Engineering the aggregate

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Outline

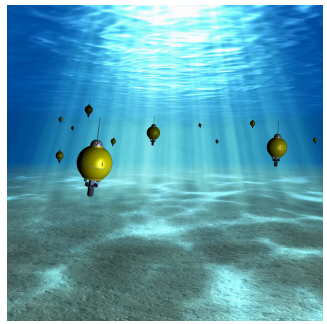
The world is becoming a crowded and complex place

Future and emerging Internet-of-things are witnessing:

- devices increasingly wearable, mobile, embedded, flying...
- increasing availability of heterogeneous wireless connectivity
- increasing availability of computational resources (device/edge/cloud)
- increasing production and analysis of data, everywhere, anytime

$\Rightarrow$ business, security, and privacy concerns will be drivers as well



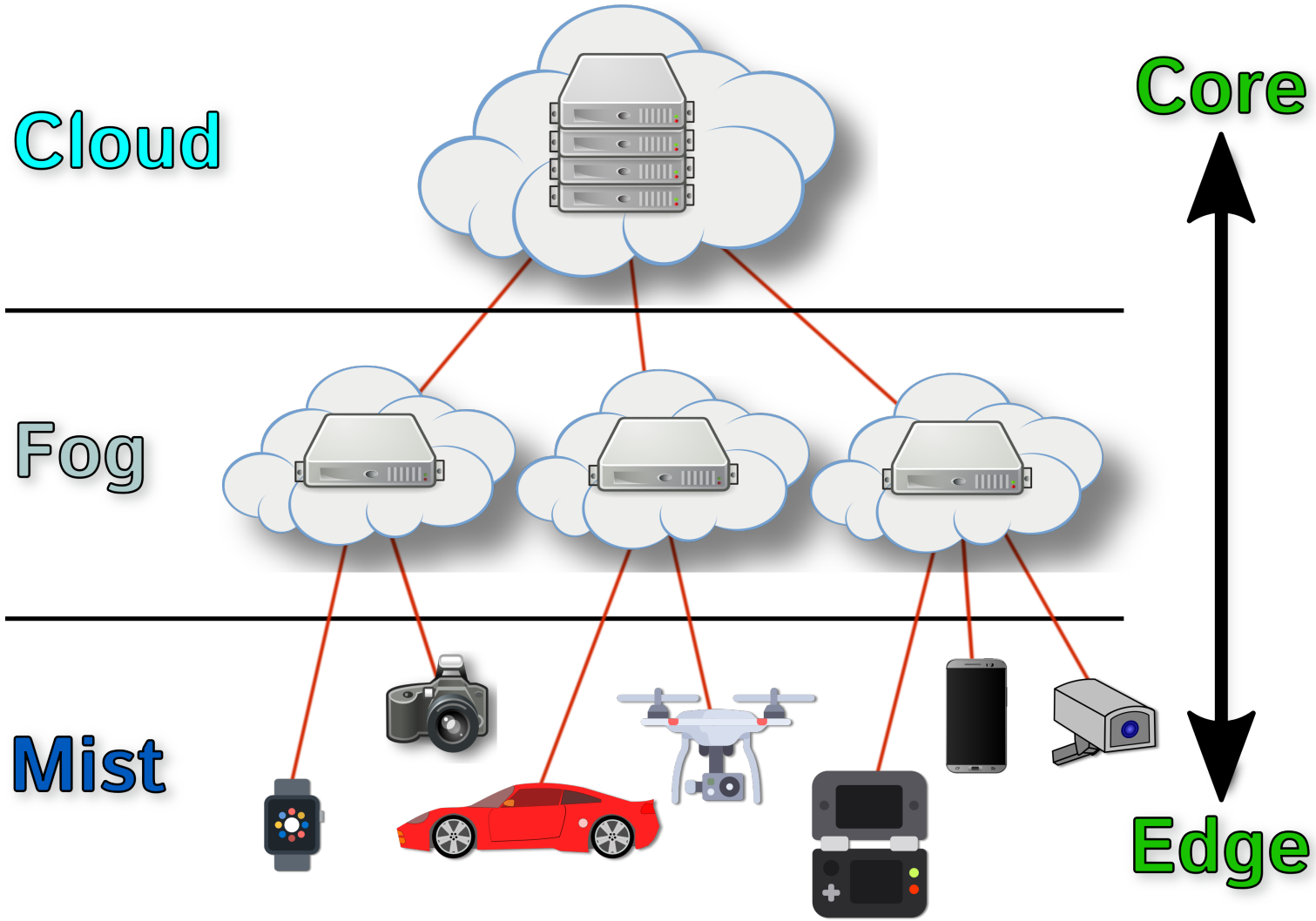



Outline

Programming models for mobile and IoT applications

- Client side
  - Single-device program: objects, functions, actors, futures, tasks, activities
  - Local intelligence
- Client-server communication
  - SOA (Http/Rest), MoM (RabbitMQ)
- Server side
  - Storage: OO, relational, NoSQL — in memory or on-disk
  - Coordination (orchestration, mediation, rules enactment)
  - Situation recognition (online/offline, mining, business intelligence, stream processing)
- Scalability server-side calls for cloud-ification
  - Not really orthogonal to the whole programming model
  - It often dramatically affects system design

Heterogeneity of deployment contexts



Implications

Where does programming effort end up into?

Programs of clients and servers highly depend on:

- Platform and API
- Communication technology
- Number, type, and dislocation of devices

$\Rightarrow$ Design and deployments hardly tolerate changes

$\Rightarrow$ IoT systems tend to be rigid, and costly to debug, evolve, and maintain

The technological result

- Few of the opportunities of large-scale IoT are currently exploited
  - Virtually, any computational mechanism (sensing, actuation, processing, storage) could involve spontaneous, adaptive cooperation of large sets of devices
- How many large-scale deployments of **adaptive** IoT systems around?
- Where are the "Collective Adaptive Systems"?

A programming model perspective

What do we lack in large-scale IoT systems?

- The plain old platform-independent programming abstraction
- Delegating to the underlying platform everything but the core logic:
  - non-functional aspects (network performance, battery saving...)
  - deployment issues

The challenge

Let's tackle the worst possible scenario:

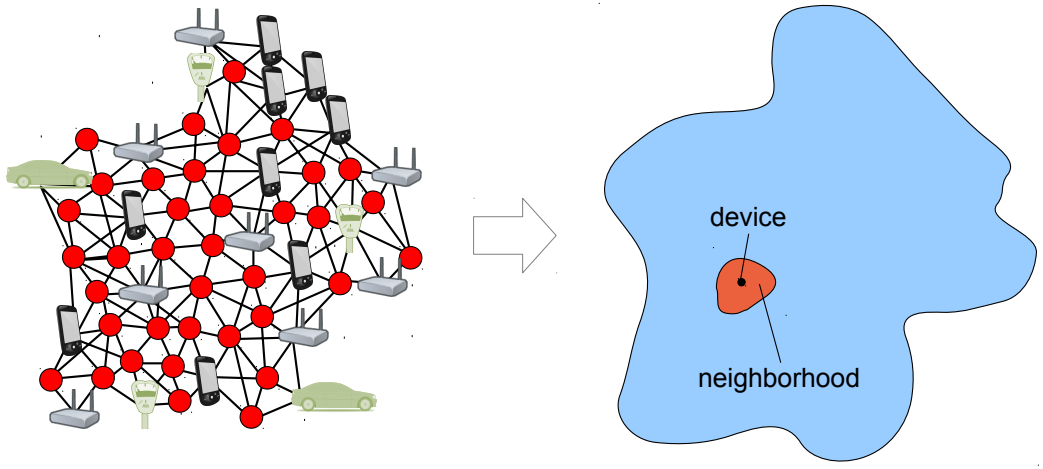
- Countless heterogeneous, moving devices unpredictably situated
- Pervasive sensing and actuation
- Contextual (spatio-temporal) behavior
- Abstract away the infrastructure
  - We can't rely on the cloud or fog
  - But we must be ready to exploit the opportunity they provide

Outline

Manifesto of aggregate computing

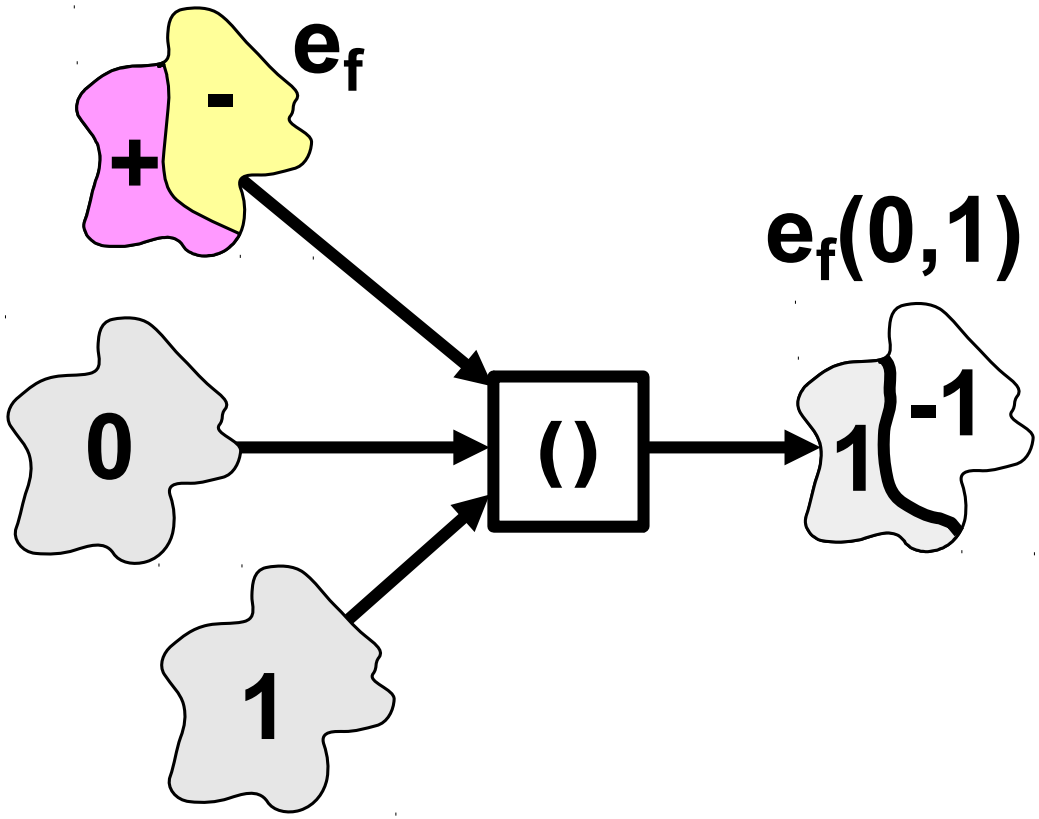
Motto: program the aggregate, not individual devices!

