

# Self-Assembly and Self-Repair of Structures with Stability and Resource Constraints

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PM: Les Lee, AFOSR

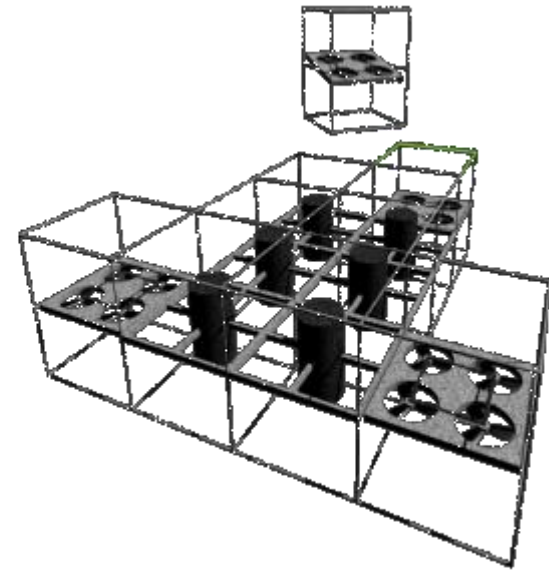
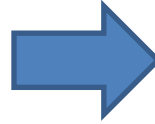
# Report Documentation Page

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# Vision

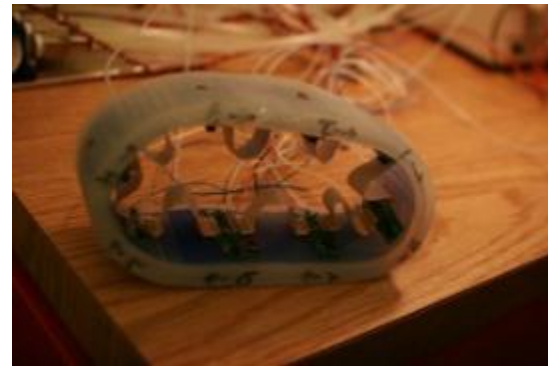


- Self-Assembly
- Self-Reconfiguration
- Self-Repair

# Computational Materials



DISTRIBUTED  
AMORPHOUS  
SCALABLE



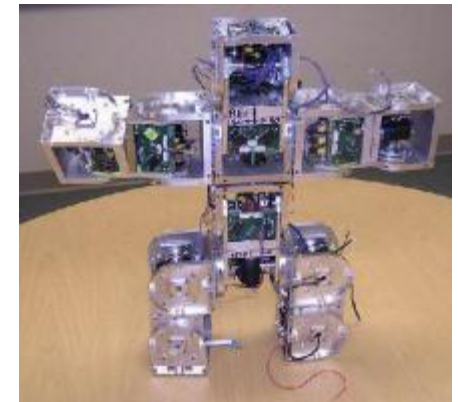
# Challenges

- How to maintain *stability* during self-assembly in air?
- How to limit sensing, actuation and computation *resources*?
- How to *self-repair*?

