Zen and the Art of Network Architecture

Larry Peterson

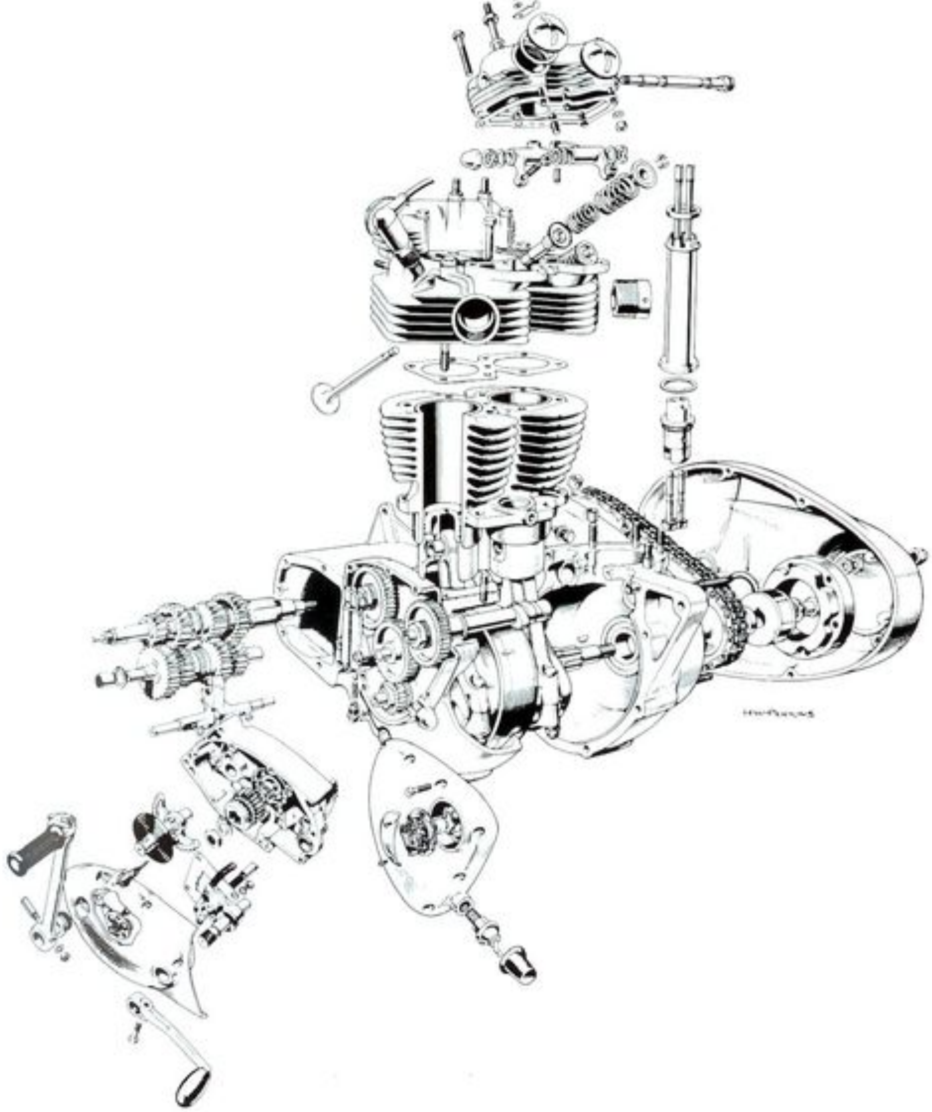
Zen and the Art of Motorcycle Maintenance

by

Robert Pirsig

- Rejected by 121 publishers (World Record)
- Classic v Romantic Perspectives
  - Rational vs Mystic
  - Analytical vs Intuitive
  - Science vs Art

Classic View



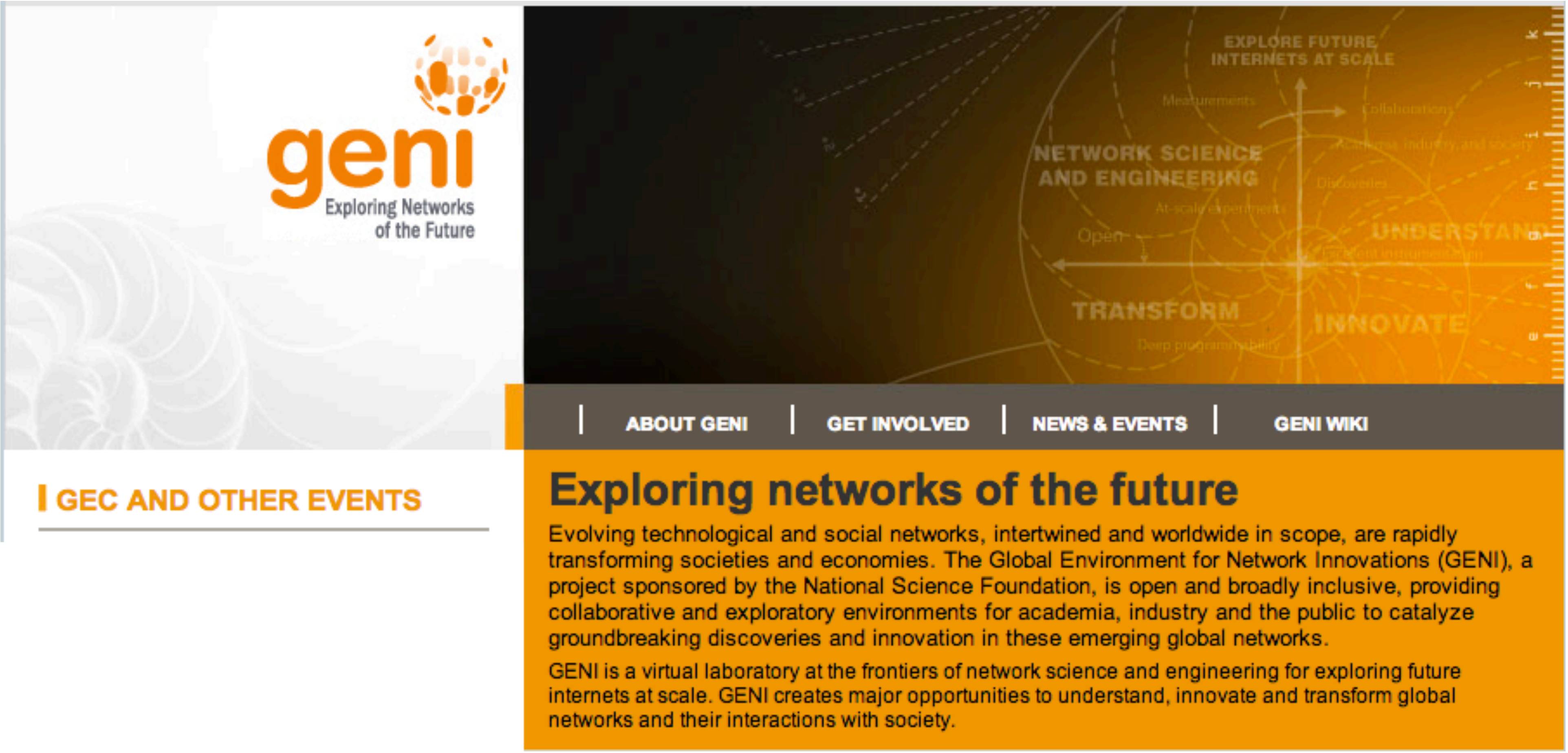
Romantic View

Quality

- Unifies Classic and Romantic Perspectives
- Whole is greater than the sum of the parts
- More about potential than measurable value

Buddhism’s First Noble Truth

Life is Suffering



GEC AND OTHER EVENTS

Exploring networks of the future

Evolving technological and social networks, intertwined and worldwide in scope, are rapidly transforming societies and economies. The Global Environment for Network Innovations (GENI), a project sponsored by the National Science Foundation, is open and broadly inclusive, providing collaborative and exploratory environments for academia, industry and the public to catalyze groundbreaking discoveries and innovation in these emerging global networks.