1. The reference computing machine
   $\Rightarrow$ an aggregate of devices as a single entity fading to the actual *space*
2. The reference elaboration process
   $\Rightarrow$ atomic manipulation of a collective data structure
3. The actual networked computation
   $\Rightarrow$ a proximity-based self-org system hidden "under-the-hood"



Computing with fields

Field: a distributed data structure mapping each device to a value



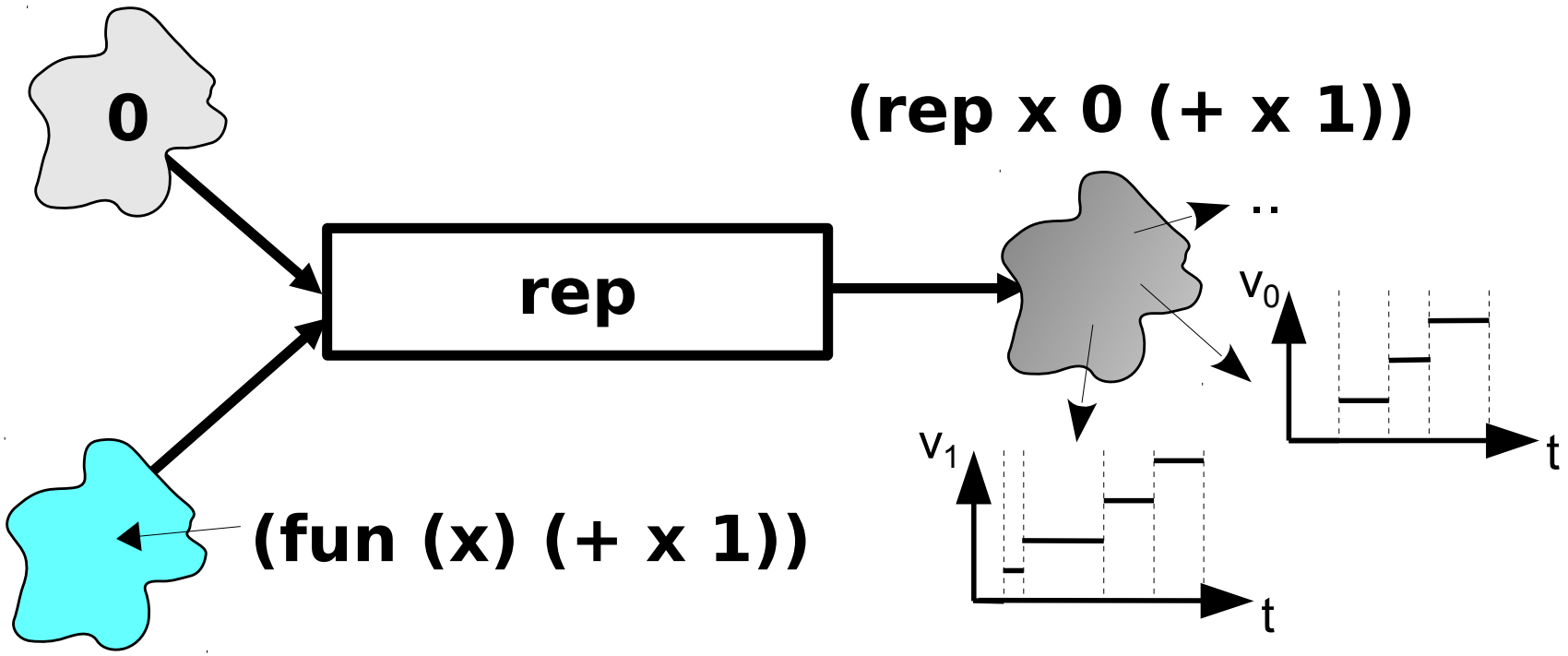
Language based approach

- The approach naturally maps on a new programming paradigm
- A core calculus for such language families exists [DVPB15]
  - Allowing for mathematical proofs of properties
  - Proofs valid for the calculus hold for any practical language based on it
- Aggregate programming languages are proven to be universal...
- ...nevertheless, integration with existing language and libraries is key
  - Don't reinvent the wheel

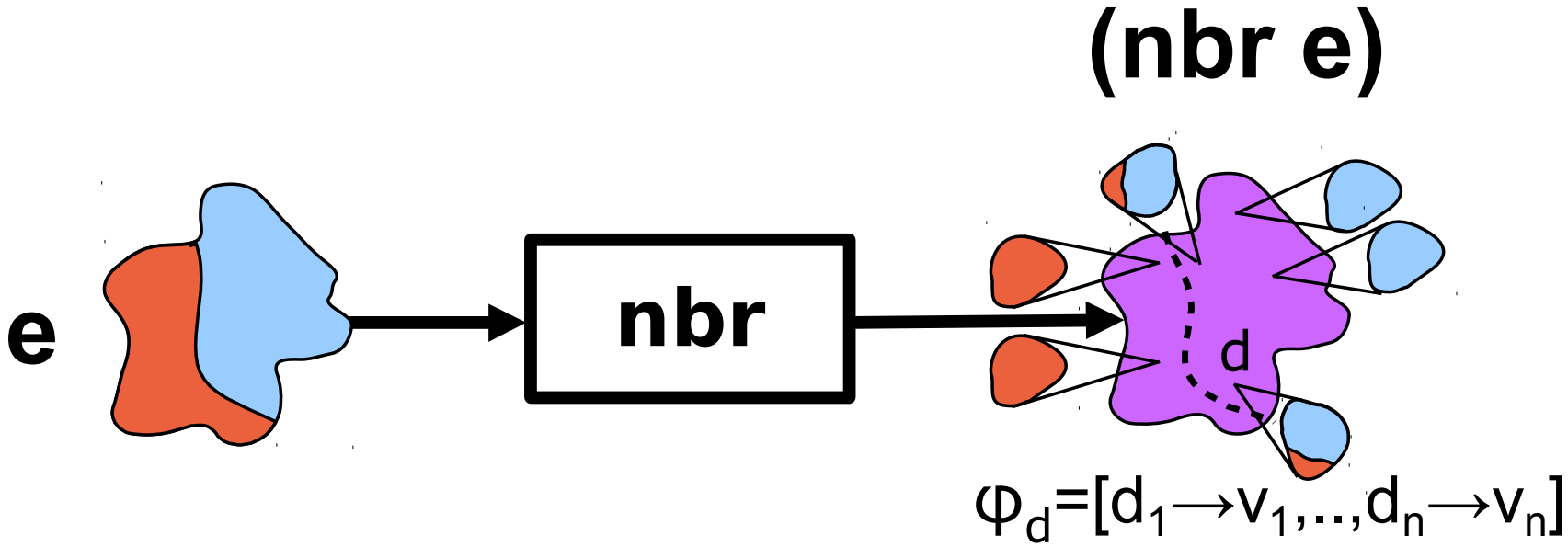
What about a middleware?

- Middlewares have explicit APIs, which we want to avoid
- Nevertheless, a middleware is required for practical languages to work
  - For networking, mostly
- Aggregate programming could be used to easily program some features of novel middlewares as well

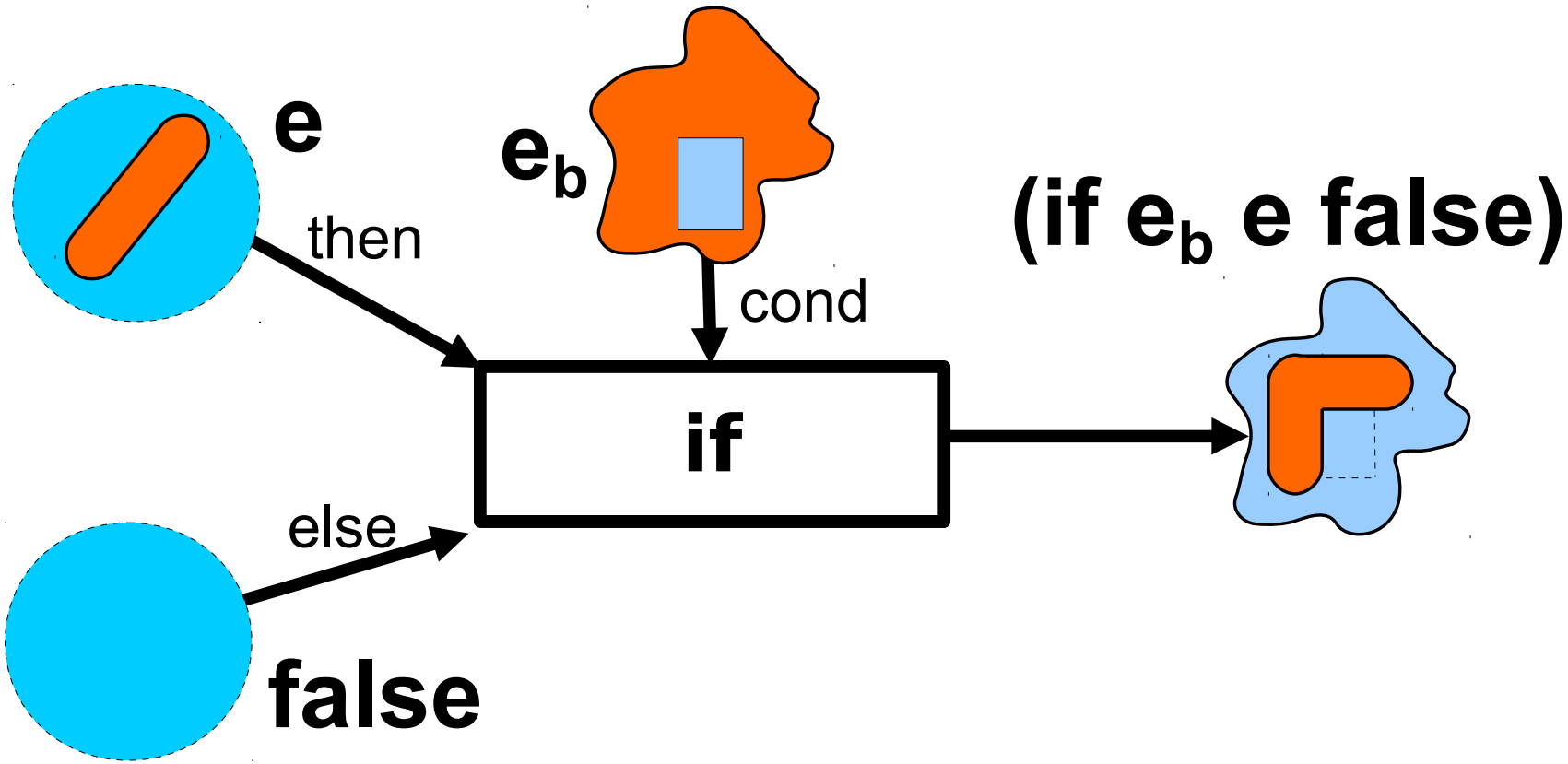
Core language constructs: evolution over time



