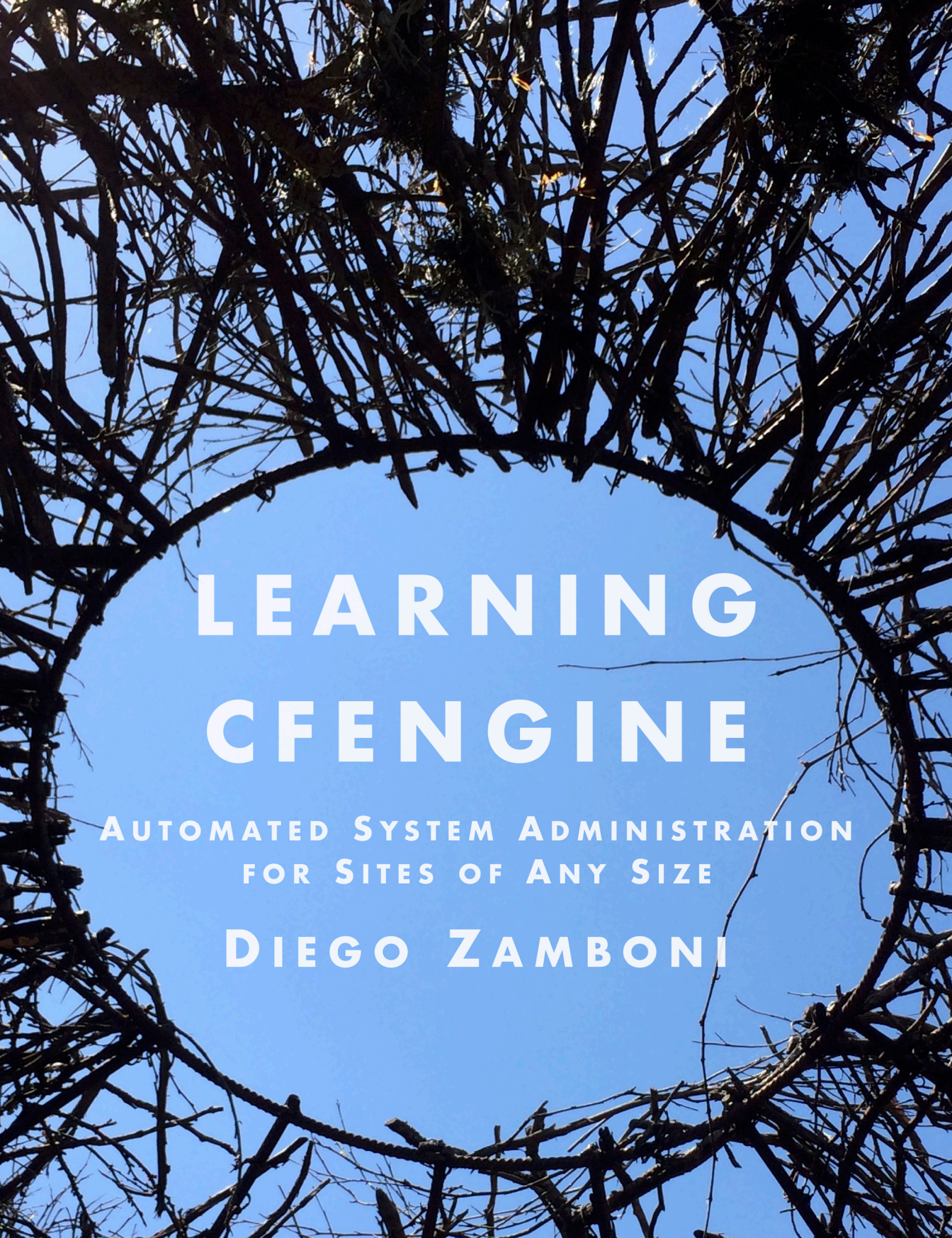

LEARNING
CFENGINE
AUTOMATED SYSTEM ADMINISTRATION
FOR SITES OF ANY SIZE
DIEGO ZAMBONI

Learning CFEngine

Automated System Administration for Sites of Any Size

Diego Zamboni

This book is for sale at http://leanpub.com/learning-cfengine

This version was published on 2018-11-02

This is a Leanpub book. Leanpub empowers authors and publishers with the Lean Publishing process. Lean Publishing is the act of publishing an in-progress ebook using lightweight tools and many iterations to get reader feedback, pivot until you have the right book and build traction once you do.

Also By Diego Zamboni

Learning Hammerspoon

Para Susi, Kari, Fabi y Nube

Contents

1. Getting Started with CFEngine

The first step toward using CFEngine is getting it installed on at least one machine so that you can start playing with it. CFEngine Community (the open source version) is available from many package management repositories, and you can also easily build it from source yourself. You can also install CFEngine Enterprise, which is free for use on up to 25 hosts. In this chapter we will go through the process of installing CFEngine on your machine, setting it up, and writing and running your first policy. Don't worry if you do not understand at first glance what all the different pieces mean—the idea of this chapter is to get you going. We will step back in CFEngine Basics to examine all the different CFEngine components.

I will mention one concept that you need to understand before we start. Your first CFEngine host will act as the *policy hub*, which is a server from where other CFEngine clients fetch their policy files. If you are just going to start playing with CFEngine, most likely you will be using it on a single host at the beginning, so the hub and the client can be on the same machine. As you grow your CFEngine installation, other machines will connect to the hub as well. Most CFEngine installations use a "star" configuration, with a single hub serving multiple machines. However, this is not a requirement—CFEngine allows you to connect its components in any architecture you desire[1].

Installing CFEngine

Remember that CFEngine exists in two versions: community edition and commercial edition. Therefore, I will describe the following options for installing CFEngine:

- Commercial edition (free for up to 25 nodes), installed from a binary package or on a pre-built virtual machine image using Vagrant.
- Community edition (free), installed from a binary package or from a package repository.
- Community edition (free), installed from source code.

[1] In fact, with CFEngine Community there is no difference at all in the software installed on a hub and on a client, just in their configuration. It is easy to convert a client into a hub (and vice versa) by bootstrapping it again with the correct options, as described in Finishing the Installation and Bootstrapping.

Which Version of CFEngine?

You should always install the latest released version of CFEngine. Some operating systems include in their repositories older versions of CFEngine, but each new release includes new features, bug fixes and other improvements that make it worth staying up to date. All examples in this book have been tested with CFEngine 3.12 LTS, the latest release at the time of writing.

Since version 3.7, CFEngine has adopted a regular 6-month release cycle for major releases. Every 18 months, the new release is labeled as LTS (Long-Term Support), which means that it will be supported for a full three years after release. You can read the details about this release schedule at https://cfengine.com/product/supported-versions/.

Testing CFEngine Enterprise using a Vagrant VM

The easiest way to give CFEngine a quick try is to use the CFEngine Enterprise binary packages, using the pre-made Vagrant configuration provided by CFEngine AS.

For the purposes of learning CFEngine while you read this book, this method of installation is highly recommended, as you can experiment with both the Community and the Enterprise features. Of course, if you are installing directly on some of the machines you manage, you need to choose the appropriate edition depending on whether you plan to purchase Enterprise licenses.

Vagrant allows us to quickly set up one or more VMs with a repeatable, consistent configuration. Using Vagrant, the CFEngine Enterprise Vagrant Environment quickly sets up a CFEngine Enterprise Hub and one client running on your own machine, both running the latest version of CFEngine Enterprise. You can find the full instructions at the CFEngine documentation page[2], but in short these are the steps you need to follow, applicable to Windows, Linux or macOS:

1. Download and install VirtualBox for your platform from https://www.virtualbox.org/

[2] https://docs.cfengine.com/docs/3.12/guide-installation-and-configuration-general-installation-installation-enterprise-vagrant.html

2. Download and install Vagrant for your platform from https://www.vagrantup.com/
3. Download and unpack the CFEngine Vagrant Environment tar file[3]. When you unpack this file, it will create a directory named `CFEngine_Enterprise_vagrant_quickstart-3.12.0-1` (or similar, depending on the current release).
4. Change into the directory created and request the status of the VMs using the `vagrant status` command:

```
$ vagrant status
Current machine states:

hub                       not created (virtualbox)
host001                   not created (virtualbox)

This environment represents multiple VMs. The VMs are all listed
above with their current state. For more information about a specific
VM, run `vagrant status NAME`.
```

5. Create and start the VMs using `vagrant up`. This may take a few minutes and you will need to be connected to the Internet, since Vagrant will need to download some VM images the first time. Vagrant will set up the VMs, install and configure CFEngine Enterprise on them

```
 $ vagrant up
 Bringing machine 'hub' up with 'virtualbox' provider...
 Bringing machine 'host001' up with 'virtualbox' provider...
 ==> hub: Importing base box 'centos-6.5-x86_64-cfengine_enterprise-
vagrant-201501201245'...
 ...
 ==> host001: Thank you for downloading the
              Getting Started with CFEngine Enterprise
 ==> host001: Vagrant Virtualbox environment
 ==> host001: Please log into the mission portal:
 ==> host001: https://localhost:9002
 ==> host001: username: admin
 ==> host001: password: admin
```

[3] https://cfengine-package-repos.s3.amazonaws.com/enterprise/Enterprise-3.12.0/misc/CFEngine_Enterprise_vagrant_quickstart-3.12.0-1.tar.gz

6. After a few minutes, you will have a new shiny CFEngine Enterprise setup consisting of one hub and one client:

```
$ vagrant status
Current machine states:

hub                       running (virtualbox)
host001                   running (virtualbox)

This environment represents multiple VMs. The VMs are all listed
above with their current state. For more information about a specific
VM, run `vagrant status NAME`.
```

You can explore the CFEngine Enterprise console using the URL and credentials printed. You can also login to any of the VMs using the `vagrant ssh` command. You can run most of our examples in the client VM, to which you can login like this:

```
$ vagrant ssh host001
Last login: Tue Jan 20 19:18:45 2015 from 10.0.2.2
[vagrant@host001 ~]$
```

The directory in which the Vagrant configuration is unpacked is mounted on the VMs under `/vagrant`. This can be very useful to share files between your host machine and the CFEngine VMs. For example, you can use your favorite local editor to type the examples and save them in that directory, and they will be available to the VMs as well so you can run them.

By default the Vagrant configuration file will create only one client VM, but you can request more by setting the `HOSTS` environment variable:

```
$ export HOSTS=3
$ vagrant status
Current machine states:

hub                       running (virtualbox)
host001                   running (virtualbox)
host002                   not created (virtualbox)
host003                   not created (virtualbox)

$ vagrant up
...
$ vagrant status
Current machine states:

hub                       running (virtualbox)
host001                   running (virtualbox)
host002                   running (virtualbox)
host003                   running (virtualbox)
```

In this way, you can experiment with a multi-node setup, all within your local machine. Be mindful of starting many VMs, lest you overload your machine.

Installing the Community Edition from Binary Packages

CFEngine Community can also be installed from binary packages that are built for most popular Linux distributions. The easiest way to do this is by using the quick-start script provided by CFEngine AS. The script automatically downloads and installs the appropriate package according to your distribution. You can use it like this (make sure to type the whole command in a single line):

```
# curl http://cfengine.package-repos.s3.amazonaws.com/quickinstall/
  quick-install-cfengine-community.sh | bash
```

Alternatively, you can download the individual package files for different Linux distributions from https://cfengine.com/product/community/. Once you download the appropriate package, install it using the corresponding tool for your operating system (for example, `rpm` or `dpkg`).

Installing the Community Edition using your system's package repositories

Many Linux distributions and macOS package managers include CFEngine in their default package repositories. In these cases, it's usually fine to install CFEngine from there. Be aware that in some cases, the packages available are for very old versions of CFEngine, so before you install it, make sure it is a recent version (preferably the latest) to have access to all the features we will discuss.

Installing the Community Edition from Source

You can download the CFEngine source code in a compressed tar file from https://cfengine.com/source-code. You can also fetch the very latest code from the CFEngine git repository by issuing the following command:

```
$ git clone git://github.com/cfengine/core.git
```

CFEngine requires the following packages (with their development-related content, such as header files):

- OpenSSL (installed by default in most Linux and Unix systems)
- One of: LMDB, QDBM or Tokyo Cabinet
- PCRE, the Perl-Compatible Regular Expressions Library (http://www.pcre.org/)

In addition, the following libraries are supported for enabling optional features. If they are installed, the CFEngine `configure` script will automatically enable the corresponding features.

- libxml2 for the ability to edit XML files.
- libacl for the ability to manipulate POSIX ACLs.
- MySQL client library for the ability to manage MySQL databases.
- PostgreSQL client library for the ability to manage PostgreSQL databases.

Once the required packages are installed, compiling and installing CFEngine is as easy as running the following commands in the CFEngine source directory:

```
$ ./configure
$ make
$ sudo make install
```

If you checked out the source code from the git repository, use the following sequence (`autogen.sh` understands the same options as `configure`, in case you want to provide any):

```
$ ./autogen.sh
$ make
$ sudo make install
```

This will compile CFEngine and install all its binaries and support files under `/var/cfengine/`. The binaries will all be located in `/var/cfengine/bin/`, so you should add this directory to your `PATH` environment variable to be able to invoke the binaries conveniently.

The configure script prints, near the end of its execution, a summary of all the CFEngine features that have been enabled, according to the optional libraries that were found. You can use this to verify that all the features you want are there, before compiling. For example, you can see here that XML support is disabled, which is most likely an indication that the libxml2 library is not installed:

```
Summary of options...
> Required libraries
-> OpenSSL: default path
-> PCRE: default path
-> DB: Tokyo Cabinet: default path
> Optional libraries
-> MySQL connector: default path
-> PostgreSQL connector: default path
-> libvirt: default path
-> libacl: default path
-> libxml2: disabled
-> Workdir: /var/cfengine
```

You can run `./configure --help` to get a list of all the valid options, and find the

detailed, latest compilation instructions at https://github.com/cfengine/core/blob/master/INSTALL.

Installing CFEngine Enterprise

If you have purchased the commercial edition of CFEngine, you will get access to the binary packages of CFEngine Enterprise for all the supported operating systems, including a native Windows installer. You will also need to register your CFEngine policy server to get a license key for it.

You can use CFEngine Enterprise for free for up to 25 nodes. This is an excellent opportunity to learn and explore the commercial features of CFEngine before committing to purchasing it.

The policy language in the commercial edition of CFEngine is a strict superset of the Community Edition, so you can start by practicing with the Community Edition, and move to the commercial edition as you gain more experience and need more advanced features, knowing that your existing policies will work just as before.

CFEngine Enterprise comes in two package files, called `cfengine-nova` and `cfengine-nova-hub`. The first one should be installed on CFEngine client machines, and the second one on the *policy hub*, the central host from where clients will fetch their policies, and where the CFEngine graphical console available with Enterprise is installed. The hub software must be installed on a 64-bit machine, so the hub packages are only available in 64-bit versions.

CFEngine Enterprise was originally called “CFEngine Nova”, which is why you will find many references to this name, including the package filenames.