GENI is a virtual laboratory at the frontiers of network science and engineering for exploring future internets at scale. GENI creates major opportunities to understand, innovate and transform global networks and their interactions with society.

Duality – Networking vs Distributed Systems

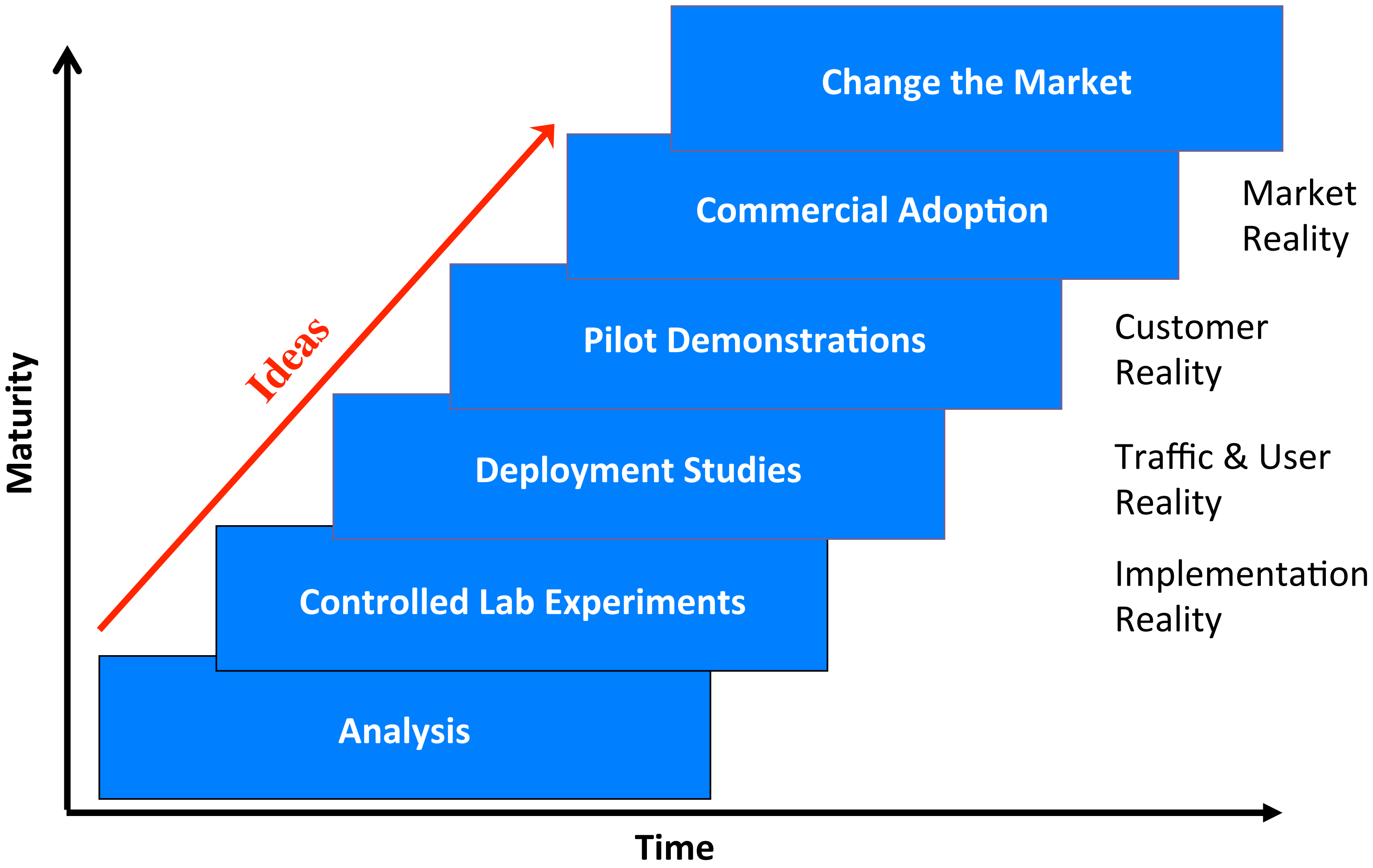
The Middle Way

- Involves Both Analysis and Intuition
- Balances Requirements*
  - Not about optimizing any one dimension
- Seeks Unifying Abstractions
  - Accommodates both *this* and *that*

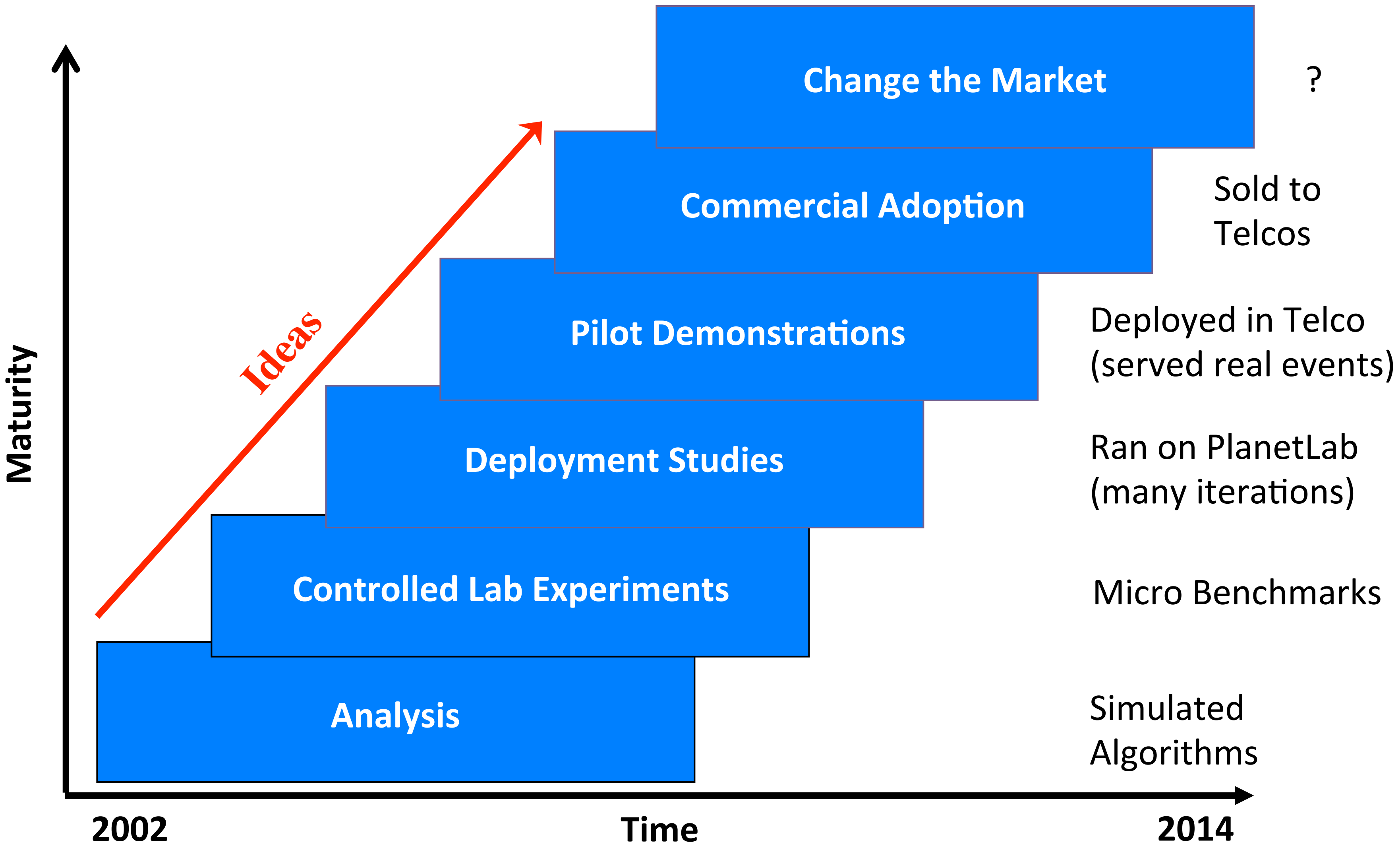
*GENI Design Principles. GDD-06-08. August 2006. Identifies 11 requirements (dimensions) and offers "rules" on resolving 7 inter-requirement tensions.

