Aggregate Programming
Part 1: Motivation & Field Calculus

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SFM16: QUANTICOL
June 2016

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A generative approach to safety

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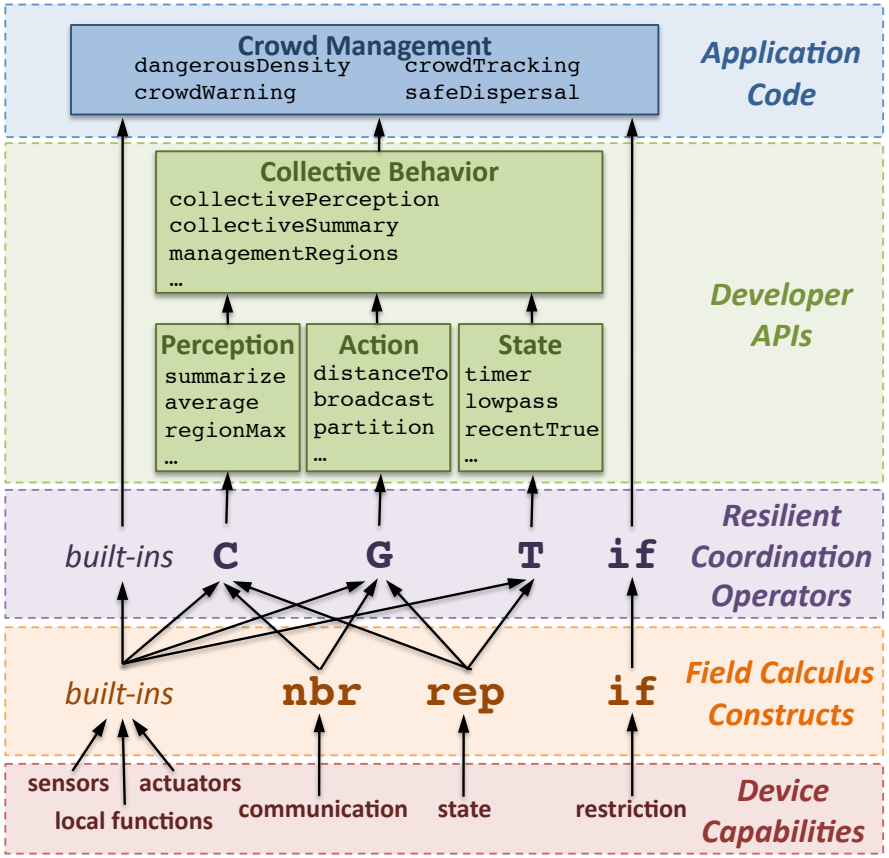
Restrict your development environment…



… to contain only resilient distributed systems.

Dealing with challenging platforms

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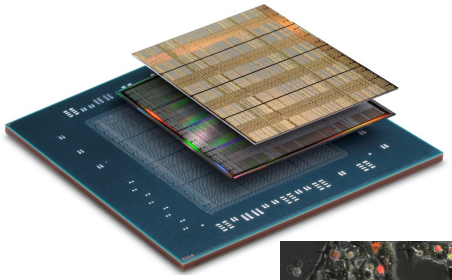
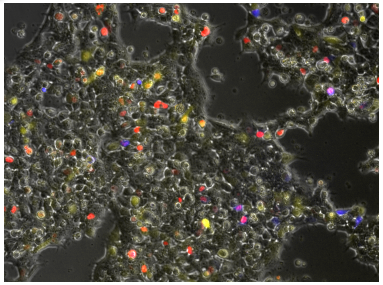
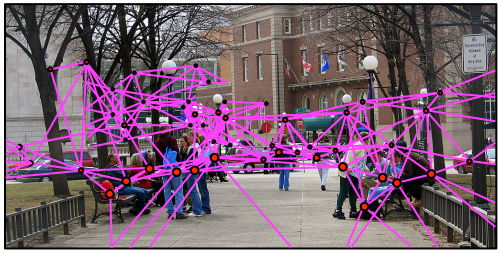
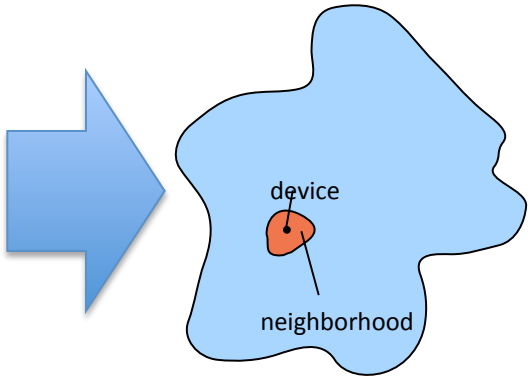
Emerging Computational Platforms







Computational Field Programming Models



Inherently Resilient Distributed Systems

Pay a little efficiency, get a lot of programmability and resilience

Traditional Monolithic Computing

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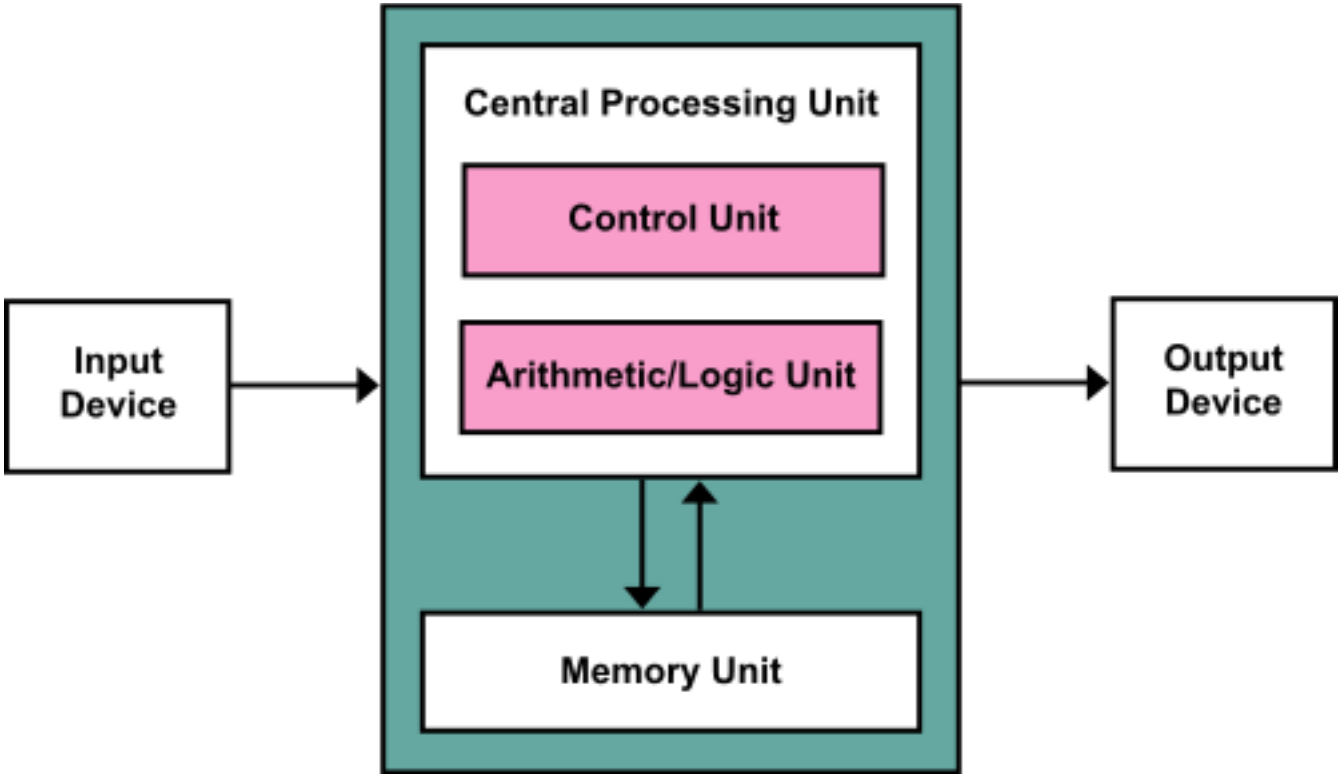

