GENI

Exploring Networks of the Future

An introduction

GENI Project Office
March 2010
www.geni.net

- 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 – 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

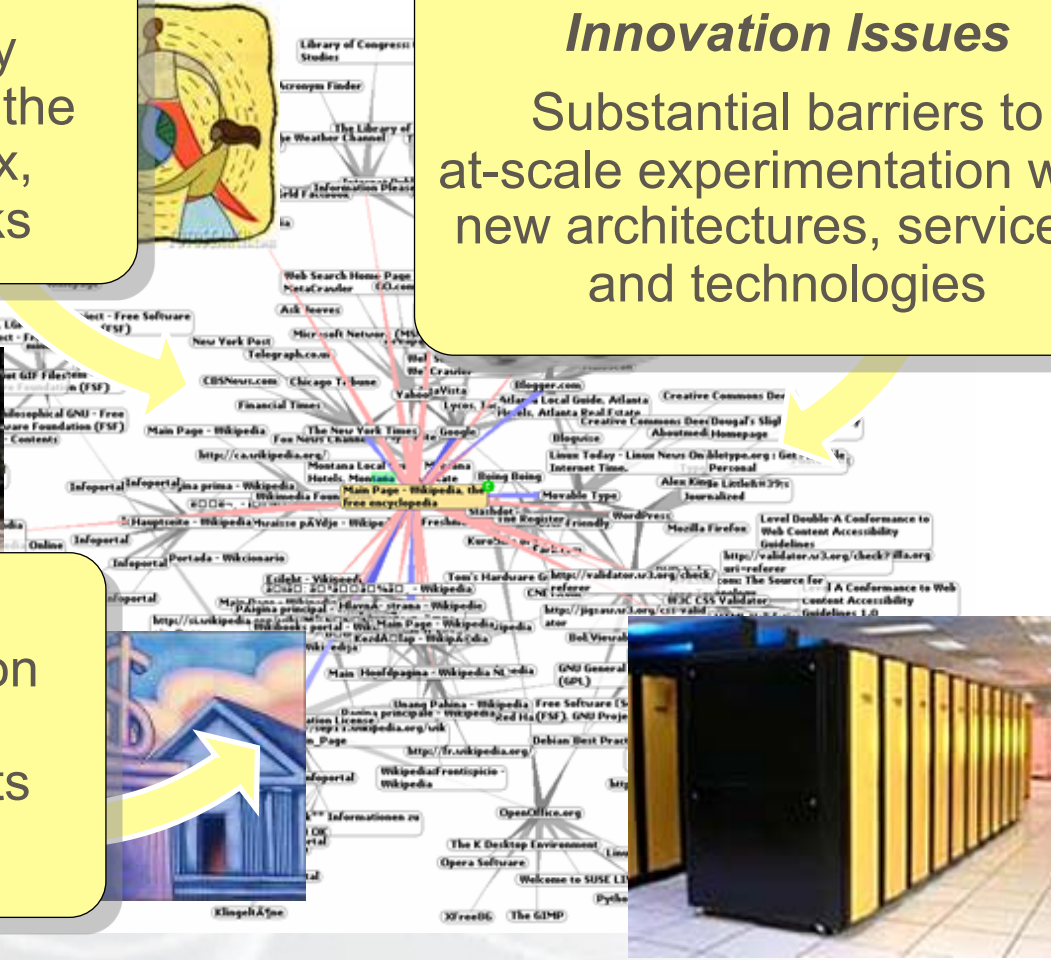We cannot currently understand or predict the behavior of complex, large-scale networks
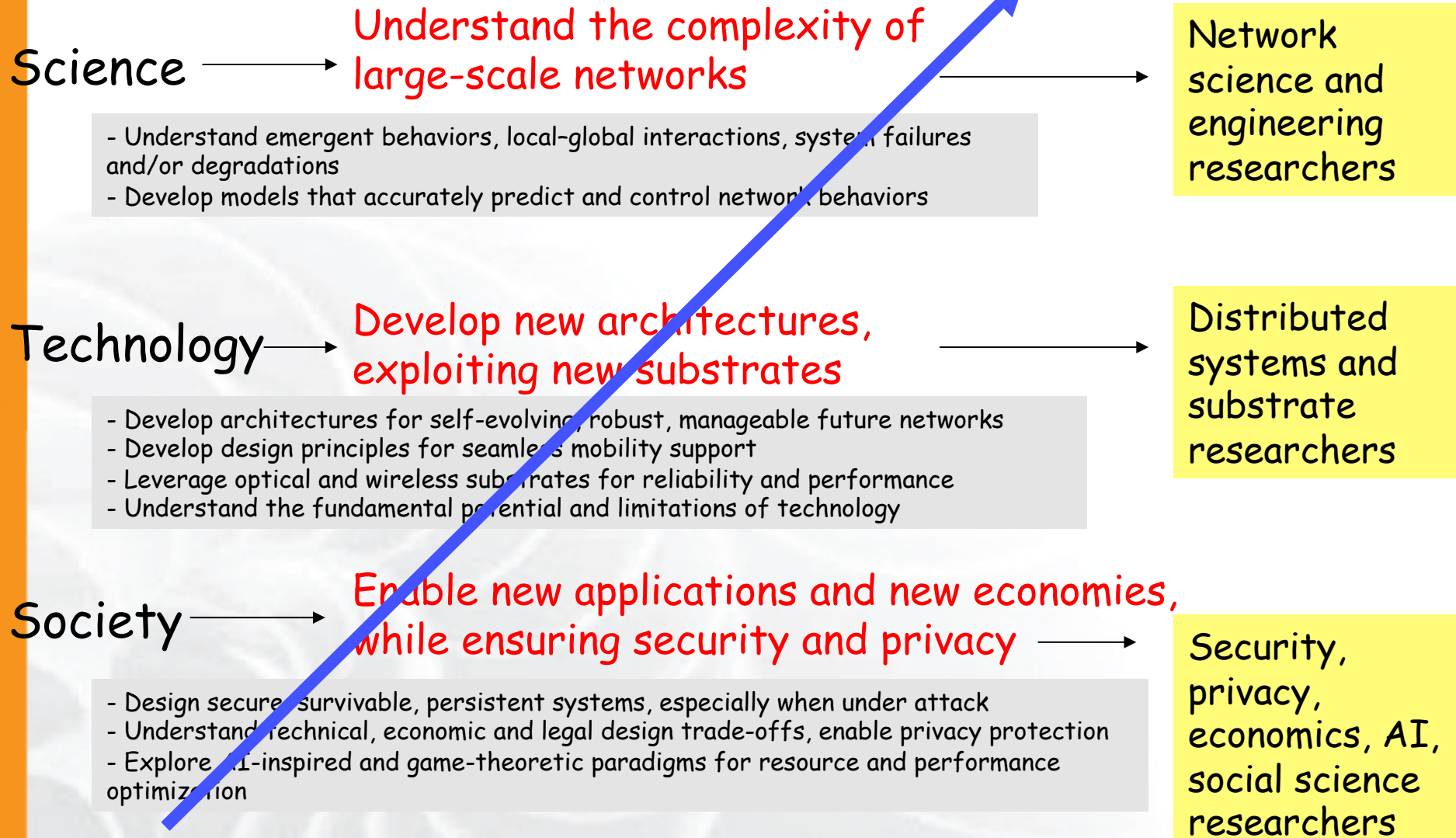
Innovation Issues

