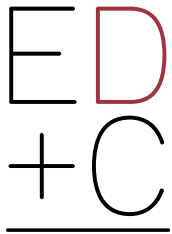


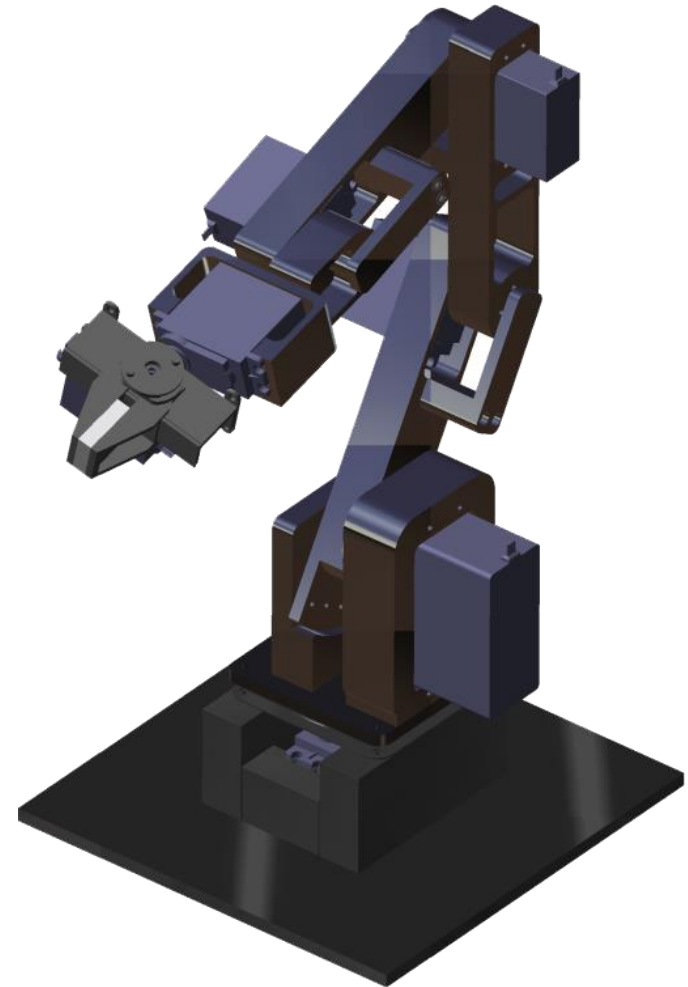
# Computational Design Synthesis and Optimization of Robots

Prof. Kristina Shea



# Challenges of Mechanical and Mechatronic Design Synthesis

- Multi-disciplinary: mechanical, electronic and software components
- A large number of different functional and behavioral elements
- Strong dependencies between geometry, behavior and function
- Complex 3D geometry parts and assemblies
- Complex geometric constraints
- Strong dependency between design and fabrication



# Computational Design Synthesis and Optimization



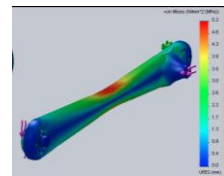
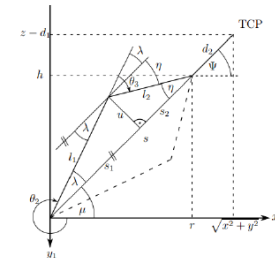
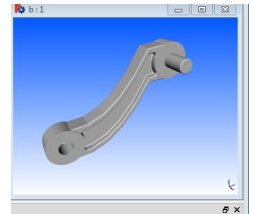
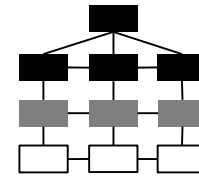
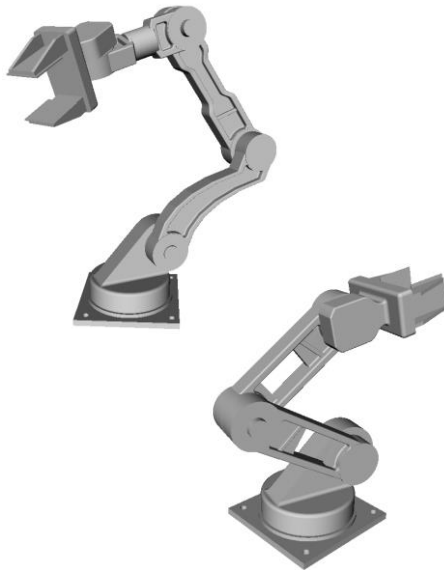
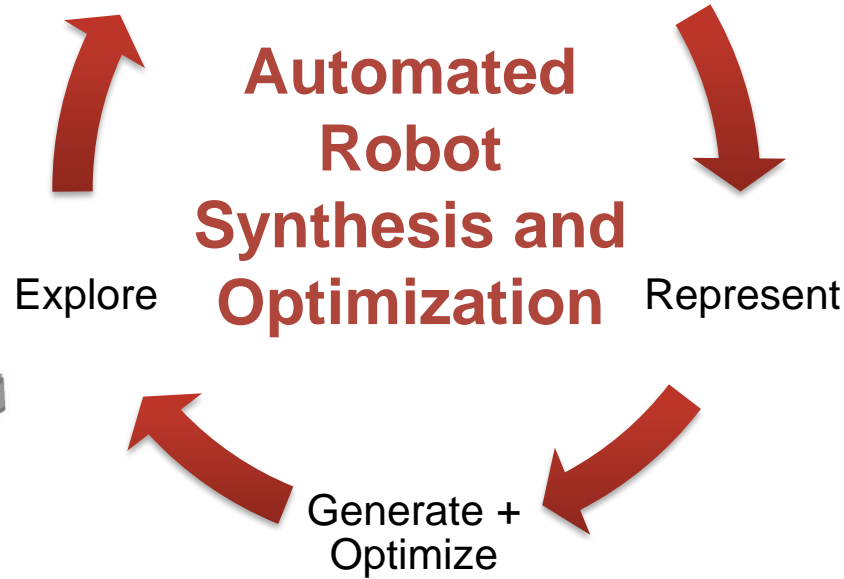
Fused Deposition Modeling



source: mired, TUM

Fabricate + Test

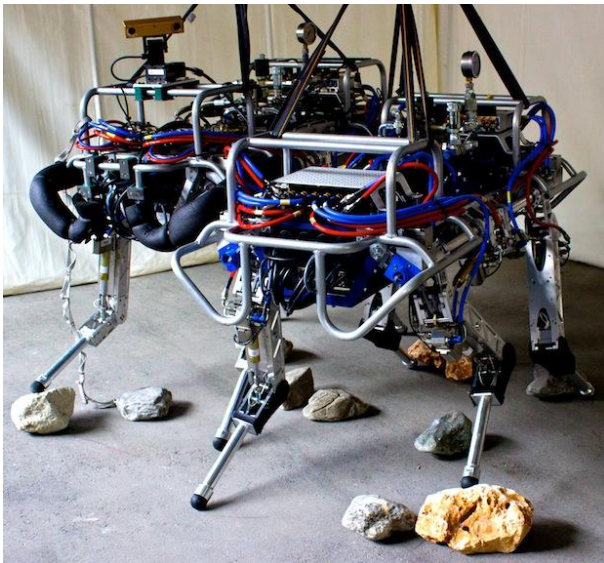
Specify Task



# Robotic Systems

## Active Robotic Systems

- Actuators and feedback control
- High task flexibility possible
- Responsive to environment
- High robustness



