Functional blueprints: a means of adaptive integration?

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BBN TECHNOLOGIES

Why doesn't growth injure animals?

Many interlinked systems

- Muscles, bones, blood, lungs, kidneys, etc...
- How is growth synchronized?
  - Not like building a house!

Consider Osgood-Schlatter's disease...

Hypothesis: Functional Blueprints

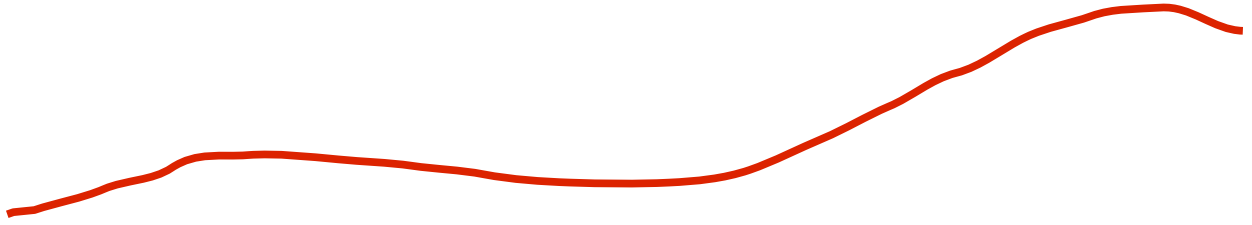
- Not “what” but “why”
  - Register stress when functionality degrades
  - Homeostatic rules for relieving stress
  - Ratios determined dynamically
- When uninhibited, a prime attribute grows
  - Stress develops in other systems, inhibiting prime
  - Homeostatic acts develop, destress linked systems
    - Secondary, tertiary links are stressed, cascading growth

Incremental integration through growth!

Functional Blueprint

1. Functional behavior that degrades gracefully
2. Metric for degree and direction of stress
3. Incremental growth program for stress relief
4. Program to construct minimal initial system

Example: Vascular System



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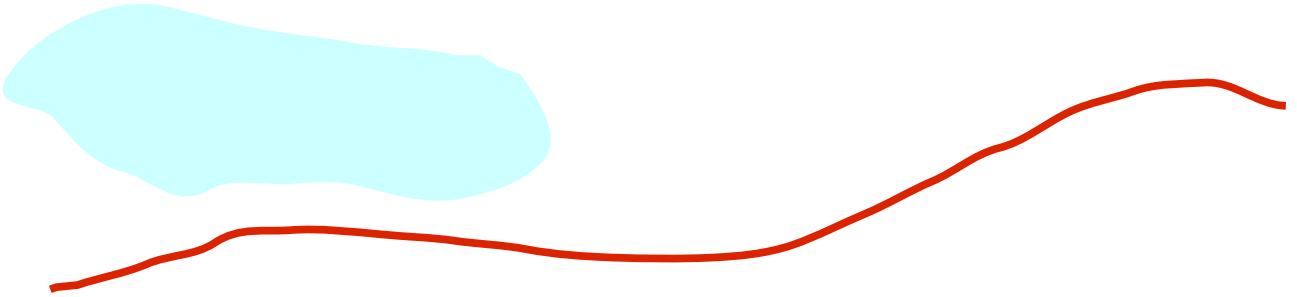

- Oxygen-starved cells signal capillary to leak

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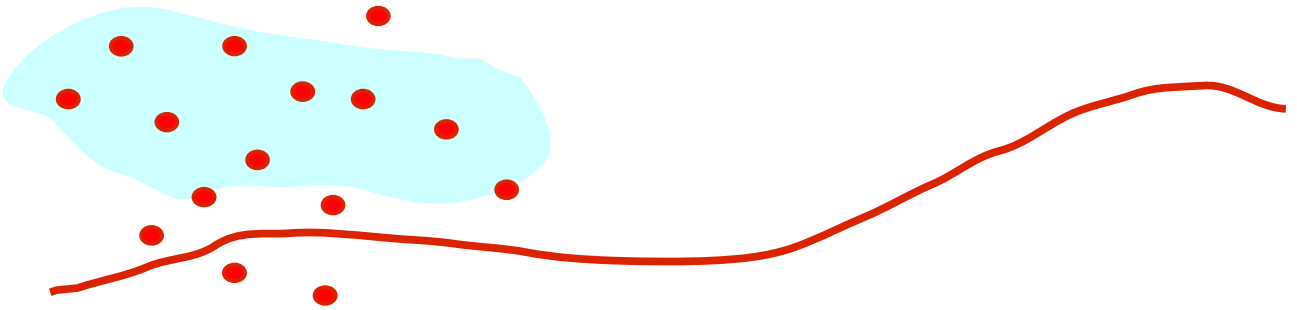