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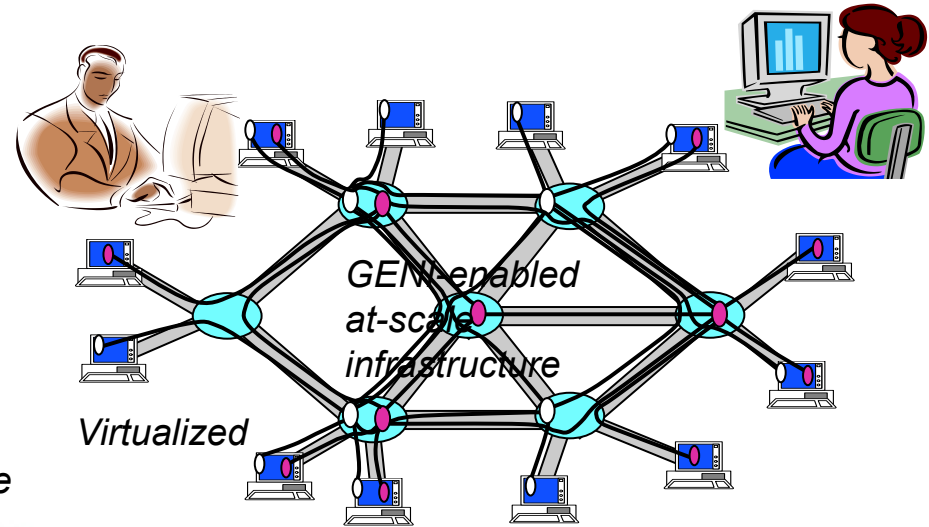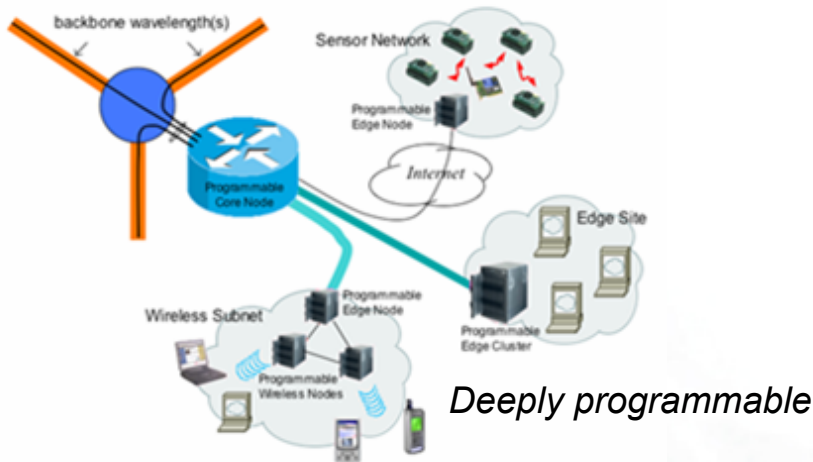
Society Issues

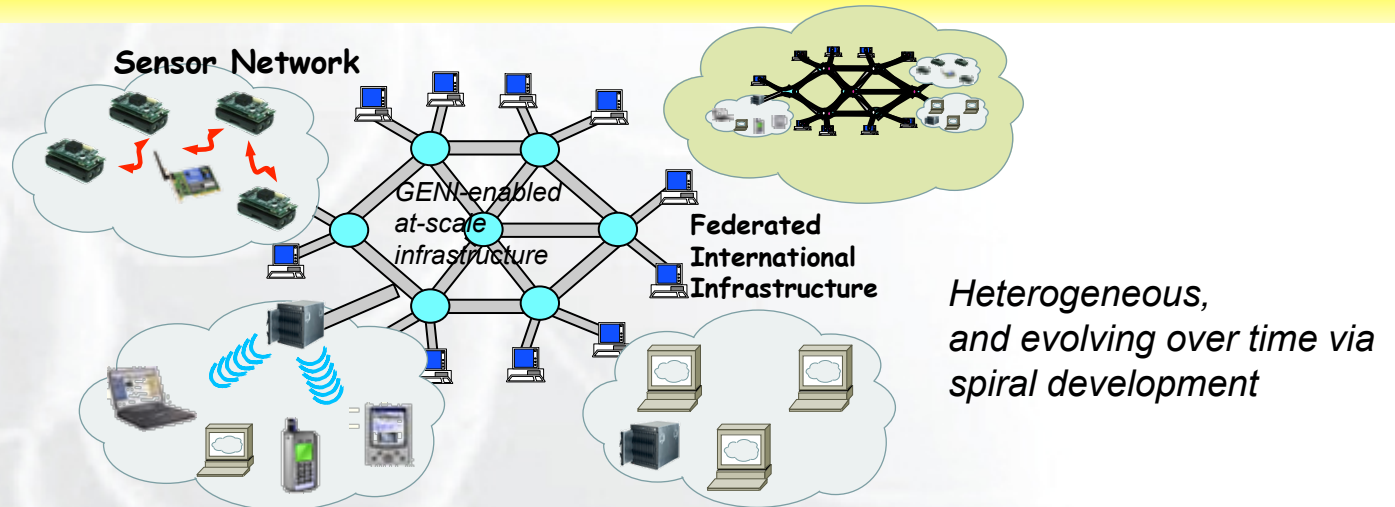We increasingly rely on the Internet but are unsure we can trust its security, privacy or resilience

July 20, 2010

Network Science & Engineering (NetSE)

geni
Exploring Networks
of the Future

Science

Understand the complexity of large-scale networks

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

Network science and engineering researchers

Technology

Develop new architectures, exploiting new substrates

- 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

Distributed systems and substrate researchers

Society

Enable new applications and new economies, while ensuring security and privacy

- 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

Security, privacy, economics, AI, social science researchers

GENI Conceptual Design
Infrastructure to support at-scale experimentation

Deeply programmable

GENI-enabled at-scale infrastructure

Virtualized

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

Sensor Network

GENI-enabled at-scale infrastructure

Federated International Infrastructure

Heterogeneous, and evolving over time via spiral development

- **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

- 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?

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 . . .
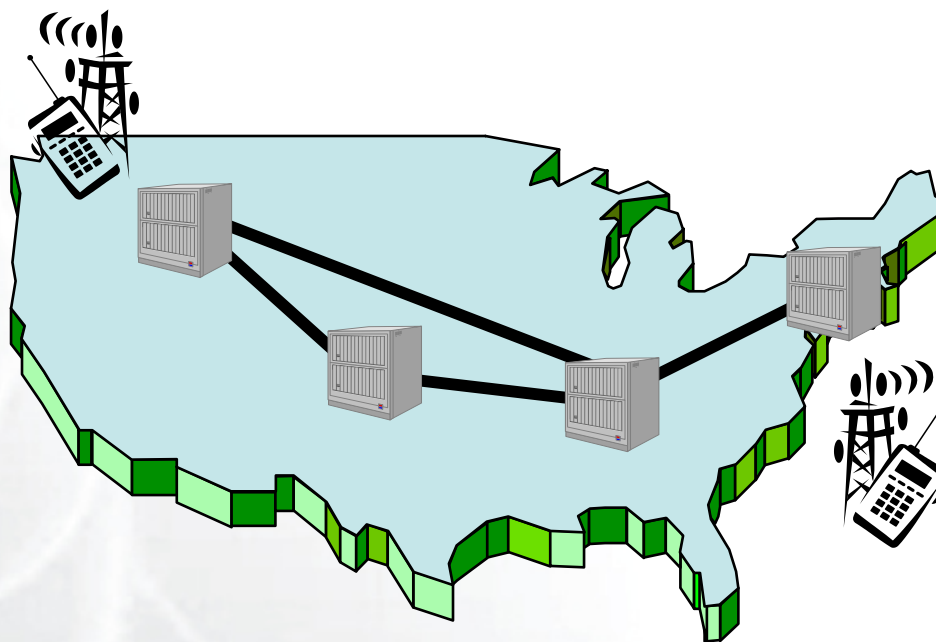
He uses a modest slice of GENI, sharing its infrastructure with many other concurrent experiments.
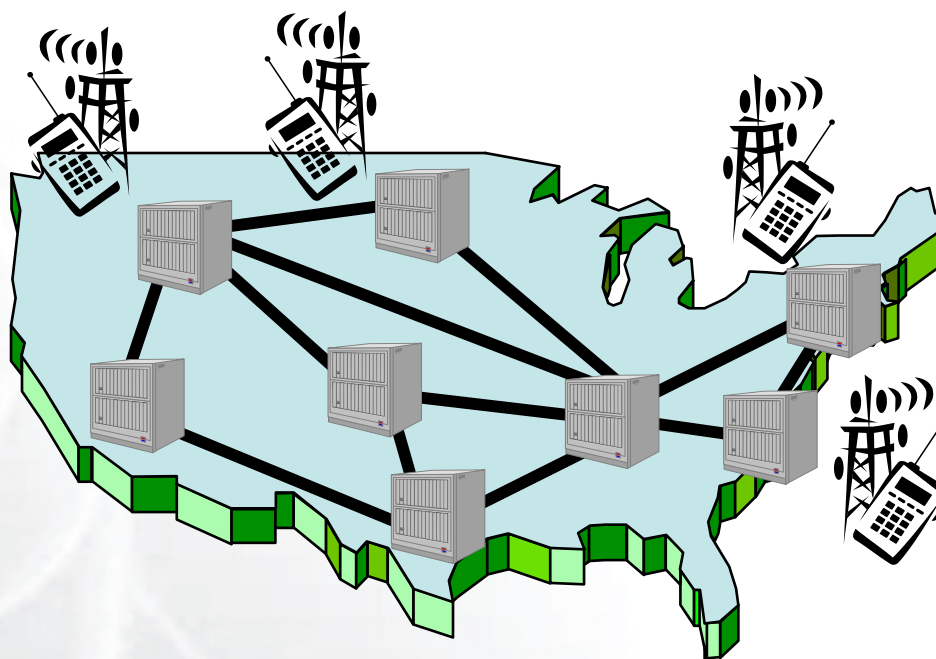
It turns into a really good idea

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.