<http://www.adrl.ethz.ch/doku.php/adrl:robots>

## Passive Robotic Systems

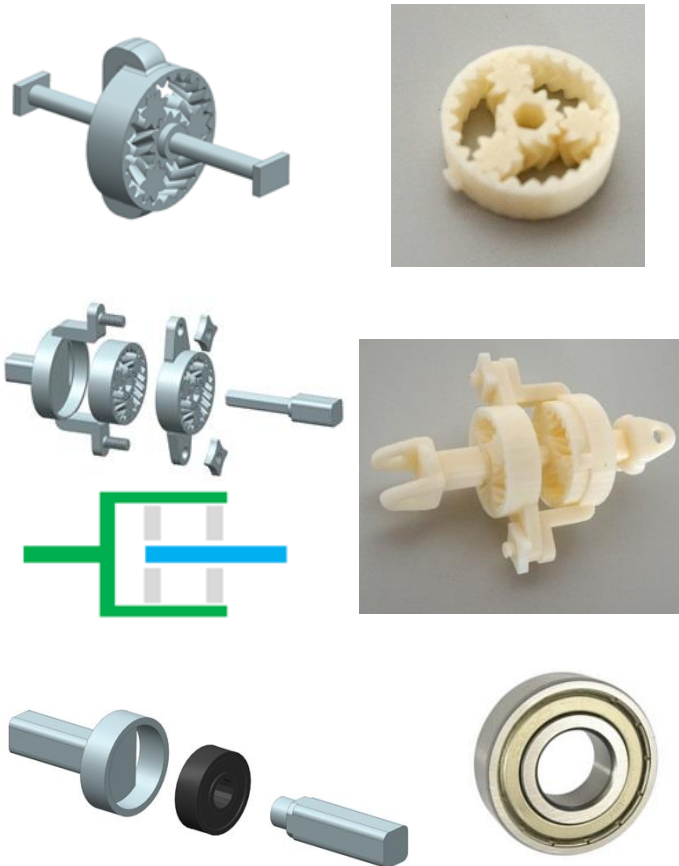
- No actuators and control
- No energy source necessary
- Potential to save energy



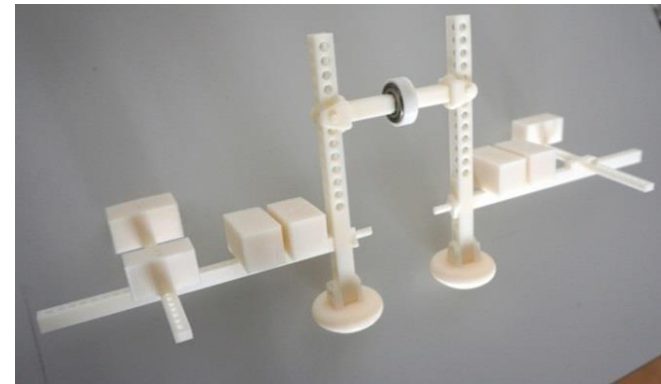
Passive dynamic walking, McGeer, T., 1990, International Journal of Robotics Research

# Prototyping of Passive Walking Robots using FDM (1)

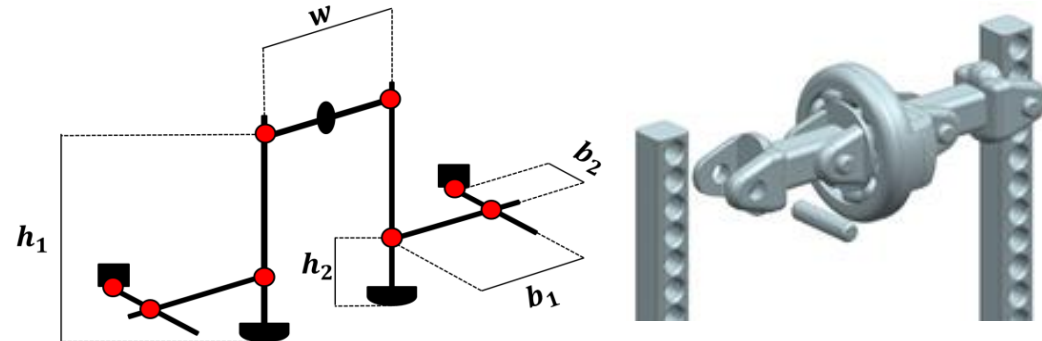
## Design of different bearings



## A modular design



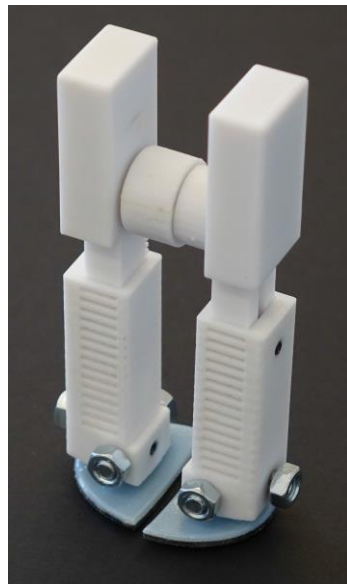
Design variables can be adjusted after printing



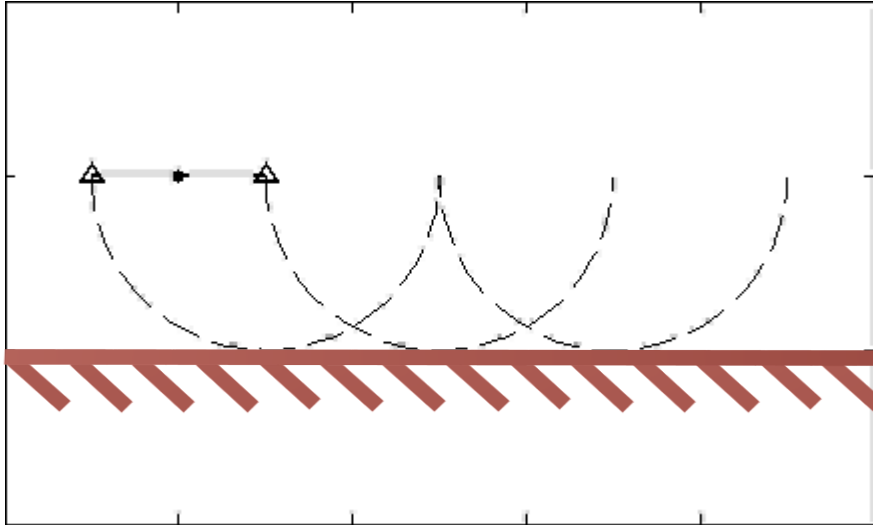
## Prototyping of Passive Walking Robots using FDM (2)



“Designing Passive Dynamic Walking Robots for Additive Manufacture”,  
Stöckli, Modica and Shea.  
Rapid Prototyping Journal, 22(5): 842-847, Bradford: Emerald, 2016.  
DOI: 10.1108/RPJ-11-2015-0170

