GENI

Exploring Networks of the Future

An introduction

GENI Project Office

March 2010

www.geni.net

Sponsored by the National Science Foundation

What is GENI?

- GENI is a virtual laboratory for exploring future internets at scale.
- GENI creates major opportunities to *understand, innovate, and transform* global networks and their interactions with society.
- GENI opens up new areas of research at the frontiers of network science and engineering, and increases the opportunity for significant socio-economic impact.

Outline

- GENI – Exploring future internets at scale
- How we'll use it; how we'll build it (Two Comic Books)
- GENI system concept
- Current status and plans: GENI Spiral 2
- How can you participate?

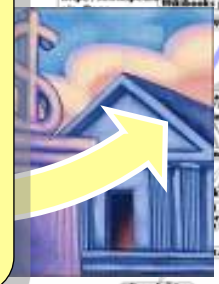
Global networks are creating extremely important new challenges

Science Issues

We cannot currently understand or predict the behavior of complex, large-scale networks

Innovation Issues

Substantial barriers to at-scale experimentation with new architectures, services, and technologies



Society Issues

We increasingly rely on the Internet but are unsure we can trust its security, privacy or resilience

Network Science & Engineering (NetSE)

Science → Understand the complexity of large-scale networks → Network science and engineering researchers

- Understand emergent behaviors, local-global interactions, system failures and/or degradations
- Develop models that accurately predict and control network behaviors

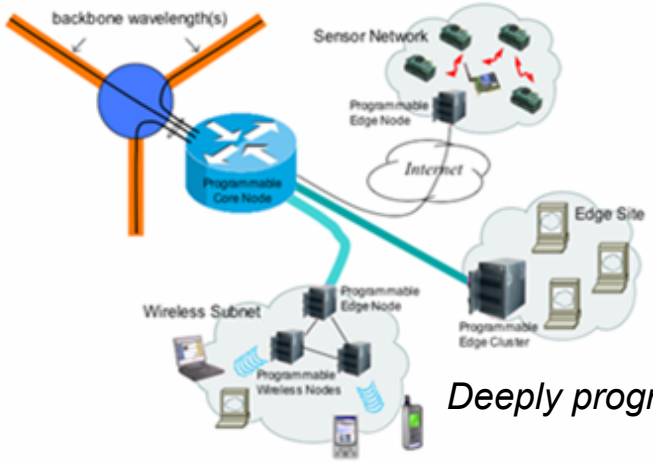
Technology → Develop new architectures, exploiting new substrates → Distributed systems and substrate researchers

- Develop architectures for self-evolving, robust, manageable future networks
- Develop design principles for seamless mobility support
- Leverage optical and wireless substrates for reliability and performance
- Understand the fundamental potential and limitations of technology

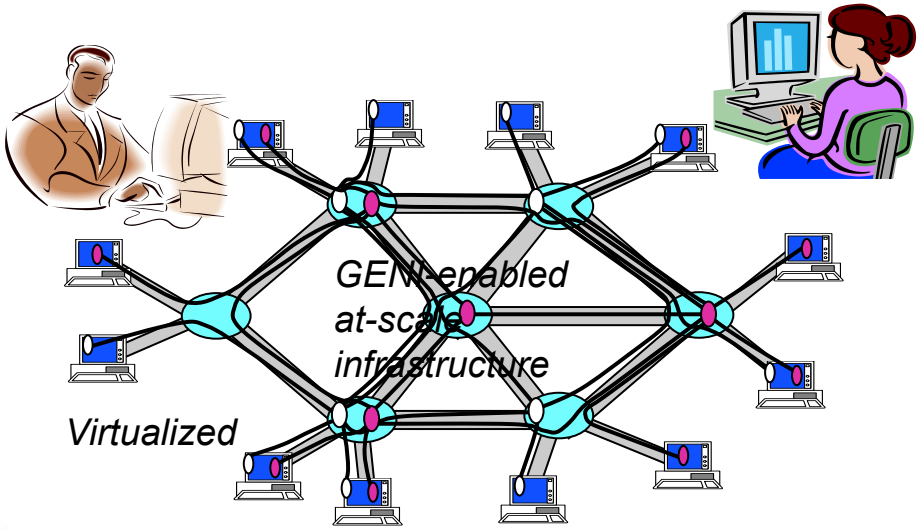
Society → Enable new applications and new economies, while ensuring security and privacy → Security, privacy, economics, AI, social science researchers

- Design secure, survivable, persistent systems, especially when under attack
- Understand technical, economic and legal design trade-offs, enable privacy protection
- Explore AI-inspired and game-theoretic paradigms for resource and performance optimization

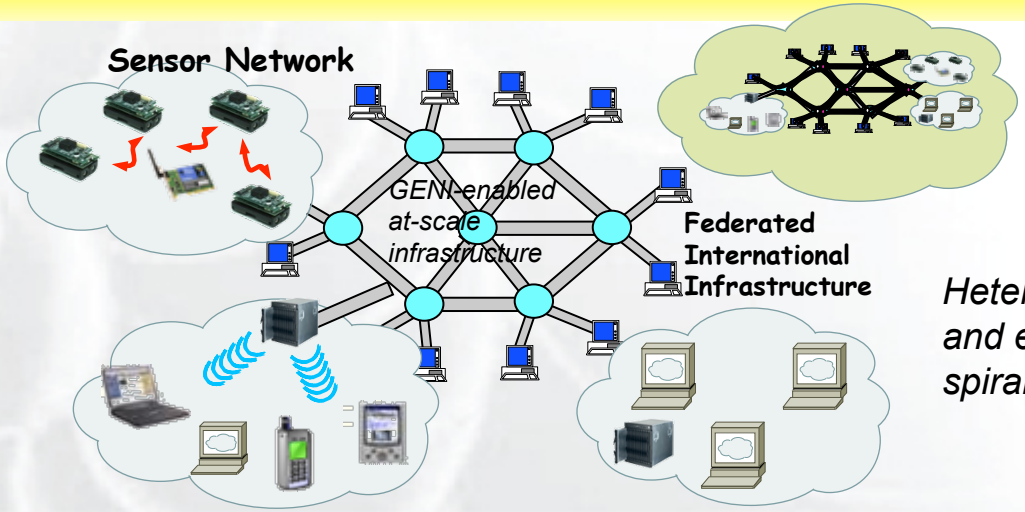
GENI Conceptual Design
Infrastructure to support at-scale experimentation



Deeply programmable



Programmable & federated, with end-to-end virtualized "slices"



Heterogeneous, and evolving over time via spiral development

Enabling “at scale” experiments

- **GENI is enabling two classes of “at scale” experiments:**
  - **Controlled and repeatable** experiments, to help improve scientific understanding of complex, large-scale networks; and
  - **“In the wild” trials** of services that piggyback or connect to today’s Internet and engage large numbers of participants.
  - With instrumentation and data archival / analysis tools for both
- **How can we afford / build GENI at sufficient scale?**
  - Clearly infeasible to build research testbed “as big as the Internet”
  - Therefore we are “GENI-enabling” testbeds, commercial equipment, campuses, regional and backbone networks
  - Key strategy for building an at-scale suite of infrastructure

Current GENI Status

GENI-enabling testbeds, campuses, and backbones


BEN
Breakable Experimental Network
ORBIT
PLANETLAB
An open platform for developing, deploying, and accessing planetary-scale services
ProtoGENI
UIC
UMASS LOWELL
THE QUILT
UPMC
PARIS UNIVERSITAS
at&t
ARISTA
Battelle
ca
ciena
cisco
CNRI
FUJITSU
hp
invent
IBM
infinera
INTERNET2
JEFFREY HUNKER ASSOCIATES LLC
Technology • Government • Global business • Insight with impact
JUNIPER NETWORKS
Microsoft
NETRONOME
nicira
NLR
light the future
NEC
Qwest
Radio Technology Systems
SPARTA

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  (Two Comic Books)
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How We'll Use GENI

Note that this is the "classics illustrated" version – a comic book!

Please read the Network Science and Engineering Research Agenda to learn all about the community's vision for the research it will enable. Your suggestions are very much appreciated!

A bright idea

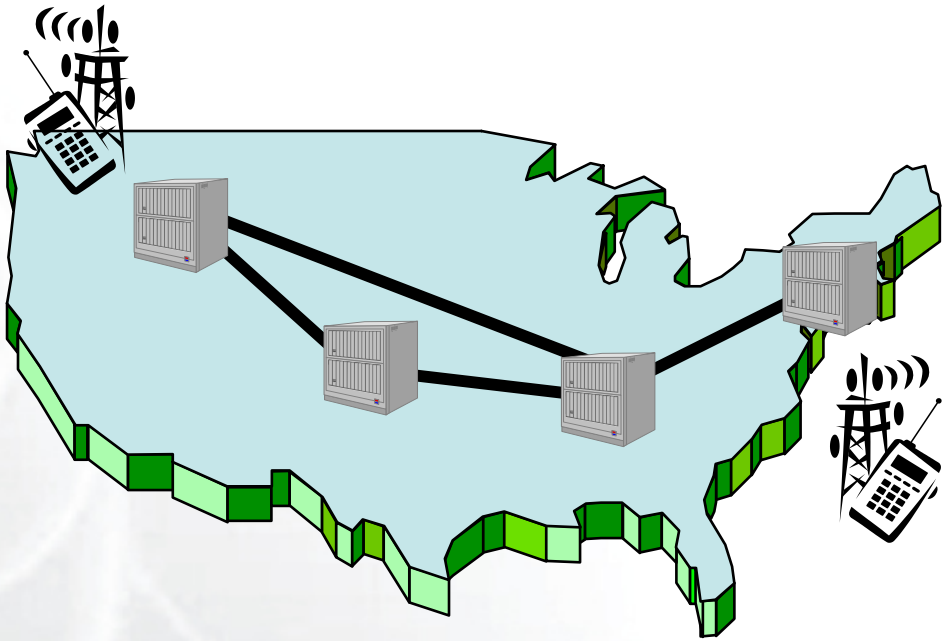
I have a great idea! The original Internet architecture was designed to connect one computer to another – but a better architecture would be fundamentally based on PEOPLE and CONTENT!