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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.

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 . . .
  - 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 <u>not</u> 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.

Planning

Design

Use

Integration

Build out

GENI Prototyping Plan
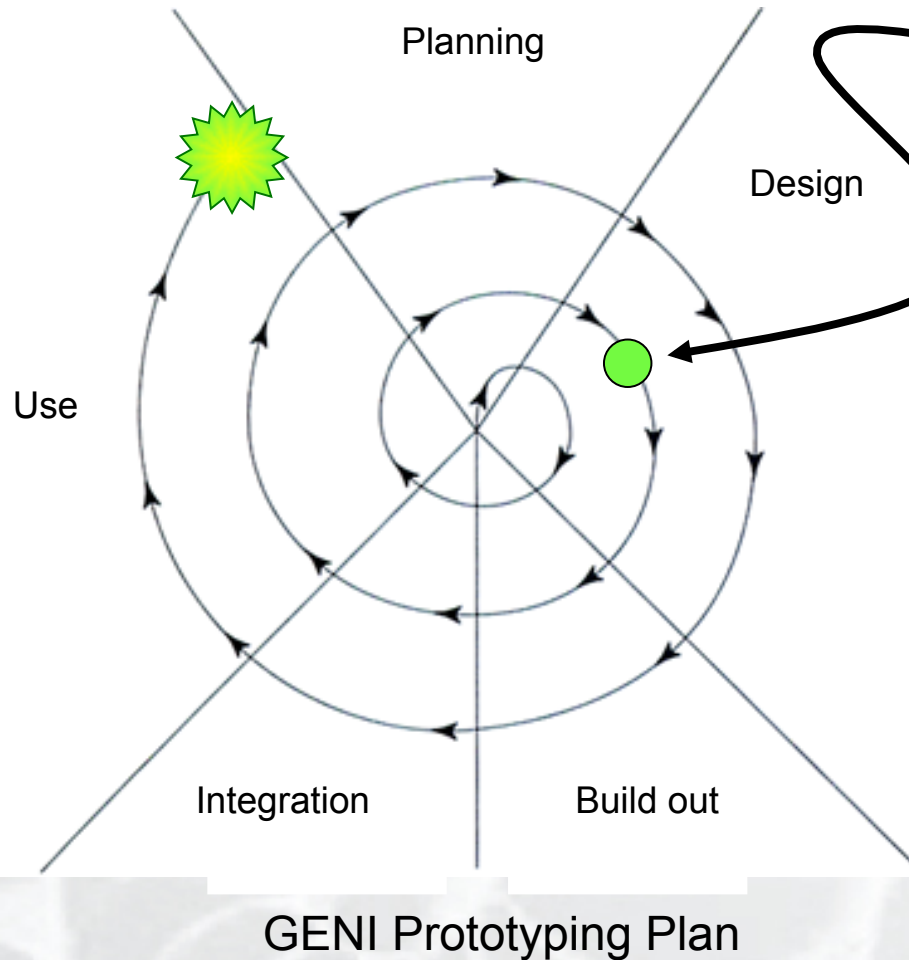
GENI Spiral 2

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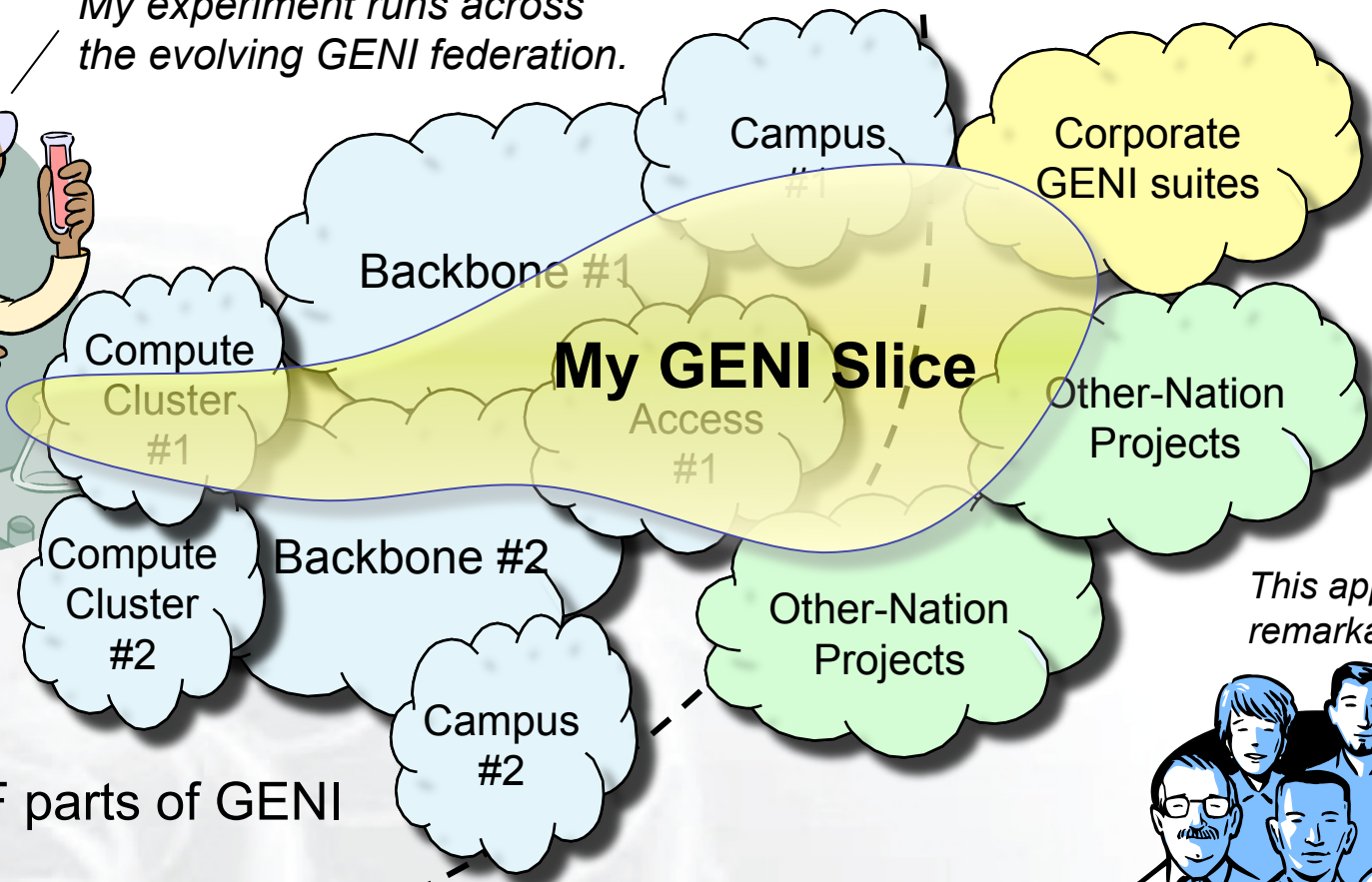
Envisioned **ultimate goal**

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.

