Version 4.0

Linux Administration II

Linux as a Network Client

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This training manual is designed to correspond to the objectives of the LPI-102 (LPIC-1, version 4.0) certification exam promulgated by the Linux Professional Institute. *Further details are available in Appendix B.*

The Linux Professional Institute *does not endorse specific exam preparation materials or techniques. For details, refer to* `info@lpi.org`.

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Contents

List of Tables

List of Figures

Preface

This training manual deals with the knowledge necessary to configure and operate a Linux workstation as part of an (existing) local area network.

It is aimed towards advanced Linux administrators and presumes knowledge on a level tested in the LPI-101 exam. This includes solid experience using the shell, a text editor, and the fundamental Linux commands as well as the basics of Linux administration. In addition, this training manual builds on the manual *Advanced Linux*, which covers topics such as shell programming, `sed` and `awk`, `cron`, and `at`.

After an introduction to the system logging service, the fundamentals of TCP/IP and Linux network configuration, this manual covers the details of network troubleshooting and explains how to start services using `inetd` and `xinetd`. In addition, we cover topics like managing the system time, printing and important network services such as the secure shell and connecting a client to a mail server. The manual closes with an introduction to encrypting files using GnuPG and an overview of Linux security.

The successful completion of this manual or comparable knowledge are a prerequisite for making the most of additional Linux courses and for obtaining *Linux Professional Institute* certification.

This courseware package is designed to support the training course as efficiently as possible, by presenting the material in a dense, extensive format for reading along, revision or preparation. The material is divided in self-contained chapters detailing a part of the curriculum; a chapter's goals and prerequisites are summarized clearly at its beginning, while at the end there is a summary and (where appropriate) pointers to additional literature or web pages with further information.

chapters
goals
prerequisites

Additional material or background information is marked by the "lightbulb" icon at the beginning of a paragraph. Occasionally these paragraphs make use of concepts that are really explained only later in the courseware, in order to establish a broader context of the material just introduced; these "lightbulb" paragraphs may be fully understandable only when the courseware package is perused for a second time after the actual course.

Paragraphs with the "caution sign" direct your attention to possible problems or issues requiring particular care. Watch out for the dangerous bends!

exercises

Most chapters also contain exercises, which are marked with a "pencil" icon at the beginning of each paragraph. The exercises are numbered, and sample solutions for the most important ones are given at the end of the courseware package. Each exercise features a level of difficulty in brackets. Exercises marked with an exclamation point ("!") are especially recommended.

Excerpts from configuration files, command examples and examples of computer output appear in `typewriter type`. In multiline dialogs between the user and the computer, user input is given in **`bold typewriter type`** in order to avoid misunderstandings. The "⊲⊲⊲⊲⊲" symbol appears where part of a command's output had to be omitted. Occasionally, additional line breaks had to be added to make

things fit; these appear as "▷
◁". When command syntax is discussed, words enclosed in angle brackets ("⟨*Word*⟩") denote "variables" that can assume different values; material in brackets ("[-f ⟨*file*⟩]") is optional. Alternatives are separated using a vertical bar ("-a|-b").

Important concepts

definitions

Important concepts are emphasized using "marginal notes" so they can be easily located; **definitions** of important terms appear in bold type in the text as well as in the margin.

References to the literature and to interesting web pages appear as "[GPL91]" in the text and are cross-referenced in detail at the end of each chapter.

We endeavour to provide courseware that is as up-to-date, complete and error-free as possible. In spite of this, problems or inaccuracies may creep in. If you notice something that you think could be improved, please do let us know, e.g., by sending e-mail to

```
info@tuxcademy.org
```

(For simplicity, please quote the title of the courseware package, the revision ID on the back of the title page and the page number(s) in question.) Thank you very much!

LPIC-1 Certification

These training materials are part of a recommended curriculum for LPIC-1 preparation. Refer to Appendix B for further information.

1

System Logging

Contents

Goals

- Knowing the syslog daemon and how to configure it
- Being able to manage log file using `logrotate`
- Understanding how the Linux kernel handles log messages

Prerequisites

- Basic knowledge of the components of a Linux system
- Handling configuration files

1.1 The Problem

Application programs need to tell their users something now and then. The completion of a task or an error situation or warning must be reported in a suitable manner. Text-oriented programs output appropriate messages on their “terminal”; GUI-based programs might use “alert boxes” or status lines whose content changes.

The operating system kernel and the system and network services running in the background, however, are not connected to user terminals. If such a process wants to output a message, it might write it to the system console’s screen; on X11, such messages might show up in the `xconsole` window.

In multi-user mode, writing a system message to the system console only is not sufficient. Firstly, it is not clear that the message will actually be read by `root`, secondly, these screen messages cannot be saved and may easily get lost.

1.2 The Syslog Daemon

The solution of this problem consists of the syslog daemon or `syslogd`. Instead of outputting a message directly, system messages with a specific meaning can be output using the `syslog()` function, which is part of the Linux C runtime library. Such messages are accepted by `syslogd` via the local socket `/dev/log`.

Kernel messages are really handled by a different program called `klogd`. This program preprocesses the messages and usually passes them along to `syslogd`. See section 1.4.

log `syslogd` proves very useful when debugging. It logs the different system messages and is—as its name suggests—a daemon program. The `syslogd` program is usually started via an init script while the system is booted. When it receives messages, it can write them to a file or sends them on across the network to another computer which manages a centralised log.

The common distributions (Debian GNU/Linux, Ubuntu, Red Hat Enterprise Linux, Fedora, openSUSE, …) have all been using, for various lengths of time, a package called “Rsyslog”, which is a more modern implementation of a `syslogd` with more room for configuration. The additional capabilities are, however, not essential for getting started and/or passing the LPI exam. If you skip the first part of the Rsyslog configuration file, the remainder corresponds, to a very large extent, to what is discussed in this chapter. There is more about Rsyslog in section 1.5.

Instead of `syslogd`, certain versions of the Novell/SUSE distributions, in particular the SUSE Linux Enterprise Server, use the Syslog-NG package instead of `syslogd`. This is configured in a substantially different manner. For the LPIC-1 exam, you need to know that Syslog-NG exists and roughly what it does; see section 1.6.

The administrator decides what to do with individual messages. The configuration file `/etc/syslog.conf` specifies which messages go where. `/etc/syslog.conf`

By default, Rsyslog uses `/etc/rsyslog.conf` as its configuration file. This is largely compatible to what `syslogd` would use. Simply ignore all lines starting with a dollar sign (`$`).

The configuration file consists of two columns and might look like this:

```
kern.warn;*.err;authpriv.none    /dev/tty10
kern.warn;*.err;authpriv.none   |/dev/xconsole
*.emerg                          *
```

Table 1.1: `syslogd` facilities

Facility	Meaning
`authpriv`	Confidential security subsystem messages
`cron`	Messages from `cron` and `at`
`daemon`	Messages from daemon programs with no more specific facility
`ftp`	FTP daemon messages
`kern`	System kernel messages
`lpr`	Printer subsystem messages
`mail`	Mail subsystem messages
`news`	Usenet news subsystem messages
`syslog`	`syslogd` messages
`user`	Messages about users
`uucp`	Messages from the UUCP subsystem
`local`*r*	($0 \leqslant r \leqslant 7$) Freely usable for local messages

Table 1.2: `syslogd` priorities (with ascending urgency)

Priority	Meaning
`none`	No priority in the proper sense—serves to exclude all messages from a certain facility
`debug`	Message about internal program states when debugging
`info`	Logging of normal system operations
`notice`	Documentation of particularly noteworthy situations during normal system operations
`warning`	(or `warn`) Warnings about non-serious occurrences which are not serious but still no longer part of normal operations
`err`	Error messages of all kinds
`crit`	Critical error messages (the dividing line between this and `err` is not strictly defined)
`alert`	"Alarming" messages requiring immediate attention
`emerg`	Final message before a system crash

```
*.=warn;*.=err              -/var/log/warn
*.crit                       /var/log/warn
*.*;mail.none;news.none     -/var/log/messages
```

The first column of each line determines which messages will be selected, and the second line says where these messages go. The first column's format is

```
⟨facility⟩.⟨priority⟩[;⟨facility⟩.⟨priority⟩]…
```

facilities

where the ⟨*facility*⟩ denotes the system program or component giving rise to the message. This could be the mail server, the kernel itself or the programs managing access control to the system. Table 1.1 shows the valid facilities. If you specify an asterisk ("*") in place of a facility, this serves as placeholder for any facility. It is not easily possible to define additional facilities; the "local" facilities `local0` to `local7` should, however, suffice for most purposes.

priorities

The ⟨*priority*⟩ specifies how serious the message is. The valid priorities are summarised in Table 1.2.

Who gets to determine what facility or priority is attached to a message? The solution is simple: Whoever uses the `syslog()` function, namely the developer of the program in question, must assign a facility and priority to their code's messages. Many programs allow the administrator to at least redefine the message facility.

selection criteria

A selection criterion of the form `mail.info` means "all messages of the mail subsystem with a priority of `info` and above". If you just want to capture messages of a single priority, you can do this using a criterion such as `mail.=info`. The asterisk ("*") stands for any priority (you could also specify "`debug`"). A preceding `!` implies logical negation: `mail.!info` deselects messages from the mail subsystem at a priority of `info` and above; this makes most sense in combinations such as `mail.*;mail.!err`, to select certain messages of low priority. `!` and `=` may be combined; `mail.!=info` deselects (exactly) those messages from the mail subsystem with priority `info`.

Multiple facilities—same priority

You may also specify multiple facilites with the same priority like `mail,news.info`; this expression selects messages of priority `info` and above that belong to the `mail` or `news` facilities.

actions

Now for the right-hand column, the messages' targets. Log messages can be handled in different ways:

- They can be written to a *file*. The file name must be specified as an absolute path. If there is a `-` in front of the path, then unlike normal `syslogd` operation, the file will not immediately be written to on disk. This means that in case of a system crash you might lose pending log messages—for fairly unimportant messages such as those of priority `notice` and below, or for messages from "chatty" facilities such as mail and news, this may not really be a problem.

  The file name may also refer to a device file (e. g., `/dev/tty10` in the example above).

- Log messages can be written to a *named pipe* (FIFO). The FIFO name must be given as an absolute path with a preceding "`|`". One such FIFO is `/dev/xconsole`.

- They can be passed *across the network* to another `syslogd`. This is specified as the name or IP address of the target system with a preceding `@` character. This is especially useful if a critical system state occurs that renders the local log file inaccessible; to deprive malicious crackers from a way to hide their traces; or to collect the log messages of all hosts in a network on a single computer and process them there.

  On the target host, the `syslogd` must have been started using the `-r` ("remote") option in order to accept forwarded messages. How to do that depends on your Linux distribution.

- They can be sent *directly to users*. The user names in question must be given as a comma-separated list. The message will be displayed on the listed users' terminals if they are logged in when the message arrives.

- They can be sent to *all logged-in users* by specifying an asterisk ("*") in place of a login name.

Changing configuration

As a rule, after installation your system already contains a running `syslogd` and a fairly usable `/etc/syslog.conf`. If you want to log more messages, for example because specific problems are occurring, you should edit the `syslog.conf` file and then send `syslogd` a `SIGHUP` signal to get it to re-read its configuration file.

You can test the `syslogd` mechanism using the `logger` program. An invocation of the form

```
$ logger -p local0.err -t TEST "Hello World"
```

produces a log message of the form

```
Aug  7 18:54:34 red TEST: Hello World
```

Most modern programming languages make it possible to access the `syslog()` function.

Exercises

1.1 [2] Find out when somebody last assumed `root`'s identity using `su`.

1.2 [!2] Reconfigure `syslogd` such that, in addition to the existing configuration, it writes all (!) messages to a new file called `/var/log/test`. Test your answer.

1.3 [3] (Requires two computers and a working network connection.) Reconfigure `syslogd` on the first computer such that it accepts log messages from the network. Reconfigure `syslogd` on the second computer such that it sends messages from facility `local0` to the first computer. Test the configuration.

1.4 [2] How can you implement a logging mechanism that is safe from attackers that assume control of the logging computer? (An attacker can always pretend further messages from being logged. We want to ensure that the attacker cannot change or delete messages that have already been written.)

1.3 Log Files

Log files are generally created below `/var/log`. The specific file names vary—refer to the `syslog.conf` file if you're in doubt. Here are some examples: `/var/log`

Debian GU/Linux collects all messages except those to do with authentication in the `/var/log/syslog` file. There are separate log files for the `auth`, `daemon`, `kern`, `lpr`, `mail`, `user`, and `uucp` facilities, predictably called `auth.log` etc. On top of that, the mail system uses files called `mail.info`, `mail.warn`, and `mail.err`, which respectively contain only those messages with priority `info` etc. (and above). Debugging messages from all facilities except for `authpriv`, `news`, and `mail` end up in `/var/log/debug`, and messages of priority `info`, `notice`, and `warn` from all facilities except those just mentioned as well as `cron` and `daemon` in `/var/log/messages`.

The defaults on Ubuntu correspond to those on Debian GNU/Linux.

On Red Hat distributions, all messages with a priority of `info` or above, except those from `authpriv` and `cron`, are written to `/var/log/messages`, while messages from `authpriv` are written to `/var/log/secure` and those from `cron` to `/var/log/cron`. All messages from the mail system end up in `/var/log/maillog`.

OpenSUSE logs all messages except those from `iptables` and the `news` and `mail` facilities to `/var/log/messages`. Messages from `iptables` go to `/var/log/firewall`. Messages that are not from `iptables` and have priority `warn`, `err`, or `crit` are also written to `/var/log/warn`. Furthermore, there are the `/var/log/localmessages` file for messages from the `local*` facilities, the `/var/log/NetworkManager` file for messages from the `NetworkManager` program, and the `/var/log/acpid` file for messages from the ACPI daemon. The mail system writes its log both to `/var/log/mail` (all messages) and to the files `mail.info`, `mail.warn`, and `mail.err` (the latter for the priorities `err` and `crit`), while the news system writes its log to `news/news.notice`, `news/news.err`, and `news/news.crit` (according to the priority)—there is no overview log file for news. (If you think this is inconsistent and confusing, you are not alone.)

Some log files contain messages concerninig users' privacy and should thus only be readable by `root`. In most cases, the distributions tend to err towards caution and restrict the access rights to all log files.

Inspecting log files You can peruse the log files created by `syslogd` using `less`; `tail` lends itself to long files (possibly using the `-f` option). There are also special tools for reading log files, the most popular of which include `logsurfer` and `xlogmaster`.

messages The messages written by `syslogd` normally contain the date and time, the host name, a hint about the process or component that created the message, and the message itself. Typical messages might look like this:

```
Mar 31 09:56:09 red modprobe: modprobe: Can't locate ...
Mar 31 11:10:08 red su: (to root) user1 on /dev/pts/2
Mar 31 11:10:08 red su: pam-unix2: session started for ...
```

You can remove an overly large log file using `rm` or save it first by renaming it with an extension like `.old`. A new log file will be created when `syslogd` is next restarted. However, there are more convenient methods.

1.4 Kernel Logging

The Linux kernel does not send its log messages to `syslogd` but puts them into an internal "ring buffer". They can be read from there in various ways—via a specialised system call, or the `/proc/kmsg` "file". Traditionally, a program called `klogd` is used to read `/proc/kmsg` and pass the messages on to `syslogd`.

Rsyslog gets by without a separate `klogd` program, because it takes care of kernel log messages directly by itself. Hence, if you can't find a `klogd` on your system, this may very likely be because it is using rsyslog.

During system startup, `syslogd` and possibly `klogd` are not immediately available—they must be started as programs and thus cannot handle the kernel's start messages directly. The `dmesg` command makes it possible to access the kernel log buffer retroactively and look at the system start log. With a command such as

```
# dmesg >boot.msg
```

you can write these messages to a file and send it to a kernel developer.

Using the `dmesg` command you can also delete the kernel ring buffer (`-c` option) and set a priority for direct notifications: messages meeting or exceeding this priority will be sent to the console immediately (`-n` option). Kernel messages have priorities from 0 to 7 corresponding to the `syslogd` priorities from `emerg` down to `debug`. The command

```
# dmesg -n 1
```

for example causes only `emerg` messages to be written to the console directly. All messages will be written to `/proc/kmsg` in every case—here it is the job of postprocessing software such as `syslogd` to suppress unwanted messages.

Exercises

1.5 [2] What does `dmesg` output tell you about the hardware in your computer?

1.5 Extended Possibilities: Rsyslog

Rsyslog by Rainer Gerhards has replaced the traditional BSD `syslogd` on most common Linux distributions. Besides greater efficiency, rsyslog's goal is supporting various sources and sinks for log messages. For example, it writes messages not just to text files and terminals, but also a wide selection of databases.

According to its own web site, "rsyslog" stands for "rocket-fast syslog". Of course one should not overestimate the value of that kind of self-aggrandisement, but in this case the self-praise is not entirely unwarranted.

The basic ideas behind rsyslog are basically as follows:

- "Sources" pass messages on to "rulesets". There is one standard built-in ruleset (`RSYSLOG_DefaultRuleset`), but you as the user get to define others.
- Every ruleset may contain arbitrarily many rules (even none at all, even though that does not make a great deal of sense).
- A rule consists of a "filter" and an "action list". Filters make yes-no decisions about whether the corresponding action list will be executed.
- For each message, all the rules in the ruleset will be executed in order from the first to the last (and no others). All rules will always be executed, no matter how the filter decisions go, although there is a "stop processing" action.
- An action list may contain many actions (at least one). Within an action list, no further filters are allowed. The actions determine what happens to matching log messages.
- The exact appearance of log messages in the output may be controlled through "templates".

Rsyslog's configuration can be found in the `/etc/rsyslog.conf` file. In this file you may use three different styles of configuration setting in parallel:

- The traditional `/etc/syslog.conf` syntax ("sysklogd").
- An obsolete rsyslog syntax ("legacy rsyslog"). You can recognise this by the commands that start with dollar signs (`$`).
- The current rsyslog syntax ("RainerScript"). This is best suited for complex situations.

The first two flavours are line-based. In the current syntax, line breaks are irrelevant.

For very simple applications you can still—and should!—use the sysklogd syntax (as discussed in the previous sections). If you want to set configuration parameters or express complex control flows, RainerScript is more appropriate. You should avoid the obsolete rsyslog syntax (even if various Linux distributions don't do this in their default configurations), except that various features of rsyslog are only accessible using that syntax.

As usual, empty lines and comment lines will be ignored. Comment lines include both lines (and parts of lines) that start with a `#` (the comment then stops at the end of the line) and C-style comments that reach from a `/*`, disregarding line breaks, until a `*/`.

C-style comments may not be nested[1], but `#` comments may occur inside C-style comments. That makes C-style comments particularly useful to "comment out" large swathes of a configuration file in order to make it invisible to rsyslog.

Rsyslog offers various features that surpass those of BSD `syslogd`. For example, you can use extended filter expressions for messages:

```
:msg, contains, "FOO"    /var/log/foo.log
```

[1]You don't get to do that in C, either, so it shouldn't be a major nuisance.

Extended filter expressions always consist of a colon at the left margin, a "property" that rsyslog takes from the message, a filter operator (here, `contains`), and a search term. In our example, all log messages whose text contains the character sequence `FOO` will be written to the `/var/log/foo.log` file.

Apart from `msg` (the log message proper), the "properties" you may use include, for example, `hostname` (the name of the computer sending the message), `fromhost` (the name of the computer that forwarded the message to rsyslog), `pri` (the category and priority of the message as an undecoded number), `pri-text` (the category and priority as a text string, with the number appended, as in "`local0.err<133>`"), `syslogfacility` and `syslogseverity` as well as `syslogfacility-text` and `syslogseverity-text` for direct access to the category and priority, `timegenerated` (when the message was received) or `inputname` (the rsyslog module name of the source of the message). There are various others; look at rsyslog's documentation.

The allowable comparison operators are `contains`, `isequal`, `startswith`, `regex`, and `eregex`. These speak for themselves, except for the latter two—`regex` considers its parameter as a simple and `eregex` as an "extended" regular expression according to POSIX. All comparison operators take upper and lower case into account.

The `startswith` comparison is useful because it is considerably more efficient than a regular expression that is anchored to the start of the message (as long as you're looking for a constant string, anyway). You should, however, be careful, because what you consider the start of the message and what rsyslog thinks of that can be quite different. If rsyslog receives a message via the syslog service, this will, for example, look like

```
<131>Jul 22 14:25:50 root: error found
```

As far as rsyslog is concerned, `msg` does not start (as one might naively assume) at the `e` of `error`, but with the space character in front of it. So if you are looking for messages that start with `error`, you should say

```
:msg, startswith, " error"   /var/log/error.log
```

There is a nice addition on the "action side" of simple rules: With traditional `syslogd`, you have already seen that an entry like

```
local0.*       @red.example.com
```

will forward log messages to a remote host via the (UDP-based) syslog protocol. With rsyslog, you may also write

```
local0.*       @@red.example.com
```

to transmit log messages via TCP. This is potentially more reliable, especially if firewalls are involved.

At the other end of the TCP connection, of course, there must be a suitably configured rsyslog listening for messages. You can ensure this, for example, via

```
module(load="imtcp" MaxSessions="500")
input(type="imtcp" port="514")
```

In the obsolete syntax,

```
$ModLoad imtcp
$InputTCPMaxSessions 500
$InputTCPServerRun 514
```

does the same thing.

Do consider that only the UDP port 514 is officially reserved for the syslog protocol. The TCP port 514 is really used for a different purpose[2]. You can specify a different port just in case:

```
local0.*       @@red.example.com:10514
```

(and that works for UDP, too, if necessary). The changes required on the server side will be easy for you to figure out on your own.

The next level of complexity are filters based on expressions that may contain arbitrary Boolean, arithmetic, or string operations. These always start with an `if` at the very left of a new line:

```
if $syslogfacility-text == "local0" and $msg startswith " FOO" ▷
 ◁ and ($msg contains "BAR" or $msg contains "BAZ") ▷
 ◁ then /var/log/foo.log
```

(in your file this should all be on one line). With this rule, messages of category `local0` will be written to the `/var/log/foo.log` file as long as they start with `FOO` and also contain either `BAR` or `BAZ` (or both). (Watch for the dollar signs at the start of the property names.)

Rsyslog supports a large number of modules that determine what should happen to log messages. You might, for example, forward important messages by e-mail. To do so, you might put something like

```
module(load="ommail")
template(name="mailBody" type="string" string="ALERT\\r\\n%msg%")
if $msg contains "disk error" then {
    action(type="ommail" server="mail.example.com" port="25"
           mailfrom="rsyslog@example.com" mailto="admins@example.com"
           subject.text="disk error detected"
           body.enable="on" template="mailBody"
           action.execonlyonceeveryinterval="3600")
}
```

into your `/etc/rsyslog.conf`.

If you have an older version of rsyslog (before 8.5.0) you will need to use the obsolete syntax to configure the `ommail` module. That might, for example, look like

```
$ModLoad ommail
$ActionMailSMTPServer mail.example.com
$ActionMailFrom rsyslog@example.com
$ActionMailTo admins@example.com
$template mailSubject,"disk error detected"
$template mailBody,"ALERT\\r\\n%msg%"
$ActionMailSubject mailSubject
$ActionExecOnlyOnceEveryInterval 3600
if $msg contains "disk error" then :ommail:;mailBody
$ActionExecOnlyOnceEveryInterval 0q
```

[2]… even though nobody nowadays is still interested in the remote-shell service. Nobody reasonable, anyway.

Rsyslog's SMTP implementation is fairly primitive, since it supports neither encryption nor authentication. This means that the mail server you specify in the rsyslog configuration must be able to accept mail from rsyslog even without encryption or authentication.

By the way, rsyslog can handle Linux kernel log messages directly. You simply need to enable the `imklog` input module:

```
module(load="imklog")
```

or (obsolete syntax)

```
$ModLoad imklog
```

A separate `klogd` process is not necessary.

Detailed information on rsyslog is available, for example, in the online documentation [rsyslog].

Exercises

1.6 [!3] (If your distribution doesn't use rsyslog already.) Install rsyslog and create a configuration that is as close to your existing `syslogd` configuration as possible. Test it with (for example) `logger`. Where do you see room for improvement?

1.7 [2] PAM, the login and authentication system, logs sign-ons and sign-offs in the following format:

```
kdm: :0[5244]: (pam_unix) session opened for user hugo by (uid=0)
⋘⋘⋖
kdm: :0[5244]: (pam_unix) session closed for user hugo
```

Configure rsyslog such that whenever a particular user (e. g. you) logs on or off, a message is displayed on the system administrator's (`root`'s) terminal if they are logged on. (*Hint:* PAM messages appear in the `authpriv` category.)

1.8 [3] (Cooperate with another class member if necessary.) Configure rsyslog such that all log messages from one computer are passed to another computer by means of a TCP connection. Test this connection using `logger`.

1.6 The "next generation": Syslog-NG

main advantages

Syslog-NG ("NG" for "new generation") is a compatible, but extended reimplementation of a syslog daemon by Balazs Scheidler. The main advantages of Syslog-NG compared to the traditional `syslogd` include:

- Filtering of messages based on their content (not just categories and priorities)
- Chaining of several filters is possible
- A more sophisticated input/output system, including forwarding by TCP and to subprocesses

The program itself is called `syslog-ng`.

For syslog clients there is no difference: You can replace a `syslogd` with Syslog-NG without problems.

You can find information about Syslog-NG in its manual pages as well as on [syslog-ng]. This includes documentation as well as a very useful FAQ collection.

Configuration file Syslog-NG reads its configuration from a file, normally `/etc/syslog-ng/syslog-ng.conf`. Unlike `syslogd`, Syslog-NG distinguishes various "entry types" in its configuration file.

entry types

Global options These settings apply to all message sources or the Syslog-NG daemon itself.

Message sources Sylog-NG can read messages in various ways: from Unix-domain sockets or UDP like `syslogd`, but also, for example, from files, FIFOs, or TCP sockets. Every message source is assigned a name.

Filters Filters are Boolean expressions based on internal functions that can, for example, refer to the origin, category, priority, or textual content of a log message. Filters are also named.

Message sinks Syslog-NG includes all logging methods of `syslogd` and then some.

Log paths A "log path" connects one or several message sources, filters, and sinks: If messages arrive from the sources and pass the filter (or filters), they will be forwarded to the specified sink(s). At the end of the day, the configuration file consists of a number of such log paths.

Options You can specify various "global" options that control Syslog-NG's general behaviour or determine default values for individual message sources or sinks (specific options for the sources or sinks take priority). A complete list is part of the Syslog-NG documentation. The general options include various settings for handling DNS and the forwarding or rewriting of messages' sender host names.

If Syslog-NG on host *A* receives a message from host *B*, it checks the `keep_hostnames()` option. If its value is `yes`, *B* will be kept as the host name for the log. If not, the outcome depends on the `chain_hostnames()` option; if this is `no`, then *A* will be logged as the host name, if it is `yes`, then Syslog-NG will log *B*/*A*. This is particularly important if the log is then forwarded to yet another host.

Message Sources In Syslog-NG, message sources are defined using the `source` keyword. A message source collects one or more "drivers". To accomplish the same as a "normal" `syslogd`, you would include the line

```
source src { unix-stream("/dev/log"); internal(); };
```

in your configuration; this tells Syslog-NG to listen to the Unix-domain socket `/dev/log`. `internal()` refers to messages that Syslog-NG creates by itself.

A Syslog-NG message source corresponding to the `-r` option of `syslogd` might look like this:

```
source s_remote { udp(ip(0.0.0.0) port(514)); };
```

Since that is the default setting,

```
source s_remote { udp(); };
```

would also do.

With `ip()`, you can let Syslog-NG listen on specific local IP addresses only. With `syslogd`, this isn't possible.

The following source specification lets Syslog-NG replace the `klogd` program:

```
source kmsg { file("/proc/kmsg" log_prefix("kernel: ")); };
```

All message sources support another parameter, `log_msg_size()`, which specifies the maximum message length in bytes.

Table 1.3: Filtering functions for Syslog-NG

Syntax	Description
`facility(`⟨*category*⟩[`,`⟨*category*⟩ …]`)`	Matches messages with one of the listed categories
`level(`⟨*priority*⟩[`,`⟨*priority*⟩ …]`)`	Matches messages with one of the listed priorities
`priority(`⟨*priority*⟩[`,`⟨*priority*⟩ …]`)`	Same as `level()`
`program(`⟨*regex*⟩`)`	Matches messages where the name of the sending program matches ⟨*regex*⟩
`host(`⟨*regex*⟩`)`	Matches messages whose sending host matches ⟨*regex*⟩
`match(`⟨*regex*⟩`)`	Matches messages which match the ⟨*regex*⟩ themselves
`filter(`⟨*name*⟩`)`	Invokes another filtering rule and returns its value
`netmask(`⟨*IP address*⟩`/`⟨*netmask*⟩`)`	Checks whether the IP address is in the given network

Filters Filters are used to sift through log messages or distribute them to various sinks. They rely on internal functions that consider specific aspects of messages; these functions can be joined using the logical operators, `and`, `or`, and `not`. A list of possible functions is shown in table **??**.

You might, for example, define a filter that matches all messages from host `green` containing the text `error`:

```
filter f_green { host("green") and match("error"); };
```

With the `level()` (or `priority()` function, you can specify either one or more priorities separated by commas, or else a range of priorities like "`warn .. emerg`".

Message Sinks Like sources, sinks consist of various "drivers" for logging methods. For example, you can write messages to a file:

```
destination d_file { file("/var/log/messages"); };
```

You can also specify a "template" that describes in which format the message should be written to the sink in question. When doing so, you can refer to "macros" that make various parts of the message accessible. For instance:

```
destination d_file {
    file("/var/log/$YEAR.$MONTH.$DAY/messages"
         template("$HOUR:$MIN:$SEC $TZ $HOST [$LEVEL] $MSG\n")
         template_escape(no)
         create_dirs(yes)
    );
};
```

The `$YEAR`, `$MONTH`, etc. macros will be replaced by the obvious values. `$TZ` is the current time zone, `$LEVEL` the message priority, and `$MSG` the messaeg itself (including the sender's process ID). A complete list of macros is part of Syslog-NG's documentation.

The `template_escape()` parameter controls whether quotes (`'` and `"`) should be "escaped" in the output. This is important if you want to feed the log messages to, say, an SQL server.

Unlike `syslogd`, Syslog-NG allows forwarding messages using TCP. This is not just more convenient when firewalls are involved, but also ensures that no log messages can get lost (which might happen with UDP). You could define a TCP forwarding sink like this:

```
destination d_tcp { tcp("10.11.12.13" port(514); localport(514)); };
```

Also very useful is forwarding messages to programs using `program()`. Syslog-NG starts the program when it is started itself, and keeps it running until itself is stopped or it receives a `SIGHUP`. This is not just to increase efficiency, but serves as a precaution against denial-of-service attacks—if a new process is started for every new message, an attacker could shut off logging by sending large amounts of matching log messages. (Other messages that would point to these shenanigans might then be dropped to the floor.)

Log paths Log paths serve to bring sources, filters, and sinks together and to actually evaluate messages. They always start with the `log` keyword. Here are a few examples based on rules you know already from our `/etc/syslog.conf` discussion:

```
# Prerequisites
source s_all { internal(); unix-stream("/dev/log"); };
filter f_auth { facility(auth, authpriv); };
destination df_auth { file("/var/log/auth.log"); };

# auth,authpriv.*   /var/log/auth.log
log {
        source(s_all);
        filter(f_auth);
        destination(df_auth);
};
```

This rule causes all messages to do with authentication to be written to the `/var/log/auth.log` file. Of course, with `syslogd`, this can be done in one line …

Here is a somewhat more complex example:

```
# kern.warn;*.err;authpriv.none    /dev/tty10
filter f_nearly_all {
    (facility(kern) and priority(warn .. emerg))
    or (not facility(authpriv,kern));
};
destination df_tty { file("/dev/tty10"); };
log {
        source(s_all);
        filter(f_nearly_all);
        destination(df_tty);
};
```

Here, too, `syslogd`'s version is a little more compact, but on the other hand this description might be easier to follow.

Every message passes through all log paths, and will be logged by all matching ones (this behaviour equals that of `syslogd`). If you want a message to not be further considered after it has passed a particular log path, you can add the `flags(final)` option to that path.

`flags(final)` does not mean that the message is logged just once; it might have been logged by other paths before the path in question.

With `flags(fallback)`, you can declare a path to be the "default path". This path will only be considered for log messages that did not match any paths that were not marked `flags(fallback)`.

Exercises

1.9 [!3] Install Syslog-NG and create a configuration that is as close to your existing `syslogd` configuration as possible. Test it with (for example) `logger`. Where do you see room for improvement?

1.10 [2] PAM, the login and authentication system, logs sign-ons and sign-offs in the following format:

```
kdm: :0[5244]: (pam_unix) session opened for user hugo by (uid=0)
◁◁◁◁◁
kdm: :0[5244]: (pam_unix) session closed for user hugo
```

Configure Syslog-NG such that whenever a particular user (e. g. you) logs on or off, a message is displayed on the system administrator's (`root`'s) terminal if they are logged on. (*Hint:* PAM messages appear in the `authpriv` category.)

1.11 [3] (Cooperate with another class member if necessary.) Configure rsyslog such that all log messages from one computer are passed to another computer by means of a TCP connection. Test this connection using `logger`. Experiment with different settings for `keep_hostnames()` and `chain_hostnames()`.

1.7 The `logrotate` Program

Depending on the number of users and the number and type of running services, the log files can grow fairly large fairly quickly. To keep the system from inundation by garbage, you should on the one hand try to put the relevant directories (e. g., `/var/log` or `/var`) on their own partitions. On the other hand there is software which checks the log files periodically according to various criteria such as the size, truncates them and removes or archives old log files. This process is called "rotation", and one such program is `logrotate`.

`logrotate` is not a daemon, but will usually be executed once a day (or so) using `cron`—or a similar service.

`logrotate` refuses to modify a log file more than once a day, except if the decision depend on the size of the log file, you're using the `hourly` criterion, or the `--force` option (`-f` for short) was specified with `logrotate`.

`/etc/logrotate.conf`
`/etc/logrotate.d`

According to convention, `logrotate` is configured using the `/etc/logrotate.conf` file and the files within the `/etc/logrotate.d` directory. The `/etc/logrotate.conf` file sets up general parameters, which can be overwritten by the files in `/etc/logrotate.d` if necessary. In `/etc/logrotate.conf`, there is in particular the "`include /etc/logrotate.d`" parameter, which causes the files from that directory to be read in that place as if they were part of the `/etc/logrotate.conf` file.

In principle, `logrotate` reads all the files named on the command line as configuration files, and the content of files mentioned later overwrites that of files mentioned earlier. The `/etc/logrotate.conf` thing is just a (reasonable) convention which is put into action by means of a suitable invocation of `logrotate` in `/etc/cron.daily/logrotate` (or something equivalent).

```
/var/log/syslog
{
    rotate 7
    daily
    missingok
    notifempty
    delaycompress
    compress
    postrotate
        invoke-rc.d rsyslog rotate >/dev/null
    endscript
}
```

Figure 1.1: Example configuration for `logrotate` (Debian GNU/Linux 8.0)

We mention this here because it gives you the basic possibility to perform, without undue hassle, separate `logrotate` runs for log files which aren't part of the regular configuration. If, for example, you have an extremely fast-growing log file of, say, a popular web server, you can manage this using a separate `logrotate` instance that runs more often than once a day.

`logrotate` watches all files that it is told about by the aforementioned configuration files, not just those created by `syslogd`. By way of example, figure 1.1 shows an excerpt of a configuration file for rsyslog from Debian GNU/Linux 8.

The first line of the example specifies the files that this configuration applies to (here, `/var/log/syslog`). You may enumerate several files or specify shell search patterns. After that, inside curly braces, there is a block of directives that define how `logrotate` should deal with the given files.

Typically, `/etc/logrotate.conf` contains directives that are outside of a brace-delimited block. These directives serve as defaults that apply to all log files in the configuration, unless something more specific is given in their own blocks of directives.

old versions

"`rotate 7`" means that at most seven old versions of each log file will be kept. When this maximum is reached, the oldest version of the log file will be deleted.

If you specify an address using `mail`, files will not be deleted but instead be sent to the address in question.

"`rotate 0`" deletes "rotated" log messages outright without keeping them at all.

The rotated files are numbered in sequence, this means that if the current version of the file is called `/var/log/syslog`, the immediately preceding version will be `/var/log/syslog.1`, the version preceding that will be `/var/log/syslog.2`, and so on.

You may use the date instead of the sequential numbers. This means that if today is July 20, 2015, and your `logrotate` run takes place daily in the wee hours, the immediately preceding version of the file is not called `/var/log/syslog.1` but `/var/log/syslog-20150720`, the version preceding that will be called `/var/log/syslog-20150719`, and so on. To use this you must specify the "`dateext`" directive.

Using "`dateformat`", you can control exactly how the date-based file extension should look like. To do so, you need to specify a string that may contain the `%Y`, `%m`, `%d`, and `%s` keys. These stand for the (four-digit) year, calendar month, and calendar day (in each case two digits and, if necessary, with a leading zero) and the seconds since 1st January 1970, 12:00 am UTC. As you can surmise from the previous paragraph, the default is "`-%Y%m%d`".

When you use `dateformat`, you should note that `logrotate` does a lexicographic sort of file names when rotating in order to find out which file is the oldest. This works with "`-%Y%m%d`", but not with "`-%d%m%Y`".

Time periods

"`daily`" means that log files should be rotated daily. Together with "`rotate 7`" this implies that you always have access to last week's logs.

There are also `weekly`, `monthly`, and `yearly`. With `weekly`, the file will be rotated when the current day of the week is earlier than the day of the week of the last rotation, or more than one week has passed since the last rotation (in the end, this means that rotation will take place on the first day of the week, which according to US custom is the Sunday). With `monthly`, the file will be rotated on the first `logrotate` run of the month (usually on the first of the month). With `yearly`, rotation takes place on the first `logrotate` run of the year. Theoretically, `hourly` rotates the log file every hour, but since `logrotate` is normally only run once a day, you will have to arrange for it to be run frequently enough.

An alternative criterion is "`size`". This will rotate a log file when a certain size has been exceeded. The file size is given as a parameter—without a unit, it will be taken to mean bytes, while the units `k` (or `K`), `M`, and `G` stand for kibibytes (2^{10} bytes), mebibytes (2^{20} bytes), or gibibytes (2^{30} bytes), respectively.

"`size`" and the time-based criteria are mutually exclusive. This means that if you specify a "`size`" criterion, rotation will depend solely on file size, no matter when the file was last rotated.

File size and time can be used together by means of the "`maxsize`" and "`minsize`" criteria. With "`maxsize`", you can specify a size which will cause `logrotate` to rotate the file even if the next official date has not been reached. With "`minsize`", the file will only be rotated at the specified point in time if it has exceeded the given size (small files will be skipped).

error messages

"`missingok`" suppresses error messages if a log file could not be found. (The default is "`nomissingok`".) "`notifempty`" does not rotate a file if it is empty (the default here is "`ifempty`").

"`compress`" lets you specify that rotated versions of the log file should be compressed.

This is by default done with `gzip` unless you request a different command using "`compresscmd`". Options for that command (which you would otherwise pass on its command line) can be defined with "`compressoptions`". The default for `gzip` is "`-6`".

The "`delaycompress`" directive ensures that a freshly rotated file is not compressed immediately after the rotation but only on the next run. While usually the sequence of files would look like

```
/var/log/syslog  /var/log/syslog.1.gz  /var/log/syslog.2.gz  …
```

"`delaycompress`" would get you the sequence

```
/var/log/syslog  /var/log/syslog.1  /var/log/syslog.2.gz …
```

(in other words, `/var/log/syslog.1` remains uncompressed). You need this setting if there is a chance that the logging program (like rsyslog) might append data to the file after it has been renamed (rotated)—this can happen because rsyslog keeps the logfile open, and renaming the file is irrelevant as far as writing to it is concerned.

This implies that you need to notify rsyslog that there is a new log file. This is what the

```
postrotate
  invoke-rc.d rsyslog rotate >/dev/null
endscript
```

directive is for. The shell commands between "postrotate" and "endscript" are executed by logrotate whenever the log file has been rotated.

The command itself is basically irrelevant (the idea counts), but what happens in the end is that rsyslog's init script will be invoked, and it will send SIGHUP to the program. Other distributions also have their ways and means.

The SIGHUP then causes rsyslog to reread its configuration file and close and reopen all log files. Since /var/log/syslog was renamed earlier on, rsyslog opens a new log file under that name.—At this point, logrotate could compress the /var/log/syslog.1 file, but it has no way of knowing when rsyslog is really done with the file. This is why this is postponed until the file gets rotated again.

Between "postrotate" and "endscript" there may be several lines with commands. logrotate concatenates them all and passes them to the shell (/bin/sh) as a whole. The commands is passed the name of the log file as a parameter, and that is available there in the customary fashion as "$1".

The postrotate commands are executed once for every log file enumerated at the start of the configuration block. This means that the commands will perhaps be executed several times. You can use the "sharedscripts" directive to ensure that the commands are executed at most once for all files that match the search pattern (or not at all, if none of the files needed to be rotated).

You can use "create" to make sure that the log file is recreated immediately after the rotation and before the postrotate commands are executed. This uses the name of the old file. The file mode, owner, and group derive from the parameters to create; the three possibilities are

```
create 600 root adm                                File mode, user, and group
create root adm                                         Just user and group
create                                                       Nothing at all
```

Unspecified file properties are taken from the previous version of the file.

This is just a selection of the most important configuration parameters. Study logrotate(8) to see the full list.

Exercises

1.12 [!1] Which system-wide defaults does logrotate establish in your distribution?

1.13 [C]onsult /etc/logrotate.conf (and possibly logrotate(8)).

1.14 [3] Configure logrotate such that your new /var/log/test log file will be rotated once it exceeds a length of 100 bytes. 10 rotated versions should be kept, these older versions should be compressed and should use a name containing the date of their creation. Test your configuration.

Commands in this Chapter

`klogd`	Accepts kernel log messages	`klogd`(8)	14, 18
`logger`	Adds entries to the system log files	`logger`(1)	16
`logrotate`	Manages, truncates and “rotates” log files	`logrotate`(8)	26
`logsurfer`	Searches the system log files for important events	`www.cert.dfn.de/eng/logsurf/`	17
`syslogd`	Handles system log messages	`syslogd`(8)	14
`tail`	Displays a file’s end	`tail`(1)	17
`xconsole`	Displays system log messages in an X window	`xconsole`(1)	14
`xlogmaster`	X11-based system monitoring program	`xlogmaster`(1), `www.gnu.org/software/xlogmaster/`	17

Summary

- The `syslogd` daemon can accept log messages from various system components, write them to files, or pass them on to users or other computers.
- Log messages may belong to diverse facilities and can have various priorities.
- Messages can be sent to `syslogd` using the `logger` command.
- Log files are generally placed in the `/var/log` directory.
- Syslog-NG is a compatible, but extended, reimplementation of a syslog daemon.
- `logrotate` can be used to manage and archive log files.

Bibliography

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2

System Logging with Systemd and "The Journal"

Contents

Goals

- Understanding the fundamentals of journald
- Being able to configure journald
- Being able to issue simple journal queries
- Understanding how journald handles log files

Prerequisites

- Basic knowledge of Linux system components
- Ability to handle configuration files
- Knowledge of the traditional system log service (chapter 1)
- Knowledge about systemd

2.1 Fundamentals

Systemd is a far-reaching renewal of the software that ensures the basic operation of a Linux computer. In a stricter sense, systemd is about starting and tracking services and managing resources. Systemd also contains an approach to system logging that is markedly different from the traditional syslogd method, the "journal", and the software components necessary to implement it.

While in the traditional approach the syslog daemon accepts log messages on UDP port 514 or the `/dev/log` socket, and (typically) writes them to text files (or forwards them to other hosts where they are written to text files), in the systemd world background services can simply write log messages to their standard error output channel and systemd will arrange for them to be passed to the logging service[1]. With systemd, log files are not text files (where every message is possibly written to several files), but messages are written to a (binary) database that can then be queried according to diverse criteria.

For example, it is quite easy to display all messages logged by a specific service during a specific period of time. In the traditional system this is fairly difficult.

In fairness, we should point out that the modern syslog implementations such as Rsyslog or Syslog-NG are, in principle, capable of writing log messages to a database. However, it will be your own responsibility to come up with a suitable database schema, to configure Rsyslog or Syslog-NG accordingly, and to develop software that allows you convenient access to the log messages. Systemd includes all this "out of the box".

The Journal isn't confined to textual log messages. It is, for instance, perfectly possible to store core dumps of crashed programs in the Journal (as long as they aren't ginormously oversized). Whether that is a unqualified great idea is, of course, debatable, and the systemd developers have already thought of an alternative method.

Systemd's log system can also interoperate with the traditional approach. If desired, it logs messages that arrive on `/dev/log` or UDP port 512, and can pass messages on to a traditional syslog daemon (or a modern reimplementation).

You have the Journal to thank, too, for the (very convenient) circumstance that "`systemctl status`" will show you the most recent log messages by the service in question:

```
# systemctl status ssh
● ssh.service - OpenBSD Secure Shell server
   Loaded: loaded (/lib/systemd/system/ssh.service; enabled)
   Active: active (running) since Mo 2015-07-27 13:37:22 CEST; 8h ago
 Main PID: 428 (sshd)
   CGroup: /system.slice/ssh.service
           └─428 /usr/sbin/sshd -D

Jul 27 13:37:23 blue sshd[428]: Server listening on 0.0.0.0 port 22.
Jul 27 13:37:23 blue sshd[428]: Server listening on :: port 22.
Jul 27 13:56:50 blue sshd[912]: Accepted password for hugo from ...sh2
Jul 27 13:56:50 blue sshd[912]: pam_unix(sshd:session): session ...=0)
Hint: Some lines were ellipsized, use -l to show in full.
```

As the final line of the output suggests, overlong lines are shortened such that they just fit on the screen. If you want to see them in full, you must invoke `systemctl` with the `-l` option.

[1]Systemd also offers its own API for log messages

Exercises

2.1 [2] What are the advantages and disadvantages of the traditional approach (text files in /var/log) compared to the database-like approach of the Journal?

2.2 Systemd and journald

The Journal is an integrated part of systemd. In the simplest case, systemd uses a limited-size ring buffer in /run/log/journal to store a certain number of log messages in RAM (which is sufficient if you want to pass the messages to a traditional log service). To take advantage of all Journal features, you should ensure that the log messages are permanently stored on disk. This is simply done by creating the directory for storage:

```
# mkdir -p /var/log/journal
# systemctl --signal=USR1 kill systemd-journald
```

(the SIGUSR1 gets systemd to transfer the RAM-based Journal to the new file on disk).

The systemd component that takes care of the Journal is called systemd-journald (or journald to its friends).

The Journal is configured by means of the /etc/systemd/journald.conf file. The [Journal] section of this file (the only one) contains, for example, the Storage parameter, which can assume any of the following values:

volatile Log messages are stored only in RAM (in /run/log/journal), even if /var/log/journal exists.

persistent Log messages are preferably stored on disk (in /var/log/journal). The directory will be created if it doesn't exist. During early boot and if the disk is not writable, systemd falls back onto /run/log/journal.

auto Similar to persistent, but the existence of the /var/log/journal directory determines whether a persistent Journal will be written—if the directory does not exist, the volatile Journal in RAM will have to do.

none No log messages will be stored in the Journal at all. You can still pass messages to a traditional syslog service.

There are a few other interesting parameters. Compress specifies whether log files (at least those exceeding a certain size) will be transparently compressed; the default value is yes. Seal lets you ensure that persistent Journal files are protected against clandestine manipulation by means of a cryptographic signature. You will only need to furnish a key (the document explains how).

The RateLimitInterval and RateLimitBurst parameters are supposed to make it more difficult to flood the log with messages. If a service produces more than RateLimitBurst messages during a period of time given by RateLimitInterval, then all further messages until that period of time is over will be ignored (the log will contain only one message detailing the number of ignored messages). By default, the limit is 1000+messages in 30 seconds; if you set either of the parameters to zero, the limitation will be lifted.

SyncIntervalSec specifies how often the Journal will be synced to disk. The Journal will always be saved immediately after a message of priority crit (or above) has been logged; as long as no such message arrives, journald will wait for the interval specified by SyncIntervalSec before saving it again. The default value is "5 minutes".

Use the `journalctl` command to inspect the log:

```
# journalctl
-- Logs begin at Mo 2015-07-27 13:37:14 CEST, end at Mo 2015-07-27▷
 ◁ 22:20:47 CEST. --
Jul 27 13:37:14 blue systemd-journal[138]: Runtime journal is using 4.
Jul 27 13:37:14 blue systemd-journal[138]: Runtime journal is using 4.
Jul 27 13:37:14 blue kernel: Initializing cgroup subsys cpuset
Jul 27 13:37:14 blue kernel: Initializing cgroup subsys cpu
Jul 27 13:37:14 blue kernel: Initializing cgroup subsys cpuacct
Jul 27 13:37:14 blue kernel: Linux version 3.16.0-4-amd64 (debian-kern
Jul 27 13:37:14 blue kernel: Command line: BOOT_IMAGE=/boot/vmlinuz-3.
```

The output strongly resembles what you would find in `/var/log/messages`, but in fact includes various improvements (which are, unfortunately, less than obvious in a printed training manual):

- The log is displayed using your favourite display program for text files (typically `less`). Using `less`, you can look at the ends of over-long lines by using the horizontal arrow keys.

  This is determined by the value of the `SYSTEMD_PAGER` environment variable, failing that the value of `PAGER`, failing that `less`. Using the `SYSTEMD_LESS` environment variable you can specify options for `less` (if you don't use the system default, this variable is ignored, but then again you can put options into `SYSTEMD_PAGER` directly).

  If you invoke `journalctl` with the `--no-pager` option or set `SYSTEMD_PAGER` to `cat` or an empty string, the output will not be displayed page by page.

- The output includes all accessible log files, even rotated ones (we'll talk more about that later).
- Time stamps are in local (zone) time, not UTC.
- Log messages of priority `notice` or `warning` are displayed in bold face.
- Log messages of priority `error` (or higher) appear in red.

`systemd-journald` tries to make sensible use of the available space. This means that new messages are normally appended to the Journal, but if a certain upper limit for the size of the Journal is reached, it tries to remove old log messages.

You can specify the `SystemMaxUse` and `RuntimeMaxUse` parameters in the `/etc/systemd/journald.conf` file. These parameters describe how much space the Journal may take up under `/var/log/journal` and `/run/log/journal`, respectively. The `SystemKeepFree` and `RuntimeKeepFree` parameters, on the other hand, determine how much space must be kept free on the file systems in question. `systemd-journald` takes into account both values (`…MaxUse` and `…KeepFree`) and confines itself to the minimum size dictated by both.

The `Runtime`… values are used when the system is booting or no persistent Journal is used. The `System`… values apply to the persistent Journal if the system has been booted far enough. When determining the space used by the Journal, only files whose names end in `.journal` will be considered.

You may specify amounts in bytes or append one of the (binary) units `K`, `M`, `G`, `T`, `P` or `E`[2].

[2]We assume it will still be some time before you will have to specify a limit for the Journal in exbibytes (2^{60} bytes), but it is reassuring that the systemd developers are apparently planning for the future.

The default value for …`MaxUse` is 10% and the one for …`KeepFree` is 15% of the file system in question. If there is less space available when `systemd-journald` starts than the …`KeepFree` value dictates, the limit is reduced even further such that space for other material remains.

Like `logrotate`, systemd "rotates" the Journal to make room for new messages. To do so, the available space is subdivided into a number of files, so the oldest can be discarded from time to time. This rotation is transparent to users, because `systemd-journald` does it of its own accord when required and `journalctl` always evaluates the full Journal, no matter how many files it consists of.

The subdivision is governed by the `SystemMaxFileSize` and `RuntimeMaxFileSize` parameters within the `/etc/systemd/journald.conf` file. They specify how large individual Journal files may become—the default is "one eighth of the total space available for the Journal", so you will always have a "prehistory" of seven files and the current file.

You may also make the log file rotation depend on time: `MaxFileSec` determines the maximum time period before systemd starts a new log file. (Usually the size-based rotation is perfectly adequate.) You can use `MaxRetentionSec` to specify an upper limit for how long old log messages are kept around. The default value for `MaxFileSec` is `1month` (`0` means "unlimited") and that for `MaxRetentionSec` is 0 (the mechanism is disabled).