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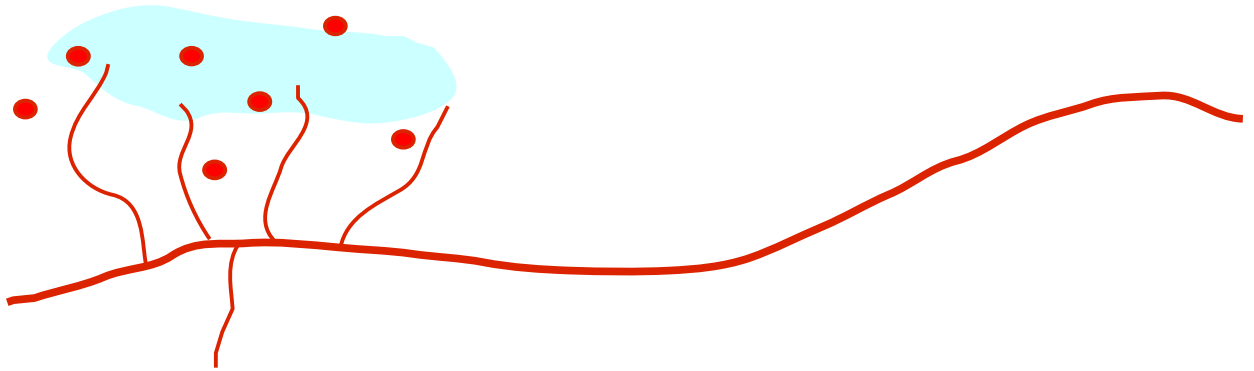

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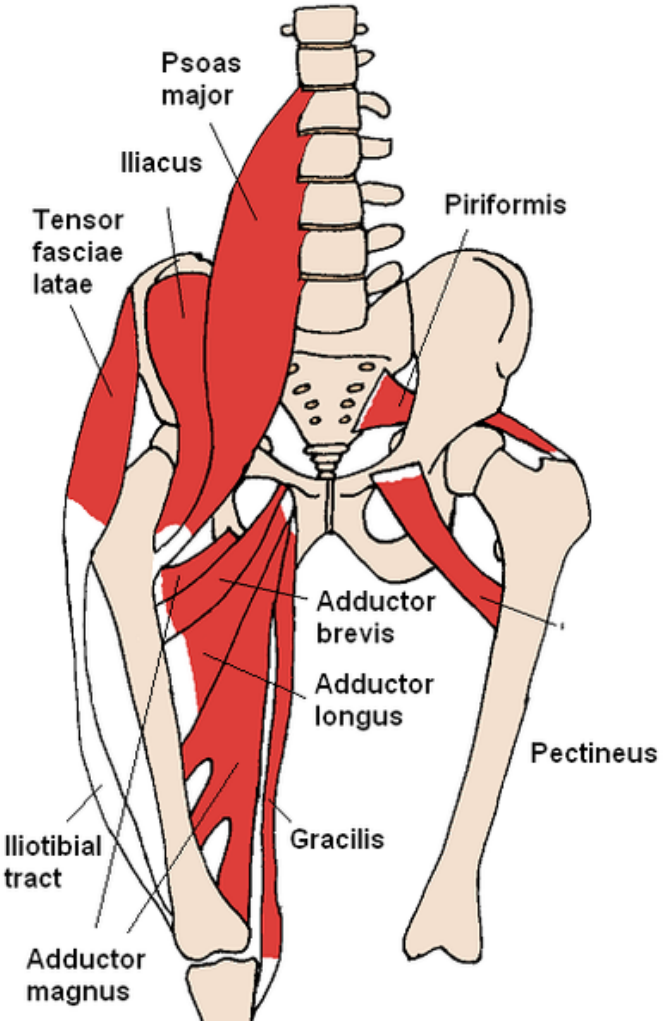
Metric: oxygen, elastic stress