3 year grant, start April 1<sup>st</sup>, 2012



Distributed Flight Array,  
Raffael d'Andrea, ETH



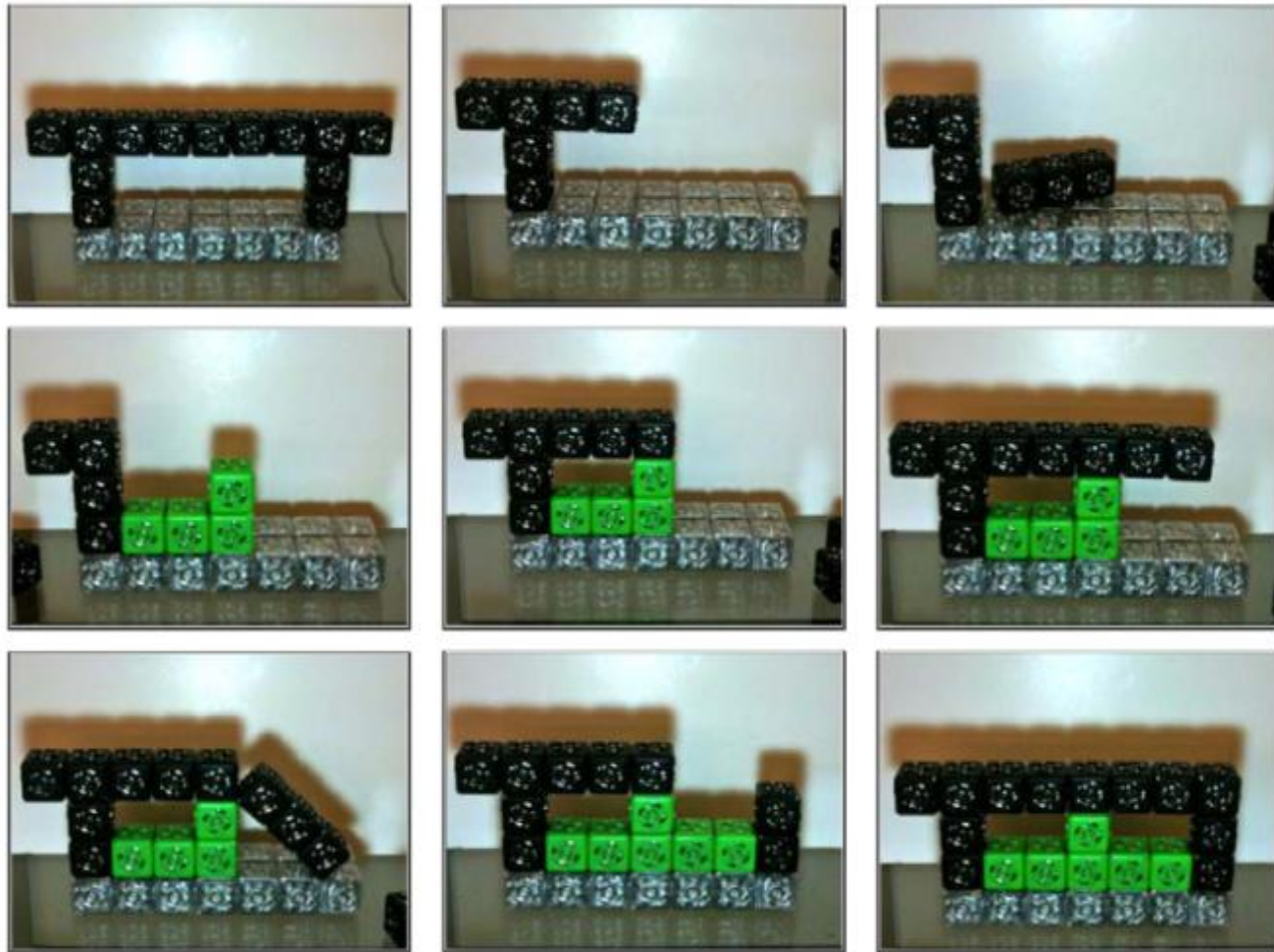
Superbot, Wei Min-Shen, USC

# 1. Stability

- Which *path* to choose to reach a desired configuration?
  - Basic physics
  - Wind, turbulences, vibrations, etc.
  - Sensor/Actuator limitations
- Adding restraints?



# Example



# Approach

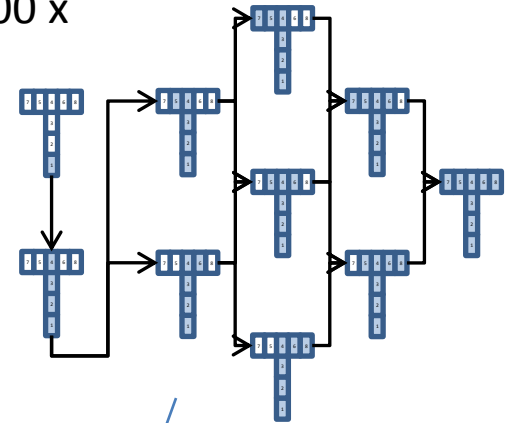
- Combination of
  - Discrete search
  - Dynamical Simulation
  - Full physics, realistic simulation



