

# Fabric

## 0.2.0

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## 1 Introduction

Fabric is a language and runtime system that supports secure federated distributed computing. This manual briefly describes the contents of the Fabric distribution package, and should get you started with running Fabric. For more information, see our paper "Fabric: A Platform for Secure Distributed Computation and Storage" published in SOSP 2009 [4].

An HTML version of this manual [is available](#).

More information about Fabric, including the latest release, can be found at the [Fabric web site](#).

### User support and feedback

If you use Fabric, we'd appreciate your letting us know. We welcome comments, bug reports, and discussion about Fabric on the [Fabric users](#) mailing list.

[Subscribe to fabric-announce](#) to be notified about new releases of Fabric and related announcements.

### Package contents

The Fabric distribution package contains the following directories:

- `bin`: Scripts for invoking the compiler, runtime, and for configuration tasks. To get usage information for a script, run it with the `--help` option.
- `doc`: The Fabric manual, internal API documentation, and licenses.
  - `doc/api`: The Fabric internal API documentation.
  - `doc/licenses`: Licensing information for Fabric and its packaged dependencies.
  - `doc/manual`: The Fabric user manual.
- `examples`: [Example Fabric programs](#).
- `src`: Source code for the Fabric compiler and runtime, and some libraries built using Fabric.
  - `src/compiler`: The Fabric and FabIL compilers (FabIL is the intermediate language that Fabric compiles into).
  - `src/system`: The parts of the Fabric runtime system that are implemented in Java.
  - `src/runtime`: The parts of the Fabric runtime system that are implemented in FabIL.
  - `src/lib`: Libraries that are built using Fabric, including the Fabric port of the Servlets with Information Flow (SIF) library [\[3\]](#).
- `etc`: Configuration files for Fabric.
- `lib`: Library dependencies for Fabric.
- `tools`: A browser to inspect the contents of a store. A useful aid in the development of Fabric programs.

## 2 Setting up Fabric

### Requirements

This Fabric distribution builds on Unix. Fabric 0.2.0 builds against Jif 3.4.0 and Polyglot 2.5.1, both included in the distribution. We recommend that you use Oracle JDK 6 or later; we have experienced problems with OpenJDK and with older versions of Java. [OpenSSL](#) is used to sign certificates. Fabric is compiled with the [Apache Ant build tool](#).

### Configuring

1. Before using Fabric, you may need to specify the location of your JDK installation. If you are not using the pre-packaged Polyglot and Jif, you will also need to specify the locations of those. Copy `config.properties.in` to `config.properties` and edit appropriately.

```
$ cp config.properties.in config.properties
$ vim config.properties
```

2. Configure the scripts in the `bin` directory. From the top-level directory, run:

```
$ ant bin
```

## Building

Fabric comes pre-compiled as Jar files in the `lib` directory. If you wish to rebuild Fabric, run `ant` from the top-level directory:

```
$ ant
```

For other useful build targets, run `ant -p` from the top-level directory.

## 3 The Fabric language

The Fabric programming language is an extension of the Jif programming language [5], which is in turn a version of Java extended with security labels that govern the confidentiality and integrity of information used in the program, and ensure that information flows in the programs respect those security policies. Therefore, a good place to start is with the [Jif manual](#).

Fabric extends Jif with several additional features:

- [using and creating persistent objects on remote stores](#)
- [nested transactions](#)
- [remote method calls](#)
- [access labels](#)
- [provider labels](#)
- [codebases](#)

These features are summarized below, but more information can be found in two papers about Fabric [4], [1].

### Persistent objects

Fabric objects are, in general, persistent. Further, they may be stored persistently at a remote node (a storage node, or store). Applications that need persistent storage do not need a database to back them; they can record information directly in objects. Fabric supports *orthogonal persistence*: programs use objects in the same way regardless of whether they are persistent or not.

Remote persistent objects are created by specifying a store to store them. For example:

```
Store s = FabricWorker.getWorker().getStore("storename");  
Object o = new Object@s(args);
```

If a store is not specified, objects are created at the same store as the object `this`. Each worker node also has a local, non-persistent store. A reference to this store can be obtained by calling `FabricWorker.getWorker().getLocalStore()`.

Every object in Fabric has an *object label* that specifies the security of the information it contains. The object label is declared by attaching it to a field or fields of the object. (If multiple fields have labels, the object label combines all of them.)

### Nested transactions

Fabric computations are organized in *transactions*, which occur, as far as the programmer can tell, atomically and in isolation from the rest of the Fabric system.

