Adaptive distributed computing for fractionated space systems

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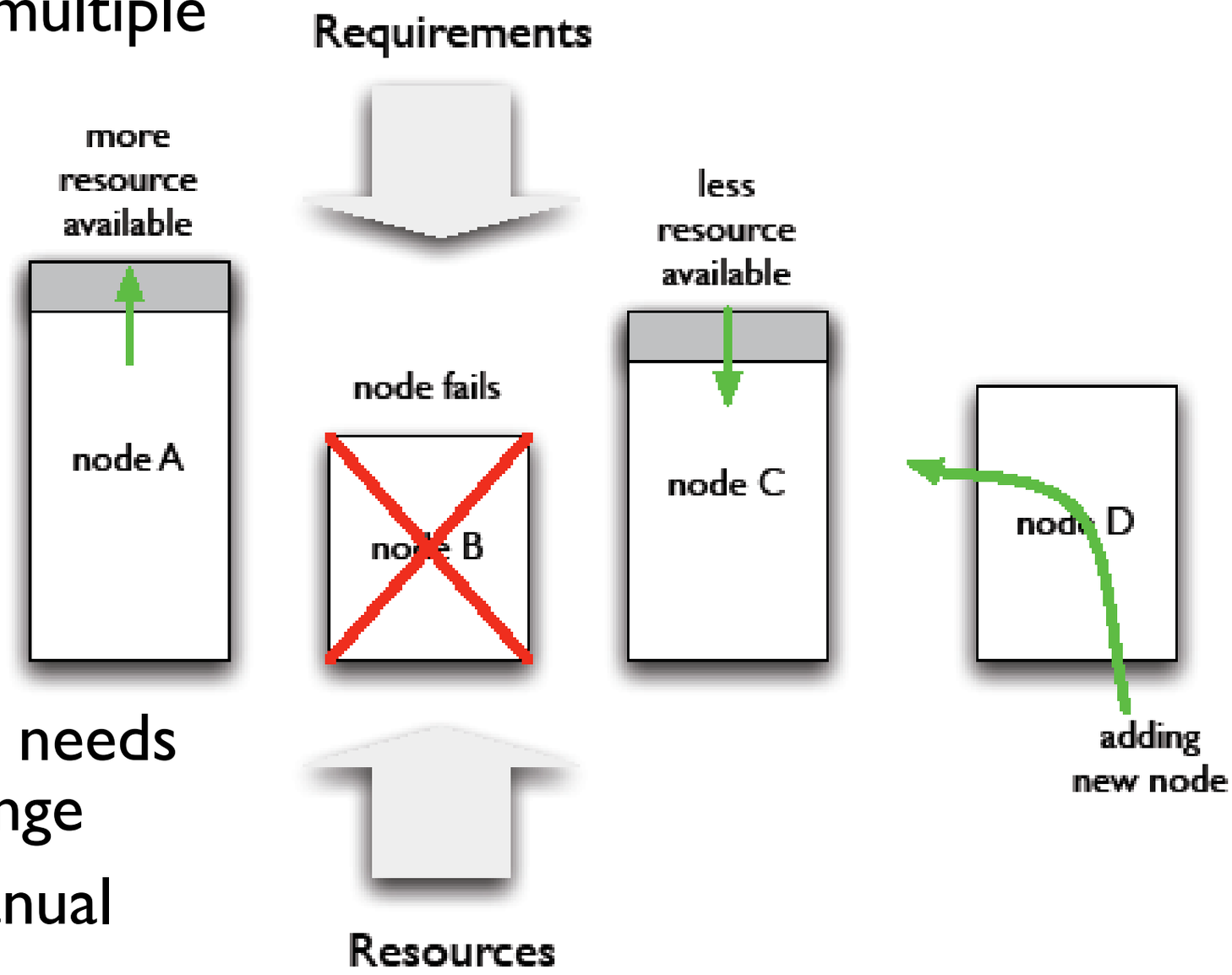
What is adaptive distributed computing?

- Distributed application uses resources at multiple nodes



- App must adapt as needs and resources change
- Automatic, not manual
- Multiple applications sharing resources

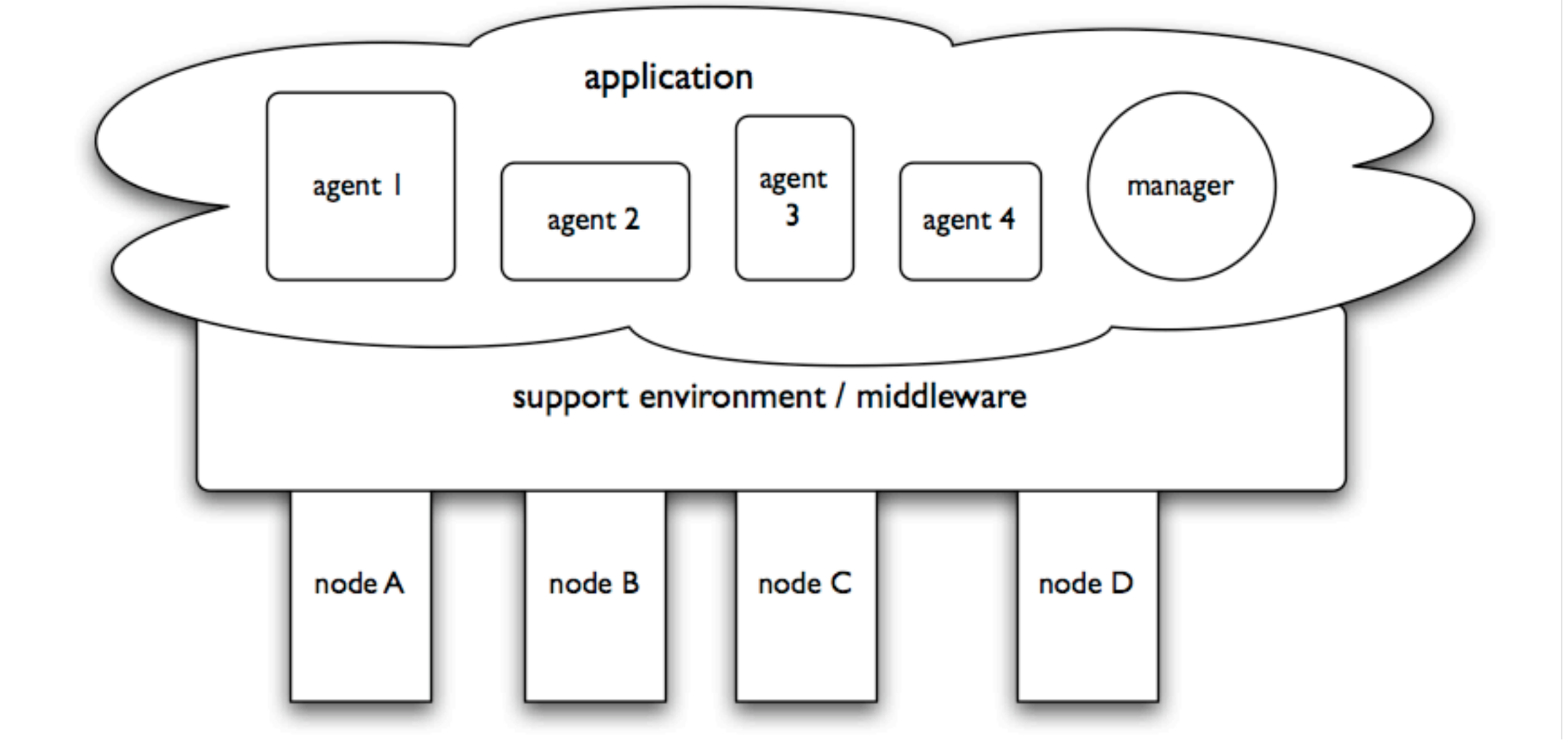
Examples

- Data analysis for mission (re)planning
  - Use as many compute cycles as possible
  - Do as much as possible in planning window
  - Experimenters/observers adding new analyses

