Workshop on Uncertainty in Automation, ICRA 2011

Aerial Robots for Construction

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Acknowledgements

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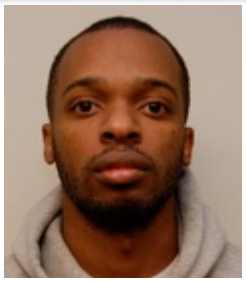
Q. Lindsey, D. Mellinger, V. Kumar, Construction of Cubic Structure with Teams of Aerial Robots, RSS, LA, June 2011

Dr. Nathan Michael

Jonathan Fink

Daniel Mellinger



Quentin Lindsey

Frank Shen

Matt Turpin

Mike Shomin

Christine Kappeyne

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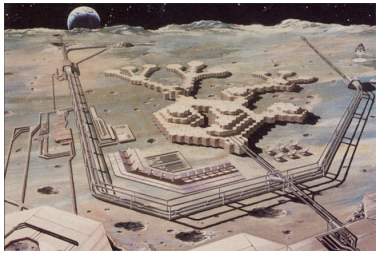
Cooperating Robots and Assembly

ABB

Kuka

Kiva Systems

Shimizu



Unmanned Air Vehicles

Aerovironment Black Widow – 2.12 oz.

UCB Smart bird

Boeing/ Insitu Scaneagle – 33 lb

Gen. Atomics – Predator B – 7,000 lb

BAE Systems Microstar – 3.0 oz.

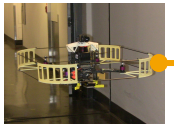
U. Penn Piper cub 6 lb

Stanford DFly

AAI Shadow 200 – 328 lb

Boeing X-45A UCAV – 12,195 lb (est)

Astec Pelican



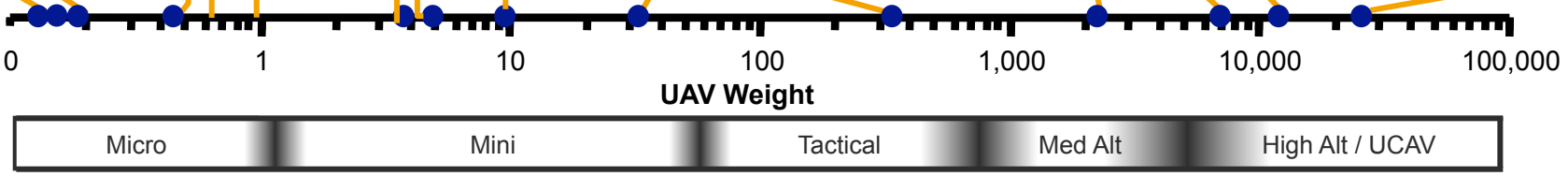
Astec Hummingbird

Allied Aero. LADF 3.8 lb

Aerovironment Pointer – 9.6 lb

Bell Eagle Eye – 2,250 lb

Northrop-Grumman Global Hawk 25,600 lb



Assembly

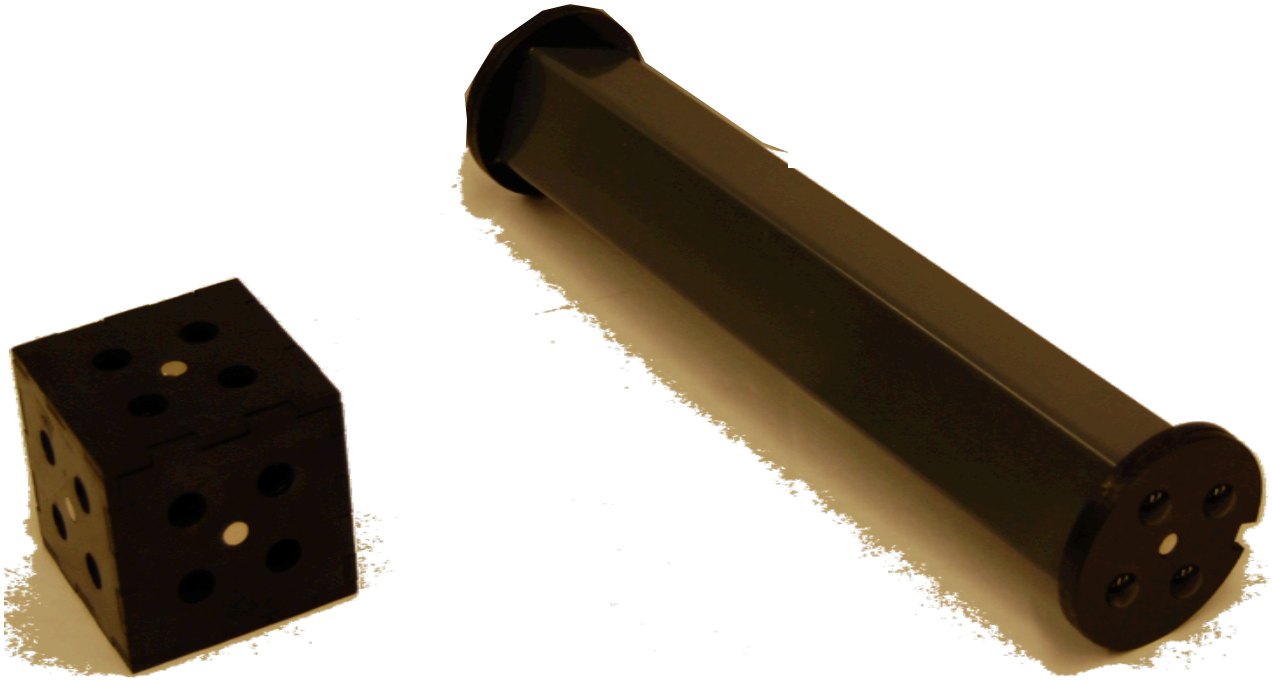
- Structured
- Mass/Batch
- Indoor
- Human intervention usually always possible
- Process tolerance
  < 0.1 mm

Construction

- Unstructured
- Customized
- Outdoor
- Potentially remote, hostile environments
- Process tolerance
  > 5 mm