That will never work! It won't scale! What about security? It's impossible to implement or operate! Show me!

Trying it out

My new architecture worked great in the lab, so now I'm going to try a larger experiment for a few months.

And so he poured his experimental software into clusters of CPUs and disks, bulk data transfer devices ('routers'), and wireless access devices throughout the GENI suite, and started taking measurements . . .



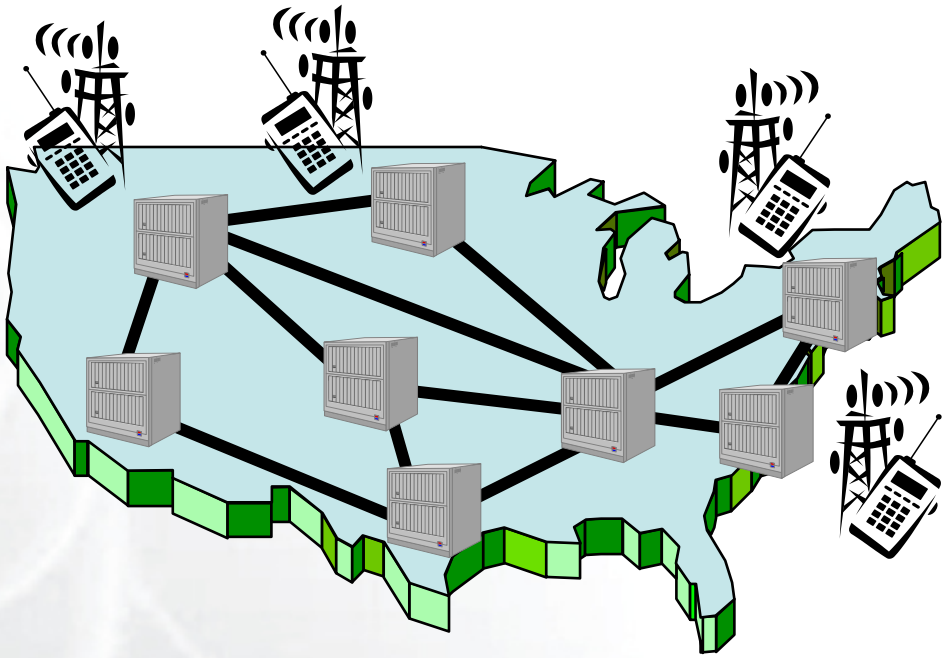
He uses a modest slice of GENI, sharing its infrastructure with many other concurrent experiments.

It turns into a really good idea

Boy did I learn a lot! I've published papers, the architecture has evolved in major ways, and I'm even attracting real users!

Location-based social networks are really cool!

His experiment grew larger and continued to evolve as more and more real users opted in . . .



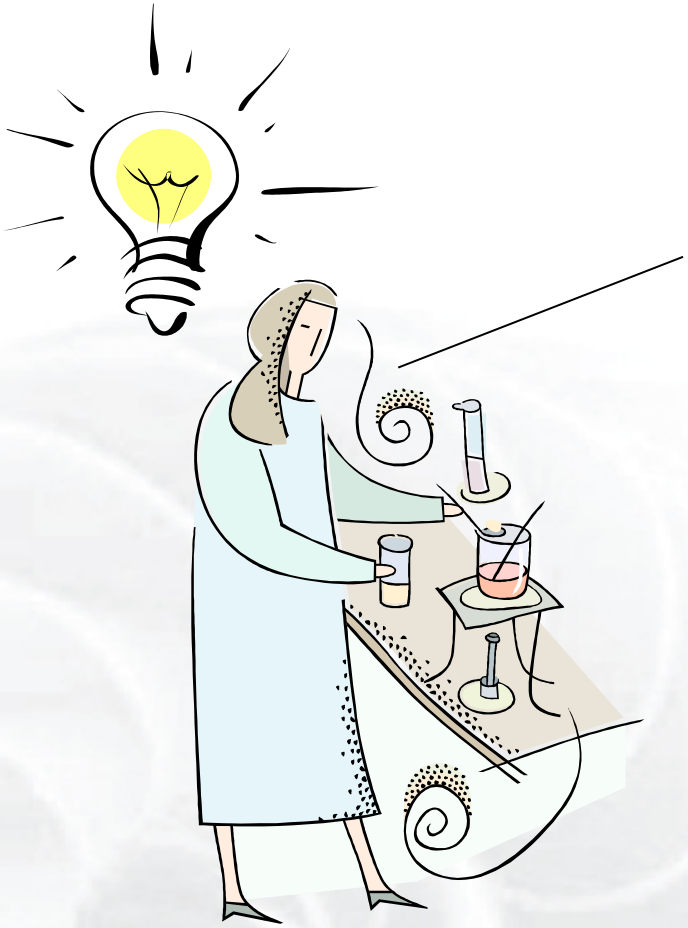
His slice of GENI keeps growing, but GENI is still running many other concurrent experiments.

Experiment turns into reality

My experiment was a real success, and my architecture turned out to be mostly compatible with today's Internet after all – so I'm taking it off GENI and spinning it out as a real company.

I always said it was a good idea, but way too conservative.

Meanwhile . . .



I have a great idea! If the Internet were augmented with a scalable control plane and realtime measurement tools, it could be 100x as reliable as it is today . . . !

And I have a great concept for incorporating live sensor feeds into our daily lives !

If **you** have a great idea, check out the **NSF CISE Network Science and Engineering** program.

Moral of this story

- GENI is meant to enable . . .
  - At-scale experiments, which may or may not be compatible with today's Internet
  - Long-running, realistic experiments with enough instrumentation to provide real insights and data
  - 'Opt in' for real users into long-running experiments
  - Large-scale growth for successful experiments, so good ideas can be shaken down at scale
- A reminder . . .
  - GENI itself is not an experiment !
  - GENI is a suite of infrastructure on which experiments run

GENI creates a huge opportunity for ambitious research!

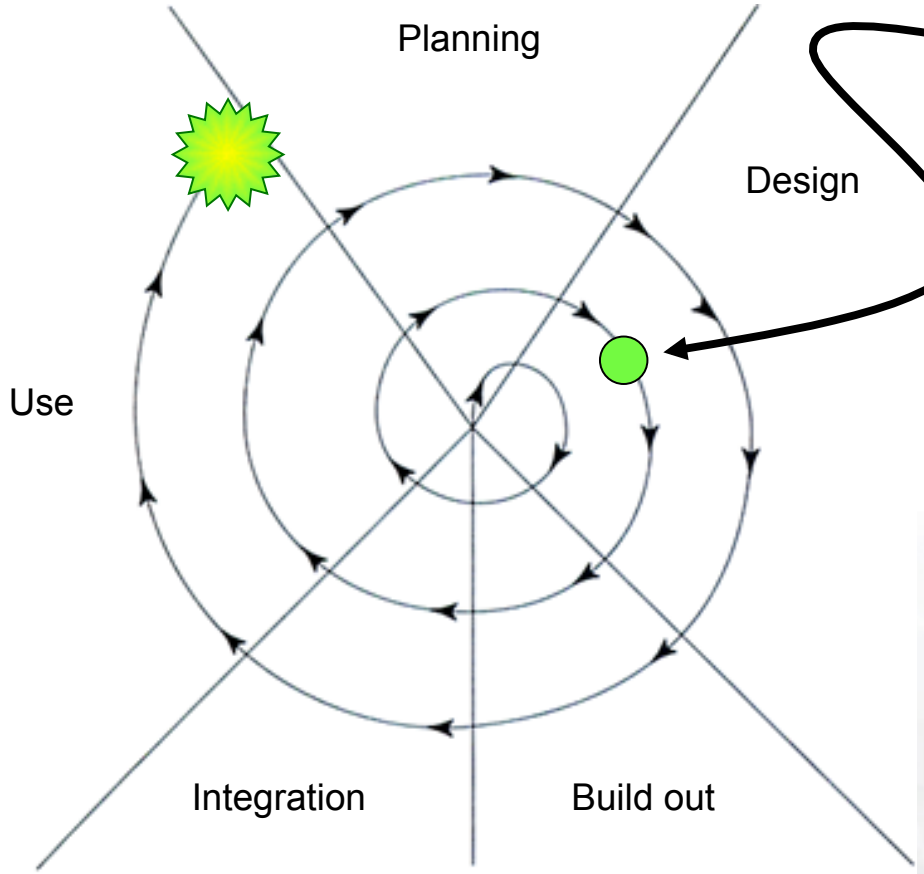
How We'll Build GENI

Note that this is the "classics illustrated" version – a comic book!

Please read the GENI System Overview and GENI Spiral 1 Overview for detailed planning information.

Spiral Development

GENI grows through a well-structured, adaptive process



GENI Prototyping Plan

GENI Spiral 2

Early experiments, meso-scale build, interoperable control frameworks, ongoing integration, system designs for security and instrumentation, definition of identity management plans.