Homeostasic: leaking, vessel grow/shrink

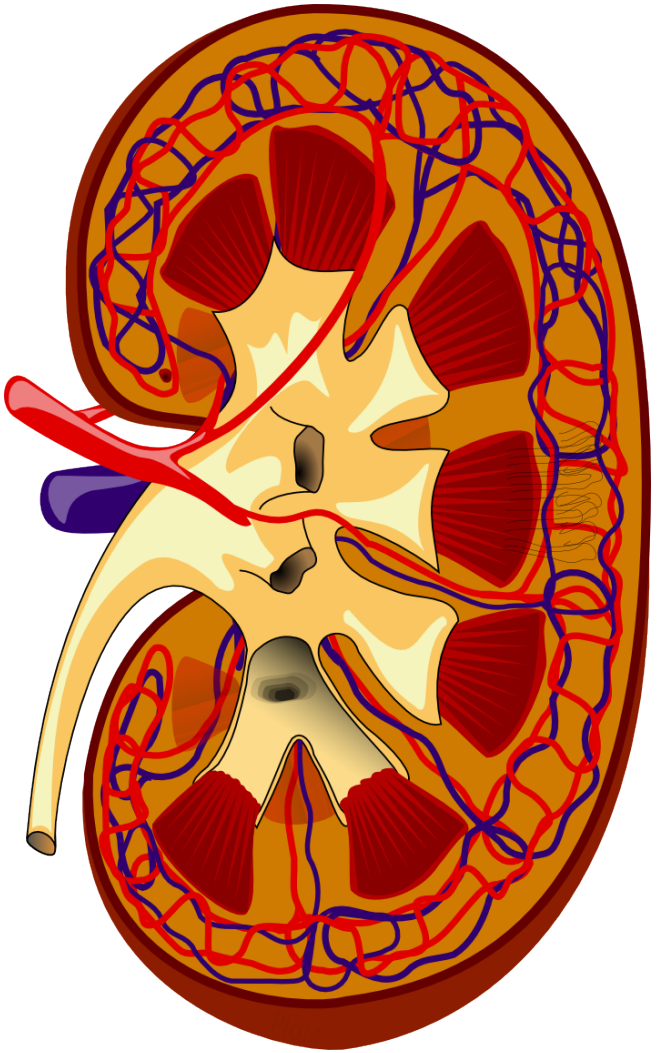
Example: Muscles?

- Grow when strained, degrade when unused
- Possible metrics:
  - Mechanical stress on muscle
  - Speed of joint flexure
- Might muscles make exploratory connections or adjust attachment sites?



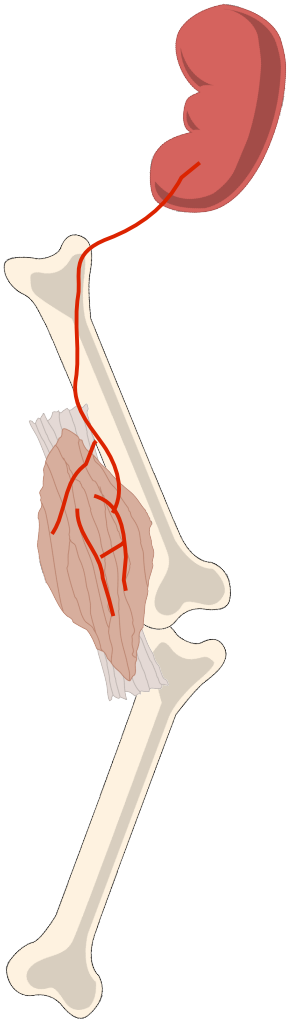
Example: Kidney?

- Growth stimuli still not entirely known
- Possible metrics:
  - Quality of filtration
  - Toxicity stress on cells



A Fable of Integrated Growth

- Bone growth→muscle stress
- Muscle growth→vascular stress
- Vascular growth→kidney stress
- Kidney growth→equilibrium
  - Bone growth re-enabled



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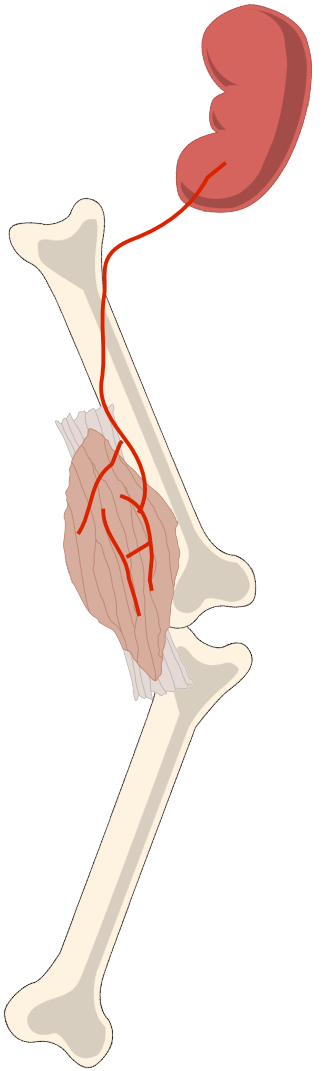

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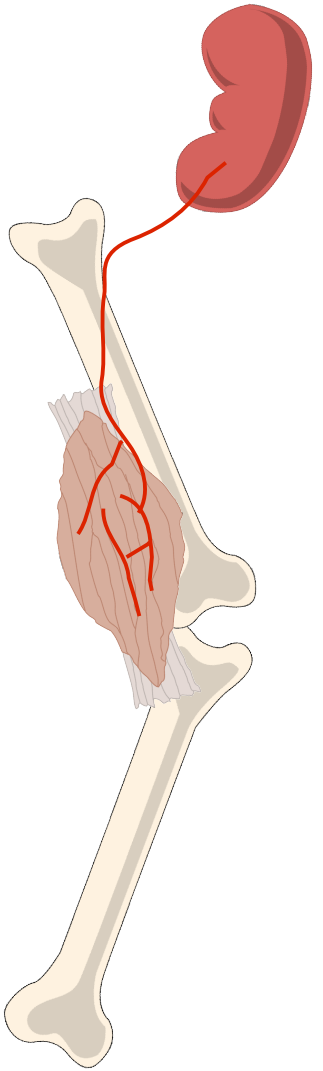

