



GENI

Exploring Networks of the Future

An introduction

GENI Project Office
November 2009
www.geni.net



Sponsored by the National Science Foundation

- I Dream of GENI: History and Concept
 - How we'll use it; how we'll build it (Two Comic Books)
 - The GENI system concept
- GENI Spiral 1 (complete)
- GENI Spiral 2 (underway)
- Looking Ahead
- 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



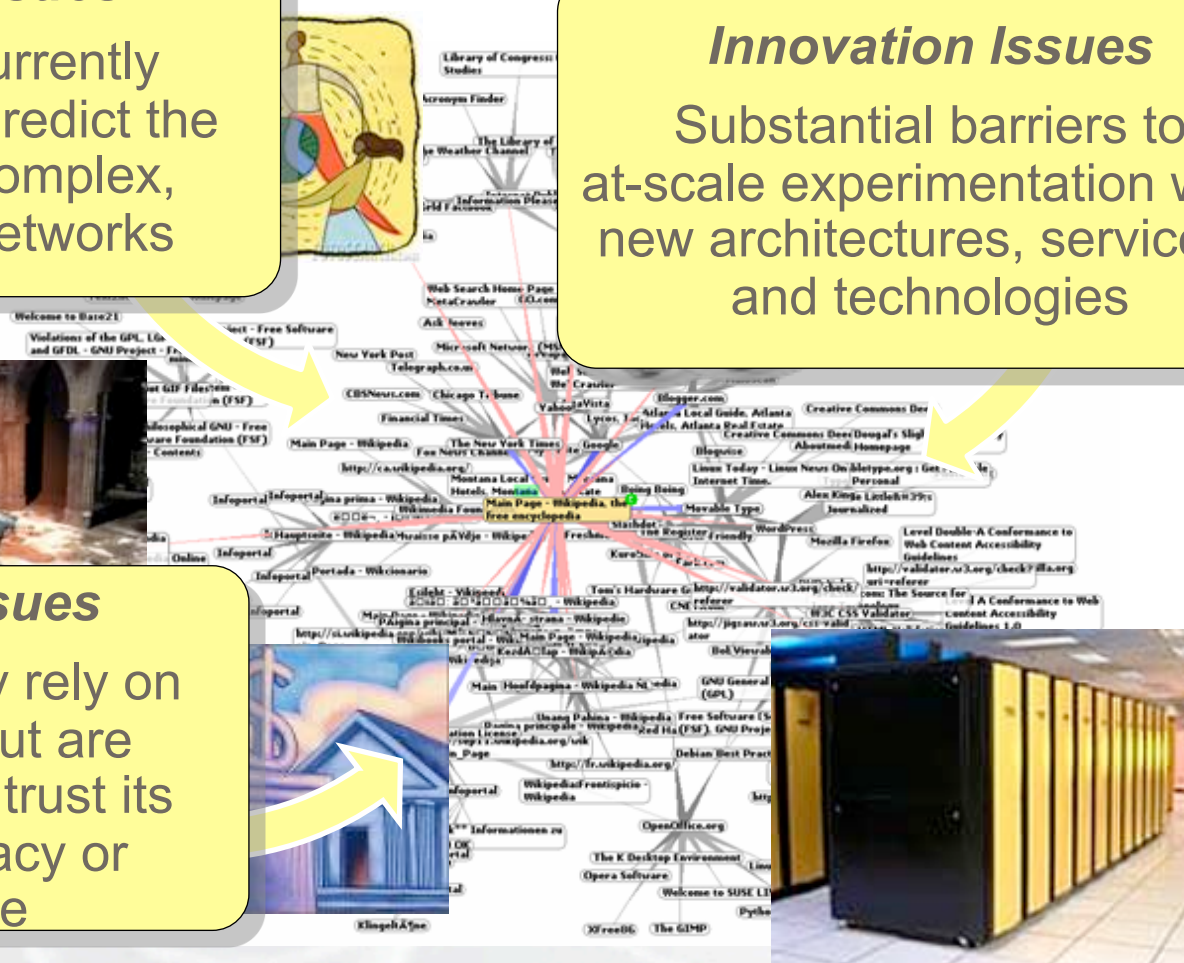
Innovation Issues

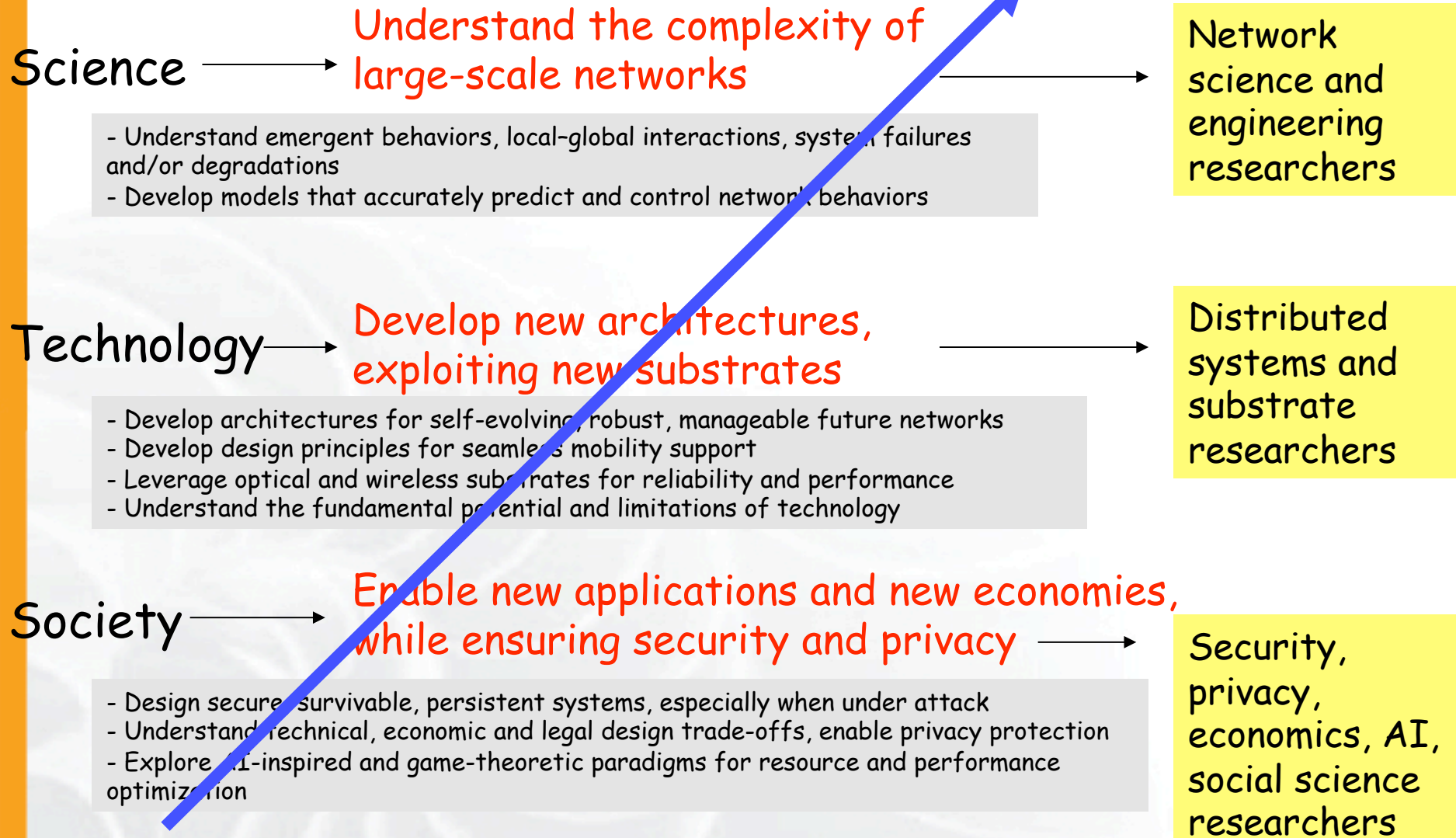
Substantial barriers to at-scale experimentation with new architectures, services, and technologies



Society Issues

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

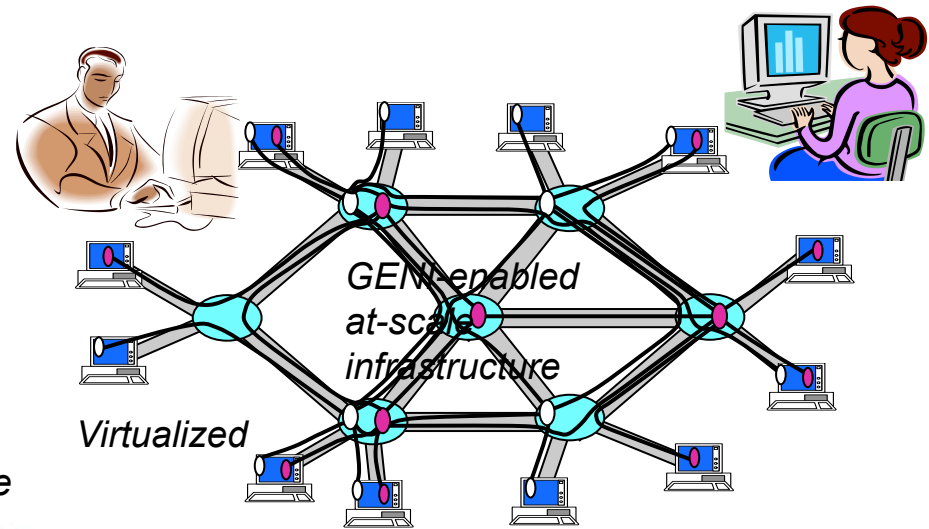
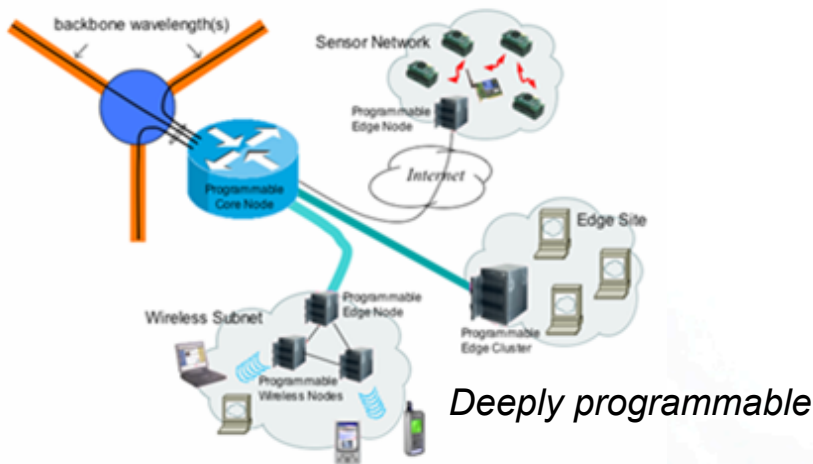