- Communication up/downlink and inter-node channels

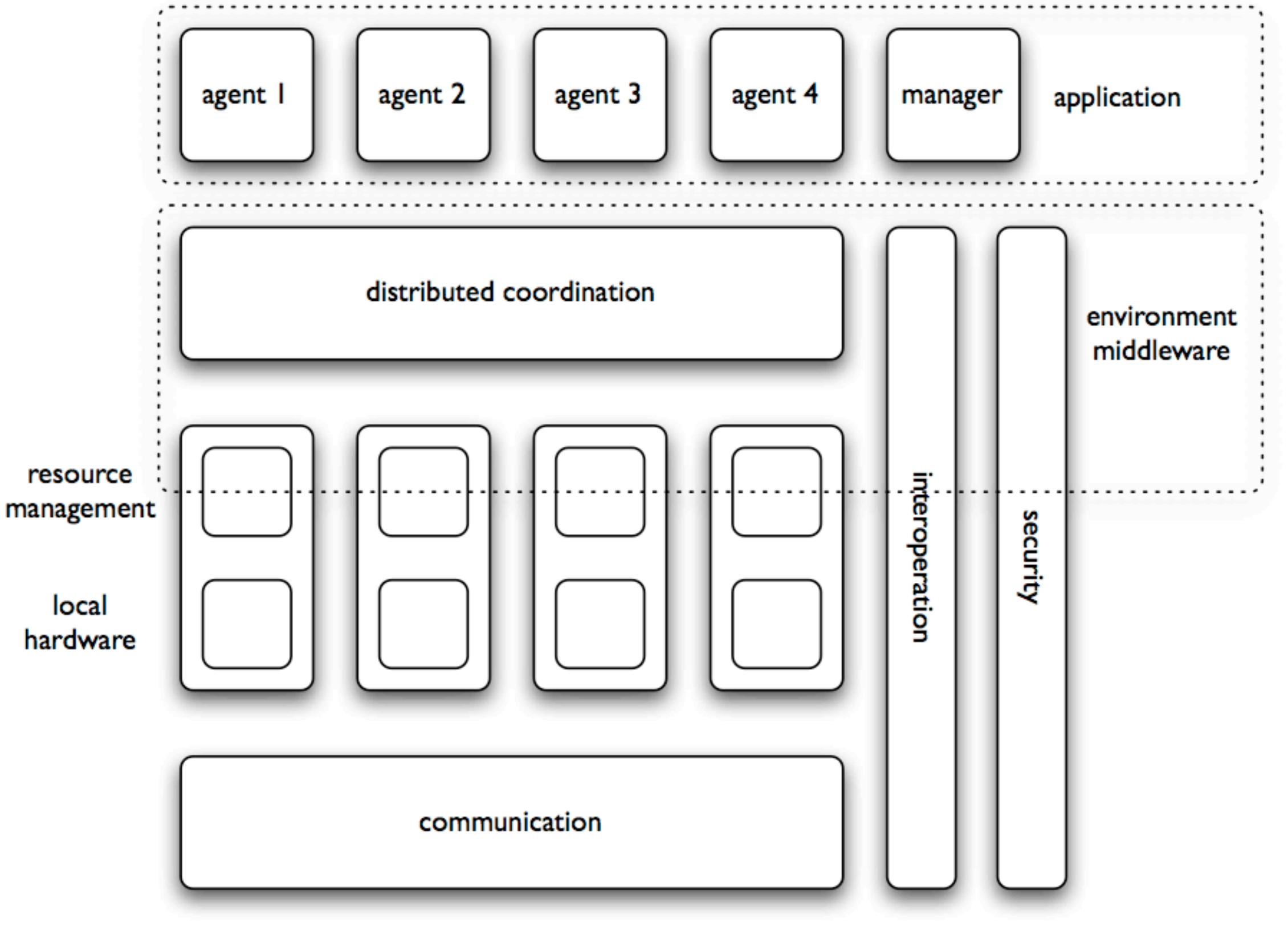
- Data storage for later transmission or analysis
  - Store extra copies when extra space
  - Retain high-priority data when running short

Architecture (high-level)



- Application consists of multiple agents, with different roles
- Middleware provides distributed environment
- Each local node provides predictable resources and services—compute, storage, communication, sensing, energy

Architecture (detail)



What can we draw upon?

- Grid and peer-to-peer systems
  - *Supercomputing clusters, PlanetLab, MPI*
- Autonomic/self-managing systems
  - *Management tools*
- Mobile adaptivity
- Group communication systems
  - *Ensemble, Horus*
- Virtual machines
  - *VMware, Hypervisor*
- Embedded/realtime OSes
  - *Commercial and experimental*

What's new here?

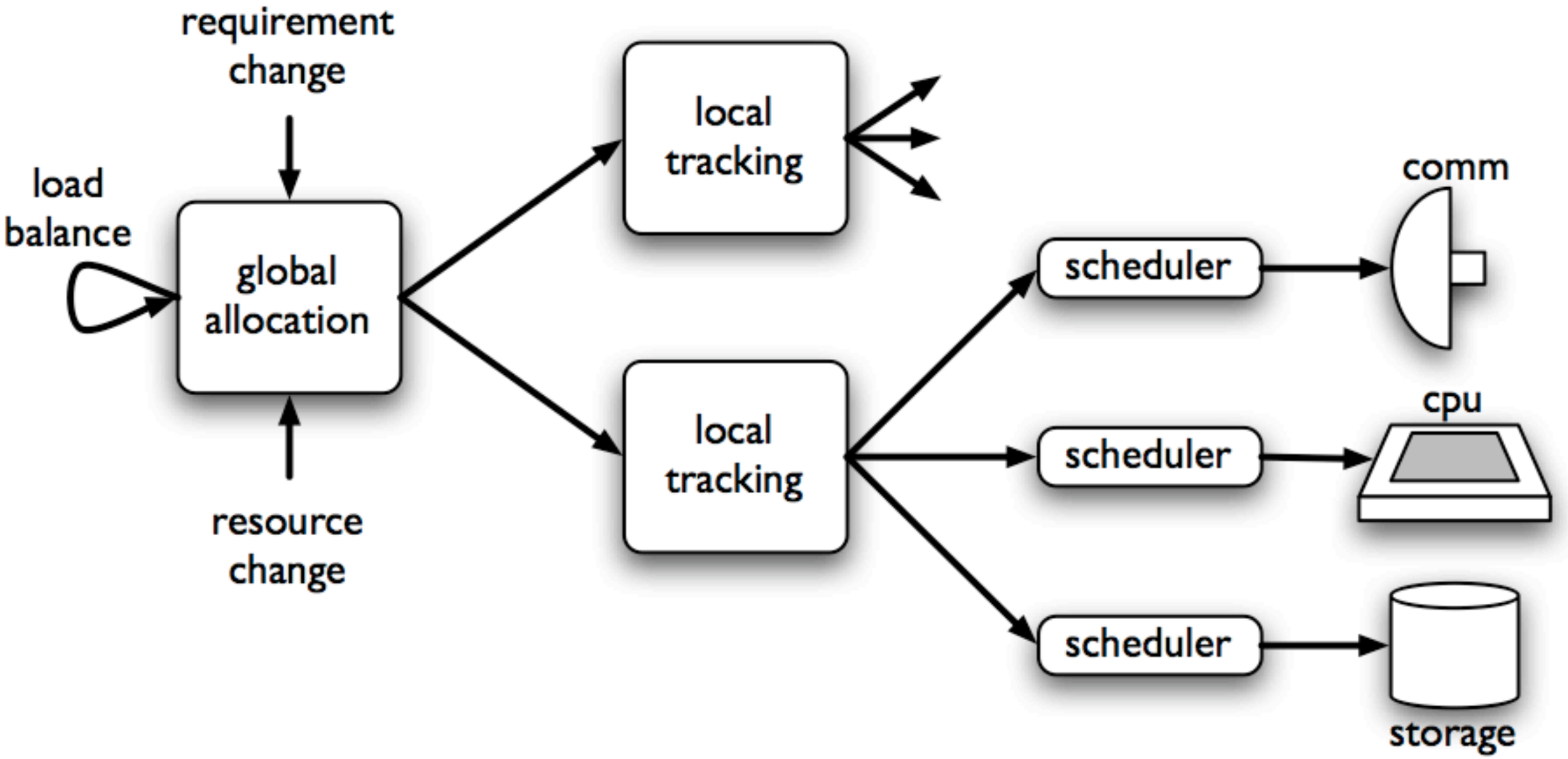
- *(Why not use an existing system?)*

- Integration of security, realtime, fault containment in middleware
- Local resource scheduling across multiple resources
- Self-managed configuration
- API for adaptive applications

