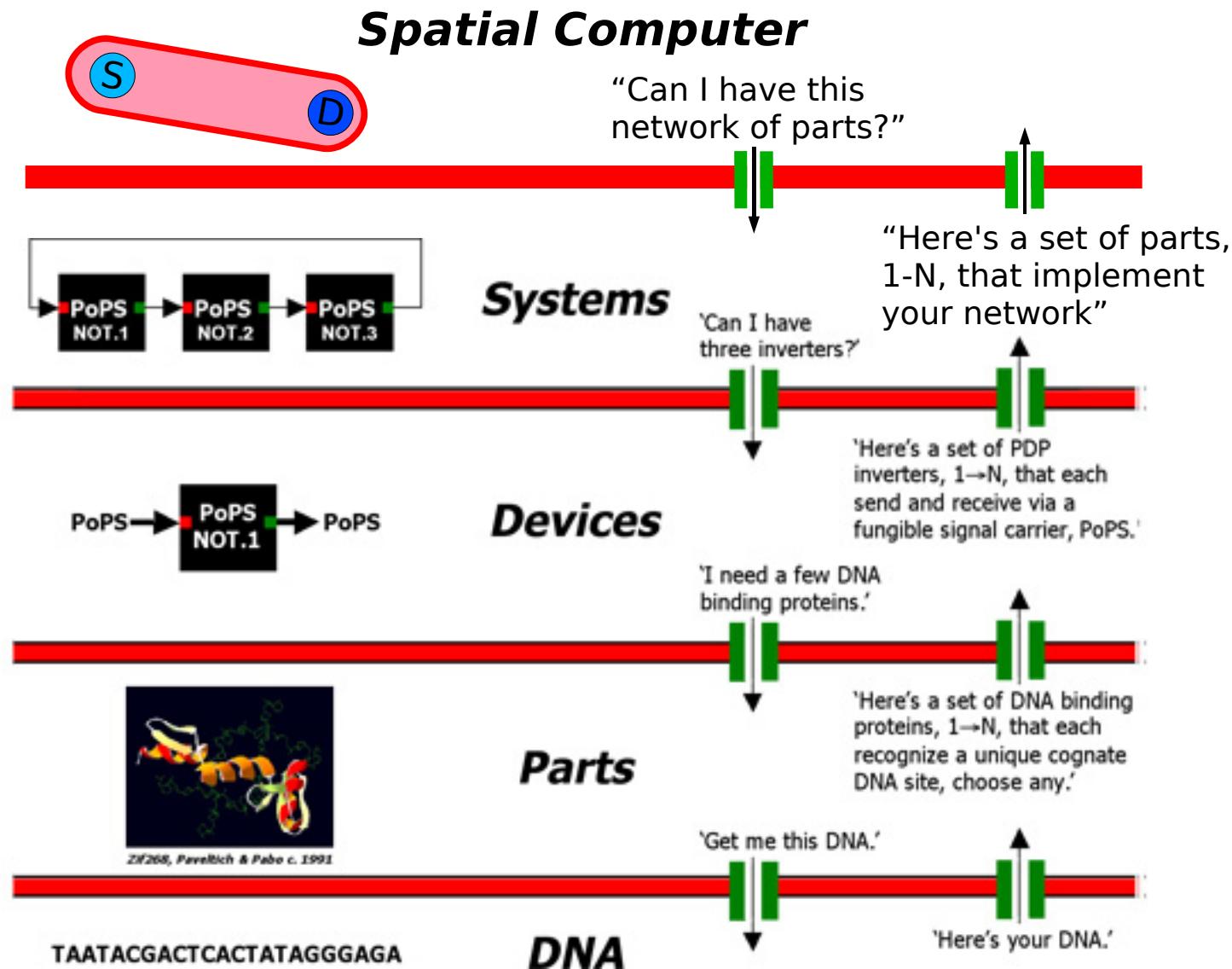


Programming Cell Aggregates

Jacob Beal
MIT CSAIL
January, 2008

Synthetic Biology Perspective



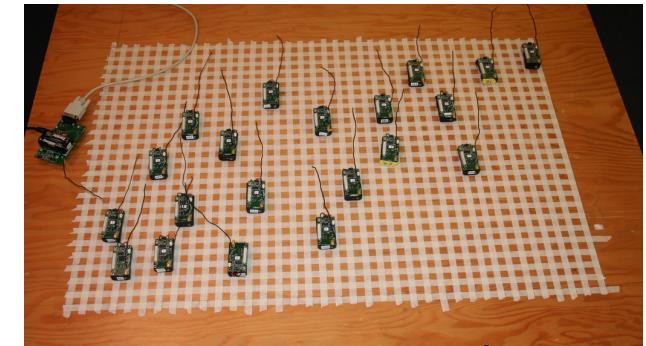
Spatial Computing Perspective



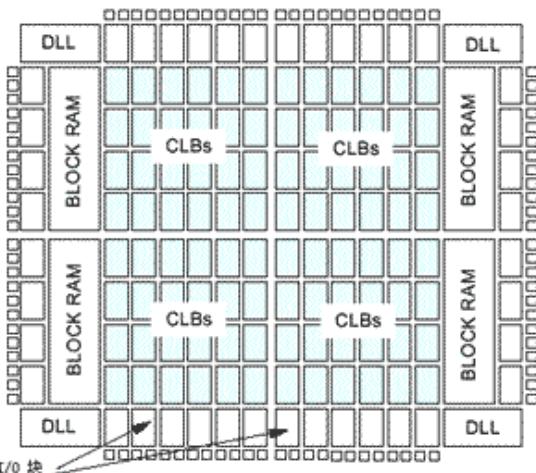
Robot Swarms



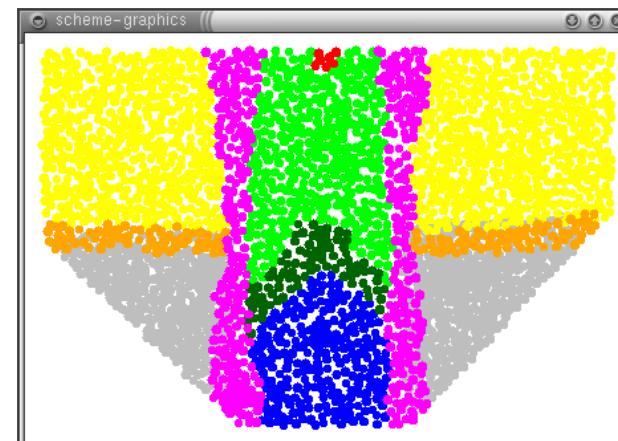
Biological Computing



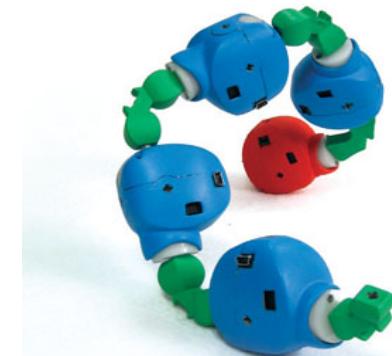
Sensor Networks



Reconfigurable Computing



Models of Morphogenesis



Modular Robotics 3

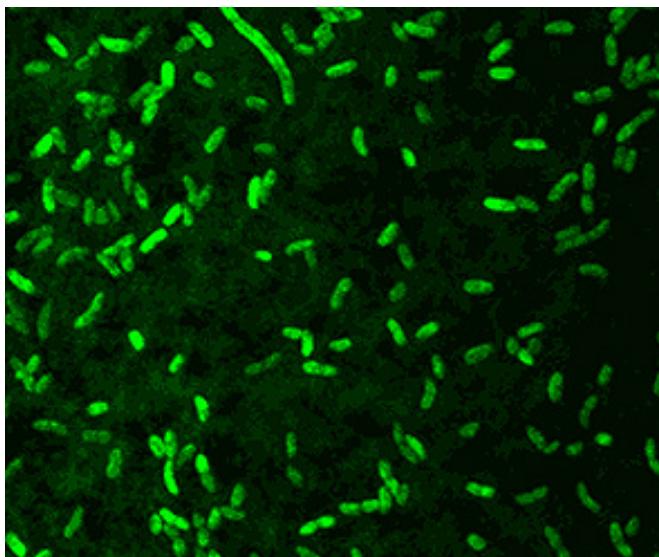
Why spatial computing?

