Net SILOs: A Network Architecture for Advanced Cross-Layer Experimentation

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http://net-silos.net/

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In Search of Next Generation Internet

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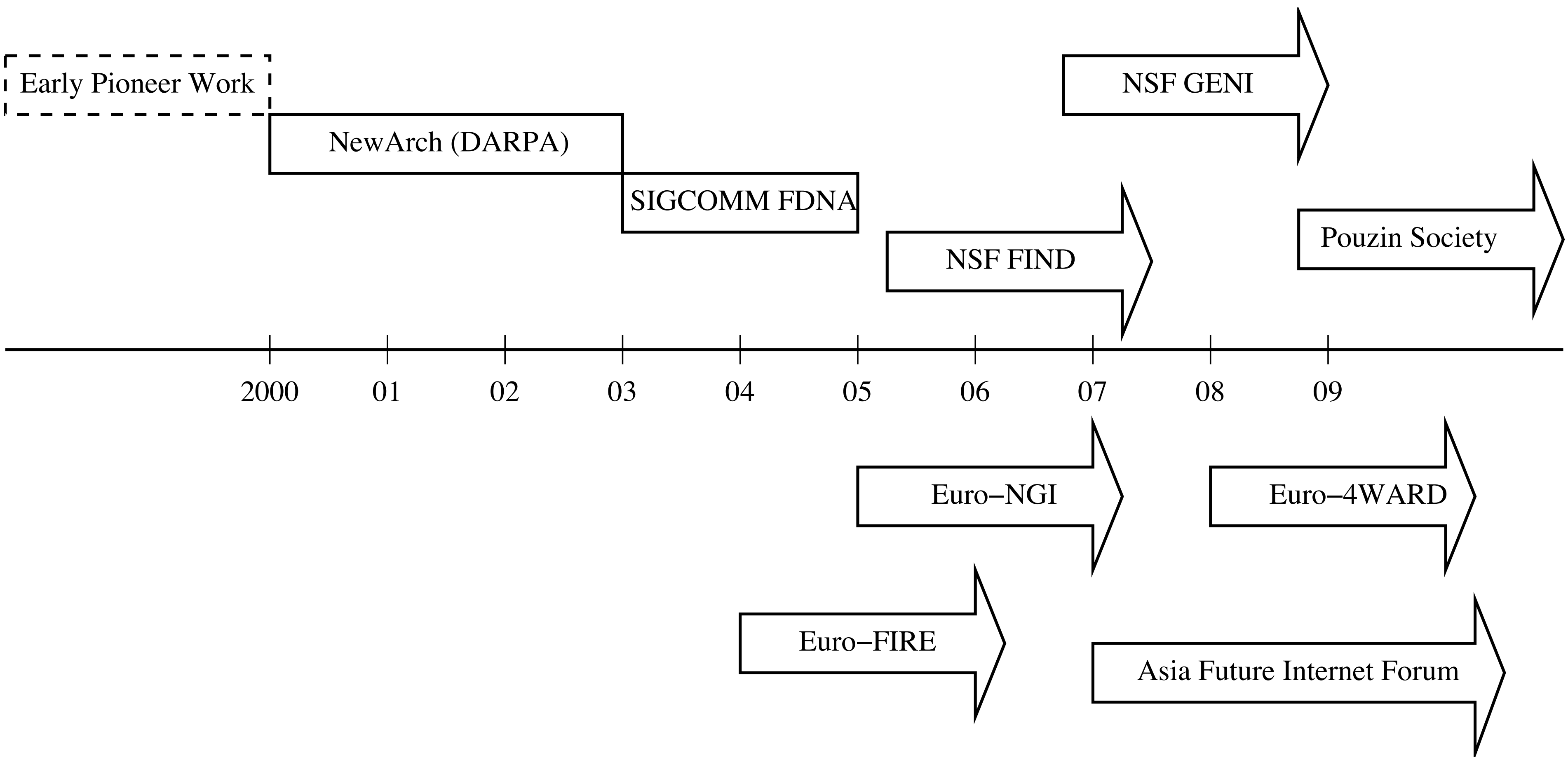

Outline

- Motivation: The Layering Conundrum
- Context: The Clean-Slate Debate
- Net SILOs: The Story So Far
- Summary and Demo

The Internet is Broken!

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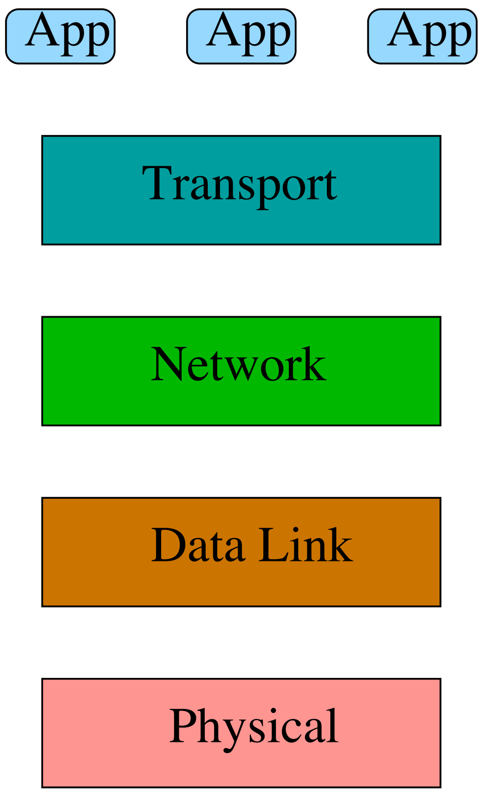
Fixed layer architecture is outdated



Challenges with Current Protocol Stack

1. Evolution: function-heavy protocols with built-in assumptions
2. Experimental implementations: require kernel modifications
3. Cross-layer design: lack of inter-layer interactions/controls

Protocol Evolution: Transport

- Several distinct functions:
  - identify application endpoints (ports)
  - e2e congestion control
  - multi-homing (SCTP)
  - reliability semantics (TCP, RDP, SCTP, etc)

  $\longrightarrow$ evolution of individual functions affects entire transport layer
- Built-in assumptions about IP addresses

