Architectural Support for Internet Evolution and Innovation

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http://net-silos.net/

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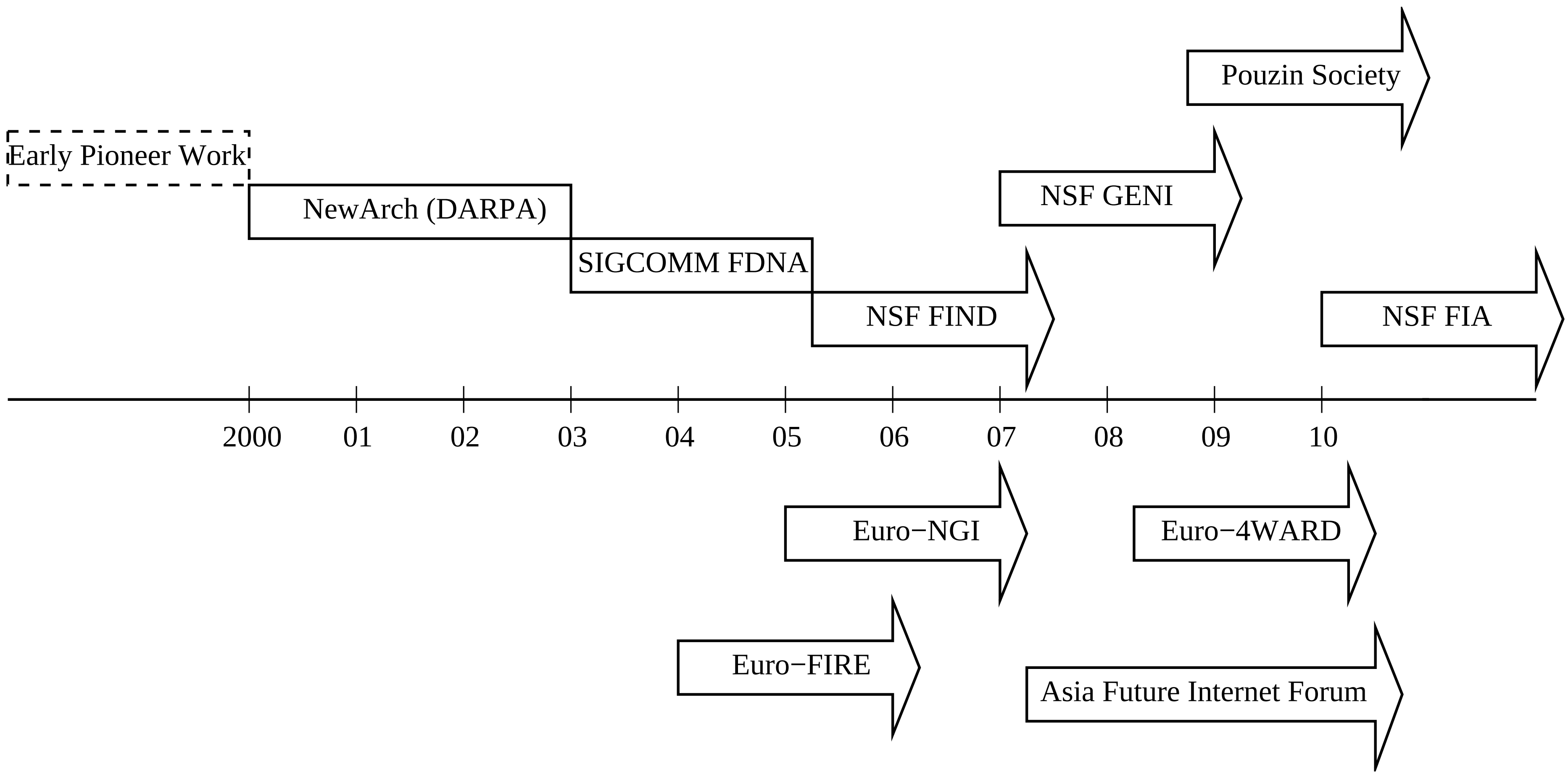
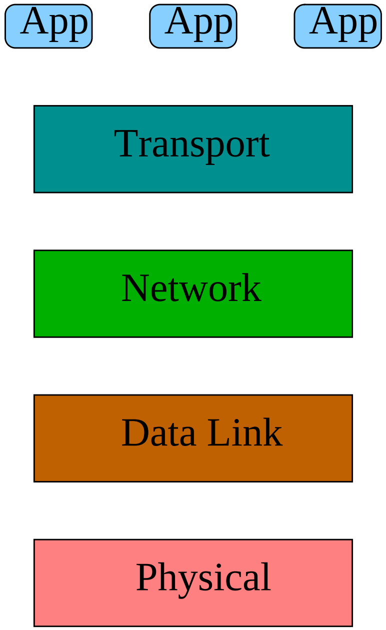
Outline

- Motivation: Challenges with Internet Architecture
- SILO: A Meta-Design Framework
- SILO as Research Tool: Cross-Layer Experimentation
- Summary and Demo

In Search of Next Generation Internet



Challenges with Current Architecture



1. Evolution: function-heavy protocols with built-in assumptions
2. High barrier to entry: for new data transfer protocols
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
- Lack of clear separation between policies and mechanisms
  - window-based flow control vs. how window size may change

  $\longrightarrow$ prevents reuse of various components
- Built-in assumptions about IP addresses

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

High Barrier to Entry

- New data transfer protocols difficult to implement/deploy
  - except for user-space
- Experimental network designs crucial for:
  - gaining insight
  - understanding protocol operation
  - discovering new knowledge 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

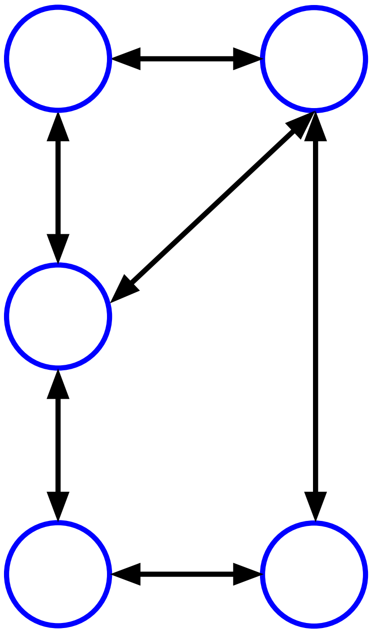
- Cross-layer design a major research theme over last decade:
  - wireless networks
  - TCP congestion control
  - optical networks (later)
  - . . .
- Adoption of ideas in operational networks quite slow:
  - no interfaces for inter-layer interactions/cross-layer controls
  - lack of experimental work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

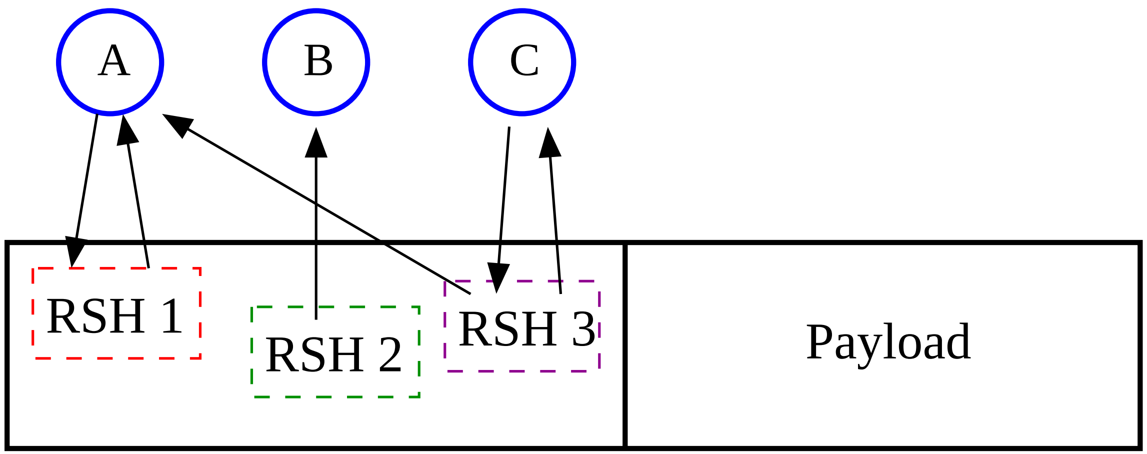
Accommodating New Functionality

- Deploy half-layer solutions (MPLS, IPSec)
  $\longrightarrow$ layers become markers for vague functional boundaries
- Adapt existing implementation to new situations
  $\longrightarrow$ TCP over wireless/large bw/delay product networks
- Implement own UDP-like data transfer
  $\longrightarrow$ no reuse or kernel optimizations
- Abandon the old: new implementations for sensor networks
  $\longrightarrow$ Internet balkanization