Goal

Assembly and Construction of 3-D Structures

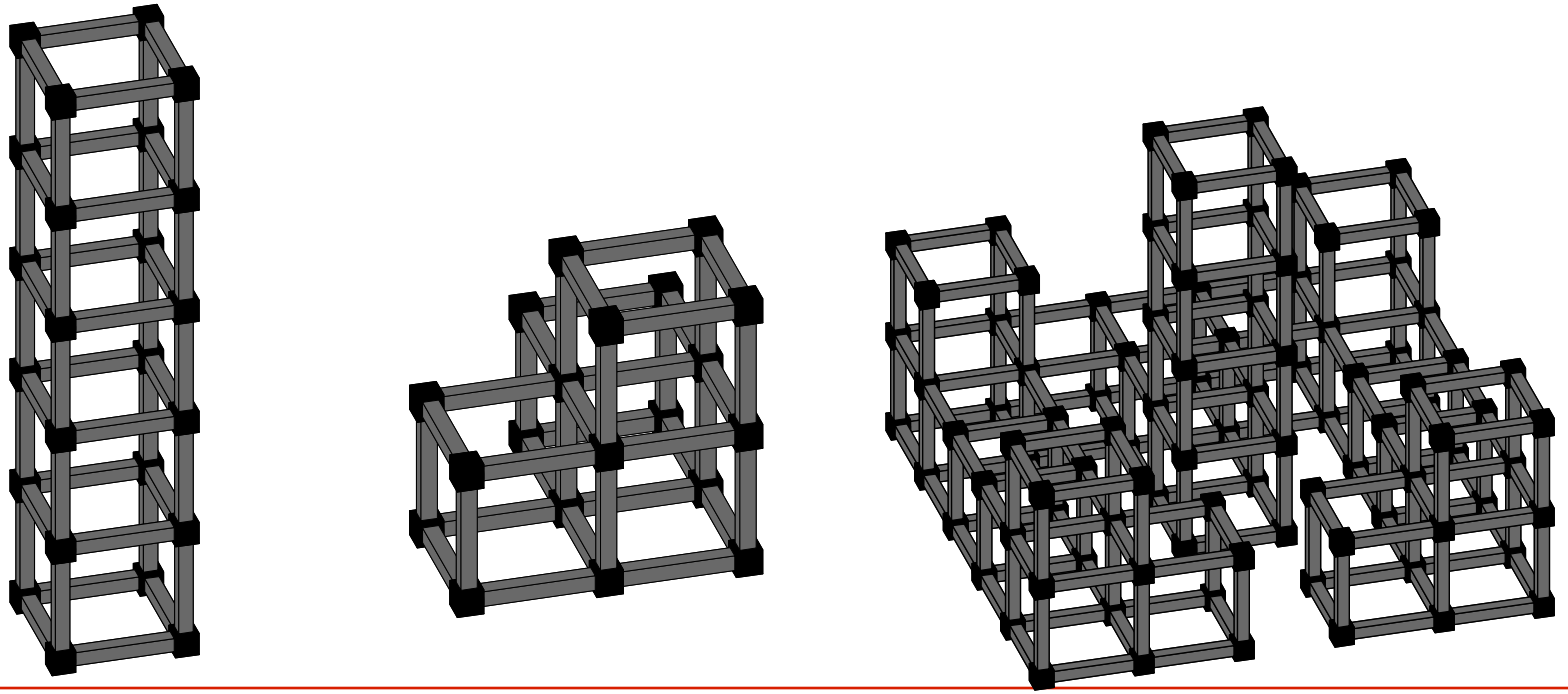


Goal

Assembly and Construction of 3-D Structures

This talk …

Special Cubic Structures



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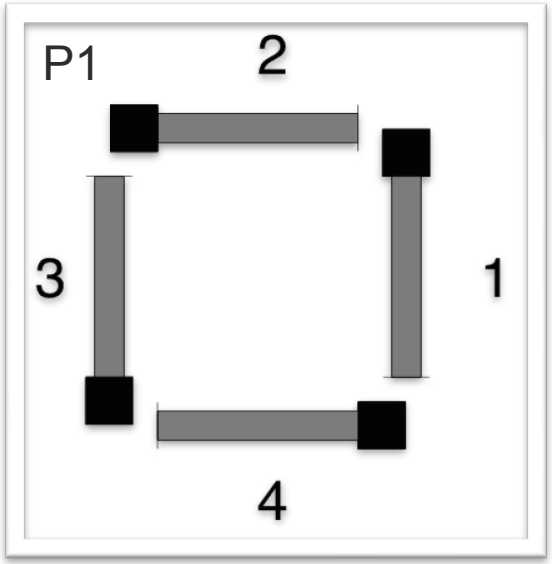
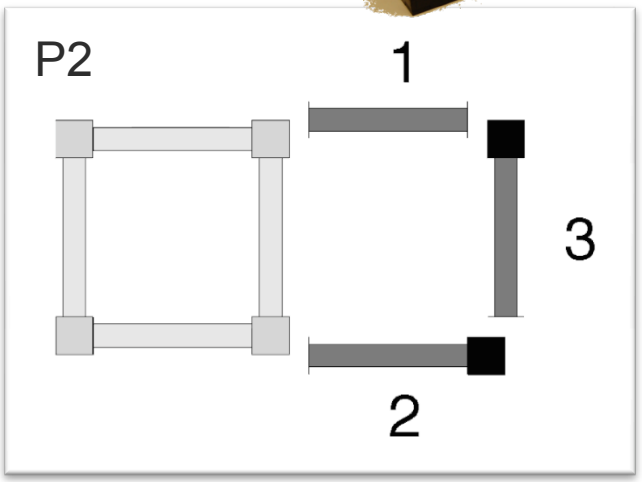
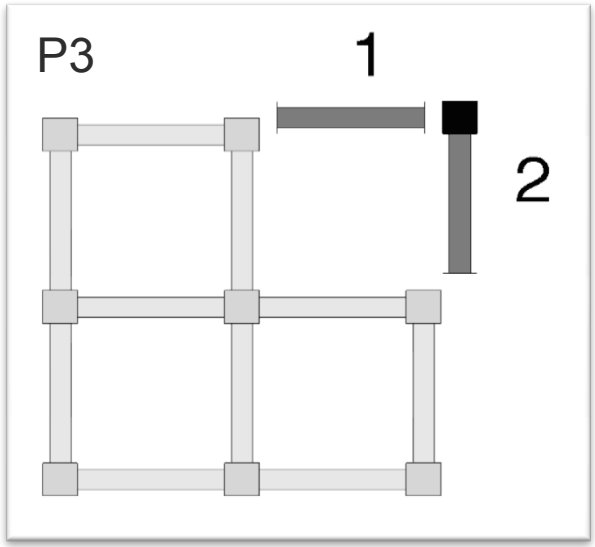
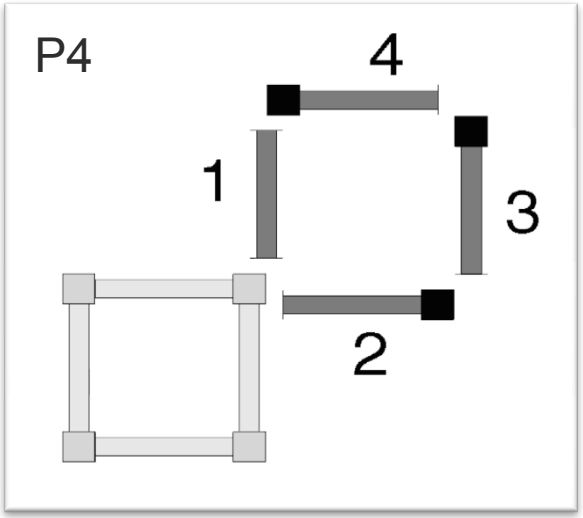
Assembly Primitives