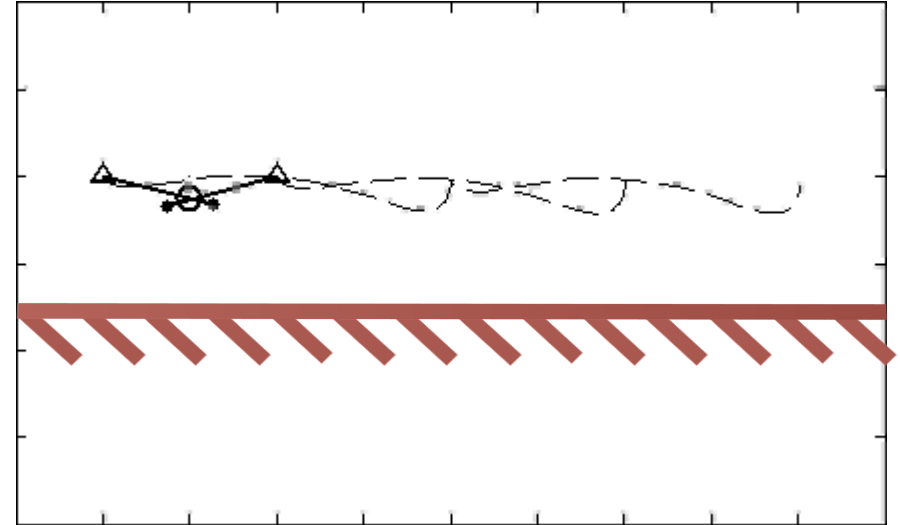


# Computational Design Synthesis of Passive Dynamic Robots



## Single Pendulum

- Simplest possible solution



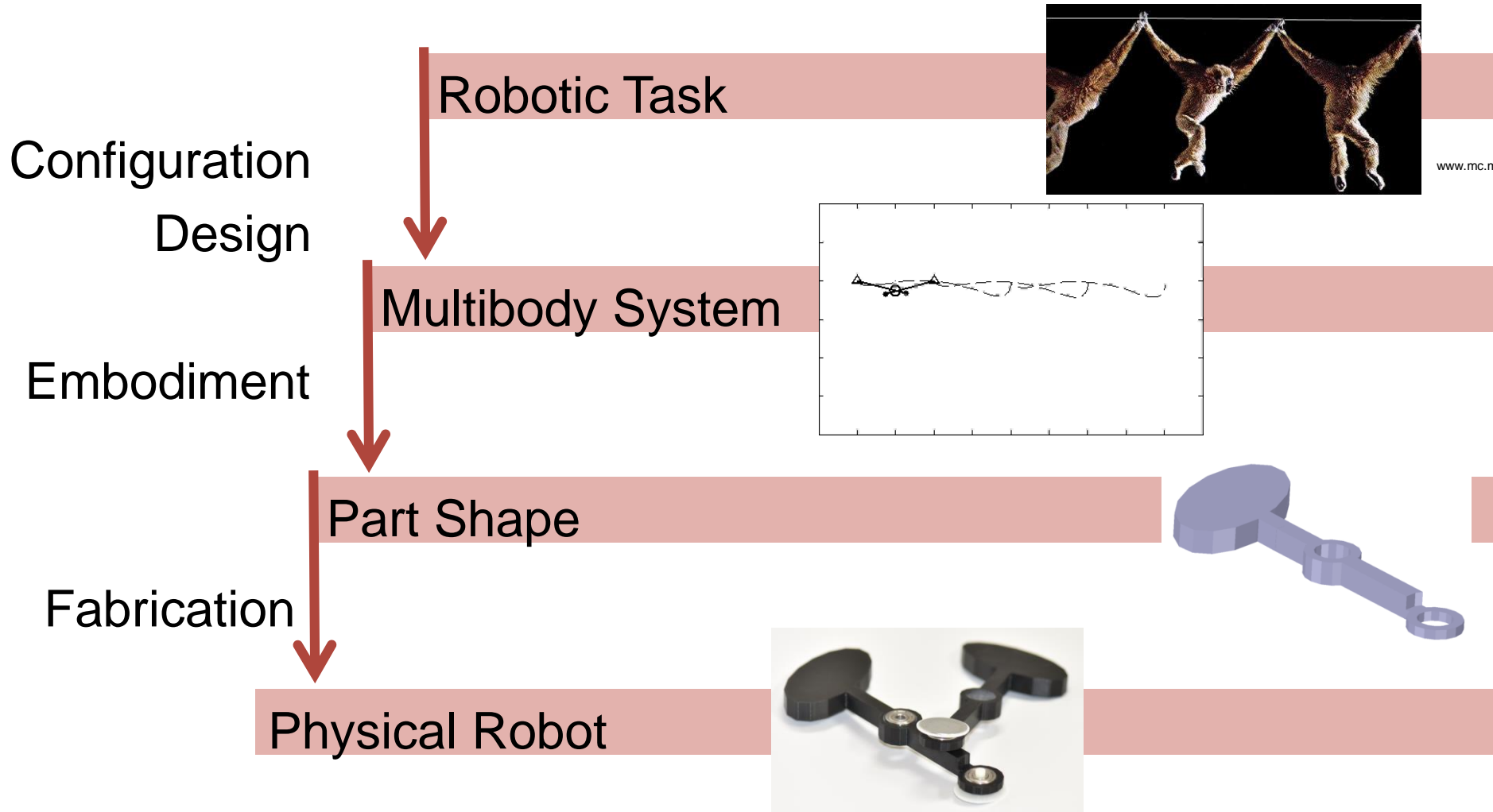
## More Complex Solutions

- Can require less space
- Can provide visual interest

“Automated Synthesis of Passive Dynamic Brachiating Robots Using a Simulation-Driven Graph Grammar Method”,  
Stöckli and Shea, Journal of Mechanical Design, 139(9), pp. 092301, New York, NY: American Society of  
Mechanical Engineers, 2017.  
DOI: 10.1115/1.4037245



# Computational Design Synthesis of Brachiating Robots





# Results – Design Space

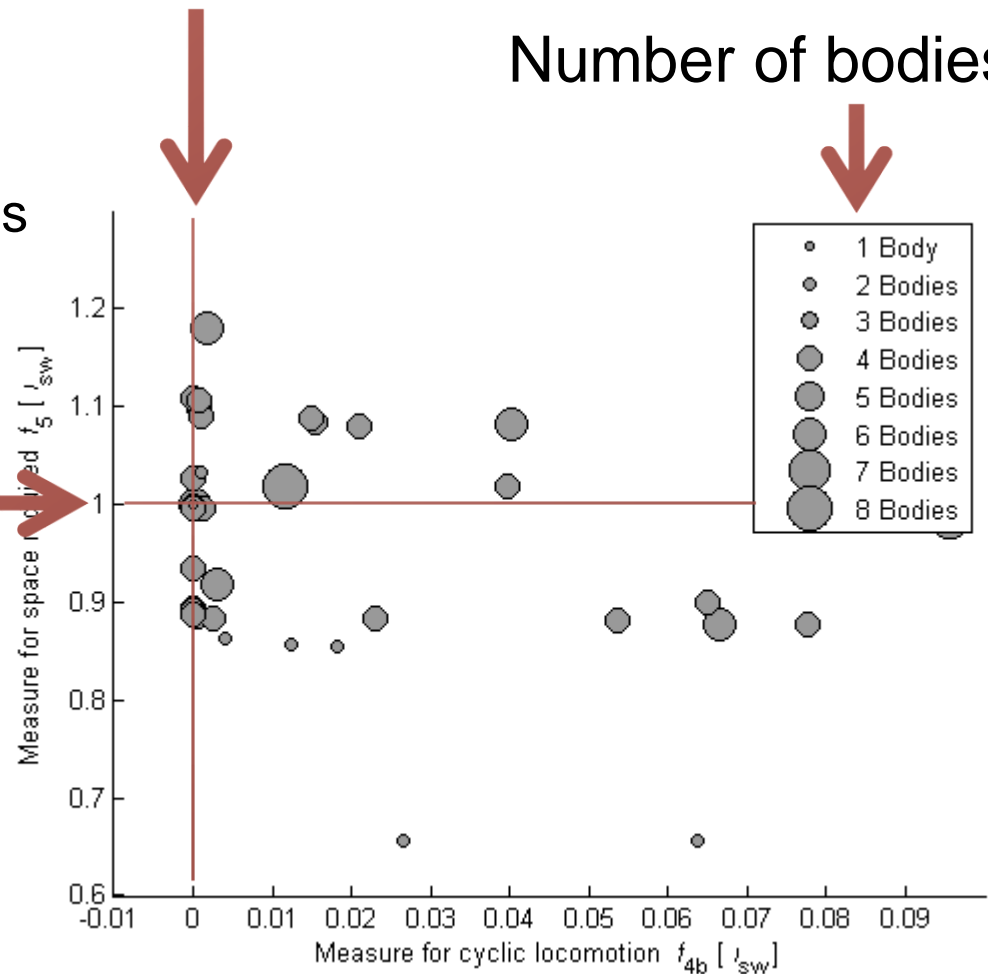
## Evaluation Plot

- Final populations of eight different topologies
- All do three successful swings
- Three Objectives:

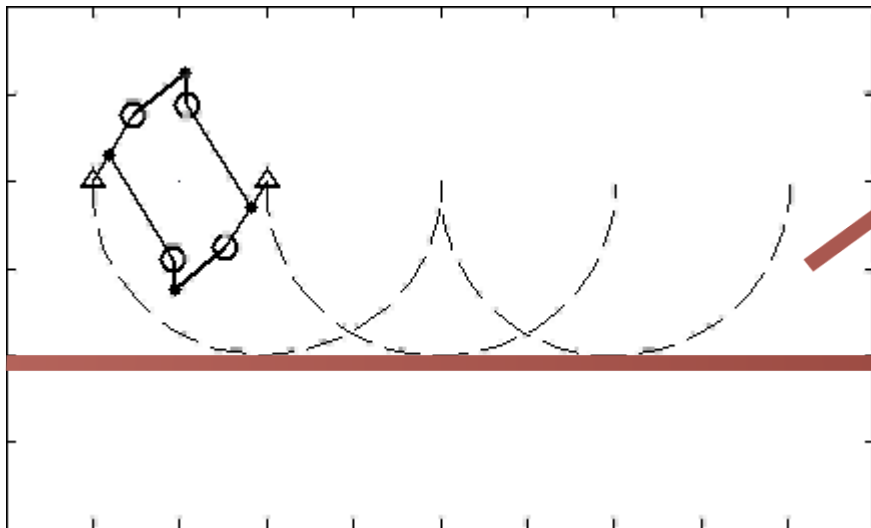
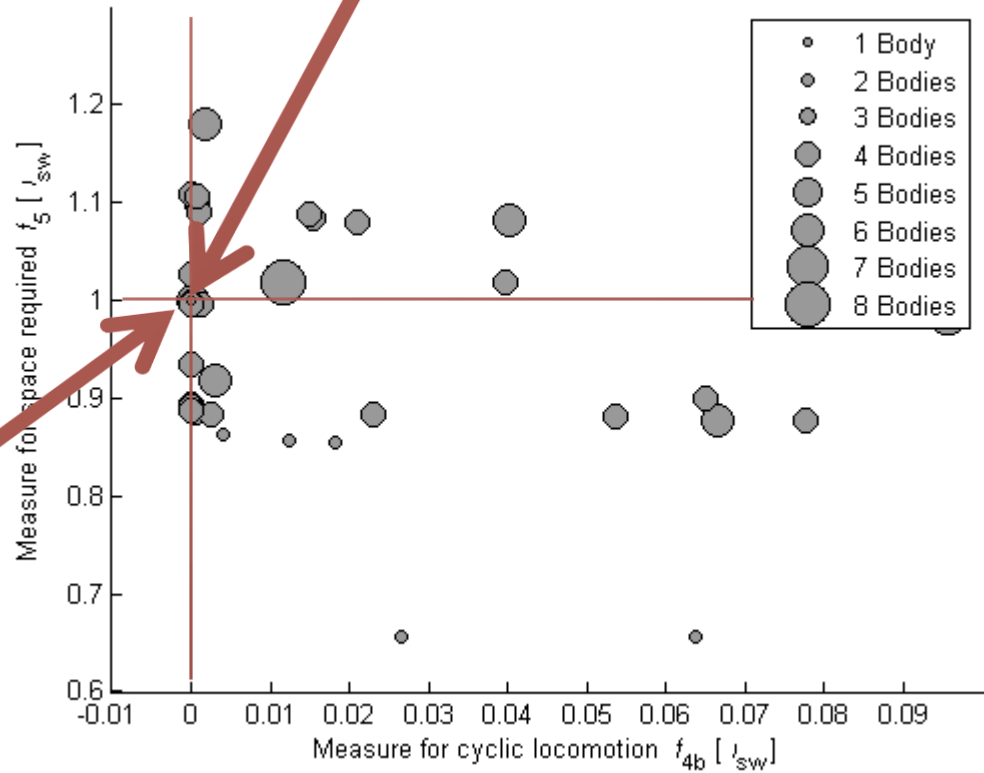
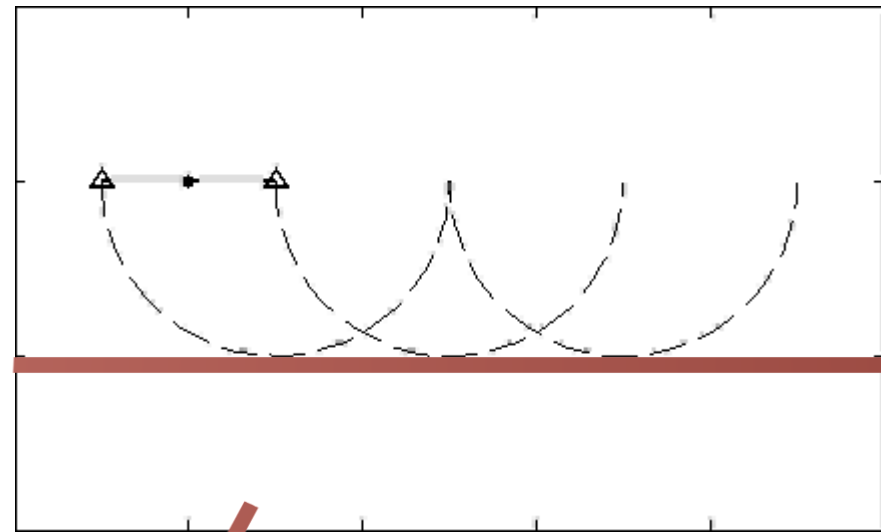
Space requirement  
of single pendulum

