MADV: Morphogenetically Assisted Design Variation

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M3 Kickoff, February 2011

Raytheon BBN Technologies

iRobot

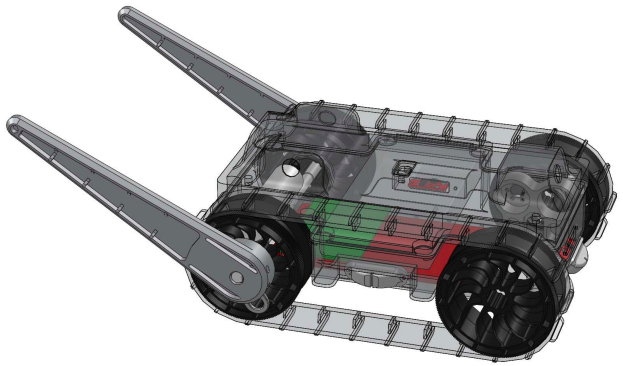
Why worry about redesign?

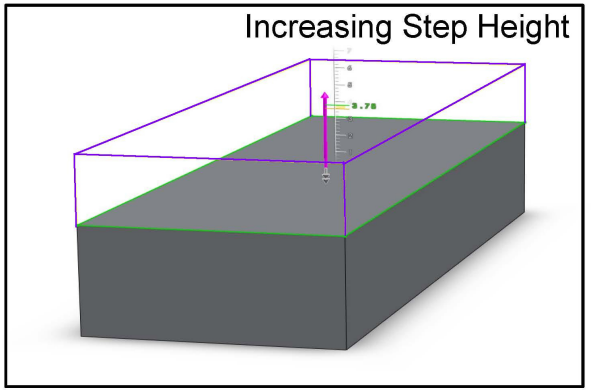
Field use experts are not engineering experts…

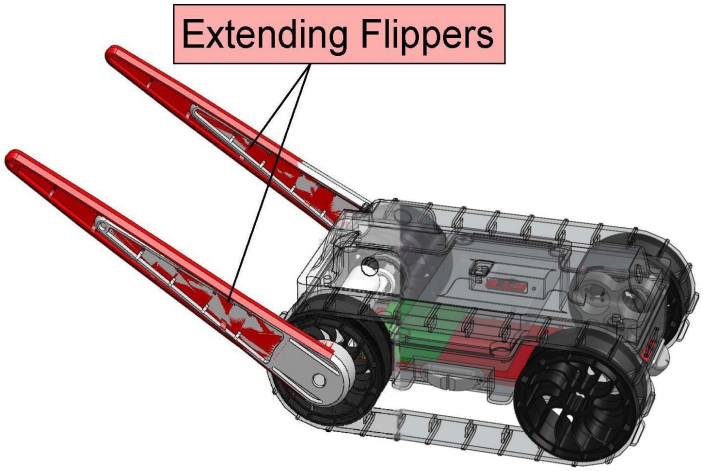
... but have good ideas for new uses and upgrades

Design Experts vs. Novices

- What needs to change for new conditions?
- What is a change's impact on other systems?