  $\longrightarrow$ transition to IPv6, support for mobility difficult

Experimental Implementations

- Experimental network designs crucial for:
  - gaining insight
  - understanding protocol operation
  - discovering new knowledge firmly rooted in physical world
- Implementations on commodity HW/SW remain challenging:
  - require modification of OS kernel
  - involve significant expertise
  - limit ability to “play” with network stack

Cross-Layer Design

- Cross-layer design a major research theme over last decade:
  - wireless networks
  - TCP congestion control
  - optical networks (next slide)
  - . . .
- Adoption of ideas in operational networks quite slow:
  - no interfaces for inter-layer interactions/cross-layer controls
  - lack of experimental work
    $\longrightarrow$ reliance on simulation with invalid assumptions

Software Defined Optics

- Optical substrate can no longer be viewed as black box

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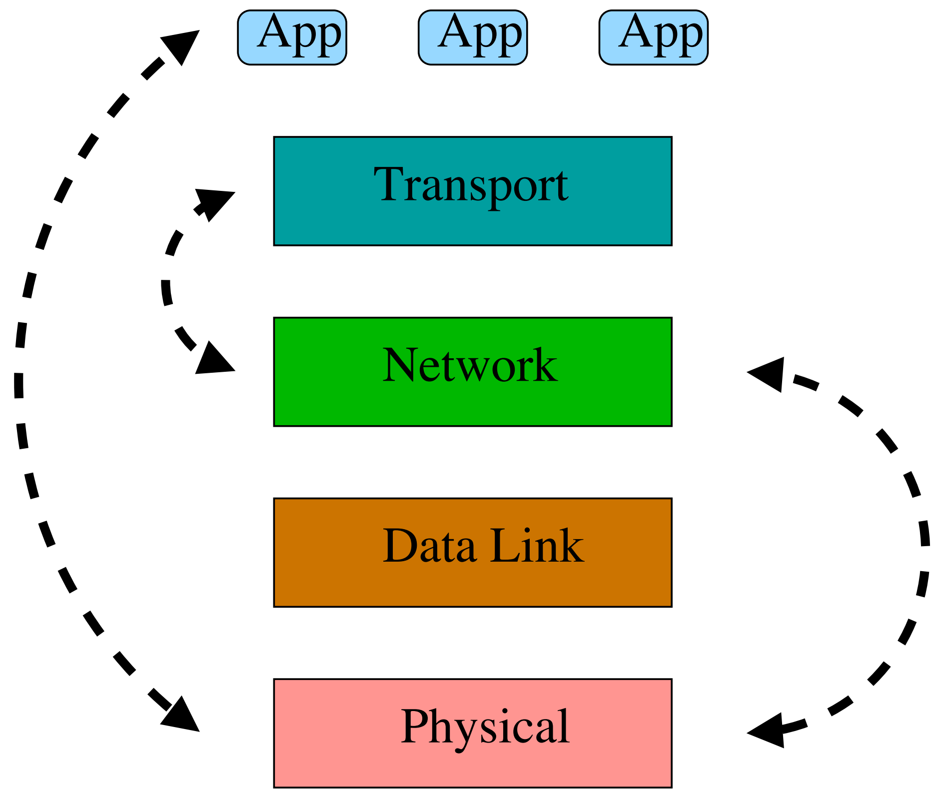
- Optical substrate can no longer be viewed as black box
- Collection of intelligent and programmable resources:
  - optical monitoring, sensing mechanisms
  - amplifiers, impairment compensation devices
  - tunable optical splitters
  - configurable add-drop
  - programmable mux-demux (e.g., adjust band size)
  - adjustable slot size
  - . . .

Cross-Layer Interactions

- Impairment-aware RWA and network design
- Placement of optical sub-systems (converters, amplifiers, regenerators)
- Traffic grooming
- Inter-layer QoS and traffic engineering
- Optical layer multicast
- Multi-layer failure localization and recovery
- . . .



The Internet is Doing Just Fine, Thank You!

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- Biological metaphor: mutation and natural selection [Dovrolis 2008]
- Evolutionary designs: more robust, less expensive
- Mid-layer protocols must be conserved – not ossified
  $\longrightarrow$ innovation at lower/upper layers of architecture

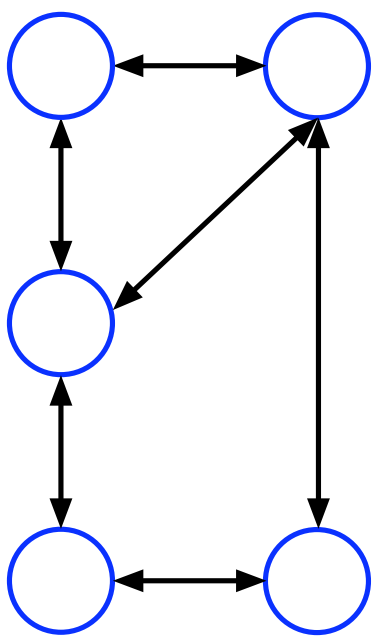
Clean-State Initiatives

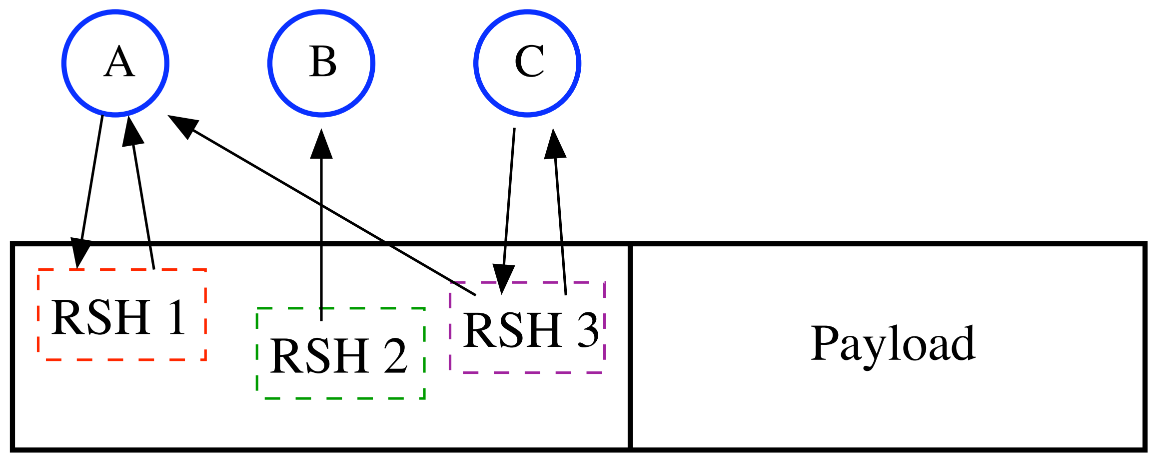
Design the Internet from scratch:

- Research in new network architectures $\longrightarrow$ FIND (US)
  - security, addressing, protocols, routing, economics, theory, $\cdots$
- large-scale experimental facilities $\longrightarrow$ GENI (US)
  - control plane, virtualization, slicing, $\cdots$

Role-Based Architecture (RBA) [BFH 2003]

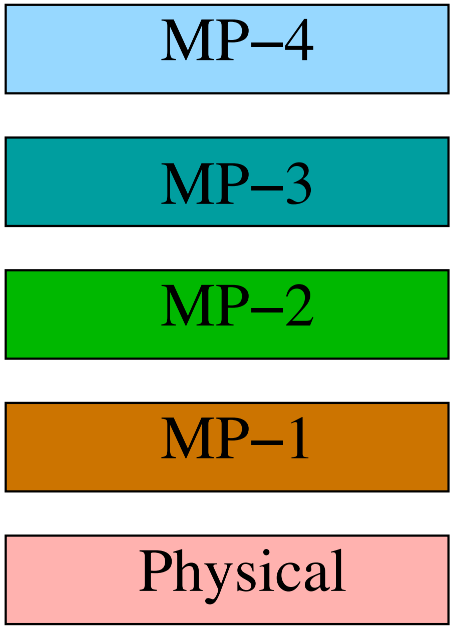
- New abstraction: organize protocols in heaps, not stacks
- Richer interactions among protocols → flexibility
- Require new system-level implementations





Recursive Network Architecture (RNA) [TP 2008]

- Meta-protocol: generic protocol layer with basic services
- Each layer in stack $\longrightarrow$ appropriately configured instantiation
- Allows reuse, cleaner cross-layer interactions, dynamic composition



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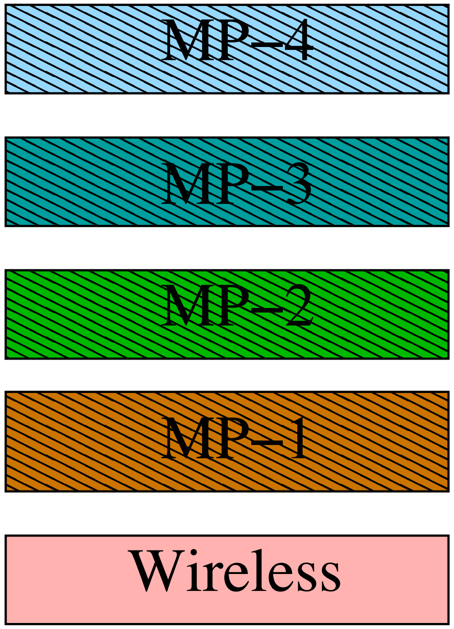

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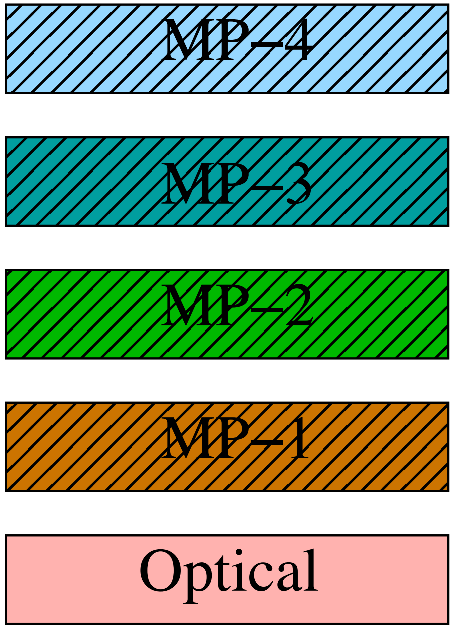

Layering As Optimization Decomposition

- Protocol layers integrated into mathematical framework [CLCD 2007] [LSS 2006]
- Global optimization problem: network utility maximization
- Decomposition into subproblems $\longrightarrow$ layering
  - optimal modules (protocols) map to different layers
  - interfaces between layers coordinate the subproblems

Layering As Optimization Decomposition

- Clean-state optimization $\longrightarrow$ layered network architecture
  - optimal layering $\neq$ TCP/IP stack
  - various representations of optimization problem $\longrightarrow$ different layered architectures
  - (loose) coupling among layers $\longrightarrow$ cross-layer considerations

Our View

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- New architecture must preserve/generalize layering
- SILO objective:

> The goal is not to design the "next" system, or the "best next" system, but rather a system that can sustain continuing change