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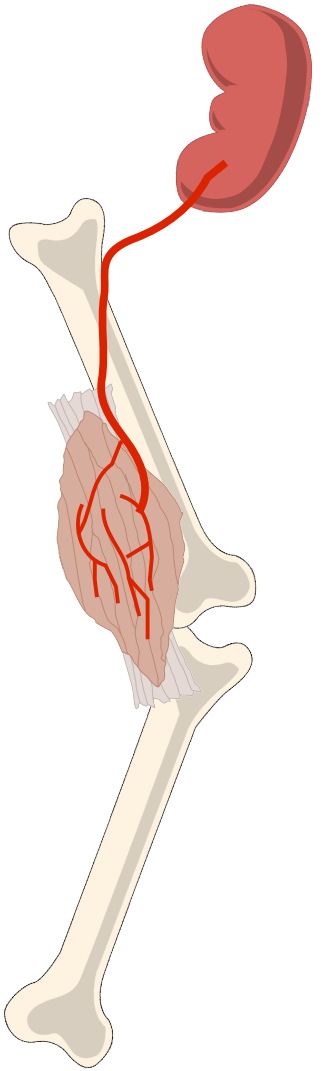

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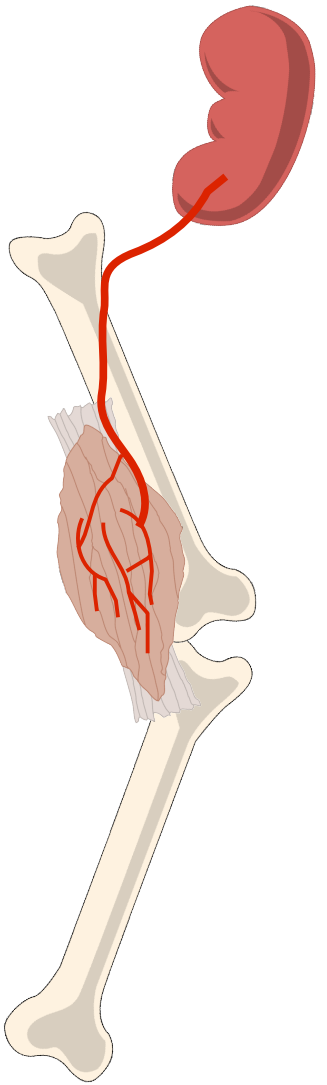
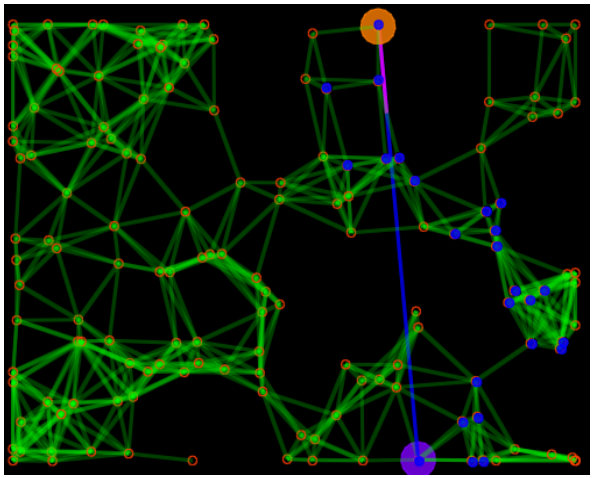