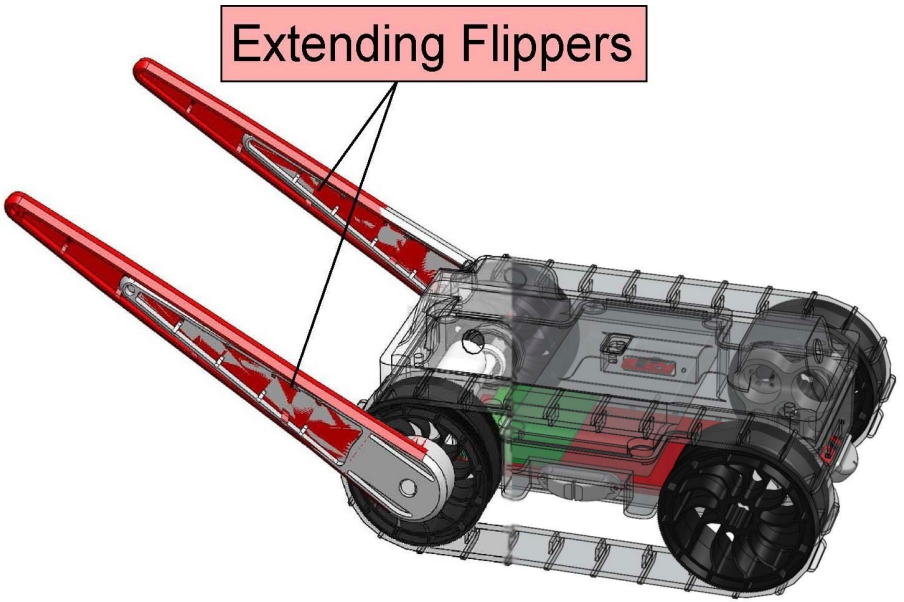






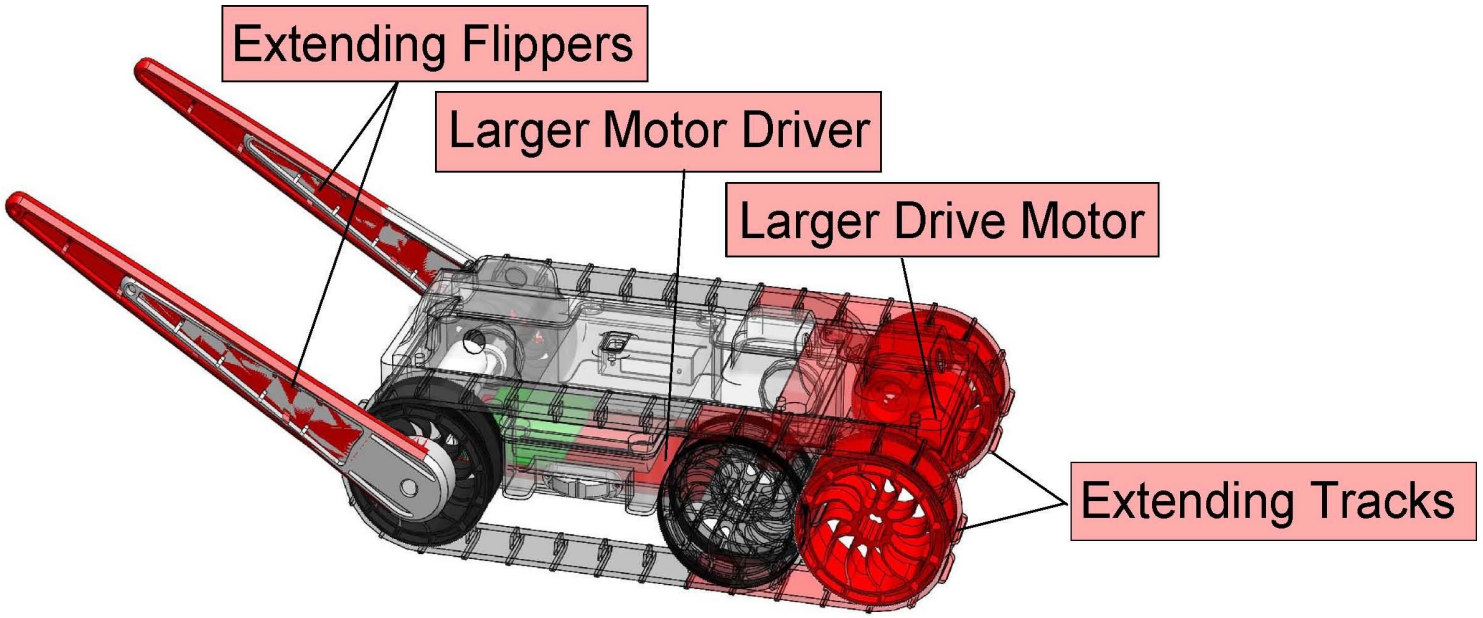
Problem: Propagating Changes

- A small change ...



Problem: Propagating Changes

- A small change ... has many consequenceses



Morphogenesis for integrated systems

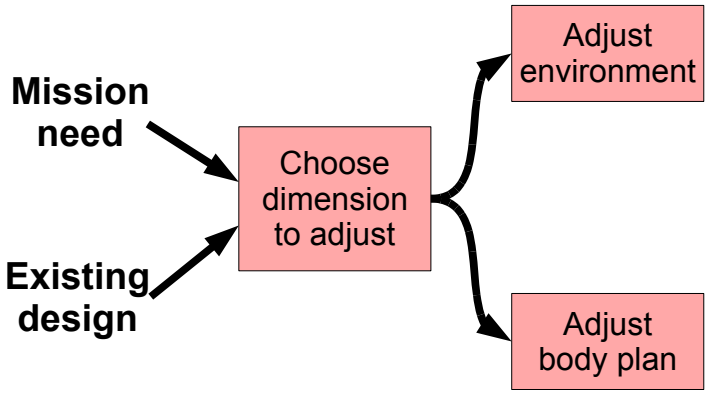
- Inspiration: Biological Systems
  - Consider the growth of animals
    - Synchronized and incremental
  - Many interlinked systems
    - Muscles, bones, blood, etc.

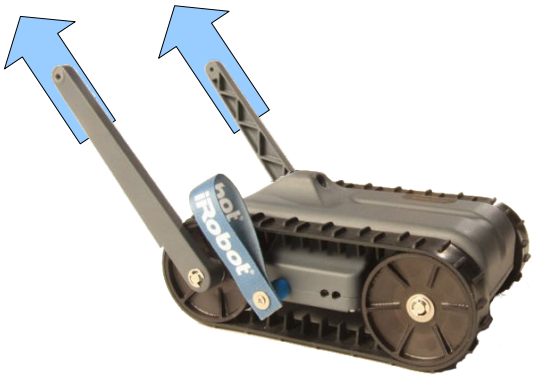
MADV: Design with Simulated Morphogenesis

Mission need

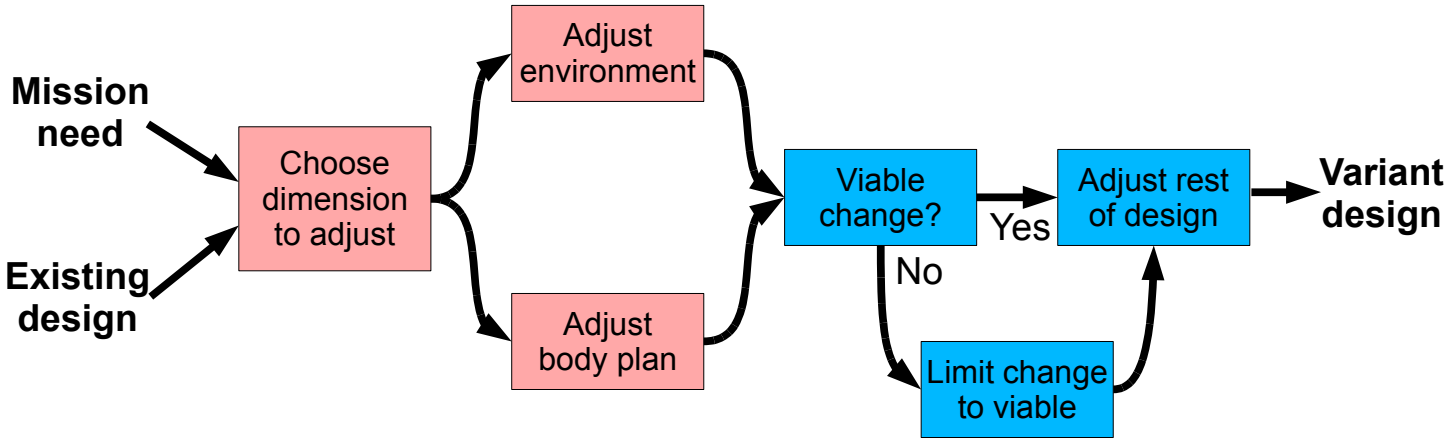
Existing design

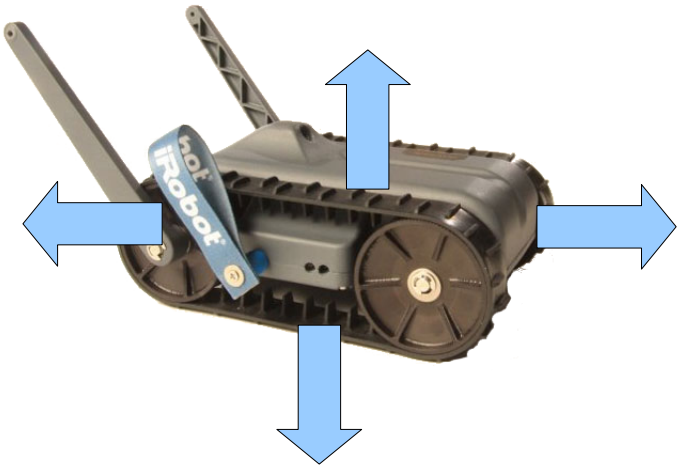
MADV: Design with Simulated Morphogenesis





