

Bodies, Brains, Amino Acids, Proteins, and Modular Robots

John Rieffel

Rodney Brooks, Again...

- *Single-cell entities arose out of the primordial soup roughly 3.5 billion years ago. A billion years passed before photosynthetic plants appeared. After almost another billion and a half years, around 550 million years ago, the first fish and Vertebrates arrived, and then insects 450 million years ago. Then things started moving fast. Reptiles arrived 370 million years ago, followed by dinosaurs at 330 and mammals at 250 million years ago. The first primates appeared 120 million years ago and the immediate predecessors to the great apes a mere 18 million years ago. Man arrived in roughly his present form 2.5 million years ago.*

*...This suggests that problem solving behavior, language, expert knowledge and application, and reason, **are all pretty simple once the essence of being and reacting are available.** That essence is the ability to move around in a dynamic environment, sensing the surroundings to a degree sufficient to achieve the necessary maintenance of life and reproduction. This part of intelligence is where evolution has concentrated its time it is much harder.*



So What?

- Start Simple
 - get the basics right first
- Co-Evolve
 - can't do it piecemeal
- But...don't things get complicated quickly?

Dealing With Complexity

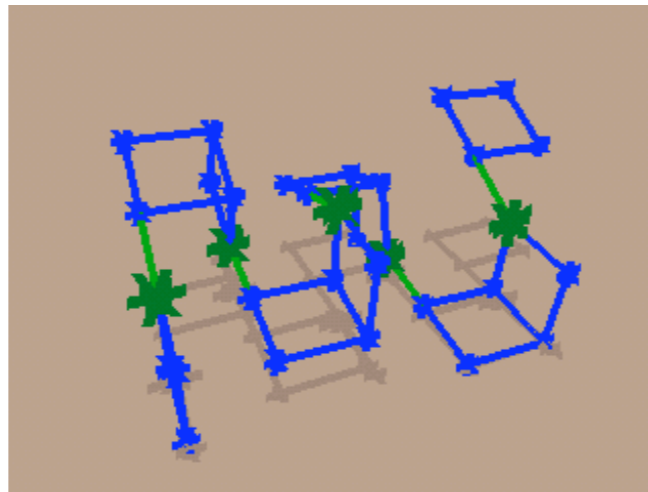
(cs146 primer)

- Hierarchical Composition
- Building Blocks
- (really two sides of the same coin)



The Construction Problem

- Just because you can design it, doesn't mean you can build it!
- Case in point:



The Construction Solution

- Get John to build it
 - (Get Stathis to build it)
- Seriously: Add “smarts” to external builder
 - Use Scaffolding
 - Better Physics Simulator
 - Or...