In `/etc/systemd/journald.conf` you can also configure log forwarding to a traditional syslog system. To do so, simply set

log forwarding

```
[Journal]
ForwardToSyslog=yes
```

Exercises

2.2 [!2] Configure your computer such that the Journal is stored persistently on disk. Ensure that this really works (e. g., by writing a message to the log using `logger`, rebooting the computer and then checking that the message is still there).

2.3 [2] Does your computer still have a traditional syslog daemon? If not, then install one (BSD `syslogd` or Rsyslog suggest themselves) and cause log messages to be forwarded to it. Convince yourself (e. g., using `logger`) that it works.

2.3 Log Inspection

You may use `journalctl` to direct very detailed queries to the Journal. We will investigate this further in this section, but here are a few introductory remarks.

Access rights While as `root` you get to see the complete log, as an ordinary user you will only be able to peruse your own log, namely the messages submitted by programs that you started yourself (or that the computer started on your behalf). If you want to have full access even as an ordinary user—we do recommend that even as an administrator you should, as far as possible, use a non-privileged user account, after all—you will need to ensure that you are part of the `adm` group:

```
# usermod -a -G adm hugo
```

You must log out and in again before this change will actually become effective.

Real-time Journal monitoring By analogy to the popular "`tail -f`" command, you can watch new messages being written to the Journal:

```
$ journalctl -f
```

This, too, will display 10 lines' worth of output before `journalctl` waits for further messages to arrive. As with the good old `tail`, you can set the number of lines using the `-n` option, and that works even without the `-f`.

Services and priorities You can use the `-u` option to restrict the output to those log messages written by a specific systemd unit:

```
$ journalctl -u ssh
-- Logs begin at Mo 2015-07-27 13:37:14 CEST, end at Di 2015-07-28 ▷
 ◁ 09:32:08 CEST. --
Jul 27 13:37:23 blue sshd[428]: Server listening on 0.0.0.0 port 22.
Jul 27 13:37:23 blue sshd[428]: Server listening on :: port 22.
Jul 27 13:56:50 blue sshd[912]: Accepted password for hugo from 192.16
Jul 27 13:56:50 blue sshd[912]: pam_unix(sshd:session): session opened
```

Instead of a specific unit name you can also give a shell search pattern to include several units. Or simply specify several `-u` options.

To only display messages of certain priorities, use the `-p` option. This takes either a single numerical or textual priority (`emerg` has the numerical value 0, `debug` 7) and limits the output to messages of that priority or above (below, if you go for numerical values). Or specify a range in the form

```
$ journalctl -p warning..crit
```

to see only those messages whose priority is in that range.

Of course you may combine the `-u` and `-p` options, too:

```
$ journalctl -u apache2 -p err
```

displays all error messages (or worse) from Apache.

The `-k` option limits the output to messages logged by the operating system kernel. This considers only messages written since the last system boot.

Time If you're only interested in messages from a certain period of time, you can limit the output accordingly. The `--since` and `--until` options let you specify a date or time in the "`2015-07-27 15:36:11`" format, and only messages written since or until that point in time will be output.

You can leave off the time completely, in which case "`00:00:00`" will be assumed. Or leave off just the seconds, then "`:00`" is implied. If you leave off the date (which of course requires a time, with or without seconds), `journalctl` will assume "today".

The `yesterday`, `today`, and `tomorrow` keywords stand for "`00:00:00`" yesterday, today, or tomorrow, respectively.

Relative time specifications are also allowed: "`-30m`" stands for "half an hour ago". ("`+1h`" stands for "in one hour", but it is unlikely that your system log will contain entries from the future[3].

[3]Unless you're the Doctor and are querying the Journal of the TARDIS.

Every system boot is assigned a unique identifier, and you can limit your search to the part of the Journal between one boot and the next. In the simplest case, "`journalctl -b`" will consider only messages from the current run:

```
$ journalctl -b -u apache2
```

With the `--list-boots` option, `journalctl` will output a list of boot identifiers to be found in the current Journal, together with the periods of time for which there are log entries:

```
$ journalctl --list-boots
-1 30eb83c06e054feba2716a1512f64cfc Mo 2015-07-27 22:45:08 CEST–▷
 ◁ Di 2015-07-28 10:03:31 CEST
 0 8533257004154353b45e99d916d66b20 Di 2015-07-28 10:04:22 CEST–▷
 ◁ Di 2015-07-28 10:04:27 CEST
```

You may refer to specific boots by passing to `-b` their index (`1` stands for the chronologically first boot in the log, `2` for the second, and so on) or the negative offset in the first column of the output of "`journalctl --list-boots`" (`0` refers to the current boot, `-1` the one before, and so on).

You may also specify the 32-character alphanumeric boot ID from the second column of "`journalctl --list-boots`" to search the Journal for that boot only. That, too, lets you add a positive or negative offset to identify boots before or after it: In the example above,

```
$ journalctl -b 8533257004154353b45e99d916d66b20-1
```

is a roundabout way of saying

```
$ journalctl -b 1
```

Arbitrary search operations If you specify a path name as a parameter, `journalctl` tries to do something reasonable with it:

- If it refers to an executable file, it looks for Journal entries made by that program.
- If it refers to a device file, it looks for entries concerning the device in question.

These search operations are special cases of a more general search mechanism offered by the Journal. Systemd does in fact log much more information than the traditional syslog mechanism[4]. You see that by invoking `journalctl` with the `--output=verbose` option (see figure 2.1.)

The first line in figure 2.1 is a time stamp for the message together with a "cursor". The cursor identifies the message inside the Journal and is needed, for example, to store log entries on remote computers.

The subsequent lines are Journal fields that refer to the message in question. Field names without a leading underscore derive from information submitted by the logging program, and as such are not necessarily trustworthy (the program could, for example, attempt to lie about its PID or its name—in `SYSLOG_IDENTIFIER`). Field names with a leading underscore are supplied by systemd and cannot be manipulated by the logging program.

[4]Again, in fairness, we must mention that these can do rather more than they must—even if they have sometimes acquired that functionality only very recently, in order to catch up with systemd's Journal.

```
Mo 2015-07-27 13:37:23.580820 CEST [s=89256633e44649848747d32096fb42▷
 ◁ 68;i=1ca;b=30eb83c06e054feba2716a1512f64cfc;m=11a1309;t=51bd9c6f▷
 ◁ 8812e;x=f3d8849a4bcc3d87]
    PRIORITY=6
    _UID=0
    _GID=0
    _SYSTEMD_SLICE=system.slice
    _BOOT_ID=30eb83c06e054feba2716a1512f64cfc
    _MACHINE_ID=d2a0228dc98041409d7e68858cac6aba
    _HOSTNAME=blue
    _CAP_EFFECTIVE=3fffffffff
    _TRANSPORT=syslog
    SYSLOG_FACILITY=4
    SYSLOG_IDENTIFIER=sshd
    SYSLOG_PID=428
    MESSAGE=Server listening on 0.0.0.0 port 22.
    _PID=428
    _COMM=sshd
    _EXE=/usr/sbin/sshd
    _CMDLINE=/usr/sbin/sshd -D
    _SYSTEMD_CGROUP=/system.slice/ssh.service
    _SYSTEMD_UNIT=ssh.service
    _SOURCE_REALTIME_TIMESTAMP=1437997043580820
```

Figure 2.1: Complete log output of journalctl

PRIORITY, SYSLOG_FACILITY, SYSLOG_IDENTIFIER, SYSLOG_PID, and MESSAGE derive from the syslog protocol and are pretty self-explanatory. _UID, _GID, _HOSTNAME, _PID, and _SYSTEMD_UNIT also explain themselves. _BOOT_ID is the identifier of the current boot, and _MACHINE_ID identifies the logging computer according to its entry in /etc/machine-id. _CAP_EFFECTIVE specifies the special capabilities of the logging process, and _TRANSPORT describes how the message reached systemd (apart from syslog, common sources are stdout for messages that the program wrote to its standard output or standard error output, or kernel for messages submitted by the operating system kernel via /dev/klog). _COMM, _EXE, and _CMDLINE all describe the command being executed. _SYSTEMD_SLICE and _SYSTEMD_CGROUP specify where in systemd's internal process management the logging process may be found. A more detailed explanation is available from systemd.journal-fields(7).

You may search for all of these fields simply by specifying them on journalctl's command line:

```
$ journalctl _HOSTNAME=red _SYSTEMD_UNIT=apache2.service
```

Search terms using different fields are implicitly joined using AND. If the same field appears in several search terms, these are implicitly joined using OR.

There is also an explicit OR:

```
$ journalctl _HOSTNAME=red _UID=70 + _HOSTNAME=blue _UID=80
```

shows all processes with the UID 70 on the host red as well as all processes with the UID 80 on the host blue. (Naturally this only works if you consolidate both these Journals on your computer.)

Of course you can combine these search terms freely with options, e. g., to set up time limits or save typing:

```
$ journalctl -u apache2 _HOSTNAME=red
```

If (like us) you can never remember which values a search term could assume, you can simply ask the Journal:

```
$ journalctl -F _SYSTEMD_UNIT
session-2.scope
udisks2.service
session-1.scope
polkitd.service
dbus.service
user@1000.service
⊲⊲⊲⊲⊲
```

As a further simplification, command line completion works for field names and values:

```
$ journalctl _SYS Tab                                              becomes
$ journalctl _SYSTEMD_ Tab
_SYSTEMD_CGROUP= _SYSTEMD_OWNER_UID= _SYSTEMD_SESSION= _SYSTEMD_UNIT=
$ journalctl _SYSTEMD_U Tab                                        becomes
$ journalctl _SYSTEMD_UNIT= Tab Tab
acpid.service      lightdm.service      ssh.service
anacron.service    networking.service   systemd-journald.service
⊲⊲⊲⊲⊲
$ journalctl _SYSTEMD_UNIT=ss Tab                                  becomes
$ journalctl _SYSTEMD_UNIT=ssh.service
```

The Journal and `journald` are immensely flexible and powerful and let the traditional method (text files in `/var/log`) appear pretty primitive in comparison.

.

Exercises

2.4 [!2] Experiment with `journalctl`. How many different user identities have sent messages to the Journal on your computer? Did anything interesting happen yesterday between 1 p. m and 2 p. m.? What were the last 10 messages of priority `warning`? Think of some interesting questions yourself and answer them.

Summary

- The "Journal" is a modern system logging service made available by systemd. It relies on binary, database-like log files.
- The Journal is stored either in `/run/log/journal` or (for persistent logging to disk) in `/var/log/journal`.
- Within systemd, `systemd-journald` takes care of the Journal. You can access the Journal using `journalctl`.
- `journalctl` allows very sophisticated queries of the Journal

3

TCP/IP Fundamentals

Contents

Goals

- Knowing the basic structure of the TCP/IP protocol family
- Knowing the fundamentals of IP addressing
- Understanding the concepts of subnetting and routing
- Knowing the most important properties of and differences between TCP, UDP, and ICMP
- Knowing about the most important TCP and UDP services
- Knowing the most relevant differences between IPv4 and IPv6

Prerequisites

- Basic knowledge of computer networks and TCP/IP services from a user's point of view is helpful

3.1 History and Introduction

3.1.1 The History of the Internet

The history of networking computers reaches back almost to the beginning of the "computer age". Most of the early techniques are all but forgotten today—the "Internet" has won the day. But what is "the Internet", anyway, and where does it come from? In this section, we give a brief overview of its history and the development of world-wide computer communications. If you already know this from elsewhere, feel free to skip to the next section. Thank you very much.

ARPAnet

The progenitor of today's Internet is ARPAnet, whose development was funded by the American defence department. It's the late 1960s.

The original object was not, as is often claimed, the construction of a communication infrastructure for the eventuality of nuclear war, but merely research into data communications, while at the same time improving communications between the corporations and universities engaged in defence research.

NCP

In 1969, the ARPAnet consisted of 4 nodes; from 1970 until 1972 the *Network Control Protocol* (NCP) was implemented as the basic communication standard on the ARPAnet. The most important service at the time was electronic mail.

In the 1970s, the idea of an "internet" that was supposed to connect already existing networks gained traction. Researchers tried to implement "TCP", a reliable communication protocol based on an unreliable transmission protocol (the idea of making available an unreliable communication protocol in the shape of UDP only came along later, which explains where the name "TCP/IP" (rather than "TCP/UDP/IP" or something similar) comes from). The first TCP implementations appeared in the early 1970s on "large" systems such as TOPS-20 or Tenex; shortly afterwards it was proved that it was possible to implement TCP even on workstation-class computers like the Xerox Alto, such that these computers could also be part of the Internet. The first ethernet was also developed at Xerox PARC in 1973.

"TCP/IP Flag Day"

MILnet

ARPAnet

NSFNET

Today's basic TCP/IP standards appeared in the early 1980s. They were trialled in BSD—the Unix variant developed at the University of California at Berkeley–, which led to its popularity among users and computer manufacturers. On 1 January 1983, the ARPAnet was converted from NCP to TCP/IP. Soon afterwards, the original ARPAnet was divided administratively into the two components, MILnet (for military applications) and ARPAnet (for defence research). Also in 1983, the development of DNS laid the groundworks for future expansion. In the subsequent years—1984 to 1986—, more TCP/IP-based networks were created, such as the National Science Foundation's NSFNET, and the notion of "the Internet" as the totality of all interconnected TCP/IP networks established itself.

At the end of 1989, Australia, Germany, Israel, Italy, Japan, Mexico, the Netherlands, New Zealand, and the United Kingdom were connected to the Internet. It now consisted of more than 160,000 nodes.

In 1990 the ARPAnet was officially decommissioned (it had been assimiliated into the Internet for a very long time), and in 1991 NFSNET was opened to commercial users. Commercial providers mushroomed. Today most of the network infrastructure is privately held.

Today we have a global network of interconnections with a uniform address space. We use open protocols and uniform communication methods, so everyone can join in the development and the net is available to anybody. Development of the Internet is far from finished, though; future improvements will try to address pressing problems such as address scarcity and the increased need for security.

3.1.2 Internet Administration

A global network like the Internet cannot function without administrative structures. These started out in the USA, since in the beginning most interconnected networks were deployed in that country. It still remains there today, more precisely with the American Department of Commerce.

Various people are irked by the dominance of the USA as far as the Internet is concerned. Unfortunately it is very difficult to figure out what to do about it, as the Americans are not willing to pass the baton formally. On the other hand, the Department of Commerce pursues a marked *laissez-faire* approach, so the opponents can arrange themselves to a certain degree with the *status quo*.

Internet Society

Theoretically, control of the Internet rests in the hands of the "Internet Society" (ISOC), an international non-profit organisation founded in 1992. Its members consist of governments, corporations, universities, other organisations and even individuals (anybody may join).

The main goal of ISOC was to give a formal framework to somewhat vaguely defined institutions such as the IETF (see below) as well as to ensure their financial support. In addition, ISOC holds copyright to the RFCs, the normative documents for the Internet, which are freely available to everybody who is interested.

ISOC's activities fall into three broad categories:

Standards ISOC is the overarching structure for a number of organisations dealing with the technical development of the Internet. These include:

- The *Internet Architecture Board* (IAB) is the committee in charge of overseeing technical development of the Internet. The IAB takes care of publishing the RFCs and counsels ISOC leadership on technical matters.

  The IAB currently has about a dozen members (humans) who have been selected by the "IETF nominating committee", one chairperson also selected by the IETF nominating committee, and a few ex-officio members and representatives of other organisations.

- The *Internet Engineering Task Force* (IETF) is tasked with actually developing Internet standards and, while doing so, cooperates closely with institutions like ISO/IEC and the World Wide Web Consortium (W3C). The IETF is an open organisation without membership, which is operated by "volunteers" (whose employers usually foot the bill). Within IETF there is a large number of "working groups" that arrange themselves into "areas" according to their subject matter. Every area has one or two "area directors" who together with the IETF chair form the *Internet Engineering Steering Group* (IESG). This committee is responsible for the IETF's activities.

  Owing to its amorphous structure it is difficult to say how large IETF is at any given time. In the first years after its institution in 1986, attendance at its regular meetings changed between 30 and 120 people. Since the explosive growth of the Internet in the 1990s the circle has become somwhat larger, even though after the bursting of the "dot-com bubble" it dropped from 3000 people in 2000 down to about 1200 today.

  The IETF's mantra is "rough consensus and running code"—it does not require unanimous decisions but does want to see most of the group behind winning ideas. There is also a big emphasis on solutions that actually work in practice. This and the fact that most of the work is performed by volunteers can lead to IETF working groups taking very long to deliver results—especially if there are too few or too many interested people who want to contribute.

- The *Internet Corporation for Assigned Names and Numbers*, ICANN for short, is another non-profit organisation that was incorporated in 1998 to take over some things that, previously, other organisations (in particular IANA, see the next bullet) had been taking care of on behalf of the US government. In particular, this means the assignment of IP addresses and DNS top-level domain names. Especially the latter is an extremely political issue and every so often brooks conflict.
- The *Internet Assigned Numbers Authority* (IANA) is in charge of actually assigning IP addresses and operating the DNS root servers. Administratively, IANA is part of ICANN. In addition, IANA is responsible for the management of all globally unique names and numbers in Internet protocols published as RFCs. In that respect it cooperates closely with IETF and the RFC editors.

  IANA delegates the assignment of IP addresses further to so-called *Regional Internet Registries* (RIRs), which each handle "distribution" (usually) to ISPs in some part of the world. Currently there are five RIRs, with RIPE NCC being in charge of Europe.

Education ISOC runs conferences, seminars, and workshops on important Internet issues, supports local Internet organisations and, through financial aid, enables experts in developing countries to take part in the discussion and development of the Internet.

Political Lobbying ISOC cooperates with governments and national and international bodies in order to further its ideas and values. The declared goal of ISO is "a future in which people in all parts of the world may use the Internet to improve their quality of life".

3.2 Technology

3.2.1 Overview

Computers process digital information. In the "real world", however, this information is represented by means of physical phenomena such as voltage, charge, or light, and the real world remains fiercely "analogue". The first challenge of data communication, then, is to transform the digital information inside the computer into something analogue—like, for example, a sequence of electrical impulses on a wire—for transmission to another computer, and transforms that back to digital information at the other end. The next challenge is to make this work if the first computer is in Berlin and the other one in New Zealand.

Local area networks
wide area networks

You can divide data networks very roughly, and without actually looking at the technology involved, into two groups: **Local area networks** (LANs) connect a small number of nodes in a geographically limited area, **wide area networks** (WANs) a potentially large number of nodes in a geographically very large ara.

With LANs, the owner (a company or other organisation or—frequently today—a household) is usually also the operator and the sole user, and the network offers high bandwidth (100 MBit/s and more). WANs, on the other hand, connect a multitude of different users who generally do not own the network, bandwidth is less, and usage more expensive.

There are many different networking technologies for very diverse requirements, ranging from very-short-range wireless connections (Bluetooth) and typical LAN technology like Ethernet to fiber connections based on ATM for WANs. As programmers and system administrators we do not want to be bothered with their gory electrical engineering details. Hence we talk about a "protocol stack" and try to separate cleanly its individual components—the "electrical" part, the basic communication between computers on the same network, the basic communication between computers on different networks, and finally concrete "services" such as electronic mail or the World Wide Web. But first things first.

3.2.2 Protocols

A "protocol" is an agreed scheme governing how two (or more) nodes on a network talk to one another. The spectrum of possible protocols ranges from rules for electrical signals on an Ethernet cable or radio signals in a WLAN up to (for example) protocols governing access to an SQL database server. Protocols can be roughly divided into three classes:

Transmission protocols (often also called "access methods") govern data transmission essentially at the level of network cards and physical connections. Their make-up depends on the physical properties and restrictions arising from their implementation in "hardware". For example, the communication between two computers across a serial "null modem cable" is completely different from the transmission of data via a radio connection on a WLAN, and the transmission protocols used follow completely different requirements.

The most common transmission protocol in LANs is Ethernet, even though current Ethernet has hardly anything to do with the eponymous original of 1973 (O. K., both involve electricity, but the resemblance stops about there). Other standards such as token-ring or field bus systems only come up for special applications. Also popular today are WLAN access methods like IEEE 802.11.

Communication protocols serve to organise the communication between computers in different networks without presupposing detailed knowledge of the medium access methods used. To use your home PC in Germany to view a web site on kangaroos served by a server at a university in Australia, you do not want to have to know that your PC is connected via Ethernet to your home router, which talks ATM to the DSLAM in the telecom shed across the road, which passes data through fiber around a few corners to Australia and so on—you just enter `www.roos-r-us.au` in your browser. It is thanks to communications protocols that your PC can find the remote web server and exchange data with it.

Communication protocols are supposed to prevent you from having to mess with transmission protocols, but of course they cannot exist without those. The goal of communication protocols is to hide the transmission protocols' gory details from you—just like your car's accelerator pedal is used to protect you from having to know the precise control data for its electronic fuel injection control system.

The communication protocols of interest to us are, of course, IP, TCP, and UDP. We shall also look at ICMP as an "infrastructure protocol" providing diagnosis, control, and error notification.

Application protocols implement actual services like electronic mail, file transfer, or Internet telephony based on communication protocols. If communication protocols are useful to send random bits and bytes to Australia and get others back, application protocols let you make sense of these bits and bytes.

Typical application protocols that you as a Linux administrator might be confronted with include SMTP, FTP, SSH, DNS, HTTP, POP3, or IMAP, possibly with "secure", that is, authenticated and encrypted,

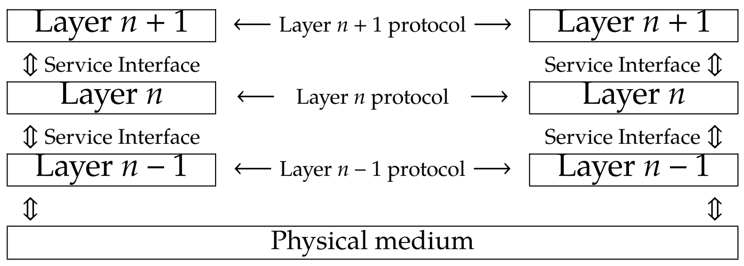

Figure 3.1: Protocols and service interfaces

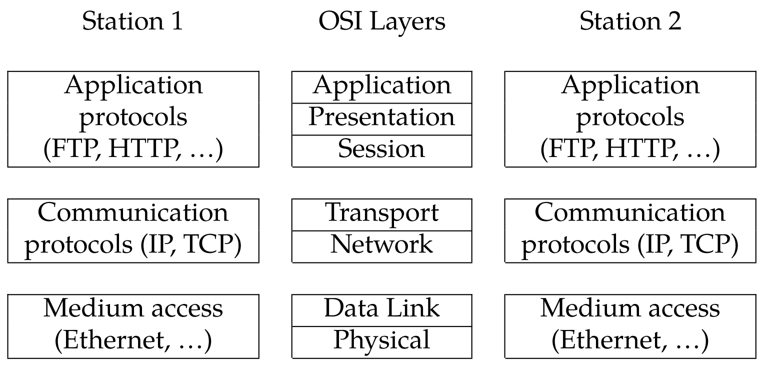
Station 1
OSI Layers
Station 2
Application protocols (FTP, HTTP, …)
Application
Presentation
Session
Application protocols (FTP, HTTP, …)
Communication protocols (IP, TCP)
Transport
Network
Communication protocols (IP, TCP)
Medium access (Ethernet, …)
Data Link
Physical
Medium access (Ethernet, …)

Figure 3.2: ISO/OSI reference model

offshoots. All of these protocols are used by application programs such as mail clients or web browsers, and are based on communication protocols such as TCP or UDP.

protocol data units

The data exchanged via a protocol are abstractly called protocol data units—depending on the protocol they may have more specific names like “packets”, “datagrams”, “segments”, or “frames”.

layer model

The fact that communication protocols are meant to hide the details of transmission protocols, and that application protocols are meant to hide the details of communication protocols lets us construct a “layer model” (Figure 3.1) where the transmission protocols take up the lowest and the application protocols the highest layer. (This is incidentally where the term “protocol stack” comes from.) Every layer on the sender’s side receives data “from above” and passes it “below”; on the receiver’s side it is received “from below” and passed on “above”. Conceptually we still say that two nodes communicate “via HTTP”, when in fact the HTTP data flow across TCP, IP, and a whole zoo of possible transmission protocols from one node to the next and still must pass the IP and TCP layers upwards before becoming visible again as HTTP data.

header

Technically, within each layer on the sender side, the corresponding protocol receives a “protocol data unit” at its service interface from the layer above and adds a “header” containing all the information important for its operation before passing it on across the service interface of the layer below. The layer below considers everything it receives on the service interface as data; the previous protocol’s header is of no concern to the lower layer. On the receiving side, packets pass through the same layers in reverse order, and every layer removes “its” header before passing the “payload data” upwards.

ISO/OSI reference model

The most well-known layer model is the “ISO/OSI reference model” (Figure 3.2). ISO/OSI (short for “Internation Organisation for Standardisation/Open Systems Interconnection”) used to be the basis of a protocol family proposed by CCITT, the world organisation of telecommunications agencies and corporations.

The ISO/OSI network standards never caught on—they were too baroque and impractical to be useful, and the standards documents were difficult to get hold of—, but the reference model with its seven (!) layers has remained and is popularly used to explain the goings-on of data transmission.

Many protocol stacks cannot be directly mapped to the ISO/OSI reference model. On the one hand, this results from the fact that not every manufacturer adheres to the definitions made by the model, on the other hand various protocol stacks predate the OSI model. Nor should you commit the mistake of confusing the ISO/OSI reference model with a binding "standard" for the structure of networking software, or even a set of instructions for networking software implementation. The ISO/OSI reference model is merely a clarification of the concepts involved and makes them easier to discuss. Even so, here is a brief overview of the layers in the model:

- Layers 1 and 2 (physical and data link layers) describe how data is sent on the "wire". This includes the medium access scheme as well as the encoding of the data.
- Layer 3 (the network layer) defines the functions required for routing, including requisite addressing.
- The transport of application data is described in layer 4 (transport layer). This distinguishes between connection-oriented and connectionless services.
- The layers 5, 6 and 7 (session, presentation, and application layers) are often not explicitly discriminated in practice (e. g., with the TCP/IP protocols). These describe the system-independent representation of data within the network and the interfaces to application protocols.
- In addition, Andy Tanenbaum [Tan02] postulates ĺayers 8 and 9 (the financial and political layers). While these layers are well-known in practice, they have so far not been incorporated into the official ISO/OSI reference model.

Exercises

3.1 [2] Review briefly the differences between transmission, communication, and application protocols. Name examples for the various types. (Do you know ones that are not part of the TCP/IP world?)

3.2 [1] What is the main difference between ISO/OSI layers 2 and 3?

3.3 TCP/IP

3.3.1 Overview

TCP/IP stands for "Transmission Control Protocol/Internet Protocol" and is currently the most wide-spread method of transferring data in computer networks ranging from two computers in a local network up to the world-wide Internet. TCP/IP is not just a single protocol but a plethora of different protocols built upon one another with possibly very different applications. This is called a "protocol family".

The protocols from the TCP/IP protocol family can roughly be placed in the context of the ISO/OSI layer model shown in figure 3.2. Here, in brief, are the most important ones:

Medium access layer Ethernet, IEEE 802.11, PPP (these are, strictly speaking, not TCP/IP protocols)

Internet layer IP, ICMP, ARP

Transport layer TCP, UDP, …

Application layer HTTP, DNS, FTP, SSH, NIS, NFS, LDAP, …

In order to understand better the process of data communication, and to be able to localise and find errors that may occur, it is very useful to know the structure of the most important protocols and the make-up of the protocol data units involved. We shall now explain the most important TCP/IP protocols from the internet and transport layers.

Exercises

3.3 [2] Which other protocols of the TCP/IP protocol family can you think of? Which of the four layers do they belong to?

3.3.2 End-to-End Communication: IP and ICMP

IP IP connects two nodes. As an ISO/OSI layer 3 protocol it is responsible for the data finding its way across the Internet from the sender to the receiver. The catch is that this way can involve very long distances consisting of diverse independent sections using markedly different networking technologies and exhibiting markedly different communication parameters. Consider a user "surfing" the Internet at home. Their computer is connected via an analogue modem and the phone network, using PPP, to a dial-in computer on an ISP's premises which provides the actual connection to the Internet. The user's web requests are then sent half-way around the world by means of ATM on fiber optics lines before arriving in a university's computing center, from where they are passed across the FDDI-based campus network to a departmental router, which transmits the data to the web server connected by Ethernet. The web page content then takes the reverse way back. The various parts of the route use not only different networking technologies, but also different "local" addresses—-while no addressing is necessary at all using PPP (there are only two communication stations), Ethernet is based on 48-bit "MAC" addresses.

ISP

address space

One of the achievements of IP is to make available a "global" address space which assigns a unique address to every node connected to the Internet, by which that node can be identified. IP also provides routing from one system to another without regard to the actual networking technology in use.

routing

connectionless protocol

IP is a **connectionless protocol**, that is, unlike the traditional telephony network (for example) it provides no fixed connection (a "wire") for two systems to communicate[1], but the data to be transmitted is divided up in small pieces, the so-called **datagrams**, which can then be addressed and delivered independently from each other. In principle, every datagram can take a different path to the receiver than the previous one; this makes IP resilient to failure of connections or routers as long as one route can be found from the source to the target node. IP does not give guarantees that all transmitted data will actually reach the receiving system, nor does it guarantee that the data which does in fact arrive will do so in the order in which it was sent. It is up to "higher-level" protocols to sort this out if the application requires it.

datagrams

Imagine you want to send a long body of text to your aunt in Australia[2]. To do this "à la IP", you would write the text on a large number of individual postcards. Chances are that on the way down under your postcards will be mixed up, and the postman there is unlikely to drop them in your aunt's letter box in precisely the same order that you posted them here. It is also quite possible for the odd postcard to be delayed or lost somewhere on the way.

[1]Even the telephone network—affectionately called POTS (for "plain old telephone system")—no longer works this way.

[2]Read "Germany" if you are reading this in Australia.

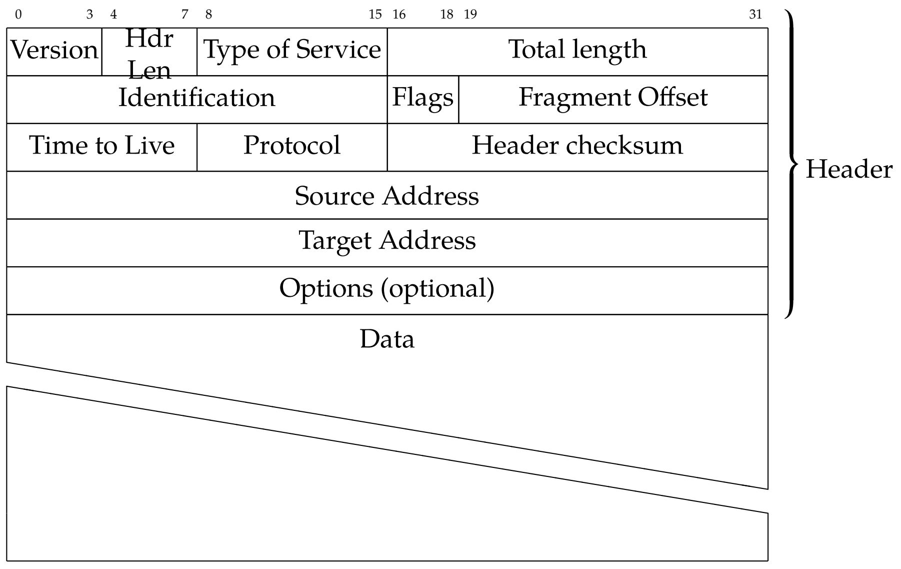

Figure 3.3: Structure of an IP datagram. Every line corresponds to 32 bits.

Why is this an advantage? The traditional telephone network with its wires connected from one end to the other was very susceptible to disturbances—if any segment on the way failed, the whole conversation broke down and needed to be reconstructed (a big deal, back in the days of manually prepared connections). If a problem or interruption develops during connectionless transmission, the network can look for alternative routes for future datagrams that detour around the damaged part. Methods like TCP make it possible to detect which data was lost due to the problem and arrange for it to be retransmitted.

Besides, IP takes care of **fragmentation**. IP datagrams may be up to 65535 bytes long, but most transmission protocols only allow much shorter protocol data units—with Ethernet, for example, at most 1500 bytes. Thus longer datagrams need to be "fragmented"—for transmission across such a medium the datagram is taken apart, split up into numbered fragments, and reassembled later. IP ensures that only datagrams with no missing fragments are officially considered received. fragmentation

The official specification of IP is [RFC0791]. You do not need to read this but it may be helpful against insomnia.

Figure 3.3 shows the structure of an IP datagram. We should briefly explain at least two of the fields:

- The "time to live" (or TTL) states the maximum life span of the datagram. It is set by the sender and decremented (reduced by 1) by each node the datagram passes through on its way to the recipient. If the TTL reaches zero, the datagram is dropped, and the sender is notified. This serves to prevent "flying Dutchmen"—datagrams that due to routing errors run in circles on the Internet without ever reaching their destination. (A common default value is 64, which considering the current extent of the Internet is usually more than enough.)
- The "type of service" (TOS) specifies the quality of service desired for the datagram. Theoretically you get to pick, in addition to one of seven precedence levels (which will be ignored), any of the attributes "low latency", "high throughput", "high reliability", or "low cost". Whether this makes any difference whatsoever as far as the actual transmission is concerned is anybody's guess, since these options are only advisory and routers like to ignore them altogether. (If that wasn't the case,

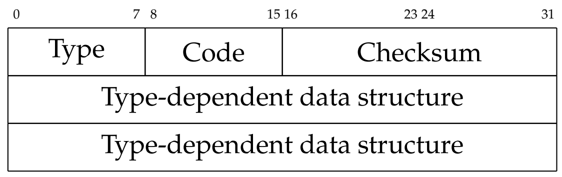

Figure 3.4: Structure of an ICMP packet

then probably all datagrams would have *all* these desirable options switched on.)

ICMP Another important protocol, is the “Internet Control Message Protocol”, or ICMP for short (see figure 3.4). It is used for network management and to report network problems, such as a failed connection or an unreachable subnet. The very well-known `ping` program, for example, uses two special ICMP messages (`echo request` and `echo reply`). The ICMP packet is encapsulated as data inside an IP datagram and contains further data fields depending on the code.

IP and Transmission Protocols To be able to use IP to transmit data regardless of the actual network technology used, we need to define on a case-by-case basis how IP datagrams are forwarded across the network in question—whether that is Ethernet, PPP over an analogue telephone line, ATM, WLAN, …

With Ethernet, for example, all nodes are connected (if only conceptually) to a shared medium—in “classic” Ethernet, a single long coaxial cable running from one node to the next, today more often using twisted-pair cables and a common star hub or switch. Everything a node sends is received by all the other nodes, but these usually pick up only those protocol data units that are actually addressed to them (today, switches help by “pre-sorting” the traffic). If two nodes transmit simultaneously, a collision occurs, which is handled by both nodes stopping transmission, waiting for a random period of time, and trying again. Such a shared Ethernet medium is also called a “segment”.

collision
segment

Every Ethernet interface has a unique address, the 48-bit “MAC address” (short for “medium access control”). Ethernet protocol data units, the so-called frames, can be sent either to particular other nodes within the segment by specifying their MAC address as the recipient—the frame will be seen by all nodes but ignored by all but the addressed node—, or else broadcast to *all* other nodes on the segment.

MAC address
frames
broadcast

Ethernet adapters usually also support a so-called “promiscuous mode”, in which all frames—even the ones that would otherwise be ignored as uninteresting—are passed to the operating system. This is used by interesting applications such as network analysis programs and cracker tools.

This is used to integrate IP and Ethernet. If a node (let’s call it *A*) wants to communicate with another node (*B*) whose IP address it knows, but whose MAC address it doesn’t know, it asks all connected nodes by Ethernet broadcast:

Node *A*: Who here has IP address `203.177.8.4`?
Node *B*: I do, and my MAC address is `00:06:5B:D7:30:6F`

This procedure follows the “Address Resolution Protocol” (ARP, [RFC0826]). Once node *A* has received node *B*’s MAC address, it stores it for a certain time in its “ARP cache” in order to not have to repeat the query for every frame; IP datagrams to nodes whose IP and MAC addresses are part of the ARP cache can be addressed directly at the Ethernet level by embeddng them as “payload data” into Ethernet frames. You can access the ARP cache using the `arp` command—not just to read, but also to write new entries. `arp` output could look like this:

ARP
ARP cache

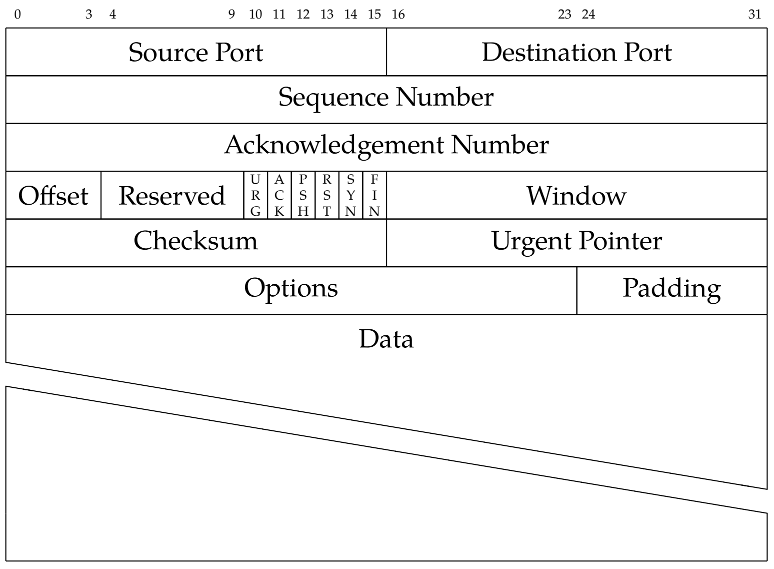

Figure 3.5: Structure of a TCP Segment

```
# arp
Address             Hwtype  Hwaddress          Flags  Mask  Iface
server.example.org  ether   00:50:DB:63:62:CD  C            eth0
```

Datagrams addressed to IP addresses that do not belong to nodes on the same Ethernet segment must be **routed** (Section 3.4.2). Routing

Exercises

3.4 [3] Estimate the minimal TTL that is necessary to be able to reach all other nodes on the Internet from your computer. How would you go about determining the minimal TTL required to reach a specific node? Is that number constant?

3.3.3 The Base for Services: TCP and UDP

TCP The "Transmission Control Protocol" (TCP) is a reliable, connection-oriented protocol defined in [RFC0793] (among others). Unlike the connectionless IP, TCP supports operations to open and tear down connections, which arrange for a "virtual" connection between the source and destination nodes—since TCP data, like all other data, is transmitted based on IP, the actual data transmission still happens unreliably and on a connectionless basis. TCP achieves reliability by means of the destination node acknowledging the receipt of each packet ("segment", in TCP parlance). Each of the two communicating nodes annotates its segments with sequence numbers, which the other node declares "received" in one of its next segments. If there is no such acknowledgement within a certain defined period of time, the sending node retries sending the segment in order to perhaps receive an acknowledgement then. To avoid loss of performance, a "sliding window" protocol is used so a number of segments can remain unacknowledged at the same time. Even so, TCP is considerably slower than IP. sequence numbers

In point of fact, TCP acknowledgements are based on octets (popularly known as bytes) rather than segments—but for our purposes the difference is mostly academic.

Every TCP segment contains a header of at least 20 bytes (figure 3.5) in addition to the IP header. (Remember: The TCP segment *including* the TCP header

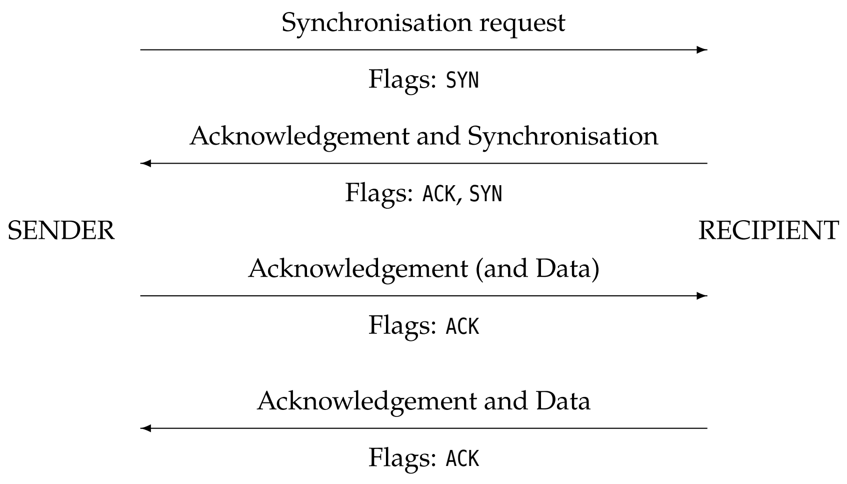

Figure 3.6: Starting a TCP connection: The Three-Way Handshake

is considered "data" by IP, the protocol of the layer below.) Errors in the data can be detected based on a checksum. Every system supports many independent, simultaneous TCP connections distinguished based on **port numbers**. port numbers

The combination of an IP address and a port number together with the IP address and the port number of the "peer" is called a "socket". (The same TCP port on a node may take part in several TCP connections to different peers—defined by the peer's IP address and port number.)

three-way handshake

flags

The virtual connection is built using the **three-way handshake** (see figure 3.6). Using the three-way handshake, the communication peers agree on the sequence numbers to be used. Two **flags** in the TCP header, SYN and ACK, play an important role in this. The first data segment sent to the recipient has the SYN flag set and the ACK flag cleared. Such a segment indicates a connection request. The recipient acknowledges this using a TCP segment that has both the SYN and ACK flags set. The sender in turn acknowledges this segment using one that has the ACK flag set but not the SYN flag. At this point the connection has been established. Subsequent TCP segments also have the ACK flag set only.—At the end of the communication, the connection is torn down by means of a two-way handshake using the FIN flag.

The two nodes need to agree about the start of a connection, but a connection can be torn down unilaterally. In fact this feature is required for commands like the following to work:

```
$ cat bla | ssh blue sort
```

This uses the Secure Shell (see chapter 10) to run the sort command on node blue, and feeds data into its standard input. (ssh reads its standard input locally, forwards the data to the remote computer, and passes it to the sort command on its standard input.) sort, however, works by reading all of its standard input, then sorting the data it read, and writing the sorted data to its standard output, which is then passed by ssh back to the local computer (and the screen).—The problem is that ssh needs to signal the remote sort that all the input has been read, and that it can start sorting and outputting the data. This happens by closing the connection "to" the remote computer. The part of the connection reading "from" the remote computer, however, remains open and can transport the sort output back—if a connection teardown always affected both directions, this application would not work.

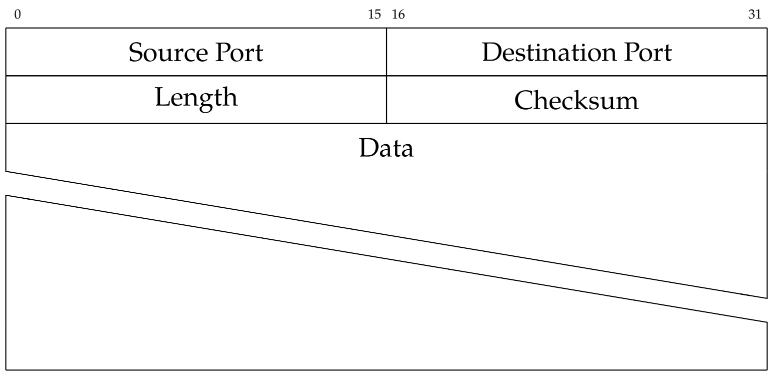

Figure 3.7: Structure of a UDP datagram

Of course, after a unilateral teardown data are still passed between the nodes in both directions, since the node that tore down the connection must still acknowledge the data it receives via the remaining part of the connection. It can no longer send payload data across the connection, though.

UDP Unlike TCP, the "User Datagram Protocol" (UDP) [RFC0768] is a connectionless and unreliable protocol. In fact it isn't much more than "IP with ports", since, like TCP, a node can support at most 65535 communication end points (UDP and TCP may use the same port number simultaneously for different purposes). UDP requires neither the connection initialisiation of TCP nor the acknowledgements, hence the protocol is much "faster"—the price to pay is that, as with IP, data can get lost or mixed up.

UDP is used either where there is only very little data to transmit, so that the cost of a TCP connection initialisation is very high in comparison—cue DNS—or where not every single bit counts but delays are unacceptable. With Internet telephony or video transmission, lost datagrams call attention to themselves through cracking noises or "snow" in the picture; a longer hiatus like the ones common with TCP would be much more obnoxious.

Ports TCP and UDP support the idea of ports, which allow a system to maintain more than one connection at any given time (OK, there are no "connections" with UDP, but even so …). There are 65536 ports each for TCP and UDP, which however cannot all be used sensibly: Port number 0 is a signal to the system's TCP/IP stack to pick an otherwise unused port.

Most ports are freely available to users of the system, but various ports are officially asigned to particular services. We distinguish **well-known ports** and **registered ports**. For example, the rules say that TCP port 25 on a system is reserved for its mail server, which is listening there to accept connections according to the "Simple Mail Transfer Protocol" (SMTP). Similarly, the TCP port 21 is reserved for the FTP server and so on. These assignments are published on a regular basis by IANA and can be found, for example, at `http://www.iana.org/assignments/port-numbers`.

well-known ports
registered ports

According to IANA, the "well-known ports" are ports 0 to 1023, while the "registered ports" are ports 1024 to 49151. If you want to release a program offering a new service, you should request one or more port numbers from IANA.

The remaining ports—from 49152 up to 65535—are called "dynamic and/or private ports" in IANA jargon. These are used for the client side of connections (it is unlikely that your system will need to maintain more than 16.000

```
# Network services, Internet style

echo        7/tcp
echo        7/udp
discard     9/tcp    sink null
discard     9/udp    sink null
systat      11/tcp   users
daytime     13/tcp
daytime     13/udp
netstat     15/tcp
qotd        17/tcp   quote
chargen     19/tcp   ttytst source
chargen     19/udp   ttytst source
ftp-data    20/tcp
ftp         21/tcp
fsp         21/udp   fspd
ssh         22/tcp                  # SSH Remote Login Protocol
ssh         22/udp                  # SSH Remote Login Protocol
telnet      23/tcp
smtp        25/tcp   mail
⊲⊲⊲⊲⊲
```

Figure 3.8: The `/etc/services` file (excerpt)

connection to TCP servers at the same time) or for the implementation of "private" servers.

When IANA reserves a port number for a TCP-based protocol, it tends to reserve the same port number for UDP as well, even though the TCP protocol in question makes no sense with UDP, and vice versa. For example, port 80 is reserved for HTTP both as a TCP and a UDP port, even though UDP-based HTTP is not currently an interesting topic. This leaves elbow room for future extensions.

On a Linux system, a table of assignments is available in the `/etc/services` file (figure 3.8). This table is used, for example, by the Internet daemon (`inetd` or `xinetd`) or the C library function `getservbyname()` to find the port corresponding to a given service name.

You can change `/etc/services`, e. g., to support your own services. Do watch for updates of the file by your distribution.

privileged ports

On Unix-like systems, ports 0 to 1023 are privileged—only `root` may open them. This is a security precaution against arbitrary users launching, e. g., their own web server on an otherwise unused port 80 in order to appear official.

3.3.4 The Most Important Application Protocols

In the previous section we introduced the idea of a "service". While communication protocols like TCP and UDP are concerned with moving data from one node to another, "services" usually rely on application protocols that assign meaning to the data exchanged using the communication protocol. If, for example, you send an e-mail message using SMTP, your computer contacts the remote SMTP server (via TCP on port 25), identifies itself, sends your address as well as that of the recipient (or recipients) and the actual message—in each case after the remote server prompted for them. The details of this conversation are specified by the application protocol, SMTP.

Table 3.1: Common application protocols based on TCP/IP

Port	C Prot	Name	Explanation
20	TCP	FTP	File transfer (data connections)
21	TCP	FTP	File transfer (control connections)
22	TCP	SSH	Secure (authenticated and encrypted) login to remote computers; secure file transfer
23	TCP	TELNET	Login to remote computers (insecure and obsolete)
25	TCP	SMTP	Electronic mail transfer
53	UDP/TCP	DNS	Name and address resolution and related directory services
80	TCP	HTTP	World Wide Web resource access
110	TCP	POP3	Access to remote e-mail mailboxes
123	UDP/TCP	NTP	Network Time Protocol (time synchronisation)
137	UDP	NETBIOS	NetBIOS name service
138	UDP	NETBIOS	NetBIOS datagram service
139	TCP	NETBIOS	NetBIOS session service
143	TCP	IMAP	Access to e-mail stored remotely
161	UDP	SNMP	Network management
162	UDP	SNMP	Traps for SNMP
389	TCP	LDAP	Directory service
443	TCP	HTTPS	HTTP via SSL (authenticated/encrypted)
465	TCP	SSMTP	SMTP via SSL (obsolete, don't use!)*
514	UDP	Syslog	Logging service
636	TCP	LDAPS	LDAP via SSL (authenticated/encrypted)*
993	TCP	IMAPS	IMAP via SSL (authenticated/encrypted)*
995	TCP	POP3S	POP3 via SSL (authenticated/encrypted)*

* These services may also be accessed via connections that are first established in the clear and then "upgraded" to authenticated and encrypted connections later on.

"Services" and "protocols" are not exactly equivalent. A "service" is something you want to use the computer for, such as e-mail, web access, or printing on a remote printer server. For many services on the Internet there are "canonical" protocols that recommend themselves—for e-mail, for example, there are hardly any alternatives to SMTP—, but some services use the same underlying protocol as others. The Web is usually accessed via HTTP and remote printer servers via the "Internet Printing Protocol" (IPP). However, if you look closely enough you will notice that IPP, as used today, is really glorified HTTP. The only difference is that HTTP uses TCP port 80 while IPP uses TCP port 631.

Table 3.1 shows a summary of some important application protocols. We will encounter several of them later on in this manual; others will covered in other Linup Front training manuals.

Bad news for LPIC-1 candidates: LPI wants you to know the port numbers and services from table 3.1 by heart (LPI objective 109.1). Have fun swotting up.

3.4 Addressing, Routing and Subnetting

3.4.1 Basics

Every network interface in a system on a TCP/IP network has at least one IP address. In this case, an "interface" is that part of a system that is able to send and receive IP datagrams. A single system can contain more than one such interface and then generally uses more than one IP address. With

```
$ /sbin/ifconfig
```

or

```
$ /sbin/ip addr show
```

you can list the configured interfaces or network devices.

IP addresses

IP addresses are 32 bits long and are usually written as "dotted quads"—they are viewed as a sequence of four eight-bit numbers written in decimal notation as values between 0 and 255, like "203.177.8.4"[3]. Each IP address is assigned to be globally unique and denotes a node in a particular network on the Internet. To do so, IP addresses are split into a network and a host part. This split is variable and can be adapted to the number of node addresses required in a network. If the host part takes n bits, $32 - n$ bits remain for the network part. The split is documented by the **network mask**, which contains a binary 1 for each bit in the IP address belonging to the network part, and a binary 0 for each bit of the host part. The network mask is notated either as a dotted quad or—frequently—as the number of ones. "203.177.8.4/24" is thus an address in a network with a network mask of "255.255.255.0".

network mask

By way of an example, let's assume a 28-node network. The next higher power of 2 is $32 = 2^5$. This means that 5 bits are required to number all the nodes. The remaining 27 bits ($32 - 5$) identify the network and are the same in all systems on that network. The network mask is 255.255.255.224, since the top three bits are set in the final "quad"—those with values 128, 64, and 32, or 224 altogether.

network address
broadcast address

By convention, the first and last IP addresses in a network are reserved for special purposes: The first address (host part all binary zeroes) is the **network address**, the last address (host part all binary ones) the **broadcast address**. In the

[3]Incidentally, it is quite legal and supported by most programs to give an IP address as a decimal number that has been "multiplied out"—in our example, 3417376772 instead of 203.177.8.4. This is the key ingredient to "trick URLs" of the form http://www.microsoft.com@3417376772/foo.html.

Table 3.2: Addressing example

Meaning	IP Address binary	decimal
Network mask	`11111111 11111111 11111111 11100000`	`255.255.255.224`
Network address	`11001011 10110001 00001000 00000000`	`203.177.8.0`
Host addresses	`11001011 10110001 00001000 00000001`	`203.177.8.1`
⋮	⋮	⋮
	`11001011 10110001 00001000 00011110`	`203.177.8.30`
Broadcast address	`11001011 10110001 00001000 00011111`	`203.177.8.31`

example above, `203.177.8.0` is the network address and `203.177.8.31` the broadcast address. The numbers 1 to 30 are available for nodes (Table 3.2).