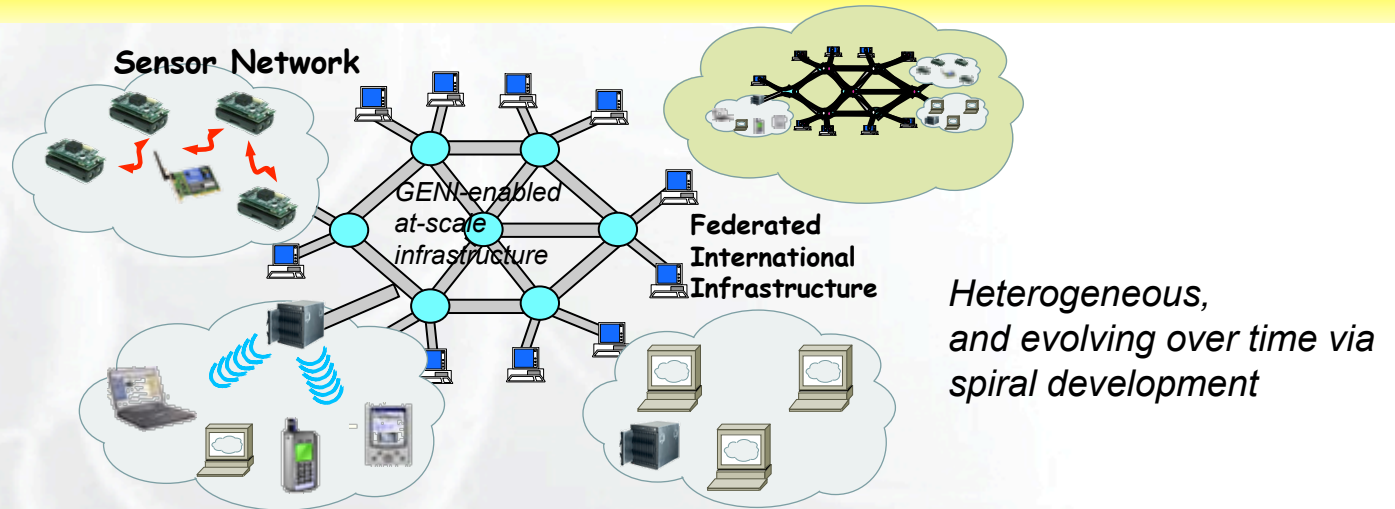
- GENI is a virtual laboratory for exploring future internets at scale.
- GENI creates major opportunities to *understand, innovate, and transform* global networks and their interactions with society.
- GENI opens up new areas of research at the frontiers of network science and engineering, and increases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

GENI Conceptual Design

Infrastructure to support at-scale experimentation



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



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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!

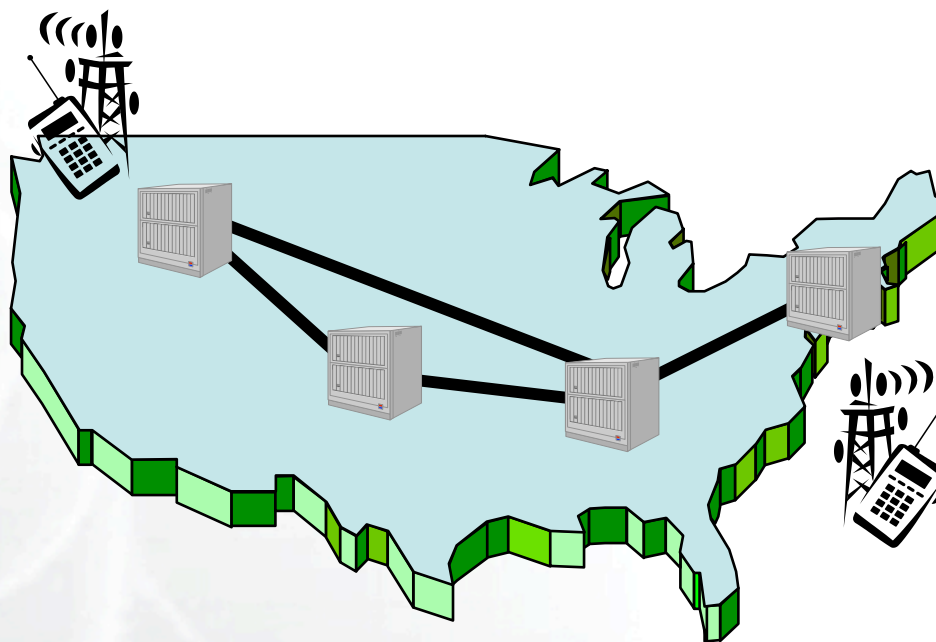
*That will never work! It won't scale!
What about security? It's impossible
to implement or operate! Show me!*





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

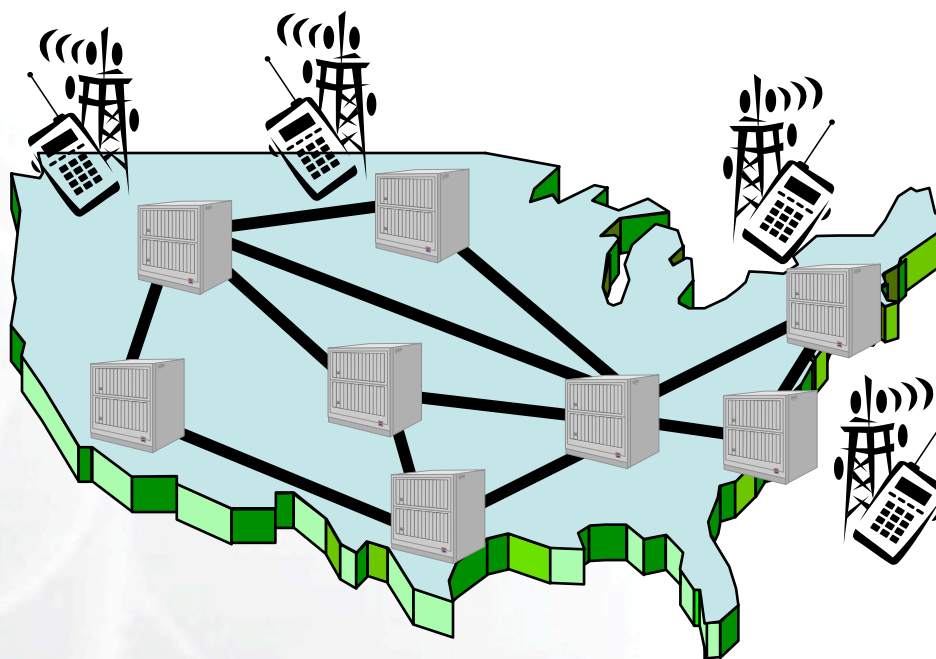


Boy did I learn a lot! I've published papers, the architecture has evolved in major ways, and I'm even attracting real users!

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

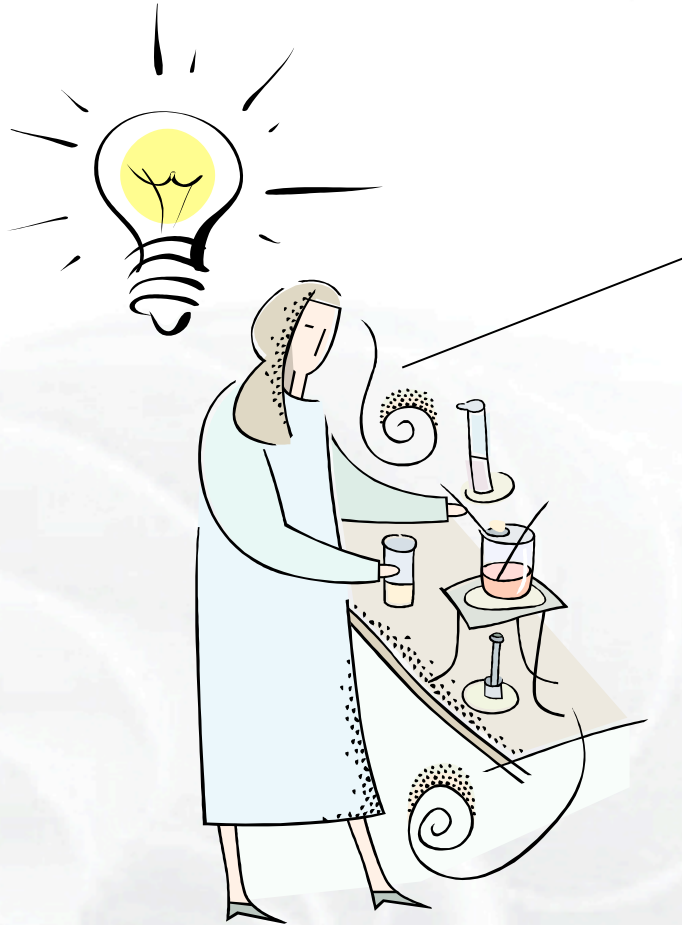


My experiment was a real success, and my architecture turned out to be mostly compatible with today's Internet after all – so I'm taking it off GENI and spinning it out as a real company.

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.