Transactions are specified with an atomic block, for example:

```
atomic {
    o1.f();
    o2.g();
}
```

The semantics of the atomic block are that statements inside the atomic block are executed simultaneously and without interference from other concurrent transactions, even those taking place at other network nodes.

Transactions may be nested freely. The results of a nested transaction are only visible to the outer transaction once it successfully commits.

### Remote method calls

Unlike in most distributed object systems, computation in Fabric stays on the same network node unless the program explicitly transfers control to another node, using a remote method call.

A remote method call is specified using the syntax `o.m@w(x)`. This is the same syntax as a Java method call, except for the annotation `@w`, which specifies the worker node at which to perform the method call.

```
RemoteWorker w = FabricWorker.getWorker().getWorker("workername");
o.m@w(args);
```

Unlike in many other distributed systems with remote calls, the objects used during the computation of the method `m` need not reside at the remote worker `w`. Also note that transactions can span multiple remote calls; these calls will be executed as a single transaction.

### Access labels

When an object is accessed during computation on a worker, but is not yet cached at the worker, the worker must fetch the object data from the node where it is stored. Thus, the contacted node learns that an access to the object has occurred. This side channel is called a *read channel*.

Read channels are controlled by extending Jif with a second label on each object, called the *access label*. It is a confidentiality-only label that bounds what can be learned from the fact that the object has been accessed. The access label ensures that the object is stored on a node that is trusted to learn about all the accesses to it, and it prevents the object from being accessed from a context that is too confidential.

The access label of an object is declared as part of the label of its fields. Given object label `{u}` and access label `{a}`, a label annotation `{u} @ {a}` means that the field, and by extension the object, has the corresponding labels.

For example, the following code declares an object containing public information (in field `data`) that can be accessed without leaking information, according to any principal that trusts node `n` to enforce its confidentiality:

```
class Public {
    int {} @ {T→n} data;
}
```

In this example, the object label is `{}` (public and untrusted), and the access label is `{T→n}` (readable by principal `n`).

If the access label is omitted from a field, its access label defaults to the label `{this.store→}`. For any object `o`, the pseudo-field `o.store` represents the node on which `o` is stored.

### Provider labels

Remote method calls make it possible to invoke a method on a remote node even when that node has not previously seen the class of the object receiving the call, or its code. To make this possible, Fabric code is stored in *class objects*, which are also persistent objects in Fabric. We refer to the act of adding a class object to Fabric as *publishing* that class.

All code has an information-flow label called the *provider label*, which bounds who can have influenced the code. In fact, this label is precisely the object label of the class object.

Inside Fabric code, the provider label can be named explicitly as `provider`. Before loading code from a class object, a Fabric node checks the information flows within the code, using the provider label to implicitly keep track of the influence that the code publisher has on computations performed by the code.

### Codebases

Unlike Java classes, Fabric class objects are accompanied by linkage specifications called *codebases*. There is no global mapping in Fabric from class names to class objects. Instead, each code publisher can choose their own mapping. Fabric helps to make sure that published code uses these namespaces consistently. Thus, codebases support *decentralized namespaces*; a class's own codebase defines the resolution of its dependencies. Linkage of a component's dependencies is fixed at publication, so nodes that download and compile mobile code independently can securely interact with each other.

Codebases are normally not visible in Fabric programs. However, to support evolution of running Fabric systems, it may be necessary to use two classes with the same fully qualified Java name within the same program. This is supported by the use of *explicit codebases*.

For example, to specify that the name `pkg.A` should be resolved through a different codebase than the default one being used in the current code, we might declare the existence of a separate codebase `cb1`:

```
package pkg;
codebase cb1;

class B extends C {
    void m(cb1.pkg.A a) {
        ...
    }
}
```

The fully qualified name `pkg.A` is resolved to a class object through a different class name than the current class, `pkg.B`. The binding between the name `cb1` and the actual Fabric codebase object is done at the time of publication.

## 4 Compiling and publishing programs

### Compiling

To compile a Fabric program `MyClass.fab`, run the Fabric compiler, `fabc`:

```
$ fabc MyClass.fab
```

The `fabc` compiler has many options similar to the `javac` compiler, including the `-d` option to output classes in a different directory, the `-classpath` option to specify the classpath, and the `-sourcepath` option to specify the source path. For a complete list of options, run:

```
$ fabc -help
```

## Publishing

The Fabric compiler can publish code to a Fabric store, making the code available for download and use by Fabric workers. Publishing code requires a running store and a configured worker. (See [Starting Fabric nodes](#).) To publish, the Fabric compiler needs a few additional parameters:

- the name of the store that will host the published code,
- the name of the worker to use for publishing, and
- a file to which to write codebase information.