The address `255.255.255.255` is a broadcast address, but not for all of the Internet, but the local network segment (for example, all the stations on the same Ethernet). This address is used if no more precise address is known, for example if a node wants to obtain an IP address and network mask via DHCP.

3.4.2 Routing

Routing is used to send IP datagrams that cannot be delivered directly within the local network on to the correct destination[4]. In fact, you might argue that routing is the central property that sets TCP/IP apart from "toy protocols" such as NetBEUI and Appletalk, and which made the Internet, as we know it, possible in the first place.

Routing applies where the recipient of an IP datagram cannot be found within the same network as the sender. The sender can figure this out straightforwardly based on the desired recipient's IP address, by considering that part of the destination address that is "covered" by its own network mask and checking whether this matches its own network address. If this is the case, the recipient is "local" and can be reached directly (Section 3.3.2 on page 50).

If the recipient cannot be reached directly, the node (at least if it is a Linux host) consults a routing table which should contain at least a "default gateway", i. e., a node that takes care of forwarding datagrams that cannot be delivered outright. (This node usually needs to be reachable directly.) Such a node is called a "router" and is either a computer in its own right or else a special appliance manufactured for the purpose.

routing table

In principle, the router proceeds just like we described: It contains various network interfaces, each of which is assigned an address and a network mask, and can deliver datagrams immediately to nodes that according to the network masks of its interfaces can be identified as being part of one of "its" networks. Other directly reachable nodes acting as routers are called upon for more forwarding if necessary.

In real life, routing tables can be considerably more complex. For example, it is possible to forward datagrams directed to particular nodes or networks to other routers that are not the default gateway.

An important observation is that a node (PC or router) usually determines just the directly following routing step (also called "hop"), instead of specifying the complete path from the original sender of the datagram to the final recipient. This

[4]This was already foreseen in the Old Testament: "He leadeth me in the paths of righteousness for his name's sake." (Psalm 23:3) Of course on the Internet there are few better methods of completely ruining your reputation than a spectacularly wrong router misconfiguration.

Table 3.3: Traditional IP Network Classes

Class	Network part	Number of networks	Hosts per network	Addresses
Class A	8 Bit	128 – 126 usable	16.777.214 ($2^{24} - 2$)	`0.0.0.0`–`127.255.255.255`
Class B	16 Bit	16.384 (2^{14})	65.534 ($2^{16} - 2$)	`128.0.0.0`–`191.255.255.255`
Class C	24 Bit	2.097.152 (2^{21})	254 ($2^{8} - 2$)	`192.0.0.0`–`223.255.255.255`
Class D	-	-	-	`224.0.0.0`–`239.255.255.255`
Class E	-	-	-	`240.0.0.0`–`254.255.255.255`

means that it is up to each router between the sender and recipient to pick that hop that it considers most sensible. Well-configured routers talk to their "neighbours" and can base their routing decisions on information about network load and possibly known blockages elsewhere in the network. A detailed discussion of this topic is beyond the scope of this manual.

In fact it is possible for a datagram to specify the complete path it wants to take to its destination. This is called "source routing", is universally frowned upon, and will be completely ignored by large parts of the network infrastructure, because on the one hand it is at odds with the idea of dynamic load distribution, and on the other hand it is a common vehicle for security issues.

3.4.3 IP Network Classes

network classes

Traditionally, the set of IP addresses from `0.0.0.0` to `255.255.255.0` was divided into several **network classes** which were called "class A", "class B", and "class C".

There are also "class D" (multicast addresses) and "class E" (experimental) addresses, but these are of little interest to the assignment of IP addresses to nodes.

Classes A to C differ by their network masks, which amounts to the number of networks available per class and the number of hosts available in these networks. While a class A address has an 8-bit network part, a class B address uses 16 bits, and a class C address 24. A fixed range of IP addresses was assigned to each of the network classes. (Table 3.3)

Due to the increasing scarcity of IP addresses the division of the IP address space into the three address classes was abandoned during the 1990s. Now we are using "classless inter-domain routing" (CIDR) according to [RFC1519]. While according to the "old" scheme the boundary between the network and host addresses could only occur in one of three different places, CIDR makes it possible to assign arbitrary network masks and thus fine-tune the size of the address range made available to a customer (usually an ISP) as well as work against the "explosion" of routing tables. An installation with sixteen adjacent "class C" networks (network mask "`/24`" can be viewed for routing purposes as one network with a `/20` netmask—a considerable simplification, since routing tables can be that much simpler. On the Internet, addresses whose network part is more than 19 bits long are no longer routed directly; in general you must arrange for a provider to manage all of the addresses and forwards the IP datagrams suitably.

3.4.4 Subnetting

Frequently a large network is too imprecise or makes no sense otherwise. Hence operators often divide their networks into several smaller networks. This happens by adding another fixed part to the fixed network part of an IP address. In our previous example, `subnetting` might work approximately like this: Instead of a "large" network with 32 addresses (for 30 nodes) you might prefer two "smaller"

Table 3.4: Subnetting Example

	IP Address	
Meaning	binary	decimal
Network mask	`11111111 11111111 11111111 11110000`	`255.255.255.240`
Network address (1)	`11001011 10110001 00001000 00000000`	`203.177.8.0`
Host addresses (1)	`11001011 10110001 00001000 00000001`	`203.177.8.1`
⋮	⋮	⋮
	`11001011 10110001 00001000 00001110`	`203.177.8.14`
Broadcast address (1)	`11001011 10110001 00001000 00001111`	`203.177.8.15`
Network address (2)	`11001011 10110001 00001000 00010000`	`203.177.8.16`
Host addresses (2)	`11001011 10110001 00001000 00010001`	`203.177.8.17`
⋮	⋮	⋮
	`11001011 10110001 00001000 00011110`	`203.177.8.30`
Broadcast address (2)	`11001011 10110001 00001000 00011111`	`203.177.8.31`

Table 3.5: Private IP address ranges according to RFC 1918

Adressraum	from	to
Class A	`10.0.0.0`	`10.255.255.255`
Class B	`172.16.0.0`	`172.31.255.255`
Class C	`192.168.0.0`	`192.168.255.255`

networks with up to 16 addresses (up to 14 nodes), for example to be able to deploy separate Ethernet cables for security. You can lengthen the network mask by 1 bit; the network, host, and broadcast addresses can be derived from this as above (Table 3.4).

subnets of different size

It isn't necessary for all subnets to have the same size. The `203.177.8.0/24` network, for example, could straightforwardly be subdivided into one subnet with 126 host addresses (e. g., `203.177.8.0/25` with the host addresses `203.177.8.1` to `203.177.8.126` and the broadcast address `203.177.8.127`) and two subnets with 62 host addresses (e. g., `203.177.8.128/26` and `203.177.8.192/26` with the respective host addresses of `203.177.8.192` up to `203.177.8.190` as well as `203.177.8.193` up to `203.177.8.255` and the broadcast addresses `203.177.8.191` and `203.177.8.255`).

smallest possible IP network

The smallest possible IP network has a 30-bit network part and a 2 bit station part. This amounts to a total of four addresses, one of which is the network address and one is the broadcast address, so two addresses are left over for statues. You will find this arrangement every so often with point-to-point links via modem or ISDN.

3.4.5 Private IP Addresses

Globally unique distribution of IP addresses

IP addresses are globally unique and must therefore be administered centrally. Hence you cannot pick your own e-mail address arbitrarily, but must apply for one—usually to your ISP, who in turn has been assigned a block of IP addresses by a national or international body (Section 3.1.2). The number of internationally possible network addresses is, of course, limited.

At the beginning of February 2011, IANA assigned the last five available `/8` address ranges to the five regional registries. It is probable that APNIC (Asia Pacific Network Information Centre) will run out of IP addresses first, possibly in mid-2011. After that, the only solutions will be begging or IPv6.

private addresses

According to [RFC1918], special IP address ranges, the private addresses, are reserved for systems that are not connected to the Internet. These addresses will not be routed on the Internet at large (Table 3.5).

You can use these addresses with impunity within your local networks—including subnetting and all other bells and whistles.

3.4.6 Masquerading and Port Forwarding

IP addresses are a scarce resource today, and that will remain so until we have all converted to IPv6 (Section 3.5). Therefore it is highly probable that you will be assigned only one "official" (i. e., non-RFC 1918) address to connect all of your network to the Internet—with home networks or ones in small companies this is even the rule. The solution (an euphemism for "lame kludge") consists of "masquerading" as well as "port forwarding". Both approaches are based on the fact that only your router is connected to the Internet by means of a public IP address. Masquerading All other nodes within your network use addresses according to [RFC1918]. Masquerading implies that your router rewrites datagrams that nodes within your network send "outside" in order to replace those nodes' IP addresses by its own, and forwards the corresponding response datagrams to the proper senders. Both the nodes inside your network and "the Internet" are not aware of the fact—the former assume that they are talking directly to the Internet, while the latter only port forwarding gets to see the (official) IP address of your router. Conversely, port forwarding enables nodes on the Internet to connect to services such as DNS, e-mail or HTTP through their respective ports on the *router*, while the router forwards the datagrams in question to a node on the inside that performs the actual service.

You should resist the temptation of making your router simultaneously your web, mail, or DNS server; the danger of an intruder compromising your router through one of the large server programs and therefore, in the worst case, getting access to all of your local network, is much too great.

NAT Port forwarding and masquerading are two examples of a concept that is generally called NAT (network address translation). In particular, we can think of masquerading as "source NAT", since the sender address of outgoing datagrams is modified[5], while port forwarding is an instance of "destination NAT"—since the destination address of datagrams addressed to us is changed.

Exercises

3.5 [1] Can the following IP addresses with the given network mask be used as host addresses in the appropriate IP network? If not, why not?

	IP Address	Network mask
a)	`172.55.10.3`	`255.255.255.252`
b)	`138.44.33.12`	`255.255.240.0`
c)	`10.84.13.160`	`255.255.255.224`

3.6 [2] Which reasons could you have to divide the address range your ISP assigned to you into subnets?

3.7 [T]he network at IP address `145.2.0.0`, with the network mask `255.255.0.0`, was divided, using the subnet mask `255.255.240.0`, into the following subnets:

- `145.2.128.0`
- `145.2.64.0`

[5]The fact that we also need to rewrite the recipient address of incoming datagrams will be ignored for convenience.

- `145.2.192.0`
- `145.2.32.0`
- `145.2.160.0`

Which other subnets are also possible? Which subnet contains the station `145.2.195.13`?

3.5 IPv6

IPv4

The most popular incarnation of IP is version 4, or "IPv4" for short. Due to the explosive growth of the Internet, this version comes up against various limits—the main problems are the increasing scarcity of addresses, the chaotic assignment of addresses, and the highly complex routing resulting from this, as well as a fairly sketchy support of security mechanisms and tools for ensuring quality of service. IPv6 is supposed to sort this out.

IPv6 properties

The most important properties of IPv6 include:

- The length of addresses was increased from 32 to 128 bits, resulting in a total of $3.4 \cdot 10^{38}$ addresses. This would suffice to assign approximately 50.000 quadrillion[6] IP addresses (a 28-digit number) to each living person on Earth. That should be enough for the foreseeable future.
- IPv6 stations can automatically obtain configuration parameters from a router when they are connected to a network. If necessary, there is still a DHCPv6 protocol.
- There are only 7 fields in an IP header, so routers can process datagrams more quickly. You get get to use several headers if necessary.
- Extended support for options and extensions, which also contributes to router processing speed.
- Improved transmission of audio and video data and better support for realtime applications.
- Increased security by means of secured data transmission and mechanisms for authentication and integrity protection.
- Extensibility to ensure the future of the protocol. The protocol does not try to cover all possiblities, since the future brings new ideas that cannot be foreseen today. Instead, the protocol is open to the integration of additional functionality in a backwards-compatible manner.

implementation

Even though the standardisation of IPv6 has been finished for some time, the general implementation leaves much to be desired. In particular the service providers are still acting coyly. Linux already supports IPv6, so the conversion of a Linux-based infrastructure to the new standard will not present big problems. You can also transport IPv6 datagrams via IPv4 for testing purposes, by embedding them into IPv4 datagrams ("tunnelling"). Thus a company could base its internal network on IPv6 and even connect several premises via a "virtual" IPv6 network within the traditional IPv4 network.

We should also stress that IPv6 is a targeted replacement for IPv4. Most IP-based protocols—starting with TCP and UDP—remain unchanged. Only at the "infrastructure level" will some protocols become extraneous or be replaced by IPv6-based versions.

[6]What our American friends would call a "septillion"

3.5.1 IPv6 Addressing

IPv6 supports 2^{128} distinct addresses—an unimaginably large number. Essentially, every grain of sand on Earth could be assigned several addresses, but that isn't even the goal: The large address space enables much more flexible address assignment for various purposes, as well as much simplified routing.

Notation Unlike IPv4 addresses, IPv6 addresses are not notated as decimal numbers, but instead as hexadecimal (base-16) numbers. Four hexadecimal digits are grouped and these groups are separated by colons. For example, an IPv6 address might look like

```
fe80:0000:0000:0000:025a:b6ff:fe9c:406a
```

Leading zeroes in a group may be omitted, and (at most) one run of "zero blocks" may be replaced by two colons. Hence, an abbreviated rendition of the address from the previous example might be

```
fe80::25a:b6ff:fe9c:406a
```

The IPv6 address `::1`—an abbreviation of

```
0000:0000:0000:0000:0000:0000:0000:0001
```

—corresponds to the IPv4 loopback address, `127.0.0.1`. IPv6 does not support "broadcast addresses" à la `192.168.1.255`—of which more anon.

IPv6 addresses may be divided into a 64-bit "network" part and a 64-bit "station" part. This implies that every IPv6 subnet contains 2^{64} addresses, i. e., Subnetting 2^{32} times as many as the whole IPv4 internet! Subnetting using variable prefix lengths, as used in IPv4 (Section 3.4.4), is not supposed to be part of IPv6. However, it is assumed that your ISP will provide you with a "`/56`" address prefix so that you can use 256 subnets with 2^{64} addresses each, which shouldn't really cramp your style. (You can specify network prefixes by appending a slash and the decimal prefix length to an address—an address like `fe80::/16` describes the network where addresses start with `fe80` and then continue arbitrarily.)

types of IPv6 addresses There are three basic types of IPv6 addresses:

- "Unicast" addresses apply to one particular network interface (a station may be equipped with several network interfaces, which will each have their own addresses).
- "Anycast" addresses refer to a group of network interfaces. These typically belong to different stations, and the "closest" station is supposed to answer. For example, you may address all routers in an IPv6 network by using the address resulting from appending an all-zero station part to the (64-bit) address prefix of the network.
- "Multicast" addresses are used to deliver the same packets to several network interfaces. As we said, IPv6 does not use broadcast; broadcast is a special case of multicast. The address `ff02::1`, for example, refers to all stations on the local network.

scopes In addition, we can distinguish various scopes:

- "Global" scope applies to addresses that are routed within the whole (IPv6) internet.
- "Link-local" scope applies to addresses that are not routed and are only valid within the same network. Such addresses are commonly used for internal administrative purposes. Link-local addresses are always located within the `fe80::/64` network; the other 64 bits are, in the most straightforward instance, derived from the MAC address of the interface.

- "Site-local" scope applies to addresses that are only routed within one "site". Nobody knows exactly what this is supposed to mean, and site-local addresses have accordingly been deprecated (again). Site-local addresses use the `fec0::/10` prefix.
- "Unique-local" addresses are similar to site-local addresses and correspond roughly to the RFC 1918 addresses (`192.168.`*x*.*y* etc.) of IPv4. However, IPv6 does make it easy to use "proper", i. e., globally visible, addresses, so you do not have to resort to using unique-local addresses in order to assign your stations any addresses at all. Hence there is no compelling reason to use unique-local addresses in the first place, other than as a fallback position if something is terribly wrong with your "real" prefix. Unique-local addresses use the `fd00::/8` prefix, and you are allowed to pick your own next 40 bits for a `/48` network (but don't pick `fd00::/48`).

several addresses

It is important to stress that, with IPv6, every network interface can have several addresses. It gets an automatic link-local address, but can have several unique-local or global addresses on top of that with no problems whatsoever. All of these addresses carry equal weight.

`ipv6calc`

A useful command for the harried IPv6 administrator is `ipv6calc`, which makes handling IPv6 addresses easier. For instance, it will output information about an address:

```
$ ipv6calc --showinfo fe80::224:feff:fee4:1aa1
No input type specified, try autodetection... found type: ipv6addr
No output type specified, try autodetection... found type: ipv6addr
Address type: unicast, link-local
Error getting registry string for IPv6 address:▷
 ◁ reserved(RFC4291#2.5.6)
Interface identifier: 0224:feff:fee4:1aa1
EUI-48/MAC address: 00:24:fe:e4:1a:a1
MAC is a global unique one
MAC is an unicast one
OUI is: AVM GmbH
```

The address in question is a link-local unicast address whose station part hints at a device manufactured by AVM GmbH (in point of fact a FRITZ!Box, a type of DSL router/PBX/home server very popular in Germany).

`ipv6calc` also serves to convert addresses from one format into another. For example, you might simulate the method used to derive the station part of an IPv6 address (also called "EUI-64") from a MAC address:

```
$ ipv6calc --in mac --out eui64 00:24:fe:e4:1a:a1
No action type specified, try autodetection... found type: geneui64
0224:feff:fee4:1aa1
```

Commands in this Chapter

arp	Allows access to the ARP cache (maps IP to MAC adresses)	`arp`(8)	50
inetd	Internet superserver, supervises ports and starts services	`inetd`(8)	54
ipv6calc	Utility for IPv6 address calculations	`ipv6calc`(8)	63
xinetd	Improved Internet super server, supervises ports and starts services	`xinetd`(8)	54

Summary

- The Internet has its roots in the initial ARPAnet of the 1960s, was put on its present technological basis in the early 1980s, and experienced incredible growth in the 1980s and 1990s.
- The ISO/OSI reference model serves to provide terminology for the structure of computer communications.
- Today TCP/IP is the most popular protocol family for data transmission across computer networks.
- ICMP is used for network management and problem reporting.
- TCP provides a connection-oriented and reliable transport service based on IP.
- Like IP, UDP is connectionless and unreliable, but much simpler and faster than TCP.
- TCP and UDP use port numbers to distinguish between different connections on the same computer.
- Different TCP/IP services have fixed port numbers assigned for them. This assignment may be inspected in the `/etc/services` file.
- IP addresses identify nodes world-wide. They are 32 bits long and consist of a network and a host part. The network mask specifies the split between these.
- In former times, the available IP addresses were divided into classes. Today we use classless routing with variable-length network masks.
- IP networks can be further subdivided into subnetworks by adjusting the network mask.
- Some IP address ranges are reserved for use in local networks. They will not be routed by ISPs.
- IPv6 lifts various restrictions of the IPv4 common today, but so far has not been widely adopted.

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4

Linux Network Configuration

Contents

Goals

- Knowing the network configuration mechanisms of the most important distributions
- Being able to configure network interfaces
- Being able to set up static routes
- Being able to configure Linux as a DHCP and DNS client

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 3)

4.1 Network Interfaces

4.1.1 Hardware and Drivers

Depending on the technology and medium access scheme used, Linux computers access the network by means of modems, ISDN adapters, Ethernet or WLAN cards or similar devices. The following sections concentrate mostly on the configuration of Ethernet adapters.

Like other hardware, a network interface on Linux is controlled by the kernel—today usually by means of modular drivers that are loaded dynamically on demand. Unlike, for example, hard disk partitions or printers, network interfaces do not appear as device files in the `/dev` directory, but are accessed via "interfaces". These interfaces are "virtual" in the sense that the kernel makes them available after a suitable driver has been loaded, and that a network interface can be accessed through more than one (mostly) independent interface. The interfaces are named; a typical name for an Ethernet interface would be `eth0`.

interfaces

Nowadays network adapters are recognised by the kernel when the system is booted; it can identify the correct driver by means of the adapter's PCI ID. It is up to the `udev` infrastructure to name the device and actually load the driver.

One obstacle that modern Linux distributions present here is that the interface name is tied to the adapter's MAC address. (Every network adapter has a globally unique MAC address which is set by the manufacturer.) Thus if you replace the network adapter inside a computer without resetting the information `udev` keeps about network adapters it has seen, chances are that your new adapter will be called `eth1`, and the configuration, which is based on an adapter called `eth0`, will not apply.

A typical place where such information ends up is the `/etc/udev/rules.d` directory. In a file like `70-persistent-net.rules` there might be lines such as

```
SUBSYSTEM=="net", DRIVERS=="?*",▷
 ◁ ATTRS{address}=="00:13:77:01:e5:4a", NAME="eth0"
```

which assign the name `eth0` to the adapter with the MAC address `00:13:77:01:e5:4a`. You can fix the MAC address by hand, or remove the line completely and have `udev` adapt the entry to the changed reality during the next system boot.

Don't tie yourself in knots if you are running Linux in a virtual machine and can't find the `70-persistent-net.rules` file. For most "virtual" network interfaces, it may not be created in the first place.

Formerly (before `udev`) it was up to the installation procedures provided by the distribution to come up with the correct drivers for network adapters, and to make these known to the system. Typically this was done by means of the `/etc/modules.conf` file, where entries such as

```
alias eth0 3c59x
```

needed to be placed—this would tell the kernel to load the driver module `3c59x.o` upon the first access to the `eth0` interface. But no more …

Of course the Linux kernel is not necessarily modular, even though the standard kernels in most distributions can't do without modules. If you compile your own kernel (see, for example, *Linux System Configuration*), you can put the drivers for your network interfaces directly into the kernel.

For special requirements, typically for computers with increased security needs such as packet-filtering routers or servers that are exposed to the Internet, you can even remove the module-loading infrastructure from the kernel completely. This makes it harder (albeit not impossible) for crackers to take over the system without being noticed.

4.1.2 Configuring Network Adapters Using `ifconfig`

Before you can use a network interface to access the network, it must be assigned an IP address, a network mask, and so on. Traditionally, this is done by hand using the `ifconfig` command:

```
# ifconfig eth0 192.168.0.75 up
# ifconfig eth0
eth0 Link encap:Ethernet  HWaddr 00:A0:24:56:E3:73
     inet addr:192.168.0.75 Bcast:192.168.0.255 Mask:255.255.255.0
     inet6 addr: fe80::2a0:24ff:fe56:e373/64 Scope:Link
     UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
     RX packets:0 errors:0 dropped:0 overruns:0 frame:0
     TX packets:6 errors:0 dropped:0 overruns:0 carrier:6
     collisions:0 txqueuelen:100
     RX bytes:0 (0.0 b)  TX bytes:460 (460.0 b)
     Interrupt:5 Base address:0xd800
```

After an IP address has been assigned, you can view the status of an interface by invoking the same command without specifying an IP address. This displays not only the current IP address but also the hardware type, the MAC (or hardware) address, the broadcast address, the network mask, the IPv6 address, and many other data. In the example you can see that the kernel will set items such as the network mask and broadcast address to default values (here those of a class C network, according to the first octet of the IP address) if no explicit values are given. Should the desired values deviate from the default you must specify them explicitly.

```
# ifconfig eth0 192.168.0.75 netmask 255.255.255.192 textbackslash
>      broadcast 192.168.0.64
# ifconfig eth0
eth0 Link encap:Ethernet  HWaddr 00:A0:24:56:E3:73
     inet addr:192.168.0.75 Bcast:192.168.0.64 Mask:255.255.255.192
     inet6 addr: fe80::2a0:24ff:fe56:e373/64 Scope:Link
⊲⊲⊲⊲⊲
```

Using the parameters `up` and `down`, you can switch individual interfaces on and off with `ifconfig`.

loopback interface

By convention, the loopback interface has the IP address `127.0.0.1` and will be configured automatically. Should this not happen for some reason, or should the configuration be lost, you can do it yourself using

```
# ifconfig lo 127.0.0.1 up
```

alias

For testing or for special requirements it may make sense to define an alias for an interface, using a different IP address, network mask, etc. This is no problem using `ifconfig`:

```
# ifconfig eth0:0 192.168.0.111
# ifconfig eth0:0
eth0:0 Link encap:Ethernet  HWaddr 00:A0:24:56:E3:72
     inet addr:192.168.0.111 Bcast:192.168.0.255 Mask:255.255.255.0
     UP BROADCAST MULTICAST  MTU:1500  Metric:1
     Interrupt:5 Base address:0xd800
```

The alias name is constructed from the interface name by adding an extension separated by a colon. What the extension looks like is immaterial (there is nothing wrong with `eth0:Mr.X`), but by convention alias names are numbered sequentially: `eth0:0`, `eth0:1`, …

Exercises

4.1 [1] Which kernel module applies to your network adapter? Is it loaded?

4.2 [!1] Check whether your network adapter is running, and which IP address is assigned to it.

4.3 [!2] Assign a new IP address to your network adapter (possibly according to your instructor's directions). Check whether you can still reach other computers on the network.

4.1.3 Configuring Routing Using `route`

Every computer in a TCP/IP network requires routing, since even the simplest node contains at least two network interfaces—the loopback interface and the interface leading to the rest of the network, like an Ethernet or WLAN card or an Internet connection. The routes for the loopback interface and the networks that are directly connected to the network adapters are set up automatically by current Linux kernels when the adapters are initialised. Other routes—in particular, the "default route" which specifies where datagrams are sent in the absence of more specific instructions—must be configured explicitly.

In principle we are distinguishing between *static* and *dynamic* routing. With the former, routes are set up manually and seldom if ever changed. With the latter, the system talks to other routers in its vicinity and adapts its routes to the current state of the network. Dynamic routing requires the installation of a "routing daemon" such as `gated` or `routed` and will not be discussed further here. The rest of this section confines itself to explaining static routing.

routing table The kernel maintains a routing table summarising the current routing configuration. It contains rules (the routes) that describe which datagrams should be sent where, based on their destination address. You can inspect the routing table using the `route` command:

```
# ifconfig eth0 192.168.0.75
# route
Kernel IP routing table
Destination  Gateway Genmask       Flags Metric Ref Use Iface
192.168.0.0  *       255.255.255.0 U     0      0   0   eth0
```

The columns in this table have the following meaning:

- The first column contains the destination address. This can be network or node addresses or the entry for the default route (called `default`). The default route gives the address for all datagrams to which no other routes apply. default route
- The second column defines a router that the datagrams in question will be passed to. Valid entries at this point include node addresses or the "*" entry if the datagrams do not need to go to another router.
- The third column contains the network mask for the destination address. If the destination address is a single node, the value `255.255.255.255` appears. The default route has the value `0.0.0.0`.
- The fourth column contains flags describing the route in more detail, including:

  `U` The route is active ("up")

  `G` The route is a "gateway route", that is, it points to a router (rather than a network that is connected directly, as in "*").

`H` The route is a "host route", that is, the destination is a specific node. `G` and `H` are not mutually exclusive and may occur together.

- The fifth and sixth columns contain data which is important for dynamic routing: The "metric" in the fifth column gives the number of "hops" to the destination; it is not evaluated by the Linux kernel, but mostly useful for programs such as `gated`. The value in the sixth column is not used on Linux.
- The seventh column details how often the route has been used.
- Finally, the eighth column optionally contains the name of the interface that should be used to forward the datagrams. This mostly applies to routers that contain several interfaces, such as Ethernet adapters in different network segments or an Ethernet adapter and an ISDN adapter.

The example illustrates that, when `ifconfig` is used to assign an IP address, the kernel not only sets up the network mask and broadcast address, but also assigns at least one route—that which forwards all datagrams whose destination address is within the network that is directly connected to that interface.

A more complicated example for a routing table might look like

```
# route
Kernel IP Routentabelle
Ziel        Router      Genmask         Flags Metric Ref Use Iface
192.168.0.0 *           255.255.255.0   U     0      0   0   eth0
192.168.2.0 *           255.255.255.0   U     0      0   0   eth1
10.10.3.0   192.168.0.1 255.255.255.0   UG    0      0   0   eth0
112.22.3.4  *           255.255.255.255 UH    0      0   0   ppp0
default     112.22.3.4  0.0.0.0         UG    0      0   0   ppp0
```

The computer in this example is apparently a router containing three network interfaces. The first three routes are network routes, and according to their destination addresses datagrams will be routed either via `eth0`, `eth1`, or the router `192.168.0.1` (which may be reached via the first route). The fourth route is a "host route" enabling a point-to-point connection to an ISP's computer via the modem, `ppp0`. The fifth route is the corresponding default route forwarding all datagrams not addressed to the local networks `192.168.0.0/24`, `192.168.2.0/24`, or `10.10.3.0/24` to the world via the modem.

The `route` command serves not just to inspect but also to manipulate the routing table. To establish the example above (three local Ethernet segments and the PPP connection) the routing table must be constructed according to the following commands:

```
# route add -net 192.168.0.0 netmask 255.255.255.0 dev eth0
# route add -net 192.168.2.0 netmask 255.255.255.0 dev eth1
# route add -net 10.10.3.0 netmask 255.255.255.0 gw 192.168.0.1
# route add -host 112.22.3.4 dev ppp0
# route add default dev ppp0
```

The first two lines in the example are not strictly necessary, as the corresponding routes will be set up automatically when the interfaces are assigned their addresses.

More generally, `route` supports the following syntax to add and delete routes:

```
route add [-net|-host] ⟨destination⟩ [netmask ⟨netmask⟩]▷
 ◁      [gw ⟨gateway⟩] [[dev] ⟨interface⟩]
route del [-net|-host] ⟨destination⟩ [netmask ⟨netmask⟩]▷
 ◁      [gw ⟨gateway⟩] [[dev] ⟨interface⟩]
```

To add a route, you must specify the corresponding parameter (`add`); then you specify whether the route is a host or network route (`-host` or `-net`), followed by the destination. For a network route, a netmask must be specified either via the `netmask` ⟨*netmask*⟩ option or by appending a CIDR-style netmask to the destination address. For each route there must be either a router (⟨*gateway*⟩) or a destination interface covering the next hop.

The example routes could be deleted like this:

```
# route del -net 192.168.0.0 netmask 255.255.255.0
# route del -net 192.168.2.0 netmask 255.255.255.0
# route del -net 10.0.3.0 netmask 255.255.255.0
# route del -host 112.22.3.4
# route del default
```

To delete a route you need to specify the same parameters as when adding it—only the gateway or interface specifications may be left off. With duplicate destinations, e. g., the same destination network via two different interfaces, the newest (least recently inserted) route will be removed.

IP forwarding

If a station is to be used as a gateway between several networks (as in the example), the kernel should forward incoming IP datagrams not intended for the station itself according to the routing table. This feature, known as **IP forwarding**, is disabled by default. Its current state can be inspected and changed using the `/proc/sys/net/ipv4/ip_forward` (pseudo) file. It contains only one character—a zero (disabled) or one (enabled)—, and is usually written to using `echo`:

```
# cat /proc/sys/net/ipv4/ip_forward
0
# echo 1 > /proc/sys/net/ipv4/ip_forward
# cat /proc/sys/net/ipv4/ip_forward
1
```

Attention: Like the other command-based settings, this is lost when the computer is shut down. (Distributions have ways of making this setting permanent; for Debian GNU/Linux, include a line containing "`ip_forward=yes`" in the `/etc/network/options` file, for the Novell/SUSE distributions, put "`IP_FORWARD="yes"`" in `/etc/sysconfig/sysctl`. For Red Hat distributions, add a line containing

```
net.ipv4.ip_forward = 1
```

to the `/etc/sysctl.conf` file.)

4.1.4 Configuring Network Settings Using `ip`

The `ip` command can be used to set up both network interfaces and routes. It is the designated successor to the commands described above. Its syntax is roughly like

```
ip [⟨options⟩] ⟨object⟩ [⟨command⟩ [⟨parameters⟩]]
```

Possible ⟨*object*⟩s include `link` (parameters of a network interface), `addr` (IP address and other addresses of a network interface), and `route` (querying, adding, and deleting routes). There are specific commands for each object type.

If no command is given, the current settings are displayed according to the `list` and `show` commands. Other typical commands are `set` for `link` objects as well as `add` and `del` for `addr` and `route` objects.

Most commands require additional parameters, since if you want to assign an IP address using "ip addr add", you will have to specify what address you are talking about.

You can find out more about the requisite syntax by invoking ip using the help subcommand. Thus, "ip help" displays all possible objects, while "ip link help" shows all parameters pertaining to link objects including their syntax. Unfortunately the syntax is not always straightforward.

If you know your way around Cisco routers you will have noted a certain similarity to the Cisco ip command. This similarity is deliberate.

For example: If you wanted to assign an IP address to a network interface, you might use the following command:

```
# ip addr add local 192.168.2.1/24 dev eth0 brd +
```

Unlike ifconfig, ip *requires* the netmask and broadcast address to be present (even if specified indirectly using brd +). The local parameter is used to specify that an IP address for a local interface is forthcoming, but since this is the default parameter for "ip addr add", the local may also be left off. You can find out about default parameters from the ip(8) manual page.

Caution: Unlike ifconfig, after having been assigned an IP address, the interface is not yet activated. This must be done separately:

```
# ip addr show dev eth0
2: eth0: <BROADCAST,MULTICAST> mtu 1500 qdisc pfifo-fast qlen 100
        link/ether 00:a0:24:56:e3:72 brd ff:ff:ff:ff:ff:ff
        inet 192.168.2.1/24 brd 192.168.2.255 scope global eth0
# ip link set up dev eth0
# ip addr show dev eth0
2: eth0: <BROADCAST,MULTICAST,UP> mtu 1500 qdisc pfifo-fast qlen 100
        link/ether 00:a0:24:56:e3:72 brd ff:ff:ff:ff:ff:ff
        inet 192.168.2.1/24 brd 192.168.2.255 scope global eth0
        inet6 fe80::2a0:24ff:fe56:e372/64 scope link
```

You can also assign interface aliases using ip:

```
# ip addr add 192.168.0.222/24 dev eth0 brd + label eth0:0
```

It is useful to learn about ip, not only because it is the upcoming standard, but also because it is often more straightforward to use than the alternatives. For example, setting and deleting routes is easier than it is with route:

```
# ip route add 192.168.2.1 via 192.168.0.254
# ip route del 192.168.2.1
```

4.2 Persistent Network Configuration

One thing is for sure: Once you have figured out the correct network configuration for your system, you do not want to set it up over and over again. Unfortunately, though, the Linux kernel forgets all about it when it is shut down.

The various Linux distributions have solved this problem in different ways:

On Debian GNU/Linux and its derivatives, the network configuration is stored in the /etc/network/interfaces file. This file is mostly self-explanatory:

```
# cat /etc/network/interfaces
auto lo eth0

iface lo inet loopback

iface eth0 inet static                                    or "… inet dhcp"
  address 192.168.0.2
  netmask 255.255.255.0
  network 192.168.0.0
  broadcast 192.168.0.255
  up route add -net 10.10.3.0/24 gw 192.168.0.1
  down route del -net 10.10.3.0/24 gw 192.168.0.1
```

In the file there is an entry for each interface. Using the `ifup` and `ifdown` commands, the interfaces can be activated or deactivated individually or (with the `-a`) collectively; when the system is booted, the `/etc/init.d/networking` script takes care of initialising the interfaces. (Alternatively, `udev` will do it, provided the interfaces in question are listed in a line like "`allow-hotplug eth0`". This is mostly interesting for network adapters that are not always available, like USB-based Ethernet or UMTS adapters.)—Lines starting with `up` contain commands that will be run when the interface is being brought up (in the order they are in the file); conversely, lines startign with `down` give commands to be executed when the interface is being shut down. You can find more examples for the strange and wonderful things that are possible with the Debian network configuration mechanism by looking at `interfaces`(5) and the `/usr/share/doc/ifupdown/examples/network-interfaces.gz` file.

YaST, the central configuration tool for the Novell/SUSE distributions, naturally contains modules to configure network adapters. Settings made using YaST are commonly stored as variables in files below `/etc/sysconfig`, where init scripts or the `SuSEconfig` program can pick them up. Network configuration settings in particular are stored in the `/etc/sysconfig/network` directory, and you can even modify the files in there manually. There is a file called `ifcfg-`⟨*interface*⟩ for each interface (e. g., `ifcfg-eth0`) which contains the settings for that particular interface. This could look like

```
BOOTPROTO='static'                                  or dhcp (among others)
BROADCAST='192.168.0.255'
ETHTOOL_OPTIONS=''
IPADDR='192.168.0.2'
MTU=''
NAME='79c970 [PCnet32 LANCE]'                                Name inside YaST
                                                          (VMware says hello)
NETMASK='255.255.255.0'                                        Or PREFIXLEN=24
NETWORK='192.168.0.0'
REMOTE_IPADDR=''                                          Remote peer with PPP
STARTMODE='auto'                                       or manual, hotplug, …
USERCONTROL='no'
```

(a more detailed explanation can be found in `ifcfg`(5)). More general network settings go into `/etc/sysconfig/network/config`.—The SUSE distributions, too, support commands called `ifup` and `ifdown`, whose function, however, is subtly different from those on Debian GNU/Linux. At least the basic invocations like "`ifup eth0`" are the same, but even "`ifup -a`" doesn't work—to start or stop all interfaces, you must call "`rcnetwork start`" or "`rcnetwork stop`". (As a consolation prize, "`rcnetwork start eth0`" also works.) Typically for SUSE, `rcnetwork` is nothing but a symbolic link to the `/etc/init.d/network` init script.

On the Novell/SUSE distributions you can configure routes using the `/etc/sysconfig/network/routes` file. The content of this file (shown here to match the example above) resembles the output of the `route` command:

```
# cat /etc/sysconfig/network/routes
10.10.3.0       192.168.0.1     255.255.255.0   eth0
112.22.3.4      0.0.0.0         255.255.255.255 ppp0
default         112.22.3.4      -               -
```

If no gateway is to be used, the correct value is "`0.0.0.0`", unset network masks or interface names are represented by a "`-`" character. Routes, too, are set by means of the "`rcnetwork restart`" command. As far as the last two routes in the example are concerned, it turns out that point-to-point routes for dialup connections are usually set up dynamically by the daemons in question (such as `pppd`).—If you want to define routes for specific interfaces, you can also put the lines in question into a file called `ifroute-`⟨*interface*⟩ (such as `ifroute-eth0`) rather than the `routes` file. The fourth column (the one containing the interface names) will then be replaced by the interface name if you leave it blank in the file.

Like SUSE, Fedora and the other Red Hat distributions use files inside a `/etc/sysconfig` directory to set various variables. As on SUSE, there are files like `ifcfg-eth0` for the configuration of each interface, but they are stored in a directory called `/etc/sysconfig/network-scripts`. However, SUSE files are not directly transferable, since their internal structure differs from the Red Hat files. On Red Hat, you might implement our example configuration for `eth0` as follows: The `/etc/sysconfig/network-scripts/ifcg-eth0` file contains

```
DEVICE=eth0
BOOTPROTO=none
ONBOOT=yes
NETWORK=192.168.0.0
NETMASK=255.255.255.0
IPADDR=192.168.0.2
USERCTL=no
```

The `ifup` and `ifdown` commands exist on Fedora, too, but as on SUSE you can only bring up or shut down one interface at any one time.

On Red Hat, static routes can be placed in a file inside `/etc/sysconfig/network-scripts` called `route-`⟨*interface*⟩ (for example, `route-eth0`). In this case, the format is like

```
ADDRESS0=10.10.3.0
NETMASK0=255.255.255.0
GATEWAY0=192.168.0.1
```

(additional routes use `ADDRESS1`, `NETMASK1`, …, `ADDRESS2` and so on). There is an older file format according to which every line of the file is simply appended to "`ip route add`", which lends itself to lines like

```
10.10.3.0/24 via 192.168.0.1
```

Finally, you can define static routes in `/etc/sysconfig/static-routes` without having to refer to individual interfaces. Lines in this file are only taken into account if they start with the `any` keyword; the remainder of the line is appended to "`route add -`" (Consistency? We don't need no steenkin' consistency!), such that a line like

```
any net 10.10.3.0 netmask 255.255.255.0 gw 192.168.0.1
```

executes the

```
route add -net 10.10.3.0 netmask 255.255.255.0 gw 192.168.0.1
```

command.

4.3 DHCP

DHCP, the "Dynamic Host Configuration Protocol" is used to save you as the administrator from having to define network parameters on every single host in the network. Instead, a Linux machine fetches its network parameters—apart from its IP address and accessories, typically the address of a default router and one or more DNS servers—from a remote DHCP server when the network adapter is brought up.

The prerequisite for this to work is, of course, an existing DHCP server. Explaining the installation and maintenance of a DHCP server is, sadly, beyond the scope of this manual, but if you are using one of the common DSL routers for Internet access or, at work, can avail yourself of the services of a competent IT department, this isn't really your problem—the required functionality will be readily available and/or can be straightforwardly activated.

Most Linux distributions make it very easy to use DHCP for configuration:

On Debian GNU/Linux or Ubuntu, simply replace, in `/etc/network/interfaces`, the line

```
iface eth0 inet static
```

and any following lines containing address or routing information by the line

```
iface eth0 inet dhcp
```

This causes the computer to obtain its address, network mask, and default route from the DHCP server. You can still use `up` and `down` to execute commands once the link has been brought up or before it is torn down.

On the Novell/SUSE distributions, change the

```
BOOTPROTO='static'
```

parameter in the file containing the configuration for the interface in question (`ifcfg-eth0` or whatever) to

```
BOOTPROTO='dhcp'
```

You may leave the `BROADCAST`, `IPADDR`, `NETMASK`, and `NETWORK` settings empty.

To use DHCP on Fedora and the other Red Hat distributions, change the configuration file of the interface to read

```
BOOTPROTO=none
```

instead of

```
BOOTPROTO=dhcp
```

You can simply omit the address parameters.

Generally, the distribution-specific network configuration methods support various other options such as VLAN (several "virtual" networks on the same wire that cannot see one another), encryption, or bonding (several network adapters work in parallel, for more capacity and/or fault tolerance). Another important use case is for a mobile computer to take part in several networks, such as at home and at the office. The options actually offered differ greatly between distributions and cannot be discussed here in detail.

4.4 IPv6 Configuration

SLAAC

To integrate your computer into an IPv6 network, in the ideal case you need to do nothing at all: The mechanism of "stateless address autoconfiguration" (SLAAC) makes it possible for everything to take place automatically. With IPv6, SLAAC plays approximately the role that DHCP would in IPv4, at least for simple applications.

Procedure

If a new IPv6 network interface is activated, the station first generates the appropriate link-local address. This assumes the `fe80::/64` prefix and derives the station part from the MAC address of the interface in question[1]. After that, the station sends a link-local "router solicitation" (RS) on that interface to the multicast address, `ff02::2`, which refers to all routers in the subnet. This causes the router (or routers) on the physical network of the interface to emit "router advertisements" (RA) containing the prefixes they are routing. On that basis, the station constructs additional (possibly globally visible) addresses for the interface.—RS and RA are part of the "Neighbor Discovery Protocol" (NDP), which in turn belongs to ICMPv6, the IPv6 counterpart to ICMP. RAs and the IPv6 addresses derived from them only remain valid for a certain time if they are not refreshed. Hence, routers send unsolicited RAs every so often; the RS only serves to avoid having to wait for the next unsolicited RA when a new interface is brought up, by making it possible to obtain the necessary information at once.

Advantages

The advantage of this approach is that it does not require explicit configuration within a DHCP server. It is also straightforward to obtain redundancy by configuring several routers within the same subnet. In addition, routers do not need to remember (as they would with DHCP) which station is currently using which IP address (hence, "stateless"). All of this does not mean, however, that in IPv6 you can do without DHCP altogether (there is DHCPv6), since there are important bits of information that can't be obtained via SLAAC (think "DNS server"—although there is a new, not yet widely supported, standard to fix that).

Querying addresses

You can check the addresses the system has assigned to an interface:

```
# ip addr show eth0
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500▷
 ◁ qdisc pfifo_fast state UP qlen 1000
  link/ether 70:5a:b6:9c:40:6a brd ff:ff:ff:ff:ff:ff
  inet 192.168.178.130/24 brd 192.168.178.255 scope global eth0
  inet6 2001:db8:56ee:0:725a:b6ff:fe9c:406a/64 scope global dynamic
     valid_lft 6696sec preferred_lft 3096sec
  inet6 fe80::725a:b6ff:fe9c:406a/64 scope link
     valid_lft forever preferred_lft forever
```

[1]The method for this is as follows: Consider the MAC address, *mn*:*op*:*qr*:*st*:*uv*:*wx*. The 3rd bit of *n* (counting from the left), which in a MAC address is always zero, is set to one (we shall call the result *n*′), and the station address is then *mn*′*op*:*qr*`ff`:`fe`*st*:*uvwx*. The MAC address `70:5a:b6:9c:40:6a`, for example, becomes the station address `725a:b6ff:fe9c:406a`.

This contains both the link-local address ("scope link", starting with fe80::) and a globally visible address ("scope global dynamic", beginning with 2001:) which the interface has obtained via SLAAC. If you look closely, you can also correlate the MAC address (in the link/ether line) with the station parts of the IPv6 addresses.

privacy

Incidentally, the station parts of your IPv6 addresses, which are derived from your MAC addresses, are a potential problem for your privacy. If you always use the same source address to surf the 'net, it is trivial to correlate your activities (web sites visited and so on) with that address. Even if, as people will say, you have nothing to hide, nobody can fault you for the queasy feeling this might give you as a matter of principle. One way of ameliorating the problem are the "privacy extensions", which add a random, otherwise unused, station part for outgoing traffic and pick a new one every so often. The privacy extensions can be activated for an interface (here eth0) using sysctl:

```
# sysctl -w net.ipv6.conf.eth0.use_tempaddr=2
# ip link set dev eth0 down
# ip link set dev eth0 up
```

To make this setting permanent, enter it in /etc/sysctl.conf.

Manual configuration

Finally, it is still possible to assign IP adresses manually. You can do this either using ifconfig:

```
# ifconfig eth0 inet6 add 2001:db8:abcd::1/64
```

or using ip:

```
# ip addr add 2001:db8:abcd::1/64 dev eth0
```

How to make this configuration permanent will depend on your distribution; the techniques for this largely correspond to those discussed in Section 4.2.

4.5 Name Resolution and DNS

The DNS or "Domain Name System" is one of the fundamental ingredients for the scalability of the Internet. Its job is to assign human-readable names to network nodes and to find the corresponding IP addresses (or vice versa). It does this by means of a worldwide distributed "database" of DNS servers.

By now, DNS takes care of many other jobs, from figuring out the mail servers for a domain to helping with spam avoidance.

resolver

Programs on a Linux machine usually do not talk to the DNS directly, but avail themselves of the services of a "resolver". This is usually part of the C runtime library. The central configuration file for the resolver is called /etc/resolv.conf. It is used, e. g., to define the DNS servers that the resolver is to consult. There are five main directives:

domain ⟨*Name*⟩ (local domain) This is the domain name that the resolver tries to append to incomplete names (typically, those that do not contain a period).

Exactly which names are considered incomplete is governed by the ndots option (see table 4.1).

search ⟨*Domain*$_1$⟩ ⟨*Domain*$_2$⟩ … (search list) As an alternative to a single entry using domain, you can specify a list of several domain names to be appended to incomplete names. The entries in the list are separated by spaces. At first the resolver tries the unchanged name. If this fails, the list entries are appended in order and these names are tried. domain and search are mutually exclusive; if both occur in a configuration, whichever line is last in the file wins.

Table 4.1: Options within `/etc/resolv.conf`

Option	Result
`debug`	Regular log messages are output to `stdout` (commonly unimplemented).
`ndots` ⟨*n*⟩	The minimum number of dots within a name which will cause the resolver to perform a direct query without accessing the search list.
`attempts` ⟨*n*⟩	The number of times the resolver will query a server before giving up. The maximum value is 5.
`timeout` ⟨*n*⟩	The initial time out for query attempts in seconds. The maximum value is 30.
`rotate`	Not only the first, but all specified servers will be queried in rotation.
`no-check-names`	Deactivates the standard check whether returned host names only contain allowable characters.

```
nameserver 192.168.10.1
nameserver 192.168.0.99
search     foo.example.com bar.example.com example.com
```

Figure 4.1: `/etc/resolv.conf` example

`nameserver` ⟨*IP address*⟩ (local DNS server) The local resolver will consult the DNS server given here. You may define up to three name servers in separate `nameserver` directives, which will be consulted in sequence if required.

`sortlist` ⟨*IP address*⟩[/⟨*network mask*⟩] (sort order) If several addresses are returned for a name, the one matching the specification here will be preferred. In the sort list there is room for up to ten entries.

`options` ⟨*Option*⟩ (options) This is used for specific resolver settings which are detailed (together with their default values) in table 4.1. In practice these are seldom, if ever, changed.

You can see a typical `/etc/resolv.conf` file in Figure 4.1.

An alternative to DNS is the "local" resolution of host names and IP addresses by means of the `/etc/hosts` file. As the sole method for name resolution this is only of interest for small networks that are not connected to the Internet, but we should mention it nevertheless—if you only need to deal with a few computers, it is conceivably more straightforward to simply configure the DNS client side and assign names and addresses to your own computers using `/etc/hosts`. You do have to take care that the file is the same on all your computers.

For small networks we recommend the `dnsmasq` program, which makes the content of an `/etc/hosts` file available via DNS, while passing all other DNS queries on to the "real" DNS. It even works as a DHCP server on the side.

The content of the `/etc/hosts` file is plain ASCII text which may contain line-based entries as well as comments starting with "`#`". These entries contain an IP address in the first column and the "fully qualified domain name" (FQDN) of a host in the second. It is also permissible to add more names on the same line. Spaces or tabs can be used to separate columns. Figure 4.2 shows the content of a typical `/etc/hosts` file.

When the Internet was new—until the early 1980s—there was essentially one big `/etc/hosts` file for everybody, and domains hadn't been invented yet. At that time the Internet consisted of fewer nodes (thousands instead of

```
#
# hosts         This file describes a number of hostname-to-address
#               mappings for the TCP/IP subsystem.  It is mostly
#               used at boot time, when no name servers are running.
#               On small systems, this file can be used instead of a
#               "named" name server.
# Syntax:
#
# IP-Address  Full-Qualified-Hostname  Short-Hostname
#
# special IPv6 addresses

127.0.0.1       localhost
192.168.0.99    linux.example.com  linux
```

Figure 4.2: The `/etc/hosts` file (SUSE)

gazillions), but the maintenance and distribution of current versions of the file came to be a growing problem. Hence, DNS.

name resolution services

The exact mechanisms the C library uses for name resolution are controlled by means of a file called `/etc/nsswitch.conf`. This determines, for example, which name resolution services are used in which order. In addition there are rules for the resolution of user names, groups, etc., which will not concern us at this point. You can refer to `nsswitch.conf`(5) for a detailed description of its syntax and function.

The part of `/etc/nsswitch.conf` pertinent to host name resolution could look like:

```
hosts: files dns
```

This means that the C library will try to resolve host names based on the local files (namely, `/etc/hosts`). Only if this fails will it query DNS.

Commands in this Chapter

dnsmasq	A lightweight DHCP and caching DNS server for small installations	`dnsmasq`(8)	79
ifconfig	Configures network interfaces	`ifconfig`(8)	68
ifdown	Shuts down a network interface (Debian)	`ifdown`(8)	74
ifup	Starts up a network interface (Debian)	`ifup`(8)	74
ip	Manages network interfaces and routing	`ip`(8)	72
route	Manages the Linux kernel's static routing table	`route`(8)	70

Summary

- Nowadays the Linux kernel loads networking drivers on demand using the `udev` infrastructure.
- The `ifconfig` command is used for low-level configuration of network interface parameters. You can use it to configure the loopback interface and to assign alias names for interfaces.
- Routes specify how IP datagrams should be forwarded to their destinations.
- The `route` command is used to configure routes.
- The `ip` command is a convenient replacement for `ifconfig` and `route`.
- The various Linux distributions offer different methods of persistent network configuration
- DHCP lets Linux hosts obtain networking parameters dynamically from a central server.
- Common name resolution mechanisms are based on DNS or local configuration files.
- The order of name resolution is specified in the `/etc/nsswitch.conf` file.

5

Network Troubleshooting

Contents

Goals

- Knowing strategies for network troubleshooting
- Being able to use tools like `ping`, `traceroute`, and `netstat` for problem analysis
- Being able to fix simple network configuration errors

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 3)
- Knowledge about Linux network configuration (chapter 4)

5.1 Introduction

System administrators love this: No sooner have you settled in comfortably in front of your computer with a nice cup of coffee or tea, looking forward to perusing the newest news on LWN.net, that a noxious person stands in the doorway: "I can't get on the network!" Alas for the peace and quiet. But what to do?

