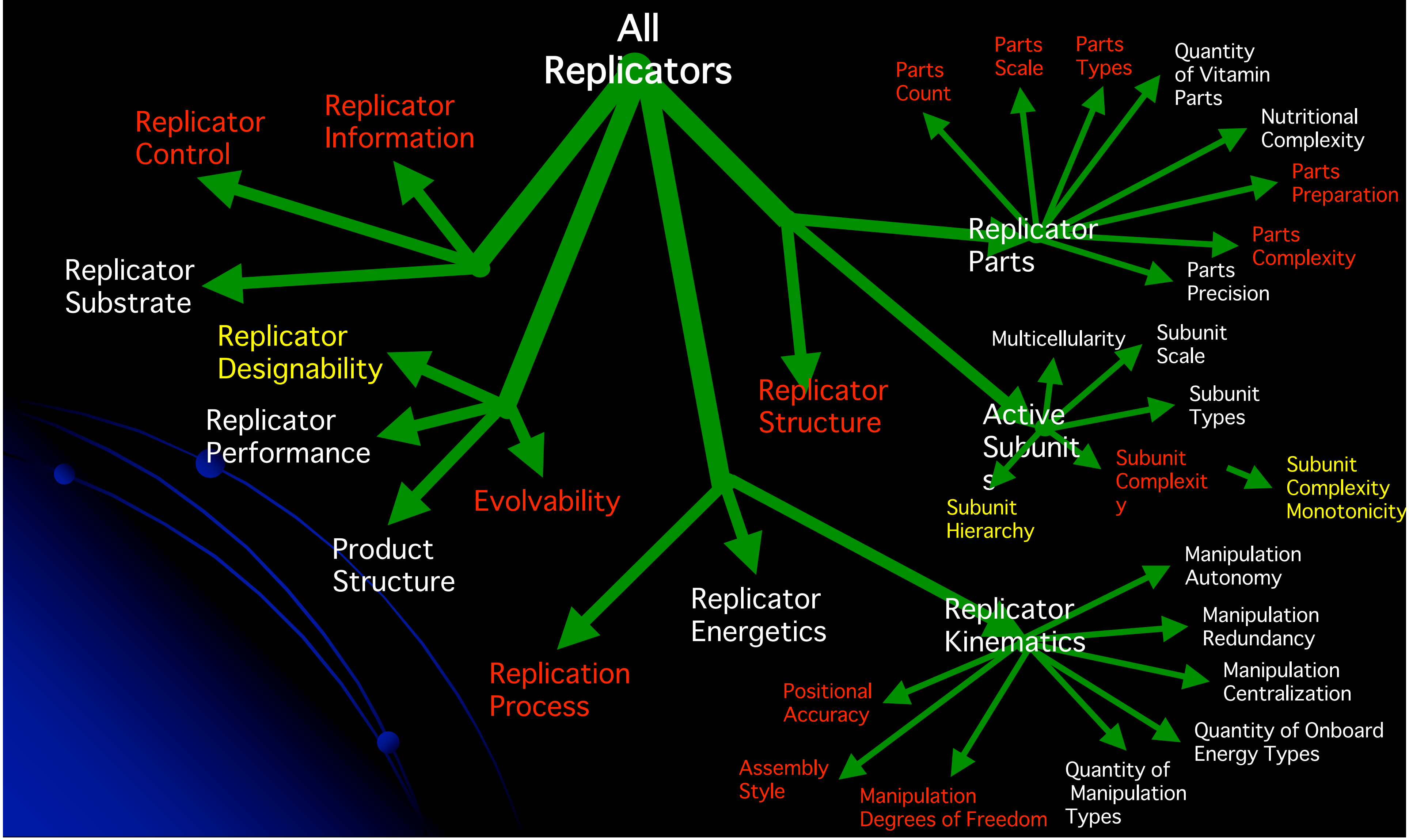
- Exploration
  - Robust
  - Hyperflexible
- Base Expansion
  - Lower launch weight
  - Resource utilization
- Terraforming
  - Politically feasible
  - Opens new frontier