Core language constructs: gather data from neighborhood

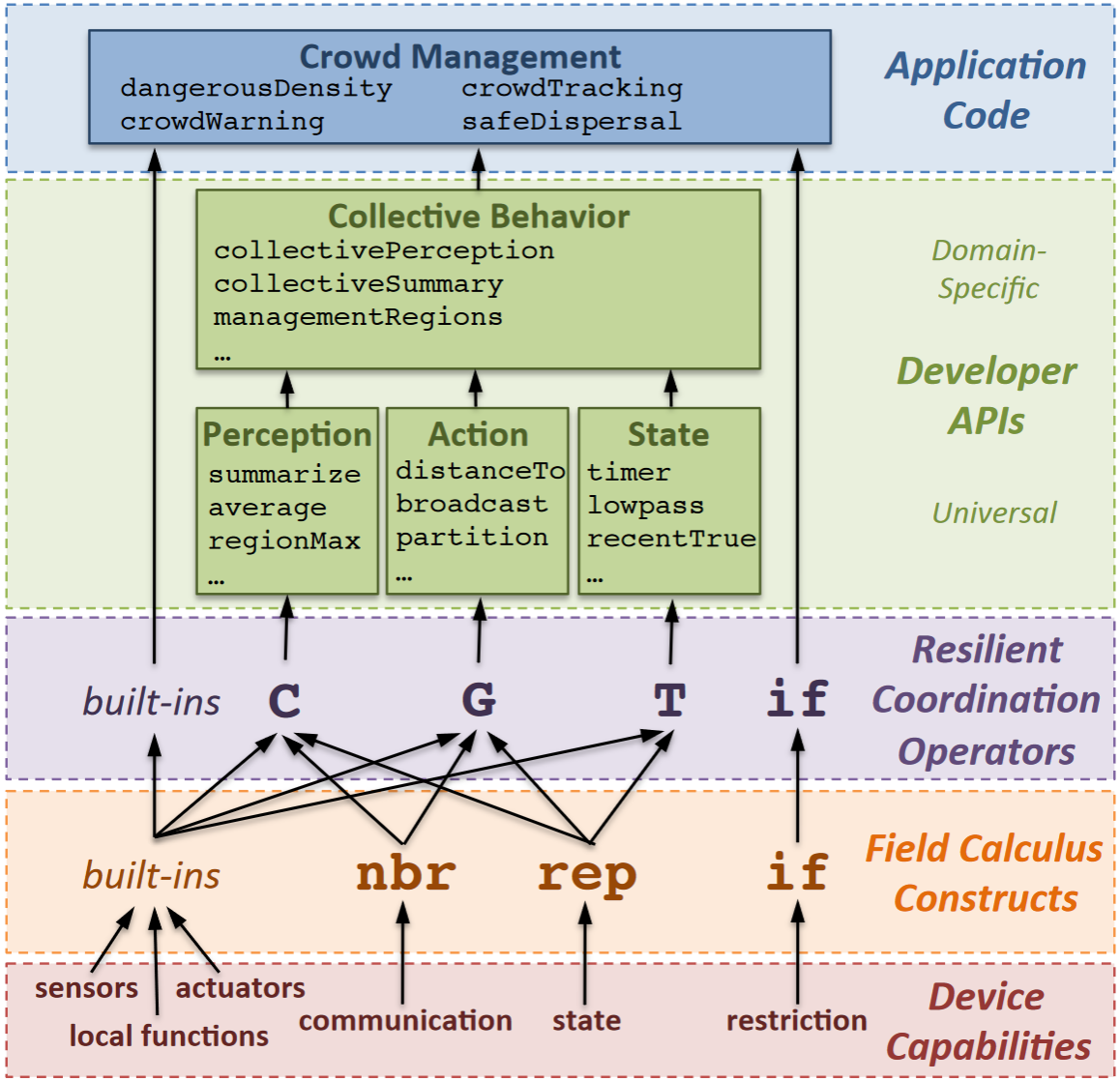


Core language constructs: domain restriction (distributed `if`)



The channel computes in a different domain, but does not get disrupted!

Scalability and compositionality [BV14, VBDP15, FPBV17]



Toolchain I

A set of practical tools are available for engineering the aggregate

Practical languages

- **Protelis**[a] [PVB15, PBV17] – Stand-alone programming language, duck-typed, Java-interoperable (with some limitations), rich library, mature
  - SASO tutorial available to learn it at
- **Scafi** [CV16] – Scala internal DSL, inherits the Scala type system

[a] `www.protelis.org`

Toolchain II

Simulation platforms

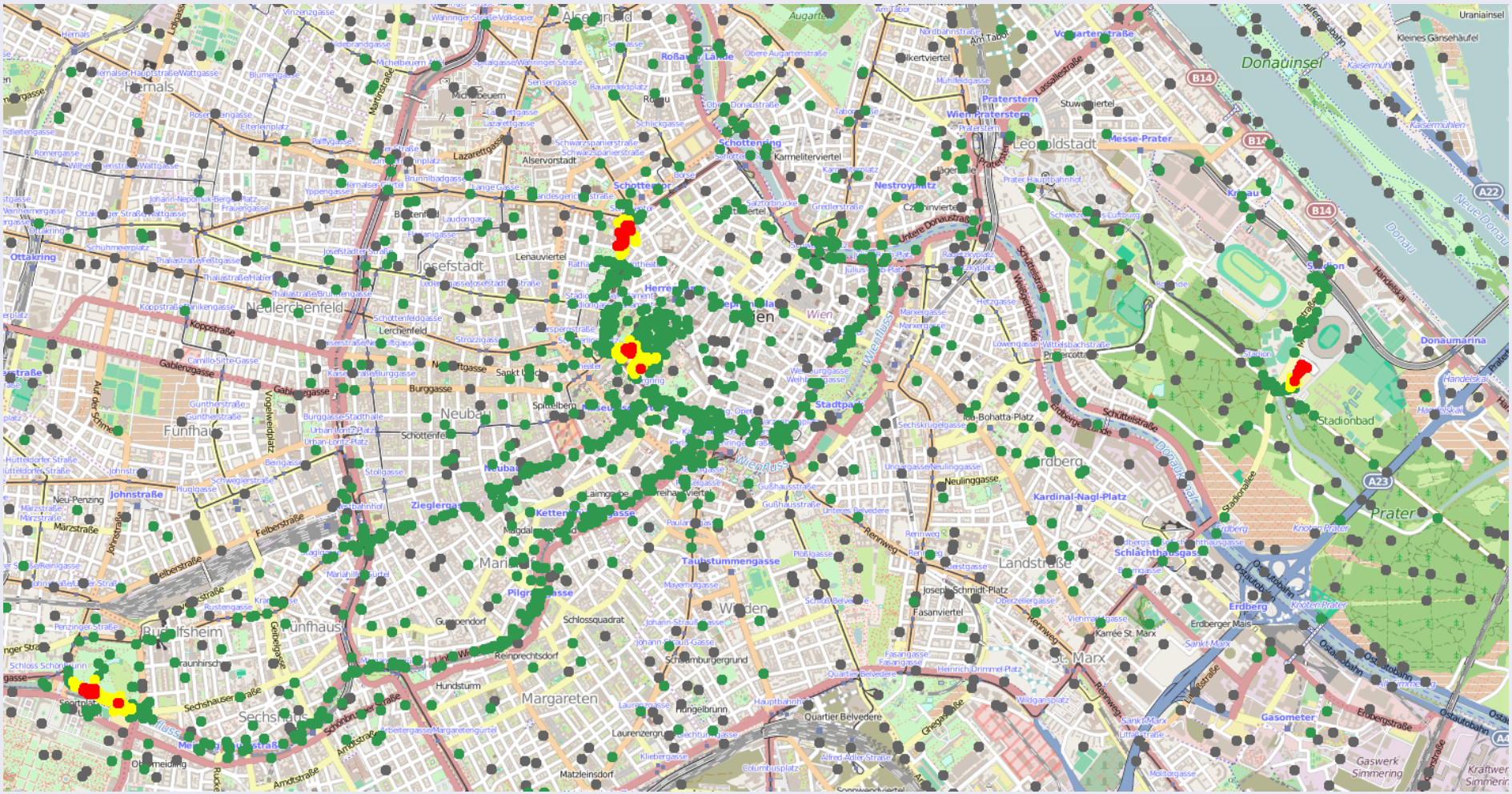
Simulation is paramount: is the only way to test and reproducibly debug a situated self-organizing system.

- **Alchemist**[a] [PMV13, VCP16b] – By far the most largely used simulator when programming in aggregate, supports both Protelis and Scafi, supports (bidimensional) euclidean spaces, floor plans, real world maps (including on-street navigation and GPS traces)
- **NASA World Wind and other simulators**[b] – Protelis can be attached reasonably easily to Java simulation platforms, NASA World Wind has been used in the past for simulating airborne drones [BUL+18].

