The Next Generation of Networked Sensor-Actuator Systems

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Five Years Ago…

Networked Wireless Sensing
In-network Processing
Distributed Collaborative Processing
Highly energy-efficient systems
Ad-hoc deployed systems (thrown from aircraft)
Data-centric Routing

Some novel (fanciful?) ideas outlining a broad research agenda…

Where are we?

Networked Wireless Sensing	
In-network Processing	
Distributed Collaborative Processing	
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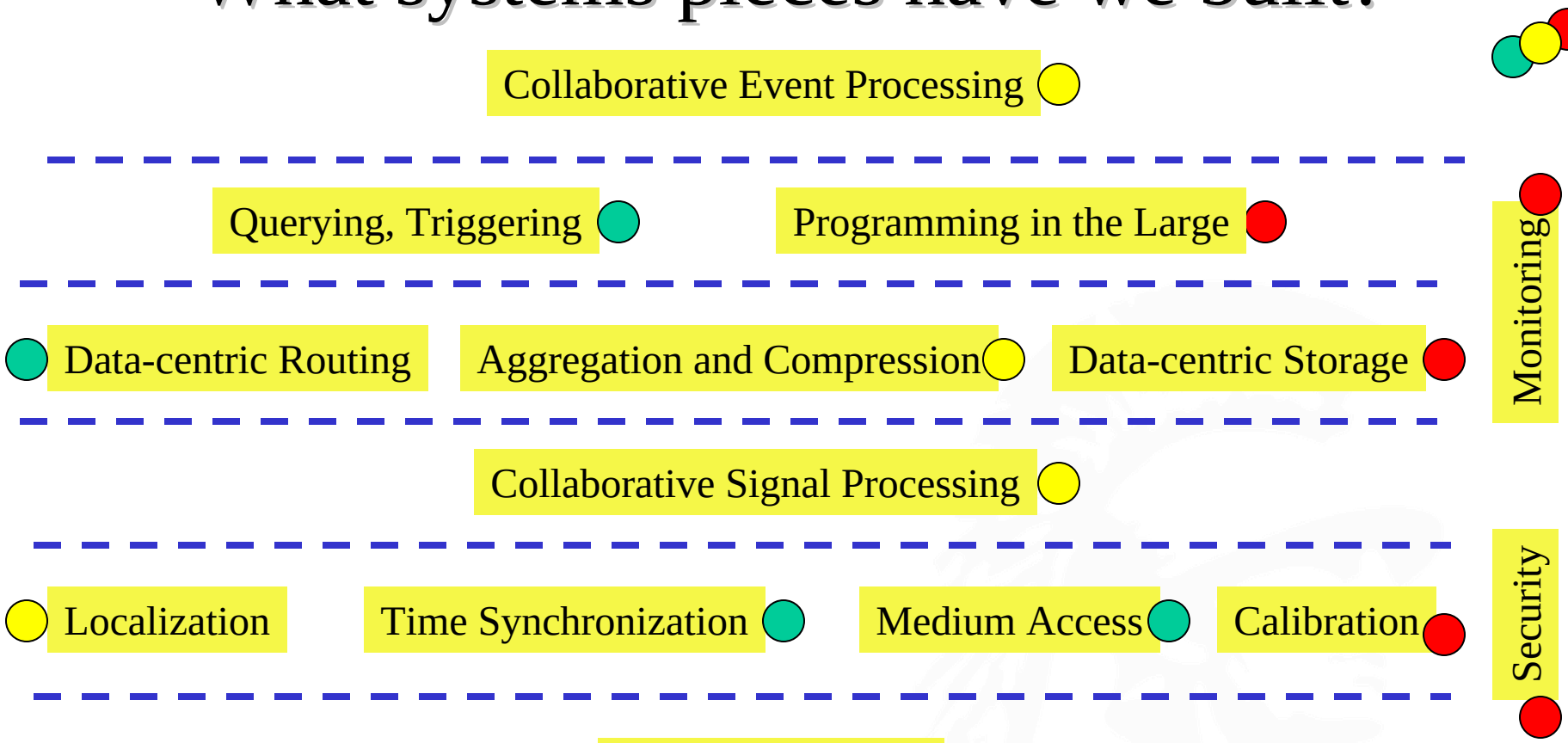
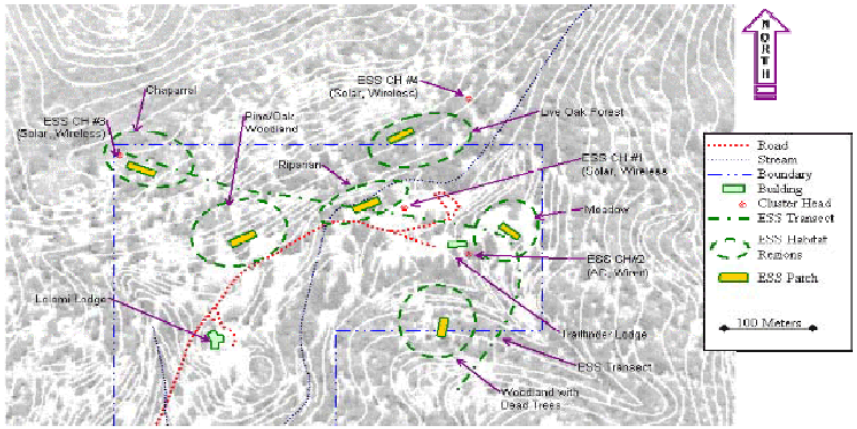
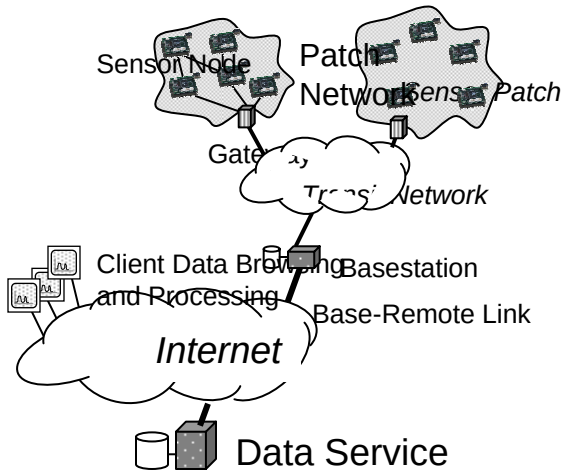
Data-centric Routing	