Path to Enlightenment

Path to Enlightenment



PlanetLab & CoBlitz



Change the Market ?

Commercial Adoption Sold to Telcos

Pilot Demonstrations Deployed in Telco (served real events)

Deployment Studies Ran on PlanetLab (many iterations)

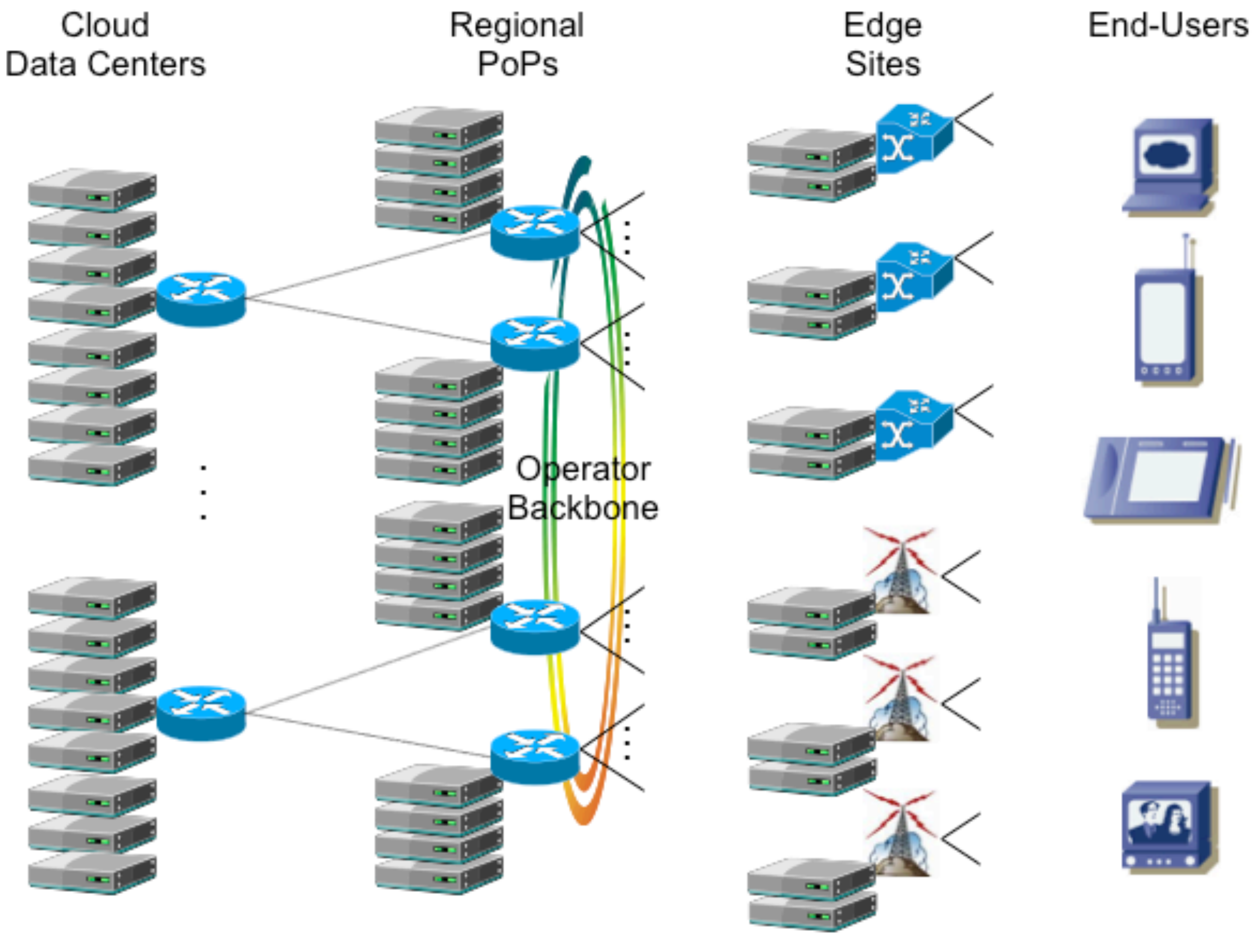
Controlled Lab Experiments Micro Benchmarks

Analysis Simulated Algorithms

Change the Market

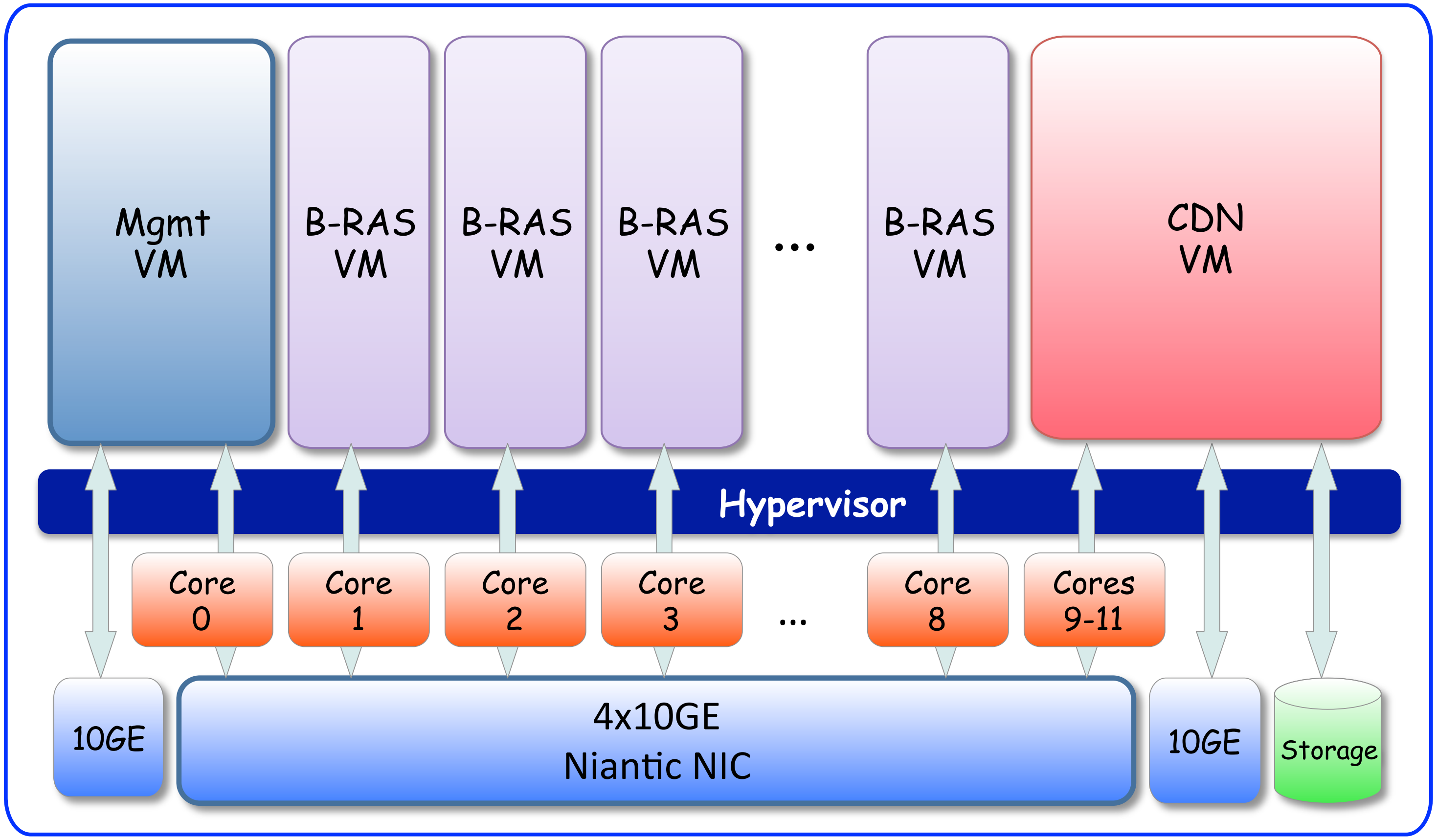
- Operator CDNs…
  - Now incentives for CDN Interconnection (CDNI)
- Virtualized Commodity Servers at the Edge…
  - Enables Network Function Virtualization (NFV)
  - Dovetails with (but distinct from) SDN