Aspects of the problem

- Resource allocation
- Groups and membership
- Communication
- Failure tolerance
- Security
- Programming model and tools
- Standardization and interoperation

Resource allocation

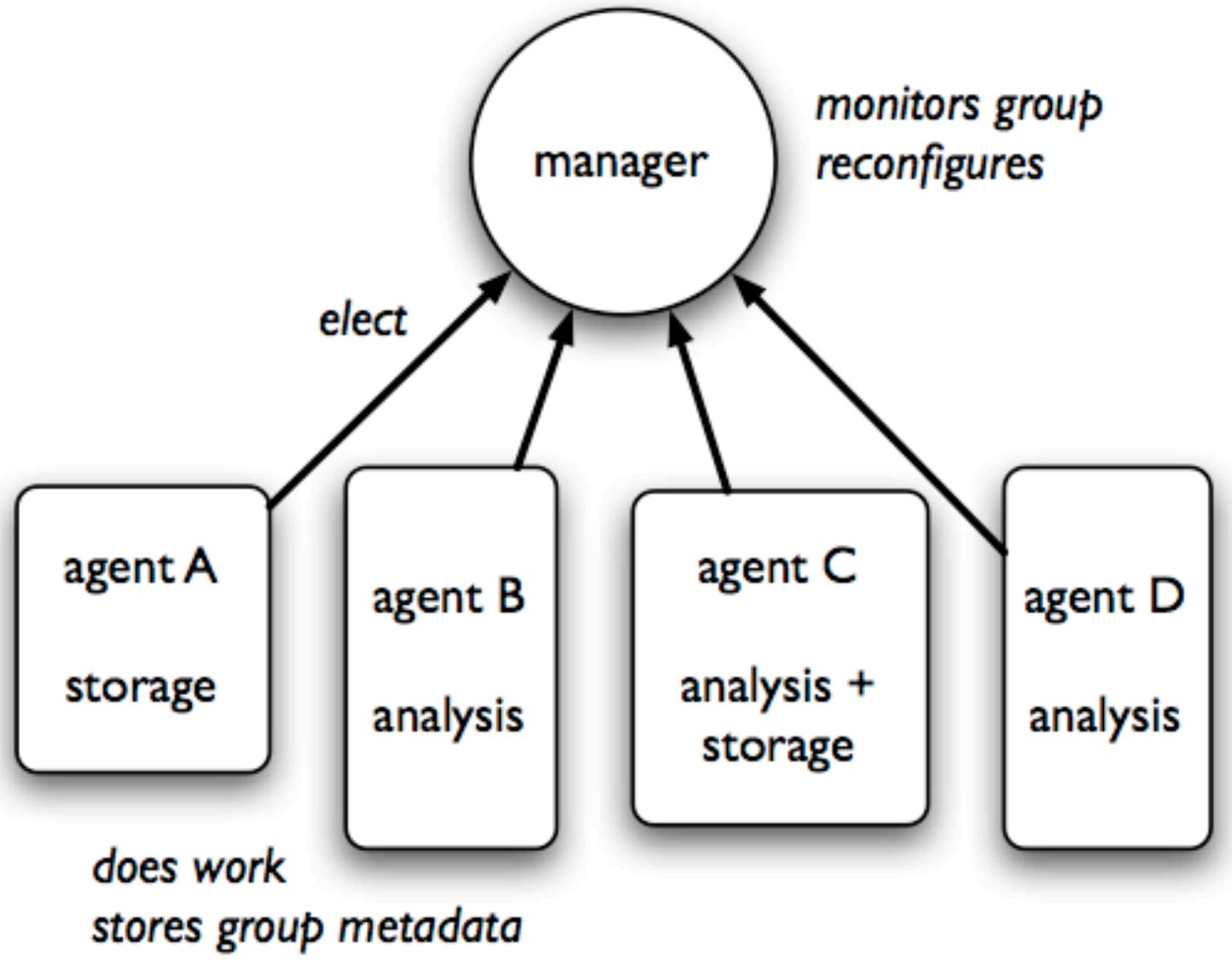


- Decision algorithm: constrained multidimensional bin-packing
- Isolation between applications

Groups and membership

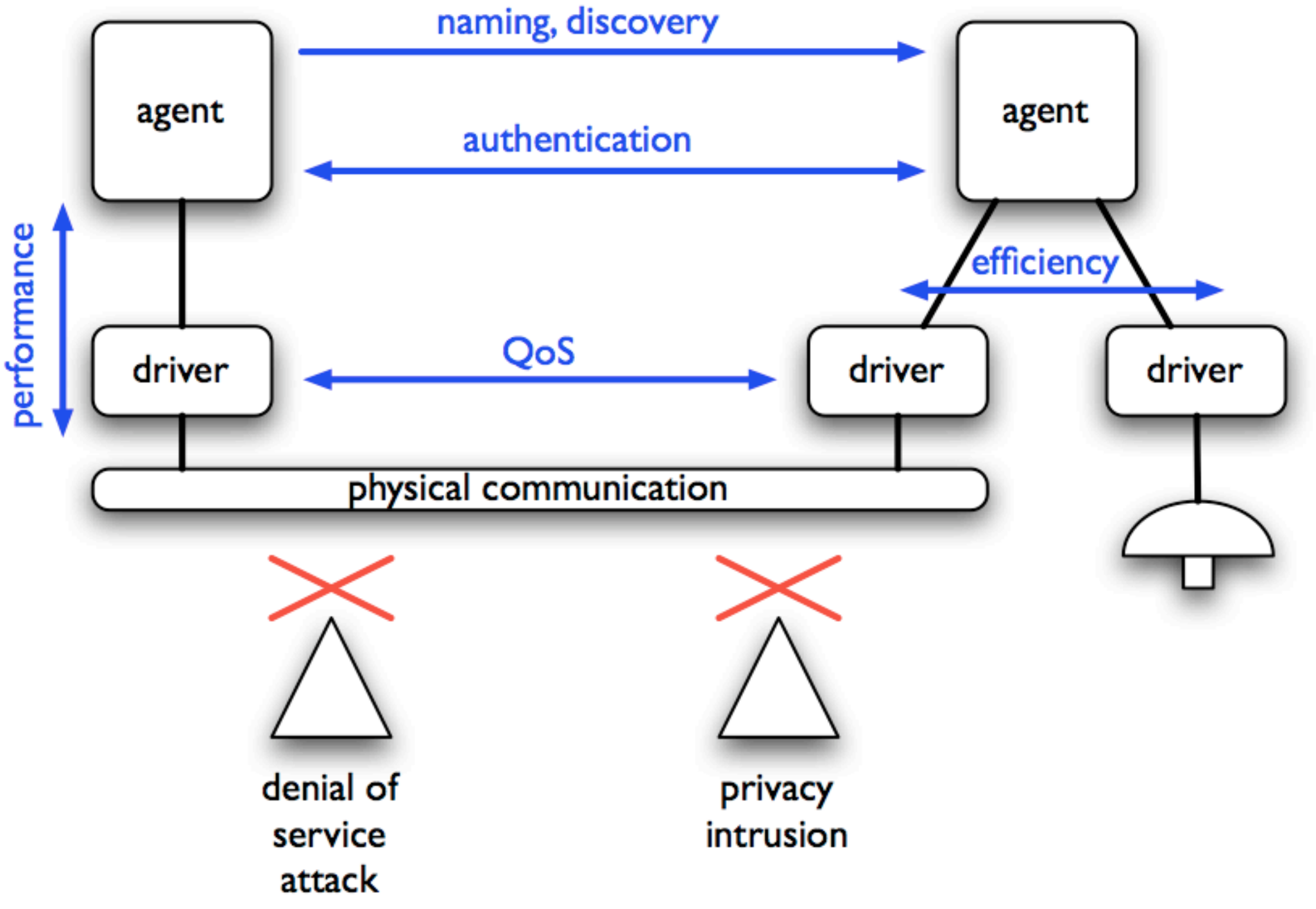
- How are the pieces of an app identified? What defines an app?