GENI grows by "GENI-enabling" heterogeneous infrastructure

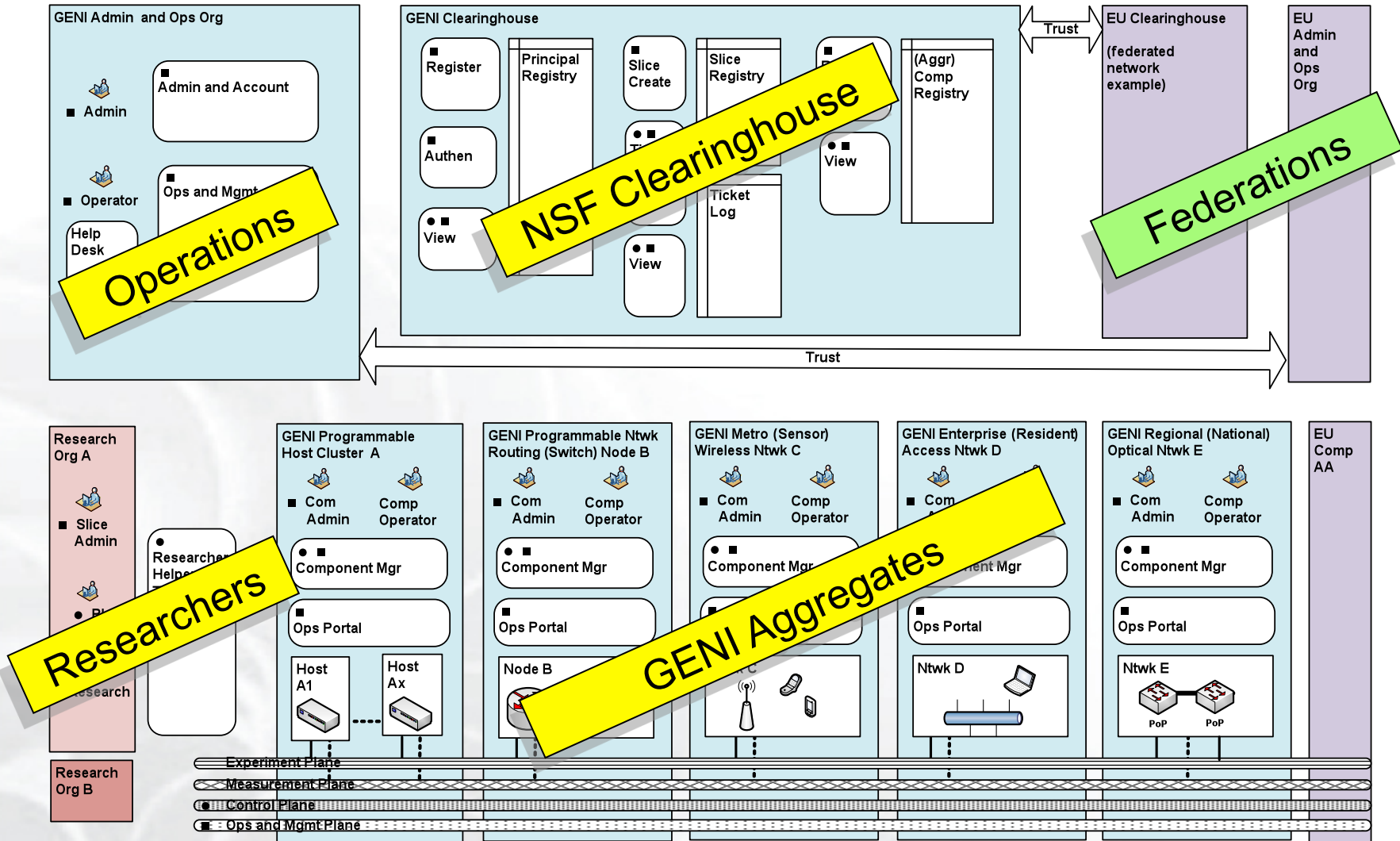*My experiment runs across the evolving GENI federation.*

Campus #1

Corporate GENI suites

Backbone #1

Compute Cluster #1

My GENI Slice

Access #1

Other-Nation Projects

Compute Cluster #2

Backbone #2

Other-Nation Projects

Campus #2

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"
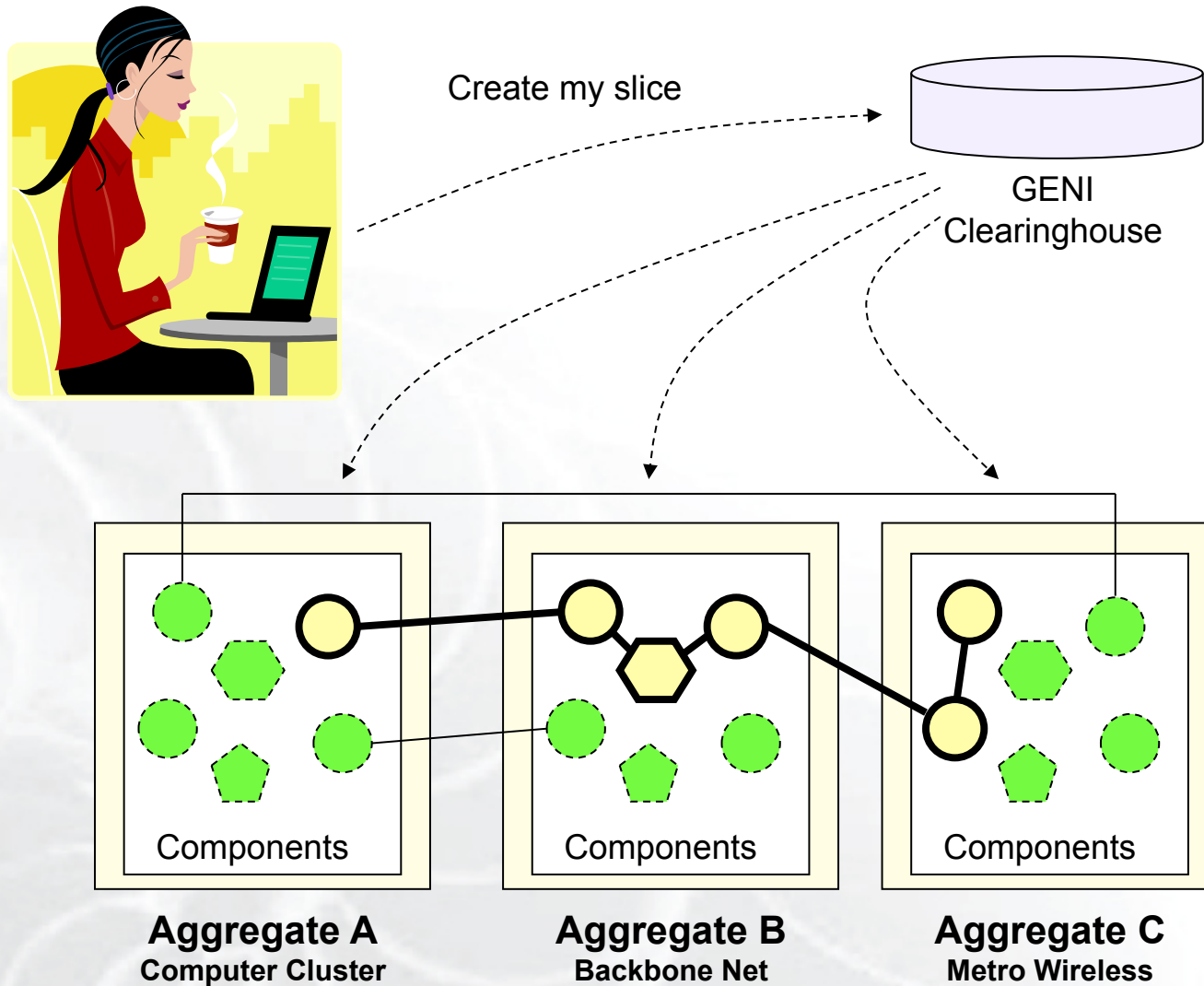
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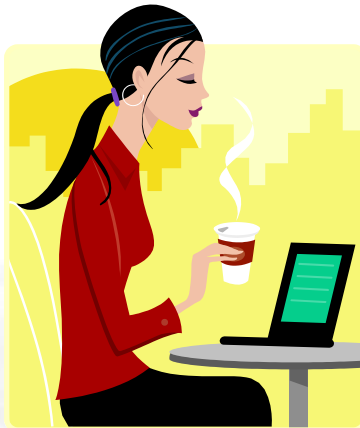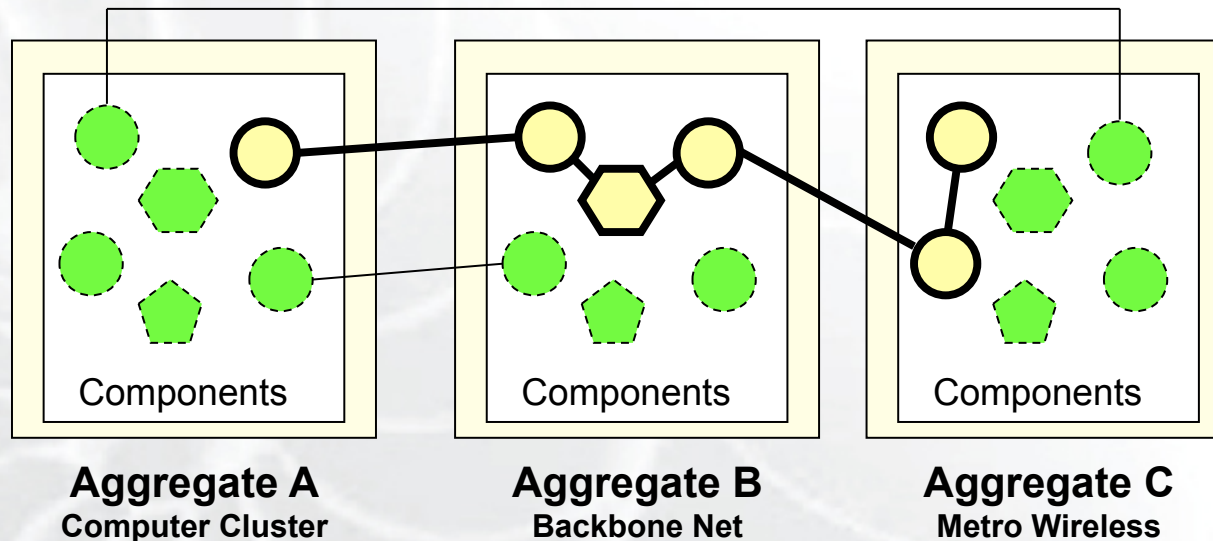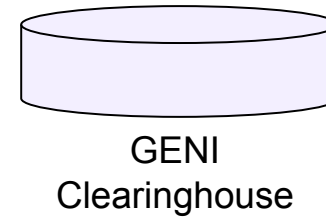- Current status and plans: GENI Spiral 2
- How can you participate?