Computer networking is a difficult topic, and therefore you should not be surprised when All Sorts Of Things Go Wrong. In this chapter we show you the most important tools and strategies to find and iron out problems.

5.2 Local Problems

The first order of the day is to convince yourself that the network adapter is present and recognised. (For starters, do take a discreet look at the back of the computer to ascertain that the cable is still sitting in the correct socket, and that the ladies and gentlemen of the cleaning squad have not played "creative reconfiguration".)

Check the output of "`ifconfig -a`". With this parameter, the program gives you an overview of *all* network interfaces inside the computer, even the ones that are not currently configured. At least `lo` and `eth0` (if the computer is networked using Ethernet) should be visible. If this isn't the case, you have already found the first problem: Possibly there is something wrong with the driver, or the adapter is not being recognised.

If, instead of `eth0`, you only see something like `eth1`, it is possible that the network card was replaced, and `udev` assigned a new interface name to the card on account of its new MAC address. This shouldn't really happen with network cards that are reasonably firmly attached to the computer (or, if it does, it should happen because you, being the administrator, did it yourself), but perhaps your colleagues have surreptitiously swapped their PC(MCIA) network adapters or USB-based UMTS dongles. The remedy is to delete the line referring to the old device from the `/etc/udev/rules.d/70-persistent-net.rules` (or some such), and to correct the interface name in the line referring to the new device. Restart `udev` afterwards.

If the output of `ifconfig` shows nothing remotely resembling your network adapter, then check, using `lsmod`, whether the driver module in question was loaded at all. If you do not know what the driver module in question is to begin with, you can search the output of "`lspci -k`" for the stanza pertaining to your network adapter. This might look like

```
02.00.0 Ethernet controller: Broadcom Corporation NetXtreme▷
 ◁ BCM5751 Gigabit Ethernet PCI Express (rev 01)
       Kernel driver in use: tg3
       Kernel modules: tg3
```

In this case you should ascertain that the `tg3` module has been loaded.

5.3 Checking Connectivity With `ping`

If the output of `ifconfig` shows the interface and the parameters displayed with it look reasonable, too (check the IP address, the network mask—very important—, and the broadcast address, in particular), then it is time for some connectivity tests. The simplest tool for this is a program called `ping`, which takes an IP address (or a DNS name) and tries to send an ICMP `ECHO REQUEST` datagram to the host in question. That host should reply with an ICMP `ECHO REPLY` datagram, which `ping` receives and reports.

First, you should check whether the computer can talk to itself:

```
# ping 127.0.0.1
PING 127.0.0.1 (127.0.0.1) 56(84) bytes of data.
64 bytes from 127.0.0.1: icmp_seq=1 ttl=64 time=0.039 ms
64 bytes from 127.0.0.1: icmp_seq=2 ttl=64 time=0.039 ms
64 bytes from 127.0.0.1: icmp_seq=3 ttl=64 time=0.032 ms
64 bytes from 127.0.0.1: icmp_seq=4 ttl=64 time=0.040 ms
                                          Interrupt using Ctrl+c …
--- 127.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 2997ms
rtt min/avg/max/mdev = 0.032/0.037/0.040/0.006 ms
```

The output tells you that the "other host" (in this case merely the loopback interface on 127.0.0.1) can be reached reliably (no packets were lost).

What about "56(84) bytes of data"? Easy: An IP datagram header without options is 20 bytes long. Added to that is the header of an ICMP ECHO REQUEST datagram at 8 bytes. This explains the difference between 56 and 84. The magic number 56 results from the fact that ping normally ensures that exactly 64 bytes of payload data are transmitted inside each IP datagram, namely the 8-byte ICMP header and 56 bytes of "padding". If "enough" padding is available, namely at least the size of a struct timeval in C (eight bytes or so), ping uses the start of the padding for a timestamp to measure the packet round-trip time.

The next step should be to "ping" your network card interface. The output there should look approximately like the other one.

If you have arrived here without running into error messages, chances are that the basic networking functionality of your computer is working. The remaining possible sources of trouble rest elsewhere in the network or else farther up your computer's protocol stack.

The next ping goes to the default gateway (or another host on the local network). If this does not work at all, the network mask might be set up wrong (possibly on the other host!?). Other possibilities include hardware trouble, such as a kink in the cable or a broken plug—which would also explain a connection that sometimes works and sometimes doesn't.

The common rectangular plugs for Ethernet cables are kept in place using a plastic thingamajig which likes to break off, in which case contact is often flaky to impossible.

"Free-flying" cables are prone to accidents with sharp implements and do not like being run over with office chairs. If you suspect that a cable is faulty you can corroborate or deny that by exchanging it for a known-working one or testing it using an Ethernet cable tester. Of course cables should really be strung inside a proper conduit, on top of the false ceiling, or below the raised floor.

Now you can continue pinging hosts outside your local network. If this works this is a good sign; if you get no answers at all, you might be dealing with a routing problem or else an overzealous firewall that filters ICMP traffic à la ping at least partly (which it shouldn't, but some people do throw out the baby with the bathwater).

ping supports a great number of options that extend the testing possibilities or change the way the program works. The most important options for the purposes of testing are probably -f (flood ping) for quickly checking out intermittent network problems, and -s to specify a size for the datagrams.

Table 5.1: Important `ping` options

Option	Meaning
`-a`	Audible pings
`-b` ⟨*network address*⟩	Broadcast ping
`-c` ⟨*count*⟩	Number of datagrams to be sent (`ping` will exit afterwards)
`-f`	"Flood ping": A dot is output for every `ECHO REQUEST` datagram sent, and a backspace character for every `ECHO REPLY` received. The result is a row of dots that tells you how many datagrams have been dropped during transmission. If you haven't simultaneously specified the `-i` option, `ping` transmits at least 100 datagrams per second (more if the network can handle more). Only `root` may do that, though; normal users are limited to a minimum interval of 0.2 seconds.
`-i` ⟨*time*⟩	Waits for ⟨*time*⟩ seconds between sending two datagrams. The default is one second, except when flood pinging as `root`.
`-I` ⟨*sender*⟩	Sets the sender address for the datagrams. The ⟨*sender*⟩ may be an IP address or the name of an interface (in which case the IP address of that interface will be used).
`-n`	Display without DNS name resolution
`-s` ⟨*size*⟩	Determines the size of the "padding" in bytes; the default value is 56. Sometimes there are problems with very large datagrams that must be fragmented, and `ping` can help diagnose these by means of this option. (Long ago it used to be possible to crash computers using very large `ping` datagrams—the dreaded "ping of death".)

-a can come in useful if you have to creep around under a table to find a loose cable.

The corresponding command to test IPv6 is called ping6 and is invoked in a manner very similar to that of ping. You just need to take care to specify the interface you want to use. Watch for the "%eth0" at the end of the IPv6 address: ping6

```
$ ping6 fe80::224:feff:fee4:1aa1%eth0
PING fe80::224:feff:fee4:1aa1%eth0(fe80::224:feff:fee4:1aa1)▷
 ◁ 56 data bytes
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=1 ttl=64 time=3.65 ms
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=2 ttl=64 time=4.30 ms
◁◁◁◁◁
```

With link-local addresses, in particular, it is possible for several interfaces to use the same address, and ambiguities must thus be avoided. Other than that, the options of ping6 correspond for the most part to those of ping.

Exercises

5.1 [!2] Compare the packet round-trip times of a ping to 127.0.0.1 to those of a ping to a remote host (another computer on the LAN or the default gateway/DSL router/…).

5.2 [2] How long does your system take to send a million datagrams to itself in flood-ping mode?

5.3 [2] (If your local network supports IPv6.) Use ping6 to check the connectivity to any IPv6 routers on your LAN (multicast address ff02::2). What answers do you receive?

5.4 Checking Routing Using traceroute And tracepath

If you cannot reach a station outside your local network using ping, this could be due to a routing problem. Programs like traceroute and tracepath help you pinpoint these problems.

The typical case is that you can in fact reach all hosts on the local network but none beyond. The usual suspects are your default route on the one hand and the host the default route points to on the other. Make sure that the output of route (or "ip route list") shows the correct default route. If a ping to the default gateway works but a ping to a host beyond the default gateway doesn't, then something may be wrong with the gateway. Check whether another host can reach other hosts beyond the gateway, and whether your host is reachable *from* the gateway. (Also keep in mind that the default router may be running a packet filter that blocks ICMP.)

A different sort of problem can arise if you are not connected directly to the router that in turn connects you to the internet, but must go across a different router. In that case it is possible that you can send ping datagrams to the Internet router, but that its replies cannot reach you because it does not have a route that will direct traffic for "your" network to the intermediate router.

traceroute is basically an extended form of ping. This does not merely check a remote node for signs of life, but displays the route that datagrams take through the network. It keeps track of the routers the datagram passes through and the quality of the connection to the routers in question.

Unlike `ping`, this is not based on ICMP, but (traditionally) on UDP. `traceroute` sends three UDP datagrams to arbitrary ports on the destination node (one hopes that not all three of these have servers listening on them). The first three datagrams have a TTL of 1, the next three a TTL of 2, and so on. The first router on the way to the destination decrements the TTL by 1. For the first round of datagrams, which only had a TTL of 1 in the first place, this means curtains—they are dropped, and the sender gets an ICMP `TIME EXCEEDED` message, which (being an IP datagram) contains the router's IP address. The second three datagrams are dropped by the second router and so on. That way you can follow the exact route of the datagrams towards the destination. Of course, the destination node itself doesn't send `TIME EXCEEDED` but `PORT UNREACHABLE`, so `traceroute` can notice that it is done.

The procedure looks roughly like this:

```
$ traceroute www.linupfront.de
traceroute to www.linupfront.de (31.24.175.68), 30 hops max,▷
 ◁ 60 byte packets
 1  fritz.box (192.168.178.1)  5.959 ms  5.952 ms  5.944 ms
 2  217.0.119.34 (217.0.119.34)  28.889 ms  30.625 ms  32.575 ms
 3  87.186.202.242 (87.186.202.242)  35.163 ms  36.961 ms  38.551 ms
 4  217.239.48.134 (217.239.48.134)  41.413 ms  43.002 ms  44.908 ms
 5  xe-11-0-1.fra29.ip4.gtt.net (141.136.101.233)  46.769 ms  ▷
 ◁ 49.231 ms  51.282 ms
 6  xe-8-1-2.fra21.ip4.gtt.net (141.136.110.101)  53.412 ms ▷
 ◁ xe-0-2-3.fra21.ip4.gtt.net (89.149.129.37)  49.198 ms ▷
 ◁ xe-8-1-2.fra21.ip4.gtt.net (141.136.110.101)  52.314 ms
 7  21cloud-gw.ip4.gtt.net (77.67.76.90)  52.547 ms  30.822 ms▷
 ◁  30.018 ms
 8  s0a.linupfront.de (31.24.175.68)  38.127 ms  38.406 ms  38.402 ms
```

The output consists of several numbered lines. One line corresponds to a group of three datagrams. It shows the node sending the `TIME EXCEEDED` message as well as the transmission time of the three datagrams.

Asterisks in the output mean that there was no answer for one of the datagrams within (usually) five seconds. That happens.

Maybe you are wondering why the output finishes with `s0a.linupfront.de` even though we wanted to reach `www.linupfront.de`. This is not a problem; the `www.linupfront.de` web site—together with a few other useful services—is hosted on a machine we call `s0a.linupfront.de`, and that happens to be the answer that DNS provides if you ask it for the name belonging to the IP address, `31.24.175.68`.

The fact that IP networks use packet switching implies, theoretically, that the output of `traceroute` is just a momentary snapshot. If you try it again, the new datagrams might in principle take a completely different route to the destination. However, this does not occur very often in practice.

The traditional technique based on UDP datagrams doesn't work in all cases today, as there are overzealous firewalls that drop datagrams addressed to "unlikely" UDP ports. You can use the `-I` option to get `traceroute` to use ICMP instead of UDP (it then works essentially like `ping`). If you need to deal with an especially overzealous firewall that filters ICMP as well, you can use a TCP-based technique by means of the `-T` option (short for "`-M tcp`"). This tries to address port 80 on the destination node and recommends itself particularly if the destination node is a web server. (You can request a different port by means of the `-p` option.)

The "TCP-based technique" does not actually open a connection to the destination node and thus stays invisible to application programs there. `traceroute` also offers some other methods.

You can use traceroute with IPv6 by giving the -6 option. A convenient abbreviation for this is traceroute6. Everything else stays the same. traceroute6

tracepath

The tracepath program does basically the same thing as traceroute, but does not offer most of the tricky options and can be invoked by regular users (without root privileges). In addition, it determines the "path MTU" (of which more anon). Here is some exemplary output produced by tracepath:

```
$ tracepath www.linupfront.de
 1?: [LOCALHOST]                         pmtu 1500
 1:  fritz.box                            13.808ms
 1:  fritz.box                             5.767ms
 2:  p5B0FFBB4.dip0.t-ipconnect.de        11.485ms pmtu 1492
 2:  217.0.119.34                         48.297ms
 3:  87.186.202.242                       46.817ms asymm  4
 4:  217.239.48.134                       48.607ms asymm  5
 5:  xe-11-0-1.fra29.ip4.gtt.net          47.635ms
 6:  xe-7-1-0.fra21.ip4.gtt.net           49.070ms asymm  5
 7:  21cloud-gw.ip4.gtt.net               48.792ms asymm  6
 8:  s0a.linupfront.de                    57.063ms reached
     Resume: pmtu 1492 hops 8 back 7
```

Just like traceroute, tracepath outputs the addresses of all routers on the route to the destination node. The remainder of the line shows the time the datagrams took as well as additional iinformation; "asymm 5", for example, means that the router's answer took 5 hops instead of the 4 hops of the request, but this information isn't always reliable.

This brings us to the "path MTU" problem, which can be explained as follows: Fundamentally, IP allows datagrams of up to 65535 bytes, but not every medium access scheme can actually transmit these datagrams in one piece. Ethernet, for example, allows frames of at most 1518 bytes, including 14 bytes for the frame header and 4 bytes for a checksum at the end of the frame. This means that an Ethernet frame can carry at most 1500 bytes of payload, and if the IP layer above wants to transmit a larger datagram, that datagram must be "fragmented", that is, split across several frames. We say that the "maximum transmission unit", or MTU, for Ethernet is 1500.

Of course the IP implementation of the sending node cannot foresee which medium access schemes will be used on the way to the destination and whether fragmentation will be necessary (and, if so, how large the fragments may be). This only comes out when data are actually transmitted. Routers should *really* be handling this transparently—if a datagram arrives at one end that is too big to be sent out in its entirety at the other end, the router could fragment it—, but router manufacturers like to shirk this resource-intensive work. Instead, datagrams are typically sent with the "don't fragment" bit in the header switched on, which forbids other routers to break them up further. If such a datagram arrives at a point where it is too big for the next hop, the router in question uses ICMP to send a "destination unreachable; fragmentation needed but forbidden; MTU would be *n*" message. In this case the sending node can try again using smaller fragments. This method is called "path MTU discovery".

The whole thing can still go gloriously wrong, namely if an overzealous firewall along the way blocks ICMP traffic. In this case the error messages concerning the required MTU never reach the sender of the datagrams, who consequently hasn't the faintest idea of what is going on. In practice this leads to web pages not being displayed correctly, and/or connections that simply "hang". The problem arises most conspicuously where "Deutsche Telekom"-style ADSL is in use, since that uses a protocol called "PPP over Ethernet" (PPPoE), which subtracts 8 bytes from the usual 1500-byte Ethernet MTU for management purposes. The problems normally disappear if you set the MTU for the interface in question to 1492 manually. The remote node then adheres to that value.

On Debian GNU/Linux (and Ubuntu) you can set the MTU for a statically configured interface by adding a `mtu` clause to the interface definition in `/etc/network/interfaces`:

```
iface eth0 inet static
    <<<<<
    mtu 1492
    <<<<<
```

This value should then become effective the next time the interface is started.

If your interface is configured via DHCP and the DHCP server sends the wrong MTU (which might happen), then you can remove the `interface-mtu` clause from the `request` entry in the `/etc/dhcp/dhclient.conf` file. This will make Linux default to the standard value of 1500 during the next DHCP negotiation. You can specify a different value explicitly using

```
iface eth0 inet dhcp
    <<<<<
    post-up /sbin/ifconfig eth0 mtu 1492
    <<<<<
```

The alternative command

```
iface eth0 inet dhcp
    <<<<<
    post-up /sbin/ip link set dev eth0 mtu 1492
    <<<<<
```

also works.

On the SUSE distributions you can set the MTU in the `ifcfg-` file corresponding to the interface in question (there is an `MTU=` line). Alternatively you can use the "`/etc/sysconfig` editor" offered by YaST, under "Hardware/Network". You then need to restart the network interface manually (using `ifdown`/`ifup`) or reboot the computer.

Like SUSE, the Red Hat distributions allow an MTU setting in the `ifcfg-` file of the interface in question. Here, too, you need to restart the interface to make the new setting effective.

If you're using IPv6: `tracepath6` is to `tracepath` what `traceroute6` is to `traceroute`.

5.5 Checking Services With `netstat` And `nmap`

If you would like to run a service but client hosts cannot connect to it, being rejected with error messages like

```
Unable to connect to remote host: Connection refused
```

you should ensure that the service actually "listens" for connections as it should. You can do this, for example, with the `netstat` program:

```
$ netstat -tul
Active Internet connections (only servers)
Proto Recv-Q Send-Q Local Address       Foreign Address  State
tcp        0      0 red.example.com:www *:*              LISTEN
tcp        0      0 red.example.com:ftp *:*              LISTEN
tcp        0      0 red.example.com:ssh *:*              LISTEN
```

The `-l` option causes `netstat` to display "listening" programs only. With the `-t` and `-u` options you can confine `netstat`'s output to TCP-based and UDP-based services, respectively.

In the output, the columns have the following meanings:

`Proto` The protocol (`tcp`, `udp`, `raw`, …) used by the socket.

`Recv-Q` The number of bytes of data that have been received but not been picked up by the application program.

`Send-Q` The number of bytes sent out that have not yet been acknowledged by the remote host.

`Local Address` Local address and port number of the socket. An asterisk ("*") in this place for "listening" sockets means they are listening on all available addresses, e. g., on `127.0.0.1` *and* the IP address of the Ethernet card.

`Foreign Address` The address and port number of the socket on the remote host.

`State` The state of the socket. `raw` sockets do not have states and `udp` sockets usually not either. States defined for `tcp` sockets include the following:

- **`ESTABLISHED`** A connection is established.
- **`SYN_SENT`** The socket tries to establish a connection and has sent the first packet of the three-way handshake, but not yet received a reply.
- **`SYN_RECV`** The socket (a "listening" one) has received and acknowledged a connection request.
- **`FIN_WAIT1`** The socket is closed, the connection is in the process of being torn down.
- **`FIN_WAIT2`** The connection is torn down and the socket waits for confirmation from the remote host.
- **`TIME_WAIT`** After the connection has been torn down, the socket waits to process packets that may still remain in the network.
- **`CLOSE`** The socket is not being used.
- **`CLOSE_WAIT`** The remote host has closed the connection and waits for the local host to close it too.
- **`LISTEN`** The socket "listens" for incoming connections. Such sockets are only displayed if you have specified the `-l` or `-a` options.

Without `-t` or `-u`, `netstat`, in addition to its TCP and UDP listings, outputs information about active Unix domain sockets. These are largely uninteresting.

If you leave off the `-l` option, you get a list of active network connections instead (those where your computer operates as a server as well as those where it acts as the client).

If your service does not show up in the output of "`netstat -tul`", this indicates that the program in question isn't running. If the service does occur in the list, one possibility is that clients are rejected by a firewall configuration before they even reach it. On the other hand, it is possible that the port in question is blocked by another program which for some reason does not work correctly. In this case you can use "`netstat -tulp`" to display the process ID and name of the the program serving the port. This takes `root` privileges, however.

`netstat` assumes that you have at least shell access, if not `root` privileges, on the computer where you want to execute the program. But what about checking "from outside" which ports are available on a host? There are solutions for this, too. The `nmap` program is a **port scanner** which checks for open, filtered, and unused TCP and UDP ports on a computer over the network. Of course the "computer" can just as well be a firewall infrastructure, thus `nmap` can help you uncover gaps in your security strategy.

port scanner

nmap is not automatically part of a Linux installation. You will probably have to install it manually.

The scanning of computers that are not part of your immediate jurisdiction can be a crime! (In some places—like Germany—, even *owning* "hacker" tools like nmap can get you in trouble if you are unlucky and/or make some bad moves.) Therefore do restrict yourself to computers where it is abundantly clear that you are allowed to use nmap. For additional security, get your client or sufficiently exalted boss to sign off on it in writing.

In the simplest case you give nmap the name or IP address of the computer to be examined (be prepared for a certain delay):

```
# nmap blue.example.com

Starting Nmap 4.68 ( http://nmap.org ) at 2009-02-04 00:09 CET
Interesting ports on blue.example.com (172.16.79.2):
Not shown: 1710 closed ports
PORT     STATE SERVICE
22/tcp   open  ssh
25/tcp   open  smtp
53/tcp   open  domain
80/tcp   open  http
443/tcp  open  https
MAC Address: 00:50:56:FE:05:04 (VMWare)

Nmap done: 1 IP address (1 host up) scanned in 9.751 seconds
```

nmap considers ports "open" if a service can be reached. Ports for which the target host returns an error message are marked "closed", while ports where there is no reaction at all (e. g., because the inquiry packets are simply thrown away by the target host or a firewall, and not even an error message is sent in reply) are designated "filtered".

If you do not specify otherwise, nmap analyses the target host's TCP ports using a "SYN scan". For each of the ports under consideration, the program sends a TCP segment with the SYN flag set (as if it wanted to start a new connection). If the target host answers with a TCP segment that has the SYN and ACK flags set, nmap assumes that the port is in use. However, it takes no further action (in particular, it does not acknowledge the segment), so the "half-open" connection is thrown out by the target host after the statutory timeouts have occurred. If instead the target host answers with a segment with the RST flag set, the port is "closed". If after several tries there is no answer or only ICMP unreachability messages, the port is set to "filtered".—SYN scans require root privileges.

Other techniques that nmap offers include the "TCP connect scan" (which does not require special privileges but is clumsy and easily recognised by the target host), the "UDP scan" and several other variants of TCP-based scans, e. g., to discover firewall rulesets. Consult the documentation in nmap(1).

nmap can not only identify the active ports on a host, but can in many cases even tell you which software is used to serve the ports. For this, you need to specify the -A option and be *very* patient indeed. For this, nmap relies on a database of "signatures" of diverse programs that comes with the software.

The features of nmap surpass by far what we can present in this training manual. Read the documentation (in nmap(1)) and at all times be aware on the legal restriction mentioned earlier.

5.6 Testing DNS With host And dig

If connections to hosts addressed by name take ages to set up or fail to be established after some delay, while trying to make the same connection based on the IP address is as quick as usual, the DNS may be to blame. Conversely, your computer may take a long time to connect because the remote host tries to find a name for *your* IP address and runs into some problem or other there. To test DNS, you can, for instance, use the host and dig programs.

"And what about nslookup?" we hear you say. Sorry, but nslookup has been deprecated for a while and is only still supported for compassionate reasons.

host is a very simple program, which in the most straightforward case accepts a DNS name and outputs the IP address(es) that derive from it:

```
$ host www.linupfront.de
www.linupfront.de is an alias for s0a.linupfront.de.
s0a.linupfront.de has address 31.24.175.68
```

And it also works the other way round:

```
$ host 193.99.144.85
85.144.99.193.in-addr.arpa domain name pointer www.heise.de
```

(Don't ask.)

You can compare the output of several DNS servers by specifying the IP address (or the name, but the IP address is safer) as part of your query:

```
$ host www.linupfront.de 127.0.0.1
Using domain server:
Name: 127.0.0.1
Address: 127.0.0.1#53
Aliases:

www.linupfront.de is an alias for s0a.linupfront.de.
s0a.linupfront.de has address 31.24.175.68
```

In this way you can check whether a DNS server gives the correct answers.

You can request particular types of DNS record by using the -t option, as in

```
$ host -t mx linupfront.de                          MX record desired
linupfront.de mail is handled by 10 s0a.linupfront.de
```

With -l you can obtain a list of the most important names in a domain—at least if you're allowed. Together with the -a option, this gives you a list of *all* names.

The dig program does essentially what host does, but allows for more detailed analysis. It provides more extensive output than host:

```
$ dig www.linupfront.de

; <<>> DiG 9.9.5-10-Debian <<>> www.linupfront.de
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 1443
;; flags: qr rd ra; QUERY: 1, ANSWER: 2, AUTHORITY: 0, ADDITIONAL: 0
;; QUESTION SECTION:
;www.linupfront.de.             IN      A

;; ANSWER SECTION:
www.linupfront.de.      3600    IN      CNAME   s0a.linupfront.de.
s0a.linupfront.de.      3600    IN      A       31.24.175.68

;; Query time: 51 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Wed Jul 22 18:00:34 CEST 2015
;; MSG SIZE  rcvd: 69
```

To resolve IP addresses into names, you must specify the `-x` option:

```
$ dig -x 31.24.175.68

; <<>> DiG 9.9.5-10-Debian <<>> -x 31.24.175.68
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 63823
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;68.175.24.31.in-addr.arpa.     IN      PTR

;; ANSWER SECTION:
68.175.24.31.in-addr.arpa. 86400 IN     PTR     s0a.linupfront.de.

;; Query time: 50 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Wed Jul 22 18:01:31 CEST 2015
;; MSG SIZE  rcvd: 74
```

To query a specific DNS server, give its address after a `@`:

```
$ dig www.linupfront.de @192.168.20.254
```

You can specify a DNS record type after the name you're looking for:

```
$ dig linupfront.de mx

; <<>> DiG 9.9.5-10-Debian <<>> linupfront.de mx
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 15641
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;linupfront.de.                 IN      MX

;; ANSWER SECTION:
linupfront.de.          3600    IN      MX     10 s0a.linupfront.de.

;; Query time: 49 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Wed Jul 22 17:59:36 CEST 2015
;; MSG SIZE  rcvd: 51
```

In principle, you can also use the getent command to test name resolution: getent

```
$ getent hosts www.linupfront.de
31.24.175.68    s0a.linupfront.de www.linupfront.de
```

The difference between host and dig on the one side and getent on the other side is that the former two query the DNS directly. The latter command, however, queries the C library. This means on the one hand that the lookup order given in /etc/nsswitch.conf is obeyed. On the other hand you will receive the answer in the form that you would otherwise encounter in /etc/hosts.

In /etc/nsswitch.conf there is usually a line like

```
hosts: files dns
```

This means that /etc/hosts will be looked at first, then DNS. The advantage is that you get to see exactly what application programs using the C library get to see. For example, for some reason there might be a definition in /etc/hosts for some name, which then has precedence over the DNS (because the DNS will no longer be consulted after a match in /etc/hosts).

From other getent applications, you may be used to something like

```
$ getent passwd
```

giving you a list of all users known to the system, in /etc/passwd format, even if the users aren't all listed in the local password file. This may work for users but doesn't have to (if you are working in a large enterprise, your user database administrators may have prevented this). For DNS, a command like

```
$ getent hosts
```

will *definitely* not lead to all names in the worldwide DNS being listed. (Which is probably for the best, all things considered.)

DNS is a very intricate topic with ample room for mistakes. However, the detailed diagnosis of DNS problems requires considerable knowledge. DNS is treated in detail in the Linup Front training manual, *The Domain Name System*.

5.7 Other Useful Tools For Diagnosis

5.7.1 telnet and netcat

The telnet command is used to log on to a remote host using the TELNET protocol or—more generally—to contact an arbitrary TCP port. TELNET should no longer be used for remote access, as no strong authentication is used and data is transmitted in the clear (without encryption). The Secure Shell (ssh, chapter 10) is a reasonable alternative.

The telnet client program, however, is very suitable to test many other services. With "telnet ⟨*address*⟩ ⟨*service*⟩'', a connection to any port can be established ("⟨*service*⟩" is either a port number or a service name from "/etc/services"). Therefore "telnet 192.168.0.100 80" opens a connection to a web server. In this case it would even be possible to request resources from the server using suitable HTTP commands. Here's a different example:

```
$ telnet 192.168.0.1 22
Trying 192.168.0.1...
Connected to 192.168.0.1.
Escape character is '^]'.
SSH-2.0-OpenSSH_6.7p1 Debian-6
```

In this case, `telnet` connects to the SSH port on a remote host, the remote `sshd` answers with its protocol and program version.

The "escape character" lets you take a "time-out" from the TCP connection in order to enter `telnet` commands. The most interesting commands are probably `close` (terminates the connection), `status` (displays the connection status), and `!` (can be used to execute commands on the local computer while the connection is ongoing):

```
$ telnet 192.168.0.1 22
Trying 192.168.0.1...
Connected to 192.168.0.1.
Escape character is '^]'.
SSH-2.0-OpenSSH_6.7p1 Debian-6
Ctrl+Esc
telnet> status
Connected to 192.168.0.1.
Operating in obsolete linemode
Local character echo
Escape character is '^]'.
_
```

The "`!`" command may be deactivated in your copy of `telnet`. In that case you can still suspend the `telnet` program to the background using the `z` command (think "shell job control"), and reactivate it again later with the shell's `fg` command.

An alternative to the TELNET client, `telnet`, is the `netcat` program. In the simplest case, `netcat` behaves like `telnet` (even though it is much less chatty):

```
$ netcat 192.168.0.1 22
SSH-2.0-OpenSSH_6.7p1 Debian-6
```

The command is frequently called `nc` instead of (or in addition to) `netcat`. The rest stays the same, though.

There are two popular versions of `netcat` in circulation, a "traditional" version (by somebody called "Hobbit") and one from the OpenBSD system. The latter has many more features (such as support for IPv6 or Unix domain sockets). For the rest of this section we are assuming the OpenBSD `netcat`.

On Debian GNU/Linux, the default `netcat` is the traditional version (from the `netcat-traditional` package). If you want to use the souped-up version, you need to install the `netcat-openbsd` package. The OpenBSD `netcat` installs itself under the `nc` name *only*; the traditional version remains accessible as `netcat` unless you deinstall that package.

In addition to the client side of a TCP connection, `netcat` also implements the server side if desired (it doesn't do anything particularly useful by itself, though). For example, you can make it listen to a connection on port 4711 using the

```
$ nc -l 4711
```

command. You can then, in a different window, use

```
$ nc localhost 4711
```

to connect to your "server". Whatever you type on the client side appears on the server and vice-versa. The poor person's file transfer works as follows: On the target host, type

poor person's file transfer

```
$ nc -l 4711 >myfile
```

and on the source host, type

```
$ nc red.example.com 4711 <myfile
```

5.7.2 `tcpdump`

The `tcpdump` program is a network sniffer which analyses the packets moving through a network interface. The network adapter is switched to "promiscuous mode", where it reads and reports all packets (and not, as usual, only those addressed to the local interface). Therefore the command can only be used by the `root` user.

network sniffer

Here is a brief example of its use:

```
# tcpdump -ni eth0
tcpdump: listening on eth0
14:26:37.292993 arp who-has 192.168.0.100 tell 192.168.0.1
14:26:37.293281 arp reply 192.168.0.100 is-at 00:A0:24:56:E3:75
14:26:37.293311 192.168.0.1.35993 > 192.168.0.100.21: S 140265170:
140265170(0) ...
14:26:37.293617 192.168.0.100.21 > 192.168.0.1.35993: S 135130228:
135130228(0) ack 140265171 ...
14:26:37.293722 192.168.0.1.35993 > 192.168.0.100.21: . ack 1 ...
                                                Program interrupted
5 packets received by filter
0 packets dropped by kernel
```

This example shows how a connection to an FTP server is assembled. The "`-ni eth0`" parameters switch off DNS and port name resolution and involve the `eth0` interface only. For each packet, the program displays the exact time, source and destination hosts, any flags in the TCP header (S: `SYN` bit), the sequence number of the data, a possibly-set `ACK` bit, the expected sequence number of the next segment, and so on.

The first packet shown here does not contain a destination address, it is an ARP query: The computer with the `192.168.0.100` address is asked for its MAC address—which it presents in the second packet. The next few packets show a typical three-way handshake.

5.7.3 `wireshark`

`wireshark` is a network sniffer like `tcpdump`. However, `wireshark` comes with a much more impressive feature set. It is a GUI program which allows for detailed analysis of all network packets. Its output consists of three window panes: The topmost displays incoming packets, the bottommost decodes the data in hexadecimal notation, and the center pane allows the convenient and detailed dissection of header information (and payload data).

Like `nmap`, `wireshark` is not a standard Unix tool and usually needs to be installed specifically. Both `tcpdump` and `wireshark` must be used with care, since it is easy to break existing law even within a LAN. After all, there might be data displayed which are nobody's business.

Until some years ago, the `wireshark` program was called `ethereal` and may conceivably be found under this name on older machines.

Commands in this Chapter

`getent`	Gets entries from administrative databases	`getent`(1)	94
`host`	Searches for information in the DNS	`host`(1)	93
`nmap`	Network port scanner, analyses open ports on hosts	`nmap`(1)	91
`ping`	Checks basic network connectivity using ICMP	`ping`(8)	84
`ping6`	Checks basic network connectivity (for IPv6)	`ping`(8)	85
`tcpdump`	Network sniffer, reads and analyzes network traffic	`tcpdump`(1)	97
`telnet`	Opens connections to arbitrary TCP services, in particular TELNET (remote access)	`telnet`(1)	95
`tracepath`	Traces path to a network host, including path MTU discovery	`tracepath`(8)	89
`tracepath6`	Equivalent to `tracepath`, but for IPv6	`tracepath`(8)	90
`traceroute`	Analyses TCP/IP routing to a different host	`traceroute`(8)	87

Summary

- Programs like `netstat`, `telnet`, `nmap`, `tcpdump` or `wireshark` provide powerful tools to diagnose problems with network services.

6

inetd and xinetd

Contents

Goals

- Knowing how services can be started using inetd and xinetd
- Controlling access using the TCP wrapper and xinetd

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 3)
- Knowledge about Linux network configuration (chapter 4)

6.1 Offering Network Services with `inetd`

6.1.1 Overview

A Linux system as a network server can offer a wealth of services—TELNET, FTP, POP3, IMAP, … Each of these services is accessed by means of a specific TCP or UDP port. There are basically two methods of offering such a service: One is by running a specialised process (a daemon) that listens to connections to the port in question. A web server, for example, accepts and processes connections to TCP port 80, while a DNS server takes charge of UDP port 53.

Another possibility is to delegate listening to many ports to a program that will, if a connection comes in on any of these ports, start another program that will perform the actual service. The `inetd`, or "Internet daemon", is such a program.

Why would you want to use a program like `inetd`? There are some obvious advantages:

- Many services are very seldom used. However, a specialised daemon for such a service would tie up system resources even when the service is not in use (if only swap space). On current machines this is less of a problem than it used to be, but the principle stays the same.

- The development of simple network services is simplified radically. While you need considerable expertise to write free-standing daemons that adhere to all the rules and, for example, do not gobble up all the free memory in the computer over time, with `inetd`-based services you can confine yourself to reading from standard input and writing to standard output. `inetd` takes care of passing data sent by the remote client to the server on standard input, and routes its standard output back to the client. This does not at all involve network programming in the proper sense of the word. Also, your server will terminate after the session and free all of its resources.

`inetd` also (or particularly) lends itself to implementing services involving long-lived "sessions" such as FTP or SMTP (on less frequented hosts). This makes it possible to amortise the cost of starting the serving process over a longer period of time. It would be an exceedingly stupid idea to run, say, a web server via `inetd`, since the cost of starting and initialising the complete HTTP server for every single HTTP request bears no relation to the actual work to be done.

6.1.2 `inetd` Configuration

`inetd`'s configuration settings are contained in the `/etc/inetd.conf` file. Every line of the configuration file that is not either empty or a comment describes one service. A line might, for example, look like this:

```
ftp  stream  tcp  nowait  root  /usr/sbin/ftpd ftpd
```

service name — The first word on the line identifes the service by name or port number; a service name must correspond to an entry in the `/etc/services` file which gives the port number assigned to the service. socket type — The second entry on the line specifies the socket type used by the service. Possible values include `stream` (like here), `dgram`, `raw`, `rdm`, and `seqpacket`. In practice, you are only likely to encounter `stream` and `dgram`.

protocol — Next there is the protocol to be used to access the service. Protocol names must be defined in the `/etc/protocols` file. Typical values include `tcp` or `udp`, where `stream` in the preceding column rather forces `tcp`. The same applies to `dgram` and `udp`.

parallelism — The fourth field contains either `wait` or `nowait`. This entry controls how `dgram` sockets (a. k. a. UDP) are used; for other socket types, `nowait` should be specified. `wait` implies that once a service is accessed, the port in question is considered "occupied" until the incoming request has been completely taken care of. Only after that can new requests be considered. `nowait` means that the port is freed immediately, so that new requests can be handled at once.

Instead of just `nowait`, you can also put `nowait.`*n*, where the integer *n* specifies the maximum number of server processes that `inetd` will create within 60 seconds. If .*n* is omitted, a default value of 40 applies.

The next entry gives the user name with whose permissions the service is to run, while the remainder of the line specifies the command to start the service including any parameters. The first "word" is the name of the program file to be executed, and the second a string that is to be passed to the process in question as the "program name". Only then do the usual command line parameters start. Hence, in the example above, the word `ftpd` is not the `/usr/sbin/ftpd` command's first parameter, but the name of the process whose code is taken from `/usr/sbin/ftpd`! In other words: The program file `/usr/sbin/ftpd` is executed without parameters, but the resulting FTP server process thinks its name was `ftpd` rather than `/usr/sbin/ftpd`.

user name

command

It is easy to add services to `inetd`'s configuration or remove them again—you just need to come up with a suitable line for the `inetd.conf` file. Existing services can easily be removed by "commenting out" the lines in question with a "`#`" character in the first column.

Adding services

Removing services

After any changes to the `inetd` configuration file, you need to tell `inetd` to reread its configuration by sending it a `SIGHUP` signal. With most distributions, this is conveniently done by invoking `inetd`'s init script with the `reload` parameter.

reread configuration

Exercises

6.1 [!1] Enable the `echo` service within `inetd.conf` and reload the configuration. Check the service using the "`telnet localhost echo`" command.

6.2 [2] Why does an FTP server lend itself better to being invoked by `inetd` than a WWW server?

6.3 [3] (For programmers.) Write and install a service implementing Julius Caesar's cipher: Every letter is replaced by the letter 3 positions on in the alphabet, thus `A` by `D`, `B` by `E`, and so on. Replace `X` by `A`, `Y` by `B`, and `Z` by `C`:

```
$ telnet localhost caesar
Trying 127.0.0.1...
Connected to linux.example.com.
Escape character is '^]'.
GALLIA OMNIS DIVISA EST IN PARTES TRES
JDOOLD RPQLV GLYLVD HVW LQ SDUWHV WUHV
Ctrl+]
telnet> close
Connection closed.
```

For simplicity, you may restrict yourself to encrypting the 26 uppercase letters and pass all other characters through verbatim. Test your solution using `telnet`.

6.2 The TCP Wrapper—tcpd

One problem with `inetd` consists of intruders trying to access services. Every service ought to check its own requests to find which ones considers acceptable and which ones to refuse. Since many of today's services do not feature this type of access control, a central service was created to make it available to all services. This is the "TCP wrapper", `tcpd`. If a service is accessed, `inetd` first starts the TCP wrapper instead of the actual service. The TCP wrapper logs the connection attempt using `syslog`. After that, it checks (by means of the `/etc/hosts.allow` and `/etc/hosts.deny` files) whether the client host is allowed to use the service in question.

access control

Table 6.1: Text substitutions in command entries in /etc/hosts.allow and /etc/hosts.deny

Key	Meaning
%a	The client's IP address
%c	"Client information": As much information as the client will provide, for example ⟨*user*⟩@⟨*host*⟩, ⟨*user*⟩@⟨*address*⟩, ⟨*host*⟩ oder ⟨*address*⟩
%d	The name of the desired service
%h	The client's name (or its IP address, if the name cannot be determined)
%n	The client's name (or unknown or paranoid, if the actual name cannot be determined)
%p	The spawned process's PID
%s	"Server information": ⟨*service*⟩@⟨*host*⟩, ⟨*service*⟩@⟨*address*⟩ or simply ⟨*service*⟩
%u	The client-side user name or unknown
%%	A single percent sign

/etc/hosts.allow /etc/hosts.deny tcpd first checks /etc/hosts.allow for an entry explicitly whitelisting the current attempt. If there is one, access is granted. Otherwise, it searches the /etc/hosts.deny file for an entry forbidding the current attempt. If there is one, access is refused. Otherwise it is finally granted. If either /etc/hosts.allow or /etc/hosts.deny do not exist at all, they are considered empty.

The usual and probably "more secure" philosophy would be to deny all access that is not explicitly permitted. However this does not agree with the idea that an unconfigured TCP wrapper should behave as if it wasn't present at all.

The /etc/hosts.allow and /etc/hosts.deny files look substantially the same. Basically, entries in these files consist of fields separated by colons and look rougly like

```
pop3d : 192.168.10.0/24
```

daemon name The first entry contains the name of a daemon to be started (the second field from the command in /etc/inetd.conf) or a number of daemon names separated by commas.

If the entry is supposed to apply to all programs, then put the ALL keyword; if it is supposed to apply to all but a few programs, then put "ALL EXCEPT …" (again with a comma-separated list of daemon names).

The second field gives the hosts the entry should apply to. In the simplest case this is a host's name or IP address. Here, too, ALL stands for all possible clients. There are also the keywords KNOWN (all hosts whose names tcpd can determine from their IP address), LOCAL (all hosts whose names do not contain a dot), UNKNOWN (all hosts whose names tcpd *cannot* determine from their IP address), and PARANOID (all hosts whose name and address resolution via DNS gives conflicting answers). Complete IP networks can be specified by means of their network address and mask.

Therefore, the line in the example allows or forbids all stations on the 192.168.10.0/24 network from accessing the POP3 daemon, depending on whether it occurs in /etc/hosts.allow or /etc/hosts.deny.

options After the client specification there may be more comma-separated fields giving options for processing the connection, like

```
ALL: ALL: spawn echo "Access by %u@%h to %d" >>/var/log/net.log
```

You can use spawn to specify a shell command that is executed in a child process. That command's standard input, output, and error output are connected to /dev/

null so the input and output of the actual command (specified in /etc/inetd.conf) are not interfered with. Before the command is executed, "%" expressions in the command string will be replaced according to the connection request; the possible replacements are given in table 6.1. In our example, information on the attempted access is logged to the /var/log/net.log file.

Here are some more options for access rules:

twist (followed by a shell command) replaces the current process by the command (again after replacing "%" expressions), where standard input, output, and error output will be connected to the remote client. This allows you to "take over" a connection.

```
in.ftpd : 10.0.0.0/8 : twist /bin/echo 421 Go away.
```

rejects incoming FTP connections from the 10.0.0.0/8 network with the specified message without having to trouble the FTP server. This option must be placed at the end of an entry.

allow and deny accept or refuse a connection request, no matter what file the entry occurs in. This makes it possible to keep all of the configuration in /etc/hosts.allow (for example) instead of distributing it across both files. These options must be placed at the end of an entry.

umask corresponds to the umask command of the shell.

setenv sets an environment variable (including "%" replacement), as in

```
in.ftpd : 10.0.0.0/8 : setenv HOME /tmp
```

Do note, however, that many daemons "sanitise" their environment and remove entries that look strange to them.

user sets the user or the user and group for the process:

```
user nobody                                   Set user to nobody
user nobody.nogroup               Set user to nobody, group nogroup
```

This is useful because inetd will otherwise execute all daemons as root.

banners (followed by a directory name) (Only for TCP services.) Checks whether the specified directory contains a file named like the daemon process in question, and, if so, copies that file's content to the client. "%" expressions will be replaced.

As a matter of fact, this is the "extended" command language of the TCP wrapper as per host_options(5). The standard version (which you are not going to run into on Linux) confines itself to allowing a shell command as the third field of an entry. It is documented in host_access(5).

Since inetd, together with tcpd, does not start the actual service when a connection is attempted, but merely invokes the wrapper with a suitable set of arguments, entries in the /etc/inetd.conf file look somewhat different in this case.

```
ftp  stream  tcp  nowait  root  /usr/sbin/tcpd ftpd -l -a
```

This means that, in fact, the /usr/sbin/tcpd program (the TCP wrapper) is invoked but it is passed "ftpd -l -a" as the command line. Here, ftpd is the command name from the point of view of tcpd, which it uses to locate the actual command—the FTP server—to be started when access is granted. The same name is used to find corresponding entries (if any) in /etc/hosts.allow and /etc/hosts.deny.

Nowadays many files are linked to libwrap directly, which is the part of tcpd that does the actual work. These programs do not need to be launched via inetd and tcp to benefit of the TCP wrapper's access control features.

Exercises

6.4 [!2] The configuration line

```
ps  stream  tcp  nowait  root  /bin/ps ps auxw
```

defines a service that produces a process list when the ps port (freely invented) is accessed. Use the TCP wrapper to limit access to this service to the local host.

6.5 [2] Cause a message to be written to the syslog when the service from Exercise 6.4 is accessed—for example, using the local0 category and info priority.

6.3 xinetd

6.3.1 Overview

extended Internet daemon

Some modern distributions include a possible replacement for the inetd-tcpd combination, xinetd (***extended Internet daemon***). xinetd brings together all features—port supervision, access control, and logging—and uses a single centralised configuration file.

6.3.2 xinetd Configuration

/etc/xinetd.conf

sections

xinetd's configuration file is usually called /etc/xinetd.conf. In this file, blank lines or lines beginning with a "#" character are ignored. The configuration settings are collected in sections, every one of which begins with a keyword corresponding to a service name from /etc/services, and which contains assignments of values to attributes, like

```
default
    {
        ⟨attribute⟩ ⟨operator⟩ ⟨parameter⟩ [⟨parameter⟩ …]
        …
    }

service ⟨service name⟩
    {
        ⟨attribute⟩ ⟨operator⟩ ⟨parameter⟩ [⟨parameter⟩ …]
        …
    }
```

default settings

specific sections

In practice, the most important operator is "=", which assigns a specific set of values to an attribute. Attributes that can have several values at once also support the "+=" and "-=" operators to add or remove values. The "default" section contains default settings that apply to all services as long as their sections do not contain more specific values. If they do, the default values are either replaced by or combined with the more specific ones. Each additional section gives more detailed information for a specific service. Table 6.2 shows some important attributes.—The exact syntax as well as more attributes may be found in the documentation for the xinetd.conf file. A /etc/xinetd.conf file might, for example, look like this:

```
defaults
{
    log_type        = FILE /var/log/xinetd.log
    log_on_success  = HOST EXIT DURATION
    log_on_failure  = HOST ATTEMPT RECORD
```

Table 6.2: Attributes in the /etc/xinetd.conf file

Attribute	Meaning
type	Allows specifications like INTERNAL (i. e., the service is implemented by xinetd directly), or UNLISTED (i. e., the service has no entry in /etc/services).
socket_type	Includes values like stream, dgram or raw.
protocol	The protocol used by the service, must be in /etc/protocols.
wait	If yes, it is a single-threaded service; no allows xinetd to start the service several times simultaneously.
user	The user whose privileges are used to execute the service; this must be a valid system user.
instances	Maximum number of simultaneous instances of the service (if "wait = no")
server	File name of the actual server program
server_args	Invocation parameters for the server program
interface	IP address for the interface used by xinetd to listen for service requests
only_from	Only the specified clients (as DNS names, IP addresses or network addresses) may access the service.
no_access	These clients may not access the service.
access_times	The service is only available at the given times.
log_type	Determines the type of logging done by xinetd—SYSLOG or FILE.
log_on_success	Determines what information to log on a successful connection attempt, e. g., HOST (the client's name), USERID (the client user according to [RFC1413]) etc.
log_on_failure	Defines what information to log on an unsuccessful connection attempt, such as ATTEMPT (the failed attempt) etc.
disable	Deactivates the service (corresponds to "commenting out" a line in /etc/inetd.conf)
disabled	Can be set in the defaults section to disable a number of services, such as "disabled finger ftp"

```
    instances       = 2
}

service telnet
{
    socket_type     = stream
    protocol        = tcp
    wait            = no
    user            = root
    server          = /usr/sbin/in.telnetd
    server_args     = -n
    only_from       = localhost
    no_access       =
}
```

First, this example sets up default values for some attributes. Afterwards, some more specific definitions for the telnet service are given. The set of attributes allowable in a section depends on the service to be configured.

On SUSE distributions, the /etc/xinetd.conf file often merely contains the defaults section. Another line containing "includedir /etc/xinetd.d" causes all the files in the /etc/xinetd.d directory to be read as if they were part of the /etc/xinetd.conf file. These files then contain the configurations for individual services. /etc/xinetd.d

6.3.3 Launching xinetd

xinetd can be passed a number of options controlling the way it works: options

-syslog ⟨*category*⟩ Causes xinetd to send its log messages to the syslog daemon within the given ⟨*category*⟩. Possible categories include daemon, auth, user, and

Table 6.3: xinetd and signals

Signal	Effect
SIGHUP	Causes a "hard reconfiguration": xinetd rereads its configuration file and terminates the servers which are no longer enabled in the new configuration. For all other servers, access control is redone and all connections that do not pass are reset. If there are more connections to a service than allowed by instances, a random set of servers is terminated until the limit is observed again.
SIGQUIT	Terminates xinetd
SIGTERM	Terminates all active services, then xinetd
SIGUSR1	Creates a memory dump in file /var/run/xinetd.dump
SIGIOT	Causes xinetd to perform an internal consistency check in order to ensure that its data structures have not been damaged

the eight categories local0 to local7.

-filelog ⟨*file*⟩ Determines the file name used by xinetd to write its log messages to. This option and the -syslog are mutually exclusive.

-f ⟨*file*⟩ Causes xinetd to read ⟨*file*⟩ as its configuration file. The default value is /etc/xinetd.conf.

-inetd_compat Causes xinetd to read inetd's configuration file, /etc/inetd.conf, in addition to its own configuration file.

To start xinetd using these parameters, you should (on a SUSE distribution) extend the XINETD_BIN variable in the /etc/init.d/xinetd script by the desired options (the variable's value will have to be enclosed in quotes).

It is also possible to control xinetd by means of signals. The most important signals and their effects are summarised in Table 6.3.

6.3.4 Parallel Processing of Requests

Services started by xinetd can be subdivided in two groups (see the wait and instances attributes). If a new process is started for each access to the service, the service is called "multithreaded". If a service only accepts a new request after the preceding one has been finished, the service is called "single-threaded". Datagram-based services (i. e., those based on UDP) are frequently single-threaded, while TCP-based services are always multithreaded.

6.3.5 Replacing inetd by xinetd

There is nothing that prevents you from using inetd and xinetd in parallel on the same system (other than that the distribution's package management system may balk at the idea). You should, however, ensure that the two do not try to manage the same ports!

If you want to replace an existing inetd by xinetd on a system, you can use some tools that make inetd's configuration usable for xinetd. By default, the xinetd package contains the itox program. Using the

tools

```
# itox </etc/inetd.conf >/etc/xinetd.conf
```

command, you can create a xinetd configuration file from your inetd configuration file. It is important to note that only enabled services will be taken over into the new configuration file. If you want to keep all entries in your old file, you should activate them first (by un-commenting them) and then disable them again in the new file.

Exercises

6.6 [!2] Enable the `echo` service in `xinetd.conf` (or the corresponding file in `/etc/xinetd.d`) and reload the configuration. Check the service using the "`telnet localhost echo`" command.

6.7 [3] Define a `ps` service along the lines of Exercise 6.4 and restrict access to this service to local processes.

6.8 [2] Configure `xinetd` such that the `ps` service is only available on the loopback interface (`127.0.0.1`).

6.9 [3] Which of the two methods to limit a service to the local host—TCP wrappers or binding to `127.0.0.1`—is preferable?

Commands in this Chapter

`inetd`	Internet superserver, supervises ports and starts services	`inetd`(8)	100
`tcpd`	"TCP wrapper", permits or denies access depending on the client's IP address	`tcpd`(8)	101
`xinetd`	Improved Internet super server, supervises ports and starts services	`xinetd`(8)	104

Summary

- `inetd` observes the ports for a set of services whose serving processes need only be started on request, instead of having to run in the background at all times.
- `inetd` is configured by means of the `/etc/inetd.conf` file.
- The TCP wrapper, `tcpd`, can limit access to specific network services to specific computers.
- `xinetd` is a more modern implementation of `inetd`'s and `tcpd`'s functionality—port supervision, access control, and logging.