Envisioned **ultimate goal**

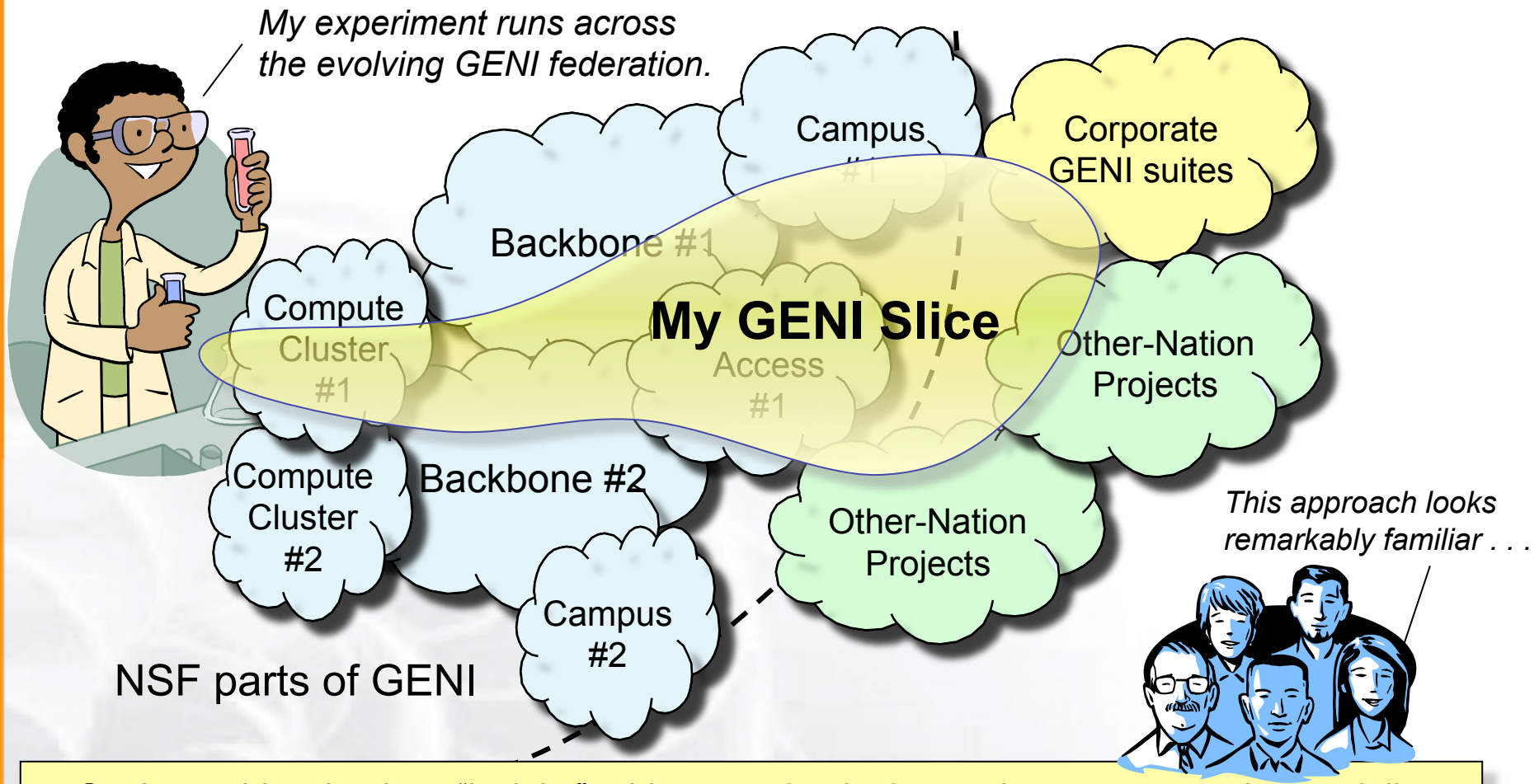
Example: Planning Group's desired GENI suite, probably trimmed some ways and expanded others. Incorporates large-scale distributed computing resources, high-speed backbone nodes, nationwide optical networks, wireless & sensor nets, etc.

- ## Spiral Development Process

  Re-evaluate goals and technologies yearly by a systematic process, decide what to prototype and build next.

Federation

GENI grows by "GENI-enabling" heterogeneous infrastructure



Goals: avoid technology "lock in," add new technologies as they mature, and potentially grow quickly by incorporating existing infrastructure into the overall "GENI ecosystem"

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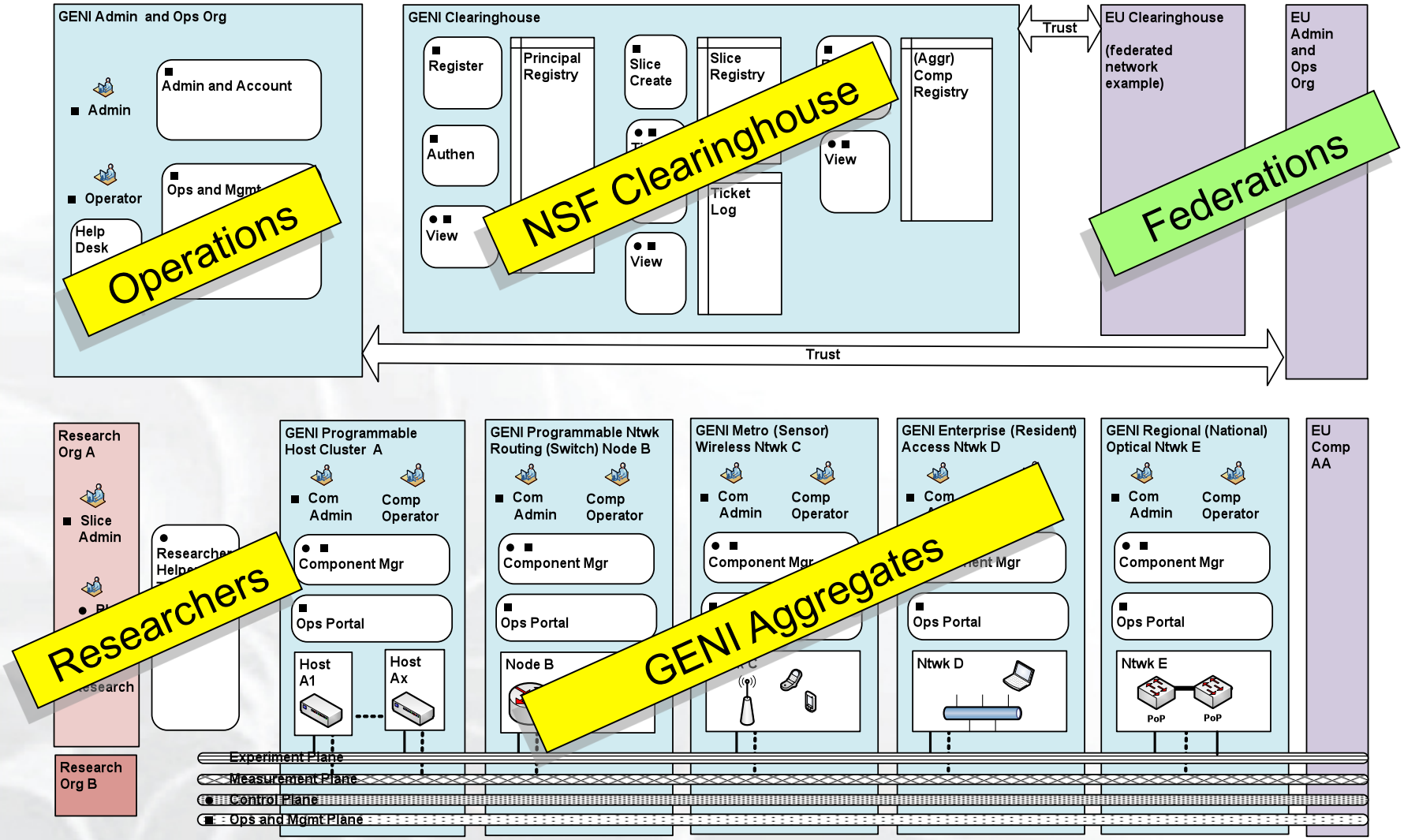
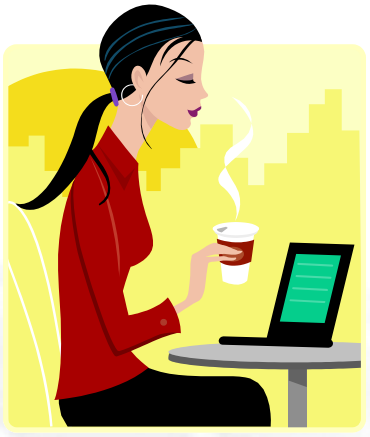
GENI System Diagram (simplified)



Resource discovery

Aggregates publish resources, schedules, etc., via clearinghouses



Researcher

What resources can I use?

GENI Clearinghouse

These

Components

Components

Components

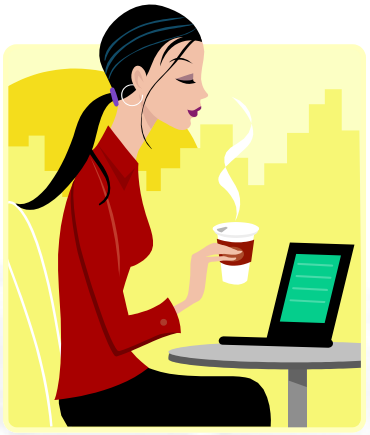
Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless

Slice creation

Clearinghouse checks credentials & enforces policy
Aggregates allocate resources & create topologies



