

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

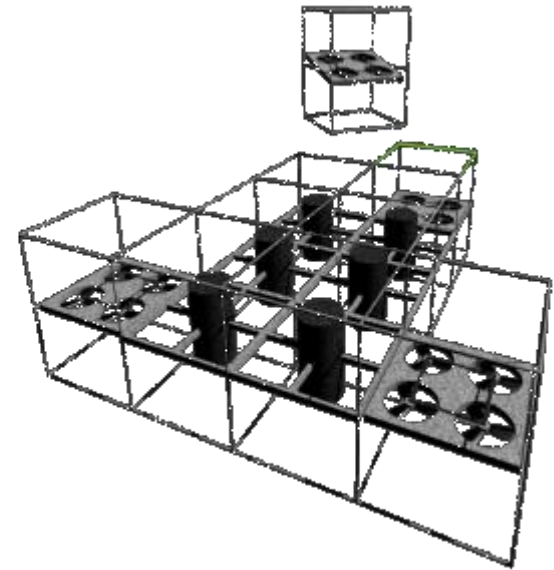
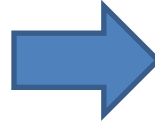
Nikolaus Correll
Department of Computer Science
University of Colorado at Boulder

PM: Les Lee, AFOSR

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



Vision

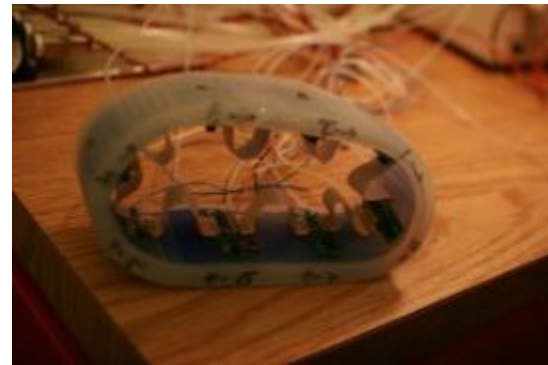


- Self-Assembly
- Self-Reconfiguration
- Self-Repair

Computational Materials



DISTRIBUTED
AMORPHOUS
SCALABLE

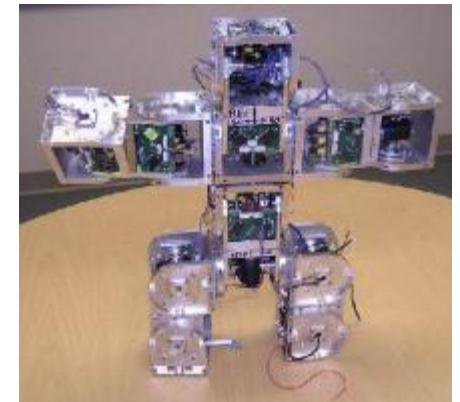


Challenges

