G E N I

Global Environment for Network Innovations

Lifecycle of a GENI Experiment

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1 Document Scope

This section describes this document's purpose, its context within the overall GENI document tree, the set of related documents, and this document's revision history.

1.1 Purpose of this Document

This document describes an experimenter's view of the lifecycle of an experiment in the GENI environment. The purpose of this document is to understand the workflow of the experimenter and identify tools and services needed to simplify experimentation in GENI.

1.2 Context for this Document

Figure 1 below shows the context for this document within GENI's overall document tree.

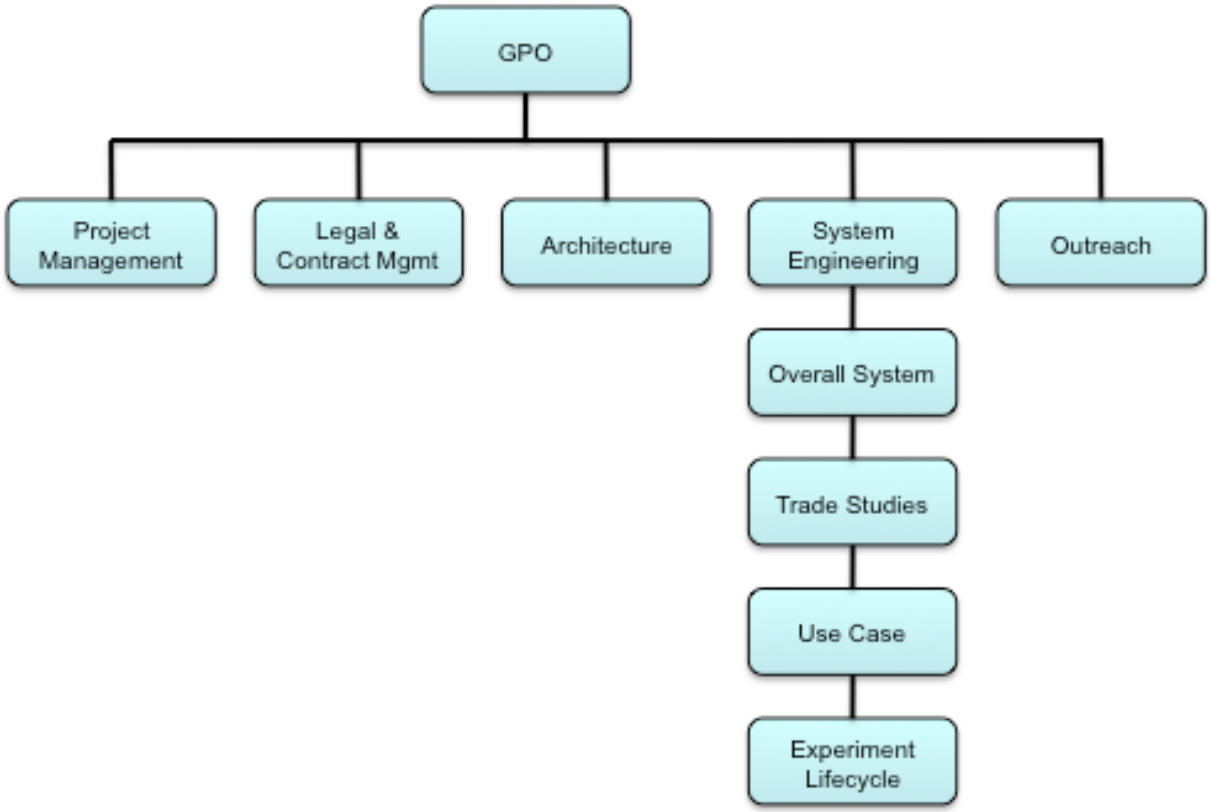

Figure 1. This document within the GENI Document Tree.

1.3 Related Documents

The following documents of exact date listed are related to this document, and provide background information, requirements, etc., that are important for this document.