Pointwise



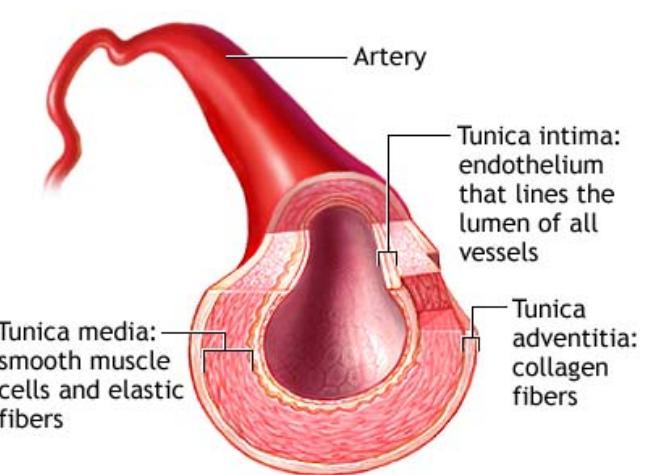
(UT Austin)

Global



(*v. fischeri* Genome Project)

Differentiated



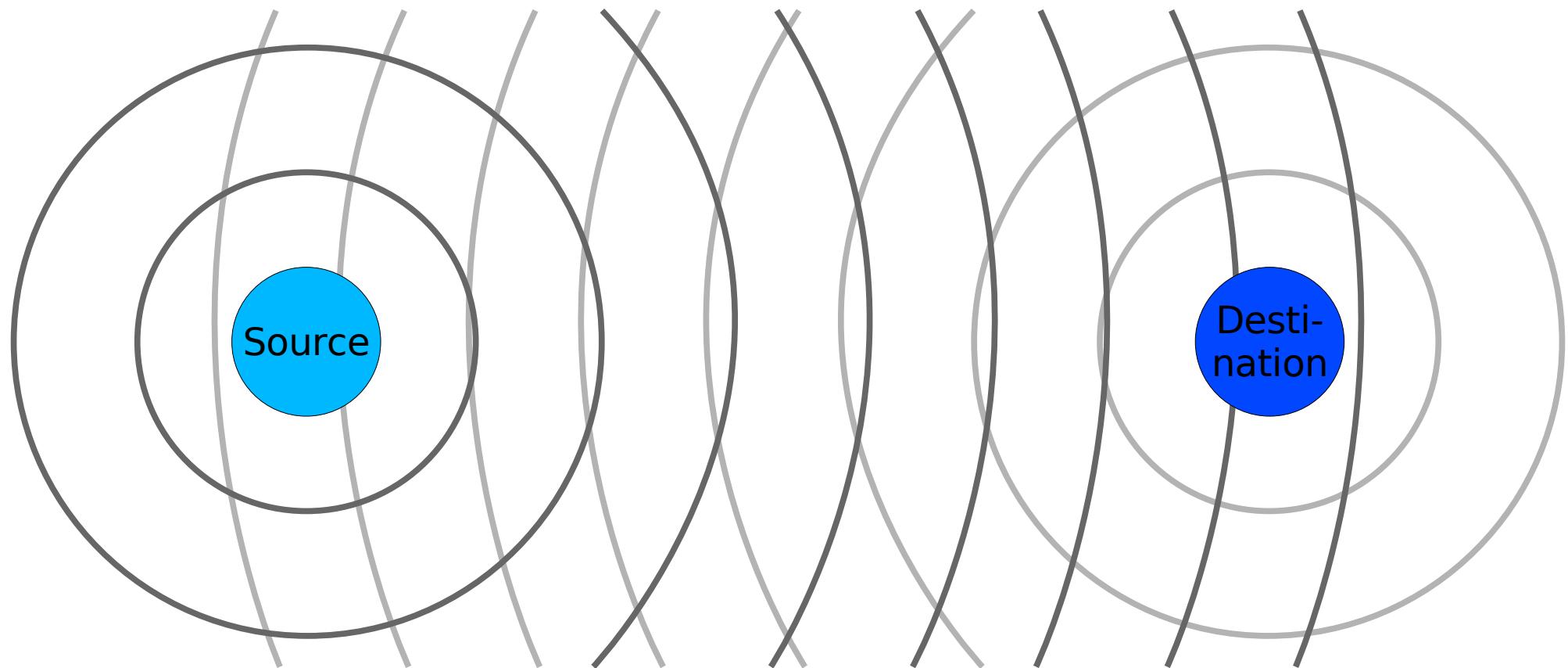
ADAM.