Ideal cyclic locomotion

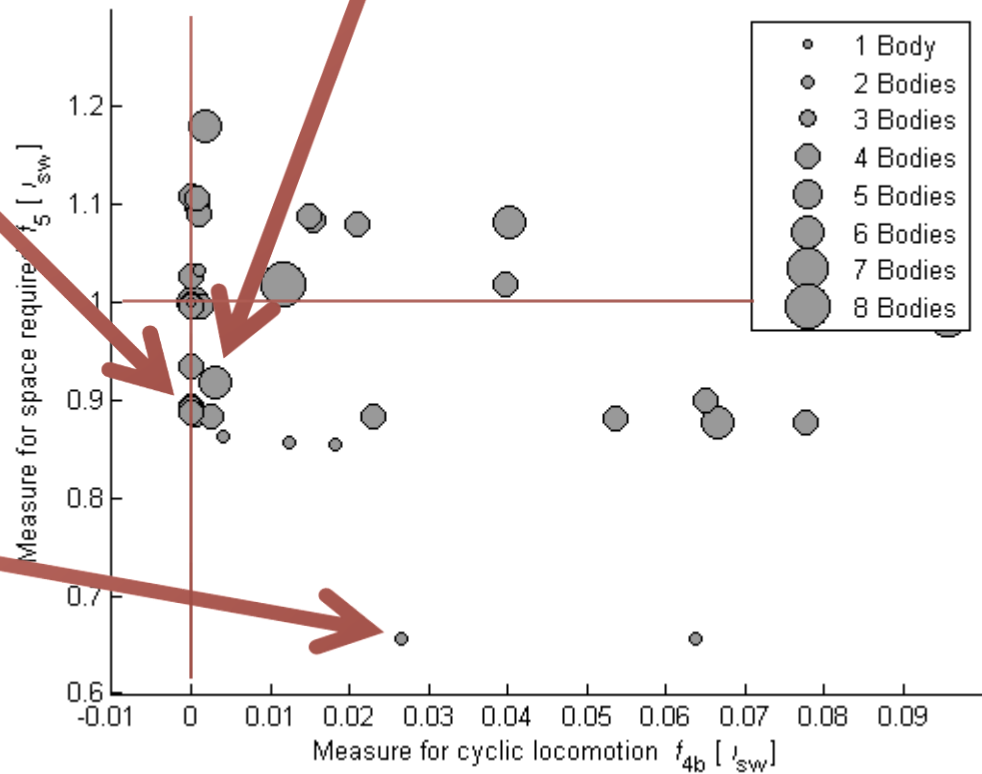
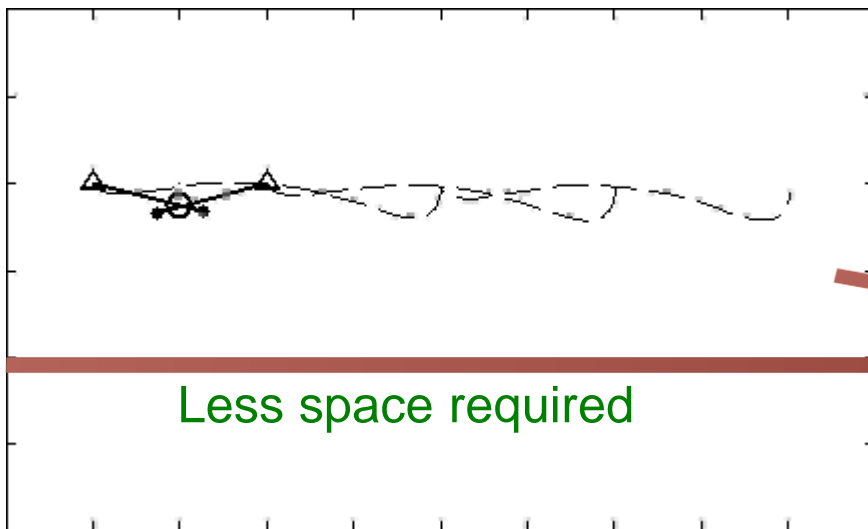
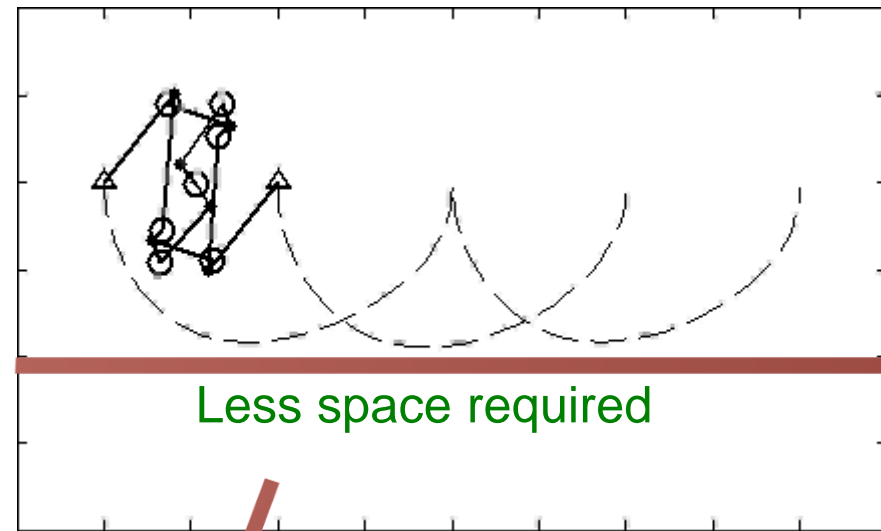
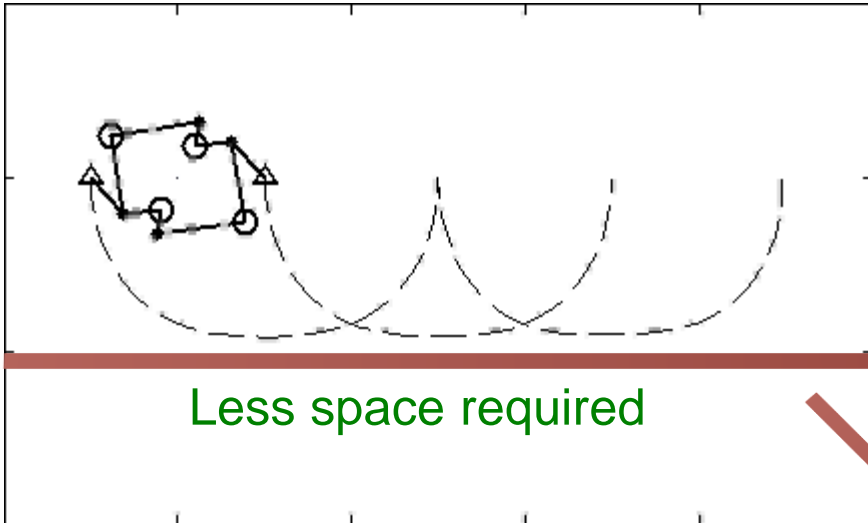
Number of bodies



# Results

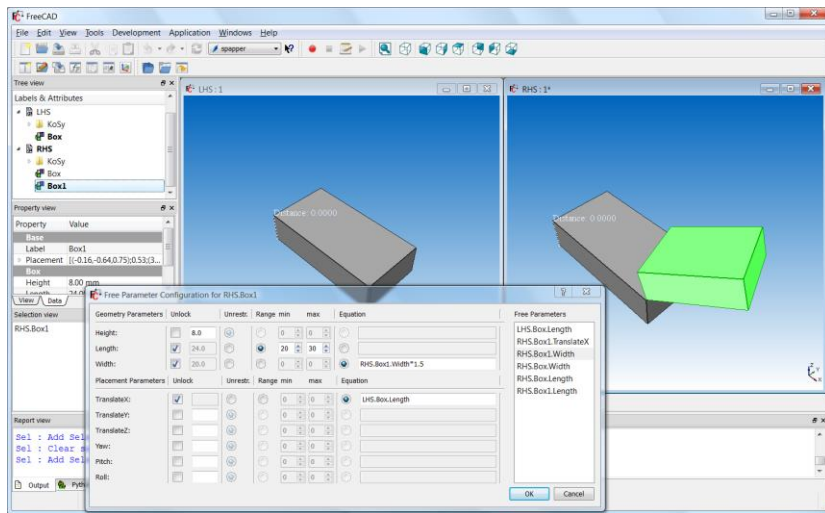


# Results



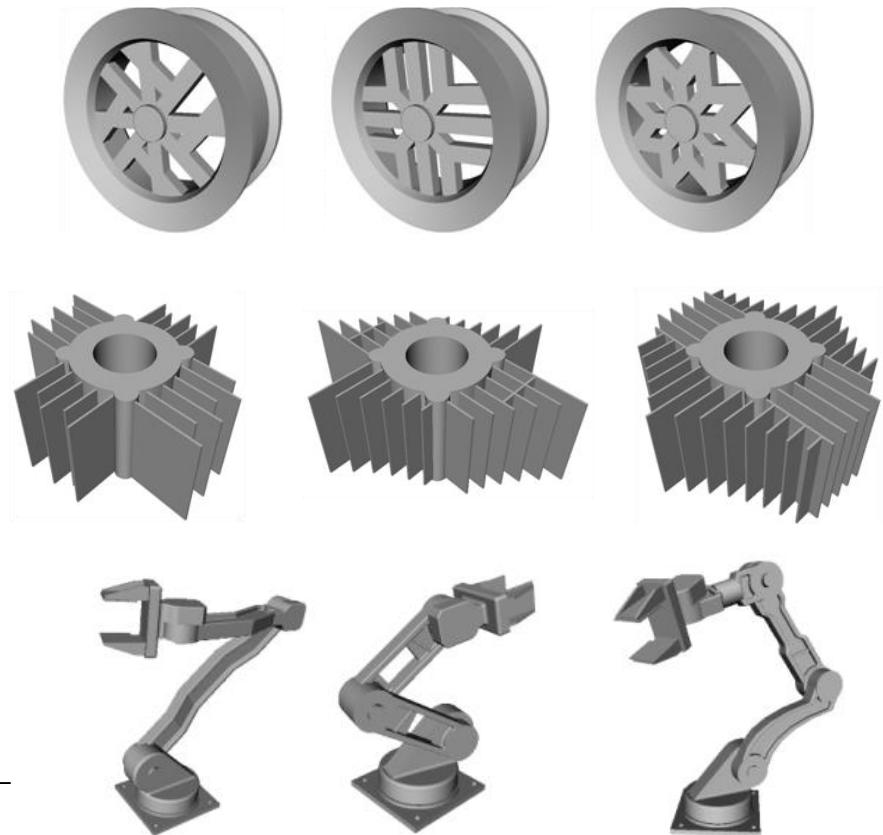
# CAD-Based Generative Design

An interactive environment for parametric spatial grammar rule definition, generative design and search space exploration.



<https://sourceforge.net/projects/spapper/>

Hoisl, F. and Shea, K. (2011) "An Interactive, Visual Approach to Developing and Applying Parametric Three-Dimensional Spatial Grammars", *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 25 (4): 333 – 356.