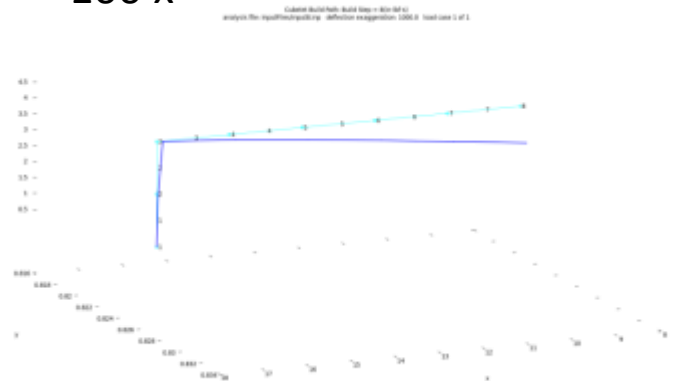
<http://correll.cs.colorado.edu>

Gazebo / ODE

10000 x



100 x

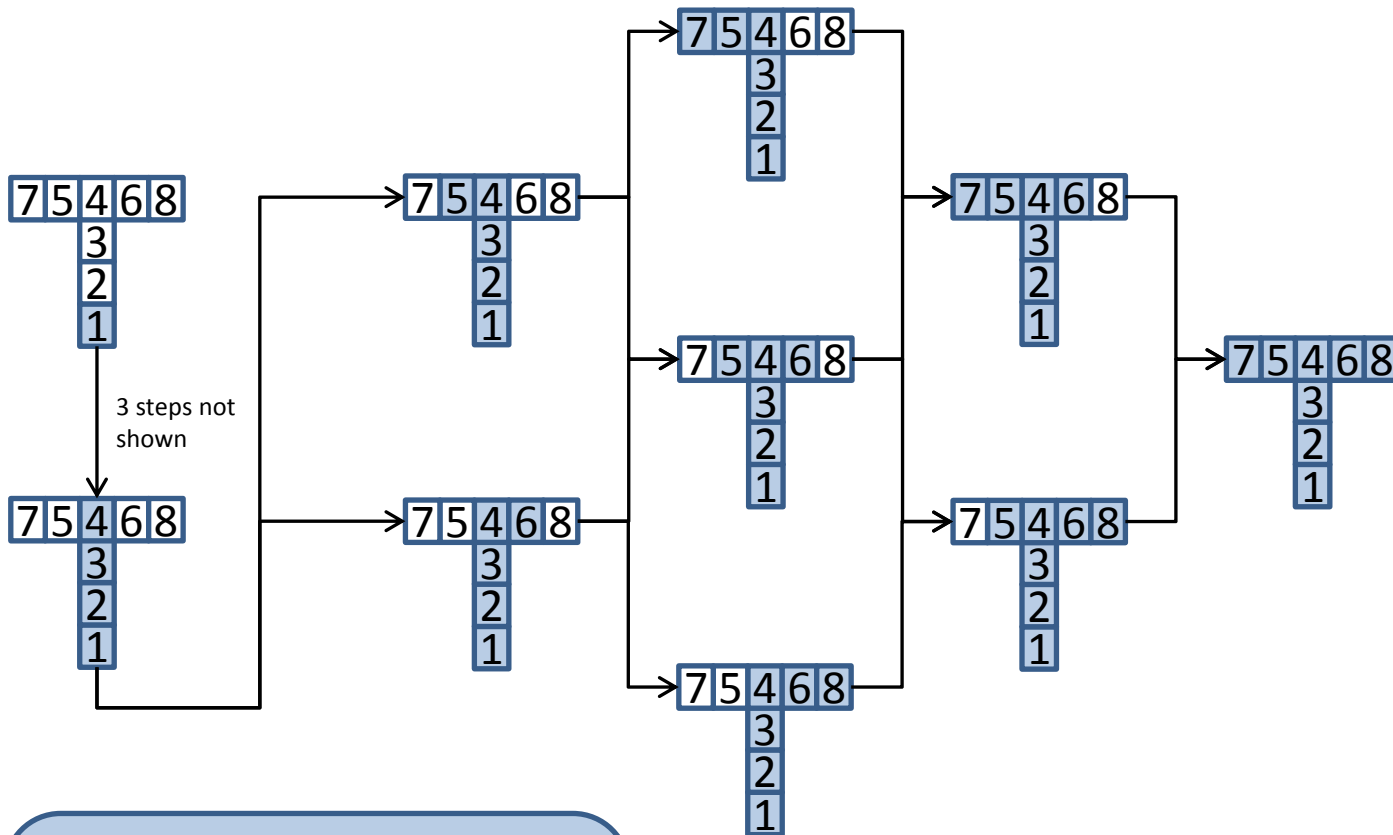


Frame3DD



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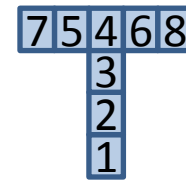
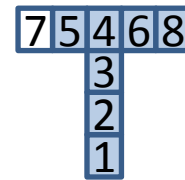
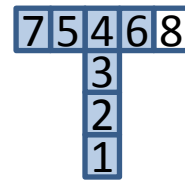
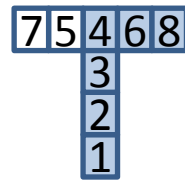
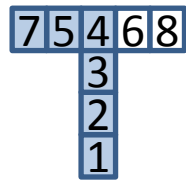
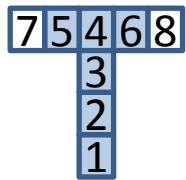
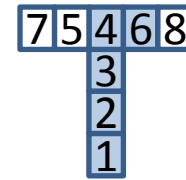
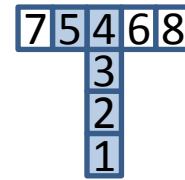
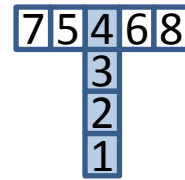
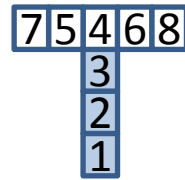
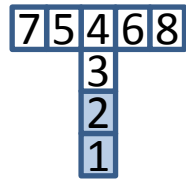