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



Distributed Flight Array,
Raffael d'Andrea, ETH



Superbot, Wei Min-Shen, USC

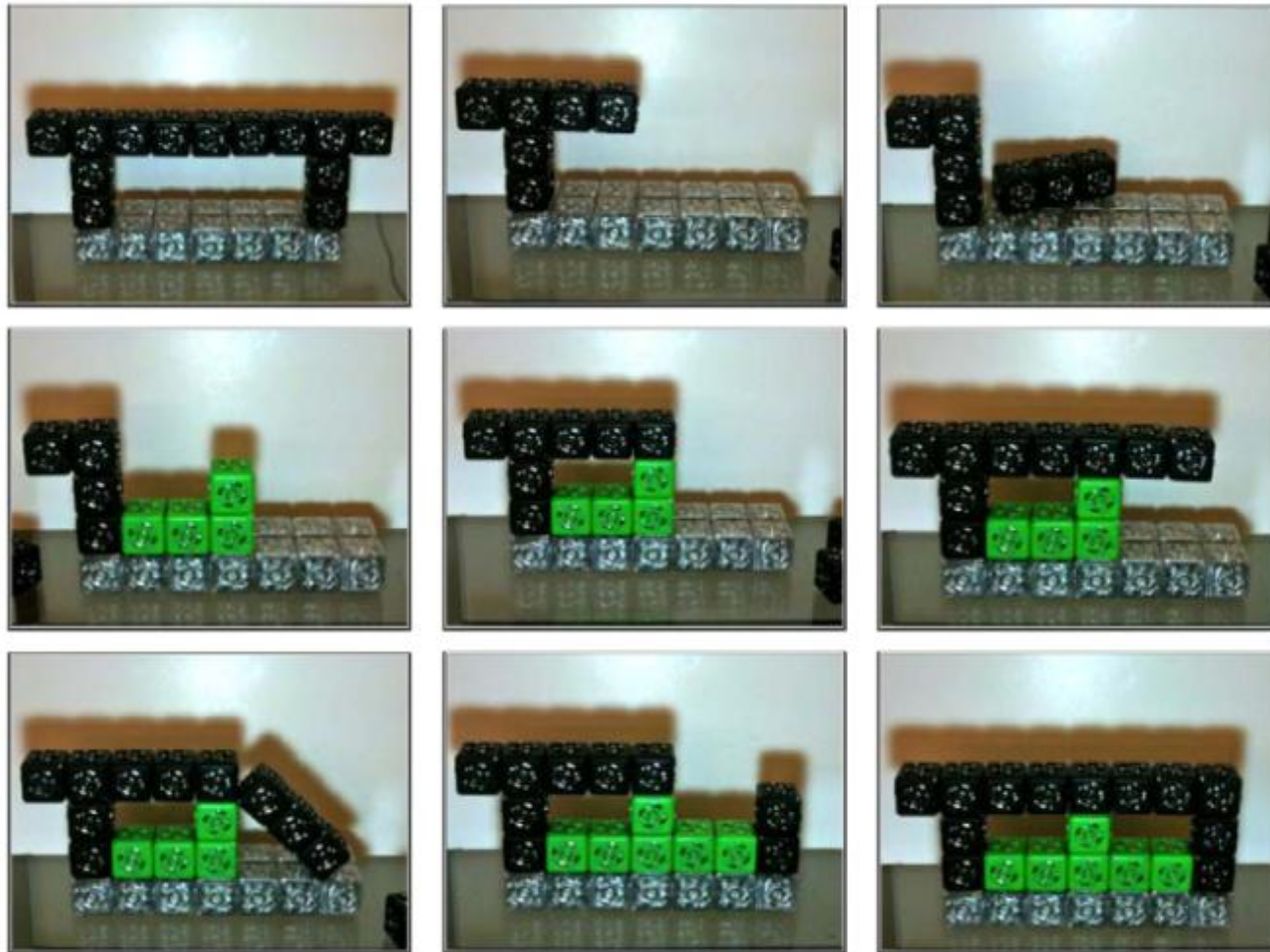
3 year grant, start April 1st, 2012

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

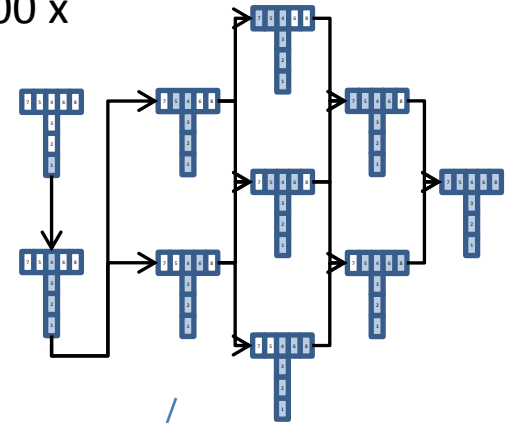
10 x



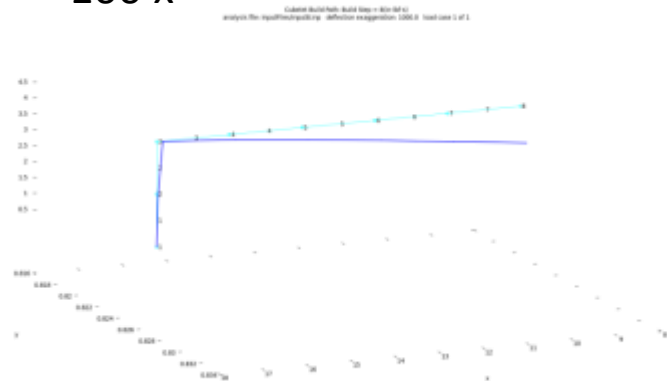
<http://correll.cs.colorado.edu>

Gazebo / ODE

10000 x



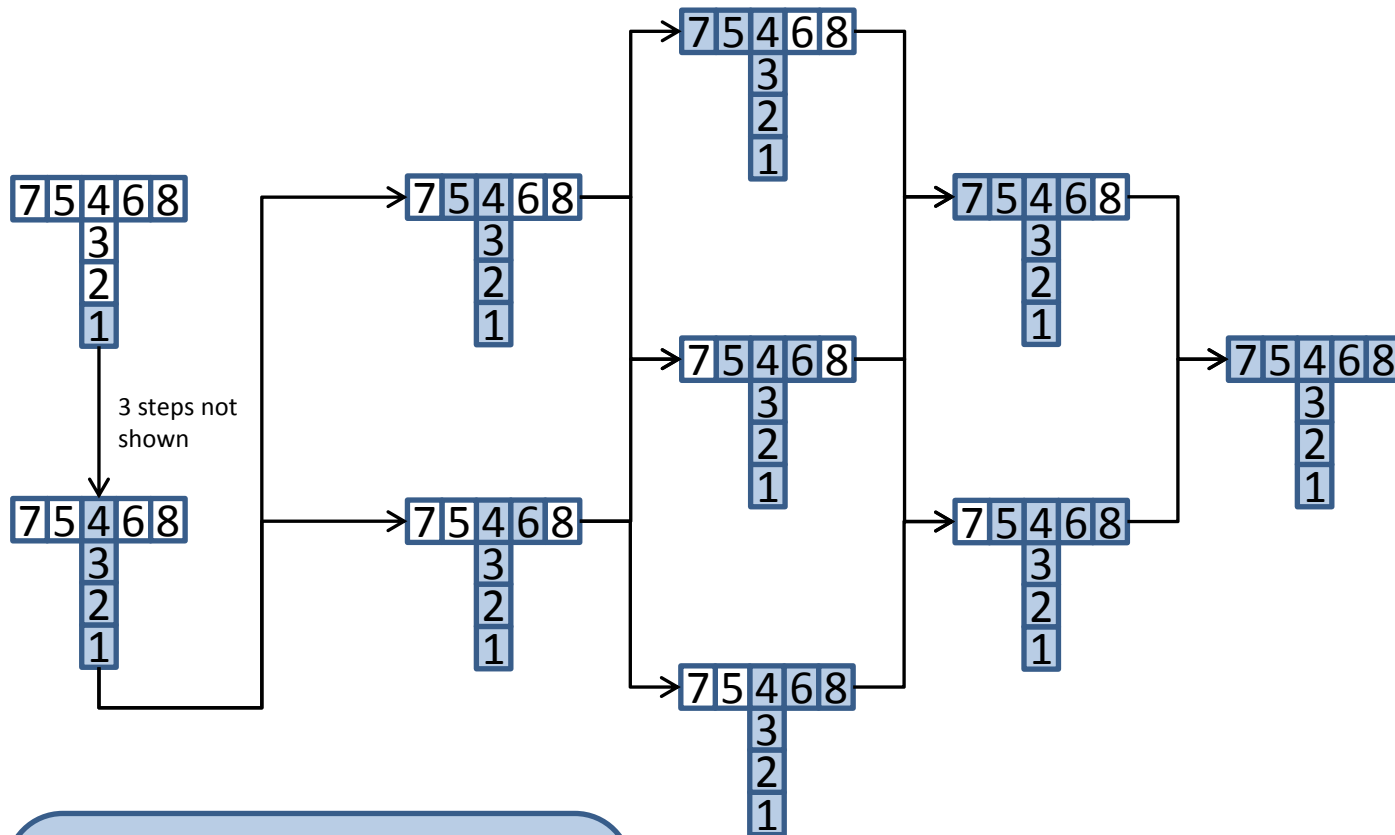
100 x



Frame3DD

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Boulder