Bibliography

RFC1413 M. St. Johns. "Identification Protocol", February 1993.
`http://www.ietf.org/rfc/rfc1413.txt`

7

Network services with systemd

Contents

Goals

- Understanding the activation of persistent services using systemd
- Understanding socket activation for services based on systemd
- Being able to integrate network services into systemd targets

Prerequisites

- Linux system administration knowledge
- Knowledge about TCP/IP basics (chapter 3)
- Knowledge about Linux network configuration (Chapter 4)
- Knowledge about systemd

7.1 Introductory Remarks

Systemd is now a very popular alternative to the traditional System-V init system. For this reason it makes sense to explain about network services with systemd.

A more complete introduction to systemd may be found in the Linup Front training manual, *Linux Administration I* (ADM1).

As far as network services are concerned, we may distinguish between "persistent" services which are started when the system is booted, and services that are started on demand by means of socket activation. The former correspond to services that on System-V init are typically started using init scripts, while the latter correspond to services managed by `inetd` or `xinetd`.

7.2 Persistent Network Services

From systemd's point of view, persistent network services do not differ greatly from other persistent services that are started and managed by systemd. They take care of their own network connections, and systemd has nothing to do with them. Systemd's only job consists of starting the service at the correct time (like System-V init would) and potentially keeping an eye on the service in case it crashes before its time (which System-V wouldn't do, at least not unless you have installed additional software that manages this.)

You therefore need to provide a unit file for your service and make this known to systemd (using "`systemctl enable`"). After that, everything should happen automatically. You can of course elect to manage the service manually using "`systemctl start`" and friends.

If you don't have a unit file for your service, but do have an init file for System-V init, you can use this with impunity—after all, systemd is compatible.

Many services expect to be started "when the network is available". The problem with this is that this is a very vague concept. Will it be enough if at least one network interface is up and has an IP address? Do other hosts need to be actually reachable? The standard gateway? The DNS server? Google? What about WLAN or cellular interfaces that are sometimes active and sometimes aren't? One of the shortcomings of System-V init is that this complexity is completely swept under the rug—the init script for "the network" is executed, and then we postulate that the computer is networked and that that will not change until it is shut down again.

Systemd uses three different targets to handle the "network is available" concept:

`network-pre.target` is a goal that is used by services that need to be started *before* the network is activated. For the most part, this includes services that configure a firewall, such that it is available before network interfaces are brought up, and thus there is no "vulnerable phase" between the start of networking and the initialisation of the firewall. This target cannot be activated manually.

Network management software should depend on `network-pre.target`, but only in the temporal sense with

```
[Unit]
After=network-pre.target
```

You should avoid an explicit dependency using `Requires` or `Wants`.

Services that are to be started before the network is activated should have

```
[Unit]
Wants=network-pre.target
Before=network-pre.target
```

in their configuration.

`network.target` only stipulates that the local network software was initialised. It does not make any assumptions as to whether actual network interfaces have been configured. The main purpose of this target is to provide a synchronisation point during a *shutdown* of the system—if all services that presume availability of "the network" are started *after* `network.target` was reached, then that implies that on shutdown they will be deactivated *before* `network.target` is deactivated. This means that no network service has its connection forcibly severed.

You may not start `network.target` manually, and neither is the target presupposed by network services using `Requires` or `Wants`. Such a clause should only occur in the configuration of the network management software. Services that need to be shut down before the network is brought down should have

```
[Unit]
After=network.target
```

in their systemd configuration.

`network-online.target` explicitly waits for the network to become available, where the exact meaning of "becoming available" is determined by the network management software. (A configured external IP address, for example, would be an obvious prerequisite.) In principle, services that depend on the network can have a `Requires` or `Wants` for this target.

The recommendation is not to overdo this. Many network services have no problem serving *local* clients, even though no external network connection is available. The dependency is more useful for *clients* that want to access remote services and do not work without a network connection.

A typical example for this are remote file systems. For this reason, systemd ensures that, for each remote file system in `/etc/fstab`, a dependency on `network-online.target` will be generated. If you do not have a remote file system in `/etc/fstab` and no service otherwise depends on `network-online.target`, the target will not be taken into account on boot—which is a good idea, since unnecessary delays will be avoided in case no network is available.

Systemd interprets a `$network` dependency in a System-V init script as

```
[Unit]
Wants=network-online.target
After=network-online.target
```

Exercises

7.1 [2] Find out which service on your system depends on `network.target` via either `Requires` or `Wants`. How does your system define an "active network"?

7.2 [2] Which services on your system depend on an "active network"?

7.3 Socket Activation

"Socket activation" is the idea of starting a service only when connection requests to it are received. Traditionally, this used to be handled by `inetd` (later `xinetd`), a daemon that listens to a number of ports and, on noticing any activity, activates the background service corresponding to the port in question. Systemd extends this notion and uses it for other services as well.

Systemd recommends socket activation for Unix domain sockets in particular, but there is no problem whatever with using it for TCP or UDP sockets, too.

There are three basic scenarios where socket activation is worthwhile:

1. When the system is booting, socket activation can enhance parallelism and avoid explicit dependencies. Systemd initialises the required communication channels and orchestrates the launch, in parallel, of the corresponding services when requests are received. This is useful for services that are used often and permanently and that should be started as soon as possible, such as syslog or D-Bus.

2. Rarely used services are started on demand, by means of systemd opening the known port associated with the service and listening for connection requests. If connection requests do arrive, systemd launches the actual service and passes the *listening* socket to the service. The service can then handle further requests on its own. One example of this is the printer service, CUPS.

3. Rarely used services are started on demand, by means of systemd opening the known port associated with the service and listening for connection requests. If connection requests do arrive, systemd launches the actual service and passes it the socket for the *actual connection*. The service handles that specific connection and then terminates again. This is less efficient than the other two scenarios, but such services are very convenient to implement since systemd takes care of all the networking requirements. Services where this approach makes sense include, for example, FTP or SSH, especially on hosts where they are used infrequently. This avoids having daemons sleep idly in the background.

   This flavour is the one most often associated with `inetd`. `inetd` can also handle the second scenario in our list, but that is only used extremely rarely.

To enable socket activation with systemd for a service like the Secure Shell chapter 10), we first take a look at how the respective configuration would look like in `inetd` or `xinetd`—namely, for `inetd`:

```
ssh stream tcp nowait root /usr/sbin/sshd sshd -i
```

(the "`-i`" option ensures that the SSH daemon, `ssd`, works with `inetd` rather than as a free-standing service). And for `xinetd`:

```
service ssh {
      socket_type = stream
      protocol = tcp
      wait = no
      user = root
      server = /usr/sbin/sshd
      server_args = -i
}
```

Of course you also need to know that the Secure Shell uses TCP port 22. In the inetd configuration, this is denoted implicitly by the ssh in the first column; this is a reference to the /etc/services file, which contains the actual port number.

To construct an equivalent configuration for systemd, you need two files. First, you must describe the port that systemd listens on (on behalf of the Secure Shell). This is done in a file called sshd.socket[1]:

```
# sshd.socket
[Unit]
Description=Secure Shell service (socket for socket activation)

[Socket]
ListenStream=22
Accept=yes

[Install]
WantedBy=sockets.target
```

Here, ListenStream=22 is the moral equivalent to "ssh stream tcp" with inetd, and Accept=yes corresponds to nowait—systemd is supposed to accept individual connection requests on the Secure Shell's behalf and pass them on.

A second unit file is used to actually start instances of the SSH daemon if they are required. Since several SSH connections may be active at the same time, we define this unit file as a "template", sshd@.service:

```
# sshd@.service
[Unit]
Description=Secure Shell service (per-connection server)

[Service]
ExecStart=-/usr/sbin/sshd -i
StandardInput=socket
```

In ExecStart we specify how the daemon is to be started (the minus sign at the start declares that exit codes other than zero should be considered successful). StandardInput=socket ensures that the daemon can actually talk to the client side (standard output and standard error output tag along with this).

You may now ask yourself why systemd needs two files to do something that inetd manages in a single line. The answer to that is that this makes systemd a lot more flexible than inetd. In particular, the "listening" port and the actual connections are cleanly separated from one another, and you could, for example, stop the unit responsible for the port (and thereby inhibit further connections) without influencing existing connections. (Of course that also works without systemd, but then you have to figure out by yourself which processes are doing what.)

Using these two files we can reload systemd and launch the service:

```
# systemctl daemon-reload
# systemctl start sshd.socket
```

Do note that we started the sshd.socket file rather than the sshd@.service file. Due to the former, systemd is now waiting for connections:

[1]A port in TCP (and UDP) is a communication *end point*, while a socket describes an active *connection*, or combination of two ports (client and server). This admittedly subtle difference apparently didn't quite make it to the systemd developers.

```
[Unit]
Description=OpenBSD Secure Shell server
After=network.target auditd.service
ConditionPathExists=!/etc/ssh/sshd_not_to_be_run

[Service]
EnvironmentFile=-/etc/default/ssh
ExecStart=/usr/sbin/sshd -D $SSHD_OPTS
ExecReload=/bin/kill -HUP $MAINPID
KillMode=process
Restart=on-failure

[Install]
WantedBy=multi-user.target
Alias=sshd.service
```

Figure 7.1: Unit file for Secure Shell daemon (Debian 8)

```
# systemctl status sshd.socket
● mysshd.socket - Secure Shell service (socket for socket activation)
   Loaded: loaded (/etc/systemd/system/sshd.socket; disabled)
   Active: active (listening) since Di 2015-07-28 13:12:45 CEST; 2s ago
   Listen: [::]:22 (Stream)
 Accepted: 1; Connected: 0
```

To enable the service on a permanent basis you would use "`systemctl enable sshd.socket`". This isn't really required for our little experiment.

If you then invoke `ssh` (possibly in a different window) to connect to the computer, this should work. The systemd status should be something like

```
# systemctl --full | grep ssh
sshd@1-192.168.56.101:22-192.168.56.1:46618.service ▷
 ◁ loaded active running  Secure Shell service (per-connection ▷
 ◁ server) (192.168.56.1:46618)
sshd.socket ▷
 ◁ loaded active running  Secure Shell service (socket for socket ▷
 ◁ activation)
```

You could now stop the client connection if required using something like

```
# systemctl kill sshd@1-192.68.56.101:22-192.168.56.1:46618▷
 ◁ .service
```

(don't be scared—systemd does command line completion for service names, so you don't need to type all of this yourself).

It is not a stupid idea at all to configure the Secure Shell for systemd in this way. Many distributions, however, still rely on a SSH daemon that is running permanently in the background. Figure 7.1 shows a unit file for that (from Debian 8).

Systemd replaces `inetd` but not necessarily `xinetd`, as the latter contains a few built-in conveniences that systemd does not offer. You can very probably do without the standard services `ECHO`, `DISCARD`, `TIME`, and `DAYTIME`, and various service options are no longer relevant today (cue "TCPMUX"). You might possibly miss the TCP Wrappers, although it must be said that (a) you may be better served by an actual firewall, and (b) nobody prevents you from using the `tcpd` program with systemd, much like we used to do with `inetd`.

By way of compensation, systemd can do many nice things that neither `inetd` nor `xinetd` will touch. In addition, having to *not* learn two additional formats for configuration files shoudl also be worth something.

(This section is inspired in part by [Poe11].)

Exercises

7.3 [!2] Install and launch a socket-activated Secure Shell server as shown above. Try a few connections and also try terminating specific connections. (In the—likely—case that there is an active Secure Shell server on your system already: Call the files `mysshd.socket` and `mysshd.service` and pick another port, such as 10022.)

7.4 [2] Create systemd `.socket` and `.service` files which implement the classic DAYTIME service. This provides the current date and time on TCP port 13:

```
$ telnet localhost 13
Trying ::1...
Connected to localhost.
Escape character is '^]'.
Tue 28 Jul 13:56:14 CEST 2015
Connection closed by foreign host.
```

Summary

- With systemd, persistent network services do not differ greatly from other persistent services.
- Systemd manages service activation depending on network availability based on the `network-pre.target`, `network.target`, and `network-online.target` targets.
- Systemd offers flexible and powerful capabilities for "socket activation" of services on demand.

Bibliography

Poe11 Lennart Poettering. "Converting inetd Services (systemd for Administrators, Part XI)", September 2011. `http://0pointer.de/blog/projects/inetd.html`

8
System Time

Contents

Goals

- Learning how Linux manages the time and date
- Being able to maintain the time on a computer by means of NTP

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 3)
- Knowledge about Linux network configuration (chapter 4)

8.1 Introduction

The concept of "time" is really quite a complex topic. Our "civil" time, that is, the time that is announced by telephone, that trains, buses, and planes run by and that governs the television programme, derives predominantly from two sources. The clocks of the world run according to the so-called "coordinated universal time" (or UTC), typically with a fixed offset for the time zone—"Central European time", or CET, for example, is calculated by adding one hour to UTC. UTC in turn depends essentially on the "international atomic time" (TAI), a weighted average of approximately 300 atomic clocks in more than 50 national laboratories throughout the world, in the sense that one second of UTC is equivalent to one second of TAI.

UTC

The atomic clocks synchronise themselves to one another via satellite to a deviation of about 0.1 milliseconds (there are some outliers that only manage roughly 10 milliseconds).

UTC is also adjusted to the mean solar time at the meridian of Greenwich (also called UT1). Since the Earth's rotation decelerates slowly due to influences such as tidal friction and plate tectonics, UT1 seconds are minimally longer than those of UTC. Hence every so often UTC must put in a "leap second" so the atomic UTC and the astronomical UT1 do not drift apart too much. The rule is that UTC and UT1 should not differ by more than 0.9 seconds.

UT1

leap second

Leap seconds can potentially happen twice a year, typically at the end of the months of June and December. They are usually announced 6 months ahead. Since the concept was introduced in 1972 until July 2015 there have been 26 leap seconds. (In 1972, UTC already differed from TAI by 10 seconds, so the difference is now 36 seconds altogether.)

Leap seconds are increasingly considered a nuisance. The leap second of 30 June 2012, for example, triggered a bug in the Linux kernel which in extreme cases could lead to computers locking up completely. Hence, since several years the ITU, the international body in charge, has been dealing with a proposal to do away with leap seconds altogether. Opinions on this vary vehemently; a decision has for now been postponed until November, 2015.

Do not confuse leap seconds with the leap days of the Gregorian or the leap months of the Islamic calendar. While the latter are based on the definition of the calendar and are—barring calendrical reforms—predictable, leap seconds derive from astronomical observations and are inserted as needed (albeit with some advance warning).

For people in real life like ourselves, UTC and the "zone times" derived from it, such as CET, are most important. The emphasis Linux places on time managements takes this into account.

8.2 Clocks and Time on Linux

CMOS clock

kernel clock

Every PC has a battery-operated hardware or CMOS clock which is set via the firmware and keeps running even if the computer is switched off. Linux uses the CMOS clock only during system boot, to set the internal kernel clock.

The kernel clock counts time in consecutive seconds since 1 January 1970, 00:00 UTC. When the system is booted, the current date and time are read from the CMOS clock, converted to kernel time, and used to initialise the kernel clock. This is done using the `hwclock` program. The system needs to know whether the CMOS clock is set to UTC or the local "zone time" (such as CET/CEST); the latter may be necessary for the sake of other operating systems on the computer:

`hwclock`

```
# hwclock --hctosys -u                                    CMOS clock in UTC
# hwclock --hctosys                                CMOS clock in local time
```

The kernel clock is used, e. g., for file system time stamps. You can query it using the `date` command, while `hwclock` without arguments outputs the time according to the CMOS clock.

Linux on 32-bit systems uses a signed 32-bit integer variable to store the time. The latest point in time that can be represented is thus $2^{31} - 1 =$ 2,147,483,647 seconds from 1 January 1970, midnight UTC, in other words 19 January 2038, 3 hours, 14 minutes, 7 seconds[1]. By that time we'll all be using if not 64-bit machines then hopefully a patched Linux kernel …

If you require a time representation for your own software, you should not necessarily use that of the Linux kernel, since it is mostly geared towards the internal use of the operating system (such as the aforementioned file time stamps). As a programmer for a bank or insurance company—just for the sake of discussion—you could be required to deal with post-2038 dates even today, for example if you want to sell capital life insurance to someone who is 30 years old today, to be paid out when they retire at 65 (or presumably 75). Conversely, many of your customers will be born before 1 January 1970, and negative Linux time stamps aren't really defined (even though the C library usually does the Right Thing with them).

The time zone is set in `/etc/timezone`; this contains an entry like "`Europe/Berlin`" naming a file below `/usr/share/zoneinfo`. This (unreadable) file contains time zone data such as the offset from UTC, the daylight saving time rules, and similar details. `/etc/localtime` is a copy of the file named by `/etc/timezone`. Users can pick an arbitrary time zone by means of the `TZ` environment variable.

Linux provides various tools to manage time zone files: The "time zone compiler", `zic` lets you create your own time zone files and convert them to the format required by the C library; `zdump` outputs a time zone file (or most of its content, anyway) in a readable format. The manual pages, `tzset`(3) and `tzfile`(5), are also worth reading.

You can find out more about time zones on Linux from the Linup Front training manual, *Advanced Linux*.

Setting the kernel clock

The kernel clock can be set using the `date` command, by passing the desired date and time as a parameter (administrator privileges are required):

```
# date 020318012009.30
```

sets the clock to 18:01:30 on 3 February 2009 (we shall leave it to you as an exercise to figure out exactly how the parameter is constructed). As a minimum you need to pass the day, month, hour, and minute:

```
# date 02031801
```

Use the `-u` option to set the clock in UTC.

The GNU `date` program common on Linux lets you use a somewhat more intuitive syntax to set the clock:

```
# date --set --date="2015-07-20 18:01:30 +0100"
```

Your graphical desktop environment may allow you to set the clock in a more convenient manner, too.

Settting the CMOS clock

To set the CMOS clock while the system is running, first set the kernel clock using `date`. Then you can transfer the kernel time to the CMOS clock using "`hwclock --systohc`". Alternatively, the `--date` to `hwclock` option lets you set the CMOS clock directly (without the kernel clock noticing). In any case, `hwclock` tries to store data concerning the systematic deviation of the CMOS clock to `/etc/adjtime`. CMOS clocks are, as a rule, terribly inexact.

Common Linux distributions transfer the kernel clock's time to the CMOS clock on system shutdown. This is based on the premise that the kernel time can be kept very exact using the methods described in the next section, while the CMOS time drifts off to who knows where—hence it is not a bad idea to get it back on the straight and narrow every so often.

Exercises

8.1 [1] Linux for stock brokers: State the commands necessary to display three clocks (e. g., using `xclock`) that show the time of the major stock exchanges (New York, Frankfurt, Tokyo).

8.2 [2] During which periods since the start of Linux time zone information did daylight saving time apply in Germany? (*Hint:* `zdump`)

8.3 Time Synchronisation with NTP

It is often important for all hosts on a computer network to use approximately the same system time. Network file systems like NFS or authentication infrastructures like Kerberos can get more than miffed at computers whose time deviates noticeably from that of the server, and stable system operation cannot be assured in that way. Hence it is a very sensible idea to synchronise the clocks of all hosts on the local network as far as possible, and doing that automatically would of course be best.

The traditional program for time synchronisation is called `netdate`, but you should give it a wide berth because it does not work correctly.

It also makes a lot of sense to synchronise the clocks of all computers on the network not only to one another, but to tie it to an accurate external time base like an atomic clock. Since you are probably not among those fortunate (?) enough to keep one sitting in your cellar, you will have to resort either to a receiver for a radio time signal (such as DCF77 in Germany, or GPS satellites) or a time server accessible via the Internet. Publically-available time servers are often operated by universities or ISPs.

It is clumsy to set the clock "by leaps" since specific points in time may be passed by, or they may occur twice. This may lead to problems with programs like `cron`. It is better to keep the kernel time accurate during system operation by making it run faster or slower in a controlled fashion, in order to even out differences without interrupting the sequence of seconds since 1 January 1970.

NTP

You should use the "Network Time Protocol" (NTP) to do so. More information about the protocol is available in [RFC1305] or on `http://www.ntp.org/`.

`ntpd`

A very popular daemon for time synchronisation is called `ntpd`. It can act as a client and communicate via NTP with radio-controlled clocks or time servers, or act as a server and pass its synchronised time on to other hosts. `ntpd` is configured by means of the `/etc/ntp.conf` file, which could contain something like

```
# Local clock -- not a good time source
server 127.127.1.0
```

[1]Or thereabouts—since the odd leap second will be introduced in the meantime.

```
fudge  127.127.1.0 stratum 10   # unsynchronised
# Time servers from the public pool
server 0.de.pool.ntp.org iburst
server 1.de.pool.ntp.org iburst
server 2.de.pool.ntp.org iburst
# Miscellaneous
driftfile /var/lib/ntp/ntp.drift
logfile   /var/log/ntp
```

The first `server` entry relates to the local clock, which is not considered reliable and will be used only in emergencies (e. g., if no time server can be reached). The `stratum` value describes the "distance" of the clock from the official atomic time; a computer that is connected directly to the atomic clock is at `stratum` 1, a computer that gets its time from that computer is at `stratum` 2, and so on.

Finding a time server isn't all that easy. NTP with many clients can tax a network or a time server fairly heavily, which is why institutions like the German Federal Physical-Technical Institute in Brunswick, Germany, which used to operate public time servers, have gone off the idea. The best approach if you do not have a time server accessible directly is to use the "NTP pool".

In networks based on Microsoft's Active Directory, the domain controllers also serve as time servers. This makes sense since Active Directory, being based on Kerberos, requires a reasonably accurate common time within the network.

The NTP pool consists of various publically available time servers which are accessed by clients by means of a DNS "round-robin" scheme. This means that an address like `0.pool.ntp.org` points fairly randomly to one of several thousand public time servers anywhere in the world. Since all provide roughly the same time, this isn't a big problem for clients—but for server operators this means that the load is shared equally, rather than being concentrated on a few time servers merely because their names are especially well-known.

The `iburst` option on the `server` lines ensures that your `ntpd` will very quickly acquire the current time when it is starting up.

In practice you should specify three time servers from the NTP pool, as in the example above:

```
server 0.pool.ntp.org iburst                    Anywhere in the world
server 1.pool.ntp.org iburst
server 2.pool.ntp.org iburst
```

You may get a better-quality time by concentrating on geographic "partial pools":

```
server 0.europe.pool.ntp.org                    Anywhere in Europe
server 0.de.pool.ntp.org                        Anywhere in Germany
```

This helps keep the network load low. If your ISP offers a time server you can also use that and two time servers from the pool.

Newer versions of `ntpd` support the `pool` directive, which is optimised for the use of NTP pools:

```
pool de.pool.ntp.org
```

You can specify more than one `pool` directive (duplicate servers will be removed), but one is basically enough.

If you consider synchronising the time for a complete network to the NTP pool, you should make one of the computers on your network an NTP server and synchronise only this one to the NTP pool. The other hosts on your network should obtain their time from your local time server.

In that situation you should probably not confine yourself to a single time server. Configure at least two (e. g., `ntp1.example.com` and `ntp2.example.com`) and point from one to the other with

```
peer ntp2.example.com   # on ntp1, the other way round on ntp2
```

This means that the two time servers can synchronise to each other. On the clients, use

```
server ntp1.example.com iburst
server ntp2.example.com iburst
```

Do note that this lets you tolerate losing one time server, but your Internet connection to the external time servers remains a reliability bottleneck. If you want to be sure, you need several independent Internet connections (and ideally ones that don't leave the building through the same cable duct where they can fall prey to an over-eager backhoe). If you don't have these already because of other considerations, then at this point it may be cheaper to buy a few DCF77 or GPS receivers.

If you have a large local network, the constant synchronisation messages of the various `ntpd`s can create a considerable load on the network. In such a situation it is cleverer to configure the server as a "broadcast server" that periodically sends unsolicited time announcements to "everyone". With a directive like

```
broadcast 192.168.0.255
```

you can turn your `ntpd` into a broadcast server that will send time announcements to the `192.168.0.0/24` network. (Of course the broadcast server must get its own time from somewhere; therefore you will still need the `server` or `pool` directives.) On the clients, you should use the

```
broadcastclient
```

directive—`server` or `pool` are not required there.

With the broadcast approach, an attacker can easily impersonate a broadcast server in order to distribute spurious time announcements. To avoid this, time announcements should be cryptographically authenticated. (This is in fact the default, and must be deactivated explicitly in case it is not desired.) In the simplest case, you can generate a set of symmetric keys using the `ntp-keygen` command:

```
# mkdir /etc/ntp-keys
# cd /etc/ntp-keys
# ntp-keygen -M
Using OpenSSL version OpenSSL 1.0.1k 8 Jan 2015
Using host blue group blue
Generating new md5 file and link
ntpkey_md5_blue->ntpkey_MD5key_blue.3646747865
```

This generates a key file `/etc/ntp-keys/ntpkey_MD5key_blue.3646747865` as well as a symbolic link `ntpkey_md5_blue` in the same directory. The file contains ten MD5 keys and ten SHA1 keys that you get to pick from:

```
# cat /etc/ntp-keys/ntpkey_md5_blue
# ntpkey_MD5key_blue.3646747865
# Fri Jul 24 19:31:05 2015

 1 MD5 hPQB+WrQH|XwILq!Na,  # MD5 key
 2 MD5 devt/tV(zTA@_w5EG6;  # MD5 key 3 MD5 Evk8O2yl0EySK4[C@&g  # MD5 key
◁◁◁◁◁
10 MD5 $&,7*SQGITy-t?B/8pb&  # MD5 key
11 SHA1 92fc0c06cfe754a949ee79497d59c378878c4ac1  # SHA1 key
12 SHA1 a300fe27c8765a96139ac7f4dcc3f65c78e7c341  # SHA1 key
◁◁◁◁◁
```

The index (left-hand column) of the desired key must then be specified in the `/etc/ntp.conf` file:

```
keys /etc/ntp-keys/ntpkey_md5_blue
broadcast 192.168.0.255 key 1
```

The key file must also be available on the clients. There you need to enter the following lines in `/etc/ntp.conf`:

```
keys /etc/ntp-keys/ntpkey_md5_blue
trustedkey 1
broadcastclient
```

Important: The symmetric keys should not be readable for ordinary users.

Newer versions of `ntpd` also support an asymmetric encryption scheme. The details for that are part of `ntpd`'s documentation.

`ntp.drift` The `ntp.drift` file is used to store the systematic drift of the CMOS clock. `ntpd` must observe it for some time to do so, but then works without constantly referring back to the time servers.

There are no manual pages for `ntpd`. Documentation is only available in HTML format, e. g., on `http://doc.ntp.org/`.

`ntpdate` You can set the clock "approximately" by using the `ntpdate` program, which you can invoke simply be giving one or more time servers as arguments. This sets the time once, which is of course not as nice as having it constantly corrected using `ntpd`, but may at times be sufficient (especially if you repeat it periodically using `cron`):

```
# ntpdate 0.de.pool.ntp.org 1.de.pool.ntp.org
# hwclock --systohc
```

This approach is also necessary if you have an older version of `ntpd` that does not support the `iburst` option for servers. This is because for `ntpd` to be able to do its fine-tuning, its time must be at least approximately correct, and `ntpdate` helps ensure this.

`ntpd` can keep a dialup connection to the Internet fairly busy. You should not use it to synchronise to remote time servers without a leased line (or flat rate). An alternative for users of dialup connections that are charged based on time is `chrony` `chrony` (not part of LPIC-1); see `http://chrony.sunsite.dk/`.

You can use the `ntpq` command to control NTP servers. It supports a number `ntpq` of commands that you can either specify on the command line or else enter at an interactive prompt. For example, you can look at the time servers that are currently being used:

```
$ ntpq -c peers
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
+panel1.web2.c 5.9.80.113     3 u    7   64   17 33.347 -78.427  1.152
+alvo.fungus.a 91.195.238.4   3 u    7   64   17 32.989 -84.727  2.352
*ntp3.kashra-s .PPS.          1 u    3   64   17 61.659 -80.267  1.383
 liste.cc      192.53.103.104 2 u    2   64   17 34.967 -78.630  1.063
```

("`ntpq -p`" would do the same thing.)

By way of a brief explanation: `remote` is the (possibly remote) time server. `refid` is the source that the time server obtains its time from. `st` is the stratum, or the time server's distance from the atomic clock. `t` specifies which role your host plays with regard to the remote host—`u` stands for "unicast client", other possible values include `b` for "broadcast or multicast client", `l` for a local reference clock, `s` for a symmetric peer, and so on. `when` denotes the period of time since the last contact with the remote server—a number without a unit refers to minutes, `h` and `d` after the number stand for hours and days, respectively. `poll` specifies the polling frequency; officially, the values range from 4 to 17 (2^4 = 16 seconds to 2^{17} = 131072 seconds, or approximately 36.4 hours), but in real life you are more likely to encounter values (in seconds) from 64 to 1024. `reach` intimates how successful recent queries to the server were: Interpret the value as the octal representation of an 8-bit shift register, where the least significant bit represents the most recent query. Therefore the value 17 stands for four successful queries (unsuccessful queries are represented as value-zero bits). Finally, `delay` lists the time for a "round trip" of a datagram to the remote host in milliseconds, `offset` the mean difference between the times on this host and those on the remote host (again in milliseconds)[2], and `jitter` the mean fluctuation in the remote host's time signals, or the RMS of the difference of successive time announcements (again in milliseconds).

The first character of each line denotes the status of the remote host:

Space The remote host does not talk to this host, *is* this host, or uses this host as a time source.

x (or "-") This remote host is ignored because its time does not appear accurate enough.

Good remote host, but it is still being ignored (because there are six better ones); qualifies as a stand-in.c

+ Good remote host that is being taken into account.

***** Currently the preferred ("primary") remote host.

The `refid` can assume any out of a large set of values. You are most likely to see either an IP address or one of the common abbreviations:

.LOCL. Local clock of the unreliable kind (with a very high stratum value).

.PPS. ("pulse per second") A very accurate time signal such as an atomic clock or a GPS receiver. GPS satellites are considered atomic clocks[3]; a host with a GPS receiver is therefore considered to be on stratum 1. The maximum inaccuracy can be measured in microseconds per second. The PPS signal only provides a very precise sequence of seconds, similar to a metronome; you need to get the actual time from elsewhere.

[2]This uses root-mean-square (RMS), which for n values corresponds to $\sqrt{(x_0^2 + x_1^2 + ... + x_{n-1}^2)/n}$. This means that larger differences carry a greater weight.

[3]Which is even technically accurate.

.DCFa. (and .DCFp.) The DCF77 time signal, which is broadcast from a long-wave radio transmitter in Mainflingen (south-east of Frankfurt am Main, Germany) and can be received throughout most of Europe. The possible accuracy depends on the amount of trouble you want to go to on the receiving side; very simple and cheap receivers like those in popular radio-controlled clocks and watches synchronise to a precision of ±0.1 second, while more accurate receivers use the amplitude-modulated signal (.DCFa.) to achieve practical low-single-digit millisecond precision. If you use the phase-modulated time signal (.DCFp.) and really take pains, you can get to precisions of a few microseconds, depending on the time of day and year.

.BCST. The remote end is a network where this host serves as a broadcast server.

The ntpq program supports a large number of commands which you can use to talk to NTP servers and query data or even (if you have appropriate access rights) change their configuration. Here are a few more examples:

```
$ hostname
blue
$ ntpq
ntpq> peers
     remote           refid   st t when poll reach delay offset jitter
=====================================================================
*red.example.com 129.70.132.37 3 u    1   64  377  1.375 -0.074  0.482
ntpq> associations

ind assid status  conf reach auth condition  last_event cnt
==========================================================
  1  3445  765a    no   yes   ok   sys.peer    sys_peer  5
ntpq> readvar 3445
associd=3445 status=765a authenb, auth, reach, sel_sys.peer, 5 events,▷
 ◁ sys_peer,
srcadr=red.example.com, srcport=123, dstadr=192.168.56.102,
dstport=123, leap=00, stratum=3, precision=-23, rootdelay=37.216,
rootdisp=40.298, refid=129.70.132.37,
reftime=d95fc8c2.3be84526  Sun, Jul 26 2015 22:59:46.234,
rec=d95fc9d8.309cefd3  Sun, Jul 26 2015 23:04:24.189, reach=376,
unreach=0, hmode=6, pmode=5, hpoll=6, ppoll=6, headway=0, flash=00 ok,
keyid=1, offset=0.245, delay=1.375, dispersion=0.960, jitter=0.524,
xleave=0.273,
filtdelay=   1.38  1.38  1.38  1.38  1.38  1.38  1.38  1.38,
filtoffset=  0.24  0.47 -0.07  0.56  0.04 -0.31 -0.06 -0.86,
filtdisp=    0.00  1.01  2.00  2.96  3.95  4.95  5.94  6.92
ntpq> readvar 3445 stratum
stratum=3
```

Exercises

8.3 [2] Discuss the advantages and disadvantages of the various time sources available to ntpd—radio-controlled clock or time server on the Internet.

8.4 [1] Use ntpdate to synchronise your computer's clock to a time server on the Internet.

8.5 [!2] Configure an NTP server on your computer to synchronise its time with that of one or more appropriate time servers. Ensure that the NTP server sets the clock on startup, even if prior to that the time was really wildly wrong (*Hint:* Stop `ntpd`, change the clock using `date`, and then restart `ntpd`.)

8.6 [3] Use a suitable testing environment (lab or classroom network, or a virtualised LAN) to configure a local NTP server and client(s). The latter should fetch their time from the local server (not the Internet). Also experiment with several NTP servers on the network.

8.7 [2] (Building on the previous exercise.) Try the distribution of time announcements by broadcast. Configure a computer as a broadcast server (generate a set of keys to enable this) and another one as a broadcast client. Change the clock on the client and restart `ntpd` there. Observe, using Wireshark, how the client resets its clock. How long does that take? What happens if you subsequently reset the clock again without restarting `ntpd`?

Commands in this Chapter

date	Displays the date and time	date(1)	118
hwclock	Controls a PC's CMOS clock	hwclock(8)	118
ntp-keygen	Generates key material for `ntpd`	ntp-keygen(8)	122
ntpq	Controls NTP servers	ntpq(8)	123
zdump	Outputs the current time or time zone definitions for various time zones	zdump(1)	119
zic	Compiler for time zone data files	zic(8)	119

Summary

- A PC-based Linux system has two clocks: The kernel clock and a battery-driven CMOS clock. Linux uses the CMOS clock only to set the kernel clock when the system is started.
- Linux uses an internal clock that counts seconds in sequence.
- The `hwclock` program is used to manage the CMOS clock.
- With `ntpd`, you can synchronise the clock of your Linux computer to an official time base using NTP.

Bibliography

Clock-Mini-HOWTO00 Ron Bean. "The Clock Mini-HOWTO", November 2000.
`http://www.tldp.org/HOWTO/Clock.html`

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9

Printing on Linux

Contents

Goals

- Understanding the basic processing of print jobs on Linux
- Knowing the CUPS printing system
- Being able to use CUPS user commands for printing
- Being able to administer CUPS printer queues
- Knowing how to install and configure a CUPS server for local, remote and/or network printers

Prerequisites

- Basic knowledge of shell-level I/O
- Editing of text files
- Use of a web browser
- TCP/IP basics (for network printing)

9.1 Overview

In spite of all "paperless office" dreams, most of the work done on a computer ends up on paper sooner or later. Good printing support is therefore mandatory for a modern operating system like Linux—and, with hindsight, not to be taken for granted.

In a multi-user system like Linux, printing is a much more complex task than in traditional "single-user systems" such as DOS or Windows (where it only becomes more complicated if you want to make system x's printer available to users on systems y, z, …). On a Linux system, several logged-in users may "print" a document at the same time, but somehow these jobs must be ordered and printed one after the other. There is nothing wrong in principle with opening the printer like a file (the device is usually called "`/dev/lp0`") and writing data to it, which the Linux kernel will pass on to the actual printer. Only this might lead to several printing processes' output being mixed up. Additionally, this approach would link application programs very closely to the printer model in use and its interface (the parallel port). This is why it is preferable to send printer output to a program that will buffer the printer data until the printer is "free", rather than to the printer itself. Furthermore, this gives an opportunity to, e. g., transparently translate PostScript data produced by the application to a printer-specific language. Such a program (system), which will buffer printer data until they can be printed and then forward them to the printer, is called a **spooler**[1].

spooler

queue

The most common abstraction is that of a **queue**: Print jobs are not sent to a printer directly, but to a queue, where they wait to be processed. Several queues can be assigned to a single "physical" printer, for example one for jobs on normal paper and another for jobs on glossy paper. Similarly, jobs sent to one queue can be passed on to a queue on another computer that organises the actual printing.

Berkeley LPD

The "traditional" Unix/Linux spooler system goes back to BSD and is called **Berkeley LPD** (short for "line printer daemon"). Berkeley LPD supports locally connected printers (e. g., via parallel or serial interfaces) and printers connected to other hosts.

LPD problems

Berkeley LPD is well suited to drive simple daisy-wheel or matrix printers (page printers, too, with some restrictions), but is not quite up to the manifold features of modern printing technology. Nowadays, even simple printers offer simplex and duplex printing, various resolutions, colour or black-and-white printing, economy modes, and many other options that in principle can be enabled or disabled independently of each other. The only way of modelling this in Berkeley LPD is to define different queues, which will lead to a combinatorial explosion even for a single printer. Other weaknesses of Berkeley LPD include the facts that only system administrators may configure printers, that it is tedious to configure all hosts on the network identically, and that Berkeley LPD supports neither printer classes (i. e., several printers being served from the same queue) nor accounting for print jobs.

`/etc/printcap`

With Berkeley LPD, the **`/etc/printcap`** file is used to define the queues available on computer.

Common Unix Printing System

CUPS

Nowadays, the default printing package on almost all common Linux distributions is the **Common Unix Printing System** or **CUPS**. This is a newly conceived printing system, which does offer user commands that are largely compatible to those of Berkeley LPD but functions in a wholly different manner. The same applies to its administration.

Internet Printing Protocol

CUPS is based on the **Internet Printing Protocol**, which is standardised

[1]The popular etymology is "SPOOL", an acronym of "Simultaneous Peripheral Operation On-Line". According to [Jargon], however, this is a "backronym", i. e., a *post-hoc* interpretation of a word as an acronym.

in [RFC2910, RFC2911] and intended to replace the old Berkeley LPD protocol [RFC1179]. Mostly, IPP provides standard operations that can be used to query a printer—in a loose sense, this includes not only "genuine" printers but also printer servers driving one or more non-IPP printers—for its capabilities and feed jobs to it. This includes a type of "negotiation"; a print job may contain a "laundry list" of features such as "two-sided", "toner-saving", etc., which will be matched as closely as possible. You can specify whether, if a desired feature cannot be provided, the job should be rejected or whether the printer should try to approximate what is wanted.

IPP itself makes no assumptions as to *how*, i. e., using what type of protocol or connection, you want to talk to a printer. The canonical transport protocol suggested for IPP, though, is HTTP (see [RFC2910]). This approach has various advantages:

- HTTP is an established and well-understood protocol
- You get various desirable protocol features such as encryption (SSL), proxy support, user authentication, virtually for free, since suitable support exists in HTTP
- Users and system administrators may use standard Web browsers to communicate with IPP servers (a. k. a. printers). Web browser are available on every platform of consequence, starting with PDAs, so that a CUPS-based printing system may be administered from virtually anywhere
- It is easy for printer manufacturers to offer IPP support, since today's high end printers often support a web-based configuration interface, anyway. Nowadays there are many freely available HTTP servers which are suitable as the basis of an IPP implementation within a printer or printer server.

IETF

Furthermore, IPP is being developed under the auspices of the Internet Engineering Task Force and as such enjoys widespread manufacturer support. It is to be assumed that IPP will emerge as an operating-system independent standard solution for network printing. Even half-way current versions of Microsoft Windows (Windows 2000 and Windows ME or later) can access IPP-based printers by default; support can be retro-fitted to older Windows versions—the package is called "Internet Printing Support for Windows" and can be found on Microsoft's web site.

CUPS is an IPP implementation for various Unix version (including Linux) which is developed and distributed under the GPL by a US company called *Easy Software Products*.

ESP was recently acquired by Apple—not an entirely unreasonable move given that MacOS X uses CUPS for printer control, too. So far the freedom of the code has not been called into question.

At the heart of the system there is an HTTP server (called the "scheduler" by CUPS), which not only accepts and processes IPP requests, but also provides the online documentation and allows status queries for printers and jobs. In addition, it keeps and updates a list of available printers. Access to the HTTP server is possible either via HTTP or via a programming interface, the "CUPS API", and CUPS uses the latter to provide user-level commands similar to those of BSD (`lpr`, `lpq`, `lprm`, …) and those of Unix System V (`lp`, `lpstat`, …). Furthermore, CUPS includes various **filters** for different input data formats as well as some **back ends** to drive printers using different connections such as the parallel and serial interfaces, USB, SMB, AppDirect (as used for HP JetDirect-enabled printers) or LPD. In any event, the user sees just the IPP-capable "printer" implemented by CUPS.

filters

back ends

9.2 Commands for Printing

Printing Files: `lpr`, `lp`, and `mpage` In principle, you can print data directly by simply

"direct" printing

sending them to the interface that the printer is connected to:

```
# cat data.txt >/dev/lp0
```

(depending on the permissions you may have to have administrator privileges to do so). This presupposes that nobody else is just then printing something else the same way, and the data must be in a format that the printer understands. More expensive printers, for example, require PostScript input (if not some proprietary format) and perhaps cannot handle plain-text data at all. We still mention this method because it may be useful for troubleshooting; if you can get your printer to print something this way, then at least the hardware, cabling, and other essentials are all right, and you can search the problem within the print system software on your Linux system.

troubleshooting

system programs

In daily life you should rather be using one of the system programs that do not access the printer interface directly but talk to the local printing system (such as CUPS). This way, you will achieve clean sequential job processing, and data conversion into a format suitable for the printer is also arranged much easier.

`lpr`

The most common program for printing is `lpr`. You can use it to either print another program's standard output or the result of a pipeline:

```
$ pr -l50 manual.txt | lpr
```

Or you pass the program a list of files to be printed:

```
$ lpr file1.txt file2.ps
```

When invoking `lpr` you can pass various options: With

```
$ lpr -#3 -Plaser file1.txt
```

for example, three copies of `file1.txt` will be printed to printer `laser` (strictly speaking, submitted to the `laser` queue).

selecting a queue

Unless you specify otherwise, `lpr` submits jobs to the `lp` queue (*Attention:* Some distributions, such as those by SUSE, enable the administrator to change this globally). If you do not want to give a queue name with each job, using the `-P` option, you can set the `PRINTER` environment variable to the name of the desired queue.

`lp`

Besides the `lpr` command, which derives from the Berkeley LPD tradition, many systems support a nearly-equivalent program called `lp`. This comes from Unix System V and is familiar to many users of proprietary Unix systems. The `lp` command

```
$ lp -n 3 -d color file.txt
```

is equivalent to the last `lpr` example shown above.

The CUPS version of `lp` allows a few things that don't work with `lpr`, like retroactive modification of jobs after they have been spooled (as long as they have not yet been printed). This makes it possible to delay print jobs or "freeze" them for an indeterminate period of time before being re-enabled.

The CUPS versions of `lpr` and `lp` support various options that influence the printed output. For example you can request duplex (double-sided) printing using

```
$ lpr -o sides=two-sides-long-edge manual.pdf
```

or print two reduced pages on one by means of

```
$ lpr -o number-up=2 manual.pdf
```

Something like

```
$ lpr -o landscape sign.ps
```

prints in landscape format (the long edge of the paper is at the top and bottom).

The options that are permissible in each specific case depend on the abilities of the printer in question, but here are some common CUPS options:

`media=`⟨*type*⟩ Specifies the paper size and source. Valid values for the paper size include `A4` or `Letter`, a paper source might be given by the tray names `Upper` or `Lower`. The exact values for various printers can be derived from the corresponding PPD files.

`landscape` Prints in landscape format

`sides={one-sided,two-sided-short-edge,two-sided-long-edge}` Controls two-sided printing. `two-sides-short-edge` is useful for landscape pages, `two-sided-long-edge` for portrait pages. `one-sided` causes one-sided printing on queues that use two-sided printing by default.

`jobsheets=`⟨*start*⟩[`,`⟨*end*⟩] Determines whether a "banner" or "burst" page will be printed at the beginning or end of the job. This page contains information about the submitter of the job, date, time, and, e. g., a classification level. The available banner pages depend on the system in question; the standard options include `none` (no banner page), `standard` (no classification), and various pages à la `unclassified`, `confidential`, `topsecret`.

`page-ranges=`⟨*list*⟩ Prints only part of the job's pages. The ⟨*list*⟩ is a comma-separated sequence of page numbers or ranges of pagenumbers, such as "`1-4,7,9-12`".

`page-set={even,odd}` Prints only even-numbered (`even`) or odd-numbered (`odd`) pages.

`outputorder={normal,reverse}` Prints the job's pages in normal or reverse order.

`number-up={1,2,4,6,9,16}` Prints 1, 2, 4, 6, … pages of the job scaled down on one physical page.

`page-border={none,single,single-thick,double,double-thick}` When printing "n-up", no frame will be drawn around each scaled-down page (`none`), a single or double thick or thin frame …

`number-up-layout={btlr,btrl,lrbt,lrtb,rlbt,rltb,tblr,tbrl}` The order of pages for "n-up" printing: `btlr` stands for "*bottom to top, left to right*", `rltb` for "*right to left, top to bottom*" and so on.

`prettyprint` (For text printing.) Outputs a header line on each page containing the page number, the job name (usually the name of the file being printed), and the date. Also attempts syntax highlighting for C and C++ programs, and prints comment lines in italics.

A more extensive list of options is part of the CUPS documentation, which a CUPS server makes available via HTTP on port 631, on the computer with the CUPS server itself, for example, as `http://localhost:631/help/options.html?TOPIC=Getting+Started`.

Tracking Print Jobs Even as a normal user, you may want to figure out the state of the printer queues: Is it worth getting up and walking over to the printer room at the other end of the corridor, or does Mr. Jones from accounting still print his 500-page report for the board while your letter is queued behind that?

The `lpq` command is useful to do this: Called without parameters, it displays the contents of the default queue:

```
$ lpq
lp is ready and printing
Rank   Owner   Job  Files           Total Size
active hugo    333  report.ps       1112942 bytes
```

As with `lpr`, you can specify the name of another queue using the `-P` option, otherwise the value of the `PRINTER` environment variable, alternatively `lp`, applies.

`lpq` with the `-a` option displays the jobs in all queues, and `-l` displays a "long" list (with more information). If ⟨*interval*⟩ is given, the list is redisplayed every ⟨*interval*⟩ seconds until the queue is empty.

The `lpstat` program works quite differently. It uses options to determine what sort of status is to be displayed:

`-a` Shows whether the queues accept jobs

`-c` Displays printer classes and corresponding printers

`-d` Display the current default printer

`-o` [⟨*queue*⟩] Displays the content of ⟨*queue*⟩ (or all queues if none was specified)

`-p` Displays all printers (queues) and show whether they are currently enabled for printing

`-r` Display whether the CUPS server is running

`-s` Displays a status summary (equivalent to "`lpstat -dcp`")

`-t` Displays all status information (equivalent to "`lpstat -rdcvapo`")

`-v` Displays the printers (queues) and the corresponding interfaces and locations

(again, this is just an excerpt from the full list of options).

Cancelling Jobs If you change your mind after submitting a print job, you can cancel it using `lprm`. You will need the job number that `lpq` outputs in the "`Job`" column:

```
$ lprm 333
```

Since job numbers are assigned per queue, you may have to specify a queue name by means of the `-P` option. You can get rid of all your pending print jobs using

```
$ lprm -
```

Cancelling others' jobs

As a normal user, you can only cancel your own print jobs (Mr. Jones would not be amused). To cancel other users' print jobs using `lprm`, you must assume administrator privileges.

Limitations

You can only use `lprm` to cancel jobs that have not been sent to the printer. Today's printers often sport large internal memories which can hold one jobs or many that are still far from actually being printed, and your computer cannot usually influence these jobs any longer. Whether a big job can be cancelled that is currently half-way through being sent to the printer depends on the system.

The System-V-like command, `cancel`, expects a combination of the queue name and job number:

```
cancel ⟨queue name⟩-⟨job number⟩
```

```
application/pdf         pdf string(0,%PDF)
application/postscript  ai eps ps string(0,%!) string(0,<04>%!) \
                        contains(0,128,<1B>%-12345X) + \
                        (contains(0,1024,"LANGUAGE=POSTSCRIPT") \
                         contains(0,1024,"LANGUAGE = Postscript") \
                         contains(0,1024,"LANGUAGE = POSTSCRIPT"))
image/gif               gif string(0,GIF87a) string(0,GIF89a)
image/png               png string(0,<89>PNG)
image/jpeg              jpeg jpg jpe string(0,<FFD8FF>) &&\
                        (char(3,0xe0) char(3,0xe1) char(3,0xe2) char(3,0xe3)\
                         char(3,0xe4) char(3,0xe5) char(3,0xe6) char(3,0xe7)\
                         char(3,0xe8) char(3,0xe9) char(3,0xea) char(3,0xeb)\
                         char(3,0xec) char(3,0xed) char(3,0xee) char(3,0xef))
image/tiff              tiff tif string(0,MM) string(0,II)
```

Figure 9.1: The `mime.types` file (excerpt)

Default Values for Printing Options The printing options that you can specify using the `-o` option with `lpr` and `lp` have certain system-wide defaults which were established when the queue was first installed. Later on, it is possible to change these defaults either as the administrator (so they will apply to all users) or as a user (so they will apply for oneself). Of course this does not keep users from being able to use command-line options to set up different options on a job-by-job basis.

Printing options are set using the `lpoptions` command, which accepts the same `-o` options as `lpr` and `lp`. These options are applied to all queues or, if a particular queue was selected using the `-p` options, that queue only. `lpoptions` enters the options in question into the `~/.lpoptions` file, where `lpr` and `lp` can pick them up later. "`lpoptions -l`" displays the option names, their possible values, and the current values (labelled using an asterisk).

If the system administrator invokes `lpoptions` as user `root`, the options apply to all users as the system-wide default. There are no printer options for `root`.

Exercises

9.1 [2] Check out some of CUPS's printing options: Try, for example, to print a job scaled down, backwards or two-sided, or to select particular page ranges.

9.2 [2] Set up a queue as a "normal" user such that normally two pages of a job will be scaled down and printed alongside each other on a landscape page. Ensure that jobs with no particular options are really printed like that. Then print a non-scaled job without permanently changing the default settings.

9.3 CUPS Configuration

9.3.1 Basics

If a user submits a print job on CUPS—either via one of the BSD- or System-V-like programs provided with CUPS, or a program that uses the CUPS API directly, such as KDE's `kprinter`—, the job is stored in the appropriate queue first. In addition to the actual print data, this includes "metadata" such as the submitter's user name or the desired options for the print-out (two-sided, …). The scheduler removes the job from the queue and tries first to convert the print data to PostScript.

print job

queue

```
application/pdf        application/postscript  33      pdftops
application/postscript  application/vnd.cups-postscript 66      pstops
application/vnd.hp-HPGL application/postscript  66      hpgltops
application/x-shell     application/postscript  33      texttops
text/plain              application/postscript  33      texttops
text/html               application/postscript  33      texttops
image/gif               application/vnd.cups-postscript 66      imagetops
image/png               application/vnd.cups-postscript 66      imagetops
image/jpeg              application/vnd.cups-postscript 66      imagetops
```

Figure 9.2: The `/etc/cups/mime.convs` file (excerpt)

To do so, it consults the `/etc/cups/mime.types` file (see Figure 9.1) in order to determine the data type in question. `mime.types` contains the names of MIME types and, with each MIME type, a set of criteria used to recognise files of that type. For example, the rule

```
image/gif    gif string(0,GIF87a) string(0,GIF89a)
```

identifies a file as a GIF image if its name ends in "`gif`", or the content starts with either of the strings "`GIF87a`" or "`GIF89a`". (The exact rules for criteria are stated in detail at the beginning of the `mime.types` file.)