Similarly to the Community edition, the easiest way to install Enterprise is by using the existing quick-install script, which you can download as follows (type the command in a single line):

```
$ wget http://s3.amazonaws.com/cfengine.packages/
  quick-install-cfengine-enterprise.sh
```

You then need to run the script with the argument `hub` or `agent`, depending on the type of host you want to install:

```
$ sudo bash ./quick-install-cfengine-enterprise.sh hub    # on the hub
$ sudo bash ./quick-install-cfengine-enterprise.sh agent  # on other hosts
```

You can also download the packages individually from https://cfengine.com/product/cfengine-enterprise-free-25/, and install them on your hosts using their corresponding installation mechanism.

If you have a commercial license (this is, you have purchased a license to use Enterprise on more than 25 hosts), you need to install the license key `license.dat` that you get from CFEngine by running the following command:

```
# cf-key --install-license ./license.dat
```

After this, you can continue with the bootstrap process as described next.

Finishing the Installation and Bootstrapping

After installation, there may be a few finishing steps left to perform, depending on your installation method. If you are using the CFEngine Enterprise Vagrant setup as described in Testing CFEngine Enterprise using a Vagrant VM, then all VMs are already correctly bootstrapped, and you can skip this section. Otherwise, follow these steps:

1. Run the command `/var/cfengine/bin/cf-key`. This will generate a private- and public-key pair for the current host.

   ```
   # /var/cfengine/bin/cf-key
   Making a key pair for cfengine, please wait, this could take a minute...
   ```

   These keys are necessary when operating in a distributed CFEngine environment. This command also sets up under `/var/cfengine/` the basic directory structure used by CFEngine. The generated keys will be stored in `/var/cfengine/ppkeys/`.

   If the keys already exist (CFEngine-provided binary packages run this command automatically during the installation) you will see the following message:

   ```
   # /var/cfengine/bin/cf-key
   A key file already exists at /var/cfengine/ppkeys/localhost.pub
   ```

2. CFEngine installs its binaries by default in `/var/cfengine/bin/`. Some binary packages may also copy them to `/usr/local/sbin/` to have them in the same directory as other system utilities. You may want to add the correct directory to the `PATH` environment variable in your shell setup.

3. On the policy hub, CFEngine expects to find its "master files" under `/var/cfengine/masterfiles/`. This is meant to be the master copy of its policy files, from where they will be copied to the work directory (`/var/cfengine/inputs/` by default). If the `/var/cfengine/masterfiles/` directory is empty or nonexistent (this will be the case if you installed from source), you need to populate it with the sample `masterfiles` directory from the CFEngine distribution, which normally gets installed in `/var/cfengine/share/CoreBase/`:

   ```
   # ls /var/cfengine/masterfiles
   # cp -Rp /var/cfengine/share/CoreBase/* /var/cfengine/masterfiles/
   # ls -F /var/cfengine/masterfiles/
   cf-sketch-runfile.cf  controls/  def.cf     libraries/
   promises.cf           services/  update.cf
   ```

   We will examine these files in detail later on.

4. Finally, CFEngine needs to be "bootstrapped" to a CFEngine policy server. This registers the client with the server, copies the masterfiles to their final working location in `/var/cfengine/inputs/` and starts the base `cf-execd` daemon. The policy server also needs to be bootstrapped to itself.

   The `cf-execd` daemon controls the periodic execution of `cf-agent`, which is the one that actually executes the promises in the provided policies (we will look in more detail at the different components in CFEngine Components).

   To bootstrap a client, first find the IP address of your policy server, using the `ifconfig` command (`ipconfig` under Windows). Let's assume it is 10.0.2.15. Run the `cf-agent` command with the `--bootstrap` option. For example, if you run the command on the policy server itself, you will see the following:

```
# /var/cfengine/bin/cf-agent --bootstrap "10.0.2.15"
2013-07-03T06:12:34   notice: Q: "...f-serverd"":
2013-07-03T06:12:34   notice: Server is starting...
2013-07-03T06:12:34   notice: R: This host assumes the role of policy server
2013-07-03T06:12:34   notice: R: Updated local policy from policy server
2013-07-03T06:12:34   notice: R: Started the server
2013-07-03T06:12:34   notice: R: Started the scheduler
2013-07-03T06:12:35   notice: Bootstrap to '10.0.2.15' completed successfully!
```

The `cf-agent` command recognizes you are using the machine's own IP address to bootstrap, and configures it as a policy server. You can verify the success of this command by looking at the process list. You should see at least the `cf-execd` process, and maybe some others that are started automatically by it:

```
# ps ax | grep cf
84284 ??         0:00.22 /var/cfengine/bin/cf-execd
84287 ??         0:00.15 /var/cfengine/bin/cf-serverd
```

The policy server should be the first host you bootstrap. Once you have it running, you can boostrap CFEngine on other hosts by providing the server's IP address to the `cf-agent --bootstrap` command.

Auxiliary Files

The CFEngine distribution includes not only the binaries, but also a large library of documentation and examples. The examples normally get installed in `/var/cfengine/share/doc/` (in previous versions they were installed under `/usr/local/share/cfengine/` or `/usr/local/share/doc/cfengine/`, and can be of big help for getting started. These directories include examples of CFEngine configurations for different tasks and demonstrate the use of different CFEngine constructs. The `examples` directory contains a large number of mostly-self-contained files that demonstrate and exercise different CFEngine abilities.

Your First CFEngine Policy

Now that you have CFEngine installed and running, let us start by writing a first simple policy. If you have finished the bootstrapping process described in

Finishing the Installation and Bootstrapping, you can be sure that CFEngine is properly installed. You can also check this by running the following command:

```
# cf-agent --version
CFEngine Core 3.12.2
CFEngine Enterprise 3.12.2
```

For our first policy, let us tackle a task that is simple to explain, yet can be useful in real systems. We will add a line to the `/etc/motd` file to indicate that CFEngine is running on this machine. And to keep with tradition, we will also print out a "Hello world!" message to the console when the policy is run.

I recommend you type the code as you read through the example, and save it in a file named `edit_motd.cf` so you can run it from CFEngine when we are done.

If you are using the Vagrant quick-start setup, you can save this file under the same directory, and it will be available in the VMs under the `{{{file(/vagrant)}}}` directory.

CFEngine instructions (called "promises") are contained in units called "bundles". In our case, we will define a bundle called `edit_motd`. Here is the bundle code:

```
bundle agent edit_motd
{
 vars:
   "motd" string => "/etc/motd";

 files:
   "$(motd)"
     create => "true",
     edit_line => addmessage;

 reports:
   "Hello world!";
}
```

This is the part of the policy that tells CFEngine what to do. Here is how it works:

- In CFEngine, a bundle of type `agent` (identified by its declaration `bundle agent`, followed by an arbitrary identifier, in this case `edit_motd`) could be considered the equivalent of a subroutine, and contains promises that CFEngine evaluates and acts on, if needed. It is split into sections that correspond to different types of promises, which are the lines that start with a word and end with a single colon. In this bundle, we have three sections: `vars:`, `files:`, and `reports:`.

- The `vars:` section is used to declare variables. CFEngine has several variable types, including strings, lists, arrays, and numbers (both integers and floating-point numbers are supported). Here we are declaring a single string value named `motd`, which contains the path of the file we want to edit. If you are testing this on a system where you don't have `root` privilege, you should change this path to some file you can edit, for example `/tmp/motd`.

  In a CFEngine policy, everything is expressed as promises, even variable declarations. In this case, `motd` promises to be a string variable containing the value `"/etc/motd"`. We will reference this variable later in the policy. Scalar variable references are indicated by a dollar sign followed by the variable name enclosed in either parentheses or braces. Both `${motd}` and `$(motd)` refer to the same variable.

- In the `files:` section we indicate the file-related operations we want to perform. In this case, the promiser is `"$(motd)"` which expands the `motd` variable into its value, so the promiser becomes `"/etc/motd"`, telling CFEngine which file to edit.

  The rest of the promise, up until the semicolon, is called the *body* of the promise, and is formed by `attribute => value` pairs, separated by commas. In this case we have two attribute specifications: `create => "true"` and `edit_line => addmessage`. The former simply indicates that the file needs to be created if it doesn't exist yet. The latter means that lines in `/etc/motd` will be edited according to the specification given by a bundle named `addmessage` (which we haven't seen yet).

  Casting this into CFEngine terminology: All *promisers* in the `files:` section are interpreted by CFEngine as files (or directories) on the system, so the promise in our sample policy means that the `/etc/motd` file *promises* to be edited according to the instructions given by the body of the promise. The value of the `edit_line` parameter is the name of an `edit_line` *bundle*. This means that it's not a single value, but rather the name of a named collection of attributes that specifies the behavior of `edit_line`. Here is its definition:

```
bundle edit_line addmessage {
 insert_lines:
   "This system is managed by CFEngine 3";
}
```

A bundle is also a container of promises, and is also divided in sections. The type of each bundle is given by the second word in its declaration (in this case, `edit_line`). You can see that the `edit_motd` bundle had `agent` as its type, which means it is an "execution" bundle that can be called directly (in this case, from the `bundlesequence` declaration, although there are other means for executing agent bundles that we will cover later). Thus, the first line assigns the type `edit_line` to the `addmessage` bundle, meaning that it can be used only as the value of an `edit_line` attribute. Additionally, the type of a bundle defines what sections are valid in it, and how the promises in it are interpreted. An `edit_line` bundle must contain promises that perform edits on a file. In this case, it contains an `insert_lines:` section, so promises are interpreted as lines that must be present in the file. The only promise in this bundle is a string that contains the message we want to insert in the file. The string itself is the promiser and no additional attributes are given, which means the line will always be inserted into the file, *unless it is there already* (this is CFEngine's way of ensuring convergent behavior: if it always inserted a line, the file would never converge to a stable state).

In summary, what this means is that the given line will be inserted into `/etc/motd` if it's not there already.

- Finally, the `edit_motd` bundle has a `reports:` section, which is meant to produce output during the execution of the policy. Promises in a `reports:` section indicate messages and how they will be handled. By default, the promised message will be printed to the console. In our case, we will print the message `Hello world!` to the console every single time the promise is executed.

This completes our first policy, so let us look at it in one piece:

```
bundle agent edit_motd
{
 vars:
   "motd" string => "/etc/motd";

 files:
   "$(motd)"
     create => "true",
     edit_line => addmessage;

 reports:
   "Hello world!";
}

bundle edit_line addmessage
{
 insert_lines:
   "This system is managed by CFEngine 3";
}
```

Type this in and save it to a file, for example `edit_motd.cf`. You can then execute it with the following command:

```
# cf-agent --no-lock --inform --bundlesequence edit_motd --file ./edit_motd.cf
    info: Using command line specified bundlesequence
    info: Edit file '/etc/motd'
R: Hello world!
```

These are the options we used:

- `--no-lock` (can be abbreviated as `-K`) means “Ignore locking constraints during execution,” which in practice means “always execute all promises.” Normally, CFEngine obeys certain time periods between successive evaluations of the same promise, to avoid overloading the systems. The `--no-lock` option disables those constraints, and so is useful for testing policies that you may run several times in quick succession.
- `--inform` (short `-I`) means “Print basic information about changes made to the system,” essentially telling CFEngine to show you the actions that it is taking. If not specified, CFEngine’s output is quite terse, so again, this is useful when you are testing policies to get more information about what CFEngine is doing.

- `--bundlesequence` (short `-b`) tells CFEngine which bundle to execute within the file (the bundle sequence can also be specified within the policy file, but specifying it in the command line will make it easier to integrate with the rest of the system policy).
- `--file` (short `-f`) tells CFEngine to use the specified file as its input. Otherwise it will try to read `/var/cfengine/inputs/promises.cf` You can also omit the `-f` and simply give the filename as the last argument to the command.

Now examine the `/etc/motd` file, and you will see that the following line has been added to it:

```
This system is managed by CFEngine 3
```

If you run the command again, the output changes:

```
# cf-agent -K -I -b edit_motd -f ./edit_motd.cf
    info: Using command line specified bundlesequence
R: Hello world!
```

The `/etc/motd` file already contains the message, so it is not edited again. Now try editing it by hand and removing or modifying the existing line. If you run `cf-agent` again, the message will reappear.

Congratulations! You have written and executed your first CFEngine policy. This is a very basic operation, but its structure is very similar to that of any other CFEngine policy, and allows enough flexibility and expressibility to tackle the most complex configuration tasks.

In Unix machines, you can use “shebang” notation to make your policy files executable, just like any other script in a Unix system. To do this, make sure the first line of your policy file contains the following, and that the script itself has execute permissions:

```
#!/var/cfengine/bin/cf-agent -bedit_motd
```

Then you can run the policy as a standalone script:

```
# ./edit_motd.cf
R: Hello world!
```

Usually, your policies should all be integrated into a cohesive execution controlled by `cf-execd` (see Integrating Your New Policy Into Periodic CFEngine Execution), but this technique can be useful when you have some specific policies that you want to be able to execute separately or on demand.

Most of the examples in this book are shown running as the `root` user, since that is the normal conditions under which CFEngine should be executed to have the privileges necessary to exercise changes to the system. However, during development and testing it is perfectly possible to run CFEngine as a regular user. When you run it like this, CFEngine does not look under `/var/cfengine/` for its input files, rather it looks under `$HOME/.cfagent`, so if you run `cf-agent` without specifying an input file, it will try to read `$HOME/.cfagent/inputs/promises.cf`.

For this to work, all the CFEngine executables and files (including its key files) need also to exist under `$HOME/.cfagent/`. So you need to run the following commands before you start:

```
$ cf-key   # cf-key creates all the necessary directories
Making a key pair for CFEngine, please wait, this could take a minute...
$ ln -s /var/cfengine/bin/* ~/.cfagent/bin/
```

Integrating Your New Policy Into Periodic CFEngine Execution

In the example we just saw, you were running the policy file by hand using `cf-agent`. But CFEngine is meant to save you from running things by hand! For development and testing it is fine to run your policies this way, but once they are done, you need to integrate them into the main CFEngine execution loop so that they are evaluated continuously and automatically. This is done

by integrating them into the policies executed by `promises.cf`, which is the file that CFEngine loads and executes by default.

The easiest way to do this integration is to make use of the built-in capabilities in the default CFEngine masterfiles policies to automatically load and execute certain bundles. In short, this is what we need to do:

- Enable the "autorun" feature in the policy (it comes disabled by default).
- Tag our `edit_motd` bundle with the `autorun` tag so that it is automatically executed.
- Copy our `edit_motd.cf` policy file to the `services/autorun` directory inside the policy directory, so that it is automatically loaded.

More specifically, these are the steps we need to follow to automatically load and execute the `edit_motd` bundle:

1. Edit the `edit_motd` bundle to add the following lines at the beginning, which specify some metadata for the bundle, including the `autorun` tag:

   ```
   meta:
     "tags" slist => { "autorun" };
   ```

2. Copy the modified `edit_motd.cf` to `/var/cfengine/masterfiles/services/autorun/` in the policy server. This directory is special because all policy files in it will be automatically loaded.
3. Create file `/var/cfengine/masterfiles/def.json` with the following contents, to enable the autorun feature:

   ```
   {
     "classes":
     {
       "services_autorun": [ "any" ]
     },
   }
   ```

If you want to trigger the changes right away, run the following commands to force an immediate update of the policies, and then to execute them:

```
# cf-agent -f /var/cfengine/inputs/update.cf -I
    info: Updated '/var/cfengine/inputs/services/autorun/edit_motd.cf'
      from source '/var/cfengine/masterfiles/services/autorun/edit_motd.cf'
      on 'localhost'
# cf-agent
R: Hello world!
```

(you may want to remove the `reports:` promise that prints the message once you have this integrated)

That's it! Now your `edit_motd` bundle will be run automatically as part of the regular CFEngine execution every five minutes, ensuring that the `/etc/motd` file is constantly kept correctly configured.