MADV: Design with Simulated Morphogenesis





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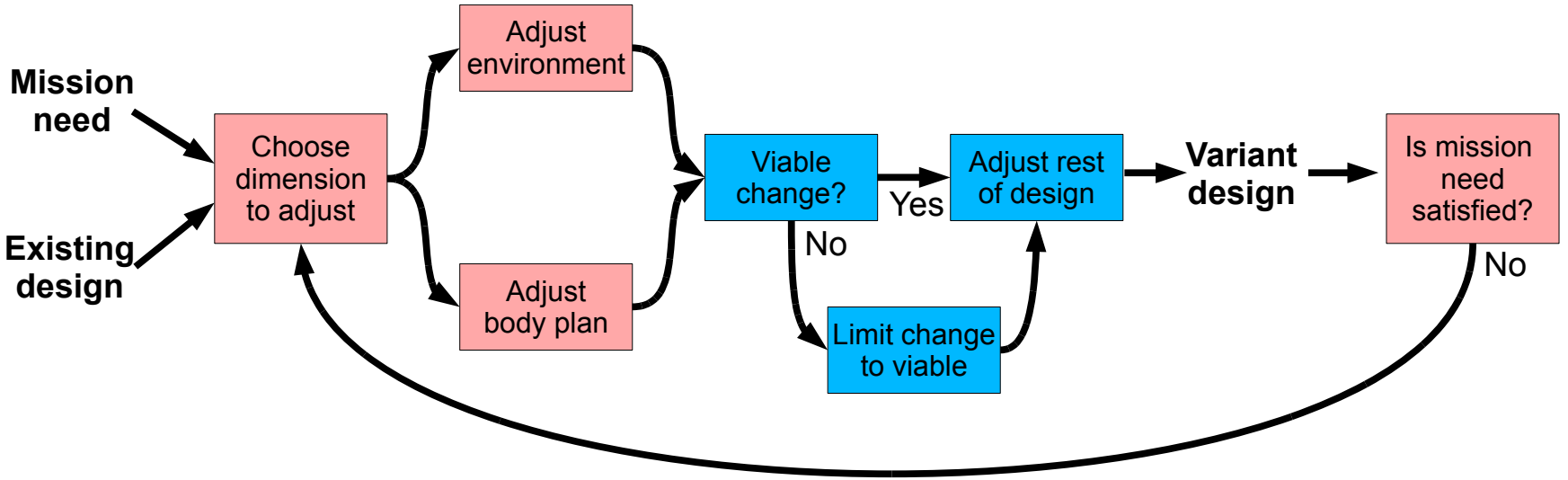
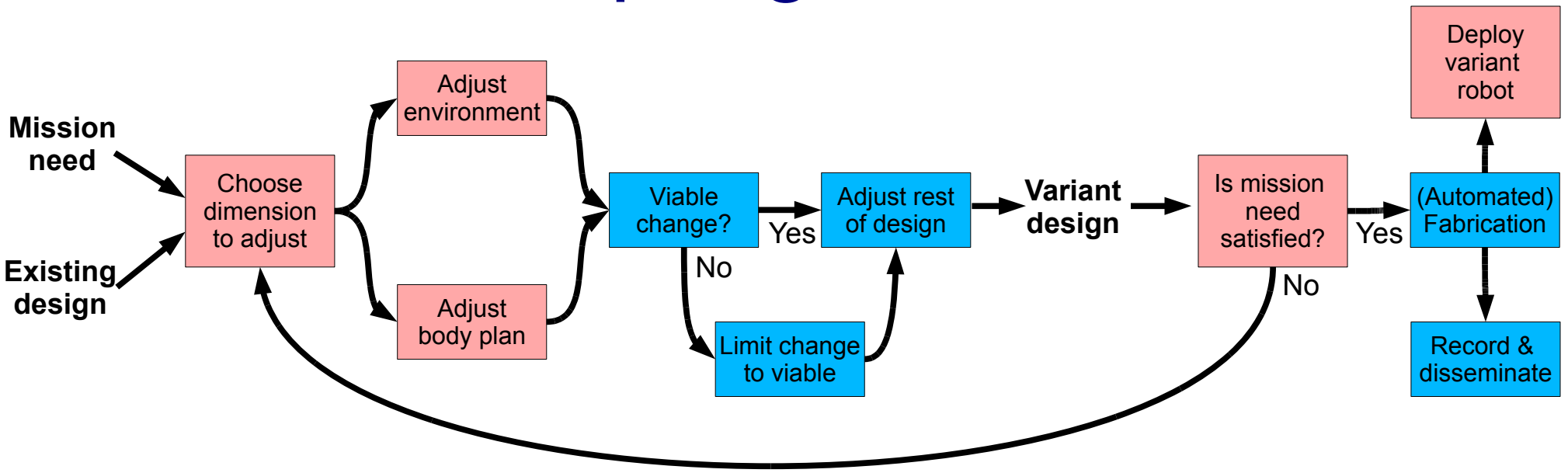


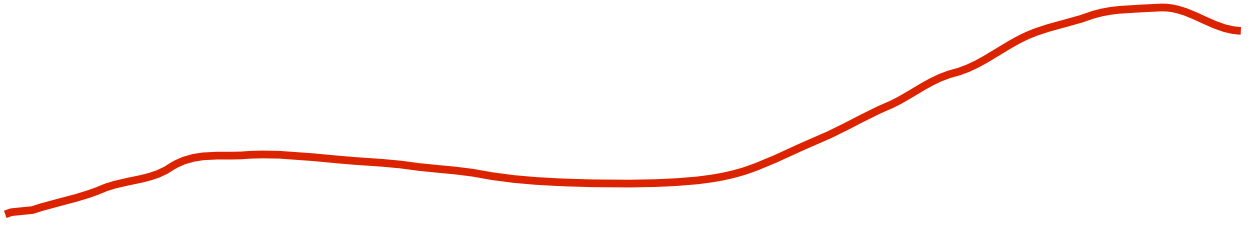
MADV: Design with Simulated Morphogenesis



What design rules can we extract from natural morphogenesis?