Create my slice

GENI Clearinghouse

Components

Components

Components

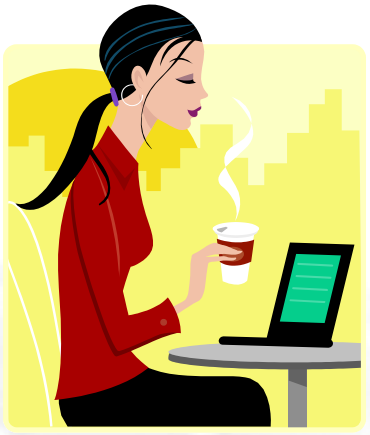
Aggregate A
Computer Cluster

Aggregate B
Backbone Net

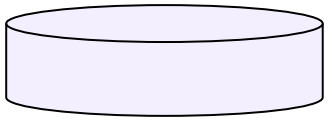
Aggregate C
Metro Wireless

Experimentation

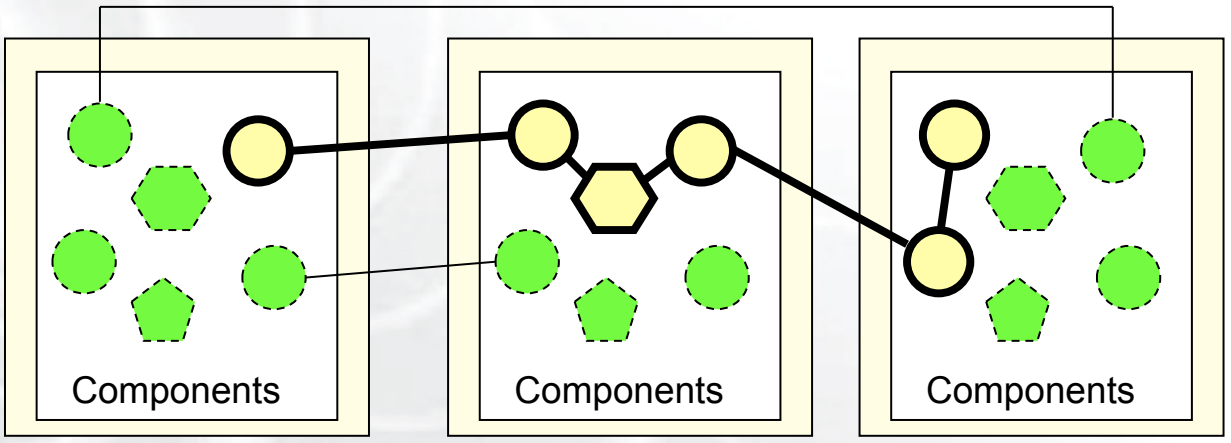
Researcher loads software, debugs, collects measurements



Experiment – Install my software, debug, collect data, retry, etc.



GENI Clearinghouse



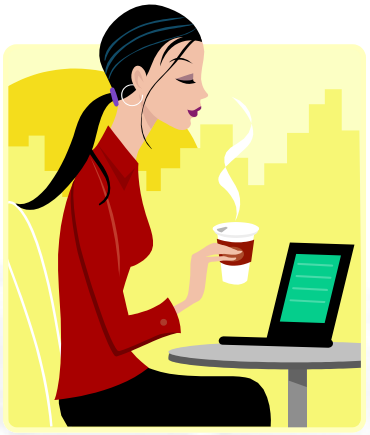
Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless

Slice growth & revision

Allows successful, long-running experiments to grow larger



Make my slice bigger !

GENI Clearinghouse

Components

Components

Components

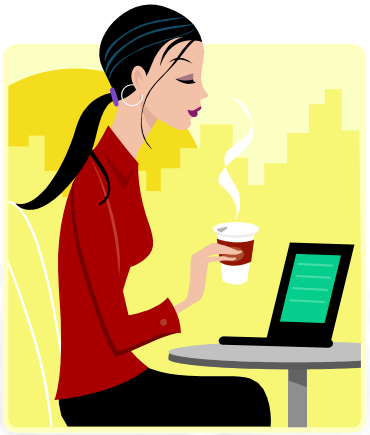
Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless

Federation of Clearinghouses

Growth path to international, semi-private, and commercial GENIs



Make my slice even bigger !

GENI Clearinghouse

Federated Clearinghouse

Components

Components

Components

Components

Aggregate A
Computer Cluster

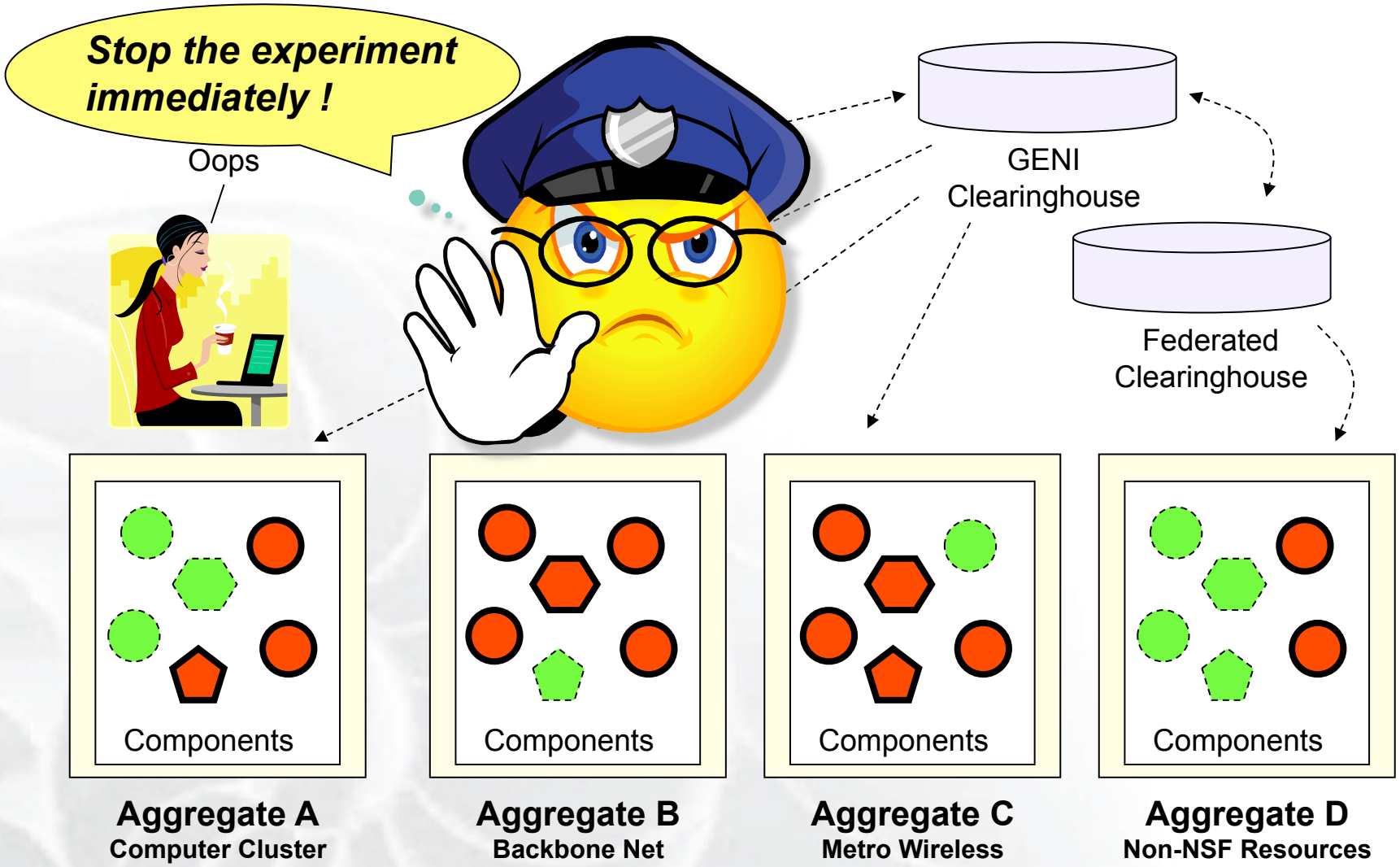
Aggregate B
Backbone Net

Aggregate C
Metro Wireless

Aggregate D
Non-NSF Resources

Operations & Management

Always present in background for usual reasons
Will need an 'emergency shutdown' mechanism



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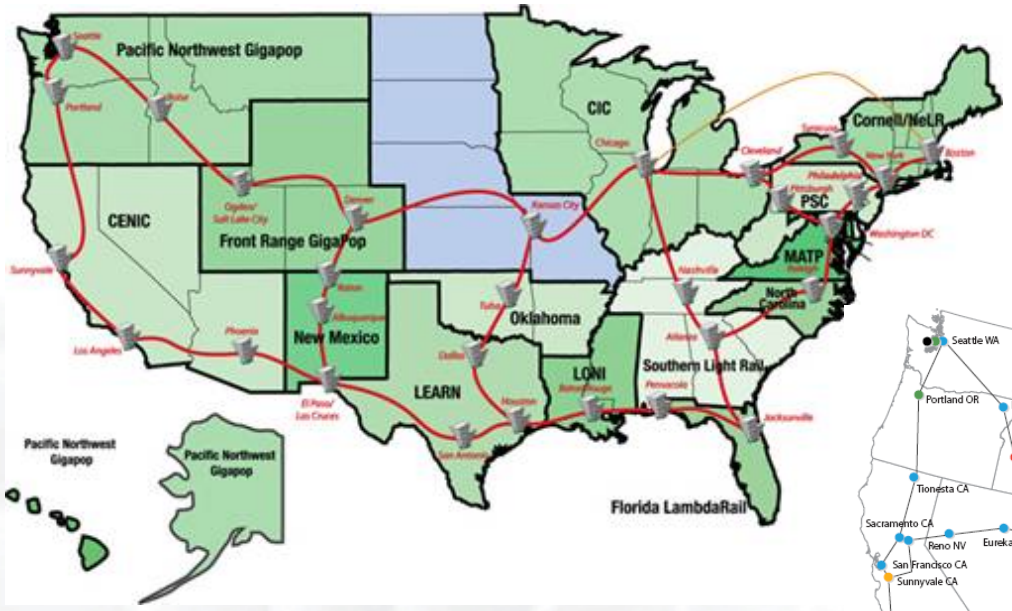
GENI Spiral 2

Sites of Spiral 2 participants

Internet2 and National LambdaRail



Internet2

10 Gbps dedicated bandwidth

ProtoGENI & SPP

National LambdaRail

Up to 30 Gbps nondedicated bandwidth

40 Gbps capacity for GENI prototyping on two national footprints to provide Layer 2 Ethernet VLANs as slices (IP or non-IP)