- Key properties
  - Consistency
  - Resilience
  - Containment
  - Security
  - Scalability

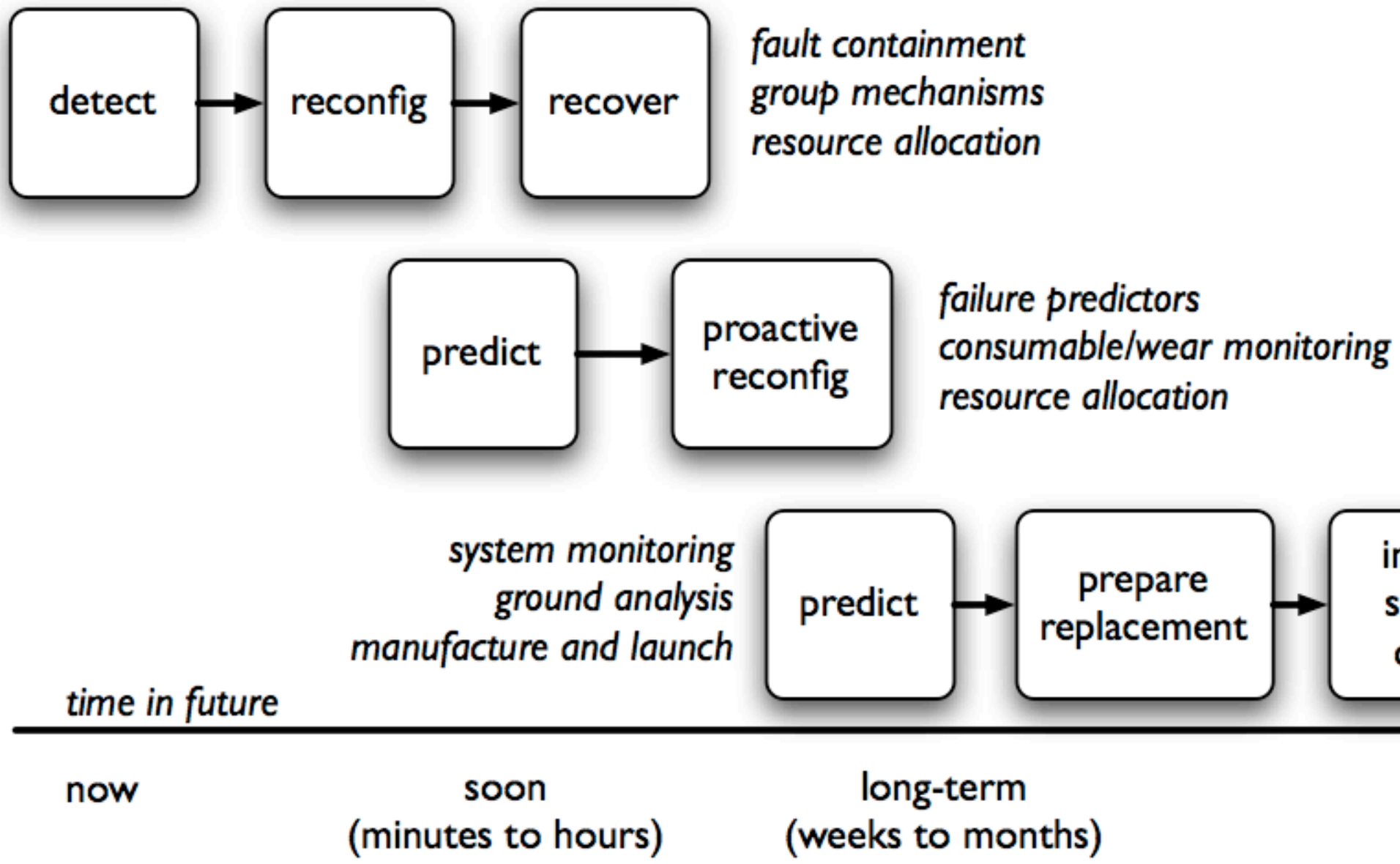


- Research focus: self-identification, decentralization, loose synchronization

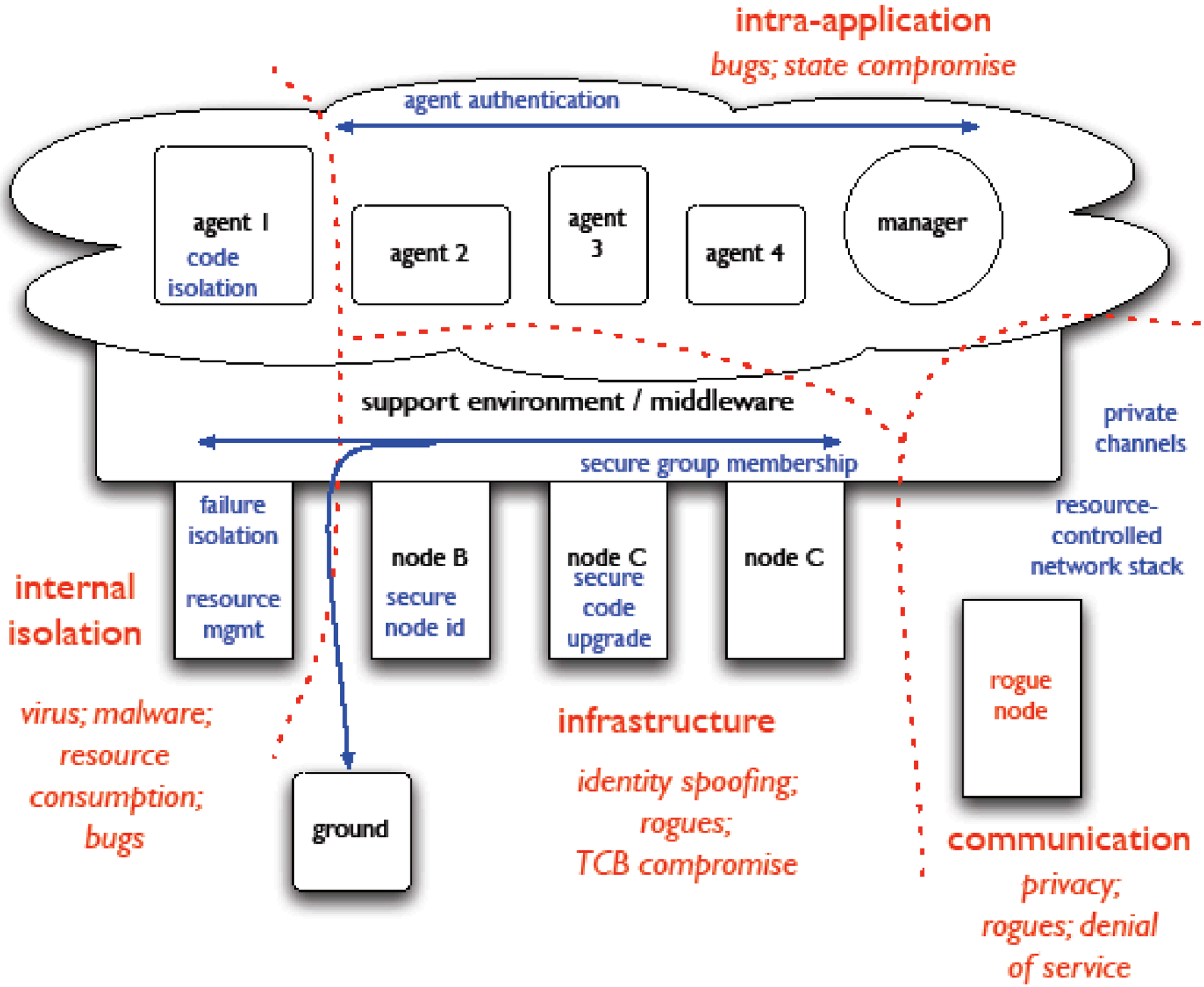
Communication



Failure tolerance



Security


intra-application
bugs; state compromise
agent authentication
agent 1
code isolation
agent 2
agent 3
agent 4
manager
support environment / middleware
private channels
secure group membership
failure isolation
resource mgmt
node B
secure node id
node C
secure code upgrade
node C
resource-controlled network stack
internal isolation
virus; malware; resource consumption; bugs
ground
infrastructure
identity spoofing; rogues; TCB compromise
rogue node
communication
privacy; rogues; denial of service

