SUSE Linux Enterprise Server

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System Analysis and Tuning Guide
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About This Guide

SUSE Linux Enterprise Server is used for a broad range of usage scenarios in enterprise and scientific data centers. SUSE has ensured SUSE Linux Enterprise Server is set up in a way that it accommodates different operation purposes with optimal performance. However, SUSE Linux Enterprise Server must meet very different demands when employed on a number crunching server compared to a file server, for example.

Generally it is not possible to ship a distribution that will by default be optimized for all kinds of workloads. Due to the simple fact that different workloads vary substantially in various aspects—most importantly I/O access patterns, memory access patterns, and process scheduling. A behavior that perfectly suits a certain workload might reduce performance of a completely different workload (for example, I/O intensive databases usually have completely different requirements compared to CPU-intensive tasks, such as video encoding). The great versatility of Linux makes it possible to configure your system in a way that it brings out the best in each usage scenario.

This manual introduces you to means to monitor and analyze your system. It describes methods to manage system resources and to tune your system. This guide does not offer recipes for special scenarios, because each server has got its own different demands. It rather enables you to thoroughly analyze your servers and make the most out of them.

General Notes on System Tuning

Tuning a system requires a carefully planned proceeding. Learn which steps are necessary to successfully improve your system.

Part II, “System Monitoring” (page 7)

Linux offers a large variety of tools to monitor almost every aspect of the system. Learn how to use these utilities and how to read and analyze the system log files.

Part III, “Kernel Monitoring” (page 69)

The Linux kernel itself offers means to examine every nut, bolt and screw of the system. This part introduces you to SystemTap, a scripting language for writing kernel modules that can be used to analyze and filter data. Collect debugging information and find bottlenecks by using kernel probes and use perfmon2 to access the CPU's performance monitoring unit. Last, monitor applications with the help of Oprofile.
Part IV, “Resource Management” (page 111)
Learn how to set up a tailor-made system fitting exactly the server's need. Get to know how to use power management while at the same time keeping the performance of a system at a level that matches the current requirements.

Part V, “Kernel Tuning” (page 151)
The Linux kernel can be optimized either by using sysctl or via the /proc file system. This part covers tuning the I/O performance and optimizing the way how Linux schedules processes. It also describes basic principles of memory management and shows how memory management could be fine-tuned to suit needs of specific applications and usage patterns. Furthermore, it describes how to optimize network performance.

Part VI, “Handling System Dumps” (page 191)
This part enables you to analyze and handle application or system crashes. It introduces tracing tools such as strace or ltrace and describes how to handle system crashes using Kexec and Kdump.

TIP: Getting the SUSE Linux Enterprise SDK
Some programs or packages mentioned in this guide are only available from the SUSE Linux Enterprise Software Development Kit (SDK). The SDK is an add-on product for SUSE Linux Enterprise Server and is available for download from http://download.suse.com/.

Many chapters in this manual contain links to additional documentation resources. This includes additional documentation that is available on the system as well as documentation available on the Internet.

For an overview of the documentation available for your product and the latest documentation updates, refer to http://www.suse.com/doc or to the following section:

1 Available Documentation
We provide HTML and PDF versions of our books in different languages. The following manuals for users and administrators are available for this product:
Deployment Guide (↑Deployment Guide)
Shows how to install single or multiple systems and how to exploit the product inherent capabilities for a deployment infrastructure. Choose from various approaches, ranging from a local installation or a network installation server to a mass deployment using a remote-controlled, highly-customized, and automated installation technique.

Administration Guide (↑Administration Guide)
Covers system administration tasks like maintaining, monitoring, and customizing an initially installed system.

Security Guide (↑Security Guide)
Introduces basic concepts of system security, covering both local and network security aspects. Shows how to make use of the product inherent security software like AppArmor (which lets you specify per program which files the program may read, write, and execute), and the auditing system that reliably collects information about any security-relevant events.

Security and Hardening (↑Security and Hardening)
Deals with the particulars of installing and setting up a secure SUSE Linux Enterprise Server, and additional post-installation processes required to further secure and harden that installation. Supports the administrator with security-related choices and decisions.

System Analysis and Tuning Guide (page i)
An administrator’s guide for problem detection, resolution and optimization. Find how to inspect and optimize your system by means of monitoring tools and how to efficiently manage resources. Also contains an overview of common problems and solutions, and of additional help and documentation resources.

Virtualization with Xen (↑Virtualization with Xen)
Offers an introduction to virtualization technology of your product. It features an overview of the various fields of application and installation types of each of the platforms supported by SUSE Linux Enterprise Server as well as a short description of the installation procedure.

Virtualization with KVM for IBM System z (↑Virtualization with KVM for IBM System z)
Offers an introduction to setting up and managing virtualization with KVM (Kernel-based Virtual Machine) on SUSE Linux Enterprise Server. Learn how to man-
age KVM with libvirt or QEMU. The guide also contains detailed information about requirements, limitations, and support status.

AutoYaST (↑AutoYaST)
AutoYaST is a system for installing one or more SUSE Linux Enterprise systems automatically and without user intervention, using an AutoYaST profile that contains installation and configuration data. The manual guides you through the basic steps of auto-installation: preparation, installation, and configuration.

Storage Administration Guide (↑Storage Administration Guide)
Provides information about how to manage storage devices on a SUSE Linux Enterprise Server.

In addition to the comprehensive manuals, several quick start guides are available:

Installation Quick Start (↑Installation Quick Start)
Lists the system requirements and guides you step-by-step through the installation of SUSE Linux Enterprise Server from DVD, or from an ISO image.

Linux Audit Quick Start
Gives a short overview how to enable and configure the auditing system and how to execute key tasks such as setting up audit rules, generating reports, and analyzing the log files.

AppArmor Quick Start
Helps you understand the main concepts behind AppArmor®.

Virtualization with Linux Containers (LXC) (↑Virtualization with Linux Containers (LXC))
Gives a short introduction to LXC (a lightweight “virtualization” method) and shows how to set up an LXC host and LXC containers.

Find HTML versions of most product manuals in your installed system under /usr/share/doc/manual or in the help centers of your desktop. Find the latest documentation updates at http://www.suse.com/doc where you can download PDF or HTML versions of the manuals for your product.

2 Feedback
Several feedback channels are available:
Bugs and Enhancement Requests
For services and support options available for your product, refer to http://www.suse.com/support/.

To report bugs for a product component, log in to the Novell Customer Center from http://www.suse.com/support/ and select My Support > Service Request.

User Comments
We want to hear your comments about and suggestions for this manual and the other documentation included with this product. Use the User Comments feature at the bottom of each page in the online documentation or go to http://www.suse.com/doc/feedback.html and enter your comments there.

Mail
For feedback on the documentation of this product, you can also send a mail to doc-team@suse.de. Make sure to include the document title, the product version, and the publication date of the documentation. To report errors or suggest enhancements, provide a concise description of the problem and refer to the respective section number and page (or URL).

3 Documentation Conventions

The following typographical conventions are used in this manual:

- /etc/passwd: directory names and filenames

- placeholder: replace placeholder with the actual value

- PATH: the environment variable PATH

- ls, --help: commands, options, and parameters

- user: users or groups

- Alt, Alt + F1: a key to press or a key combination; keys are shown in uppercase as on a keyboard

- File, File > Save As: menu items, buttons
• **amd64 em64t ipf**: This paragraph is only relevant for the architectures amd64, em64t, and ipf. The arrows mark the beginning and the end of the text block. ►

**ipseries zseries**: This paragraph is only relevant for the architectures System z and ipseries. The arrows mark the beginning and the end of the text block. ►

• *Dancing Penguins* (Chapter Penguins, ↑Another Manual): This is a reference to a chapter in another manual.
Part I. Basics
General Notes on System Tuning

This manual discusses how to find the reasons for performance problems and provides means to solve these problems. Before you start tuning your system, you should make sure you have ruled out common problems and have found the cause (bottleneck) for the problem. You should also have a detailed plan on how to tune the system, because applying random tuning tips will not help (and could make things worse).

Procedure 1.1: General Approach When Tuning a System

1. Be sure what problem to solve
2. Rule out common problems
3. Find the bottleneck
   3a. Monitor the system and/or application
   3b. Analyze the data
4. Step-by-step tuning

1.1 Be Sure What Problem to Solve

Before you start tuning your system, try to describe the problem as exactly as possible. Obviously, a simple and general “The system is too slow!” is no helpful problem description. If you plan to tune your Web server for faster delivery of static pages, for
example, it makes a difference whether you need to generally improve the speed or whether it only needs to be improved at peak times.

Furthermore, make sure you can apply a measurement to your problem, otherwise you will not be able to control if the tuning was a success or not. You should always be able to compare “before” and “after”.

1.2 Rule Out Common Problems

A performance problem often is caused by network or hardware problems, bugs, or configuration issues. Make sure to rule out problems such as the ones listed below before attempting to tune your system:

• Check `/var/log/warn` and `/var/log/messages` for unusual entries.

• Check (using `top` or `ps`) whether a certain process misbehaves by eating up unusual amounts of CPU time or memory.

• Check for network problems by inspecting `/proc/net/dev`.

• In case of I/O problems with physical disks, make sure it is not caused by hardware problems (check the disk with the smartmontools) or by a full disk.

• Ensure that background jobs are scheduled to be carried out in times the server load is low. Those jobs should also run with low priority (set via `nice`).

• If the machine runs several services using the same resources, consider moving services to another server.

• Last, make sure your software is up-to-date.

1.3 Finding the Bottleneck

Finding the bottleneck very often is the hardest part when tuning a system. SUSE Linux Enterprise Server offers a lot of tools helping you with this task. See Part II, “System Monitoring” (page 7) for detailed information on general system monitoring applications and log file analysis. If the problem requires a long-time in-depth analysis, the Linux kernel offers means to perform such analysis. See Part III, “Kernel Monitoring” (page 69) for coverage.
Once you have collected the data, it needs to be analyzed. First, inspect if the server's hardware (memory, CPU, bus) and its I/O capacities (disk, network) are sufficient. If these basic conditions are met, the system might benefit from tuning.

### 1.4 Step-by-step Tuning

Make sure to carefully plan the tuning itself. It is of vital importance to only do one step at a time. Only by doing so you will be able to measure if the change provided an improvement or even had a negative impact. Each tuning activity should be measured over a sufficient time period in order to ensure you can do an analysis based on significant data. If you cannot measure a positive effect, do not make the change permanent. Chances are, that it might have a negative effect in the future.
Part II. System Monitoring
System Monitoring Utilities

There are number of programs, tools, and utilities which you can use to examine the status of your system. This chapter introduces some of them and describes their most important and frequently used parameters.

For each of the described commands, examples of the relevant outputs are presented. In the examples, the first line is the command itself (after the > or # sign prompt). Omissions are indicated with square brackets ([...]) and long lines are wrapped where necessary. Line breaks for long lines are indicated by a backslash (\).

```bash
# command -x -y
output line 1
output line 2
output line 3 is annoyingly long, so long that \ we have to break it
output line 4
[...]  
output line 98
output line 99
```

The descriptions have been kept short so that we can include as many utilities as possible. Further information for all the commands can be found in the manual pages. Most of the commands also understand the parameter --help, which produces a brief list of possible parameters.

### 2.1 Multi-Purpose Tools

While most of the Linux system monitoring tools are specific to monitor a certain aspect of the system, there are a few “swiss army knife” tools showing various aspects
of the system at a glance. Use these tools first in order to get an overview and find out which part of the system to examine further.

## 2.1.1 vmstat

vmstat collects information about processes, memory, I/O, interrupts and CPU. If called without a sampling rate, it displays average values since the last reboot. When called with a sampling rate, it displays actual samples:

### Example 2.1: vmstat Output on a Lightly Used Machine

tux@mercury:~> vmstat -a 2
procs -----------memory---------- ---swap-- -----io---- -system-- -----cpu-------
 r b swpd free inact active si so bi bo in cs us sy id wa st
 0 0 0 750992 570648 548848 0 0 0 8 9 0 0 100 0 0
 0 0 0 750984 570648 548912 0 0 0 63 48 1 0 99 0 0
 0 0 0 751000 570648 548912 0 0 0 55 47 0 0 100 0 0
 0 0 0 751000 570648 548912 0 0 0 56 50 0 0 100 0 0
 0 0 0 751016 570648 548944 0 0 0 57 50 0 0 100 0 0

### Example 2.2: vmstat Output on a Heavily Used Machine (CPU bound)

tux@mercury:~> vmstat 2
procs -----------memory----------- ---swap-- -----io---- -system-- -----cpu-------
r b swpd free buff cache si so bi bo in cs us sy id wa st
32 1 26236 459640 110240 6312648 0 0 9944 2 4552 6597 95 5 0 0 0
23 1 26236 396728 110336 6136224 0 0 9588 0 4468 6273 94 6 0 0 0
35 0 26236 554920 110508 6166508 0 0 7684 27992 4474 4700 95 5 0 0 0
28 0 26236 518184 110516 6039996 0 0 10830 4 4446 4670 94 6 0 0 0
21 5 26236 716468 110684 6074872 0 0 8734 20534 4512 4061 96 4 0 0 0

**TIP**

The first line of the vmstat output always displays average values since the last reboot.

The columns show the following:

- **r** shows the number of processes in the run queue. These processes are waiting for a free CPU slot to be executed. If the number of processes in this column is constantly higher than the number of CPUs available, this is an indication of insufficient CPU power.
Shows the number of processes waiting for a resource other than a CPU. A high number in this column may indicate an I/O problem (network or disk).

swpd
The amount of swap space (KB) currently used.

free
The amount of unused memory (KB).

inact
Recently unused memory that can be reclaimed. This column is only visible when calling `vmstat` with the parameter `-a` (recommended).

active
Recently used memory that normally does not get reclaimed. This column is only visible when calling `vmstat` with the parameter `-a` (recommended).

buff
File buffer cache (KB) in RAM. This column is not visible when calling `vmstat` with the parameter `-a` (recommended).

cache
Page cache (KB) in RAM. This column is not visible when calling `vmstat` with the parameter `-a` (recommended).

si
Amount of data (KB) that is moved from swap to RAM per second. High values over a long period of time in this column are an indication that the machine would benefit from more RAM.

so
Amount of data (KB) that is moved from RAM to swap per second. High values over a longer period of time in this column are an indication that the machine would benefit from more RAM.

bi
Number of blocks per second received from a block device (e.g. a disk read). Note that swapping also impacts the values shown here.

bo
Number of blocks per second sent to a block device (e.g. a disk write). Note that swapping also impacts the values shown here.
in
Interrupts per second. A high value indicates a high I/O level (network and/or disk).

cs
Number of context switches per second. Simplified this means that the kernel has to replace executable code of one program in memory with that of another program.

us
Percentage of CPU usage from user processes.

sy
Percentage of CPU usage from system processes.

id
Percentage of CPU time spent idling. If this value is zero over a longer period of time, your CPU(s) are working to full capacity. This is not necessarily a bad sign—rather refer to the values in columns \( r \) and \( b \) to determine if your machine is equipped with sufficient CPU power.

wa
If "wa" time is non-zero, it indicates throughput lost due to waiting for I/O. This may be inevitable, for example, if a file is being read for the first time, background writeback cannot keep up, and so on. It can also be an indicator for a hardware bottleneck (network or hard disk). Lastly, it can indicate a potential for tuning the virtual memory manager (refer to Chapter 15, *Tuning the Memory Management Subsystem* (page 177)).

st
Percentage of CPU time used by virtual machines.

See `vmstat --help` for more options.

2.1.2 System Activity Information: sar and sadc

`sar` can generate extensive reports on almost all important system activities, among them CPU, memory, IRQ usage, IO, or networking. It can either generate reports on
the fly or query existing reports gathered by the system activity data collector (sadc). sar and sadc both gather all their data from the /proc file system.

NOTE: sysstat Package

sar and sadc are part of sysstat package. You need to install the package either with YaST, or with zypper in sysstat.

2.1.2.1 Automatically Collecting Daily Statistics With sadc

If you want to monitor your system about a longer period of time, use sadc to automatically collect the data. You can read this data at any time using sar. To start sadc, simply run /etc/init.d/boot.sysstat start. This will add a link to /etc/cron.d/ that calls sadc with the following default configuration:

- All available data will be collected.
- Data is written to /var/log/sa/saDD, where DD stands for the current day. If a file already exists, it will be archived.
- The summary report is written to /var/log/sa/sarDD, where DD stands for the current day. Already existing files will be archived.
- Data is collected every ten minutes, a summary report is generated every 6 hours (see /etc/sysstat/sysstat.cron).
- The data is collected by the /usr/lib64/sa/sa1 script (or /usr/lib/sa/sa1 on 32-bit systems)
- The summaries are generated by the script /usr/lib64/sa/sa2 (or /usr/lib/sa/sa2 on 32-bit systems)

If you need to customize the configuration, copy the sa1 and sa2 scripts and adjust them according to your needs. Replace the link /etc/cron.d/sysstat with a customized copy of /etc/sysstat/sysstat.cron calling your scripts.

2.1.2.2 Generating reports with sar

To generate reports on the fly, call sar with an interval (seconds) and a count. To generate reports from files specify a filename with the option -f instead of interval and
count. If filename, interval and count are not specified, `sar` attempts to generate a report from `/var/log/sa/saDD`, where `DD` stands for the current day. This is the default location to where `sadc` writes its data. Query multiple files with multiple `-f` options.

```bash
sar 2 10                         # on-the-fly report, 10 times every 2
  seconds
sar -f ~/reports/sar_2010_05_03  # queries file sar_2010_05_03
sar                              # queries file from today in /var/log/sa/
cd /var/log/sa &&\
sar -f sa01 -f sa02              # queries files /var/log/sa/0[12]
```

Find examples for useful `sar` calls and their interpretation below. For detailed information on the meaning of each column, please refer to the `man (1)` of `sar`. Also refer to the man page for more options and reports—`sar` offers plenty of them.

## CPU Utilization Report: `sar`

When called with no options, `sar` shows a basic report about CPU usage. On multi-processor machines, results for all CPUs are summarized. Use the option `-P ALL` to also see statistics for individual CPUs.

```
mercury:~ # sar 10 5
Linux 2.6.31.12-0.2-default (mercury) 03/05/10  _x86_64_   (2 CPU)

14:15:43   CPU    %user   %nice   %system   %iowait    %steal     %idle
14:15:53   all    38.55    0.00      6.10      0.10      0.00     55.25
14:16:03   all    12.59    0.00      4.90      0.33      0.00     82.18
14:16:13   all    56.59    0.00      8.16      0.44      0.00     34.81
14:16:23   all    58.45    0.00      3.00      0.00      0.00     38.55
14:16:33   all    86.46    0.00      4.70      0.00      0.00      8.55
Average:   all    49.94    0.00      5.38      0.18      0.00     44.50
```

If the value for `%iowait` (percentage of the CPU being idle while waiting for I/O) is significantly higher than zero over a longer period of time, there is a bottleneck in the I/O system (network or hard disk). If the `%idle` value is zero over a longer period of time, your CPU(s) are working to full capacity.

## Memory Usage Report: `sar -r`

Generate an overall picture of the system memory (RAM) by using the option `-r`:

```
mercury:~ # sar -r 10 5
Linux 2.6.31.12-0.2-default (mercury) 03/05/10  _x86_64_   (2 CPU)

16:12:12   kmemfree  kmemused  %memused  kbuffers  kbcached  kbcommit  %commit
```
The last two columns (kbcommit and %commit) show an approximation of the total amount of memory (RAM plus swap) the current workload would need in the worst case (in kilobyte or percent respectively).

Paging Statistics Report: sar –B

Use the option –B to display the kernel paging statistics.

The majflt/s (major faults per second) column shows how many pages are loaded from disk (swap) into memory. A large number of major faults slows down the system and is an indication of insufficient main memory. The %vmeff column shows the number of pages scanned (pgscand/s) in relation to the ones being reused from the main memory cache or the swap cache (pgsteal/s). It is a measurement of the efficiency of page reclaim. Healthy values are either near 100 (every inactive page swapped out is being reused) or 0 (no pages have been scanned). The value should not drop below 30.

Block Device Statistics Report: sar –d

Use the option –d to display the block device (hdd, optical drive, USB storage device, ...). Make sure to use the additional option –p (pretty-print) to make the DEV column readable.
If your machine uses multiple disks, you will receive the best performance, if I/O requests are evenly spread over all disks. Compare the Average values for tps, rd_sec/s, and wr_sec/s of all disks. Constantly high values in the svctm and %util columns could be an indication that the amount of free space on the disk is insufficient.

**Network Statistics Reports: sar –n **KEYWORD**

The option –n lets you generate multiple network related reports. Specify one of the following keywords along with the –n:

- **DEV:** Generates a statistic report for all network devices
- **EDEV:** Generates an error statistics report for all network devices
- **NFS:** Generates a statistic report for an NFS client
- **NFSD:** Generates a statistic report for an NFS server
- **SOCK:** Generates a statistic report on sockets
- **ALL:** Generates all network statistic reports

**2.1.2.3 Visualizing sar Data**

sar reports are not always easy to parse for humans. kSar, a Java application visualizing your sar data, creates easy-to-read graphs. It can even generate PDF reports. kSar takes data generated on the fly as well as past data from a file. kSar is licensed under the BSD license and is available from [http://ksar.atomique.net/](http://ksar.atomique.net/).
2.2 System Information

2.2.1 Device Load Information: iostat

iostat monitors the system device loading. It generates reports that can be useful for better balancing the load between physical disks attached to your system.

The first iostat report shows statistics collected since the system was booted. Subsequent reports cover the time since the previous report.

tux@mercury:~> iostat
Linux 2.6.32.7-0.2-default (geeko@buildhost)  02/24/10  _x86_64_

avg-cpu:  %user  %nice  %system  %iowait  %steal  %idle
          0,49    0,01    0,10    0,31    0,00   99,09

Device:            tps  Blk_read/s  Blk_wrtn/s  Blk_read  Blk_wrtn
sda               1,34         5,59        25,37    1459766    6629160
sda1              0,00         0,01         0,00       1519          0
sda2              0,87         5,11        17,83    1335365    4658152
sda3              0,47         0,47         7,54     122578    1971008

When invoked with the -n option, iostat adds statistics of network file systems (NFS) load. The option -x shows extended statistics information.

You can also specify which device should be monitored at what time intervals. For example, iostat -p sda 3 5 will display five reports at three second intervals for device sda.