- A number of biological systems can:
  - Operate under minor stress
  - Incrementally adjust to relieve stress
  - Use stress as a signal to trigger adjustment

Example: Vascular System



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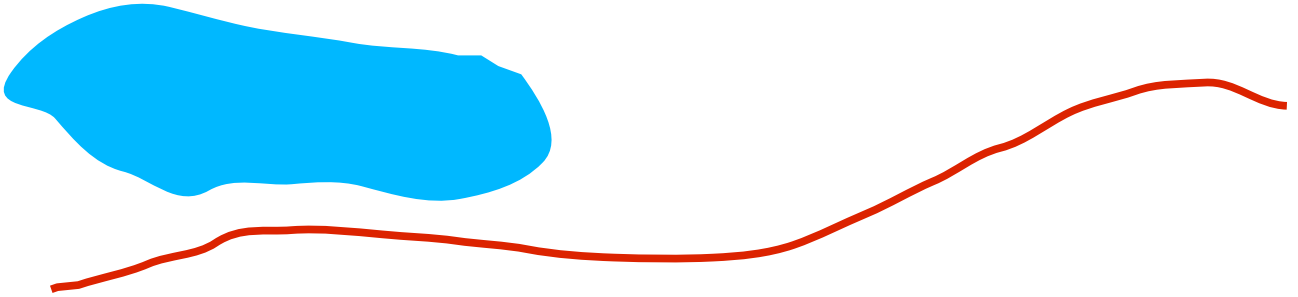

- Oxygen-starved cells signal capillary to leak

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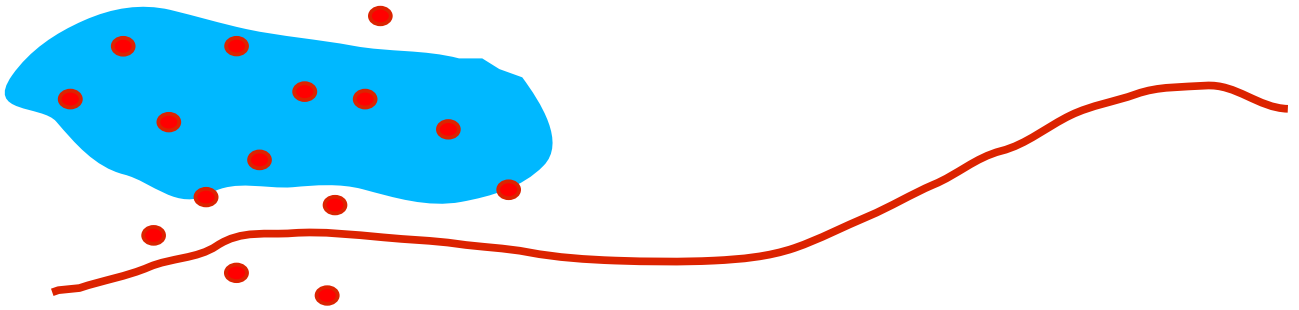

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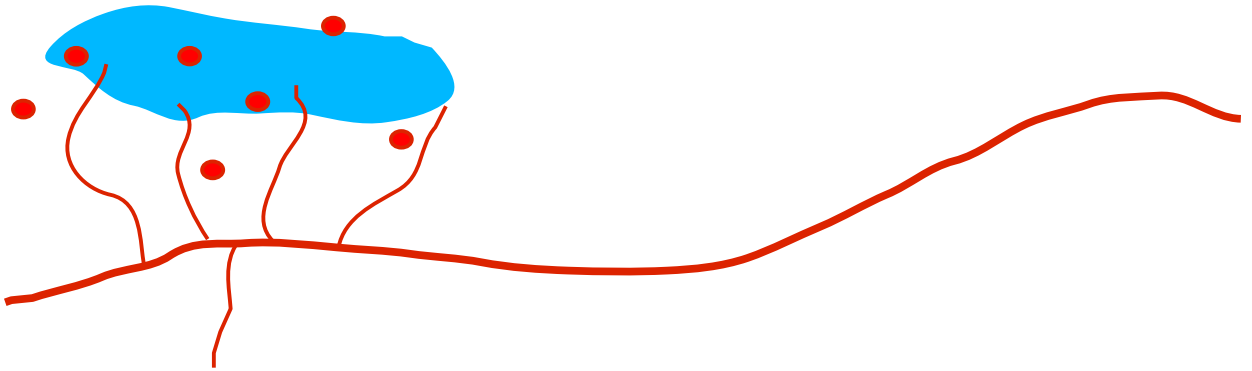

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Stress: oxygen, elastic stress