Geometric Program: Channel



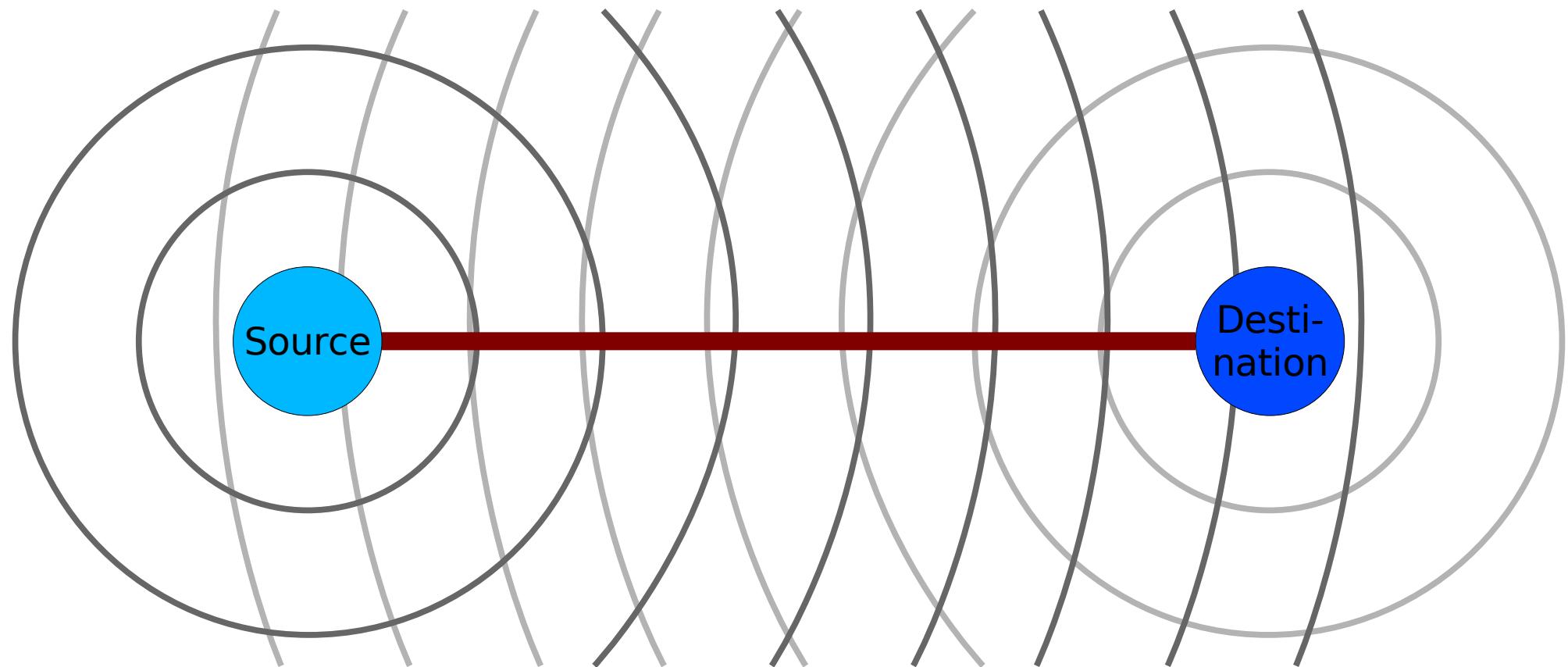
(cf. Butera) 5

Geometric Program: Channel



(cf. Butera) 6

Geometric Program: Channel



(cf. Butera) 7

Geometric Program: Channel



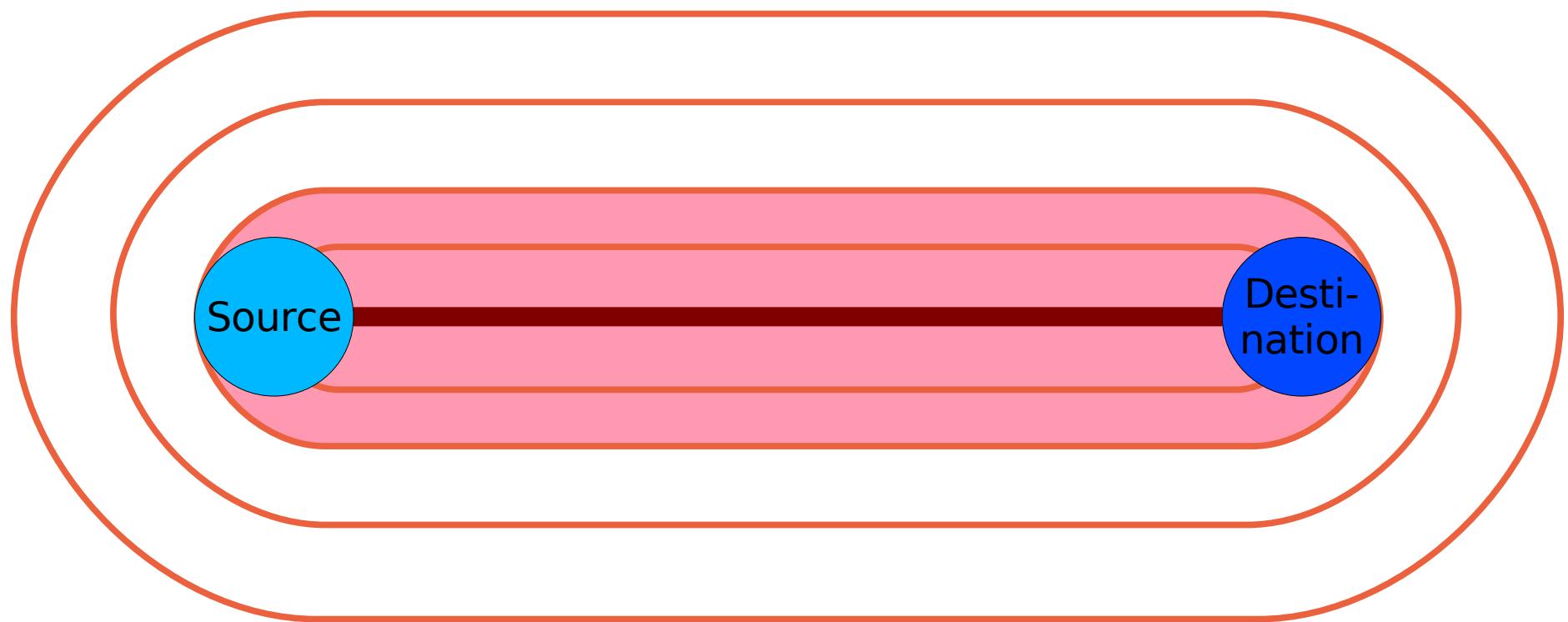
(cf. Butera) 8

Geometric Program: Channel



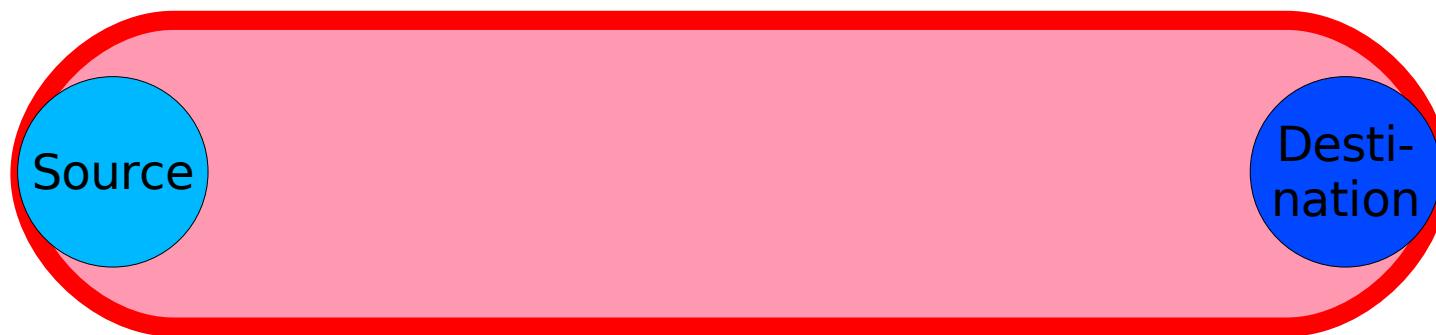
(cf. Butera) 9

Geometric Program: Channel



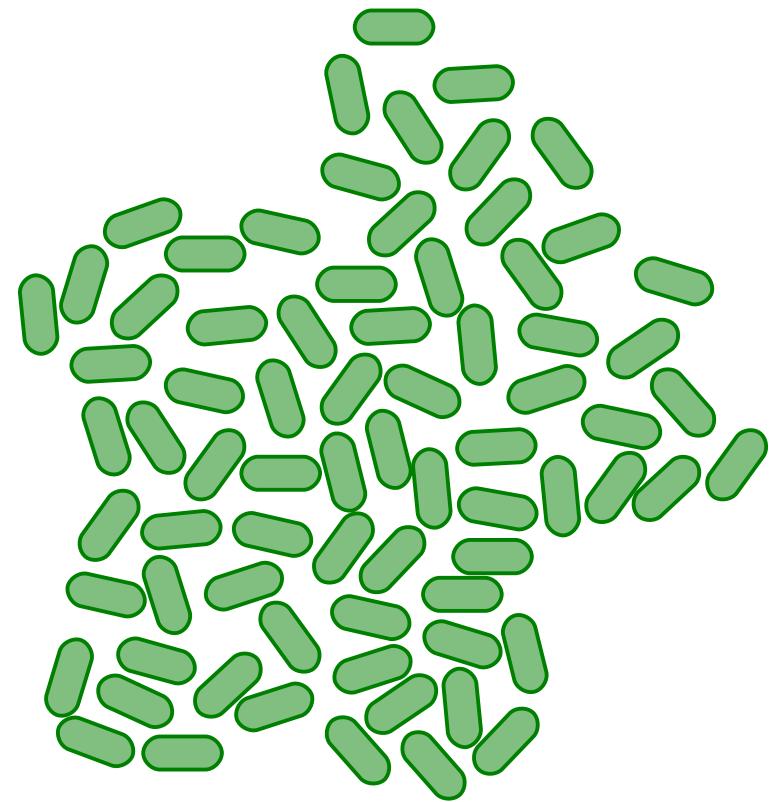
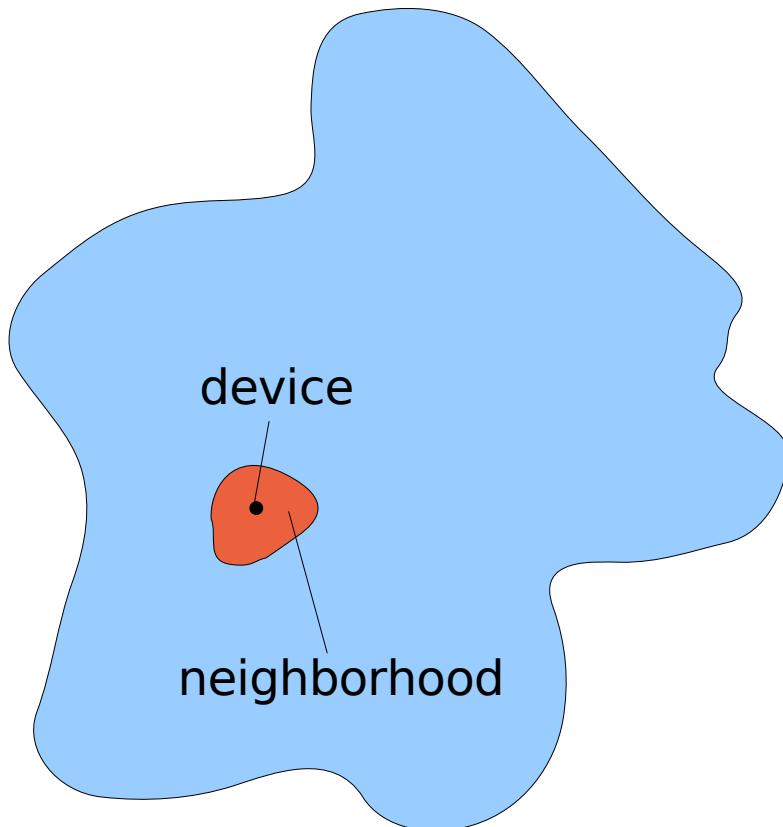
(cf. Butera)10