Building the GENI Meso-scale Prototype

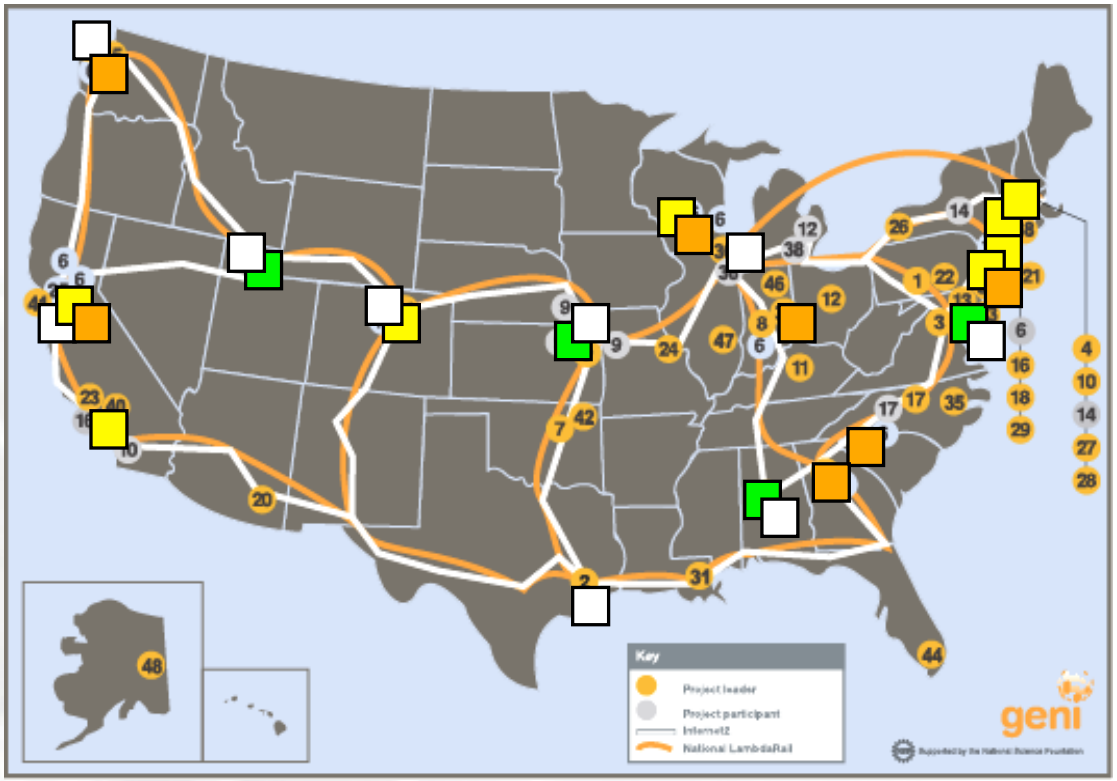
Current plans for locations & equipment

OpenFlow

Stanford
U Washington
Wisconsin
Indiana
Rutgers
Princeton
Clemson
Georgia Tech

ShadowNet

Salt Lake City
Kansas City
DC
Atlanta



WiMAX

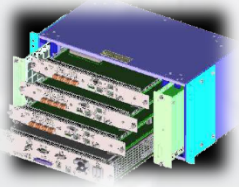
Stanford
UCLA
UC Boulder
Wisconsin
Rutgers
Polytech
UMass
Columbia

OpenFlow Backbones

Seattle
Salt Lake City
Sunnyvale
Denver
Kansas City
Houston
Chicago
DC
Atlanta

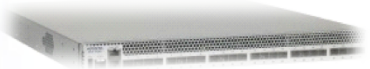
HP ProCurve 5400 Switch

Juniper MX240 Ethernet Services Router



NEC WiMAX Base Station

Cisco 6509 Switch



Arista 7124S Switch

NEC IP8800 Ethernet Switch

Infrastructure examples

DRAGON core nodes
Mid-Atlantic Crossroads

WAIL, U. Wisconsin-Madison

DieselNet, U. Mass Amherst

ViSE,
U. Mass Amherst

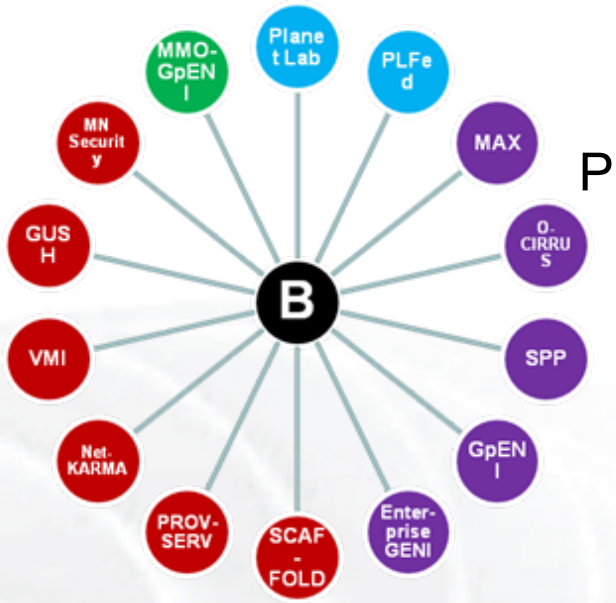
SPPs, Wash U.

ORBIT, Rutgers WINLAB

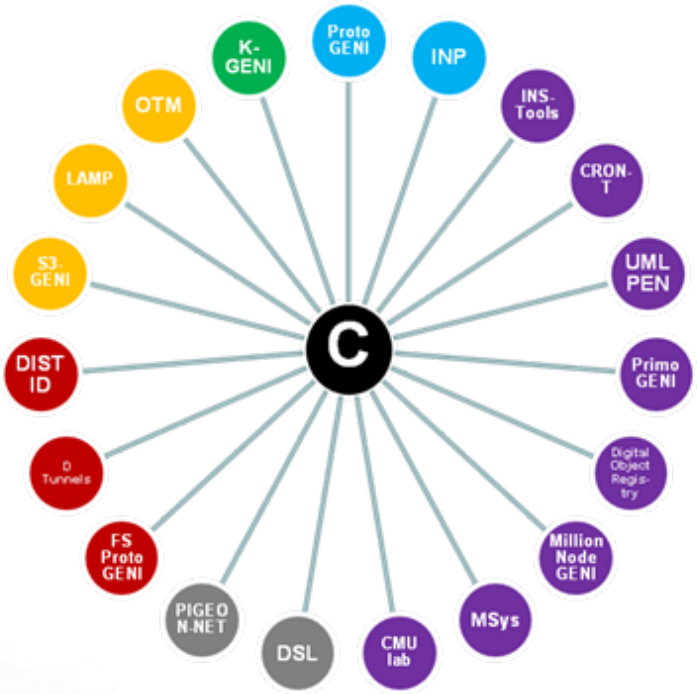
Spiral 2 Academic-Industrial Teams

Project Name	Project Lead	Project Participants
1. CMUlab	Carnegie Mellon University	
2. D Meas, LEARN	University of Houston	Columbia University
3. Digital Object Registry	Corporation for National Research Initiatives (CNRI)	
4. CLOUD-CTL, DOME, ViSE	University of Massachusetts Amherst	
5. DTunnels	The Georgia Institute of Technology	
6. EnterpriseGENI, OpenFlow	Stanford University	Princeton University, University of California, Berkeley
	Clemson University	
	Georgia Institute of Technology	
	Indiana University	
	Nicira Networks	
	Princeton University	
	Rutgers University	
	University of Wisconsin	
	University of Washington	
7. GENI4YR	Langston University	
8. GMOC, netKarma, K-GENI	Indiana University	
9. GpENI	University of Kansas	Kansas State University, University of Nebraska-Lincoln
	The University of Missouri-Kansas City	
10. GushProto	Williams College	UC San Diego
11. INSTOOLS, ISM Infrastructure	University of Kentucky	
12. KANSEI, OTM	Ohio State University	Wayne State University
13. MAX	University of Maryland	
14. MeasurementSys	University of Wisconsin-Madison	Boston University, Colgate University
15. MillionNodeGENI, Security	University of Washington	
16. ORBIT, WiMAX	Rutgers University	UCLA, Los Angeles, CA
	Columbia University, NY, NY	University of Colorado, Boulder, CO
	Polytechnic University of NYU, Brooklyn, NY	University of Massachusetts, Amherst, University of Wisconsin, Madison, WI
17. ORCA/BEN	The Renaissance Computing Institute (RENCI)	Duke University
18. PlanetLab, Scaffold, Federation	Princeton University	Universite Pierre et Marie Curie (UPMC)
19. ProtoGENI	University of Utah	
20. PROVSERV	University of Arizona	
21. ERM	Columbia	
22. REGOPT	Pittsburgh Supercomputing Center (PSC)	
23. SECARCH, Distributed Identity	SPARTA, Inc.	
24. SPP	Washington University	
25. TIED	USC Information Sciences Institute	University of California, Berkeley
26. UB_OANets	SUNY Buffalo	
27. UMLPEN	University of Massachusetts Lowell	
28. CR-GENI	University of Colorado Boulder	Radio Technology Systems LLC, Rutgers University
29. CRON-T	Louisiana State University	
30. Design of Information Subs	MIT	
31. DSL, HIVE	UC Davis	Batelle, CA Labs
32. EXP-SEC	University of Alabama	
33. FPGA-RADIO	Clemson University	
34. GENI IMF	North Carolina State University	The Renaissance Computing Institute (RENCI), Columbia University
35. iGENI	Northwestern University	University of Illinois Chicago
36. LAMP	University of Delaware	Internet2
37. LEFA, Supercharged Planetlab	Internet2	Brown University
38. NLR	Cypress, CA	
39. Open--CIRRUS	HP Labs, Palo Alto	UCSD
40. OKGems	Oklahoma State University	
41. PIGEON-NET	Howard University	
42. PrimoGENI	Florida International University	
43. QUILT	The Quilt	
44. S3-GENI	Purdue University	HP Labs
45. SEC-POL	University of Illinois (NCSA)	
46. VMI	University of Alaska Fairbanks	