Adjustment: leaking, vessel grow/shrink

Implementing Morphogenesis: Functional Blueprints

1. Functional behavior that degrades gracefully
2. Metric for degree and direction of stress
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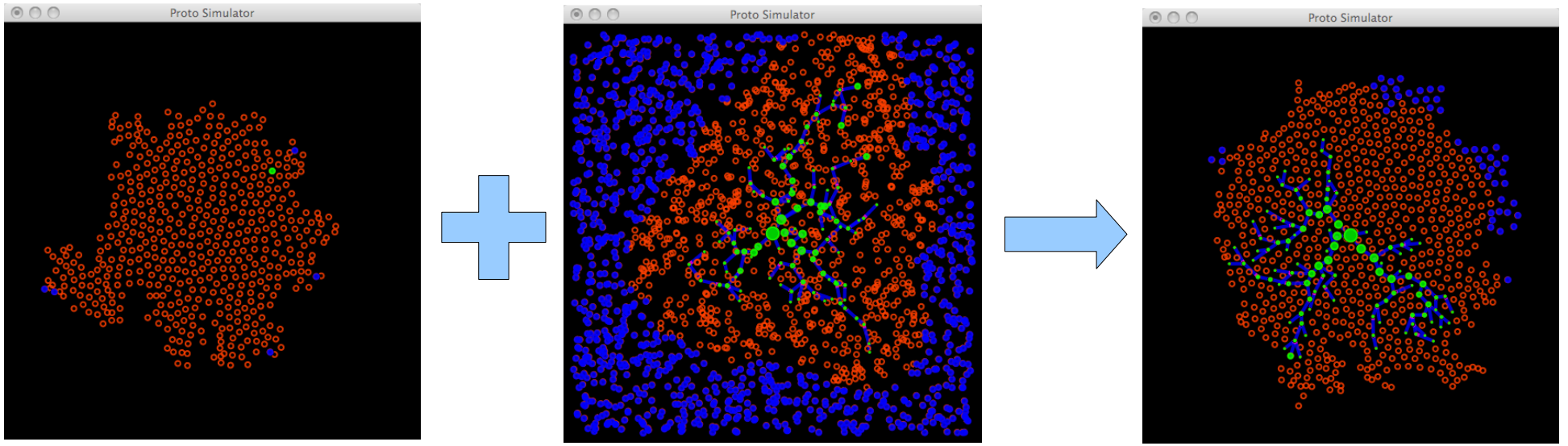
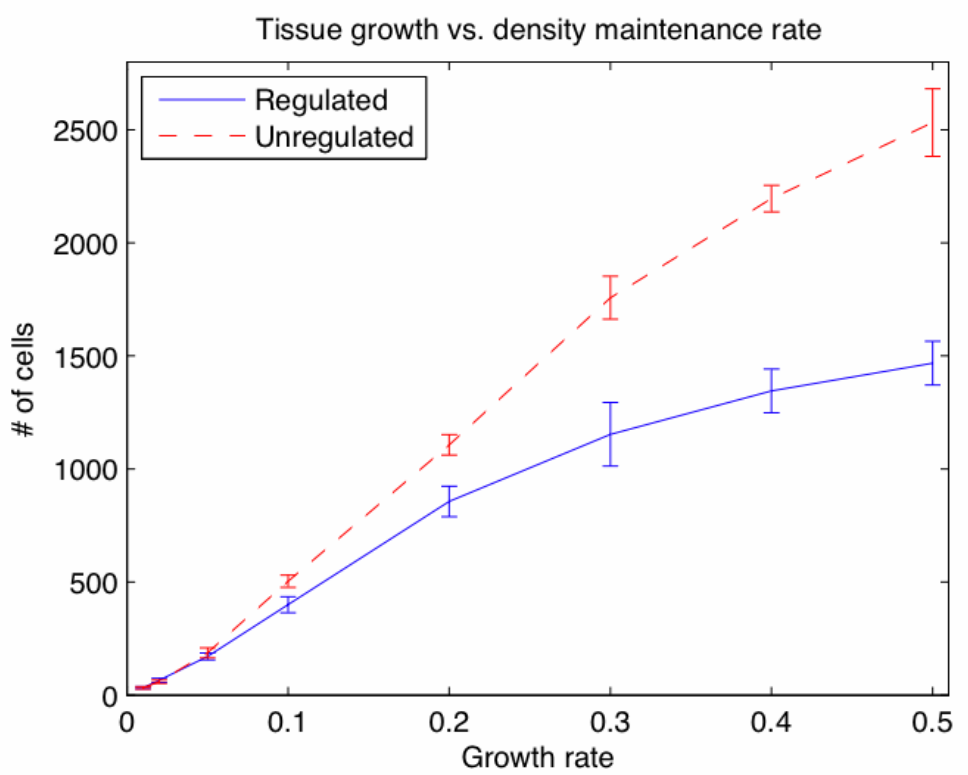
Let's try this idea out on the vascular system...

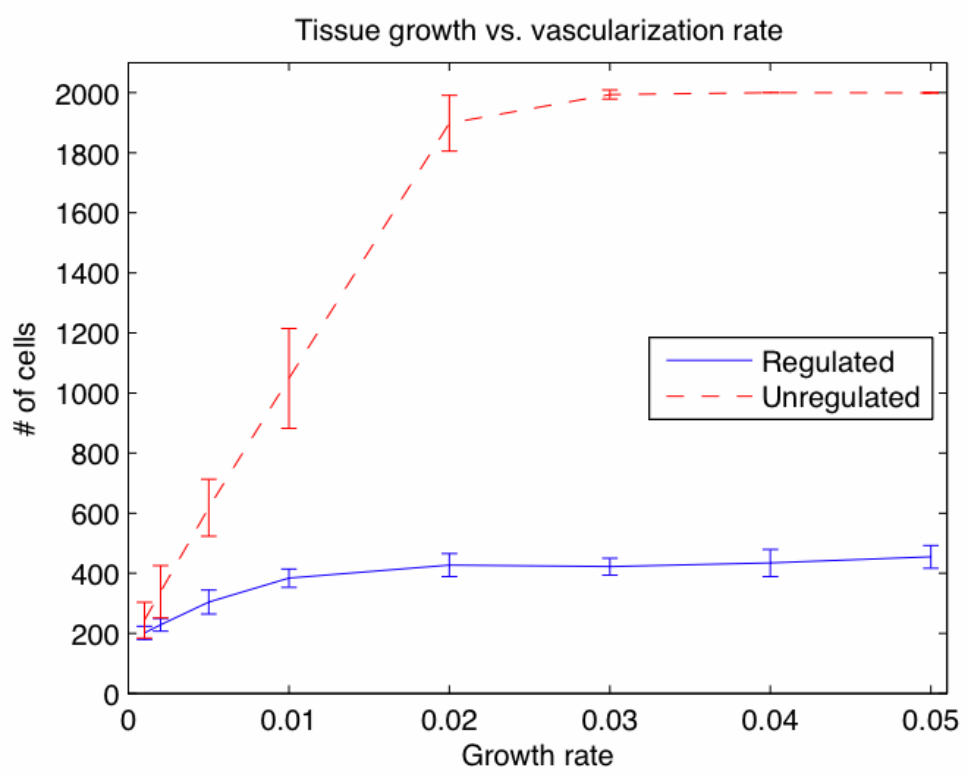
A (Cartoon) Simulation of Tissue Growth

- Cell density by motion, cloning, apoptosis
- Vascularization grows toward underserved regions, keeping branching factor limited
- Composed: co-regulate by vascular service