Commodity Servers in the Net



NFV Proof-of-Concept

– with BT, Intel & HP –



Path to Enlightenment

- See Reality Clearly – Assumptions hide the truth
- Experience-Based – Users reveal hidden assumptions
- Operationalize – The New Bar!
  - Deploy & Operate > Implement > Thought Experiment

Entropy

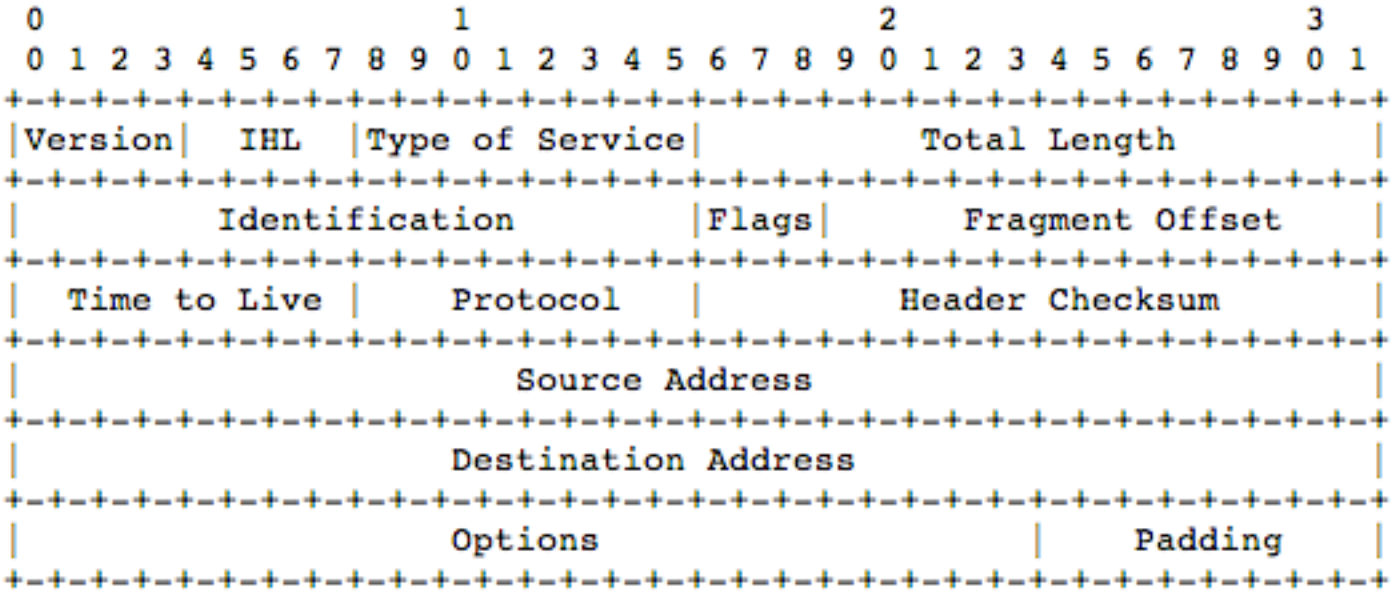
- A Measure of Engineering's Effect on Architecture
  - Natural part of the process
- Design Principles*
  - Acknowledge the dynamic nature of systems
- How Architecture Manifests
  - Represents the "fixed point" of an architecture

*Peterson and Roscoe. PlanetLab Design Principles. *Operating Systems Review, 40(1):11-16*, January 2006.

Identifies 13 design invariants to guide evolution.

Manifestation of an Architecture

- Circa 1981 (ASCII renderings of protocol headers)



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Manifestation of an Architecture

- Circa 2013 (Django Object Class Definition)

```
class Slice(PlCoreBase):
    tenant_id = models.CharField(max_length=200, help_text="Keystone tenant id")
    name = models.CharField(unique=True, help_text="The Name of the Slice",
max_length=80)
    enabled = models.BooleanField(default=True, help_text="Status for this Slice")
    omf_friendly = models.BooleanField()
    description=models.TextField(blank=True,help_text="High level description of the
slice and expected activities", max_length=1024)
    slice_url = models.URLField(blank=True, max_length=512)
    site = models.ForeignKey(Site, related_name='slices', help_text="The Site this Node
belongs too")
    tags = generic.GenericRelation(Tag)
    serviceClass = models.ForeignKey(ServiceClass, related_name = "slices", null=True,
default=ServiceClass.get_default)
    creator = models.ForeignKey(User, related_name='slices', blank=True, null=True)
```

Lessons

- Part Analysis, Part Intuition
  - Whole is greater than the sum of its parts
- Unifying Abstractions
  - Duality is an opportunity
- Balance Requirements
  - Not about optimizing a single dimension
- Experience (Reality) Driven
  - Deploy It, Operationalize It, Use It
- Dynamicity (Evolution) is the Norm
  - Define Principles and Invariants

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Putting Lessons to Action

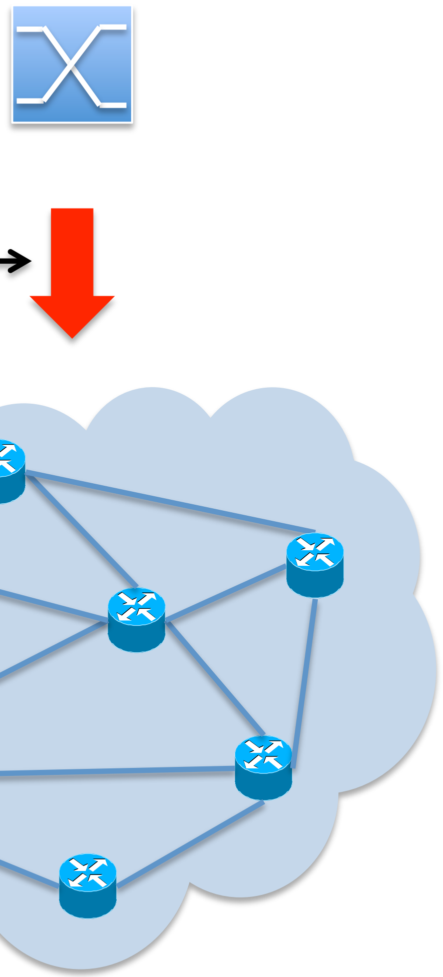
- Software Defined Networking (SDN)
  - Separating the Control and Data Planes
- Network Function Virtualization (NFV)
  - Data plane functions running in VMs on commodity servers
- Scalable Cloud Applications and Services (Apps)
  - Applications running on top of the network

Or… Finding the middle way for Open Networking Lab (ON.Lab) and the PlanetLab Consortium (PLC)

Distinctions without a Difference

- Three implementation points for "network functions"
  - SDN, NFV, Apps
- Blurring the SDN/Application Line
  - Is a proxy that cuts-through uninteresting flows a Controller?
  - Is a scalable Controller that uses a NoSQL DB an App?
  - Is a CDN that manages a caching hierarchy a Controller?
- Blurring the NFV/Application Line
  - Is a proxy an example of NFV or is it an application?
- Blurring the NFV/SDN Line
  - Is a firewall in the data plane or the control plane?