- GENI is meant to enable . . .
 - Trials of new architectures, 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

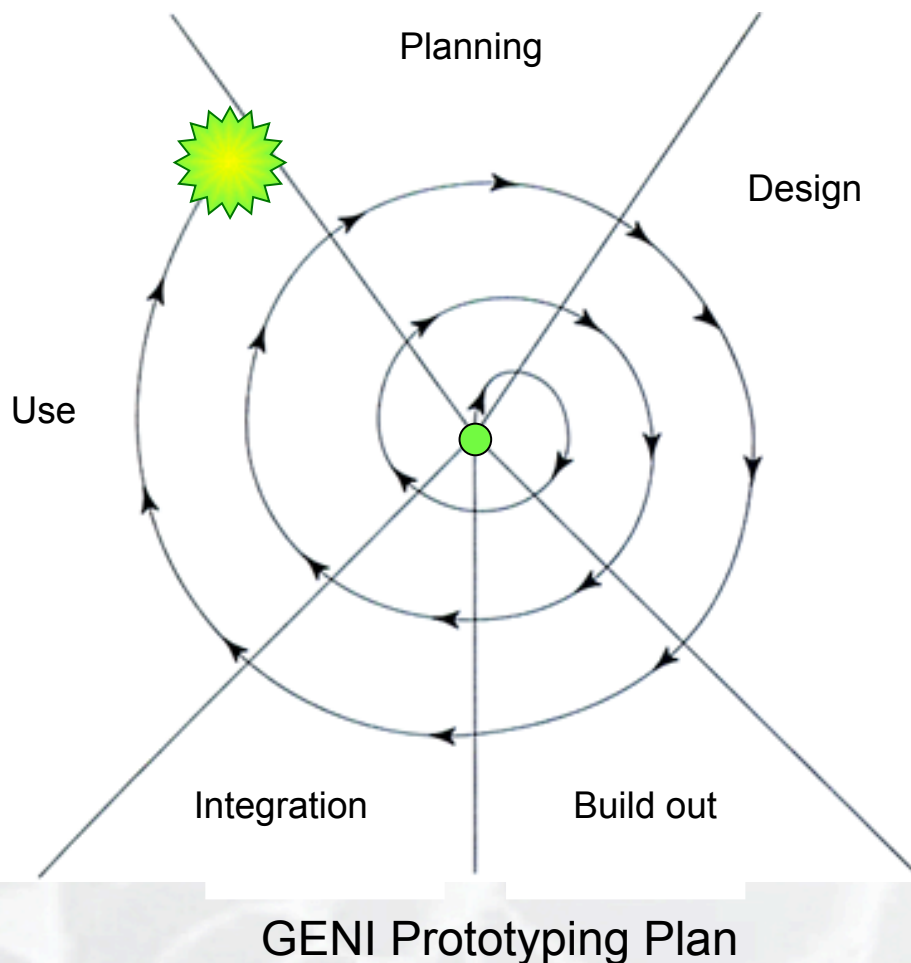
Note that this is the “classics illustrated” version – a comic book!

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

Spiral 2 Overview & Meso Scale Plan coming soon!

Spiral Development

GENI grows through a well-structured, adaptive process



- An achievable **Spiral 1**

Rev 1 control frameworks, federation of multiple substrates (clusters, wireless, regional / national optical net with early GENI 'routers', some existing testbeds), Rev 1 user interface and instrumentation.



- Envisioned **ultimate goal**

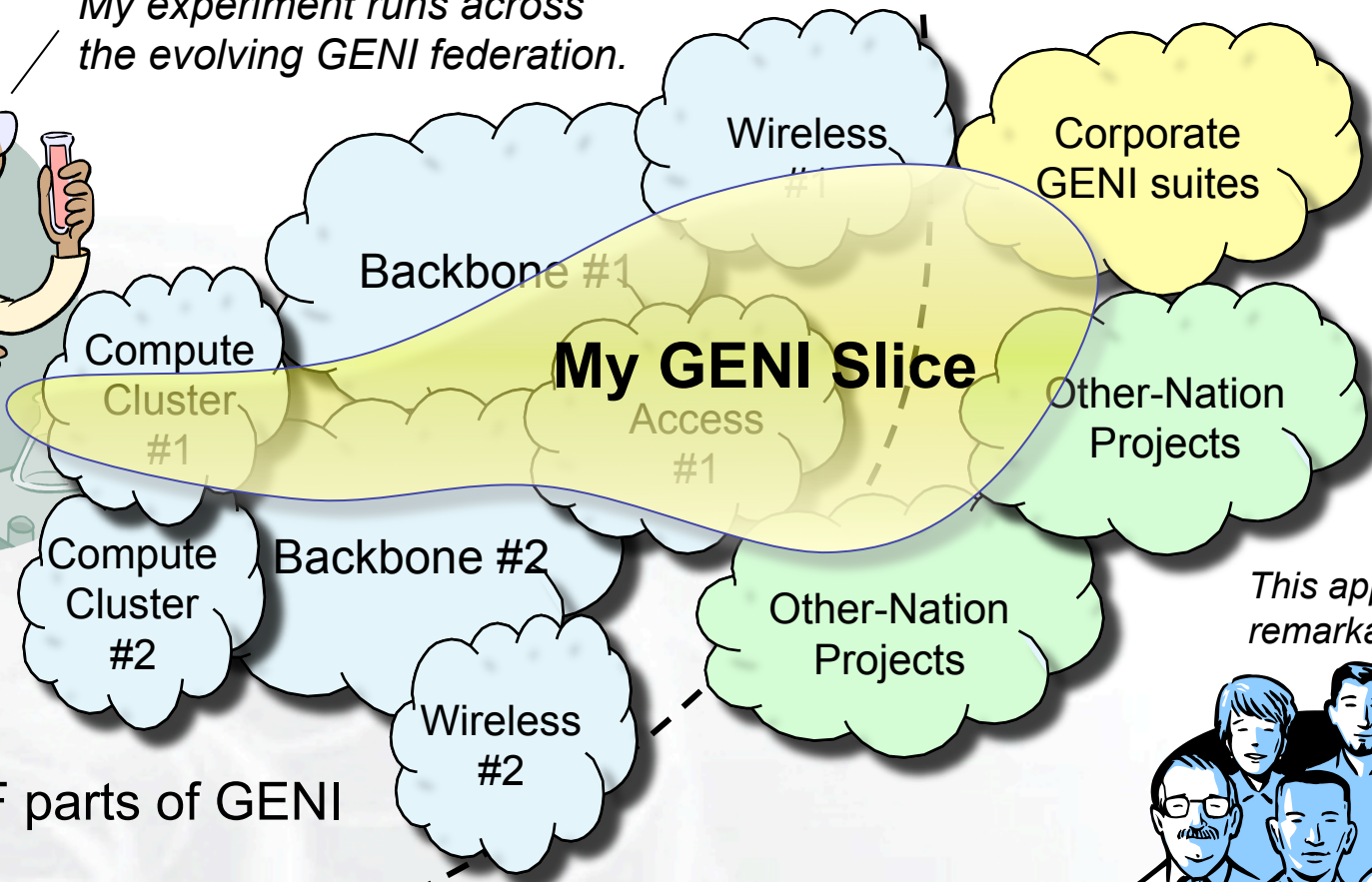
Example: Planning Group's desired GENI suite, probably trimmed some ways and expanded others. Incorporates large-scale distributed computing resources, high-speed backbone nodes, nationwide optical networks, wireless & sensor nets, etc.

- **Spiral Development Process**

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

GENI grows by integrating heterogeneous infrastructure

My experiment runs across the evolving GENI federation.



NSF parts of GENI

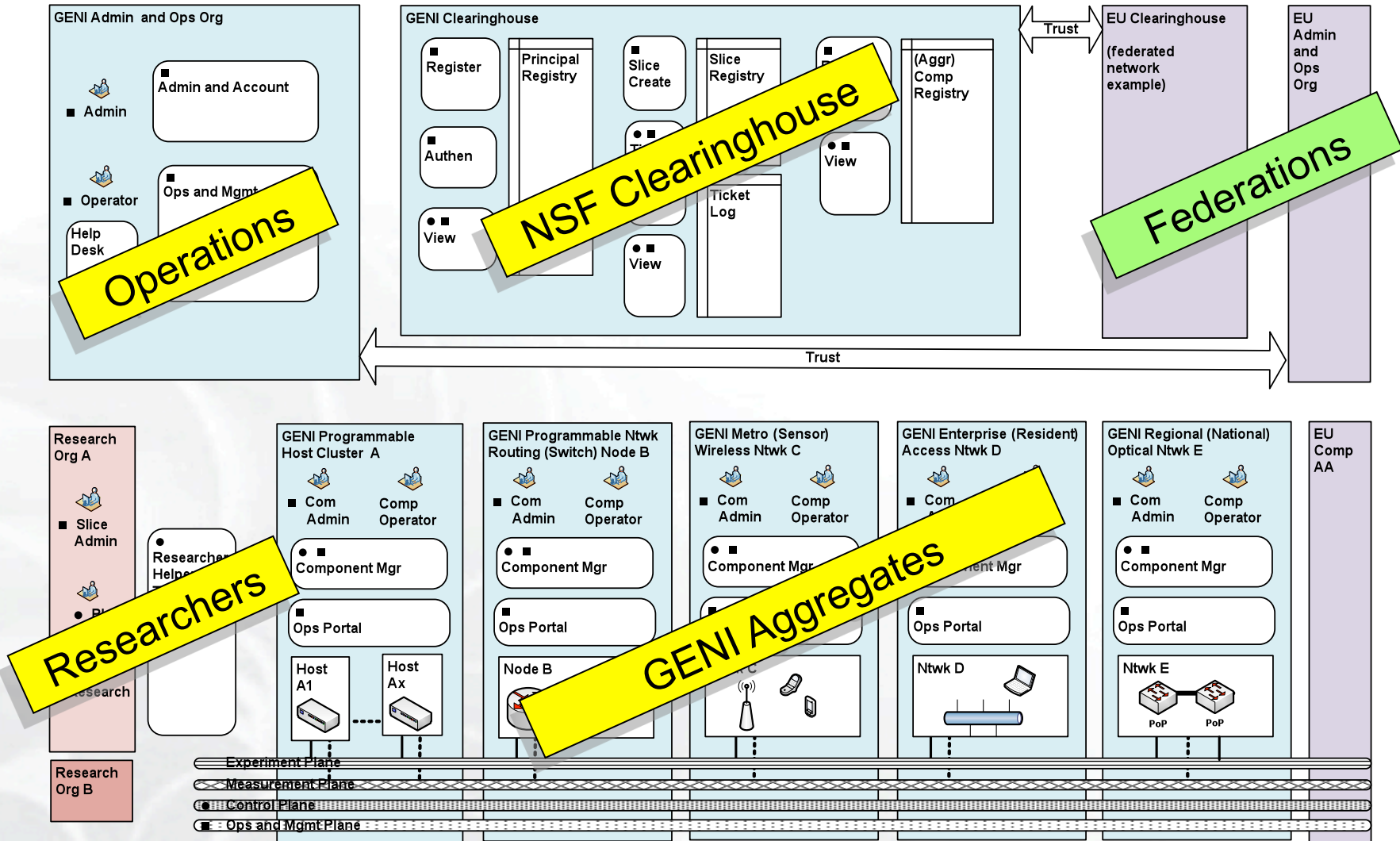
This approach looks remarkably familiar . . .