Role-Based Architecture (RBA) [BFH 2003]

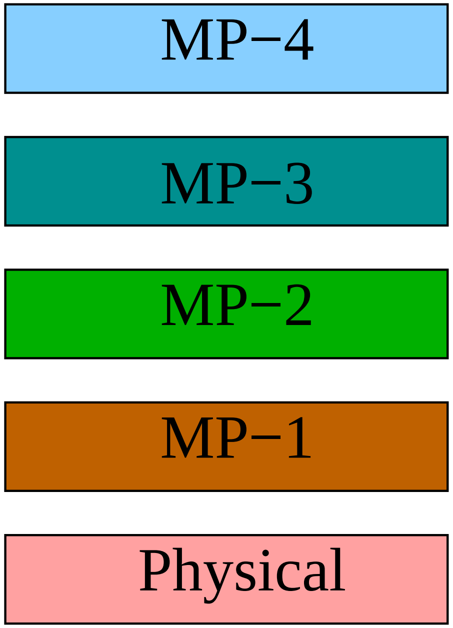
- New abstraction: organize protocols in heaps, not stacks
- Richer interactions among protocols → flexibility
- Require new system-level implementations





Recursive Network Architecture (RNA) [TP 2008]

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



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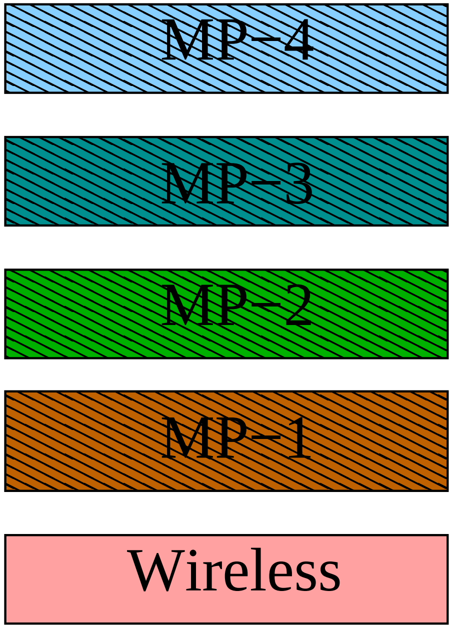

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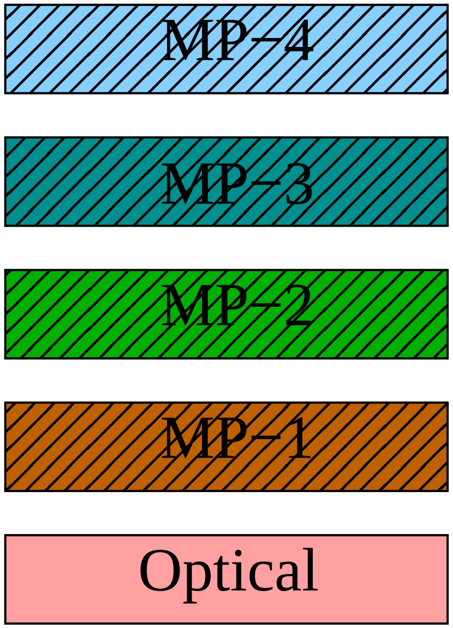
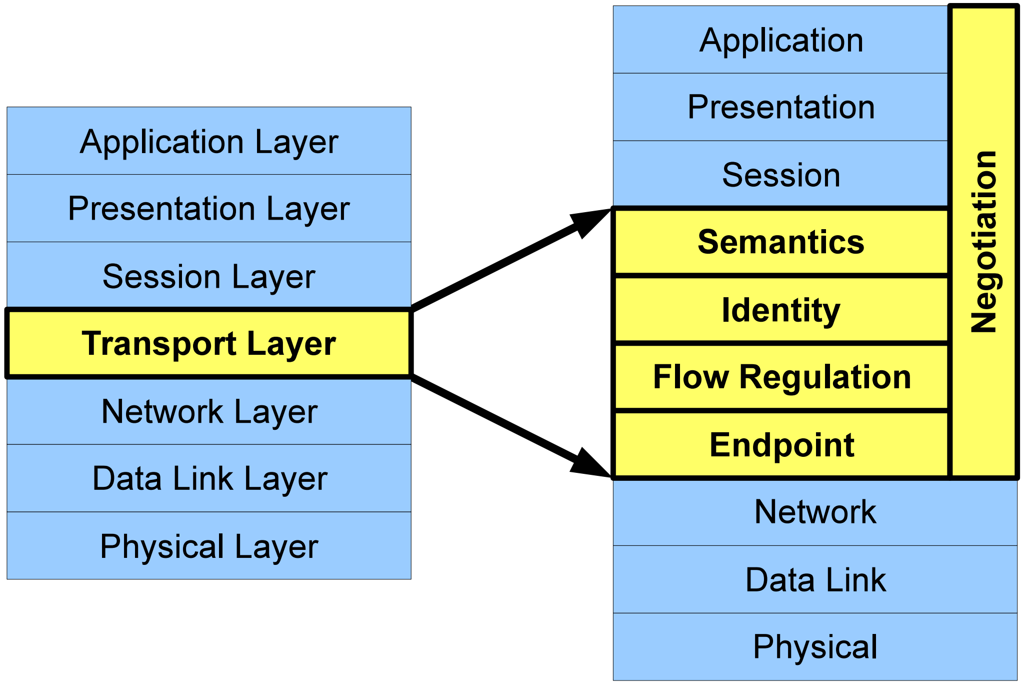


Tng – Transport Next-Generation [FI2009]

- Decomposes function-heavy transport layer
  - "true" e2e functions ⟶ reliable packet transport
  - "middlebox" functions ⟶ endpoint naming, congestion control
- Negotiation plane ⟶ cross-layer interactions



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

- Internet architecture houses an effective design
- But: it is not itself effective in enabling evolution
- New architecture must be designed for adaptability/evolvability
- New architecture must preserve/generalize layering
- SILO objective: design for change

What is Architecture?

- Fundamental elements/principles vs. design decisions

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- Fundamental elements/principles vs. design decisions
- Diverse points of view → FIND projects target: addressing, naming, routing, protocol architecture, security, management, economics, communication technologies (wireless, optical), $\cdots$
- Our definition:

> it is precisely the characteristics of the system that does not change itself, but provides a framework within which the system design can change and evolve

Meta-Design Framework

- Obtain a meta-design that explicitly allows for future change
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The goal is not to design the “next” system, or the “best next” system, but rather a system that can sustain continuing change