1.3.1 National Science Foundation (NSF) Documents

Document ID	Document Title and Issue Date

1.3.2 GENI Documents

Document ID	Document Title and Issue Date
GENI-SE-SY-SO-02.0	GENI System Overview (September 29, 2008)

1.3.3 Standards Documents

Document ID	Document Title and Issue Date
N / A	

1.3.4 Other Documents

Document ID	Document Title and Issue Date
N / A	

1.4 Document Revision History

The following table provides the revision history for this document, summarizing the date at which it was revised, who revised it, and a brief summary of the changes. This list is maintained in reverse chronological order so the newest revision comes first in the list.

Revision	Date	Revised By	Summary of Changes
V. 1.0	19 Jan 2009	V. Thomas	Initial draft.

2 GENI Overview

The Global Environment for Network Innovations (GENI) is an ambitious effort to create a large-scale experimental network research facility that will allow researchers to escape today's Internet-circumscribed research environment.

GENI is envisioned as a national-scale research facility for network science and engineering, which will then grow and federate worldwide to support millions or perhaps billions of devices. It will allow controlled end-to-end experimentation, at large scale, of new global computing / communications architectures, which may or may not be compatible with the Internet.

Unlike traditional network testbeds, GENI is conceived as a general-purpose facility that should place no limits on the network architectures, services, and applications that can be evaluated. Unlike traditional network testbeds that either limit researchers to incremental changes or limit researchers to synthetic workloads, GENI is designed to allow both clean-slate designs and experimentation with real users under real-world conditions. Unlike traditional testbeds that provide no credible deployment path to the commercial world, GENI represents a model in which incremental adoption of new services has the potential to drive wide-spread deployment.

It will support a wide range of experimental protocols, and data dissemination techniques; running over a substantial fiber optic infrastructure with next-generation optical switches, novel high-speed routers, city-wide experimental urban radio networks, high-end computational clusters, and sensor grids. All infrastructures can be shared among a large number of individual, simultaneous experiments with extensive instrumentation that makes it easy to collect, analyze, and share real measurements.

Core concepts for GENI are as follows:

- **Programmability** – researchers may download software into GENI nodes to control how those nodes behave;
- **Virtualization and Other Forms of Resource Sharing** – whenever feasible, nodes implement virtual machines, which allow multiple researchers to simultaneously share the infrastructure; and each experiment runs within its own, isolated slice created end-to-end across the experiment's GENI resources;
- **Federation** – Different parts of GENI are owned and/or operated by different organizations, and the NSF portion of GENI forms only a part of the overall 'ecosystem'; and
- **Slice-based Experimentation** – GENI experiments will be an interconnected set of reserved resources on platforms in diverse locations. Researchers will remotely discover, reserve, configure, program, debug, operate, manage, and teardown distributed systems established on the GENI substrate.

3 Document Overview

This document describes an experimenter's view of the lifecycle of an experiment in the GENI environment. The objective of this document is to understand the workflow of the experimenter and identify tools and services needed to simplify experimentation in GENI.

An experiment is a researcher-defined use of a slice; an experiment runs in a slice. A slice is a substrate-wide network of computing and communication resources capable of running an experiment or a wide-area network service. Many different experiments can run in a particular slice concurrently or over time.

It is hoped GENI experimenter tools and services will hide details of slices and other GENI control framework constructs from most researchers. The remainder of this document intentionally does not use terms such as slices or slivers. Rather, terms such as experiments and resources that are more natural to the experimenter are used. Resources include computation, communication, measurement, and storage resources. They can be contained in a single physical device or distributed across a set of devices.

GENI will have users with a wide range of abilities and needs. At one end of the spectrum are users such as undergraduates using GENI for class projects. These users need tools and services that make it easy to quickly set up and run short-lived experiments. At the other end of the spectrum are researchers who need a great deal of control over their experiments or over the data collected by the experiments. These users may need large numbers of very specific types of resources and may need them for extended periods of time. Such experiments will need to tolerant to changes in resources available to them as these resources may fail, be taken down for maintenance or upgraded.