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

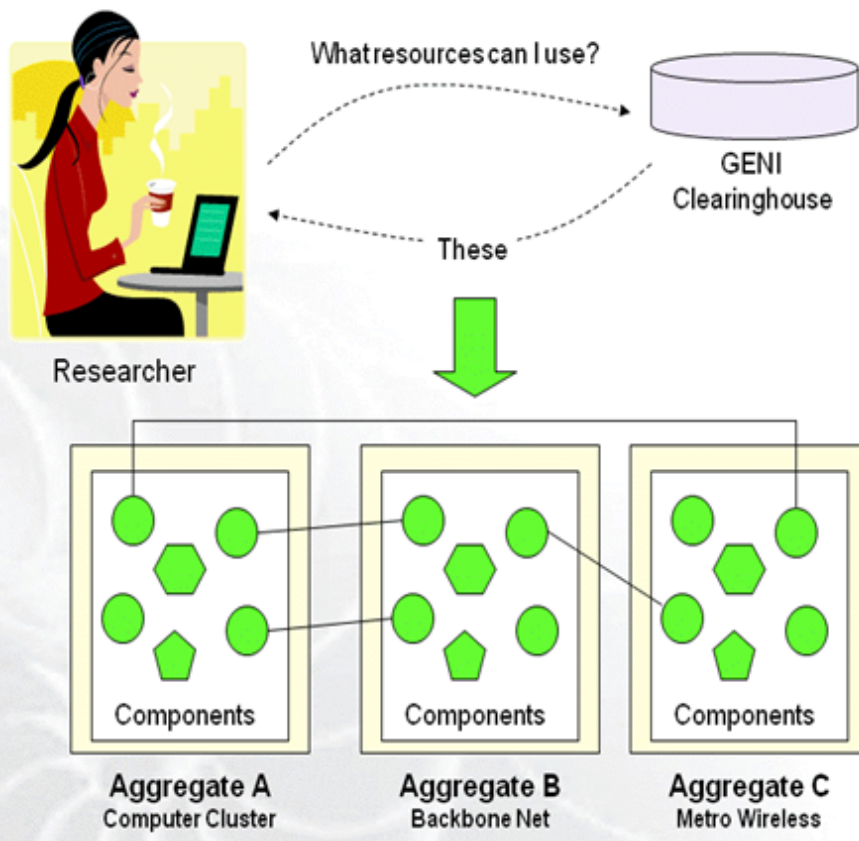
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 - **The GENI system concept**
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GENI System Diagram (simplified)



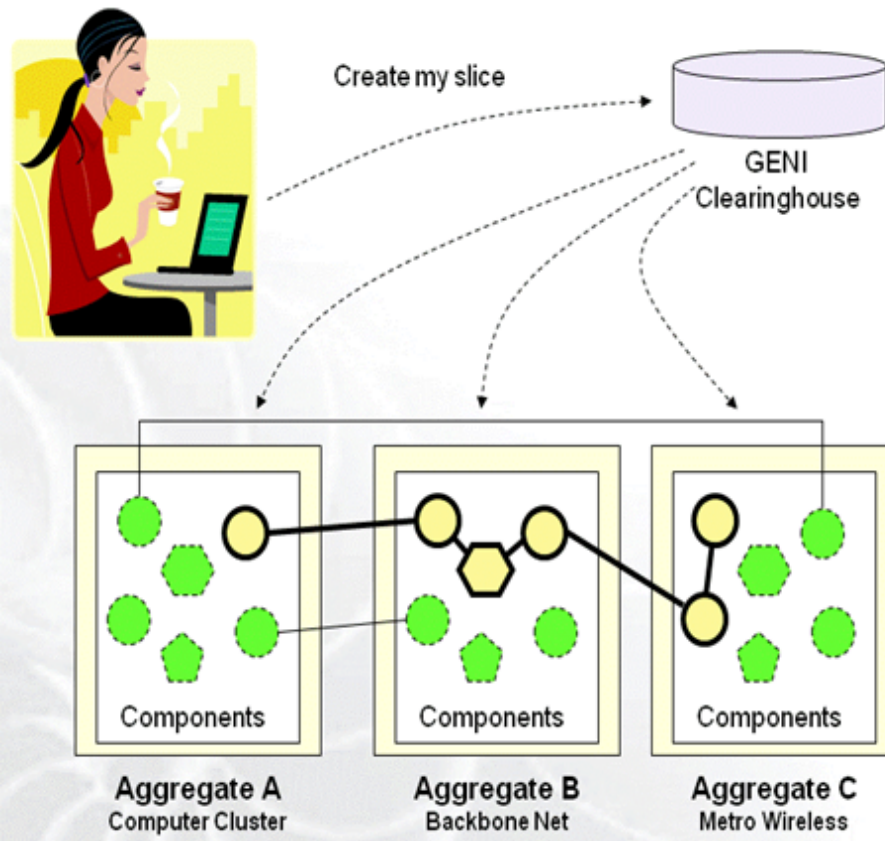
Resource discovery

Aggregates publish resources, schedules, etc., via clearinghouses



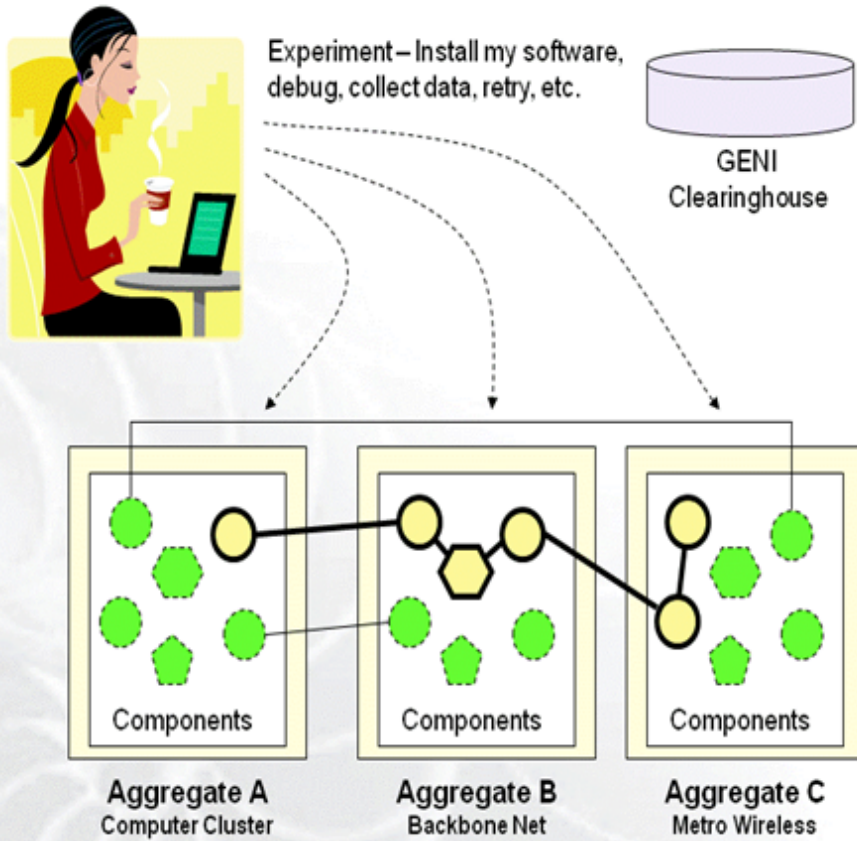
Slice creation

Clearinghouse checks credentials and enforces policy; aggregates allocate resources and create topologies