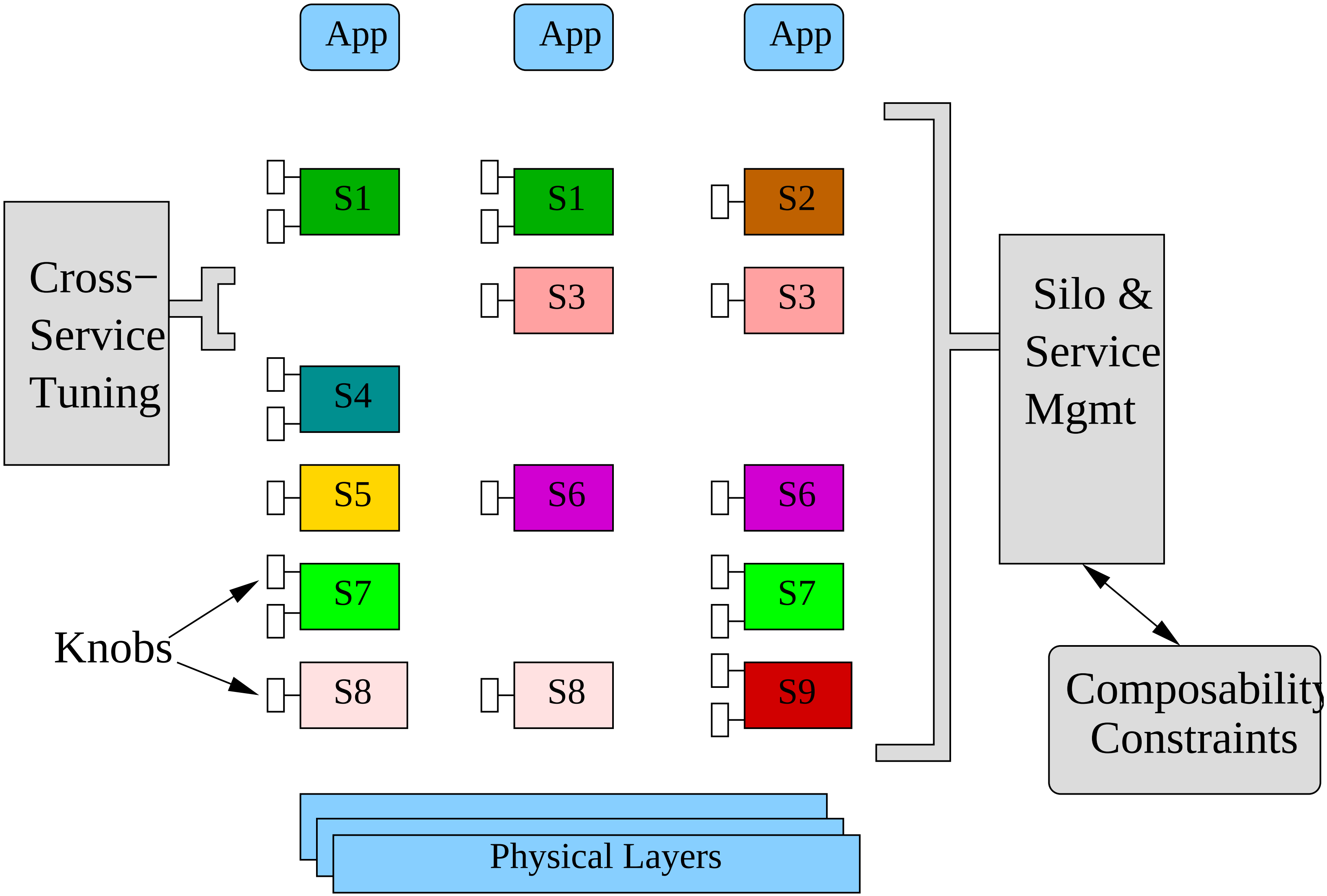
SILO Architecture Highlights

- 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

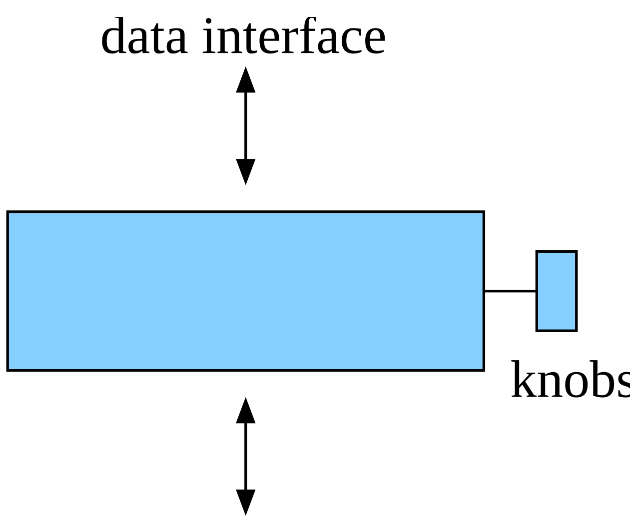
- Silo: vertical composition of services
  → preserves layering principle
- Per-flow instantiation of silos
  → introduces flexibility and customization
- Decoupling of layers and services
  → services introduced at point in stack where necessary

Silos: Generalized Protocol Stacks



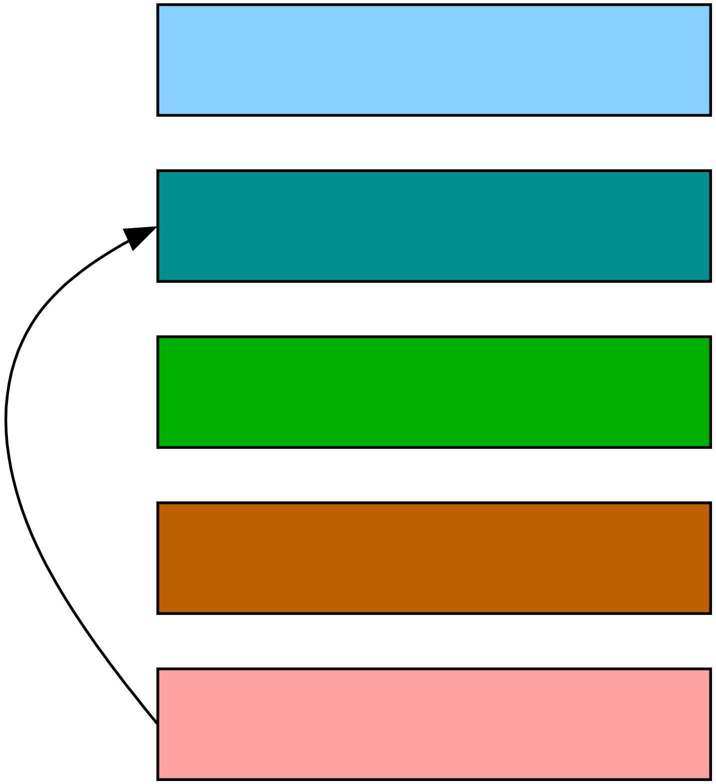
Inter-Layer Interactions (1)

- 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



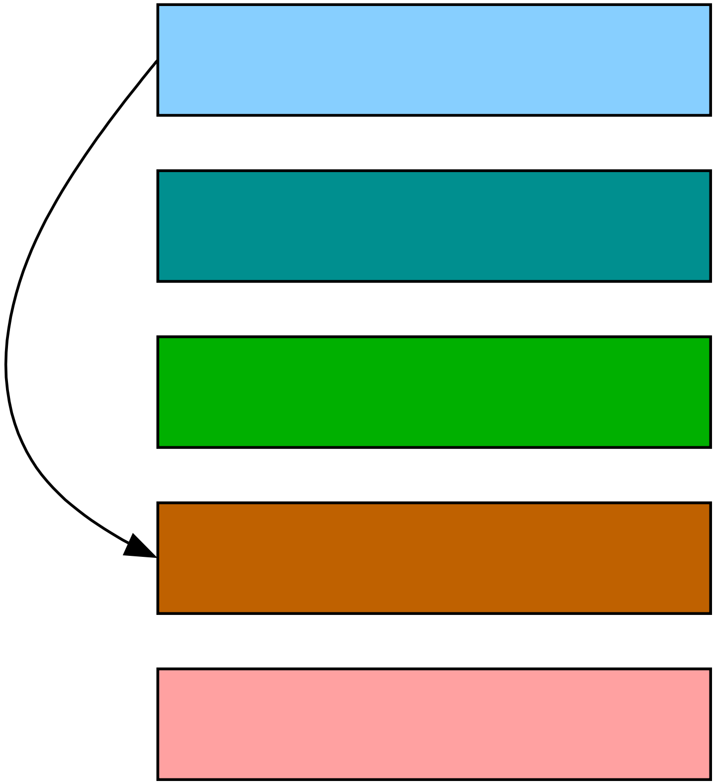
Inter-Layer Interactions (2)