2. CFEngine Basics

In this chapter we will take a more detailed look at the basic concepts behind CFEngine, including its theoretical foundation, the syntax and constructs of its policy language, and some unique aspects of its behavior. I will also point you to some of the many online resources available for learning and improving your CFEngine skills.

Basic Principles

One of CFEngine's unique characteristics is that it is built upon predefined, solid theoretical and behavioral principles. These principles guide the design and implementation of all the CFEngine components and of its policy language, and ensure that the behavior of those components remains consistent. These principles are: desired-state configuration, a minimum base set of native operations, promise theory, and convergent configuration. Let us look at them in more detail.

Desired-State Configuration

CFEngine is different from many other automation mechanisms in that you do not need to tell it what to do. Instead, you specify the state in which you wish the system to be, and CFEngine will automatically decide the actions to take to reach the desired state, or as close to it as possible. In programming language terms, we say that the CFEngine policy language is *declarative*, as opposed to *imperative*.

These are some examples of the things that you can express to CFEngine as desired states:

- "Make sure file `/etc/ssh/sshd_config` contains the line `UseDNS no`"
- "Make sure user `mysql` exists/does not exist"
- "Make sure process `httpd` is (not) running"

At a higher level of abstraction, you can encapsulate CFEngine operations and express high-level desired states:

- “Make sure all web servers have Apache installed”
- “Make sure all `root` accounts have the same, centrally-designated password”
- “Make sure parameters `UseDNS` and `PermitRootLogin` are disabled on all `sshd` configurations, except on servers dbsrv01 and dbsrv02, where `PermitRootLogin` should be enabled”

And at an even higher level, you can express top-level desired states like these:

- “Configure host dbsrv01 as a database server”
- “Create a new cluster of VMs to use as web servers”
- “Give me a new datacenter in EC2 region ap-northeast-1”

Of course, at some point, CFEngine needs to know what specific changes to make to the system, and how to make them. To this effect, CFEngine knows how to perform a number of native operations on the system.

Basic CFEngine Operations

These are some of the basic operations that CFEngine natively knows how to perform:

- Extract information from the system itself about its current state and configuration.
- Inspect and modify the contents of text, XML or JSON files.
- Check for and manipulate file permissions and ownerships.
- Check for existence of processes running in the system.
- Check for existence of users in the system.
- Run programs and check their exit status.
- Check and manipulate packages installed on the system.
- Check and manipulate services on Unix systems.
- Query and manipulate databases and their contents (as of this writing, MySQL, PostgreSQL and SQLite are supported).
- Examine and manipulate POSIX Access Control Lists (ACLs).

This is by necessity an incomplete list—it reflects only the major features implemented by major promise types in CFEngine. There are many other operations implemented by functions or by CFEngine's monitoring components that allow both querying and modifying the system. Plus CFEngine is constantly evolving, so by the time you read this, new features may have appeared.

The commercial version of CFEngine has some additional capabilities, including the following:

- Check and manipulate the Windows registry, event logs, and services.
- Query and manipulate LDAP (and, by extension, Active Directory) databases.
- Examine and manipulate Windows Access Control Lists (ACLs).

These operations are sufficient to perform most configuration tasks on a system. At the lowest possible level, CFEngine contains functional specifications of how to make changes to the system. At the highest level, however, you declare what you want as shown in Desired-State Configuration, and leave the details to CFEngine.

CFEngine ships with some built-in libraries that perform more advanced operations using these basic capabilities, and you can also build your own or use existing libraries to perform custom checks and activities.

Promise Theory

CFEngine 3 works on top of a theoretical model called Promise Theory. This theory models the behavior of autonomous agents in an environment without central authority, based only on promises of behavior made by each agent, and shows that even without central control, the system can converge to a stable state.

Promise Theory underlays one of the basic tenets of CFEngine: voluntary cooperation. In CFEngine, each system participates voluntarily, makes promises only about its own behavior (if you think about it, it makes no sense for a system to make promises about someone else's behavior), and cannot be forced to accept commands or information from any external entities. This gives CFEngine very strong security properties, since it means that CFEngine running on a host cannot be coerced into modifying its behavior according to some external influence. It may *choose* to do so (for example, by getting policies from a central server), but unlike many other configuration management

systems, CFEngine does not require you to open a command channel through which each host can be given instructions (all you can do is “ping” clients so that they run their policies before their scheduled time, or to query them for information, but never to perform arbitrary actions or commands).

It’s worth mentioning that CFEngine’s principle of voluntary cooperation is more than a theoretical nicety in terms of security: in its entire 25-year history (spanning versions 1 through 3), CFEngine has had only seven published vulnerabilities, only three of which were remotely exploitable. The last one of those was published in 2005, still in CFEngine 2. CFEngine 3 has the impressive record of zero published vulnerabilities since its release in 2009.

A promise is simply a declaration of *intent*, a model of the desired state of the promiser. A promise does not imply that the desired state will be reached in the next iteration (or ever), but implies a capability for verifying whether the promise has been satisfied. Through this seemingly simple characteristic, promise theory allows CFEngine to deal with a crucial aspect of systems management: operational uncertainty. Systems are under constant change, both intentional (changing requirements, changing software, changing user behavior, security attacks) and accidental (disconnected network links, disappearing resources, software crashes) and have to react to it, often with incomplete information. Promise theory allows CFEngine to deal with these conditions in a resilient fashion.

Promise Theory was developed initially as the foundation for CFEngine’s behavior (in fact, the policy language in CFEngine 3 was redesigned to reflect this theory), but it has found more general applications in Computer Science and in other disciplines such as Economics and Organization.

According to Promise Theory, everything in CFEngine 3 is a promise, with specifications of what to do if the promise is already satisfied, if the promise was not satisfied but could be fixed, if the promise was not satisfied and could not be fixed, etc. The following table shows some examples of promises you could find in a CFEngine policy, and of the possible actions CFEngine could take automatically if the promise is not kept.

Examples of objects (promisers), promises, and repair actions in CFEngine.

Promiser	Promises to...	If not currently kept, CFEngine will...
A variable	...hold a certain value of a certain type.	...store the appropriate value in the variable.
A file	...have certain characteristics (permissions, ownership, ACLs, etc.).	...set the desired properties on the file.
A file	...exist and to have certain content.	...create the file if needed, modify its content (add, remove or edit lines) to match the desired state.
A user account	...exist and have certain characteristics (home directory, group, etc.)	...create the user account with the desired characteristics.
A process	...be running on the system.	...run the appropriate command to create the process.
A shell command	...have been executed.	...execute the command and collect its output and exit status.
A directory on the policy hub	...provide access to its content to certain clients.	...reconfigure its access rules to permit or block the access as desired.
An output message	...be generated when certain conditions arise, with a certain frequency and in a certain format.	...produce the appropriate message.

When a promise is not already satisfied (e.g., a file does not exist as it should), CFEngine will take the necessary actions to fix it, according to both its built-in rules and any additional promises declared in the policy.

Depending on the current state of the system with respect to a given promise, on the actions that CFEngine took when evaluating a promise, and on the result of those actions, CFEngine defines the following promise states:

- **Promise kept:** The state of the system was already as described by the promise, so no action had to be taken.
- **Promise repaired:** The state of the system was not as required by the promise, so CFEngine took the appropriate actions, and repaired the system state to match the requirements of the promise.
- **Repair failed:** Repair actions were attempted by CFEngine, but they failed for some reason (for example, lack of permissions to edit a file).

Depending on why the repair action failed, one of the following states may also be set:

- **Repair denied:** Repair actions were attempted by CFEngine, but they failed due to lack of access to some resource.
- **Repair timeout:** Repair actions were attempted by CFEngine but took too long to execute, and CFEngine cancelled the operation.

A CFEngine policy is constructed out of individual promises that get executed in certain order, and that can interact with other promises. After a promise is evaluated (executed), you can determine its state and act based on it, triggering further actions such as reporting, command execution, or evaluation of other promises.

Convergent Configuration

One of CFEngine's basic principles is that of *convergent configuration*. This means that you don't have to leave the system in the desired state on the first pass. Instead, you make changes incrementally, getting closer to the objective every time, independently of the starting state of the system. A CFEngine policy may not leave the system completely configured on the first pass, but at least it will make some changes. On subsequent passes, it will continue to make changes, eventually bringing it as close as possible to the desired state.

One advantage of convergent configuration, and of the declarative nature of CFEngine, is that you do not need to know the current state of the system in order to correct it. If the system is already in the desired state, a correctly written CFEngine policy will do nothing. If it's not, CFEngine will iteratively make discrete changes to bring it closer to the ideal, taking only the necessary actions to correct the existing deviations.

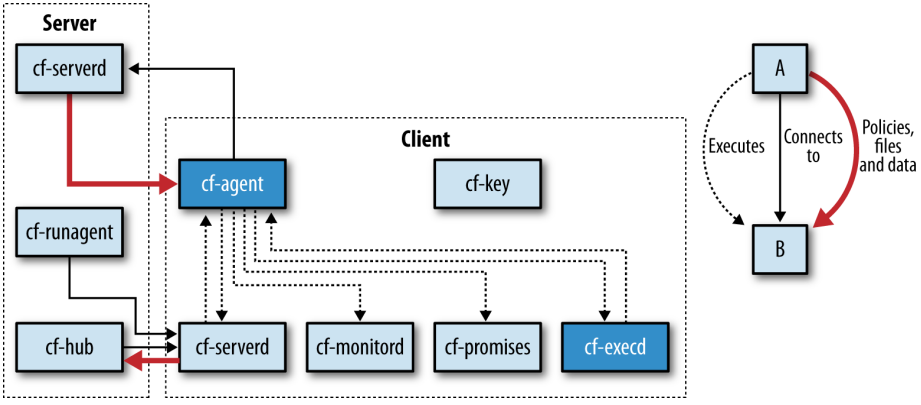
In order to carry out convergent configuration, CFEngine performs three passes over its policy. During each pass, all the promises in the policy are evaluated. There may be some promises that cannot be evaluated until the second or third pass due to dependencies between different components of the policy, so the multiple passes help CFEngine bring things to a convergent state as soon as possible.

CFEngine Components

A CFEngine installation contains multiple components that perform different, specific functions, as shown in the following figure. Dotted lines represent

components that execute others, solid lines represent communication among components, and bold lines indicate data flow.

Let's look in more detail at the functionality and role of each one of these components.



CFEngine components and their relationships

- **`cf-agent`:** This process is the "instigator of change," the program that evaluates policies and acts on them, making any necessary changes to the system. `cf-agent` is normally started directly by the user (for example, we have been running it manually from the command line to test the policies in this book), or by one of `cf-execd` (as a mechanism for starting it at regular intervals) or `cf-serverd` (in response to the `cf-runagent` command executed from a different host). Note that depending on its policies, `cf-agent` can in turn be responsible for restarting `cf-execd`, `cf-serverd` or `cf-monitord` if they have stopped for any reason (in addition, `cf-promises` is used by `cf-agent` to validate its policies before attempting to run them).

  By default, `cf-agent` will attempt to run `/var/cfengine/inputs/promises.cf` (more precisely, the file found by expanding the string `$(sys.workdir)/inputs/promise` when invoked, unless a different file is specified using the `-f` command-line option. If the filename executed produces an error, `cf-agent` will try to run `/var/cfengine/inputs/failsafe.cf`. The idea is for `failsafe.cf` to be a barebones policy that does little more than try to restore the CFEngine policies to a working state. Normally `failsafe.cf` will attempt to update the local policies from the policy hub, and it may also try to start `cf-execd` and `cf-monitord` to have at least a minimal CFEngine infrastructure running. If the `failsafe.cf` file is not found, `cf-agent` will generate it from a built-in template.

- **`cf-execd`:** This process executes `cf-agent` in a periodic basis, collecting

its output, and potentially emailing it somewhere. By default, `cf-execd` runs `cf-agent` every five minutes, but you can modify its behavior using an `executor control` body. For example:

```
body executor control
{
  any::

      splaytime  => "10";
      mailto     => "cfengine@example.org";
      mailfrom   => "cfengine@$(sys.host).example.org";
      smtpserver => "mail.example.org";

      schedule => { "Min00_05", "Min30_35" };

}
```

In this case, the `schedule` attribute tells `cf-execd` to only run `cf-agent` every 30 minutes (more precisely, whenever either the `Min00_05` or `Min30_35` classes are enabled, which would be the case between 00-05 and 30-35 minutes of every hour). The `splaytime` parameter tells `cf-execd` that the execution could be delayed up to 10 minutes (this is useful in large installations to prevent all the clients from connecting to the server at once). The `mailto`, `mailfrom` and `smtpserver` attributes determine how email reports will be sent.

It is common for `cf-execd` to be the one process started by the operating system (for example, through a `cron` job or an `init` script) when the system starts. `cf-execd` then runs `cf-agent`, which makes sure through the appropriate policies that `cf-execd`, `cf-monitord`, and `cf-serverd` are running in the background, if needed.

- **`cf-serverd`:** This component implements server functionality in CFEngine—the ability to listen for connections from clients and serve files to them. `cf-serverd` also has the ability to listen for connections from the `cf-runagent` process in other hosts, and according to its configuration, respond by executing `cf-agent` locally (this is the one reason why you may want to run `cf-serverd` on CFEngine clients: if you want the policy hub to be able to remotely instruct clients to run `cf-agent`). We will look in more detail at the `cf-serverd` configuration in Clients and Servers. `cf-serverd` listens on port TCP/5308, and this is the only port that needs to be open for the clients to be able to communicate with the server.
- **`cf-runagent`:** Invokes `cf-agent` on remote hosts so that they evaluate their policies. This is the only form of control a remote machine may exercise

over another in CFEngine. We will talk more about this in CFEngine Remote Execution Using cf-runagent.

- **`cf-key`:** This is one of the first commands you run when installing CFEngine on a new host. It creates a cryptographic key pair for the current host, which is used for authentication when communicating with the policy hub or any other CFEngine server.
- **`cf-monitord`:** This process is intended to run continuously in the background. It collects statistical information about different aspects of the system and makes it available to `cf-agent` through the special`mon` variable context. Some examples of the information collected by `cf-monitord` are the numbers of users with active processes in the system (`mon.value_users`), free space in the root disk partition (`mon.value_diskfree`), and kernel load average (`mon.value_loadavg`). For most values `cf-monitord` also keeps a running average and the standard deviation (for example, `mon.av_loadvg` and `mon.dev_loadavg`).
- **`cf-hub`:** This process exists only in CFEngine Enterprise, and is responsible for collecting from all the clients information about their current status, reports and monitoring information, for analysis and reporting purposes. `cf-hub` periodically connects to the `cf-serverd` process on all the clients it knows about (this is, all the clients that have bootstrapped to it) to collect this information. If it cannot connect to a client, this information is also reported in the Enterprise console.