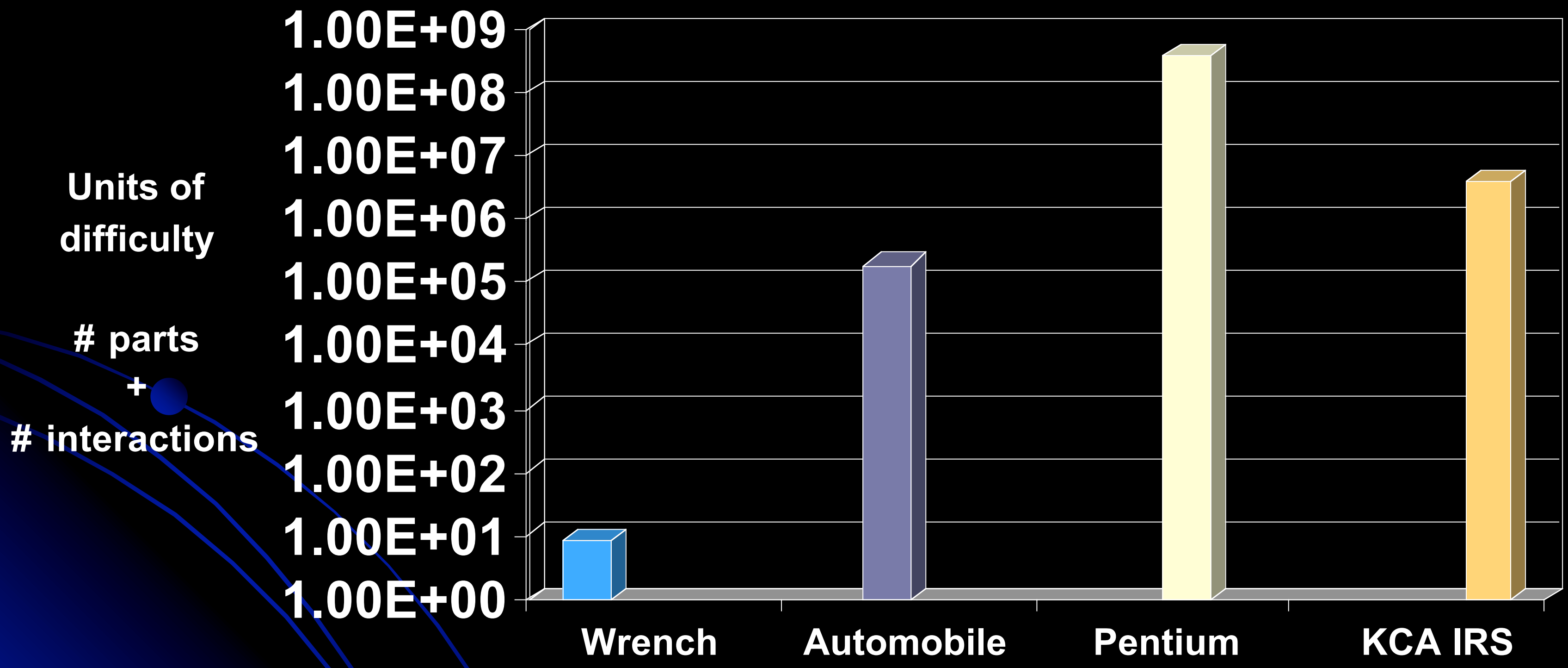
Accomplishments

Goals	Accomplishments
Characterize unexplored area	Explored Multi-Dimensional Space
Quantify the difficulty	Not trivial, but less than a Pentium
Confirm or refute approach	**Refined Approach** • Useful IRS • Developed Hierarchy of Subsystems, Cells, Facets, & Parts • Transporter, Assembler, & Controller • Low-level simpler than high-level • Top-Down vs Bottom-Up • Self-Assembly for input Parts • Standard concepts • Universal Constructor is approach, not goal
Design a KCA IRS	**Developed Requirements** **Preliminary Design**
Simulate designs	**Modeled Simulations** • Sensor Position • NAND gate and op-amp self-assembly • Facet • Transporter and Assembler

Characterizing Replication: Adjusting the Freitas/Merkle 116-Dimension Design Space