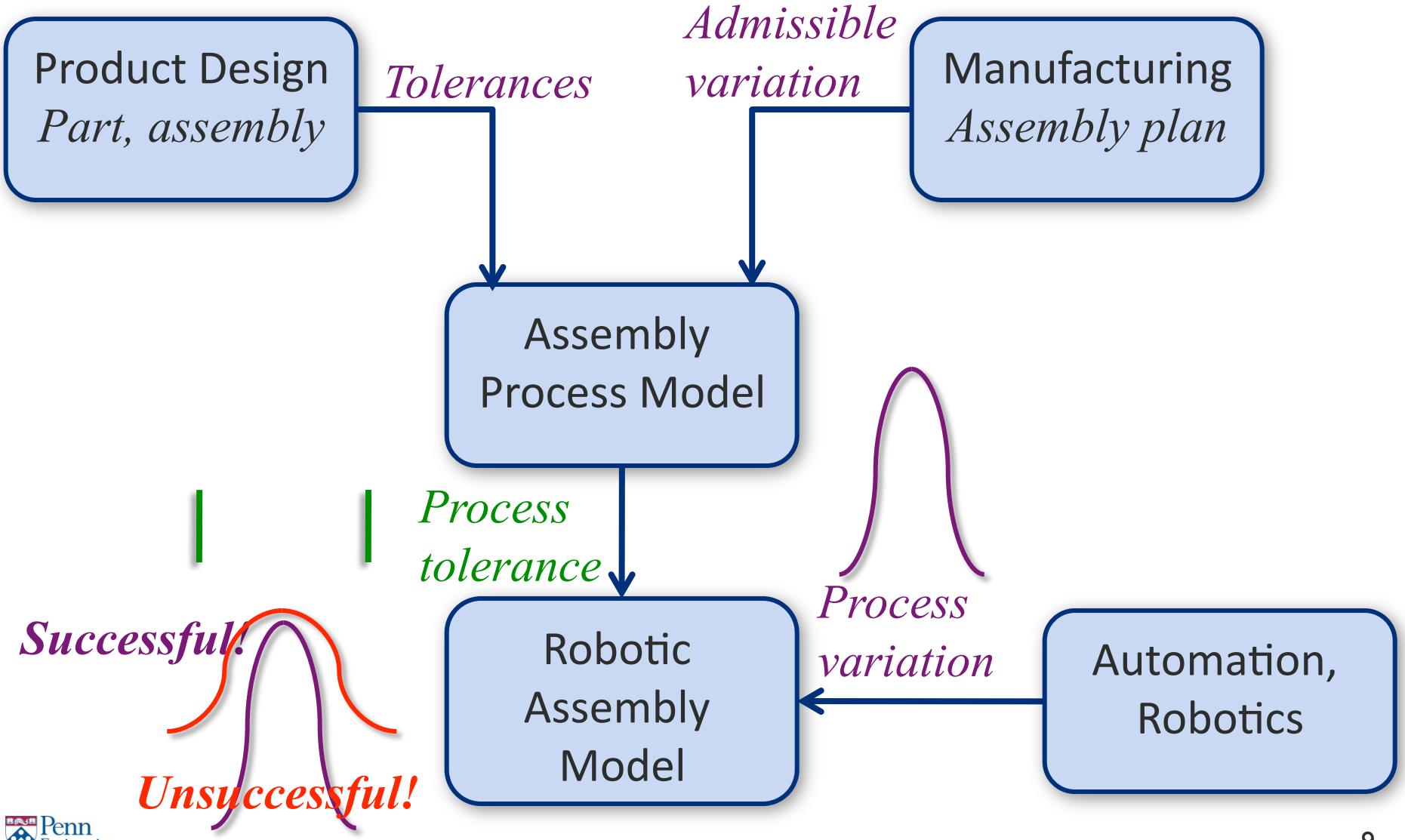




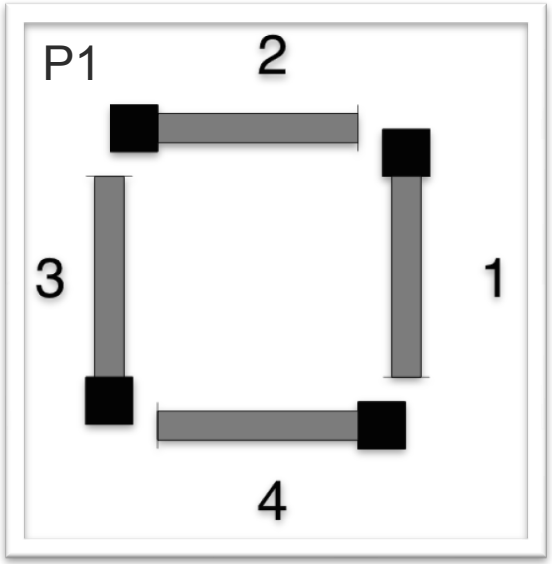


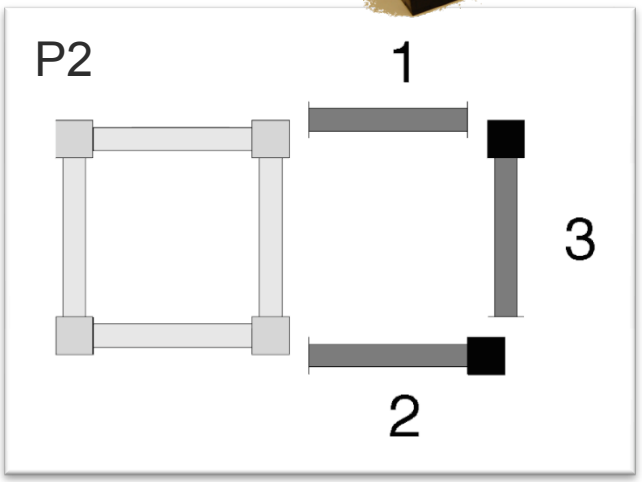


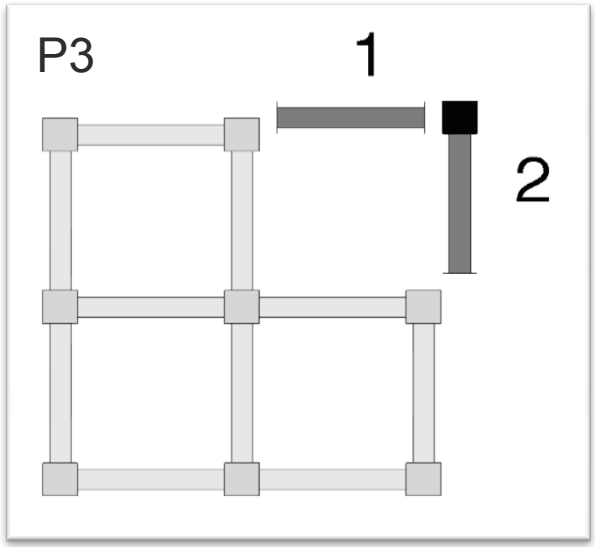
Tolerances and Variation

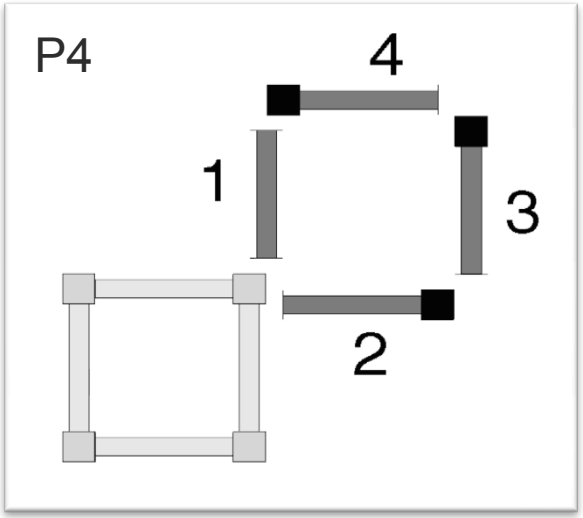


Assembly Primitives





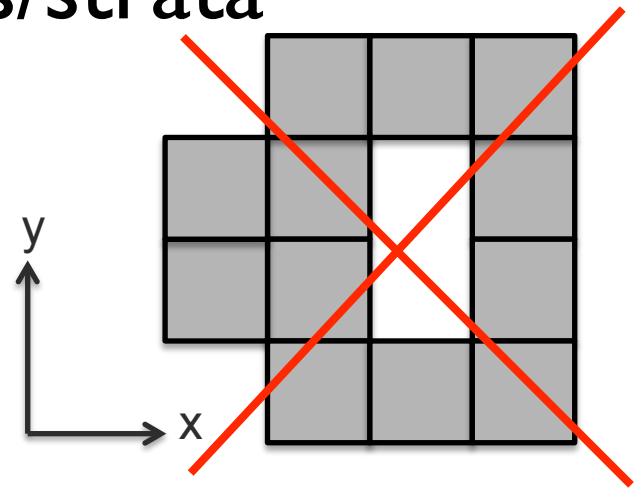




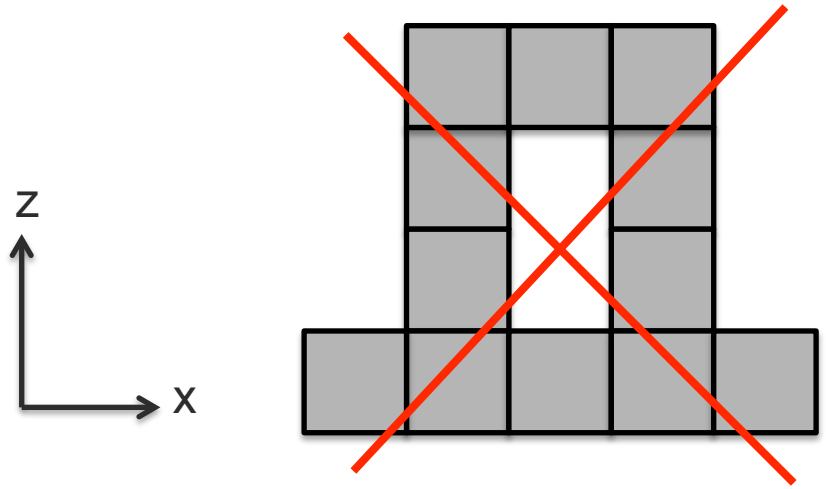
Special Cubic Structures

Structures consisting of layers/strata

- No holes in any 2D stratum



- No cantilevered sections



Wavefront Raster (WFR) Algorithm

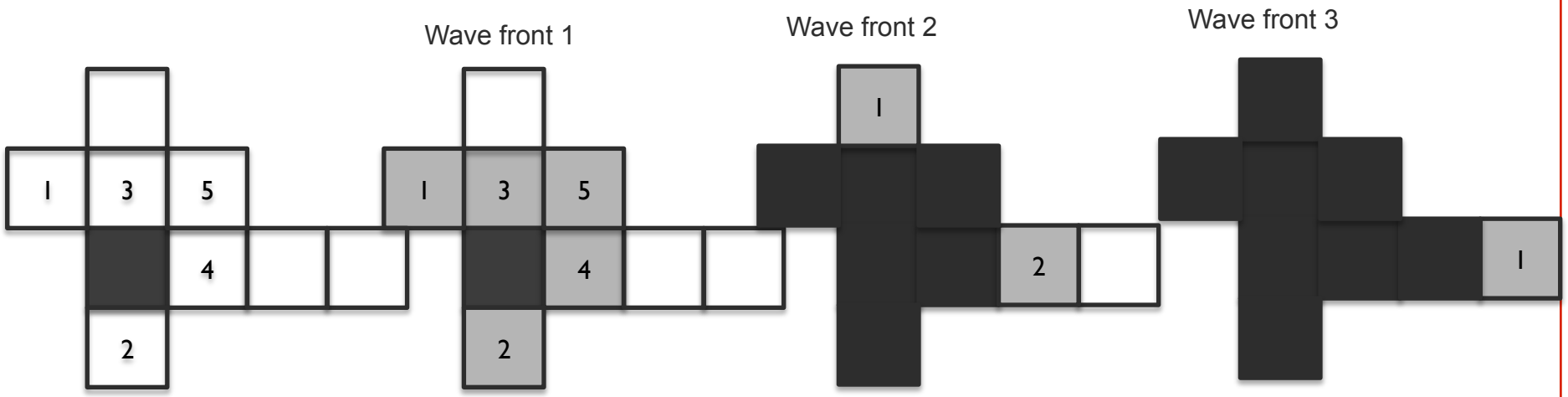
1: Build any square in the 2-D region

2: **while** not finished **do**

3: mark squares immediately connected to already built region

4: **for** (leftmost column) to (rightmost column)

5: build marked squares in column from bottom to top



Quad Rotors

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[Mellinger, Michael and Kumar, ISER 2010; Mellinger and Kumar, ICRA 2011]

Cooperative Grasping and Lifting

$$\mathbf{u}^* = \arg\min_{\mathbf{u}}\{\mathbf{J}|\mathbf{A}\mathbf{u} = \mathbf{w}\}, \quad \mathbf{J} = \sum_i \mathbf{f}_i^T \mathbf{Q}\mathbf{f}_i$$