A First Example

Let's consider the simple case of modifying the configuration of an `ssh` server. At the top level, we need to make sure the sshd service is up and running. With CFEngine, we can simply write the following:

```
services:
  "ssh";
```

This will by default enable and make sure the service is running, on any operating system. If we wanted to make sure the service is not running, we would simply need to write:

```
services:
  "ssh" service_policy => "stop";
```

Now, let's go down a level and change the configuration of the ssh daemon. Traditionally, we would do this sort of task with a shell script. The following snippet from a shell script is intended to add a line to `/etc/ssh/sshd_config` to prevent `root` logins:

```
# echo "PermitRootLogin no" >> /etc/ssh/sshd_config
```

As is, this code will add a new line to the file every time it runs. It assumes that the file does not contain the line already. Of course, you can add checks for this, but the code quickly becomes unreadable:

```
#  (grep -iq 'PermitRootLogin' /etc/ssh/sshd_config ||
   echo "PermitRootLogin no" >> /etc/ssh/sshd_config) &&
   sed -i 's/^.*PermitRootLogin.*$/PermitRootLogin no/;' /etc/ssh/sshd_config
```

This snippet uses the `grep` command to determine if the file alredady contains the `PermitRootLogin` string, and based on the result either adds the corresponding line or uses the `sed` command to edit the existing line.

Compare this with the equivalent CFEngine declaration:

```
files:
  "/etc/ssh/sshd_config"
    comment => "Disallow direct root login",
    edit_line => replace_or_add(".*PermitRootLogin.*", "PermitRootLogin no");
```

The CFEngine policy will add the line only if it is not there already. Additionally, you can see that CFEngine rules allow comments as rule attributes. These comments can be made available as the policy executes, allowing administrators to better understand and debug the actions taken by CFEngine.

Rules in CFEngine can be as detailed or as high-level as you wish. For example, you could generalize the SSH configuration file mechanism and express it like this (and we will look into the details of how to do this in Editing `/etc/sshd_config`):

```
bundle agent main {
 vars:
   # SSHD configuration to set
   "sshd" data => parsejson('{
     "Protocol": "2",
     "X11Forwarding": "yes",
     "UseDNS": "no",
     "PermitRootLogin": "no"
   }');

files:
    "/etc/ssh/sshd_config"
      handle    => "sshd_config",
      comment   => "Set sshd configuration",
      edit_line => set_config_values("sshd"),
      classes   => if_repaired("restart_sshd");

commands:
  restart_sshd::
    "/etc/init.d/sshd reload"
      handle  => "sshd_restart",
      comment => "Restart sshd if the config file was modified";
}
```

This CFEngine policy allows you to define arbitrary configuration parameters in the `sshd` array defined at the top (in the `vars:` section), which will be applied by the `files:` section by modifying or adding only those parameters that need to be fixed. Finally, `sshd` will be restarted only if any changes were made. In other words, the promise of having the right parameters in the file could be satisfied just by checking that they're set properly already (the "Promise kept" state described earlier), so the restart will take place only in the "Promise repaired" state.

Let's go back to our description of promises, to start figuring out what is happening in this policy. The `vars:` section is simply variable declarations—in this case, an array indexed by configuration parameter names, and containing the values of each parameter. In the `files:` section, the `/etc/ssh/sshd_config` file promises to have its content edited according to the specifications contained in the `set_config_values()` *bundle* (a named collection of CFEngine promises), and to set the `restart_sshd` class if the file needed to be repaired (i.e. modified to satisfy the promise). Finally, in the `commands:` section, the `/etc/init.d/sshd reload` command promises to run only if the `restart_sshd` class is set (if this

class is set, it means that the file was modified, so the daemon needs to be restarted for the changes to take effect).

Not shown in this example is the `set_config_values()` bundle. This bundle is part of the CFEngine Standard Library (described in CFEngine Standard Library), and which takes care of the actual editing of the file to set the desired parameters, using the built-in file-editing primitives in CFEngine. We will examine this bundle in detail in Editing `/etc/sshd_config`.

CFEngine allows you to express configuration policies at the level of abstraction you wish, leaving lower-level details out of sight but available when you need them. Now, let's take a more detailed look at the syntax of a CFEngine policy.

The CFEngine Policy Language

The syntax of the CFEngine 3 configuration files is very uniform, since everything is a promise. In general, every element in a CFEngine policy has the following structure:

```
promise_type:
  class_expression::
    "promiser" -> { "promisee1", "promiseeX" }
        attribute1 => value1,
        attributeX => valueX;
        ...
```

The values that `promise_type` can have depend on the type of container in which the promise is stored (and we will look at them in detail in Bundles, Bodies, and Namespaces). The value of `promise_type` determines how the "*promiser*" is interpreted, which *attributes* are valid and how their corresponding *values* are used. The attribute values can be either constant values, variables of the types described in Data Types and Variables in CFEngine, or container names as described in Bundles, Bodies, and Namespaces. The type of allowed values is fixed for each attribute.

The *promisees* are optional and, if specified, contain references to other promises that depend on the current one, and are used for documentation. In this way, we can specify which promises affect others or who might care about a particular promise. CFEngine has the ability to produce reports that include this information. Note that specifying promisees has no effect on the execution order of the policy, they are merely for informational purposes. Promisees can be arbitrary strings.

The `class_expression`, if specified, allows the promise to be conditionally executed depending on the value of the expression. If omitted it defaults to `any`, which is always defined (you can also use the class expression line `any::` to make this explicit). We will look at them in detail in Classes and Decision Making.

Depending on the type of promise, almost all elements of this syntax, except for the `promise_type` and the *`promiser`*, are optional. For example, to unconditionally execute a command, we would simply state it like this:

```
commands:
  "/bin/ls /";
```

In this case `commands:` is the promise type, and specifies that the promisers in the following section are to be interpreted as commands to execute. The promiser, `"/bin/ls /"` indicates the command to run. Since no attributes are specified, the command will always be executed and its output reported by CFEngine.

You can find some guidance on the style and form of policy writing in the CFEngine Policy Style Guide.

Data Types and Variables in CFEngine

CFEngine supports different data types:

- Scalars can be strings, integers or floating-point numbers;
- Lists contain an ordered set of scalars
- Arrays contain sets of key/value pairs.
- Data containers can hold arbitrary data structures, including lists and associative arrays.

Please note that “native” CFEngine arrays are being deprecated in favor of data containers, which are much more flexible and robust. You should use them whenever possible. Most functions which take the native types are also able to handle data containers.

Variable declarations

Variables in CFEngine are declared in the `vars:` section (they are promises of type `vars:`) of a bundle. `vars:` is one of the common promise types (along with `classes:` and `reports:`) that can be included in any type of bundle. `vars:` promises adhere to the common structure described in The CFEngine Policy Language, which in this case is interpreted as follows:

```
vars:
    "variable"
      type => value;
```

The promiser is the name of the variable in quotes. The type of the variable is given as an attribute, and its value indicates the value to store in the variable. For short values, we normally write the whole declaration in a single line for brevity:

```
vars:
  "name"   string => "Diego";
  "year"   int    => "2011";
  "colors_rgb" slist  => { "red", "green", "blue" };
  "colors_cmyk" data => '[ "cyan", "magenta", "yellow", "black" ]';
  "user" data => '{
    "name": "Diego Zamboni",
    "username": "zzamboni",
    "id": 501
  }';
```

Let us now look at the details of the different data types available in CFEngine.

Strings

Strings in CFEngine are declared using the string type. String values must always be enclosed by single or double quotes (there is no difference in their behavior). If you need to include a double quote in a double-quoted string, you need to precede it with a backslash (and similarly for single quotes inside single-quoted strings). You can create multiline strings simply by splitting them across multiple lines. To reference a string variable (and any scalar variable), you need to enclose the variable name in parentheses or curly braces, and precede them with a dollar sign.

You can interpolate variables into a string simply by referencing them inside the string. The following example shows some examples of strings:

```
body common control
{
     bundlesequence => { "test" };
}

bundle agent test
{
 vars:
   "s1" string => "one";
   "s2" string => 'this
is a
multine string';
   "s3" string => 'with "quotes"';

 reports:
  cfengine::
   "s1 = \"$(s1)\"";
   "s2 = $(s2)";
   "s3 = $(s3)";
}
```

If you save this short policy into a file and run it, you will get the following output:

```
# cf-agent --no-lock -f ./ch03_4.cf
R: s1 = "one"
R: s2 = this
is a
multine string
R: s3 = with "quotes"
```

Note that the strings in the `reports:` section adhere to the same rules, and contain the interpolated values of the declared variables.

Numbers

CFEngine supports both integers and floating-point numbers, denoted by the int and real types. Note that numeric values are also given as strings in CFEngine, but they are checked for validity before they are stored in the variable. For integers, CFEngine supports the suffixes `k`, `m`, and `g` to represent

powers of 10 (that is, 1000, etc.), and the suffixes `K`, `M`, and `G` to represent powers of 2 (that is, 1024, etc.). Real numbers can be specified in decimal or exponential notation. For example:

```
body common control
{
        bundlesequence => { "test" };
}

bundle agent test
{
  vars:
      "i1" int => "25";
      "i2" int => "10k";
      "i3" int => "10K";
      "r1" real => "1.2";
      "r2" real => "10e-5";

  reports:
    cfengine::
      "i1 = $(i1)";
      "i2 = $(i2)";
      "i3 = $(i3)";
      "r1 = $(r1)";
      "r2 = $(r2)";
}
```

Produces the following output:

```
# cf-agent --no-lock -f ./ch03_5.cf
R: i1 = 25
R: i2 = 10000
R: i3 = 10240
R: r1 = 1.200000
R: r2 = 0.000100
```

Lists

CFEngine supports ordered lists of any of the scalar types: lists of strings (slist), lists of integers (ilist) and lists of reals (rlist). In all cases, the values have to

be specified as strings, but they are interpreted and validated according to the declared type. You can assign and store lists across variables of different types, as long as the values can be converted. This means you can always assign an ilist or an rlist into an slist, but you can assign an slist into an ilist or rlist only if it contains valid values according to the type of the destination variable.

You can refer to list variables by using an at-sign (@) before the variable name. By doing this you can pass the whole list to a function that expects a list argument. You can also specify a list as part of another list value, and it will be expanded in place. The following example illustrates these points:

```
body common control
{
        bundlesequence => { "test" };
}

bundle agent test
{
  vars:
      "l1" ilist => { "1", "2", "3" };
      "l2" rlist => { "1.0", "2.0", "3.0" };
      "l3" slist => { "one", "two", "three", @(l1), @(l2) };

  reports:
    cfengine::
      "l3 = $(l3)";
}
```

When you run it you get the following output:

```
# cf-agent --no-lock -f ./ch03_6.cf
R: l3 = one
R: l3 = two
R: l3 = three
R: l3 = 1
R: l3 = 2
R: l3 = 3
R: l3 = 1.0
R: l3 = 2.0
R: l3 = 3.0
```

Both `@(l1)` and `@(l2)` are being expanded inside `@(l3)`, so that its final value is this:

```
{ "one", "two", "three", "1", "2", "3", "1.0", "2.0", "3.0" }
```

In this example we are also using CFEngine implicit looping by referring to the `@(l3)` array as a scalar `$(l3)`. See Looping in CFEngine for a full explanation of how this works.

Data Containers

Object of type `data` can contain arbitrary data structures, including lists or hashes (associative arrays). Such objects can commonly be represented in JSON or YAML formats. CFEngine provides functions to read both of those formats, either from files or from strings.

The basic functions that return data container objects are `parsejson()` and `parseyaml()` (for parsing strings), `readjson()` and `readyaml()` (for parsing files). For declaring fixed values, CFEngine allows specifying the data structure as a string which can contain either JSON or YAML.

```
bundle agent main
{
 vars:
   # Parse JSON explicitly
   "animals_json" data => parsejson('{ "animals": [ "dog", "cat", "crow" ] }');
   # Parse YAML explicitly - no header needed
   "animals_yaml" data => parseyaml("animals:
        - dog
        - cat
        - crow");
   # Parsed as JSON
   "colors_json" data => '[ "red", "green", "blue" ]';
   # Parsed as YAML thanks to the "---" header
   "colors_yaml" data => '---
        - red
        - green
        - blue';

   # Serialize the objects to their string representation
   "a1" string => format("%S", "animals_json");
```

```
   "a2" string => format("%S", "animals_yaml");
   "c1" string => format("%S", "colors_json");
   "c2" string => format("%S", "colors_yaml");

 reports:
   "animals_json = $(animals_json[animals])";
   "animals_yaml = $(animals_yaml[animals])";
   "colors_json = $(colors_json)";
   "colors_yaml = $(colors_yaml)";
   "a1 = $(a1)";
   "a2 = $(a2)";
   "c1 = $(c1)";
   "c2 = $(c2)";
}
```

Running this code produces the output you might expect. Note that regardless of the original format, the JSON and YAML specifications parse to identical objects.

```
R: animals_json = dog
R: animals_json = cat
R: animals_json = crow
R: animals_yaml = dog
R: animals_yaml = cat
R: animals_yaml = crow
R: colors_json = red
R: colors_json = green
R: colors_json = blue
R: colors_yaml = red
R: colors_yaml = green
R: colors_yaml = blue
R: a1 = {"animals":["dog","cat","crow"]}
R: a2 = {"animals":["dog","cat","crow"]}
R: c1 = ["red","green","blue"]
R: c2 = ["red","green","blue"]
```

A couple of notes about data containers:

- They are immutable once created. However, you can combine them into new objects using the `mergedata()` function.

- In many respects, `data` objects behave in the same way as "traditional" CFEngine lists and arrays, but they are not subject to many of their limitations in size and behavior.
- Data containers are returned by several different functions, including the JSON or YAML parsing functions mentioned above, but also `data_regextract()`, `data_readstringarray()`, `data_expand()` and others.
- In my experience, parsing of YAML strings works better when the string is specified in multiple lines as shown above instead of using embedded newline characters (`\n`) as shown in the documentation.

Data containers are undoubtedly the most powerful data type in CFEngine, and you will see them used extensively through this book.

Arrays

Arrays are sets of values indexed by a string (they are commonly called *hashes* in other programming languages). Array elements can contain scalars, lists or other arrays, even within the same array.

The Array data type in CFEngine is in the process of being fully replaced by Data Containers, which are much more powerful and flexible. Whenever possible you should use containers instead of arrays. We describe them here since you will still find them in many CFEngine policies.