# Spatial Grammars

Rule R:  $A \rightarrow B$

$C' = C - t(A) + t(B)$

Shape Grammar  $G = (S, L, R, I)$

S finite set of shapes

L finite set of labels

R finite set of rules

I the initial shape where  $I \in (S, L)^0$  (vocabulary)

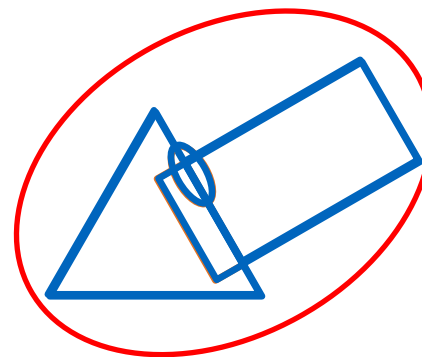
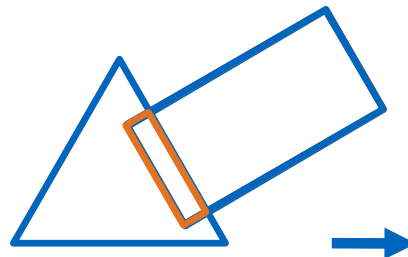
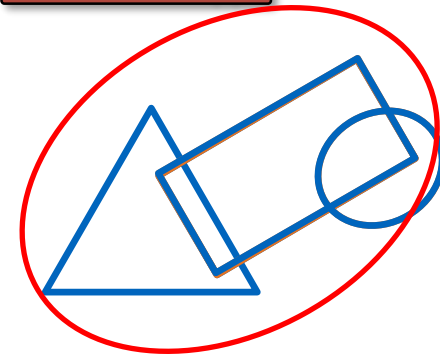
Rule (R)



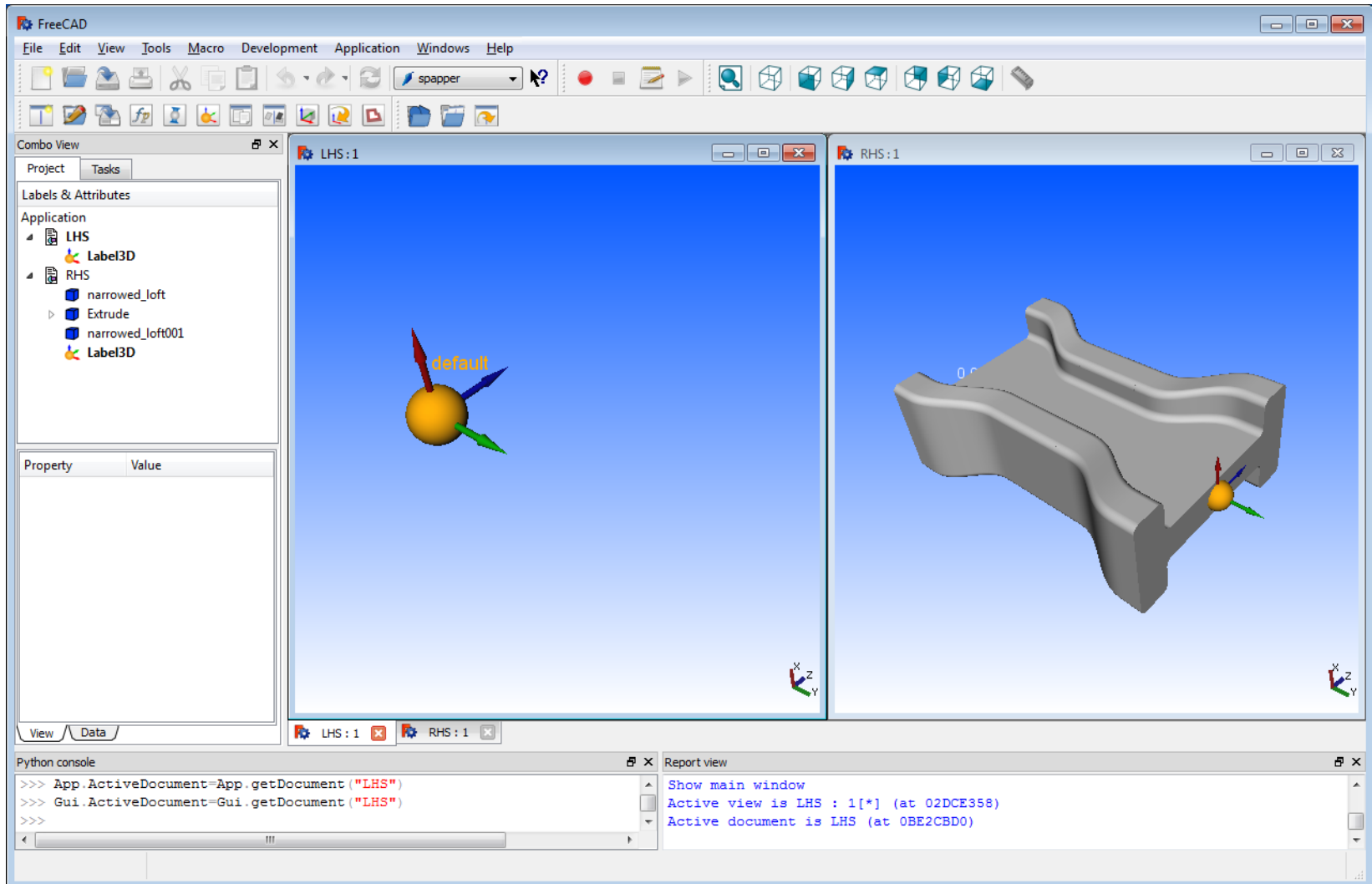
Object (A)



Matching  
Condition (t)