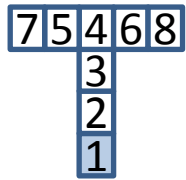
# Tee Structure Assembly Graph



## Valid Assembly Sequences:

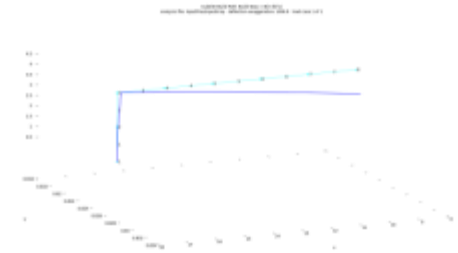
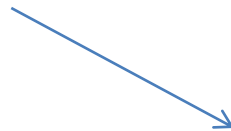
- 1, 2, 3, 4, 5, 6, 7, 8
- 1, 2, 3, 4, 5, 6, 8, 7
- 1, 2, 3, 4, 5, 7, 6, 8
- 1, 2, 3, 4, 6, 5, 7, 8
- 1, 2, 3, 4, 6, 5, 8, 7
- 1, 2, 3, 4, 6, 8, 5, 7

# Tee Structure Assembly Graph Nodes

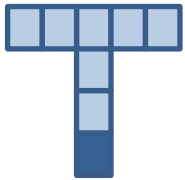


## Analysis Sequences:

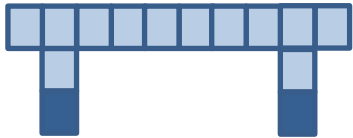
- 1
- 1, 2
- 1, 2, 3
- 1, 2, 3, 4
- 1, 2, 3, 4, 5
- 1, 2, 3, 4, 6
- 1, 2, 3, 4, 5, 6
- 1, 2, 3, 4, 5, 7
- 1, 2, 3, 4, 6, 8
- 1, 2, 3, 4, 5, 6, 7
- 1, 2, 3, 4, 5, 6, 8
- 1, 2, 3, 4, 5, 6, 7, 8