The following command will use the worker `MyWorker` to publish `MyClass.fab` to the store `MyStore`, outputting the URL of the resulting codebase to the file `codebase.url`:

```
$ fabc -deststore MyStore -worker MyWorker -publish-only \  
-codebase-output-file codebase.url MyClass.fab
```

The Fabric compiler can also compile against published code by specifying the codebase file on the classpath:

```
$ fabc -worker MyWorker -classpath @codebase.url MyClass2.fab
```

Code dependent on published code can similarly be published:

```
$ fabc -deststore MyStore -worker MyWorker -publish-only \  
-codebase-output-file codebase2.url \  
-classpath @codebase.url MyClass2.fab
```

## 5 The Fabric runtime system

There are three types of nodes in the Fabric design: stores, workers, and dissemination nodes. In the current implementation, there are no separate dissemination nodes; rather each worker and store participates as a peer in the dissemination network.

- [Creating Fabric nodes](#)
- [Starting Fabric nodes](#)

### 5.1 Creating Fabric nodes

Fabric nodes run relative to an *application home* directory, which contains the nodes' configuration and state. As a transitional naming mechanism, the application home can also contain naming information, specifying how to contact other Fabric nodes.

This guide demonstrates how to create and configure a Fabric node. As a running example, the node we create will be named `valinor` and will use `/opt/fabric` as the application home. The commands given are relative to the Fabric installation directory.

The name of the node can be any legal DNS hostname. This should ideally match the host machine's DNS name. However, with the transitional naming mechanism, a node's name need not have a DNS entry, nor is it required to match the host machine's DNS name.

### Create a certificate authority

Fabric uses SSL to secure communication between nodes, so each node must have an X.509 certificate signed by a certificate authority (CA). While commercial CAs may be used, the Fabric distribution uses OpenSSL to provide a custom CA for convenience.

This Fabric distribution comes with a CA whose key pair and certificate have been pre-generated. Using this pre-generated CA avoids having to distribute the CA certificate across separate Fabric installations, but is insecure. For security, we recommend creating your own CA:

```
$ bin/make-ca
```

By default, this creates a CA in `etc/ca` of the Fabric installation, overwriting any previously generated CA, and saves the CA certificate in `etc/ca/ca.crt`.

### Generate a key pair and certificate

Each Fabric node needs a key pair and a signed X.509 certificate. These can be created in one of two ways. The [first method](#) is provided for convenience. The [second method](#) is suggested for better flexibility.

#### Method 1: Using `make-node`

This method creates the key pair and certificate in a single step, using the CA in the Fabric installation to sign the certificate.

```
$ bin/make-node --app-home /opt/fabric --name valinor
```

This creates a Java keystore `/opt/fabric/etc/keys/valinor.keystore` containing the node's private key and certificate. Before importing the certificate into the node's keystore, the CA certificate will be displayed, and you will be asked whether it should be trusted.

#### Method 2: Using `genkey`

This method creates the key pair and certificate in multiple steps, and is useful if you are using a commercial CA, or if the CA is on a separate Fabric installation.

Generate the key pair and the certificate-signing request (CSR).

```
$ bin/genkey --app-home /opt/fabric --name valinor
```

This creates a Java keystore `/opt/fabric/etc/keys/valinor.keystore` containing the node's private key, and a CSR in `/opt/fabric/etc/csr/valinor.csr`.

Have the CSR signed by a CA. To sign using Fabric's CA facility:

```
$ bin/ca-sign /opt/fabric/etc/csr/valinor.csr /tmp/valinor.crt
```

This creates a signed certificate in `/tmp/valinor.crt`.

Once you have a signed certificate, import it and the CA's certificate into the node's keystore:

```
$ bin/import-cert --keystore /opt/fabric/etc/keys/valinor.keystore \  
  --ca etc/ca/ca.crt /tmp/valinor.crt
```

Before importing the certificates, this will display the CA certificate and ask you whether it should be trusted.



### Import other CA certificates

If this node will be communicating with nodes whose certificates are signed by other CAs, you will also need to import the certificates of those CAs.

```
$ bin/add-trusted-ca --keystore /opt/fabric/etc/keys/valinor.keystore \
  other-ca.crt
```

Before importing the certificate into the node's keystore, this will display the CA certificate and ask you whether it should be trusted.