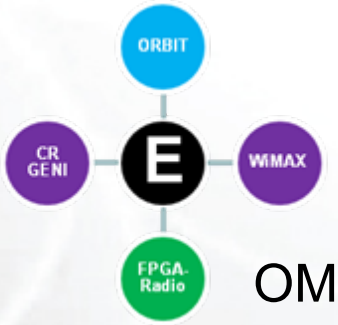
Spiral 2 Control Framework Teams



PlanetLab

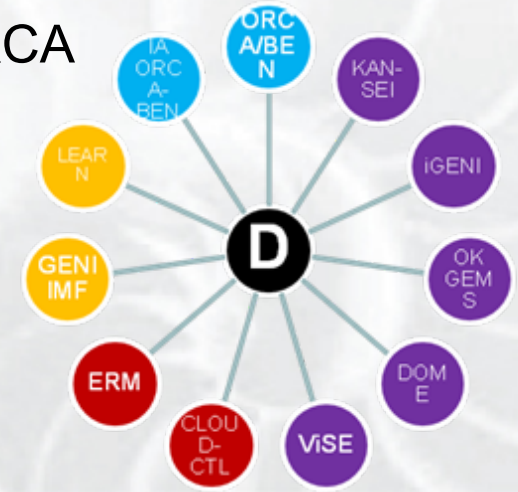


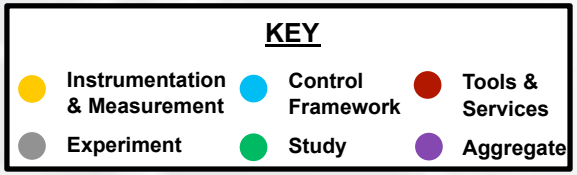
ProtoGENI



OMF

ORCA

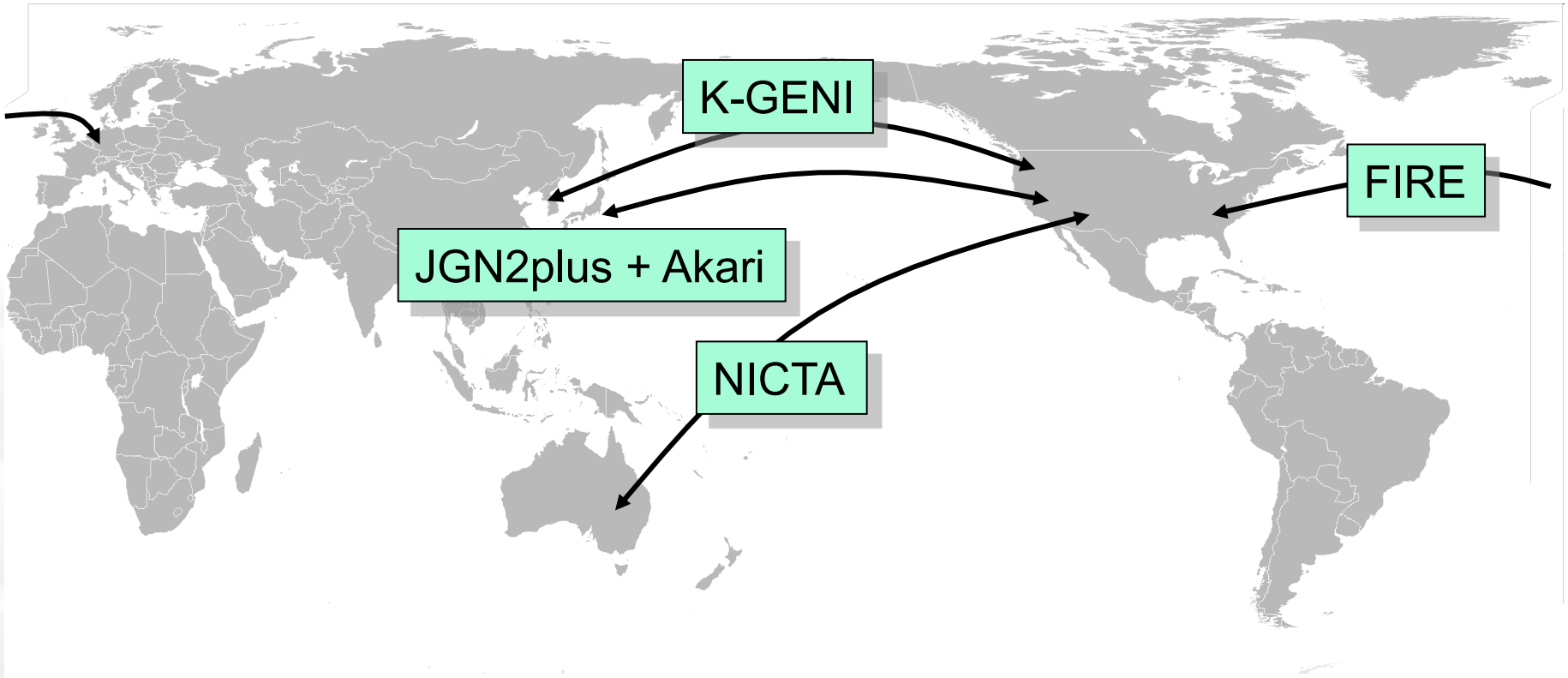




Key goals for Spiral 2

- Overarching goal
  - Get real experiments up and running
- Technical emphases
  - Integration, particularly of the meso-scale prototype
  - Interoperability
  - Instrumentation
  - Identity management

GENI's emerging international collaborations



The GENI Project Office is interested in federation with peer efforts outside the US, based on equality and arising from direct, "researcher to researcher" collaborations.

Spiral 2 accelerates GENI's roll-out

- Creates a compelling infrastructure for entirely new forms of **network science and engineering experimentation** at a much larger scale than has previously been available
- Stimulates **broad community participation and "opt in"** by early users across 14 major campuses, which can then grow by a further 21 campuses as the build-out progresses, with a strong partnership between researchers and campus infrastructure operators
- Forges a **strong academic / industrial base** by GENI-enabling commercial equipment from Arista, Cisco, HP, Juniper, and NEC, with software from AT&T Labs and Nicira.

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GENI is designed & built by the community
via an open, transparent, & fair GPO Process

- All design, prototyping, & development is performed by the research community (academia & industry)
  - Working Groups, open to all
    - The locus for all GENI technical design
    - Patterned on the early IETF
    - Discuss by email, create documents, meet 3x per year
    - Each led by Chair(s), plus a professional System Engineer
- Openness is emphasized
  - Design process is open, transparent, and broadly inclusive
  - Open-source solutions are strongly preferred
  - Intellectual property is OK, under no-fee license for GENI use
- GPO is fair and even-handed

GENI Engineering Conferences
Meet every 4 months to review progress together

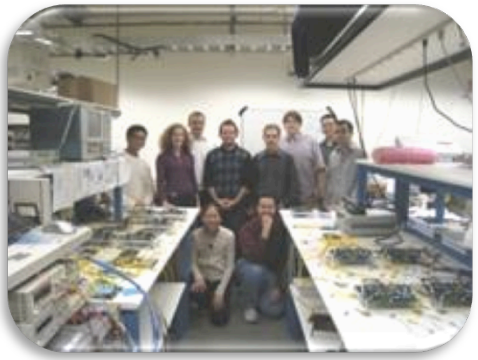
- **8th meeting, open to all:**
  July 20 – 22, 2010, San Diego, CA
  - Team meetings, integrated demos, Working Group meetings
  - Also discuss GPO solicitation, how to submit a proposal, evaluation process & criteria, how much money, etc.
  - **Travel grants** to US academics for participant diversity
- Subsequent Meetings, open to all who fit in the room
  - Held at regular 4-month periods
  - Held on / near university campuses (volunteers?)
  - All GPO-funded teams required to participate
  - Systematic, open review of each Working Group status (all documents and prototypes / trials / etc.)
  - Also time for Working Groups to meet face-to-face
  - Discussion will provide input to subsequent spiral goals

Get involved!

ViSE Team

PlanetLab Team

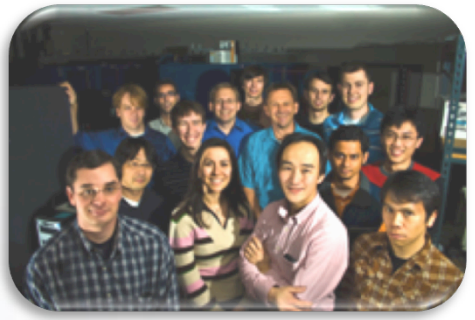
ERM Team



ORCA/BEN Team

GUSH Team

Enterprise GENI Team



GPO points of contact

- Prototyping . . . Aaron Falk: afalk@bbn.com
- Experiments . . . Mark Berman: mberman@bbn.com
- Campus CIOs . . . Heidi Dempsey: hdempsey@bbn.com
- Industry . . . Chip Elliott: celliott@bbn.com

Send team photos to mgillis@bbn.com

GENI is a huge opportunity!