# Other Structures



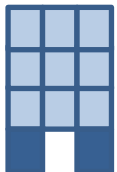
Tee



Bridge



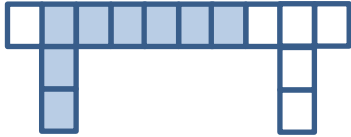
2D w/ Hole



2D w/ enclosed

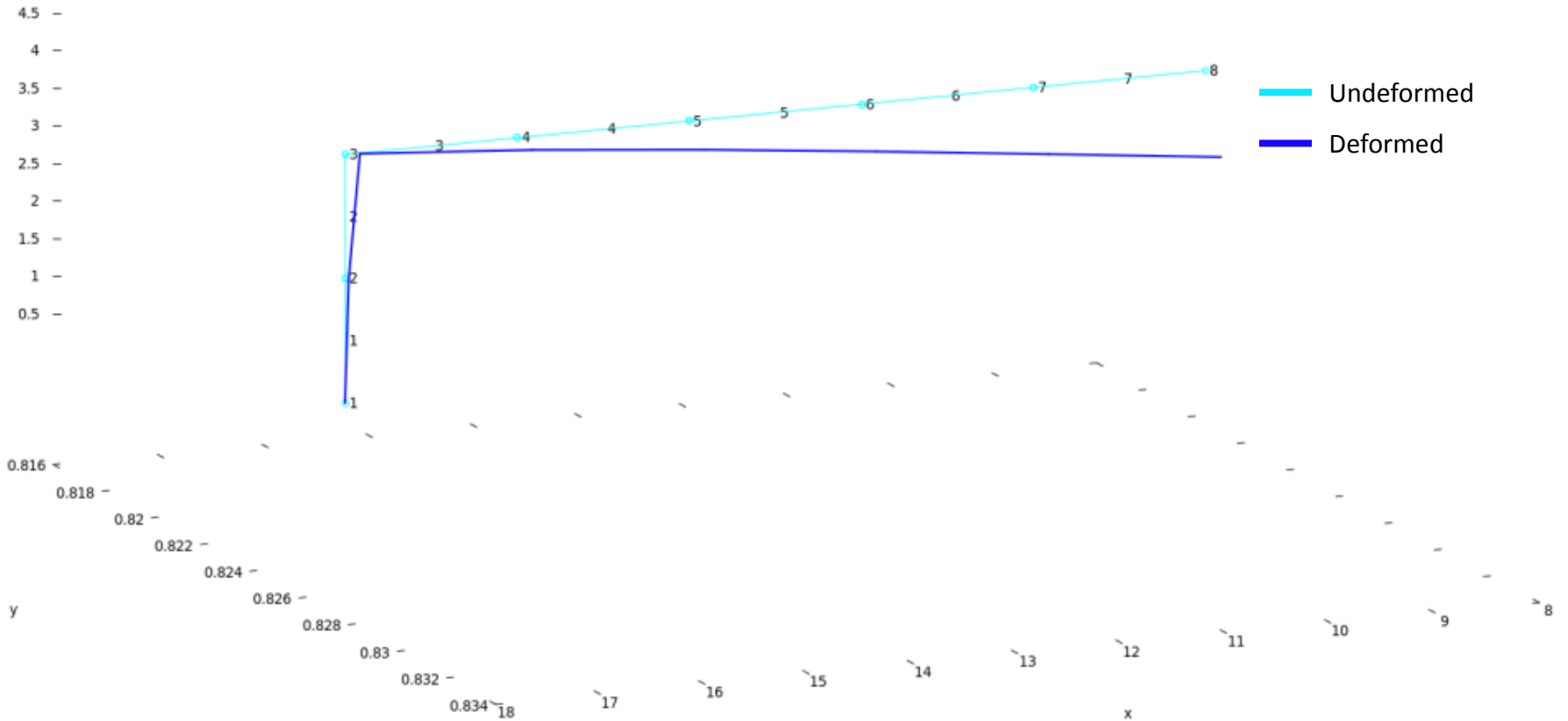
Valid Assembly Paths	Graph Nodes to analyze
6	12
78	60
452	76
7985	243

# Frame3DD FEA: Partial Bridge



Analyzed Structure

Cubelet Build Path: Build Step = 8(in-lbf-s)  
analysis file: InputFiles/input8.inp deflection exaggeration: 1000.0 load case 1 of 1



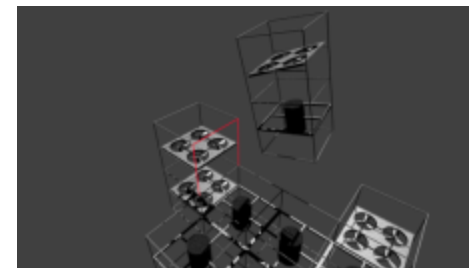
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# Discussion: Stable Paths

- Fast heuristics needed for discrete search
  - Encode basic physics
  - Encode geometric constraints
- Identification of “critical” elements that need restraints
- Frame3DD -> arbitrary physics
  - From static assemblies to flying and swimming

7985?