What systems pieces have we built?



What kinds of systems?

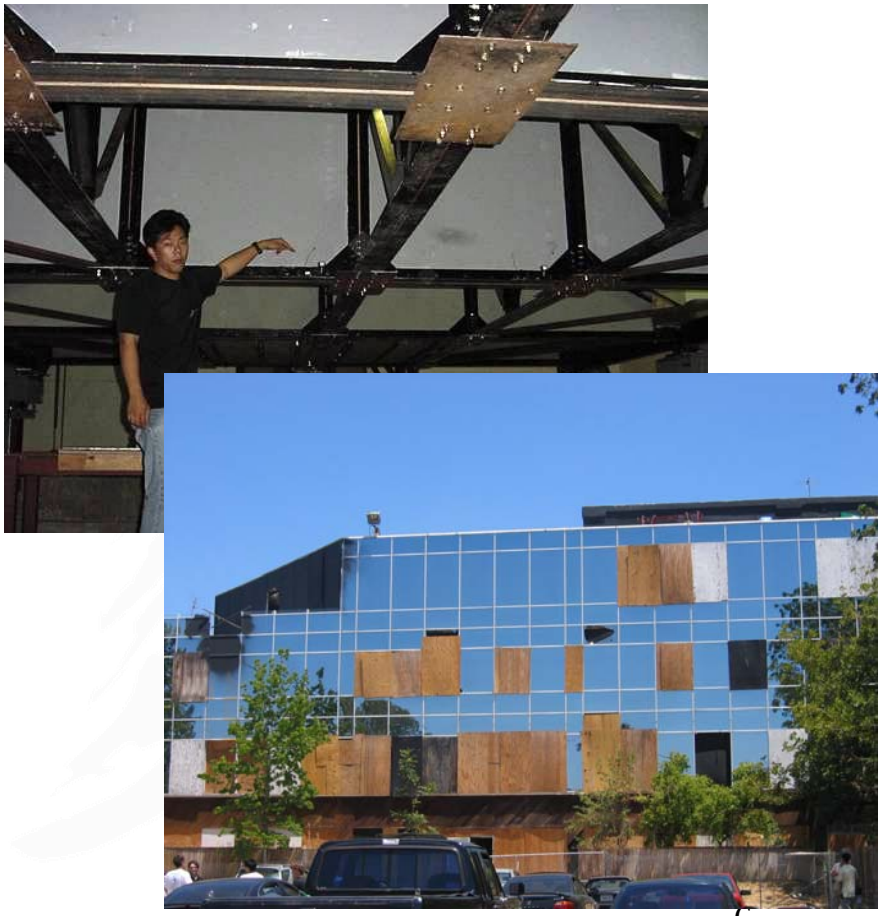




- Hierarchical *data-acquisition* systems
  - James Reserve
  - Great Duck Island
- *First-generation systems*

Another First Generation System: *Wisden*

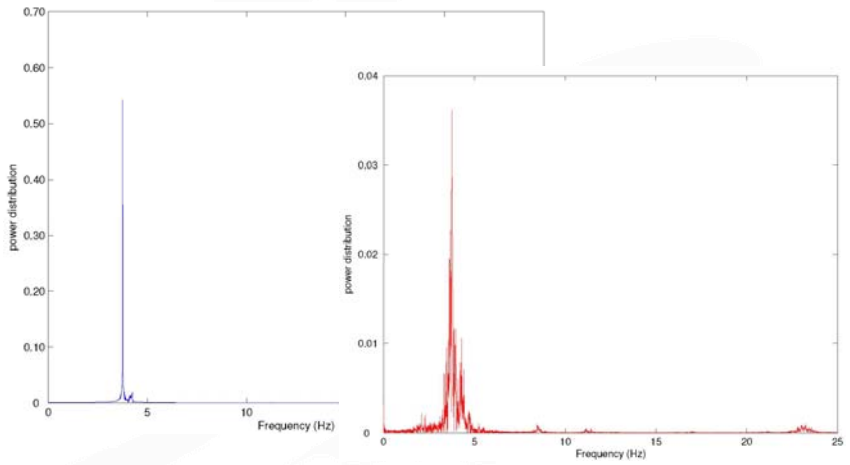
- Simple abstraction
  - A wireless *structural* data acquisition system
  - Important!
- Features
  - Reliable multi-hop data transfer
  - Compression
  - Time stamping
- Status
  - Testing on ceiling structure
  - Initial data collection on the Four Seasons experiment