Programming model and tools

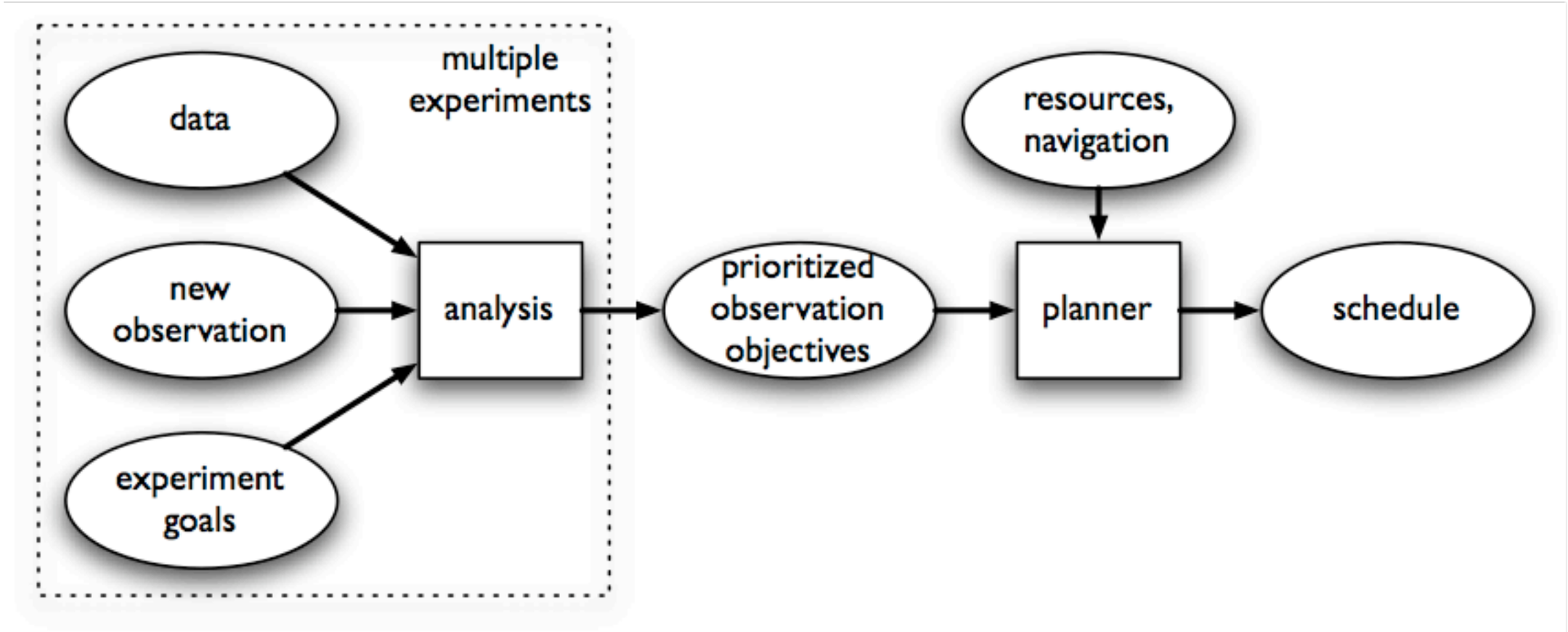
- Language and API
- Development tools

- Test framework
  - Continuous test, fast regression test
- Simulators
- Model checkers

Standardization and interoperation

- Expect satellites added over time
  - Multiple vendors, versions
- Interoperation ⇒ standards
- Defining standards
  - Venue? when ready? formal models?
- Interoperability tests
  - Formal checking
  - Testing

Putting this together

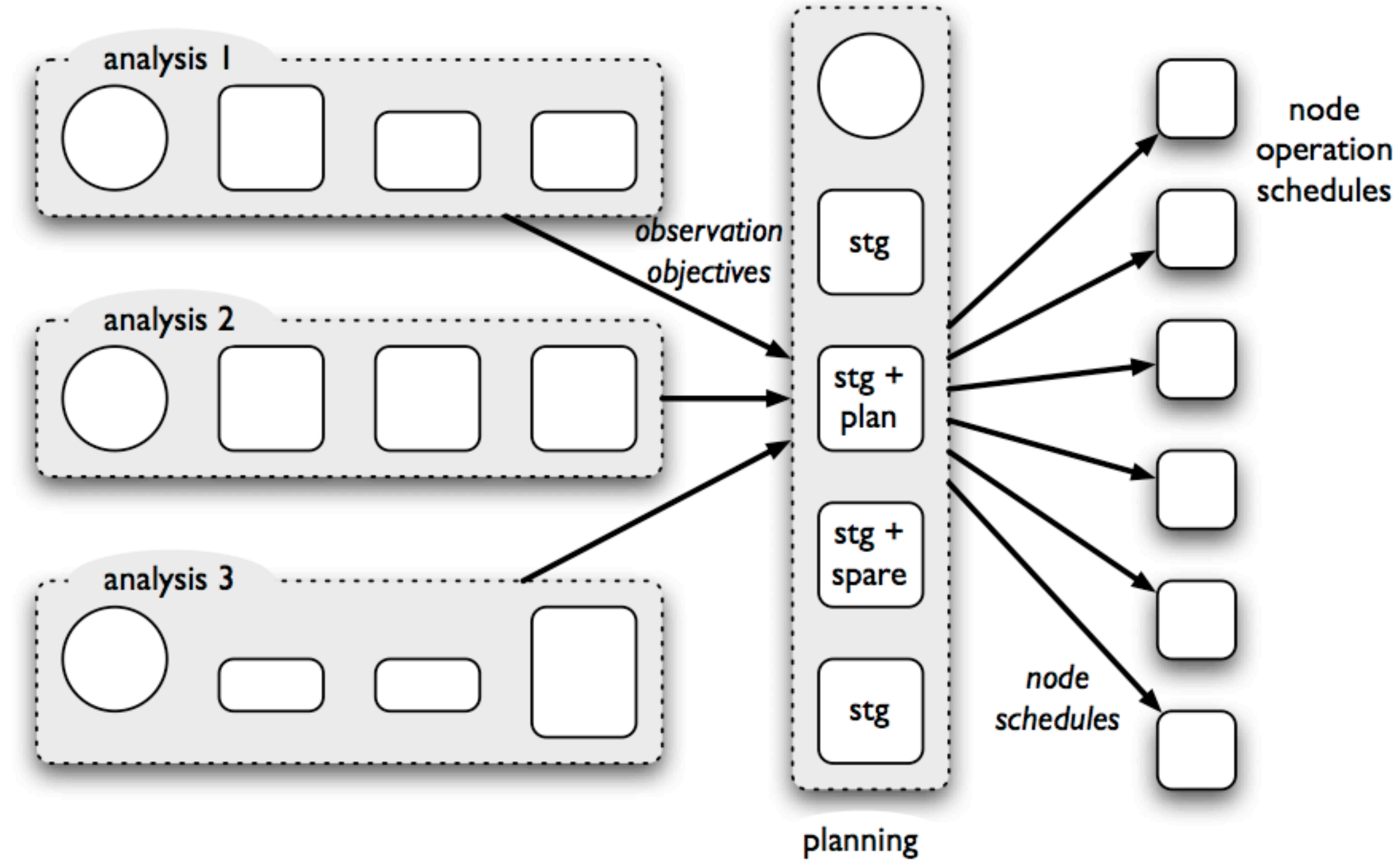


Notional mission: multiple experiments, onboard mission (re)planning

Inspired by:

Chien et al., "An autonomous Earth-observing sensorweb." *IEEE Intelligent Systems*, May/June 2005, pp. 16-24.