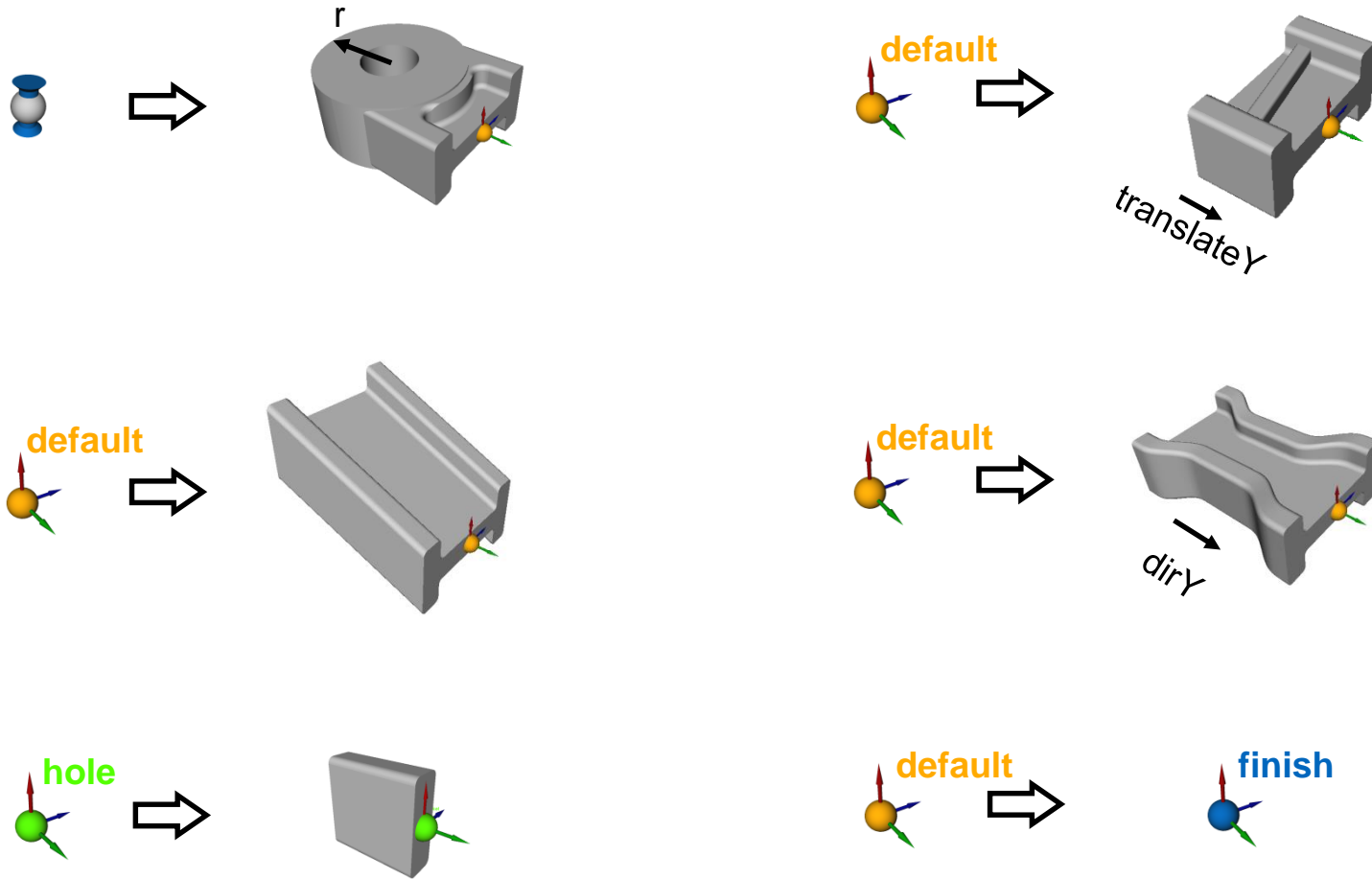


# Robot Arm Concepts – 3D Labels

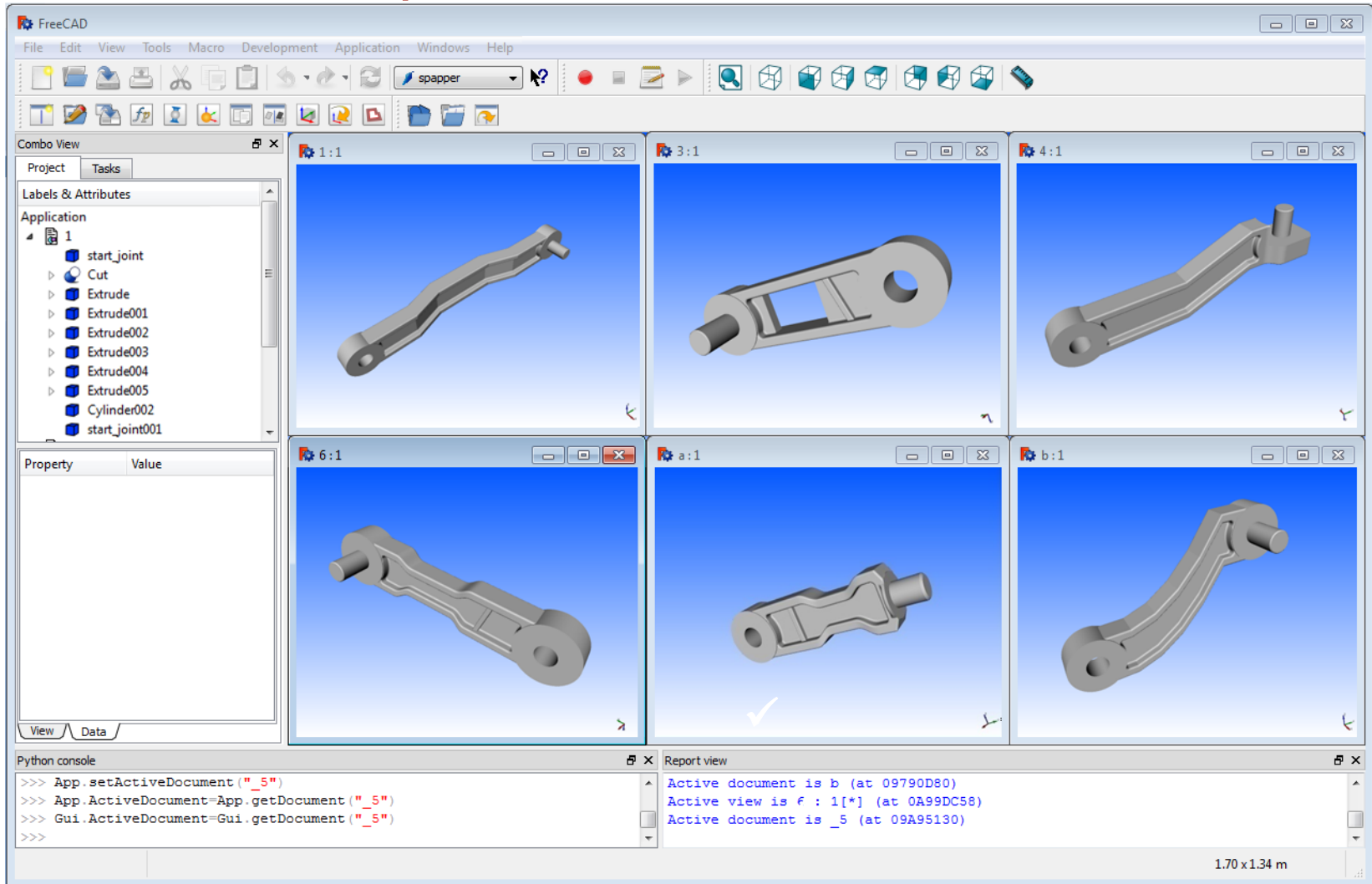




# Robot Arm Components – 3D Labels



# Generated Components

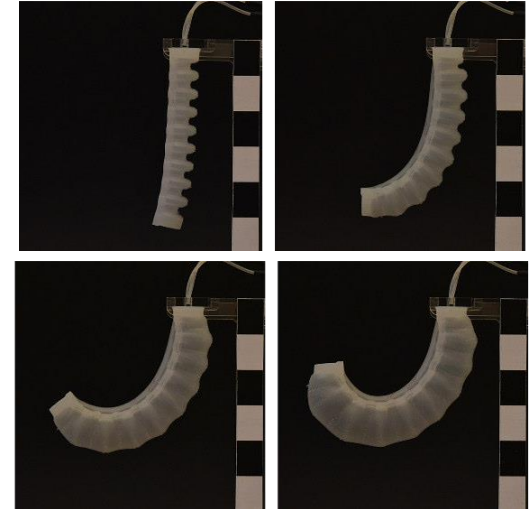
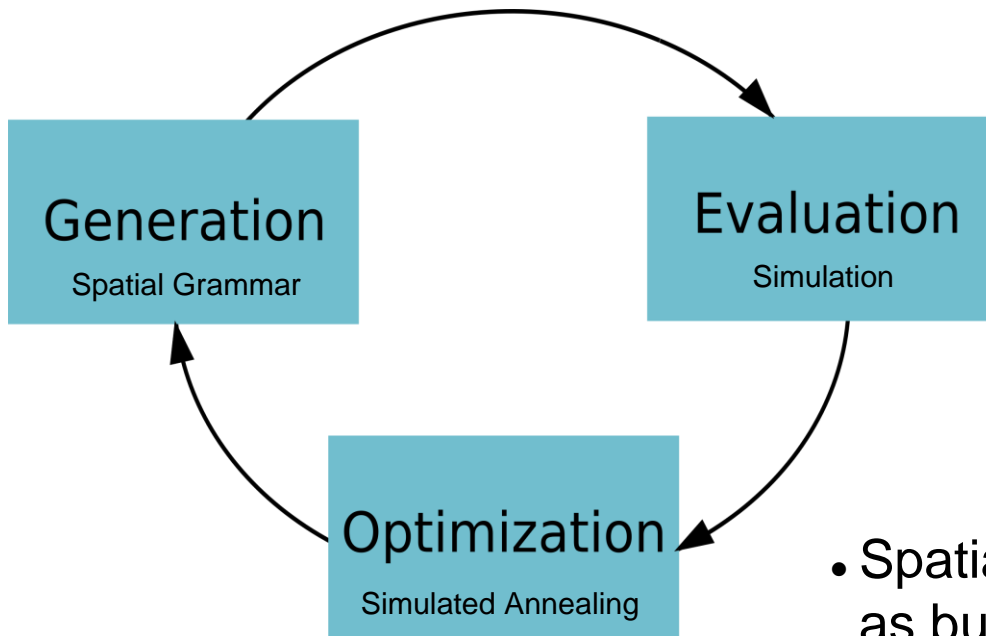