Chasing The Daemon

- Get rid of an external constructor entirely!
- i.e. Self Assembly

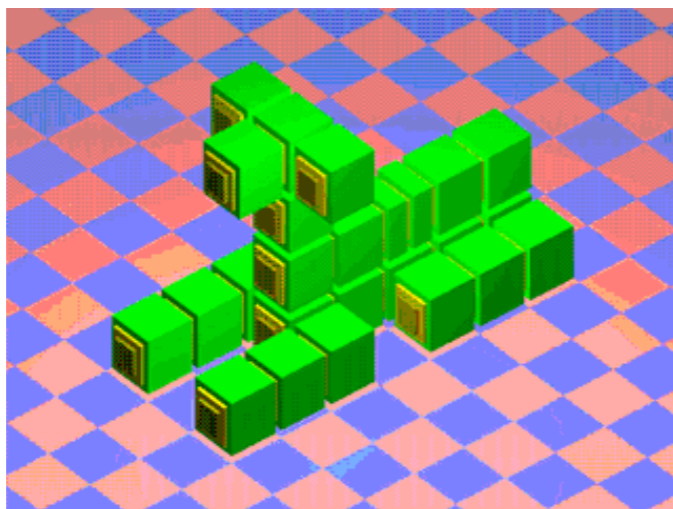
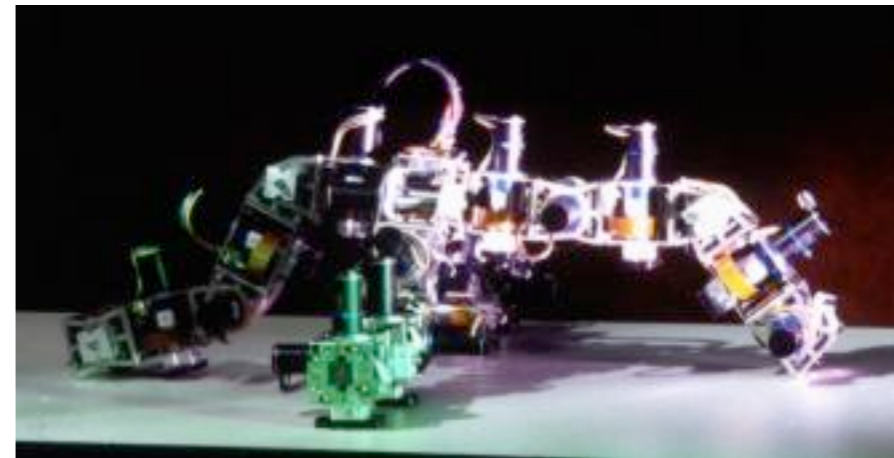
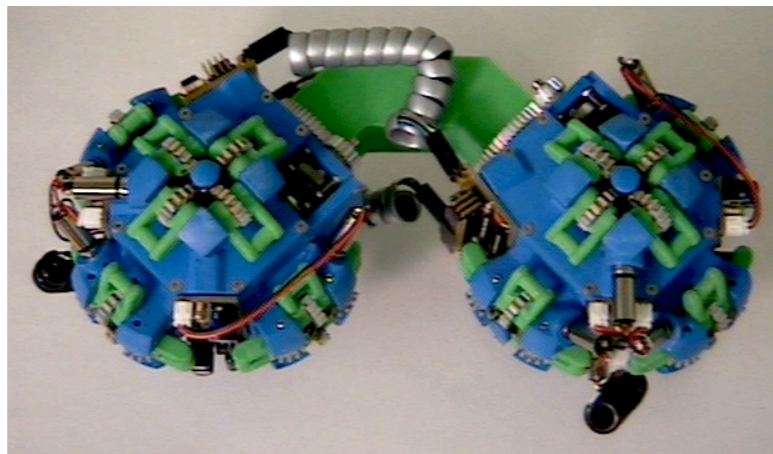


Chasing the Daemon

- Self Assembly + Building Blocks
- = Modular Robotics



Chasing the Daemon



Chasing the Daemon...

- These are all top-down approaches
 - Very Complicated
- Make it Simpler!
 - Remember Brooks



Chasing the Daemon

- Self Assembly + Building Blocks
- =Cellular Chemistry



Cellular Chem. 101

- Amino Acids + Ribosome = Proteins
- Only 20 Amino Acids (why?)
 - thousands (millions?) of proteins



Cellular Chem. 101

- Chemistry
 - strong: peptide bonds, S bonds
 - weak: hydrogen bonds, etc
- Structure
 - primary (sequence)
 - secondary (helices, sheets)
 - tertiary (folding)
 - quaternary (cross-protein)



Protein Structure

- Structure IS function:
 - prions
 - mad cow, alzheimer's, etc



Bottom-up Modular Robotics

- Use artificial chemistry to arrive at simple building blocks capable of self-assembly into a variety of structures.

Artificial Chemistry (John's Definition)

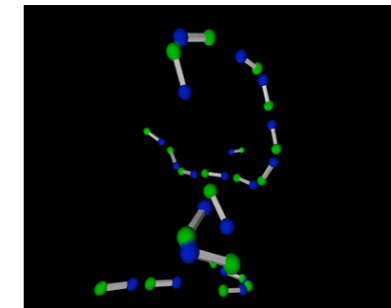
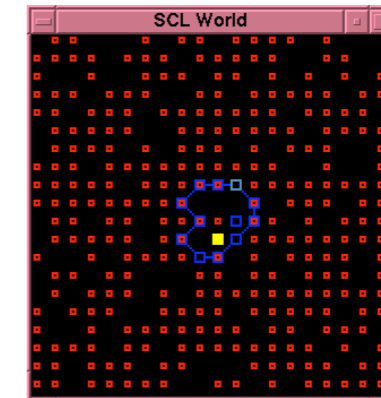
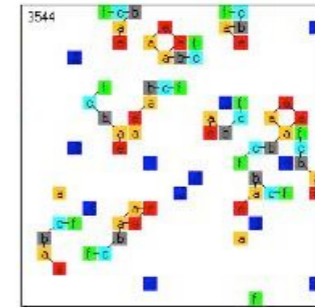
- simulation of:
 - things (elements) floating around in a vat
 - interacting (bonding)