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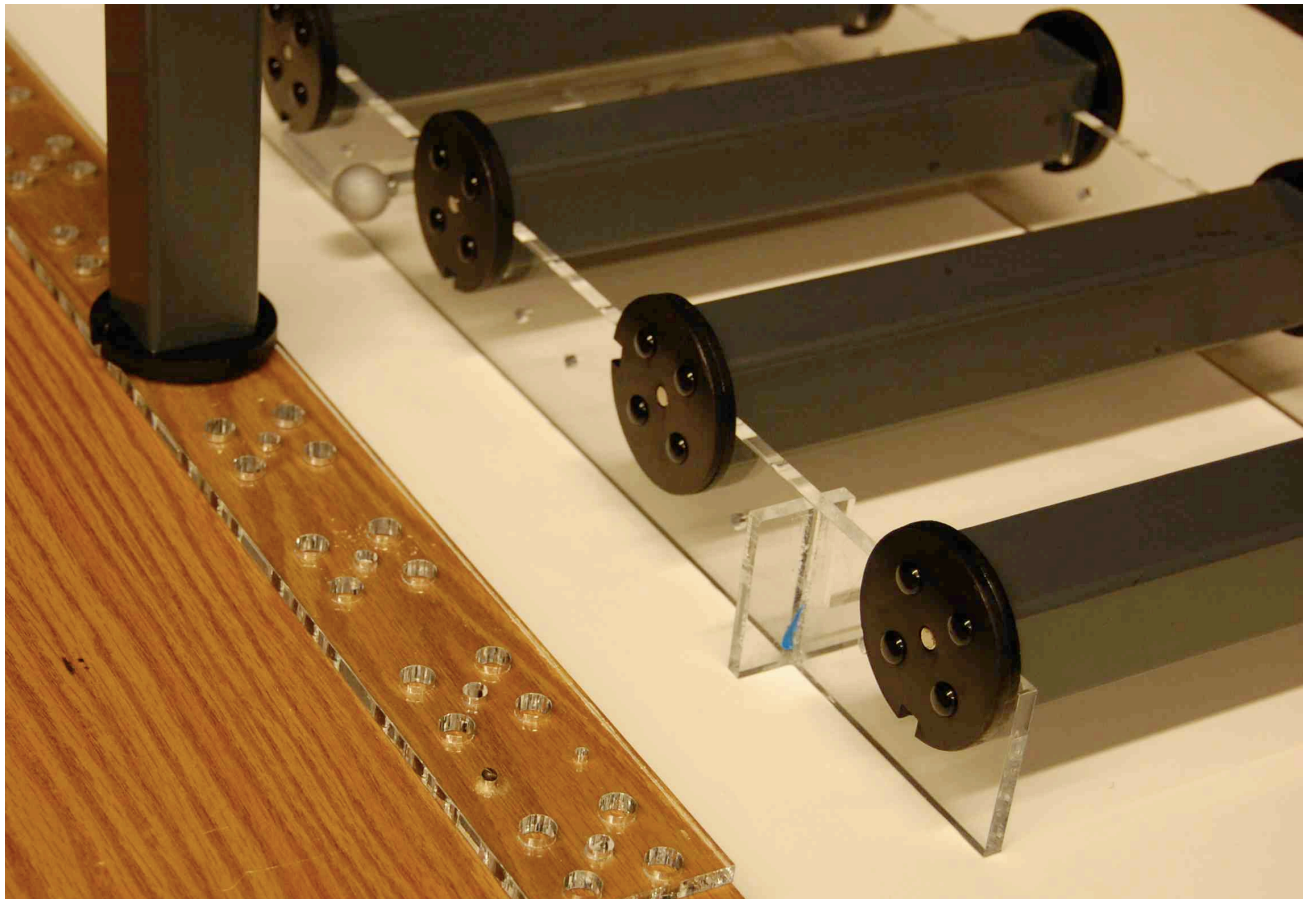
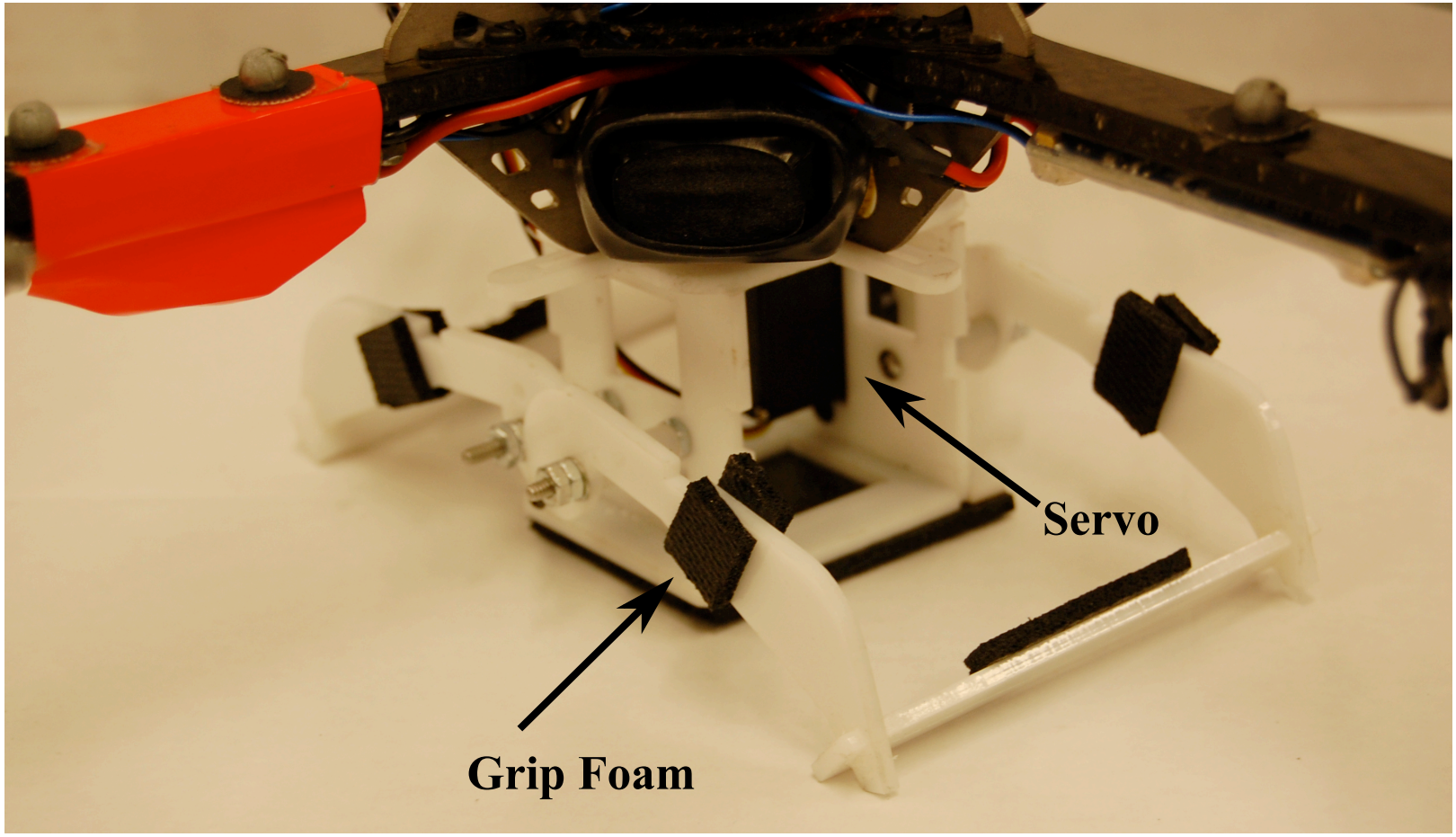
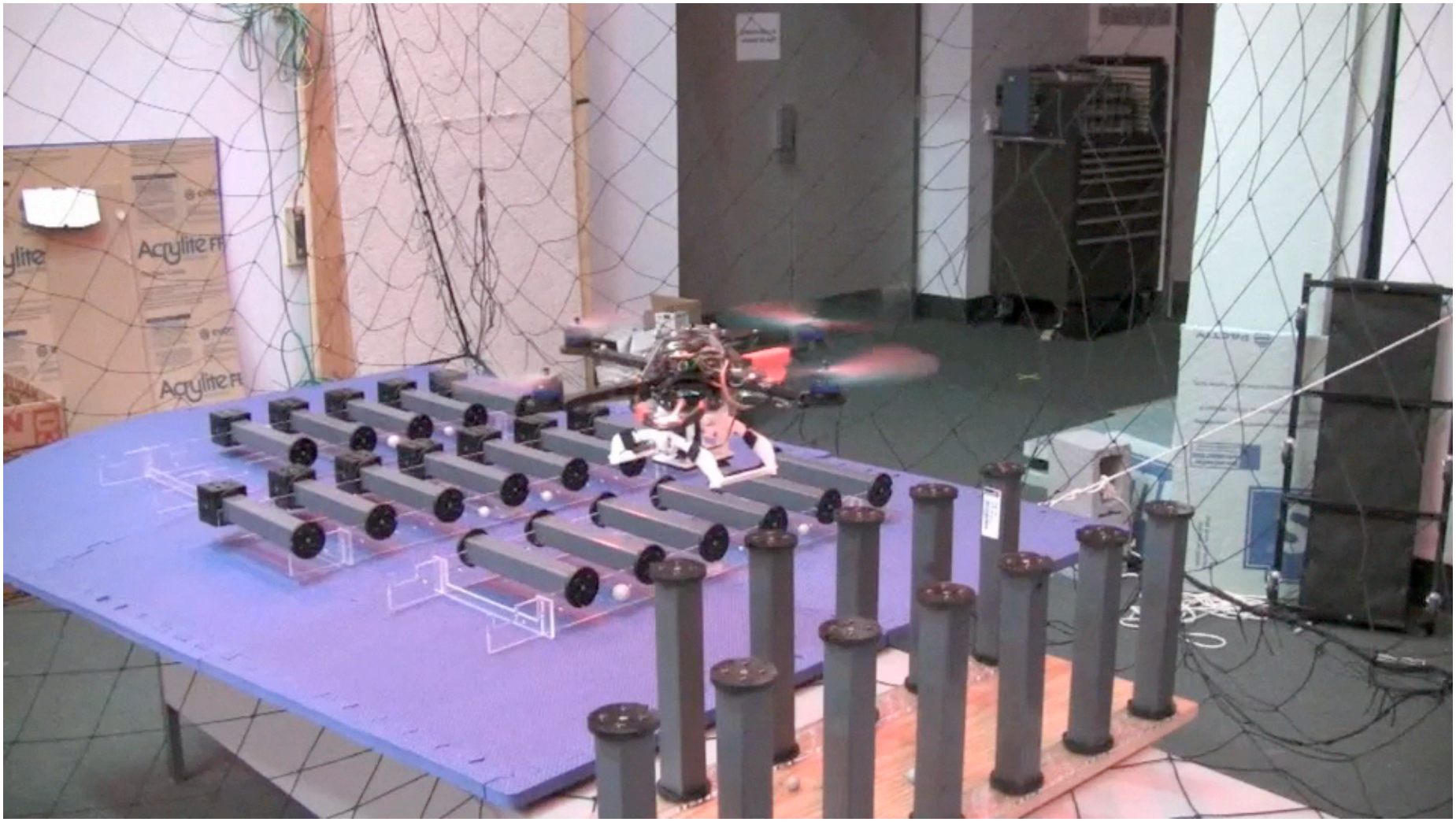
Part Bins