The workflow described in this document is largely independent of the type of GENI user. The tools and services developed to support this workflow must however be cognizant of the different needs of these users.

Figure 2 shows a high-level view of the lifecycle of an experiment within GENI. The boxes in the figure represent different phases of the lifecycle. Even though these phases are laid out sequentially for convenience of presentation it is understood that some experiments may cycle between phases or may skip some phases.

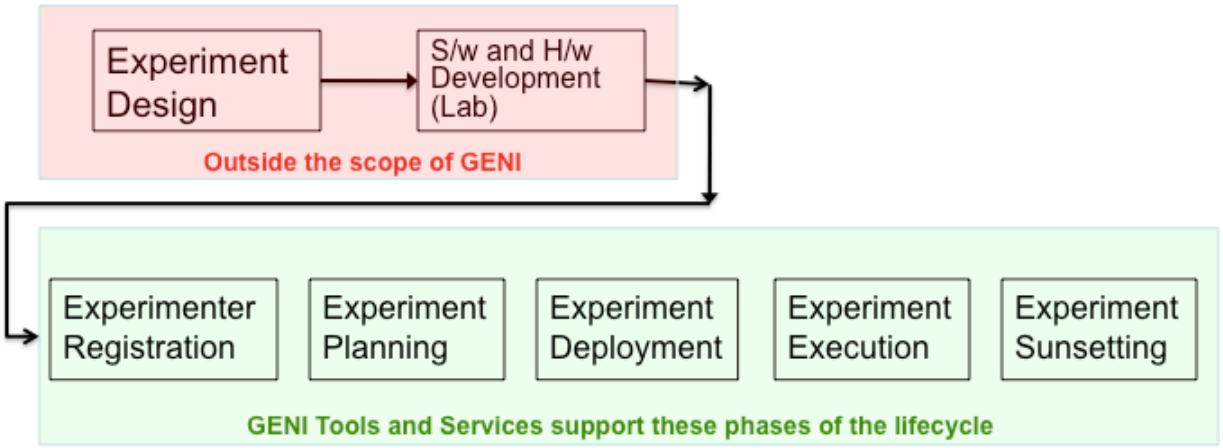

Figure 2. Top-level view of the lifecycle of a GENI experiment.

The first two phases of the lifecycle are *Experiment Design* and *Software and Hardware Development*. Experiment design is related to formulating a hypothesis to be tested, identifying controlled and uncontrolled variables and developing a system for measuring system responses that validate or invalidate the hypothesis. The next phase, software and hardware development, occurs in the lab and serves to validate the experiment design on a small scale. This lab phase may be skipped if the experiment requires resources that are only available in GENI. Both these phases are outside the scope of GENI and are therefore not elaborated on further in this document.

Experimenter Registration is related to authenticating users and giving them appropriate GENI credentials. This lifecycle phase is described in greater detail in Section 4.

Experiment Planning is the phase where the user plans how the experiment will be conducted in the GENI environment: Determine the resources needed and tools needed to program these resources, the instrumentation services available and their setup, etc.. This phase is described in Section 5

Experiment Deployment is related to actually obtaining GENI resources and installing the software and hardware needed to run the experiment. This is described in Section 6.

Experiment Execution is the actual running of the experiment: Starting, pausing, resetting, growing, shrinking and stopping the experiment. This phase is described in Section 7.

Experiment Sunsetting is related to archiving the experiment so it is available to other experiments to repeat, modify or extend. It also includes transition of technology demonstrated by the experiment to product. This is described in Section 8.

4 Experiment Registration

Experimenters register with research organizations on the basis of existing or planned experiments. In essence, the research organization vouches that a particular experiment is indeed being planned or conducted, and that this particular individual is authorized to participate in the experiment as a researcher. Multiple researchers with different researchers organizations may collaborate on the same experiment. Experimenter registration enables trust relationships to be established among collaborators on an experiment: Research organizations vouch for their researchers, clearinghouses vouch for research organizations registered with them, and clearinghouses set up trust relationships amongst themselves. Experimenter registration also establishes relationships between researchers and experiments, and hence GENI slices.