N. Xu *et al., "A Wireless Sensor Network for Structural Monitoring"*, Proc. ACM Sensys 2004

Wisden: Experiences

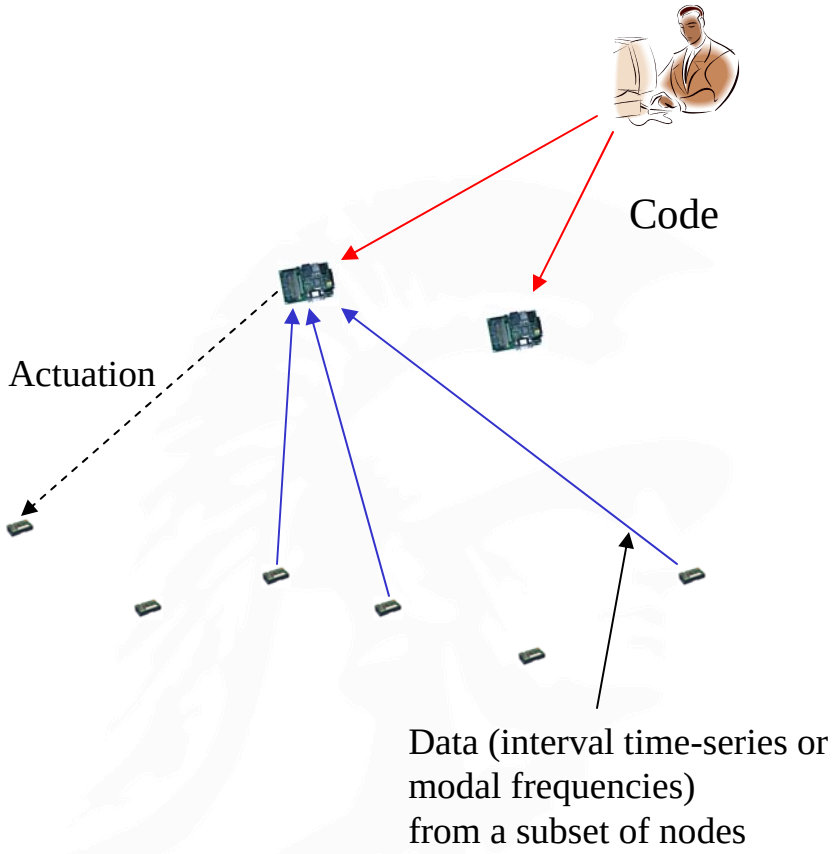
- Performance
  - Reasonable
  - But:
    - » bugs remain
    - » need to work on scaling
- Deployability
  - One data point …
  - "Mostly wire-less" is important
- Use
  - rapid, cheap, reasonably accurate instrumentation
  - some push from the structural engineering community to deploy these systems in their test structures
    - » simplicity of abstraction was essential
- Next steps
  - Hierarchical data collection using Stargates