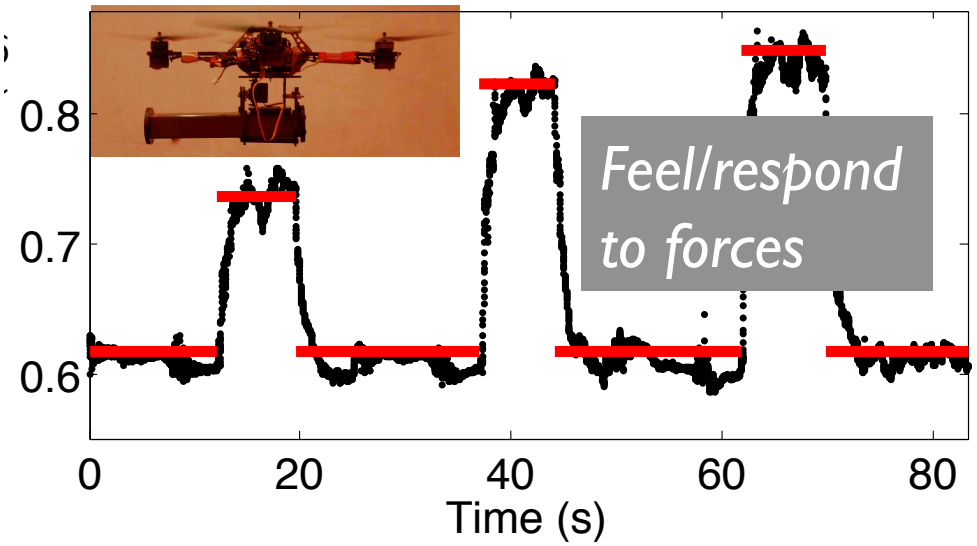
Gripper



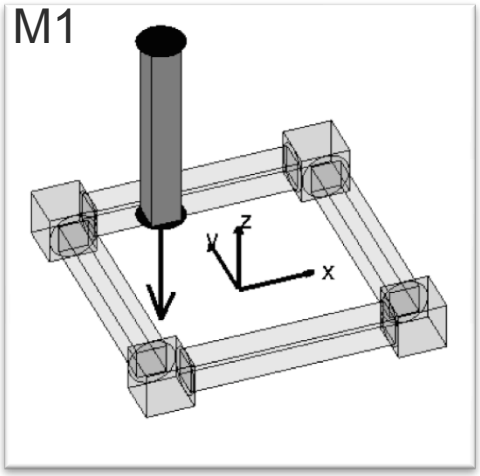

Acylite FF
Acylite FF

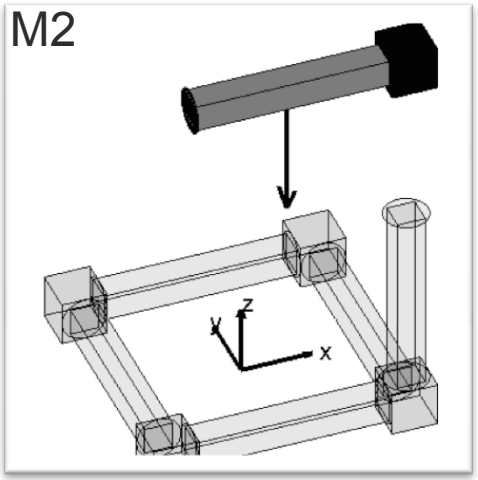
Force Feedback

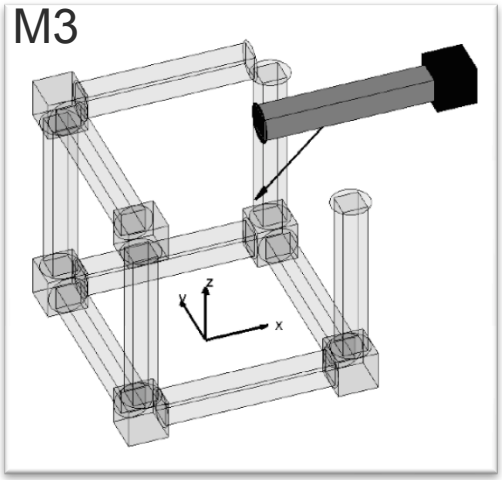
- Can estimate mass, moments of inertia
- Confirm stable prehension

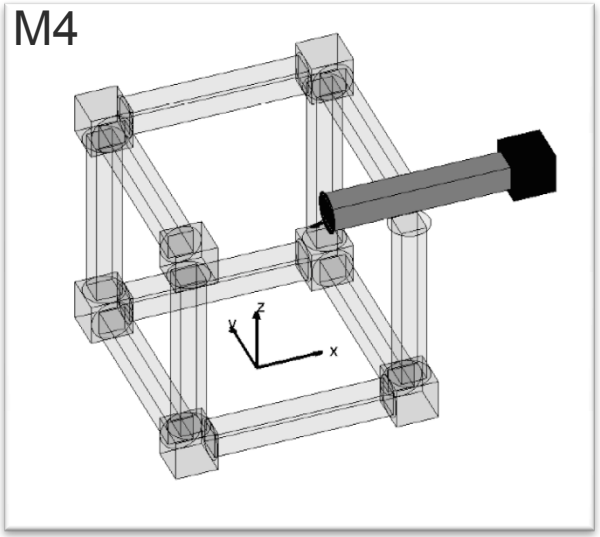


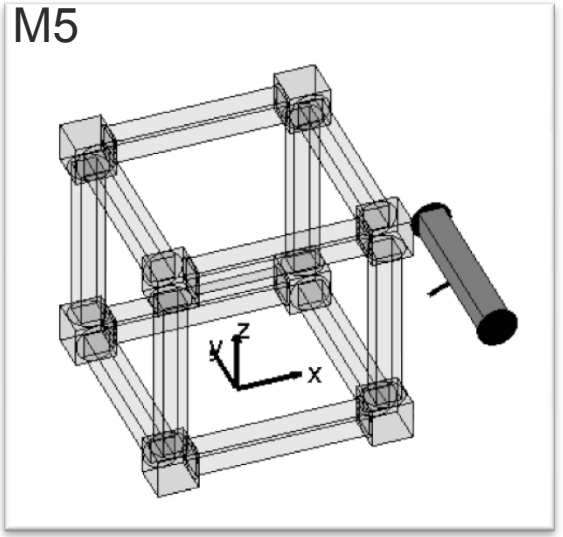
Assembly Modes











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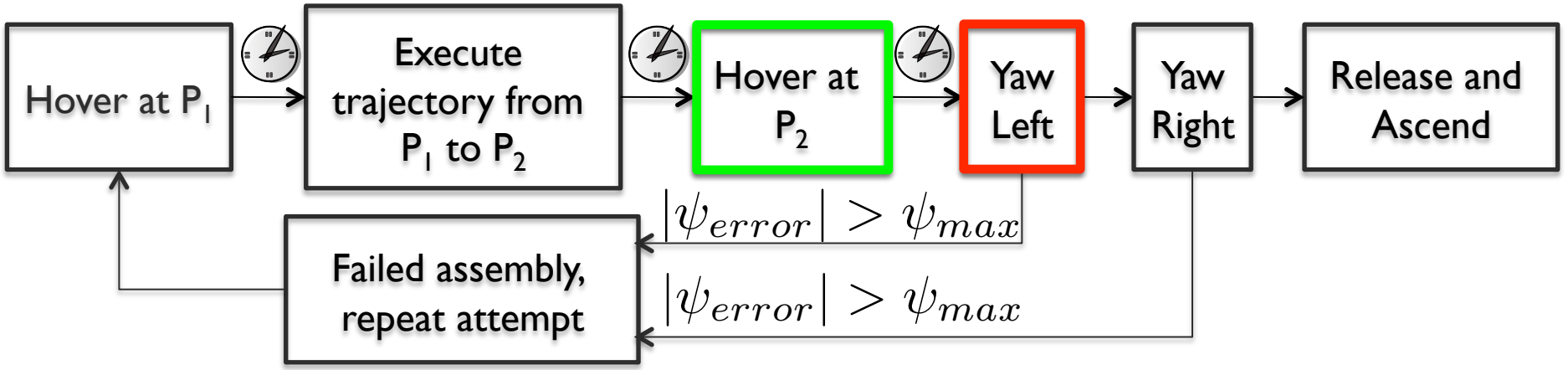
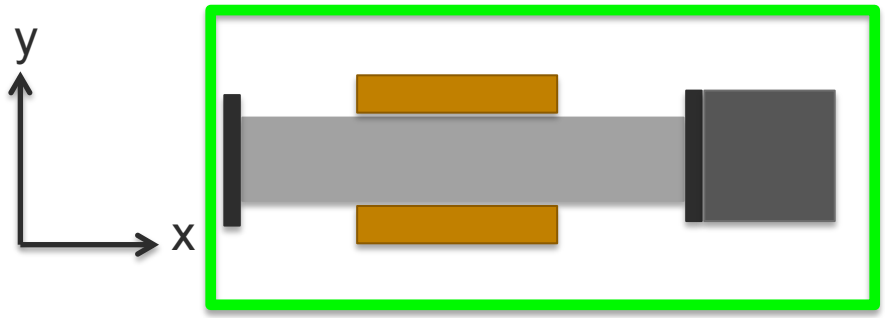
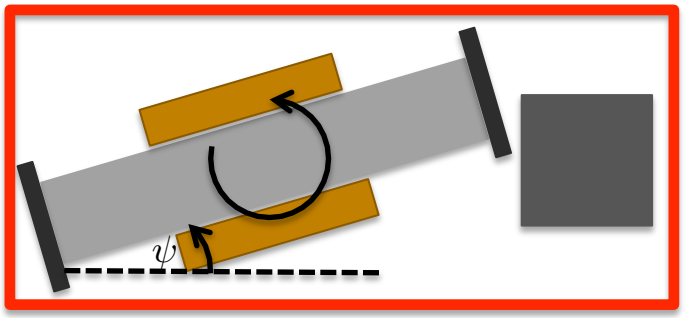
Assembly