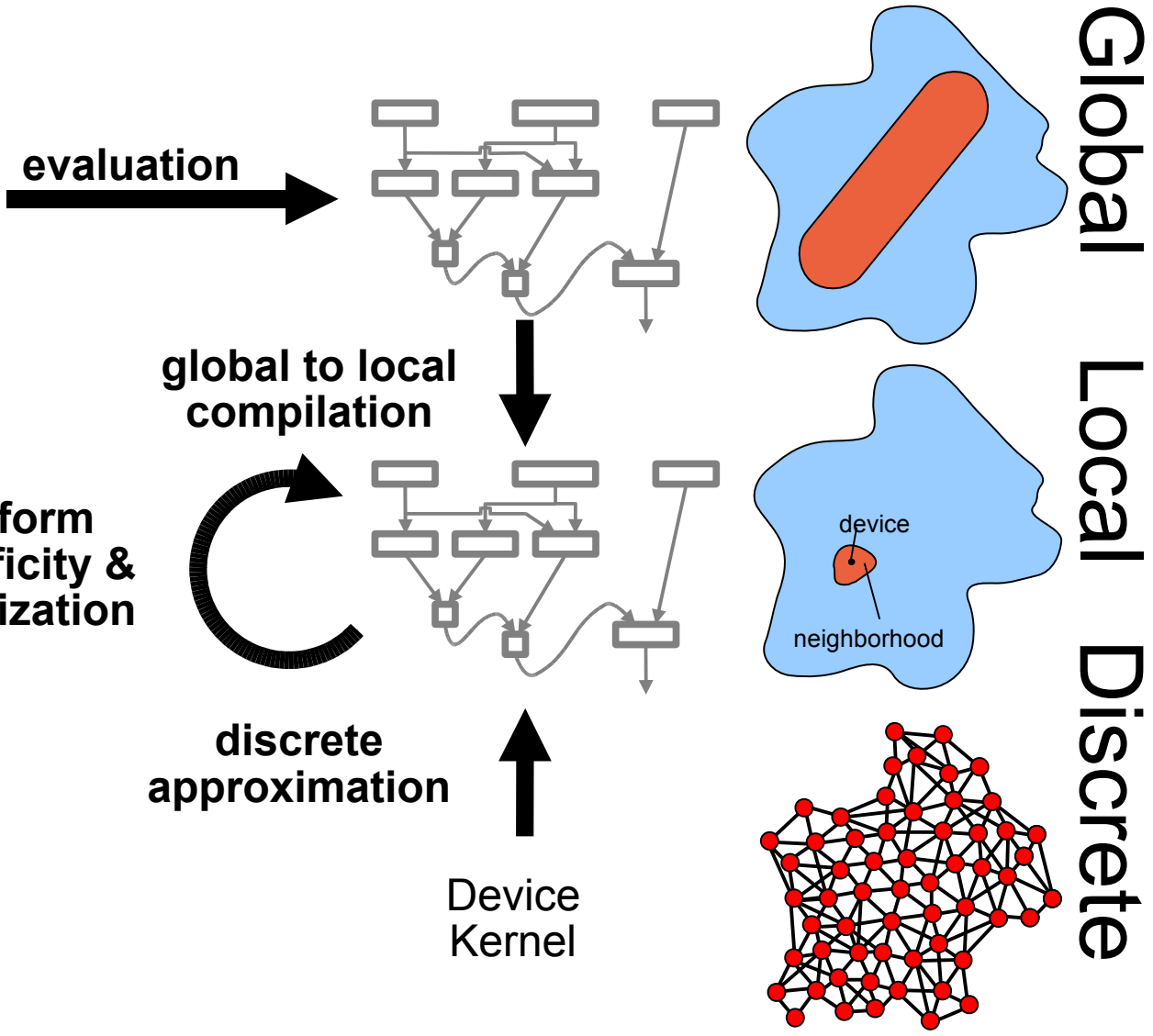
A modest first (cartoon) simulation...

- Tissue maintains homoegeneity by cell motion, cloning, apoptosis
- Vascularization grows toward underserved regions, keeping branching factor limited
- Composed form:
  - tissue grows only when well served by vascularization
  - vascularization stimulated by tissue growing to develop underserved regions

Proto: Computing with Fields

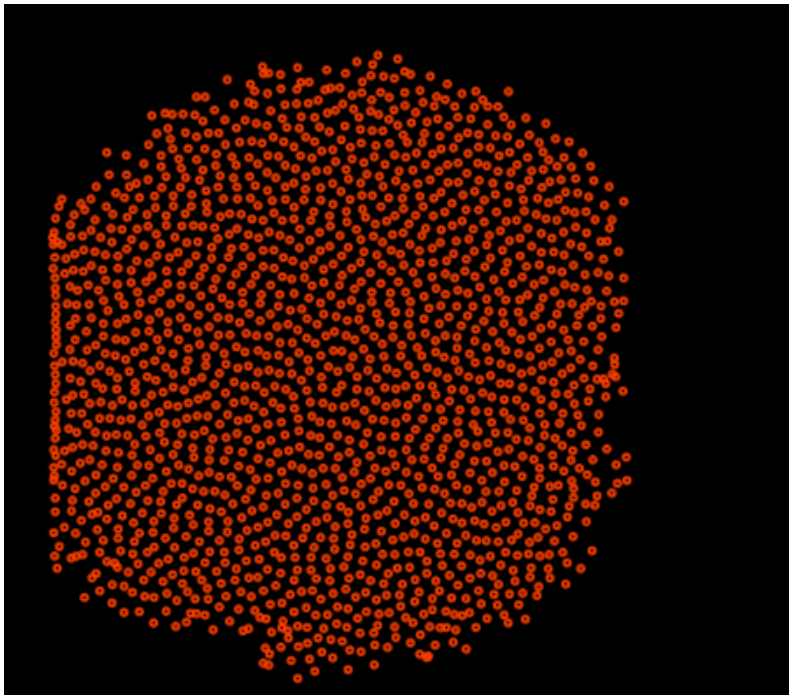
```
(def gradient (src) ...)
(def distance (src dst) ...)
(def dilate (src n)
  (<= (gradient src) n))
(def channel (src dst width)
  (let* ((d (distance src dst))
         (trail (<= (+ (gradient src)
                       (gradient dst))
                    d)))
    (dilate trail width)))
```