Upward information passing



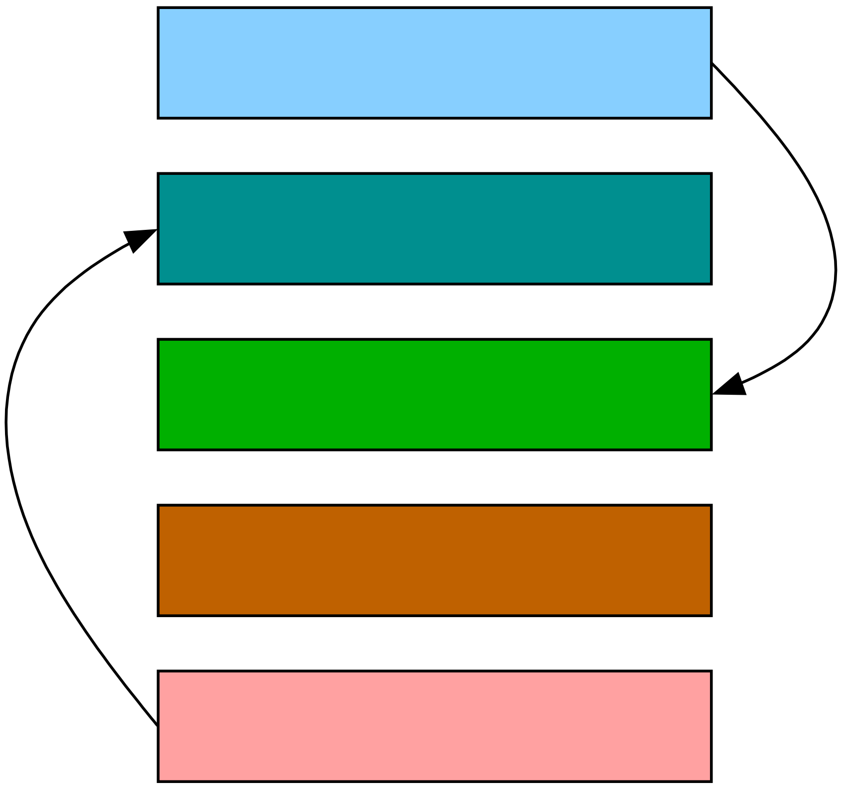
Inter-Layer Interactions (2)

Downward information passing



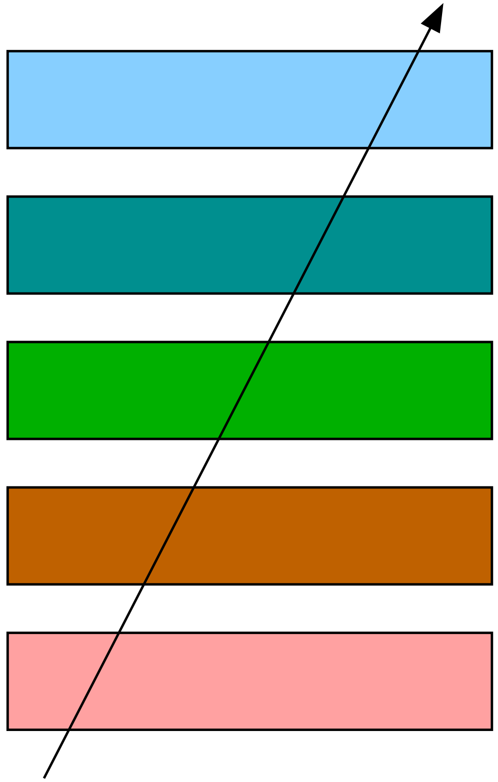
Inter-Layer Interactions (2)

Up-and-down information passing



Inter-Layer Interactions (2)

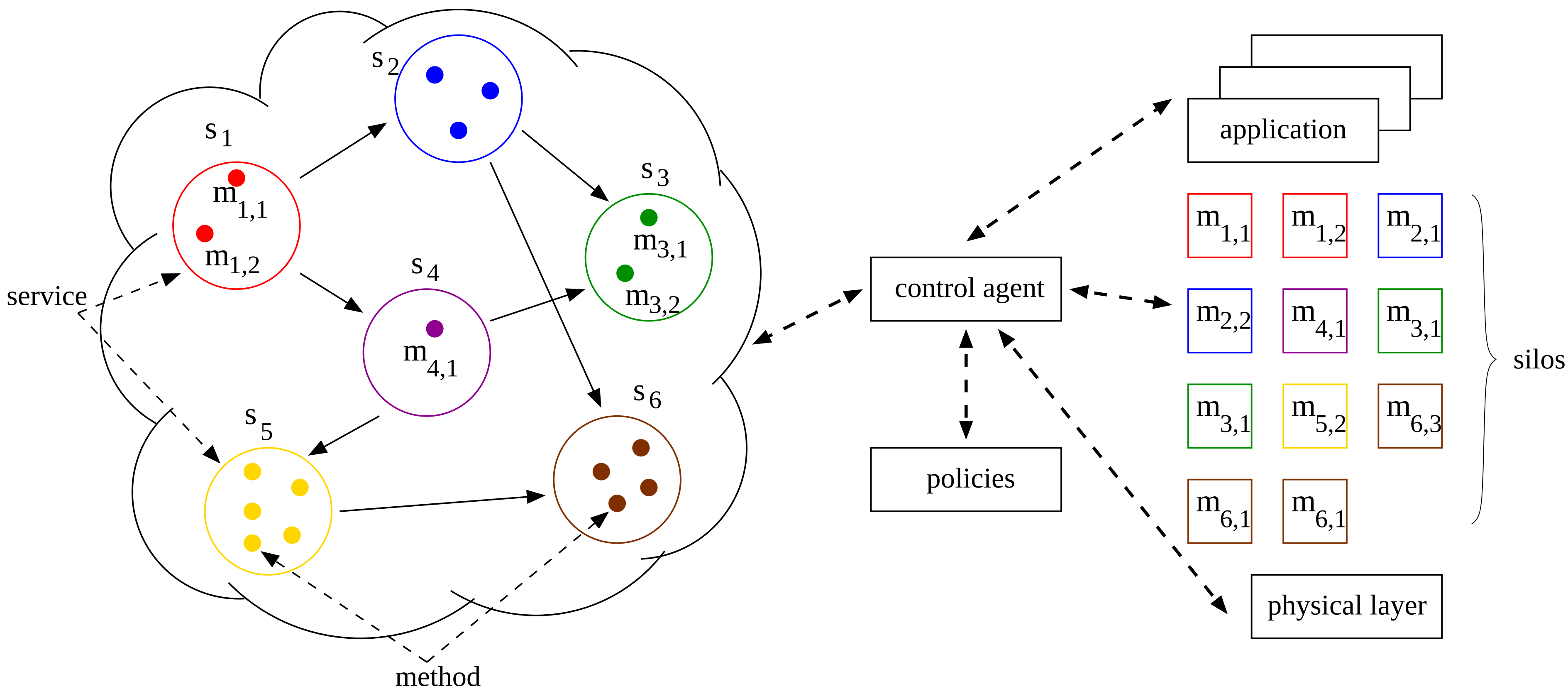
Silo-wide optimization/calibration



Design for Change

- Architecture does not dictate services to be implemented
- Provide mechanisms to:
  - 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