### Configure the node

Our node `valinor` reads its configuration information from the files `etc/config.properties` and `etc/config/valinor.properties` in the application home. The first file, `config.properties`, specifies configuration values that are common to all nodes that share the application home. These values can be overridden in the node-specific file `valinor.properties`.

The Fabric distribution offers `etc/config/EXAMPLE.properties.in` as a template for a configuration file. Copy this to `/opt/fabric/etc/config/valinor.properties` and edit the file:

```
$ cp etc/config/EXAMPLE.properties.in /opt/fabric/etc/config/valinor.properties
$ vim /opt/fabric/etc/config/valinor.properties
```

Fabric nodes are configured using several parameters.

#### Configuration parameters common to all nodes

##### Required

- `fabric.node.password` specifies the password for the node's keystore file.

##### Optional

- `fabric.node.keystore` specifies the name of the node's keystore file. By default, this is `NODE_NAME.keystore`. In our example, this is `valinor.keystore`. This file must be located in the `etc/keys` directory of the application home.
- `fabric.node.hostname` specifies the IP address or the DNS name of the node's host machine. By default, this is the same as the node's name.
- `fabric.node.fetchmanager.class` specifies the class for the dissemination layer implementation. Valid options include `fabric.dissemination.PastryFetchManager` and `fabric.dissemination.DummyFetchManager`. By default, `PastryFetchManager` is used.
- `fabric.worker.port` specifies the network port on which the node should listen for remote calls. The default worker port is 3372.
- `fabric.worker.adminPort` specifies the network port on which the worker should listen for administrative connections. The default administrative port is 3572.

#### Configuration parameters for worker nodes

##### Required

- `fabric.worker.homeStore` specifies the name of the store that will hold the worker's principal object.

### Configuration parameters for storage nodes

#### Optional

- `fabric.store.port` it specifies the network port on which the store should listen for connections. The default store port is 3472.
- `fabric.store.db.class` specifies the class for the store's back-end database. Valid options include `fabric.store.db.BdbDB` and `fabric.store.db.MemoryDB`. The default is `fabric.store.db.BdbDB`.

### Configure name resolution

We must specify how other nodes can contact the node we just created. Ideally, this is done by adding a DNS entry with with an `A` (or `AAAA`) record containing the host machine's IP address and a `TXT` record specifying the node's network-port configuration. A store listening on port 3472 should have a `TXT` record "`fabric-store: 3472`". Similarly, a worker listening on port 3372 should have a `TXT` record "`fabric-worker: 3372`". (Default values are assumed if these records do not exist.) This use of the `TXT` record prevents the node's network-port configuration from being tied to the node's name (à la <http://example.com:8080/>) and allows the port configuration to change over time.

However, because this use of DNS is non-standard, we provide a transitional mechanism for resolving node names. To resolve a node, Fabric first looks in the `etc/config` directory of the application home. If it finds a `.properties` configuration file for the node, then it uses the configuration information found in that file. Otherwise, DNS is used.

When resolving a node, this transitional naming mechanism must be used if (a) the node's name does not match the host machine's DNS name, or (b) the node has a non-default port configuration and no corresponding `TXT` records in DNS.

To contact such a node, `valinor` must have a copy of the node's `.properties` configuration file in the `etc/config` directory of the application home. Similarly, if `valinor` relies on the transitional mechanism to be found, then its `.properties` configuration file must be copied to any node that will contact `valinor`.

## 5.2 Starting Fabric nodes

Continuing with the example from the [previous section](#), our example node will be named `valinor` and will use `/opt/fabric` as the application home. The commands given are relative to the Fabric installation directory.

### Starting a store

To start `valinor` as a store:

```
$ bin/fab-store --app-home /opt/fabric --name valinor
```

While the store is running, you are presented with a shell for the store's colocated worker. You can use this shell to run Fabric applications from within the colocated worker. (See [Running Fabric programs](#).)

The node's class path must include any non-mobile application classes that it will use. This can be specified with the `--jvm-cp` option:

```
$ bin/fab-store --jvm-cp /path/to/classes --app-home /opt/fabric \
  --name valinor
```

### Starting a worker

The following command starts `valinor` as a worker that is initially idle, but is available to receive remote calls.

```
$ bin/fab --app-home /opt/fabric --name valinor
```

While the worker is running, you are presented with the worker's shell. You can use this shell to run Fabric applications from within the worker. (See [Running Fabric programs.](#))

The worker's class path must include any non-mobile application classes that it will use. This can be specified with the `--jvm-cp` option:

```
$ bin/fab --jvm-cp /path/to/classes --app-home /opt/fabric \
  --name valinor
```

## 6 Running Fabric programs

This guide demonstrates how to run a Fabric program. As a running example, we will use a worker named `valinor`, with `/opt/fabric` as the application home. The commands given are relative to the Fabric installation directory.