Registered experimenters are given permissions to perform one or more tasks within the context of a GENI experiment. For example, some experimenters may be permitted to browse resources (GENI components) while others might be permitted to browse and lease resources for running experiments.

GENI clearinghouses may have policies related to experimenters registered with other clearinghouses. For example a GENI clearinghouse in Europe may permit users registered with the NSF clearinghouse in the US browse resources but not lease them.

4.1 Tools and Services for User Registration

GENI must provide administrative tools to register users and provide them the necessary credentials to use GENI.

5 Experiment Planning

Experiment planning in GENI includes the four steps shown in Figure 3. The *Present Credentials* phase is where the experimenter presents to GENI credentials issued during registration and is authenticated by GENI as being a registered user.

The experimenter then creates an experiment, which is an identifier for the context within which he or she will discover resources and control them. Experiments have names and unique identifiers.

Experiments may have multiple experimenters associated with them. Different experimenters may have different privileges with respect to that experiment such as the ability to add new experimenters and assign them privileges, the ability to add or remove resources to the experiment and the ability of view data collected by the experiment. Experimenters with different privileges may be added at any time during the life of an experiment.

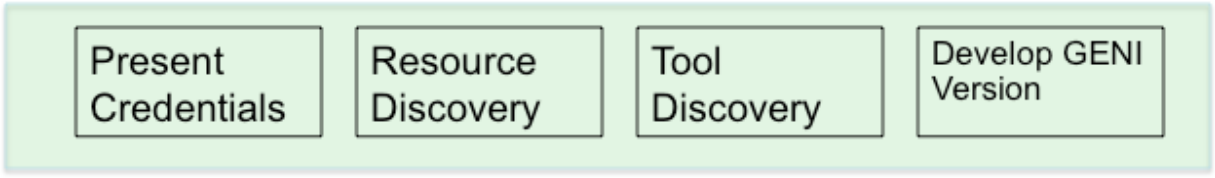

Figure 3. Steps in the Experiment Planning phase of the experiment lifecycle.

In the *Resource Discover* phase the experimenter looks for the resources needed to run an experiment. Resource discovery can happen in one of many ways:

1. Automatically from an experiment specification. GENI will support one or more *experiment specification languages*. This language is used to describe attributes of an experiment including resources needed, configuration of these resources and data to be collected during the execution of the experiment.
2. Programmatically. The experimenter must be able to write a script or program that queries clearinghouses for resources.
3. From an interactive user interface. Experimenters must be able to browse the clearinghouses for resources using an interactive interface such as a shell-like environment or a graphical environment.

For scalability, resource discovery might be a multi-step process with the experimenter initially getting course information about resource aggregates and then being able to refine queries to get more detailed information on specific resources or aggregates.

GENI may also permit experimenters to lease resources as they browse them, if the experimenter is permitted to lease resources.

Once resources needed to run the experiment are discovered, the experimenter will need to learn about the tools needed to program and configure these resources. This happens in the *Tool Discovery* step. In this step experimenters may learn about constraints to be accounted for when programming and using these resources. Tool discovery may also point to emulators for specialized resources that can be used to develop and validate software before it is deployed on GENI.

Finally, in the *Develop GENI Version* step the experimenter develops the software and configuration files that will eventually be loaded into the resources to be used for the experiment. This software may be tested in a lab, using emulators for specialized resources or on GENI itself.

5.1 Tools and Services for Experiment Planning

GENI must provide a tool that can interpret an experiment specification and query appropriate clearinghouses for resources.

GENI clearinghouses must provide an API that can be used to query for resources. Software libraries that make it easy to invoke these libraries over a network must also be provided.

GENI must provide a graphical tool for browsing resources. This interface would ideally use familiar techniques used to browse resources in other domains such as searching for files in a file system or books in an on-line catalogue.

In addition to information about a resource, a GENI Rspec might have information needed by an experimenter to use the resource. The Rspec may have this information embedded in it or may have pointers to this information. GENI must provide tools for extracting this information from the Rspec and making it available to the experimenter in a useful and easy to use format.