The venerable von Neumann model is breaking down in several ways…

The End of Moore's Law

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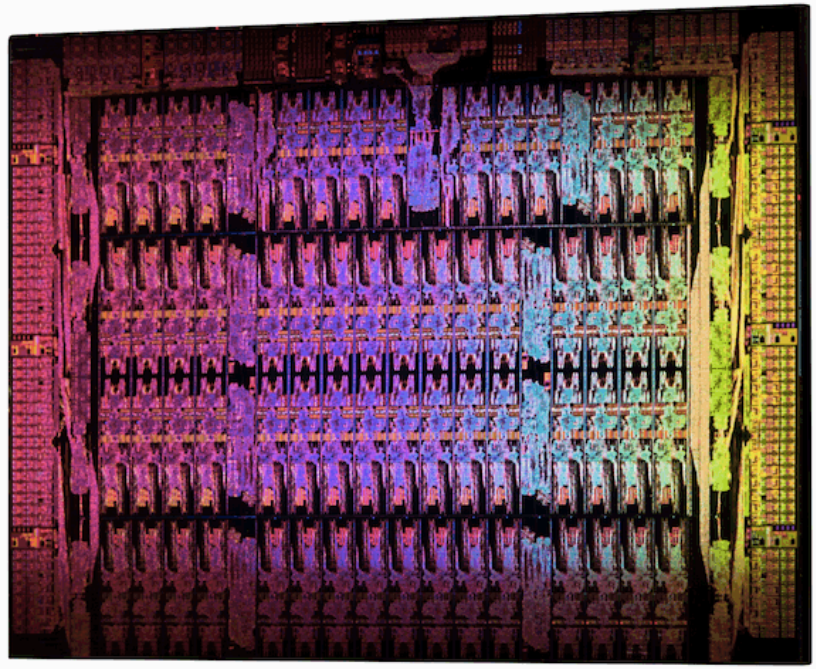
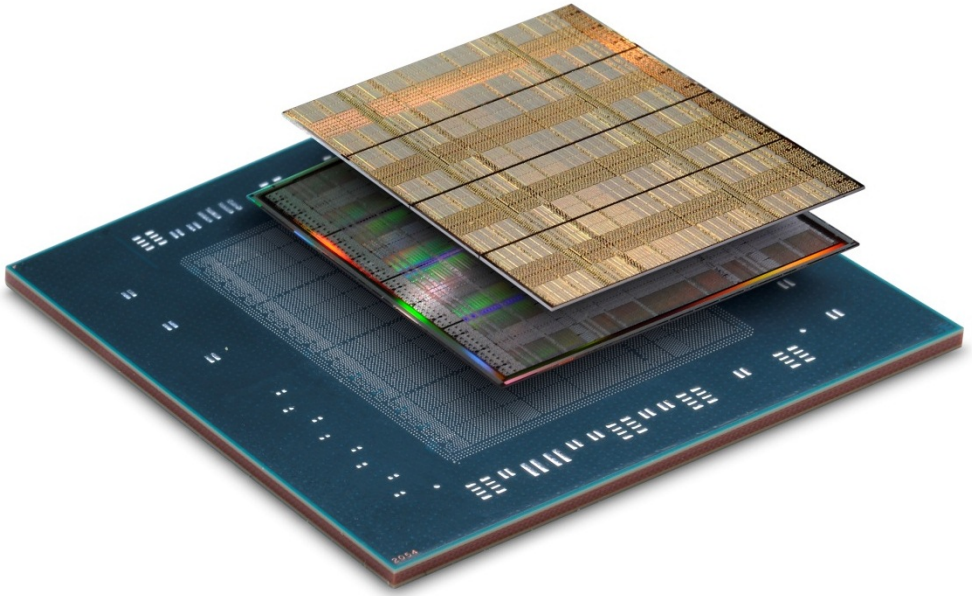