Topology



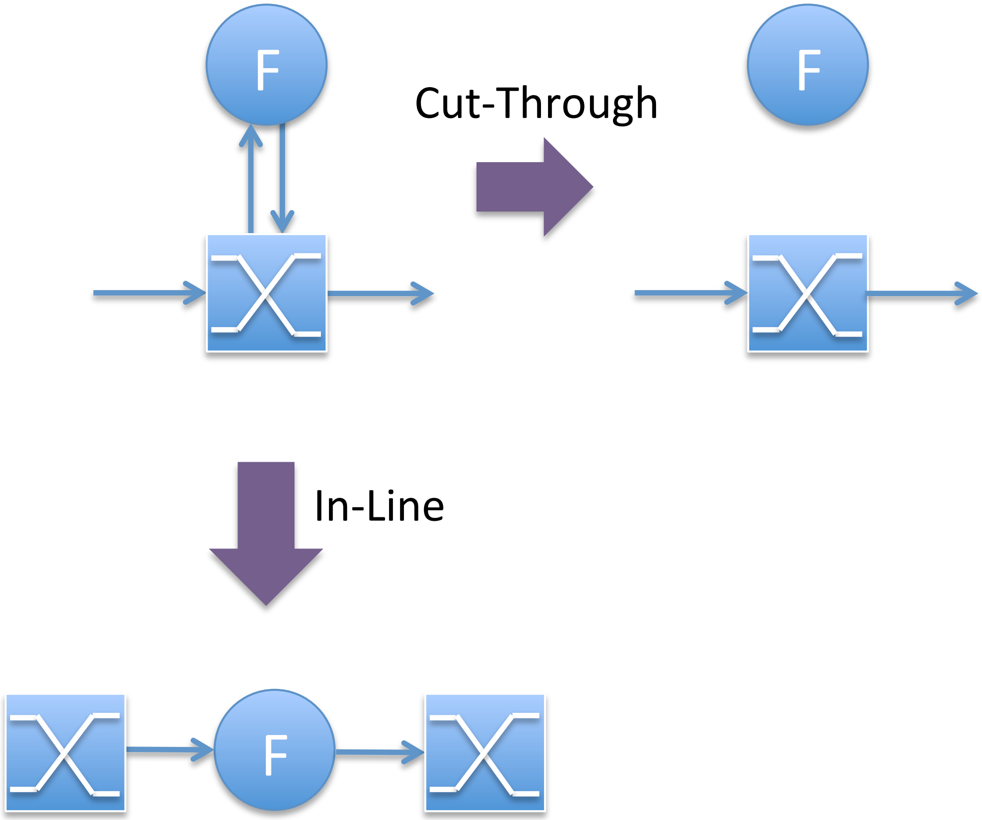
Virtual Toplogy
(Big Switch)

Network Virtualization Layer →

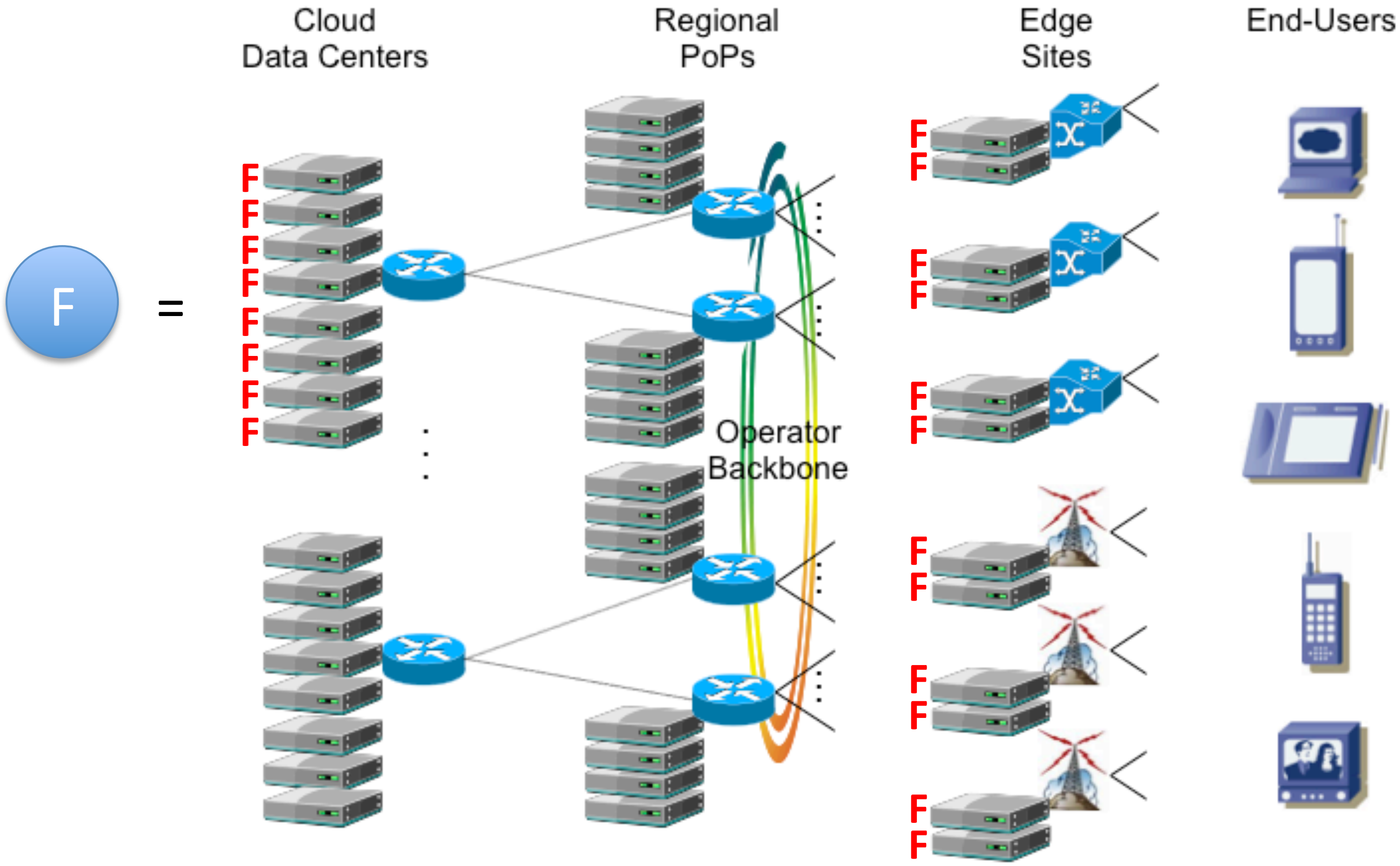
- Topology Isolation
- Address Space Isolation
- Semantic Isolation

Physical Topology

Topology Optimizations



Scaling Functions



Interesting question: How to partition functions into DC and edge “subroutines”?

Refactoring the Space

- Model all “network functions” as scalable services
  - Application vs Controller vs NFV distinction is arbitrary
- Use SDN to bootstrap a virtualization layer that…
  - Isolates virtual networks from each other
  - Maps virtual topology to physical topology
    - Maintains this mapping in the presence of failures, etc.
    - Tunnels vs OpenFlow is an implementation choice
    - Supports a cut-through optimization (service hint)
- NFV reduces to an implementation choice
  - Put function “in line” at the edge when appropriate

XaaS – Everything-as-a-Service

- Service as a Unifying Abstraction
  - Unifies across resources (Compute, Network, Storage)
  - Unifies across the network (DC, WAN, Access)
  - Unifies across service levels (IaaS, PaaS, SaaS)
- XOS – XaaS Operating System
  - Defines *service* as a first class object
  - Supports managing services, not servers
  - Supports seamless service extensions to XOS
  - Integrates service orchestration with resource provisioning
  - Supports both service isolation and service composition