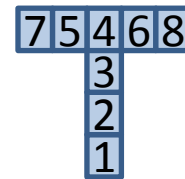
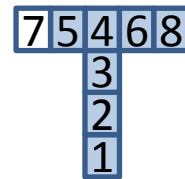
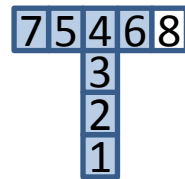
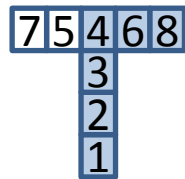
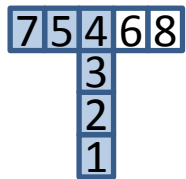
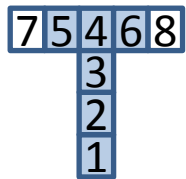
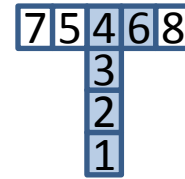
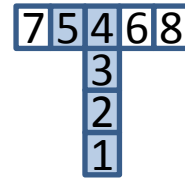
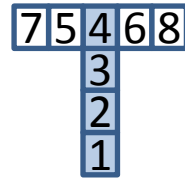
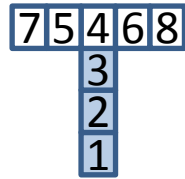
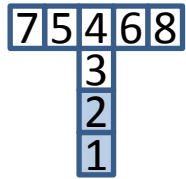
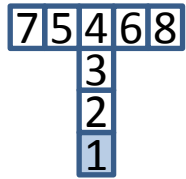
Tee Structure Assembly Graph



Valid Assembly Sequences:

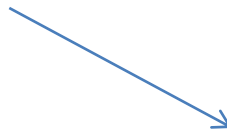
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 1, 2, 3, 4, 6, 5, 8, 7
 1, 2, 3, 4, 6, 8, 5, 7

Tee Structure Assembly Graph Nodes

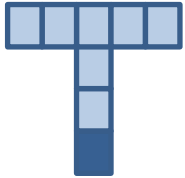


Analysis Sequences:

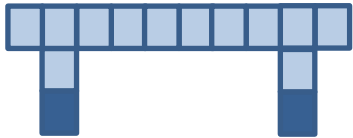
1
1, 2
1, 2, 3
1, 2, 3, 4
1, 2, 3, 4, 5
1, 2, 3, 4, 6
1, 2, 3, 4, 5, 6
1, 2, 3, 4, 5, 7
1, 2, 3, 4, 6, 8
1, 2, 3, 4, 5, 6, 7
1, 2, 3, 4, 5, 6, 8
1, 2, 3, 4, 5, 6, 7, 8