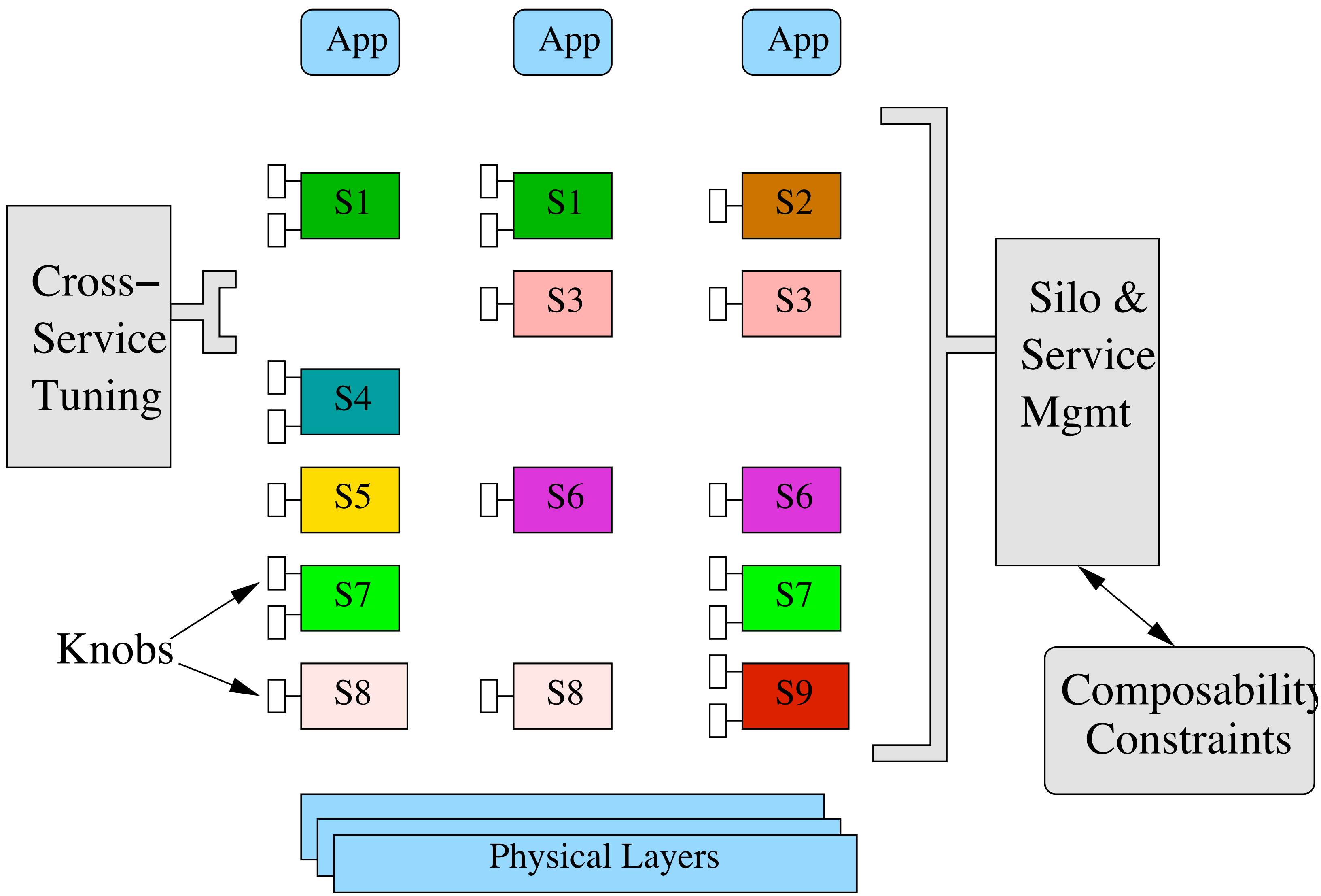
SILO Architecture Highlights

- Building Blocks: services of fine-grain functionality
- Design Principles:
  1. Generalize traditional layer stack
  2. Enable inter-layer interactions:
     - knobs: explicit control interfaces
  3. Design for change:
     - facilitate introduction of new services
  4. Separate control from data functions

Generalization of Layering

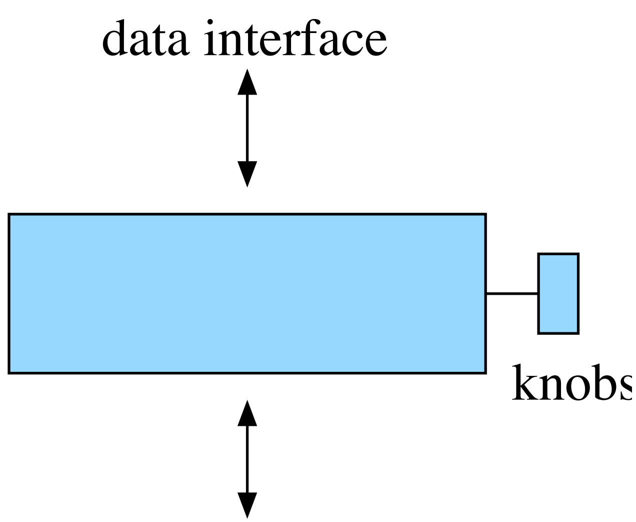
- Silo: vertical composition of services
  $\longrightarrow$ preserves layering principle
- Per-flow instantiation of silos
  $\longrightarrow$ introduces flexibility and customization
- Decoupling of layers and services
  $\longrightarrow$ services introduced at point in stack where necessary

Silos: Generalized Protocol Stacks



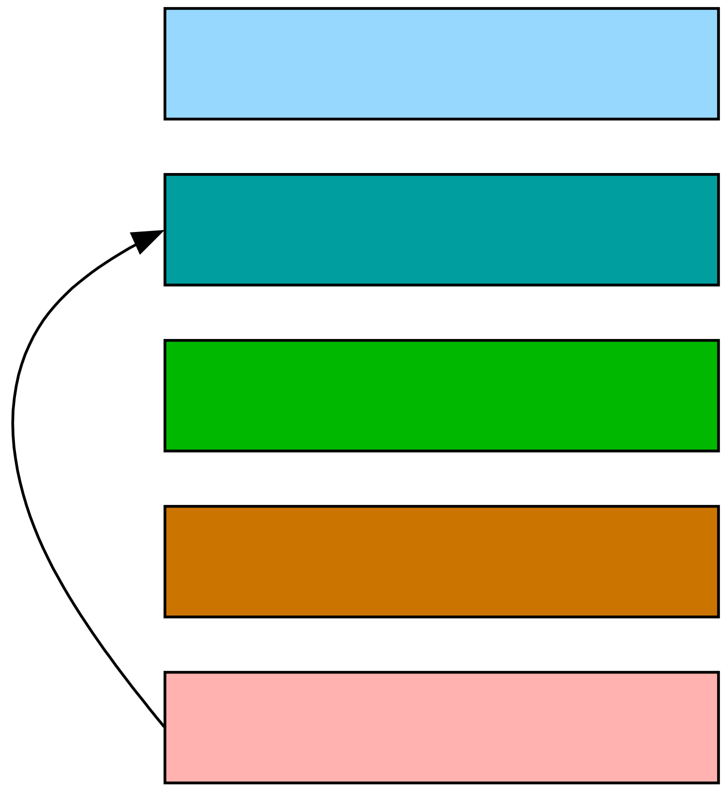
Inter-Layer Interactions (1)

- Knobs: explicit control interfaces
  - adjustable parameters specific to functionality of service
  - enable info exchange among services
- Algorithms may optimize jointly the behavior of services in a silo