Aggregates publish resources, schedules, etc., via clearinghouses

What resources can I use?

GENI
Clearinghouse

These

Researcher

Components

Components

Components

Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless
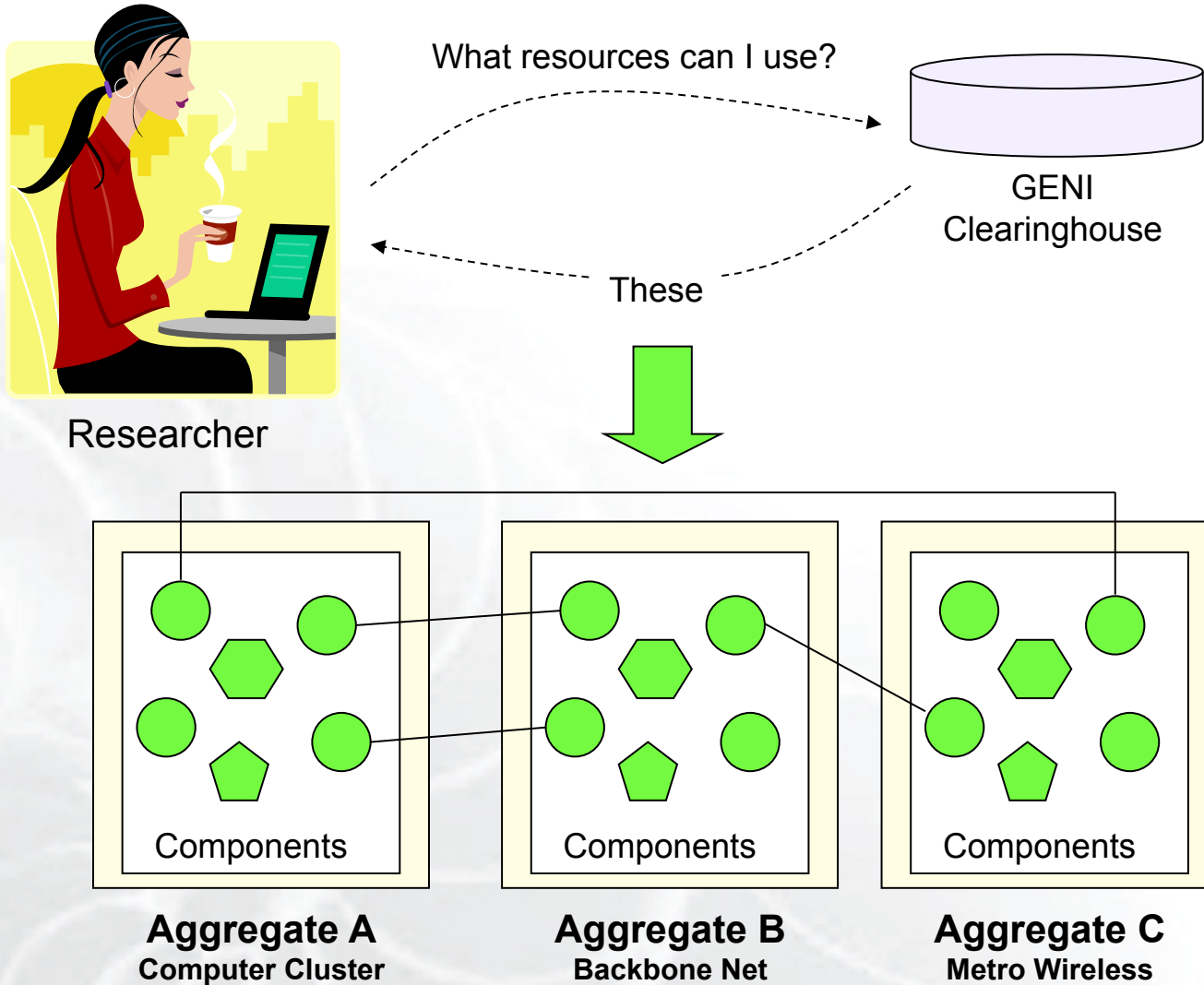
Slice creation
Clearinghouse checks credentials & enforces policy
Aggregates allocate resources & create topologies

Create my slice

GENI Clearinghouse

Components

Components

Components

Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless

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

GENI Clearinghouse

Components

Components

Components

Aggregate A
Computer Cluster

Aggregate B
Backbone Net

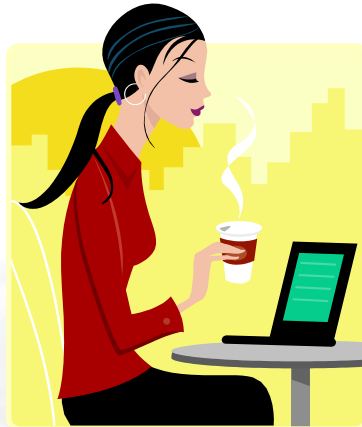**Aggregate C**
Metro Wireless

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
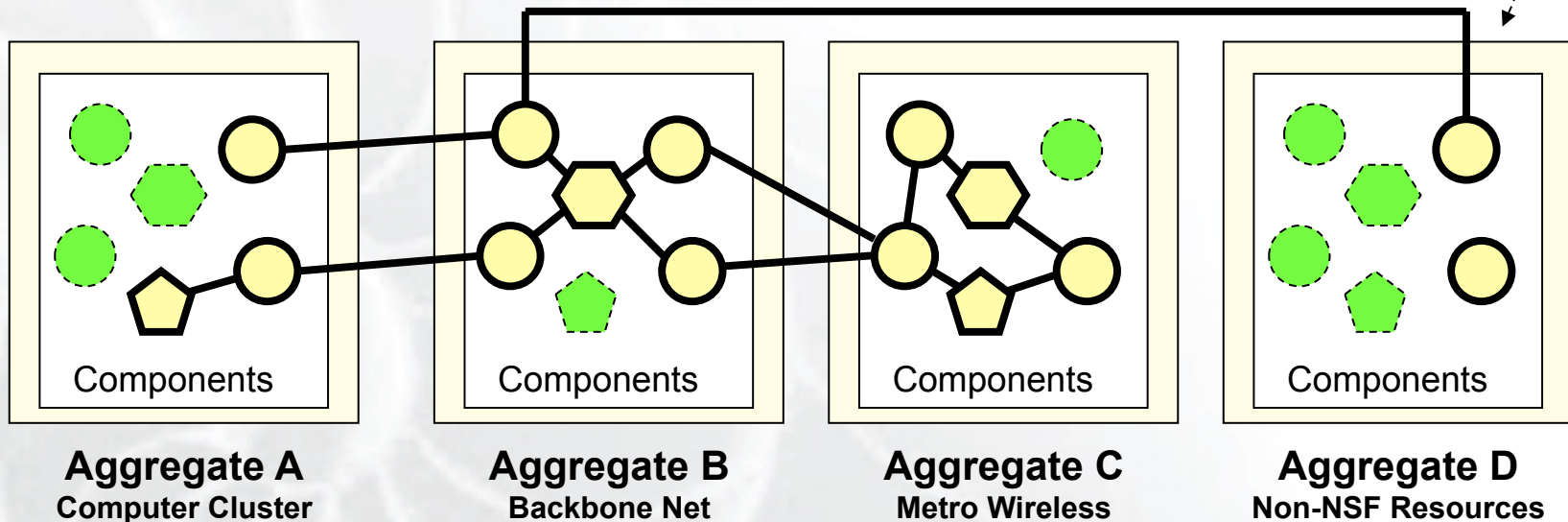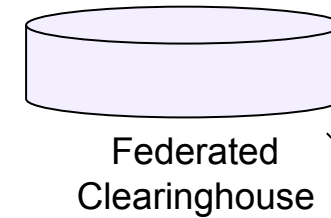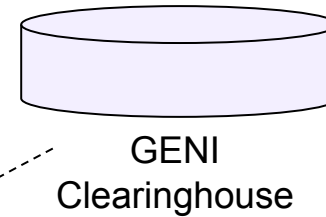**Backbone Net**