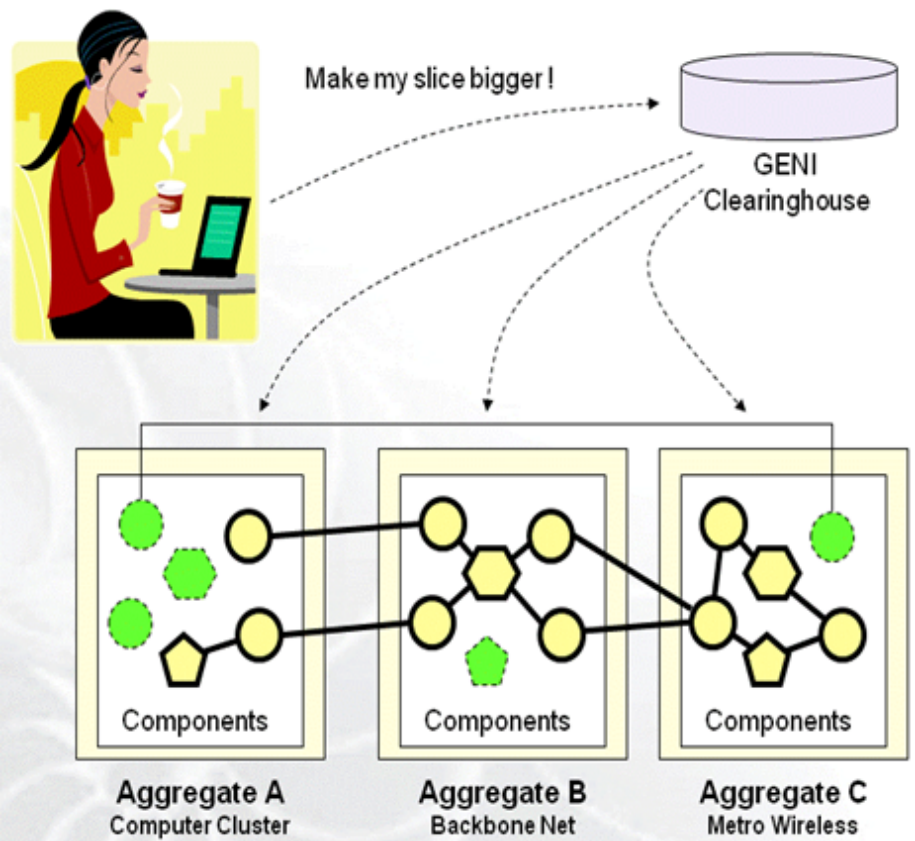
Experimentation

Researcher loads software, debugs, collects measurements



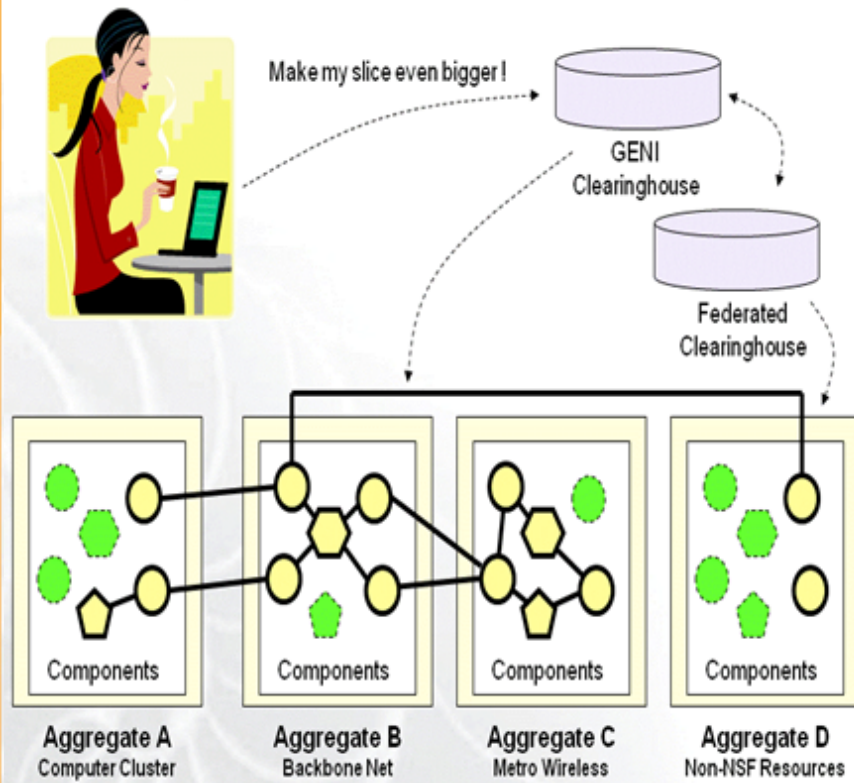
Slice growth & revision

Allows successful, long-running experiments to grow larger



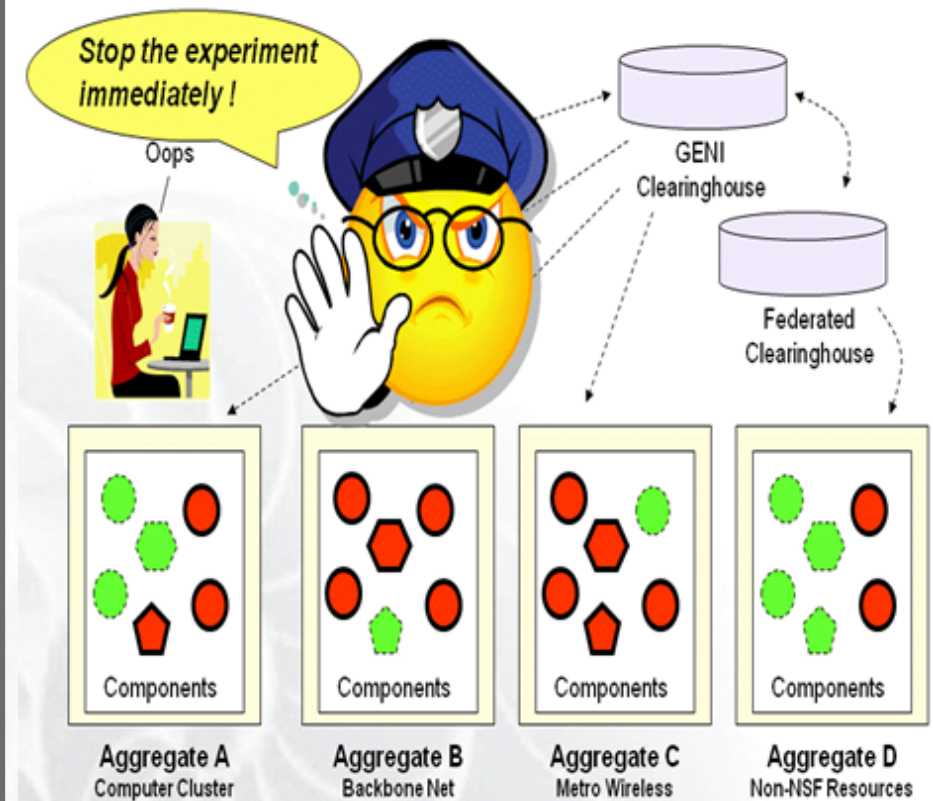
Federation of Clearinghouses

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



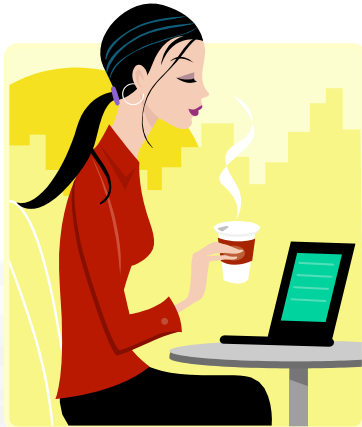
Operations & Management

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

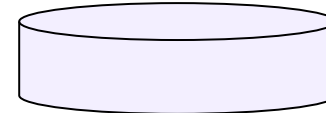


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Key goals achieved in GENI Spiral 1



Create my slice



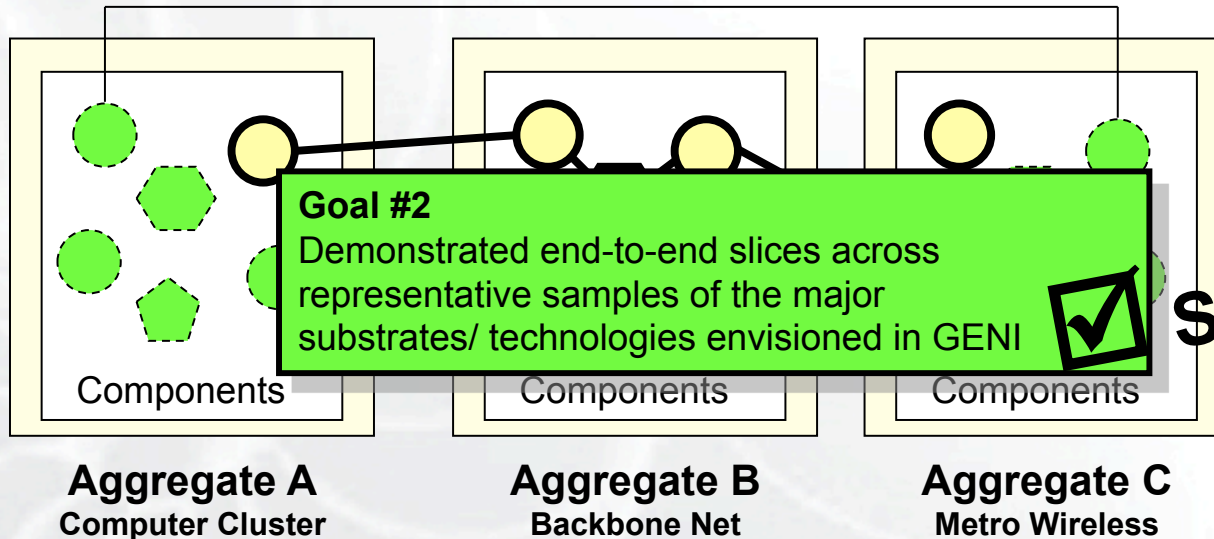
GENI
Clearinghouse

Goal #1

Funded multiple, competing technologies/
teams to develop GENI Clearinghouse
technology, encouraged strong
competition within the first few spirals



Success!



Goal #2

Demonstrated end-to-end slices across
representative samples of the major
substrates/ technologies envisioned in GENI



Success!

Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless

Infrastructure examples in Spiral 1



DRAGON core nodes
Mid-Atlantic Crossroads



WAIL, U. Wisconsin-Madison



DieselNet, U. Mass Amherst



ViSE,
U. Mass Amherst



SPPs, Wash U.



ORBIT, Rutgers WINLAB

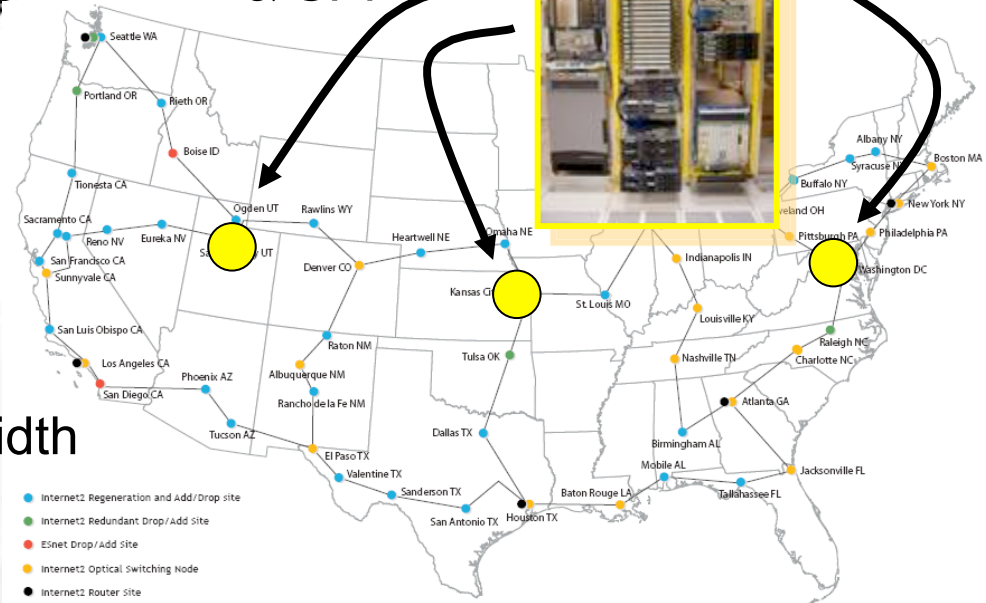
World-class expertise in GENI Partners Internet2 and National Lambda Rail



Internet2

10 Gbps dedicated bandwidth

ProtoGENI
& SPP



National Lambda Rail

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)

- Provided the very first, national-scale prototype of an interoperable infrastructure suite for Network Science and Engineering experiments.
- Created the earliest GENI prototype with broad academic and industrial participation.
- Interconnected national backbones and regional optical networks, campuses, compute and storage clusters, metropolitan wireless and sensor networks, instrumentation and measurement.

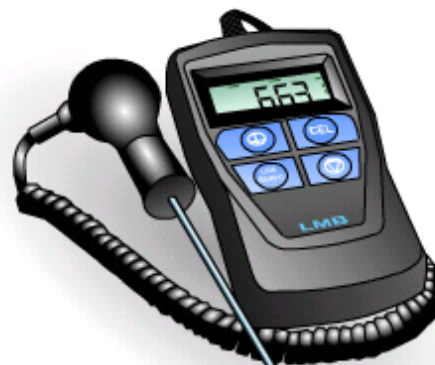
Nothing like GENI has ever existed; the projects in Spiral 1 have created an integrated, end-to-end, virtualized, and sliceable infrastructure suite.

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Welcome to Spiral 2!