Putting this together



Contacts and information

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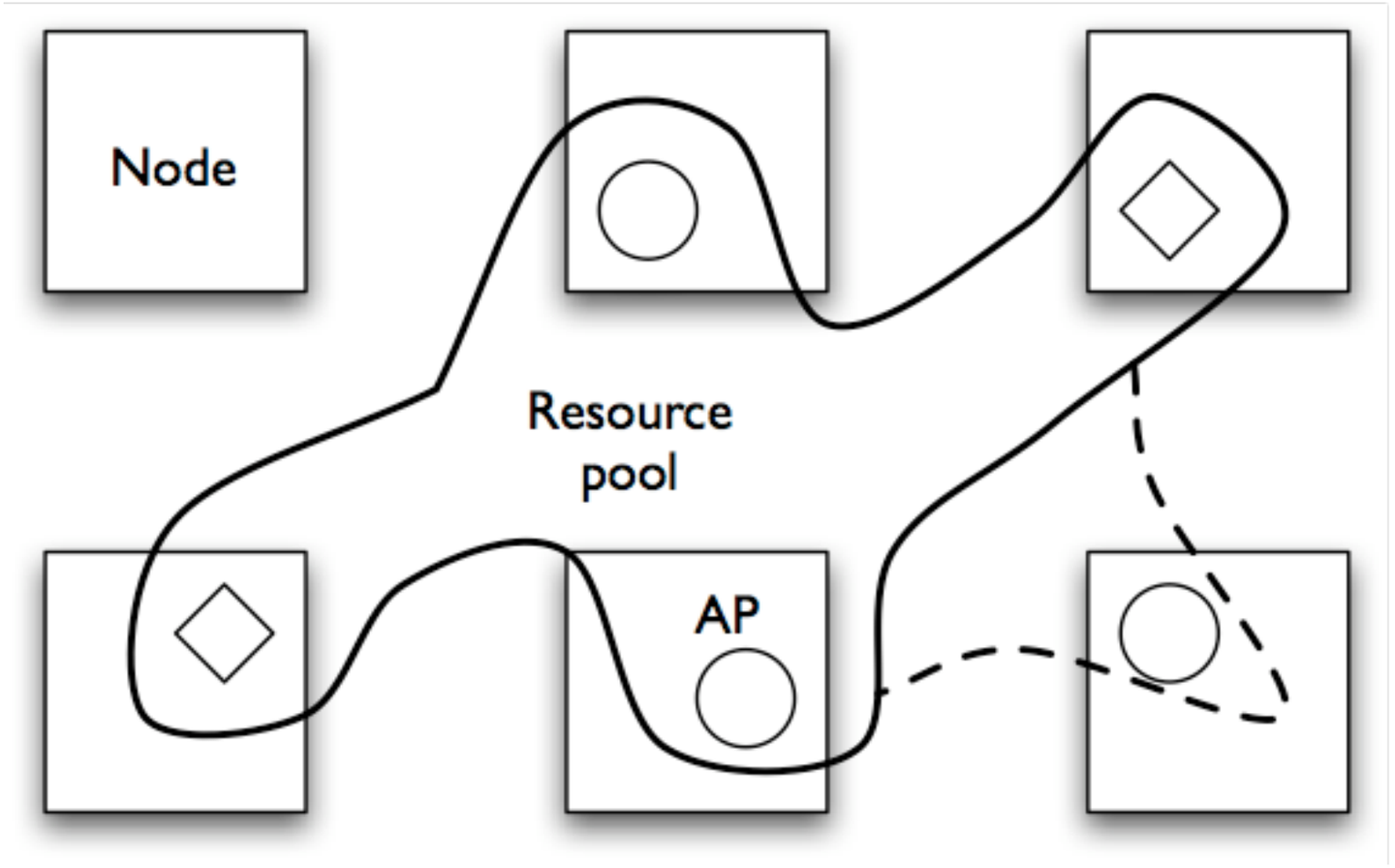
- In conjunction with SSRC, UC Santa Cruz, and PDL, Carnegie Mellon Univ.

Backup slides

K2 distributed storage system

- Vehicle for research—*not* a product
- No central administration; federate when global view needed
- Delegate function to as low a level as possible
- Provide support to higher-level application management

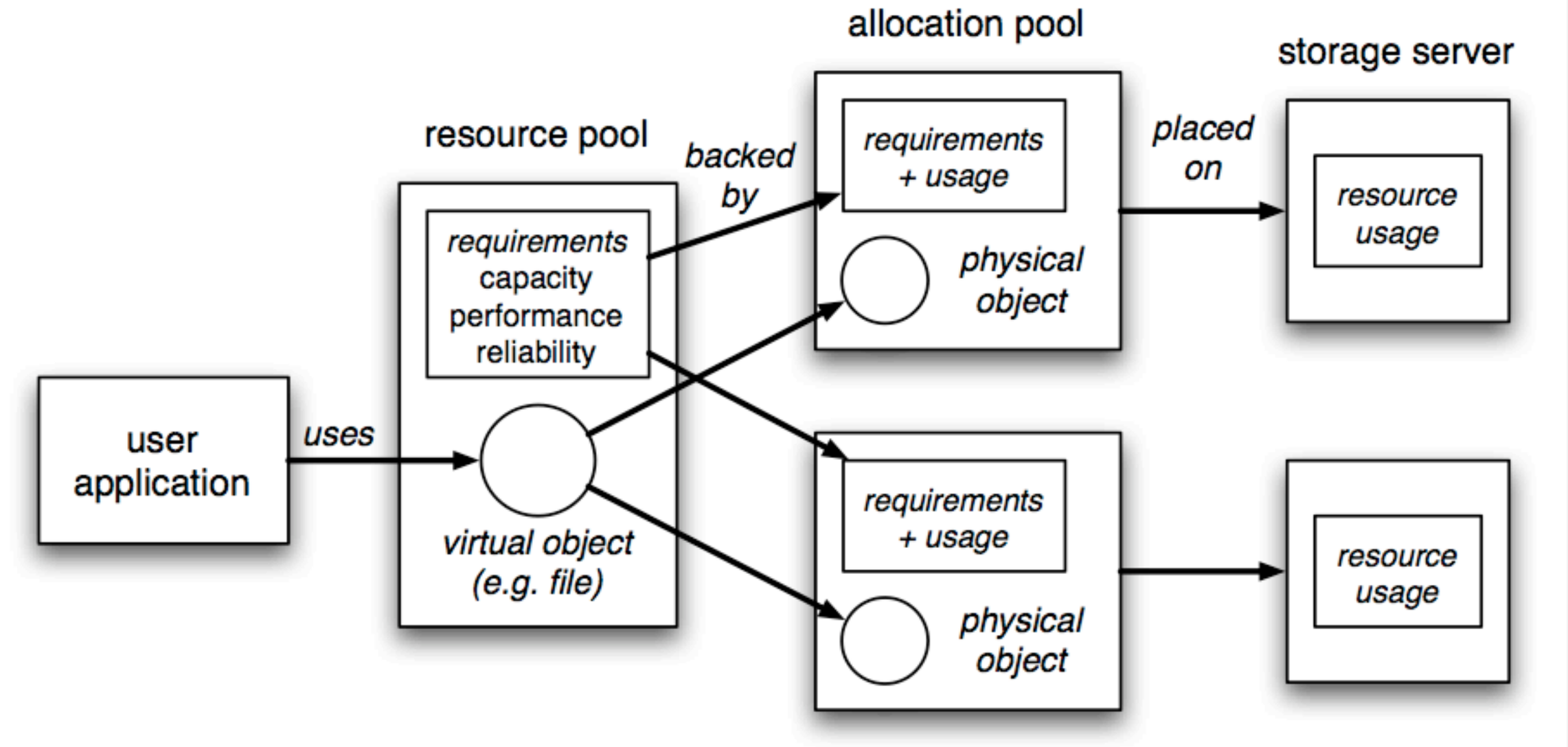


Resource pools: external view

- A virtual collection of storage
- One per user or application
- Each pool is independent
- Specified by:
  - Capacity, Performance, Reliability
  - Reserve and limit