NOTE: sysstat Package

iostat is part of sysstat package. To use it, install the package with zypper in sysstat

2.2.2 Processor Activity Monitoring: mpstat

The utility mpstat examines activities of each available processor. If your system has one processor only, the global average statistics will be reported.
With the \(-P\) option, you can specify the number of processors to be reported (note that 0\ is the first processor). The timing arguments work the same way as with the \texttt{iostat}\ command. Entering \texttt{mpstat -P 1 2 5} prints five reports for the second processor (number 1) at 2 second intervals.

\begin{verbatim}
tux@mercury:~> mpstat -P 1 2 5
Linux 2.6.32.7-0.2-default (geeko@buildhost)  02/24/10  _x86_64_
  08:57:10 CPU %usr %nice %sys %iowait %irq %soft %steal %guest %idle
  08:57:12 1 4.46 0.00  5.94  0.50  0.00  0.00  0.00  0.00  89.11
  08:57:14 1 1.98 0.00  2.97  0.99  0.00  0.99  0.00  0.00  93.07
  08:57:16 1 2.50 0.00  3.00  0.00  0.00  1.00  0.00  0.00  93.50
  08:57:18 1 14.36 0.00  1.98  0.00  0.00  0.50  0.00  0.00  83.17
  08:57:20 1 2.51 0.00  4.02  0.00  0.00  2.01  0.00  0.00  91.46
Average:  1  5.17 0.00  3.58  0.30  0.00  0.90  0.00  0.00  90.05
\end{verbatim}

\subsection*{2.2.3 Task Monitoring: \texttt{pidstat}}

If you need to see what load a particular task applies to your system, use \texttt{pidstat}\ command. It prints activity of every selected task or all tasks managed by Linux kernel if no task is specified. You can also set the number of reports to be displayed and the time interval between them.

For example, \texttt{pidstat -C top 2 3} prints the load statistic for tasks whose command name includes the string “top”. There will be three reports printed at two second intervals.

\begin{verbatim}
tux@mercury:~> pidstat -C top 2 3
Linux 2.6.27.19-5-default (geeko@buildhost)  03/23/2009  _x86_64_
  09:25:42 AM   PID  %usr %system  %guest %CPU  CPU Command
  09:25:44 AM   23576  37.62  61.39   0.00 99.01\   1\ top
  09:25:44 AM   23576  37.00  62.00   0.00 99.00\   1\ top
  09:25:46 AM   23576  37.00  62.00   0.00 99.00\   1\ top
  09:25:46 AM   23576  38.00  61.00   0.00 99.00\   1\ top
Average:        PID  %usr %system  %guest %CPU  CPU Command
Average:       23576  37.54  61.46   0.00 99.00\   -\ top
\end{verbatim}
2.2.4 Kernel Ring Buffer: dmesg

The Linux kernel keeps certain messages in a ring buffer. To view these messages, enter the command `dmesg`:

```
tux@mercury:~> dmesg
[...]
end_request: I/O error, dev fd0, sector 0
subfs: unsuccessful attempt to mount media (256)
e100: eth0: e100_watchdog: link up, 100Mbps, half-duplex
NET: Registered protocol family 17
IA-32 Microcode Update Driver: v1.14 <tigran@veritas.com>
microcode: CPU0 updated from revision 0xe to 0x2e, date = 08112004
IA-32 Microcode Update Driver v1.14 unregistered
bootsplash: status on console 0 changed to on
NET: Registered protocol family 10
Disabled Privacy Extensions on device c0326ea0(lo)
IPv6 over IPv4 tunneling driver
powernow: This module only works with AMD K7 CPUs
bootsplash: status on console 0 changed to on
```

Older events are logged in the files `/var/log/messages` and `/var/log/warn`.

2.2.5 List of Open Files: lsof

To view a list of all the files open for the process with process ID `PID`, use `-p`. For example, to view all the files used by the current shell, enter:

```
tux@mercury:~> lsof -p $$
COMMAND  PID   USER   FD   TYPE DEVICE  SIZE/OFF NODE NAME
bash    5552 tux  cwd    DIR    3,3    1512 117619 /home/tux
bash    5552 tux  rtd    DIR    3,3     584      2 /
bash    5552 tux  txt    REG    3,3  498816 13047 /bin/bash
bash    5552 tux  mem    REG    0,0              0 [heap] (stat: No such
bash    5552 tux  mem    REG    3,3  217016 115687 /var/run/nscd/passwd
bash    5552 tux  mem    REG    3,3  208464 11867 /usr/lib/locale/en_GB.
[...]  
bash    5552 tux  mem    REG    3,3  366   9720 /usr/lib/locale/en_GB.
bash    5552 tux  mem    REG    3,3  97165  8828 /lib/id-2.3.6.so
bash    5552 tux  0u   CHR  136,5              7 /dev/pts/5
bash    5552 tux  1u   CHR  136,5              7 /dev/pts/5
bash    5552 tux  2u   CHR  136,5              7 /dev/pts/5
bash    5552 tux  255u  CHR  136,5              7 /dev/pts/5
```

The special shell variable `$ $$`, whose value is the process ID of the shell, has been used.

The command `lsof` lists all the files currently open when used without any parameters. There are often thousands of open files, therefore, listing all of them is rarely use-
ful. However, the list of all files can be combined with search functions to generate useful lists. For example, list all used character devices:

```
tux@mercury:~> lsof | grep CHR
bash 3838 tux 0u CHR 136,0 2 /dev/pts/0
bash 3838 tux 1u CHR 136,0 2 /dev/pts/0
bash 3838 tux 2u CHR 136,0 2 /dev/pts/0
bash 3838 tux 255u CHR 136,0 2 /dev/pts/0
bash 5552 tux 0u CHR 136,5 7 /dev/pts/5
bash 5552 tux 1u CHR 136,5 7 /dev/pts/5
bash 5552 tux 2u CHR 136,5 7 /dev/pts/5
bash 5552 tux 255u CHR 136,5 7 /dev/pts/5
X 5646 root mem CHR 1,1 1006 /dev/mem
lsof 5673 tux 0u CHR 136,5 7 /dev/pts/5
lsof 5673 tux 2u CHR 136,5 7 /dev/pts/5
grep 5674 tux 1u CHR 136,5 7 /dev/pts/5
grep 5674 tux 2u CHR 136,5 7 /dev/pts/5
```

When used with `-i`, `lsof` lists currently open Internet files as well:

```
tux@mercury:~> lsof -i
[...]
pidgin 4349 tux 17r IPv4 15194 0t0 TCP jupiter.example.com:58542->www.example.net:https (ESTABLISHED)
pidgin 4349 tux 21u IPv4 15583 0t0 TCP jupiter.example.com:37051->aol.example.org:aol (ESTABLISHED)
evolution 4578 tux 38u IPv4 16102 0t0 TCP jupiter.example.com:57419->imap.example.com:imaps (ESTABLISHED)
npviewer. 9425 tux 40u IPv4 24769 0t0 TCP jupiter.example.com:51416->www.example.com:http (CLOSE_WAIT)
npviewer. 9425 tux 49u IPv4 24814 0t0 TCP jupiter.example.com:43964->www.example.org:http (CLOSE_WAIT)
ssh 17394 tux 3u IPv4 40654 0t0 TCP jupiter.example.com:35454->saturn.example.com:ssh (ESTABLISHED)
```

### 2.2.6 Kernel and udev Event Sequence Viewer: udevadm monitor

`udevadm monitor` listens to the kernel uevents and events sent out by a udev rule and prints the device path (`DEVPATH`) of the event to the console. This is a sequence of events while connecting a USB memory stick:

**NOTE: Monitoring udev Events**

Only root user is allowed to monitor udev events by running the `udevadm` command.
2.2.7 Information on Security Events: audit

The Linux audit framework is a complex auditing system that collects detailed information about all security related events. These records can be consequently analyzed to discover if, for example, a violation of security policies occurred. For more information on audit, see Part “The Linux Audit Framework” (↑Security Guide).

2.3 Processes

2.3.1 Interprocess Communication: ipcs

The command ipcs produces a list of the IPC resources currently in use:

```
------ Shared Memory Segments -------
        key    shmid  owner  perms  bytes  nattch  status
0x00000000  58261504  tux    600    393216  2  dest
0x00000000  58294273  tux    600    196608  2  dest
0x00000000  83886083  tux    666     43264  2
0x00000000  83951622  tux    666    192000  2
```

System Monitoring Utilities
2.3.2 Process List: ps

The command `ps` produces a list of processes. Most parameters must be written without a minus sign. Refer to `ps --help` for a brief help or to the man page for extensive help.

To list all processes with user and command line information, use `ps axu`:

```
tux@mercury:~> ps axu
USER       PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
root         1  0.0  0.0    696   272 ?        S    12:59   0:01 init [5]
root         2  0.0  0.0      0     0 ?        SN   12:59   0:00 [ksoftirqd
root         3  0.0  0.0      0     0 ?        S<   12:59   0:00 [events
[...
  ...]
tux    4047  0.0  6.0 158548 31400 ?        Ssl  13:02   0:06 mono-best
  ...]
tux    4818  0.0  0.3   4192  19172 pts/0    Ss   15:59   0:00 /usr/sbin/sshd -o PidFile=/var/run/sshd.init.pid
  ...]
tux    4959  0.0  0.1   2324   816 pts/0    R+   16:17   0:00 ps axu
```

To check how many `sshd` processes are running, use the option `-p` together with the command `pidof`, which lists the process IDs of the given processes.

```
tux@mercury:~> ps -p $(pidof sshd)
  ...]
PID TTY      STAT   TIME COMMAND
  ...]
  ...]
```

The process list can be formatted according to your needs. The option `-L` returns a list of all keywords. Enter the following command to issue a list of all processes sorted by memory usage:

```
tux@mercury:~> ps ax --format pid,rss,cmd --sort rss
PID   RSS CMD
  ...]
```
3     0 [events/0]
4     0 [khelper]
5     0 [kthread]
11    0 [kblockd/0]
12    0 [kacpid]
472   0 [pdflush]
473   0 [pdflush]

[...]
4028 17556 nautilus --no-default-window --sm-client-id default2
4118 17800 ksnapshot
4114 19172 sound-juicer
4023 25144 gnome-panel --sm-client-id default1

**Useful ps Calls**

`ps aux --sort column`
Sort the output by `column`. Replace `column` with

- `pmem` for physical memory ratio
- `pcpu` for CPU ratio
- `rss` for resident set size (non-swapped physical memory)

`ps axo pid,%cpu,rss,vsz,args,wchan`
Shows every process, their PID, CPU usage ratio, memory size (resident and virtual), name, and their syscall.

`ps axfo pid,args`
Show a process tree.

### 2.3.3 Process Tree: pstree

The command **pstree** produces a list of processes in the form of a tree:

```
tux@mercury:~> pstree
init+-+-NetworkManagerD
   |   |-acpid
   |   |-3* [automount]
   |   |-cron
   |   |-cupsd
   |   |-2* [dbus-daemon]
   |   |-dbus-launch
   |   |-dcopserver
   |   |-dhcpcd
   |   |-events/0
   |   |-gpg-agent
   |   |-hald+-hald-addon-acpi
```
The parameter `-p` adds the process ID to a given name. To have the command lines displayed as well, use the `-a` parameter:

### 2.3.4 Table of Processes: top

The command `top`, which stands for *table of processes*, displays a list of processes that is refreshed every two seconds. To terminate the program, press `Q`. The parameter `-n 1` terminates the program after a single display of the process list. The following is an example output of the command `top -n 1`:

```
tux@mercury:~> top -n 1
top - 17:06:28 up  2:10,  5 users,  load average: 0.00, 0.00, 0.00
Tasks:  85 total,   1 running,  83 sleeping,   1 stopped,   0 zombie
Cpu(s):  5.5% us,  0.8% sy,  0.8% ni, 91.9% id,  1.0% wa,  0.0% hi,  0.0% si
Mem:    515584k total,   506468k used,     9116k free,    66324k buffers
Swap:   658656k total,        0k used,   658656k free,   353328k cached

PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
1 root      16   0   700  272  236 S  0.0  0.1   0:01.33 init
2 root      34  19     0    0    0 S  0.0  0.0   0:00.00 ksoftirqd/0
3 root      10  -5     0    0    0 S  0.0  0.0   0:00.27 events/0
4 root      10  -5     0    0    0 S  0.0  0.0   0:00.01 khelper
5 root      10  -5     0    0    0 S  0.0  0.0   0:00.00 kthread
11 root      10  -5     0    0    0 S  0.0  0.0   0:00.05 kblockd/0
12 root      20  -5     0    0    0 S  0.0  0.0   0:00.00 kacpid
472 root     20  0    578  272  236  S  0.0  0.1   0:00.06 pdflush
473 root     15   0   420  108  63  S  0.0  0.0   0:00.06 pdflush
475 root     11  -5     0    0    0 S  0.0  0.0   0:00.00 aio/0
474 root     15   0   490  108  63  S  0.0  0.0   0:00.07 kswapd0
681 root     10  -5     0    0    0 S  0.0  0.0   0:00.01 kseriod
839 root     10  -5     0    0    0 S  0.0  0.0   0:00.02 reiserfs/0
923 root     13  -4  1712  552 344  S  0.0  0.1   0:00.67 udevd
1343 root    10  -5     0    0    0 S  0.0  0.0   0:00.00 khubd
1587 root    20  0    578  272  236  S  0.0  0.1   0:00.00 shpchpd_event
```

By default the output is sorted by CPU usage (column \%CPU, shortcut Shift + P). Use following shortcuts to change the sort field:

Shift + M: Resident Memory (RES)
Shift + N: Process ID (PID)
Shift + T: Time (TIME+)

To use any other field for sorting, press F and select a field from the list. To toggle the sort order, Use Shift + R.

The parameter \-U UID monitors only the processes associated with a particular user. Replace UID with the user ID of the user. Use \texttt{top \-U $(id -u)} to show processes of the current user

### 2.3.5 System z hypervisor monitor: hyptop

\texttt{hyptop} provides a dynamic real-time view of a System z hypervisor environment, using the kernel infrastructure via debugfs. It works with either the z/VM or the LPAR hypervisor. Depending on the available data it, for example, shows CPU and memory consumption of active LPARs or z/VM guests. It provides a curses based user interface similar to the \texttt{top} command. \texttt{hyptop} provides two windows:

- \texttt{sys\_list}: Shows a list of systems that the currently hypervisor is running
- \texttt{sys}: Shows one system in more detail

You can run \texttt{hyptop} in interactive mode (default) or in batch mode with the \-b option. Help in the interactive mode is available by pressing ? after \texttt{hyptop} is started.
Output for the sys_list window under LPAR:

12:30:48 | CPU-T: IFL(18) CP(3) UN(3)  ?=help

<table>
<thead>
<tr>
<th>system</th>
<th>#cpu</th>
<th>cpu</th>
<th>mgm</th>
<th>Cpu+</th>
<th>Mgm+</th>
<th>online</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)</td>
<td>(%)</td>
<td>(hm)</td>
<td>(hm)</td>
<td>(dhm)</td>
<td></td>
</tr>
<tr>
<td>H05LP30</td>
<td>10</td>
<td>461.14</td>
<td>10.18</td>
<td>1547:41</td>
<td>8:15</td>
<td>11:05:59</td>
</tr>
<tr>
<td>H05LP33</td>
<td>4</td>
<td>133.73</td>
<td>7.57</td>
<td>220:53</td>
<td>6:12</td>
<td>11:05:54</td>
</tr>
<tr>
<td>H05LP50</td>
<td>4</td>
<td>99.26</td>
<td>0.01</td>
<td>146:24</td>
<td>0:12</td>
<td>10:04:24</td>
</tr>
<tr>
<td>H05LP02</td>
<td>1</td>
<td>99.09</td>
<td>0.00</td>
<td>269:57</td>
<td>0:00</td>
<td>11:05:58</td>
</tr>
<tr>
<td>TRX2CF1</td>
<td>1</td>
<td>2.14</td>
<td>0.03</td>
<td>3:24</td>
<td>0:04</td>
<td>11:06:01</td>
</tr>
<tr>
<td>H05LP13</td>
<td>6</td>
<td>1.36</td>
<td>0.34</td>
<td>4:23</td>
<td>0:54</td>
<td>11:05:56</td>
</tr>
<tr>
<td>TRX1</td>
<td>19</td>
<td>1.22</td>
<td>0.14</td>
<td>13:57</td>
<td>0:22</td>
<td>11:06:01</td>
</tr>
<tr>
<td>TRX2</td>
<td>20</td>
<td>1.16</td>
<td>0.11</td>
<td>26:05</td>
<td>0:25</td>
<td>11:06:00</td>
</tr>
<tr>
<td>H05LP55</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0:22</td>
<td>0:00</td>
<td>11:05:52</td>
</tr>
<tr>
<td>H05LP56</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>0:00</td>
<td>0:00</td>
<td>11:05:52</td>
</tr>
<tr>
<td></td>
<td>413</td>
<td>823.39</td>
<td>23.86</td>
<td>3159:57</td>
<td>38:08</td>
<td>11:06:01</td>
</tr>
</tbody>
</table>

Output for the "sys_list" window under z/VM:

12:32:21 | CPU-T: UN(16)  ?=help

<table>
<thead>
<tr>
<th>system</th>
<th>#cpu</th>
<th>cpu</th>
<th>Cpu+</th>
<th>online memuse memmax wcur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)</td>
<td>(%)</td>
<td>(hm)</td>
<td>(dhm) (GiB) (GiB) (#)</td>
</tr>
<tr>
<td>T6360004</td>
<td>6</td>
<td>100.31</td>
<td>959:47</td>
<td>53:05:20</td>
</tr>
<tr>
<td>T6360005</td>
<td>2</td>
<td>0.44</td>
<td>1:11</td>
<td>3:02:26</td>
</tr>
<tr>
<td>T6360014</td>
<td>2</td>
<td>0.27</td>
<td>0:45</td>
<td>10:18:41</td>
</tr>
<tr>
<td>DTCVSW1</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>53:16:42</td>
</tr>
<tr>
<td>T6360002</td>
<td>6</td>
<td>0.00</td>
<td>166:26</td>
<td>40:19:18</td>
</tr>
<tr>
<td>OPERATOR</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>53:16:42</td>
</tr>
<tr>
<td>T6360008</td>
<td>2</td>
<td>0.00</td>
<td>0:37</td>
<td>30:22:55</td>
</tr>
<tr>
<td>T6360003</td>
<td>6</td>
<td>0.00</td>
<td>3700:57</td>
<td>53:03:09</td>
</tr>
<tr>
<td>NSSLCP1</td>
<td>1</td>
<td>0.00</td>
<td>0:02</td>
<td>53:16:41</td>
</tr>
<tr>
<td>EREP</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>53:16:42</td>
</tr>
<tr>
<td>PERFSVM</td>
<td>1</td>
<td>0.00</td>
<td>0:53</td>
<td>2:21:12</td>
</tr>
<tr>
<td>TCP1P</td>
<td>1</td>
<td>0.00</td>
<td>0:01</td>
<td>53:16:42</td>
</tr>
<tr>
<td>DATAMOVE</td>
<td>1</td>
<td>0.00</td>
<td>0:05</td>
<td>53:16:42</td>
</tr>
<tr>
<td>DIRMAINT</td>
<td>1</td>
<td>0.00</td>
<td>0:04</td>
<td>53:16:42</td>
</tr>
<tr>
<td>DTCVSW2</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>53:16:42</td>
</tr>
<tr>
<td>RACFVM</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>53:16:42</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>101.57</td>
<td>5239:47</td>
<td>53:16:42</td>
</tr>
</tbody>
</table>

Output for the sys window under LPAR:

14:08:41 | H05LP30 | CPU-T: IFL(18) CP(3) UN(3)  ? = help

cpu  type  cpu  mgm  visual.
<table>
<thead>
<tr>
<th></th>
<th>(str)</th>
<th>(%)</th>
<th>(%)</th>
<th>(vis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>IFL</td>
<td>96.91</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>IFL</td>
<td>81.82</td>
<td>1.46</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>IFL</td>
<td>88.00</td>
<td>2.43</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>IFL</td>
<td>92.27</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IFL</td>
<td>83.32</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IFL</td>
<td>92.46</td>
<td>2.59</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>IFL</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>IFL</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>
2.3.6 A top-like I/O Monitor: iotop

The iotop utility displays a table of I/O usage by processes or threads.

**TIP**

`iotop` is not installed by default. You need to install it manually with `zypper` in `iotop as root`.

`iotop` displays columns for the I/O bandwidth read and written by each process during the sampling period. It also displays the percentage of time the process spent while swapping in and while waiting on I/O. For each process, its I/O priority (class/level) is shown. In addition, the total I/O bandwidth read and written during the sampling period is displayed at the top of the interface.

Use the left and right arrows to change the sorting, `R` to reverse the sorting order, `O` to toggle the `--only` option, `P` to toggle the `--processes` option, `A` to toggle the `--accumulated` option, `Q` to quit or `I` to change the priority of a thread or a process' thread(s). Any other key will force a refresh.

Following is an example output of the command `iotop --only`, while `find` and `emacs` are running:

```
tux@mercury:~> iotop --only
Total DISK READ: 50.61 K/s | Total DISK WRITE: 11.68 K/s
TID PRIO USER DISK READ DISK WRITE SWAPIN IO> COMMAND
3416 be/4 ke 50.61 K/s 0.00 B/s 0.00 % 4.05 % find /
275 be/3 root 0.00 B/s 3.89 K/s 0.00 % 2.34 % [jbd2/sda2-8]
5055 be/4 ke 0.00 B/s 3.89 K/s 0.00 % 0.04 % emacs
```

`iotop` can be also used in a batch mode (`-b`) and its output stored in a file for later analysis. For a complete set of options, see the manual page (`man 1 iotop`).
2.3.7 Modify a process' niceness: nice and renice

The kernel determines which processes require more CPU time than others by the process' nice level, also called niceness. The higher the “nice” level of a process is, the less CPU time it will take from other processes. Nice levels range from -20 (the least “nice” level) to 19. Negative values can only be set by root.

Adjusting the niceness level is useful when running a non time-critical process that lasts long and uses large amounts of CPU time, such as compiling a kernel on a system that also performs other tasks. Making such a process “nicer”, ensures that the other tasks, for example a Web server, will have a higher priority.

Calling nice without any parameters prints the current niceness:

tux@mercury:~> nice
0

Running nice command increments the current nice level for the given command by 10. Using nice -n level command lets you specify a new niceness relative to the current one.

To change the niceness of a running process, use renice priority -p process id, for example:

renice +5 3266

To renice all processes owned by a specific user, use the option -u user. Process groups are reniced by the option -g process group id.

2.4 Memory

2.4.1 Memory Usage: free

The utility free examines RAM and swap usage. Details of both free and used memory and swap areas are shown:

tux@mercury:~> free
   total used free shared buffers cached
Mem: 2062844 2047444 15400 0 129580 921936
-/+ buffers/cache: 995928 1066916
Swap: 2104472 0 2104472

The options \(-b, -k, -m, -g\) show the output in bytes, KB, MB, or GB, respectively. The parameter \(-d\) delay ensures that the display is refreshed every delay seconds. For example, free \(-d\) 1.5 produces an update every 1.5 seconds.