Intel Xeon Phi: 61 cores



Xilinx Virtex-7: 2M Logic cells

High-performance computing = mesh

Networked Devices Everywhere

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New Computational Materials

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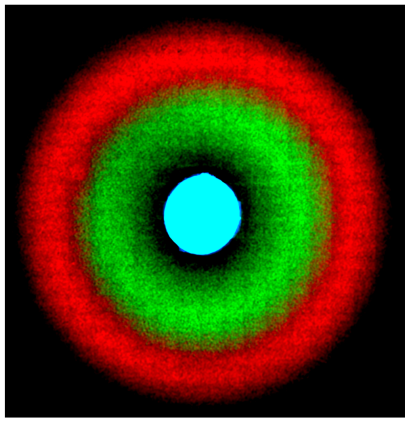
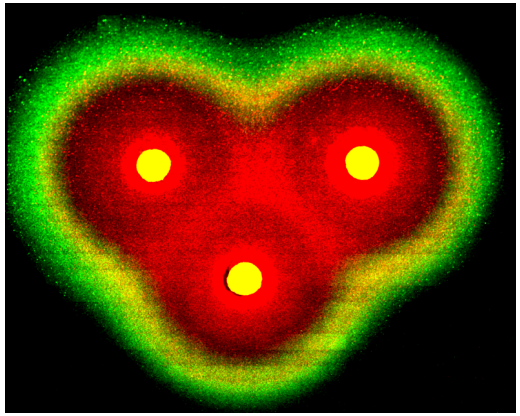
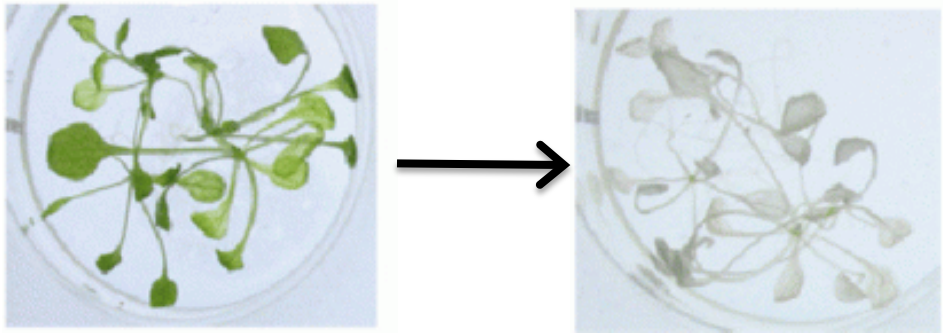
- Synthetic Biology:

[Levskaya]

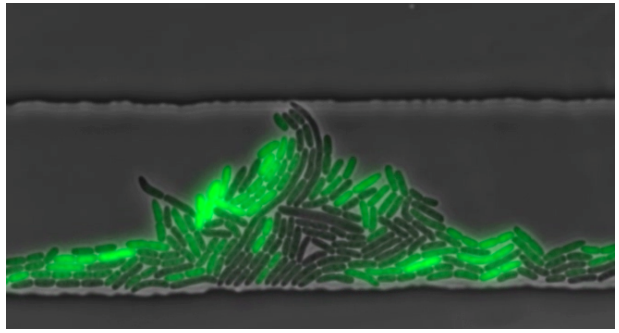




[Weiss]



[Medford]



[Hasty]

Other emerging areas too, including nanoassembly, active materials…

Fundamentally different models

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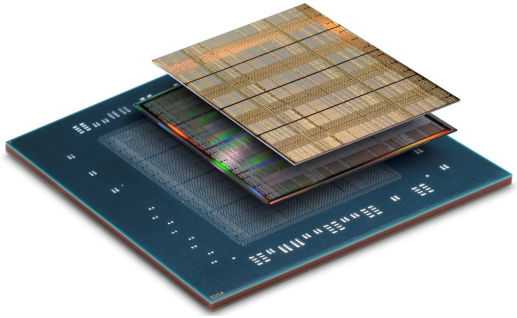

Isolate Systems
Extremely High FLOPs

High Dispersion
Moderate FLOPs

High Resolution Sense/Act
Abysmal FLOPs

How can we program aggregates adaptively & efficiently?

Are there commonalities that cross substrates?

Example: Services for Mass Events

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Example: Managing Crowd Danger

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Device-Centric Programming

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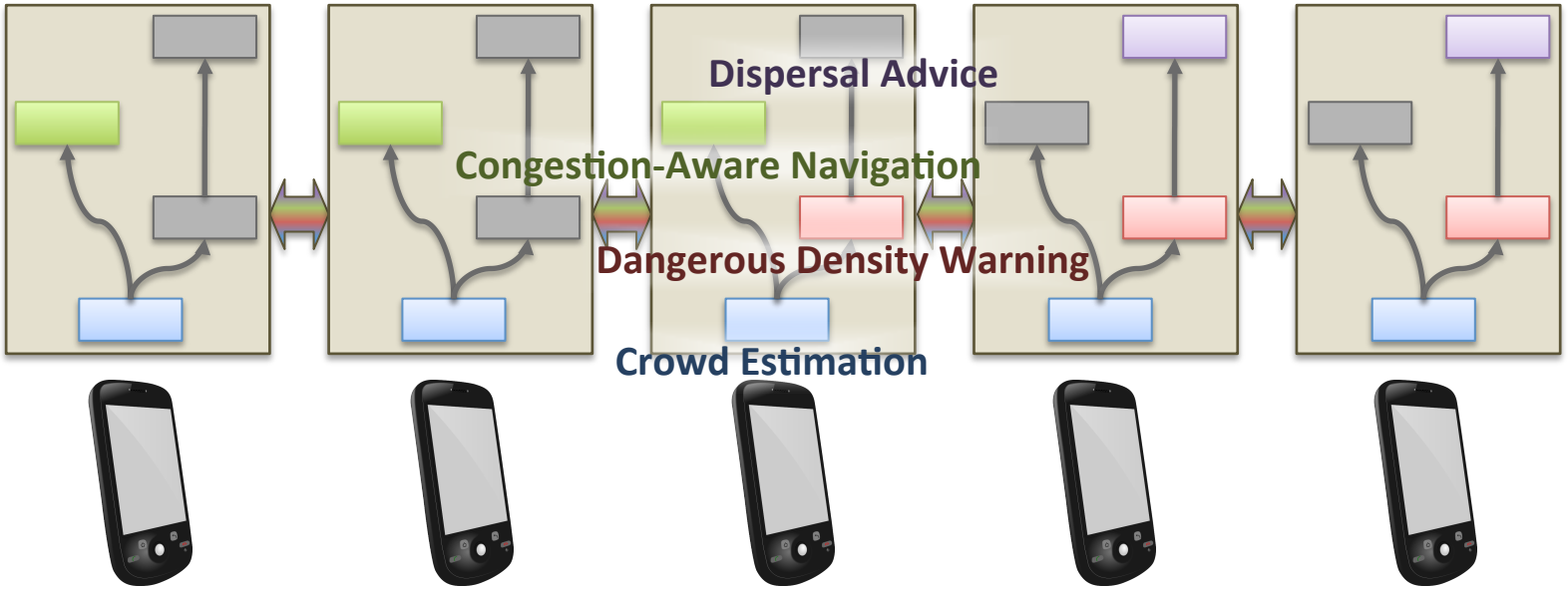

- Explicit design of adaptation and communication
- Complex per-device multi-service application
- Intractable to ensure correct behavior