Other Structures



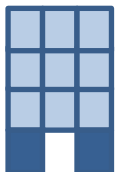
Tee



Bridge



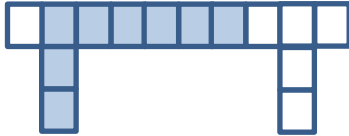
2D w/ Hole



2D w/ enclosed

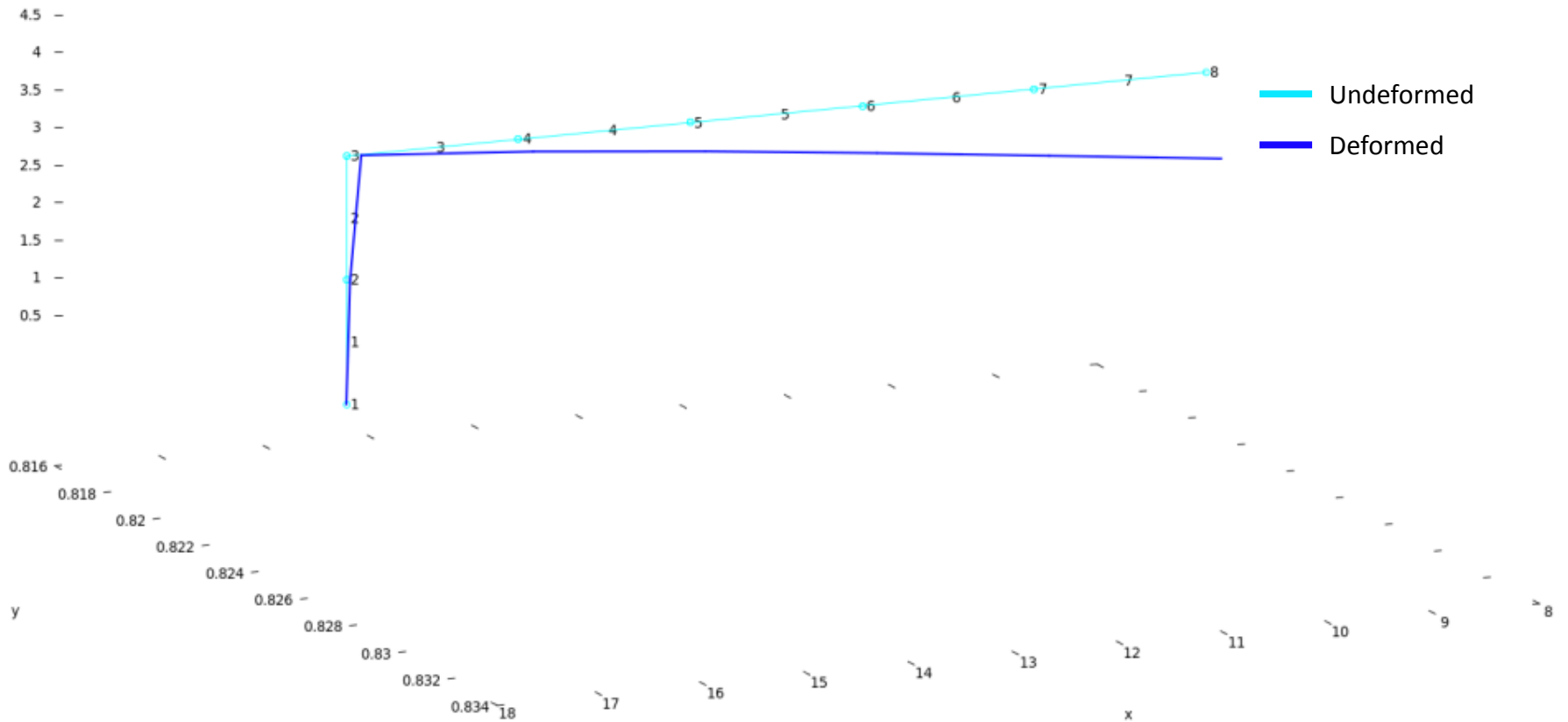
Valid Assembly Paths	Graph Nodes to analyze
6	12
78	60
452	76
7985	243

Frame3DD FEA: Partial Bridge



Analyzed Structure

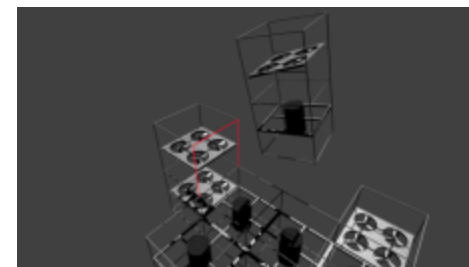
Cubelet Build Path: Build Step = 8(in-lbf-s)
analysis file: InputFiles/input8.inp deflection exaggeration: 1000.0 load case 1 of 1



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?