**2.4.2 Detailed Memory Usage: /proc/meminfo**

Use /proc/meminfo to get more detailed information on memory usage than with free. Actually free uses some of the data from this file. See an example output from a 64-bit system below. Note that it slightly differs on 32-bit systems due to different memory management):

```
tux@mercury:~> cat /proc/meminfo
MemTotal:    8182956 kB
MemFree:     1045744 kB
Buffers:     364364 kB
Cached:      5601388 kB
SwapCached:  1936 kB
Active:      4048268 kB
Inactive:    2674796 kB
Active(anon): 663088 kB
Inactive(anon): 107108 kB
Active(file): 3385180 kB
Inactive(file): 2567688 kB
Unevictable: 8 kB
Mlocked:      4 kB
SwapTotal:   2096440 kB
SwapFree:    2076692 kB
Dirty:       44 kB
Writeback: 0 kB
AnonPages:   756108 kB
Mapped:      147320 kB
Slab:        329216 kB
SReclaimable: 300220 kB
SUnreclaim:  28996 kB
PageTables:  21092 kB
NFS_Unstable: 0 kB
Bounce:      0 kB
WritebackTmp: 0 kB
CommitLimit: 6187916 kB
Committed_AS: 1388160 kB
VmallocTotal: 34359738367 kB
VmallocUsed: 133384 kB
VmallocChunk: 34359570939 kB
HugePages_Total: 0
HugePages_Free: 0
```
HugePages_Rsvd: 0
HugePages_Surp: 0
Hugepagesize: 2048 kB
DirectMap4k: 2689024 kB
DirectMap2M: 5691392 kB

The most important entries are:

\textit{MemTotal}
Total amount of usable RAM

\textit{MemFree}
Total amount of unused RAM

\textit{Buffers}
File buffer cache in RAM

\textit{Cached}
Page cache (excluding buffer cache) in RAM

\textit{SwapCached}
Page cache in swap

\textit{Active}
Recently used memory that normally is not reclaimed. This value is the sum of memory claimed by anonymous pages (listed as \textit{Active(anon)}) and file-backed pages (listed as \textit{Active(file)})

\textit{Inactive}
Recently unused memory that can be reclaimed. This value is the sum of memory claimed by anonymous pages (listed as \textit{Inactive(anon)}) and file-backed pages (listed as \textit{Inactive(file)}).

\textit{SwapTotal}
Total amount of swap space

\textit{SwapFree}
Total amount of unused swap space

\textit{Dirty}
Amount of memory that will be written to disk

\textit{Writeback}
Amount of memory that currently is written to disk
Mapped
Memory claimed with the mmap system call

Slab
Kernel data structure cache

SReclaimable
Reclaimable slab caches (inode, dentry, etc.)

Committed_AS
An approximation of the total amount of memory (RAM plus swap) the current workload needs in the worst case.

2.4.3 Process Memory Usage: smaps

Exactly determining how much memory a certain process is consuming is not possible with standard tools like top or ps. Use the smaps subsystem, introduced in Kernel 2.6.14, if you need exact data. It can be found at /proc/pid/smaps and shows you the number of clean and dirty memory pages the process with the ID PID is using at that time. It differentiates between shared and private memory, so you are able to see how much memory the process is using without including memory shared with other processes.

2.5 Networking

2.5.1 Basic Network Diagnostics: ifconfig

ifconfig is a powerful tool to set up and control network interfaces. As well as this, you can use it to quickly view basic statistics about one or all network interfaces present in the system, such as whether the interface is up, the number of errors or dropped packets, or packet collisions.

If you run ifconfig with no additional parameter, it lists all active network interfaces. ifconfig -a lists all (even inactive) network interfaces, while ifconfig net_interface lists statistics for the specified interface only.

# ifconfig br0
br0       Link encap:Ethernet   HWaddr 00:25:90:98:6A:00
          inet addr:10.100.2.76   Bcast:10.100.63.255  Mask:255.255.192.0
2.5.2 Ethernet Cards in Detail: ethtool

ethtool can display and change detailed aspects of your ethernet network device. By default it prints the current setting of the specified device.

```
# ethtool eth0
Settings for eth0:
    Supported ports: [ TP ]
    Supported link modes: 10baseT/Half 10baseT/Full
                          100baseT/Half 100baseT/Full
                          1000baseT/Full
    Supports auto-negotiation: Yes
    Advertised link modes: 10baseT/Half 10baseT/Full
                           100baseT/Half 100baseT/Full
                           1000baseT/Full
    Advertised pause frame use: No
[...]
    Link detected: yes
```

The following table shows ethtool's options that you can use to query the device for specific information:

**Table 2.1: List of ethtool's Query Options**

<table>
<thead>
<tr>
<th>ethtool's option</th>
<th>it queries the device for</th>
</tr>
</thead>
<tbody>
<tr>
<td>-a</td>
<td>pause parameter information</td>
</tr>
<tr>
<td>-c</td>
<td>interrupt coalescing information</td>
</tr>
<tr>
<td>-g</td>
<td>Rx/Tx (receive/transmit) ring parameter information</td>
</tr>
<tr>
<td>-i</td>
<td>associated driver information</td>
</tr>
<tr>
<td>-k</td>
<td>offload information</td>
</tr>
<tr>
<td>-S</td>
<td>NIC and driver-specific statistics</td>
</tr>
</tbody>
</table>
2.5.3 Show the Network Status: netstat

netstat shows network connections, routing tables (-r), interfaces (-i), masquerade connections (-M), multicast memberships (-g), and statistics (-s).

tux@mercury:~> netstat -r
Kernel IP routing table

<table>
<thead>
<tr>
<th>Destination</th>
<th>Gateway</th>
<th>Genmask</th>
<th>Flags</th>
<th>MSS</th>
<th>Window</th>
<th>irtt</th>
<th>Iface</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.168.2.0</td>
<td>*</td>
<td>255.255.254.0</td>
<td>U</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>eth0</td>
</tr>
<tr>
<td>link-local</td>
<td>*</td>
<td>255.255.0.0</td>
<td>U</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>eth0</td>
</tr>
<tr>
<td>loopback</td>
<td>*</td>
<td>255.0.0.0</td>
<td>U</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>lo</td>
</tr>
<tr>
<td>default</td>
<td>192.168.2.254</td>
<td>0.0.0.0</td>
<td>UG</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>eth0</td>
</tr>
</tbody>
</table>

tux@mercury:~> netstat -i
Kernel Interface table

<table>
<thead>
<tr>
<th>Iface</th>
<th>MTU</th>
<th>Met</th>
<th>RX-OK</th>
<th>RX-ERR</th>
<th>RX-DRP</th>
<th>RX-OVR</th>
<th>TX-OK</th>
<th>TX-ERR</th>
<th>TX-DRP</th>
<th>TX-OVR</th>
<th>Flg</th>
</tr>
</thead>
<tbody>
<tr>
<td>eth0</td>
<td>1500</td>
<td>0</td>
<td>1624507</td>
<td>129056</td>
<td>0</td>
<td>0</td>
<td>7055</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>BNRU</td>
</tr>
<tr>
<td>lo</td>
<td>16436</td>
<td>0</td>
<td>23728</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23728</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>LRU</td>
</tr>
</tbody>
</table>

When displaying network connections or statistics, you can specify the socket type to display: TCP (-t), UDP (-u), or raw (-r). The -p option shows the PID and name of the program to which each socket belongs.

The following example lists all TCP connections and the programs using these connections.

mercury:~ # netstat -t -p
Active Internet connections (w/o servers)

Protocol Recv-Q Send-Q Local Address Foreign Address State PID/Program Name

[...]
tcp      0      0 mercury:33513  www.novell.com:www-http ESTABLISHED 6862/ff

tcp      0      352 mercury:ssh  mercury2:.trc-netpoll ESTABLISHED 19422/s

tcp      0      0 localhost:ssh localhost:17828 ESTABLISHED -

In the following, statistics for the TCP protocol are displayed:

tux@mercury:~> netstat -s -t
Tcp:

   2427 active connections openings
   2374 passive connection openings
   0 failed connection attempts
   0 connection resets received
   1 connections established
   27476 segments received
   26786 segments send out
   54 segments retransmitted
   0 bad segments received.
   0 resets sent

[...]
2.5.4 Interactive Network Monitor: iptraf

The iptraf utility is a menu based Local Area Network (LAN) monitor. It generates network statistics, including TCP and UDP counts, Ethernet load information, IP checksum errors and others.

**TIP**

*iptraf is not installed by default, install it with zypper in iptraf as root*

If you enter the command without any option, it runs in an interactive mode. You can navigate through graphical menus and choose the statistics that you want iptraf to report. You can also specify which network interface to examine.

*Figure 2.1: iptraf Running in Interactive Mode*

```
<table>
<thead>
<tr>
<th>Protocol</th>
<th>Total Packets</th>
<th>Total Bytes</th>
<th>Total Errors</th>
<th>Total Drop</th>
<th>Total Reorder</th>
<th>Total Retry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1363</td>
<td>254627</td>
<td>914</td>
<td>99898</td>
<td>469</td>
<td>168646</td>
</tr>
<tr>
<td>IP</td>
<td>1363</td>
<td>254627</td>
<td>914</td>
<td>76041</td>
<td>463</td>
<td>154788</td>
</tr>
<tr>
<td>TCP</td>
<td>938</td>
<td>173286</td>
<td>470</td>
<td>24526</td>
<td>468</td>
<td>153744</td>
</tr>
<tr>
<td>ICMP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other IP</td>
<td>156</td>
<td>6280</td>
<td>156</td>
<td>6280</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-IP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Total rates: 77.2 kbit/sec Broadcast packets: 136
54.4 packets/sec Broadcast bytes: 25070
39.5 kbit/sec ICMP errors: 0
39.6 packets/sec
14.8 packets/sec

~exit
```

The command iptraf understands several options and can be run in a batch mode as well. The following example will collect statistics for network interface eth0 (-i) for 1 minute (-t). It will be run in the background (-B) and the statistics will be written to the iptraf.log file in your home directory (-L).
```
tux@mercury:~> iptraf -i eth0 -t 1 -B -L ~/iptraf.log
```

You can examine the log file with the *more* command:
```
tux@mercury:~> more ~/iptraf.log
Mon Mar 23 10:08:02 2010; ******** IP traffic monitor started ********
```
Mon Mar 23 10:08:02 2010; UDP; eth0; 107 bytes; from 192.168.1.192:33157 to \ 
  239.255.255.253:427
Mon Mar 23 10:08:02 2010; VRRP; eth0; 46 bytes; from 192.168.1.252 to \ 
  224.0.0.18
Mon Mar 23 10:08:03 2010; VRRP; eth0; 46 bytes; from 192.168.1.252 to \ 
  224.0.0.18
Mon Mar 23 10:08:03 2010; VRRP; eth0; 46 bytes; from 192.168.1.252 to \ 
  224.0.0.18
[...]
Mon Mar 23 10:08:06 2010; UDP; eth0; 132 bytes; from 192.168.1.54:54395 to \ 
  10.20.7.255:111
Mon Mar 23 10:08:06 2010; UDP; eth0; 46 bytes; from 192.168.1.92:27258 to \ 
  10.20.7.255:8765
Mon Mar 23 10:08:06 2010; UDP; eth0; 124 bytes; from 192.168.1.139:43464 to \ 
  10.20.7.255:111
Mon Mar 23 10:08:06 2010; VRRP; eth0; 46 bytes; from 192.168.1.252 to \ 
  224.0.0.18
--More--(7%)

2.6 The /proc File System

The /proc file system is a pseudo file system in which the kernel reserves important
information in the form of virtual files. For example, display the CPU type with this
command:

tux@mercury:~> cat /proc/cpuinfo
processor : 0
vendor_id : GenuineIntel
cpu family : 15
model : 4
model name : Intel(R) Pentium(R) 4 CPU 3.40GHz
stepping : 3
cpu MHz : 2800.000
cache size : 2048 KB
physical id : 0
[...]

Query the allocation and use of interrupts with the following command:

tux@mercury:~> cat /proc/interrupts
CPU0
  0:   3577519   XT-PIC  timer
  1:    130   XT-PIC  i8042
  2:     0   XT-PIC  cascade
  5:   564535   XT-PIC  Intel 82801DB-ICH4
  7:     1   XT-PIC  parport0
  8:     2   XT-PIC  rtc
  9:     1   XT-PIC  acpi, uhci_hcd:usb1, ehci_hcd:usb4
Some of the important files and their contents are:

/proc/devices
   Available devices

/proc/modules
   Kernel modules loaded

/proc/cmdline
   Kernel command line

/proc/meminfo
   Detailed information about memory usage

/proc/config.gz
   gzip-compressed configuration file of the kernel currently running

Further information is available in the text file /usr/src/linux/Documentation/filesystems/proc.txt (this file is available when the package kernel-source is installed). Find information about processes currently running in the /proc/NNN directories, where NNN is the process ID (PID) of the relevant process. Every process can find its own characteristics in /proc/self/:

tux@mercury:~> 1s -l /proc/self
lrwxrwxrwx 1 root root 64 2007-07-16 13:03 /proc/self -> 5356

tux@mercury:~> 1s -l /proc/self/
total 0
  dr-xr-xr-x 2 tux users 0 2007-07-16 17:04 attr
  -r-------- 1 tux users 0 2007-07-16 17:04 auxv
  -r--r--r-- 1 tux users 0 2007-07-16 17:04 cmdline
  lrwxrwxrwx 1 tux users 0 2007-07-16 17:04 cwd -> /home/tux
  -r-------- 1 tux users 0 2007-07-16 17:04 environ
  lrwxrwxrwx 1 tux users 0 2007-07-16 17:04 exe -> /bin/ls
  dr-x------- 2 tux users 0 2007-07-16 17:04 fd
  -rwr-r--r-- 1 tux users 0 2007-07-16 17:04 loginuid
  -r--r--r-- 1 tux users 0 2007-07-16 17:04 maps
  -rw------- 1 tux users 0 2007-07-16 17:04 mem
  -r--r--r-- 1 tux users 0 2007-07-16 17:04 mounts

10:          0          XT-PIC  uhci_hcd:usb3
11:      71772          XT-PIC  uhci_hcd:usb2, eth0
12:     101150          XT-PIC  i8042
14:      33146          XT-PIC  ide0
15:     149202          XT-PIC  ide1
NMI:          0
LOC:          0
ERR:          0
MIS:          0
The address assignment of executables and libraries is contained in the maps file:

tux@mercury:~> cat /proc/self/maps
08048000-0804c000 r-xp 00000000 03:03 17753 /bin/cat
0804c000-0804d000 rw-p 00004000 03:03 17753 /bin/cat
0804d000-0804e000 rw-p 0804d000 00:00 0 [heap]
b7d27000-b7d5a000 r--p 00000000 03:03 11867 /usr/lib/locale/en_GB.utf8/
b7d5a000-b7e32000 r--p 00000000 03:03 11868 /usr/lib/locale/en_GB.utf8/
b7e32000-b7e33000 rw-p b7e32000 00:00 0
b7e33000-b7f45000 r-xp 00000000 03:03 8837 /lib/libc-2.3.6.so
b7f45000-b7f46000 r--p 00112000 03:03 8837 /lib/libc-2.3.6.so
b7f46000-b7f48000 rw-p 00113000 03:03 8837 /lib/libc-2.3.6.so
b7f48000-b7f4c000 rw-p b7f48000 00:00 0
b7f52000-b7f53000 r--p 00000000 03:03 11842 /usr/lib/locale/en_GB.utf8/
 [...]
b7f55000-b7f61000 r--s 00000000 03:03 9109 /usr/lib/gconv/gconv-module
b7f61000-b7f62000 r--p 00000000 03:03 9720 /usr/lib/locale/en_GB.utf8/
b7f62000-b7f76000 r-xp 00000000 03:03 8828 /lib/id-2.3.6.so
b7f76000-b7f80000 rw-p 00013000 03:03 8828 /lib/id-2.3.6.so
bfd61000-bfd6f000 rw-p bfd61000 00:00 0 [stack]
ffffe000-ffffff000 ---p 00000000 00:00 0 [vdso]

2.6.1 procinfo

Important information from the /proc file system is summarized by the command procinfo:

tux@mercury:~> procinfo
Linux 2.6.32.7-0.2-default (geeko@buildhost) (gcc 4.3.4) #1 2CPU

Memory: Total Used Free Shared Buffers
Mem: 2060604 2011264 49340 0 200664
Swap: 2104472 112 2104360

Bootup: Wed Feb 17 03:39:33 2010 Load average: 0.86 1.10 1.11 3/118 21547

user : 2:43:13.78 0.8% page in : 71099181 disk 1: 2827023r 968
nice : 1d 22:21:27.87 14.7% page out: 690734737
system: 13:39:57.57 4.3% page act: 138388345
IOwait: 18:02:18.59 5.7% page dea: 29639529
hw irq: 0:03:39.44 0.0% page flt: 9539791626
To see all the information, use the parameter `-a`. The parameter `-nN` produces updates of the information every $N$ seconds. In this case, terminate the program by pressing `q`.

By default, the cumulative values are displayed. The parameter `-d` produces the differential values. `procinfo -dn5` displays the values that have changed in the last five seconds:

### 2.6.2 System Control Parameters: `/proc/sys/`

System control parameters are used to modify the Linux kernel parameters at runtime. They can be checked with the `sysctl` command, or by looking into `/proc/sys/`. A brief description of some of `/proc/sys/`'s subdirectories follows.

**/proc/sys/vm/**

Entries in this path relate to information about the virtual memory, swapping, and caching.

**/proc/sys/kernel/**

Entries in this path represent information about the task scheduler, system shared memory, and other kernel-related parameters.

**/proc/sys/fs/**

Entries in this path relate to used file handles, quotas, and other file system-oriented parameters.

**/proc/sys/net/**

Entries in this path relate to information about network bridges, and general network parameters (mainly the `ipv4` subdirectory).
2.7 Hardware Information

2.7.1 PCI Resources: lspci

NOTE: Accessing PCI configuration.

Most operating systems require root user privileges to grant access to the computer's PCI configuration.

The command `lspci` lists the PCI resources:

```
mercury:~ # lspci
00:00.0 Host bridge: Intel Corporation 82845G/GL[Brookdale-G]/GE/PE DRAM Controller/Host-Hub Interface (rev 01)
00:01.0 PCI bridge: Intel Corporation 82845G/GL[Brookdale-G]/GE/PE Host-to-AGP Bridge (rev 01)
00:1d.0 USB Controller: Intel Corporation 82801DB/DBL/DBM (ICH4/ICH4-L/ICH4-M) USB UHCI Controller #1 (rev 01)
00:1d.1 USB Controller: Intel Corporation 82801DB/DBL/DBM (ICH4/ICH4-L/ICH4-M) USB UHCI Controller #2 (rev 01)
00:1d.2 USB Controller: Intel Corporation 82801DB/DBL/DBM (ICH4/ICH4-L/ICH4-M) USB UHCI Controller #3 (rev 01)
00:1d.7 USB Controller: Intel Corporation 82801DB/DBM (ICH4/ICH4-M) USB2 EHCI Controller (rev 01)
00:1e.0 PCI bridge: Intel Corporation 82801 PCI Bridge (rev 81)
00:1f.0 ISA bridge: Intel Corporation 82801DB/DBL (ICH4/ICH4-L) LPC Interface Bridge (rev 01)
00:1f.1 IDE interface: Intel Corporation 82801DB (ICH4) IDE Controller (rev 01)
00:1f.3 SMBus: Intel Corporation 82801DB/DBL/DBM (ICH4/ICH4-L/ICH4-M) SMBus Controller (rev 01)
00:1f.5 Multimedia audio controller: Intel Corporation 82801DB/DBL/DBM (ICH4/ICH4-L/ICH4-M) AC'97 Audio Controller (rev 01)
01:00.0 VGA compatible controller: Matrox Graphics, Inc. G400/G450 (rev 85)
02:08.0 Ethernet controller: Intel Corporation 82801DB PRO/100 VE (LOM) Ethernet Controller (rev 81)
```

Using `-v` results in a more detailed listing:

```
mercury:~ # lspci -v
00:00.0 Host bridge: Intel Corporation 82845G/GL[Brookdale-G]/GE/PE DRAM Controller/Host-Hub Interface (rev 01)
  Flags: bus master, 66MHz, medium devsel, latency 64, IRQ 19
  Memory at f0000000 (32-bit, non-prefetchable) [size=128K]
  I/O ports at d010 [size=8]
```

System Monitoring Utilities
Capabilities: [dc] Power Management version 2
Capabilities: [e4] PCI-X non-bridge device
Kernel driver in use: e1000
Kernel modules: e1000

Information about device name resolution is obtained from the file `/usr/share/pci.ids`. PCI IDs not listed in this file are marked “Unknown device.”

The parameter `-vv` produces all the information that could be queried by the program. To view the pure numeric values, use the parameter `-n`.