- GENI is rapidly taking shape across the US
- GENI Spiral 2 will . . .
  - get real experiments up and running
  - on a “meso-scale” prototype that spans more than a dozen GENI campuses and 2 backbones
- Get involved!

www.geni.net

Clearinghouse for all GENI news and documents

Control Framework Working Group

GENI Engineering Conference 6
Salt Lake City, UT

System Engineer: Aaron Falk

March 16, 2010

www.geni.net

Sponsored by the National Science Foundation

Working Group Charter

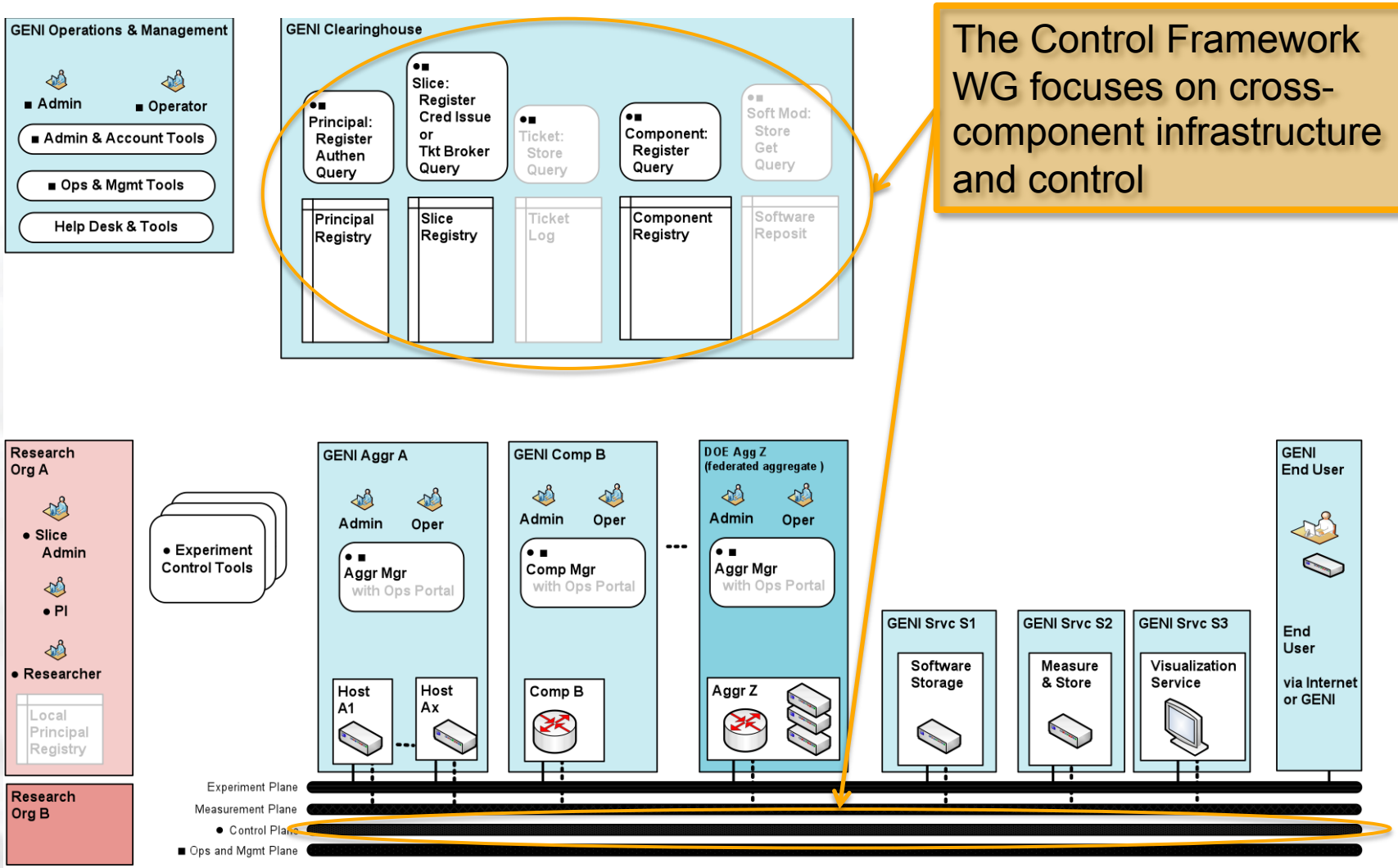
- What is universal across GENI components? How will evolution be accommodated with or without a full transition of all GENI nodes at once?

- http://groups.geni.net/geni/wiki/GeniControl

Working Group Charter (cont.)

- Component control: obtaining and managing resources
- Slice control: interfaces and mechanisms for establishing and controlling slices
- Access control within GENI: usage policy representation and administration mechanisms)
- Interactions external to GENI: federation
- Key enablers: identity, authentication

Relationship to GENI Architecture



Working Group Mechanics

- Chairs: Jeff Chase, Duke University,
  Rob Ricci, University of Utah
- GPO Systems Engineer: Aaron Falk
- Email list to discuss topics of interest
  - Open to all; subscribe via wiki page.
- Working Group wiki
  - Any email list subscriber can contribute to wiki
  - http://groups.geni.net/geni/wiki/GeniControl
- Face-to-face meetings at GECs

Working Group Objectives for Spiral 2

- Define a shared CF-aggregate API
  - Function calls & resource representation
- Two parallel threads of work:
  - Converge APIs of PL and PG control frameworks
    - Reconcile PlanetLab and ProtoGENI naming, credentials, limited compute & network Rspecs
  - Define missing elements elements needed for more general next-gen API
    - Framework for policies, scheduling, more general resource representation

WG Meeting

- Thursday 9:00AM-11:00AM
- Agenda:
  - Common PL-PG AM interface
    (Tom Mitchell, GPO) - 20min
  - Recap of stitching discussion on mailing list: general points of agreement and points of disagreement
    (Aaron Falk, GPO) - 10min
  - Authorization, Trust Management, and Identity Management (Jeff Chase, Duke) - 10 min
  - GENI Federation Scenarios and Requirements
    (Sangjin Jeong, ETRI) - 10 min
  - Panel: Rob Ricci, Jeff Chase, Max Ott, Rob Sherwood, Dave Irwin, John Wroclawski, Justin Cappos - 70 min
    - Candidate topics: federation, authorization, liveness phases

GENI Instrumentation and Measurement Working Group

GENI Engineering Conference 7
Duke University, Durham, NC

GPO System Engineer: Harry Mussman

March 16, 2010

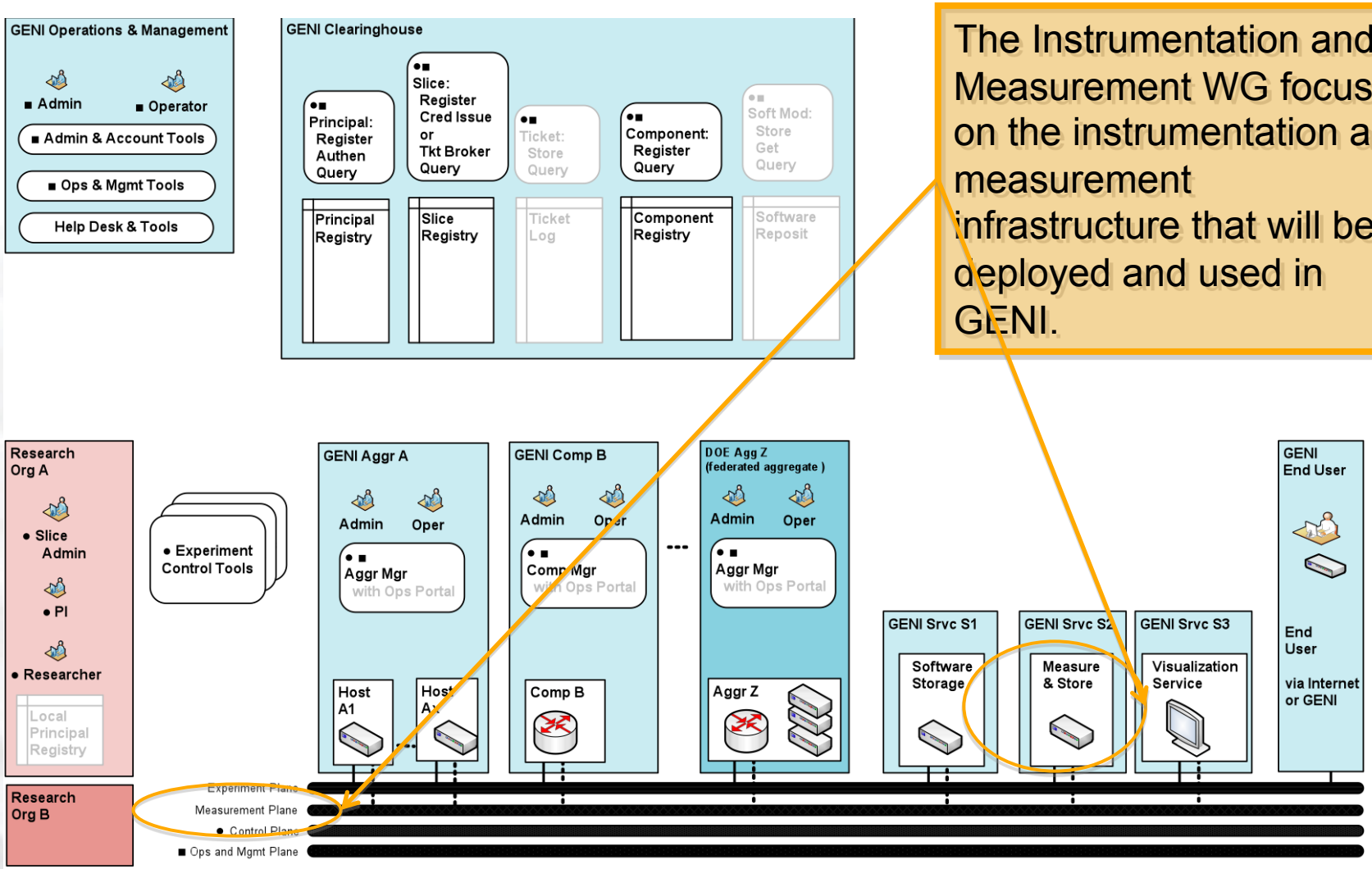
www.geni.net

Sponsored by the National Science Foundation

Instrumentation and Measurement WG Charter

- **Scope:**
  - Discuss, develop and build consensus around the architectural framework for the instrumentation and measurement infrastructure that will be deployed and used in GENI
  - Deploy basic instrumentation and measurement capabilities in GENI Spiral 2

Relationship to GENI Architecture



The Instrumentation and Measurement WG focuses on the instrumentation and measurement infrastructure that will be deployed and used in GENI.