Quantifying Difficulty of IRS Design



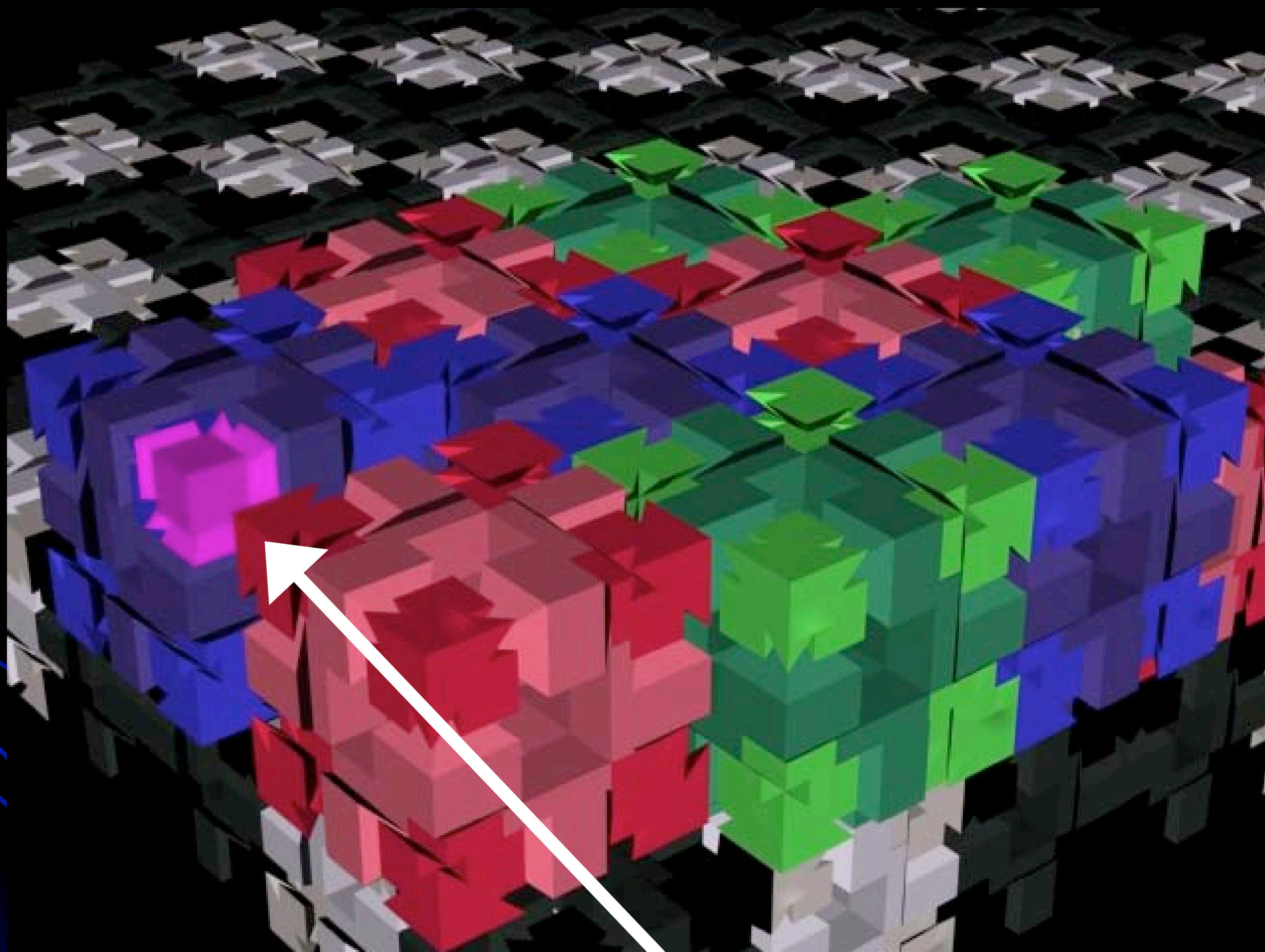
Hierarchy

Biology	KCA IRS	Computer
Horse	**Replicating System:** Useful	Processor
Brain and Muscles	**Subsystems:** Transporter, Connector, and Controller	Bus/Memory, ALU, and Controller
Cells	**Cells:** Cubic devices with only three limited degrees of freedom	Finite State Machines, Shift Registers, Adders, and Multiplexers
Organelles	**Facets:** Symmetrical implementation	
Proteins	**Parts:** Inert, Simpler than higher levels	NAND gates
Genes	**Self-assembling Subparts:** Wires, Transistors, Actuators	Transistors, Wires
Molecules	Molecules	Molecules

The Bottom-up Hierarchical Approach:
The essential problem in replication

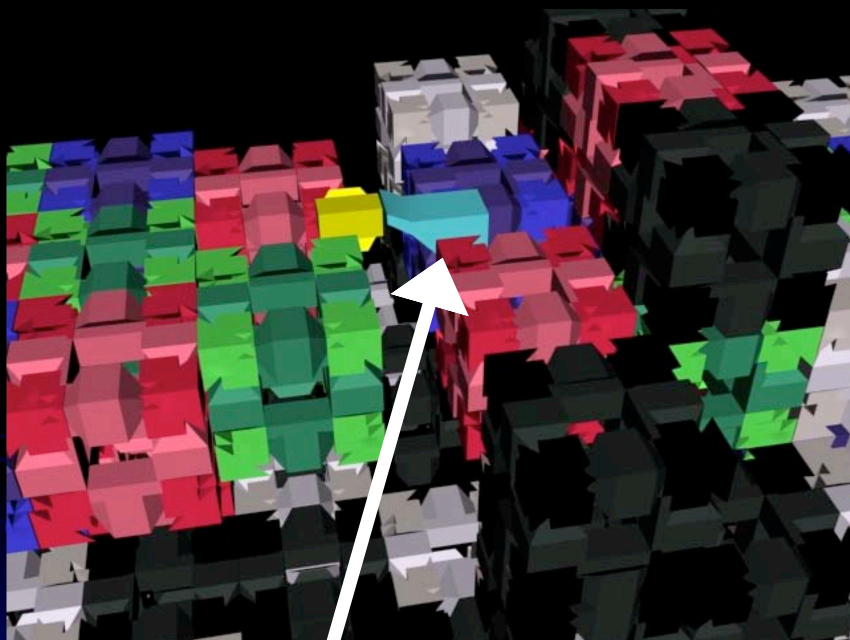
- Well-ordered environment,
- Simple inert *parts*
- Symmetric *facets*
- Modular *cells*
- Transporter, Connector, and Controller *subsystems*
- Indirectly-Replicating *System*

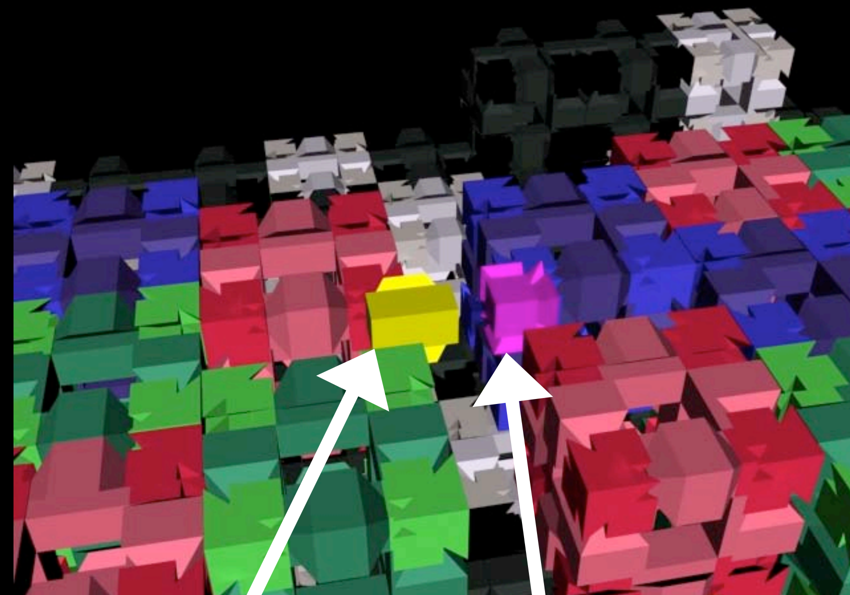
Transporter Subsystem



(pink corner structural part)