Inter-Layer Interactions (2)

Upward information passing



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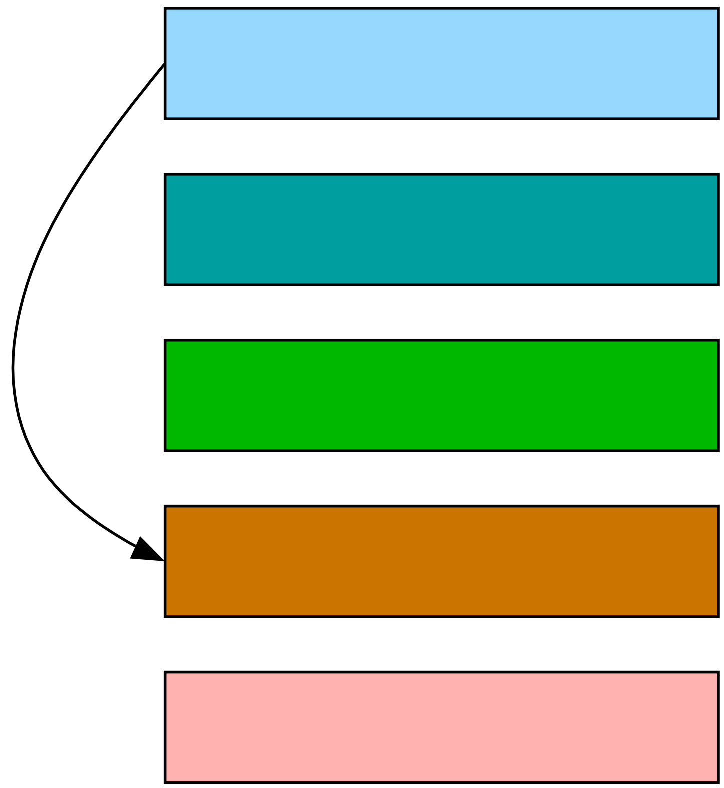
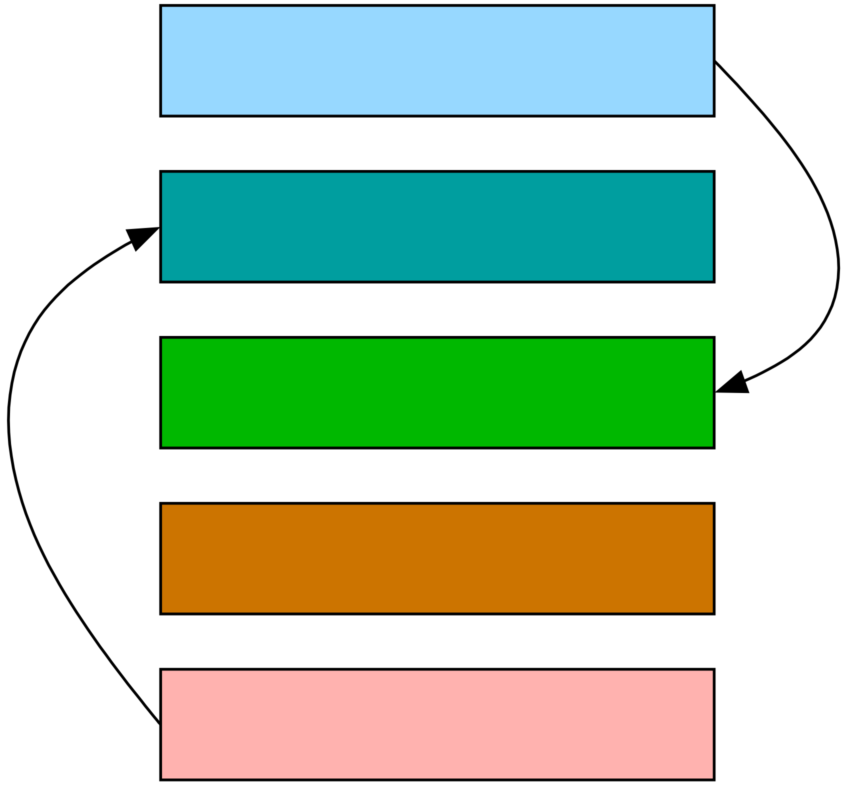
Downward information passing



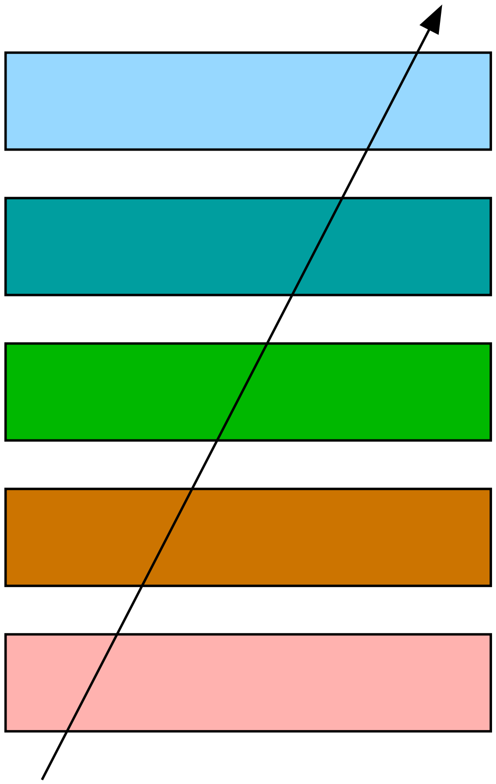
Inter-Layer Interactions (2)

Up-and-down information passing



Inter-Layer Interactions (2)