Hover at P_1
Execute trajectory from P_1 to P_2
Hover at P_2
Yaw Left
Yaw Right
Release and Ascend
Failed assembly, repeat attempt
$|\psi_{error}| > \psi_{max}$
$|\psi_{error}| > \psi_{max}$


y
x


ψ

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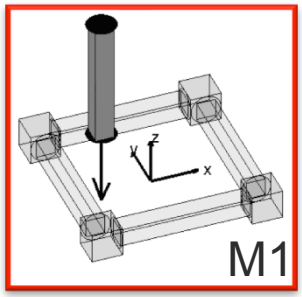
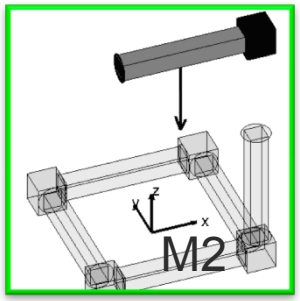
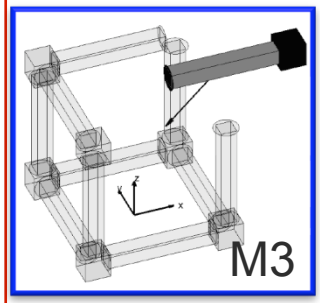
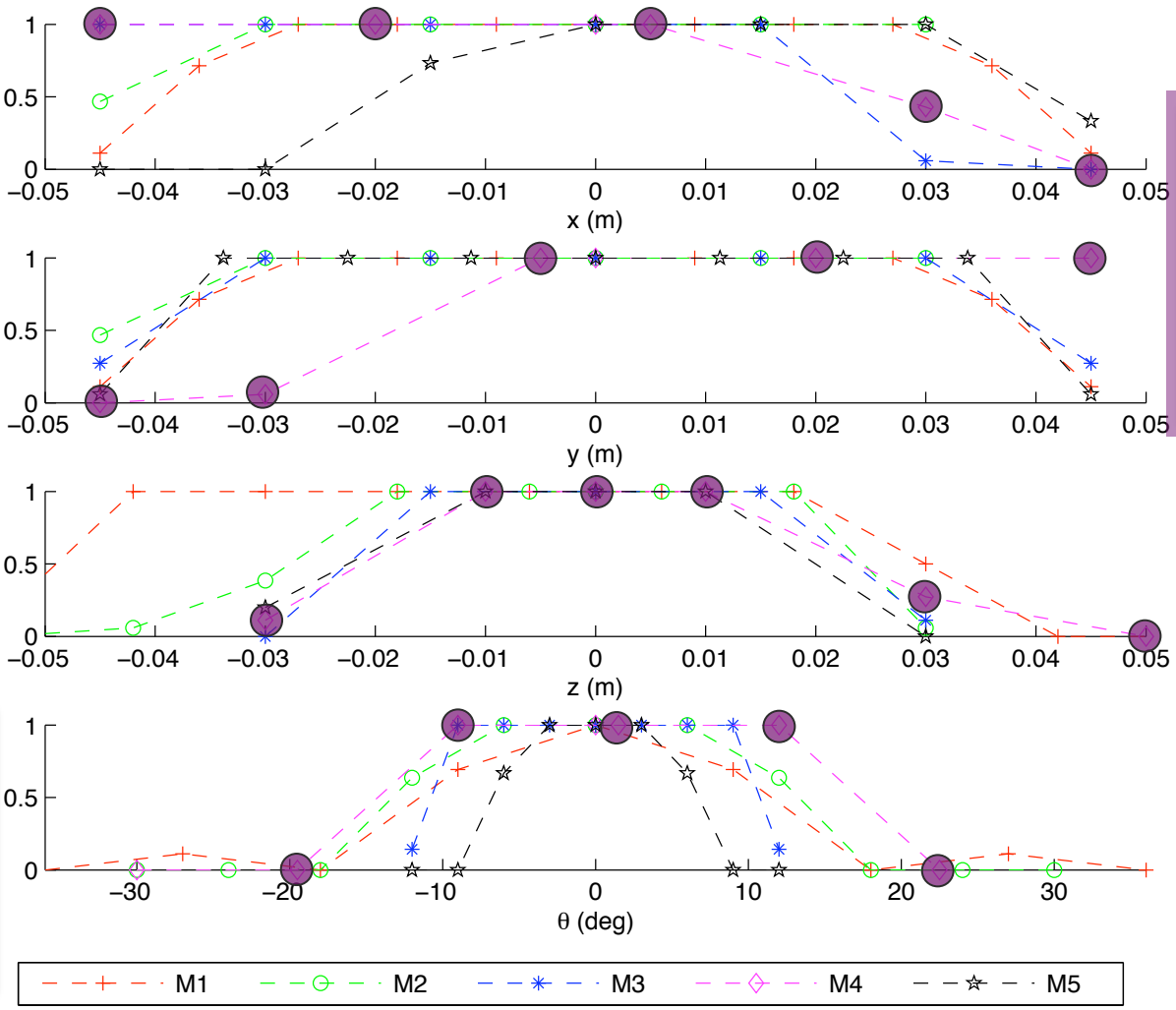
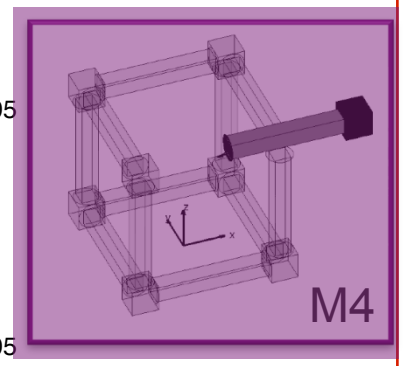
Assembly Errors

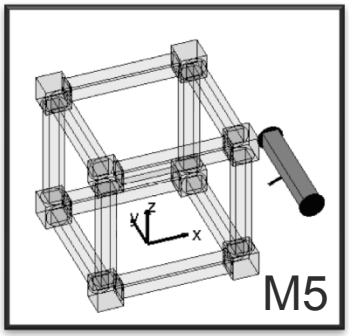


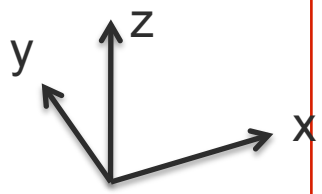












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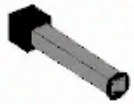
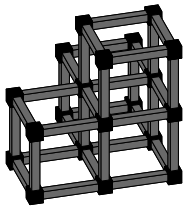
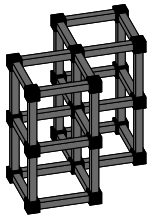
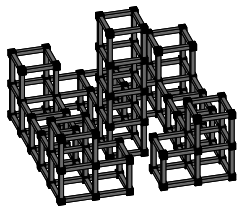