- Beal & Bachrach

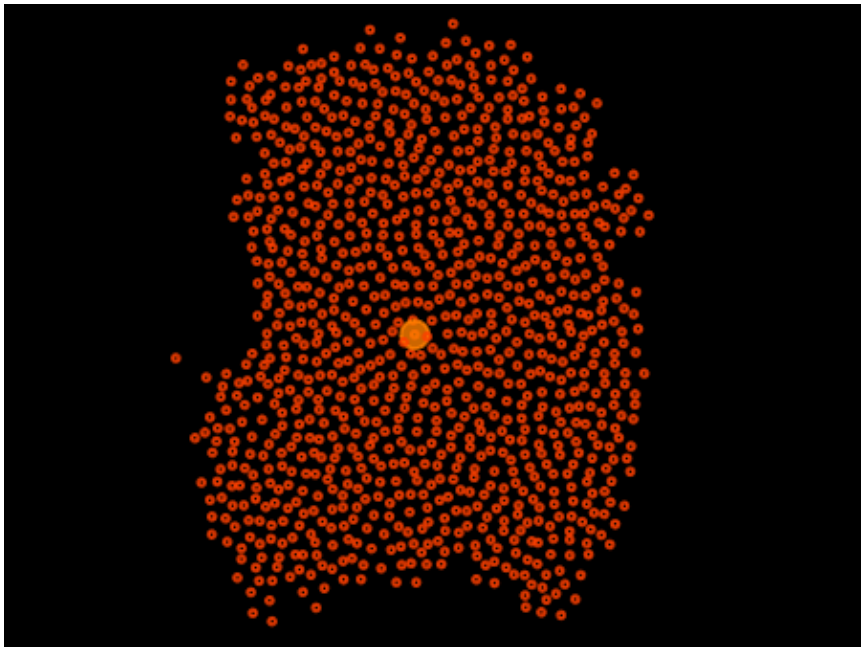
Tissue Growth



```
(def simple-tissue ()
  (let ((packing (num-nbrs)))
    (clone (and (< packing 8) (< (rnd 0 1) 0.1)))
    (die (and (> packing 12) (< (rnd 0 1) 0.1))))
  (disperse 0.9))
```

```
proto "(mov (simple-tissue))" -m -s 0.1 -dist-dim -25 -15 -5 5 -dim 500 500 -rad 2 -w
```

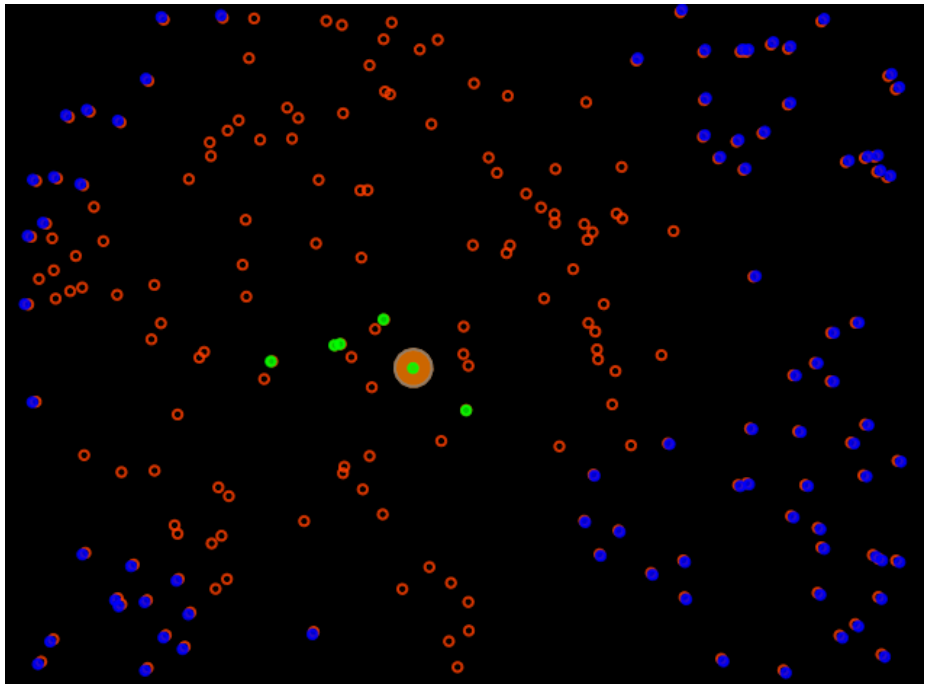
Regulatable Growth



```
(def tissue (grow shrink)
  (let ((packing (num-nbrs)))
    (clone (and grow (and (< packing 8) (< (rnd 0 1) 0.1))))
    (die (or (and (> packing 12) (< (rnd 0 1) 0.1))
             (and shrink (< (rnd 0 1) (* 0.1 (- 8 packing)))))))
  (disperse 0.8))
```

```
proto "(mov (tissue (< (timer) 200) (delay (gradcast (sense 1) (sense 1)))))" -m -s 0.1 -l -dim 500 500 -dist-dim -5 5 -5 5 -n 10 -rad 2
```