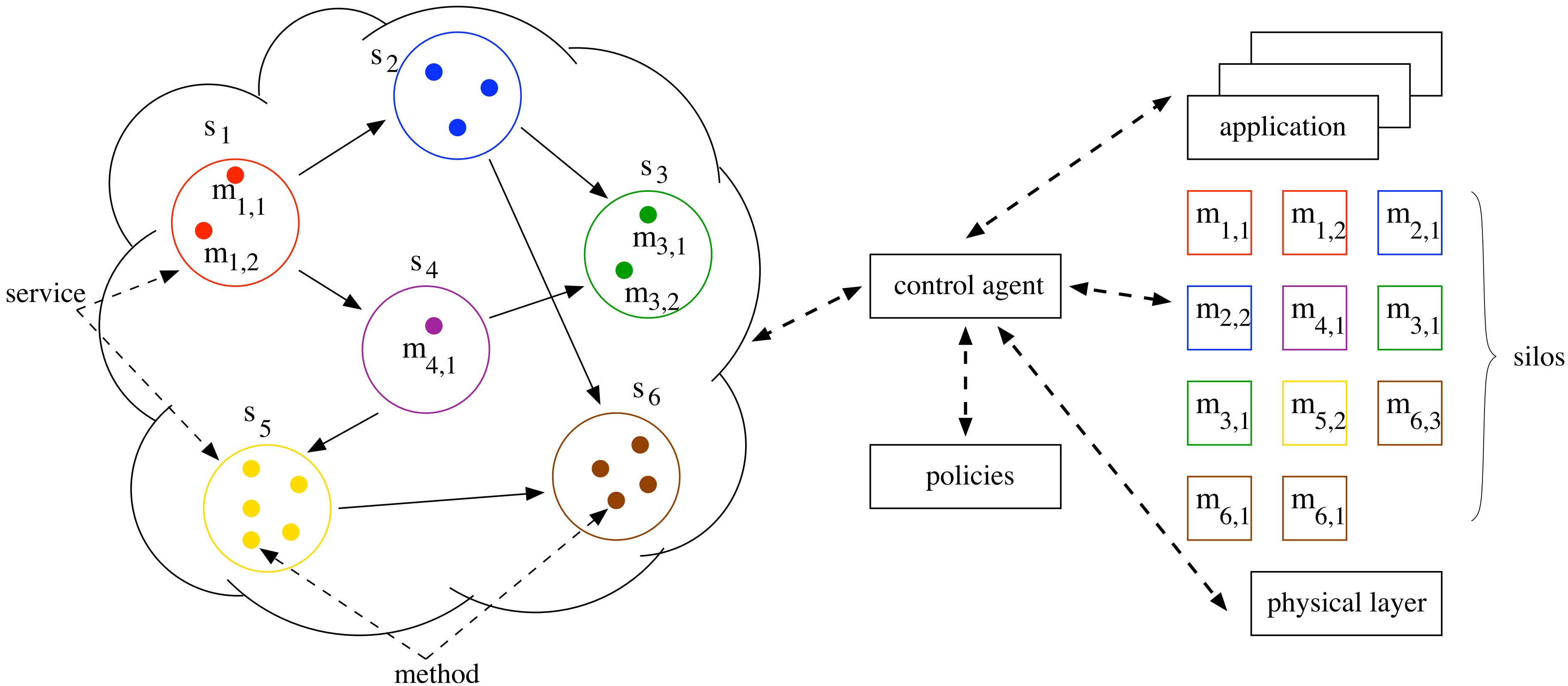
Silo-wide optimization/calibration



Design for Change

- Architecture does not dictate services to be implemented
- Provide mechanisms for:
  - introduce new services
  - compose services into silos
- Ontology of services: describes
  - service semantics $\longrightarrow$ function, data/control interfaces
  - relationship among services $\longrightarrow$ relative ordering constraints

Ontology – Networking Knowledge

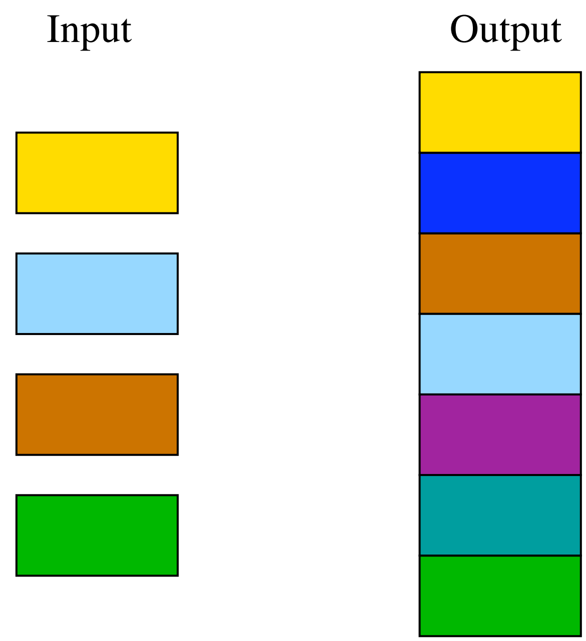


Service Composition

- Constraints on composing services A and B:
  - A requires B
  - A forbids B
  - A must be above (below) B
  - A must be immediately above (below) B
  - Negations, AND, OR
- Minimal set:
  - Requires, Above, ImmAbove, NotImmAbove
- All pairwise condition sets realizable
  - Forbids = (A above B) AND (B above A)
  - Above = NOT Below

Service Composition Problem

- Given: a set of essential services $\leftarrow$ application
- Obtain a valid ordering of these and additional services
  - or, identify conflicts with constraints
- Simple composition algorithm implemented
- Ongoing research in formalizing the problem