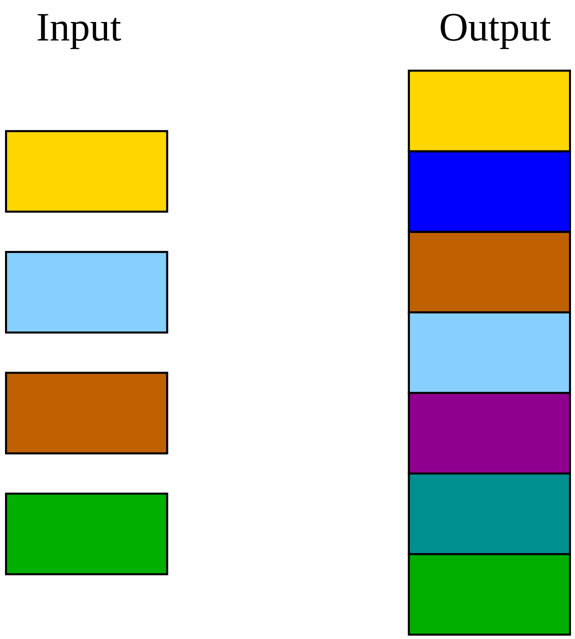


Service Composition

- 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 ⟵ 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



The SILO Hourglass

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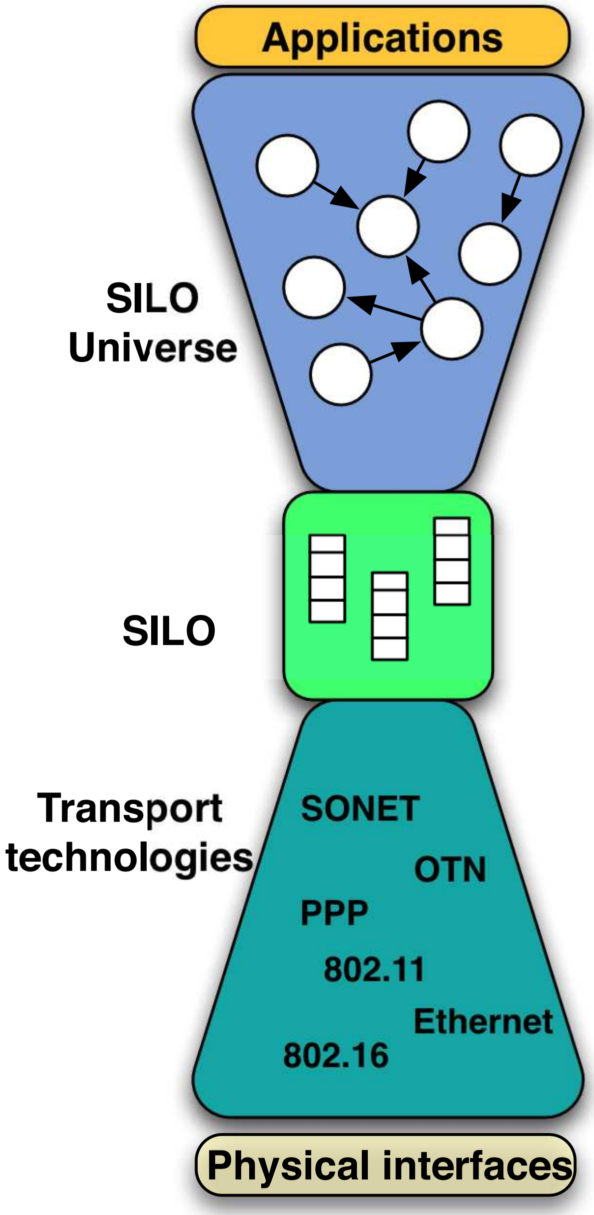
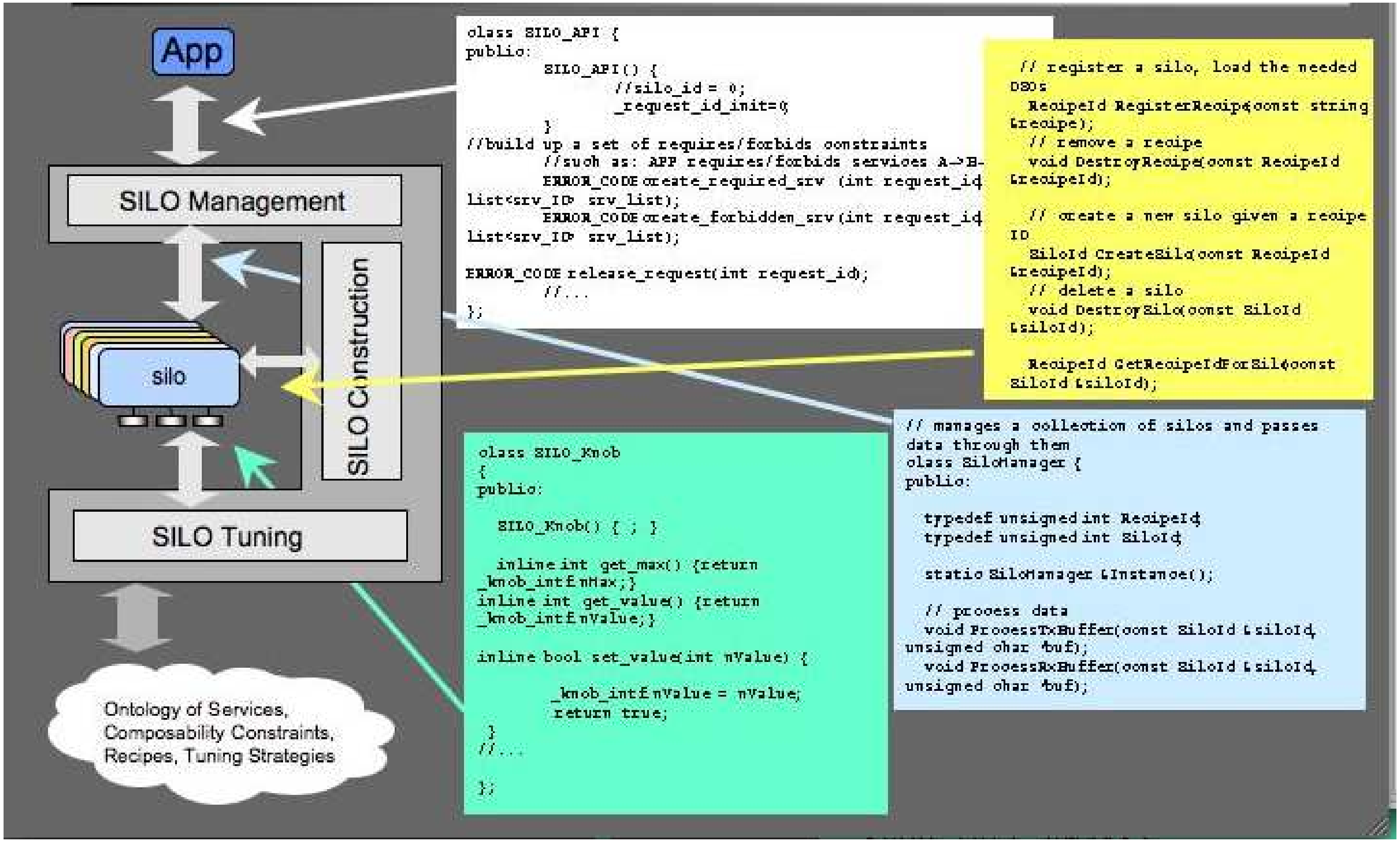