In CFEngine, arrays are declared element by element, as if they were regular variables, except their name contains the index surrounded by brackets. There is no shortcut for declaring the whole array in a single step. There are certain functions that operate on arrays, such as `getindices()` and `getvalues()`, and they receive as argument the name of the array as a string. For example, we could use an array to store user account information:

```
body common control
{
     bundlesequence => { "test" };
}

bundle agent test
{
 vars:
   "user[name]"              string => "zamboni";
   "user[fullname][first]"   string => "Diego";
   "user[fullname][last]"    string => "Zamboni";
   "user[dirs]"              slist => { "/home/zamboni",
                                        "/tmp/zamboni",
                                        "/export/home/zamboni" };

   "fields"     slist => getindices("user");
   "userfields" slist => getindices("user[fullname]");

 reports:
  cfengine::
   "user fields = $(fields)";
   "account name = $(user[name])";
   "$(userfields) name = $(user[fullname][$(userfields)])";
   "user dir = $(user[dirs])";
}
```

This example is intentionally contrived to show how you can store different data types in an array. Note how `@(fields)` is being automatically populated by `getindices()` based on the indices declared for the `user` array. In other words, the statement:

```
"fields"     slist => getindices("user");
```

creates a variable named `fields` that refers to a list of three strings taken from the indices: `name`, `fullname`, and `dirs`. The list can then be used to loop through the `user` array, like before. Additionally, `@(userfields)` is being populated with the indices of the array stored in `user[fullname]`:

```
"userfields" slist => getindices("user[fullname]");
```

Finally, observe that `user[dirs]` contains a list of strings, and we are looping over that list as we would over a regular list variable (such as `@(fields)` or `@(userfields)` in this example) by referencing it as a scalar:

```
"user dir = $(user[dirs])";
```

Here is its output:

```
# cf-agent --no-lock -f ./ch03_7.cf
R: user fields = dirs
R: user fields = fullname
R: user fields = name
R: account name = zamboni
R: first name = Diego
R: last name = Zamboni
R: user dir = /home/zamboni
R: user dir = /tmp/zamboni
R: user dir = /export/home/zamboni
```

Classes and Decision Making

Classes are the key to controlling flow and making decisions in a CFEngine policy. In CFEngine, classes are named boolean values that can be either *true* (the class is defined) or *false* (the class is undefined). Classes can represent any characteristic of the system, information that is known (true) or unknown (false), or any condition that you want to indicate in the policy. They can be volatile (they stop existing as soon as the current CFEngine run is over) or persistent for a period of time you define. While many important classes are predefined by CFEngine (hard classes), you can define others for your particular needs (soft classes).

Hard classes

These are defined automatically by CFEngine when it runs, and represent mainly information about the system or the current environment that is discovered by CFEngine. Examples of hard classes include:

- Host information (e.g., class `doomsday` would be defined if the hostname of the machine where `cf-agent` is running is “doomsday” and class `ipv4_192_168_1_2` would be defined if the host’s IP address is 192.168.1.2).

- Time information (e.g., class `Hr5` would be set if CFEngine is running between 5 and 6 AM, class `Min15_20` is defined if it is currently between minutes 15 and 20 of the hour, and class `Mon` would be set if it's Monday).
- Operating system information (e.g., `linux` would be set on any Linux system, and `suse_9` would be set if the Linux distribution is SuSE 9).

To see the full list of hard classes defined on a particular system, run the following command (partial example output from a macOS machine at 15:31 GMT on a Tuesday):

```
# cf-promises --show-classes | grep hardclass
  127_0_0_1       inventory,attribute_name=none,source=agent,hardclass
  192_168_1_107   inventory,attribute_name=none,source=agent,hardclass
  64_bit          source=agent,hardclass
  8_cpus          source=agent,derived-from=sys.cpus,hardclass
  Afternoon       time_based,...,source=agent,hardclass
  Day2            time_based,...,source=agent,hardclass
  GMT_Afternoon   time_based,...,source=agent,hardclass
  GMT_Day2        time_based,...,source=agent,hardclass
  GMT_Hr15        time_based,...,source=agent,hardclass
  GMT_January     time_based,...,source=agent,hardclass
  GMT_Lcycle_2    time_based,...,source=agent,hardclass
  GMT_Min30_35    time_based,...,source=agent,hardclass
  GMT_Min31       time_based,...,source=agent,hardclass
  GMT_Tuesday     time_based,...,source=agent,hardclass
  GMT_Yr2018      time_based,...,source=agent,hardclass
  Hr16            time_based,...,source=agent,hardclass
  January         time_based,...,source=agent,hardclass
  Lcycle_2        time_based,...,source=agent,hardclass
  Min30_35        time_based,...,source=agent,hardclass
  Min31           time_based,...,source=agent,hardclass
  Q3              time_based,...,source=agent,hardclass
  Tuesday         time_based,...,source=agent,hardclass
  Yr2018          time_based,...,source=agent,hardclass
  any             source=agent,hardclass
  cfengine        inventory,attribute_name=none,source=agent,hardclass
  cfengine_3      inventory,attribute_name=none,source=agent,hardclass
  ...
```

Soft classes

These are defined by the policy during its execution. For example, a class could be defined in the following cases:

- Depending on whether a certain file exists. In this example, we set the `devel_host` class if the `/var/sitedata/devel_host.flag` file exists, using the built-in `fileexists()` function to perform the check:

```
classes:
  "devel_host" expression =>
                fileexists("/var/sitedata/devel_host.flag");
```

Setting a class like this might be useful, for example, to establish whether certain executable programs or other capabilities are present on a system before invoking them, or to apply different configurations to the system.

- As a Boolean expression of other classes. In this example, `test_host` will be defined if any of `testhost1`, `testhost2`, or `testhost3` classes is defined. These might be the hostnames of the machines in which you want the `test_host` class to be defined:

```
classes:
  "test_host" or => { "testhost1", "testhost2", "testhost3"};
```

Setting a class like this might be useful to run certain operations on certain systems—tests in this case.

- As an indication of the status of a particular promise. In this example, if any changes are made to the `/etc/ssh/sshd_config` file by the `edit_line` attribute, CFEngine would consider the promise as *repaired*, in which case the `restart_sshd` class will be defined:

```
files:
  "/etc/ssh/sshd_config"
    edit_line => set_config_values("sshd"),
    classes   => if_repaired("restart_sshd");
```

  Setting a class like this might be useful to keep track of the state of the system, and make sure that CFEngine follows up on an operation during its next pass.

Note that classes can be explicitly defined in a `classes:` section, but as you can see in the third example, they can also be defined by the common `classes` attribute, which you can use in all promises to set or unset classes based on the result of the promise. Several `classes` bodies are predefined in the CFEngine standard library, including `if_repaired`, `if_ok`, `if_notkept`, `if_else`, `always` and `classes_generic`.

The `classes_generic` body provides a useful way to set consistent class names depending on the outcome of a promise. If you specify, for example:

```
classes => classes_generic("foo");
```

Then, depending on the state of the promise, you will get one of `foo_repaired`, `foo_failed`, `foo_denied`, `foo_timeout` or `foo_kept` defined. This body also defines a few other class name patterns, including `foo_reached`, which gets defined regardless of the promise outcome and can be used to determine if a promise has been evaluated at all.

You may see “classes” described sometimes as “contexts”. This term expresses the idea of a particular *context* (be it time or date, operating system, architecture, etc.) in which a host is at the moment. The CFEngine team has decided to keep using *class* in all official documentation to avoid confusion, but *context* might still be used in some explanations when it makes things clearer.

Apart from defining classes, you need a way to act on them. This is what the `class_expression` shown in The CFEngine Policy Language is for. A class expression in CFEngine is a boolean expression constructed with class names and the boolean operators AND (`&` or `.`), OR (`|`) and NOT (`!`). Parenthesis can be used to group parts of the expression. When a line ends with a double colon, it is evaluated as a class expression. Only if the class expression is true are the lines that follow evaluated. The following are examples of valid class expressions:

```
# True if the linux class is defined
linux::
# True if both reboot_needed and linux are defined
reboot_needed.linux::
# True if reboot_needed is defined and neither linux nor windows are defined
reboot_needed.!(linux|windows)::
# The any class is always defined, so whatever follows will always be evaluated
any::
```

Additionally, you can use the `ifvarclass` attribute in most promise types to condition the evaluation of one promise to the result of the included class expression. For example, the following two promises are equivalent:

```
commands:
  # First command is conditioned by the ifvarclass attribute
  "/usr/sbin/shutdown -r now"
    ifvarclass => "linux";

  # Second command is conditioned by the class expression before it
  linux::
    "/usr/sbin/shutdown -r now";
```

The `ifvarclass` attribute allows you to place a condition around a single promise. It has the advantage of specifying the class expression as a string, which means you can use variables in the class expression, and they will be expanded before evaluating the expression. This allows a lot of flexibility in the types of conditions that you can use. For example, you can construct class names on the fly using variables:

```
body common control
{
     bundlesequence => { "test" };
}

bundle agent test
{
 vars:
   "words" slist => { "chair", "darwin", "table", "linux" };
 reports:
  cfengine::
   "Class $(words) is defined"
     ifvarclass => "$(words)";
   "Class $(words) is not defined"
     ifvarclass => "!$(words)";
}
```

In this example, the `reports:` section is looping through all the strings in the `@(words)` list (see Looping in CFEngine), and the corresponding message is printed depending on whether the class named after the current value is

defined. Note how the class expression for the second report (“not defined”) includes the NOT character at the beginning. Here is its output on a Mac (whose base operating system is Darwin, so the `darwin` class is defined):

```
# cf-agent --no-lock -f ./ch03_8.cf
R: Class darwin is defined
R: Class chair is not defined
R: Class table is not defined
R: Class linux is not defined
```

Class expressions can also be used to define other classes using the `expression` attribute in a `classes:` promise. For example, the `test_host` class shown above could also be defined like this:

```
classes:
  "test_host" expression =\> "testhost1|testhost2|testhost3";
```

Finally, classes can be made persistent, even across invocations of `cf-agent`, by using the `persistence` attribute in the class declaration. Its value should be the length of time, in minutes, for which the class should retain its value after being evaluated. This can be useful if the class value is the result of a time-consuming or otherwise expensive operation, to avoid recomputation every time `cf-agent` runs.

Note that setting a class as persistent does not mean it will not be reevaluated every time cf-agent runs, only that its previous value will be available during the persistence period. To avoid unnecessary reevaluation, the usual practice is to use a “flag class” with the same persistence period. For example:

```
bundle agent test
{
 classes:
  !cache_is_active::
   "line_exists" expression => regline(".*foo.*", "/tmp/test_data.txt"),
     persistence => "1";
   "cache_is_active" expression => "any",
     persistence => "1";
 reports:
  line_exists::
   "Line exists in file";
  !line_exists::
```

```
   "Line does not exist in file";
}
```

In this case, we are using `cache_is_active` as the "flag class" to indicate whether we should recompute the value of `line_exists`, which would arguably be a very costly class to compute. In this case we are using `regline()` to look for a line containing "foo" in the file `/tmp/test_data.txt`). In the `classes:` section, we evaluate the classes only when `cache_is_active` is not defined. In this case, we set `cache_is_active` unconditionally (using the special expression `"any"`), and set `line_exists` depending on the result of the function, both with the same persistence period. This means that within one minute, no matter how many times `cf-agent` executes, the classes will not be reevaluated and their cached values will be reported. You can test this behavior in the previous example by running it, then editing the file, and observing that the changes are not detected until a minute has passed since the last execution. In deployment, this can be extremely useful to limit reevaluation of complex or costly class expressions whose values change slowly or infrequently.

Bundles, Bodies, and Namespaces

CFEngine policies can grow quite complex, so it would not be very scalable simply to list promises back to back. For this reason, and to promote reusability, CFEngine groups its syntax elements into two types of structures: *bundles* and *bodies*, and they in turn can be grouped into *namespaces*.

Bundles

Bundles are the most general and powerful grouping mechanism. They are the only elements that can contain promises. A bundle can contain many promises, possibly separated into sections. The structure described at the beginning of The CFEngine Policy Language can be contained only inside a bundle. Bundles are defined as follows:

```
bundle type name(arguments)
{
  promise_type:
    class_expression::
      promise
      ...
}
```

The *name* of the bundle is an arbitrary string that you can use to identify it. The *type* of the bundle has to be one of the CFEngine-recognized types, and it defines the semantics of the bundle (that is, how are the promises in it interpreted), as well as the promise type sections it can contain. All bundles can receive an arbitrary number of arguments. If no arguments are needed, the parenthesis are optional.

The bundle types defined by CFEngine are:

- **`agent`:** Bundles of type `agent` are "executable" bundles that can be called from the main `bundlesequence` declaration, or as method calls in the `methods:` section of another agent bundle. In this respect they could be compared to subroutines in other programming languages. They are the most extensive and powerful type of bundle, and the ones that actually implement any changes that we want to make in the system. These bundles can contain the following promise types:
  - `commands:` to specify commands to be executed
  - `files:` to edit and manipulate files
  - `methods:` to call other agent bundles
  - `packages:` to query and manipulate software packages in the system
  - `processes:` to query and manipulate running processes
  - `storage:` to query and configure file systems
  - `services:` to configure system services in Unix-like systems (CFEngine Enterprise also supports Windows system services)
  - `databases:` to manipulate and configure databases
  - `guest_environments:` to manipulate and configure virtual environments
- **`common`:** Bundles of this type are just like `agent` bundles, but are special in two ways:
  - The variables and classes defined in them are automatically available to every other bundle in your policy.
  - They are evaluated by all the CFEngine components (`cf-agent`, `cf-serverd`, `cf-monitord`, etc.)

  For these reasons, they are a good place to define globally useful variables and classes. For example:

```
bundle common g
{
 vars:
   "localdir"    string => "/usr/local";
   "confdir"     string => "/etc";
 classes:
   "testhost"    or => { "testhost1", "testhost2" };
}
```

This example defines two variables with strings that will be useful in other parts of the policy, and which we can reference as `$(g.localdir)` and `$(g.confdir)` (in general, any variable can be accessed from anywhere else by prefixing it with the name of the bundle where it was defined). Also defined is a class based on whether either of the classes `testhost1` or `testhost2` is defined (this would be the case if the current host has any of those names, and is a common way of defining a class for a certain group of hosts—more on this in Defining Classes for Groups of Hosts). This class is automatically made global, which means it can be used in any other bundle.

All variables in CFEngine are local to the bundle in which they are defined. However, they can be accessed from any other bundle by prefixing them with the bundle name in which they are defined, separated by a dot, as in `$(g.localdir)`.

Most classes in CFEngine are local to the bundle in which they are defined, and they cannot be accessed from anywhere else (there is no mechanism for specifying the bundle of a class). The exceptions are:

- Classes defined in a `common` bundle are automatically global.
- Classes defined by the `classes` attribute in a promise (as a result of its status) are automatically global. This is useful because these classes are commonly used as a signaling mechanism across promises and bundles.
- Since CFEngine 3.5.0, both `classes:` promises and `classes` bodies can specify a scope attribute, which can take the values "`bundle`" (the default for `classes:` promises) and "`namespace`" (the default for `classes` bodies)

Note that `common` bundles are not necessarily evaluated before regular `agent` bundles, although this is a common misconception. You can (and should) put them in `bundlesequence` to ensure they are evaluated at the correct moment (normally, you would put them at the beginning of the execution sequence, to ensure the values defined in them are properly available to all other bundles).

- **`edit_line`:** Bundles of type `edit_line` can be used to change a file, one of the most common and most complex operations performed by CFEngine. These bundles must be specified as the value of the `edit_line` attribute in a file-editing promise (this is, a promise of type `files:`). `edit_line` bundles themselves can be quite complex and contain their own set of allowable promise types, which include:
  - `insert_lines:` to add lines to a file
  - `delete_lines:` to remove lines from a file
  - `field_edits:` to make field-oriented changes in a file
  - `replace_patterns:` to make regular expression substitutions in a file
- **`server`:** Bundles of type `server` control the behavior of the `cf-serverd` process, which has the task of serving files to other CFEngine machines that request them (`cf-serverd` normally runs on the CFEngine policy hub). This type of bundle can contain two promise types:
  - `access:` to define access permissions to different resources on the server.
  - `roles:` to define which users can indicate classes (and which classes they can define) in the server process, to alter the behavior of the `cf-serverd` daemon. One of CFEngine's strong security features is that remote machines can never execute arbitrary commands. Instead, they can execute certain bundles. Some users, as defined by `roles:` promises, may have the ability to set custom classes when invoking those remote promises, thus allowing them to modify the promises' behavior, but only as allowed by the remote bundle and its handling of the defined classes.
- **`monitor`:** Bundles of this type are supported only in commercial editions of CFEngine. They define custom parameters that CFEngine can monitor automatically, and specify how to react to changes in their values. CFEngine natively knows how to monitor a large set of system values, such as CPU and memory utilization. This type of bundle supports only one section called `measurements:`, which contains promises defining what and how to monitor it, and how to react to changes.