### From the command line

The following command starts the worker, executes the class `hello.Main`, and shuts down the worker. If the worker is already running, then the command attaches to the already-running worker and executes `hello.Main` from within that instance.

```
$ bin/fab --jvm-cp /path/to/classes --app-home /opt/fabric \
  --name valinor hello.Main
```

The `--jvm-cp` option specifies a path containing the (non-mobile) class `hello.Main` and any non-mobile classes it uses.

To execute a mobile class, specify the class's codebase-relative name. For example,

```
$ bin/fab --app-home /opt/fabric --name valinor \
  fab:///helloStore/35/hello.Main
```

### From the worker shell

If a class name is not given when starting a worker, then the worker starts idle and the user is given a worker shell:

```
$ bin/fab --app-home /opt/fabric --name valinor
```

```
Worker started
```

```
valinor>
```

Stores also have worker shells for their colocated worker:

```
$ bin/fab-store --app-home /opt/fabric --name valinor
```

```
Worker started
```

```
Store started
```

```
valinor>
```

To execute a non-mobile class from within the worker, simply enter the class's name into the shell:

```
valinor> hello.Main
Hello, world!

valinor>
```

The worker must have the requisite non-mobile classes on its class path, as specified by the `--jvm-cp` command-line option when starting the worker.

To execute a mobile class, enter the class's codebase-relative name:

```
valinor> fab://helloStore/35/hello.Main
Hello, world!

valinor>
```

## 7 Example programs

The `examples` directory in the distribution contains several example Fabric programs. Each example includes a separate README describing how to build and run the example. The Fabric nodes required to run each example come pre-configured. We briefly list the examples here.

- `examples/hello`: Every programmer's favorite program, ported to Fabric. This example creates a persistent object containing the message "hello world" and then outputs that message on the console.
- `examples/sif-hello`: A demonstration of the Fabric port of the Servlets with Information Flow (SIF) library [3]. This example shows how web services can be built on top of Fabric.
- `examples/travel`: A more complete demonstration of Fabric's features. This application involves coordination between an airline, bank, and customer to negotiate the purchase of a ticket. Each principal (airline, bank, and customer) also has a web-based user interface written using the SIF library.
- `examples/auction`: A mobile bidding-agent program. This application demonstrates the mobile-code support of Fabric [1]. It models an auction in which participants submit confidential strategies for bidding and selling.
- `examples/friendmap`: Another mobile-code demonstration. This program models a mash-up of social network and a mapping service to map a friend's confidential location.
- `examples/OO7`: This is an implementation of the OO7 Object Oriented Database Benchmark [2]. It is written using FabIL, the intermediate language for Fabric, and thus does not benefit from the static information-flow checking that the full Fabric language provides.
- `examples/blog`: This is a simple web application implemented in FabIL. It is similar in structure to the Course Management System that we used for evaluating performance of Fabric [4].

## 8 Version history

### Version 0.2.0 (Oct 2012)

- Support for mobile code [1]

- [Provider labels](#)
  - [Access labels](#)
  - Type fingerprint checking for remote calls and objects
- Support for [codebases](#)
- Support for heterogeneous field labels
- Workers have interactive consoles. These can be used to run Fabric programs or invoke the Fabric compiler from within the worker.
- Workers listen for administrative connections. If a second instance of a worker is launched, it will attach to the first instance on the administrative port and execute commands within the first instance. This is a convenience feature to enable scripting of worker commands.
- Added `DummyFetchManager`, which implements a degenerate dissemination layer.
- Added `bin/dump-bdb`, which dumps the contents of a store's BDB-backed object database
- Various performance improvements.

Version 0.1.0 (Sep 2010)

Initial release. [\[4\]](#)

## 9 Credits

The current Fabric developers are:

- [Jed Liu](#)
- [Owen Arden](#)
- Michael D. George
- [K. Vikram](#)

The Fabric project group is supervised by [Prof. Andrew C. Myers](#) at the [Cornell University Computer Science Department](#).

Past Fabric developers are:

- Lucas Waye
- [Danfeng Zhang](#)
- [Xin Qi](#)
- Xin Zheng

[Nate Nystrom](#) was involved in the early stages of the Fabric project.

[Steve Chong](#) provided guidance on extending Jif and provided quick bug fixes to the base Jif compiler.

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This work does not necessarily represent the opinions, expressed or implied, of any of these sponsors.

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