Aggregate Programming

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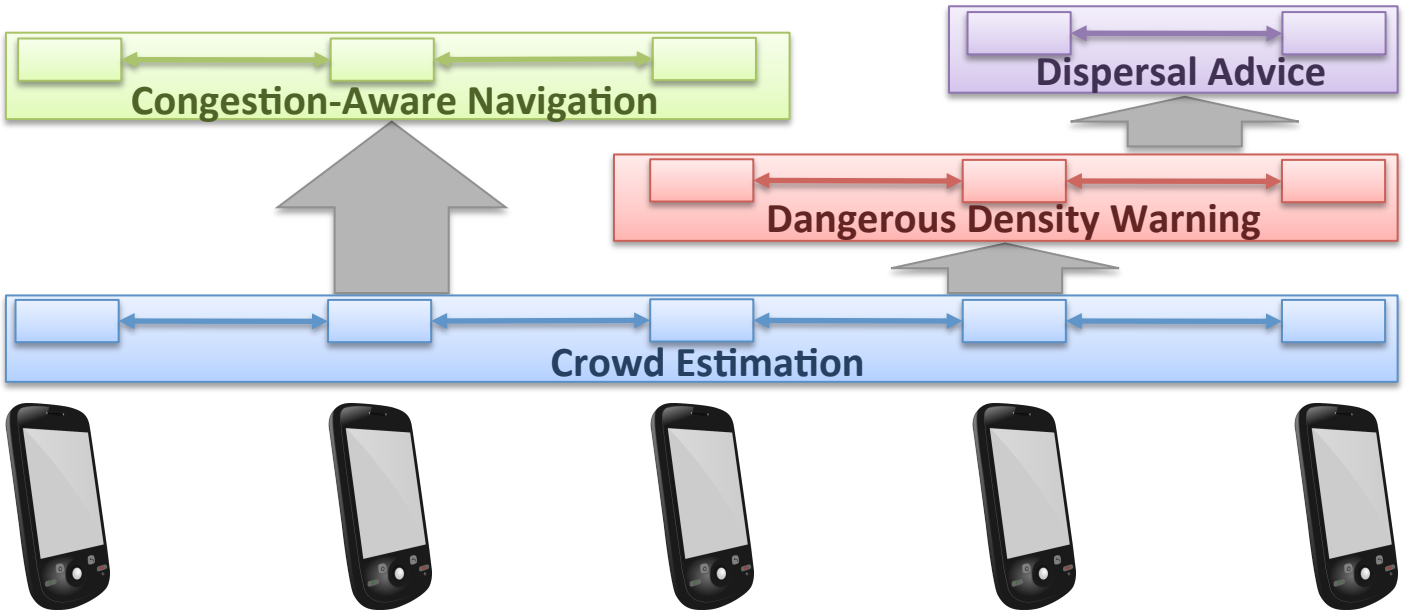

- Implicit adaptation and communication
- Code each collective service independently
- Compose via scope and information flow

Aggregate Programming

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Aggregate Programming Stack

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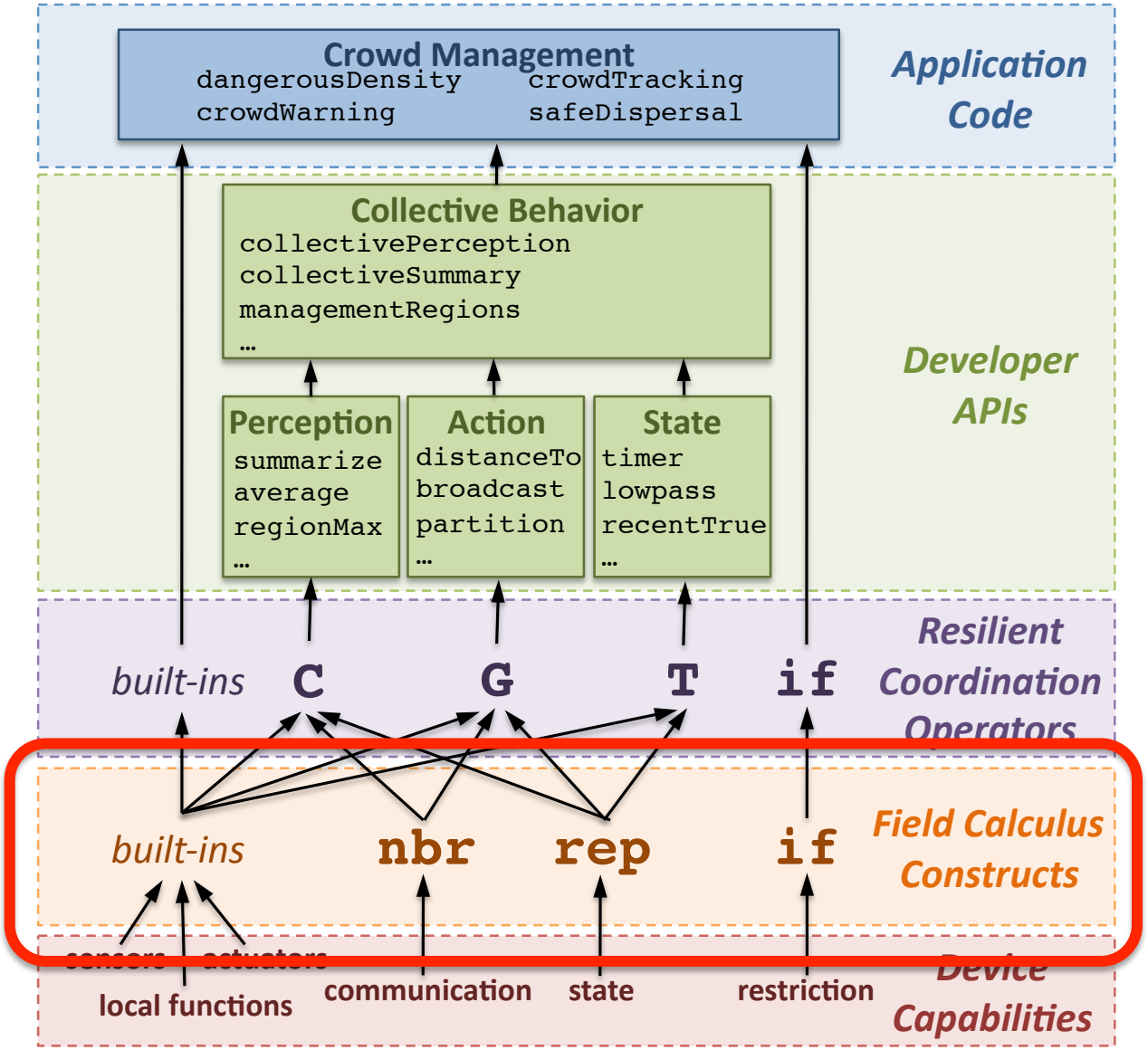