Certain generic promise types are allowed in all bundle types:

- `vars:` to define variables
- `classes:` to define classes
- `reports:` to define produced output
- `meta:` to define metadata about a bundle.

Bodies

Bodies are collections of attributes and values that can be used as values to other attributes. Bodies cannot contain promises nor sections, although they can receive arguments, and can contain class expressions to specify different values for some of the attributes. Bodies, just like bundles, have a type, which indicates the attribute to which they can be passed, as well as the attributes they can contain. The generic structure of a body is:

```
body type name(arguments)
{
  attribute1 => value1;
  attribute2 => value2;
  ...
[class_expression::]
  attributeN => valueN;
}
```

Some common bodies you will use include:

- `control` bodies are special structures that are not referenced in any promises, but that control the behavior of different aspects of CFEngine itself. There are different types of control bodies, depending on the component whose behavior they control. The one you are bound to use is the `common control` body. Among other things, it is in this body that you specify which bundles will be executed in your policy and in which order, using the `bundlesequence` attribute, and which additional files to read, using the `inputs` attribute:

  ```
  body common control
  {
          inputs => { "tests.cf" };
          bundlesequence => { "test" };
  }
  ```

  This block tells CFEngine to load the file `tests.cf` and to execute the `test` bundle. Every CFEngine policy needs to have a `bundlesequence` definition, and this is most commonly done through a `common control` body. (You can also specify it with the `-b` option to `cf-agent`, but I normally do this only when testing policy components.)

  As you might imagine, `common control` supports many other attributes that specify global CFEngine behavior. There are also `control` bodies for specific CFEngine components, including the following:

  - `agent control` bodies to specify promise-evaluation behavior such as minimum time between consecutive evaluations of the same promise (`ifelapsed`), classes that tell CFEngine to abort (`abortclasses`), and many others.
  - `server control` bodies to specify server behavior, such as addresses and users from which connections will be allowed (`allowconnects`, `allowusers`) and the interface to which the `cf-serverd` process should bind (`bindtointerface`).
  - Others such as `monitor control`, `runagent control`, `executor control`, `hub control` and `file control`.

- `classes` bodies specify which classes will be defined depending on the outcome of a promise. These bodies are valid attributes for all promise types. For example, consider the following file promise:

```
"/var/run/somefile"
  create => "true",
  classes => passfail;
```

  - In this case, `passfail` is the name of a body, of type

`classes`, that needs to be defined somewhere else. For example:

-

```
body classes passfail
{
  promise_kept     => { "fileexisted" };
  promise_repaired => { "filecreated" };
  repair_failed    => { "fileerror" };
}
```

  - There are several things you should notice here. First, the type of the body part is `classes`, which means it can be used only as the value of a `classes` attribute in a promise. The name `passfail` is an arbitrary identifier. The documentation for the classes body type lists the attributes it can contain. In this case, if `/var/run/somefile` already existed (the promise was *kept*), the `fileexisted` class will be defined after the promise runs. If `/var/run/somefile` did not exist and CFEngine was able to create it (the promise was *repaired*), `filecreated` will be defined. And if the file cannot be created for some reason (the *repair failed*), the `fileerror` class will be defined. These classes can be used later on to control other promises. And more importantly, the `passfail` body can be used in many different promises, allowing for encapsulation and code reutilization.

An important thing to notice is that body parts can also have parameters, which allows even further customization of their behavior. For example, suppose we want the repaired/kept/failed classes to contain an arbitrary identifier to help us differentiate among multiple file checks. We could define `passfail` as follows:

```
body classes passfail(id)
{
  promise_kept     => { "$(id)_existed" };
  promise_repaired => { "$(id)_created" };
  repair_failed    => { "$(id)_error" };
}
```

We would then have to modify the files promises to something like this:

```
"/var/run/somefile"
  create => "true",
  classes => passfail("somefile");
```

Now `"somefile"` is being passed as an argument to the `passfail` body part, and used as part of the class names to define. This means that depending on the result of the promise, the classes `somefile_existed`, `somefile_created` or `somefile_error` will be defined, instead of the generic names we had used before.

The `classes_generic` body defined in the CFEngine Standard Library behaves much like our `passfail` body, but considers all possible promise outcomes, and defines several classname patterns for each outcome. For example, if a promise is repaired and you call `classes_generic("somefile")` you will get the following classes defined: `promise_repaired_somefile`, `somefile_repaired`, `somefile_ok` and `somefile_reached`.

- `action` is another attribute that can be used in any promise, and defines how the promise should be evaluated and fixed. Using it we can define that promises should only be checked but not fixed, whether the actions related to the promise should occur in the background, how often promises should be checked, logging behavior for the promise, and other attributes. For example, the following promise will warn if a certain line does not exist in `/etc/motd` but will not fix it, and will issue the warning only every hour, even if CFEngine checks more frequently:

```
bundle agent test
{
 files:
   "/etc/motd"
     edit_lines => insert_lines("Unauthorized access will be prosecuted."),
     action => warn_hourly;
}

body action warn_hourly
{
   # Produce warning only, don't fix anything
     action_policy => "warn";
     ifelapsed => "60";
}
```

- `copy_from` is an attribute that can be used only in `files:` promises, and indicates from where and how a file will be copied. It is an extremely flexible attribute, since it allows us to request local or remote file copies, how the files will be compared, whether the file will be encrypted in transit, and many other parameters. For example, the following two bodies are from CFEngine's standard library:

```
body copy_from secure_cp(from,server)
{
     source      => "$(from)";
     servers     => { "$(server)" };
     compare     => "digest";
     encrypt     => "true";
     verify      => "true";
}

body copy_from remote_cp(from,server)
{
     servers     => { "$(server)" };
     source      => "$(from)";
     compare     => "mtime";
}
```

  Both handle copying files from a remote server, and take both a server address and a source file as arguments. The first one specifies that the connection will be encrypted (using an internal CFEngine mechanism),

that the files will be verified after copying them, and that files will be compared by computing a cryptographic hash of their contents. The second one is simpler, indicating no need for encryption or verification, and the comparison will be made using simply the time of last modification (`mtime`) of both files. The former, more expensive verification mechanism allows us to reliably detect changes in the files in cases when their modification date might not be a reliable indicator. In both cases, the comparison mechanism allows CFEngine to skip the expensive copy operation if the files already match.

- `depth_search` is another attribute of `files:` promises that allows us to control recursive operations. It specifies how deep to traverse, which directories to skip, and other parameters. For example:

```
body depth_search recurse_ignore(d,list)
{
     depth => "$(d)";
     exclude_dirs => { @(list) };
}
```

This definition specifies that only directories up to `$(d)` levels deep will be traversed (the special string `"inf"` can be used to specify infinite recursion), and allows the caller to specify a list of directories to exclude.

Putting `copy_from` and `depth_search` together, we can already create a working file-copy promise:

```
bundle agent update_inputs
{
 vars:
   "server"  string => "10.1.1.1";
   "inputs" string => "/var/cfengine/masterfiles/inputs";
 files:
   "$(sys.workdir)/inputs"
     copy_from => remote_cp("$(server)", "$(inputs)"),
     depth_search => recurse_ignore("inf", { "_.*" });
}
```

Here we will be copying all files from the directory `/var/cfengine/masterfiles/inputs` on server 10.1.1.1 onto the local `/var/cfengine/inputs` directory (`$(sys.workdir)` is an internal variable that CFEngine defines to be its working directory, normally `/var/cfengine`). A recursive copy of infinite depth will be done, but all directories starting with an underscore (_) will be ignored (the patterns provided have to be regular expressions and not shell metacharacter

expressions, hence the `_.*` instead of just `_*`). Note that it is not possible to use `depth_search` in conjunction with `edit_line`. For editing files, the precise file to be edited needs to be specified.

- `edit_defaults` is an attribute of `files:` promises that controls parameters of the file-editing process. You can specify whether backups should be made of the original file, the maximum size of a reasonable file for editing, and whether the file should be emptied and recreated every time. In the following example, timestamped copies of the file will be kept every time the file is changed:

```
bundle agent editexample
{
 files:
   "/etc/motd"
     create => "true",
     edit_line => insert_lines("Unauthorized use will be prosecuted"),
     edit_defaults => backup_timestamp;
}

body edit_defaults backup_timestamp
{
     empty_file_before_editing => "false";
     edit_backup => "timestamp";
     max_file_size => "300000";
}
```

- `edit_field` is an attribute of `field_edits:` promises that performs field-based editing in a file (it must be specified as an attribute in a promise of type `field_edits:`, which in turn is allowable only inside `edit_line` bundles). It specifies what characters to use as delimiters and which actions will be taken on which fields. For example, the following definition from the Standard Library performs generic field-editing operations using user-provided information:

```
body edit_field col(split,col,newval,method)
{
      field_separator    => "$(split)";
      select_field       => "$(col)";
      value_separator    => ",";
      field_value        => "$(newval)";
      field_operation    => "$(method)";
      extend_fields      => "true";
      allow_blank_fields => "true";
}
```

The `split` argument specifies a regular expression to use as separator (thus it gets assigned to the `field_separator` attribute), `col` indicates the column on which to operate and gets assigned to `select_field` (by default CFEngine starts counting from one, although this behavior can be changed using the `start_fields_from_zero` attribute in the `edit_field` body), `newval` indicates the value to insert or delete from that field (it gets used for `field_value`, each field can contain multiple values separated by `value_separator`, a comma in this case), and `method` indicates which operation to perform (`set`, `delete`, `append`, `prepend`, etc.).

The `col()` body definition can be used to edit colon-separated files, such as `/etc/passwd` in Unix systems. This `set_user_field()` bundle is also defined in the Standard Library:

```
bundle edit_line set_user_field(user,field,val)
{
 field_edits:
   "$(user):.*"
     comment => "Edit a user attribute in the password file",
     edit_field => col(":","$(field)","$(val)","set");
}
```

This bundle takes three arguments: the user to edit (`user`), the field number to edit (`field`), and the value to set in that field (`val`). In `field_edits:` promises, the promiser is interpreted as a regular expression that is matched against all the lines in the file, to select which lines to edit. In this case, the value of the `$(user)` parameter is used to select the line that starts with that string, followed by a colon and any other text (`"$(user):.*"` —the pattern is automatically anchored by CFEngine to the beginning and end of the line, so there is no need for the ^ character to specify that the pattern must start at the beginning of the line). Once a line is selected, the `edit_field` attribute uses `col()` to perform the actual field-change

operation, The separator is specified as a colon, the field number and the new value are passed directly from the arguments `$(field)` and `$(val)`, and the operation to perform is `"set"`, which tells CFEngine to replace the old value of the field with the new one.

To put this in context, note that `set_user_field()` is an `edit_line` bundle, which means it has to be used as the argument to the `edit_line` attribute of a `files:` promise. For example:

```
files:
    # Set the 7th field (shell) of user "nobody" to "/bin/false"
    "/etc/passwd"
      edit_line => set_user_field("nobody", "7", "/bin/false");
```

Many other body attributes are allowed in CFEngine for different promise types. I have shown here some of the most common ones, but you can find the full listing and details in the CFEngine Reference documentation.

The distinction between bundles and bodies can be confusing at first. Remembering these points may help:

- Bodies are named groups of *attributes*, whereas bundles are collections of *promises*. Promises are the units that actually *do something* in CFEngine (for example, run a command or add a line to a file), whereas attributes specify characteristics of how things are done (for example, whether to run the command in a shell, or where in the file to add the line).
- The value of an attribute can be a basic data type (string, integer, list, container, etc.), it can be the name of a body, or it can be the name of a bundle.
- The type of an attribute's value is fixed, and determined by the attribute itself (for example, the value of the `depth_search` attribute in a `files:` promise is always a body, and the value of an `edit_line` attribute is always a bundle).
- Bodies can inherit attributes from other bodies by using the `inherit_from` attribute. In this way you can modularize and better structure your body definitions.
- For bodies and bundles, their type is always the name of the attribute to which they correspond. For example, bodies to be used with the `depth_search` attribute are always declared as `body depth_search xyz`, where `xyz` is an arbitrary name of your choosing. The same goes for bundles: bundles to be used with the `edit_line` attribute are always declared as `bundle edit_line xyz`.

- There are only three types of “top level” bundles that are not used as arguments to attributes: `agent`, `server` and `monitor`.
- The promise types (sections) that can appear in a bundle are determined by the bundle type. For example, `commands:` promises can only appear in bundles of type `agent`.

Namespaces

By default, all bodies, bundles, and classes in CFEngine exist in a common namespace. This makes it easy to call bundles and bodies from anywhere in the policy. However, as a policy grows in size to handle a large or complex infrastructure, and particularly if multiple people are in charge of writing policies, the possibility for naming conflicts increases—for example, it becomes entirely possible that a bundle named `restart_service` will be defined in two different files that correspond to different services.

To avoid this problem, files can be assigned to `/namespaces/`. Bundles, bodies, and global classes with the same name can coexist, as long as they are in separate namespaces. To declare a namespace for the current file, you use a `body file control` declaration, like this:

```
body file control
{
        namespace => "name1";
}
```

If no namespace declaration is found, the `default` namespace is used. Note that the namespace declaration is placement-sensitive: it affects everything on the file after its appearance, and it can appear multiple times in a single file. This means that you can in principle declare bundles and bodies belonging to different namespaces in the same file. I strongly advise against this practice to avoid confusion, and recommend limiting each file to a single namespace, if any, by placing the `body file control` declaration at the top.

When you call a bundle or a body, CFEngine will look for it *only in the current namespace* (whether it’s `default` or a declared one). To access things in a different namespace, you need to prepend their names with the namespace, separated by a colon. For example:

```
methods:
  "any" usebundle => namespace:bundle("arg");

files:
  "/tmp/file"
    create => true,
    perms => namespace:myperms;
```

Note that namespacing also affects global classes: they will be global only within the namespace in which they are declared. Global classes from other namespaces can also be used by prefixing them with the namespace, separated by a colon.

Bundles and bodies in the CFEngine Standard Library are declared in the default namespace. To call them from a namespaced file, you need to explicitly prefix them with `"default:"`.

We will not use namespaces in the examples in this book, to keep things simple. However, namespacing is a powerful mechanism that will help you grow your policies with a minimum of naming conflicts, so I encourage you to use them whenever appropriate.

Normal Ordering

CFEngine does not have any flow control statements, at least not in the sense with which you may be familiar from imperative programming languages (the concept of implicit flow control may be familiar to you if you have done any declarative programming before, for example in Prolog). A lot of the behavior of CFEngine is hard-coded, and this includes the order in which things are evaluated. This is called *normal ordering*, and is determined based on what makes sense for different types of bundles and promises. For example, it makes no sense to first create a file and then delete it, while it makes sense to first delete it and then create it again. Normal ordering can, if needed, be overriden by defining classes after an operation completes, and then defining other operations based on that class (for details, see Controlling Promise Execution Order).