Connector Subsystem



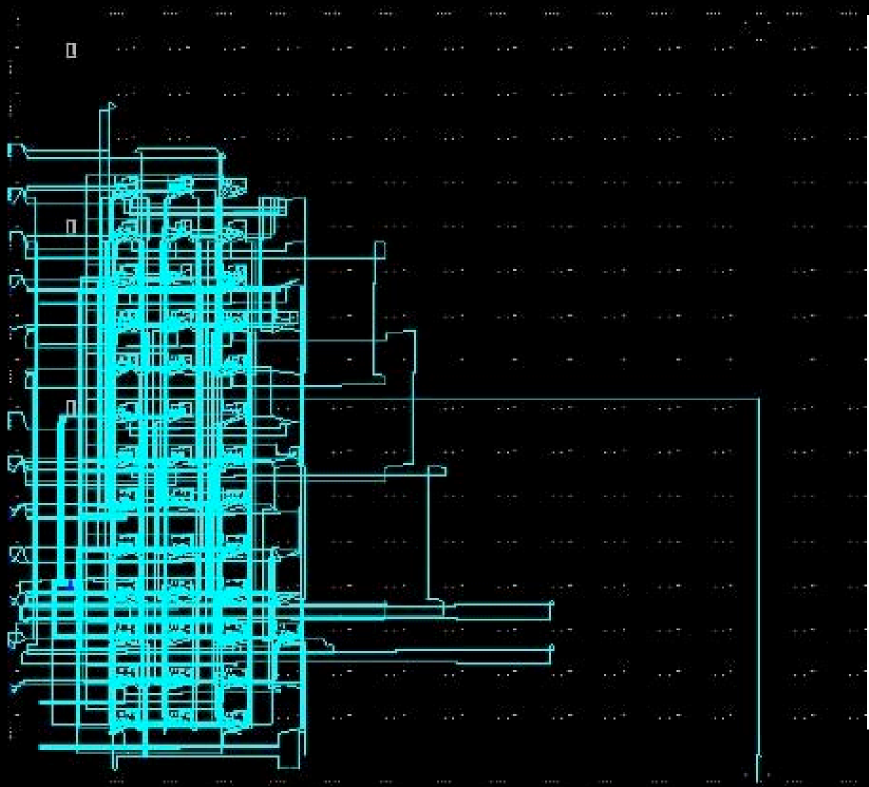


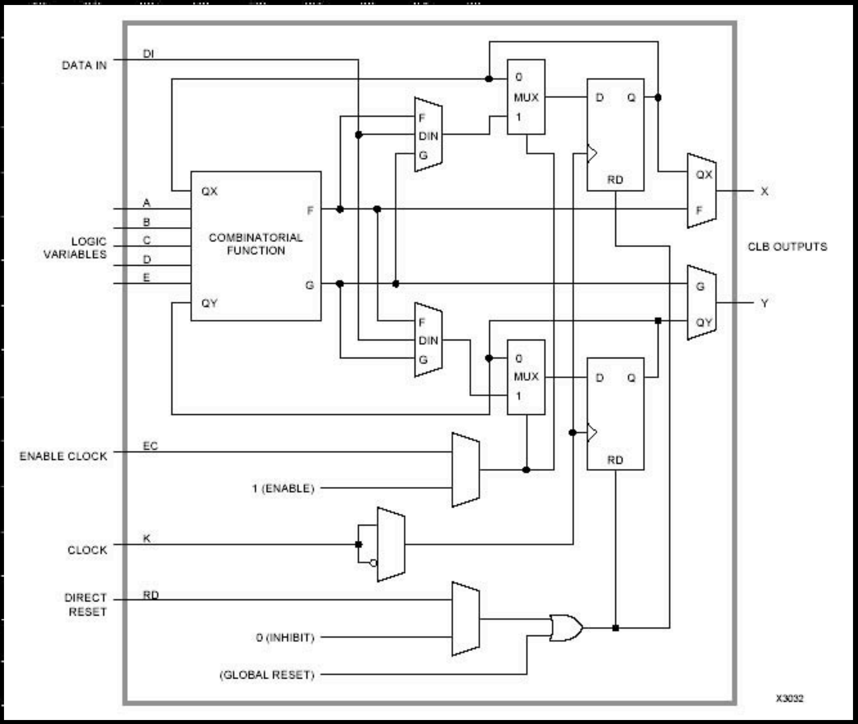
(light blue preparation tool)

(yellow edge structural part)