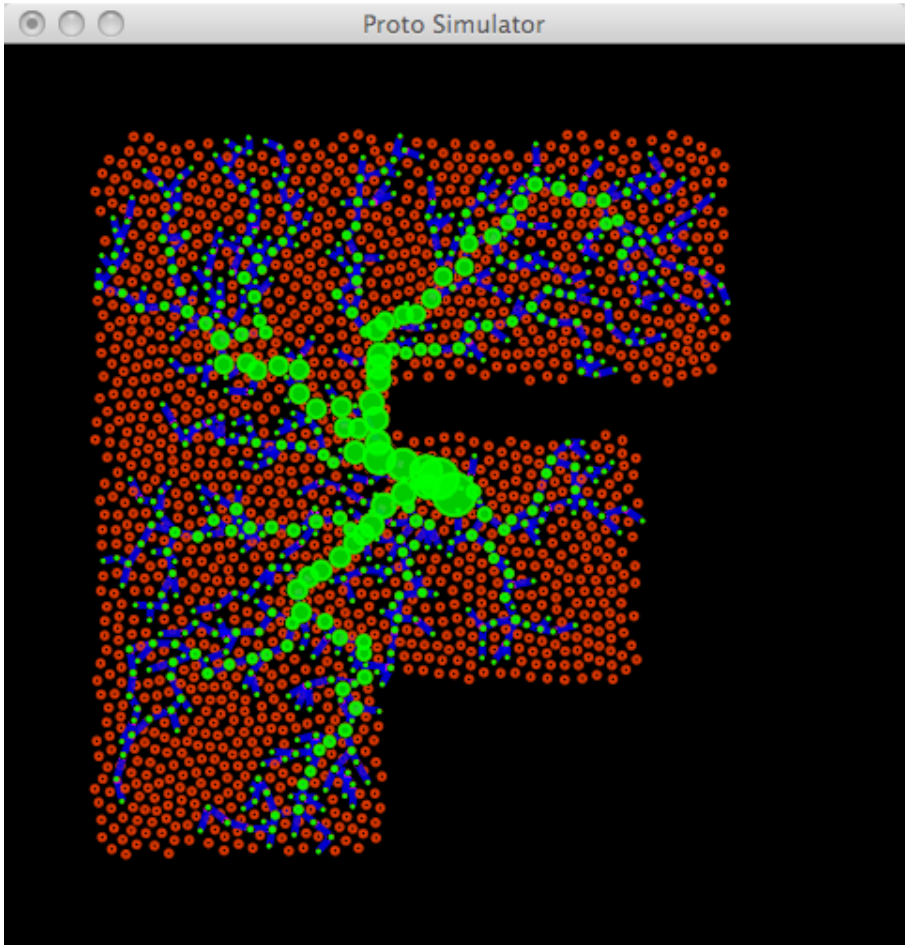


Vascularization/Density Co-Regulation

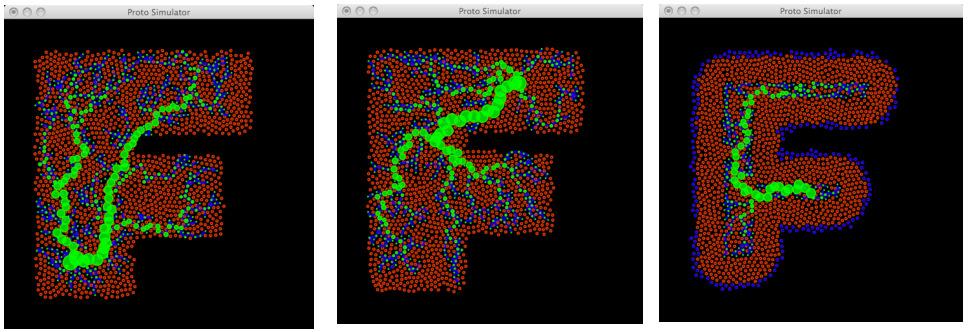




Modulation of Composed System

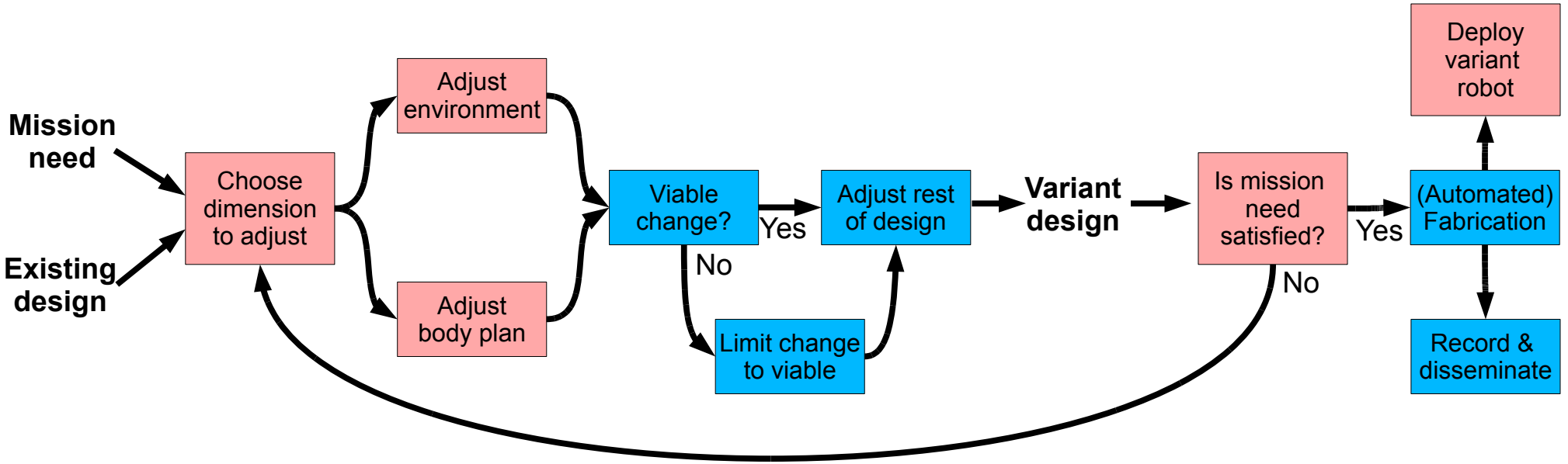



```
(def growf (src vlim)
  (let ((grow (in_bounds))
        (kill (not (out_bounds)))
        (v (vascularize-mod src
             (or (not vlim) (vin_bounds))
             50 0.02)))
    (if (not src)
      (mov (cell-density
             (and (or vlim grow) (2nd v))
             (and kill (not vlim)) 0.1))
      (tup 0 0 0))
    (drawvasc v)))
```