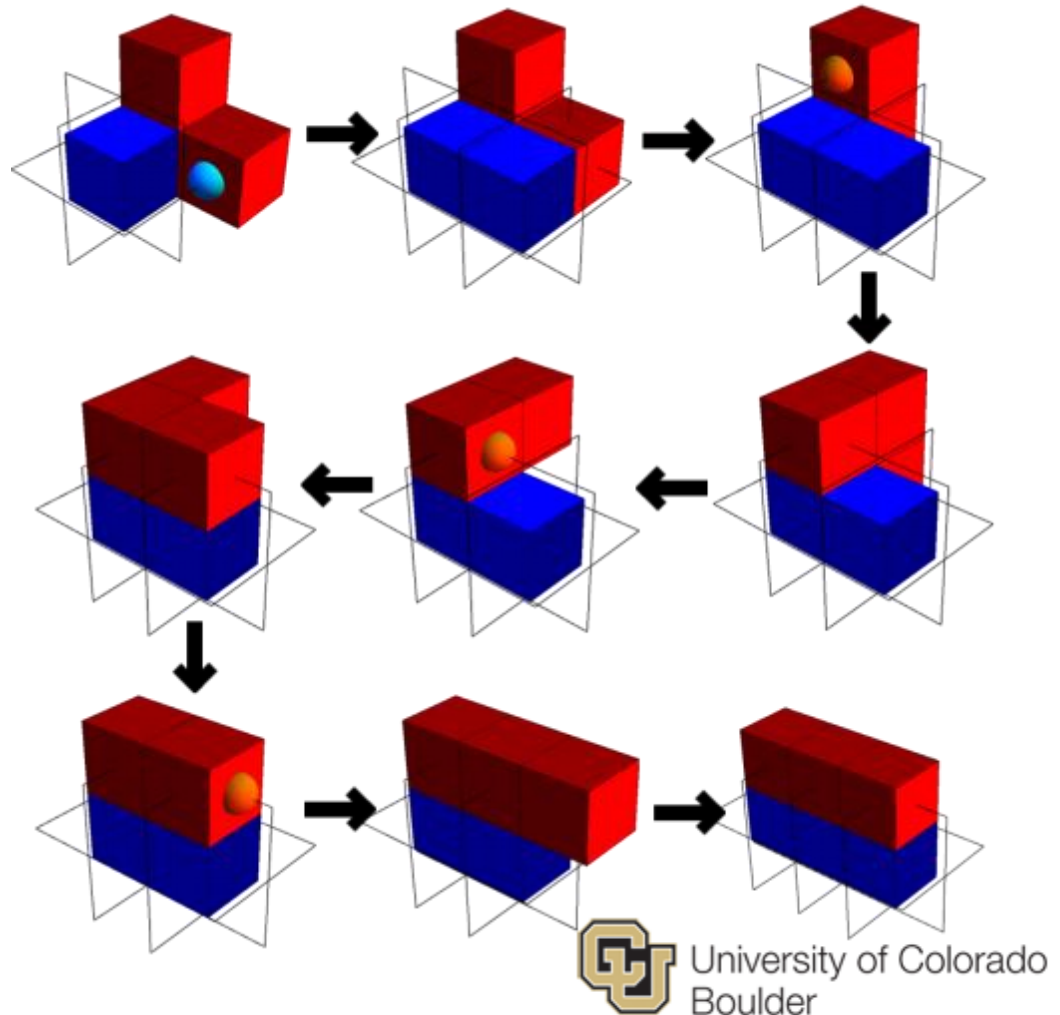
2. Resources

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

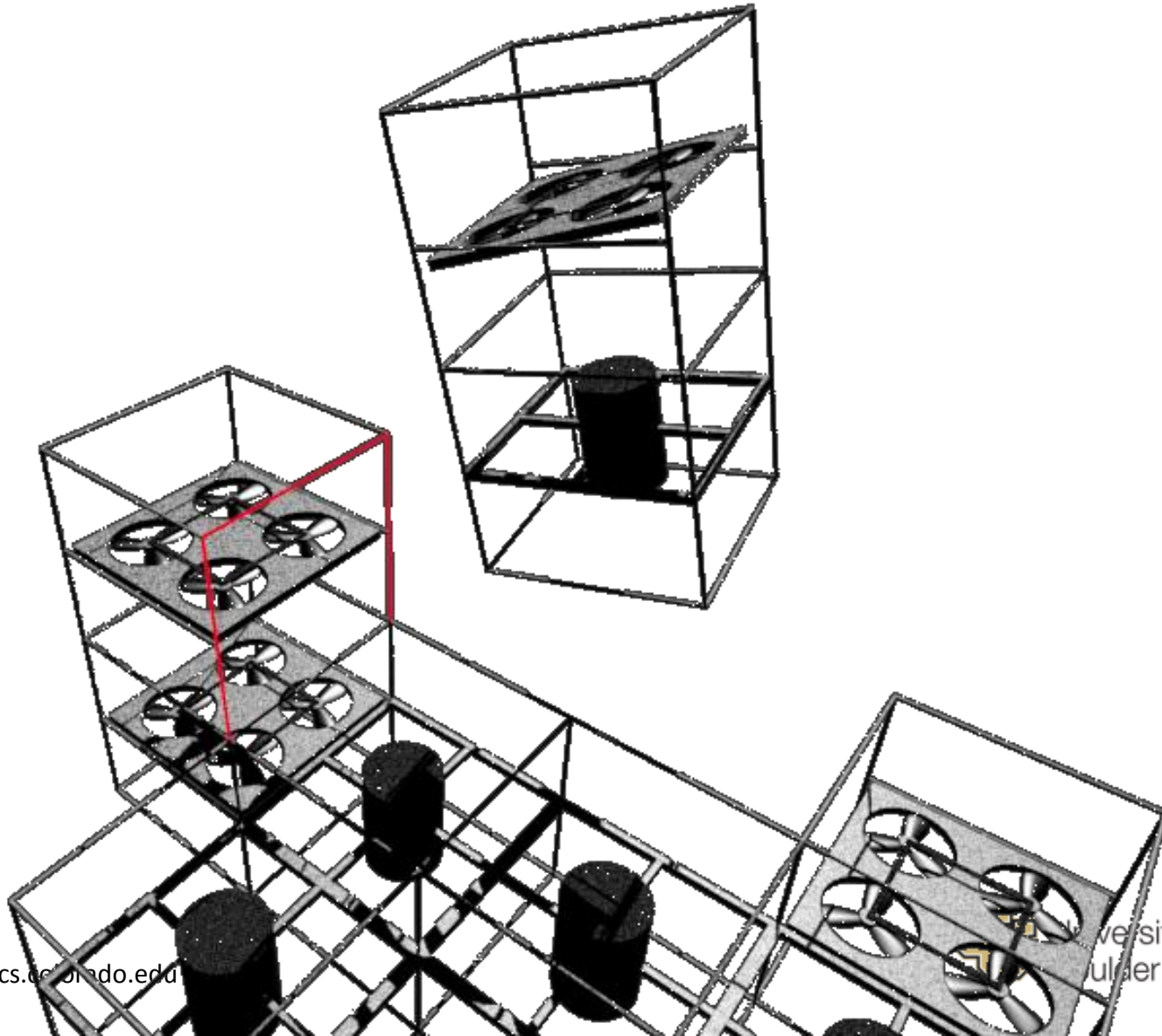


Approach: Intelligent Scaffolds