(pink corner structural part

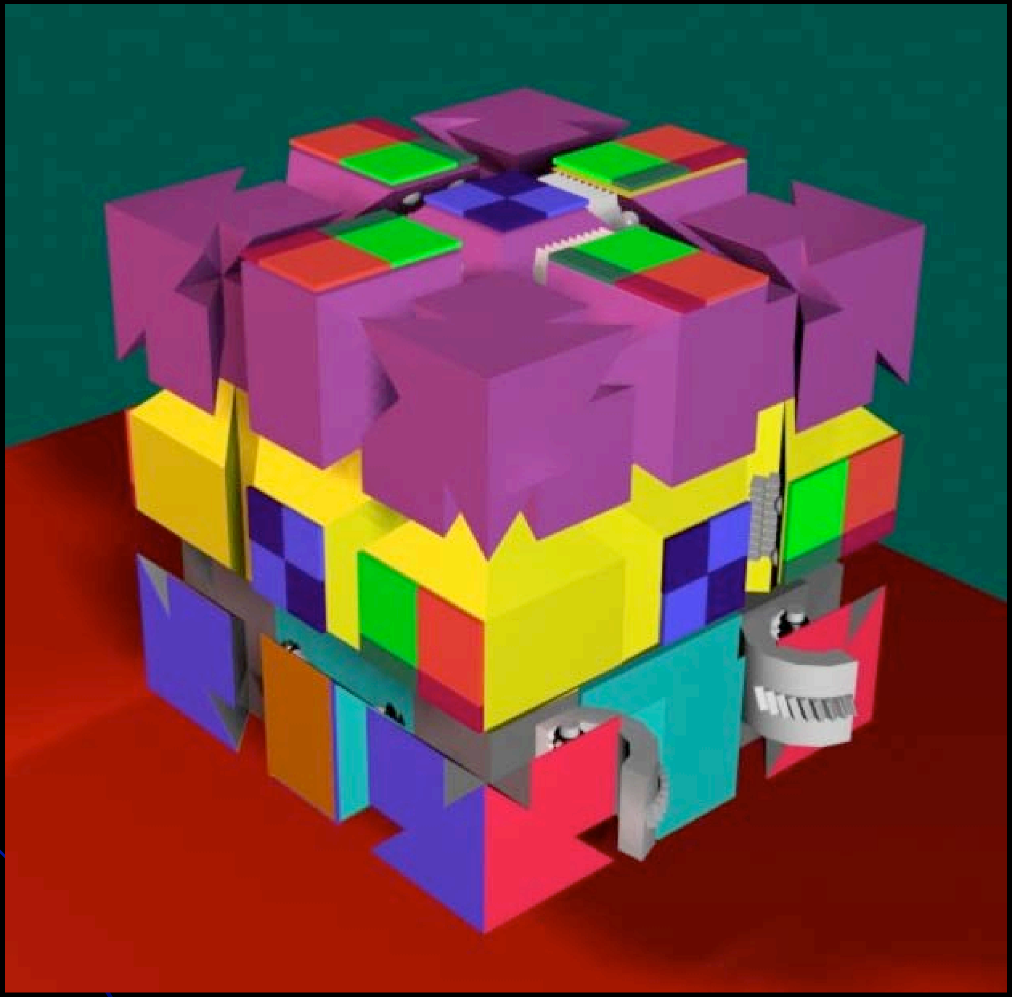
Controller Subsystem





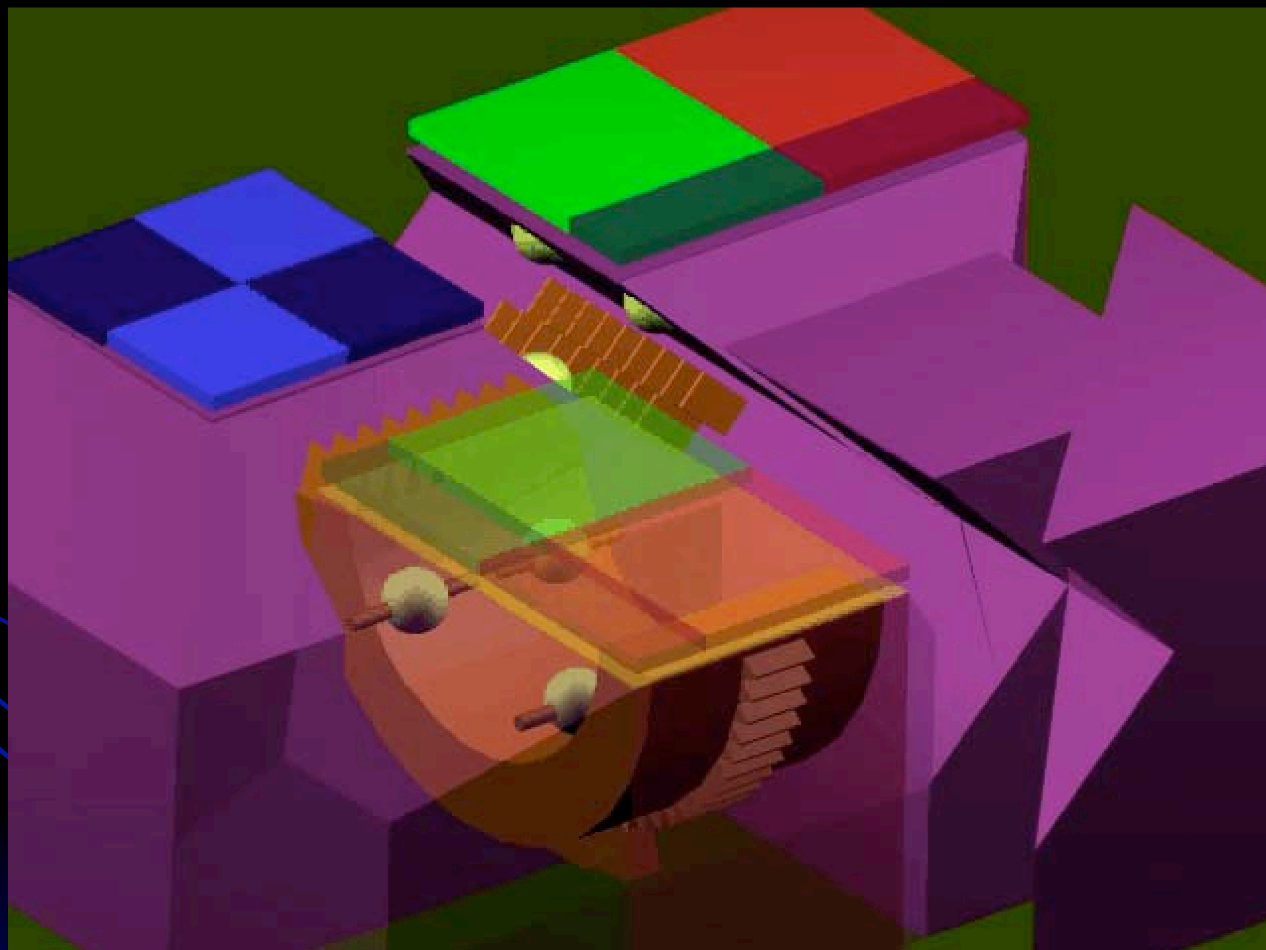
FPGA Editor View of a PicoBlaze Macro in an XC2S50E Spartan-IIE Device