Bundles of type `common` are a good place to define variables and classes that will be accessible to all other bundles in the policy. Variables defined in common bundles are accessible from other bundles (just like all variables) by prefixing them with the bundle name, as in `$(bundle.variable)`. For classes, the rules slightly more complicated, but easy to understand:

- In `common` bundles, classes defined by `classes` promises are by default `namespace` scoped (i.e. they can be used from any bundle in the current namespace). They can be `bundle` scoped (made accessible only from the current bundle) by using the `scope` attribute.
- In `agent` bundles classes defined by `classes` promises are by default `bundle` scoped. They can be `namespace` scoped by using the `scope` attribute.
- In all bundles, classes defined as the result of a promise via a `classes` body are by default `namespace` scoped. They can be `bundle` scoped by using the `scope` attribute.

CFEngine has mechanisms to detect variable/class dependencies and a best-effort algorithm to make sure all necessary values are available before an expression or promise is evaluated. You can help it ensure consistency and convergence by including bundles of type `common` in the `bundlesequence` declaration, even though this is not strictly needed.

CFEngine executes `agent` bundles three times in an attempt to achieve a convergent state. In each iteration, the sections in the bundle will be executed in the following order:

1. `vars`
2. `classes`
3. `interfaces`
4. `files`.
5. `packages`
6. `guest_environments`
7. `methods`
8. `processes`
9. `services`
10. `commands`
11. `storage`
12. `databases`
13. `reports`

Within `edit_line` bundles, the following order will be kept:

1. `vars`
2. `classes`
3. `delete_lines`
4. `field_edits`
5. `insert_lines`
6. `replace_patterns`
7. `reports`

Within each section, promises will be executed in the order in which they appear in the policy. Multiple executions of each bundle mean that you can, for example, define a variable, then define a class based on that variable, and then define other variables depending on that class.

Within `server` bundles, the normal ordering is as follows:

1. `vars`
2. `classes`
3. `access`
4. `roles`

Although syntactically correct, `reports:` promises that appear inside a `server` bundle are not evaluated.

Within `monitor` bundles, the normal ordering is as follows (sections marked with * are only available in CFEngine Enterprise):

1. `vars`
2. `classes`
3. `measurements` *
4. `reports`

Normal ordering provides a fairly rigid structure to the execution of CFEngine policies. It is common when you first start writing CFEngine policies, particularly if you are familiar with imperative programming, to try to "fight" the normal ordering to fit what you want to do. When you encounter a case in which you are positive that normal ordering needs to be changed, I encourage you to back up and rethink at a higher level the task you want to accomplish. Most of the time, you will find that structuring the task in some other way will make the need to reorder operations go away, and will in fact make more sense with the way CFEngine "thinks."

Looping in CFEngine

One of the most evident examples of "thinking in CFEngine" is the concept of implicit looping. It is one of the most basic behaviors, one of the most confusing to a CFEngine beginner, and one of the most powerful once you harness it.

First, let us define it: in CFEngine 3, if you refer to a list variable (normally called `@(var)`) as a scalar (`$(var)`), CFEngine interprets it to mean "iterate over all the values in the list."

Let's try it. Type in the following policy:

```
body common control
{
     bundlesequence => { "test" };
}

bundle agent test
{
 vars:
   "colors" slist => { "red", "green", "blue" };
 reports:
  cfengine::
   "$(colors)";
}
```

Now run it:

```
# cf-agent --no-lock --inform -f ./looping1.cf
R: red
R: green
R: blue
```

The lines that start with `"R: "` indicate messages produced by the `reports:` promises in the policy. You can see that the single promise in the `reports:` section has been repeated for every value in the list, therefore printing all the values.

You can also try nested looping:

```
body common control
{
     bundlesequence => { "test" };
}

bundle agent test
{
 vars:
   "colors" slist => { "red", "green", "blue" };
   "tone"   slist => { "dark", "light" };
 reports:
  cfengine_3::
   "$(tone) $(colors)";
}
```

This returns the following:

```
# cf-agent -K -f ./looping2.cf
R: dark red
R: dark green
R: dark blue
R: light red
R: light green
R: light blue
```

Simple enough, isn't it? In this explicit example, the behavior is clear. The real power of implicit looping comes when you realize that it can be used in *any* type of promise, and that it means the *whole promise* will be executed as many times

as there are items in the list. Also, the looping variable can be used anywhere—in defining variables or classes, in executing commands, or in making decisions with classes.

Let's look at a real example in which implicit looping saved the day (this was, incidentally, the time when this really "clicked" in my head as I was starting with CFEngine 3). I needed to determine which network interface in a system was configured in a certain network segment, to apply some configuration commands.

CFEngine has a built-in array variable called `sys.ipv4` that contains the IP addresses of all the network interfaces in the system, indexed by interface name. My first thought was that I needed a function that gave me all the values stored in this array, so I could compare them against my desired IP address range and find the one I needed.

To my surprise, I realized that CFEngine has a `getindices()` function, but no equivalent `getvalues()` function (actually this function was added as of version 3.1.5, but wasn't available when I came up with this solution, and in any case this is much more elegant). After turning the problem over a lot in my head, I came to the realization that the `getvalues()` function is not needed in this case. Here is the code I came up with:

```
body common control
{
     bundlesequence => { "find_netif" };
}

bundle agent find_netif
{
 vars:
   "nics" slist => getindices("sys.ipv4");
   # Regex we want to match on the IP address
   "ipregex" string => "192\.168\.1\..*";

 classes:
   "ismatch_$(nics)" expression => regcmp("$(ipregex)",
                                          "$(sys.ipv4[$(nics)])");

 reports:
  cfengine::
   "NICs found: $(nics) ($(sys.ipv4[$(nics)]))";
```

```
    "Matched NIC: $(nics) ($(sys.ipv4[$(nics)]))"
      ifvarclass => "ismatch_$(nics)";
}
```

Let us look at this in detail.

- First, we get a list (using `getindices()` of all the network interfaces in the system, and store it in the nics variable. We also assign into ipregex the regular expression for the IP address range I want to match (in this case, 192.168.1.*).
- Then we use this list, referenced as a scalar, in the `classes:` promise, to define a number of classes named after each of the interfaces, by using `$(nics)` in the class name itself. The definition of the class depends on whether the IP address of that network interface (`$(nics)` is used again in the call to the `regcmp()` method) matches the regular expression of the IP address I want to find. The result is that, for each NIC on the system, the corresponding class is defined if its IP address matches, and undefined if it does not.
- Finally, we print all the interfaces by using `$(nics)` in a report message, and we also print only the matching ones by conditioning the second message using the `ifvarclass => "ismatch_$(nics)"` attribute. The reference to `$(nics)` in the `ifvarclass` attribute is also expanded to each value in turn, so the second message is printed only for those NICs whose corresponding class is defined.

So you see, we do not need the `getvalues()` function after all. In this example I used the defined classes to print messages, but in my real example I used them to append the appropriate configuration statements to a file—but only for those interfaces that matched the IP range I wanted.

I encourage you to look at that example again, and make sure you understand it. There are no looping constructs anywhere—in fact, they do not exist in the CFEngine syntax at all. It may take a while getting used to this. Whenever you are constructing a policy and you think "I definitely need a `while` loop to do this," take a step back and see whether you can recast the problem using implicit looping. The definition of classes based on a condition using implicit looping is a powerful technique, and you will see it used in many of the examples in this book.

Prior to CFEngine 3.3.0, looping was allowed only for local lists (those declared in the current bundle). Starting with 3.3.0 this limitation was removed, and you can now loop over lists from any bundle, provided that you properly qualifiy its name with the bundle name where it is declared (`$(bundle.var)`).

Thinking in CFEngine

As we have seen, CFEngine imposes a rigid structure on many aspects of its operation. Two prime examples are normal ordering and implicit looping, which help get rid of the need for explicit control flow statements. For the most part, you do not tell CFEngine how to do things. Rather, you tell it *what you want to achieve* and write out the low-level building blocks of how to achieve certain promises, and CFEngine will put them together for you to bring the system to the desired state.

If you are like me, you have been programming for some time before you encountered CFEngine, and your brain is wired to think about problems and tasks in a certain way. This will almost inevitably cause a clash when you have to "let go" of the control and lend it over to CFEngine.

I have personally found that what works for me is to step back from the details of the task at hand, and think at a higher level: "what am I trying to achieve?" Often this gives a different perspective on why you are doing certain things, and how you are trying to achieve them. My main advice is to keep practicing, and to use the community resources available to study examples and to get feedback on your promises from more experienced users.

Clients and Servers

One of CFEngine's key strengths is autonomy. A machine in which CFEngine is installed and configured does not need a network connection to operate, and as long as its policies are well defined, it will continue to obey those policies and maintain the system as configured. For instance, a laptop that is sometimes connected to the company network, but is also often away, will continue to benefit from CFEngine running on it.

However, the true power of CFEngine lies in its ability to manage thousands of machines with very little effort, and for this you need to distribute the corresponding policies to all those hosts. Fortunately, CFEngine makes it very easy to set up a client-server environment in which one or more hosts act as policy hubs, distributing policies and data to others. As we saw in Finishing the Installation and Bootstrapping, all it requires is a single command to configure CFEngine and tell it which machine to use as its policy hub:

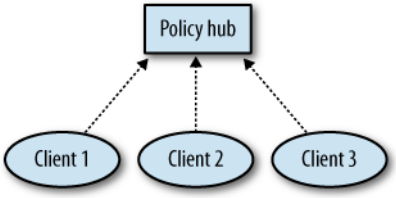
```
# cf-agent --bootstrap x.y.z.w
```

Prior to CFEngine 3.5.0 the bootstrapping options were different. This is the command you have to run for older versions:

```
# cf-agent --bootstrap --policy-server x.y.z.w
```

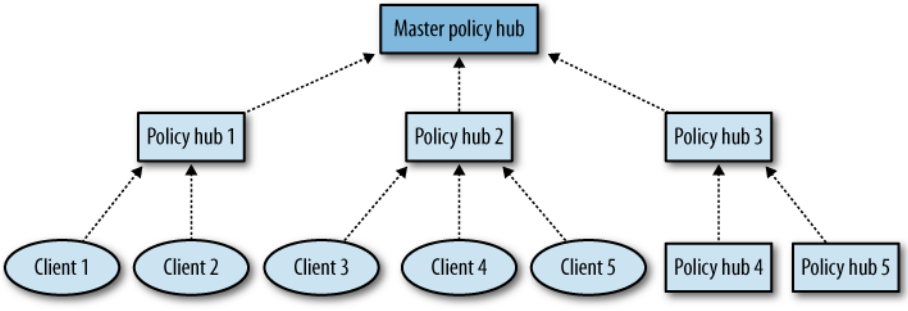
This command works on both the policy hub itself and its clients. In the hub, `cf-agent` will recognize its own IP address and configure the host as a policy hub.

In its simplest form, and one perfectly suitable for all but the largest of organizations, you can have a single policy hub with multiple clients fetching policies and files from it, as shown in the following figure.



The simplest form of CFEngine distributed deployment, with a single policy hub and multiple clients

In larger and more complex environments, you can have a more complex structure. A CFEngine policy hub can itself be a client for some other hub, thus creating a hierarchy of CFEngine policy distribution points, as shown next.



More complex CFEngine distributed deployment, with multiple policy hubs in a hierarchy

The need for a hierarchical structure could be dictated by technical requirements (e.g., geographically disperse sites, low-bandwidth links between them, traffic blocking) or administrative needs (e.g., different teams in charge of

different locations, needing to make their own customizations to the top-level inherited policies). CFEngine is flexible enough to accomodate any of them. Ideally, all the policy files should propagate from the top-level, where they are maintained in a master repository, but you could also have several disjoint trees in your organization.

CFEngine follows a strict pull-only philosophy: only the client can make requests to the server, asking for the information and files it needs. The server cannot push anything onto the clients. This convention makes it very simple to configure the network to allow communication between CFEngine clients and servers. Only one port—TCP/5308—is necessary for the client to connect to the server. All communication, including file transfers, takes place through this port.

The `cf-runagent` command can be used on the server to contact the clients. In this case port, TCP/5308 also needs to be open from the server to the clients, and `cf-serverd` needs to be running on the clients to process those connections. Note, however, that `cf-runagent` does not allow the server to execute arbitrary commands on the clients. All that it does is instruct `cf-agent` on the client to "wake up" and process its policies immediately, instead of waiting for the next scheduled run. We will see the details of this configuration in CFEngine Remote Execution Using cf-runagent.

The decision to only allow the clients to pull from the server (and not the server to push things onto the clients) is also rooted in promise theory. An entity cannot make promises about anyone other than itself. Because of this, the operation of a distributed system cannot depend on one entity forcing others to do something. Entities may request information from others, but they may make promises only about their own behavior. *Voluntary cooperation* is one of CFEngine's core principles.

On the other hand, CFEngine is designed with resilience and graceful degradation in mind. If a client becomes disconnected from the network, CFEngine continues managing it using the latest locally-stored version of the policies until it restores connectivity. This allows clients to continue working during network outages, network congestion, security incidents, or other circumstances that may prevent connectivity to the master policy hub.

CFEngine Server Configuration

The CFEngine server functionality is provided by the `cf-serverd` process. It is configured using a `server control` body block like in the following example,

taken from the default configuration provided with CFEngine (this is part of the `/var/cfengine/inputs/controls/cf_serverd.cf` file generated when you bootstrap CFEngine):

```
body server control
{
     denybadclocks          => "false";
     allowconnects          => { "127.0.0.1" , "::1", @(def.acl) };
     allowallconnects       => { "127.0.0.1" , "::1", @(def.acl) };
     trustkeysfrom          => { "127.0.0.1" , "::1", @(def.acl) };
     skipverify             => { ".*$(def.domain)", "127.0.0.1" , "::1",
                                 @(def.acl) };
     allowusers             => { "root" };
     maxconnections         => "100";

   # Uncomment the line below to allow remote users to run
   # cf-agent through cf-runagent

   # cfruncommand           => "$(sys.cf_agent)";
}
```

The default policy files produced by CFEngine when you bootstrap a client are an excellent starting point and provide a lot of basic functionality. I advise you to go over them and try to get at least a general understanding of what they do. Most of the parts you may need to customize are in `def.cf`, `promises.cf` and some of the files under `controls/`, as needed.

This body defines the set of machines from which connections will be allowed `allowconnects`), those that will be allowed to connect multiple times simultaneously `allowallconnects`),[1] those whose public keys will be trusted if they have not been seen before `trustkeysfrom`) and those whose DNS record will not be checked for consistency `skipverify`). Also specified are the maximum number of simultaneous connections `maxconnections`), the users that will be allowed to connect `allowusers`), and whether machines with out-of-sync clocks will be blocked `denybadclocks`).

Additionally, per-directory and per-file ACLs can be defined in the `access_rules()` bundle, whose default version contains the following:

[1] Normally each host is allowed only one connection at a time.

```
bundle server access_rules()
{
 access:
  any::
   "$(def.dir_masterfiles)"
     handle => "server_access_rule_grant_access_policy",
     comment => "Grant access to the policy updates",
     admit => { ".*\.$(def.domain)", @(def.acl) };
 roles:
}
```

This bundle contains promises of type `access:`, which define the ACLs to apply. In this case, directory `$(def.dir_masterfiles)` (which expands by default to `/var/cfengine/masterfiles`) will be accessible by all machines in the `$(def.domain)` domain, plus those defined explicitely in the `@(def.acl)` list.