6 Experiment Deployment

The deployment phase of a GENI experiment entails the four steps shown in Figure 4. The *Present Credentials* step authenticates the user and verifies he is indeed permitted to lease GENI resources and use them for experimentation.

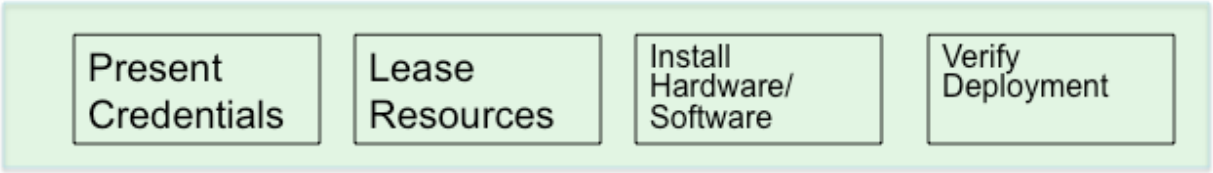

Figure 4. Steps in the Experiment Deployment phase of the experiment lifecycle.

The experimenter then leases resources for the experiment. Leases ensure requested resources are made available to the experiment at the times specified by the experimenter. The process of leasing resources is similar to that of browsing for resources and can be done in three ways: Automatically from an experiment specification, programmatically, or using an interactive user interface. The experimenter specifies a start time and duration for resources leases.

The experimenter can then configure the resources obtained: Install software, configure components, set topologies, turn on Internet feeds, connect to already running experiments (experiment composition), etc..

Finally, the experimenter can verify the deployment: Verify the necessary resources have been obtained and programmed with the right versions of software and traffic flows are as expected. The verification of a deployment that uses intermittently connected resources may be a challenge.

6.1 Tools and Services for Experiment Deployment

GENI must provide researchers with a checklist of items to be considered before deploying an experiment.

GENI must provide a tool that can interpret an experiment specification and lease resources at appropriate clearinghouses for resources.

GENI must provide tools for coordinating schedules to permit sharing of resources that cannot be sliced and for composition of large experiments. Organizations providing GENI resources might be encouraged to support a common format for calendar information.

GENI must provide a tool for managing software in distributed experiments: pushing software to large numbers of components, installing this software, tracking software versions, etc..

GENI must provide a mechanism that allows one experiment to connect with another already running experiment.

GENI must provide tools and services to validate an experiment setup: Resources allocated to the experiment, versions of software installed and communication paths set up.

An experimenter must be able to save a list of resources leased in this phase and, at a future time, request these same resources be made available to the experiment. This will allow the experimenter to return to a configuration that has been validated.

7 Experiment Execution

Figure 5 shows the steps in the experiment execution phase of the lifecycle. Once the experiment is set up, the experimenter controls it by starting, pausing, resuming, restarting and stopping the experiment. Experiments can be controlled at different levels of granularity: The entire experiment, at a resource level or at an experimenter defined resource grouping. Additionally, different experimenters may be allowed different levels of control on experiments.

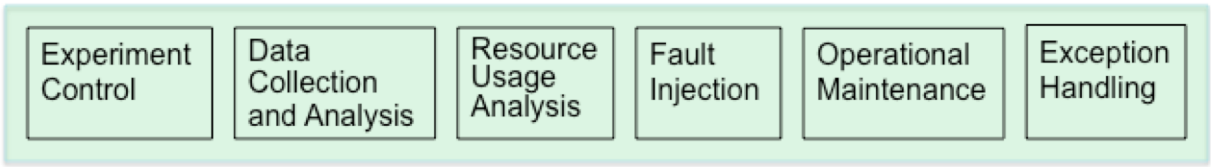

Figure 5. Steps in the Experiment Execution Phase of the experiment lifecycle.

Other experiment control related activities include growing or shrinking the experiment by adding or removing resources, adjusting the level of instrumentation, turning on or off flows to and from the Internet, and connecting or disconnecting from other on-going experiments.