Unit Cell

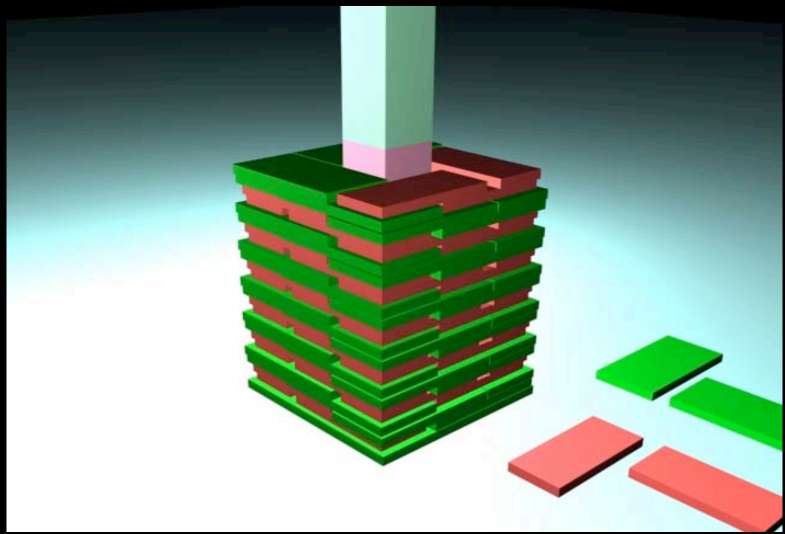


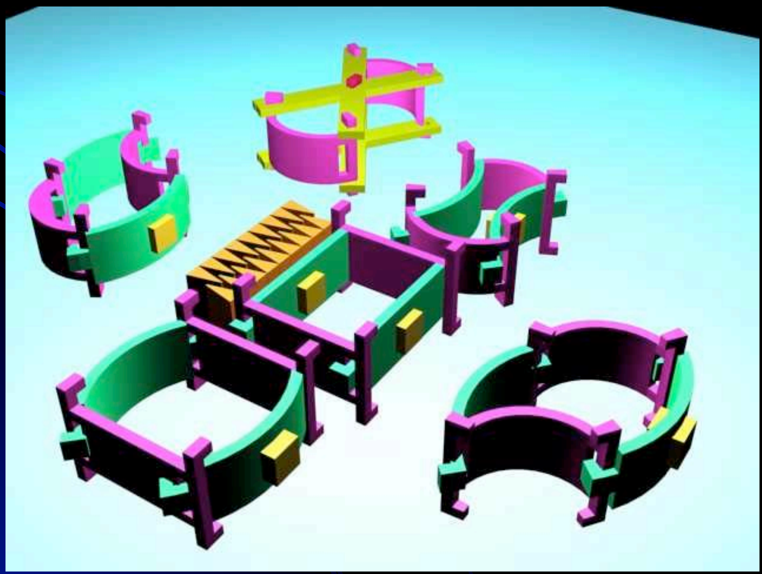
(different styles of tabs, actuators, and sensors shown)