## 2.7.2 USB Devices: lsusb

The command `lsusb` lists all USB devices. With the option `-v`, print a more detailed list. The detailed information is read from the directory `/proc/bus/usb/`. The following is the output of `lsusb` with these USB devices attached: hub, memory stick, hard disk and mouse.

```
mercury:/ # lsusb
Bus 004 Device 007: ID 0ea0:2168 Ours Technology, Inc. Transcend JetFlash 2.0 / Astone USB Drive
Bus 004 Device 006: ID 04b4:6830 Cypress Semiconductor Corp. USB-2.0 IDE Adapter
Bus 004 Device 005: ID 05e3:0605 Genesys Logic, Inc.
Bus 004 Device 001: ID 0000:0000
Bus 003 Device 001: ID 0000:0000
Bus 002 Device 001: ID 0000:0000
Bus 001 Device 005: ID 046d:c012 Logitech, Inc. Optical Mouse
Bus 001 Device 001: ID 0000:0000
```

## 2.8 Files and File Systems

### 2.8.1 Determine the File Type: file

The command `file` determines the type of a file or a list of files by checking `/usr/share/misc/magic`.

```
tux@mercury:~> file /usr/bin/file
/usr/bin/file: ELF 64-bit LSB executable, x86-64, version 1 (SYSV),
for GNU/Linux 2.6.4, dynamically linked (uses shared libs), stripped
```

The parameter `-f list` specifies a file with a list of filenames to examine. The `-z` allows `file` to look inside compressed files:
The parameter `-i` outputs a mime type string rather than the traditional description.

```bash
tux@mercury:~> file -i /usr/share/misc/magic
/usr/share/misc/magic: text/plain charset=utf-8
```

### 2.8.2 File Systems and Their Usage: mount, df and du

The command `mount` shows which file system (device and type) is mounted at which mount point:

```bash
tux@mercury:~> mount
/dev/sda2 on / type ext4 (rw,acl,user_xattr)
proc on /proc type proc (rw)
sysfs on /sys type sysfs (rw)
devtmpfs on /dev type devtmpfs (rw,mode=0755)
tmpfs on /dev/shm type tmpfs (rw,mode=1777)
devpts on /dev/pts type devpts (rw,mode=0620,gid=5)
/dev/sda3 on /home type ext3 (rw)
securityfs on /sys/kernel/security type securityfs (rw)
fusectl on /sys/fs/fuse/connections type fusectl (rw)
gvfs-fuse-daemon on /home/tux/.gvfs type fuse.gvfs-fuse-daemon (rw,nosuid,nodev,user=tux)
```

Obtain information about total usage of the file systems with the command `df`. The parameter `-h` (or `--human-readable`) transforms the output into a form understandable for common users.

```bash
tux@mercury:~> df -h
Filesystem                        Size  Used Avail Use% Mounted on
/dev/sda2                         20G   5,9G   13G   32% /
devtmpfs                          1,6G  236K  1,6G    1% /dev
tmpfs                             1,6G  668K  1,6G    1% /dev/shm
/dev/sda3                         208G   40G  159G   20% /home
```

Display the total size of all the files in a given directory and its subdirectories with the command `du`. The parameter `-s` suppresses the output of detailed information and gives only a total for each argument. `-h` again transforms the output into a human-readable form:
2.8.3 Additional Information about ELF Binaries

Read the content of binaries with the `readelf` utility. This even works with ELF files that were built for other hardware architectures:

```
tux@mercury:~> readelf --file-header /bin/ls
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
  Class:          ELF64
  Data:          2's complement, little endian
  Version:       1 (current)
  OS/ABI:        UNIX - System V
  ABI Version:   0
  Type:           EXEC (Executable file)
  Machine:       Advanced Micro Devices X86-64
  Version:       0x1
  Entry point address:       0x402540
  Start of program headers:   64 (bytes into file)
  Start of section headers:   95720 (bytes into file)
  Flags:                   0x0
  Size of this header:       64 (bytes)
  Size of program headers:   56 (bytes)
  Number of program headers:       9
  Size of section headers:   64 (bytes)
  Number of section headers:       32
  Section header string table index:   31
```

2.8.4 File Properties: `stat`

The command `stat` displays file properties:

```
tux@mercury:~> stat /etc/profile
File: '/etc/profile'
  Size: 9662    Blocks: 24    IO Block: 4096  regular file
  Device: 802h/2050d Inode: 132349   Links: 1
  Access: (0644/-rw-r--r--) Uid: ( 0/ root) Gid: ( 0/ root)

The parameter `--file-system` produces details of the properties of the file system in which the specified file is located:

```
tux@mercury:~> stat /etc/profile --file-system
```
2.9 User Information

2.9.1 User Accessing Files: fuser

It can be useful to determine what processes or users are currently accessing certain files. Suppose, for example, you want to unmount a file system mounted at /mnt. `umount` returns "device is busy." The command `fuser` can then be used to determine what processes are accessing the device:

```
tux@mercury:~> fuser -v /mnt/*
```

<table>
<thead>
<tr>
<th>USER</th>
<th>PID ACCESS COMMAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>/mnt/notes.txt       tux    26597 f....  less</td>
<td></td>
</tr>
</tbody>
</table>

Following termination of the `less` process, which was running on another terminal, the file system can successfully be unmounted. When used with `-k` option, `fuser` will kill processes accessing the file as well.

2.9.2 Who Is Doing What: w

With the command `w`, find out who is logged onto the system and what each user is doing. For example:

```
tux@mercury:~> w
```

```
14:58:43 up 1 day,  1:21,  2 users,  load average: 0.00, 0.00, 0.00
USER      TTY       LOGIN@   IDLE   JCPU   PCPU WHAT
          :0        12:25    ?xdm?   1:23   0.12s /bin/sh /usr/bin/startkde
root      pts/4    14:13   0.00s  0.06s  0.00s w
```

If any users of other systems have logged in remotely, the parameter `-f` shows the computers from which they have established the connection.

2.10 Time and Date
2.10.1 Time Measurement with time

Determine the time spent by commands with the `time` utility. This utility is available in two versions: as a shell built-in and as a program (`/usr/bin/time`).

```
tux@mercury:~> time find . > /dev/null
real    0m4.051s
user    0m0.042s
sys     0m0.205s
```

1. The real time that elapsed from the command's start-up until it finished.
2. CPU time of the user as reported by the `times` system call.
3. CPU time of the system as reported by the `times` system call.

2.11 Graph Your Data: RRDtool

There are a lot of data in the world around you, which can be easily measured in time. For example, changes in the temperature, or the number of data sent or received by your computer's network interface. RRDtool can help you store and visualize such data in detailed and customizable graphs.

RRDtool is available for most UNIX platforms and Linux distributions. SUSE® Linux Enterprise Server ships RRDtool as well. Install it either with YaST or by entering

```
zypper install rrdtool
```
in the command line as root.

---

**TIP**

There are Perl, Python, Ruby, or PHP bindings available for RRDtool, so that you can write your own monitoring scripts with your preferred scripting language.

---

2.11.1 How RRDtool Works

RRDtool is a shortcut of Round Robin Database tool. Round Robin is a method for manipulating with a constant amount of data. It uses the principle of a circular buffer, where there is no end nor beginning to the data row which is being read. RRDtool uses Round Robin Databases to store and read its data.
As mentioned above, RRDtool is designed to work with data that change in time. The ideal case is a sensor which repeatedly reads measured data (like temperature, speed etc.) in constant periods of time, and then exports them in a given format. Such data are perfectly ready for RRDtool, and it is easy to process them and create the desired output.

Sometimes it is not possible to obtain the data automatically and regularly. Their format needs to be pre-processed before it is supplied to RRDtool, and often you need to manipulate RRDtool even manually.

The following is a simple example of basic RRDtool usage. It illustrates all three important phases of the usual RRDtool workflow: creating a database, updating measured values, and viewing the output.

2.11.2 Simple Real Life Example

Suppose we want to collect and view information about the memory usage in the Linux system as it changes in time. To make the example more vivid, we measure the currently free memory for the period of 40 seconds in 4-second intervals. During the measuring, the three hungry applications that usually consume a lot of system memory have been started and closed: the Firefox Web browser, the Evolution e-mail client, and the Eclipse development framework.

2.11.2.1 Collecting Data

RRDtool is very often used to measure and visualize network traffic. In such case, Simple Network Management Protocol (SNMP) is used. This protocol can query network devices for relevant values of their internal counters. Exactly these values are to be stored with RRDtool. For more information on SNMP, see http://www.net-snmp.org/.

Our situation is different - we need to obtain the data manually. A helper script free_mem.sh repetitively reads the current state of free memory and writes it to the standard output.

tux@mercury:~> cat free_mem.sh
INTERVAL=4
for steps in {1..10}
do
  DATE=`date +%s`
```
Points to Notice

• The time interval is set to 4 seconds, and is implemented with the `sleep` command.

• RRDtool accepts time information in a special format - so called *Unix time*. It is defined as the number of seconds since the midnight of January 1, 1970 (UTC). For example, 1272907114 represents 2010-05-03 17:18:34.

• The free memory information is reported in bytes with `free -b`. Prefer to supply basic units (bytes) instead of multiple units (like kilobytes).

• The line with the `echo` ... command contains the future name of the database file (`free_mem.rrd`), and together creates a command line for the purpose of updating RRDtool values.

After running `free_mem.sh`, you see an output similar to this:

```
tux@mercury:~> sh free_mem.sh
rrdtool update free_mem.rrd 1272974834:1182994432
rrdtool update free_mem.rrd 1272974839:1162817536
rrdtool update free_mem.rrd 1272974843:1096269824
rrdtool update free_mem.rrd 1272974847:1034219520
rrdtool update free_mem.rrd 1272974851:909438976
rrdtool update free_mem.rrd 1272974855:832454656
rrdtool update free_mem.rrd 1272974859:829120512
rrdtool update free_mem.rrd 1272974863:1180377088
rrdtool update free_mem.rrd 1272974867:1179369472
rrdtool update free_mem.rrd 1272974871:1181806592
```

It is convenient to redirect the command's output to a file with

```
sh free_mem.sh > free_mem_updates.log
```

to ease its future execution.

2.11.2.2 Creating Database

Create the initial Robin Round database for our example with the following command:

```
rrdtool create free_mem.rrd --start 1272974834 --step=4 \
```

```
Points to Notice

- This command creates a file called `free_mem.rrd` for storing our measured values in a Round Robin type database.

- The `--start` option specifies the time (in Unix time) when the first value will be added to the database. In this example, it is one less than the first time value of the `free_mem.sh` output (1272974835).

- The `--step` specifies the time interval in seconds with which the measured data will be supplied to the database.

- The `DS:memory:GAUGE:600:U:U` part introduces a new data source for the database. It is called `memory`, its type is `gauge`, the maximum number between two updates is 600 seconds, and the minimal and maximal value in the measured range are unknown (U).

- `RRA:AVERAGE:0.5:1:24` creates Round Robin archive (RRA) whose stored data are processed with the consolidation functions (CF) that calculates the average of data points. 3 arguments of the consolidation function are appended to the end of the line.

If no error message is displayed, then `free_mem.rrd` database is created in the current directory:

```
tux@mercury:~> ls -l free_mem.rrd
-rw-r--r--  1 tux users  776 May  5 12:50 free_mem.rrd
```

2.11.2.3 Updating Database Values

After the database is created, you need to fill it with the measured data. In Section 2.11.2.1, “Collecting Data” (page 45), we already prepared the file `free_mem_updates.log` which consists of `rrdtool update` commands. These commands do the update of database values for us.

```
tux@mercury:~> sh free_mem_updates.log; ls -l free_mem.rrd
-rw-r--r--  1 tux users  776 May  5 13:29 free_mem.rrd
```

As you can see, the size of `free_mem.rrd` remained the same even after updating its data.
2.11.2.4 Viewing Measured Values

We have already measured the values, created the database, and stored the measured value in it. Now we can play with the database, and retrieve or view its values.

To retrieve all the values from our database, enter the following on the command line:

```bash
tux@mercury:~> rrdtool fetch free_mem.rrd AVERAGE --start 1272974830 --end 1272974871
memory
1272974832: nan
1272974836: 1.1729059840e+09
1272974840: 1.1461806080e+09
1272974844: 1.0807572480e+09
1272974848: 1.0030243840e+09
1272974852: 8.9019289600e+08
1272974856: 8.3162112000e+08
1272974860: 9.1693465600e+08
1272974864: 1.1801251840e+09
1272974868: 1.1799787520e+09
1272974872: nan
```

**Points to Notice**

- **AVERAGE** will fetch average value points from the database, because only one data source is defined (Section 2.11.2.2, “Creating Database” (page 46)) with AVERAGE processing and no other function is available.

- The first line of the output prints the name of the data source as defined in Section 2.11.2.2, “Creating Database” (page 46).

- The left results column represents individual points in time, while the right one represents corresponding measured average values in scientific notation.

- The **nan** in the last line stands for “not a number”.

Now a graph representing the values stored in the database is drawn:

```bash
tux@mercury:~> rrdtool graph free_mem.png --start 1272974830 --end 1272974871 --step=4
DEF:free_memory=free_mem.rrd:memory:AVERAGE
LINE2:free_memory#FF0000
--vertical-label "GB"
--title "Free System Memory in Time"
--zoom 1.5
--x-grid SECOND:1:SECOND:4:SECOND:10:0:%X
```
Points to Notice

- `free_mem.png` is the filename of the graph to be created.

- `--start` and `--end` limit the time range within which the graph will be drawn.

- `--step` specifies the time resolution (in seconds) of the graph.

- The `DEF:`... part is a data definition called `free_memory`. Its data are read from the `free_mem.rrd` database and its data source called `memory`. The average value points are calculated, because no others were defined in Section 2.11.2.2, “Creating Database” (page 46).

- The `LINE:`... part specifies properties of the line to be drawn into the graph. It is 2 pixels wide, its data come from the `free_memory` definition, and its color is red.

- `--vertical-label` sets the label to be printed along the y axis, and `--title` sets the main label for the whole graph.

- `--zoom` specifies the zoom factor for the graph. This value must be greater than zero.

- `--x-grid` specifies how to draw grid lines and their labels into the graph. Our example places them every second, while major grid lines are placed every 4 seconds. Labels are placed every 10 seconds under the major grid lines.

Figure 2.2: Example Graph Created with RRDtool

2.11.3 For More Information

RRDtool is a very complex tool with a lot of sub-commands and command line options. Some of them are easy to understand, but you have to really study RRDtool to make it produce the results you want and fine-tune them according to your liking.
Apart from RRDtool’s man page (man 1 rrdtool) which gives you only basic information, you should have a look at the RRDtool home page [http://oss.oetiker.ch/rrdtool/]. There is a detailed documentation [http://oss.oetiker.ch/rrdtool/doc/index.en.html] of the rrdtool command and all its sub-commands. There are also several tutorials [http://oss.oetiker.ch/rrdtool/tut/index.en.html] to help you understand the common RRDtool workflow.

If you are interested in monitoring network traffic, have a look at MRTG [http://oss.oetiker.ch/mrtg/]. It stands for Multi Router Traffic Grapher and can graph the activity of all sorts of network devices. It can easily make use of RRDtool.
Monitoring with Nagios

Nagios is a stable, scalable and extensible enterprise-class network and system monitoring tool which allows administrators to monitor network and host resources such as HTTP, SMTP, POP3, disk usage and processor load. Originally Nagios was designed to run under Linux, but it can also be used on several UNIX operating systems. This chapter covers the installation and parts of the configuration of Nagios (http://www.nagios.org/).

3.1 Features of Nagios

The most important features of Nagios are:

- Monitoring of network services (SMTP, POP3, HTTP, NNTP, etc.).
- Monitoring of host resources (processor load, disk usage, etc.).
- Simple plug-in design that allows administrators to develop further service checks.
- Support for redundant Nagios servers.

3.2 Installing Nagios

Install Nagios either with zypper or using YaST.
For further information on how to install packages see:

- Section “Using Zypper” (Chapter 6, *Managing Software with Command Line Tools*, ↑*Administration Guide*)

- Section “Installing and Removing Packages or Patterns” (Chapter 9, *Installing or Removing Software*, ↑*Deployment Guide*)

Both methods install the packages nagios and nagios-www. The later RPM package contains a Web interface for Nagios which allows, for example, to view the service status and the problem history. However, this is not absolutely necessary.

Nagios is modular designed and, thus, uses external check plug-ins to verify whether a service is available or not. It is recommended to install the nagios-plugin RPM package that contains ready-made check plug-ins. However, it is also possible to write your own, custom check plug-ins.

### 3.3 Nagios Configuration Files

Nagios organizes the configuration files as follows:

/\texttt{etc/nagios/nagios.cfg}

Main configuration file of Nagios containing a number of directives which define how Nagios operates. See \url{http://nagios.sourceforge.net/docs/3_0/configmain.html} for a complete documentation.

/\texttt{etc/nagios/resource.cfg}

Containing path to all Nagios plug-ins (default: /\texttt{usr/lib/nagios/plugins}).

/\texttt{etc/nagios/command.cfg}

Defining the programs to be used to determine the availability of services or the commands which are used to send e-mail notifications.

/\texttt{etc/nagios/cgi.cfg}

Contains options regarding the Nagios Web interface.

/\texttt{etc/nagios/objects/}

A directory containing object definition files. See Section 3.3.1, “Object Definition Files” (page 53) for a more complete documentation.
3.3.1 Object Definition Files

In addition to those configuration files Nagios comes with very flexible and highly customizable configuration files called *Object Definition* configuration files. Those configuration files are very important since they define the following objects:

- Hosts
- Services
- Contacts

The flexibility lies in the fact that objects are easily enhanceable. Imagine you are responsible for a host with only one service running. However, you want to install another service on the same host machine and you want to monitor that service as well. It is possible to add another service object and assign it to the host object without huge efforts.

Right after the installation, Nagios offers default templates for object definition configuration files. They can be found at `/etc/nagios/objects`. In the following see a description on how hosts, services and contacts are added:

**Example 3.1: A Host Object Definition**

```plaintext
define host {
    name                  SRV1
    host_name              SRV1
    address                192.168.0.1
    use                    generic-host
    check_period           24x7
    check_interval         5
    retry_interval         1
    max_check_attempts     10
    notification_period    workhours
    notification_interval  120
    notification_options   d,u,r
}
```

The `host_name` option defines a name to identify the host that has to be monitored. `address` is the IP address of this host. The `use` statement tells Nagios to inherit other configuration values from the generic-host template. `check_period` defines whether the machine has to be monitored 24x7. `check_interval` makes Nagios checking the service every 5 minutes and `retry_interval` tells Nagios to schedule host check retries at 1 minute intervals. Nagios tries to execute the checks multiple times when they do not pass. You can define how many attempts Nagios should do
with the max_check_attempts directive. All configuration flags beginning with notification handle how Nagios should behave when a failure of a monitored service occurs. In the host definition above, Nagios notifies the administrators only on working hours. However, this can be adjusted with notification_period. According to notification_interval notifications will be resend every two hours. notification_options contains four different flags: d, u, r and n. They control in which state Nagios should notify the administrator. d stands for a down state, u for unreachable and r for recoveries. n does not send any notifications anymore.

**Example 3.2: A Service Object Definition**

```
define service {
    use                    generic-service
    host_name              SRV1
    service_description    PING
    contact_groups         router-admins
    check_command          check_ping!100.0,20%!500.0,60%
}
```

The first configuration directive use tells Nagios to inherit from the generic-service template. host_name is the name that assigns the service to the host object. The host itself is defined in the host object definition. A description can be set with service_description. In the example above the description is just PING. Within the contact_groups option it is possible to refer to a group of people who will be contacted on a failure of the service. This group and its members are later defined in a contact group object definition. check_command sets the program that checks whether the service is available, or not.

**Example 3.3: A Contact and Contactgroup Definition**

```
define contact {
    contact_name          admins
    use                    generic-contact
    alias                  Nagios Admin
    e-mail                 nagios@localhost
}

define contactgroup {
    contactgroup_name      router-admins
    alias                  Administrators
    members                admins
}
```

The example listing above shows the direct contact definition and its proper contactgroup. The contact definition contains the e-mail address and the name of
the person who is contacted on a failure of a service. Usually this is the responsible administrator. use inherits configuration values from the generic-contact definition.

An overview of all Nagios objects and further information about them can be found at: http://nagios.sourceforge.net/docs/3_0/objectdefinitions.html.

3.4 Configuring Nagios

Learn step-by-step how to configure Nagios to monitor different things like remote services or remote host-resources.

3.4.1 Monitoring Remote Services with Nagios

This section explains how to monitor remote services with Nagios. Proceed as follows to monitor a remote service:

**Procedure 3.1: Monitoring a Remote HTTP Service with Nagios**

1. Create a directory inside /etc/nagios/objects using mkdir. You can use any desired name for it.
2. Open /etc/nagios/nagios.conf and set cfg_dir (configuration directory) to the directory you have created in the first step.
3. Change to the configuration directory created in the first step and create the following files: hosts.cfg, services.cfg and contacts.cfg
4. Insert a host object in hosts.cfg:

```
define host {
    name host.name.com
    host_name host.name.com
    address 192.168.0.1
    use generic-host
    check_period 24x7
    check_interval 5
    retry_interval 1
```
max_check_attempts 10
contact_groups admins
notification_interval 60
notification_options d,u,r
}

5 Insert a service object in services.cfg:

define service {
    use generic-service
    host_name host.name.com
    service_description HTTP
    contact_groups router-admins
    check_command check_http
}

6 Insert a contact and contactgroup object in contacts.cfg:

define contact {
    contact_name max-mustermann
    use generic-contact
    alias Webserver Administrator
    e-mail mmustermann@localhost
}

define contactgroup {
    contactgroup_name admins
    alias Administrators
    members max-mustermann
}

7 Execute rcnagios restart to (re)start Nagios.

8 Execute cat /var/log/nagios/nagios.log and verify whether the following content appears:

    [1242115343] Nagios 3.0.6 starting... (PID=10915)
    [1242115343] Local time is Tue May 12 10:02:23 CEST 2009
    [1242115343] LOG VERSION: 2.0
    [1242115343] Finished daemonizing... (New PID=10916)

If you need to monitor a different remote service, it is possible to adjust check_command in step Step 5 (page 56). A full list of all available check programs can be obtained by executing ls /usr/lib/nagios/plugins/check_*

See Section 3.5, “Troubleshooting” (page 58) if an error occurred.
3.4.2 Monitoring Remote Host-Resources with Nagios

This section explains how to monitor remote host resources with Nagios.

Proceed as follows on the Nagios server:

Procedure 3.2: Monitoring a Remote Host Resource with Nagios (Server)

1. Install nagios-nsca (for example, zypper in nagios-nsca).

2. Set the following options in `/etc/nagios/nagios.cfg`:
   
   ```
   check_external_commands=1
   accept_passive_service_checks=1
   accept_passive_host_checks=1
   command_file=/var/spool/nagios/nagios.cmd
   ```

3. Set the `command_file` option in `/etc/nagios/nsca.conf` to the same file defined in `/etc/nagios/nagios.conf`.

4. Add another host and service object:
   
   ```
   define host {
         name foobar
         host_name foobar
         address 10.10.4.234
         use generic-host
         check_period 24x7
         check_interval 0
         retry_interval 1
         max_check_attempts 1
         active_checks_enabled 0
         passive_checks_enabled 1
         contact_groups router-admins
         notification_interval 60
         notification_options d,u,r
   }
   
   define service {
         use generic-service
         host_name foobar
         service_description diskcheck
         active_checks_enabled 0
         passive_checks_enabled 1
         contact_groups router-admins
         check_command check_ping
   }
   ```
5 Execute `rcnagios restart` and `rcnsca restart`.

Proceed as follows on the client you want to monitor:

**Procedure 3.3: Monitoring a Remote Host Resource with Nagios (client)**

1 Install `nagios-nsca-client` on the host you want to monitor.

2 Write your test scripts (for example a script that checks the disk usage) like this:

```bash
#!/bin/bash

NAGIOS_SERVER=10.10.4.166
THIS_HOST=foobar

# Write own test algorithm here
#

# Execute On SUCCESS:
echo "$THIS_HOST;diskcheck;0;OK: test ok" \  
  | send_nsca -H $NAGIOS_SERVER -p 5667 -c /etc/nagios/send_nsca.cfg -d ";"

# Execute On Warning:
echo "$THIS_HOST;diskcheck;1;Warning: test warning" \  
  | send_nsca -H $NAGIOS_SERVER -p 5667 -c /etc/nagios/send_nsca.cfg -d ";"

# Execute On FAILURE:
echo "$THIS_HOST;diskcheck;2;CRITICAL: test critical" \  
  | send_nsca -H $NAGIOS_SERVER -p 5667 -c /etc/nagios/send_nsca.cfg -d ";"

3 Insert a new cron entry with `crontab -e`. A typical cron entry could look like this:

```
*/5 * * * * /directory/to/check/program/check_diskusage
```

### 3.5 Troubleshooting

**Error:** ABC 'XYZ' specified in ... '...' is not defined anywhere!

Make sure that you have defined all necessary objects correctly. Be careful with the spelling.
(Return code of 127 is out of bounds – plugin may be missing)

Make sure that you have installed nagios-plugins.