Once the MIME type of the print file is known, CUPS can try to convert this to a printable format, namely `application/vnd.cups-postscript`. Various filter programs are provided to help with this, and their use is described within the `/etc/cups/mime.convs` file (Figure 9.2). This lists various programs (at the right-hand side of a line) that are able to convert data from the type given in the leftmost column to that given in the second column. Every conversion is assigned a "cost" which can be used to prefer direct conversions to indirect ones. For example, HPGL data can be converted to the CUPS PostScript format via `application/postscript`, which incurs a "cost" of 99 units; if there was a direct converter, it would be preferred if its cost was less than 99.

filter programs

pstops

Most formats are converted to "generic" PostScript first, while the `pstops` program is used to convert it to CUPS-specific PostScript. This is quite an important step, since the `pstops` program used for this will, e. g., determine and log the number of pages in the job (which is not immediately obvious from the PostScript file without executing it at least rudimentarily). In addition, `pstops` provides some other very useful extras that were not usual at all for Unix printing systems in the pre-CUPS era—for example, several pages can be scaled down and output on a single physical sheet (`ps-n-up`), or particular pages can be selected from a larger job for actual printing (`psselect`), without the application having to support this feature at all.

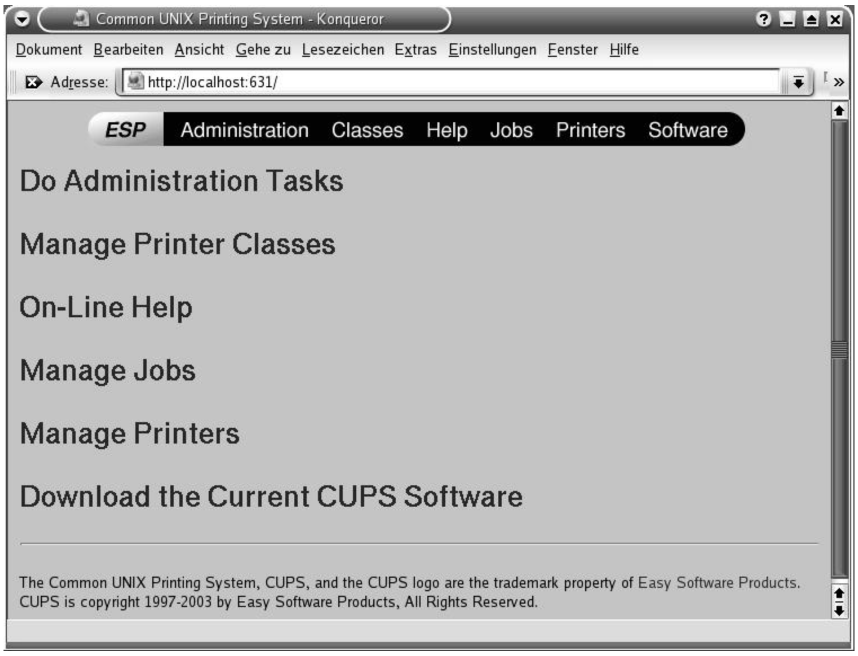
extras

The CUPS-specific PostScript file will then be either passed on directly (if the job is to end up on a genuine PostScript printer) or translated to a printer-specific language such as PCL or ESC/P with GhostScript. The actual printer output (or transfer to another print server) will be performed by one of the "back ends" in `/usr/lib/cups/backend`.

PCL
ESC/P

The most important element of the CUPS configuration for a certain printer are **PPD files** (short for "PostScript Printer Description"). A printer's PPD file describes which special options (resolution, duplexing, various paper feeding methods, …) the printer supports, and CUPS can pass this information on to application programs that then allow the user convenient access to each printer's capabilities. For a PostScript printer, a PPD file should be furnished (or made available on the Web) by the manufacturer; for many—even non-PostScript—printers, PPD files as well as many other hints can be found on `http://www.linuxprinting.org`. PPD files are useful for PostScript as well as non-PostScript printers and thus can be

PPD files


Common UNIX Printing System - Konqueror
Dokument Bearbeiten Ansicht Gehe zu Lesezeichen Extras Einstellungen Fenster Hilfe
Adresse: http://localhost:631/
ESP Administration Classes Help Jobs Printers Software

Do Administration Tasks

Manage Printer Classes

On-Line Help

Manage Jobs

Manage Printers

Download the Current CUPS Software

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Figure 9.3: The CUPS web interface

found somewhere for nearly all printers. There is a reasonable chance that either CUPS or the Linux distribution will contain PPD files for all but the most extraordinary printer models; if necessary, an additional software package from the distribution may have to be installed.

Exercises

9.3 [2] Check on `http://www.linuxprinting.org` whether your printer is supported by Linux, and download a PPD file for it if one exists.

9.3.2 Installing and Configuring a CUPS Server

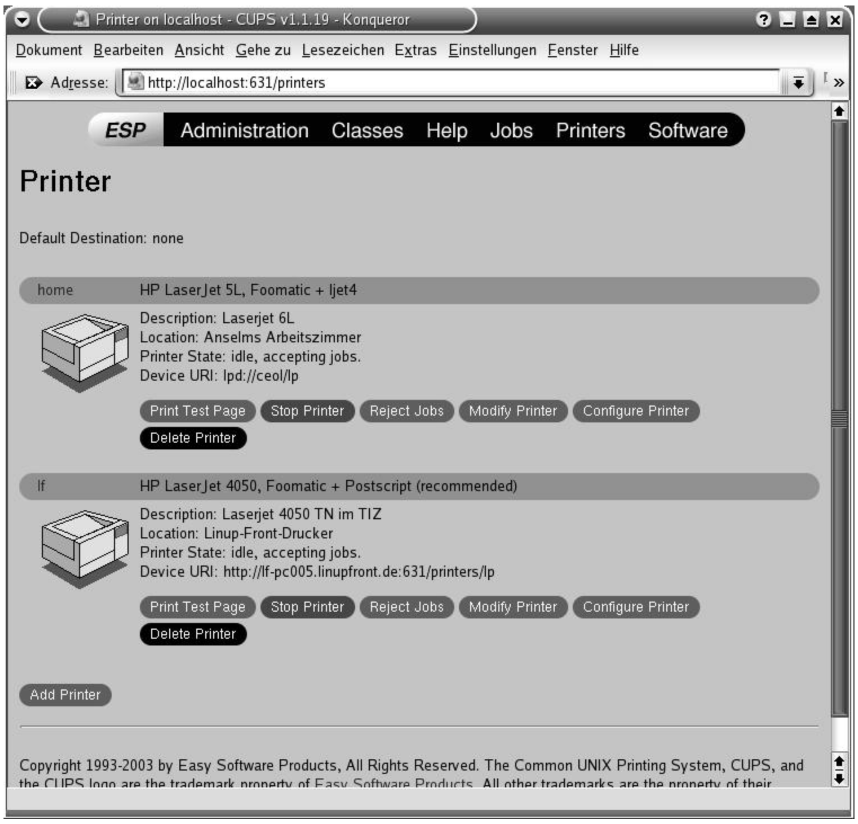
Today, CUPS is part of all important Linux distributions or can at least be installed straightforwardly.

The Novell/SUSE distributions have been using CUPS as the default printing system for a very long time.

For Debian GNU/Linux and Ubuntu, CUPS is available as the packages `cups` (Server), `cups-bsd` (LPD-like commands), and `cups-client` (System-V-like commands). On top of that there is a whole lot of other support packages (try "`apt-cache search cups`").

CUPS allows various methods for printer configuration. The CUPS web server lets you create printer queues using a WWW browser, and there are also command line tools to do so. The Novell/SUSE distributions contain a CUPS module for SUSE's system administration tool, YaST2.

Configuration Using a Web Browser To configure printer queues using a web browser, invoke the `http://localhost:631/` URL on the CUPS machine (631 is the TCP port assigned to IPP). The CUPS interface should be displayed (Figure 9.3).—In principle, this can be accessed from any computer, but in the default configuration, IPP operations are only accepted from the same host. Via the *Printers* button you can reach the printer administration page (Figure 9.4 shows an example with two printers already installed), and by means of the *Add Printer* button there you will obtain the page to add new printers (Figure 9.5).


Printer on localhost - CUPS v1.1.19 - Konqueror
Dokument Bearbeiten Ansicht Gehe zu Lesezeichen Extras Einstellungen Fenster Hilfe
Adresse:
ESP Administration Classes Help Jobs Printers Software
Print Test Page
Stop Printer
Reject Jobs
Modify Printer
Configure Printer
Delete Printer
Add Printer

http://localhost:631/printers

Printer

Default Destination: none

home HP LaserJet 5L, Foomatic + ljet4

Description: Laserjet 6L
Location: Anselms Arbeitszimmer
Printer State: idle, accepting jobs.
Device URI: lpd://ceol/lp

lf HP LaserJet 4050, Foomatic + Postscript (recommended)

Description: Laserjet 4050 TN im TIZ
Location: Linup-Front-Drucker
Printer State: idle, accepting jobs.
Device URI: http://lf-pc005.linupfront.de:631/printers/lp

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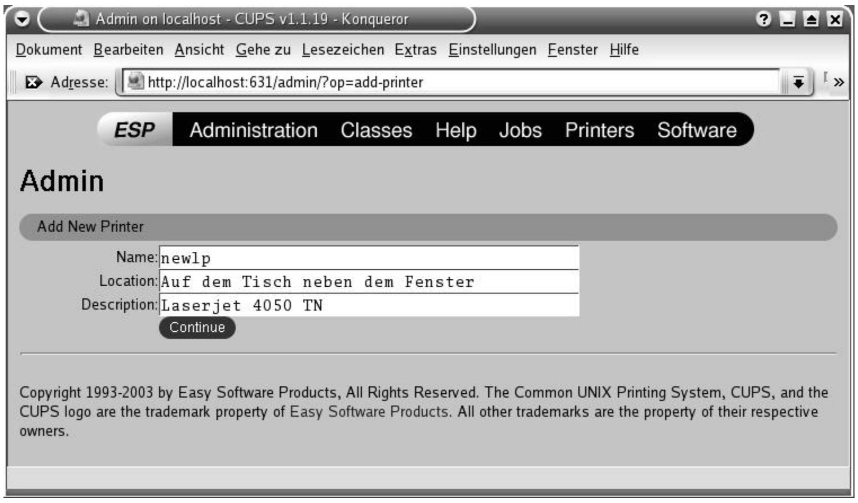
Figure 9.4: The CUPS web interface: Printer management


Admin on localhost - CUPS v1.1.19 - Konqueror
Dokument Bearbeiten Ansicht Gehe zu Lesezeichen Extras Einstellungen Fenster Hilfe
Adresse:
ESP Administration Classes Help Jobs Printers Software
Continue

http://localhost:631/admin/?op=add-printer

Admin

Add New Printer

Name: newlp
Location: Auf dem Tisch neben dem Fenster
Description: Laserjet 4050 TN

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Figure 9.5: The CUPS web interface: Adding a printer

Here you will have to enter a name for the printer (actually the queue) first; the other two fields ("Location" and "Description") are not strictly necessary but may help users to relate the queue name to an actual printer (they need to know where to collect their print-outs).

The next dialog is used to select a back end. This includes options such as parallel or serial interfaces, USB, or various networked options such as LPD, IPP, JetDirect, or Windows printers (via Samba). Depending on what you select here, you will have to enter a URL for the printer (e. g., `lpd://lpdserver/lp` or `ipp://ippserver/printers/myprinter`) which determines how the printer is really supposed to be accessed; for printers connected directly to interfaces or the USB this is very straightforward.

Finally, you need to pick a particular printer model. CUPS offers you the PPD files stored below `/usr/share/cups/model`—with the GPL version, these are just a few for the most common printers, but on the one hand manufacturers such as SUSE may have increased the number of options somewhat, and on the other hand you are free to download a matching PPD file from `www.linuxprinting.org` and put it there. After the final confirmation, your new printer is available below *Printers* and may be used. It is probably best to begin by printing a test page ("*Print Test Page*") in order to check whether the creation really did work.

The SUSE distributions' YaST2 administration tool provides a printer configuration GUI which is about as convenient as CUPS's own web interface. Unlike vanilla CUPS, YaST contains a vastly more extensive database of PPD files and also tries to recognise the printer type automatically. After the printer has successfully been recognised, YaST allows either a "fast automatic setup", where several queues, e. g., for colour and black-and-white printing, will be set up, or a "normal setup" where you will be expected to enter queue names, printer locations and types, etc., manually. Within the normal setup, you can also specify options for the queue such as the paper size and resolution, burst pages (if desired) or access control for specific users, which are not accessible via the CUPS web interface but must be set up using command line tools or configuration files.

Finally, it is also possible to install new printers using the `lpadmin` command-line tool. `lpadmin` is based on the eponymous System V tool, but not completely compatible. You could, for example, configure a Laserjet printer connected to the parallel interface as follows:

```
# lpadmin -p newlp -E -v parallel:/dev/lp0 -m laserjet.ppd
```

Here, `newlp` is the new queue's name, the `-E` option enables the queue so it will accept jobs, the `-v` option specifies the connection details for the printer, and the `-m` option names the printer's PPD file (which must be located within `/usr/share/cups/model`). A description and location as in the web interface can be specified using the `-D` and `-L` options. More information can be found in `lpadmin`(8).

The `lpinfo` command may be handy for printer installation. "`lpinfo -v`" outputs a list of available connection types, and "`lpinfo -m`" provides a list of PPD files (and thus printer types).

"`lpadmin -p`" also lets you modify existing printer configurations. "`lpadmin -x`" removes a printer that is no longer required.

In any case, the installed printers' configuration is placed in the `/etc/cups/printers.conf` file. For every installed printer there is a PPD file in `/etc/cups/ppd` (Figure 9.6).

General configuration settings for the CUPS scheduler can be found in the `/etc/cups/cupsd.conf` file. This file's syntax is very like that of the Apache web server's configuration file. Most important are the settings for access permissions and authentication. By default, the CUPS scheduler may only be accessed from

```
# Printer configuration file for CUPS v1.1.19
# Written by cupsd on Thu Jul 31 23:51:00 2003
<DefaultPrinter newlp>
Info Laserjet 4050 TN
Location Auf dem Tisch neben dem Fenster
DeviceURI lpd://localhost/lp
State Idle
Accepting Yes
JobSheets none none
QuotaPeriod 0
PageLimit 0
KLimit 0
</Printer>
<Printer home>
Info Laserjet 6L
◁◁◁◁◁
```

Figure 9.6: An /etc/cups/printers.conf file (excerpt)

the local host (the IP address 127.0.0.1). To use CUPS as a printer server in a local network, this restriction must be relaxed somewhat. This can be done by means of definitions such as

```
<Location /printers>
  Order Deny,Allow
  Deny from all
  Allow from 127.0.0.1
  Allow from 192.168.123.0/24
</Location>
```

or

```
<Location /printers/newlp>
  Order Allow,Deny
  Allow from 127.0.0.1
  Allow from 192.168.123.0/24
  Deny from 192.168.123.45
</Location>
```

The first example restricts access to all printers to the local system and the computers within network 192.168.123.0/24; in the second example, access to printer newlp only is enabled for the local system and the computers within the 192.168.123.0/24 network, except that host 192.168.123.45 is excluded. Access to the CUPS web administration interface can be controlled in a similar manner.

Besides this authentication based on IP addresses, user-based authentication via user names and passwords is also possible, as is using SSL or TLS to secure IPP operations, where the CUPS server and (possibly) the user are authenticated using X.509 certificates. In effect, this makes it possible to use CUPS as a secure, efficient "fax" service on the Internet.

Exercises

9.4 [1] Which different back ends does your CUPS implementation provide?

9.5 [2] Install a printer. If no printer is connected directly to your system, specify a network printer as the destination for print jobs (your trainer will provide you with any required information).

9.6 [2] Make your printer queue accessible to the other systems within the local network. Assure yourself that these systems may submit print jobs and that these will be printed.

9.7 [2] Why can it make sense to install several queues for the same printer?

9.3.3 Miscellaneous Hints

T-Shirts and Such To print images in mirror image from arbitrary application commands—e. g., on t-shirt transfer paper—, the `mirror` option can be used:

```
$ lpr -o mirror mypic.jpg
```

Troubleshooting When CUPS printing does not work like it should, you should inspect the CUPS log first. CUPS logs details of its work to `/var/log/cups/error_log` (the location may vary between distributions). The amount of log data written depends on the `LogLevel` directive in the `/etc/cups/cupsd.conf` file; the `debug2` value writes the most extensive protocol.

Commands in this Chapter

cancel	Cancels a submitted print job	cancel(1)	132
lp	Submits a print job	lp(1)	130
lpadmin	Manages printer job queues	lpadmin(8)	137
lpinfo	Displays available printer devices and drivers	lpinfo(8)	137
lpoptions	Manages default settings for printer queues	lpoptions(1)	133
lpq	Displays a printer queue's status	lpq(1)	131
lpr	Submits a print job	lpr(1)	130
lprm	Cancels a print job	lprm(1)	132
pstops	Prepares PostScript print jobs for CUPS		134

Summary

- Printing on Linux is a complex task.
- CUPS is an implementation of the "Internet Printing Protocol", an HTTP-based industry standard for accessing network printers.
- CUPS allows the customisation of the system for given printers using PPD files. It supports filter programs for various data formats and can handle different types of printer connection.
- Printers for CUPS can be configured via the CUPS internal web server, the command line, or distribution-specific tools such as "YaST" on the SUSE distributions.

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10
The Secure Shell

Contents

Goals

- Knowing how to use and configure the Secure Shell (SSH)

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 3)
- Knowledge about Linux network configuration (chapter 4)
- A basic awareness of cryptography is helpful

10.1 Introduction

SSH ("Secure Shell") is a TCP/IP-based networking protocol. It provides data transmission in a public network using strong authentication and encryption. Its applications include interactive sessions, file transfer, and the secure forwarding of other protocols ("tunneling").

Encryption is important to keep unauthorised people listening to the network traffic from being able to read the content being transferred. Authentication ensures one the one hand that you as the user are talking to the correct server, and on the other hand that the server lets you access the correct user account.

OpenSSH **OpenSSH**, which comes with most Linux distributions, is a freely available implementation of this protocol. This implementation contains some SSH clients as well as an SSH server (`sshd`).

attacks Used properly, SSH can prevent the following attacks:

- "DNS spoofing", i. e., forged or adulterated DNS entries.
- "IP spoofing", where an attacker sends datagrams from one host which pretend that they come from another (trusted) host.
- IP source routing, where a host can pretend that datagrams come from another (trusted) host.
- Sniffing of passwords and content transmitted in the clear on hosts along the transmission path.
- Manipulation of transmitted data by hosts along the transmission path.
- Attacks on the X11 server by means of sniffed authentication data and spoofed connections to the X11 server.

Use SSH offers a complete replacement for the insecure TELNET, RLOGIN and RSH protocols. In addition, it enables users to copy files from or to remote hosts and is thus a secure replacement for RCP and many applications of FTP.

protocol versions There are two versions of the SSH protocol, 1 and 2. Most servers can accept connections using both versions. Still, please do avoid version 1, which exhibits various security vulnerabilities.

10.2 Logging Into Remote Hosts Using `ssh`

To log into a remote host using SSH, you need to invoke the `ssh` command, for example like

```
$ ssh blue.example.com
hugo@blue.example.com's password: geHe1m
Last login: Mon Feb  2 10:05:25 2009 from 192.168.33.1
Debian GNU/Linux (etch/i686) blue.example.com
hugo@blue:~$ _
```

`ssh` assumes that your user name on the remote host is the same as the local one. If this isn't the case, you can set your remote user name like

```
$ ssh hschulz@blue.example.com
```

Under the hood, approximately the following steps take place to establish the connection:

- Client and server send each other information about their host keys, supported cryptographic schemes, and so on. The client checks whether the server's public key is the same as it used to (see below for more information) and negotiates a shared secret with the server, which then serves as the (symmetric) key to encrypt the connection. At the same time the client checks the server's authenticity and breaks the connection if there is any doubt. The (gory) details are in [RFC4253].
- The server checks the client's authenticity using one of several different methods (in this case it asks for a password). The password is already sent over the encrypted connection and, unlike other protocols like FTP or TELNET, cannot be "sniffed" by people who listen in.

The first step is quite important. The following example shows what happens if you contact the remote host for the first time:

```
$ ssh blue.example.com
The authenticity of host 'blue.example.com (192.168.33.2)' can't be▷
 ◁ established.
RSA key fingerprint is 81:24:bf:3b:29:b8:f9:f3:46:57:18:1b:e8:40:5a▷
 ◁ :09.
Are you sure you want to continue connecting (yes/no)? _
```

The host blue.example.com is still unknown here, and ssh asks you to verify its host key. *This is to be taken seriously.* If you skip this verification step, you lose the guarantee that nobody is listening in to your connection.

The danger is here that somebody will intercept your connection request and pretend that they are blue.example.com. Behind the scenes they can establish their own connection to blue.example.com and pass everything along that you (naively) send to them, and conversely forward blue's answers back to you. You don't see the difference, but the attacker can read everything that you transmit. This is called a "man-in-the-middle attack".

To check, you need to contact the remote system's administrator (e. g., by telephone) and ask them to read their public host key's "fingerprint". This can be displayed using "ssh-keygen -l" and must be identical to the "RSA key fingerprint" from the SSH login dialogue.

SSH key pairs

The SSH key pairs of a host can be found in the ssh_host_*x*_key and ssh_host_*x*_key.pub files within the /etc/ssh directory. *x* stands for a specific cryptographic method which clients can use to check the server's authenticity.

Possible values for *x* include (July 2015):

rsa The RSA algorithm. This is secure (according to the current state of the art), as long as you use keys that are longer than 1024 bits. (2048 bits sound good. Use 4096 bits if you're Edward Snowden or are otherwise assuming that organisations like the NSA have it in for you specifically—and not only accidentally at random.)

dsa The DSA algorithm. This only allows 1024-bit keys and should be avoided today, also because it is susceptible to weaknesses in random number generation.

ecdsa The DSA algorithm based on elliptic curves. This lets you pick between 256, 384, and 521 bits[1]. (Elliptic curves do not need as many bits, so the lower numbers are unproblematic.)

[1]Yes, indeed 521, this is not a typo for 512. ($2^{521} - 1$ is a Mersenne prime number, and that makes the implementation faster. 521 bits are pretty much overkill, though.

`ed25519` A fast and (according to current knowledge) very secure method invented by Daniel J. Bernstein. Within the Secure Shell context this is still fairly new.

You probably won't go wrong with 2048-bit RSA, at least for the next few years. If you're sure that your clients and servers support Ed25519, then that is a suitable alternative.

A "key pair", just so we mention this, is a set of two matching keys (!), one private and one public. The public key may be told to everyone as long as the private key stays confidential. Whatever is encrypted using the public key can *only* be decrypted using the private key from the same pair, and vice versa.

If the remote host's public key is authentic, then reply to the question with "`yes`". `ssh` then stores the public key in the `~/.ssh/known_hosts` file to use as a base for comparison during future connection requests.

Should you ever see a message like

```
$ ssh blue.example.com
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@    WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!     @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now (man-in-the-middle▷
 ◁ attack)!
It is also possible that the RSA host key has just been changed.
The fingerprint for the RSA key sent by the remote host is
38:fa:2e:d3:c7:c1:0f:26:2e:59:e8:16:a4:0a:0b:94.
Please contact your system administrator.
Add correct host key in /home/hugo/.ssh/known_hosts to get rid of▷
 ◁ this message.
Offending key in /home/hugo/.ssh/known_hosts:4
RSA host key for blue.example.com has changed and you have requested▷
 ◁ strict checking.
Host key verification failed.
```

when trying to establish an `ssh` connection, you may be about to become the victim of a man-in-the-middle attack—the public key that the server presents does not equal the one stored for the server in the `known_hosts` file. You should contact the remote host's administrator to find out what is going on—perhaps the host key needed to be changed for other reasons.

You can change this behaviour by changing the appropriate setting in the `~/.ssh/config` file:

```
StrictHostKeyChecking ask                              default setting
StrictHostKeyChecking no                        always accept everything
StrictHostKeyChecking yes                       never accept anything new
```

When "`StrictHostKeyChecking yes`" is set, you can only establish connections to hosts that are already in your `known_hosts` file. All others will be refused.

After having established a connection using `ssh`, you can use the remote host as if you sat in front of it. You can close the connection using `exit` or Ctrl+d.

Unless you specify otherwise, during interactive `ssh` sessions the tilde ("~") will be considered a special "escape character" if it occurs immediately after a newline character. This lets you control `ssh` during an ongoing session. In particular, the "`~.`" sequence will close the connection, which may come in useful if a program has become stuck at the "other end". You can do other interesting things—look at the "ESCAPE CHARACTERS" section of `ssh`(1).

Incidentally, ssh does not restrict you to interactive sessions, but lets you execute single commands on the remote host:

```
$ ssh blue.example.com hostname
hugo@blue.example.com's password: geHe1m
blue.example.com
$ _
```

Of course you need to take into account that the shell on *your* computer will try to process the command line in order to replace shell wildcard patterns etc. before it is transmitted to the remote host. Use backslashes or quotes if you are in doubt.

Exercises

10.1 [!1] Use the ssh command to log in to another host (if necessary, your instructor will tell you which one). What happens? Log out and log in again to the same host. What is different?

10.2 [2] Remove the remote host's entry created during Exercise 10.1 from the ~/.ssh/known_hosts file and set the StrictHostKeyChecking parameter in the ~/.ssh/ssh_config file to yes. Try logging in to the remote host again. What happens? What happens if the option StrictHostKeyChecking is set to no?

10.3 [2] Must the ~/.ssh/known_hosts file be readable for the user only and if so, why? (If not, why not?)

10.4 [!2] Execute the hostname and date commands on the remote host, using a single invocation of the ssh command.

10.3 Other Useful Applications: scp and sftp

Using scp you can copy files between two hosts via an SSH connection:

```
$ scp blue.example.com:hello.c .
hugo@blue.example.com's password: geHe1m
hello.c   100% |***********************| 33 KB   00:01
```

The syntax is based on the cp command: Just like with cp, you can specify two file names (source and destination) or a list of file names and a destination directory. With the -r option, scp copies directory contents recursively.

You may even copy files between two different remote hosts:

```
$ scp hugo@blue.example.com:hello.c \
>    hschulz@pink.example.com:hello-new.c
```

The sftp command is inspired loosely by common FTP clients, but needs an SSH connection. It has nothing whatsoever to do with FTP otherwise—in particular, you cannot use it to communicate with an FTP server.

After having established a connection using a command like

```
$ sftp hugo@blue.example.com
```

you can use commands such as get, put, or mget to transfer files between your local host and the remote host, inspect the contents of a directory on the remote host using ls, and change into different directories there by means of cd. At the beginning of a session you will be placed in your home directory on the remote computer.

10.4 Public-Key Client Authentication

Normally the SSH server will authenticate you as a user by means of a pasword that is assigned to your account on the server (usually in `/etc/passwd` or `/etc/shadow`). Since the password is queried only after the encrypted connection has already been established, this is in principle safe from unwanted listeners. However, you may be bothered by the fact that your password itself is stored on the server—even though it is encrypted, the password file could fall in the hands of crackers who then apply "John the Ripper" to it. It would be better if nothing secret about you would be stored on the remote host at all.

You can achieve this by using public-key client authentication instead of the simple password-based client authentication. In a nutshell, you create a key pair consisting of a public and a private key and deposit the public key on the SSH server. The public key does not need to be specially protected (it is a *public* key, after all); you will need to sit on the private key, but it will never leave your own computer (which you never let out of your sight, don't you?).

You can also put your private key on an USB stick if you think that will be more secure.

The server can authenticate you as the rightful owner of the private key matching the deposited public key by generating a random number, encrypting it using the public key, and sending it to you. You decrypt (or rather, your `ssh` decrypts) the encrypted random number using the private key. The result is returned to the server, which compares it to its original random number, and if the two match it believes you that you are yourself.

Of course all of this takes place across the encrypted connection and is therefore secure from unwanted listeners and scumbags that want to mess with your data.

To use public-key client authentication, you first need to generate a key pair. This is done using the `ssh-keygen` command:

```
$ ssh-keygen -t rsa -b 2048                                      or ed25519
Generating public/private rsa key pair.
Enter file in which to save the key (/home/hugo/.ssh/id_rsa): ↩
Created directory '/home/hugo/.ssh'.
Enter passphrase (empty for no passphrase): secret
Enter same passphrase again: secret
Your identification has been saved in /home/hugo/.ssh/id_rsa.
Your public key has been saved in /home/hugo/.ssh/id_rsa.pub.
The key fingerprint is:
39:ab:15:f4:2f:c4:e6:21:26:c4:43:d7:27:22:a6:c4 hugo@blue
The key's randomart image is:
+---[RSA 2048]----+
|   .  . ..       |
|    Eoo.. o .    |
|   . o+... o     |
|    .. o +       |
|      . S *      |
|       o O o     |
|        o o .    |
|       o   .     |
|      .          |
+-----------------+
```

The command first asks where you would like the key pair to be stored. The default is reasonable and you should simply confirm it.

Next, ssh-keygen asks for a "passphrase". This is used to encrypt the private key in order to prevent somebody who happens to find your private key from impersonating you to the SSH server.

You can (and should) really use a longer sentence here. A shorter password from a variegated mixture of letters, digits, and special caharacter is probably O. K., too. The usual rules for that kind of secret apply.

You must use keys without a passphrase for non-interactive SSH connections, e. g., for shell scripts and cron jobs. In this case you just press ↩ when you are asked for the passphrase.

It is possible to connect a public key on the server with a particular command. Client connections using this public key will then not launch a shell session; instead, the command in question will be started directly. This can significantly mitigate the security risk connected with unencrypted private keys for the use of scripts.

The result of ssh-keygen are the two files id_rsa and id_rsa.pub in the ~/.ssh directory. The former contains the private and the latter the public key.

If you have specified "-t ed25519" during the key generation, the files are, of course, called id_ed25519 and id_ed25519.pub.

The ssh-keygen command also shows you the fingerprint of the public key and a "randomart image". The latter is a graphical representation of the public key, a kind of graphical fingerprint. Theoretically this should enable you to tell at a glance whether a public key has changed or not. The idea is, with all due respect, debatable.

Of course nobody prevents you from invoking ssh-keygen multiple times in order to generate several key pairs with different encryption methods. (Or several key pairs with the same encryption method for use with different servers. You will naturally need to ensure that these use different file names.)

The next step is to deposit the public key, i. e., the content of the id_rsa.pub file, in the ~/.ssh/authorized_keys file in your user account on the remote host. This is most easily done using the ssh-copy-id command:

```
$ ssh-copy-id hugo@blue.example.com
hugo@blue.example.com's password: geHe1m                    Ein letztes Mal
Now try logging into the machine, with "ssh 'hugo@blue.example.com'",▷
 ◁ and check in:

  .ssh/authorized_keys

to make sure we haven't added extra keys that you weren't expecting.

$ _
```

Of course you could just as well do that "the hard way" using scp and/or ssh. Just make sure not to overwrite any keys that may already exist in ~/.ssh/authorized_keys and that you would want to hang on to.

If you set the PasswordAuthentication entry in the /etc/ssh/sshd_config file on the server to no and PubkeyAuthentication to yes, then users can *only* authenticate via the public key method. This is basically a good idea since crackers enjoy running automatic programs that try obvious passwords on SSH servers.

Public-key authentication, if you are using a passphrase, is not more convenient than password authentication, but considerably more secure. If you want to log in to the same host as the same user several times in a row, constantly re-entering the passphrase can be a nuisance, though. The `ssh-agent` was developed to help with this.

`ssh-agent` The `ssh-agent` program remembers the passphrase and passes it to SSH client programs as needed. The program is started using, e. g., "`ssh-agent bash`". This `ssh-add` opens a new `bash`, in which you must add the passphrase using `ssh-add`:

```
$ ssh-add
Enter passphrase for /home/test/.ssh/id_rsa: Quoth the raven
Identity added: /home/test/.ssh/id_rsa (/home/test/.ssh/id_rsa)
```

Every instance of `ssh`, `scp`, or `sftp` started from the new shell gets the passphrase from the SSH agent. The agent "forgets" the passphrase once you leave the shell using `exit` or instruct it, using "`ssh-add -D`", to forget all stored identities..

With Debian GNU/Linux, the login shell/GUI may be started with the `ssh-agent` active right away, so you can `ssh-add` your passphrase at the very beginning of your session.

To be fair, we ought to mention that `ssh-agent` increases convenience to the detriment of security. If you leave your computer unattended (or if you lose your "suspended" laptop), an unauthorised person might be able to use the SSH programs without being asked for a passphrase. The same applies to programs that somehow get access to your session, such as viruses, worms and other vermin …

Exercises

10.5 [!2] Using `ssh-keygen`, create an RSA key pair for SSH version 2. (Remember, at least 2048 bits!) Install the public key on the remote host and check that you are no longer asked for the remote password upon login. What do you need to enter instead?

10.6 [!1] Determine your public key's "fingerprint".

10.7 [2] Under what circumstances might you want to refrain from using a passphrase for your private key?

10.5 Port Forwarding Using SSH

10.5.1 X11 Forwarding

executing GUI programs Using X11 forwarding, you can execute graphical programs on a remote host, where graphics output and keyboard/mouse input take place on your local computer. You merely need to use `ssh` to log in to the remote host, giving the `-X` (uppercase X!) option. On the server side, X11 forwarding (parameter `X11Forwarding` in `/etc/ssh/sshd_config`) must be enabled.

After logging in using "`ssh -X [`⟨*user name*⟩`@]`⟨*host*⟩" you may execute arbitrary X clients whose input and output are directed to the local X server. This is due to several factors:

- When logging in using `-X`, the `DISPLAY` variable is set up to point to a "proxy" X server provided by `sshd`. This directs X clients started on the remote host to this server.

- Everything a remote X client sends to the proxy X server is sent to the (real) X server on the SSH client.

- All the X11 traffic is encrypted so eavesdroppers cannot listen in (tunneling).

You can also enable X11 forwarding globally in order to avoid having to type the `-X` option. You just need to add "`ForwardX11 yes`" to your `~/.ssh_config` (or `/etc/ssh/ssh_config` for a system-wide default).

X11 forwarding is preferable to the standard X packet redirection (using `DISPLAY`) not only because of its increased security but also because it is much more convenient. You pay for this with some extra effort for encryption, which on modern hardware ought to be barely noticeable.

Even X11 forwarding is not without its security risks. Users who can circumvent file access rights on the remote host (e. g., because they are `root`) may access your local X11 display. For this reason you should probably avoid enabling X11 forwarding globally. The same risk exists, of course, with "conventional" X11 redirection using `DISPLAY`.

10.5.2 Forwarding Arbitrary TCP Ports

Port forwarding

SSH can forward and tunnel not only the X protocol, but also nearly every other TCP-based protocol. This can be set up using the `-R` and `-L` options. The following command tunnels connections to the local TCP port 10110 first via an SSH connection to the computer `blue.example.com`. From there it continues (unencrypted) to the TCP port 110 (POP3) on the `mail.example.com` host:

```
$ ssh -L 10110:mail.example.com:110 hugo@blue.example.com
```

The benefit of this approach is approximately as follows: Imagine your firewall blocks POP3 but passes SSH. By means of the port redirection you can enter the internal network via SSH and then connect from the `blue.example.com` host to the mail server on the internal network. In your mail program you need to specify `localhost` and the local TCP port 10110 as the "POP3 server".

You could theoretically forward the local TCP port 110, but you need to be `root` to do it.

The name of the forwarding destination host (here `mail.example.com`) is resolved from the perspective of the SSH server (here `blue.example.com`). This means that a redirection of the form

```
$ ssh -L 10110:localhost:110 hugo@blue.example.com
```

connects you to port 110 on `blue.example.com` rather than your own computer.

A port forwarding like

```
-L 10110:mail.example.com:10
```

opens port 10110 on *all* IP addresses on your computer. This opens the redirection, in principle, to all other hosts that can reach this port over the network. To prevent this you can use the fact that `ssh` allows you to specify a local address for the redirected port: With

```
-L localhost:10110:mail.example.com:110
```

the redirection only applies to the local interface.

If you invoke ssh as shown, you get an interactive session on top of the port forwarding. If you do not need this—because the forwarding takes place within a cron job—you can specify the -N option, which restricts ssh to do the port forwarding and not establish an interactive session.

Another (possibly better) technique for automatically forwarding services uses a ssh invocation like

```
$ ssh -f -L 10110:mail.example.com:110 blue sleep 10
$ getmail_fetch -p10110 localhost hugomail MaIl123 Maildir/
```

The -f option causes the ssh process to go to the background immediately before the “sleep 10” command is executed. This means that a command that you execute immediately after the ssh command (here getmail_fetch, which retrieves e-mail via POP3) has 10 seconds to establish a connection to the local port 10110. The ssh process exits either after 10 seconds or else when the (last) connection via the local port 10110 is torn down, whichever occurs later.

Port forwarding also works the other way round:

```
$ ssh -R 10631:localhost:631 hugo@blue.example.com
```

opens the TCP port 10631 *on the SSH server*, and connections that programs there make with that port will be redirected across the SSH connection to your local host. Your local host then takes care of redirecting the decrypted data to the destination, here port 631 on your local host itself. (This type of port forwarding is considerably less important than the one using -L.)

The -R port forwarding usually binds the remote port to the localhost interface on the SSH server. In principle you can pick another interface as shown above (“*” implies “all”), but whether that works depends on the configuration of the SSH server.

You can also add port forwarding after the fact. Do this using the “~C” key combination (it must be an uppercase C), which gives you a “command line”:

```
⊲⊲⊲⊲⊲                                     An SSH session is in progress here
remote$ ↩
remote$ ~ C
ssh> -L 10025:localhost:25
Forwarding port.
⊲⊲⊲⊲⊲                                                 SSH session goes on
```

On the “command line” you can add -L and -R options (among other things), as if you had typed them directly on the ssh command line. Using -KR, followed by the port number, you can also cancel an -R port forwarding (unfortunately there is no -KL). With the “~#” command you can check the currently active connections:

```
⊲⊲⊲⊲⊲
remote$ ~#
The following connections are open:
  #2 client-session (t4 r0 i0/0 o0/0 fd 6/7 cfd -1)
  #3 direct-tcpip: listening port 10025 for localhost port 25, ▷
   ◁ connect from 127.0.0.1 port 57250 ▷
   ◁ (t4 r1 i0/0 o0/0 fd 9/9 cfd -1)
⊲⊲⊲⊲⊲
```

As you have undoubtedly gleaned from the preceding sections, ssh provides the opportunity for all sorts of shenanigans that would bring tears to the eyes of a corporate IT security officer. Please do consider this chapter a presentation of some of the features of ssh, not a recommendation to actually use as many of them as possible (at least not without a sound reason). As the operator of an SSH server you should, in particular, study its documentation (such as `sshd_config`(5)) in order to find out how to suppress use of the more dangerous options. Unfortunately there is not enough room in this manual for a complete treatment of the SSH server configuration.

Exercises

10.8 [!1] How can you use `ssh` to conveniently start X11 clients as `root` from an unprivileged user account on the same host?

10.9 [3] Use `ssh` to forward port 4711 (or some other suitable local port) to the `echo` port (port 7) of a remote host. Check using a packet sniffer (`tcpdump` or `wireshark`) that a connection to the local port 4711, e. g. using "`telnet localhost 4711`", actually causes an encrypted data transfer to the remote host and is decrypted only there.

Commands in this Chapter

scp	Secure file copy program based on SSH	`scp`(1)	145
sftp	Secure FTP-like program based on SSH	`sftp`(1)	145
ssh	"'Secure shell"', creates secure interactive sessions on remote hosts	`ssh`(1)	142
ssh-add	Adds private SSH keys to `ssh-agent`	`ssh-add`(1)	148
ssh-agent	Manages private keys and pass phrases for SSH	`ssh-agent`(1)	148
ssh-copy-id	Copies public SSH keys to other hosts	`ssh-copy-id`(1)	147
ssh-keygen	Generates and manages keys for SSH	`ssh-keygen`(1)	146
sshd	Server for the SSH protocol (secure interactive remote access)	`sshd`(8)	142

Summary

- The Secure Shell allows convenient and secure interactive sessions on remote hosts (and thus replaces TELNET, RSH and RLOGIN) as well as the secure transmission of files similar to RCP or FTP.
- OpenSSH is a powerful, freely available Secure Shell implementation.
- The user may choose from password authentication and public key authentication. The latter is more secure but more difficult to set up.
- The Secure Shell can forward X11 graphics display and interaction as well as arbitrary TCP connections across the encrypted channel.

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11

Electronic Mail

Contents

Goals

- Knowing the most common mail server programs on Linux by name
- Being able to configure basic mail forwarding and aliases
- Knowing the most important commands for mail server management

Prerequisites

- Kenntnisse über Linux”=Systemadministration
- Kenntnisse über TCP/IP”=Grundlagen (Chapter 3)
- Kenntnisse über Linux”=Netzkonfiguration (Chapter 4)

11.1 Fundamentals

Electronic mail is one of the most popular services on the Internet. Mail transfer agents, or MTAs—programs that forward or receive electronic mail—, play a central role in this. While users interact directly with mail user agents, or MUAs—programs such as KMail, Mutt, or Outlook Express—, to read, compose, reply to, sort, or delete messages, MUAs avail themselves of the services of MTAs to transport messages to their recipients. MTAs can be located with ISPs or be installed locally. Tasks performed by MTAs also include address rewriting to "canonical" form or one suitable for replying to, retrying mail deliveries that failed, notifying the sender of errors during delivery, or optimising for delivery time, network load, or cost. Among themselves, MTAs on the Internet communicate using SMTP (the "Simple Mail Transfer Protocol").

In the context of electronic mail, other protocols such as POP3 or IMAP are also important, but not for LPIC-1 certification. The topic is treated in detail in the Linup Front training manual, *Linux Mail Servers*.

11.2 MTAs for Linux

Sendmail

One common MTA for Unix and Linux systems is the Sendmail program, which was originally implemented by Eric Allman at the University of California in Berkeley in the early 1980s. In spite of its extremely complex configuration and a long history of security vulnerabilities Sendmail still commands a large community of devoted users (even among Linux distributors). Other popular MTAs include Postfix by Wietse Venema, Exim by Philip Hazel, and Qmail by Dan J. Bernstein.

Postfix
Exim
Qmail

In a vicious fit of "design by committee", the developers of the LPIC-1 certification have decreed that candidates must know *all* of these MTAs—fortunately only on a very basic level. Just as fortunately, at least Postfix and Exim make efforts to be compatible with Sendmail as far as certain aspects of their configuration and command structure are concerned; only Qmail actively tries to be different. We shall be explaining the most important properties of all these MTAs on a fundamental level as required for LPIC-1.

architecture

Generally speaking, Sendmail and Exim resemble each other closest as far as their architecture is concerned. With both, the complete MTA is running as one single process. Postfix and Qmail, on the other hand, separate the MTA functionality into a whole family of processes, mostly for security. The advantage of this approach is that every process can concentrate on one part of the task, communication between the individual processes is only possible across well-defined interfaces, and every process can run with the minimal set of privileges required. While, at least potentially, all parts of Sendmail and Exim have access to administrator privileges, with Postfix and Qmail this is restricted to the "foreman process" as well as (typically) those processes that deliver mail to users and hence need to be able to assume their identities (which requires administrator privileges). Qmail deliberately offers only restricted functionality, also for security reasons (features that are not there cannot have vulnerabilities); this omits many features that other MTAs provide out of the box and which must be added explicitly to Qmail. Of the MTAs mentioned here, Sendmail and Qmail are most difficult to maintain by far.

If you are in a position to pick your own MTA, then absolutely do go for Postfix.

11.3 Basic Functionality

An MTA like Sendmail has two major jobs to perform:

- Receiving messages
  It **listens** on the SMTP port, TCP port 25, for connections from other MTAs that want to deliver mail to local recipients. These messages are written to users' mailboxes by means of an MDA or "mail delivery agent" or else forwarded, e. g., to other addresses according to their preferences. To receive messages on TCP port 25, the MTA must either run permanently as a free-standing daemon or be started on demand by a "super server" such as `inetd` or `xinetd`. The latter is only worthwhile if there is very little mail to process. MDA
- Sending messages
  It **sends** messages that have been submitted for delivery by local MUAs and other programs either by calling the MTA directly or by sending it via SMTP and port 25. Since these messages may be addressed to local users as well as remote ones, this function cannot be separated from mail reception.

You do not need to make use of both functions at once. For example, if you do not foresee receiving messages from the Internet—say, because your computer isn't connected to the Net directly—you do not need to run an MTA on TCP port 25, at least not on other IP addresses than `localhost`.

Conversely, you can allow sending local mail without delivering it; in local area networks it is common to just designate one host as the mail server and, on the other hosts, to install a minimally configured MTA that just forwards all submitted mail to the mail server, which then delivers it locally or sends it to the Internet.

mailboxes
Usually, Sendmail delivers messages to local users to their mailboxes in the `/var/mail` directory (on many systems the officially deprecated `/var/spool/mail` directory is still in use, often mapped to `/var/mail` using a symbolic link), where MUAs, or IMAP or POP servers can pick them up. Every mailbox is a file whose name corresponds to that of the user it belongs to; new messages are simply appended to that file. For this to work reliably, all programs using the mailbox must be able to *lock* it, so the MUA does not try to delete messages while the MTA appends new ones; the absence of standardised and reliable file locking methods on Linux sometimes makes this a risky endeavour.

Unlike Sendmail, Qmail uses its own mailbox format called "Maildir", which instead of one large file for all messages uses an intricate arrangement of directories where each message occupies its own file. This obviates most problems with locking. By convention, Maildir-style mailboxes are not located in `/var/mail` but in a user's home directory, which makes backups and quota management easier.

By default, Postfix and Exim operate like Sendmail, but optionally also allow the delivery of mail to Qmail-style Maildir files.

Queue
Sendmail tries to get rid of messages to remote recipients as soon as possible; if this does not work outright, e. g., if the receiving station is not available, or if you are on a dial-up connection and want to delay the actual sending until a worthwhile number of messages has been queued, any undelivered messages are stored in the `/var/spool/mqueue` directory. The other MTAs also use similar directories to store undelivered messages and other internal data—`/var/spool/postfix` for Postfix, `/var/spool/exim` (or something like this) for Exim, or `/var/qmail` for Qmail.

It is usually a good idea not to place such directories—`/var/mail` and `/var/spool/mqueue` & co.—on the `/` partition, so eager mail senders or recipients cannot fill up all of the disk space there and thereby put the system as a whole into jeopardy.

11.4 Managing The Mail Queue

The MTAs store undelivered messages—due to errors at the other end or local thriftiness with dialup access—in queues. If you want to check what is actually in the queue, you can use the `mailq` command on Sendmail (which is an abbreviation for "`sendmail -bp`").

The same applies to Exim and Postfix, which deliberately come with Sendmail-compatible programs for this purpose; only with Qmail do you have to resort to its own software such as `qmail-qread` or `qmail-stat`.

Processing the queue

A daemonised Sendmail can process the queue at given fixed intervals. This is a good idea so delivery attempts can be retried later if the destination MTAs could not be reached. You can arrange for Sendmail to do this by passing the `-q` option on the command line, immediately followed by a time specification:

```
# sendmail -bd -q30m
```

starts Sendmail as a daemon and causes it to run through its queue every 30 minutes.

You can get Sendmail to process its queue immediately by invoking it with `-q` (without an interval):

```
# sendmail -q
```

Sendmail then tries to deliver all the messages in the queue. You can execute this command automatically after your computer has established a dialup connection, or use `cron` to make a connection to the Net at appropriate times and deliver mail. Here, too, Postfix and Exim work substantially the same; to get Qmail to process its queue, you need to send `SIGALRM` to the `qmail-send` process.

11.5 Local Delivery, Aliases And User-Specific Forwarding

Usually, Sendmail & co. write messages to local recipients to their mailbox in `/var/mail` (Qmail uses the `Maildir` directory in their home directories instead). However, there are several methods of changing this default:

`/etc/aliases`
Forwarding

The `/etc/aliases` file (possibly also `/etc/mail/aliases`) allows you to configure a different delivery method for certain local addresses: An entry like

```
root: hugo
```

forwards messages addressed to `root` to the local user `hugo` instead—a very sensible approach, since you should not read mail as `root` for security reasons. You can also forward messages to several destination addresses:

```
hugo: \hugo, hschulz@example.net
```

This forwards messages addressed to `hugo` both to the `hschulz@example.net` address and `hugo`'s local mailbox. The backslash is necessary to avoid an endless loop.

The following example illustrates some other features of `/etc/aliases`:

```
file:    /tmp/mailfile.txt
program: "|/usr/local/bin/program foo"
list:    :include:/var/lib/list.txt
```

Messages to `file` are simply appended to `/tmp/mailfile.txt`. The format is identical to that of the mailboxes in `/var/mail`. Messages to `program` are passed to the "`/usr/local/bin/program foo`" command on its standard input. And messages to `list`, finally, cause the `/var/lib/list.txt` file to be consulted; every line in this file may be another forwarding instruction in the same format as used on the right-hand side of `/etc/aliases`. (This is particularly useful for "mailing lists", which can store their subscriber lists in such files so mailing list software can manipulate them easily.)

Postfix and Exim understand this sort of alias file as well, sometimes with additional features; for example, it may be possible to control whether message forwarding to files or programs is allowed in `/etc/aliases` only, in `:include:` lists, or combinations of these.

Mail forwarding with Qmail

To configure forwarding with Qmail, you must create a file for the address in question in `/var/qmail/alias`:

```
echo &hugo >/var/qmail/alias/.qmail-root
```

forwards all mail to `root` to `hugo` instead. (The "`&`" at the start indicates that the rest of the line is an e-mail address.) In Qmail's alias files you can do approximately what you can do with Sendmail and friends; the only feature not supported directly are `:include:` lists.

Binary format

Sendmail & co. do not read `/etc/aliases` directly but use a binary database format which allows quicker access. The details are system-dependent! For your changes to `/etc/aliases` to become effective, you must transform the file to the binary format using the `newaliases` command (short for "`sendmail -bi`").

Here, too, Postfix and Exim behave roughly in the same manner; Postfix also comes with a program called `postalias` which does the same thing. Qmail, as mentioned above, does its own thing and does not use a binary format, so the problem does not come up.

`~/.forward`

Users can make their own arrangements by putting the same style of forwarding specification allowed on the right-hand side of `/etc/aliases` into a file called `.forward` inside their home directories. Sendmail observes these settings when a message is to be delivered to the user in question. The most popular example may well be

```
$ cat /home/hugo/.forward
\hugo, "|/usr/bin/vacation hugo"
```

The `vacation` program is an automatic "mail answering service" which replies to incoming messages using the content of the `~/.vacation.msg` file. You can use this to inform your correspondents that you are unavailable for a prolonged period of time because of a vacation or other absence.

Postfix and Exim can also handle `.forward` files. Qmail supports a moral equivalent under the name of `.qmail-default` (the possible entries are subtly different, check `dot-qmail`(5)).

The delivery of messages to arbitrary programs and thus the remote invocation of arbitrary programs via the Internet by people without actual access privileges to the system does present a security risk. Many system administrators confine the choice of programs allowed in `~/.forward` to a few selected ones that are considered safe.

security risk

Commands in this Chapter

`mailq`	Displays the state of the mail queue (Sendmail & co.)	`sendmail`(1)	155
`newaliases`	Updates a mail server's alias database (Sendmail/Postfix)	`newaliases`(1)	157
`sendmail`	MTA administrative command (Sendmail, but also other – compatible – MTAs)	`sendmail`(1)	155
`vacation`	Automatic e-mail responder, e. g., for longer absences	`vacation`(1)	157

12

Introduction to GnuPG

Contents

Goals

- Understanding GnuPG
- Generating and managing GnuPG keys
- Encrypting and decrypting files
- Signing files and verifying signatures

Prerequisites

- Working with files on Linux
- Basic text editing
- Cryptography knowledge is a plus

`adm2-gpg.tex (0cd20ee1646f650c)`

12.1 Asymmetric Cryptography and the "Web of Trust"

encryption

signing

GnuPG allows you to encrypt and sign files and email messages. An encrypted file is a file containing data that is scrambled in such a way that only authorised persons can view or process it. Authorised persons have to decrypt the file with the correct key in order to access it. By signing some data, you can document the fact that you created or approved of the data. When the data are changed afterwards, the signature becomes invalid. GnuPG signatures are an inherent part of package management tools like `apt` or RPM. They play an important role in the verification of package data in Linux distributions.

The encryption performed by GnuPG cannot be broken easily. Even modern and well-equipped intelligence organizations lack the computing power to retrieve the plain text from a GnuPG-encrypted file without knowing the key. This is why there are countries where the use of cryptographic software like GnuPG is illegal[1]. One country that used to regulate the use of cryptographic software is France, where encryption was forbidden in 1996. In the meantime the government yielded to reason, though. In 1999, the ban was lifted.