The experimenter can turn on and off different levels of instrumentation. Experiment instrumentation includes measurement of the performance of the experimenter's distributed software and measurement of the performance and utilization of GENI resources used by the experiment. Instrumentation data may be viewed in real-time or saved for future analysis.

The experimenter can specific automatic actions to be taken when parts of the experiment fail, if the resources being used by the experiment become unavailable or additional resources become available. The experimenter can also inject faults into the system. Faults can include the failure of resources, a reduction in the amount of resources available to the experiment, duplicate messages, etc.

Experimenter can also monitor and maintain experiments from an operational point of view. They can use tools to troubleshoot their experiment setup if things don't go as planned; for example, tools for browsing GENI system logs and diagnosing problems. They may also have available a "help-desk" for help with troubleshooting experiments.

7.1 Tools and Services for Experiment Execution

GENI must provide experimenter tools to control an experiment programmatically or using an interactive tool. An experimenter or a group of experimenters must be able to monitor and control experiments from multiple locations. Ideally, they would be able to control an experiment from any computer using a browser-based interface.

GENI must also provide experimenters tools and libraries to implement standard distributed system mechanisms such as barriers where different parts of the distributed program cannot progress until all parts have reached the barrier; detection of distributed quiescence where the distributed program has reached a state where every program component is waiting on some other component and there are no messages in transit to and from these components; and checkpointing the state of the experiment and the resources being used.

Good instrumentation tools are critical to GENI's success because of the importance of measurement and analysis in scientific experiments. The tools should allow the experimenter to dynamically vary the level of instrumentation, control the flow of measurements to analysis tools and archive this data. The instrumentation system must have minimal or no impact to the performance of the experiment. As mentioned earlier, the experimenter must be able to instrument GENI resources in addition to his or her program. Mechanisms must be provided to control access to the collected data as this some experiments may collect data or traffic that is subject to privacy policies.

GENI must provide tools to visualize the collected data.

GENI must provide tools for injecting a variety of different kinds of faults in a controlled manner. Users must be able to add their own fault-injection tools to a GENI provided fault-injection framework.

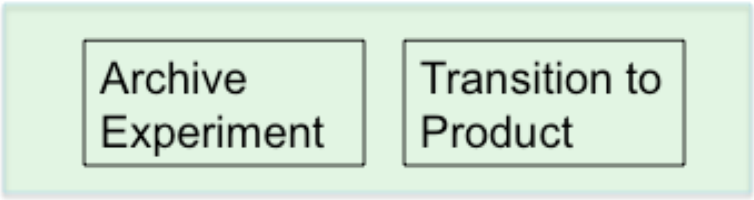

Figure 6. Possible options for sunsetting a GENI experiment.

GENI must provide tools and services for debugging operational problems with an experiment such as the inability to reach or obtain certain resources or unexpected behavior of resources. GENI may also have an help-desk for helping experimenters troubleshoot operational problems.

GENI must provide mechanisms for researchers to specify actions to be taken when certain standard or user defined exceptions occur during experimentation.

8 Experiment Sunsetting

Figure 6 shows possible options for a GENI experiment at the end of its lifecycle. The experimenter may choose to archive the experiment so it is available to future researchers to re-run or to extend. An experiment archive must include a formal description of the experiment in an experiment description language, a human readable description in a natural language, experimental results and any special considerations for repeating the experiment.

Technology developed by an experiment may also be transitioned to a product. The steps to product are outside the scope of this document.

8.1 Tools and Services for Experiment Sunsetting

GENI must provide experimenters with a checklist for archiving experiments. It must also provide facilities for archiving experiments and tools for verifying the minimum required information about an experiment is stored in the archives.

9 Other Experimenter Support Services

GENI researchers must have access to example programs and program outlines they can modify and extend as they develop their own distributed programs.

All GENI tools and services must provide online help and user documentation.

Acronyms

The following table defines acronyms used within the GENI Project.

GENI	Global Environment for Network Innovations