Geometric Program: Channel



(cf. Butera)11

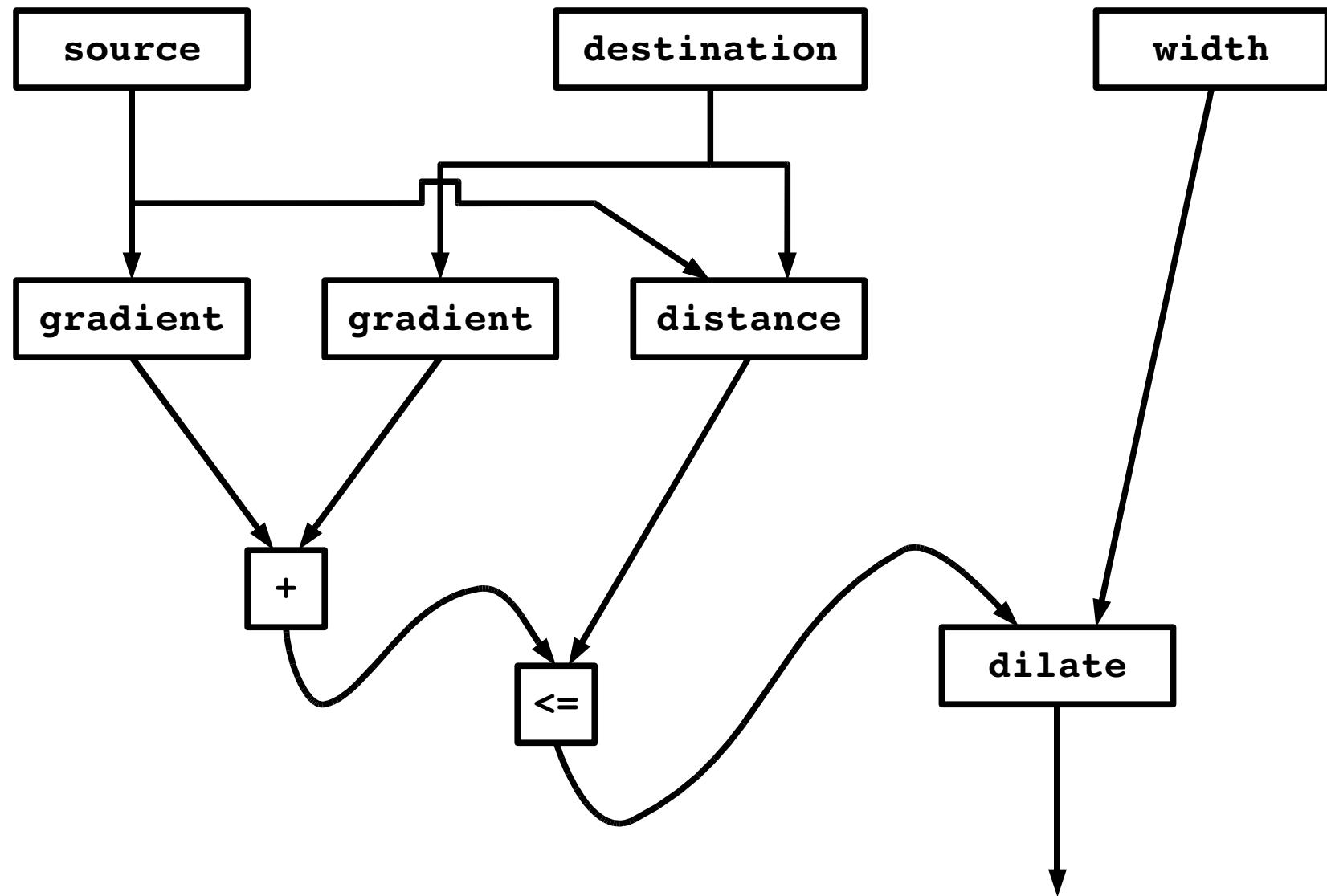
Amorphous Medium



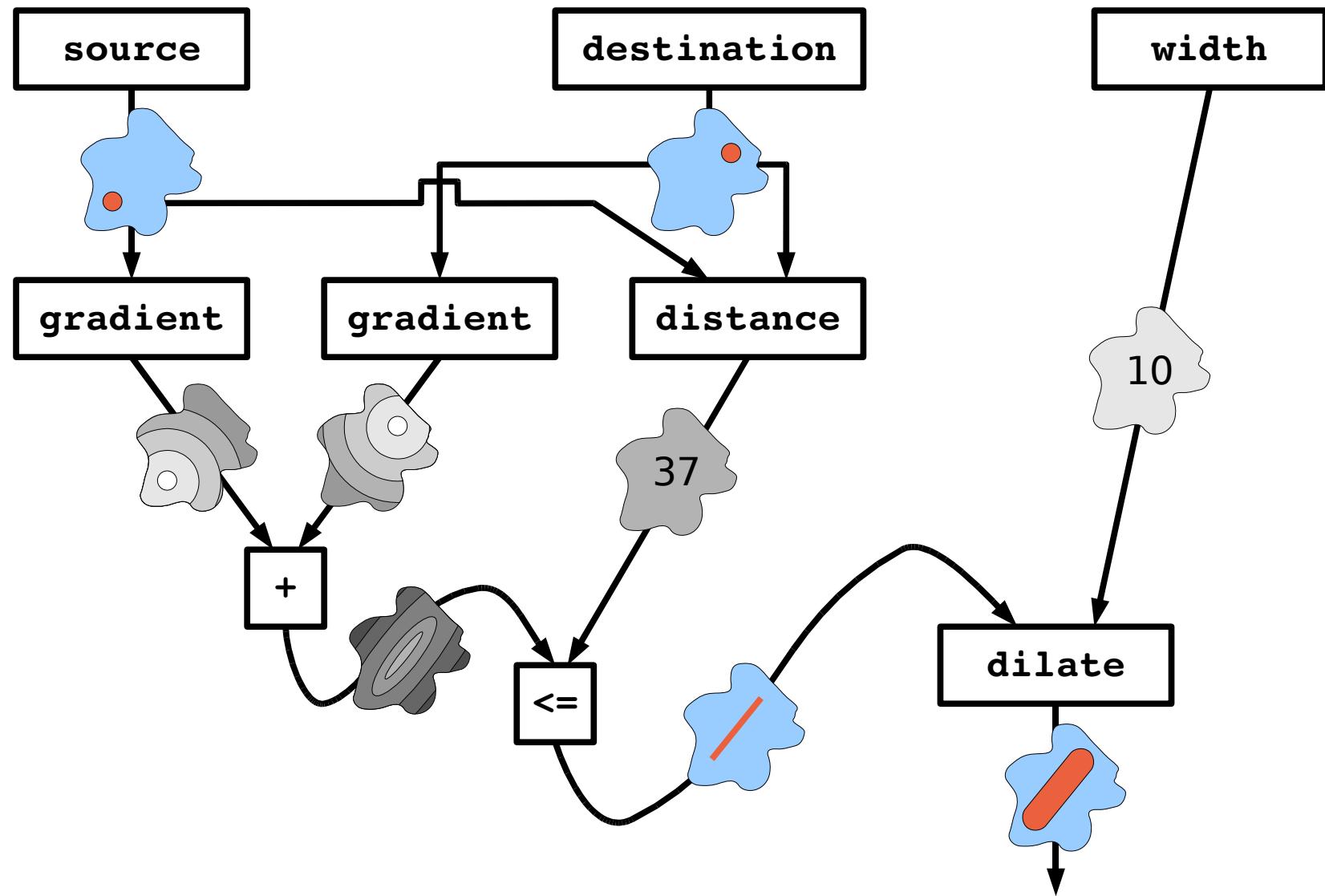
- Continuous space & time
- Infinite number of devices
- See neighbors' past state