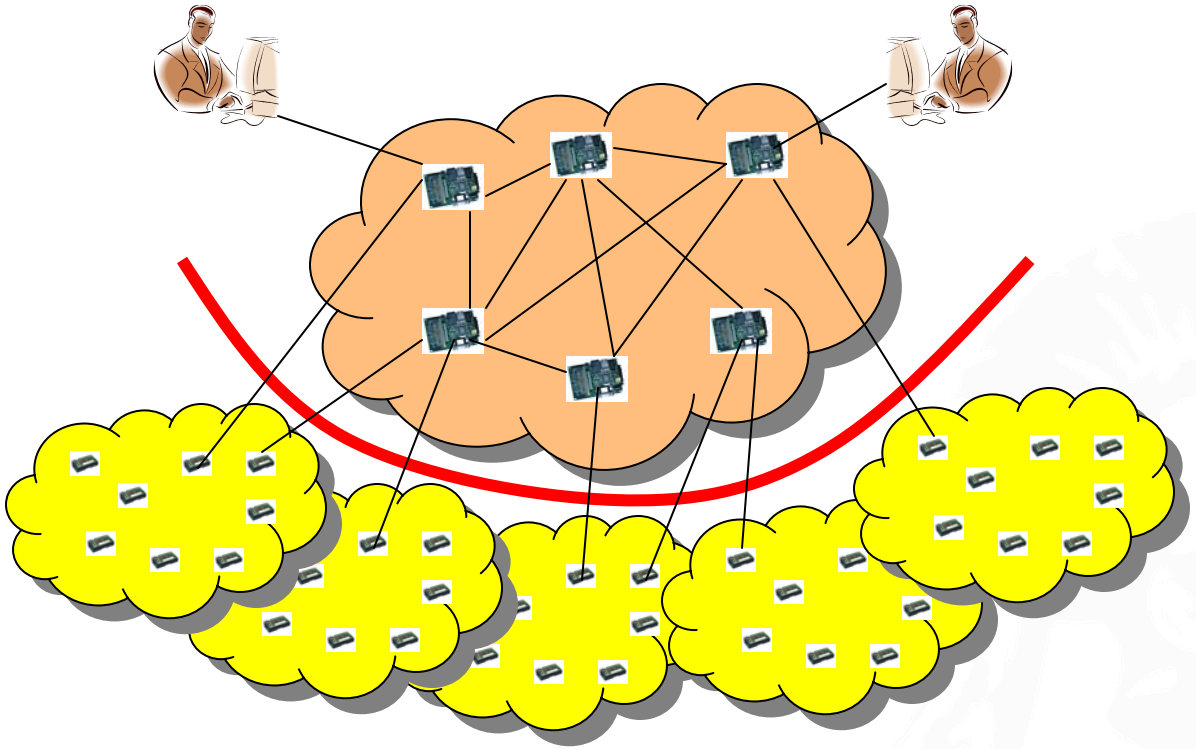
Where do we go from here?