Example: Mesh-Network Cell Phones

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Geometric Program: Channel

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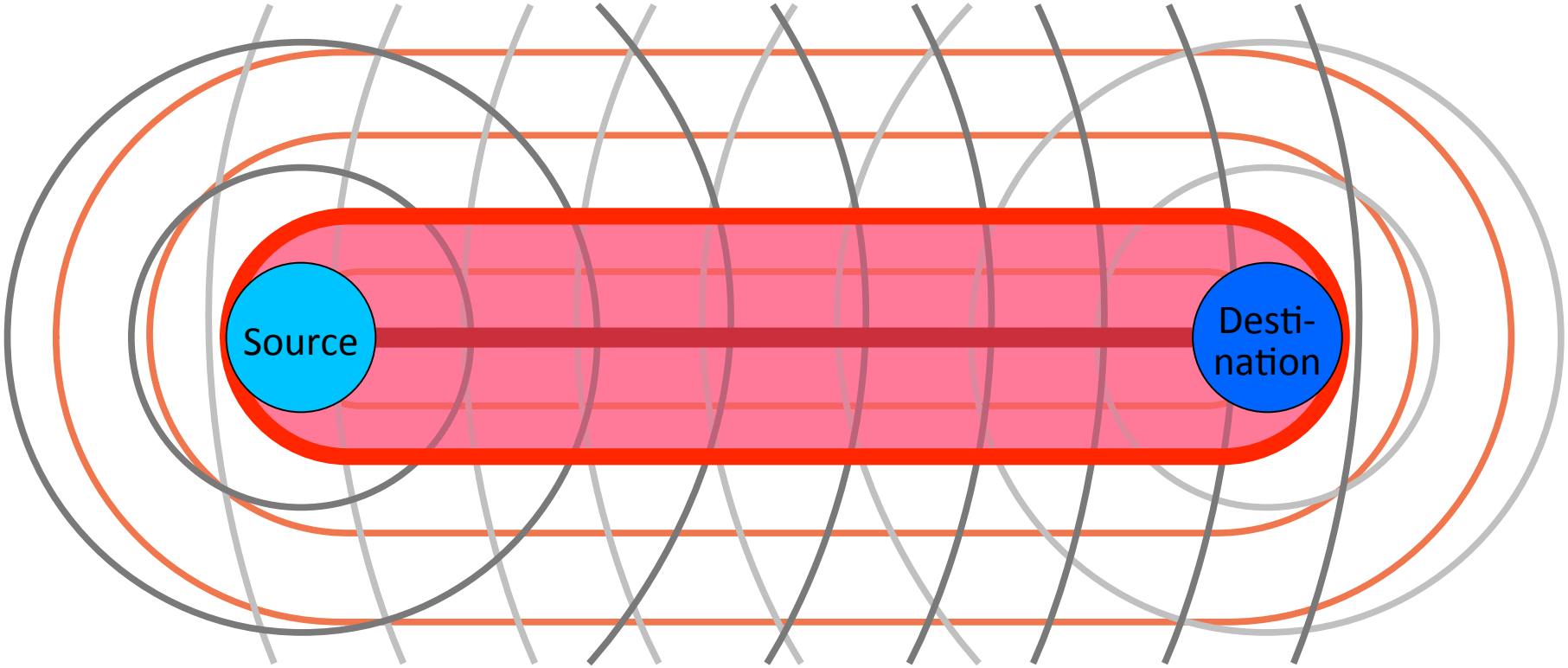

(cf. Butera)

Computing with fields

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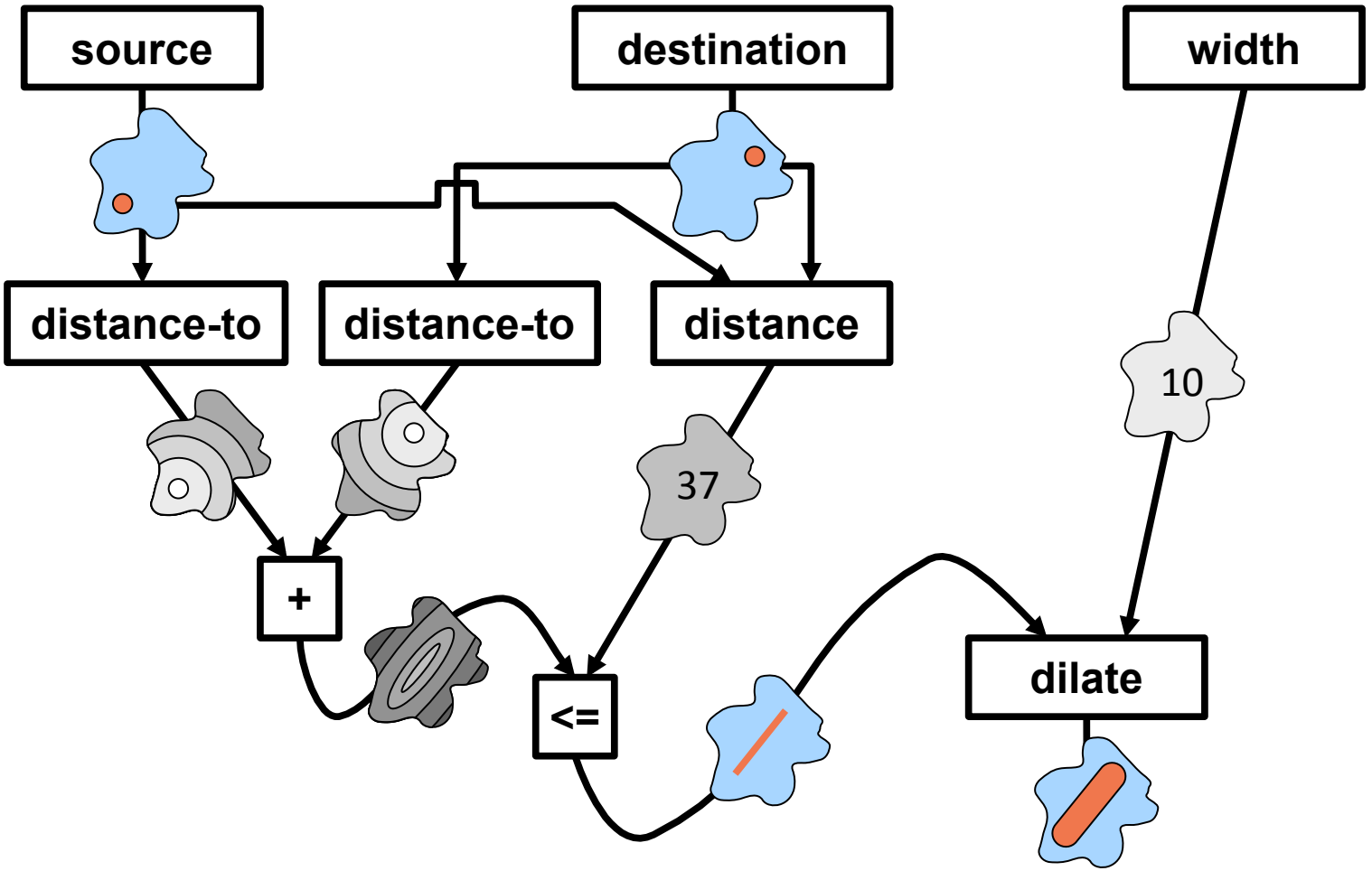