SILO Software Prototype



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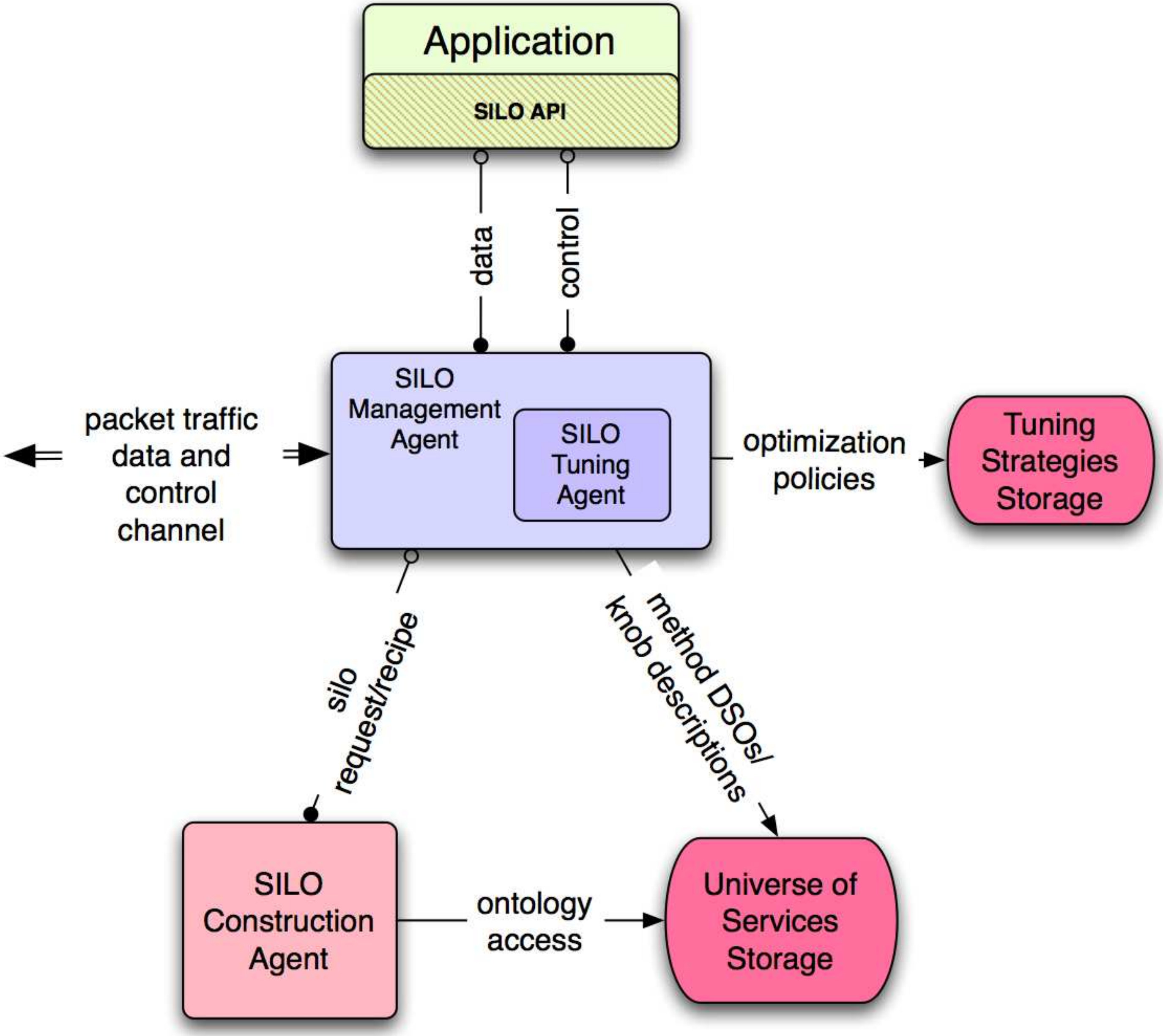
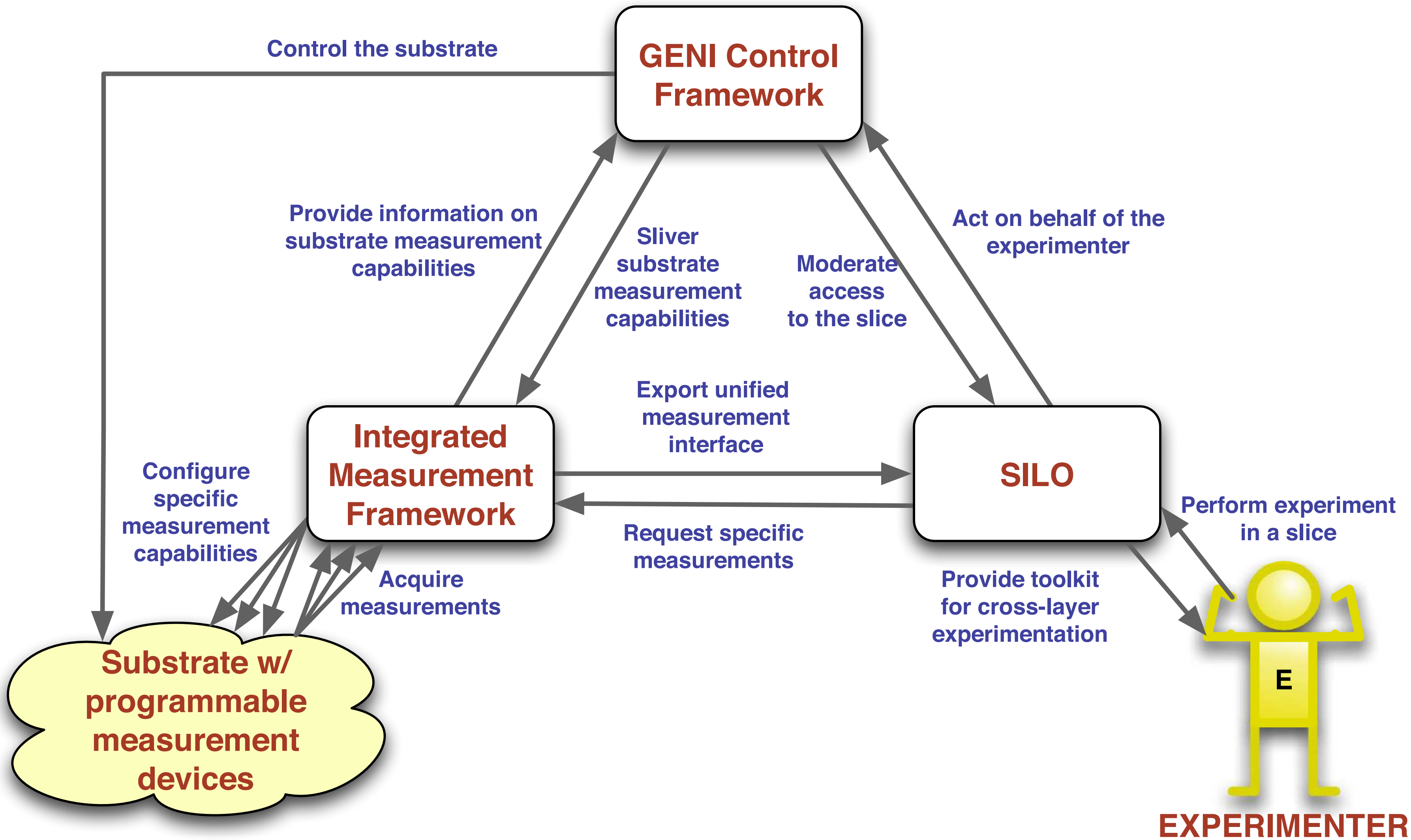
Prototype Architecture



SILO As a Research Tool



SILO As a Research Tool

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

Software Defined Optics

- Optical substrate can no longer be viewed as black box

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- Collection of intelligent and programmable resources:

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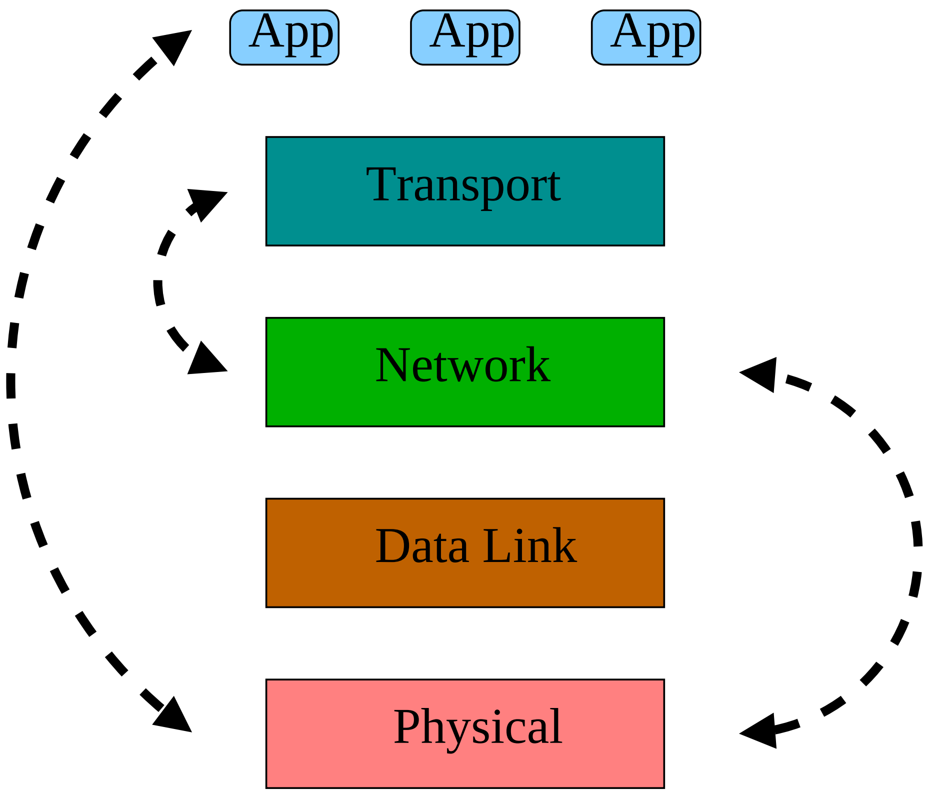
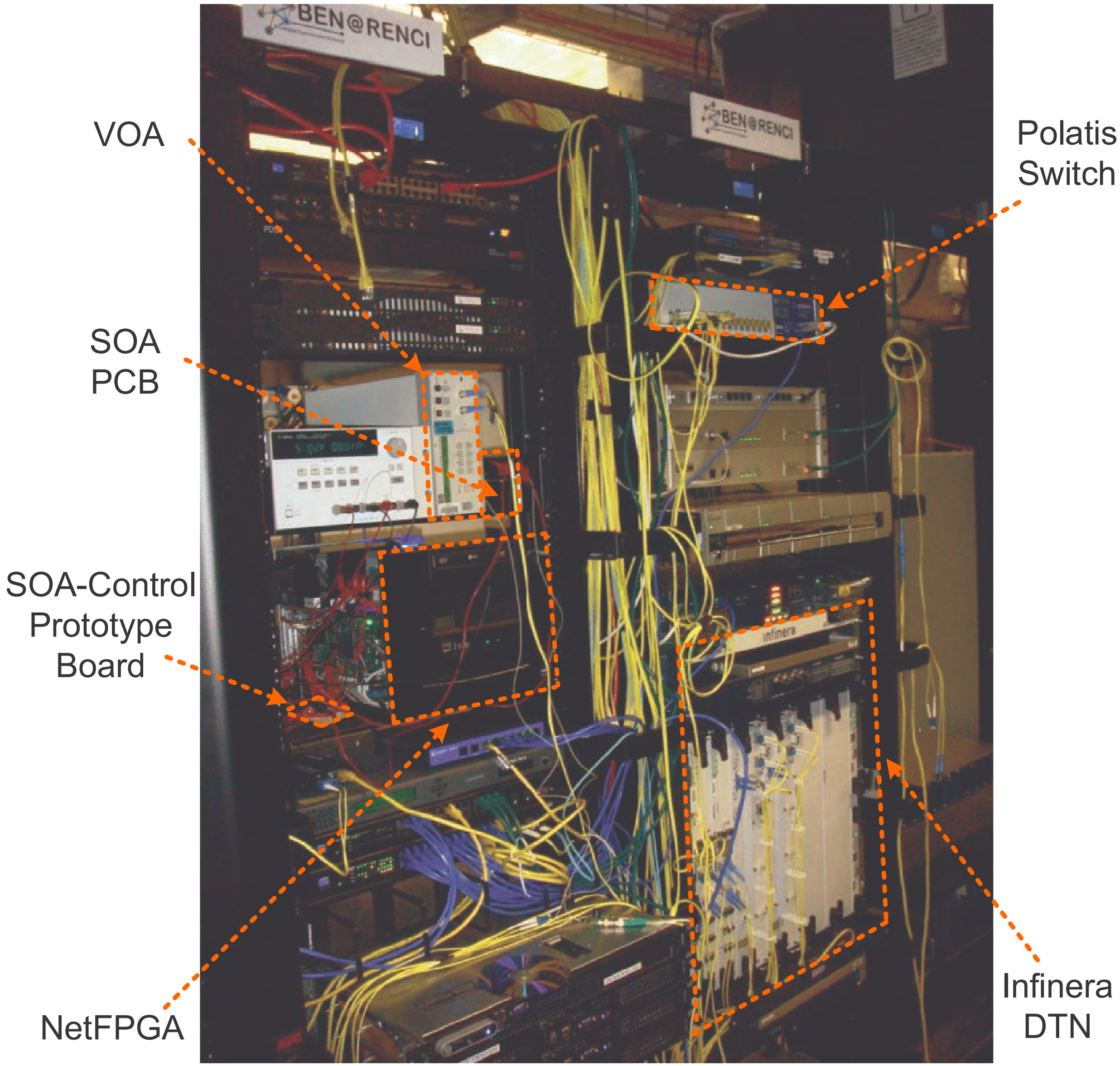
- Optical substrate can no longer be viewed as black box
- Collection of intelligent and programmable resources:
  - optical monitoring, sensing mechanisms
  - amplifiers, impairment compensation devices
  - tunable optical splitters
  - configurable add-drop
  - programmable mux-demux (e.g., adjust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

Cross-Layer Interactions

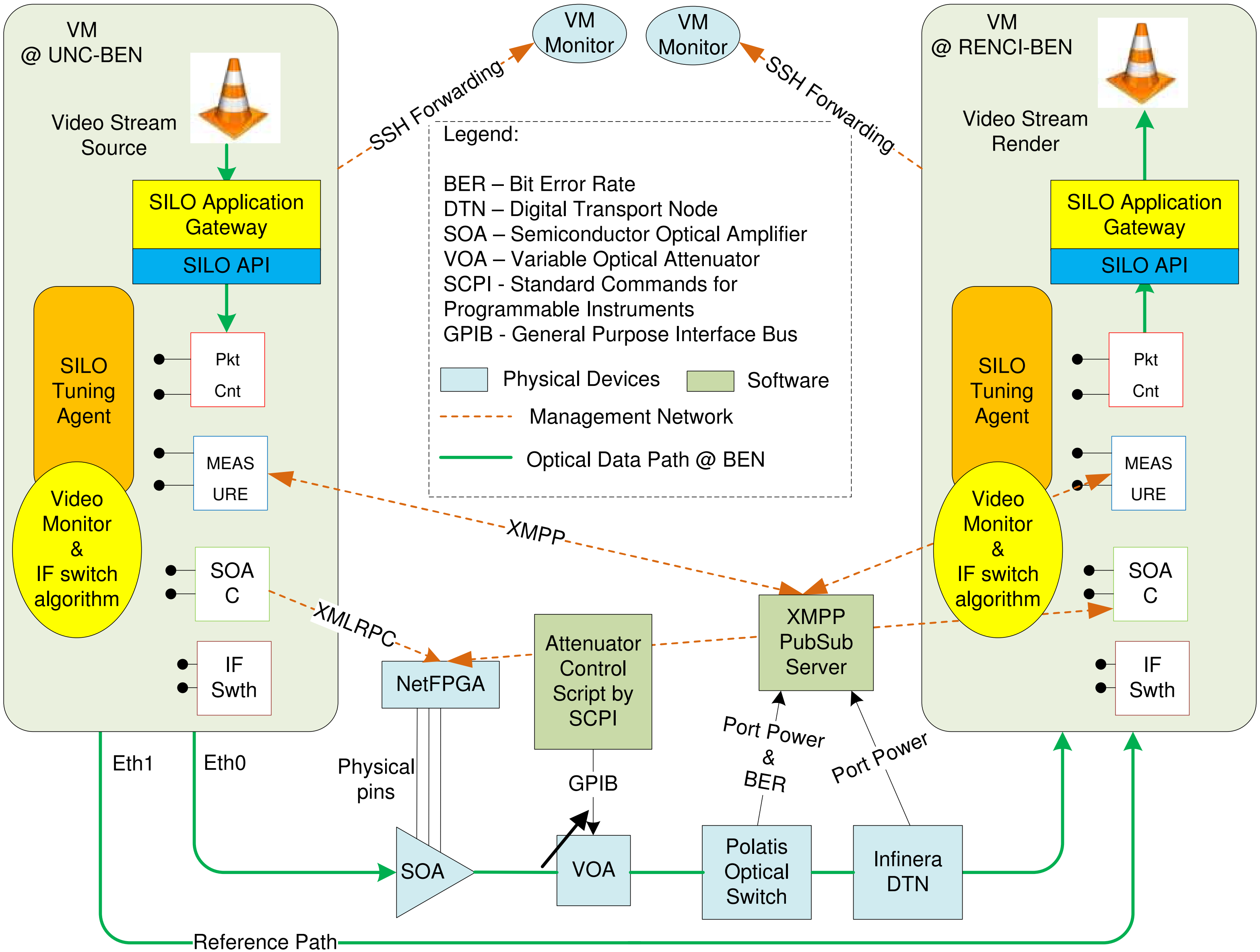
- Impairment-aware RWA and network design
- Placement of optical sub-systems (converters, amplifiers, regenerators)
- Traffic grooming
- Inter-layer QoS and traffic engineering
- Optical layer multicast
- Multi-layer failure localization and recovery
- . . .