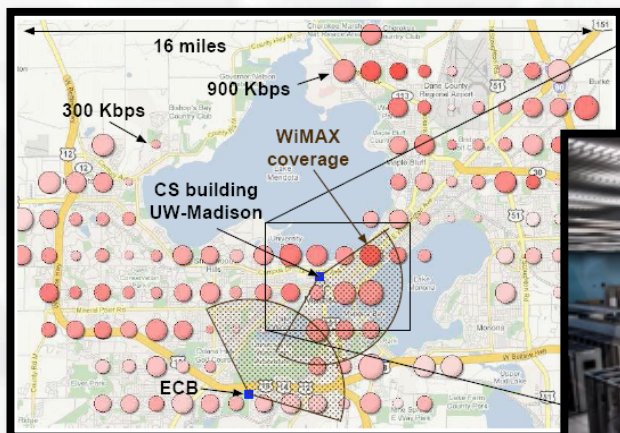
Software Tools



Measurement & Archival

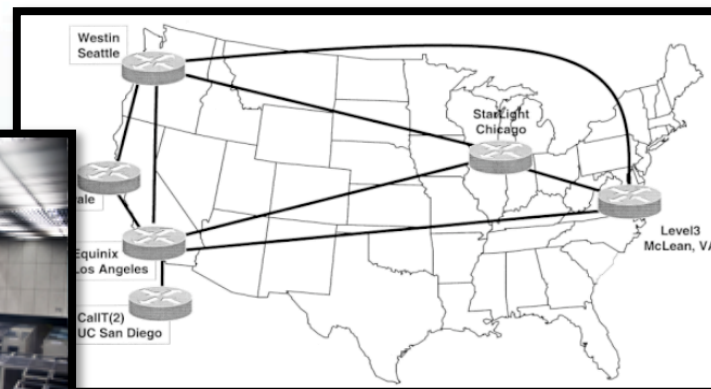


Security Expertise



Outdoor testbeds

Clouds



Lightpaths

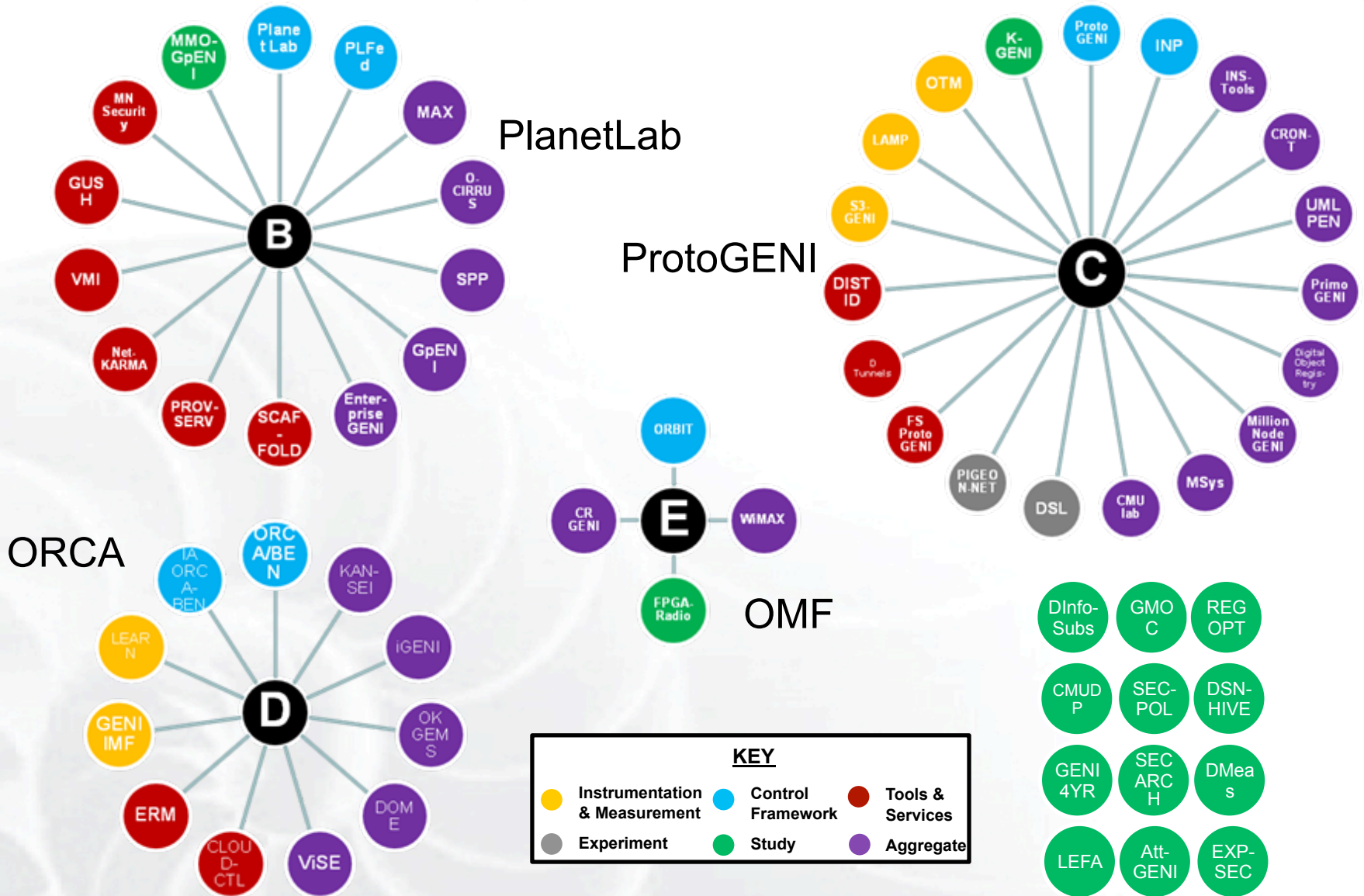


Spiral 2 Academic-Industrial Teams

Project Name	Project Lead	Project Participants
1. CMUlab	Carnegie Mellon University	Columbia University
2. D Meas, LEARN	University of Houston	
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 UC San Diego
10. GushProto	Williams College	
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 University of Colorado, Boulder, CO University of Massachusetts, Amherst University of Wisconsin, Madison, WI
		Columbia University, NY, NY Polytechnic University of NYU, Brooklyn, NY
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	Battelle 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
		University of Illinois Chicago Internet2 Brown University
35. IGENI	Northwestern University	
36. LAMP	University of Delaware	
37. LEFA, Supercharged Planetlab	Internet2	
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



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

First experimenters to try out GENI Thank you, brave pioneers !

- **Dr. Ed Birrane**, Johns Hopkins APL
 - Spacecraft Data and Relay Management using Delay Tolerant Networking
- **Prof. Jiang Li**, Howard University
 - Opportunistic Mobile Wireless Networks
- **Prof. Nirmala Shenoy**, RIT
 - A Floating-Cloud Tiered Internet Architecture
- **Prof. Felix Wu**, UC Davis
 - Davis Social Links

If you want to try out experiments on GENI, we'll help!
Please contact Mark Berman (mberman@bbn.com)

Building the GENI Meso-scale Prototype

Current plans for locations & equipment

OpenFlow

- Stanford
- U Washington
- Wisconsin
- Indiana
- Rutgers
- Princeton
- Clemson
- Georgia Tech

WiMAX

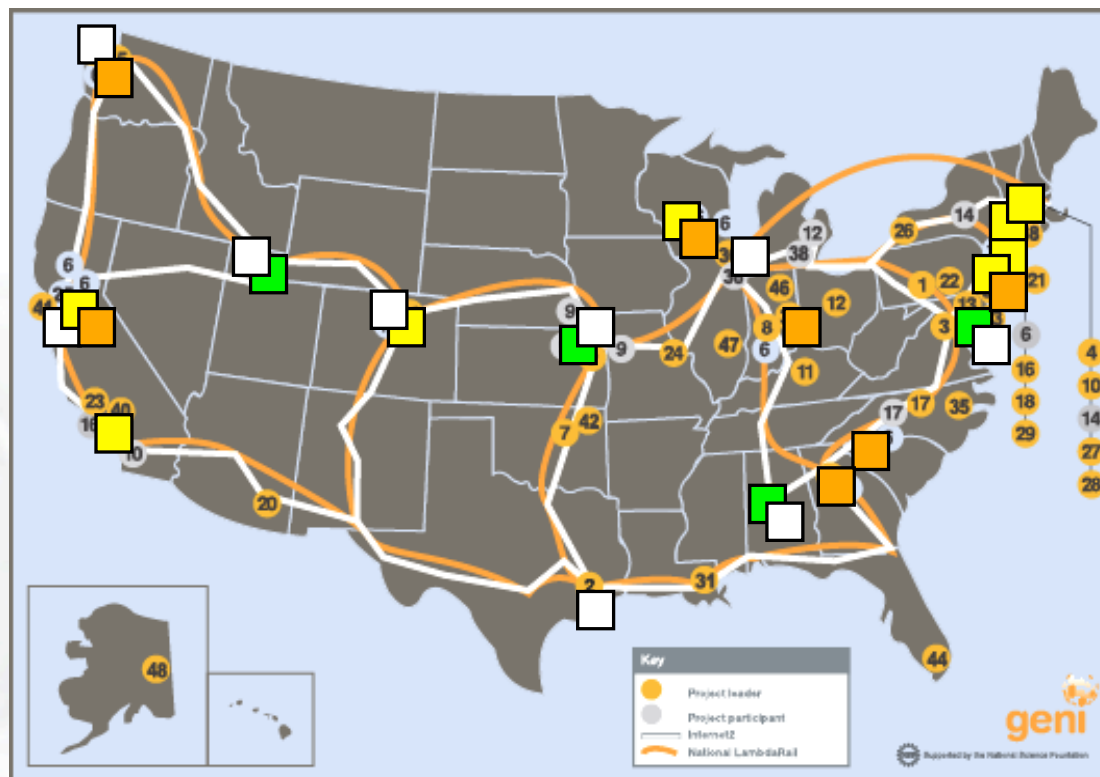
- Stanford
- UCLA
- UC Boulder
- Wisconsin
- Rutgers
- Polytech
- UMass
- Columbia