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

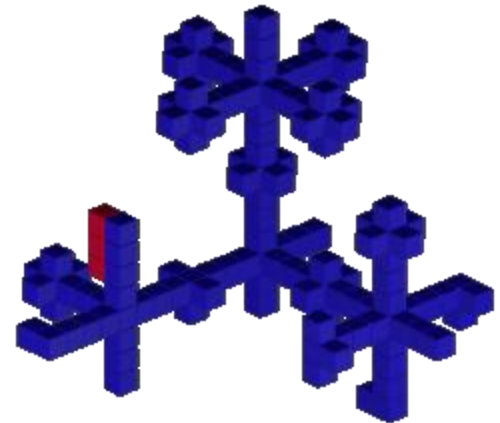


Intelligent Scaffolds



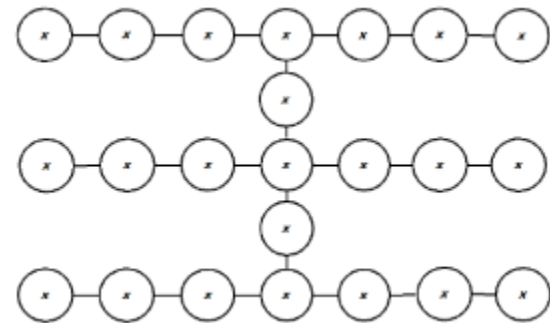
Discussion: Resources

- 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