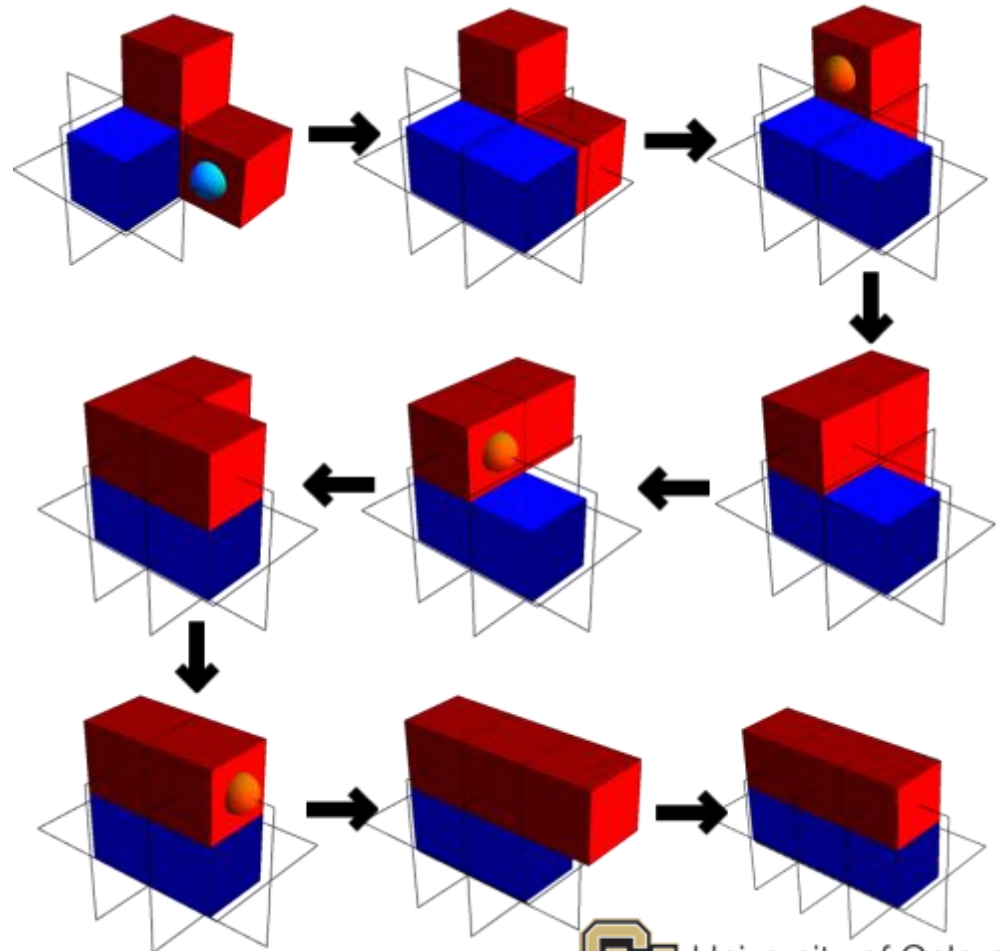
## 2. Resources

- How to limit the number of building blocks with actuation, sensing, and computation?
  - Weight
  - Cost
- Approach: “Intelligent Scaffolds”