Note that most of these parameters include the `@(def.acl)` and `$(def.domain)` variables. These are references to the `acl` and `domain` variables defined in the `def()` bundle, which is defined in `/var/cfengine/inputs/def.cf`:

```
bundle common def
{
 vars:
   "domain"  string => "example.com",
     comment => "Define a global domain for all hosts",
     handle => "common_def_vars_domain";
   "acl" slist => { "$(sys.policy_hub)/16" },
     comment => "Define an acl for the machines to be granted accesses",
     handle => "common_def_vars_acl";
   "dir_masterfiles" string => translatepath("$(sys.workdir)/masterfiles"),
     comment => "Define masterfiles path",
     handle => "common_def_vars_dir_masterfiles";
}
```

You are expected to edit the `def()` bundle before putting CFEngine into production, in particular two values:

- The $(domain) variable must contain the domain name of your current environment. This is used in the code shown earlier to limit access to machines from this domain. It is also used in some other contexts in the default `promises.cf` file.

- The @(acl) variable is a list containing all the IP addresses that should have access to the server. This promise uses the value of `$(sys.policy_hub)` (an automatically-set variable that contains the IP address of the hub from which the host was bootstrapped) and determines its local class-B network (/16). The assumption is that the policy hub will in most cases be in the same network as the client. Of course, this range may well be too broad or too narrow according to your needs, so you must edit it accordingly.

You can also define these parameters using the `def.json` file, formally known as augments. Instead of modifying `def.cf`, you can create `/var/cfengine/masterfiles/def.jso` in your server with the corresponding values, like this:

```
{
    "vars": {
        "domain": "example.com",
        "acl": [ "$(sys.policy_hub)/16" ],
        "dir_masterfiles": "$(sys.workdir)/masterfiles"
    }
}
```

Updating Client Files from the Server

One of the main tasks of the policy hub is to distribute policy files, and any other necessary files, to its clients. This is a crucial operation, since it makes it possible to update files on the hub and have them propagate automatically to all the clients. To this effect, CFEngine provides ample capabilities for efficient and secure file transfer.

The default policy installed with CFEngine contains a bundle called `cfe_internal_update()` which is executed *on the clients* (remember that the CFEngine policy hub cannot instruct the clients to do anything). It takes care of all these tasks automatically, but you may want to modify it according to your needs. It is contained in the file `/var/cfengine/inputs/update.cf`, and in a nutshell these are the tasks it performs:

- Check whether the host key files exist (under `/var/cfengine/ppkeys/`), and run `cf-key` to create them if they are not present.
- Start the `cf-serverd`, `cf-monitord` and `cf-execd` processes if they are not running.

- Copy updated files from `/var/cfengine/masterfiles/` on the policy hub to `/var/cfengine/inputs/` on all machines (both the clients and the policy hub) to put them in production.
- Symlink CFEngine binaries from `/var/cfengine/bin/` to `/usr/local/sbin/` for easier access.
- Ensure all critical directories and files have the correct permissions.

For now we will look only at the file-copying operations, but I encourage you to read through the whole bundle to get an idea of what it does. These are the crucial parts:

```
bundle agent cfe_internal_update
{
 vars:
   "inputs_dir"
     string => translatepath("$(sys.workdir)/inputs"),
     comment => "Directory containing Cfengine policies",
     handle => "update_vars_inputs_dir";
   "master_location"
     string => "/var/cfengine/masterfiles",
     comment => "The master cfengine policy directory on the policy host",
     handle => "update_vars_master_location";
 files:
   "$(inputs_dir)"
     comment => "Copy policy updates from master source on policy server",
     handle => "update_files_inputs_dir",
     copy_from => u_rcp("$(master_location)","$(sys.policy_hub)"),
     depth_search => u_recurse("inf"),
     file_select  => u_input_files,
     classes => u_if_repaired("update_report");
}
```

- The `$(inputs_dir)` variable contains the directory where the local CFEngine installation expects to find its policy files. On Unix/Linux hosts this is normally `/var/cfengine/inputs`, but the location can vary in different platforms. For this reason, we are using the `$(sys.workdir)` variable, which is automatically defined to be the base directory of the local CFEngine installation. We are also using the translatepath() function to translate the Unix-style path into the local style (for example, using backslashes instead of forward slashes on Windows).

- The `$(master_location)` variable contains the directory on the policy hub where the "master files" are located, and from where they will be copied to the local host. The policy hub has to be a Unix-style host, so in this case we don't need to perform any path translation.
- The `files:` promise is the one that does the actual work. The promiser is the destination directory `$(inputs_dir)`, to which the files will be copied according to the parameters specified by the promise attributes that follow.
- The `copy_from` attribute indicates the source of the files. The value of this attribute is a body, defined in the same `update.cf` file as follows:

```
body copy_from u_rcp(from,server)
{
    source      => "$(from)";
    compare     => "digest";
    trustkey    => "true";
  !am_policy_hub::
    servers => { "$(server)" };
}
```

  This body receives as arguments the directory and the host from where the files should be copied. `$(master_location)` is the variable defined before, and `$(sys.policy_hub)` is a special CFEngine variable that is set when the client is bootstrapped, as described in #bootstrapping-cfengine. Additionally, it indicates that the files should be compared using a cryptographic digest (`compare => "digest"`), and that the client should trust the cryptographic keys presented by the server (`trustkey => "true"`). The `servers` attribute is set only when the `am_policy_hub` class is not set, and `am_policy_hub` is a hard class set only on the policy hub, so the effect is that on the policy hub, the file copy operation will be done locally, from `/var/cfengine/masterfiles/` to `/var/cfengine/inputs/`.

- The `depth_search` attribute is used to indicate a recursive file copy operation of infinite depth. Its value is another body:

```
body depth_search u_recurse(d)
{
  depth => "$(d)";
  exclude_dirs => { "\.svn", "\.git" };
}
```

  The `depth` attribute is set to the passed argument (which can be a number, or the special value `"inf"` for infinite recursion). The `exclude_dirs` at-

tribute is also used to skip version-control directories that may be present in the server (assuming that version control is done using Subversion or Git).

- The `file_select` attribute is used to control which types of files are copied. This is another body:

```
body file_select u_input_files
{
  leaf_name => { ".*.cf",".*.dat",".*.txt" };
  file_result => "leaf_name";
}
```

  In this case we are asking CFEngine to copy only files whose names end with `.cf`, `.dat` and `.txt`. There are many criteria that can be specified in a `file_select` body, and for this reason we need the `file_result` attribute to tell CFEngine on which criteria we want to match (in this case it is the only one available).

- The `classes` attribute indicates that if any files are copied (which flags the promise as "repaired"), then the `update_report` class should be set. This class can be used in other parts of the policy to execute any actions necessary (for example, produce a report) when the files are updated. This is yet another body that sets the appropriate class: pass:

```
body classes u_if_repaired(x)
{
        promise_repaired => { "$(x)" };
}
```

File-copy promises are extremely flexible and powerful. Policy and binary updates are automatically handled by the built-in CFEngine policies, but I encourage you to read the documentation for `files:` promises to get a good idea of the wide range of tasks they can perform.

Why is this bundle in the `update.cf` file instead of the `promises.cf` file? The default CFEngine policy instructs `cf-execd` (this is defined in the `body executor control` in `/var/cfengine/inputs/controls/cf_execd.cf`) to always evaluate `update.cf` before running `promises.cf`, to ensure that all files are properly updated. Additionally, if there is any failure in policy evaluation, `cf-agent` automatically tries to load `failsafe.cf`, which performs many of the same update operations to try and bring CFEngine back into operation.

CFEngine Remote Execution Using cf-runagent

One of the basic premises of CFEngine is that clients operate autonomously. If there is a central coordination point, like the policy hub, it is up to the clients to connect to it and fetch policies or files. However, in practice, the server (or some other machine) sometimes needs to "ping" the clients and ask them to do something. This is where `cf-runagent` comes in. It does not allow arbitrary actions to be executed, but simply asks the remote machine to run `cf-agent` and evaluate its policies. The remote host (in most cases it would be a CFEngine client) needs to have `cf-serverd` running and configured to listen for connections from `cf-runagent`.

Allow me to emphasize this point: `cf-runagent` does not allow the execution of arbitrary commands or arbitrary actions on a remote host. It simply instructs the host to run `cf-agent` and start evaluating its policies. This is useful when you don't want to wait until the next regular execution of `cf-agent` (for example, critical policy or operating system updates).

The behavior of the `cf-runagent` command can be configured as part of the CFEngine policy in a `runagent control` body, which allows you to specify, among other things, a list of hosts that will be contacted by default when running the command. On the client side (the one to which the `cf-runagent` command will connect), the `server control` body specifies whether `cf-runagent` connections will be allowed, and what they will be allowed to do. It can also specify a list of remote users that will be allowed to set custom classes when running `cf-runagent`. This allows more fine-grained control of the policy behavior.

`cf-runagent` connections are handled by `cf-serverd`, so if you need this functionality you will also need to open port TCP/5308 traffic from the server to the clients.

Because of its potential security implications, the `cf-runagent` functionality comes disabled in the CFEngine default policy. To enable it, you need to uncomment the `cfruncommand` attribute in the server control body, shown in CFEngine Server Configuration:

```
cfruncommand => "$(sys.cf_agent)";
```

This instructs `cf-serverd` to listen for connections from `cf-runagent`, and to execute `cf-agent` in response to them (remember that this is all that `cf-runagent` allows you to do: wake up `cf-agent`). We still need to instruct cf-serverd to allow access to the `cf-agent` binary (its path is stored in the special variable `$(sys.cf_agent)`, normally `/var/cfengine/bin/cf-agent`) from the policy hub. We need to do this in the `access_rules()` bundle, stored in `/var/cfengine/inputs/controls/cf_serverd.cf`:

```
bundle server access_rules()
{
 access:
  any::
...
  "$(sys.cf_agent)"
    handle => "grant_access_policy_agent",
    comment => "Grant access to the agent (for cf-runagent)",
    admit => { "$(sys.policy_hub)" };
}
```

In this case, we are telling `cf-serverd` to allow access to the `cf-agent` binary only to the policy hub, as defined by the special variable `$(sys.policy_hub)`.

Finally, we need to tell the policy hub which hosts to contact by default when `cf-runagent` is executed. We need to do this explicitly in the `runagent control` body:

```
body runagent control
{
    # A list of hosts to contact when using cf-runagent
  any::
    hosts => { "127.0.0.1" };
    # , "myhost.example.com:5308", ...
}
```

Note that defining this list is not strictly necessary, as the list of hosts can be specified in the command line when running `cf-runagent`, using the `--hail` option.

CFEngine Information Resources

CFEngine has been around for a long time, and it has developed a solid body of documentation and information. In addition to community support, the company that was formed to provide commercial support for CFEngine, CFEngine AS, provides extensive documentation and information, most of it free of charge.

One word of caution: Some of the information you find online may still be geared towards CFEngine 2. While you can apply many of the basic ideas, be aware

that the syntax of CFEngine 3 is completely different and incompatible with the previous version.

Let's look at some of the information resources available for CFEngine

Manuals and Official Guides

Most of the documentation made available by CFEngine AS can be found at the CFEngine Documentation web page. The core documentation includes the following:

- *CFEngine Reference*: the most complete and authoritative reference for CFEngine concepts, installation, syntax, and examples.
- *CFEngine Guide*: documents that describe different aspects of CFEngine, including its design, architecture and components, basic language concepts and more.

Apart from the core documents, you will find a growing collection of Special Topics Guides, a series of shorter documents that focus on specific advanced aspects of working with CFEngine. You can find documentation about best practices for different topics, such as team collaboration, integrating CFEngine into change management practices or specific frameworks such as the ITIL standard, reporting capabilities, knowledge management, etc.

CFEngine Standard Library

The CFEngine Standard Library contains implementations of a large number of commonly-used promise bundles and bodies. It includes bundles for tasks such as editing files in common formats, interfacing with common package and service managers, editing text files, and copying files. The standard library allows you to focus on the task at hand without having to worry about the details, and also serves as a fantastic source of examples, based on which you can extend or define your own bundles and bodies for CFEngine configuration. This library is constantly evolving, and users are encouraged to submit changes and additions to it. The CFEngine standard library is hosted in the `cfengine/masterfiles` repository on GitHub, but is included with the CFEngine distribution, so if you have installed CFEgine from the official packages, the Standard Library is already installed on your macines.

The CFEngine Standard Library used to be known as the Community Open Promise Body Library (COPBL). This name is no longer being used, but you may still see some references to it.

The Standard Library is split into multiple files by promise type. For example, all bodies and bundles related to `files:` promises are stored in `$(sys.libdir)/files.cf` (the special `$sys.libdir` variable defaults to `/var/cfengine/inputs/lib`, but it may change depending on your installation or the user under which you are running CFEngine). You need to load the parts that you are going to use in your policy, for example:

```
body common control
{
  inputs => { "$(sys.libdir)/common.cf",
              "$(sys.libdir)/files.cf",
              "$(sys.libdir)/commands.cf" };
}
```

If you want to load the whole standard library, you can also just load the included `stdlib.cf` file, which in turn loads the others:

```
body common control
{
   inputs => { "$(sys.libdir)/stdlib.cf" };
}
```

The default `promises.cf` file in all CFEngine distributions automatically loads the standard library using the correct method for the current version of CFEngine, so you only need to worry about how to load it (and which parts to load) for standalone policy files you write. In this book, for the examples that need it, we will sometimes see the `stdlib.cf` file, and others the specific files from the library.

The standard library provides you with most of the basic building blocks for implementing different tasks using CFEngine.

Community Forum and IRC channel

The official CFEngine help forum can be found in Google Groups, at https://groups.google.com/forum/?fromgroups#!forum/help-cfengine, and is a fantastic resource of information and help. Both CFEngine developers and advanced users participate actively in the forum, providing a friendly and fertile ground for newcomers to ask questions and learn about CFEngine, and for experienced

users to exchange information, discuss advanced aspects, and provide feedback to the developers.

The official IRC channel is called `#cfengine` and hosted on http://freenode.net/ (use your favorite IRC client to connect to it). It is a good place to ask questions and have informal discussions with CFEngine users, engineers and developers. I would advise you to post complex questions to the forum, and use IRC only for quick questions or conversations.

CFEngine Bug Tracker

The official mechanism for reporting bugs or feature requests is the CFEngine issue tracker.

Other Community Resources

CFEngine users have also developed and made available an incredible amount of useful resources. Here is the list of some of the most useful ones.

- Neil H. Watson's CFEngine 3 Tutorial was one of the first tutorials available specifically for CFEngine 3, and provides a very useful, hands-on guide to CFEngine installation and setting up an initial scheme for experimenting.
- Jessica Greer's Yale University's CFEngine 3 library shows many real-world examples of bodies and bundles used to maintain Yale's computers with CFEngine.
- Aleksey Tsalolikhin's Guide to CFEngine 3 Body of Knowledge is a great collection of links to a lot of the information available about CFEngine 3, including many of the resources already mentioned. Aleksey is a prolific CFEngine expert and trainer.
- As a companion to this book, I would recommend reading and exploring the CFEngine Language Concepts page from CFEngine AS, and to always have the CFEngine Reference pages handy for the full details about the CFEngine policy language.