Facet Animation

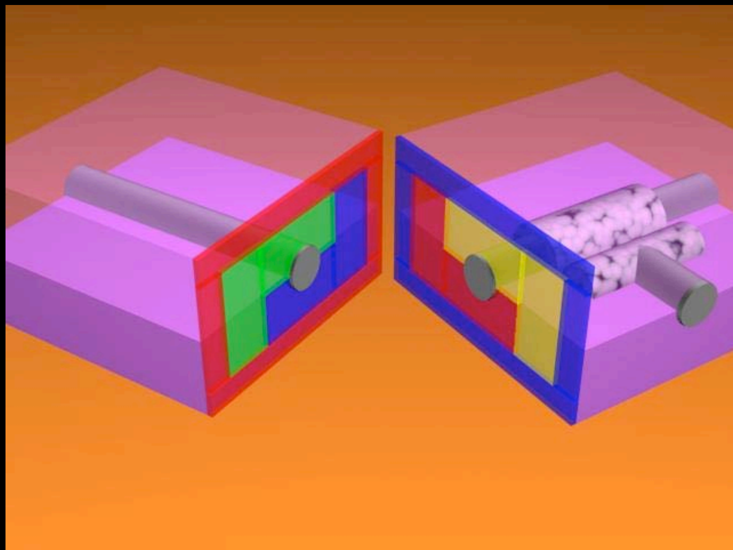


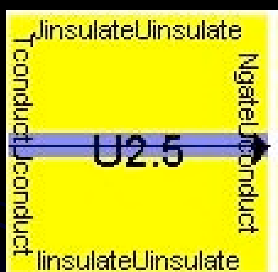
Parts: Structure, Sensors & Actuators

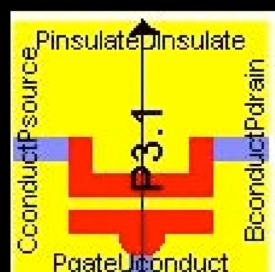


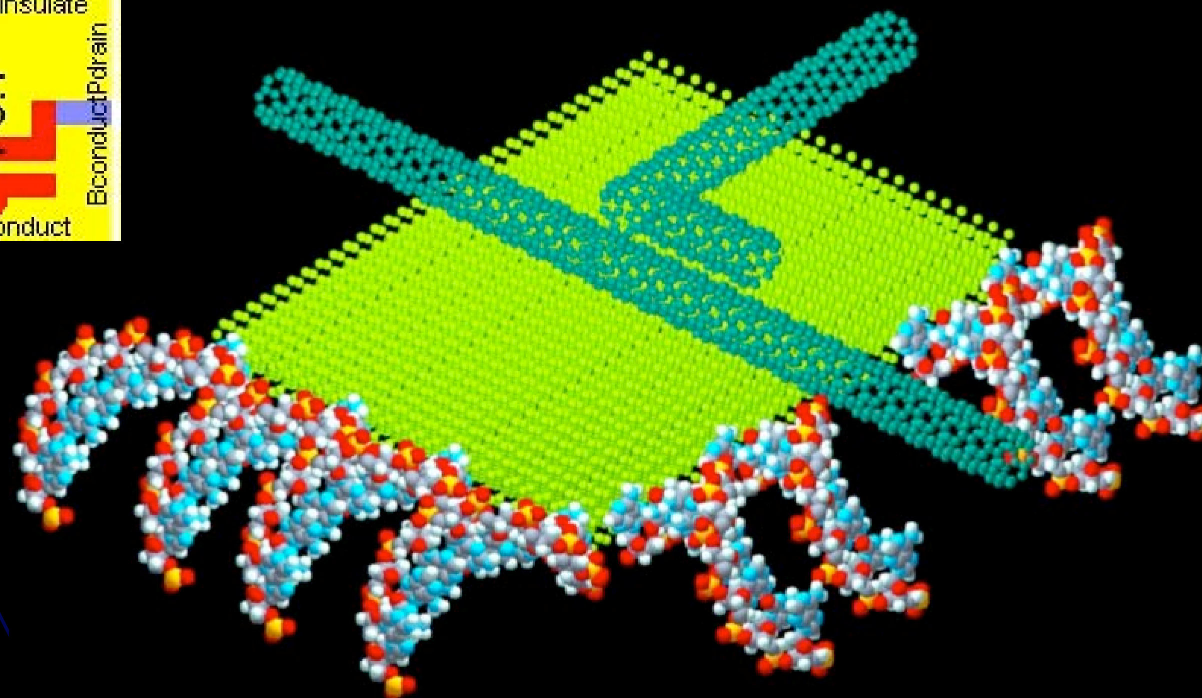


Self-assembling Wang Tiles

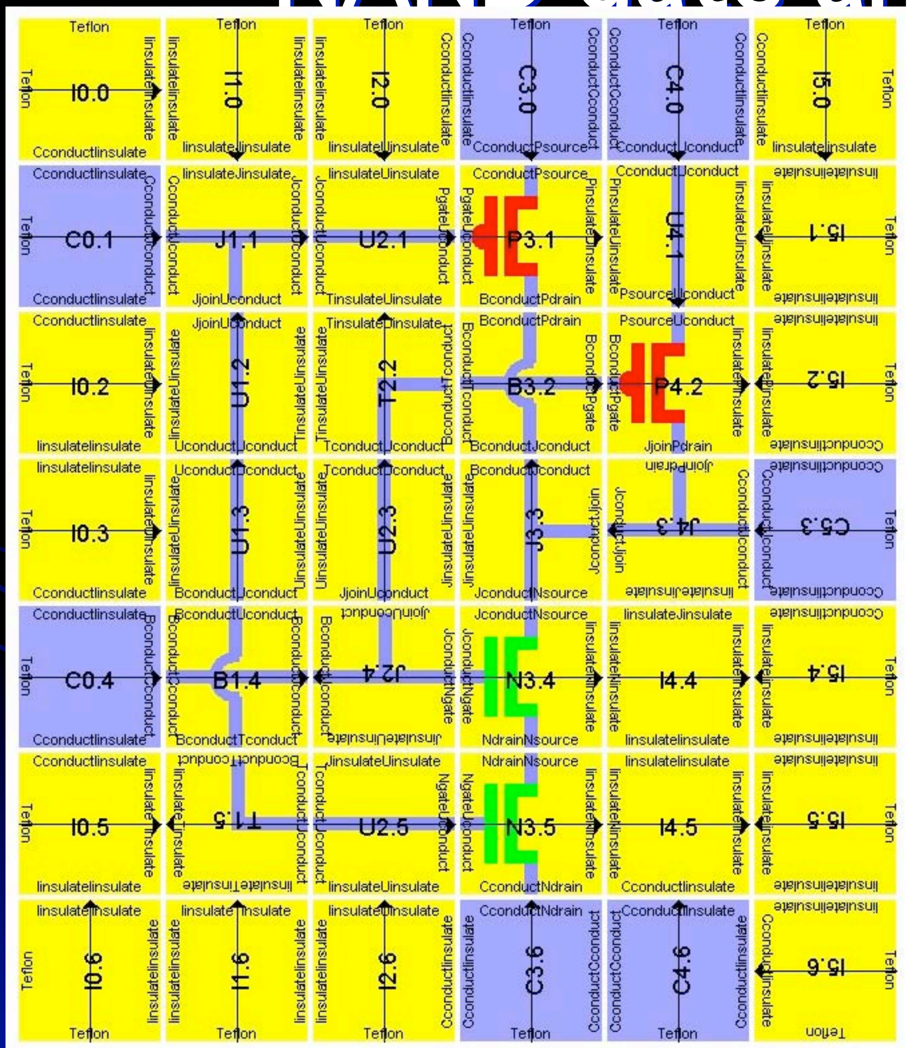


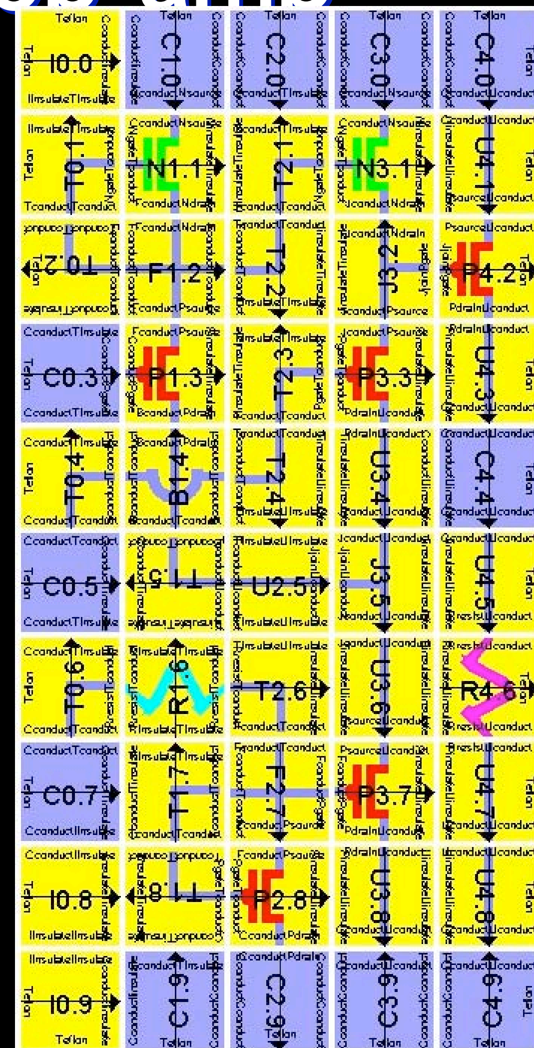




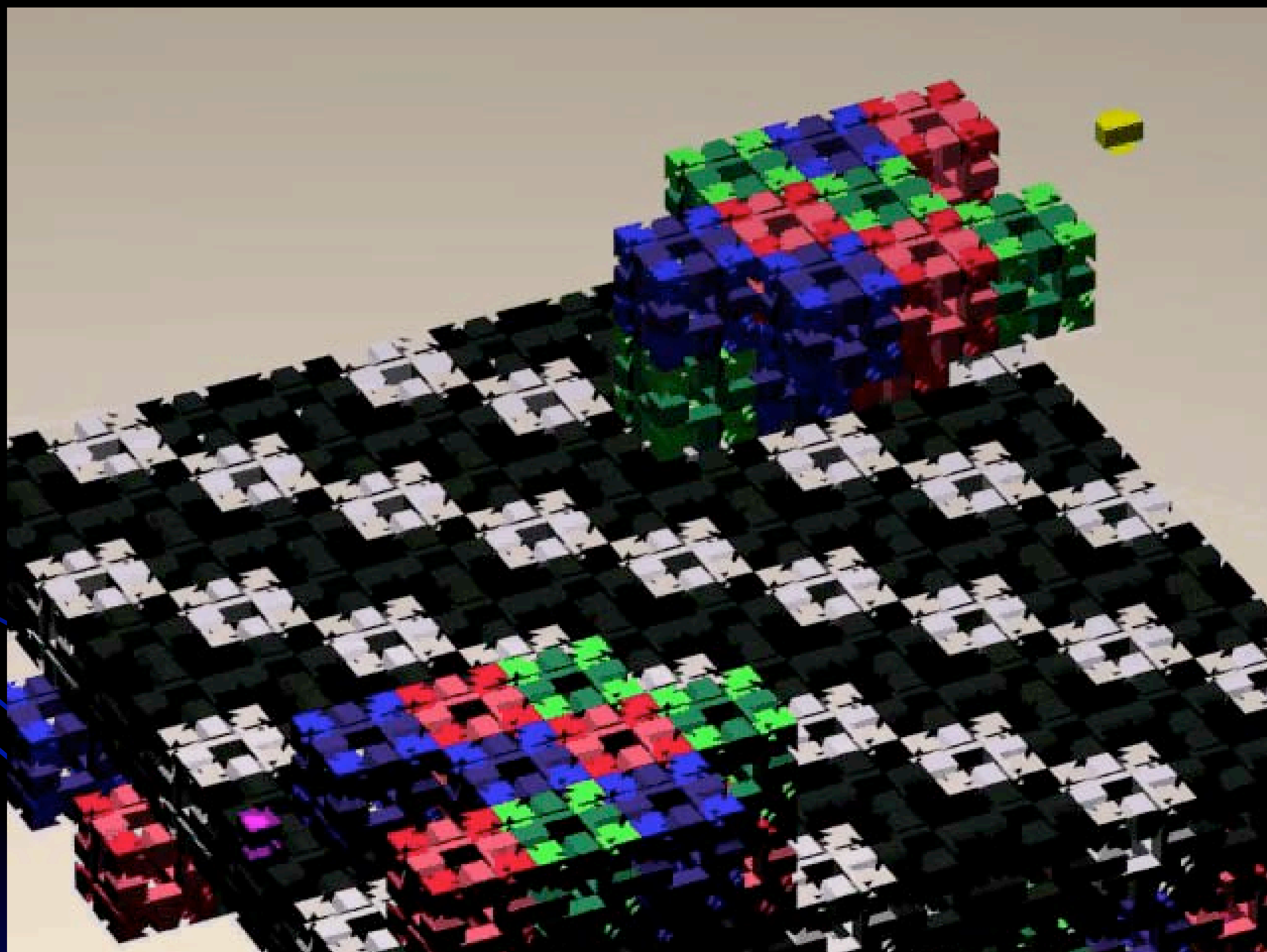


Semi-automated Design of Self-Assembling NAND gate and op-amp





Simulation of Transporter and Connector



Conclusion and Future Directions

No roadblocks!

- Final Design for macro physical prototypes
- Build physical prototypes
- Build and run small cell collections
- Build and run subsystems
- Build macro scale IRS
- Write Place and Route software
- Refine concept at nano scale

Acknowledgements

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