(Higher Order) Field Calculus

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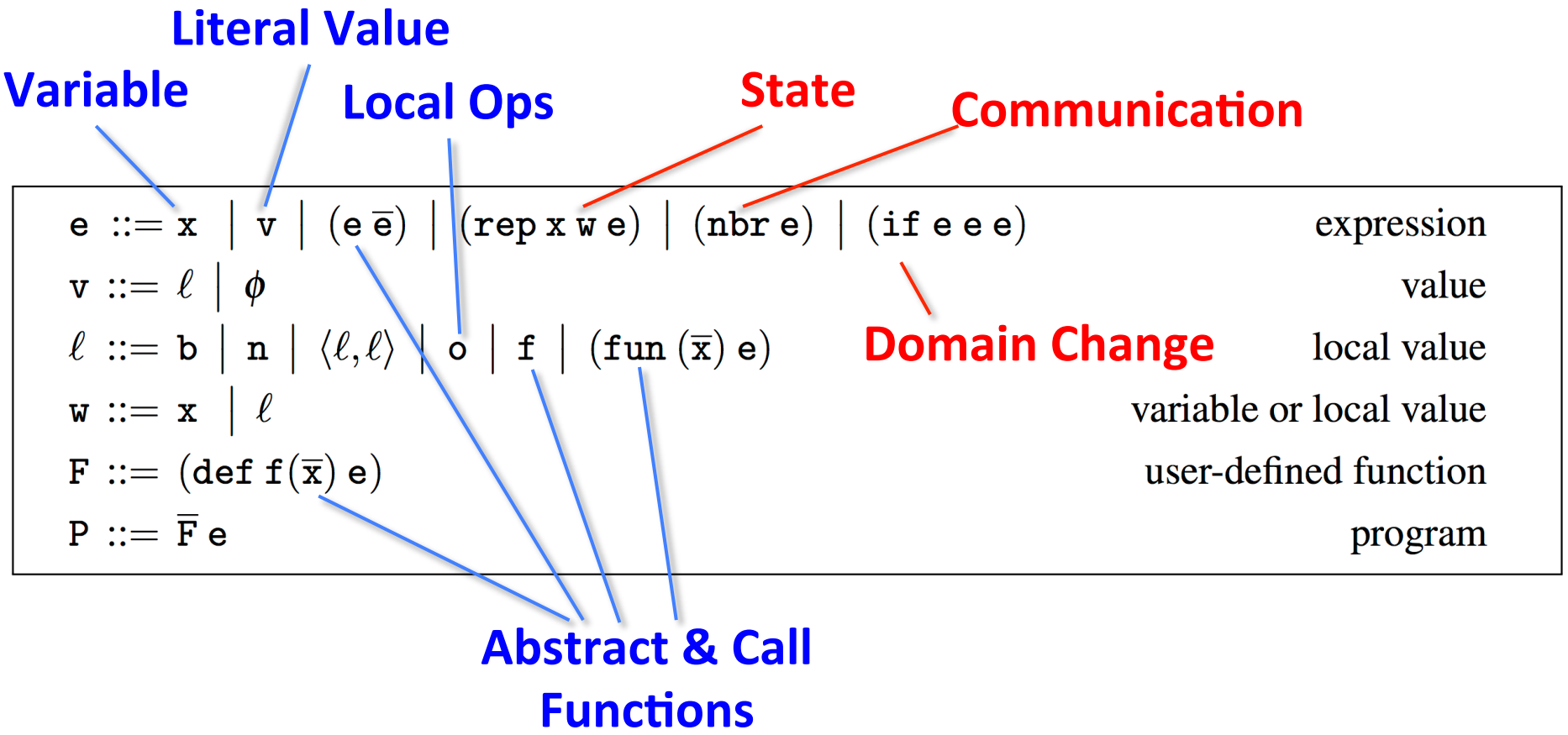

[Viroli et al., '13, Damiani et al., '15]