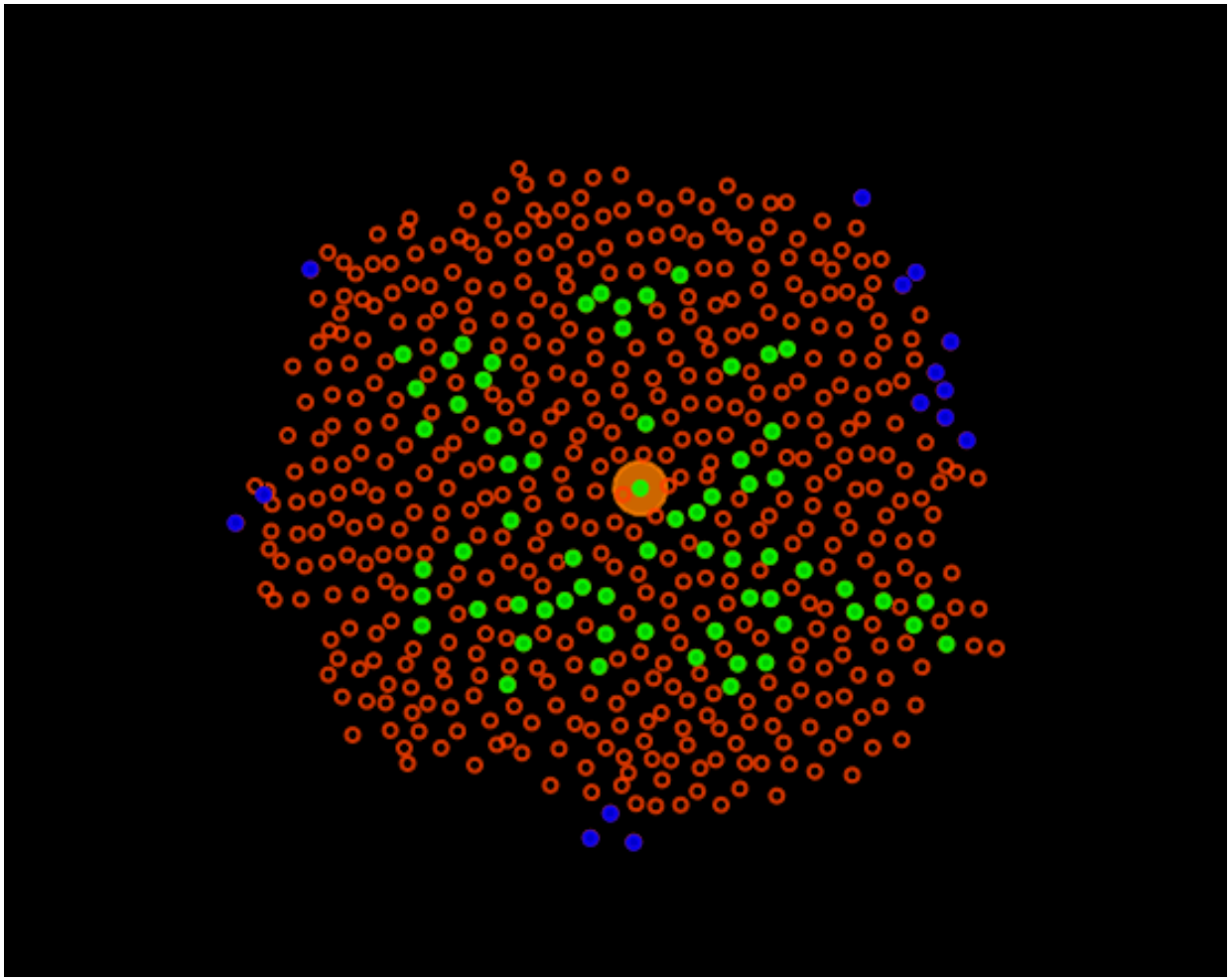
Vascularization



```
(def vascularize (source serv-range)
  (rep (tup vessel served parent)
       (tup source source (if source (mid) -1))
       (mux source
            (tup 1 1 -1)
            (let ((service (< (gradient vessel) serv-range))
                  (server (gradcast vessel (mid)))
                  (children (sum-hood (= (mid) (nbr parent)))))
              (mux vessel
                   (mux (or (muxand (any-hood (and (= (nbr (mid)) parent)
                                                   (> (nbr children) 2)))
                                    (< (rnd 0 1) 0.1))
                            (not (any-hood (= (nbr (mid)) parent))))
                        (tup 0 1 -1)    ; vessel is discarded
                        (tup 1 1 (probe parent 0))) ; vessels stay fixed
                   (mux (muxand (muxand (any-hood (nbr vessel))
                                        (dilate (not served) serv-range))
                                (< (rnd 0 1) 0.02))
                        (tup 1 1 server)
                        (tup 0 service -1)))))))
```