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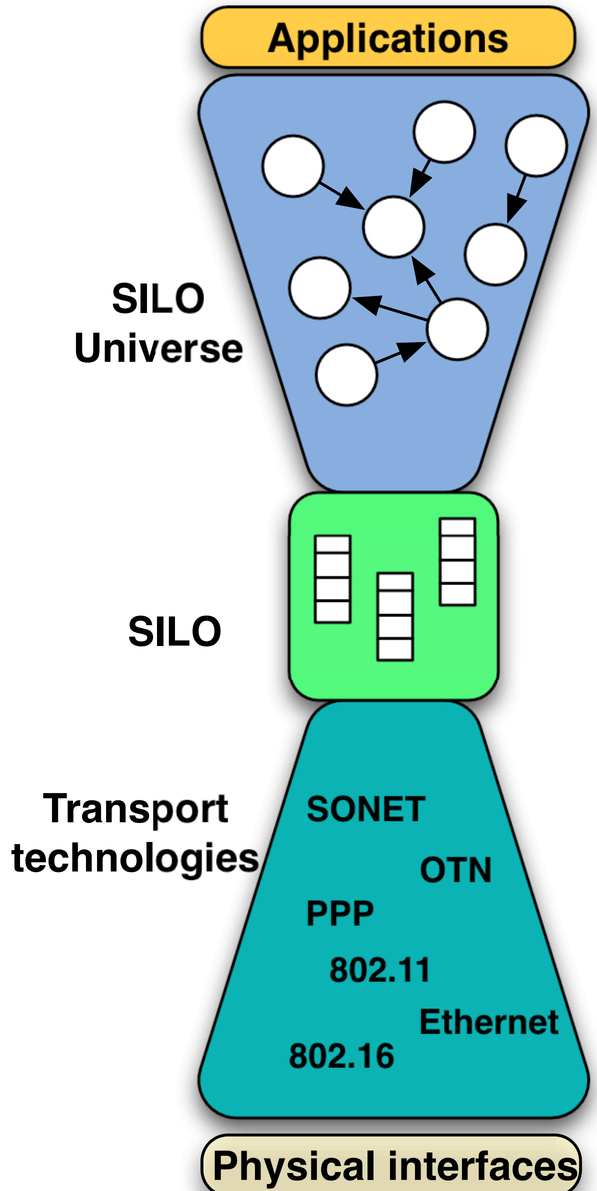
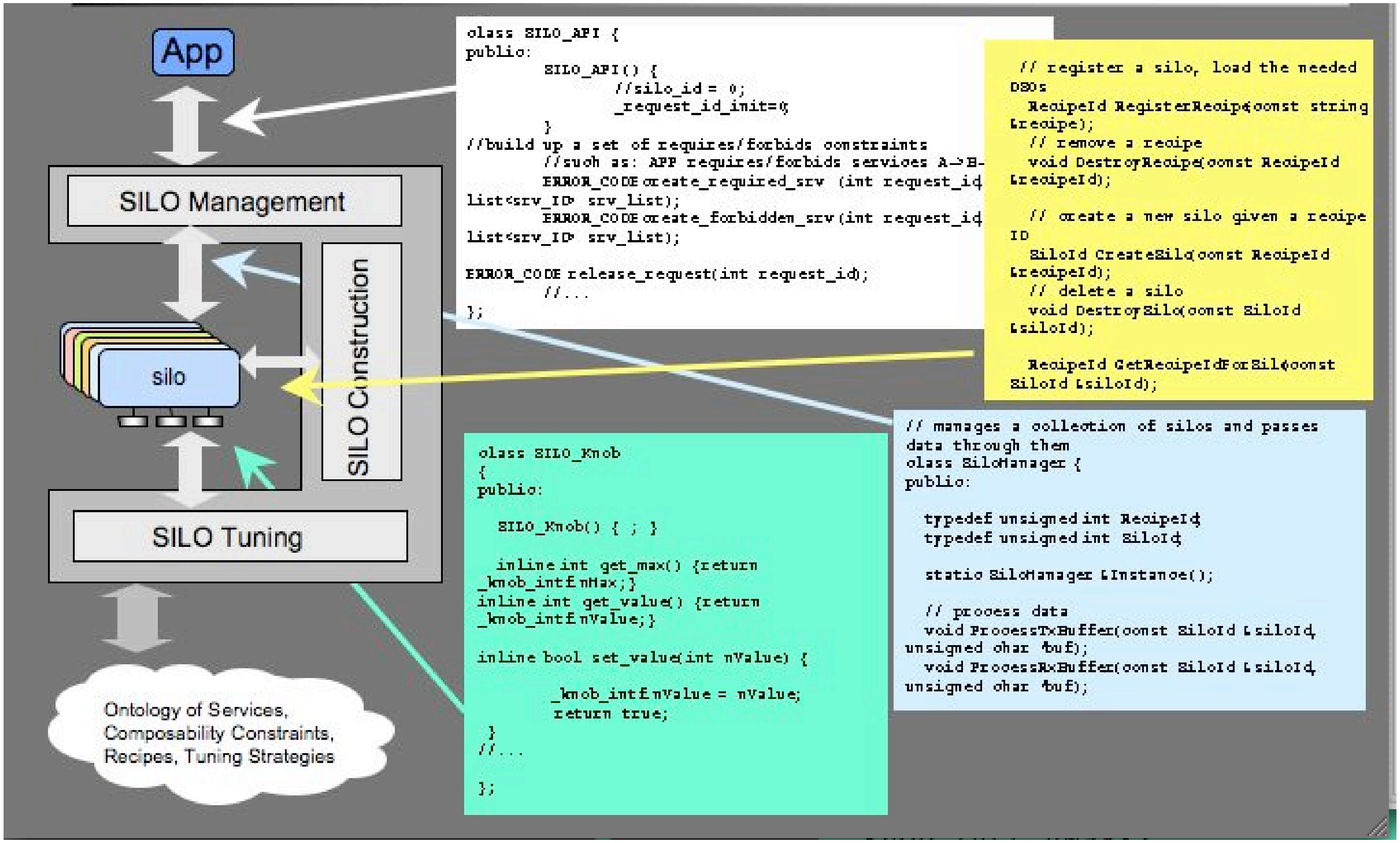