ShadowNet

- Salt Lake City
- Kansas City
- DC
- Atlanta

OpenFlow Backbones

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



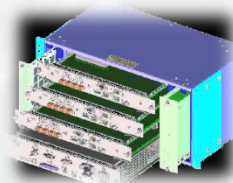
HP ProCurve 5400 Switch



Juniper MX240 Ethernet Services Router



Arista 7124S Switch



NEC WiMAX Base Station



Cisco 6509 Switch



NEC IP8800 Ethernet Switch

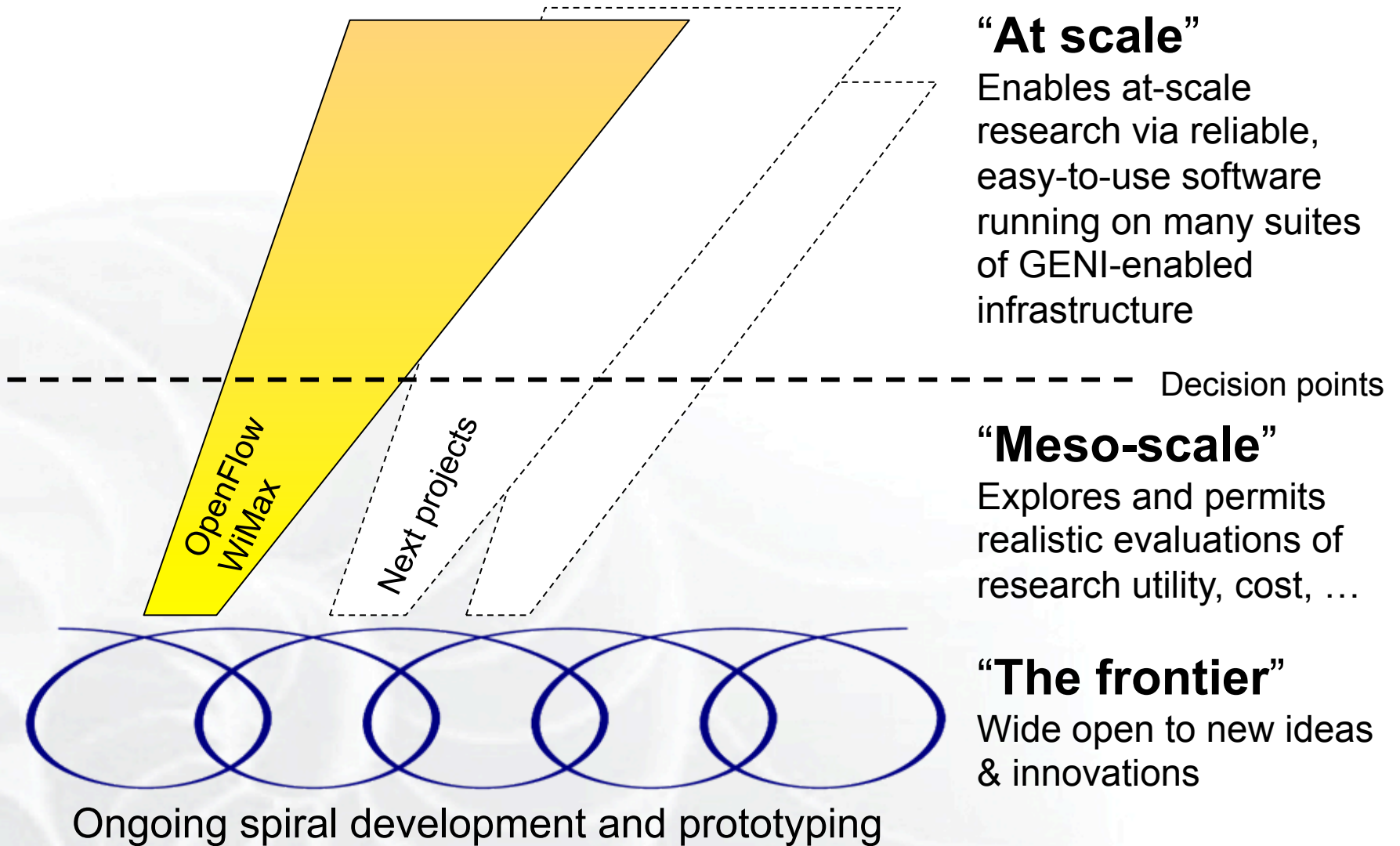
Spiral 2 accelerates GENI's roll-out

- 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 Project Plan – Current approach

We'd like feedback, questions, & suggestions



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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

- **7th meeting, open to all:**
March 16–18, 2010, RENCI, Chapel Hill, NC
 - 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

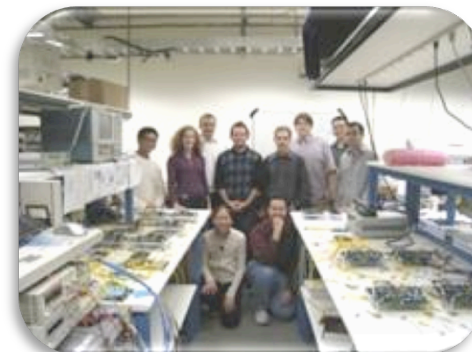
ViSE Team



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: Christopher Small

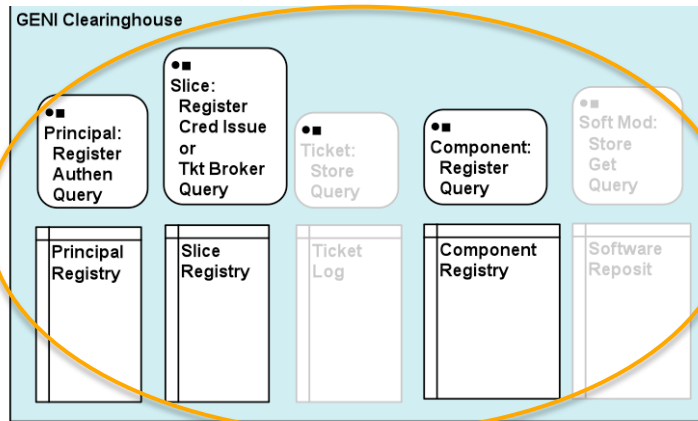
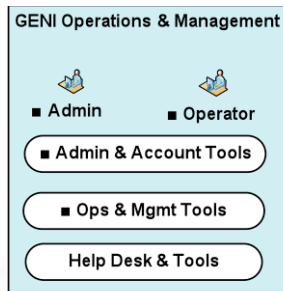
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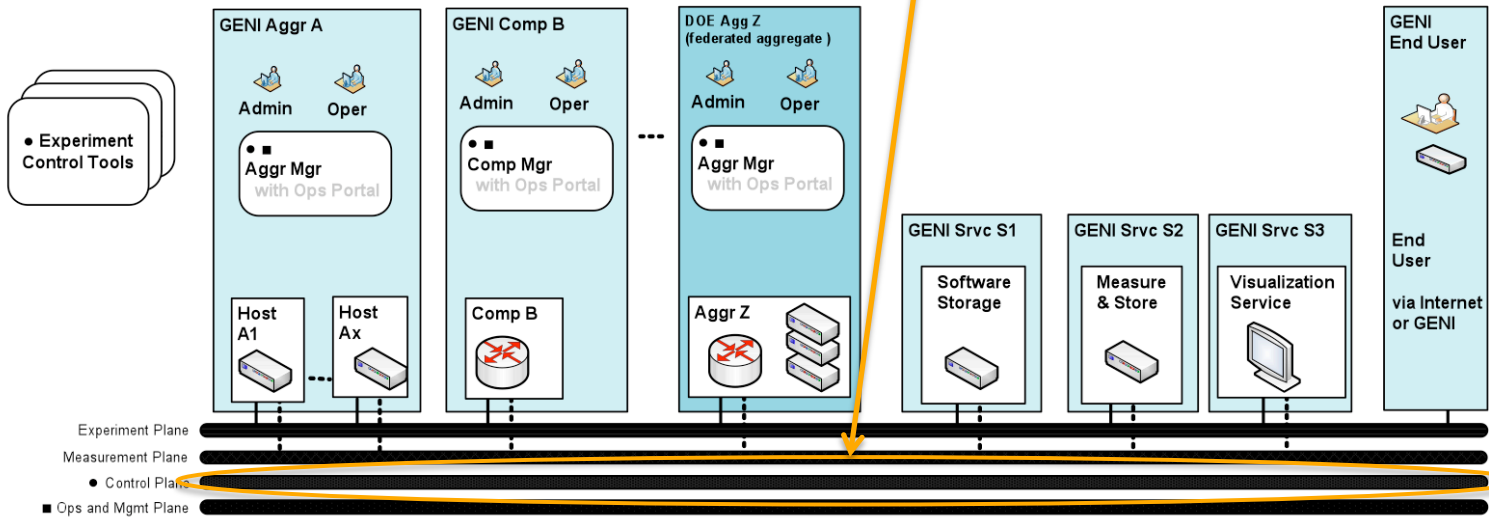
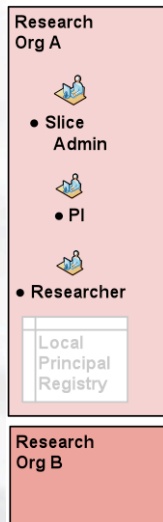
- **What is universal across GENI components?
How will evolution be accommodated with or
without a full transition of all GENI nodes at
once?**
- **<http://groups.geni.net/geni/wiki/GeniControl>**

- **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



The Control Framework WG focuses on cross-component infrastructure and control



- **Chairs: Jeff Chase, Duke University,
Rob Ricci, University of Utah**
- **GPO Systems Engineer: Christopher Small**
- **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**

- **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 needed for more general next-gen API**
 - Framework for policies, scheduling, more general resource representation

- **Wednesday 9:00AM-11:00AM**

- **Agenda:**

- 9:00AM-9:30AM Framing talks
 - Rob Ricci (Utah) – *Current approaches to resource representation*
 - Guido Appenzeller (Stanford) – *Spiral One integration experiences*
 - Jeff Chase (Duke) – *Next-generation need for scheduling, stitching, and resource representation*
 - Steve Schwab (SPARTA) – *Next-generation need for identity and authentication services*
- 9:30AM-10:30AM Panel discussion
 - Guido Appenzeller, Andy Bavier, Jeff Chase, Aaron Falk, Rob Ricci, Steve Schwab, Ivan Seskar
- 10:30AM-11:00AM Wrap-up and next steps

- **Introduce working group to the major goals of Spiral Two, and begin work on accomplishing these goals.**

GENI Instrumentation and Measurement Working Group

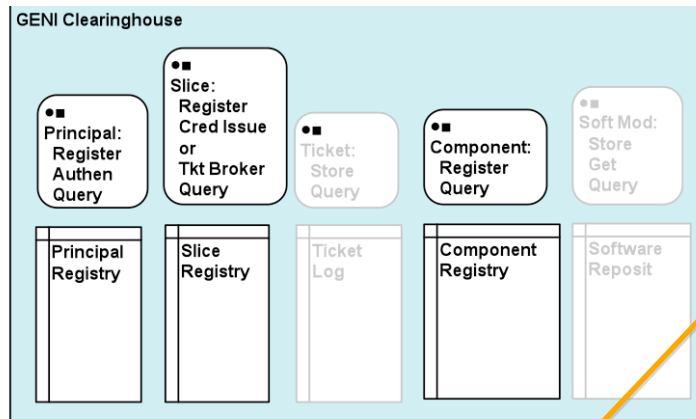
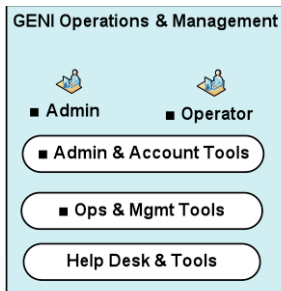
**GENI Engineering Conference 6
Salt Lake City, UT**