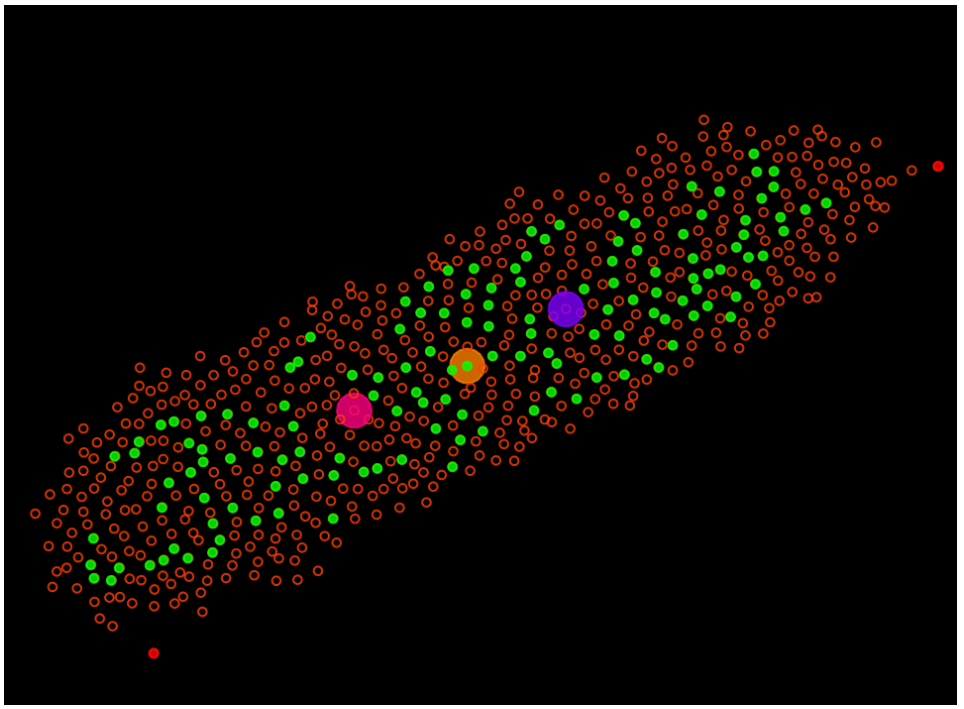
proto "(let ((v (vascularize (sense 1) 50))) (green (1st v)) (blue (not (2nd v))))" -n 200 -l -s 0.1 -m

Vascularization Regulating Growth



proto "(let ((v (vascularize (sense 1) 50))) (green (1st v)) (blue (not (2nd v))) (mov (tissue (2nd v) 0)))" -m -s 0.1 -n 10 -rad 2 -dim 500 500 -dist-dim -5 5 -5 5 -l

And on to more complexity...



```
(def growbar (target-aspect)
  (let* ((v (vascularize (sense 1) 50))
         (cval (probe (hox (sense 2) (sense 3)) 1))
         (safe_x (mux (< (1st cval) (inf)) (1st cval) 0))
         (dap (- (rep ap+ safe_x (max-hood (nbr ap+)))
                 (rep ap- safe_x (min-hood (nbr ap-)))))
         (max-lateral (/ (max (probe dap 0) 1) target-aspect)))
    (* (+ 1 (* 0 (+ (green (1st v)) (blue (not (2nd v))))))
       (tissue (and (2nd v) (not (> (2nd cval) max-lateral)))
               (> (2nd cval) max-lateral)))))
```

proto "(mov (growbar 2))" -m -s 0.1 -n 10 -rad 2 -dim 500 500 -dist-dim -5 5 -5 5 -l

Contributions

- Functional blueprints
  - Adaptive integration → increased evolvability
  - Do biological systems work this way?
- Simple demonstration in simulation
  - Proto as a candidate modeling language

Spatial Computing Opportunities

- Workshop @ IEEE SASO:
  - Submission: July 10th
  - Workshop: Sept 14th
- ACM TAAS Special Issue
  - Submission deadline: August 1st

ACM Transactions on Autonomous and Adaptive Systems

http://www.spatial-computing.org