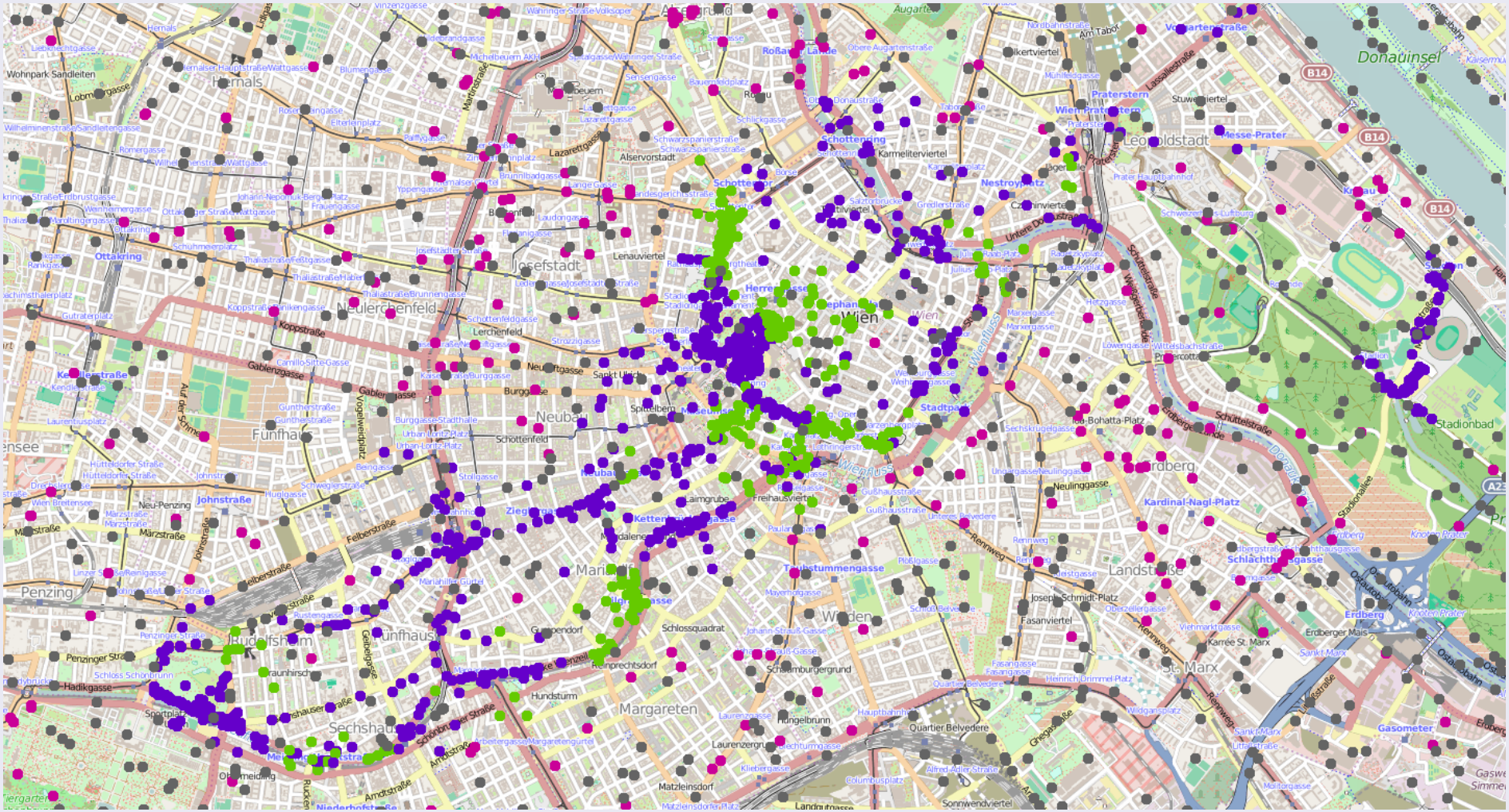
[a] `www.alchemistsimulator.github.io`
[b] `https://github.com/Protelis/Protelis-Demo-Visualized`

Outline

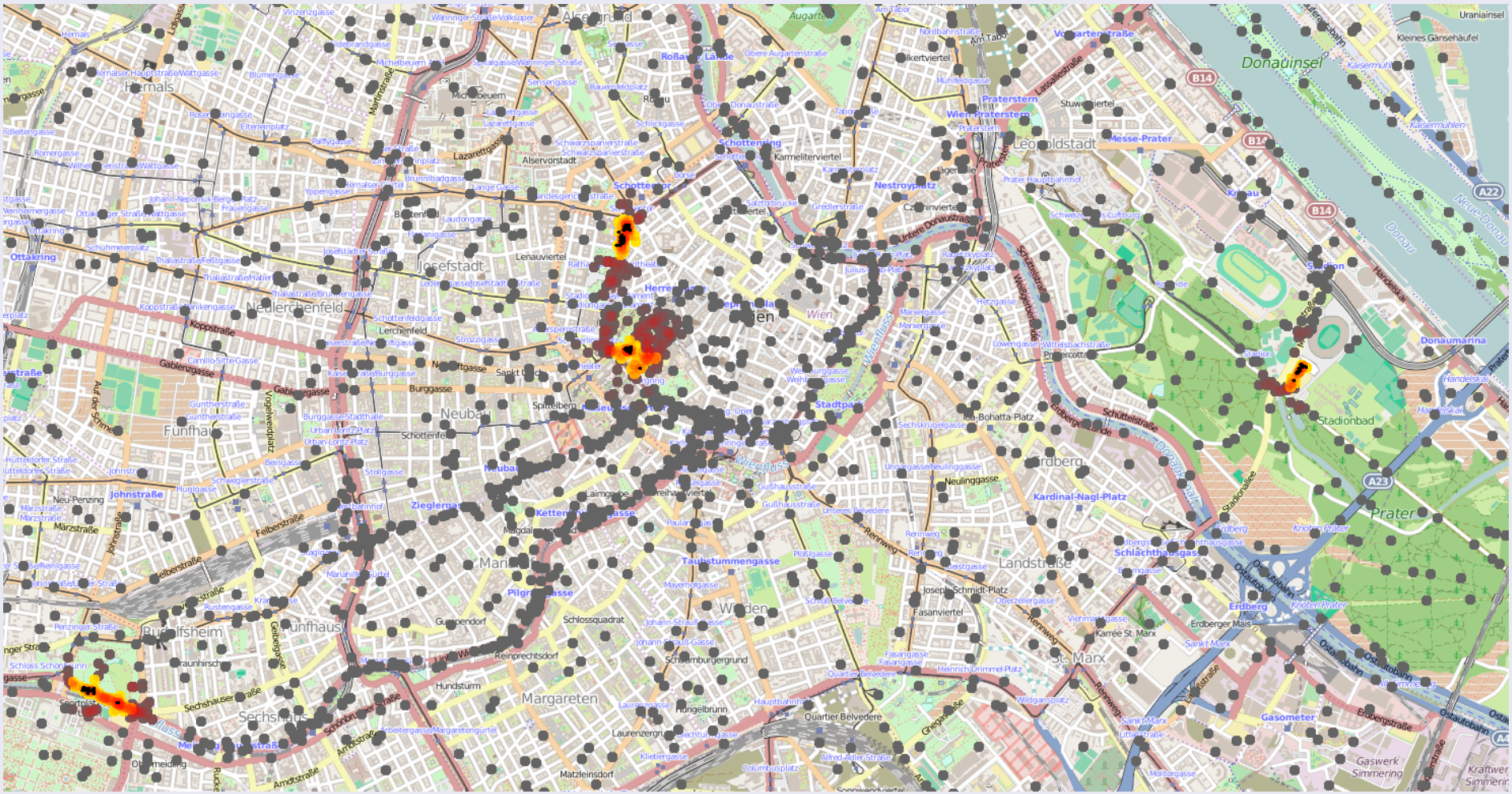
Crowd density estimation [BPV15]



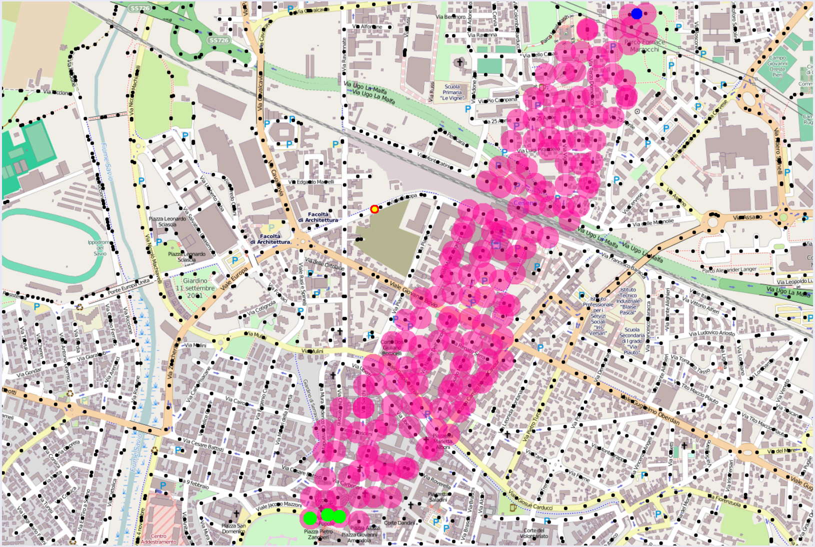
Metaprogramming: P2P version upgrade [BPV15]



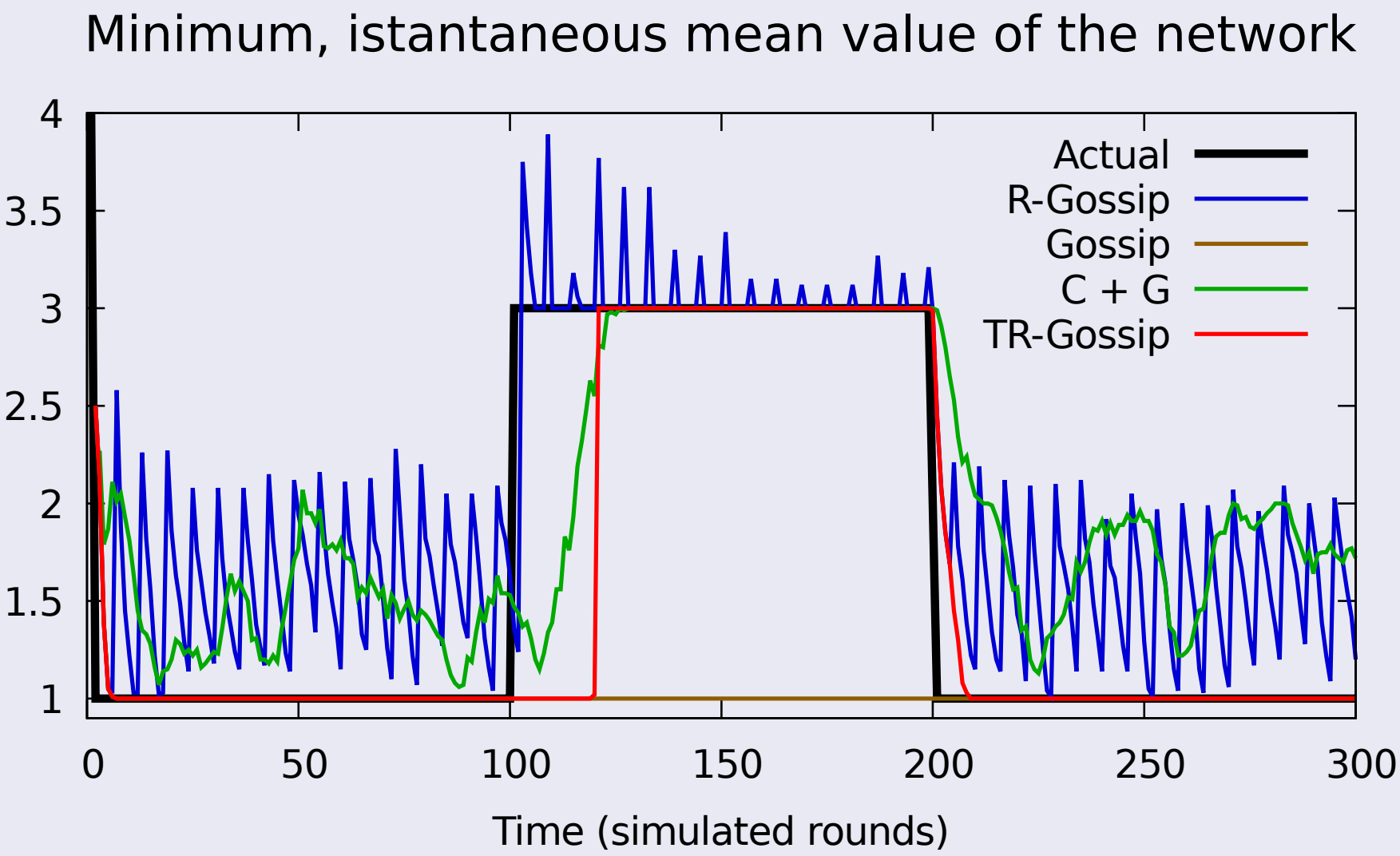
Metaprogramming: process priority modulation [BPV15]