It is up to you to assess the value of digital GnuPG signatures. Developers of Debian GNU/Linux software packages have to sign their packages before uploading them to the Debian FTP server, where they are accessible by the public. The signature does not tell you anything about the quality of the package. Its only purpose is to make sure that the developers themselves uploaded the packages and no malicious packages were introduced to the software collection by third parties.

In order to explain the principles behind GnuPG, we will have to digress a little bit.

symmetric cryptography

There are basically two approaches to cryptography. Cryptography is a method for encrypting and decrypting data. The first approach is called "symmetric cryptography". It uses the same key for encrypting and decrypting data. When Alice and Bob[2] wish to exchange private data using a symmetric method, they have to invent a key first. The same key has to be known to both of them. When Charlie enters the game, three different keys are needed: one for the communication between Alice and Bob, one for Alice and Charlie, and one for Bob and Charlie. Four parties need six keys, ten parties need 55 keys, 100 parties need 5050 keys, etc. The number of keys grows geometrically in relation to the number of parties involved. All the keys are secrets, so they have to be distributed in such a way that no third party can come to know them.

The major issue with symmetric cryptography is not cryptography itself but key distribution. First, keys have to be transmitted in a secure way, so cryptography would be useful for distributing them in the first place. Second, on the Internet with millions of potential users the number of keys required for every user to be able to communicate confidentially with every other would be so astronomical that probably no other data could be stored. Both of these problems are solved by "asymmetric cryptography".

asymmetric cryptography

key pairs

Asymmetric cryptography uses different keys for encrypting and decrypting data. A set of asymmetric keys is called a key pair. Each key pair consists of a "public key" and a "private key". The public key can safely be made public, while the private key must be kept secret. Now Alice can send a private message to Bob by encrypting it with Bob's public key. Bob then uses his private key to decrypt the message. Because only Bob knows his private key, the message is safe during transmission.

[1]However: "If cryptography is outlawed, only outlaws will have cryptography".

[2]Cryptographers invariably refer to two parties who want to exchange private data as "Alice" and "Bob".

We ignore a few details here, the most import one being that virtually all known asymmetric cryptograhic methods are too slow and too cumbersome to use to transfer large amounts of private data. This is why asymmetric methods are often used to exchange the *keys* used to encrypt and decrypt data symmetrically. (Symmetric cryptography is fast and efficient and can easily process vast amounts of data.)

"hybrid" encryption

Here is a concrete example: When Alice wants to communicate with Bob confidentially, she first generates a random key for a symmetric cryptosystem, encrypts this key—call it *S*—with Bob's public key and sends the result to Bob. Bob uses his private key to decrypt Alice's message and thus obtains the key, *S*. Now Alice and Bob can use *S* in their symmetric cryptosystem to exchange confidential messages to their heart's content.

Signatures

Signatures work exactly the other way around. Alice signs a file by encrypting it with her *private* key. Bob can verify that Alice signed a file by decrypting it with Alice's public key (which he can easily obtain because it is public, after all). When the decryption results in consistent data, the file must have been signed using Alice's private key.

cryptographic message digest

In practice, you would not encrypt the entire file using an asymmetric method because, as we said, they are too cumbersome and slow. Instead, you would generate a "cryptographic message digest" of the file instead and sign that. Common methods for computing such digests include MD5 and SHA-1. Using a digest is about as safe as encypting the entire file, because whenever the file changes the value of the digest changes, too.

key authenticity

Asymmetric cryptography solves the problem of key distribution, but introduces another problem. How does Bob know that the key which he uses to verify Alice's signature is really Alice's public key? Maybe a malicious person (cryptographers call this person "Mallory") foisted the wrong key on him. What is missing in this process is some means of verifying the authenticity of public keys.

The Secure Shell sidesteps this problem by letting the user authenticate the keys. Whenever the `ssh` program contacts an unknown server, it asks you whether you want to include its public key in your list of known hosts. (This is explained in detail in Chapter 10.) At this point it is completely up to you to verify the authenticity of the key presented to you.

certification authorities

The SSL and TLS infrastructures, as used, for example, by "secure" web sites, solve this problem by introducing a hierarchy of so-called certification authorities. The entire construct is called a "public key infrastructure" (PKI). The certification authorities assert that a specific key "belongs" to a specific person and attest to this claim by means of a digital signature. A set consisting of a public key, the owner of a digital signature, and the signature and name of the certification authority is called a **certificate**. As a user you can verify the signature on the certificate using the certification authority's public key (which you have obtained from a trustworthy source—typically the more important ones come with your web browser). When the technical details have been worked out, the question whether you trust the signature on a given certificate boils down to the question whether you trust the people and the work of the certification authority.

certificate

web of trust

GnuPG deliberately does *not* use the hierarchical structure explained above, but an approach that is known as the "web of trust". There are no central certification authorites that all users must trust no matter if they want to (of course, people who do not trust the certification authorities would not use their services). Instead, the concept assumes that users of GnuPG sign the public keys of people they know personally, thereby documenting that the key belongs to a specific person. Assume you want to send a private message to Charlie, whom you do not know in person. Somewhere in the depths of the Internet you dig up a public

GnuPG key that claims to be Charlie's. Whether you can trust this key or not depends on the question whether you (or your GnuPG program) can form a "chain of trust" from yourself to the key in question. Maybe you have signed Alice's public key, and Alice used her public key to sign Bob's public key. Bob, in turn, may be an old buddy of Charlie's, and so he has signed Charlie's public key. In other words, Bob's signature on Charlie's key says "This key belongs to Charlie", so if Bob's signature is correct then everything is fine. Bob's signature on Charlie's key can be verified using Bob's public key, and the authenticity of Bob's public key is documented by Alice's signature on Bob's key. Alice's signature, in turn, can be verified with *her* public key. The fact that Alice's public key really belongs to Alice, finally, has been signed by yourself. When all signatures in a chain of trust are valid, you can assume with reasonable certainty that the key of Charlie actually belongs to Charlie—it is "valid".

owner trust

In practice, the method described here is a bit too naive. This is why GnuPG supports a concept called owner trust: For each public key that you have available you can remember the degree of pedantry their owners apply when they are dealing with GnuPG keys. Owner trust levels range from "full" (their signature on a key is as good as your own) to "marginal" (the owner uses her keys quite carefully) to "none" (the owner uses her keys rather sloppily). You can also assign an "unknown" trust level to an owner. Note that trust levels should not depend on how much you care for a person, but only on how much *they* care about GnuPG keys.

GnuPG will consider a public key "valid" if

- the chain of trust connecting you to the owner of the key has no more than 5 links, and
- it has been signed by a sufficient number of keys that *you* consider trustworthy. More specifically:
  - you have signed the key yourself, or
  - it is signed with a key that you trust "fully", or
  - it is signed with three keys that you trust "marginally".

(These parameters can be adjusted, though. The above are the default values.)

As a GnuPG user who wants to take part in the web of trust, you will have to abide by a few rules. Most importantly, you should sign other people's keys only if you are absolutely positive about their identity. When in doubt, ask the person for a piece of official photo identification (or even two)—nobody will resent this degree of diligence. Never sign keys based on hearsay!

Exercises

12.1 [!2] Which advantages does the "web of trust" have over the PKI approach? Which advantages does PKI have over the "web of trust"?

12.2 [2] Imagine the following model: A GnuPG key is "valid", if the chain of trust connecting you to the owner of the key has no more than three links or it has been signed by yourself, with a "fully" trusted key, or with at least two "marginally" trusted keys. We use a simplified model here to make things more obvious.

Now consider the following: Alice has herself signed Bob's and Carla's public keys. Bob and Carla have both signed Doris's public key. Carla and Doris have also signed Eric's public key.

1. When Alice trusts Bob "fully" and Carla "marginally", which keys are valid from Alice's point of view?

2. What changes if Alice trusts Doris "marginally"?
3. Eric signs Fiona's public key. What needs to happen to make Fiona part of Alice's web of trust?

12.2 Generating and Managing GnuPG Keys

12.2.1 Generating Key Pairs

In principle you do not need your own GnuPG key pair in order to send encrypted messages to other people or to verify their signatures. All you have to do is to obtain the public keys in question. However, a successful signature check merely indicates that a file has not been tampered with—to verify that the signature was *really* generated by the person who claims to have created it, you have to take part in the web of trust. This is the only way to make sure that a signature is "valid" according to the rules outlined in the previous section. So the first step to seriously using GnuPG is the generation of your own key pair.

When you use GnuPG to check the integrity of distribution packages, your distributor normally ships a set of public keys that can be used for verification. When these keys are contained on a pressed CD-ROM (as opposed to a burned one) that you bought in a shop and that was contained in some kind of decorative wrapper with a company logo on it, then chances are good that these keys will be trustworthy. With CD-ROMs burned by one of your "buddies", though, things well be different.

A key pair is generated by running the `gpg` program with the `--gen-key` option: Generating a key pair

```
$ gpg --gen-key
This program comes with ABSOLUTELY NO WARRANTY.
This is free software, and you are welcome to redistribute it
under certain conditions. See the file COPYING for details.

Please select what kind of key you want:
   (1) DSA and Elgamal (default)
   (2) DSA (sign only)
   (5) RSA (sign only)
Your selection? 1
DSA keypair will have 1024 bits.
ELG-E keys may be between 1024 and 4096 bits long.
What keysize do you want? (2048) 2048
Requested keysize is 2048 bits
```

The default option, "DSA and Elgamal" actually generates *two* key pairs: a DSA key pair for signing data and an inferior Elgamal key pair for encrypting and decrypting data.[3] 2048 bits are a resonable value these days. 1024 bits are a bit shaky while 4096 bits sound rather paranoid (and both the computing effort and sizes of signatures increase with growing key sizes).

Next you have to assign a life time to the key. Private users can safely choose the option "key does not expire":

```
Please specify how long the key should be valid.
         0 = key does not expire
      <n>  = key expires in n days
```

[3] "DSA" and "Elgamal" are the cryptographic algorithms that GnuPG uses by default. The first one is the "Digital Signature Algorithm", which cannot be used to encrypt data. The latter is a method first described by Taher Elgamal in 1984. The algorithm is based on the observation that discrete logarithms are hard to compute in cyclic groups. This conjecture is not proven, though.

```
      <n>w = key expires in n weeks
      <n>m = key expires in n months
      <n>y = key expires in n years
Key is valid for? (0) 0
Key does not expire at all
Is this correct? (y/N) y
```

You can still change the life time of the key afterwards, but in this case you will have to redistribute the key in order to make this change known to the public.

The next step is to assign a "User ID" to your key. This ID consists of a name, an email address, and an (optional) comment:

```
You need a user ID to identify your key; the software constructs
the user ID from the Real Name, Comment and Email Address in
this form:
    "Heinrich Heine (Der Dichter) <heinrichh@duesseldorf.de>"

Real name: Moh Kohn
Email address: mkohn@example.org
Comment: sample key
You selected this USER-ID:
  "Moh Kohn (sample key) mkohn@example.org"

Change (N)ame, (C)omment, (E)mail or (O)kay/(Q)uit? O
```

Finally you have to specify a "passphrase" that will be used to encrypt your private key. Best choose a long text with no obvious meaning:

```
You need a Passphrase to protect your secret key.

Enter passphrase: Three! @pes eat 96,547 dumplings?

Repeat passphrase: Three! @pes eat 96,547 dumplings?
```

A good passphrase is essential to the security of GnuPG! It is your only protection should the key pair—especially the private key—ever fall into the wrong hands.

In the last step the key pairs themselves will be generated. This step requires high-quality random numbers. Linux typically generates those by measuring the times between I/O events, like key presses, movements of the mouse, etc:

```
We need to generate a lot of random bytes. It is a good idea
to perform some other action (type on the keyboard, move the mouse,
utilize the disks) during the prime generation; this gives the random
number generator a better chance to gain enough entropy.
+++++++++....++++++++++..++++++++++.++++++++++++++++++++++++++++++++
<<<<<
gpg: key 7AA07E27 marked as ultimately trusted
public and secret key created and signed.

gpg: checking the trustdb
gpg: 3 marginal(s) needed, 1 complete(s) needed, PGP trust model
gpg: depth: 0  valid:   4  signed:   0  trust: 0-, 0q, 0n, 0m, 0f, 4u
pub   1024D/7AA07E27 2009-02-18
      Key fingerprint = 3934 663E 7C0F 42F0 0085  5D73 4F82 971E ◁
▷ 7AA0 7E27
uid                  Moh Kohn (sample key) <mkohn@example.org>
sub   2048g/DDC38B28 2009-02-18
```

At this point you are almost done.

You should consider creating a "revocation certificate", too. You can use a revocation certificate to declare your public key invalid in case your private key should get compromised or become lost. It states that the key that it invalidates should not longer be used to encrypt data. The revoked key can still be used for verifying existing signatures, though. A revocation certificate is created this way:

revocation certificate

```
$ gpg --output revoke.asc --gen-revoke "Moh Kohn"

sec  1024D/7AA07E27 2009-02-18 Moh Kohn (sample key)▷
 ◁ <mkohn@example.org>

Create a revocation certificate for this key? (y/N) y
Please select the reason for the revocation:
  0 = No reason specified
  1 = Key has been compromised
  2 = Key is superseded
  3 = Key is no longer used
  Q = Cancel
(Probably you want to select 1 here)
Your decision? 1

Enter an optional description; end it with an empty line:
> My private key was compromised or became lost.
>
Reason for revocation: Key has been compromised
My private key was compromised or became lost.
Is this okay? (y/N) y
```

At this point you will be asked for your passphrase. After entering it, the revocation certificate will be stored in the file `revoke.asc`.

The revocation certificate generated here is intended for use in a worst-case scenario, that is, for the case that your key becomes permanently unusable. Should you decide to revoke your key for a different reason some day (like item two or three in the above menu), feel free to create a fresh revocation certificate that reflects your reason better.

The revocation certificate should be stored on a medium that you can lock away, and not on your computer. When an attacker gets their hands on the certificate, they can use it to make your key unusable. Best store a printed copy of the certificate, too, so you can type it in by hand in the worst case (it is not too long).

12.2.2 Publishing a Public Key

The next step would be to publish your public key in order to make it available to your family, friends, enemies, etc. To do so, you will have to "export" the key first. The `--list-keys` option makes GnuPG list all public keys that you can use so far (at this point, this will most probably just be your freshly generated key):

exporting keys

```
$ gpg --list-keys
/home/mkohn/.gnupg/pubring.gpg
------------------------------
pub   1024D/7AA07E27 2009-02-18
uid                  Moh Kohn (sample key) <mkohn@example.org>
sub   2048g/DDC38B28 2009-02-18
```

Your public key is exported by the `--export` option of GnuPG. As in the command creating the revocation certificate, the `--output` option can be used to specify a file name to which the output will be written. The `--armor` option generates output in ASCII format, so it can be sent via email or published on a web site:

```
$ gpg --output moh.gpg --armor --export "Moh Kohn"
$ cat moh.gpg
-----BEGIN PGP PUBLIC KEY BLOCK-----
Version: GnuPG v1.4.7 (FreeBSD)

mQGiBEmb8M0RBAC19ul+0kPiqMvg3LDwVUWAwonYQhBM5mv1nnyQQAHMkMYmnsqO
WTKSFFtnS09rHMrSdB6kcIz1qa422W/pz7UbZeYyjtWUeSStXF8Gz6K408wjnx1R
8E1bS03W6OnIcLw5NyFKGWl7ASEvD+BFi6Irfd8ZuI57YmeloqWLtE2xkwCgvIph
rhi1leaDcz3HAzvyEN1EkVkD/0Aw2VgacyBeyepqSwDrspYvLpxa/awkkvK7DUoD
◁◁◁◁◁
```

key servers

A more efficient way of publishing your public key is to upload it to a "key server". This is also done with the help of the `gpg` program:

```
$ gpg --keyserver hkp://subkeys.pgp.net --send-keys 7AA07E27
```

Most key servers synchronise their data, so it is normally sufficient to upload your key to only one of them. The magic ID `7AA07E27` is the "key ID"—it can be found in the output of "`gpg --list-keys`".

12.2.3 Importing and Signing Public Keys

When you find a public key in an email message or on a web site, you will have to import it into your "key ring" before you can use it. This is how it works:

```
$ gpg --import /tmp/jane.gpg
gpg: key 5526DE34: "Jane Loopy (no comment!)▷
 ◁ <jloopy@example.net>" imported
gpg: Total number processed: 1
gpg:               imported: 1

$ gpg --list-keys
/home/mkohn/.gnupg/pubring.gpg
------------------------------
pub   1024D/7AA07E27 2009-02-18
uid                  Moh Kohn (sample key) <mkohn@example.org>
sub   2048g/DDC38B28 2009-02-18

pub   1024D/5526DE34 2009-01-04
uid                  Jane Loopy (no comment!) <jloopy@example.net>
sub   2048g/045B6B4F 2009-01-04
```

Now the new key is part of your key ring, but you are not done yet. How do you know that the key you just imported really is the public key of Jane Loopy? You should better verify that it is authentic. Best generate the "fingerprint" of the key and ask Jane personally whether it is correct:

fingerprint

```
$ gpg --fingerprint "Jane Loopy"
pub   1024D/5526DE34 2009-01-04
      Key fingerprint = D533 80FD B930 1BCD 2F6B  4C25 F92F 82B0▷
 ◁ 5526 DE34
uid                     Jane Loopy (no comment!) <jloopy@example.net>
sub   2048g/045B6B4F 2009-01-04
```

To verify the authenticity of the key you could, for example, call Jane (if you are 100% positive that you can identify her by her phone voice). Of course, this works best if the phone number does *not* originate from the same source (email message, web site, etc.) as the key in question.

You may consider printing the fingerprint of your GnuPG key on your calling card or prepare some slips of paper containing the key data. Prepared in this way, when you meet a person and want to swap signatures, you can hand them a copy of the fingerprint and—if necessary—identify yourself. So the other person can fetch your public key from a key server and use the fingerprint to make sure that the key really belongs to you. They can then sign the key and send you a copy, so you can integrate the signature into your "official" public key.

key signing parties

Another popular means of verifying keys are so-called "key signing parties", where, for example, members of open-source projects such as Debian perform mutual mass verification of their GnuPG keys: The user IDs and public key fingerprints of all participants are collected and distributed to all persons taking part in the event. Then every participant checks the ID of each person on the list and marks the keys that they are willing to trust. Once the lists are complete, the keys can be signed later, when things wind down.

Signing a Key

Let us say that you have successfully verified the authenticity of Jane Loopy's public key (the details are left to your imagination). Now you can sign Jane's key. Jane obviously benefits from your signing her key, because her key is now considered to be valid by all people who consider *your* key to be valid (modulo the constraints of Section 12.1). But you benefit from signing the key, too, because you are now connected to Jane's Web of Trust. You can assume that keys which have been signed by Jane are valid, too.

Of couse, "owner trust" plays a role, too. In your key ring you can make a note of the degree to which you trust Jane's knowledge of GnuPG and her diligence in handling keys. This note affects the validity of keys signed by Jane. When you are not sure about Jane's skills, keys signed by Jane will have to be signed by other people in your web of trust in order to become valid. When you trust Jane fully, though, her signature alone is sufficient.

You can sign Jane's key as follows:

```
$ gpg --sign-key "Jane Loopy"

pub  1024D/5526DE34  created: 2009-02-18  expires: never▷
 ◁ usage: SC
                     trust: unknown       validity: unknown
sub  2048g/045B6B4F  created: 2009-02-18  expires: never▷
 ◁ usage: E
[unknown] (1). Jane Loopy (no comment!) <jloopy@example.net>

pub  1024D/5526DE34  created: 2009-02-18  expires: never▷
 ◁ usage: SC
                     trust: unknown       validity: unknown
 Primary key fingerprint: D533 80FD B930 1BCD 2F6B  4C25 F92F▷
 ◁  82B0 5526 DE34

     Jane Loopy (no comment!) <jloopy@example.net>

Are you sure that you want to sign this key with your
key "Moh Kohn <mkohn@example.org>" (7AA07E27)

Really sign? (y/N) y
```

At this point the program once more prompts for your passphrase.

Checking signatures

The signatures on a key can be listed and checked at the same time by using the `--check-sigs` option:

```
$ gpg --check-sigs "Jane Loopy"
pub   1024D/5526DE34 2009-01-04
uid                  Jane Loopy (no comment!) <jloopy@example.net>
sig!3       5526DE34 2009-01-04  Jane Loopy (no comment!)▷
 ◁ <jloopy@example.net>
sig!         7AA07E27 2009-01-04  Moh Kohn (sample key)▷
 ◁ <mkohn@example.org>
sub   2048g/045B6B4F 2009-01-04
sig!         5526DE34 2009-01-04  Jane Loopy (no comment!)▷
 ◁ <jloopy@example.net>
```

Here you see the signature of Jane herself (which is automatically created when the key is generated) and your own one. The exclamation mark after the `sig` at the beginning of the line indicates that the signature could be verified successfully. When a signature is "bad", there would be a minus sign ("`-`") instead.

All the above signatures can be checked by you, because you own copies of all of the required public keys (yes, this is a cycle). When a signature cannot be checked because a public key is lacking, that signature will be ignored.

The "`gpg --list-sigs`" command lists all signatures without checking them. Signatures with missing public keys will appear as "`[User-ID not found]`".

For managing keys, you would use the `--edit-key` option of `gpg`:

```
$ gpg --edit-key "Jane Loopy"
gpg (GnuPG) 1.4.7; Copyright (C) 2006 Free Software Foundation, Inc.
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.

pub  1024D/5526DE34  created: 2009-02-18  expires: never▷
 ◁ usage: SC
                     trust: unknown       validity: ultimate
sub  2048g/045B6B4F  created: 2009-02-18  expires: never▷
 ◁ usage: E
[ultimate] (1). Jane Loopy (no comment!) <jloopy@example.net>

Command> _
```

You can now enter commands. "`fpr`" lists the fingerprint of a key and "`sign`" signs a key. There are lots of of other commands. "`help`" prints a summary. An important command is "`trust`". It changes the owner trust level:

```
Command> trust
pub  1024D/5526DE34  created: 2009-02-18  expires: never▷
 ◁ usage: SC
                     trust: unknown       validity: ultimate
sub  2048g/045B6B4F  created: 2009-02-18  expires: never▷
 ◁ usage: E
[ultimate] (1). Jane Loopy (no comment!) <jloopy@example.net>

Please decide how far you trust this user to correctly verify other
users' keys (by looking at passports, checking fingerprints from
different sources, etc.)
```

```
  1 = I don't know or won't say                      Default case
  2 = I do NOT trust                        That person is a bungler
  3 = I trust marginally              So, so, but fundamentally OK
  4 = I trust fully                    Is knowledgeable and careful
  5 = I trust ultimately                              Only yourself
  m = back to the main menu

Your decision? 4
```

The difference between "full" and "ultimate" is the difference between yourself and other persons. You might trust other people's keys "fully" but should only trust your own keys "ultimately".

The "trust database" of GnuPG is updated only when the program is started for the next time (this is a complex process), so when you plan to change multiple trust levels, you should do this in a single session and then restart `gpg`.

If you should ever want to revoke your public key (you *did* create a revocation certificate, didn't you?), you have to import the revocation certificate to your key ring first:

```
$ gpg --import revoke.asc
```

You can then send the revoked key to the usual key servers.

Exercises

12.3 [!2] Create a key pair as described in Section 12.2.1. Make sure that the public key exists and is signed with itself. This should happen automatically when the key pair is generated.

12.4 [!2] Log in to a different account and create another key pair. Export its public key, log in to your account and import that public key. Make sure the key is now part of your key ring. (*In a course:* You do not have to create a new key pair. Just swap keys with another participant.)

12.5 [2] Sign the key imported in Exercise 12.4 by running "`gpg --sign-key`" or "`gpg --edit-key`". Check the signatures on the public key. Export the key, log in to the other account and import it there. (*In a course*: Swap signed keys.)

12.6 [3] Use just one more account (you will thank us later!) in order to create a third key pair. Import the key generated in Exercise 12.5 to the key ring of that third account. What does "`gpg --check-sigs`" say about it? Is the key valid in that account? If not, how can you make it valid?

12.7 [2] Assign "full owner trust" to the key you have just imported (use the "`gpg --edit-key`" command). How does this modification affect the "validity" of the key?

12.3 Encrypting and Decrypting Data

In order to encrypt a file using GnuPG, you need the public key of the recipient of the file. A public key can be thought of as an open safe. You encrypt data by putting them into the safe, closing the door and turning the wheels of the combination lock. The only person who can access the data now is the person who knows the combination of the safe. The private key is the "combination" needed to access the encrypted data.

So if you want to send some sensitive data to Jane Loopy, you need her public key. Jane needs her private key in order to decrypt your message. If she wants to send you an encrypted reply, she needs your public key, and you need your own private key to decrypt it.

This is how it works:

```
$ gpg --output text.txt.gpg --encrypt▷ ◁ --recipient "Jane Loopy" text.txt
```

This command encrypts the file `text.txt` such that only Jane Loopy can read it. The encrypted version is stored in the file `text.txt.gpg`. The output file is specified with the `--output` option, as usual.

Even here you can use the `--armor` option to create an ASCII version of the encrypted message. Such a version can be sent via email, for example.

You can encrypt a message in such a way that multiple recipients can read it. Just specify one `--recipient` option for each recipient. Note, though, that this is implemented by including an individually encrypted copy for each recipient in the output file.

Jane Loopy can decrypt the received message by using her private key:

```
jane$ gpg --output text.txt --decrypt text.txt.gpg

You need a passphrase to unlock the secret key for
user: "Jane Loopy (no comment!) <jloopy@example.net>"
2048-bit ELG-E key, ID 045B6B4F, created 2009-02-18▷
 ◁ (main key ID 5526DE34)

Enter passphrase: DonauDampfSchiff
gpg: encrypted with 2048-bit ELG-E key, ID 045B6B4F,▷
 ◁ created 2009-01-04
      "Jane Loopy (no comment!) <jloopy@example.net>"
```

If you wish to encrypt a file that you just want to to keep to yourself, you do not need asymmetric cryptography. The "`gpg --symmetric`" command uses a key that will be derived from a passphrase. The same passphrase is used to decrypt the file:

```
$ echo "Hello World!" | gpg --output hw.gpg --symmetric
Enter passphrase: foobar
Repeat passphrase: foobar
$ gpg --decrypt hw.gpg
gpg: CAST5 encrypted data
Enter passphrase: foobar
gpg: encrypted with 1 passphrase
Hello World!
gpg: WARNING: message was not integrity protected
```

(Of course you should not use the same passphrase that you use for protecting your private GnuPG keys.)

Above example also demonstrates how GnuPG reads encrypted data from the standard input stream (first command) and writes decrypted data to the standard output stream (second command).

Exercises

12.8 [!2] Pick a file and encrypt it in such a way that in can be decrypted with the private key generated in Exercise 12.4. Make sure that the file really can be decrypted.

12.9 [1] Use symmetric encryption to encrypt a file of your choice. Decrypt the file and make sure that the decrypted output is equal to the original file.

12.4 Signing Files and Verifying Signatures

You can also use your key pair to *sign* a file. Signing a file annotates the content of the file with a time stamp and a "digest". When the file is modified after signing it, verifying the signature will fail. This mechanism is used, for example, to sign software packages of distributions, thereby allowing you to verify that it was the maintainer of a package who uploaded it—and not some malicious cracker. You can be pretty sure that properly signed packages will not introduce any malware, like viruses or trojans. You can also use a signature to sign a manuscript when sending it to your publisher, so they can be sure that they receive the original work and not a copy that has been tampered with.

A side effect of this approach is that it is very difficult for you to claim that a document with your digital signature was *not* signed by yourself—this would imply that your private key has been compromised.

Difference between digital signatures and real-life signatures

There is a certain tendency toward giving digital signatures as created by GnuPG the same legal status as a signature on a sheet of paper. This is unfortunate or even dangerous, though, because there is a considerable difference between the act of signing your name on a piece of paper and the act of typing a passphrase and pressing ↩. On a sheet of paper, you sign exactly what is written on that sheet and nothing else. In cases of doubt there is a strong presumption that you really meant what you signed. However, when signing a digital document, there is (given the current state of art) absolutely no guarantee beyond a warm fuzzy feeling in your stomach that the computer *really* signs exactly the intended document (and *only* that document and not simultaneously, say, a purchase agreement for an industrial dishwasher). This is why in a legal dispute, destroying the claim that a digital signature is equal to a real-life signature will be a walk in the park for an competent expert. This is not a desirable situation.

To sign a file with GnuPG, run `gpg` with the `--sign` option:

```
$ gpg --output text.txt.sig --sign text.txt
```

(Because the file is signed with your private key, you have to enter your passphrase.) The signed file will be compressed as well. It is written to the output file in binary format.

You can verify a signature with "`gpg --verify`":

```
$ gpg --verify text.txt.sig
gpg: Signature made Fri Feb 20 10:25:44 2009 CET▷
 ◁ using DSA key ID 5526DE34
gpg: Good signature from "Jane Loopy (no comment!)▷
 ◁ <jloopy@example.net>"
```

"`gpg --decrypt`" not only checks the signature but also decompresses the file and writes it to the standard output stream:

```
$ gpg --decrypt text.txt.sig
Hello World!
gpg: Signature made Fri Feb 20 10:25:44 2009 CET▷
 ◁ using DSA key ID 5526DE34
gpg: Good signature from "Jane Loopy (no comment!)▷
 ◁ <jloopy@example.net>"
```

As usual the `--output` option can be used to write the decompressed data directly to a file.

The compressed binary format is not practicable for including it in email messages. In this case you would use the `--clearsign` option instead, which generates a plain text version of its output. The resulting file contains both the signed data and the signature in ASCII format:

plain-text signature

```
$ gpg --clearsign text.txt
```

Such a file looks like this:

```
-----BEGIN PGP SIGNED MESSAGE-----
Hash: SHA1

Hello World!
-----BEGIN PGP SIGNATURE-----
Version: GnuPG v1.4.7 (FreeBSD)

iD8DBQFJnnknT4KXHnqgficRAi4hAKChHaGsOGcY0XPAyvjiX8dYajKjSQCgtPcf
ofupzVXHGmgugA1n5yp2uls=
=UH8U
-----END PGP SIGNATURE-----
```

Plain-text signatures are used, for example, in the Debian project. The `.dsc` files which accompany source code packages contain the MD5 checksums of the original source code (typically a `.tar.gz` file) and the patch containing Debian-specific changes, and are signed by the package maintainer. This allows you to check, upon installing a package, that the version you have was in fact created by the package maintainer. Similarly, a new version of a package that is to be made available on the Debian servers as part of a distribution must be accompanied by GnuPG-signed `.changes` file listing the files the package consist of together with their MD5 checksums. Files that are uploaded without a `.changes` file signed by a Debian developer will be discarded.

Incidentally, the “`PGP`” in the ASCII output of GnuPG is not a typo. GnuPG is an implementation of the “OpenPGP” standard [RFC4880], which is based on a program called “Pretty Good Privacy” (PGP) by Phil Zimmermann. “GnuPG” is short for “GNU Privacy Guard”—one of the usual GNU puns.

Sometimes you may want to sign a file without changing it by adding the signature. This is necessary, for example, when submitting a package to a Linux distributor or when you want to guarantee the authenticity of a source code archive that you are publishing. When annotating a `tar` archive with a signature, it would no longer be a valid `tar` archive, so you have to keep the signature in a separate file. This is called a “detached signature”. In order to create a detached signature, use the `--detach-sign` option of `gpg`:

Detached Signature

```
$ gpg --output text.txt.sig --detach-sign text.txt
```

To verify a file using a detached signature, you need (of course) the signature and the file that is being signed by that signature. The `--verify` option of `gpg` also verifies detached signatures:

```
$ gpg --verify text.txt.sig text.txt
```

The first file name following `--verify` is the name of the file containing the signature and the second one specifies the signed file. When only one file name is passed to `--verify`, the program assumes that the name specifies the signature file and the name of the content file is the same name but with the `.sig` part removed. When the `--armor` option is used, `gpg` removes the `.asc` suffix instead of `.sig`.

Exercises

12.10 [!1] Sign an arbitrary file using GnuPG. Then verify the authenticity of the signature.

12.11 [!2] Use the key generated in Exercise 12.5 to sign a file. Copy the signed file to your own account and use your own key ring to check the signature. What happens?

12.12 [2] Repeat Exercise 12.11 using the account and key ring from Exercise 12.6. What happens now?

12.5 GnuPG Configuration

GnuPG keeps its configuration files in the directory `~/.gnupg`. Some of the files that can typically be found in that directory include: `~/.gnupg`

`pubring.gpg` The ring of public keys. This file contains the public keys which you have generated or imported.

`secring.gpg` The ring of secret keys. This file contains the private keys of your key pairs.

`trustdb.gpg` This file contains the owner trust levels of the keys on your public key ring. Because these are private data reflecting your personal views, they are kept in a separate file and not in the public key ring file (which you may want to make available to others).

`random_seed` This file is used by GnuPG to keep track of the state of the random number generator.

`gpg.conf` This file contains various options and parameters used by `gpg`. The file is documented very well.

Some parameters that you might want to tweak in `gpg.conf` include the following: `gpg.conf`

`keyserver` Specifies you favorite keyserver, e.g.:

```
keyserver hkp://keys.gnupg.net
```

`no-greeting` Supresses the copyright notice that is printed initially by `gpg`.

`group` Defines “groups” that save you some typing when encrypting files. Imagine the following entry in your `gpg.conf` file: groups

```
group beatles = john paul 0x12345678 ringo
```

When you specify the "`--recipient beatles`" option, GnuPG interprets this as three individual `--recipient` options with names and one with a key ID.

Groups only work one level deep. Thus you cannot have groups that contain other groups.

GnuPG is an important program, but it is not really straightforward. This is why you may want to study its documentation in depth. A good starting point would be the `gpg`(1) man page. More extensive documentation can be found on `http://www.gnupg.org/`.

Exercises

12.13 [2] Add a group consisting of the keys generated in Exercise 12.5 and Exercise 12.6 to your `gpg.conf` file. Encrypt a file by sending it to that group. Make sure that both of the recipients are capable of decrypting the file.

12.14 [5] Read [Keysigning-Party-HOWTO08] and organise a key signing party with a suitable group of people (course participants, colleagues, friends). (What to make of the word "party" is up to you, but whatever you do should at least involve some key signing.)

Commands in this Chapter

`gpg`	Encrypts and signs files	`gpg`(1)	163

Summary

- GnuPG allows you to encrypt and sign files and email messages.
- The authenticity of a GnuPG key is guaranteed by the "web of trust".

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13

Linux and Security: An Introduction

Contents

Goals

- Searching the file system for security-related entries (device files, SUID and SGID bits, etc.)
- Understanding and using resource limits
- Configuring and using `sudo`
- Understanding fundamental problems of network security

Prerequisites

- Linux system configuration
- Linux network configuration (Chapter 4)

13.1 Introduction

"Security" is an important topic for everyone who operates a computer. In the age of the Internet, this topic is no longer in the domain of system administrators of big companies, universities, and Internet service providers exclusively. Unfortunately, even your personal computer at home, which is just used by yourself and maybe your family, can be used as a stepping stone by crackers who want to make use of your fast DSL connection to flood the Internet with spam or malware, making themselves (and, in the process, you) quite unpopular. By choosing Linux as your operating system, you already reduced the dangers significantly, but this is not a reason to to rest on one's laurels[1]

Security on Linux systems is a complex and ambitious topic, so we will only be able to cover it in the broadest sense in this chapter. If you are administering a critical system that provides Internet or intranet services for an enterprise, we would like to recommend the Linup Front document *Linux Security*, which offers a much more in-depth discussion of the topic. In the meantime, the following sections provide a summary of some fundamental aspects.

13.2 File System Security

If one wanted to summarise the properties of the Linux file system in a few sentences, the following two conclusions would become obvious (among others):

1. Everything is a file (even "devices");
2. There is a system of access permissions which is fairly simple yet sufficient for most purposes.

This has various very useful and convenient consequences, but also some consequences that you as a security-conscious administrator should watch out for:

Device files

- Device files work anywhere in the file system, not just in `/dev`. If an attacker manages to create a device file of the proper type (e. g., that of `/dev/hda` or `/dev/kmem`), you are toast. The file does not even have to have the same name as the "official" device file, it just needs to have the correct type and major and minor device numbers.

Executable files

- Users can make any of their own files executable by setting their `x` bits. This is not a problem in most cases (it is even an advantage compared to other operating systems that will execute any file whose name has a particular extension), but not an insurmountable obstacle. Every so often problems are found in Linux that enable an unprivileged user to gain administrator privileges by executing a "normal" program, and that path is also available to programs that a user downloaded from somewhere on the Net.

Set-UID and set-GID

- The set-UID and set-GID mechanisms allow "ordinary" users to run programs with the permissions of other users (preferably `root`). Set-UID and set-GID programs, too, can be located anywhere in the file system.

As an administrator you can attempt to minimise the risk by restricting "unusual" file types to areas of the file system where such files are to be expected. However, you should also actively look out for possibly problematic files. Here are a few clues:

Removable media

Removable media are the most obvious way to introduce unusual files to the system. This includes files of types that a user would not be allowed to create using their local account. For instance, an unprivileged user may not run a command like

[1] Your author's old physics teacher used to say that "he who rests on his laurels is wearing them in the wrong place."

```
# mknod /home/hugo/vacation.jpg c 1 2                    See /dev/kmem
```

but if they manage to mount a USB stick that contains an ext3 file system with such a file, then they have hit the jackpot. (It is easy to prepare such a USB stick on your own Linux machine at home.)

Linux avoids this scenario by not letting ordinary users mount removable media at all. The only secure way to allow this is to add specific mount points to `/etc/fstab` that contain the `user` or `users` option. Both of these options imply the `nodev` option, which makes the system ignore device files on the mounted media. `nodev` At this point we could consider the problem solved, but we would like to remind you that an `/etc/fstab` entry like

```
/dev/sda1 /media/usbstick auto noauto,user,dev 0 0
```

should not be created without pondering its implications.

Set-UID programs pose a similar problem. Just as ordinary users may not create device files, they may not create set-UID files owned by `root`, either—and this is fine the way it is. However, just as a user might introduce a device file on a removable medium, they might introduce a small set-UID `root` program that will launch a shell.

Common shells like bash are reluctant to let themselves be started as set-UID `root` processes. At least somewhat. However, an attacker will not be stopped by such minor annoyances. They can also bring in their own shell that they compiled themselves with the set-UID detection code removed. (Or they can consult the Bash manual and read up on the `-p` option.)

The way in which Linux avoids this issue is basically the same as the one that is used to handle device files. The `user` and `users` options to `mount` also imply the `nosuid` option, which prevents the execution of set-UID programs on the file system `nosuid` in question.

To be precise, `nosuid` does not prevent the programs from being executed, it just makes the system ignore the set-UID and set-GID bits.

`nosuid` is without effect, and hence dangerous, if you have the `suidperl` program installed on your system. This is a special interpreter for the Perl programming language that is intended for the execution of set-UID scripts on systems that normally do not allow the execution of set-UID scripts (like Linux). `suidperl` is itself a set-UID program owned by `root`. It does for Perl scripts what the kernel does for native executables: before executing the program, it changes the identity of the user running the program to the identity of the user owning the program. Stupid. Very stupid indeed. (See, for example, [McC08].)

The `noexec` `mount` option can prevent the execution of programs (including `noexec` scripts) from the file system in question. This option, too, is implied by the `user` and `users` options. However, it does not present a big obstacle because a user can still copy the file to their home directory and execute it from there. (In earlier Linux versions, you could even run programs on `noexec` file systems by typing something like

```
$ /lib/ld-linux.so.2 /mnt/program
```

—but as of kernel version 2.6 this is no longer possible. Whew.)

Of course the `nosuid` and `nodev` options protect only against suspicious files on removable media (at first). It does not help against files created by clever crackers who exploited a security hole in a network service and want to create a convenient back door so they can come back later. A set-UID shell with an innocuous name like `.foobarrc` would be just fine.

There is nothing to keep you from enabling the `nosuid` and `nodev` options explicitly for *all* file systems where users can create files. Besides removable media, this applies mainly to `/home`, `/tmp`, and `/var/tmp`.

For all the prevention, as a system administrator you could do worse than scanning your system for such files on a regular basis (preferably at night when then system is not so busy). The tool of choice for this task is `find`.

Finding Set-UID files

To find all set-UID and set-GID files on your system, you would use `find`'s `-perm` option. The full command would look like this:

```
# find / -perm /06000 -type f -print
```

(Remember that `find` combines multiple criteria with an implicit logical AND.)

The "`-perm /06000`" part is specific to GNU `find`, which is popular on Linux systems. Traditional Unix versions of `find` require you to use the more tedious

```
\( -perm -04000 -o -perm -02000 \)
```

instead.

Without the "`-type f`" part, the output would include directories with the set-GID bit set. However, such directories are not interesting from a security administrators point of view.

Printing full information in the style of "`ls -l`" for each file found instead of just its name may save you some work. Just use the `-ls` action in place of `-print`.

You should be aware of all the set-UID and set-GID programs on your systems—

List of set-UID programs

it is best to prepare a list that you check manually and later compare automatically (e. g., using `cron`) to the list of actual set-UID and set-GID programs on the system. Have yourself be notified if a program on the list is missing from the system, or—more importantly—a program appears on the system that is not on the list. Some distributions do this by default.

Finding device files

Device files can be located in a similar way. Just scan your system for files that are block or character devices:

```
# find / \( -type b -o -type c \) -ls
```

Of course it makes little sense to include the `/dev` directory in the search. Unfortunately, it cannot be excluded explicitly. All you can do is to tell `find` to stop when it encounters the `/dev` directory:

```
# find / -path /dev -prune -o \( -type b -o -type c \) -ls
```

Or, of course, you could pipe the output of `find` through "`grep -v ^/dev`" to exclude the `/dev` entries from the result.

Tripwire
AIDE

The auditing of your file system can be implemented much more efficently: Tools like Tripwire or AIDE are used to detect and report changes to important system file (both programs and configuration). Such modifications typically happen when "root kits" are installed on a system. The details of these tools are beyond the scope of this document. Please refer to the Linup Front document, *Linux Security*, for a detailed discussion.

Exercises

13.1 [!1] Why is it a problem for an ordinary user to have direct access to the /dev/hda file (or an equivalent file with a different name)?

13.2 [!2] Make sure that the nodev, nosuid, and noexec options of mount really do what they are supposed to do. You can use the /tmp file system for your test, if it is a separate file system; it is best to set the options by means of something like

```
# mount -o remount,nodev /tmp
```

(If /tmp is not a separate file system, you can, through something like

```
# dd if=/dev/zero of=/tmp/testfs bs=1M count=32
# mke2fs -F /tmp/testfs
# mount -o loop,nodev /tmp/testfs /mnt
```

create a file system in a file for testing.)

13.3 [2] Create a comprehensive list of all set-UID and set-GID programs that are installed on your system. (*For extra credit:* Consider why these programs need to have their set-UID and set-GID bits set.)

13.4 [2] Check whether the above method for finding device files outside of /dev works. Create a few device files anywhere on your system (and remove them again afterwards).

13.3 Users and Files

Sometimes it is useful to find out who is currently logged on to a computer. The simplest command to do so is called who: who

```
$ who
hugo     :0          2015-07-27 13:39 (:0)
hugo     pts/0       2015-07-27 13:56 (red.example.com)
```

The first column shows the user name and the second the terminal on which the user is logged in. ":0" there denotes the X11 server with that display name; other names (such as pts/0) refer to a device file below /dev.

Terminal names of the form pts/… denote "pseudo-terminals", typically terminal windows in a graphical environment or secure-shell sessions.

The remainder of the line shows the date and time at which the session started. After that, the remote end of the session may be listed in parentheses; in the example, the user hugo on pts/0 comes from a host called red.example.com.

If you have several terminal windows or one terminal window with several subwindows, it is very likely that all these sessions will be counted as separate "users". Don't let yourself be confused by that.

who supports a few command-line options of further interest: -H causes a header line with column titles to be output; -b outputs the date and time of the last system reboot, and -r the current runlevel (if appropriate). -a displays everything that who can output. With -m, only the user whose terminal is connected to who's standard input will be displayed.

If you invoke who with two parameters that are not options, that will be interpreted as "who -m". The actual parameter text is immaterial. This enables the classic

```
$ who am i
hugo     pts/0        2015-07-27 13:56 (red.example.com)
```

but all sorts of other possibilities also exist:

```
$ who is cool
$ who wants icecream
```

This is not to be confused with the `whoami` command (without spaces), which outputs the effective user name:

```
$ whoami
hugo
```

`w` command The `w` command is a close relative of `who`'s:

```
# w
 18:06:32 up  4:29,  2 users,  load average: 0,01, 0,02, 0,05
USER  TTY   FROM            LOGIN@ IDLE   JCPU  PCPU WHAT
hugo  :0    :0              13:39 ?xdm?  40.21s 0.06s /usr/bin▷
 ◁/lxsession -s
hugo  pts/0 red.example.com 13:56  0.00s  0.11s 0.00s w
```

The first line shows the current time and the "uptime", namely the time the computer has been running since the last boot, the number of active users, and the system load. Then there is one line for every logged-in user, in the manner of `who`. The `LOGIN@` shows when the user has logged on (as a wall-clock time or—if the log-on is farther in the past—a date). `IDLE` is the amount of time the user has been doing nothing. `JCPU` is the total CPU time used by all processes in this session (excluding finished background jobs, but including currently-running background jobs) and `PCPU` is the CPU time used so far by the currently-running process. `WHAT` is the current command line.

`w`'s options aren't as interesting: `-h` suppresses the header line and `-s` the `LOGIN` column. The other options are even more boring.

If you specify a user name, then only information about that user will be output.

`last` While `who` and `w` are concerned with the present, you can use `last` to look back on the past and check who was logged on when:

```
# last
hugo   pts/0       red.example.com Mon Jul 27 13:56   still logged in
hugo   :0          :0              Mon Jul 27 13:39   still logged in
reboot system boot 3.16.0-4-amd64  Mon Jul 27 13:37 - 18:20  (04:43)
hugo   :0          :0              Sun Jul 26 17:43 - crash  (19:53)
reboot system boot 3.16.0-4-amd64  Sun Jul 26 17:43 - 18:20 (1+00:37)
hugo   pts/2       red.example.com Fri Jul 24 20:00 - crash (1+21:42)
hugo   :0          :0              Fri Jul 24 19:15 - crash (1+22:27)
hugo   :0          :0              Fri Jul 10 14:19 - 19:15 (14+04:55)
hugo   :0          :0              Fri Jul 10 13:22 - 14:19  (00:56)
reboot system boot 3.16.0-4-amd64  Fri Jul 10 12:46 - 18:20 (17+05:33)
```

Here, too, you have the user, the terminal (or `:0`), the remote end, the start date and time, the end time, and the session duration for every session. If the session end time is `crash`, then the computer didn't have the opportunity to log the actual end of the session (which may happen with virtual machines). The `reboot` lines

Table 13.1: Access codes for processes with `fuser`

Code	Description
`c`	Used as current directory
`e`	Used as executable program text
`f`	Opened as file (for reading)*
`F`	Opened as file (for writing)*
`r`	Used as root directory
`m`	Used as shared library or memory-mapped file

* = The `f` and `F` codes are not displayed in ordinary output.

refer to system reboots, and in those cases the third column (where the remote end of the session would otherwise be displayed) gives the name of the operating system kernel being booted.

`last` looks at the `/var/log/wtmp` file (unless you use the `-f` option to specify another file). If you give one or more user or terminal names, then only the activities of those users (or terminals) will be displayed.

The information output by `last` can, with a certain amount of justification, be viewed as sensitive. After all, they let you retroactively check who was logged on where and when—which is sometimes useful for debugging, but could also get you on the wrong side of your corporate data-protection officer or staff representative. Be circumspect, and do not keep this data for *too* long without discussing this with somebody in charge.

Sometimes you want to find out which process or user is currently using some resource on the system (the typical example is when you want to unmount a file system, but the system won't let you because some process is still using a file or directory on that file system). This is what the `fuser` command[2] is for—it takes as its parameter the name of a file or a file system (or several files/filesystems) and lists all processes "using" these objects: `fuser`

```
$ cd /home/hugo
$ (echo hello; sleep 600) >test.txt
# In a different window:
$ fuser /home/hugo /home/hugo/test.txt
/home/hugo:           767c  1360c  1465c  1467c  1488c  1489c
/home/hugo/test.txt:  1488  1489
```

`fuser`'s output is, by default, a list of PIDs followed by a letter that specifies how the process in question is using the resource. The possible letters are in Table 13.1.

The `-v` option gives you more complete output:

```
# fuser -v /home/hugo/test.txt
                      USER        PID ACCESS COMMAND
  /home/hugo/test.txt: hugo       1488 F.... bash
                      hugo       1489 F.... sleep
```

(The `ACCESS` column uses the codes from Table 13.1 once more.)

The `-m` option widens the search from "the named file or directory" to "some file or directory on the same file system as the named file or directory". The

```
# fuser -m /srv
```

[2]We read that as "eff user" rather than "fyooser".

command, for example, will list all processes that access any file (or directory) on the file system where `/srv` resides. This is, of course, extremely useful if, on your system, `/srv` is on its own file system and you would like to unmount it.

To be able to sort out the "I want to unmount this file system but Linux won't let me" case even more efficiently, you can use the `-k` option to send a signal (`SIGKILL` by default, unless you specify otherwise) to the processes in question:

```
# fuser -mk -TERM /srv; sleep 10; fuser -mk /srv
```

leaves the processes 10 seconds to put their affairs in order, after which they (or whichever ones are left) will get the axe. If you add the `-w` option, only those processes who write to the resource(s) will be terminated. With `-i`, you will be asked for every process whether you really want to kill it.

`fuser` will not only identify the users of files, but also those of TCP and UDP ports:

```
# fuser -n tcp ssh
ssh/tcp:     428   912   914
```

The `-n` option chooses the "namespace" (`file`—the default—, `tcp`, or `udp`), and after that you may specify port numbers or symbolic port names (from `/etc/services`).

As long as there is no ambiguity, you may specify port numbers also in the `ssh/tcp` format, and leave off the `-n` option.

`fuser` for TCP or UDP ports works best as `root`. Ordinary users usually do not have access to the required data structures.

Exercises

13.5 [!2] Check out the `who` and `w` commands. Convince yourself that terminal session in the graphical environment count as separate user sessions.

13.6 [1] Use `who` to display the date and time of the last system boot.

13.7 [3] (For your `sed` and `awk`-fu.) Write a script that calculates how long a user was logged on *in total* (within the horizon of `last`).

13.4 Resource Limits

When multiple users share the same system (be it through terminals or logging in via the network using `ssh`), it is important that no single user be able to monopolise the system's resources to the detriment of the others. Even if you are the only user on a system, it may make sense to rein in single processes if they appear too greedy. To facilitate this, Linux offers a mechanism called "resource limits".

Resource limits let you specify upper bounds for various resources that users (or single processes belonging to them) may consume. With the `ulimit` shell command you can get an overview of the resources in question—the `-a` option of the command lists all resource limits and their current settings:

```
$ ulimit -a
core file size          (blocks, -c) 0
data seg size           (kbytes, -d) unlimited                dynamic memory
scheduling priority             (-e) 0                      nice value (quirky)
```

```
file size               (blocks, -f) unlimited
pending signals                 (-i) 8181
max locked memory       (kbytes, -l) 32
max memory size         (kbytes, -m) unlimited                    ignored
open files                      (-n) 1024
pipe size            (512 bytes, -p) 8
POSIX message queues     (bytes, -q) 819200
real-time priority              (-r) 0
stack size              (kbytes, -s) 8192
cpu time               (seconds, -t) unlimited
max user processes              (-u) 8181
virtual memory          (kbytes, -v) unlimited
file locks                      (-x) unlimited
```

For each of these resource limits there is a "soft limit" and a "hard limit". The difference is that it takes administrator privileges to raise the hard limit (you may always lower it). Users can set arbitrary soft limits but only up to the current hard limit. In the shell, hard limits are modified using "`ulimit -H`" and soft limits using "`-S`"; when neither one or the other are specified, both the hard and soft limit are set to the same value.

soft limit
hard limit

When no value is specified for a resource limit, its current value is displayed:

```
$ ulimit -n 512                              Allow 512 open files per process
$ ulimit -n                                              What limit did I set?
512
```

Resource limits are process attributes (just like the current working directory or the process environment) and are handed down by a process to its child processes.