Aggregate C
Metro Wireless
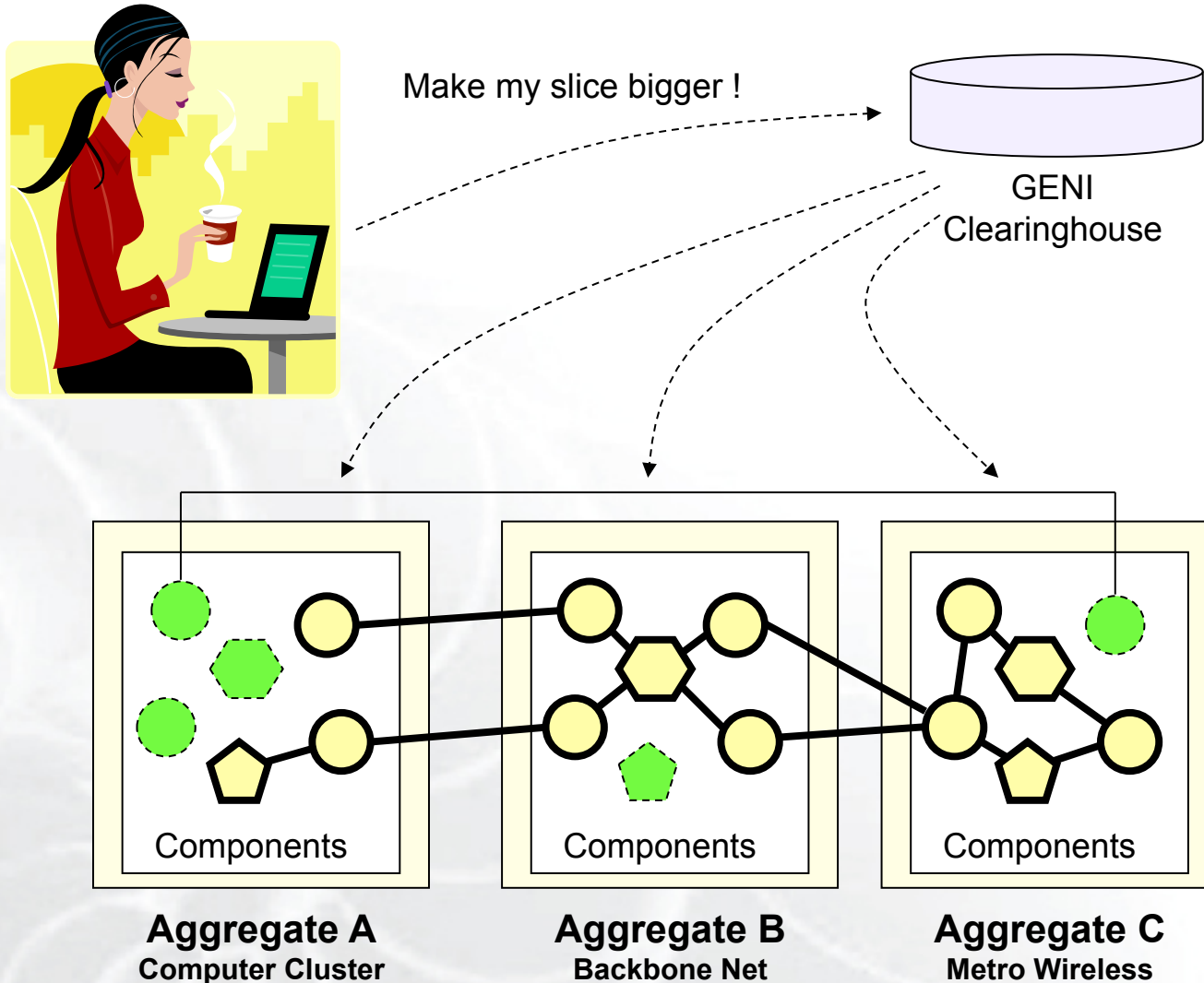
Federation of Clearinghouses
Growth path to international, semi-private, and commercial GENIs

Make my slice even bigger !

GENI Clearinghouse

Federated Clearinghouse

Components

Aggregate A
Computer Cluster

Components

Aggregate B
Backbone Net

Components

Aggregate C
Metro Wireless

Components

Aggregate D
Non-NSF Resources
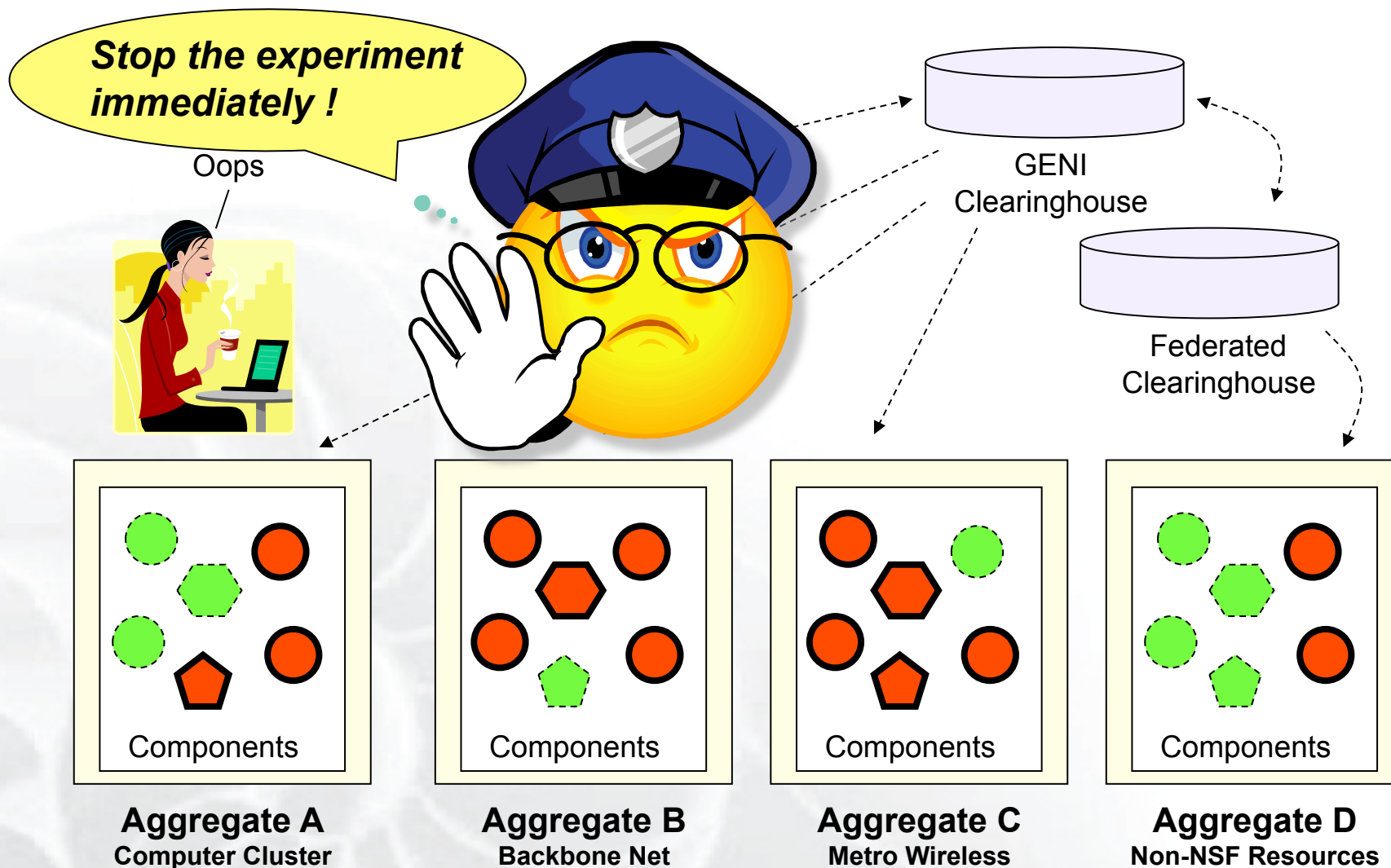
Operations & Management
Always present in background for usual reasons
Will need an 'emergency shutdown' mechanism