SILO Software Prototype



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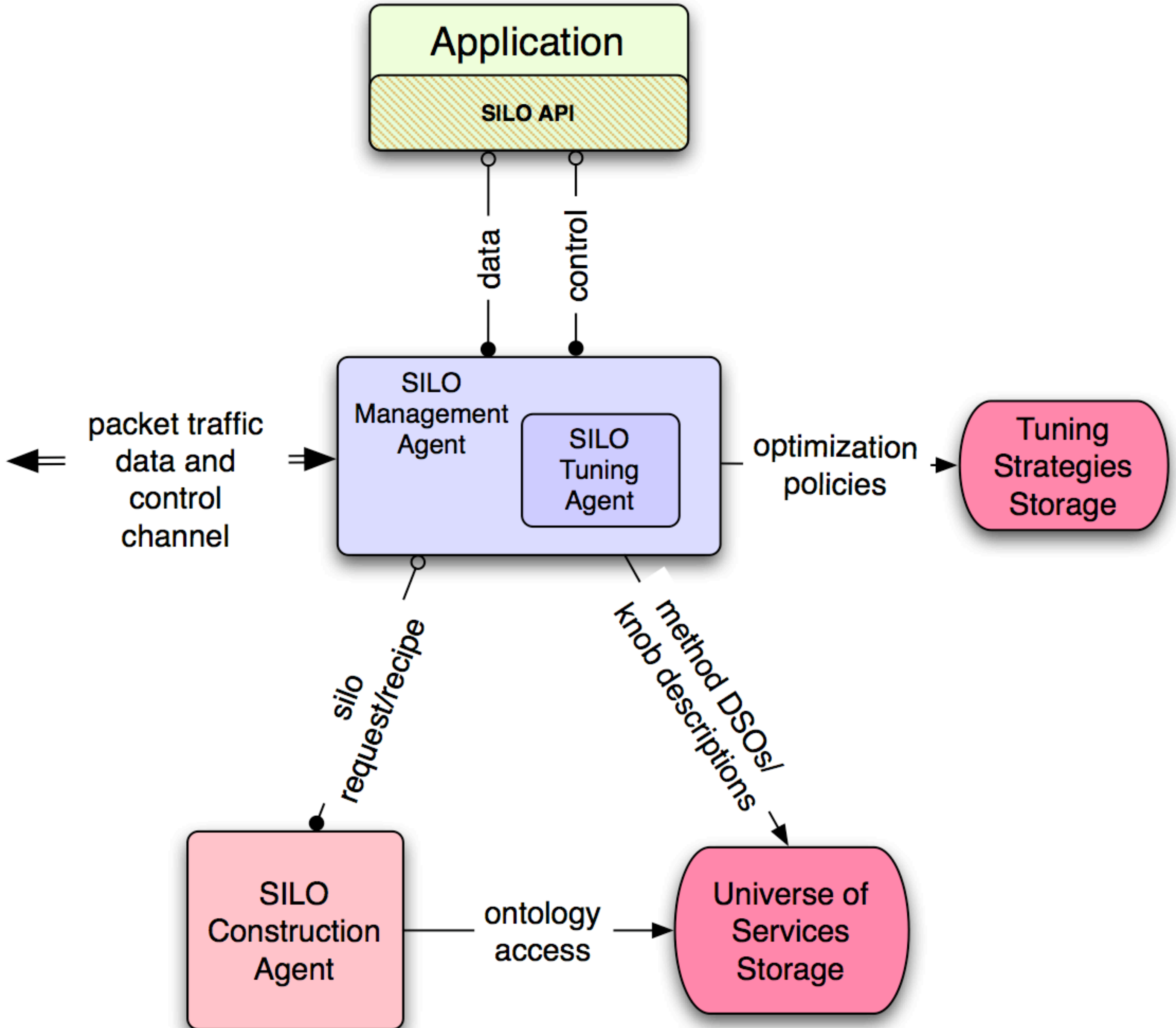
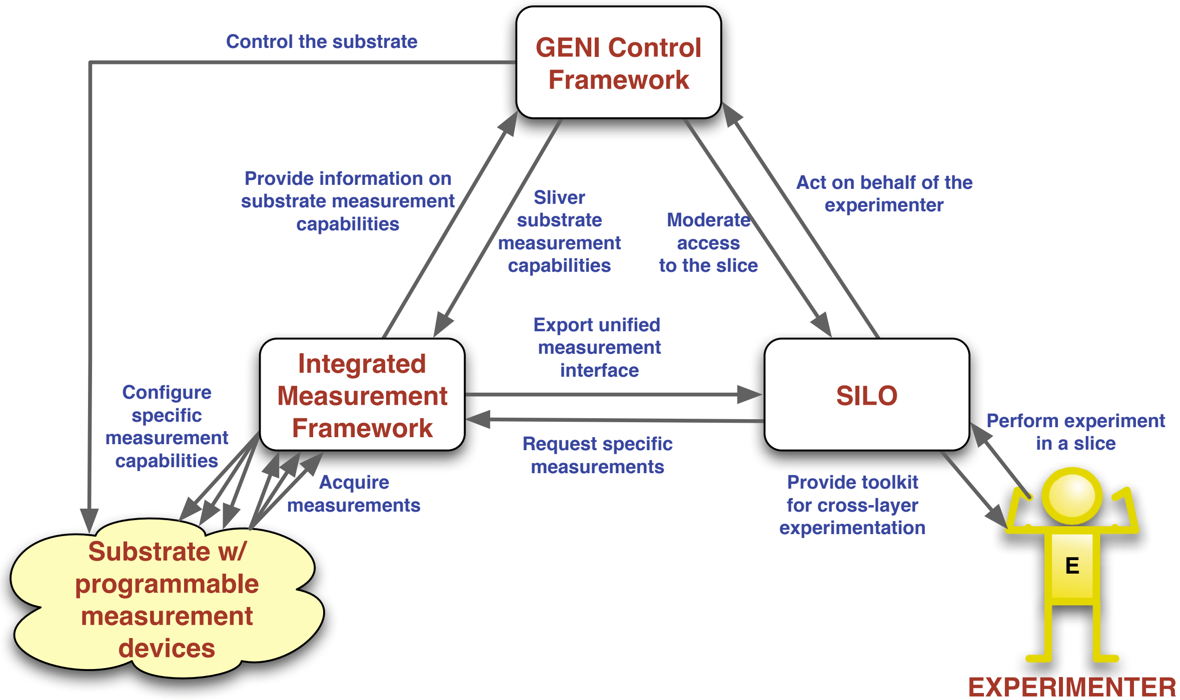
Prototype Architecture



SILO As a Research Tool

- Deploys in a slice
- Researcher brings:
  - custom services
  - tuning algorithms
  - ontology updates
- Connect to measurement framework → cross-layer protocol experimentation tool



Summary

- Vision – enable flexibility, evolution: “design for change”
  - fine-grain, reusable services, explicit control interface
    - enables experimentation, flexibility, community of innovation
  - per-flow service composition (silos)
    - ease of evolution, policies
- Framework – provide architectural support to vision:
  - constrained composition
  - commoditize cross-layer interaction / optimization

Ongoing Efforts

- New research directions
  - silos in the core
  - software defined optics
  - virtualization and slicing
- Extend the prototype
  - portfolio of reusable services
  - optical testbed deployment $\longrightarrow$ breakable experimental net (BEN)
- Explore synergies with other (FIND) projects