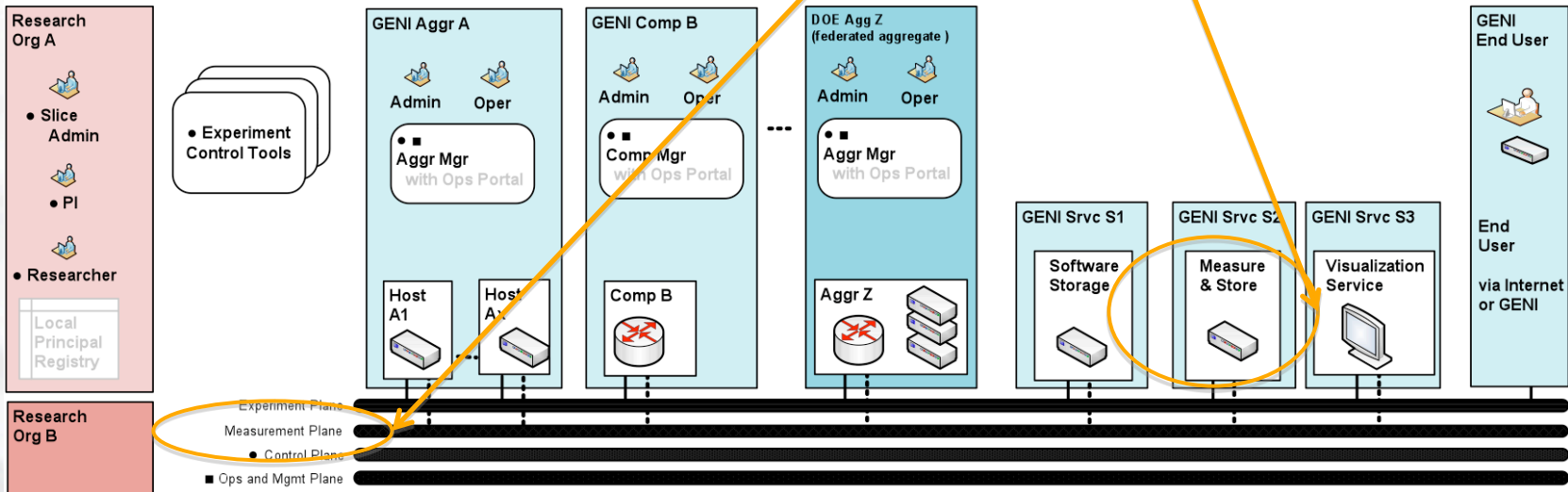
GPO System Engineer: Harry Mussman
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- **Scope:**
 - **Discuss, develop and build consensus around the architectural framework for the instrumentation and measurement infrastructure that will be deployed and used in GENI**
 - **Deploy minimal instrumentation and measurement capability 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.



- **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/GenInstMeas>**
- **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 GEC6 on Wed, Nov 18, 9am – 11am

- **Define an architecture for instrumentation and measurement, and its relationship to the control framework**
- **Deploy minimal capability in GENI Spiral 2**

- Welcome and introduction, by Paul Barford (10min)
- Initial view of WG Objectives for Spiral 2 , by Paul Barford (10min)
- Short presentations by Spiral 2 projects involving instrumentation and measurement design and prototyping: (60min)
- [Instrumentation and Measurement for GENI \(1628\)](#) PI: Paul Barford
- [Instrumentation Tools for a GENI Prototype \(1642\)](#) PI: James Griffioen
- [OnTimeMeasure \(1764\)](#) PI: Prasad Calyam
- [Leveraging and Abstracting Measurements, perfSONAR \(1788\)](#) PI: Martin Swany
- [Scalable, Extensible, and Safe Monitoring of GENI \(1723\)](#) PI: Sonia Fahmy
- [Virtual Machine Introspection and ... for GENI \(1773\)](#) PI: Kara Nance
- [Embedding real-time substrate measurements \(1631\)](#) PI: Keren Bergman
- [Programmable Measurements over LEARN \(1733\)](#) PI: Deniz Gurkan
- [Integrated Measurement Framework \(1718\)](#) PI: Rudra Dutta
- [ORBIT measurements arrangement \(1660\)](#) PI: Marco Gruteser
- Discussion of WG Objectives for Spiral 2, by Paul Barford (30min)
- Wrap up, by Harry Mussman (10min)

Objectives for WG Meeting at GEC6

- **Short presentations by Spiral 2 projects involving instrumentation and measurement design and prototyping**
- **Build consensus on WG Objectives for Spiral 2**

Experimenter Tools and Services Working Group

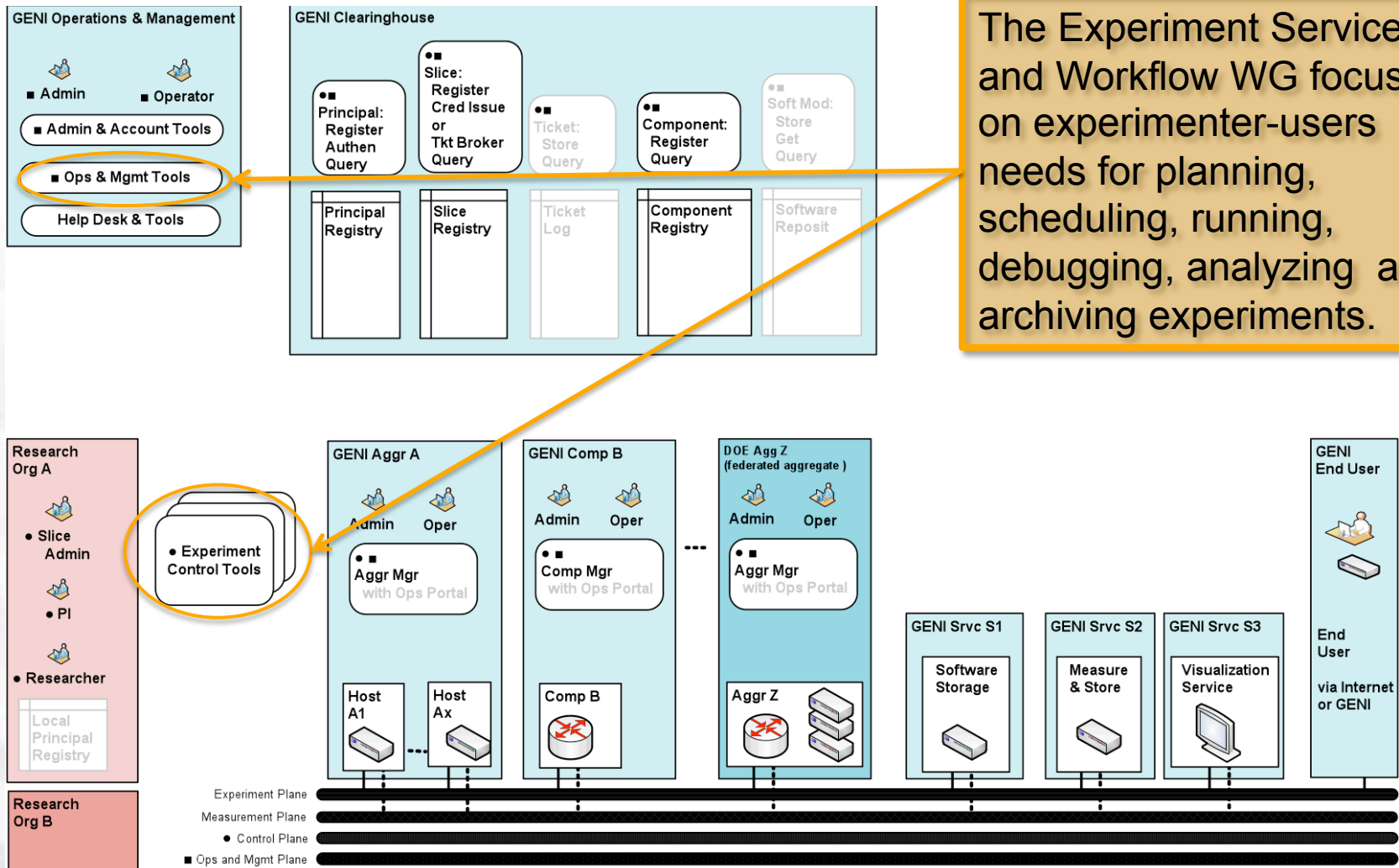
GENI Engineering Conference 6
Salt Lake City, UT



Vic Thomas
Nov. 16, 2009
www.geni.net

- **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



- **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**

- **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

- **Tomorrow at 3.30pm in Room**

- **Agenda:**

- 3.30pm - 3.35pm **Introduction to the WG** **Vic Thomas**
- 3.35pm - 3.45pm **Service Composition Experiment...** **JongWon Kim**
- 3.45pm - 4.45pm **GENI Experimenters Presentations**
 - 3.45pm **Social Networking Apps and Gaming** **Felix Wu**
 - 4.00pm **Data Intensive Applications** **Emmanuel Cecchet**
 - 4.15pm **Shared Measurement Services** **Sonia Fahmy**
 - 4.30pm **Provenance registry for GENI** **Beth Plale**
- 4.45pm - 5.15pm **Control Framework Panel: What we can/can't support**
 - **Panelists: Larry Peterson, Rob Ricci, Jeff Chase, Ivan Seskar**
- 5:15pm - 5:30pm **Wrap-up - Discussion of WG Findings and Outbrief Presentation**

- **Tool developers understand what experimenters need**
 - Help identify and prioritize tool features/capabilities
- **Experimenters understand what tool support they can expect**

- **Chairs:** Ivan Seskar, Rutgers University; Jim Williams, Indiana University; Ron Hutchins, Georgia Tech
- **GPO Systems Engineer:** Heidi Picher Dempsey
- **Charter being redefined at GEC6**
 - focus on campus issues for networks, operational issues and security
 - Come give your input at the working group meeting! lightning talks!
- **Email list**
 - <http://lists.geni.net/mailman/listinfo/omis-wg>
- **Working Group Wiki page**
 - <http://groups.geni.net/geni/wiki/GeniOmis>
- **Agenda for GEC6**
 - <http://groups.geni.net/geni/wiki/Gec6OmisAgenda>
 - <http://groups.geni.net/geni/wiki/GeniServices>



Heidi Picher Dempsey