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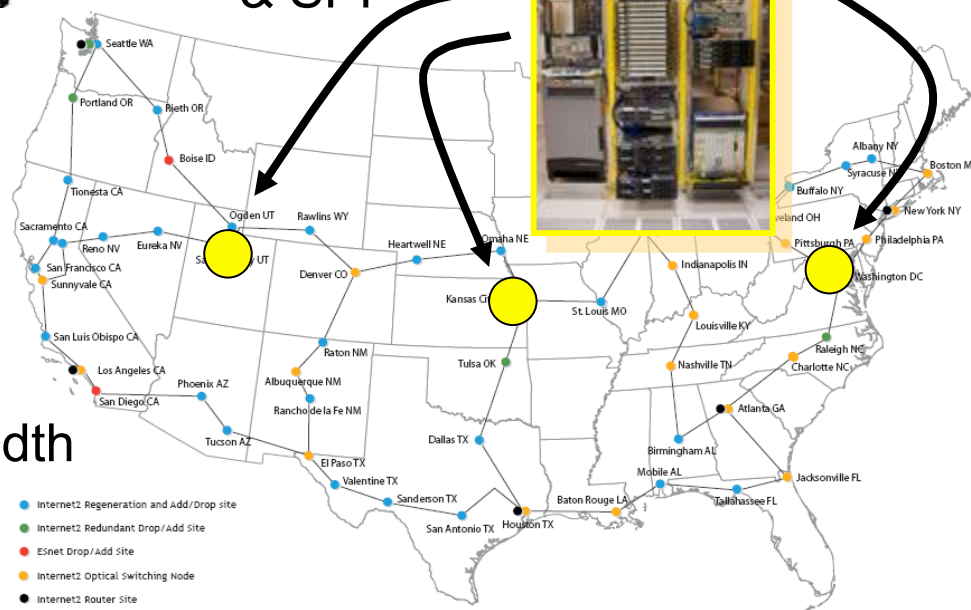- Current status and plans: GENI Spiral 2
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Key

- 🟠 Project leader
- ⚪ Project participant
- ▭ Internet2
- 〰 National LambdaRail

Internet2 and **National LambdaRail**

Internet2
10 Gbps dedicated bandwidth

ProtoGENI & SPP

National LambdaRail
Up to 30 Gbps nondedicated bandwidth

- Internet2 Regeneration and Add/Drop site
- Internet2 Redundant Drop/Add Site
- ESnet Drop/Add Site
- Internet2 Optical Switching Node
- Internet2 Router Site

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 ⬛
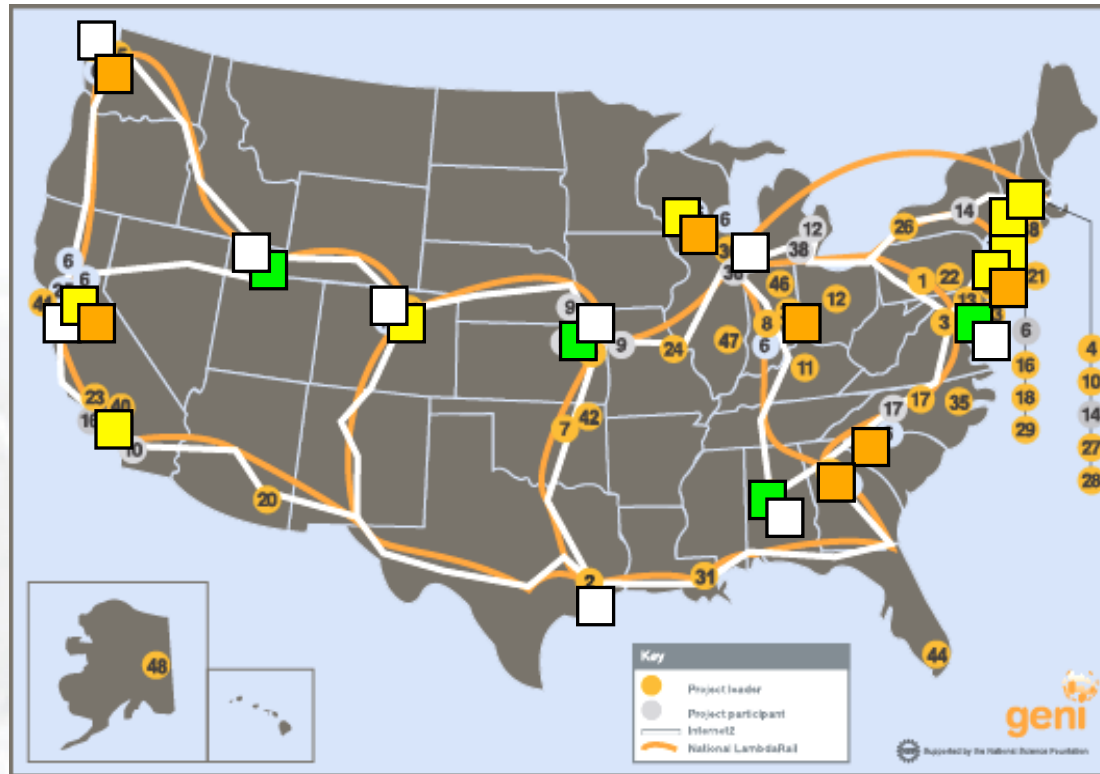
Salt Lake City
Kansas City
DC
Atlanta

WiMAX ⬛

Stanford
UCLA
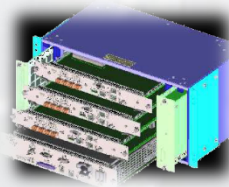UC Boulder
Wisconsin
Rutgers
Polytech
UMass
Columbia