E-mail notification does not work

Make sure that you have installed and configured a mail server like postfix or exim correctly. You can verify if your mail server works with echo "Mail Server Test!" | mail foo@bar.com which sends an e-mail to foo@bar.com. If this e-mail arrives, your mail server is working correctly. Otherwise, check the log files of the mail server.

3.6 For More Information

The complete Nagios documentation
http://nagios.sourceforge.net/docs/3_0/toc.html

Object Configuration Overview
http://nagios.sourceforge.net/docs/3_0/
configobject.html

Object Definitions
http://nagios.sourceforge.net/docs/3_0/
objectdefinitions.html

Nagios Plugins
http://nagios.sourceforge.net/docs/3_0/plugins.html
Analyzing and Managing System Log Files

System log file analysis is one of the most important tasks when analyzing the system. In fact, looking at the system log files should be the first thing to do when maintaining or troubleshooting a system. SUSE Linux Enterprise Server automatically logs almost everything that happens on the system in detail. Normally, system log files are written in plain text and therefore, can be easily read using an editor or pager. They are also parsable by scripts, allowing you to easily filter their content.

4.1 System Log Files in /var/log/

System log files are always located under the /var/log directory. The following list presents an overview of all system log files from SUSE Linux Enterprise Server present after a default installation. Depending on your installation scope, /var/log also contains log files from other services and applications not listed here. Some files and directories described below are “placeholders” and are only used, when the corresponding application is installed. Most log files are only visible for the user root.

**acpid**
Log of the advanced configuration and power interface event daemon (acpid), a daemon to notify user-space programs of ACPI events. acpid will log all of its activities, as well as the STDOUT and STDERR of any actions to syslog.

**apparmor**
AppArmor log files. See Part “Confining Privileges with AppArmor” (↑Security Guide) for details of AppArmor.
audit
Logs from the audit framework. See Part “The Linux Audit Framework” (↑Security Guide) for details.

boot.msg
Log of the system init process—this file contains all boot messages from the Kernel, the boot scripts and the services started during the boot sequence.

Check this file to find out whether your hardware has been correctly initialized or all services have been started successfully.

boot.omsg
Log of the system shutdown process - this file contains all messages issued on the last shutdown or reboot.

ConsoleKit/*
Logs of the ConsoleKit daemon (daemon for tracking what users are logged in and how they interact with the computer).

cups/
Access and error logs of the Common UNIX Printing System (cups).

faillog
Database file that contains all login failures. Use the faillog command to view. See man 8 faillog for more information.

firewall
Firewall logs.

gdm/*
Log files from the GNOME display manager.

krb5
Log files from the Kerberos network authentication system.

lastlog
The lastlog file is a database which contains info on the last login of each user. Use the command lastlog to view. See man 8 lastlog for more information.

localmessages
Log messages of some boot scripts, for example the log of the DHCP client.

mail*
Mail server (postfix, sendmail) logs.
messages
   This is the default place where all Kernel and system log messages go and should be the first place (along with /var/log/warn) to look at in case of problems.

NetworkManager
   NetworkManager log files

news/*
   Log messages from a news server.

ntp
   Logs from the Network Time Protocol daemon (ntpd).

pk_backend_zypp
   PackageKit (with libzypp backend) log files.

puppet/*
   Log files from the data center automation tool puppet.

samba/*
   Log files from samba, the Windows SMB/CIFS file server.

SaX.log
   Logs from SaX2, the SUSE advanced X11 configuration tool.

scpm
   Logs from the system configuration profile management (scpm).

warn
   Log of all system warnings and errors. This should be the first place (along with /var/log/messages) to look at in case of problems.

wtmp
   Database of all login/logout activities, runlevel changes and remote connections. Use the command last to view. See man 1 last for more information.

xinetd.log
   Log files from the extended Internet services daemon (xinetd).

Xorg.0.log
   X startup log file. Refer to this in case you have problems starting X. Copies from previous X starts are numbered Xorg. ? . log.
YaST2/*  
All YaST log files.

zypp/*  
libzypp log files. Refer to these files for the package installation history.

zypper.log  
Logs from the command line installer zypper.

4.2 Viewing and Parsing Log Files

To view log files, you can use your favorite text editor. There is also a simple YaST module for viewing /var/log/messages, available in the YaST Control Center under Miscellaneous > System Log.

For viewing log files in a text console, use the commands less or more. Use head and tail to view the beginning or end of a log file. To view entries appended to a log file in real-time use tail -f. For information about how to use these tools, see their man pages.

To search for strings or regular expressions in log files use grep. awk is useful for parsing and rewriting log files.

4.3 Managing Log Files with logrotate

Log files under /var/log grow on a daily basis and quickly become very big. logrotate is a tool for large amounts of log files and helps you to manage these files and to control their growth. It allows automatic rotation, removal, compression, and mailing of log files. Log files can be handled periodically (daily, weekly, or monthly) or when exceeding a particular size.

logrotate is usually run as a daily cron job. It does not modify any log files more than once a day unless the log is to be modified because of its size, because logrotate is being run multiple times a day, or the --force option is used.

The main configuration file of logrotate is /etc/logrotate.conf. System packages as well as programs that produce log files (for example, apache2) put their
own configuration files in the /etc/logrotate.d/ directory. The content of /etc/logrotate.d/ is included via /etc/logrotate.conf.

Example 4.1: Example for /etc/logrotate.conf

```
# see "man logrotate" for details
# rotate log files weekly
weekly

# keep 4 weeks worth of backlogs
rotate 4

# create new (empty) log files after rotating old ones
create

# use date as a suffix of the rotated file
dateext

# uncomment this if you want your log files compressed
#compress

# comment these to switch compression to use gzip or another
# compression scheme
compresscmd /usr/bin/bzip2
uncompresscmd /usr/bin/bunzip2

# RPM packages drop log rotation information into this directory
include /etc/logrotate.d
```

**IMPORTANT**

The create option pays heed to the modes and ownerships of files specified in /etc/permissions*. If you modify these settings, make sure no conflicts arise.

logrotate is controlled through cron and is called daily by /etc/cron.daily/logrotate. Use /var/lib/logrotate.status to find out when a particular file has been rotated lastly.

### 4.4 Monitoring Log Files with logwatch

logwatch is a customizable, pluggable log-monitoring script. It parses system logs, extracts the important information and presents them in a human readable manner. To use logwatch, install the logwatch package.
logwatch can either be used at the command-line to generate on-the-fly reports, or via cron to regularly create custom reports. Reports can either be printed on the screen, saved to a file, or be mailed to a specified address. The latter is especially useful when automatically generating reports via cron.

The command-line syntax is easy. You basically tell logwatch for which service, time span and to which detail level to generate a report:

```bash
# Detailed report on all kernel messages from yesterday
logwatch --service kernel --detail High --range Yesterday --print

# Low detail report on all sshd events recorded (incl. archived logs)
logwatch --service sshd --detail Low --range All --archives --print

# Mail a report on all smartd messages from May 5th to May 7th to root@localhost
logwatch --service smartd --range 'between 5/5/2005 and 5/7/2005' \ 
--mailto root@localhost --print
```

The `--range` option has got a complex syntax—see logwatch --range help for details. A list of all services that can be queried is available with the following command:

```
ls /usr/share/logwatch/default.conf/services/ | sed 's/\.conf//g'
```

logwatch can be customized to great detail. However, the default configuration should be sufficient in most cases. The default configuration files are located under `/usr/share/logwatch/default.conf/`. Never change them because they would get overwritten again with the next update. Rather place custom configuration in `/etc/logwatch/conf/` (you may use the default configuration file as a template, though). A detailed HOWTO on customizing logwatch is available at `/usr/share/doc/packages/logwatch/HOWTO-Customize-LogWatch`. The following config files exist:

- **logwatch.conf**
  The main configuration file. The default version is extensively commented. Each configuration option can be overwritten on the command line.

- **ignore.conf**
  Filter for all lines that should globally be ignored by logwatch.

- **services/*.conf**
  The service directory holds configuration files for each service you can generate a report for.

- **logfiles/*.conf**
  Specifications on which log files should be parsed for each service.
4.5 Using logger to Make System Log Entries

`logger` is a tool for making entries in the system log. It provides a shell command interface to the syslog(3) system log module. For example, the following line outputs its message in `/var/log/messages`:

```
logger -t Test "This messages comes from $USER"
```

Depending on the current user and hostname, `/var/log/messages` contains a line similar to this:

```
Sep 28 13:09:31 venus Test: This messages comes from tux
```
Part III. Kernel Monitoring
SystemTap—Filtering and Analyzing System Data

SystemTap provides a command line interface and a scripting language to examine the activities of a running Linux system, particularly the kernel, in fine detail. SystemTap scripts are written in the SystemTap scripting language, are then compiled to C-code kernel modules and inserted into the kernel. The scripts can be designed to extract, filter and summarize data, thus allowing the diagnosis of complex performance problems or functional problems. SystemTap provides information similar to the output of tools like `netstat`, `ps`, `top`, and `iostat`. However, more filtering and analysis options can be used for the collected information.

5.1 Conceptual Overview

Each time you run a SystemTap script, a SystemTap session is started. A number of passes are done on the script before it is allowed to run, at which point the script is compiled into a kernel module and loaded. In case the script has already been executed before and no changes regarding any components have occurred (for example, regarding compiler version, kernel version, library path, script contents), SystemTap does not compile the script again, but uses the `*.c` and `*.ko` data stored in the SystemTap cache (`~/.systemtap`). The module is unloaded when the tap has finished running. For an example, see the test run in Section 5.2, “Installation and Setup” (page 74) and the respective explanation.
5.1.1 SystemTap Scripts

SystemTap usage is based on SystemTap scripts (*.stp). They tell SystemTap which type of information to collect, and what to do once that information is collected. The scripts are written in the SystemTap scripting language that is similar to AWK and C. For the language definition, see http://sourceware.org/systemtap/langu​ref/.

The essential idea behind a SystemTap script is to name events, and to give them handlers. When SystemTap runs the script, it monitors for certain events. When an event occurs, the Linux kernel runs the handler as a sub-routine, then resumes. Thus, events serve as the triggers for handlers to run. Handlers can record specified data and print it in a certain manner.

The SystemTap language only uses a few data types (integers, strings, and associative arrays of these), and full control structures (blocks, conditionals, loops, functions). It has a lightweight punctuation (semicolons are optional) and does not need detailed declarations (types are inferred and checked automatically).

For more information about SystemTap scripts and their syntax, refer to Section 5.3, “Script Syntax” (page 76) and to the stapprobes and stapfuncs man pages, that are available with the systemtap-docs package.

5.1.2 Tapsets

Tapsets are a library of pre-written probes and functions that can be used in SystemTap scripts. When a user runs a SystemTap script, SystemTap checks the script's probe events and handlers against the tapset library. SystemTap then loads the corresponding probes and functions before translating the script to C. Like SystemTap scripts themselves, tapsets use the filename extension *.stp.

However, unlike SystemTap scripts, tapsets are not meant for direct execution—they constitute the library from which other scripts can pull definitions. Thus, the tapset library is an abstraction layer designed to make it easier for users to define events and functions. Tapsets provide useful aliases for functions that users may want to specify as an event (knowing the proper alias is mostly easier than remembering specific kernel functions that might vary between kernel versions).
5.1.3 Commands and Privileges

The main commands associated with SystemTap are `stap` and `staprun`. To execute them, you either need `root` privileges or must be a member of the `stapdev` or `stapusr` group.

`stap`
SystemTap front-end. Runs a SystemTap script (either from file, or from standard input). It translates the script into C code, compiles it, and loads the resulting kernel module into a running Linux kernel. Then, the requested system trace or probe functions are performed.

`staprun`
SystemTap back-end. Loads and unloads kernel modules produced by the SystemTap front-end.

For a list of options for each command, use `--help`. For details, refer to the `stap` and the `staprun` man pages.

To avoid giving `root` access to users just for running SystemTap, you can make use of the following SystemTap groups. They are not available by default on SUSE Linux Enterprise, but you can create the groups and modify the access rights accordingly.

`stapdev`
Members of this group can run SystemTap scripts with `stap`, or run SystemTap instrumentation modules with `staprun`. As running `stap` involves compiling scripts into kernel modules and loading them into the kernel, members of this group still have effective `root` access.

`stapusr`
Members of this group are only allowed to run SystemTap instrumentation modules with `staprun`. In addition, they can only run those modules from `/lib/modules/kernel_version/systemtap/`. This directory must be owned by `root` and must only be writable for the `root` user.

5.1.4 Important Files and Directories

The following list gives an overview of the SystemTap main files and directories.

`/lib/modules/kernel_version/systemtap/`
Holds the SystemTap instrumentation modules.
/usr/share/systemtap/tapset/
    Holds the standard library of tapsets.

/usr/share/doc/packages/systemtap/examples
    Holds a number of example SystemTap scripts for various purposes. Only available if the systemtap-docs package is installed.

~/.systemtap/cache
    Data directory for cached SystemTap files.

/tmp/stap*
    Temporary directory for SystemTap files, including translated C code and kernel object.

## 5.2 Installation and Setup

As SystemTap needs information about the kernel, some kernel-related packages must be installed in addition to the SystemTap packages. For each kernel you want to probe with SystemTap, you need to install a set of the following packages that exactly matches the kernel version and flavor (indicated by * in the overview below).

---

**IMPORTANT: Repository for Packages with Debugging Information**

If you subscribed your system for online updates, you can find “debuginfo” packages in the *-Debuginfo-Updates online installation repository relevant for SUSE Linux Enterprise Server 11 SP4. Use YaST to enable the repository.

For the classic SystemTap setup, install the following packages (using either YaST or zypper).

- systemtap
- systemtap-server
- systemtap-docs (optional)
- kernel-*--base
- kernel-*--debuginfo
- kernel-*--devel
• kernel-source-*

• gcc

To get access to the man pages and to a helpful collection of example SystemTap scripts for various purposes, additionally install the systemtap-docs package.

To check if all packages are correctly installed on the machine and if SystemTap is ready to use, execute the following command as root.

```bash
stap -v -e 'probe vfs.read {printf("read performed\n"); exit()}'
```

It probes the currently used kernel by running a script and returning an output. If the output is similar to the following, SystemTap is successfully deployed and ready to use:

Pass 1: parsed user script and 59 library script(s) in 80usr/0sys/214real ms.
Pass 2: analyzed script: 1 probe(s), 11 function(s), 2 embed(s), 1 global(s) in 140usr/20sys/412real ms.
Pass 3: translated to C into "/tmp/stapDwEk76/stap_1856e21ea1c246da85ad8c66b4338349_4970.c" in 160usr/0sys/408real ms.
Pass 4: compiled C into "stap_1856e21ea1c246da85ad8c66b4338349_4970.ko" in 2030usr/360sys/10182real ms.
Pass 5: starting run.
read performed
Pass 5 (page 75): run completed in 10usr/20sys/257real ms.

1. Checks the script against the existing tapset library in /usr/share/systemtap/tapset/ for any tapsets used. Tapsets are scripts that form a library of pre-written probes and functions that can be used in SystemTap scripts.
2. Examines the script for its components.
3. Translates the script to C. Runs the system C compiler to create a kernel module from it. Both the resulting C code (*.c) and the kernel module (*.ko) are stored in the SystemTap cache, ~/.systemtap.
4. Loads the module and enables all the probes (events and handlers) in the script by hooking into the kernel. The event being probed is a Virtual File System (VFS) read. As the event occurs on any processor, a valid handler is executed (prints the text read performed) and closed with no errors.
5. After the SystemTap session is terminated, the probes are disabled, and the kernel module is unloaded.

In case any error messages appear during the test, check the output for hints about any missing packages and make sure they are installed correctly. Rebooting and loading the appropriate kernel may also be needed.
5.3 Script Syntax

SystemTap scripts consist of the following two components:

SystemTap Events (Probe Points) (page 77)
    Name the kernel events at the associated handler should be executed. Examples for
    events are entering or exiting a certain function, a timer expiring, or starting or ter-
    minating a session.

SystemTap Handlers (Probe Body) (page 78)
    Series of script language statements that specify the work to be done whenever a
    certain event occurs. This normally includes extracting data from the event context,
    storing them into internal variables, or printing results.

An event and its corresponding handler is collectively called a probe. SystemTap
events are also called probe points. A probe's handler is also referred to as
probe body.

Comments can be inserted anywhere in the SystemTap script in various styles: using ei-
ther #, /* */ or // as marker.

5.3.1 Probe Format

A SystemTap script can have multiple probes. They must be written in the following
format:

    probe event {statements}

Each probe has a corresponding statement block. This statement block must be en-
closed in {} and contains the statements to be executed per event.

Example 5.1: Simple SystemTap Script

The following example shows a simple SystemTap script.

    probe begin
    {
        printf ("hello world\n")
        exit ();
    }

1  Start of the probe.
2  Event begin (the start of the SystemTap session).
Start of the handler definition, indicated by {. 
First function defined in the handler: the printf function. 
String to be printed by the printf function, followed by a line break (/n). 
Second function defined in the handler: the exit() function. Note that the SystemTap script will continue to run until the exit() function executes. If you want to stop the execution of the script before, stop it manually by pressing Ctrl + C. 
End of the handler definition, indicated by }. 

The event begin (the start of the SystemTap session) triggers the handler enclosed in { }, in this case the printf function which prints hello world followed by a new line, then exits. 

If your statement block holds several statements, SystemTap executes these statements in sequence—you do not need to insert special separators or terminators between multiple statements. A statement block can also be nested within another statement blocks. Generally, statement blocks in SystemTap scripts use the same syntax and semantics as in the C programming language. 

5.3.2 SystemTap Events (Probe Points) 

SystemTap supports a number of built-in events. 

The general event syntax is a dotted-symbol sequence. This allows a breakdown of the event namespace into parts. Each component identifier may be parametrized by a string or number literal, with a syntax like a function call. A component may include a * character, to expand to other matching probe points. A probe point may be followed by a ? character, to indicate that it is optional, and that no error should result if it fails to expand. Alternately, a probe point may be followed by a ! character to indicate that it is both optional and sufficient. 

SystemTap supports multiple events per probe—they need to be separated by a comma (,). If multiple events are specified in a single probe, SystemTap will execute the handler when any of the specified events occur. 

In general, events can be classified into the following categories: 

• Synchronous events: Occur when any process executes an instruction at a particular location in kernel code. This gives other events a reference point (instruction address) from which more contextual data may be available.
An example for a synchronous event is `vfs.file_operation`: The entry to the `file_operation` event for Virtual File System (VFS). For example, in Section 5.2, “Installation and Setup” (page 74), `read` is the `file_operation` event used for VFS.

- **Asynchronous events**: Not tied to a particular instruction or location in code. This family of probe points consists mainly of counters, timers, and similar constructs.

Examples for asynchronous events are: `begin` (start of a SystemTap session—as soon as a SystemTap script is run), `end` (end of a SystemTap session), or timer events. Timer events specify a handler to be executed periodically, like `example timer.s(seconds)`, or `timer.ms(milliseconds)`.

When used in conjunction with other probes that collect information, timer events allow you to print out periodic updates and see how that information changes over time.

**Example 5.2: Probe with Timer Event**

For example, the following probe would print the text “hello world” every 4 seconds:

```bash
probe timer.s(4) {
    printf("hello world\n")
}
```

For detailed information about supported events, refer to the `stapprobes man page`. The `See Also` section of the man page also contains links to other man pages that discuss supported events for specific subsystems and components.

### 5.3.3 SystemTap Handlers (Probe Body)

Each SystemTap event is accompanied by a corresponding handler defined for that event, consisting of a statement block.

#### 5.3.3.1 Functions

If you need the same set of statements in multiple probes, you can place them in a function for easy reuse. Functions are defined by the keyword `function` followed by a name. They take any number of string or numeric arguments (by value) and may return a single string or number.
function function_name(arguments) {
  statements
}
probe event {
  function_name(arguments)
}

The statements in function_name are executed when the probe for event executes. The arguments are optional values passed into the function.

Functions can be defined anywhere in the script. They may take any

One of the functions needed very often was already introduced in Example 5.1, “Simple SystemTap Script” (page 76): the printf function for printing data in a formatted way. When using the printf function, you can specify how arguments should be printed by using a format string. The format string is included in quotation marks and can contain further format specifiers, introduced by a % character.

Which format strings to use depends on your list of arguments. Format strings can have multiple format specifiers—each matching a corresponding argument. Multiple arguments can be separated by a comma.

Example 5.3: printf Function with Format Specifiers

printf ("%s (%d) open
", execname(), pid())

1. Start of the format string, indicated by ".
2. String format specifier.
3. Integer format specifier.
4. End of the format string, indicated by ".

The example above would print the current executable name (execname()) as string and the process ID (pid()) as integer in brackets, followed by a space, then the word open and a line break:

[...]
vmware-guestd(2206) open
hald(2360) open
[...]

Apart from the two functions execname() and pid() used in Example 5.3, “printf Function with Format Specifiers” (page 79), a variety of other functions can be used as printf arguments.

Among the most commonly used SystemTap functions are the following:

tid()
  ID of the current thread.
pid()
    Process ID of the current thread.

uid()
    ID of the current user.

cpu()
    Current CPU number.

execname()
    Name of the current process.

gettimeofday_s()
    Number of seconds since UNIX epoch (January 1, 1970).

ctime()
    Convert time into a string.

pp()
    String describing the probe point currently being handled.

thread_indent()
    Useful function for organizing print results. It (internally) stores an indentation counter for each thread (tid()). The function takes one argument, an indentation delta, indicating how many spaces to add or remove from the thread's indentation counter. It returns a string with some generic trace data along with an appropriate number of indentation spaces. The generic data returned includes a time stamp (number of microseconds since the initial indentation for the thread), a process name, and the thread ID itself. This allows you to identify what functions were called, who called them, and how long they took.

    Call entries and exits often do not immediately precede each other (otherwise it would be easy to match them). In between a first call entry and its exit, usually a number of other call entries and exits are made. The indentation counter helps you match an entry with its corresponding exit as it indents the next function call in case it is not the exit of the previous one. For an example SystemTap script using thread_indent() and the respective output, refer to the SystemTap Tutorial: http://sourceware.org/systemtap/tutorial/Tracing.html#fig:socket-trace.