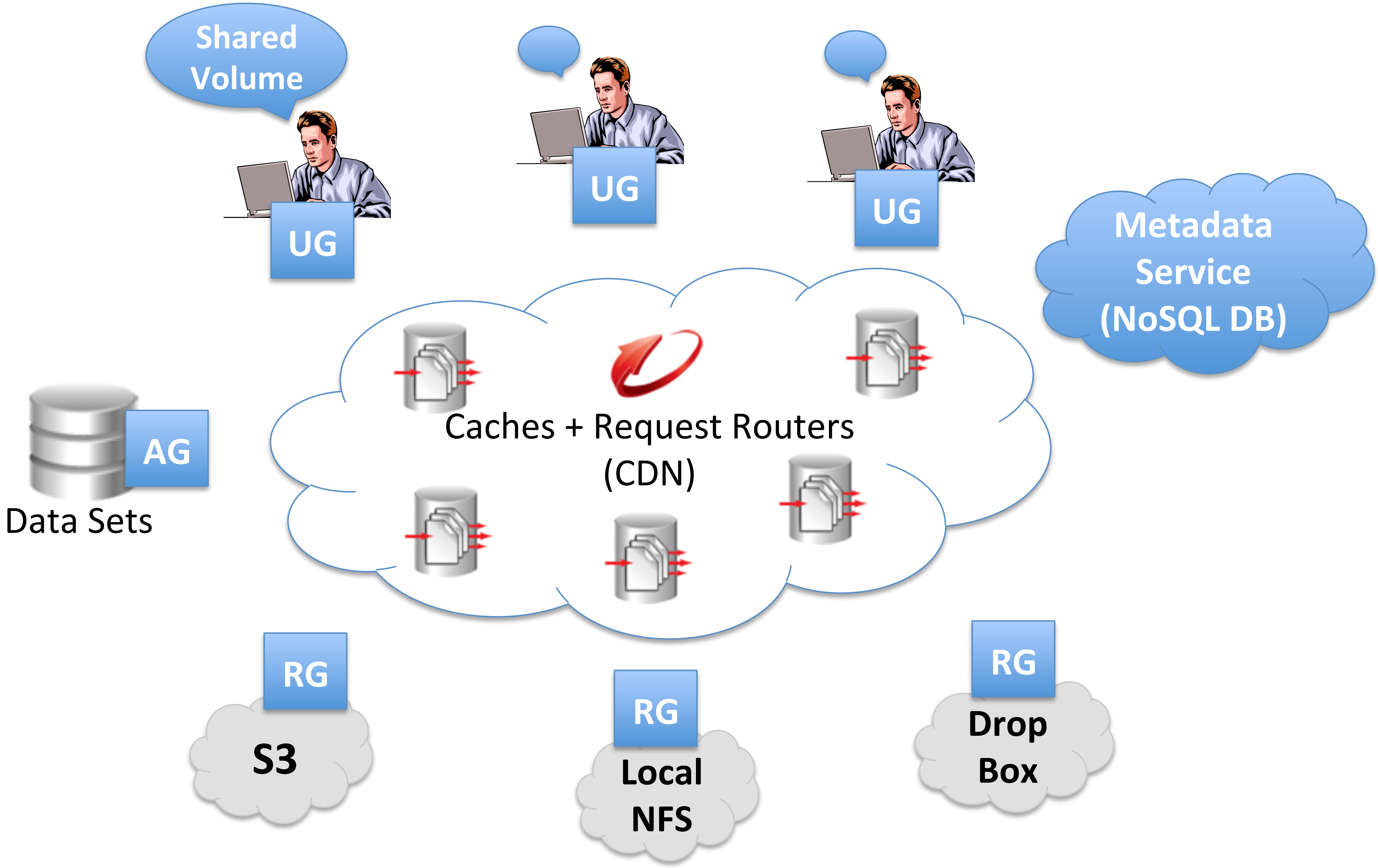
Service Abstraction

- Provides a well-defined function
- Exports a programmatic (REST) interface
- Available network-wide (location independent)
- Scalable, elastic, and resilient
  - Scales with the number of users (self-balancing)
  - Seamlessly grows/shrinks based on demand
  - Built out of unreliable components (self-healing)
- Runs in a set of VMs connected by one or more VNs
- Build new services by composing with existing services
  - Some are building blocks (*NoSQL DB*), some are user-facing (*Facebook*)*,* and some are both (*DropBox*)

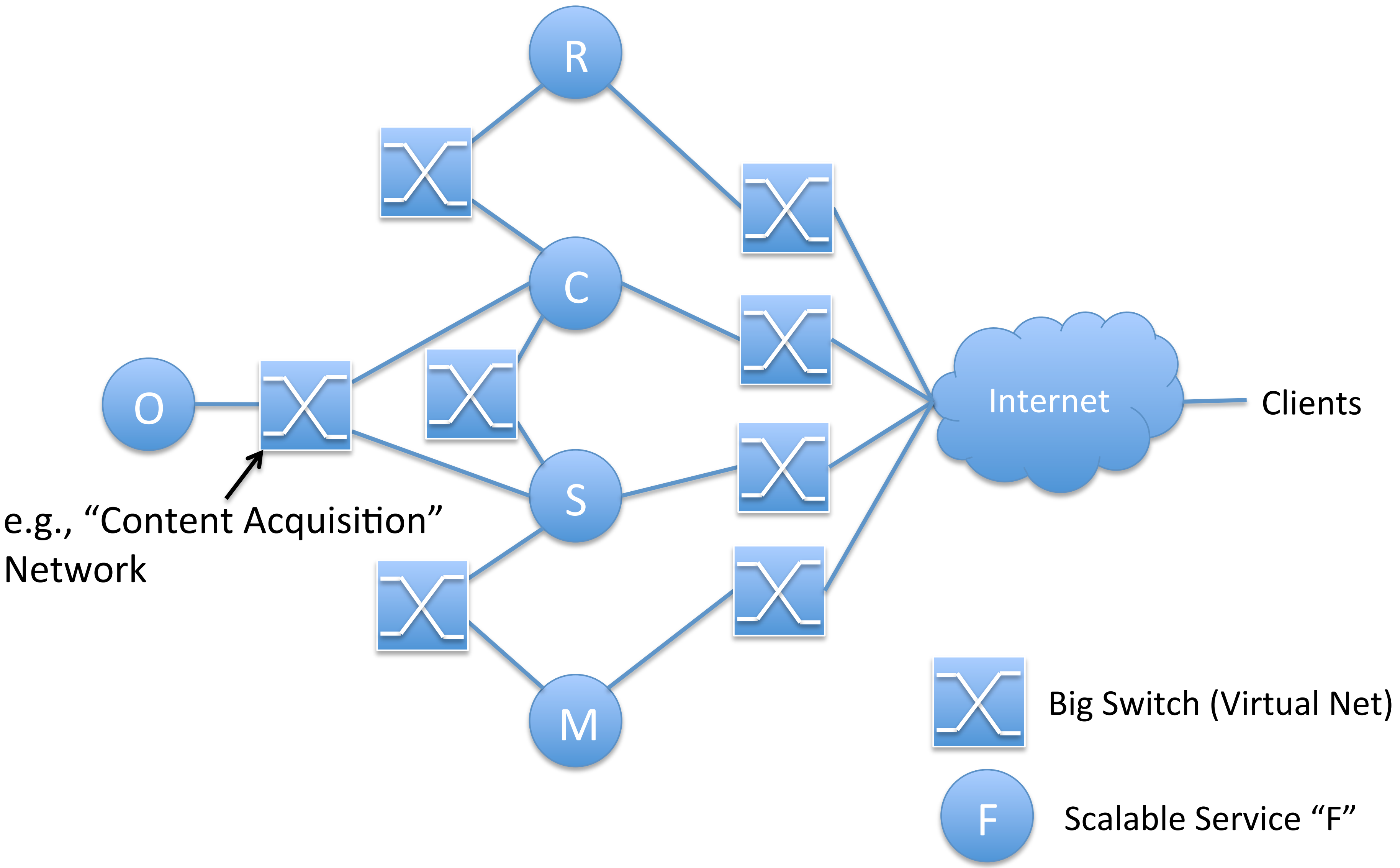
Examples of Service Composition

- CoBlitz: Operator CDN (Now Akamai Aura)
  - HyperCache (HPC)
  - Request Router (RR)
  - Intercept Service (IS)
- Syndicate: Scalable Storage Service
  - Durability of Cloud Storage (S3, DropBox, Google Drive, Box)
  - Scalability of a CDN (HPC, RR)
  - Coherence of a Local FS (NoSQL DB – Google App Eng)
- Third: Scalable Monitoring & Analytics Service
  - Distributed data collection, analysis, and archiving
  - Leverages Storm, Cassandra, RabbitMQ and ZooKeeper

Syndicate


Shared Volume
UG
UG
UG
Metadata Service (NoSQL DB)
AG
Data Sets
Caches + Request Routers (CDN)
RG
S3
RG
Local NFS
RG
Drop Box