Field Calculus Example

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```
(def distance-to (region)
  (rep d
       infinity
       (mux region
            0
            (min-hood
             (+ (nbr d)
                (nbr-range))))))
```

Let's go examine this in simulation…

Field Calculus is Space-Time Universal

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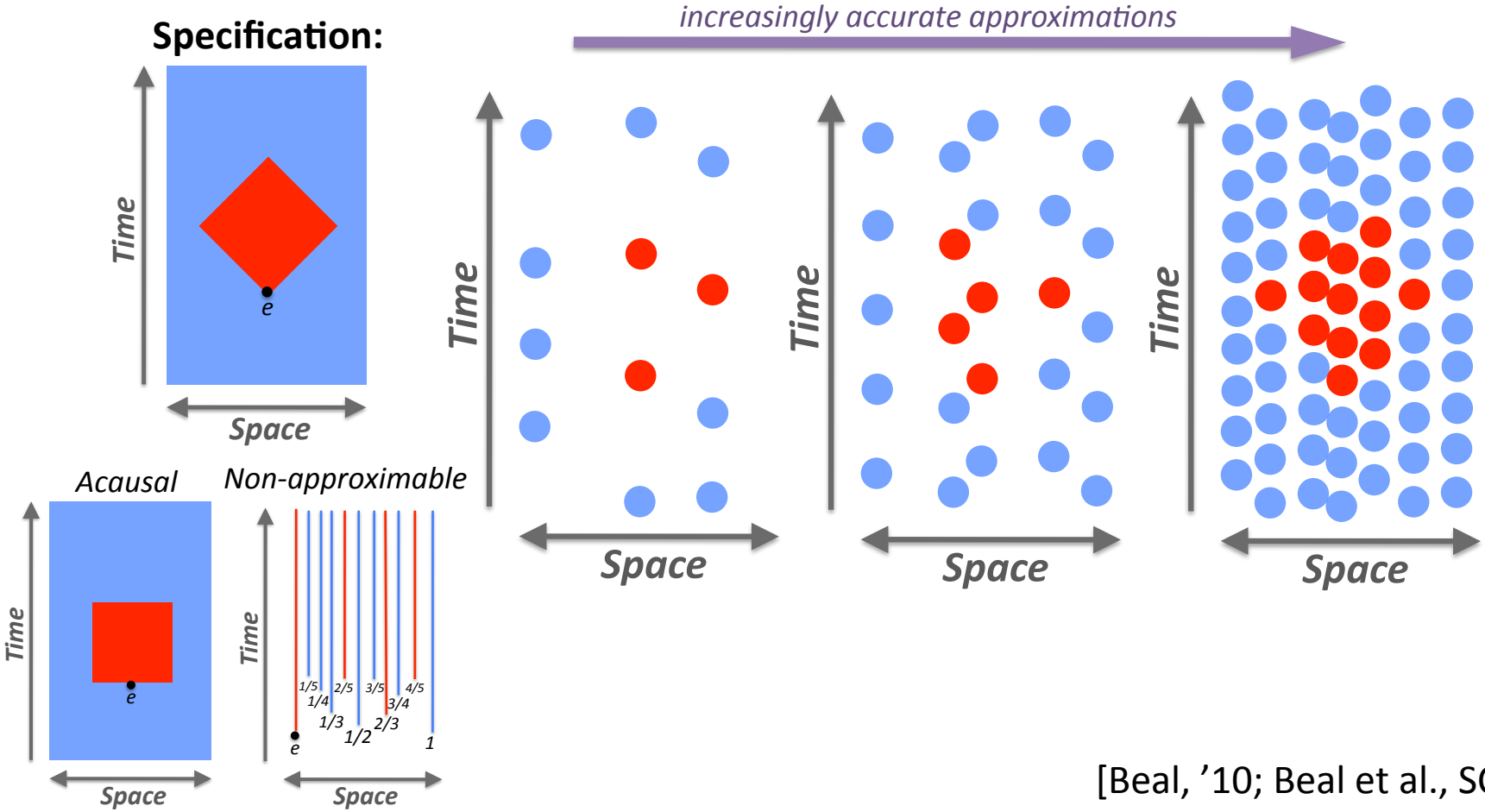
Space-time Universal = arbitrarily good approximation of any causal, finitely-approximable computation



[Beal, '10; Beal et al., SCW 14]

Instantiation: Proto

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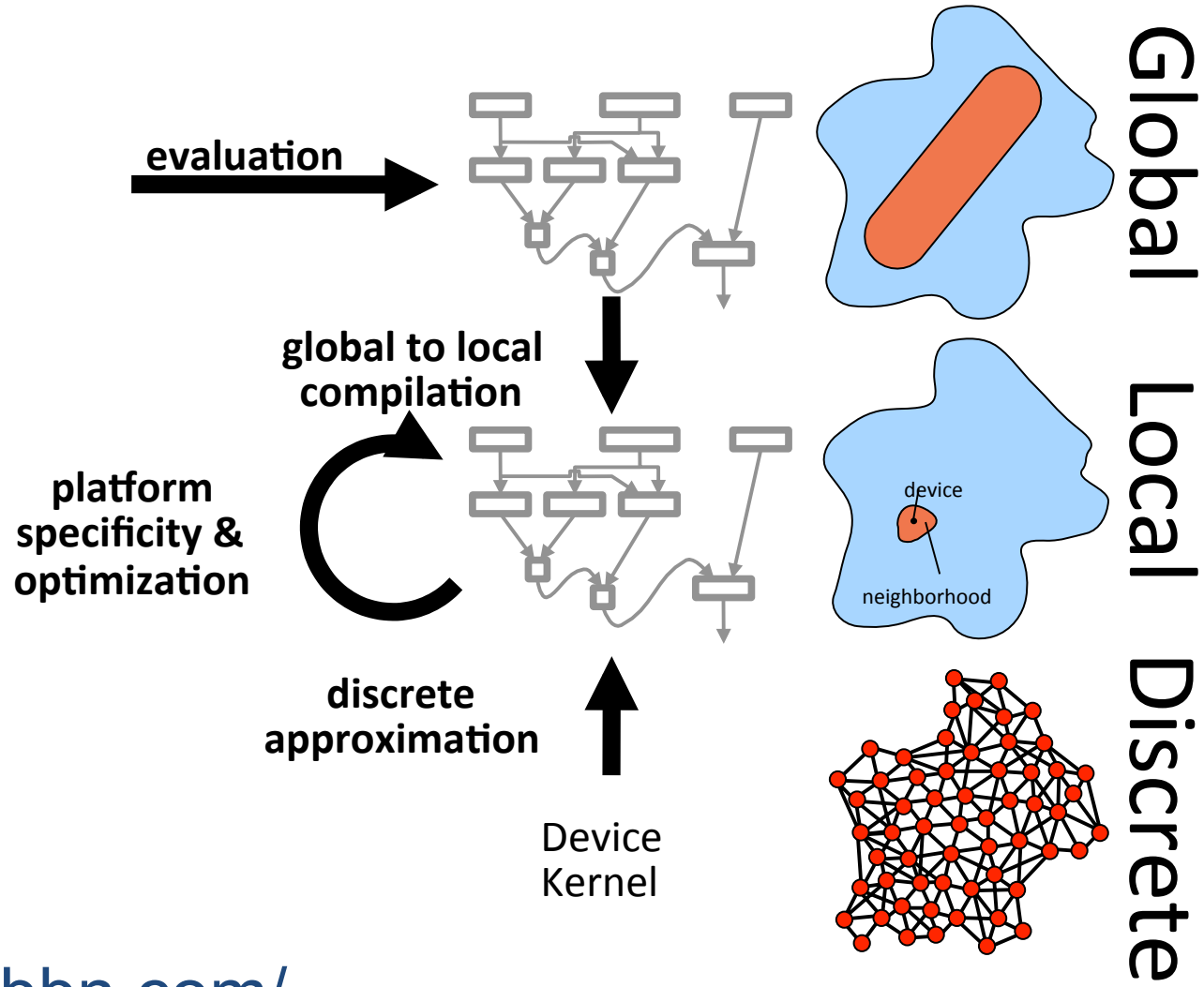
```
(def gradient (src) ...)
(def distance (src dst) ...)
(def dilate (src n)
  (<= (gradient src) n))
(def channel (src dst width)
  (let* ((d (distance src dst))
         (trail (<= (+ (gradient src)
                       (gradient dst))
                    d)))
    (dilate trail width)))
```



http://proto.bbn.com/

[Beal & Bachrach, '06]

Instantiation: Protelis

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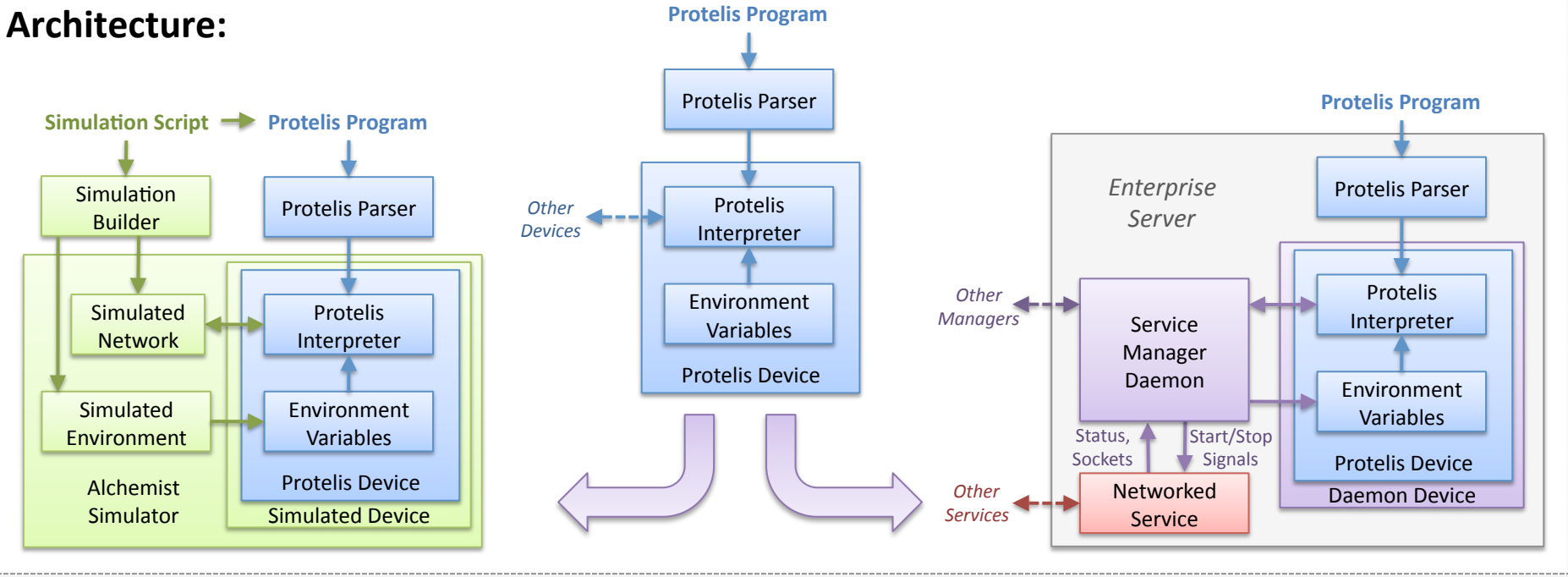
- Java-hosted & integrated
- Java-like syntax
- Eclipse support