    For more information about supported SystemTap functions, refer to the stapfuncs man page.
5.3.3.2 Other Basic Constructs

Apart from functions, you can use several other common constructs in SystemTap handlers, including variables, conditional statements (like if/else, while loops, for loops, arrays or command line arguments.

Variables

Variables may be defined anywhere in the script. To define one, simply choose a name and assign a value from a function or expression to it:

```
foo = gettimeofday()
```

Then you can use the variable in an expression. From the type of values assigned to the variable, SystemTap automatically infers the type of each identifier (string or number). Any inconsistencies will be reported as errors. In the example above, `foo` would automatically be classified as a number and could be printed via `printf()` with the integer format specifier (`%d`).

However, by default, variables are local to the probe they are used in: They are initialized, used and disposed of at each handler evocation. To share variables between probes, declare them global anywhere in the script. To do so, use the `global` keyword outside of the probes:

```
Example 5.4: Using Global Variables

global count_jiffies, count_ms
probe timer.jiffies(100) { count_jiffies ++ }
probe timer.ms(100) { count_ms ++ }
probe timer.ms(12345)
{
  hz=(1000*count_jiffies) / count_ms
  printf("jiffies:ms ratio %d:%d => CONFIG_HZ=%d\n",
    count_jiffies, count_ms, hz)
  exit()
}
```

This example script computes the CONFIG_HZ setting of the kernel by using timers that count jiffies and milliseconds, then computing accordingly. (A jiffy is the duration of one tick of the system timer interrupt. It is not an absolute time interval unit, since its duration depends on the clock interrupt frequency of the particular hardware platform). With the `global` statement it is possible to use the variables `count_jiffies` and `count_ms` also in the probe `timer.ms(12345)`. With `+` the value of a variable is incremented by 1.
Conditional Statements

There are a number of conditional statements that you can use in SystemTap scripts. The following are probably most common:

If/Else Statements
They are expressed in the following format:

```plaintext
if (condition) statement1
else statement2
```

The `if` statement compares an integer-valued expression to zero. If the condition expression is non-zero, the first statement is executed. If the condition expression is zero, the second statement is executed. The `else` clause is optional. Both `and` can also be statement blocks.

While Loops
They are expressed in the following format:

```plaintext
while (condition) statement
```

As long as `condition` is non-zero, the statement is executed. `and` can also be a statement block. It must change a value so `condition` will eventually be zero.

For Loops
They are basically a shortcut for `while` loops and are expressed in the following format:

```plaintext
for (initialization; conditional; increment) statement
```

The expression specified in `initialization` is used to initialize a counter for the number of loop iterations and is executed before execution of the loop starts. The execution of the loop continues until the loop condition is false. (This expression is checked at the beginning of each loop iteration). The expression specified in `increment` is used to increment the loop counter. It is executed at the end of each loop iteration.

Conditional Operators
The following operators can be used in conditional statements:

```plaintext
==: Is equal to

!=: Is not equal to

>=: Is greater than or equal to
```
5.4 Example Script

If you have installed the `systemtap-docs` package, you can find a number of useful SystemTap example scripts in `/usr/share/doc/packages/systemtap/examples`.

This section describes a rather simple example script in more detail: `/usr/share/doc/packages/systemtap/examples/network/tcp_connections.stp`.

**Example 5.5:** Monitoring Incoming TCP Connections with `tcp_connections.stp`

```plaintext
#!/usr/bin/env stap
probes begin {
    printf("%6s %16s %6s %6s %16s
",  
            "UID", "CMD", "PID", "PORT", "IP_SOURCE")
}
probes kernel.function("tcp_accept").return?,  
    kernel.function("inet_csk_accept").return? {
    sock = $return
    if (sock != 0)
        printf("%6d %16s %6d %6d %16s
", uid(), execname(), pid(),  
                inet_get_local_port(sock), inet_get_ip_source(sock))
}
```

This SystemTap script monitors the incoming TCP connections and helps to identify unauthorized or unwanted network access requests in real time. It shows the following information for each new incoming TCP connection accepted by the computer:

- User ID (UID)
- Command accepting the connection (CMD)
- Process ID of the command (PID)
- Port used by the connection (PORT)
- IP address from which the TCP connection originated (IP_Souce)

To run the script, execute

`stap /usr/share/doc/packages/systemtap/examples/network/tcp_connections.stp`
5.5 User-Space Probing

For debugging user-space applications (like DTrace can do), SUSE Linux Enterprise Server 11 SP4 supports user-space probing with SystemTap: Custom probe points can be inserted in any user-space application. Thus, SystemTap lets you use both Kernel- and user-space probes to debug the behavior of the whole system.

To get the required utrace infrastructure and the uprobes Kernel module for user-space probing, you need to install the kernel-trace package in addition to the packages listed in Section 5.2, “Installation and Setup” (page 74).

Basically, utrace implements a framework for controlling user-space tasks. It provides an interface that can be used by various tracing “engines”, implemented as loadable Kernel modules. The engines register callback functions for specific events, then attach to whichever thread they wish to trace. As the callbacks are made from “safe” places in the Kernel, this allows for great leeway in the kinds of processing the functions can do. Various events can be watched via utrace, for example, system call entry and exit, fork(), signals being sent to the task, etc. More details about the utrace infrastructure are available at http://sourceware.org/systemtap/wiki/utrace.

SystemTap includes support for probing the entry into and return from a function in user-space processes, probing predefined markers in user-space code, and monitoring user-process events.

To check if the currently running Kernel provides the needed utrace support, use the following command:

```
grep CONFIG_UTRACE /boot/config-`uname -r`
```

For more details about user-space probing, refer to https://sourceware.org/systemtap/SystemTap_Beginners_Guide/user_space-probing.html.

5.6 For More Information

This chapter only provides a short SystemTap overview. Refer to the following links for more information about SystemTap:
http://sourceware.org/systemtap/
  SystemTap project home page.

http://sourceware.org/systemtap/wiki/
  Huge collection of useful information about SystemTap, ranging from detailed user
  and developer documentation to reviews and comparisons with other tools, or Fre-
  quently Asked Questions and tips. Also contains collections of SystemTap scripts,
  examples and usage stories and lists recent talks and papers about SystemTap.

http://sourceware.org/systemtap/documentation.html
  Features a SystemTap Tutorial, a SystemTap Beginner's Guide, a Tapset Developer's
  Guide, and a SystemTap Language Reference in PDF and HTML format. Also lists
  the relevant man pages.

You can also find the SystemTap language reference and SystemTap tutorial in your in-
stalled system under /usr/share/doc/packages/systemtap. Example Sys-

temTap scripts are available from the example subdirectory.
Kernel Probes

Kernel probes are a set of tools to collect Linux kernel debugging and performance information. Developers and system administrators usually use them either to debug the kernel, or to find system performance bottlenecks. The reported data can then be used to tune the system for better performance.

You can insert these probes into any kernel routine, and specify a handler to be invoked after a particular break-point is hit. The main advantage of kernel probes is that you no longer need to rebuild the kernel and reboot the system after you make changes in a probe.

To use kernel probes, you typically need to write or obtain a specific kernel module. Such module includes both the init and the exit function. The init function (such as register_kprobe()) registers one or more probes, while the exit function un-registers them. The registration function defines where the probe will be inserted and which handler will be called after the probe is hit. To register or unregister a group of probes at one time, you can use relevant register_<probe_type>probes() or unregister_<probe_type>probes() functions.

Debugging and status messages are typically reported with the printk kernel routine. printk is a kernel-space equivalent of a user-space printf routine. For more information on printk, see Logging kernel messages [http://www.win.tue.nl/~aeb/linux/lk/lk-2.html#ss2.8]. Normally, you can view these messages by inspecting /var/log/messages or /var/log/syslog. For more information on log files, see Chapter 4, Analyzing and Managing System Log Files (page 61).
6.1 Supported Architectures

Kernel probes are fully implemented on the following architectures:

- i386
- x86_64 (AMD-64, EM64T)
- ppc64
- arm
- ppc

Kernel probes are partially implemented on the following architectures:

- ia64 (does not support probes on instruction slot1)
- sparc64 (return probes not yet implemented)

6.2 Types of Kernel Probes

There are three types of kernel probes: kprobes, jprobes, and kretprobes. Kretprobes are sometimes referred to as return probes. You can find vivid source code examples of all three type of kernel probes in the /usr/src/linux/samples/kprobes/directory (package kernel-source).

6.2.1 Kprobe

Kprobe can be attached to any instruction in the Linux kernel. When it is registered, it inserts a break-point at the first bytes of the probed instruction. When the processor hits this break-point, the processor registers are saved, and the processing passes to kprobes. First, a pre-handler is executed, then the probed instruction is stepped, and, finally a post-handler is executed. The control is then passed to the instruction following the probe point.
6.2.2 Jprobe

Jprobe is implemented through the kprobe mechanism. It is inserted on a function's entry point and allows direct access to the arguments of the function which is being probed. Its handler routine must have the same argument list and return value as the probed function. It also has to end by calling the `jprobe_return()` function.

When jprobe is hit, the processor registers are saved, and the instruction pointer is directed to the jprobe handler routine. The control then passes to the handler with the same register contents as the function being probed. Finally, the handler calls the `jprobe_return()` function, and switches the control back to the control function.

In general, you can insert multiple probes on one function. Jprobe is, however, limited to only one instance per function.

6.2.3 Return Probe

Return probes are also implemented through kprobes. When the `register_kretprobe()` function is called, a kprobe is attached to the entry of the probed function. After hitting the probe, the Kernel probes mechanism saves the probed function return address and calls a user-defined return handler. The control is then passed back to the probed function.

Before you call `register_kretprobe()`, you need to set a `maxactive` argument, which specifies how many instances of the function can be probed at the same time. If set too low, you will miss a certain number of probes.

6.3 Kernel probes API

Kprobe's programming interface consists of functions, which are used to register and unregister all used kernel probes, and associated probe handlers. For a more detailed description of these functions and their arguments, see the information sources in Section 6.5, “For More Information” (page 91).

`register_kprobe()`  
Inserts a break-point on a specified address. When the break-point is hit, the `pre_handler` and `post_handler` are called.
register_jprobe()
Inserts a break-point in the specified address. The address has to be the address of
the first instruction of the probed function. When the break-point is hit, the spec-
ified handler is run. The handler should have the same argument list and return
type as the probed.

register_kretprobe()
Inserts a return probe for the specified function. When the probed function returns,
a specified handler is run. This function returns 0 on success, or a negative error
number on failure.

unregister_kprobe(), unregister_jprobe(),
unregister_kretprobe()
Removes the specified probe. You can use it any time after the probe has been
registered.

register_kprobes(), register_jprobes(),
register_kretprobes()
Inserts each of the probes in the specified array.

unregister_kprobes(), unregister_jprobes(),
unregister_kretprobes()
Removes each of the probes in the specified array.

disable_kprobe(), disable_jprobe(), disable_kretprobe()
Disables the specified probe temporarily.

enable_kprobe(), enable_jprobe(), enable_kretprobe()
Enables temporarily disabled probes.

6.4 Debugfs Interface

With recent Linux kernels, the Kernel probes instrumentation uses the kernel debugfs
interface. It helps you list all registered probes and globally switch all the probes on or
off.
6.4.1 How to List Registered Kernel Probes

The list of all currently registered kprobes is in the /sys/kernel/debug/kprobes/list file.

```
saturn.example.com:~ # cat /sys/kernel/debug/kprobes/list
```
```
c015d71a  k  vfs_read+0x0   [DISABLED]
c011a316  j  do_fork+0x0
```
```
c03dedc5  r  tcp_v4_rcv+0x0
```

The first column lists the address in the kernel where the probe is inserted. The second column prints the type of the probe: k for kprobe, j for jprobe, and r for return probe. The third column specifies the symbol, offset and optional module name of the probe. The following optional columns include the status information of the probe. If the probe is inserted on a virtual address which is not valid anymore, it is marked with [GONE]. If the probe is temporarily disabled, it is marked with [DISABLED].

6.4.2 How to Switch All Kernel Probes On or Off

The /sys/kernel/debug/kprobes/enabled file represents a switch with which you can globally and forcibly turn on or off all the registered kernel probes. To turn them off, simply enter

```
echo "0" > /sys/kernel/debug/kprobes/enabled
```

on the command line as root. To turn them on again, enter

```
echo "1" > /sys/kernel/debug/kprobes/enabled
```

Note that this way you do not change the status of the probes. If a probe is temporarily disabled, it will not be enabled automatically but will remain in the [DISABLED] state after entering the latter command.

6.5 For More Information

To learn more about kernel probes, look at the following sources of information:
• Thorough but more technically oriented information about kernel probes is in /usr/src/linux/Documentation/kprobes.txt (package kernel-source).

• Examples of all three types of probes (together with related Makefile) are in the /usr/src/linux/samples/kprobes/ directory (package kernel-source).

• In-depth information about Linux kernel modules and printk kernel routine is in The Linux Kernel Module Programming Guide [http://tldp.org/LDP/lkmpg/2.6/html/lkmpg.html]

• Practical but slightly outdated information about practical use of kernel probes is in Kernel debugging with Kprobes [http://www.ibm.com/developerworks/library/l-kprobes.html]
Perfmon2 is a standardized, generic interface to access the performance monitoring unit (PMU) of a processor. It is portable across all PMU models and architectures, supports system-wide and per-thread monitoring, counting and sampling.

### 7.1 Conceptual Overview

The following subsections give you a brief overview about Perfmon.

#### 7.1.1 Perfmon2 Structure

Performance monitoring is “the action of collecting information related to how an application or system performs”. The information can be obtained from the code or the CPU/chipset.

Modern processors contain a performance monitoring unit (PMU). The design and functionality of a PMU is CPU specific: for example, the number of registers, counters and features supported will vary by CPU implementation.

The Perfmon interface is designed to be generic, flexible and extensible. It can monitor at the program (thread) or system levels. In either mode, it is possible to count or sample your profile information. This uniformity makes it easier to write portable tools. Figure 7.1, “Architecture of perfmon2” (page 94) gives an overview.
Each PMU model consists of a set of registers: the performance monitor configuration (PMC) and the performance monitor data (PMD). Only PMCs are writeable, but both can be read. These registers store configuration information and data.

### 7.1.2 Sampling and Counting

Perfmon2 supports two modes where you can run your profiling: sampling or counting.

*Sampling* is usually expressed by an interval of time (time-based) or an occurrence of a defined number of events (event-based). Perfmon indirectly supports time-based sampling by using an event-based sample with constant correlation to time (for example, `unhalted_reference_cycles`).

In contrast, *Counting* is expressed in terms of a number of occurrences of an event.

Both methods store their information into a sample. This sample contains information about, for example, where a thread was or instruction pointers.

The following example demonstrates the counting of the `CPU_OP_CYCLES` event and the sampling of this event, generating a sample per 100000 occurrences of the event:

```
pfmon --no-cmd-output -e CPU_OP_CYCLES_ALL /bin/ls
1306604 CPU_OP_CYCLES_ALL
```
The following command gives the count of a specific function and the procentual amount of the total cycles:

```
pfmon --no-cmd-output --short-smpl-periods=100000   -e CPU_OP_CYCLES_ALL /bin/ls
```

```
# results for [28119:28119<-[28102] ] (/bin/ls)
# total samples : 12
# total buffer overflows : 0
#
#   event00
# counts %self   %cum code addr
  1  8.33%  8.33% 0x2000000000007180
  1  8.33% 16.67% 0x20000000000195a0
  1  8.33% 25.00% 0x2000000000019260
  1  8.33% 33.33% 0x2000000000014e60
  1  8.33% 41.67% 0x200000000001f38c0
  1  8.33% 50.00% 0x200000000001ea481
  1  8.33% 58.33% 0x2000000000020b260
  1  8.33% 66.67% 0x20000000000203490
  1  8.33% 75.00% 0x20000000000203360
  1  8.33% 83.33% 0x20000000000203440
  1  8.33% 91.67% 0x4000000000002690
  1  8.33%100.00% 0x200000000001cfdf1
```

## 7.2 Installation

In order to use Perfmon2, first check the following preconditions:

**SUSE Linux Enterprise 11**

Supported architectures are IA64, x86_64. The package `perf` (Performance Counters for Linux) is the supported tool for x86 and PPC64.

**SUSE Linux Enterprise 11 SP1**

Supported architecture is IA64 only.

The `pfmon` on SUSE Linux Enterprise 11 supports the following processors (taken from `/usr/share/doc/packages/pfmon/README`):

**Table 7.1: Supported Processors**

<table>
<thead>
<tr>
<th>Model</th>
<th>Processor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel IA-64</td>
<td>Itanium (Merced), Itanium 2 (McKinley, Madison, Deerfield), Itanium 2</td>
</tr>
<tr>
<td>Model</td>
<td>Processor</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9000/9100 (Montecito, Montvale) and Generic</td>
<td>9000/9100 (Montecito, Montvale) and Generic</td>
</tr>
<tr>
<td>AMD X86</td>
<td>Opteron (K8, fam 10h)</td>
</tr>
<tr>
<td>Intel X86</td>
<td>Intel P6 (Pentium II, Pentium Pro, Pentium III, Pentium M); Yonah (Core Duo, Core Solo); Netburst (Pentium 4, Xeon); Core (Merom, Penryn, Dunnington) Core 2 and Quad; Atom; Nehalem; architectural perfmon v1, v2, v3</td>
</tr>
</tbody>
</table>

Install the following packages depending on your architecture:

Table 7.2: Needed Packages

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>ia64</td>
<td>pfmon</td>
</tr>
</tbody>
</table>

7.3 Using Perfmon

In order to use Perfmon, use the command line tool pfmon to get all your information.

**NOTE: Mutual Exclusion of Perfmon and OProfile Sessions**

On x86 architectures it is not possible to start a Perfmon session and a OProfile session. Only one can be run at the same time.

7.3.1 Getting Event Information

To get a list of supported events, use the option `-l` from pfmon to list them. Keep in mind, this list depends on the host PMU:

```
 pfmon -l
 ALAT_CAPACITY_MISS_ALL
```
ALAT_CAPACITY_MISS_FP
ALAT_CAPACITY_MISS_INT
BACK_END_BUBBLE_ALL
BACK_END_BUBBLE_FE
BACK_END_BUBBLE_L1D_FPU_RSE
...
CPU_CPL_CHANGES_ALL
CPU_CPL_CHANGES_LVL0
CPU_CPL_CHANGES_LVL1
CPU_CPL_CHANGES_LVL2
CPU_CPL_CHANGES_LVL3
CPU_OP_CYCLES_ALL
CPU_OP_CYCLES_QUAL
CPU_OP_CYCLES_HALTED
DATA_DEBUG_REGISTER_FAULT
DATA_DEBUG_REGISTER_MATCHES
DATA_EAR_ALAT
...

Get an explanation of these entries with the option \(-i\) and the event name:

```
pfmon -i CPU_OP_CYCLES_ALL
Name    : CPU_OP_CYCLES_ALL
Code    : 0x12
Counters: [ 4 5 6 7 8 9 10 11 12 13 14 15 ]
Desc    : CPU Operating Cycles -- All CPU cycles counted
Umask   : 0x0
EAR     : None
ETB     : No
MaxIncr : 1 (Threshold 0)
Qual    : None
Type    : Causal
Set     : None
```

### 7.3.2 Enabling System-Wide Sessions

Use the \(--\text{system-wide}\) option to enable monitoring all processes that execute on a specific CPU or sets of CPUs. You do not have to be \texttt{root} to do so; per default, user level is turned on for all events (option \(-u\)).

It is possible that one system-wide session can run concurrently with other system-wide sessions as long as they do not monitor the same set of CPUs. However, you cannot run a system-wide session together with any per-thread session.

The following examples are taken from an Itanium IA64 Montecito processor. To execute a system-wide session, perform the following procedure:

1. Detect your CPU set:
pfmon -v --system-wide
... 
selected CPUs (2 CPU in set, 2 CPUs online): CPU0 CPU1

2 Delimit your session. The following list describes options which are used in the examples below (refer to the man page for more details):

-\texttt{-e/\textbar --events}

Profile only selected events. See Section 7.3.1, “Getting Event Information” (page 96) for how to get a list.

-\texttt{--cpu-list}

Specifies the list of processors to monitor. Without this options, all available processors are monitored.

-\texttt{-t/\textbar --session-timeout}

Specifies the duration of the monitor session expressed in seconds.

Use one of the three methods to start your profile session.

- Use the default events:

\begin{verbatim}
pfmon --cpu-list=0-2 --system-wide -k -e
CPU_OP_CYCLES_ALL,IA64_INST_RETIRED
<press ENTER to stop session>
CPU0                       7670609 CPU_OP_CYCLES_ALL
CPU0                       4380453 IA64_INST_RETIRED
CPU1                       7061159 CPU_OP_CYCLES_ALL
CPU1                       4143020 IA64_INST_RETIRED
CPU2                       7194110 CPU_OP_CYCLES_ALL
CPU2                       4168239 IA64_INST_RETIRED
\end{verbatim}

- Use a timeout expressed in seconds:

\begin{verbatim}
pfmon --cpu-list=0-2 --system-wide --session-timeout=10 -k -e
CPU_OP_CYCLES_ALL,IA64_INST_RETIRED
<session to end in 10 seconds>
CPU0                      69263547 CPU_OP_CYCLES_ALL
CPU0                      38682141 IA64_INST_RETIRED
CPU1                      87189093 CPU_OP_CYCLES_ALL
CPU1                      54684852 IA64_INST_RETIRED
CPU2                      64441287 CPU_OP_CYCLES_ALL
CPU2                      37883915 IA64_INST_RETIRED
\end{verbatim}

- Execute a command. The session is automatically started when the program starts and automatically stopped when the program is finished:
pfmon --cpu-list=0-1 --system-wide -u -e
   CPU_OP_CYCLES_ALL,IA64_INST_RETIRED -- ls -l /dev/null
crw-rw-rw- 1 root root 1, 3 27. Mär 03:30 /dev/null
CPU0                          38925 CPU_OP_CYCLES_ALL
CPU0                          7510 IA64_INST_RETIRED
CPU1                          9825 CPU_OP_CYCLES_ALL
CPU1                          1676 IA64_INST_RETIRED

3 Press the Enter key to stop a session:

4 If you want to aggregate counts, use the -aggr option after the previous command:

```
pfmon --cpu-list=0-1 --system-wide -u -e
   CPU_OP_CYCLES_ALL,IA64_INST_RETIRED --aggr
<press ENTER to stop session>
```

```
52655 CPU_OP_CYCLES_ALL
53164 IA64_INST_RETIRED
```

7.3.3 Monitoring Running Tasks

Perfmon can also monitor an existing thread. This is useful for monitoring system daemons or programs which take a long time to start. First determine the process ID you wish to monitor:

```
ps ax | grep foo
10027 pts/1    R     2:23  foo
```

Use the found PID for the --attach-task option of pfmon:

```
pfmon --attach-task=10027
3682190 CPU_OP_CYCLES_ALL
```

7.4 Retrieving Metrics From DebugFS

Perfmon can collect statistics which are exported through the debug interface. The metrics consists of mostly aggregated counts and durations.