Assembly Results with Three Robots

Simulation

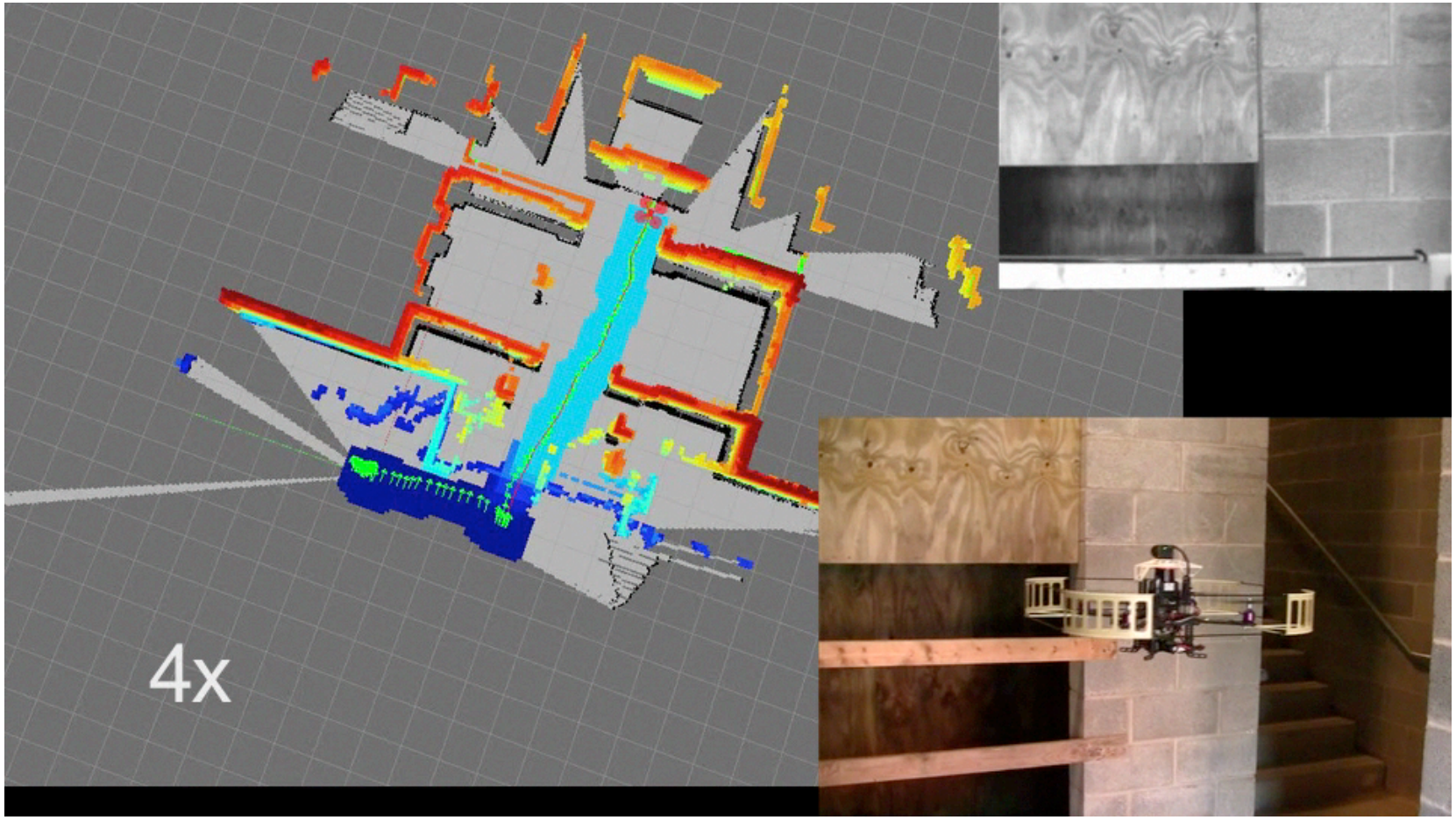
				
Number of Parts	32	34	40	192
Successful Attempts Trial 1 Trial 2	32 32	33 34	40 39	
Actual Time	449.6 450.7	486.6 486.2	588.2 587.3	
Column retries	5 5	3 1	8 3	
Beam retries	4 5	2 2	5 1	
Time (in simulation)	443.6	480.4	581.9	2642.0

Challenges

- Distributed assembly

Challenges

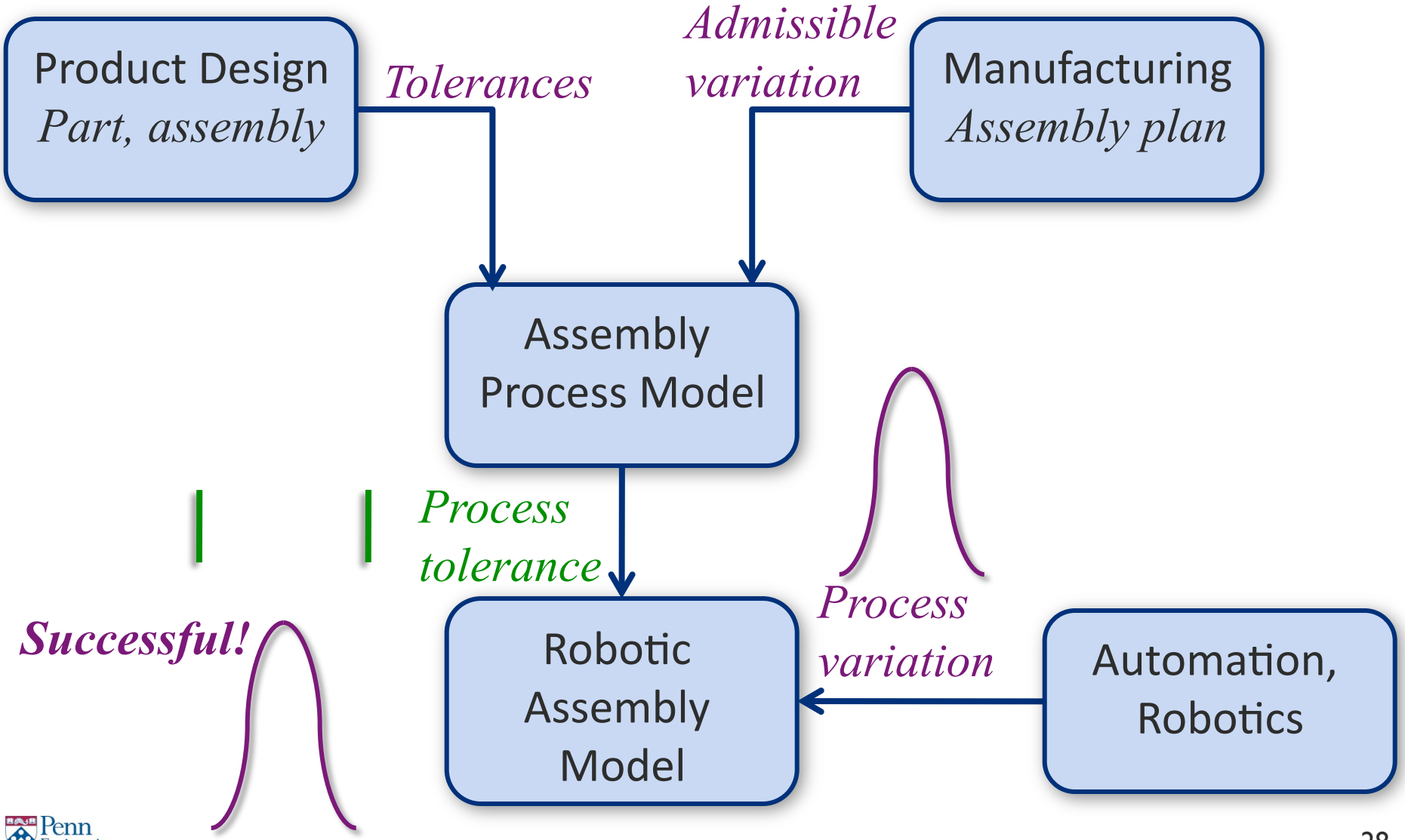
- Distributed assembly
- Unstructured environments



Challenges

- Distributed assembly
- Unstructured environments
- Part design and payloads

Robotic Assembly/Construction



Conclusion

- Agile, small, aerial robots create new opportunities for robotics
- SWAP constraints
- Force feedback enables adaptation
- Networks enable functionality beyond what can be achieved by individual robots