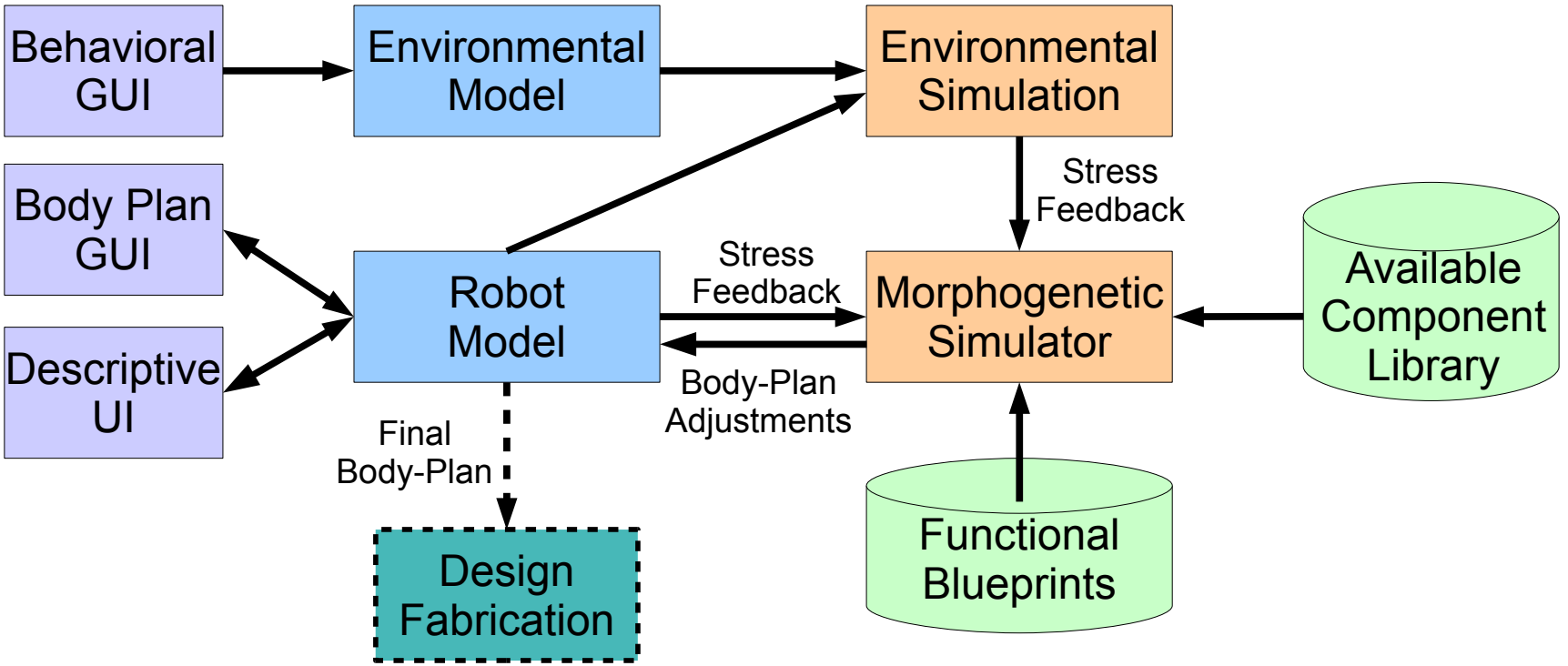
proto "(growf (= (mid) 0) 0)" -m -s 0.5 -n 10 -rad 2 -dim 500 500 -dist-dim -5 5 -5 5 -l -sv -DD fixedpt 0 0 -L simple-life-cycle

Back to MADV...



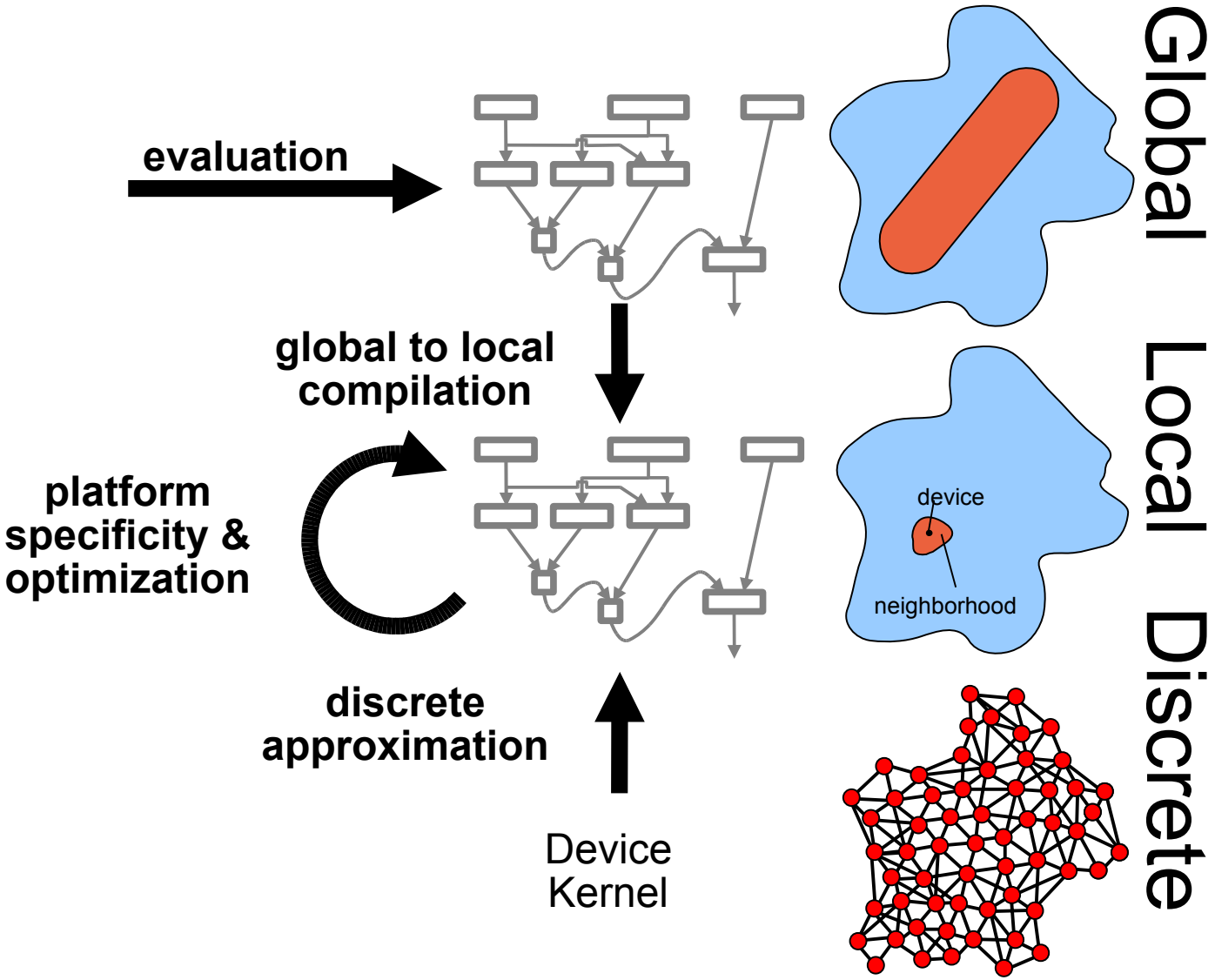
- What about the rest...
  - Components? User interaction?