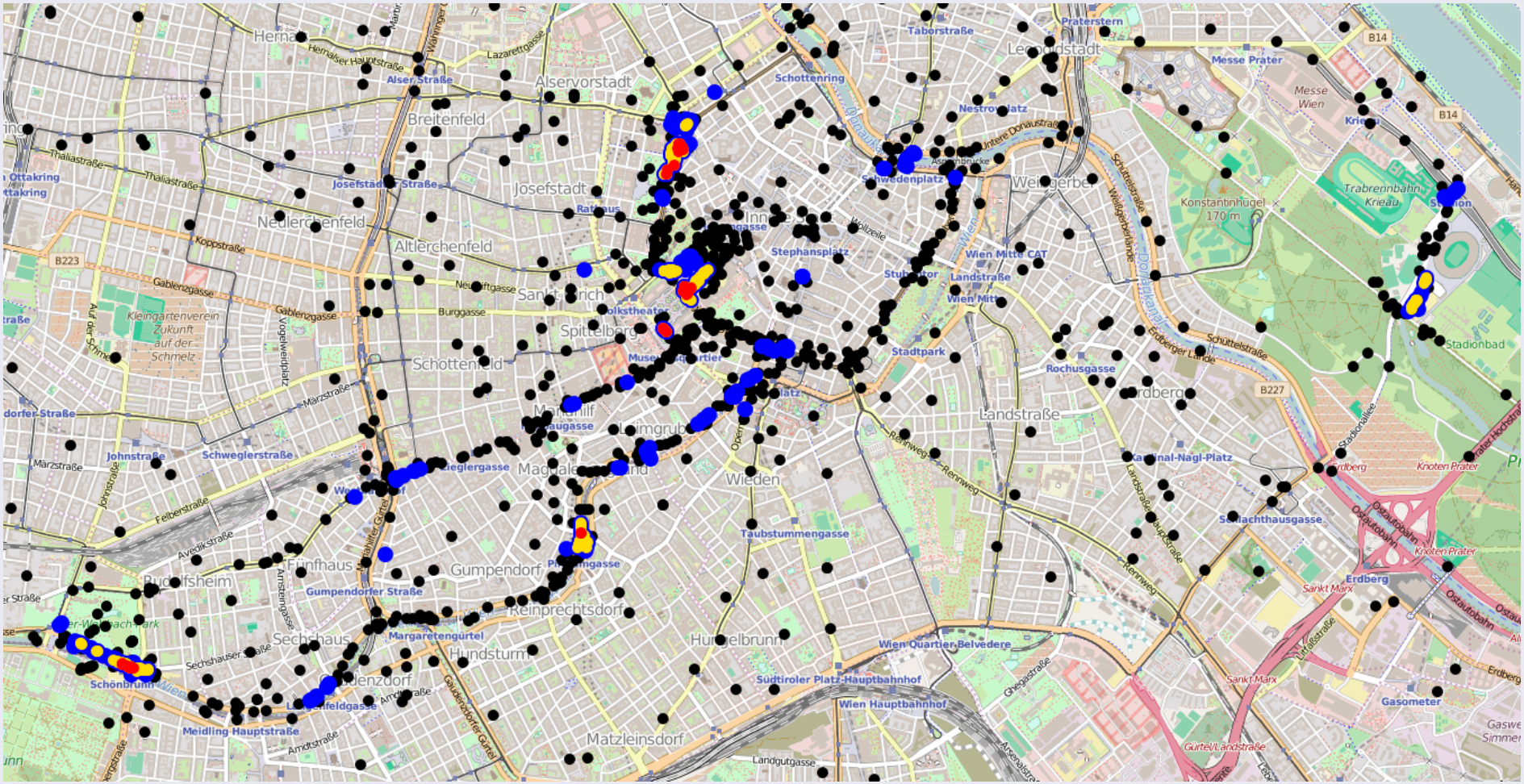
Resilient P2P communication with replicated channel [VPR+15, VPRC17]



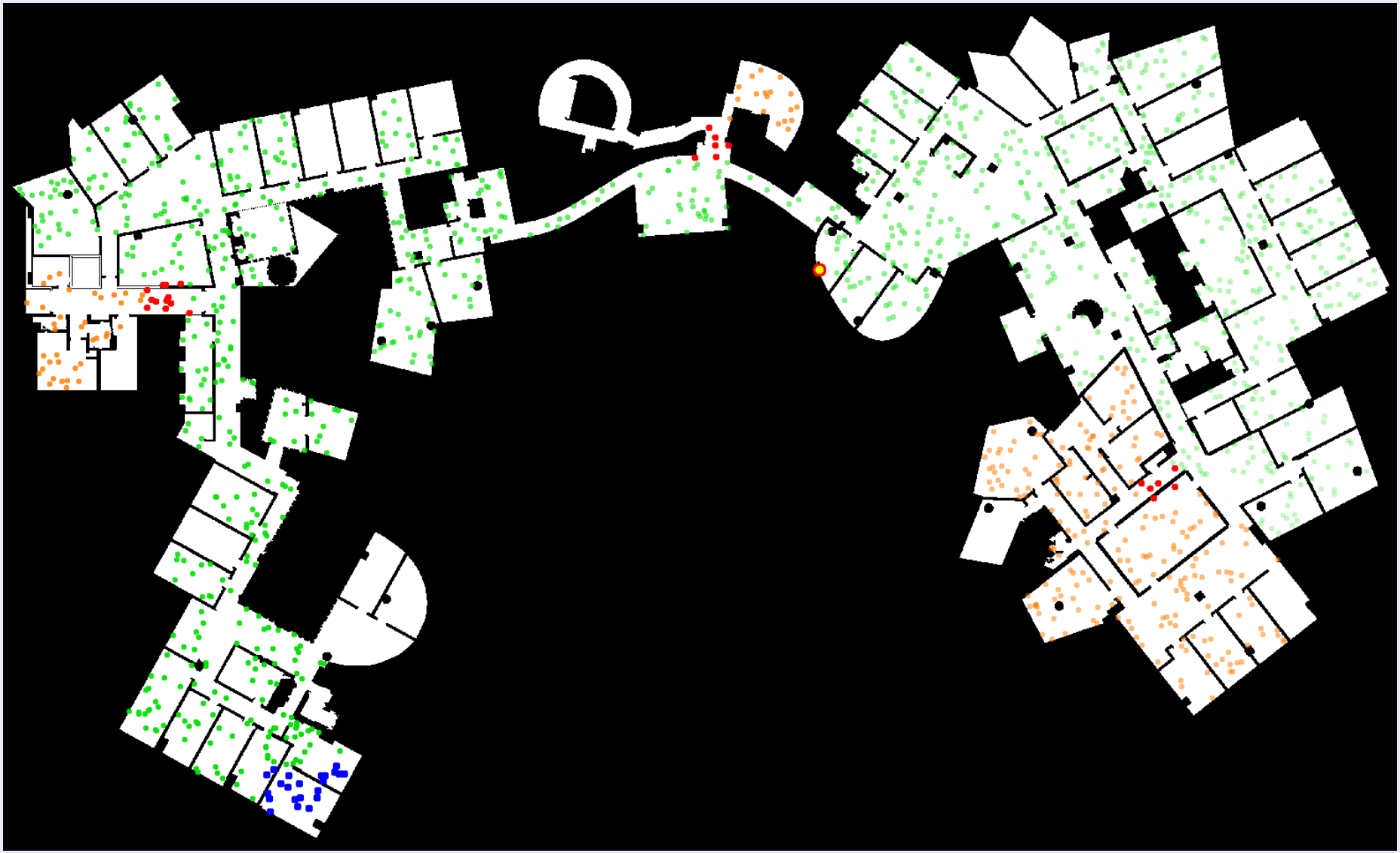
Metaprogramming: improved gossip dynamics [PBV16]



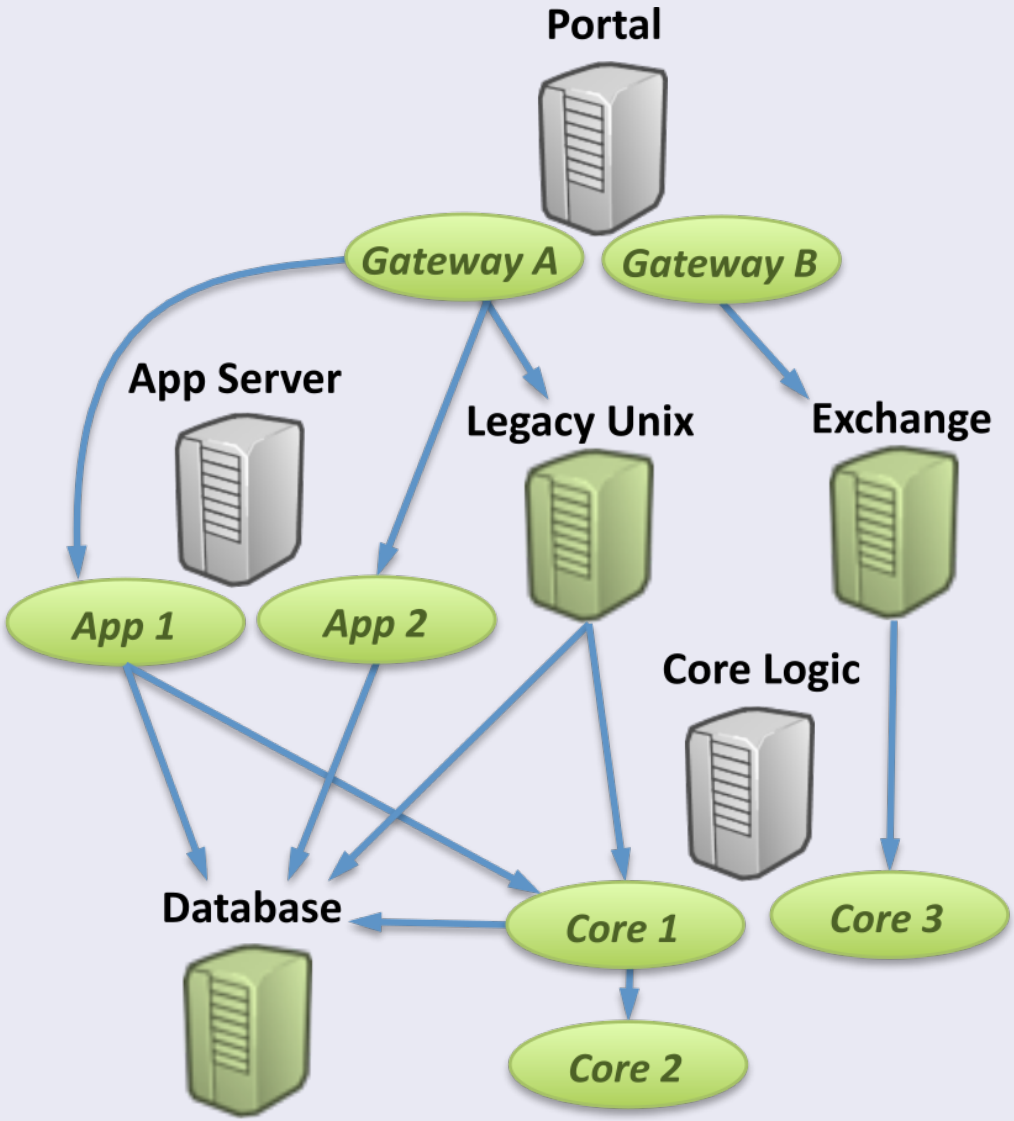
Crowd dispersal [VBPB16]