Service Isolation/Composition

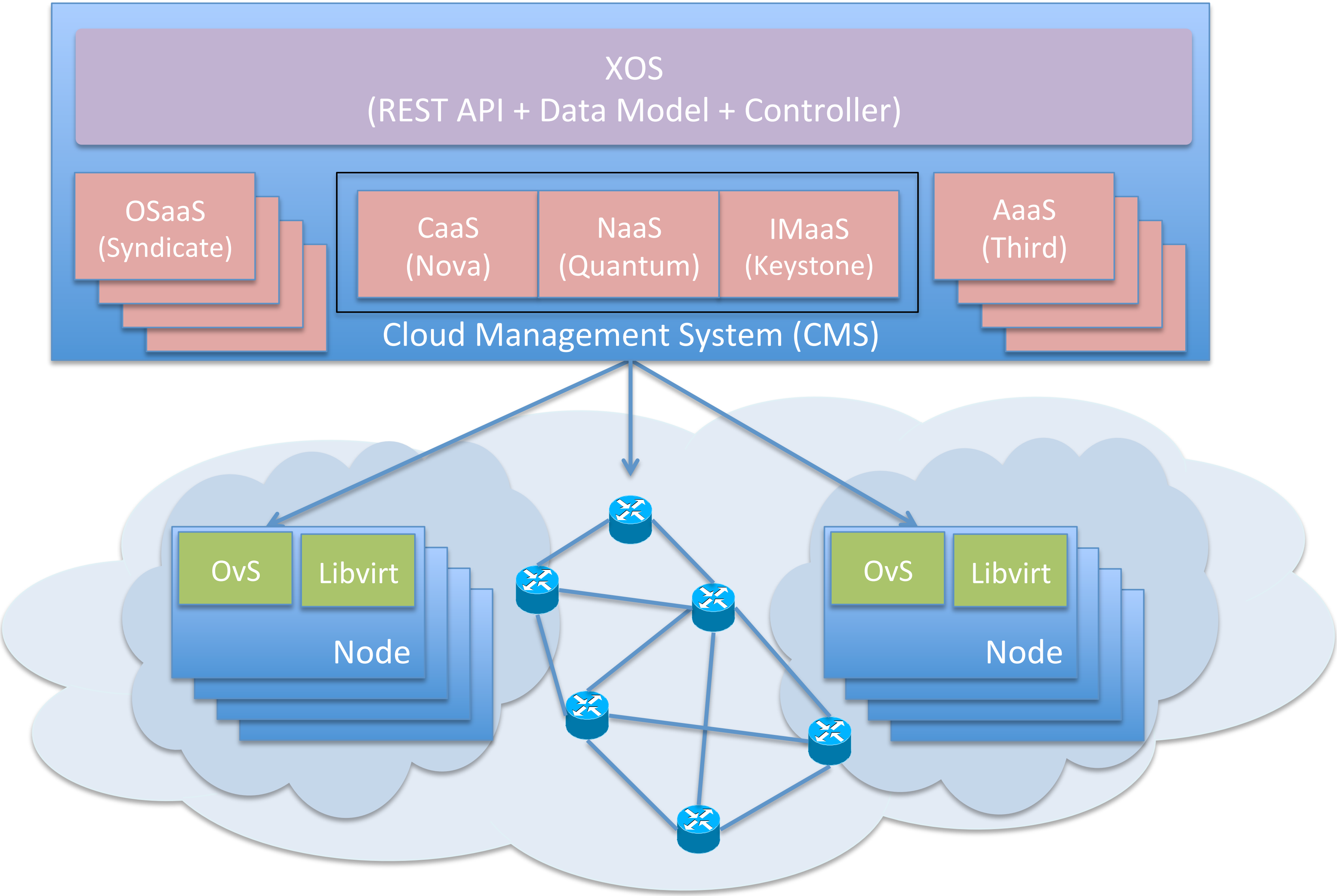


e.g., “Content Acquisition” Network

Big Switch (Virtual Net)

Scalable Service “F”

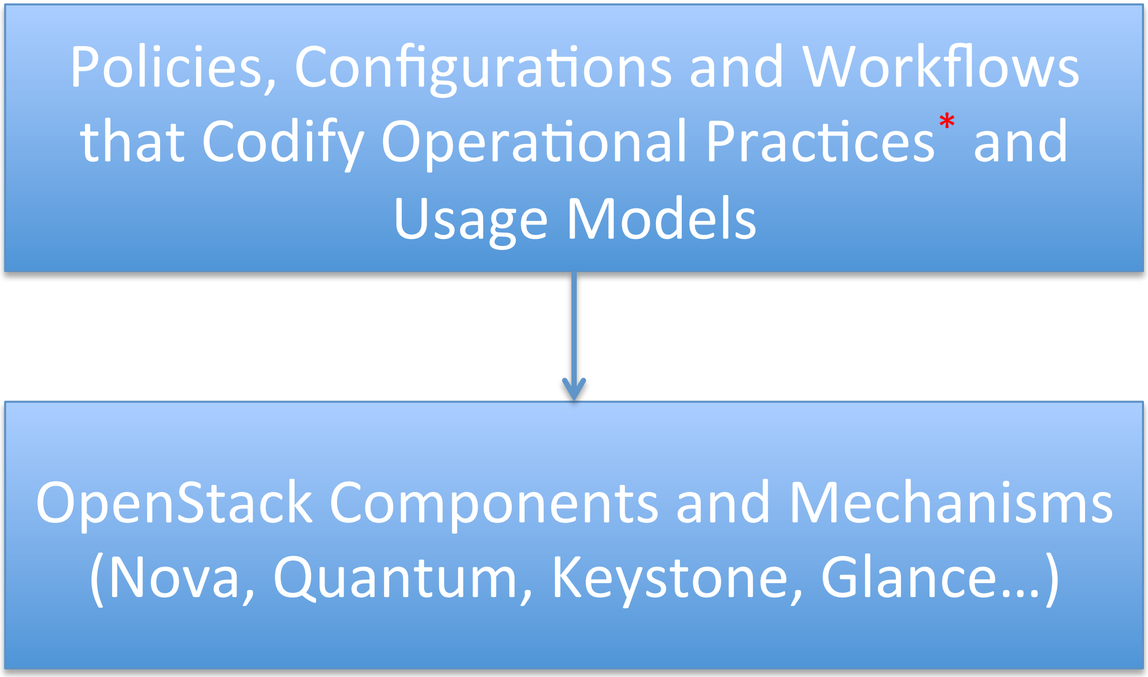
XOS


XOS
(REST API + Data Model + Controller)
OSaaS
(Syndicate)
CaaS
(Nova)
NaaS
(Quantum)
IMaaS
(Keystone)
AaaS
(Third)
Cloud Management System (CMS)
OvS
Libvirt
Node
OvS
Libvirt
Node

XOS Data Model

- Service runs in one or more Slices
  - Extend data model with service-specific objects
  - Define “shim” so programs can access service from VMs
- Slice is a resource container
  - Set of VMs + Set of VNs
  - Constraint-based VM placement
  - VMs added and deleted over time
  - VNs provide service *isolation* and *composition*
- Each VN is…
  - A big switch that fully connects all VMs in Slice
  - Private or Public (routable)
  - Closed or Open (available for multiple slices to join)