Programming Structural Monitoring Algorithms

- Scaling requirements
  - "The more the better…"
  - Upwards of 200 nodes in a moderately sized building
- If we can't continuously acquire structural data
  - we believe it is possible to implement structural monitoring algorithms with functionality shown
- *How do we architect this system?*



Architecting For Scale

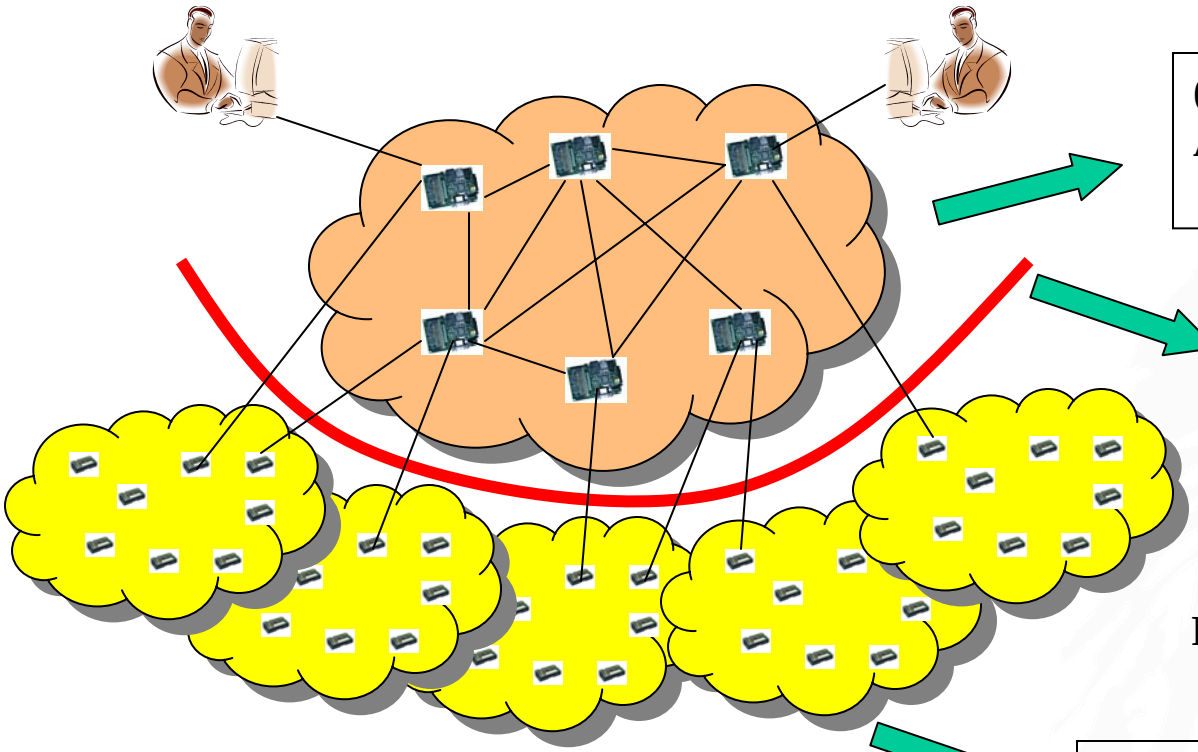


Possibly powered devices, wireless mesh for communications

Relatively impoverished devices, small depth clusters

Hierarchy for scaling is obvious, but what functionality goes where (where does the processing go)?

Thesis: Second Generation Networked Sensor Systems



(Distributed) computing substrate
Application development happens here

Simplify this interface!
- sensor-addressable tasking
- (reliable) data collection
- *generic* signal processing
  - this can evolve

Programmable data acquisition

Still need duty cycling, MAC, localization,timesynch, routing, congestion control *etc.* here

CENS

Why do it this way?

- Standardizes the impoverished part of the network
  - This is the hardest to get right and *where most of the networking research challenges are!*
  - Generic API can be re-used, (little or) no application development on that side
- Takes the application developers to regimes they're much more comfortable handling
- Will get us where we want (deployable systems) faster
- Software organization is an orthogonal issue

Does this Architecture Generalize?