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

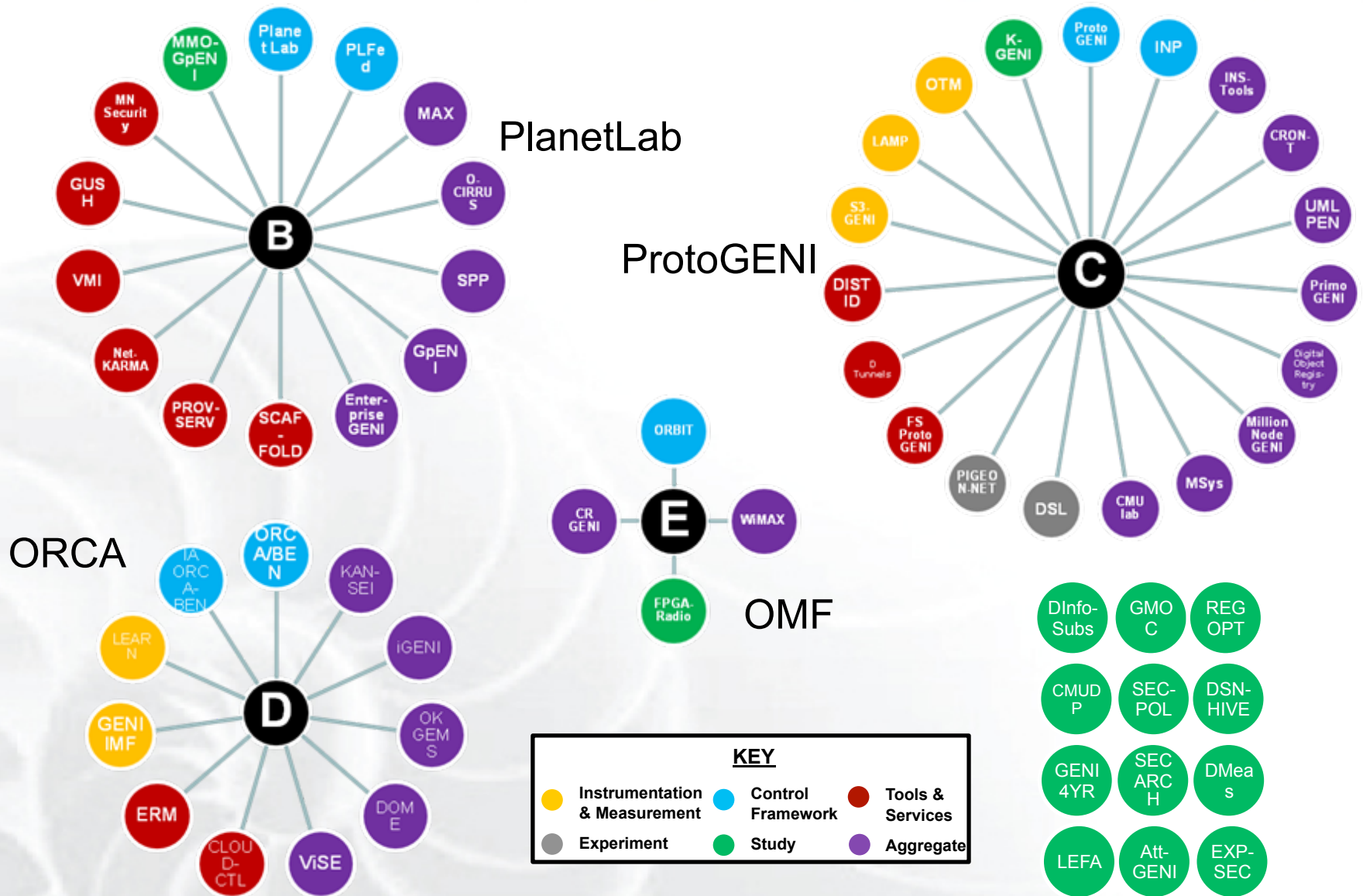**DieselNet, U. Mass Amherst**

**ViSE,
U. Mass Amherst**

SPPs, Wash U.

ORBIT, Rutgers WINLAB

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
	Clemson University	University of California, Berkeley
	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,
	The University of Missouri-Kansas City	University of Nebraska-Lincoln
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

ORCA

OMF

KEY

- 🟡 Instrumentation & Measurement
- 🔵 Control Framework
- 🔴 Tools & Services
- ⚪ Experiment
- 🟢 Study
- 🟣 Aggregate

- ## Overarching goal
  - Get real experiments up and running

- ## Technical emphases
  - Integration, particularly of the meso-scale prototype
  - Interoperability
  - Instrumentation
  - Identity management

K-GENI

FIRE

JGN2plus + Akari

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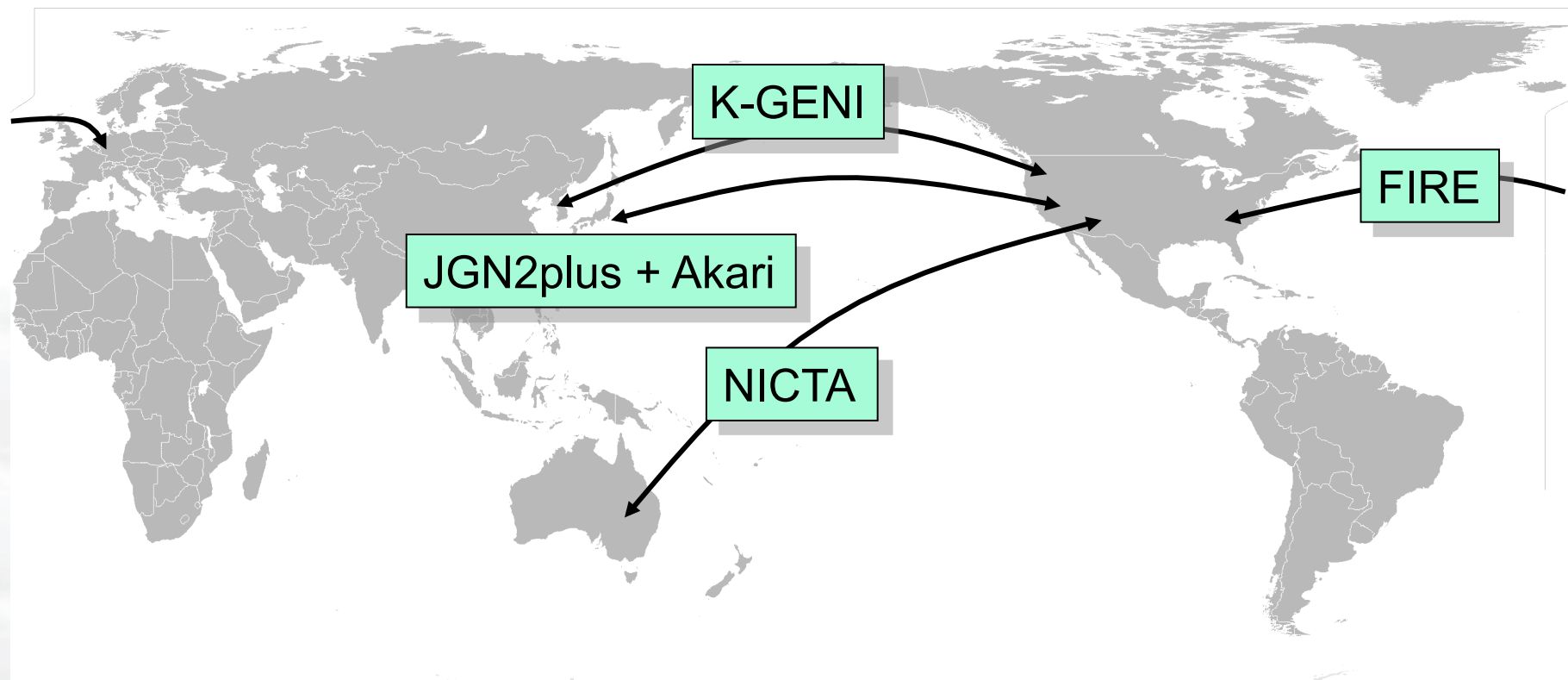
The GENI Project Office is interested in federation with peer efforts outside the US, based on equality and arising from direct, "researcher to researcher" collaborations.

- 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 Solicitation 3 – Proposals due Aug. 20

- Overview
  - Solicitation issued May 28, 2010
  - Proposals due August 20, 2010
  - Total funds ~ $3.5 M / yr for 3 years, as always subject to availability of funds
  - Existing / new GENI participants both welcome

- Strong preference given to . . .
  - Joint Academic / Industrial teams
  - Active participation of campus / regional infrastructure providers (e.g., letter from campus CIO)

- Main solicitation interests:
  - Enhanced Meso-scale prototyping
    - Regional switches
    - Backbone switches
    - WiMAX
    - GENI-racks
  - Instrumentation and Measurement Systems
  - Experiment support, training, education, and curriculum development
  - Other good ideas

www.geni.net
Solicitation and background information

- **9th meeting, open to all:
  November 9th – 11th, Arlington, VA**
  - 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
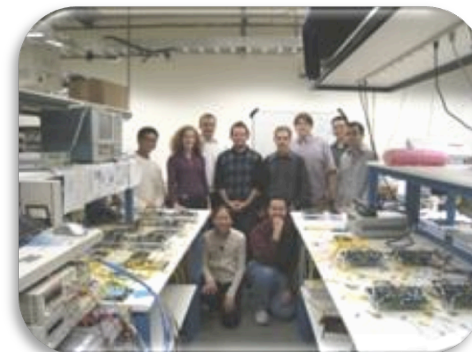 - Discussion will provide input to subsequent spiral goals

Get involved!

ViSE Team
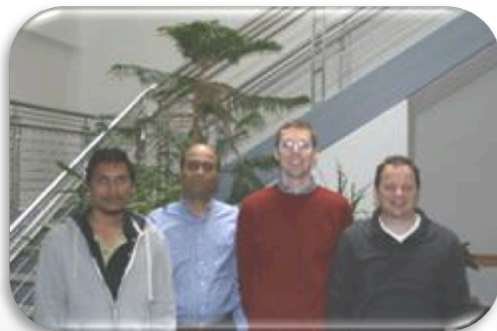
PlanetLab Team

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