Operationalizing OpenStack

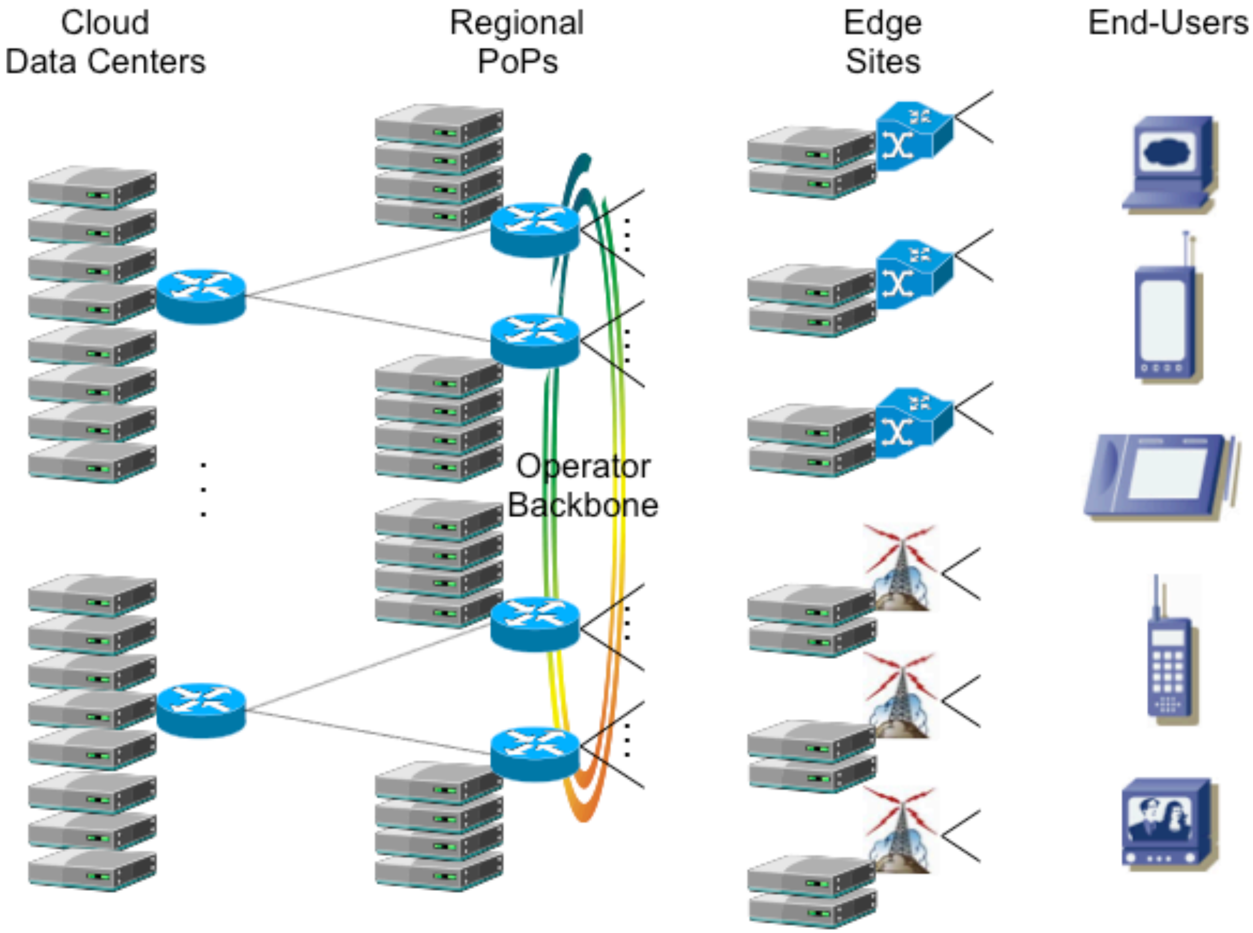


Policies, Configurations and Workflows that Codify Operational Practices[*] and Usage Models

OpenStack Components and Mechanisms (Nova, Quantum, Keystone, Glance…)

[*] Understanding and Resolving Conflicts on PlanetLab. November 2008. Unpublished Note.

OpenCloud Pilot – Hardware

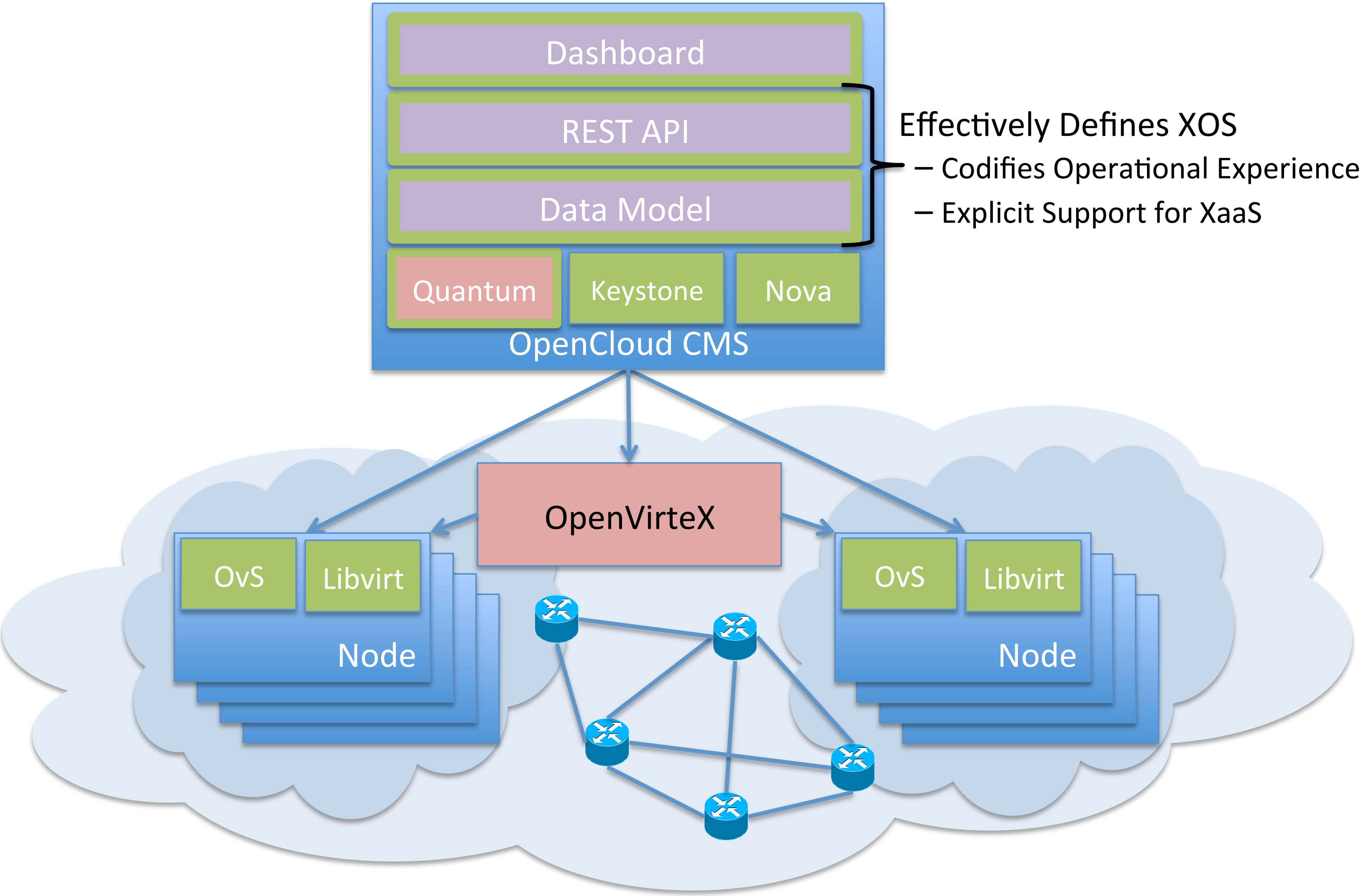


ViCCI
(5 SDN-Capable
Data Centers)

Internet2
(SDN-Capable
Backbone + **ViNI**)

PlanetLab
(500+ Sites, many
with campus SDN)

OpenCloud Pilot – Software



Effectively Defines XOS

- Codifies Operational Experience
- Explicit Support for XaaS

Status

- Near-term Development
  - Initial prototype of OpenCloud (XOS) running in the lab
  - Will deploy on operational system this fall
  - Deployment will include exemplar services
  - Integrating generalized Network Virtualization is next
- Longer term research questions
  - What are the right abstractions to support XaaS?
  - How do XaaS and Software Routers “meet in the middle”?
  - How is functionality best split between DC and the edge?
  - What is the performance impact of service composition?

Conclusions

I am indebted to many people, including…

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- Guru Parulkar
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