- What does this generalize to?
  - Clearly, *not* to ad-hoc deployments
  - Perhaps to engineered deployments in human artifacts
    - » A variety of other sensing modes …
    - » … on buildings, bridges, ships, warehouses *etc.*
    - » *These could form 80-90% of sensor net deployments*
- Isn't structural monitoring rather specialized?
  - No, it is a precursor to tomorrow's applications
  - Sensor net users will always ask for more data, from many perspectives
    - » leads to higher quality decisions from noisy data

Does this Architecture Generalize?

- At least one other application will likely be architected this way
  - Habitat monitoring in the James Reserve
- Features
  - "Mote herding"
  - Computation to decide which cameras to actuate

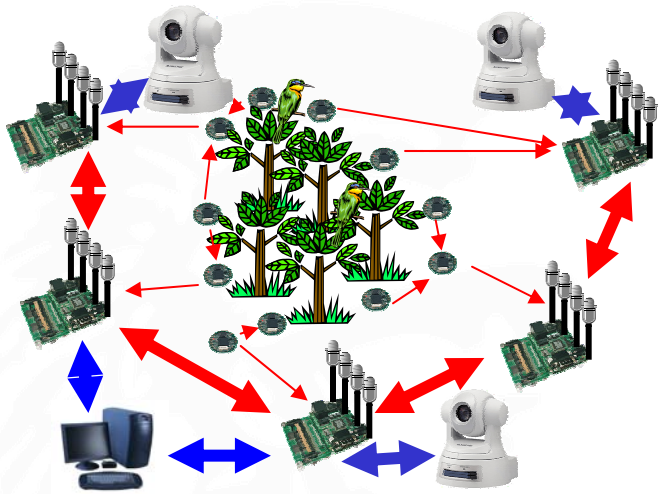


Figure courtesy Lew Girod and Thanos Stathopoulos

Is this Architecture Generic?

- Research will probably focus on two axes at a time
- The hierarchical architecture is generic in that it can accommodate all three dimensions
  - … but, at any given time, such a system might be less capable than one focused on two dimensions alone.

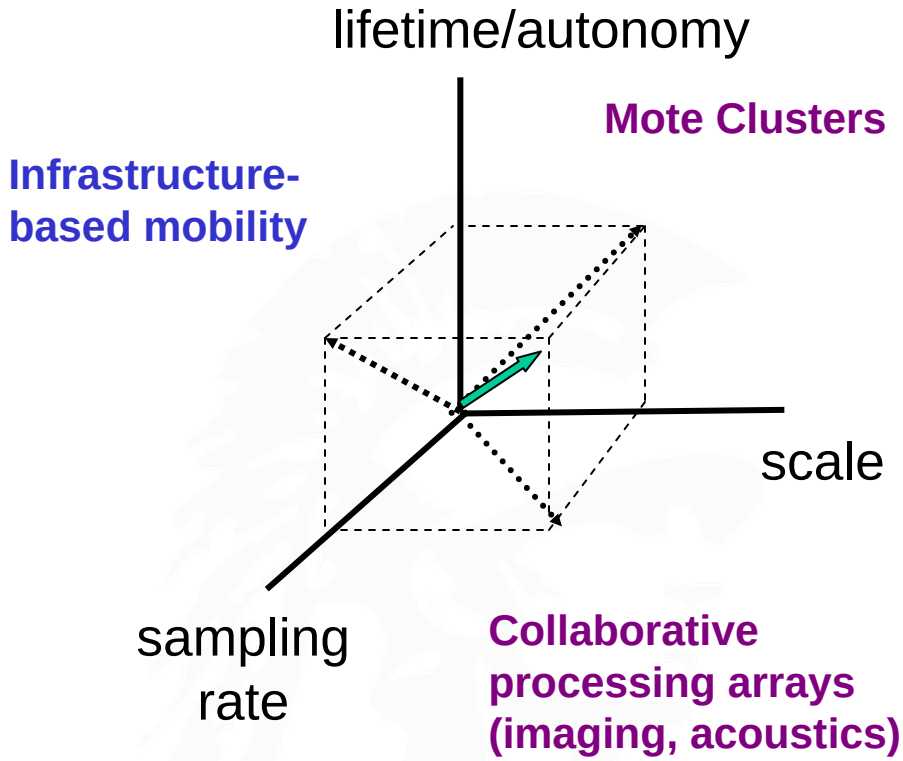


Figure courtesy Deborah Estrin

But what about this vision?

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The *third* generation!