WG Mechanics

- Co-Chairs:
  - Paul Barford, Univ of Wisconsin
  - Bruce Maggs, Duke Univ and Akamai
- GPO Systems Engineer:
  - Harry Mussman
- All announcements, minutes, presentations, etc., on WG wiki page at: http://groups.geni.net/geni/wiki/GeniInstMeas
- Mailing list to discuss topics of interest:
  - Subscribe at: http://lists.geni.net/mailman/listinfo/inst-meas-wg
  - Any mailing list subscriber can contribute to the wiki
- WG meetings at GECs:
  - Meeting at GEC7 on Wed, Mar 17, 3:30pm – 5:30pm

DRAFT WG Objectives for Spiral 2

- Define an architecture for instrumentation and measurement
- Deploy basic instrumentation and measurement capabilities in GENI

WG Meeting at GEC7
Wed, Mar 17, 3:30pm – 5:30pm

- Introductions (5min)
- Major WG issues and goals, by Paul Barford/Univ Wisconsin (15min)
- Short presentations by four I&M projects, covering priority architecture topics: definition and configuration of I&M services; measurement data schema; and measurement plane options (60min)
- Instrumentation Tools (1642), by James Griffioen/U Kentucky
- OMF/OML (1660), by Max Ott/NICTA, Marco Gruteser/Rutgers WINLAB
- perfSONAR for ntwk measurements (1788), by Martin Swany/U Delaware
- DatCat project, by Brad Huffaker/CAIDA at UC SanDiego SuperCompCtr
- GENI I&M Architecture document Harry Mussman/BBN GPO (15min) Review of v0.1 DRAFT, with proposed I&M services and configuration, priority topics and suggested WG discussion topics
- Identify next steps for WG, by Bruce Maggs/Duke U (15min)
- Wrap up, by Harry Mussman/BBN GPO (5min)

Objectives for WG Meeting at GEC7

- Begin discussion of priority architecture topics: definition and configuration of I&M services; measurement data schema; and measurement plane options

- Identify next steps for WG

Campus/OMIS Working Group


Heidi Picher Dempsey

- Chairs: Ivan Seskar, Rutgers University; Jim Williams, Indiana University; Ron Hutchins, Georgia Tech
- GPO Systems Engineer: Heidi Picher Dempsey
- Focus on campus issues for networks, operational issues and security
- Common operational procedures for GENI projects proposed, adopted, documented
- If your project is going to be operational in GENI Spiral 2, you should participate in this working group
- You can present a lightning talk (requests to omis-wg@geni.net)

Campus/OMIS Working Group


Heidi Picher Dempsey

- GEC7 highlights:
  - Emergency Stop functions up for working group approval
  - GENI Concept of Operations up for working group review
  - Campus security requirements discussion
- Email list
  - http://lists.geni.net/mailman/listinfo/omis-wg
- Working Group Wiki page
  - http://groups.geni.net/geni/wiki/GeniOmis
- Agenda for GEC7
  - http://groups.geni.net/geni/wiki/Gec7OmisAgenda

Experimenter Tools and Services Working Group

GENI Engineering Conference 7
Durham, NC

Vic Thomas

16 March 2010

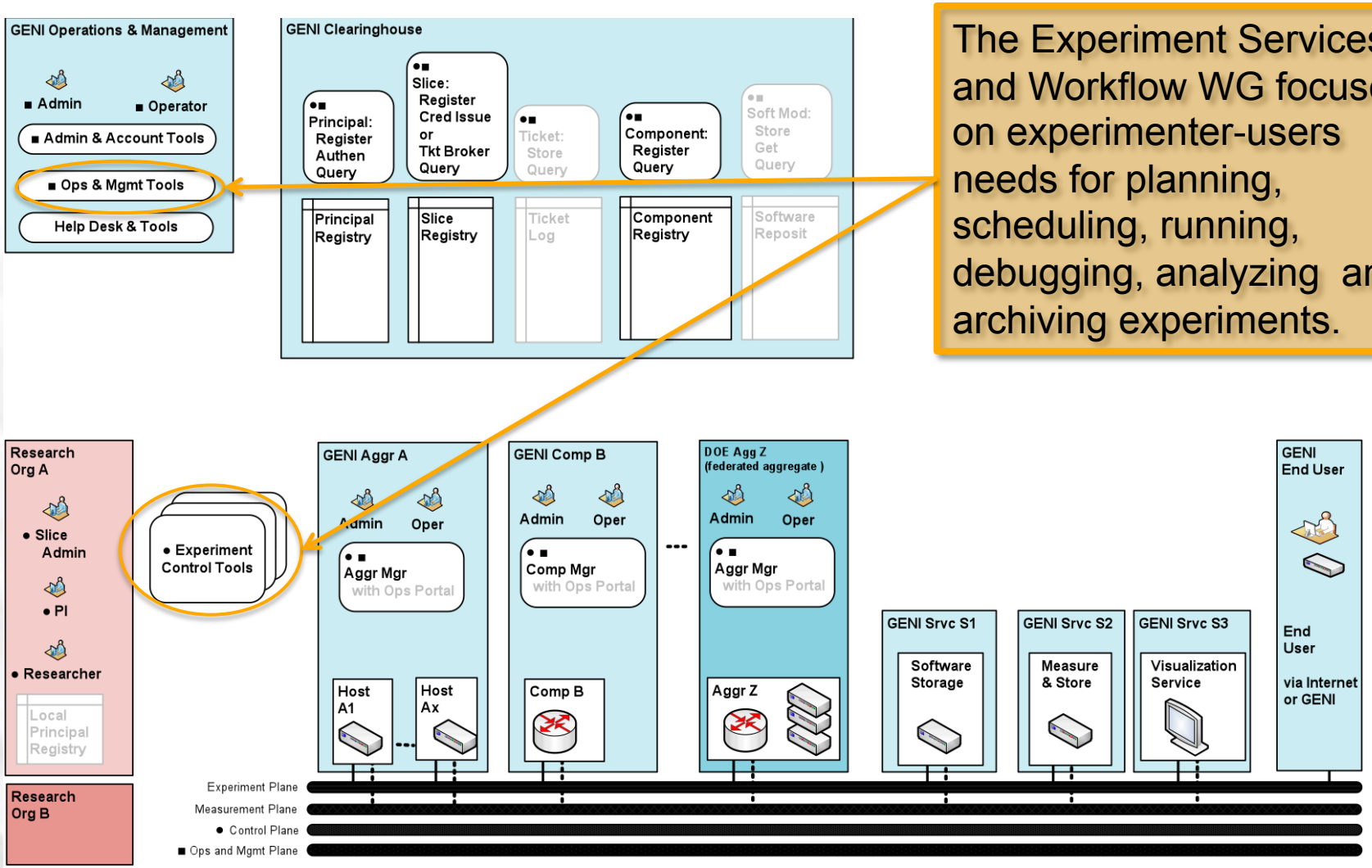
www.geni.net

Sponsored by the National Science Foundation

Working Group Charter

- Identify and specify tools and services needed to run experiments on GENI
  - Planning, scheduling, deploying, running, debugging, analyzing, growing/shrinking experiments
  - Collaboration
    - Multiple researchers on an experiment
    - Building on other experiments
- http://www.geni.net/wg/services-wg.html

Relationship to GENI Architecture



The Experiment Services and Workflow WG focuses on experimenter-users needs for planning, scheduling, running, debugging, analyzing and archiving experiments.

Working Group Mechanics

- Chairs:
  - Prof. Jeannie Albrecht, Williams College
  - Prof. Jim Griffioen, University of Kentucky
- GPO Systems Engineer: Vic Thomas
- Email list to discuss topics of interest
  - Open to all
  - Subscribe at URL on previous slide
- Working Group Wiki page
  - http://groups.geni.net/geni/wiki/GeniServices
  - Any email list subscriber can contribute to wiki
- Face-to-face meetings at GECs

Working Group Objectives for Spiral 2

- Support early experiments/experimenters on GENI
  - Make experimentation as easy as possible for these pioneers
- Spiral 2 priorities
  - Understand experimenter's needs
  - Identify tools and services they will need
  - Work with control frameworks and tool developers to support experimenter needs as best we can
- Longer term objectives
  - Develop requirements and specifications for experimenter tools and services
  - Define requirements imposed on other GENI sub-systems

- Thursday March 18 at 9am
- Agenda:
  - ~5 minutes - Opening remarks (James Griffioen)
  - ~10 minutes - Experiment scenarios of interest to four year colleges and minority institutions (Paoli Wognakou)
  - ~15 minutes - *New* control framework features for running/describing experiments.
    - ProtoGENI (Robert Ricci)
    - ORBIT (Max Ott)
    - ORCA (Anirban Mandal)
  - ~50 minutes - Tools update: Experimenter tools that are already working and available
    - PlanetLab Tools (Jeannie Albrecht)
    - ProtoGENI Measurement Tools (Jim Griffioen/Charles Thomas)
    - TIED tools (Ted Faber)
    - Orbit tools (Max Ott)
    - Million Node GENI tools (Justin Cappos)
  - ~15 minutes - Services update: What services are available and, more importantly, how do we use them?
    - ABAC Service (Steve Schwab/Jay Jacobs)
  - ~15 minutes - Wrap-up and discussion (Jeannie Albrecht)

Meeting Objectives

- Understand current tool/service capabilities
- New control framework features available to tool/service developers