- Approximate with:
- Discrete network of devices
 - Signals transmit state

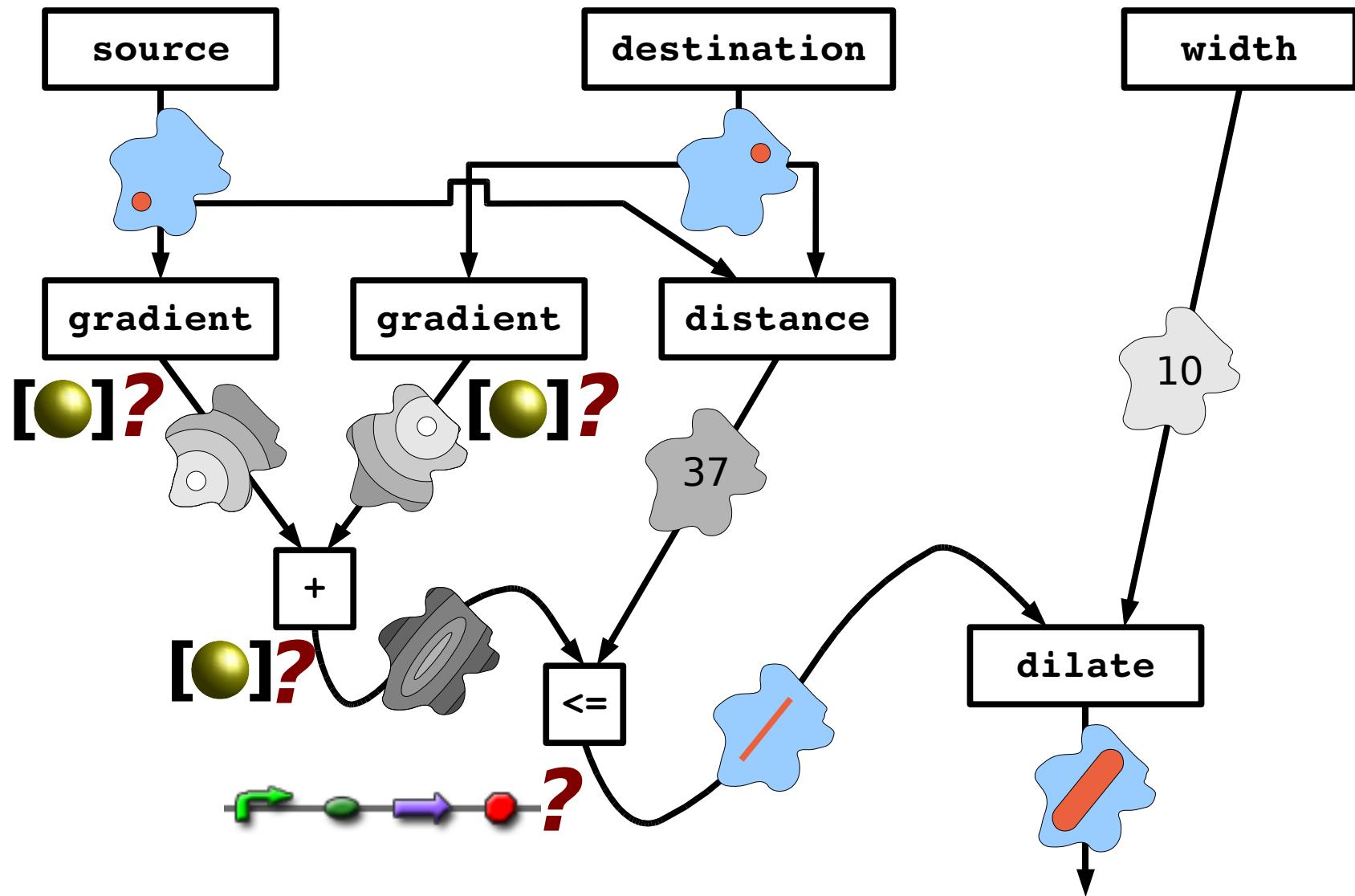
Computing with fields



Computing with fields



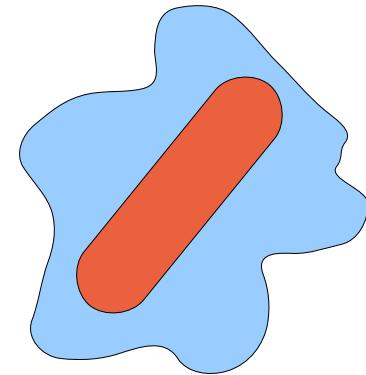
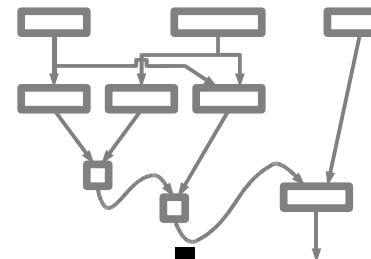
Computing with fields