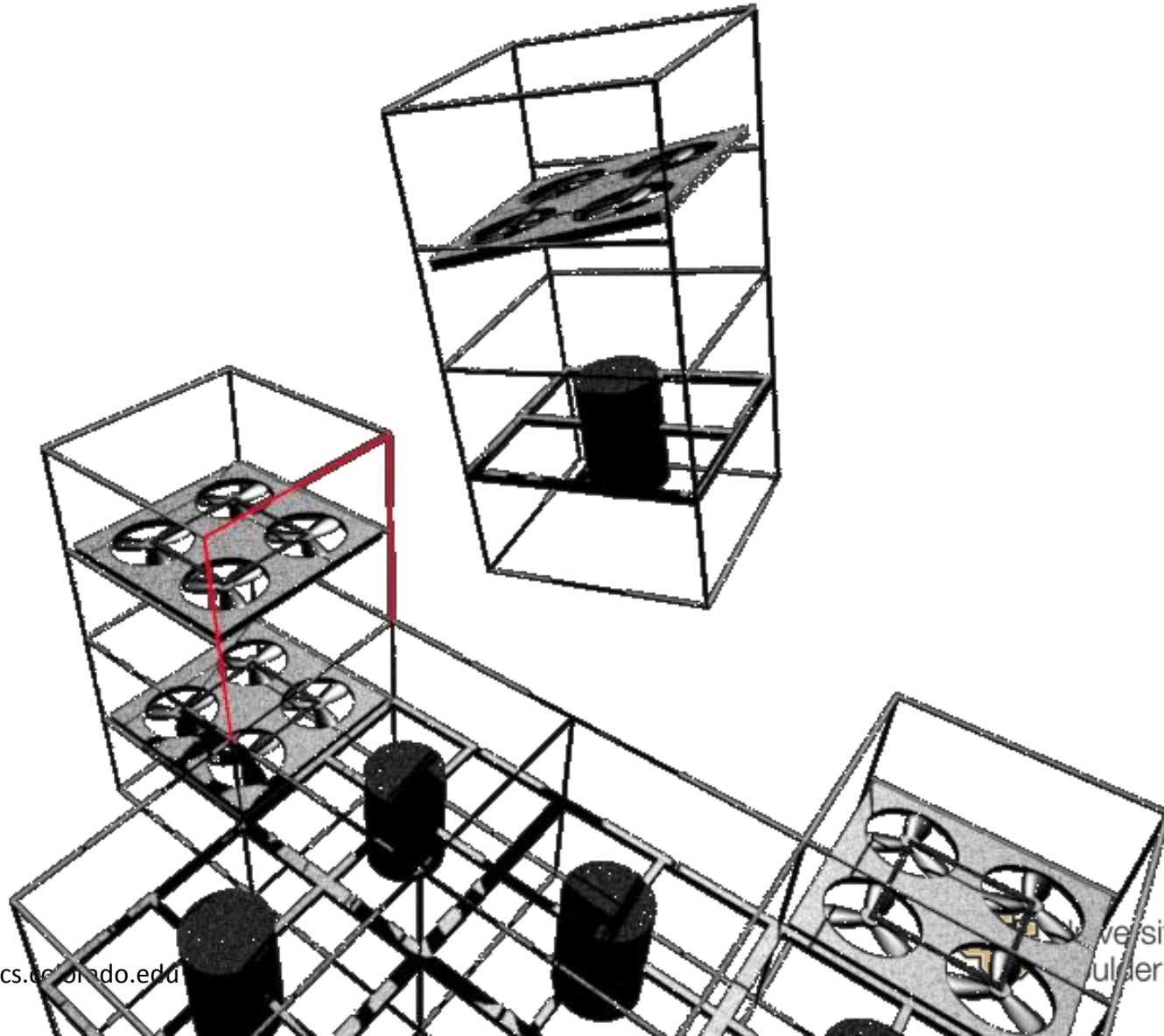


# Approach: Intelligent Scaffolds

- Scaffolds (red) coordinate construction
- Three Scaffold blocks can construct any computable structure

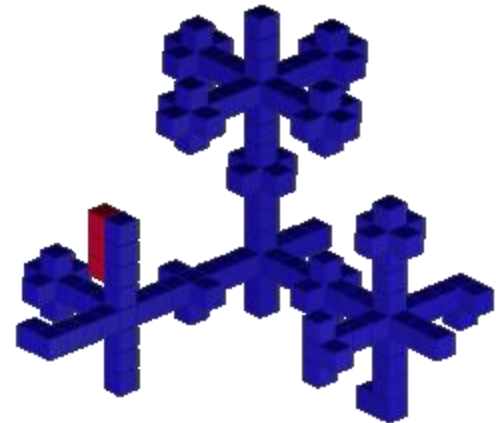


# Intelligent Scaffolds



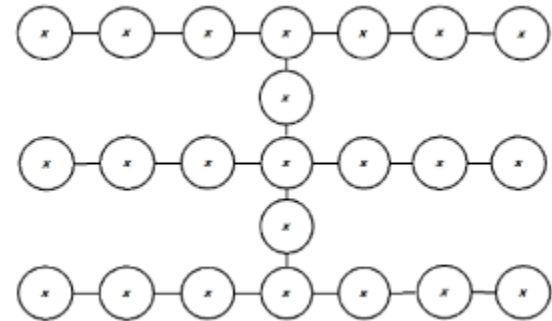
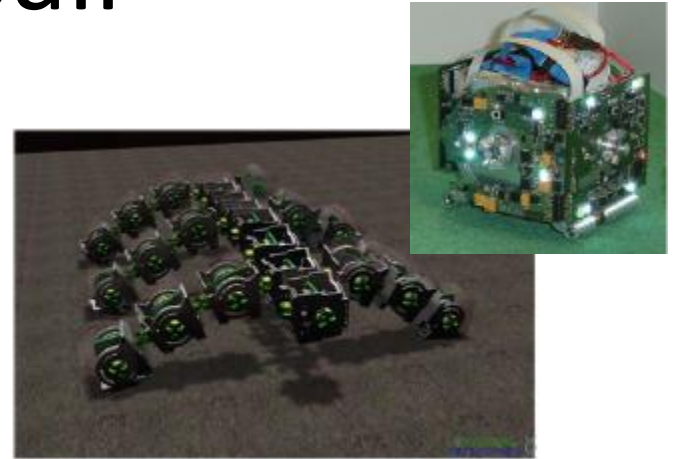
# Discussion: Resources