MADV Architecture



Enabling Technology: Proto

```
(def gradient (src) ...)
(def distance (src dst) ...)
(def dilate (src n)
  (<= (gradient src) n))
(def channel (src dst width)
  (let* ((d (distance src dst))
         (trail (<= (+ (gradient src)
                       (gradient dst))
                    d)))
    (dilate trail width)))
```



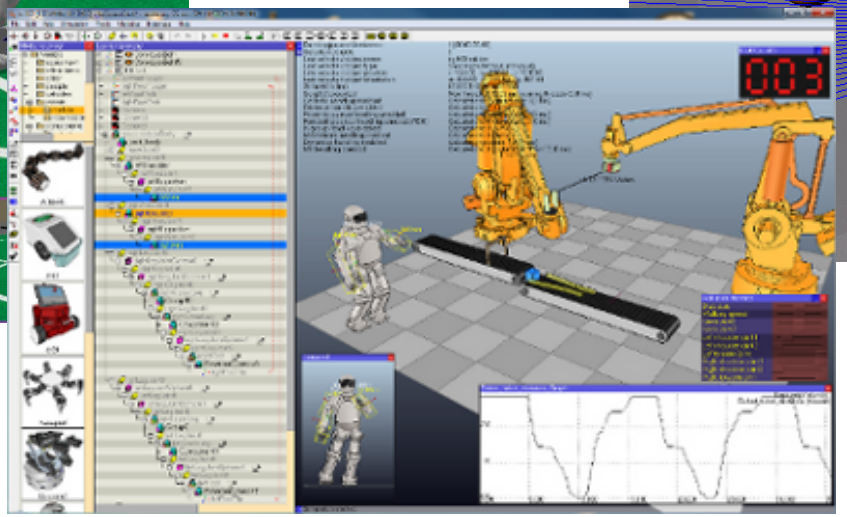
[Beal & Bachrach '06]

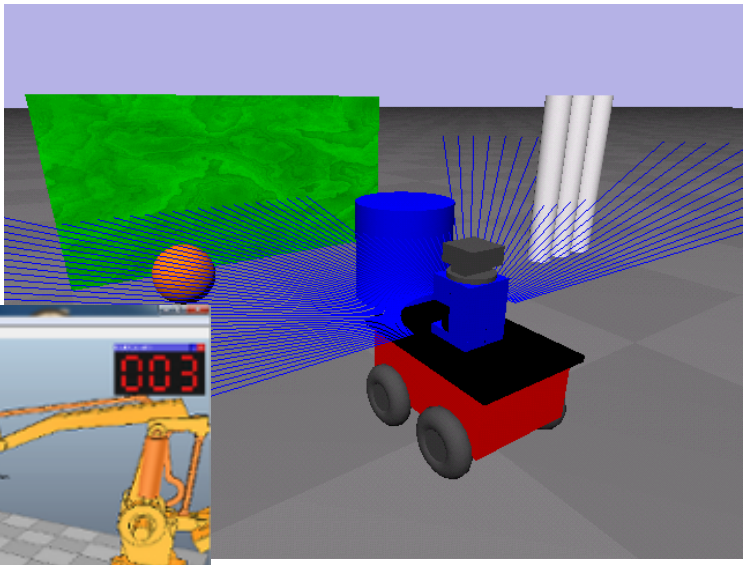
Enabling Technology: ODE

- Free & open Newtonian physics engine
- Proven in robotics research:

Webots

V-REP

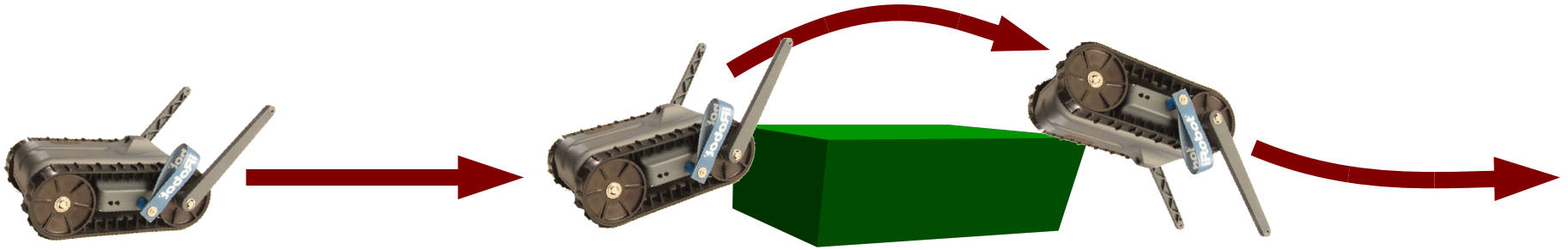




Gazebo

Behavioral Interface

- "Obstacle course" UI enables novice users to indirectly specify design changes
- Real-time feedback on the impact of a change



Research Tasks

- Design open miniDroid platform for experiment
- Create functional blueprints for miniDroid
- Morphogenetic and environmental simulation
- Mathematical theory & analysis for functional blueprints
- Cellular modelling of solids (FEA + Proto)

Anticipated Impact... and Invitation!

- New engineering approach based on simulation of natural morphogenesis
- Real-time feedback guiding use through viable design space
- Intuitive feedback on cost/scale of redesign
- Provable complexity bounds allowing scale-up

*Could **you** produce or use functional blueprints?*

Raytheon BBN Technologies

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