Proto

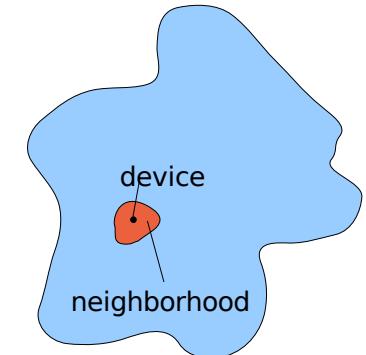
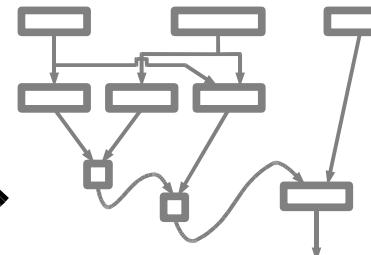
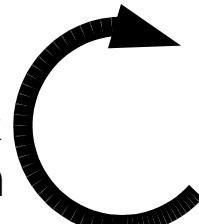
```
(def gradient (src) ...)  
(def distance (src dst) ...)  
(def dilate (src n)  
  (<= (gradient src) n))  
(def channel (src dst width)  
  (let* ((d (distance src dst))  
         (trail (<= (+ (gradient src)  
                      (gradient dst))  
                  d)))  
    (dilate trail width)))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

evaluation



Global

global to local compilation

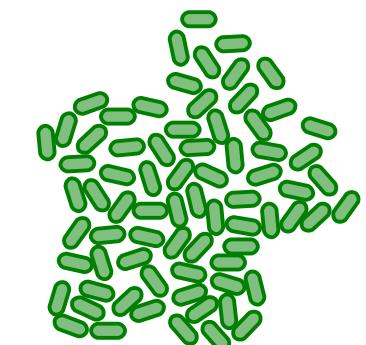


Local

platform specificity & optimization