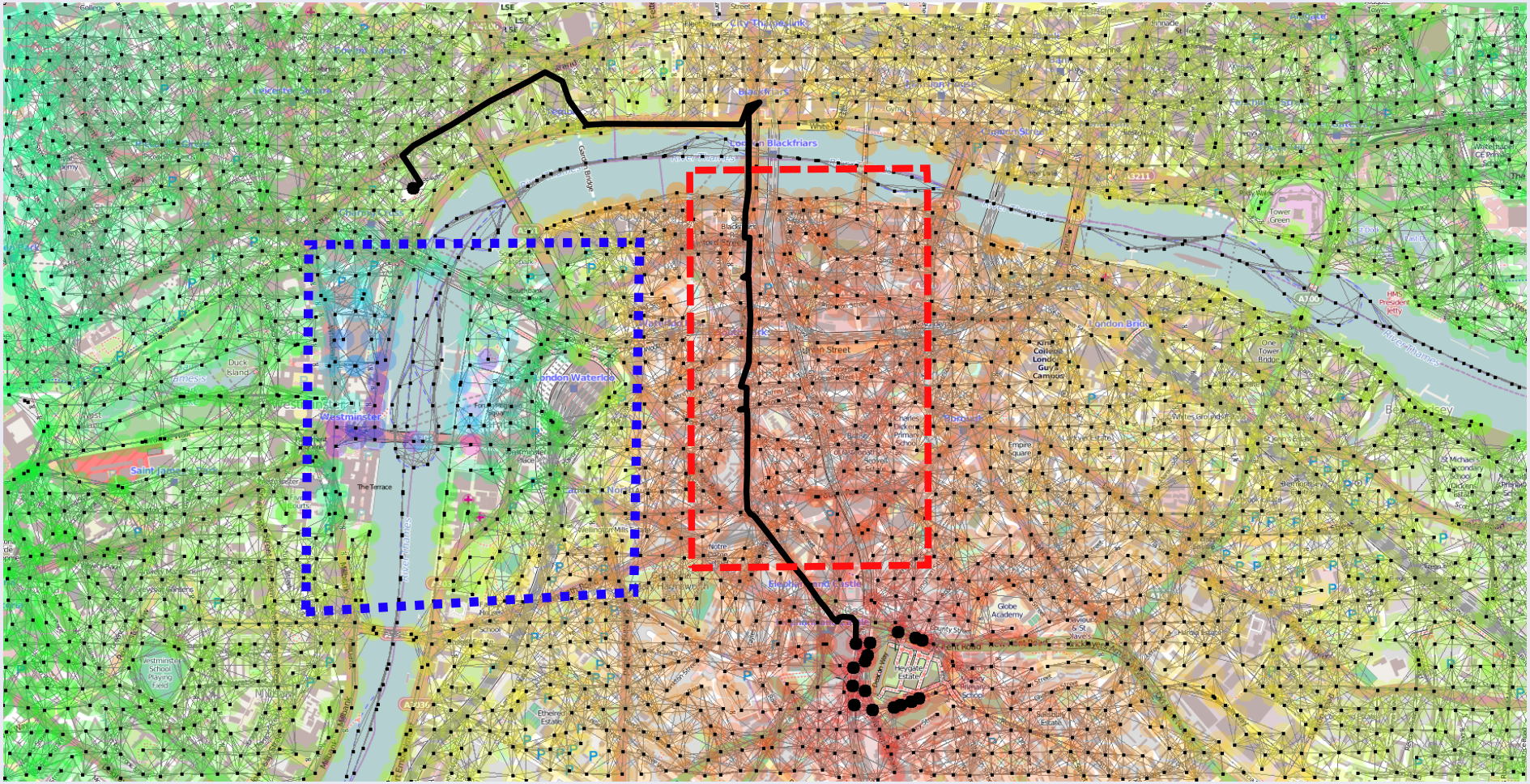
Indoor alarm and selective dispersal [VCP16b]



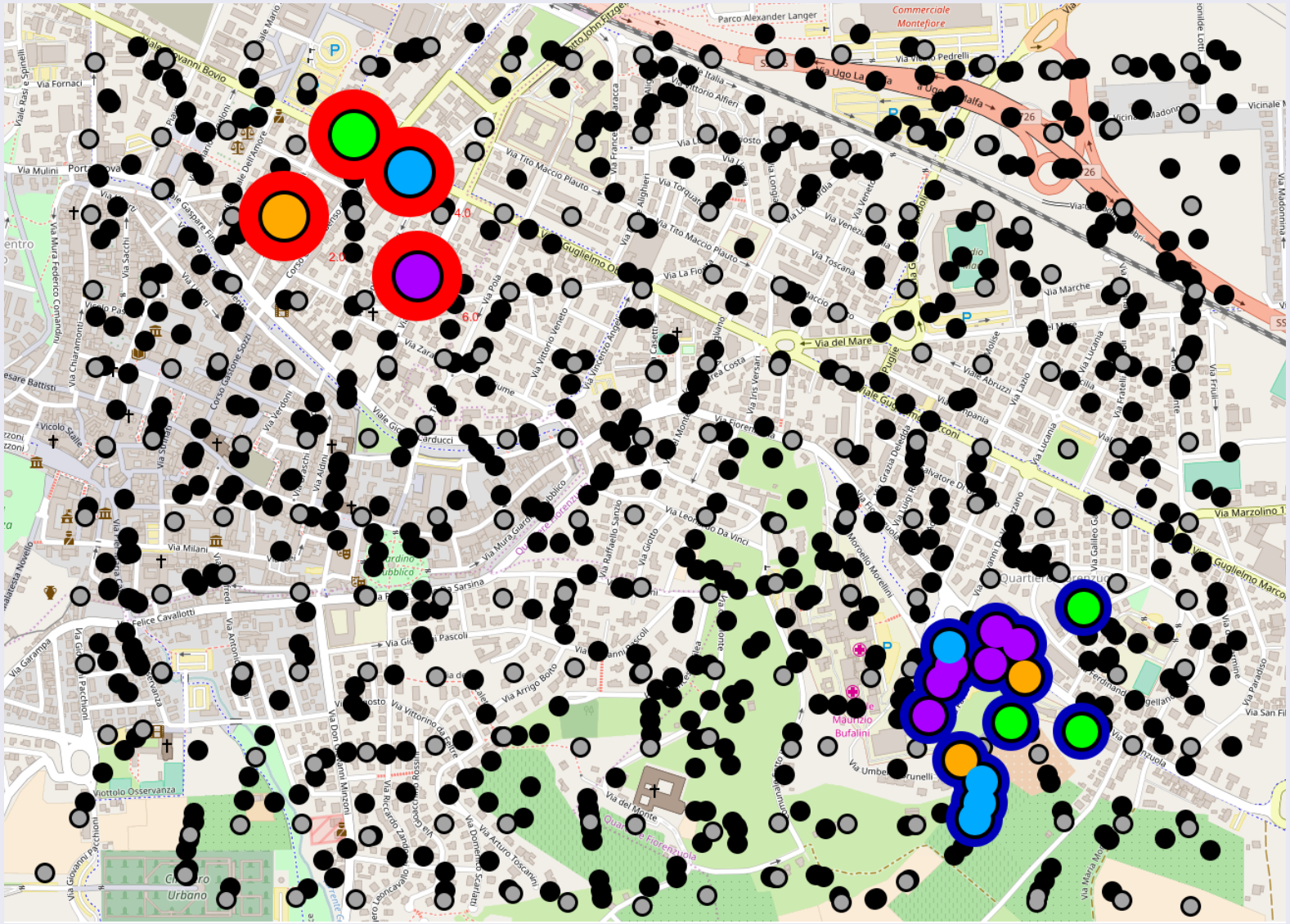
Distributed Recovery for Enterprise Services [CBP15]