Artificial Chemistries

- Some nice features
 - parallel, distributed
 - local concentrations $>$ global concentration (Crane)
 - can capture benefits geometry (structure)

Artificial Chemistry Work

- Tim Hutton: Squirm3
 - 2d, discrete, fixed rules
- McMullin & Varela: autopoiesis
 - 2d, discrete, fixed rules
- Alan Dorin
 - 3d, continuous, fixed rules



Artificial Chemistry Work

- Saitou & Jakiela:
 - is it a chemistry?
 - simple elements
 - conformational switches as bonds
 - random robot-arm assembly
 - no higher-order structural effects
 - evolvable rules
 - evolve entire set of elements
 - goal structure fixed *a priori*



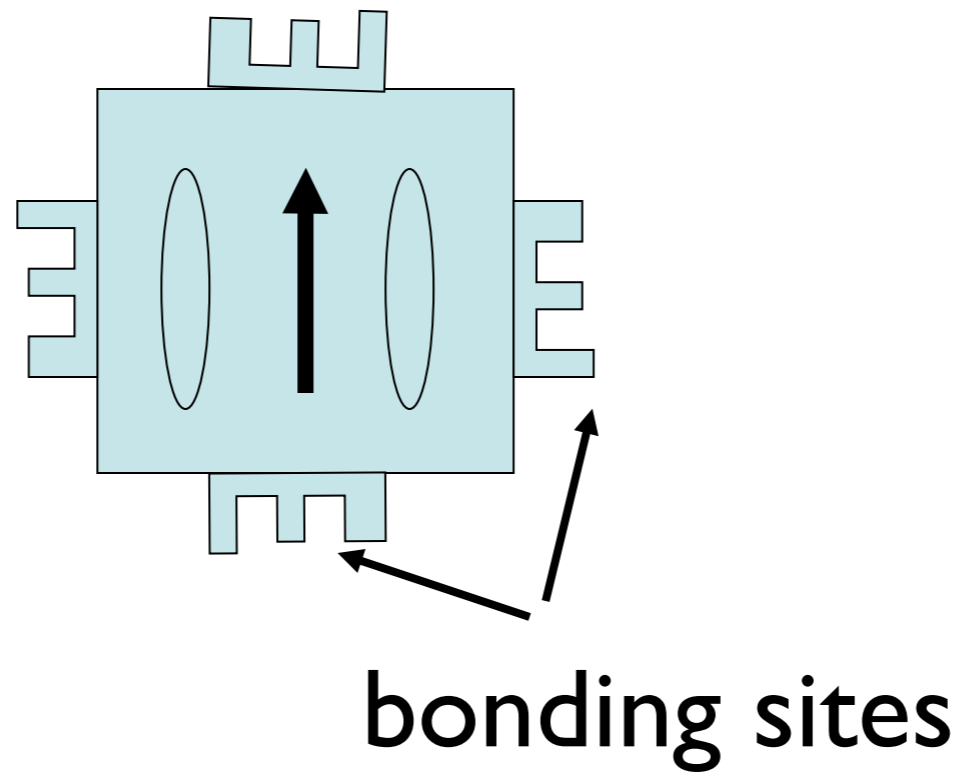
What I Want

- Ultimately:
 - 3-D, physics, mutable chemistry,
 - physically embodied cf embod. evol.
- For Now:
 - 2-D, discrete (SWARM), simple physics, mutable chemistry

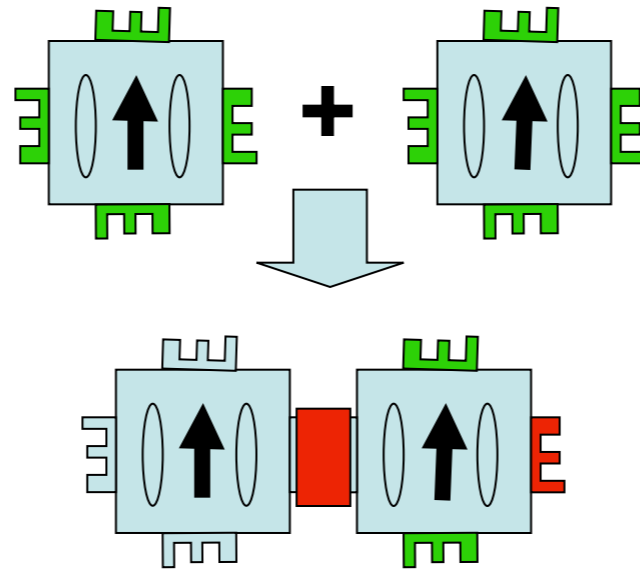


AlChemino

Element:



AlChemino



Interaction

- *can have varying strengths*
- *strength of interaction determines probability of bond formation*

Experiment #1: Hierarchical Assembly

- Can selecting for chemistries which **quickly** and **reliably** form higher order structures leads to building blocks that hierarchically assemble? (cf crane)
- For starters: long chains

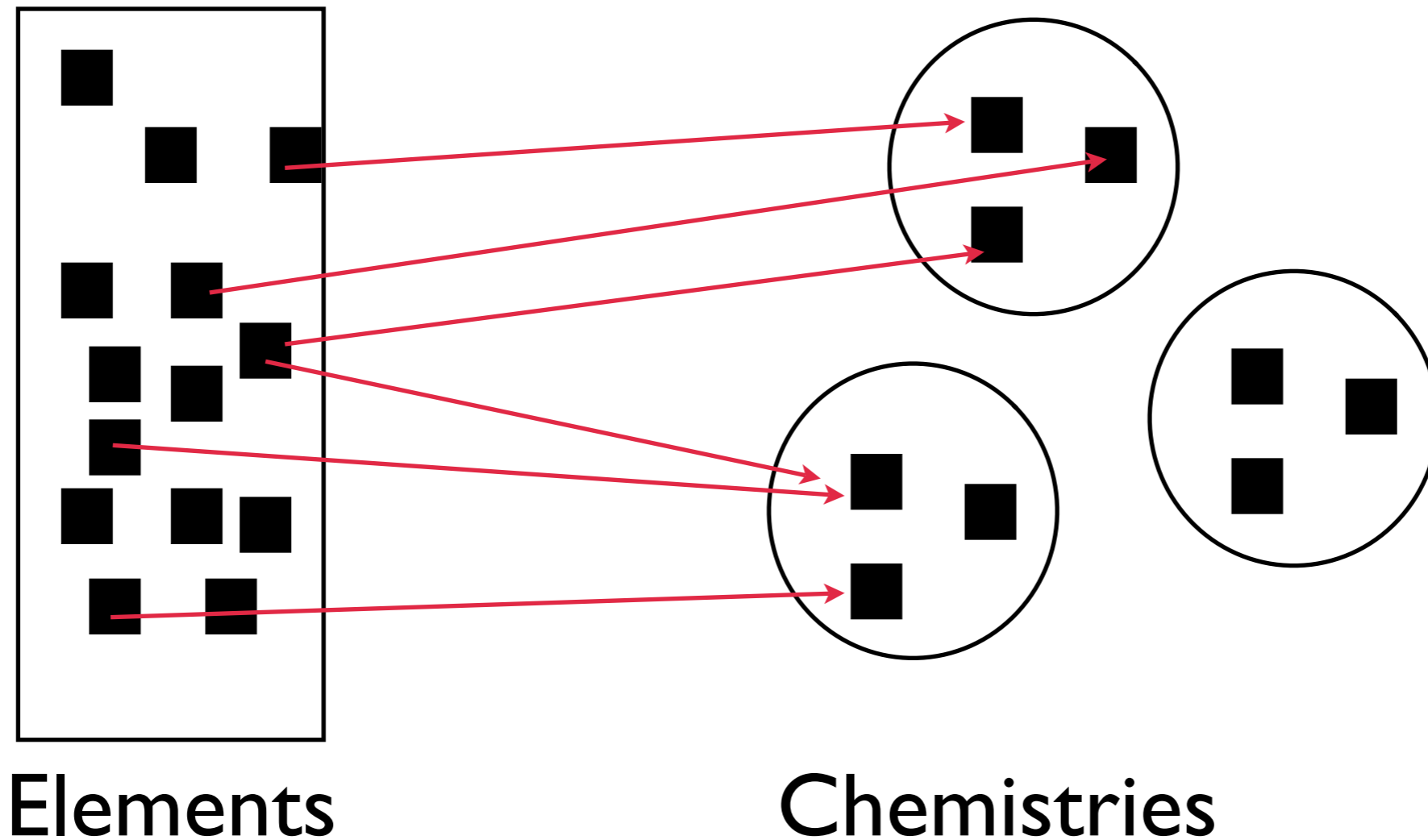


Unresolved Details

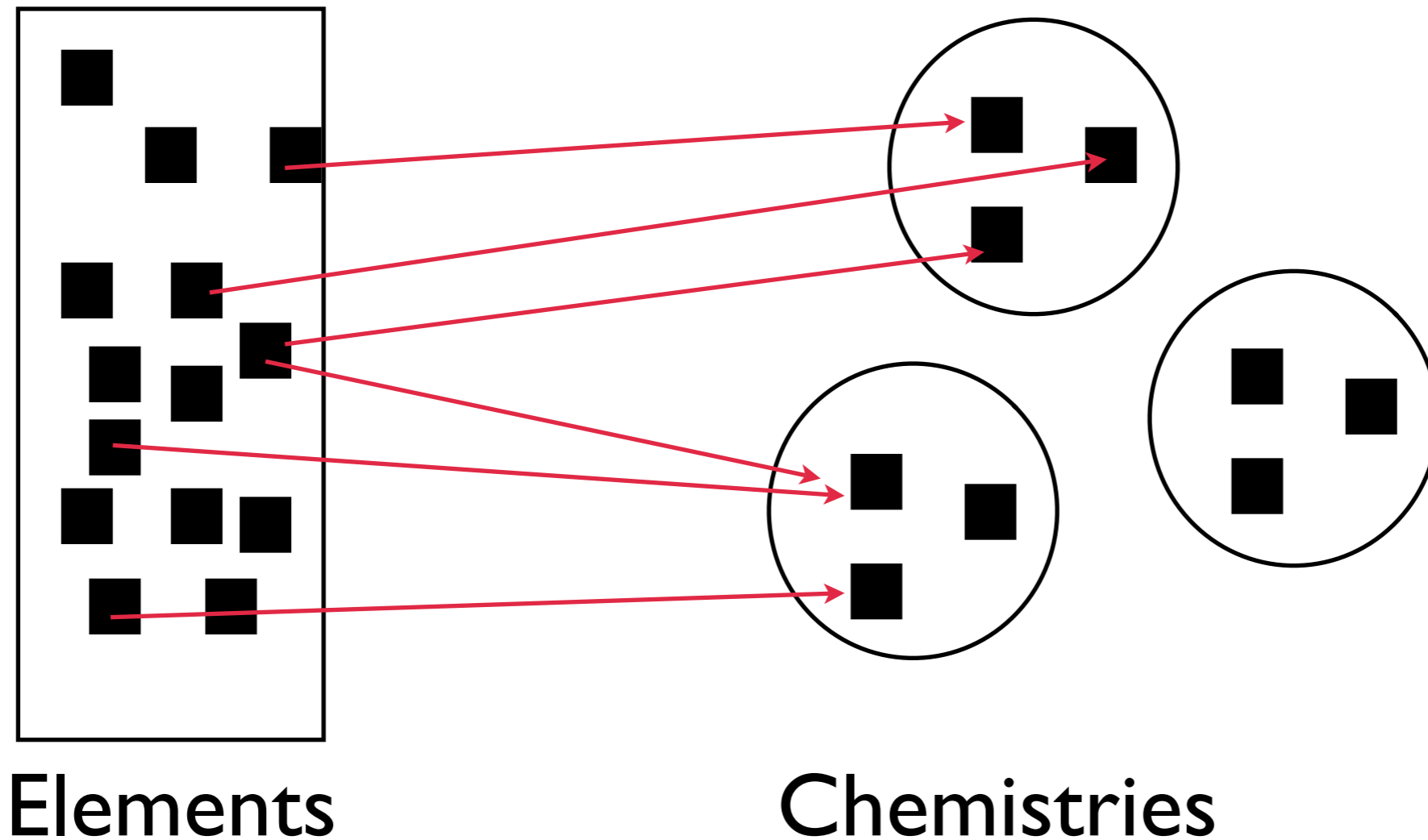
- How to represent bond sites
 - “rich” interactions (self-bonding)
 - best so far: four bits, # of 1’s.
- How to allow for catalytic elements
 - evolve entire chemistries
 - co-evolve chemistries and elements?



Co-Ev Chemistries & Elements



Co-Ev Chemistries & Elements



Gets Complicated...

- Elements
 - select for: # of chemistries containing
- Chemistries: MOO?
 - # of elements (min?)
 - length of chain
 - # of chains
 - fixed time for interactions



The Project

- identify some of the intelligence that humans bring to design projects which are missing from systems w/o humans in-the-loop.
- Three inter-locked co-evolving Systems:
 - primitives -> generality
 - means of assembly->efficiency