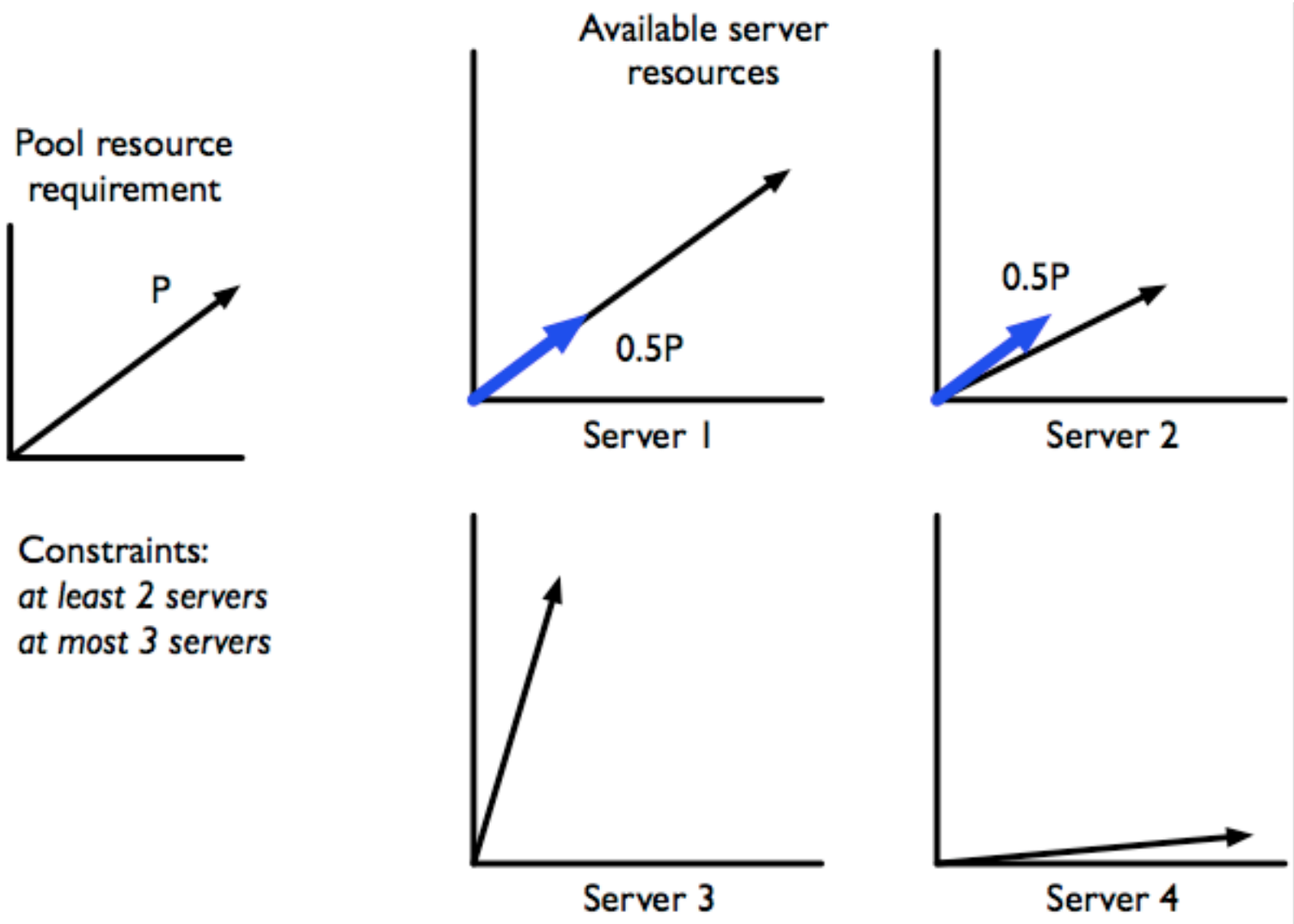
- Initially: capacity = bytes; performance = IO/s; reliability = MTTDL

Implementing pools



- Virtual pool backed by physical allocation pools
- Pools contain objects for storing user data
- Decision algorithm: how much to put where
- Storage server enforces resource allocation

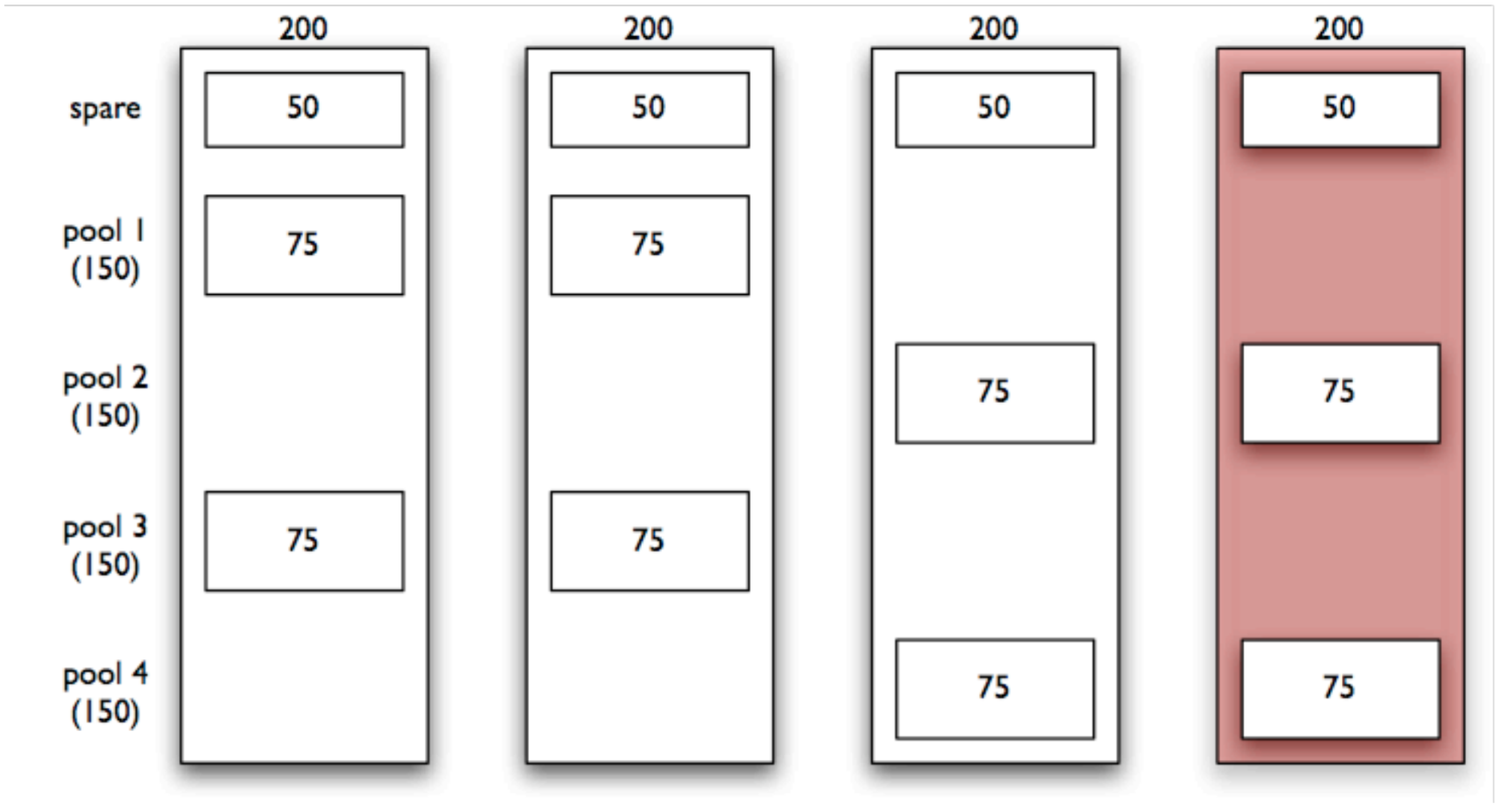
Resource allocation decisions: normal



- Normal case: online decision for one pool
  - Creating or modifying a pool's requirements
  - Load balancing
- Use constrained multidimensional bin packing
- Constraints derived from reliability requirements

Resource allocation decisions: failure

- Multi-pool assignment required
- Backtracking search for feasible solution (better is possible)