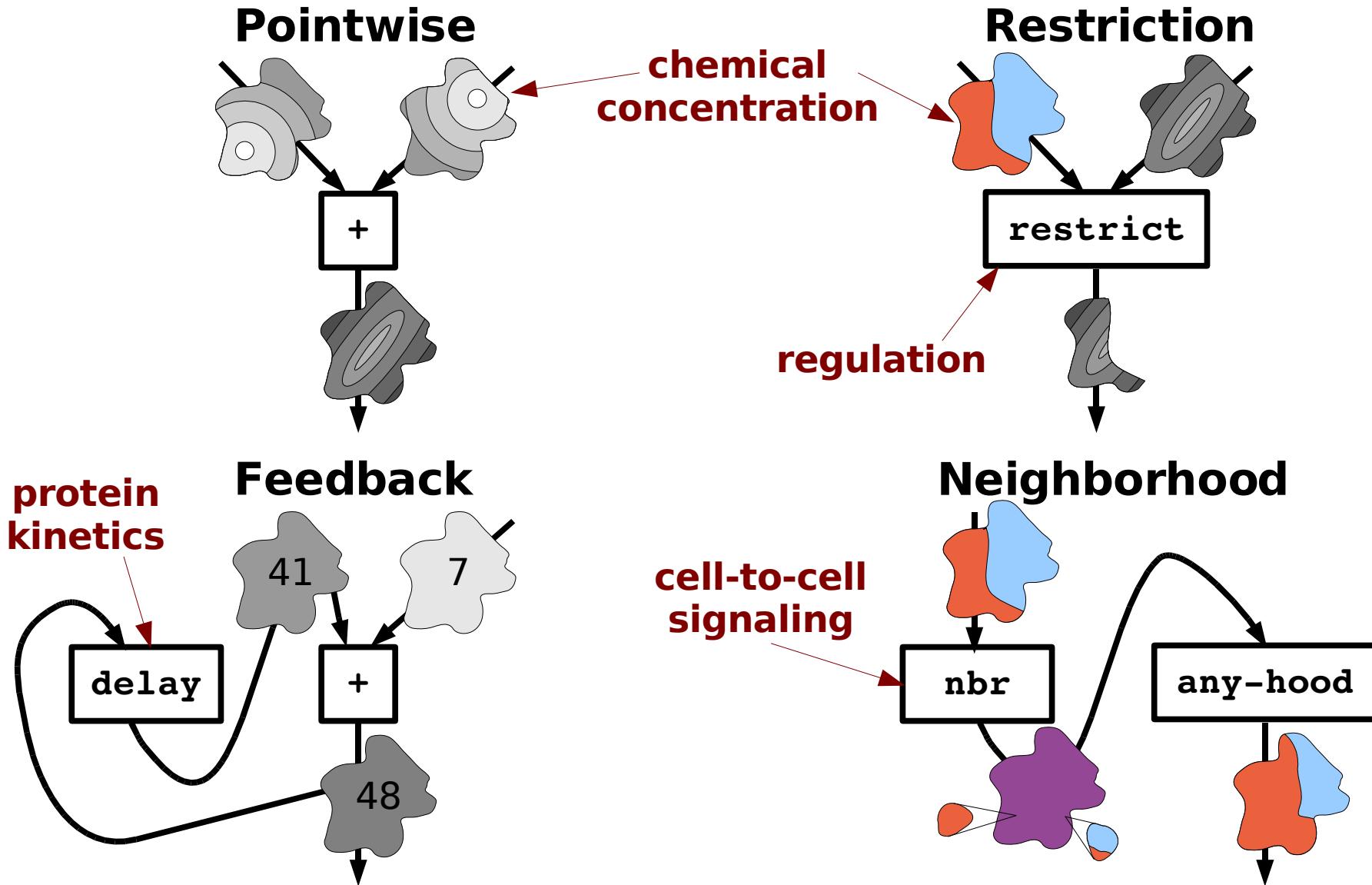
discrete approximation

Device
Kernel

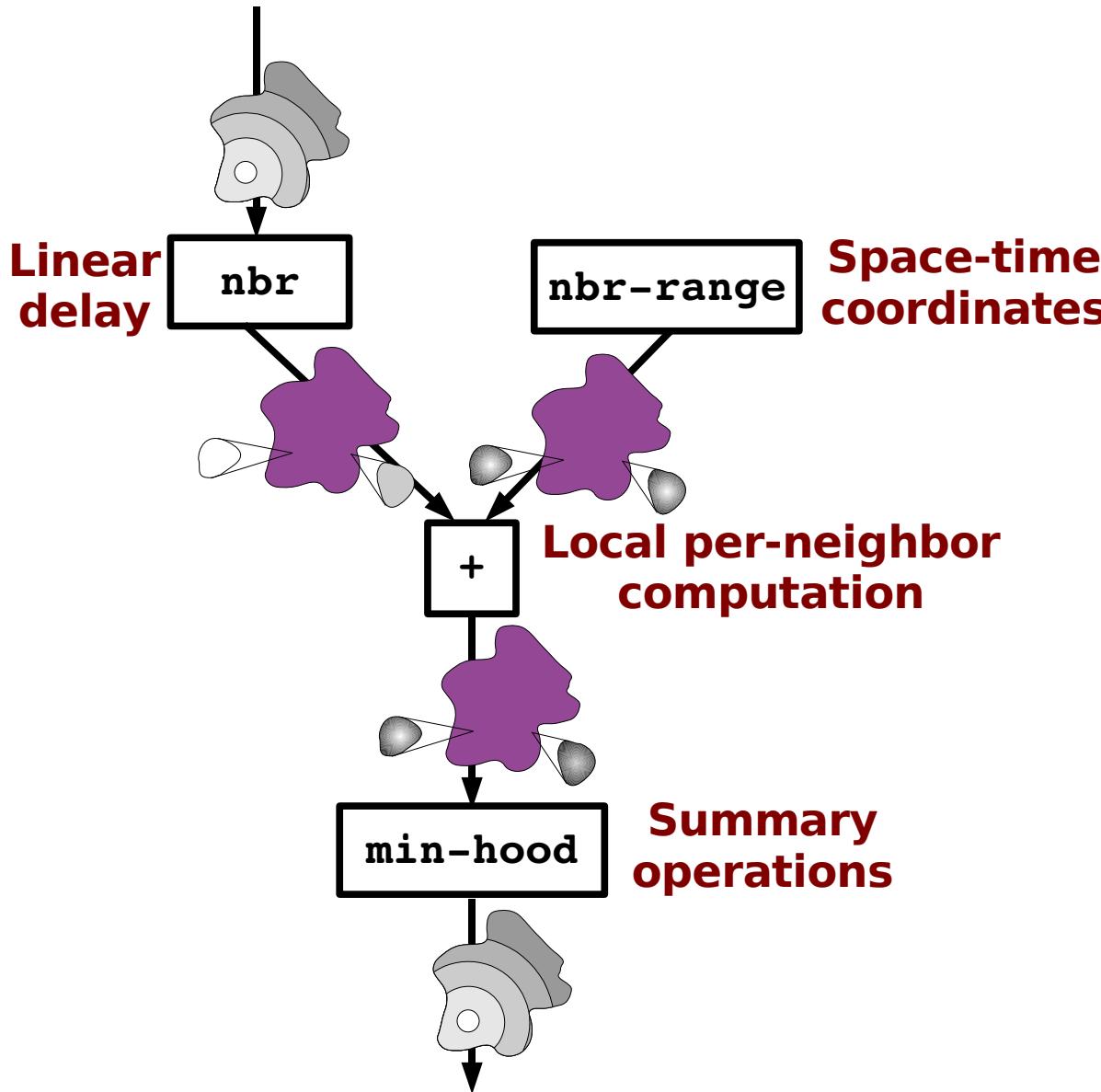


Discrete

Proto's Families of Primitives



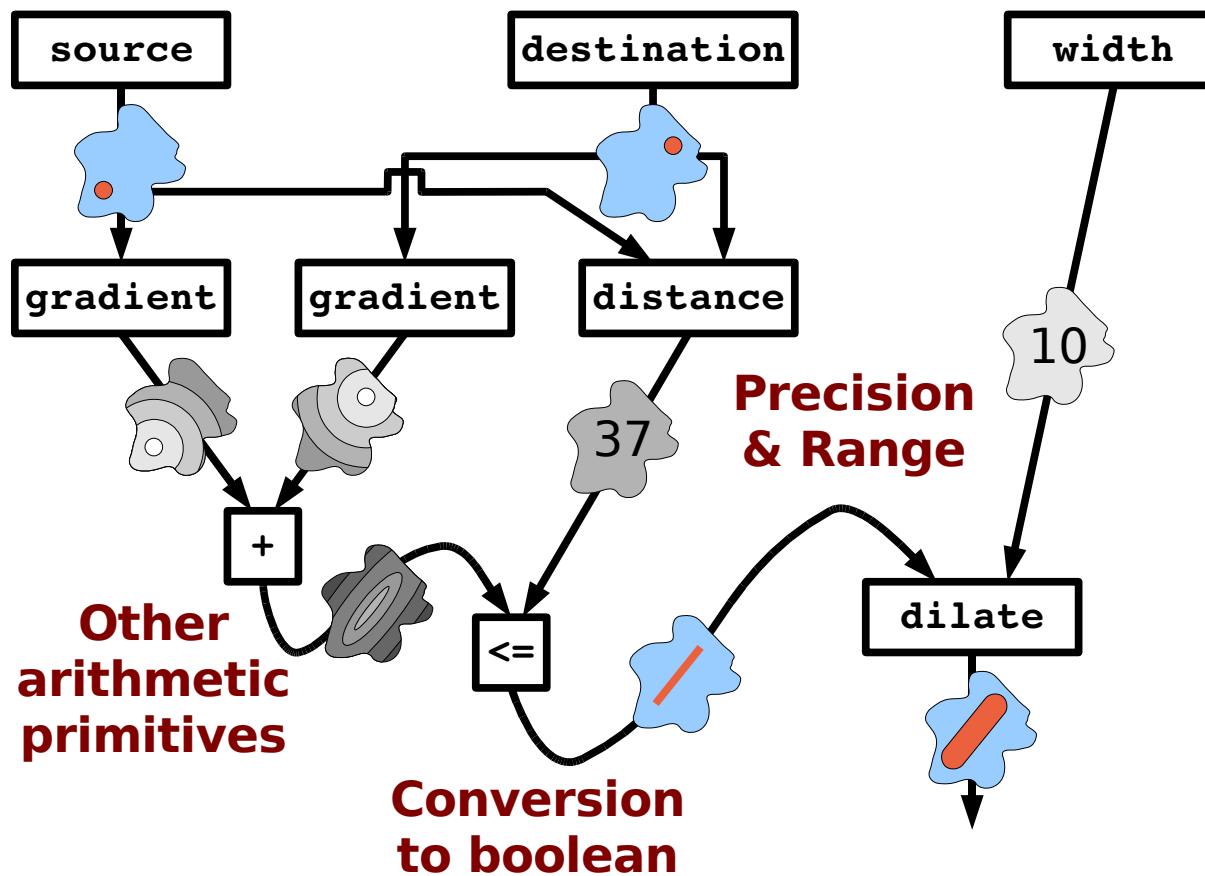
Problem: neighborhood operations



Possible solutions:

- physical/chemical constraint on diffusion
- space/time chemical signals
- compute on membranes
- invert min/all
- integration by superposition

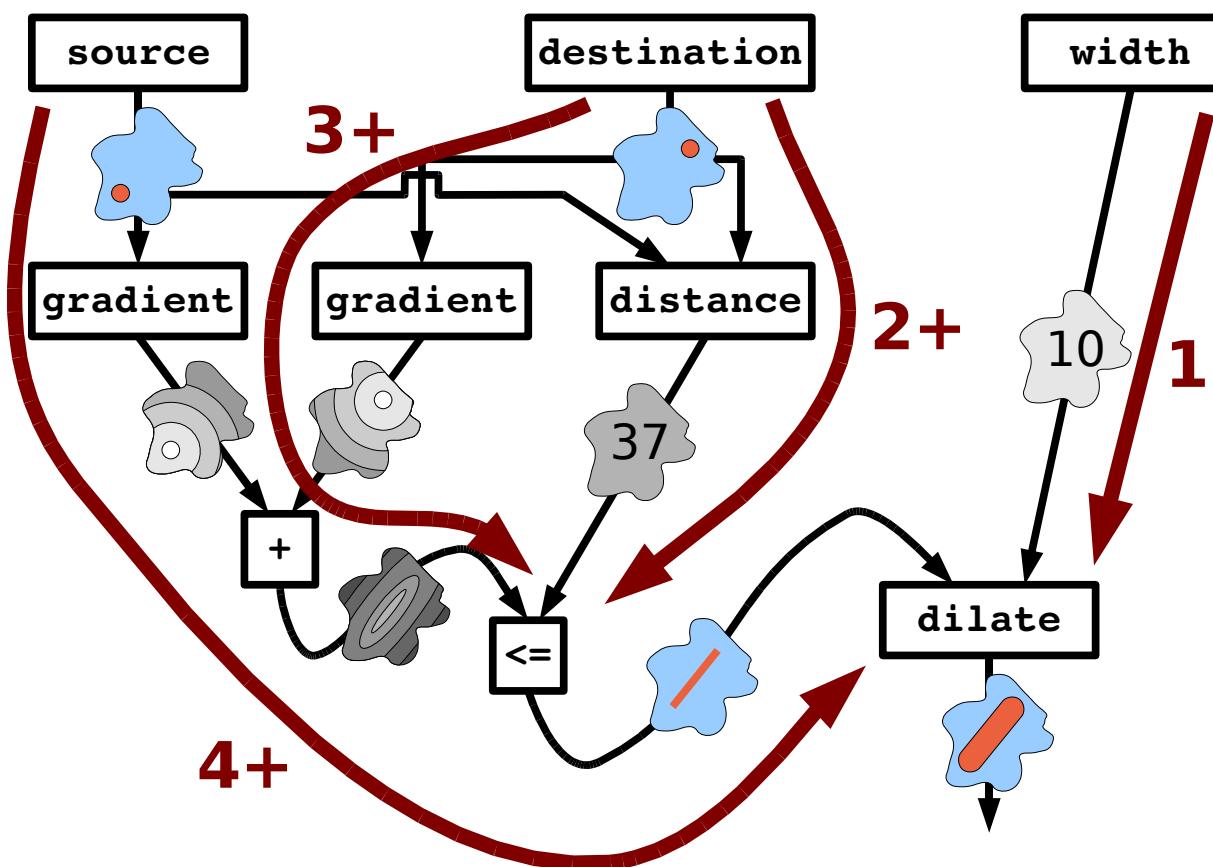
Problem: numerical operations



Possible solutions:

- multi-chemical numbers
- compiler tunes each operation for its range
- make costly operations errors or warnings
- analog libraries

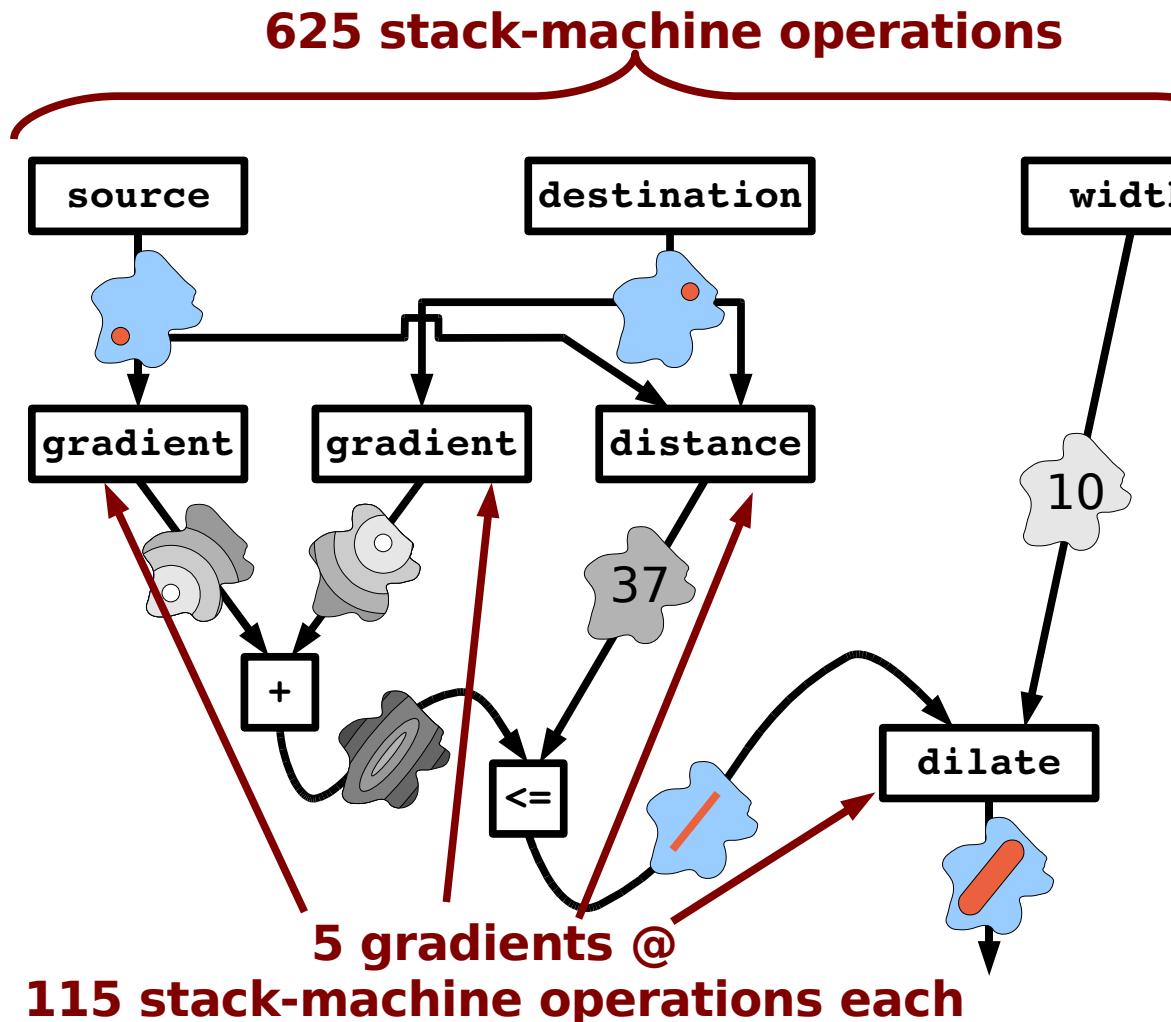