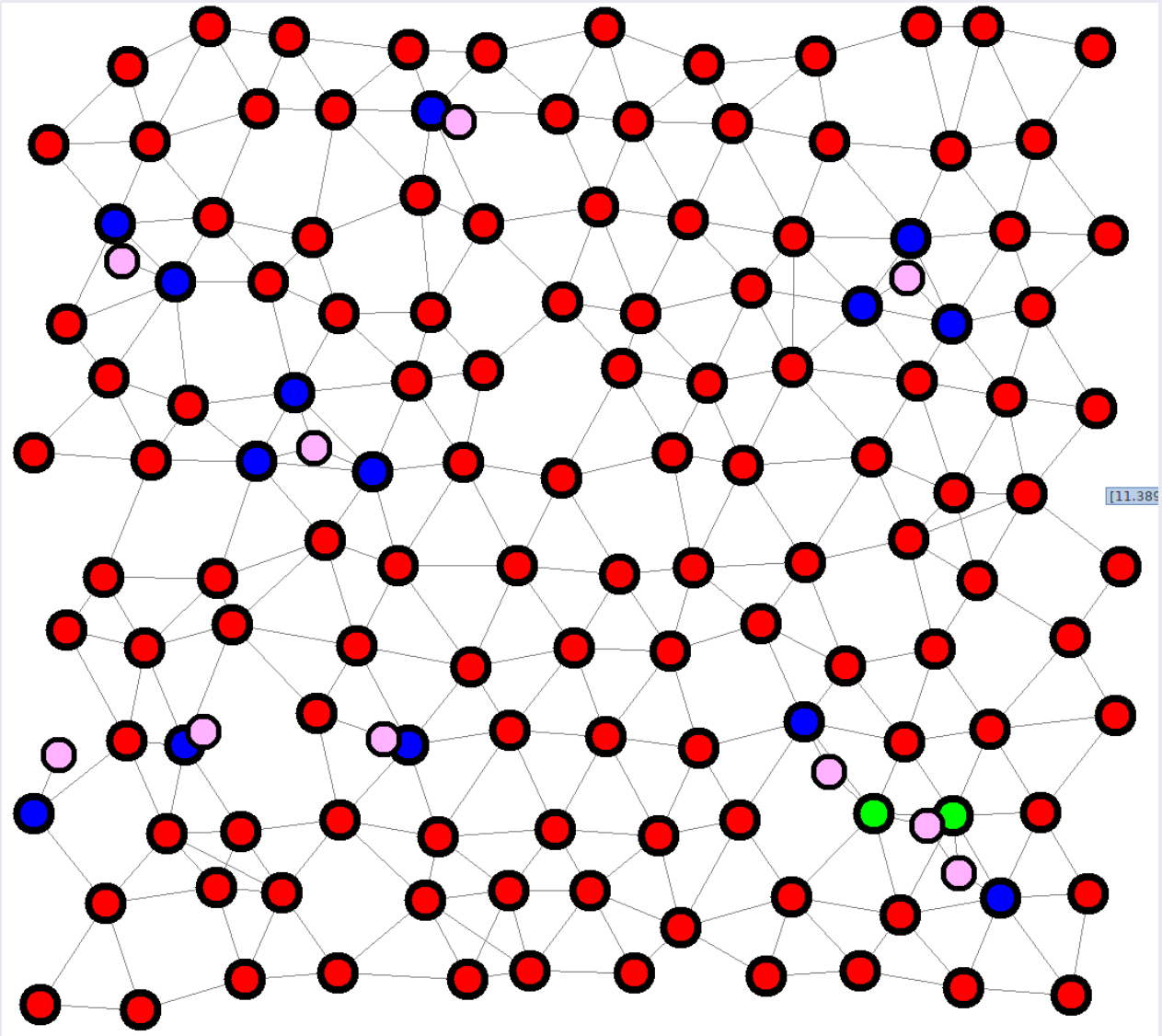
Context-sensitive steering [BVPD17, BVPD16]



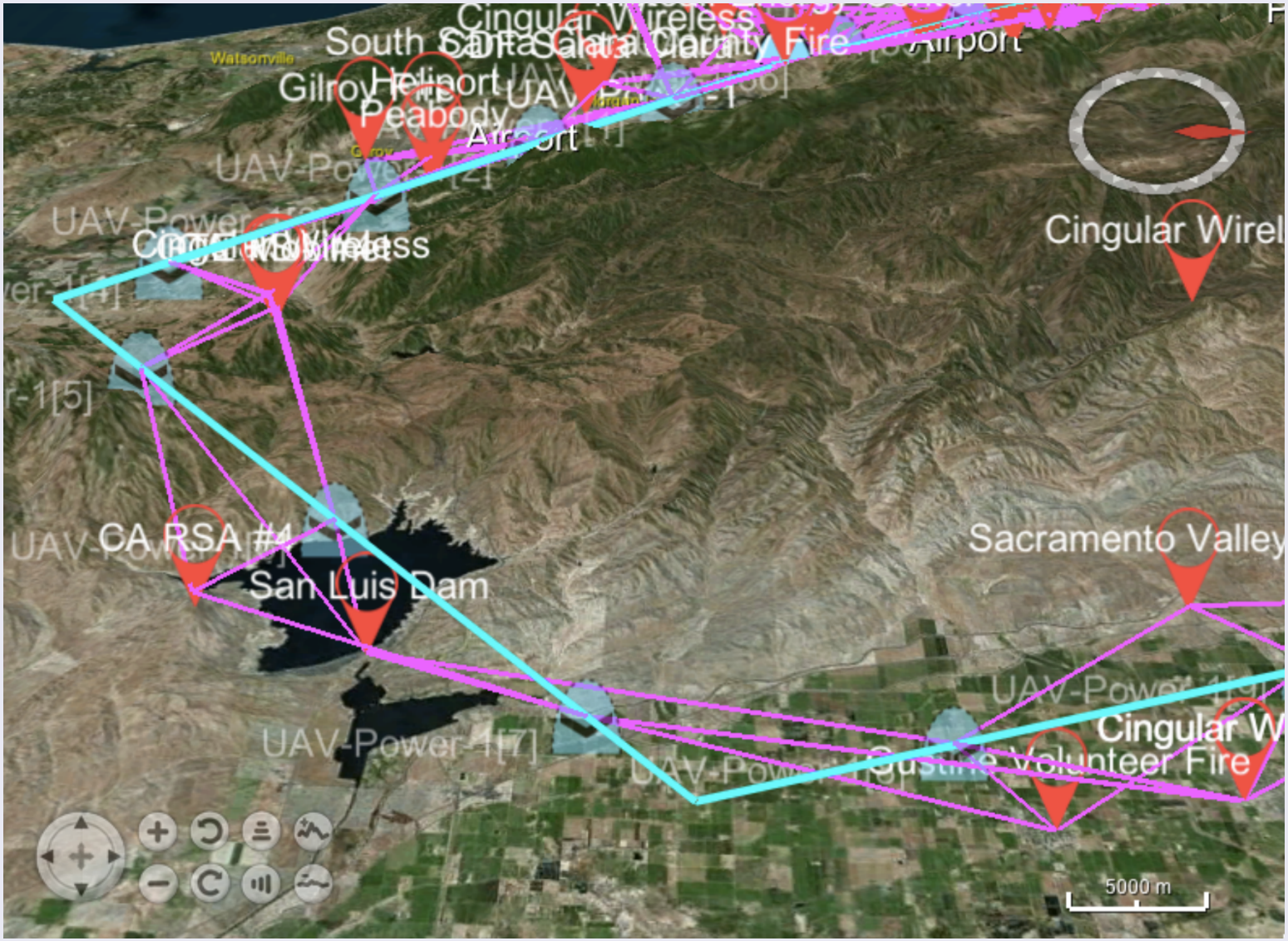
Smart allocation of limited resources [FPBV17]



Target counting in WSN [PDV17]

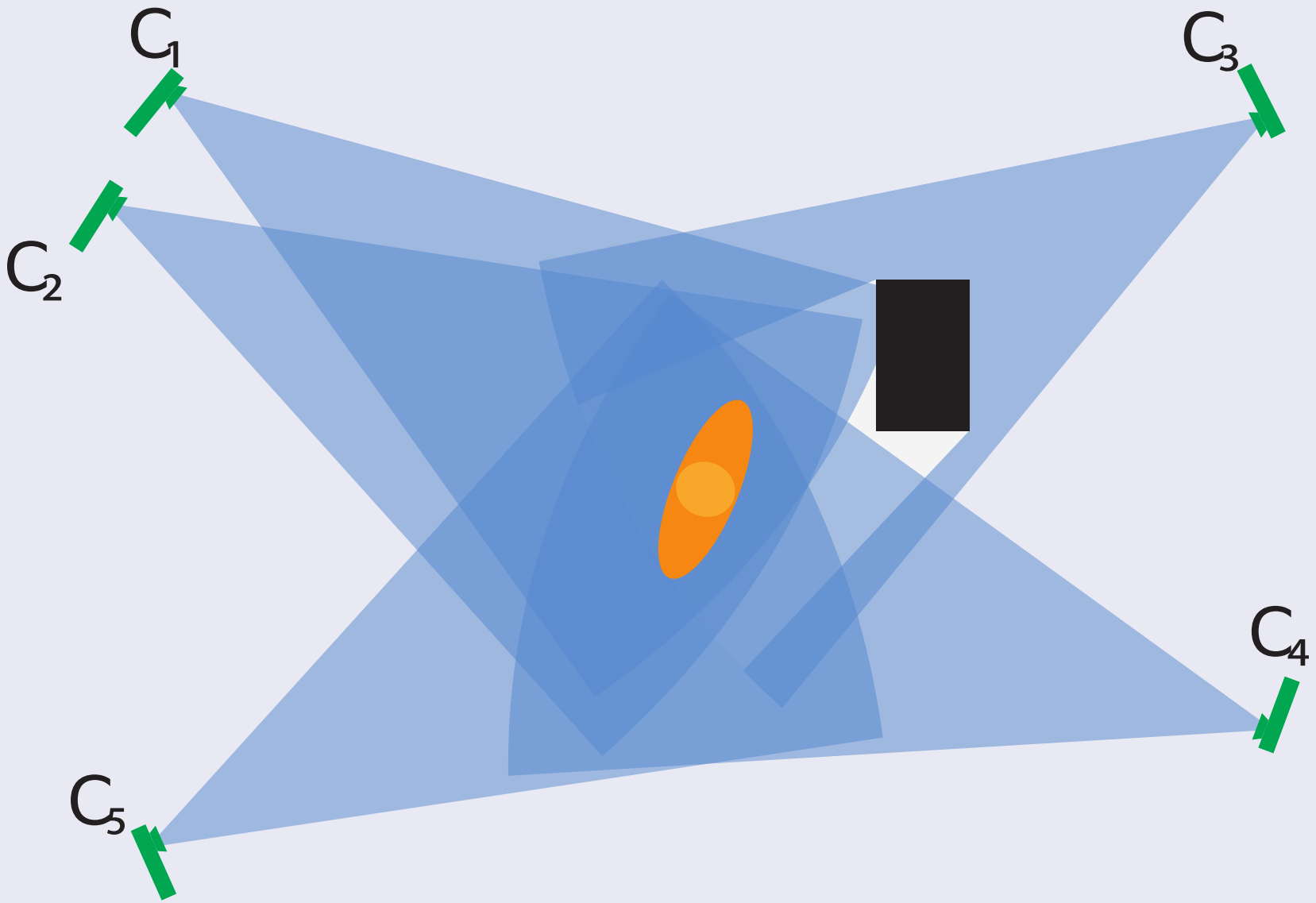


Airborne sensor sharing [BUL+18] and task reallocation [BUL+16]