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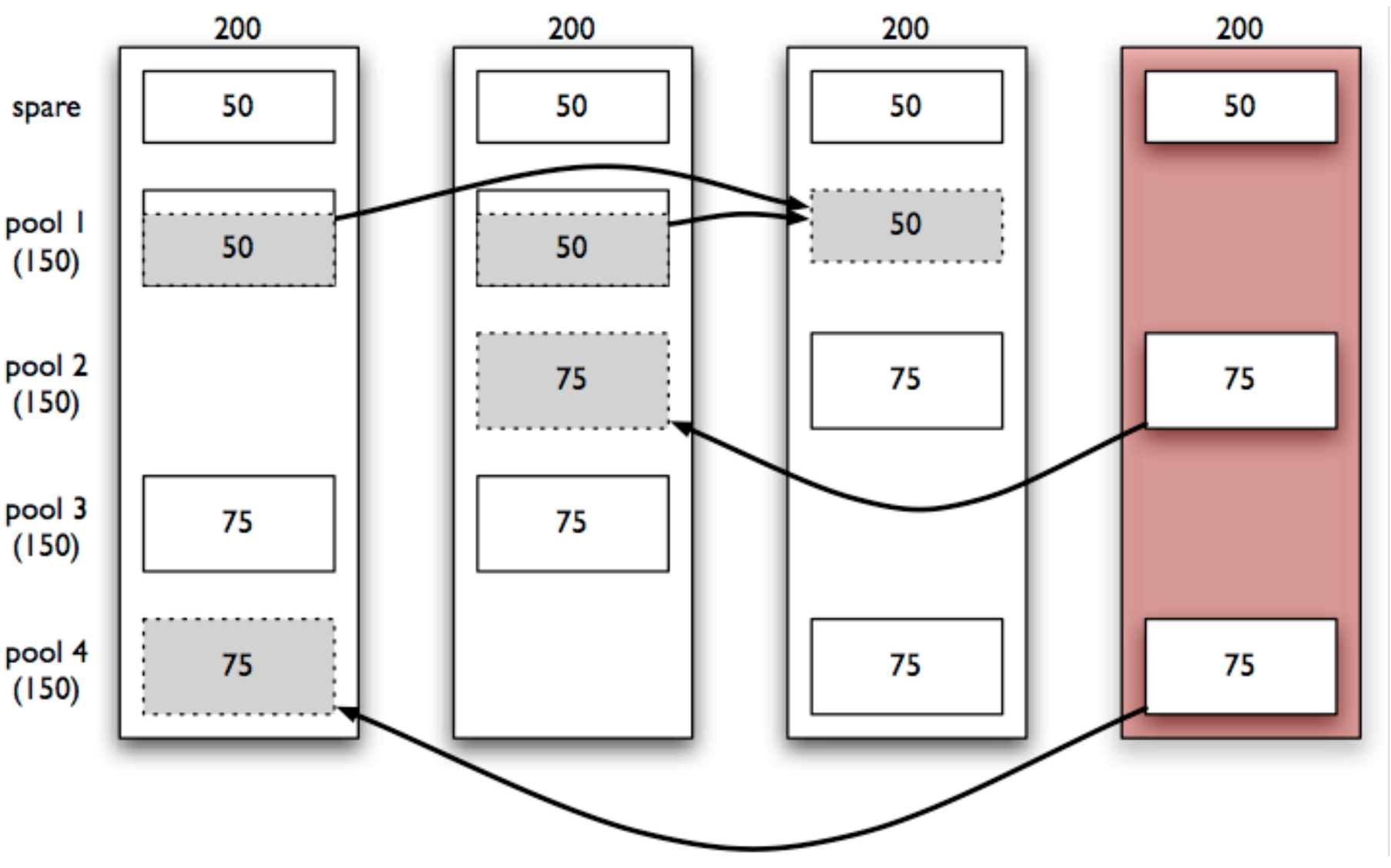
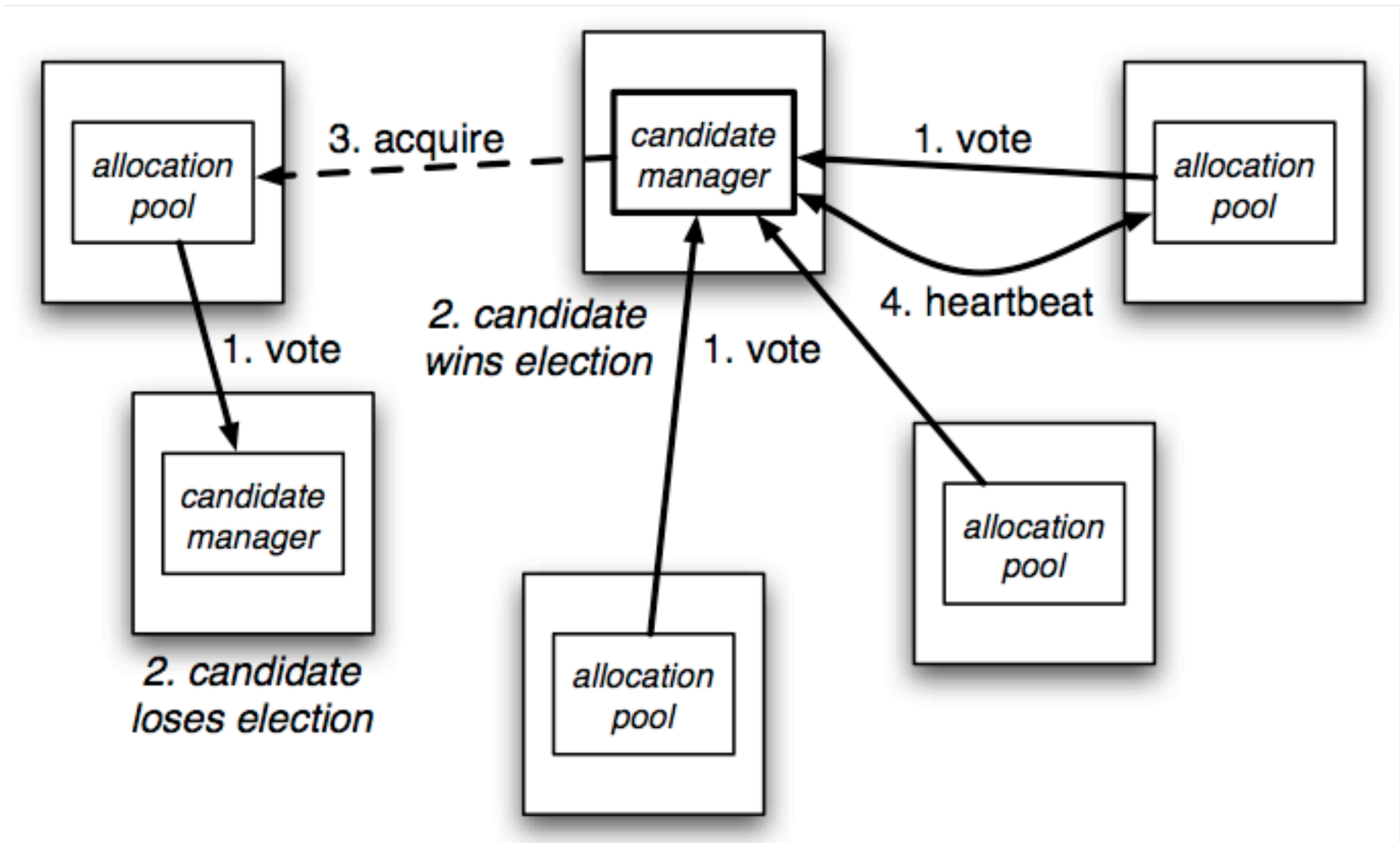


Making decisions



- Each resource pool is an independent group
- APs elect a manager; manager watches over pool
- Manager is disposable
- Manager runs decision algorithm
- All information in allocation pools

Local resource management

- Goal: isolation between pools
- Capacity: just accounting
- Performance: requires scheduler
- Tradeoff: performance vs. efficiency
- Provides reserve and limit, plus fair sharing
- Working to add cache, network