Resource limits are process attributes

Some resource limits deserve a few special remarks:

`core file size` This is most interesting to developers—"core dumps" are created when a program is stopped unexpectedly by a signal and allow you to investigate the cause. The default value of 0 means that no core dumps will be created at all; if you need them, you should use a command like

```
$ ulimit -c unlimited
```

`data seg size` When the soft limit of this resource is reached, a process will not be able to obtain more memory from the operating system. It may scrape by if it releases some memory that it no longer requires.

`scheduling priority` This is the lower (!) limit for the "nice value" of a process. Since `ulimit` does not accept negative parameters, the actual value that will be used when you type "`ulimit -e` *n*" is $20 - n$. This way of specifying a nice value is a bit contorted, but it lets you allow ordinary users to lower the nice value of a process below 0:

```
# ulimit -e 30                                                  actually −10
# /bin/su - hugo
$ nice --5 /bin/sleep 10                           works; new nice value is −5
$ nice --15 /bin/sleep 10
nice: cannot set niceness: Permission denied
```

`file size` When a process attemps to increase the size of a file to a value above this limit, it is sent a `SIGXFSZ` signal. This signal normally terminates the process, but if the process catches it, the write operation merely results in an error code , and the process can try to come up with something different.

max memory size This may sound tempting, but as of Linux 2.4.30 this value is being ignored. Even earlier on it probably didn't do what you might have wanted it to do, anyway.

open files The number of file descriptors that a process may keep open at the same time. When the limit is reached and a process attempts to open another file, that attempt will fail.

stack size The size of the process stack in Kibibytes.

Also, as of Linux 2.6.23, the size of the space used for command-line arguments and environment variables. Linux allocates one quarter of the given limit to each process initially—at least 32 memory pages, which on architectures like the x86 PC, where Linux uses 4-KiB pages, amounts to 128 KiB (the value used before Linux 2.6.23). With the default value for this resource limit, the usual amout is now 2 MiB.

cpu time When a process reaches the soft value of this resource limit, it is sent a `SIGXCPU` signal. This signal is repeated once per second until the hard limit is reached, at which point `SIGKILL` is sent.

max user processes This limit differs from the others in that it applies per user, not per process or file. It specifies the maximum number of parallel processes that a user can have running on their behalf. If it is reached, any attempts to create more processes will fail.

`ulimit` All resource limits can be set interactively using the `ulimit` shell command. They then apply to the shell in which the command was entered as well as all processes that will be started by that shell (and their childrens).

fork bomb A classic of the genre is the "fork bomb" à la

```
:(){ :|:& };:
```

(or, written down more readably)

```
f() {
  f | f &
}
f
```

This small shell command line launces a process that forks two copies of its own as child processes and puts them in the background. Each of the child processes creates two new child processes and so on … you can see what goes on here. The problem is that this type of program, if left to run uncontrolledly, occupies all of the system's process table so you as the administrator cannot launch new processes to get the situation under control. (Whenever some process terminates, the fork bomb will likely be there ahead of you to take advantage of the free slot in the process table.)—You can try to not have the problem arise in the first place by preventing users from generating enough processes to fill the process table. Something like

```
ulimit -u 128
```

(as opposed to the default value of 8191) should stop such shenanigans in their tracks without cramping your users' style too much. (Incidentally, you can check the `/proc/sys/kernel/threads-max` for the size of your system's process table.)

If your system should ever be infested by a fork bomb while you have a root shell running, you could attempt to terminate its processes even so. You have to be a bit careful, though, because, if you just say `kill`, each killed process will be replaced by a new one immediately. Instead, try to stop (rather than terminate) all the fork bomb processes. This keeps them from multiplying. Only then kill them off:

```
# killall -STOP process-name
# killall -KILL process-name
```

(Do not try this on a Solaris or BSD machine.)

Windows

When your Windows-using buddies laugh at how easily a Linux computer can be stopped dead with a single command line: A batch file containing

```
%0|%0
```

works just as well on Windows—and one can do even less about it. Five characters versus thirteen.

Resource limits for users

In order to impose restrictive resource limits on your users, you have to set them *before* the users get to take control, and such that they can't change the `ulimit` commands in question themselves (so `~/.bash_profile` is not really an option). An obvious alternative would be `/etc/profile`, but it assumes that all of your users use Bash as their login shell.

`pam_limits`

A more elegant solution would be to use a PAM module named `pam_limits`. This module is part of the login process and allows you to configure detailed resource limits for single users and groups in the `/etc/security/limits.conf` file. Further details can be found in the `pam_limits`(8) and `limits.conf`(5) manual pages.

Exercises

13.8 [!2] Choose some interesting resource limits (`file size` and `open files` come to mind) and write some shell scripts that test whether these resource limits actually apply. (You may set the resource limits to a ridiculously low value at the start of a script to make their effects more evident.)

13.9 [!2] Insert some interesting resource limits into `/etc/profile` and make sure that these limits actually affect users who log in freshly. How can you restrict the limits to specific groups of users?

13.10 [2] Add some interesting resource limits to the `/etc/security/limits.conf` file, and make sure that these limits take effect. Verify the limits by logging in as one of the affected users. (In order for this exercise to work, `pam_limits` need to be configured on your system. Check whether the `/etc/pam.d/login` file contains a line approximately like

```
session required pam_limits.so
```

If such a line exists, `pam_limits` is available on your system.)

13.11 [2] Experiment with the fork bomb by starting a "weakened" version looking approximately like

```
#!/bin/sh
# forkbomb.sh
f() {
  sleep 5
  f | f &
}
f
```

Trace the number of fork bomb processes with a command like

```
# watch 'ps auxw | grep forkbomb.sh | grep -v "\(watch\|egrep\)''
```

Finally kill the fork bomb as described in the text by using `killall`.

13.12 [2] (Not for the faint of heart.) Run the fork bomb without the additional `sleep` command. To avoid the system reboot that would probably be necessary otherwise, run the following command *beforehand*:

```
# (sleep 15 && exec /usr/bin/killall -STOP forkbomb.sh) &
```

(Or try the experiment in a virtual machine.)

13.5 Administrator Privileges With `sudo`

The `su` command allows ordinary users to assume the identity of `root` (if they know the correct password). The system does log that `su` was used[3], but afterwards the user in question has full administrator privileges—if it is just the intern who is supposed to start the weekly backup, this may be too much of a good thing. It would be nicer if certain users could be allowed to execute *certain* commands as `root`.

This is exactly what `sudo` is for. Using this command, the `root` account is not really used directly any longer. Instead, suitably privileged users can use something like

```
$ sudo passwd sue
```

to execute commands as `root`. `sudo` prompts for the *user*'s (rather than `root`'s) password—a correct answer is remembered for a certain amount of time—or even dispenses with asking for a password altogether.

Some distributions—Ubuntu, Debian GNU/Linux optionally, and incidentally MacOS X—extend `sudo` privileges to the first user account created during installation and disable log-ins to the `root` account completely. This prevents naive users from working as `root` all the time, "because one can do everything".

In fact, you can configure `sudo` to expect either the password of the requesting user or that of the `root` account. However, the latter is a stupid idea on the whole. (Of course this did not stop the developers of the Novell/SUSE distributions from making it the default.) See also exercise 13.14.

By default a correctly entered password remains valid for 15 minutes (the time is configurable). The "`sudo -k`" command (which does not require a password), though, can be used to reset the remembered password, so the next time you run `sudo`, it will prompt for it again.

Disabling password requests completely is a two-edged sword. It is very convenient but the accounts of users who may do this are effectively made into `root` accounts that must be secured accordingly.

All commands executed through sudo are logged using the syslog mechanism (see Chapter 1). Entries look like this: logging

```
Feb 05 22:13:15 red sudo:  hugo : TTY=pts/5 ; PWD=/home/hugo ;▷
 ◁ USER=root ; COMMAND=/usr/bin/passwd
```

The /etc/sudoers file controls who gets to use sudo and for what. The format of the file is fairly baroque and the possibilities defy description. We explain only the very simplest usage here. /etc/sudoers

You should use the visudo command to edit the /etc/sudoers file. It drops you into your preferred editor to edit the file (it checks the VISUAL environment variable first, then the EDITOR environment variable, and finally the editor setting in /etc/sudoers before falling back to good old vi) and does a syntax check immediately after you have saved the file, before putting your new configuration into effect. This is very important because in case of an error you do not want to end up with a configuration file that will cause sudo to throw a fit, which may result in your having sawn off the branch on which you have been sitting. In addition, it makes sure that only one user is editing the file at any one time. visudo

The heart of the /etc/sudoers file is formed by lines containing rules of the form rules

```
hugo  ALL = /usr/bin/cancel [a-z]*
```

The above rule allows user hugo to run the cancel command like

```
$ sudo cancel lp-123
```

The "[a-z]*" makes sure that the parameter of the command begins with a letter, so no options can be injected. parameter

"ALL" means that this rule applies to all hosts. On a network this makes it easier to configure sudo in a single file for all hosts: If hugo is only allowed to cancel print jobs on the red host, then write ALL

```
hugo  red = /usr/bin/cancel [a-z]*
```

If the command is issued on host blue, for example, it would be rejected, even if submitted using sudo.

That a sudoers file may potentially contain rules for all hosts on a network by no means implies that the file only needs to be kept on a single host. Far from it: You as the administrator are responsible for making the file available on any host where it is supposed to be in force.

When you specify just a command (without parameters), arbitrary parameters are allowed: arbitrary parameters

```
hugo ALL = /usr/bin/cancel
```

When no parameters should be allowed at all, the only parameter specified in the sudoers file must be an empty string:

```
hugo ALL = /usr/bin/passwd ""
```

[3]… which of course helps you only if the log is kept on a different computer, as the user could alter or remove a local log after a successful su.

In this case, `hugo` would *only* be allowed to change the password of `root`. (Hang on …)

Be careful about commands like `vi` that allow users to execute shell commands. These commands are also executed with `root` privileges! To prevent this, you could add a rule like

```
hugo ALL = NOEXEC: /usr/bin/vi
```

This line stops `vi` from running child processes. (An even better approach for including editors is explained at the end of this section.)

multiple commands

You can also specify multiple commands:

```
hugo ALL = /usr/bin/cancel [a-z]*, /usr/bin/cupsenable [a-z]*
```

allows "`sudo cancel`" as well as "`sudo cupsenable`", both with (at least) one parameter.

When you specify a directory name (as an absolute path name with a trailing slash), this stands for all executable files in that directory (but not subdirectories):

```
hugo ALL = /usr/bin/                                  Everything in /usr/bin
```

command aliases

It is often more convenient to collect commands into groups. You can do this using command aliases:

```
Cmnd_Alias PRINTING = /usr/bin/cancel [a-z]*, \
                      /usr/bin/cupsenable [a-z]* \
                      /usr/bin/cupsdisable [a-z]*
◁◁◁◁◁
hugo ALL = PRINTING
```

Command aliases can be mixed with literal commands in the same rule:

```
hugo ALL = PRINTING, /usr/bin/accept [a-z]*
```

The "`ALL`" alias stands for "all commands":

```
hugo ALL = ALL
```

effectively gives `hugo` full administrator privileges.

excluding commands

A leading "`!`" character can be used to exclude commands that would otherwise be allowed by a configuration:

```
hugo ALL = /usr/bin/passwd [a-z]*, !/usr/bin/passwd root
```

allows `hugo` to change any password except `root`'s.

Do not try to be too clever with "`!`". In particular, keep away from rules like

```
hugo ALL = /bin/, !/bin/sh, !/bin/bash
```

—if `hugo` may run any command in `/bin` as `root`, nobody prevents him from doing something like

```
$ sudo cp /bin/sh /bin/mysh
$ sudo mysh
```

sudo is not cynical enough to be able to detect this kind of hanky-panky. Also watch out for combinations with ALL.

All barriers are finally dropped by a rule like

```
hugo ALL = NOPASSWD: ALL
```

which allows hugo to execute all commands as root without even being prompted for a password.

alternative users

By default sudo runs all commands as root, but you can also specify another user. With

```
hugo ALL = (mysql) /usr/bin/mysqladmin
```

hugo can run the mysqladmin command as the mysql user. To do so, he must say something like

```
$ sudo -u mysql mysqladmin flush-privileges
```

user and host aliases

There are not just alias names for commands, but also for users and hosts, so you can specify rules like this:

```
User_Alias WEBMASTERS = hugo sue
Host_Alias WEBHOSTS = www1 www2
⊲⊲⊲⊲⊲
WEBMASTERS WEBHOSTS = NOPASSWD: /usr/sbin/apache2ctl graceful
```

Values of host aliases may contain IP addresses and network addresses (with an optional netmask):

```
Host_Alias FILESERVERS = red, 192.168.17.1
Host_Alias DEVNET      = 192.168.17.0/255.255.255.0
Host_Alias FINANCENET  = 192.168.18.0/24
```

Wherever a user name is expected, you may specify a group, too. Just prefix the group's name with a percent sign:

```
%operators ALL = /usr/local/bin/do-backup
```

In addition to alias names and rules, the /etc/sudoers supports a multitude of options that control the function of sudo. Read sudo(8) and sudoers(5).

options

sudoedit

A nice extra gimmick is "sudo -e" (or sudoedit). The command

```
$ sudo -e /etc/hosts
```

is essentially equivalent to

```
$ sudo cp /etc/hosts /tmp/hosts.$$
$ sudo chown $USER /tmp/hosts.$$
$ vi /tmp/hosts.$$                                  in fact: VISUAL and friends
$ if ! sudo cmp --quiet /etc/hosts /tmp/hosts.$$ \
> then \
>   sudo cp /tmp/hosts.$$ /etc/hosts && rm -f /tmp/hosts.$$ \
> fi
```

This means that the command creates a temporary copy of the file to be edited and then passes that copy to your favorite editor. Afterwards it checks whether the copy has been changed compared to the original, and, if so, the copy replaces the original file. This method has some convenient advantages, not least that the editor runs with the ordinary user's privileges only, so they cannot spawn a `root` shell from the editor.—Incidentally, the `/etc/sudoers` file will be searched for `sudoedit` when deciding whether a user gets to use this feature.

Exercises

13.13 [!1] Configure a `sudo` rule that allows you to create new users, using the `useradd` command, from your ordinary user account.

13.14 [2] ("[!2]" for users of Novell/SUSE Distributions.) At the beginning of the previous section we noted that `sudo` may prompt for the `root` password instead of the password of the requesting user. We also called this a stupid idea. What do you think could be our reasons for this assessment?

13.15 [2] The following configuration is intended to allow the users specified in `ADMINS` to run all commands with `root` privileges, except for changing the root password.

```
ADMINS   ALL = NOPASSWD: ALL, !/usr/bin/passwd, \
                /usr/bin/passwd [A-z]*, \
                !/usr/bin/passwd root
```

Why does it not work as intended?

13.6 Basic Networking Security

On computer systems without any network connections, security is an important yet manageable topic. Unfortunately, nowadays this restriction applies to very few computers, in particular when we consider an operating system like Linux which essentially grew up on the Internet and helps define the "state of the art" of computer networking.

Therefore, as the administrator of a computer that is connected to the Internet, you have a special responsibility. Not only do you have to make sure that all services provided by your system (no matter whether these are restricted to your employer's LAN or available to the Internet at large) are provided reliably, but you must also ensure that your machine is not used as a stepping stone to hurt other Internet users—be it through sending spam or distributed denial-of-service attacks. You cannot hide behind excuses like "I am so small and insignificant, nobody will look at *me*", because they are demonstrably false—many crackers enjoy systematically checking the IP addresses used by ISPs for their customers for insecure hosts.

How do you deal with this situation? The first basic principle consists in presenting the smallest area to be attacked. Make sure that your host does not provide any services on the Internet that you do not even know exist, let alone are active. This is most easily checked using a command like

```
# netstat -tulp
```

which presents you with a list of all "open ports", i. e., the services that your computer provides, together with the IP addresses it provides them on and the processes responsible for them. If you have access to a suitably equipped host outside your own local network, you can also use `nmap` to check how your computer presents itself to the Internet.

In earlier times Linux distributors tended to activate all kinds of services with only cursory configurations. This is no longer the case today, but Lenin's maxim of "Trust is good, control is better" is still a highly recommended position as far as network security is concerned.

You should be able to justify every line that the `netstat` and `nmap` programs output. If anything appears that means nothing to you, then go and find out.

Deactivating Services

Deactivate all services that you do not need by removing the corresponding programs from the list of daemons to be started when the system comes up or commenting them out in the `/etc/inetd.conf` file. If you are using `xinetd`, add the following line to the configuration sections of any services you do not want to run:

```
disable = yes
```

Services that are not obviously superfluous can often be limited to the local host or the local network. You should make use of the option to provide a service only on the loopback interface ((`localhost`, `127.0.0.1`) whenever possible. For example, it makes sense to allow local programs to submit e-mail messages via the SMTP service of your host, but it is not necessary to allow the entire LAN or even the entire Internet to do so. All common MTAs can be configured such that they accept connections only on IP address `127.0.0.1`, port 25.

Loopback Interface

Alternatively, you can use the "TCP wrapper" to provide a service to all hosts of your LAN.

IP Address-based Authentication

Note that authentication based on IP addresses is generally not secure—it is easy for an attacker to send datagrams with arbitrary IP addresses (especially if receiving results is not essential). What does work reasonably reliably is to use the TCP wrapper to restrict a service to the IP addresses used by the local network, when you simultaneously ensure, e. g., through a suitable configuration of your firewall's packet filter, that datagrams from outside that claim sender addresses within your network are dropped.

There will be much to be said about the secure configuration of various network services elsewhere in the Linup Front training materials line—up to here, network services have not really been an important topic. Security in general is the focus of the Linup Front training manual, *Linux Security*, which explains, among other things, how to configure Linux-based packet filters and firewalls.

Exercises

13.16 [2] Check which services your system provides to the outside. Are all of these services necessary?

Commands in this Chapter

fuser	Identifies processes owning given files or sockets	`fuser`(8)	181
last	List recently-logged-in users	`last`(1)	180
sudo	Allows normal users to execute certain commands with administrator privileges	`sudo`(8)	186
sudoedit	Allows normal users to edit arbitrary files (equivalent to “`sudo -e`”)	`sudo`(8)	189
ulimit	Sets resource limits for processes	`bash`(1)	182
visudo	Allows exclusive editing of `/etc/sudoers`, with subsequent syntax check	`visudo`(8)	187
w	Displays the currently active users (and more)	`w`(1)	180
who	Displays the names of currently logged-in users	`who`(1)	179
whoami	Outputs the current (effective) user name	`whoami`(1)	180

Summary

- Security is an important topic for everyone who operates a computer.
- Users should not be allowed to mount arbitrary removable media in an unrestricted fashion. The `user` and `users` mount options imply that device files and SUID/SGID files on a medium will not be functional.
- As a system administrator you should proactively search your system for device files and SUID/SGID files that do not belong there.
- The `who` and `w` commands allow you to view the users currently using the system, while the `last` command displays historical session information.
- You can use `fuser` to identify the users of files, directories, file systems, or TCP and UDP ports.
- Resource limits can be used to keep users or system processes from monopolising resources to the detriment of other users.
- With `sudo`, individual users can be allowed to execute particular commands with administrator privileges. However, configuring the program is not exactly straightforward.
- Basic network security implies not providing superfluous services and restricting the services that are offered to the smallest possible set of users.

Bibliography

McC08 Matt McCutchen. “The suidperl Story”, March 2008.
`http://mattmccutchen.net/suidperl.html`

A

Sample Solutions

This appendix contains sample solutions for selected exercises.

1.1 Such events are customarily logged by `syslogd` to the `/var/log/messages` file. You can solve the problem most elegantly like

```
# grep 'su: (to root)' /var/log/messages
```

1.2 Insert a line

```
*.*                 -/var/log/test
```

anywhere in `/etc/syslog.conf`. Then tell `syslogd` using “`kill -HUP …`” to re-read its configuration file. If you check `/var/log` afterwards, the new file should already be there and contain some entries (which ones?).

1.3 On the receiving system, `syslogd` must be started using the `-r` parameter (see p. 16). The sending system needs a configuration line of the form

```
local0.*     @blue.example.com
```

(if the receiving system is called “`blue.example.com`”).

1.4 The only safe method consists of putting the log out of the attacker’s reach. Therefore you must send the messages to another host. If you don’t want the attacker to be able to compromise that host, too, then you should connect the logging host to the one storing the log by means of a serial interface, and configure `syslogd` such that it sends the messages to the corresponding device (`/dev/ttyS0` or something). On the storing host, a simple program can accept the messages on the serial interface and store them or process them further. Alternatively, you could of course also use an (old-fashioned) dot-matrix printer with fan-fold paper.

1.5 You can, among other things, expect information about the amount and usage of RAM, available CPUs, disks and other mass storage devices (IDE and SCSI), USB devices and network cards. Of course the details depend on your system and your Linux installation.

1.10 Versuchen Sie etwas wie

```
# We assume a suitable source definition.
filter login_hugo {
    facility(authpriv)
      and (match("session opened") or match("session closed"))
      and match("user hugo");
};
destination d_root { usertty("root"); };
log { source(...);
    filter(login_hugo);
    destination(d_root);
};
```

1.14 In `/etc/logrotate.d`, create an arbitrarily-named file containing the lines

```
/var/log/test {
    compress
    dateext
    rotate 10
    size 100
    create
}
```

2.1 Text files are, in principle, amenable to the standard Unix tools (`grep` etc.) and, as such, ideologically purer. They can be inspected without specialised software. In addition, the concept is very well understood and there are gazillions of tools that help evaluate the traditional log files. Disadvantages include the fact that text files are difficult to search, and any sort of targeted evaluation is either extremely tedious or else requires additional (non-standardised) software. There is no type of cryptographic protection against the manipulation of log entries, and the amount of information that can be written to the log is limited.

3.2 ISO/OSI layer 2 describes the interaction between two nodes that are connected directly (e. g., via Ethernet). Layer 3 describes the interaction among nodes that are not networked directly, and thus includes routing and media-independent addressing (e. g., IP over Ethernet or Token-Ring or …).

3.3 You can look to the `/etc/services` and (possibly) `/etc/protocols` files for inspiration. You will have to assign the protocols to layers by yourself. *Hint:* Practically everything mentioned in `/etc/services` belongs to the application layer.

3.4 It is, of course, impossible to give a specific answer, but usually a TTL of 30–40 should be more than sufficient. (The default value is 64.) You can determine the minimal TTL by means of sending successive packets with increasing TTL (starting at TTL 1) to the desired target. If you receive an ICMP error message from some router telling you that the packet was discarded, the TTL is still too low. (The `traceroute` program automates this procedure.) This "minimal" TTL is naturally not a constant, since IP does not guarantee a unique path for packet delivery.

3.5

1. The `127.55.10.3` address cannot be used as a host address since it is that network's broadcast address.
2. The `138.44.33.12` address can be used as a host address.

3. The 10.84.13.160 address is the network address of the network in question and is thus unavailable as a host address.

3.6 For example, to implement certain network topologies or assign parts of the address range to computers in different providers.

3.7 There are 16 subnets altogether (which is obvious from the fact that the subnet mask has four more bits set than the original netmask). Further subnets are 145.2.0.0, 145.2.16.0, 145.2.48.0, 145.2.80.0, 145.2.96.0 145.2.112.0, 145.2.144.0, 145.2.176.0, 145.2.208.0, 145.2.224.0, and 145.2.240.0. The node with the IP address 145.2.195.13 is part of the 145.2.192.0 subnet.

4.1 lsmod displays all loaded modules. "rmmod ⟨*module name*⟩" tries to unload a module, which will fail when the module is still in use.

4.2 This is done most easily with ifconfig.

4.3 Use "ifconfig ⟨*interface*⟩ ⟨*IP address*⟩". To check whether other computers can be reached, use the ping command.

5.1 The former should be on the order of tens of microseconds, the latter—depending on the networking infrastructure—in the vicinity of milliseconds.

5.2 Try something like

```
# ping -f -c 1000000 localhost
```

The total running time is at the end of the penultimate line of output from ping. (On the author's system it takes approximately 13 seconds.)

5.3 For example:

```
$ ping6 ff02::2%eth0
PING ff02::2%eth0(ff02::2) 56 data bytes
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=1 ttl=64 time=12.4 ms
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=2 ttl=64 time=5.27 ms
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=3 ttl=64 time=4.53 ms
Ctrl+c
--- ff02::2%eth0 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003ms
rtt min/avg/max/mdev = 4.531/7.425/12.471/3.581 ms
```

6.2 FTP is a protocol using fairly long-lived "sessions": You log in, send various FTP commands, receive files in return (or send some to the server, too), and finally log out again. All these actions use the same TCP connection; when the connection is started, inetd can launch the FTP server, which continues running until the connection is taken down again at the very end of the session. The HTTP protocol forming the basis of the WWW, however, uses the "request-reply" scheme: A browser asks for a resource such as http://www.example.com/test.html. It establishes a TCP connection to the WWW server, which sends the desired resource (or an error message) and then takes down the connection again. This implies that inetd would have to start a WWW server for this single resource request. Now imagine what it means to retrieve a longish HTML page with 50 embedded pictures: inetd would need to start 51 WWW server processes, all of which would have to independently run through a possibly complicated initialisation sequence before sending 100 bytes of GIF data to the client. This is far too inefficient even for testing purposes.—`inetd` is only suitable for services which are either fairly trivial (so that no extensive initialisation is necessary) or use long-lived sessions. Even for SMTP, it often makes sense to use a standalone server, instead of starting a new mail server from `inetd` for every single incoming message.

6.3 For your solution, you should first pick a suitable port number and add it to `/etc/services`, for example

```
caesar   9999/tcp
```

for port 9999. After this, a line like

```
caesar  stream  tcp  nowait  root  /usr/bin/tr tr A-Z D-ZA-C
```

in `/etc/inetd.conf` basically suffices. The problem with this deceptively simple solution is only the fact that `tr` buffers its output—so you will see the cipher text only after your program has finished. A simple C program such as

```
#include <stdio.h>
#include <ctype.h>

const char code[] = "DEFGHIJKLMNOPQRSTUVWXYZABC";

int
main (void)
{
    int c;
    setvbuf(stdout, (char *)NULL, _IOLBF, 0);
    while ((c = getchar()) != EOF) {
        putchar('A' <= c && c <= 'Z' ? code[c - 'A'] : c);
    }
    return 1;
}
```

could use “line buffering” instead, which is much more fun.

6.4 Replace the line in `/etc/inetd.conf` by something like

```
ps  stream  tcp  nowait  root  /usr/sbin/tcpd /bin/ps auxw
```

(the actual path names may differ). After that, you must suitably configure `tcpd`, for example using a line like

```
ps : ALL EXCEPT 127.0.0.1
```

in the `/etc/hosts.deny` file. Alternatively, you could add

```
ps : 127.0.0.1
```

to `/etc/hosts.allow` and

```
ps : ALL
```

to `/etc/hosts.deny`, which is more work. If you are really paranoid, put “`ALL : ALL`” into `/etc/hosts.deny` and explicitly enable specific clients and services in `/etc/hosts.allow`.

6.5 You could extend the `/etc/hosts.allow` entry like

```
ps : 127.0.0.1 : spawn /usr/bin/logger -p local0.info -t ps "%c"
```

6.7 You can define something like

```
service ps
{
    socket_type     = stream
    protocol        = tcp
    wait            = no
    user            = root
    server          = /bin/ps
    server_args     = auxw
    only_from       = localhost
    no_access       =
}
```

6.8 The `interface` attribute is handy.

6.9 The latter method has the advantage that access is definitely restricted to local processes, while the former allows, in principle, manipulations to packets' source addresses that will allow remote hosts to launch services (and thus trigger a "denial of service" attack). In this sense, the `127.0.0.1` method is safer. Of course you need to ensure that local processes do try to contact `localhost` instead of the host's FQDN. Inconvenient, but security does have its price …

7.4 This is `daytime.socket`:

```
[Unit]
Description=DAYTIME service socket

[Socket]
ListenStream=13
Accept=yes

[Install]
WantedBy=sockets.target
```

And here is `daytime@.service`:

```
[Unit]
Description=DAYTIME service (per-connection server)

[Service]
ExecStart=-/bin/date
StandardInput=socket
```

Note that this file is a "template" and hence needs to be called `daytime@.service`—otherwise systemd will not find it when `daytime.socket` is activated.

How would you ensure that the date appears in the standardised English-language (rather than, e. g., localised German if that is the system default) format?

8.1 Try something like

```
for tz in America/New_York Europe/Berlin Asia/Tokyo
do
    TZ=$tz xclock -title "$(basename $tz | tr _ ' ')" -update 1 &
done
```

8.2 According to "`zdump -v /usr/share/zoneinfo/Europe/Berlin`" during the years of 1916–18, 1940–49 (with "double daylight saving time" in 1945 and 1947), and from 1980 onwards.

8.3 Using a time server on the Internet means not having to set up and maintain additional hardware, but there can be noticeable network load. We recommend against using a time server on dial-up connections to the internet that are charged based on time, since the connection will be kept open pretty much all the time. It is also necessary to configure a firewall such that your NTP client (which then can act as a time server on the next-higher stratum inside you network) can contact the time server on the Internet. This means another possible attack vector for crackers.—The radio-controlled clock is another peripheral which can develop faults and must be maintained; fortunately, radio-controlled clocks are very cheap so you can operate two or three for redundancy … In a security-minded environment, a radio-controlled clock on a time server inside the DMZ is the method of choice since firewall security is not compromised. Besides, the DCF77 (or similar) signal is probably less easy to spoof than NTP packets.

8.6 Do note that you can't use a container-based virtualisation system because the clock is usually not virtualised (containers cannot set their own clock independently from that of the host kernel, and they can for sure not have it run fast or slow the way `ntpd` likes to do it).

8.7 By default, the broadcast server sends a datagram containing the current time every 64 seconds. If a freshly started `ntpd` on a broadcast client receives such a datagram, it waits for a random (brief) interval and then starts a number of direct queries to the broadcast server, in order to set its clock and calibrate the connection. After that, it listens only for further broadcast datagrams and slows down or speeds up the clock to reconcile any differences. If the running clock of the host differs too crassly from the time available via NTP, it prefers doing nothing over setting the time with a large jump; you need to restart `ntpd` in order to activate the automatic clock setting mechanism.

9.2 You can set the default using something like

```
$ lpoptions -d lp -o number-up=2
```

Afterwards, commands like `lp` will print scaled-down pages by default. If you do want to print something at its original size, try

```
$ lp -o number-up=1 foo.txt
```

9.7 CUPS does allow specifying various print options, but some options require manual intervention at the printer. For example, for a simple colour printer with one paper tray it might be useful to create separate print queues for "normal" jobs and for jobs to be printed on high-grade glossy paper for photographs. Normally the printer is provided with plain paper, jobs submitted to the "normal" queue are printed immediately, and photo jobs collect in the "photo" queue. Later on, you can disable the "normal" queue (jobs will still be accepted but not printed), change the paper, and enable the "photo" queue. Once all photographs have been printed, you suspend the "photo" queue again, change the paper back, and re-enable the "normal" queue.

10.1 During the first login procedure, `ssh` should ask you to confirm the remote host's public server key. During the second login procedure, the public server key is already stored in the `~/.ssh/known_hosts` file and does not need to be reconfirmed.

10.2 In the first case, the connection is refused, since no public server key for the remote host is available from `~/.ssh/known_hosts`. In the second case, the connection is established without a query.

10.3 The file contains public keys only and thus does not need to be kept secret.

10.6 Use something like

```
$ ssh-keygen -l -f ~/.ssh/id_rsa.pub
```

(Does it make a difference whether you specify `id_rsa.pub` or `id_rsa`?)

10.7 Noninteractive programs that need to use an SSH connection are often unable to enter a passphrase. In restricted cases like these, it is conceivable to use a private key without a passphrase. You should then make use of the possibility to make a public key on the remote host useable for specific commands only (in particular the ones that the noninteractive program needs to invoke). Details may be found in `sshd`(8).

10.8 Try "`ssh -X root@localhost`".

10.9 One possible command line might be

```
# ssh -L 4711:localhost:7 user@remote.example.com
```

Do consider that `localhost` is evaluated from the perspective of the `remote` host. Unfortunately, `ssh` does not allow symbolic names of well-known ports (as per `/etc/services`).

12.2

1. Alice herself has signed Bob's and Carla's keys, so these keys are obviously valid. Doris's key has been signed by Bob. Alice trusts Bob "fully" and has signed his key herself, so Doris's key is also "valid". Alice's "marginal" trust in Carla is not sufficient to make Eric's key "valid".

2. When Alice truts both Carla and Doris "marginally", Eric's key becomes "valid" because both Carla and Doris have signed it. There is a chain of two links from Alice to Carla to Eric and a chain of three links from from Alice to Bob to Doris to Eric.

3. Eric's key is "valid" and so Fiona's key is at the end of a chain of three links (Alice, Carla, and Eric), so the first condition is met. However, the trust level is problematic. Since all paths from Alice to Fiona include Eric as a link, only "full" trust in Eric can make Fiona's key "valid", at least until either Bob or both Carla and Doris have signed Fiona's key. As long as this does not happen, though, Alice needs to have herself be convinced by Eric that he is competent and diligent about GnuPG, and to trust him "fully".

13.1 With direct read permission to the device file of a file system (or even an entire disk), you can read all data stored there, no matter what the access permissions for individual files say. You just need some knowledge of the structure of the file system in question or a large USB stick and another Linux system.—With write permission to a file system's device file, you have what amounts to administrator privileges on the system concerned, since you can set arbitrary programs set-UID `root` (to mention just one obvious thing to do).

13.6 Use "`who -b`".

13.7 One solution (not the only conceivable one) would be something like

```
#!/bin/sh

last $1 \
    | sed -n '/(/{s/^.*(//; s/).*$//; p}' \
    | tr -c '[0-9\n]' ' ' \
    | awk 'NF == 2 { m += $1; s += $2 }
           NF == 3 { h += $1; m += $2; s += $3 }
           END     { m += int(s/60); s %= 60;
                     h += int(m/60); m %= 60;
                     printf "%d:%02d:%02d\n", h, m, s }'
```

13.9 Code like this may help:

```
if [ "$USER" = "hugo" ]; then
  ulimit ...
fi
```

Or this:

```
if [ $(id -g) = 1000 ]; then
  ulimit ...
fi
```

When the limits are to be applied to lots of users, try:

```
if grep "^$USER$" /etc/limitusers; then
  ulimit ...
fi
```

and store the user names in the file `/etc/limitusers`, one per line.

Finally, you can reinvent `pam_limits` by creating the file `/etc/userlimits` with content of the following form:

```
hugo -c unlimited -s 16384
susi -u 128
```

All you need is something like

```
eval ulimit $(grep "^$USER$" /etc/userlimits \
  | while read U LIMITS; do echo $LIMITS; done)
```

to enforce the resource limits.

13.14 Shared passwords are a bad idea in principle—a password that only you know can be changed whenever you want and for whatever reason, but changing a shared `root` password tends to be a big deal. This in particular because the probability for a shared password to be compromised rises exponentially in the number of people knowing it. One of the advantages of `sudo` is that you can get by 95% (or so) of the time without a generally known `root` password; it suffices to assign one specifically for that computer when it is installed, and to keep it in a safe place.

Here is the qualitative difference: While prompting for the `root` password is supposed to ensure that the user in question may use `sudo`, prompting for their *own* password is supposed to ensure that, in fact, the privileged user is invoking `sudo` rather than somebody who just happened to come across an unattended computer. This implies that this solves a completely different problem, namely that you can mostly rely on the `sudo` log. (If you check only the `root` password, the `sudo`-privileged user X can still use the `sudo`-privileged user Y's unattended computer to execute iffy commands under Y's name, which are marked as such int he log.) *Whether* the user gets to use `sudo` at all is a decision that you make at the moment when you enter the user into the `sudoers` file, and that does not need to be double-checked in every case by assuring the user knows the `root` password.

Finally: If users need to know the `root` password in order to use `sudo`, you must take steps to prevent these users from using `su` or log in as `root` directly, which would on the one hand completely sidestep `sudo`'s logging and on the other hand enable them to do things that the `sudo` configuration might not have allowed.

If you are suffering from this particular misconfiguration as a SUSE distribution user, search your `sudoers` file for a string like

```
Defaults rootpw
```

and place an exclamation point in front of the "`rootpw`" keyword to switch back to the normal behaviour. (The SUSE distribution tries to justify itself by claiming that the default behaviour is necessary so the new user can access `sudo` after installation. If that were actually the case, one ought to ask how Ubuntu, Debian, and Apple manage otherwise. In addition, it would be no skin off SUSE's nose to point this out to users in a more visible place than a comment in `/etc/sudoers`.)

13.15 All the attempts to enforce the correct usage of `passwd` are futile because users can just copy `/usr/bin/passwd` to a different file and run that file as a command instead. (Incidentally, this example used to be presented in official SUSE training manuals, in exactly the manner displayed, as a worthwhile example to be imitated.)

B
LPIC-1 Certification

B.1 Overview

The *Linux Professional Institute* (LPI) is a vendor-independent non-profit organization dedicated to furthering the professional use of Linux. One aspect of the LPI's work concerns the creation and delivery of distribution-independent certification exams, for example for Linux professionals. These exams are available world-wide and enjoy considerable respect among Linux professionals and employers.

Through LPIC-1 certification you can demonstrate basic Linux skills, as required, e. g., for system administrators, developers, consultants, or user support professionals. The certification is targeted towards Linux users with 1 to 3 years of experience and consists of two exams, LPI-101 and LPI-102. These are offered as computer-based multiple-choice and fill-in-the-blanks tests in all Pearson VUE and Thomson Prometric test centres. On its web pages at `http://www.lpi.org/`, the LPI publishes **objectives** outlining the content of the exams. objectives

This training manual is part of Linup Front GmbH's curriculum for preparation of the LPI-101 exam and covers part of the official examination objectives. Refer to the tables below for details. An important observation in this context is that the LPIC-1 objectives are not suitable or intended to serve as a didactic outline for an introductory course for Linux. For this reason, our curriculum is not strictly geared towards the exams or objectives as in "Take classes x and y, sit exam p, then take classes a and b and sit exam q." This approach leads many prospective students to the assumption that, being complete Linux novices, they could book n days of training and then be prepared for the LPIC-1 exams. Experience shows that this does not work in practice, since the LPI exams are deviously constructed such that intensive courses and exam-centred "swotting" do not really help.

Accordingly, our curriculum is meant to give you a solid basic knowledge of Linux by means of a didactically reasonable course structure, and to enable you as a participant to work independently with the system. LPIC-1 certification is not a primary goal or a goal in itself, but a natural consequence of your newly-obtained knowledge and experience.

B.2 Exam LPI-102

The following table displays the objectives for the LPI-102 exam and the materials covering these objectives. The numbers in the columns for the individual manuals refer to the chapters containing the material in question.

No	Wt	Title	ADM1	GRD2	ADM2
105.1	4	Customize and use the shell environment	–	1–2	–
105.2	4	Customize or write simple scripts	–	2–5	–
105.3	2	SQL data management	–	8	–
106.1	2	Install and configure X11	–	11	–
106.2	1	Setup a display manager	–	11	–
106.3	1	Accessibility	–	12	–
107.1	5	Manage user and group accounts and related system files	2	–	–
107.2	4	Automate system administration tasks by scheduling jobs	–	9	–
107.3	3	Localisation and internationalisation	–	10	–
108.1	3	Maintain system time	–	–	8
108.2	3	System logging	–	–	1–2
108.3	3	Mail Transfer Agent (MTA) basics	–	–	11
108.4	2	Manage printers and printing	–	–	9
109.1	4	Fundamentals of internet protocols	–	–	3–4
109.2	4	Basic network configuration	–	–	4–5, 7
109.3	4	Basic network troubleshooting	–	–	4–5, 7
109.4	2	Configure client side DNS	–	–	4
110.1	3	Perform security administration tasks	2	–	4–5, 13
110.2	3	Setup host security	2	–	4, 6–7, 13
110.3	3	Securing data with encryption	–	–	10, 12

B.3 LPI Objectives In This Manual

108.1 Maintain system time

Weight 3

Description Candidates should be able to properly maintain the system time and synchronize the clock via NTP.

Key Knowledge Areas:

- Set the system date and time
- Set the hardware clock to the correct time in UTC
- Configure the correct timezone
- Basic NTP configuration
- Knowledge of using the pool.ntp.org service
- Awareness of the ntpq command

The following is a partial list of the used files, terms and utilities:

- `/usr/share/zoneinfo/`
- `/etc/timezone`
- `/etc/localtime`
- `/etc/ntp.conf`
- `date`
- `hwclock`
- `ntpd`
- `ntpdate`
- `pool.ntp.org`

108.2 System logging

Weight 3

Description Candidates should be able to configure the syslog daemon. This objective also includes configuring the logging daemon to send log output to a central log server or accept log output as a central log server. Use of the systemd journal subsystem is covered. Also, awareness of rsyslog and syslog-ng as alternative logging systems is included.

Key Knowledge Areas

- Configuration of the syslog daemon
- Understanding of standard facilities, priorities and actions
- Configuration of `logrotate`
- Awareness of rsyslog and syslog-ng

The following is a partial list of the used files, terms and utilities:

- `syslog.conf`
- `syslogd`
- `klogd`
- `/var/log/`
- `logger`
- `logrotate`
- `/etc/logrotate.conf`
- `/etc/logrotate.d/`
- `journalctl`
- `/etc/systemd/journald.conf`
- `/var/log/journal/`

108.3 Mail Transfer Agent (MTA) basics

Weight 3

Description Candidates should be aware of the commonly available MTA programs and be able to perform basic forward and alias configuration on a client host. Other configuration files are not covered.

Key Knowledge Areas

- Create e-mail aliases
- Configure e-mail forwarding
- Knowledge of commonly available MTA programs (postfix, sendmail, qmail, exim) (no configuration)

The following is a partial list of the used files, terms and utilities:

- `~/.forward`
- sendmail emulation layer commands
- `newaliases`
- `mail`
- `mailq`
- postfix
- sendmail
- exim
- qmail

108.4 Manage printers and printing

Weight 2

Description Candidates should be able to manage print queues and user print jobs using CUPS and the LPD compatibility interface.

Key Knowledge Areas

- Basic CUPS configuration (for local and remote printers)
- Manage user print queues
- Troubleshoot general printing problems

- Add and remove jobs from configured printer queues

The following is a partial list of the used files, terms and utilities:

- CUPS configuration files, tools and utilities
- `/etc/cups/`
- lpd legacy interface (`lpr`, `lprm`, `lpq`)

109.1 Fundamentals of internet protocols

Weight 4

Description Candidates should demonstrate a proper understanding of TCP/IP network fundamentals.

Key Knowledge Areas

- Demonstrate an understanding of network masks and CIDR notation
- Knowledge of the differences between private and public »dotted quad« IP addresses
- Knowledge about common TCP and UDP ports and services (20, 21, 22, 23, 25, 53, 80, 110, 123, 139, 143, 161, 162, 389, 443, 465, 514, 636, 993, 995)
- Knowledge about the differences and major features of UDP, TCP and ICMP
- Knowledge of the major differences between IPv4 and IPv6
- Knowledge of the basic features of IPv6

The following is a partial list of the used files, terms and utilities:

- `/etc/services`
- IPv4, IPv6
- Subnetting
- TCP, UDP, ICMP

109.2 Basic network configuration

Weight 4

Description Candidates should be able to view, change and verify configuration settings on client hosts.

Key Knowledge Areas

- Manually and automatically configure network interfaces
- Basic TCP/IP host configuration
- Setting a default route

The following is a partial list of the used files, terms and utilities:

- `/etc/hostname`
- `/etc/hosts`
- `/etc/nsswitch.conf`
- `ifconfig`
- `ifup`
- `ifdown`
- `ip`
- `route`
- `ping`

109.3 Basic network troubleshooting

Weight 4

Description Candidates should be able to troubleshoot networking issues on client hosts.

Key Knowledge Areas

- Manually and automatically configure network interfaces and routing tables to include adding, starting, stopping, restarting, deleting or reconfiguring network interfaces
- Change, view, or configure the routing table and correct an improperly set default route manually
- Debug problems associated with the network configuration

The following is a partial list of the used files, terms and utilities:

- `ifconfig`
- `ip`
- `ifup`
- `ifdown`
- `route`
- `host`
- `hostname`
- `dig`
- `netstat`
- `ping`
- `ping6`
- `traceroute`
- `traceroute6`
- `tracepath`
- `tracepath6`
- `netcat`

109.4 Configure client side DNS

Weight 2
Description Candidates should be able to configure DNS on a client host.
Key Knowledge Areas

- Query remote DNS servers
- Configure local name resolution and use remote DNS servers
- Modify the order in which name resolution is done

The following is a partial list of the used files, terms and utilities:

- `/etc/hosts`
- `/etc/resolv.conf`
- `/etc/nsswitch.conf`
- `host`
- `dig`
- `getent`

110.1 Perform security administration tasks

Weight 3
Description Candidates should know how to review system configuration to ensure host security in accordance with local security policies.
Key Knowledge Areas

- Audit a system to find files with the suid/sgid bit set
- Set or change user passwords and password aging information
- Being able to use nmap and netstat to discover open ports on a system
- Set up limits on user logins, processes and memory usage
- Determine which users have logged in to the system or are currently logged in

- Basic sudo configuration and usage

The following is a partial list of the used files, terms and utilities:

- `find`
- `passwd`
- `fuser`
- `lsof`
- `nmap`
- `chage`
- `netstat`
- `sudo`
- `/etc/sudoers`
- `su`
- `usermod`
- `ulimit`
- `who`, `w`, `last`

110.2 Setup host security

Weight 3
Description Candidates should know how to set up a basic level of host security.
Key Knowledge Areas

- Awareness of shadow passwords and how they work
- Turn off network services not in use
- Understand the role of TCP wrappers

The following is a partial list of the used files, terms and utilities:

- `/etc/nologin`
- `/etc/passwd`
- `/etc/shadow`
- `/etc/xinetd.d/`
- `/etc/xinetd.conf`
- `/etc/inetd.d/`
- `/etc/inetd.conf`
- `/etc/inittab`
- `/etc/init.d/`
- `/etc/hosts.allow`
- `/etc/hosts.deny`

110.3 Securing data with encryption

Weight 3
Description The candidate should be able to use public key techniques to secure data and communication.
Key Knowledge Areas

- Perform basic OpenSSH 2 client configuration and usage
- Understand the role of OpenSSH 2 server host keys
- Perform basic GnuPG configuration, usage and revocation
- Understand SSH port tunnels (including X11 tunnels)

The following is a partial list of the used files, terms and utilities:

- `ssh`
- `ssh-keygen`
- `ssh-agent`

- `ssh-add`
- `~/.ssh/id_rsa` and `id_rsa.pub`
- `~/.ssh/id_dsa` and `id_dsa.pub`
- `/etc/ssh/ssh_host_rsa_key` and `ssh_host_rsa_key.pub`
- `/etc/ssh/ssh_host_dsa_key` and `ssh_host_dsa_key.pub`
- `~/.ssh/authorized_keys`
- `ssh_known_hosts`
- `gpg`
- `~/.gnupg/`

C

Command Index

This appendix summarises all commands explained in the manual and points to their documentation as well as the places in the text where the commands have been introduced.

`arp`	Allows access to the ARP cache (maps IP to MAC adresses)	`arp`(8)	50
`cancel`	Cancels a submitted print job	`cancel`(1)	132
`date`	Displays the date and time	`date`(1)	118
`dnsmasq`	A lightweight DHCP and caching DNS server for small installations	`dnsmasq`(8)	79
`fuser`	Identifies processes owning given files or sockets	`fuser`(8)	181
`getent`	Gets entries from administrative databases	`getent`(1)	94
`gpg`	Encrypts and signs files	`gpg`(1)	163
`host`	Searches for information in the DNS	`host`(1)	93
`hwclock`	Controls a PC's CMOS clock	`hwclock`(8)	118
`ifconfig`	Configures network interfaces	`ifconfig`(8)	68
`ifdown`	Shuts down a network interface (Debian)	`ifdown`(8)	74
`ifup`	Starts up a network interface (Debian)	`ifup`(8)	74
`inetd`	Internet superserver, supervises ports and starts services	`inetd`(8)	100, 54
`ip`	Manages network interfaces and routing	`ip`(8)	72
`ipv6calc`	Utility for IPv6 address calculations	`ipv6calc`(8)	63
`klogd`	Accepts kernel log messages	`klogd`(8)	14, 18
`last`	List recently-logged-in users	`last`(1)	180
`logger`	Adds entries to the system log files	`logger`(1)	16
`logrotate`	Manages, truncates and "rotates" log files	`logrotate`(8)	26
`logsurfer`	Searches the system log files for important events	`www.cert.dfn.de/eng/logsurf/`	17
`lp`	Submits a print job	`lp`(1)	130
`lpadmin`	Manages printer job queues	`lpadmin`(8)	137
`lpinfo`	Displays available printer devices and drivers	`lpinfo`(8)	137
`lpoptions`	Manages default settings for printer queues	`lpoptions`(1)	133
`lpq`	Displays a printer queue's status	`lpq`(1)	131
`lpr`	Submits a print job	`lpr`(1)	130
`lprm`	Cancels a print job	`lprm`(1)	132
`mailq`	Displays the state of the mail queue (Sendmail & co.)	`sendmail`(1)	155
`newaliases`	Updates a mail server's alias database (Sendmail/Postfix)	`newaliases`(1)	157
`nmap`	Network port scanner, analyses open ports on hosts	`nmap`(1)	91
`ntp-keygen`	Generates key material for `ntpd`	`ntp-keygen`(8)	122
`ntpq`	Controls NTP servers	`ntpq`(8)	123

ping	Checks basic network connectivity using ICMP	ping(8)	84
ping6	Checks basic network connectivity (for IPv6)	ping(8)	85
pstops	Prepares PostScript print jobs for CUPS		134
route	Manages the Linux kernel's static routing table	route(8)	70
scp	Secure file copy program based on SSH	scp(1)	145
sendmail	MTA administrative command (Sendmail, but also other – compatible – MTAs)	sendmail(1)	155
sftp	Secure FTP-like program based on SSH	sftp(1)	145
ssh	"'Secure shell"', creates secure interactive sessions on remote hosts	ssh(1)	142
ssh-add	Adds private SSH keys to `ssh-agent`	ssh-add(1)	148
ssh-agent	Manages private keys and pass phrases for SSH	ssh-agent(1)	148
ssh-copy-id	Copies public SSH keys to other hosts	ssh-copy-id(1)	147
ssh-keygen	Generates and manages keys for SSH	ssh-keygen(1)	146
sshd	Server for the SSH protocol (secure interactive remote access)	sshd(8)	142
sudo	Allows normal users to execute certain commands with administrator privileges	sudo(8)	186
sudoedit	Allows normal users to edit arbitrary files (equivalent to "`sudo -e`")	sudo(8)	189
syslogd	Handles system log messages	syslogd(8)	14
tail	Displays a file's end	tail(1)	17
tcpd	"TCP wrapper", permits or denies access depending on the client's IP address	tcpd(8)	101
tcpdump	Network sniffer, reads and analyzes network traffic	tcpdump(1)	97
telnet	Opens connections to arbitrary TCP services, in particular TELNET (remote access)	telnet(1)	95
tracepath	Traces path to a network host, including path MTU discovery	tracepath(8)	89
tracepath6	Equivalent to `tracepath`, but for IPv6	tracepath(8)	90
traceroute	Analyses TCP/IP routing to a different host	traceroute(8)	87
ulimit	Sets resource limits for processes	bash(1)	182
vacation	Automatic e-mail responder, e. g., for longer absences	vacation(1)	157
visudo	Allows exclusive editing of `/etc/sudoers`, with subsequent syntax check	visudo(8)	187
w	Displays the currently active users (and more)	w(1)	180
who	Displays the names of currently logged-in users	who(1)	179
whoami	Outputs the current (effective) user name	whoami(1)	180
xconsole	Displays system log messages in an X window	xconsole(1)	14
xinetd	Improved Internet super server, supervises ports and starts services	xinetd(8)	104, 54
xlogmaster	X11-based system monitoring program	xlogmaster(1), `www.gnu.org/software/xlogmaster/`	17
zdump	Outputs the current time or time zone definitions for various time zones	zdump(1)	119
zic	Compiler for time zone data files	zic(8)	119

Index

This index points to the most important key words in this document. Particularly important places for the individual key words are emphasised by **bold** type. Sorting takes place according to letters only; "`~/.bashrc`" is therefore placed under "B".