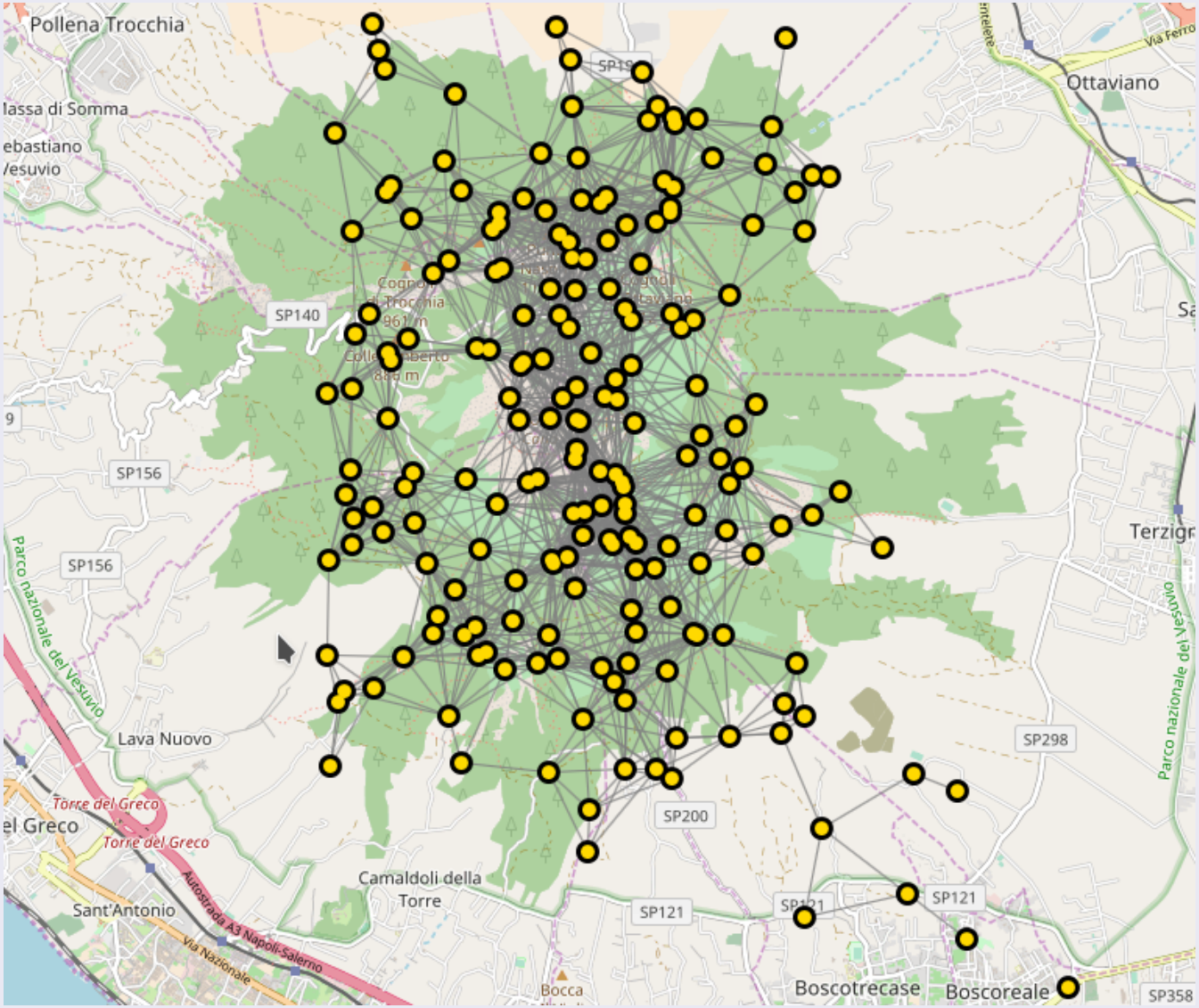


Outline

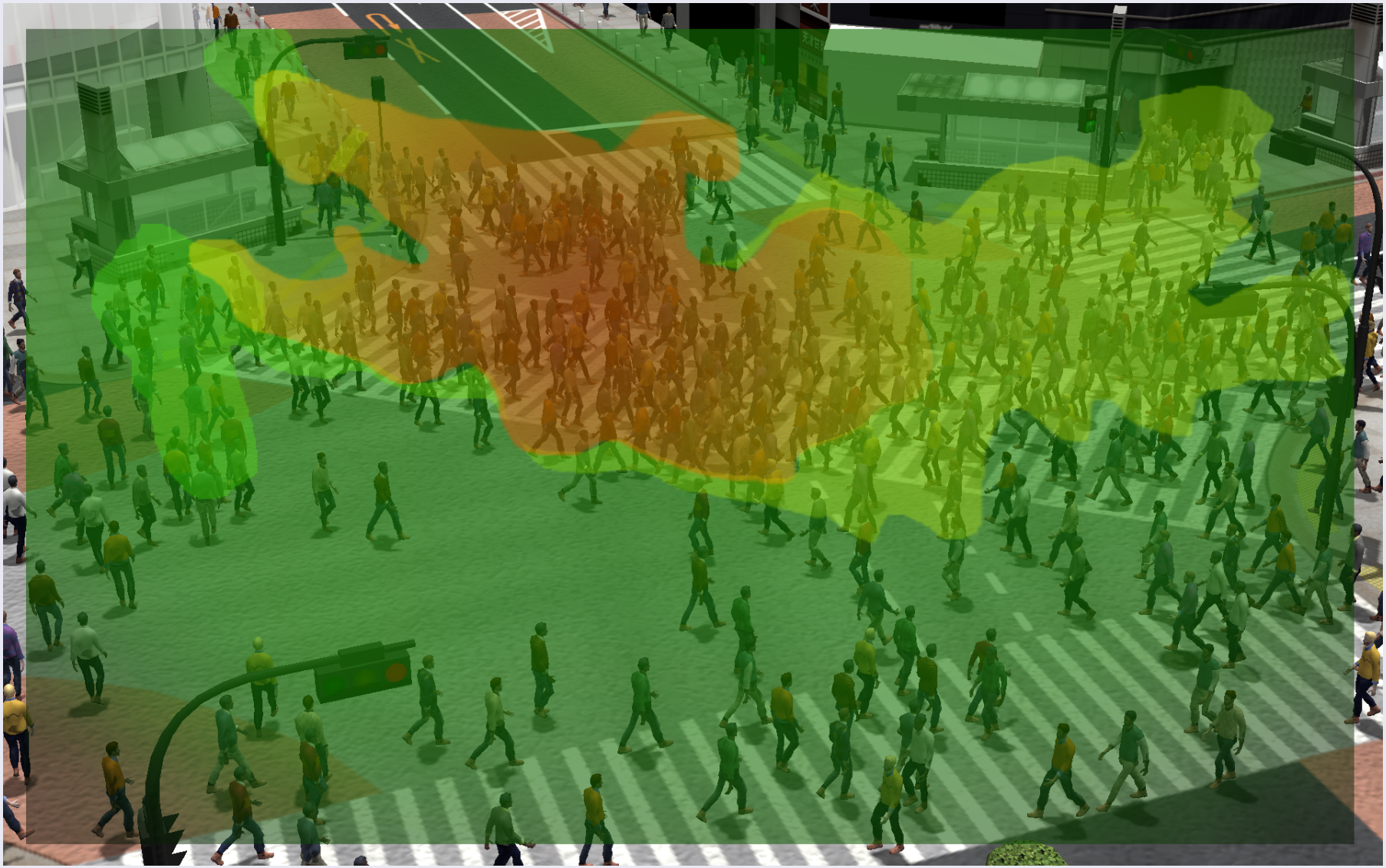
Smart cameras coordination [EL17]



Drone exploration



Augmented fields



Outline

Open issues I

Network overlays

- Aggregate programming relies on the concept of "neighbors" in order to build fields to compute upon
- The network of devices may (in opportunistic and P2P networks) or may not (in the classic Internet) reflect the actual network structure
- A better understanding of how to build network overlays for specific applications is required

Anonymous networks

- Aggregate programming is tightly bound to device identity
- An extension / restriction of the calculus for anonymous networks may expand the applicability of the approach

Open issues II

Security and privacy

- The kind of open systems aggregate computing promotes is a fertile ground for malicious attackers
  - Metaprogramming can be used to inject and diffuse malicious aggregate processes in the system rather efficiently
  - Byzantine attacks may disrupt entire algorithms
  - Malfunctioning nodes detection is (undesirably) offloaded to the application level
- Little work has been done on security [CAV17]

Open issues III

Cloud offloading

- Existing back-ends for aggregate programming do not take full advantage of cloud / fog resources
- Offloading part of the computation to the cloud when available may speed up algorithms and reduce bandwidth and battery usage
- Little has been done on this side [VCP16a]

Better understanding of aggregate alorithms through control theory

- Currently most algorithms are validated via simulation
- Possibly, a large number of them could be studied with a different perspective using control theory
- Much more solid results, better insights
- Very little work availabile [KBDM15]

Open issues IV

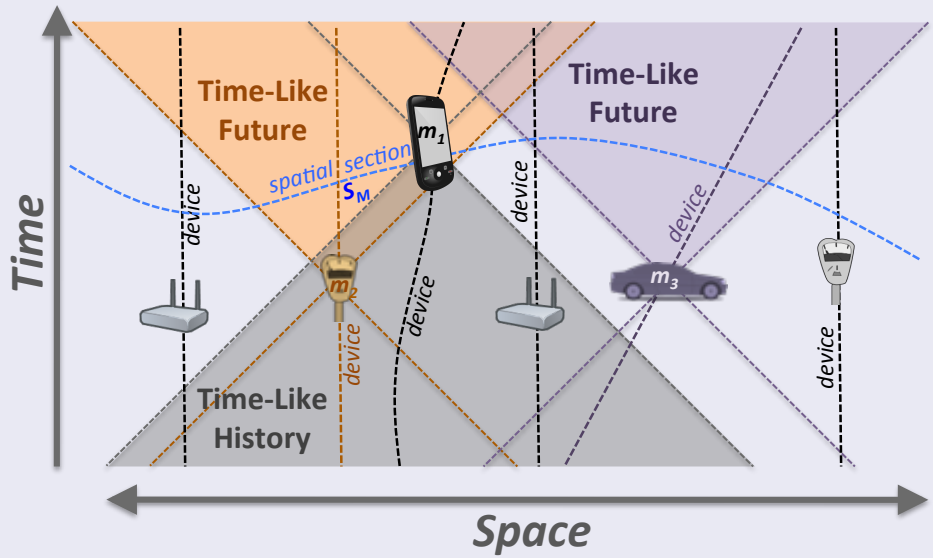
Limited resource scenarios

- None of the platforms for aggregate programming was conceived with a commitment to low resource usage
- Some early work exists to allow using LoRaWAN [All15] as network backend
- But packets sent by current implementations are huge and prevent practical use
- Strategies for reducing resource usage must be devised

Open issues V

"Computational relativity"

- Communication speed bounds the speed at which the various part of the aggregate machine perceives updates
- May be impacting on several deployments
- Somehow resembles the shift from classical mechanic to relativity



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