```
def distanceTo(source) {
  rep(d <- Infinity) {
    mux (source) { 0 }
    else { minHood(nbr{d} + nbrRange) }
  }
}
```

Architecture:



[Pianini, Viroli, & Beal, SAC '15]

Using Protelis in your projects

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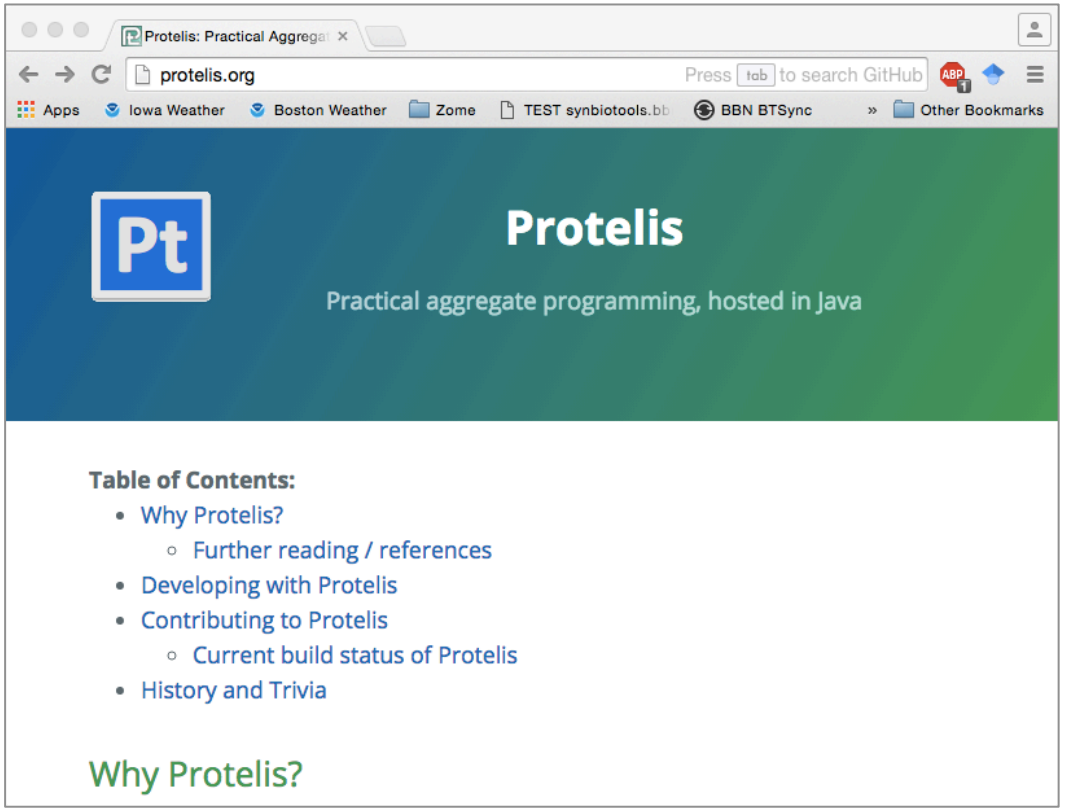
http://protelis.org



Summary

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- Aggregate programming addresses emerging networked computation challenges by separating challenges and raising to a more natural abstraction level
- Field calculus is a simple, universal model for aggregate programming
- Protelis is a field calculus implementation integrated with Java