# Generated Robot Arm Concepts



- ✓ parameterized primitives
- ✓ parametric rules
  - ✓ - shape complexity
  - ✓ - constraints
- ✓ Boolean operations,
- ✓ sweeping
- ✓ collision detection
  - ✓ - part collision avoidance
  - ✓ - design space restriction
- ✓ 3D labels
  - ✓ - constraints
  - ✓ - shape complexity

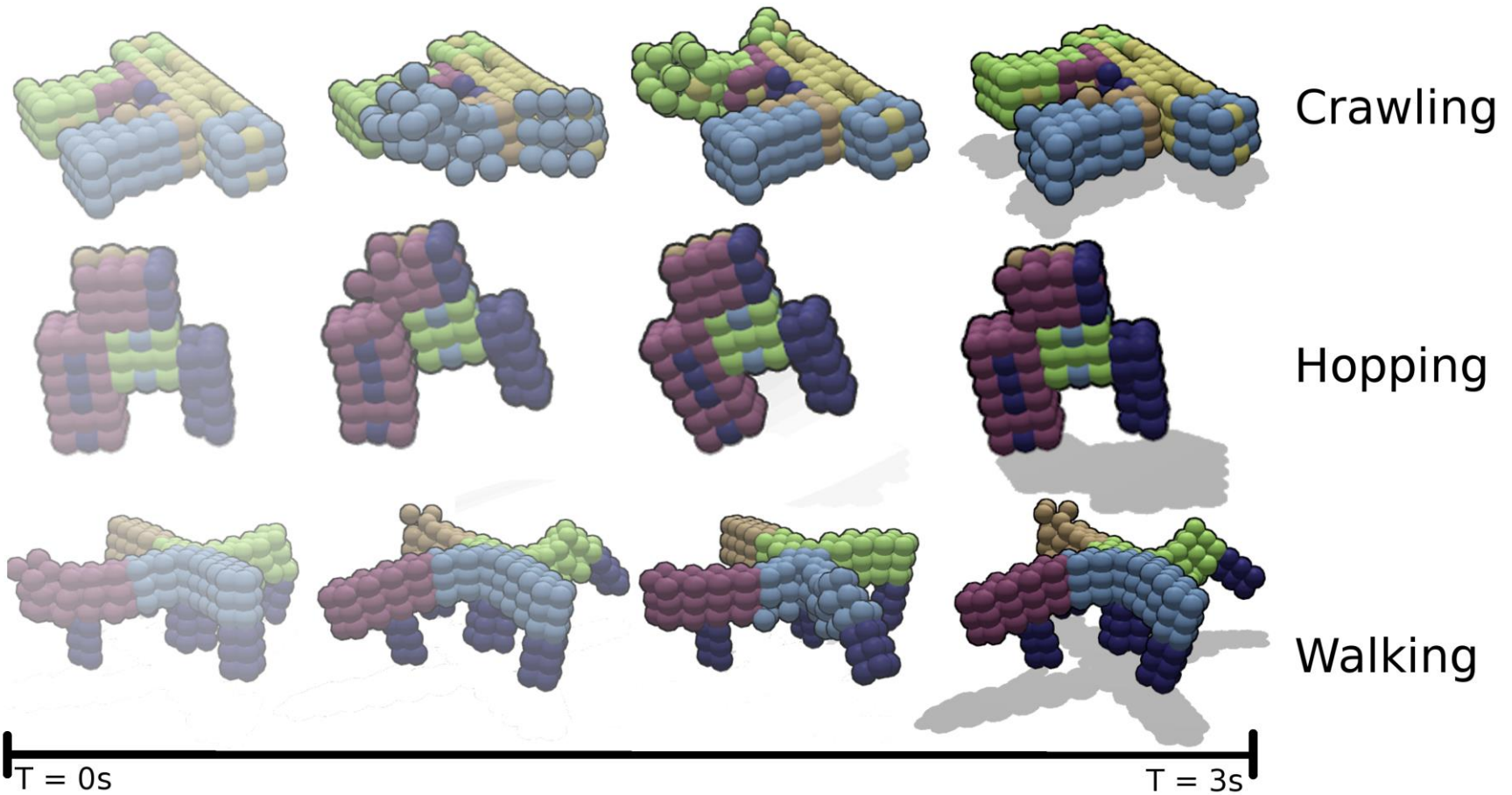
# Computational Design Synthesis of Virtual Locomotive Soft Robots



“A Spatial Grammar Method for the Computational Design Synthesis of Virtual Soft Robots”, van Diepen and Shea, ASME DETC conference 2018.

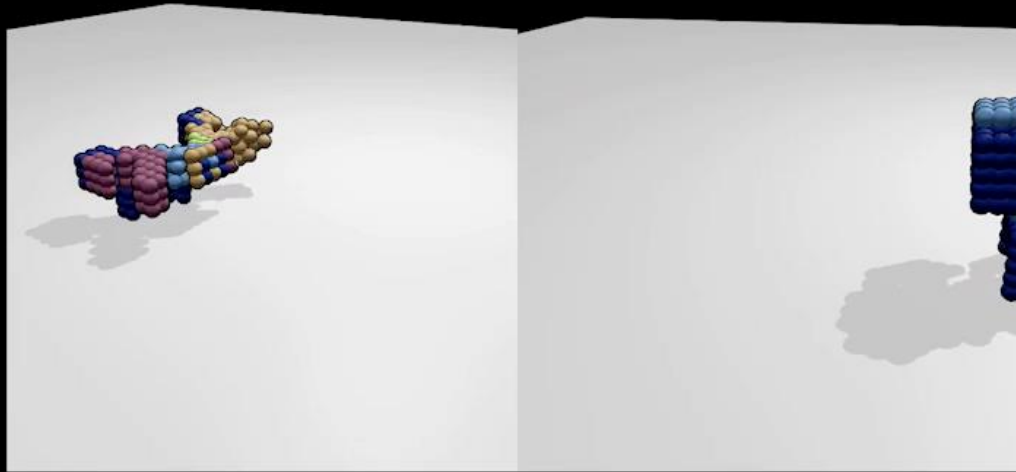
- Spatial grammar uses bending actuators as building blocks
- An actuator has a predefined, cyclic activation pattern
- Target gaits: walking, crawling, hopping

# Results



# Results in Action

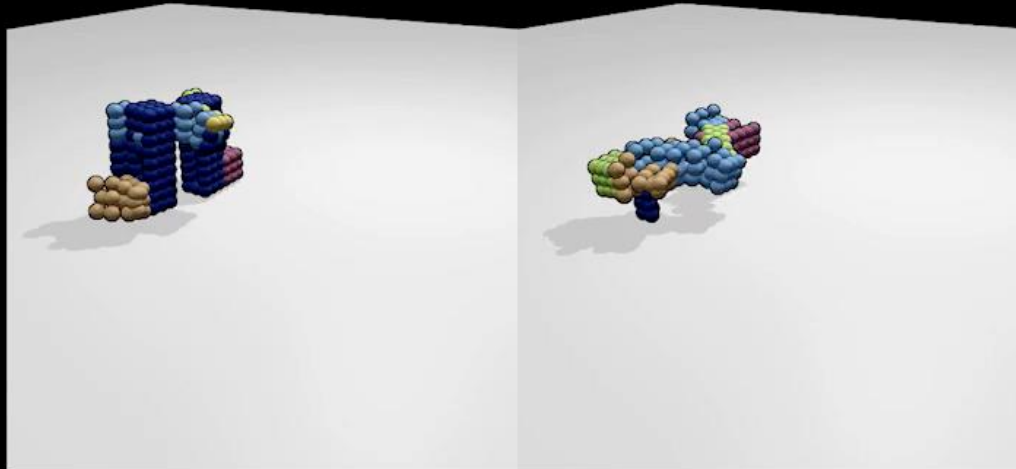
Crawling



Hopping



Walking



Walking