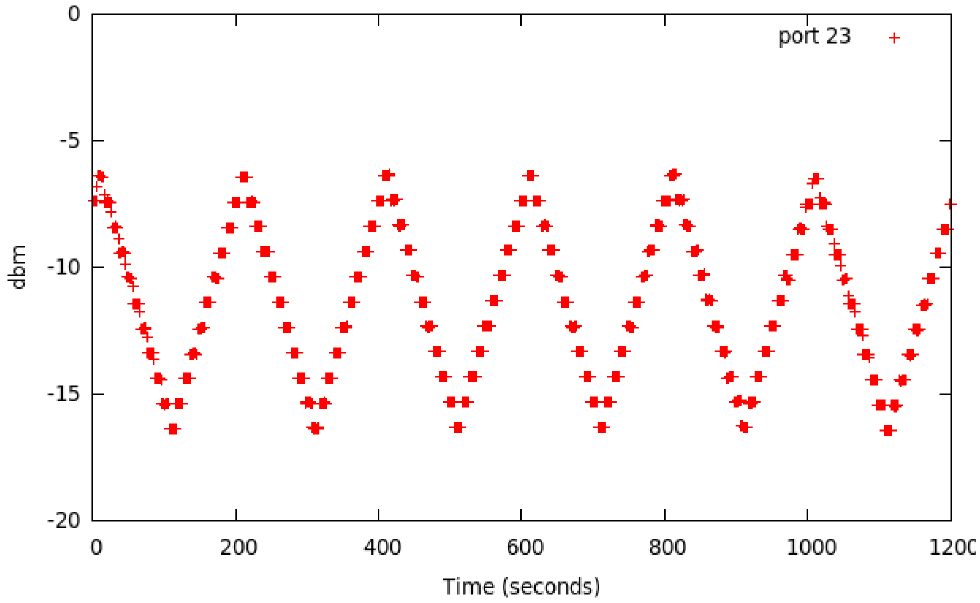
IMF Physical Infrastructure



IMF Cross-Service Demo



IMF Demo – Results



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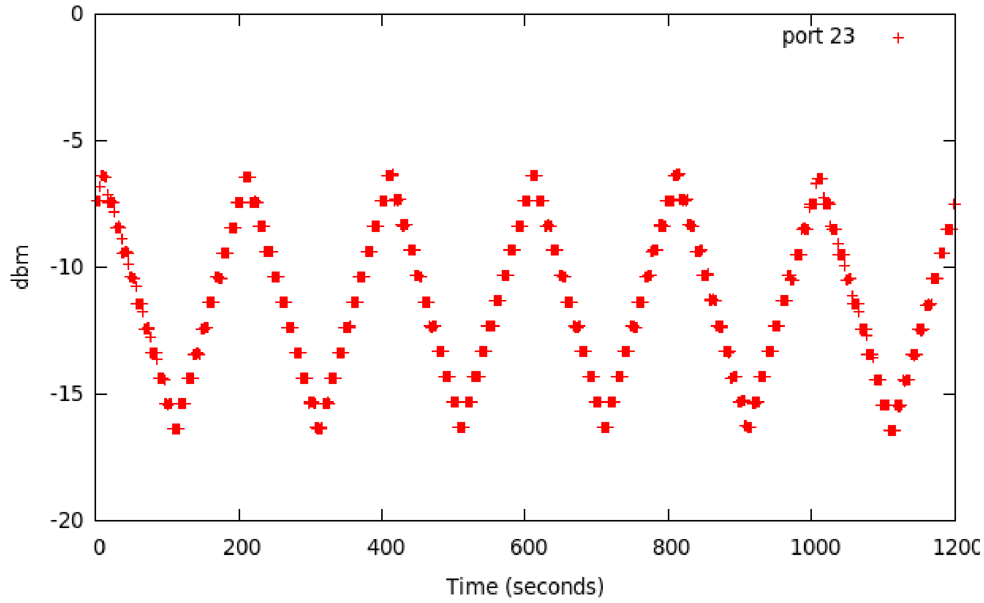

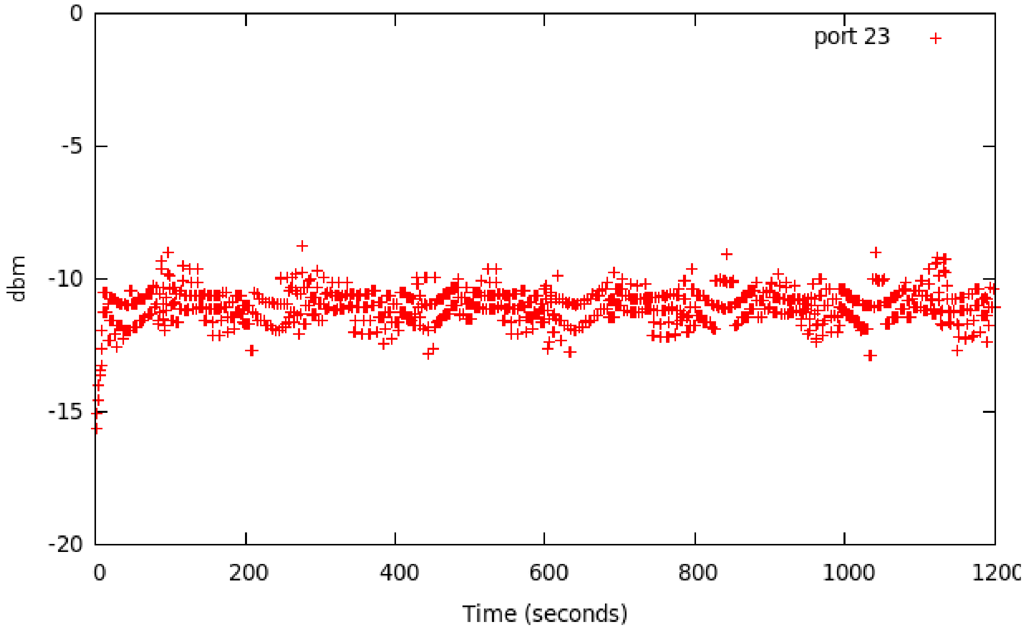

Summary

- 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 and scalability
  - policy enforcement through composition constraints
  - (generalized) virtualization as a service
- Extend the prototype
  - portfolio of reusable services
  - optical testbed deployment $\longrightarrow$ breakable experimental net (BEN)

Upcoming Book