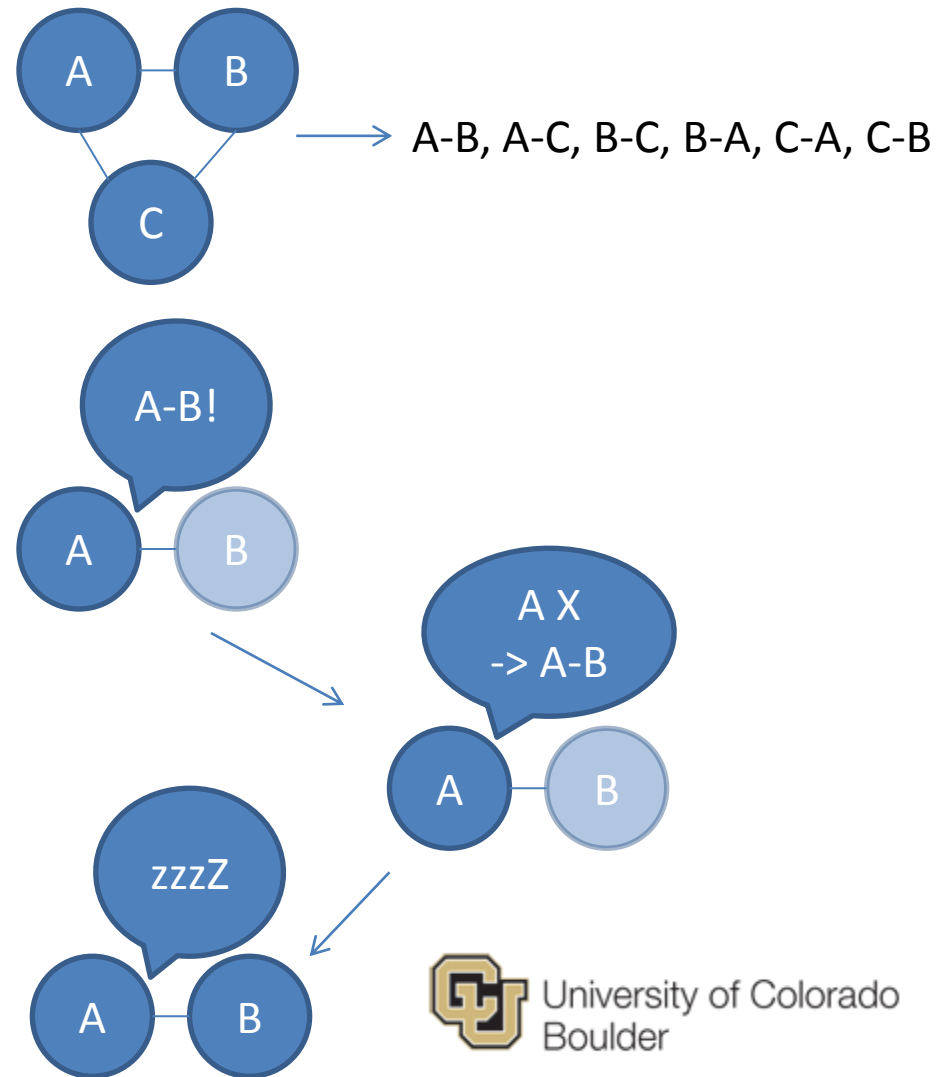


$$\phi_{fi} : X \quad A \Rightarrow Y - Z$$

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

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