- Intelligent scaffold allow trade-off between number of actuated modules (from 3 to N) and assembly time
- Need new algorithms that use *some* computation & communication in otherwise passive blocks



# 3. Self-Repair

- Challenge:
  - Detect damage
  - Execute repair
- Approach:
  - Graph grammars
  - Graph rewriting rules

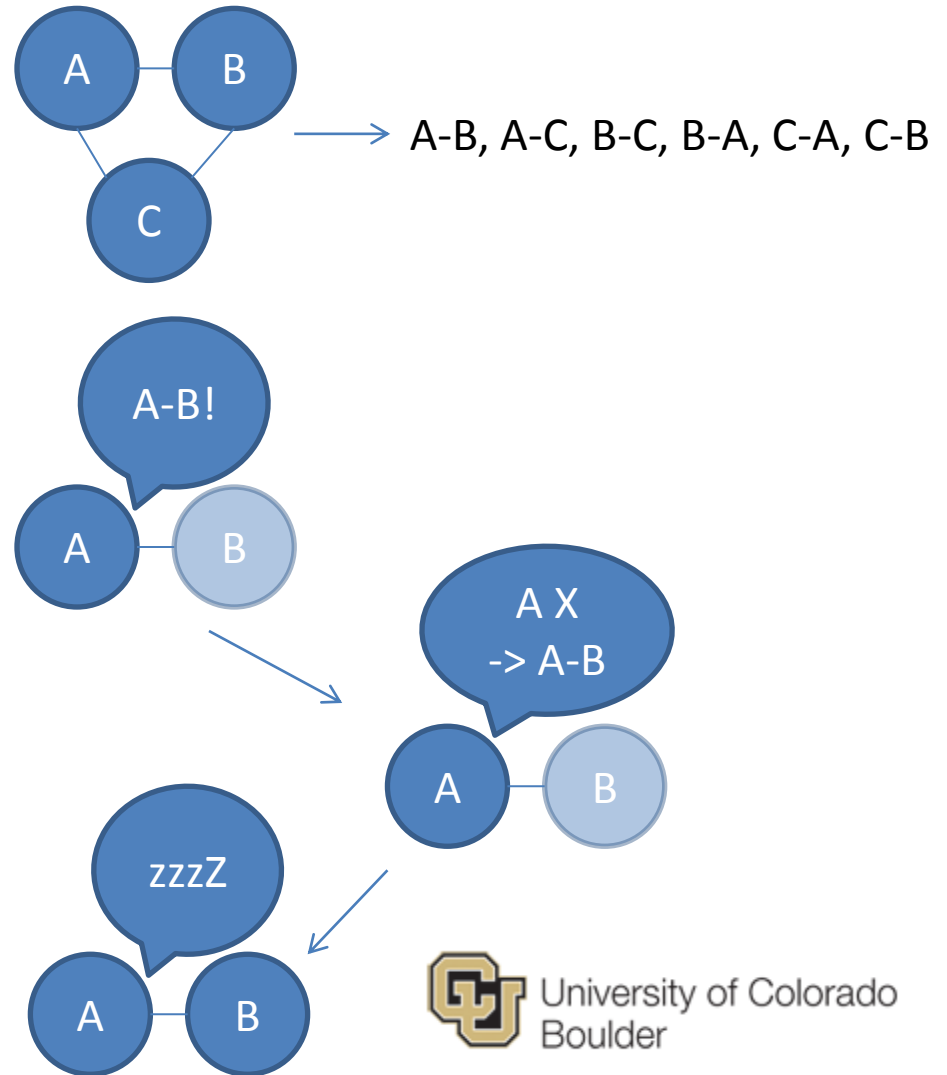


$$\phi_{fi} : X \quad A \Rightarrow Y - Z$$

$$\phi_{ri} : Y - Z \Rightarrow X \quad A$$

# 3. Self-Repair

- Generate graph grammars to *monitor* and *repair* structural integrity
- Embed monitor and repair rules into material



# Discussion: Self-Repair

- Requires additional sensing, computation, and communication
- Find right trade-off between
  - Speed of detection/repair
  - Additional resources to embed

# Outlook

- From simple physics to (simple) flight dynamics
- Study self-assembly, reconfiguration, and repair in realistic simulation
- Perform preliminary experiments in 2D and 3D