Problem: timing



Possible solutions:

- add inverters
- tweak kinetics
- add “clocks”

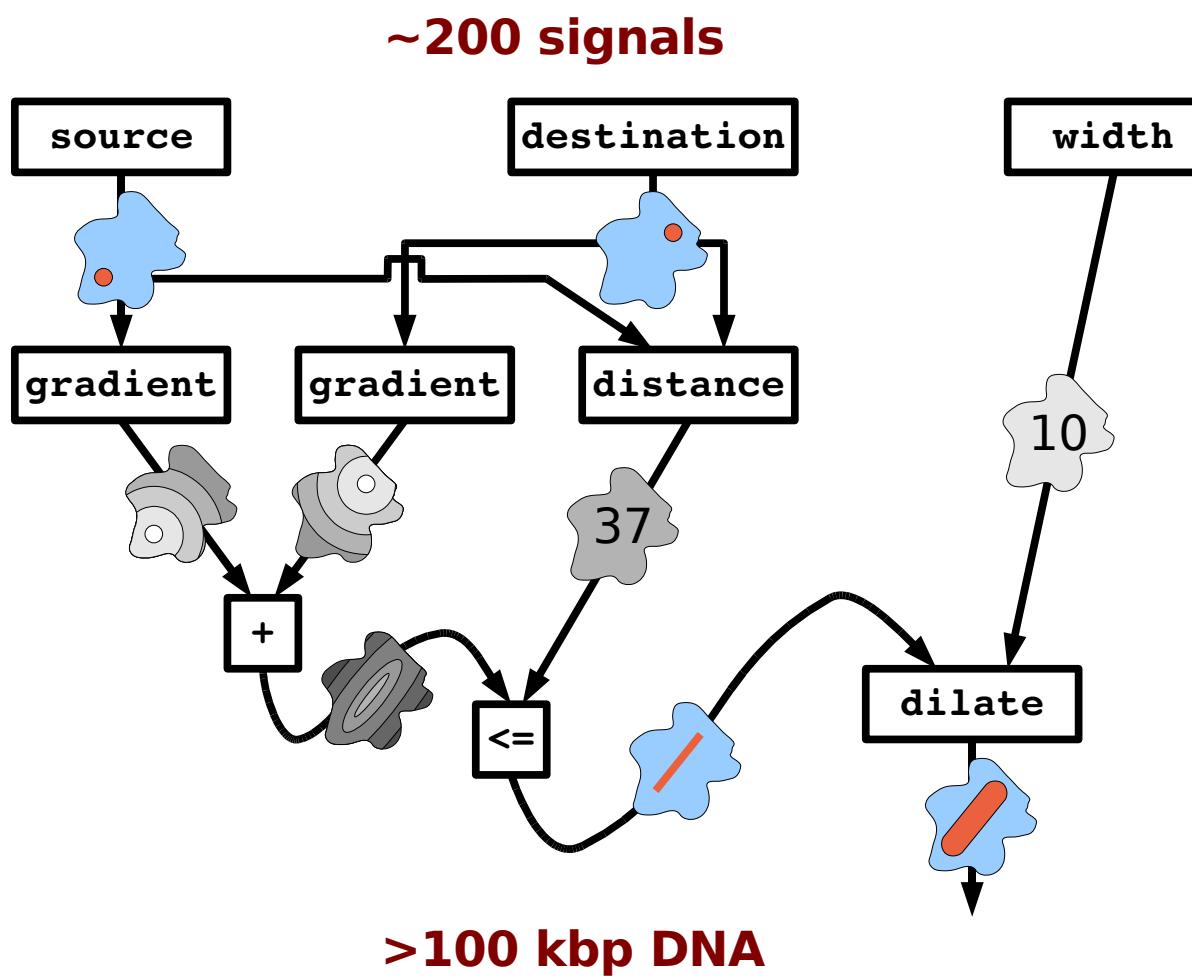
Problem: cross-talk



Possible solutions:

- many more transcription factors
- vesicles/teams
- analog libraries
- optimization:
 - Share signals in mutually exclusive code
 - CSE/DCE

Problem: metabolic load



Possible solutions:

- low-concentration signals
- analog libraries
- optimization for code size or zero values

Contributions

- Proto/Biology mapping is plausible
- Key engineering challenges:
 - neighborhood operations
 - numerical operations
 - timing
 - cross-talk
 - metabolic load