Access the data through mounting the debug file system as root under /sys/kernel/debug

```
The data is located under /sys/kernel/debug/perfmon/ and organized per CPU. Each CPU contains a set of metrics, accessible as ASCII file. The fol-
Following data is taken from the `/usr/src/linux/Documentation/perfmon2-debugfs.txt`:

**Table 7.3:** Read-Only Files in `/sys/kernel/debug/perfmon/cpu*/`

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ctxswin_count</td>
<td>Number of PMU context switch in</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>ctxswin_ns</td>
<td>Number of nanoseconds spent in the PMU context switch in routine</td>
</tr>
<tr>
<td></td>
<td>Average cost of the PMU context switch in =</td>
</tr>
<tr>
<td></td>
<td>ctxswin_ns / ctxswin_count</td>
</tr>
<tr>
<td>ctxswout_count</td>
<td>Number of PMU context switch out</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>ctxswout_ns</td>
<td>Number of nanoseconds spend in the PMU context switch out routine</td>
</tr>
<tr>
<td></td>
<td>Average cost of the PMU context switch out =</td>
</tr>
<tr>
<td></td>
<td>ctxswout_ns / ctxswout_count</td>
</tr>
<tr>
<td>fmt_handler_calls</td>
<td>Number of calls to the sampling format routine that handles PMU interrupts (typically the routine that records a sample)</td>
</tr>
<tr>
<td>fmt_handler_ns</td>
<td>Number of nanoseconds spent in the routine that handle PMU interrupt in the sampling format</td>
</tr>
<tr>
<td></td>
<td>Average time spent in this routine =</td>
</tr>
<tr>
<td></td>
<td>fmt_handler_ns / fmt_handler_calls</td>
</tr>
<tr>
<td>handle_timeout_count</td>
<td>Number of times the pfm_handle_timeout() routine is called (used for timeout-based set switching)</td>
</tr>
<tr>
<td>File</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>handle_work_count</td>
<td>Number of times \texttt{pfm_handle_work()} routine is called</td>
</tr>
<tr>
<td>ovl_intr_all_count</td>
<td>Number of PMU interrupts received by the kernel</td>
</tr>
<tr>
<td>ovl_intr_nmi_count</td>
<td>Number of non maskeable interrupts (NMI) received by the kernel from perfmon (only for X86 hardware)</td>
</tr>
<tr>
<td>ovl_intr_ns</td>
<td>Number of nanoseconds spent in the perfmon2 PMU interrupt handler.</td>
</tr>
<tr>
<td></td>
<td>Average time to handle one PMU interrupt = \frac{\text{ovfl_intr_ns}}{\text{ovfl_intr_all_count}}</td>
</tr>
<tr>
<td>ovl_intr_regular_count</td>
<td>Number of PMU interrupts which are actually processed by the perfmon interrupt handler</td>
</tr>
<tr>
<td>ovl_intr_replay_count</td>
<td>Number of PMU interrupts which were replayed on the context switch in or on event set switching</td>
</tr>
<tr>
<td>perfom_intr_spurious_count, ovl_intr_spurious_count</td>
<td>Number of PMU interrupts which were dropped because there was no active context</td>
</tr>
<tr>
<td>pfm_restart_count</td>
<td>Number of times \texttt{pfm_restart()} is called</td>
</tr>
<tr>
<td>reset_pmds_count</td>
<td>Number of times \texttt{pfm_reset_pmds()} is called</td>
</tr>
<tr>
<td>File</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>set_switch_count</td>
<td>Number of event set switches</td>
</tr>
<tr>
<td>set_switch_ns</td>
<td>Number of nanoseconds spent in the set switching routine</td>
</tr>
<tr>
<td></td>
<td>Average cost of switching sets = set_switch_ns / set_switch_count</td>
</tr>
</tbody>
</table>

This might be useful to compare your metrics before and after the perfmon run. For example, collect your data first:

```bash
cat /sys/kernel/debug/perfmon/cpu0/*; do
echo "$i:"; cat $i
done >> pfmon-before.txt
```

Run your performance monitoring, maybe restrict it to a specific CPU:

```
pfmon --cpu-list=0 ...
```

Collect your data again:

```bash
cat /sys/kernel/debug/perfmon/cpu0/*; do
echo "$i:"; cat $i
done >> pfmon-after.txt
```

Compare these two files:

```
diff -u pfmon-before.txt pfmon-after.txt
```

### 7.5 For More Information

This chapter only provides a short overview. Refer to the following links for more information:

  The project home page.

  A good overview as PDF.

Chapter 8, *OProfile—System-Wide Profiler* (page 103)  
Consult this chapter for other performance optimizations.
OPROfile—System-Wide Profiler

OPROfile is a profiler for dynamic program analysis. It investigates the behaviour of a running program and gathers information. This information can be viewed and gives hints for further optimizations.

It is not necessary to recompile or use wrapper libraries in order to use OProfile. Not even a Kernel patch is needed. Usually, when you profile an application, a small overhead is expected, depending on work load and sampling frequency.

8.1 Conceptual Overview

OPROfile consists of a Kernel driver and a daemon for collecting data. It makes use of the hardware performance counters provided on Intel, AMD, and other processors. OProfile is capable of profiling all code including the Kernel, Kernel modules, Kernel interrupt handlers, system shared libraries, and other applications.

Modern processors support profiling through the hardware by performance counters. Depending on the processor, there can be many counters and each of these can be programmed with an event to count. Each counter has a value which determines how often a sample is taken. The lower the value, the more often it is used.

During the post-processing step, all information is collected and instruction addresses are mapped to a function name.
8.2 Installation and Requirements

In order to make use of OProfile, install the `oprofile` package. OProfile works on IA-64, AMD64, s390, and PPC64 processors.

It is useful to install the `*-debuginfo` package for the respective application you want to profile. If you want to profile the Kernel, you need the `debuginfo` package as well.

8.3 Available OProfile Utilities

OProfile contains several utilities to handle the profiling process and its profiled data. The following list is a short summary of programs used in this chapter:

- **opannotate**
  
  Outputs annotated source or assembly listings mixed with profile information.

- **opcontrol**
  
  Controls the profiling sessions (start or stop), dumps profile data, and sets up parameters.

- **ophelp**
  
  Lists available events with short descriptions.

- **opimport**
  
  Converts sample database files from a foreign binary format to the native format.

- **opreport**
  
  Generates reports from profiled data.

8.4 Using OProfile

It is possible with OProfile to profile both Kernel and applications. When profiling the Kernel, tell OProfile where to find the `vmlinuz*` file. Use the `--vmlinux` option and point it to `vmlinuz*` (usually in `/boot`). If you need to profile Kernel modules, OProfile does this by default. However, make sure you read [http://oprofile.sourceforge.net/doc/kernel-profiling.html](http://oprofile.sourceforge.net/doc/kernel-profiling.html).
Applications usually do not need to profile the Kernel, so better use the `--no-vmlinux` option to reduce the amount of information.

### 8.4.1 General Steps

In its simplest form, start the daemon, collect data, stop the daemon, and create your report. This method is described in detail in the following procedure:

1. Open a shell and log in as `root`.

2. Decide if you want to profile with or without the Linux Kernel:
   - **2a Profile With the Linux Kernel** Execute the following commands, because the `opcontrol` command needs an uncompressed image:
     ```bash
     cp /boot/vmlinux-`uname -r`.gz /tmp
     gunzip /tmp/vmlinux*.
     opcontrol --vmlinux=/tmp/vmlinux*
     ```
   - **2b Profile Without the Linux Kernel** Use the following command:
     ```bash
     opcontrol --no-vmlinux
     ```
     If you want to see which functions call other functions in the output, use additionally the `--callgraph` option and set a maximum `DEPTH`:
     ```bash
     opcontrol --no-vmlinux --callgraph DEPTH
     ```

3. Start the OProfile daemon:
   ```bash
   opcontrol --start
   Using 2.6+ OProfile kernel interface.
   Using log file /var/lib/oprofile/samples/oprofiled.log
   Daemon started.
   Profiler running.
   ```

4. Start your application you want to profile right after the previous step.

5. Stop the OProfile daemon:
   ```bash
   opcontrol --stop
   ```

6. Dump the collected data to `/var/lib/oprofile/samples`:
   ```bash
   opcontrol --dump
   ```

7. Create a report:
opreport
Overflow stats not available
CPU: CPU with timer interrupt, speed 0 MHz (estimated)
Profiling through timer interrupt
     TIMER:0|
     samples   %|  
------------------
     84877 98.3226 no-vmlinux
...

8 Shutdown the OProfile daemon:

    opcontrol --shutdown

8.4.2 Getting Event Configurations

The general procedure for event configuration is as follows:

1 Use first the events CPU-CLK_UNHALTED and INST_RETIRED to find optimization opportunities.

2 Use specific events to find bottlenecks. To list them, use the command opcontrol --list-events.

If you need to profile certain events, first check the available events supported by your processor with the ophelp command (example output generated from Intel Core i5 CPU):

    ophelp
ophelp: available events for CPU type "Intel Architectural Perfmon"

See Intel 64 and IA-32 Architectures Software Developer's Manual Volume 3B (Document 253669) Chapter 18 for architectural perfmon events
This is a limited set of fallback events because oprofile doesn't know your CPU
CPU_CLK_UNHALTED: (counter: all))
     Clock cycles when not halted (min count: 6000)
INST_RETIRED: (counter: all))
     number of instructions retired (min count: 6000)
LLC_MISSES: (counter: all))
     Last level cache demand requests from this core that missed the LLC
     (min count: 6000)
     Unit masks (default 0x41)
     _________
     0x41: No unit mask
LLC_REFS: (counter: all))
     Last level cache demand requests from this core (min count: 6000)
Unit masks (default 0x4f)

----------
0x4f: No unit mask
BR_MISS_PRED_RETIREd: (counter: all))
number of mispredicted branches retired (precise) (min count: 500)

You can get the same output from opcontrol --list-events.

Specify the performance counter events with the option --event. Multiple options are possible. This option needs an event name (from ophelp) and a sample rate, for example:

```
opcontrol --event=CPU_CLK_UNHALTED:100000
```

**WARNING: Be Careful with Low Sampling Rates with CPU_CLK_UNHALTED**

Setting sampling rates is dangerous as small rates cause the system to overload and freeze.

### 8.5 Using OProfile's GUI

The GUI for OProfile can be started as root with oprof_start, see Figure 8.1, “GUI for OProfile” (page 107). Select your events and change the counter, if necessary. Every green line is added to the list of checked events. Hover the mouse over the line to see a help text in the status line below. Use the Configuration tab to set the buffer and CPU size, the verbose option and others. Click on Start to execute OProfile.

**Figure 8.1: GUI for OProfile**
8.6 Generating Reports

Before generating a report, make sure OPProfile has dumped your data to the `/var/lib/oprofile/samples` directory using the command `opcontrol --dump`. A report can be generated with the commands `opreport` or `opannotate`.

Calling `opreport` without any options gives a complete summary. With an executable as an argument, retrieve profile data only from this executable. If you analyze applications written in C++, use the `--demangle` smart option.

The `opannotate` generates output with annotations from source code. Run it with the following options:

```
opannotate --source \n  --base-dirs=BASEDIR \n  --search-dirs= \n  --output-dir=annotated/ \n  /lib/libfoo.so
```

The option `--base-dir` contains a comma separated list of paths which is stripped from debug source files. This paths were searched prior than looking in `--search-dirs`. The `--search-dirs` option is also a comma separated list of directories to search for source files.

---

**NOTE: Inaccuracies in Annotated Source**

Due to compiler optimization, code can disappear and appear in a different place. Use the information in `http://oprofile.sourceforge.net/doc/debug-info.html` to fully understand its implications.

---

8.7 For More Information

This chapter only provides a short overview. Refer to the following links for more information:

`http://oprofile.sourceforge.net`  
The project home page.

**Manpages**  
Details descriptions about the options of the different tools.
Contains the OProfile manual.

http://developer.intel.com/
Architecture reference for Intel processors.

http://www.amd.com/us-en/assets/content_type/white_papers_and_tech_docs/22007.pdf
Architecture reference for AMD Athlon/Opteron/Phenom/Turion.

Architecture reference for PowerPC64 processors in IBM iSeries, pSeries, and blade server systems.
Part IV. Resource Management
General System Resource Management

Tuning the system is not only about optimizing the kernel or getting the most out of your application, it begins with setting up a lean and fast system. The way you set up your partitions and file systems can influence the server's speed. The number of active services and the way routine tasks are scheduled also affects performance.

9.1 Planning the Installation

A carefully planned installation ensures that the system is basically set up exactly as you need it for the given purpose. It also saves considerable time when fine tuning the system. All changes suggested in this section can be made in the Installation Settings step during the installation. See Section “Installation Settings” (Chapter 6, Installation with YaST, Deployment Guide) for details.

9.1.1 Partitioning

Depending on the server's range of applications and the hardware layout, the partitioning scheme can influence the machine's performance (although to a lesser extend only). It is beyond the scope of this manual to suggest different partition schemes for particular workloads, however, the following rules will positively affect performance. Of course they do not apply when using an external storage system.

- Make sure there always is some free space available on the disk, since a full disk has got inferior performance
- Disperse simultaneous read and write access onto different disks by, for example:
• using separate disks for the operating system, the data, and the log files
• placing a mail server's spool directory on a separate disk
• distributing the user directories of a home server between different disks

9.1.2 Installation Scope

Actually, the installation scope has no direct influence on the machine's performance, but a carefully chosen scope of packages nevertheless has got advantages. It is recommended to install the minimum of packages needed to run the server. A system with a minimum set of packages is easier to maintain and has got less potential security issues. Furthermore, a tailor made installation scope also ensures no unnecessary services are started by default.

SUSE Linux Enterprise Server lets you customize the installation scope on the Installation Summary screen. By default, you can select or remove pre-configured patterns for specific tasks, but it is also possible to start the YaST Software Manager for a fine-grained package based selection.

One or more of the following default patterns may not be needed in all cases:

**GNOME Desktop Environment**
A server seldomly needs a full-blown desktop environment. In case a graphical environment is needed, a more economical solution such as as icewm or fvwm may also be sufficient.

**X Window System**
When solely administrating the server and its applications via command line, consider to not install this pattern. However, keep in mind that it is needed to run GUI applications from a remote machine. If your application is managed by a GUI or if you prefer the GUI version of YaST, keep this pattern.

**Print Server**
This pattern is only needed when you want to print from the machine.

9.1.3 Default Runlevel

A running X Window system eats up many resources and is seldomly needed on a server. It is strongly recommended to start the system in runlevel 3 (Full multiuser with net-
work, no X). You will still be able to start graphical applications from remote or use the `startx` command to start a local graphical desktop.

## 9.2 Disabling Unnecessary Services

The default installation starts a number of services (the number varies with the installation scope). Since each service consumes resources, it is recommended to disable the ones not needed. Run `YaST > System > System Services (Runlevel) > Expert Mode` to start the services management module. When using the graphical version of YaST you can click on the column headlines to sort the service list. Use this to get an overview of which services are currently running or which services are started in the server's default runlevel. Click a service to see its description. Use the `Start/Stop/Refresh` drop-down menu to disable the service for the running session. To permanently disable it, use the `Set/Reset` drop-down menu.

The following list shows services that are started by default after the installation of SUSE Linux Enterprise Server. Check which of the components you need, and disable the others:

**alsasound**

Loads the Advanced Linux Sound System.

**auditd**

A daemon for the audit system (see Part “The Linux Audit Framework” (↑Security Guide) for details). Disable if you do not use Audit.

**bluez-coldplug**

Handles cold plugging of Bluetooth dongles.

**cups**

A printer daemon.

**java.binfmt_misc**

Enables the execution of `*.class` or `*.jar` Java programs.

**nfs**

Services needed to mount NFS file systems.
9.3 File Systems and Disk Access

Hard disks are the slowest components in a computer system and therefore often the cause for a bottleneck. Using the file system that best suits your workload helps to improve performance. Using special mount options or prioritizing a process' I/O priority are further means to speed up the system.

9.3.1 File Systems

SUSE Linux Enterprise Server ships with a number of different file systems, including Btrfs, Ext3, Ext2, ReiserFS, and XFS. Each file system has its own advantages and disadvantages. Please refer to Chapter 1, Overview of File Systems in Linux (↑Storage Administration Guide) for detailed information.

9.3.1.1 NFS

NFS (Version 3) tuning is covered in detail in the NFS Howto at http://nfs.sourceforge.net/nfs-howto/. The first thing to experiment with when mounting NFS shares is increasing the read write blocksize to 32768 by using the mount options `wsize` and `rsize`.

9.3.2 Disabling Access Time (atime) Updates

Whenever a file is read on a Linux file system, its access time (atime) is updated. As a result, each read-only file access in fact causes a write operation. On a journaling file system two write operations are triggered since the journal will be updated, too. It is recommended to turn this feature off when you do not need to keep track of access times. This is possibly true for file and Web servers as well as for a network storage.
To turn off access time updates, mount the file system with the `noatime` option. To do so, either edit `/etc/fstab` directly, or use the `Fstab Options` dialog when editing or adding a partition with the YaST Partitioner.

### 9.3.3 Prioritizing Disk Access with ionice

The `ionice` command lets you prioritize disk access for single processes. This enables you to give less I/O priority to non time-critical background processes with heavy disk access, such as backup jobs. On the other hand `ionice` lets you raise I/O priority for a specific process to make sure this process has always immediate access to the disk. You may set the following three scheduling classes:

**Idle**

A process from the idle scheduling class is only granted disk access when no other process has asked for disk I/O.

**Best effort**

The default scheduling class used for any process that has not asked for a specific I/O priority. Priority within this class can be adjusted to a level from 0 to 7 (with 0 being the highest priority). Programs running at the same best-effort priority are served in a round-robin fashion. Some kernel versions treat priority within the best-effort class differently—for details, refer to the `ionice(1)` man page.

**Real-time**

Processes in this class are always granted disk access first. Fine-tune the priority level from 0 to 7 (with 0 being the highest priority). Use with care, since it can starve other processes.

For more details and the exact command syntax refer to the `ionice(1)` man page.
Kernel Control Groups

Kernel Control Groups (abbreviated known as “cgroups”) are a kernel feature that allows aggregating or partitioning tasks (processes) and all their children into hierarchical organized groups. These hierarchical groups can be configured to show a specialized behavior that helps with tuning the system to make best use of available hardware and network resources.

10.1 Technical Overview and Definitions

The following terms are used in this chapter:

• “cgroup” is another name for Control Groups.

• In a cgroup there is a set of tasks (processes) associated with a set of subsystems that act as parameters constituting an environment for the tasks.

• Subsystems provide the parameters that can be assigned and define CPU sets, freezer, or—more general—“resource controllers” for memory, disk I/O, network traffic, etc.

• cgroups are organized in a tree-structured hierarchy. There can be more than one hierarchy in the system. You use a different or alternate hierarchy to cope with specific situations.
• Every task running in the system is in exactly one of the cgroups in the hierarchy.

10.2 Scenario

See the following resource planning scenario for a better understanding (source: /usr/src/linux/Documentation/cgroups/cgroups.txt):
Figure 10.1: Resource Planning

CPU Set 1 (60%)
  Professors

CPU Set 2 (20%)
  Students

Top CPU Set (20%)

Memory
Professors (50%)
Students (30%)
System (20%)

Disk I/O
Professors (50%)
Students (30%)
System (20%)

Network I/O
WWW Browsing (20%)

Professors (15%)
Students (5%)

Network File Systems (60%)
Others (20%)
Web browsers such as Firefox will be part of the Web network class, while the NFS daemons such as (k)nfsd will be part of the NFS network class. On the other side, Firefox will share appropriate CPU and memory classes depending on whether a professor or student started it.

## 10.3 Control Group Subsystems

The following subsystems are available and can be classified as two types:

**Isolation and Special Controllers**
- cpuset, freezer, devices, checkpoint/restart

**Resource Controllers**
- cpu (scheduler), cpuacct, memory, disk I/O, network

Either mount each subsystem separately:

```bash
mount -t cgroup -o cpu none /cpu
mount -t cgroup -o cpuset none /cpuset
```

or all subsystems in one go; you can use an arbitrary device name (e.g., `none`), which will appear in `/proc/mounts`:

```bash
mount -t cgroup none /sys/fs/cgroup
```

Some additional information on available subsystems:

**Cpuset (Isolation)**

Use cpuset to tie processes to system subsets of CPUs and memory ("memory nodes"). For an example, see Section 10.4.3, "Example: Cpusets" (page 126).

**Freezer (Control)**

The Freezer subsystem is useful for high-performance computing clusters (HPC clusters). Use it to freeze (stop) all tasks in a group or to stop tasks, if they reach a defined checkpoint. For more information, see `/usr/src/linux/Documentation/cgroups/freezer-subsystem.txt`.

Here are basic commands to use the freezer subsystem:

```bash
mount -t cgroup -o freezer freezer /freezer
```
# Create a child cgroup:
mkdir /freezer/0
# Put a task into this cgroup:
echo $task_pid > /freezer/0/tasks
# Freeze it:
echo FROZEN > /freezer/0/freezer.state
# Unfreeze (thaw) it:
echo THAWED > /freezer/0/freezer.state

Checkpoint/Restart (Control)
Save the state of all processes in a cgroup to a dump file. Restart it later (or just save the state and continue).

Move a “saved container” between physical machines (as VM can do).

Dump all process images of a cgroup to a file.

Devices (Isolation)
A system administrator can provide a list of devices that can be accessed by processes under cgroups.

It limits access to a device or a file system on a device to only tasks that belong to the specified cgroup. For more information, see /usr/src/linux/Documentation/cgroups/devices.txt.

Cpuacct (Control)
The CPU accounting controller groups tasks using cgroups and accounts the CPU usage of these groups. For more information, see /usr/src/linux/Documentation/cgroups/cpuacct.txt.

CPU (Resource Control)
Share CPU bandwidth between groups with the group scheduling function of CFS (the scheduler). Mechanically complicated.

Memory (Resource Control)

- Limits memory usage of user space processes.

- Control swap usage by setting swapaccount=1 as a kernel boot parameter.

- Limit LRU (Least Recently Used) pages.
• Anonymous and file cache.
• No limits for kernel memory.
• Maybe in another subsystem if needed.

For more information, see /usr/src/linux/Documentation/cgroups/memory.txt.

Blkio (Resource Control)
The blkio (Block IO) controller is now available as a disk I/O controller. With the blkio controller you can currently set policies for proportional bandwidth and for throttling.

These are the basic commands to configure proportional weight division of bandwidth by setting weight values in blkio.weight:

```
# Setup in /sys/fs/cgroup
mkdir /sys/fs/cgroup/blkio
mount -t cgroup -o blkio none /sys/fs/cgroup/blkio
# Start two cgroups
mkdir -p /sys/fs/cgroup/blkio/group1 /sys/fs/cgroup/blkio/group2
# Set weights
echo 1000 > /sys/fs/cgroup/blkio/group1/blkio.weight
echo 500 > /sys/fs/cgroup/blkio/group2/blkio.weight
# Write the PIDs of the processes to be controlled to the appropriate groups
command1 &
echo $! > /sys/fs/cgroup/blkio/group1/tasks

cmd2 &
echo $! > /sys/fs/cgroup/blkio/group2/tasks
```

These are the basic commands to configure throttling or upper limit policy by setting values in blkio.throttle.read_bps_device for reads and blkio.throttle.write_bps_device for writes:

```
# Setup in /sys/fs/cgroup
mkdir /sys/fs/cgroup/blkio
mount -t cgroup -o blkio none /sys/fs/cgroup/blkio
# Bandwidth rate of a device for the root group; format:
# <major>:<minor> <byes_per_second>
echo "8:16 1048576" > /sys/fs/cgroup/blkio/
blkio.throttle.read_bps_device
blkio.throttle.write_bps_device
```

For more information about caveats, usage scenarios, and additional parameters, see /usr/src/linux/Documentation/cgroups/blkio-controller.txt.
Network Traffic (Resource Control)

With cgroup_tc, a network traffic controller is available. It can be used to manage traffic that is associated with the tasks in a cgroup. Additionally, cls_flow can classify packets based on the tc_classid field in the packet.

For example, to limit the traffic from all tasks from a file_server cgroup to 100 Mbps, proceed as follows:

```bash
# create a file_transfer cgroup and assign it a unique classid of 0x10 - this will be used later to direct packets.
mkdir -p /dev/cgroup
mount -t cgroup tc -otc /dev/cgroup
mkdir /dev/cgroup/file_transfer
echo 0x10 > /dev/cgroup/file_transfer/tc.classid
echo $PID_OF_FILE_XFER_PROCESS > /dev/cgroup/file_transfer/tasks

# Now create an HTB class that rate-limits traffic to 100 mbits and attach a filter to direct all traffic from the file_transfer cgroup to this new class.
tc qdisc add dev eth0 root handle 1: htb
tc class add dev eth0 parent 1: classid 1:10 htb rate 100mbit ceil 100mbit
tc filter add dev eth0 parent 1: handle 800 protocol ip prio 1 \    flow map key cgroup-classid baseclass 1:10
```

This example is taken from https://lwn.net/Articles/291161/, where you can find more information about this feature.

10.4 Using Controller Groups

10.4.1 Prerequisites

To conveniently use cgroups, install the following additional packages:

- libcgroup1 — basic user space tools to simplify resource management
- cpuset — contains the cset to manipulate cpusets
- libcpuset1 — C API to cpusets
- kernel-source — only needed for documentation purposes
- lxc — Linux container implementation
The kernel shipped with SUSE Linux Enterprise Server supports cgroups. There is no need to apply additional patches. Execute `lxc-checkconfig` to see a cgroups environment similar to the following output:

```
--- Namespaces ---
Namespaces: enabled
Utsname namespace: enabled
Ipc namespace: enabled
Pid namespace: enabled
User namespace: enabled
Network namespace: enabled
Multiple /dev/pts instances: enabled

--- Control groups ---
Cgroup: enabled
Cgroup namespace: enabled
Cgroup device: enabled
Cgroup sched: enabled
Cgroup cpu account: enabled
Cgroup memory controller: enabled
Cgroup cpuset: enabled

--- Misc ---
Veth pair device: enabled
Macvlan: enabled
Vlan: enabled
File capabilities: enabled
```

To find out which subsystems are available, proceed as follows:

```
mkdir /cgroups
mount -t cgroup none /cgroups
grep cgroup /proc/mounts
```

The following subsystems are available: perf_event, blkio, net_cls, freezer, devices, memory, cpuacct, cpu, cpuset.

### 10.4.3 Example: Cpusets

With the command line proceed as follows:

1. To determine the number of CPUs and memory nodes see `/proc/cpuinfo` and `/proc/zoneinfo`.

2. Create the cpuset hierarchy as a virtual file system (source: `/usr/src/linux/Documentation/cgroups/cpusets.txt`):
mount -t cgroup -ocpuset cpuset /sys/fs/cgroup/cpuset
cd /sys/fs/cgroup/cpuset
mkdir Charlie
mkdir Charlie
# List of CPUs in this cpuset:
echo 2-3 > cpuset.cpus
# List of memory nodes in this cpuset:
echo 1 > cpuset.mems
echo $$ > tasks
# The subshell 'sh' is now running in cpuset Charlie
# The next line should display '/Charlie'
cat /proc/self/cpuset

3 Remove the cpuset using shell commands:

rmdir /sys/fs/cgroup/cpuset/Charlie

This fails as long as this cpuset is in use. First, you must remove the inside cpusets or tasks (processes) that belong to it. Check it with:

cat /sys/fs/cgroup/cpuset/Charlie/tasks

For background information and additional configuration flags, see /usr/src/linux/Documentation/cgroups/cpusets.txt.

With the cset tool, proceed as follows:

# Determine the number of CPUs and memory nodes
cset set --list
# Creating the cpuset hierarchy
cset set --cpu=2-3 --mem=1 --set=Charlie
# Starting processes in a cpuset
cset proc --set Charlie --exec -- stress -c 1 &
# Moving existing processes to a cpuset
cset proc --move --pid PID --toset=Charlie
# List task in a cpuset
cset proc --list --set Charlie
# Removing a cpuset
cset set --destroy Charlie

10.4.4 Example: cgroups

Using shell commands, proceed as follows:

1 Create the cgroups hierarchy:

    mount -t cgroup cgroup /sys/fs/cgroup
cd /sys/fs/cgroup/cpuset/cgroup
mkdir priority
cd priority
cat cpu.shares

2 Understanding cpu.shares:

- 1024 is the default (for more information, see /Documentation/sched
uler/sched-design-CFS.txt) = 50% utilization
- 1524 = 60% utilization
- 2048 = 67% utilization
- 512 = 40% utilization

3 Changing cpu.shares

echo 1024 > cpu.shares

10.5 For More Information

- Kernel documentation (package kernel-source): files in /usr/src/lin
ux/Documentation/cgroups:
  - /usr/src/linux/Documentation/cgroups/blkio-
controller.txt
  - /usr/src/linux/Documentation/cgroups/cgroups.txt
  - /usr/src/linux/Documentation/cgroups/cpusets.txt
  - /usr/src/linux/Documentation/cgroups/devices.txt
  - /usr/src/linux/Documentation/cgroups/freezer-subsystem.txt
  - /usr/src/linux/Documentation/cgroups/memcg_test.txt
  - /usr/src/linux/Documentation/cgroups/memory.txt
• /usr/src/linux/Documentation/cgroups/resource_counter.txt

• For Linux Containers (LXC) based on cgroups, see *Virtualization with Linux Containers (LXC)* (↑*Virtualization with Linux Containers (LXC)*).


Power Management

Power management aims at reducing operating costs for energy and cooling systems while at the same time keeping the performance of a system at a level that matches the current requirements. Thus, power management is always a matter of balancing the actual performance needs and power saving options for a system. Power management can be implemented and used at different levels of the system. A set of specifications for power management functions of devices and the operating system interface to them has been defined in the Advanced Configuration and Power Interface (ACPI). As power savings in server environments can primarily be achieved on processor level, this chapter introduces some of the main concepts and highlights some tools for analyzing and influencing relevant parameters.

11.1 Power Management at CPU Level

At CPU level, you can control power usage in various ways: for example, by using idling power states (C-states), changing CPU frequency (P-states), and throttling the CPU (T-states). The following sections give a short introduction to each approach and its significance for power savings. Detailed specifications can be found at http://www.acpi.info/spec.htm.
11.1.1 C-States (Processor Operating States)

Modern processors have several power saving modes called \textit{C-states}. They reflect the capability of an idle processor to turn off unused components in order to save power. Whereas C-states have been available for laptops for some time, they are a rather recent trend in the server market (for example, with Intel\textsuperscript{*} processors, C-modes are only available since Nehalem).

When a processor runs in the \texttt{C0} state, it is executing instructions. A processor running in any other C-state is idle. The higher the C number, the deeper the CPU sleep mode: more components are shut down to save power. Deeper sleep states are very efficient concerning power consumption in an idle system. But the downside is that they introduce higher latency (the time the CPU needs to go back to \texttt{C0}). Depending on the workload (threads waking up, triggering some CPU utilization and then going back to sleep again for a short period of time) or hardware (for example, interrupt activity of a network device), disabling the deepest sleep states can significantly increase overall performance. For details on how to do so, refer to Section 11.3.2.2, “Viewing and Modifying Kernel Idle Statistics with \texttt{cpupower}” (page 141).

Some states also have submodes with different power saving latency levels. Which C-states and submodes are supported depends on the respective processor. However, \texttt{C1} is always available.

Table 11.1, “C-States” (page 132) gives an overview of the most common C-states.

\begin{table}[h]
\centering
\begin{tabular}{|l|p{8cm}|}
\hline
\textbf{Mode} & \textbf{Definition} \\
\hline
\texttt{C0} & Operational state. CPU fully turned on. \\
\hline
\texttt{C1} & First idle state. Stops CPU main internal clocks via software. Bus interface unit and APIC are kept running at full speed. \\
\hline
\texttt{C2} & Stops CPU main internal clocks via hardware. State where the proces-
\end{tabular}
\end{table}
<table>
<thead>
<tr>
<th>Mode</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>Stops all CPU internal clocks. The processor does not need to keep its cache coherent, but maintains other states. Some processors have variations of the C3 state that differ in how long it takes to wake the processor through interrupts.</td>
</tr>
</tbody>
</table>

To avoid needless power consumption, it is recommended to test your workloads with deep sleep states enabled versus deep sleep states disabled. A recent maintenance update for SUSE Linux Enterprise Server 11 SP3 provides an updated `cpupower` package with an additional `cpupower` subcommand. Use it to disable or enable individual C-states, if necessary. For more information, refer to Section 11.3.2.2, “Viewing and Modifying Kernel Idle Statistics with `cpupower`” (page 141) or the `cpupower-idle-set(1)` man page.

### 11.1.2 P-States (Processor Performance States)

While a processor operates (in C0 state), it can be in one of several CPU performance states (P-states). Whereas C-states are idle states (all but C0), P-states are operational states that relate to CPU frequency and voltage.

The higher the P-state, the lower the frequency and voltage at which the processor runs. The number of P-states is processor-specific and the implementation differs across the various types. However, P0 is always the highest-performance state. Higher P-state numbers represent slower processor speeds and lower power consumption. For example, a processor in P3 state runs more slowly and uses less power than a processor running at P1 state. To operate at any P-state, the processor must be in the C0 state where the processor is working and not idling. The CPU P-states are also defined in the Advanced Configuration and Power Interface (ACPI) specification, see [http://www.acpi.info/spec.htm](http://www.acpi.info/spec.htm).
C-states and P-states can vary independently of one another.

### 11.1.3 T-States (Processor Throttling States)

T-states refer to throttling the processor clock to lower frequencies in order to reduce thermal effects. This means that the CPU is forced to be idle a fixed percentage of its cycles per second. Throttling states range from $T_1$ (the CPU has no forced idle cycles) to $T_n$, with the percentage of idle cycles increasing the greater $n$ is.

Note that throttling does not reduce voltage and since the CPU is forced to idle part of the time, processes will take longer to finish and will consume more power instead of saving any power.

T-states are only useful if reducing thermal effects is the primary goal. Since T-states can interfere with C-states (preventing the CPU from reaching higher C-states), they can even increase power consumption in a modern CPU capable of C-states.

### 11.1.4 Turbo Features

Since quite some time, CPU power consumption and performance tuning is not only about frequency scaling anymore. In modern processors, a combination of different means is used to achieve the optimum balance between performance and power savings: deep sleep states, traditional dynamic frequency scaling and hidden boost frequencies. The turbo features (Turbo CORE* or Turbo Boost*) of the latest AMD* or Intel* processors allow to dynamically increase (boost) the clock speed of active CPU cores while other cores are in deep sleep states. This increases the performance of active threads while still complying to Thermal Design Power (TDP) limits.

However, the conditions under which a CPU core may use turbo frequencies are very architecture-specific. Learn how to evaluate the efficiency of those new features in Section 11.3.2, “Using the cpupower Tools” (page 139).
11.2 The Linux Kernel CPUfreq Infrastructure

Processor performance states (P-states) and processor operating states (C-states) are the capability of a processor to switch between different supported operating frequencies and voltages to modulate power consumption.

In order to dynamically scale processor frequencies at runtime, you can use the CPUfreq infrastructure to set a static or dynamic power policy for the system. Its main components are the CPUfreq subsystem (providing a common interface to the various low-level technologies and high-level policies), the in-kernel governors (policy governors that can change the CPU frequency based on different criteria) and CPU-specific drivers that implement the technology for the specific processor.

The dynamic scaling of the clock speed helps to consume less power and generate less heat when not operating at full capacity.

11.2.1 In-Kernel Governors

You can think of the in-kernel governors as a sort of pre-configured power schemes for the CPU. The CPUfreq governors use P-states to change frequencies and lower power consumption. The dynamic governors can switch between CPU frequencies, based on CPU utilization to allow for power savings while not sacrificing performance. These governors also allow for some tuning so you can customize and change the frequency scaling behavior.

The following governors are available with the CPUfreq subsystem:

Performance Governor

The CPU frequency is statically set to the highest possible for maximum performance. Consequently, saving power is not the focus of this governor.

Tuning options: The range of maximum frequencies available to the governor can be adjusted (for example, with the `cpupower` command line tool).

Powersave Governor

The CPU frequency is statically set to the lowest possible. This can have severe impact on the performance, as the system will never rise above this frequency no matter how busy the processors are.
However, using this governor often does not lead to the expected power savings as the highest savings can usually be achieved at idle through entering C-states. Due to running processes at the lowest frequency with the powersave governor, processes will take longer to finish, thus prolonging the time for the system to enter any idle C-states.

Tuning options: The range of minimum frequencies available to the governor can be adjusted (for example, with the `cpupower` command line tool).

On-demand Governor

The kernel implementation of a dynamic CPU frequency policy: The governor monitors the processor utilization. As soon as it exceeds a certain threshold, the governor will set the frequency to the highest available. If the utilization is less than the threshold, the next lowest frequency is used. If the system continues to be underemployed, the frequency is again reduced until the lowest available frequency is set.

For SUSE Linux Enterprise, the on-demand governor is the default governor and the one that has the best test coverage.

Tuning options: The range of available frequencies, the rate at which the governor checks utilization, and the utilization threshold can be adjusted. Another parameter you might want to change for the on-demand governor is `ignore_nice_load`. For details, refer to Procedure 11.1, “Ignoring Nice Values in Processor Utilization” (page 145).

Conservative Governor

Similar to the on-demand implementation, this governor also dynamically adjusts frequencies based on processor utilization, except that it allows for a more gradual increase in power. If processor utilization exceeds a certain threshold, the governor does not immediately switch to the highest available frequency (as the on-demand governor does), but only to next higher frequency available.

Tuning options: The range of available frequencies, the rate at which the governor checks utilization, the utilization thresholds, and the frequency step rate can be adjusted.

### 11.2.2 Related Files and Directories

If the CPUfreq subsystem is enabled on your system (which it is by default with SUSE Linux Enterprise Server), you can find the relevant files and directories under `/sys/`.
devices/system/cpu/. If you list the contents of this directory, you will find a cpu{0..x} subdirectory for each processor, and several other files and directories. A cpufreq subdirectory in each processor directory holds a number of files and directories that define the parameters for CPUfreq. Some of them are writable (for root), some of them are read-only. If your system currently uses the on-demand or conservative governor, you will see a separate subdirectory for those governors in cpufreq, containing the parameters for the governors.

NOTE: Different Processor Settings

The settings under the cpufreq directory can be different for each processor. If you want to use the same policies across all processors, you need to adjust the parameters for each processor. Instead of looking up or modifying the current settings manually (in /sys/devices/system/cpu*/ cpufreq), we advise to use the tools provided by the cpupower package or by the older cpufrequtils package for that.

11.3 Viewing, Monitoring and Tuning Power-related Settings

The following command line tools are available for that purpose:

Using the cpufrequtils Tools (page 138)
With the tools of the cpufrequtils package you can view and modify settings of the kernel-related CPUfreq subsystem. The cpufreq* commands are useful for modifying settings related to P-states, especially frequency scaling and CPUfreq governors.

Using the cpupower Tools (page 139)
The new cpupower tool was designed to give an overview of all CPU power-related parameters that are supported on a given machine, including turbo (or boost) states. Use the tool set to view and modify settings of the kernel-related CPUfreq and cpuidle systems as well as other settings not related to frequency scaling or idle states. The integrated monitoring framework can access both Kernel-related parameters and hardware statistics and is thus ideally suited for performance benchmarks. It also helps you to identify the dependencies between turbo and idle states.
Monitoring Power Consumption with powerTOP (page 143)

powerTOP combines various sources of information (analysis of programs, device drivers, kernel options, amounts and sources of interrupts waking up processors from sleep states) and shows them in one screen. The tool helps you to identify the reasons for unnecessary high power consumption (for example, processes that are mainly responsible for waking up a processor from its idle state) and to optimize your system settings to avoid these.

### 11.3.1 Using the cpufrequtils Tools

**NOTE: cpupower and cpufrequtils**

All functions of cpufrequtils are also covered by cpupower—a new set of tools that is more powerful and provides additional features. As cpupower will replace cpufrequtils sooner or later, we advise to switch to cpupower soon and to adjust your scripts accordingly.

After you have installed the cpufrequtils package, you can make use of the cpufreq-info and cpufreq-set command line tools.

#### 11.3.1.1 Viewing Current Settings with cpufreq-info

The cpufreq-info command helps you to retrieve CPUfreq kernel information. Run without any options, it collects the information available for your system:

*Example 11.1: Example Output of cpufreq-info*

```
cpufrequtils 004: cpufreq-info (C) Dominik Brodowski 2004-2006
Report errors and bugs to http://bugs.opensuse.org, please.
analyzing CPU 0:
  driver: acpi-cpufreq
  CPUs which need to switch frequency at the same time: 0
  hardware limits: 2.80 GHz - 3.40 GHz
  available frequency steps: 3.40 GHz, 2.80 GHz
  available cpufreq governors: conservative, userspace, powersave, ondemand, performance
  current policy: frequency should be within 2.80 GHz and 3.40 GHz.
    The governor "performance" may decide which speed to use within this range.
  current CPU frequency is 3.40 GHz.
analyzing CPU 1:
  driver: acpi-cpufreq
  CPUs which need to switch frequency at the same time: 1
```
using the appropriate options, you can view the current CPU frequency, the minimum and maximum CPU frequency allowed, show the currently used CPUpfreq policy, the available CPUpfreq governors, or determine the CPUpfreq kernel driver used. For more details and the available options, refer to the cpufreq-info man page or run cpufreq-info --help.

11.3.1.2 Modifying Current Settings with cpufreq-set

To modify CPUpfreq settings, use the cpufreq-set command as root. It allows you set values for the minimum or maximum CPU frequency the governor may select or to create a new governor. With the -c option, you can also specify for which of the processors the settings should be modified. That makes it easy to use a consistent policy across all processors without adjusting the settings for each processor individually. For more details and the available options, refer to the cpufreq-set man page or run cpufreq-set --help.

11.3.2 Using the cpupower Tools

After installing the cpupower package, view the available cpupower subcommands with cpupower --help. Access the general man page with man cpupower, and the man pages of the subcommands with man cpupower-subcommand.

The subcommands frequency-info and frequency-set are mostly equivalent to cpufreq-info and cpufreq-set, respectively. However, they provide extended output and there are small differences in syntax and behavior:

Syntax Differences Between cpufreq* and cpupower

- To specify the number of the CPU to which the command is applied, both commands have the -c option. Due to the command-subcommand structure, the placement of the -c option is different for cpupower:
cpupower -c 4 frequency-info (versus cpufreq-info -c 4)

cpupower lets you also specify a list of CPUs with -c. For example, the following command would affect the CPUs 1, 2, 3, and 5:

cpupower -c 1-3,5 frequency-set

- If cpufreq* and cpupower are used without the -c option, the behavior differs:

  cpufreq-set automatically applies the command to CPU 0, whereas cpupower frequency-set applies the command to all CPUs in this case. Typically, cpupower *info subcommands access only CPU 0, whereas cpufreq-info accesses all CPUs, if not specified otherwise.

11.3.2.1 Viewing Current Settings with cpupower

Similar to cpufreq-info, cpupower frequency-info also shows the statistics of the cpufreq driver used in the Kernel. Additionally, it shows if turbo (boost) states are supported and enabled in the BIOS. Run without any options, it shows an output similar to the following:

Example 11.2:  Example Output of cpupower frequency-info

analyzing CPU 0:
  driver: acpi-cpufreq
  CPUs which run at the same hardware frequency: 0 1 2 3
  CPUs which need to have their frequency coordinated by software: 0
  maximum transition latency: 10.0 us.
  hardware limits: 2.00 GHz - 2.83 GHz
  available frequency steps: 2.83 GHz, 2.34 GHz, 2.00 GHz
  available cpufreq governors: conservative, userspace, powersave, ondemand, performance
  current policy: frequency should be within 2.00 GHz and 2.83 GHz.
    The governor "ondemand" may decide which speed to use within this range.
  current CPU frequency is 2.00 GHz (asserted by call to hardware).
  boost state support:
    Supported: yes
    Active: yes

To get the current values for all CPUs, use cpupower -c all frequency-info.
11.3.2.2 Viewing and Modifying Kernel Idle Statistics with cpupower

The `idle-info` subcommand shows the statistics of the cpuidle driver used in the Kernel. It works on all architectures that use the cpuidle Kernel framework.

**Example 11.3:**  *Example Output of cpupower idle-info*

```
CPUidle driver: ACPI_FFH_INTEL_MWAIT
CPUidle governor: menu

Analyzing CPU 0:
Number of idle states: 3
Available idle states: C1 C2
C1:
Flags/Description: ACPI FFH INTEL MWAIT 0x0
Latency: 1
Usage: 3156464
Duration: 233680359
C2:
Flags/Description: ACPI FFH INTEL MWAIT 0x10
Latency: 1
Usage: 273007117
Duration: 103148860538
```

After finding out which processor idle states are supported with `cpupower idle-info`, individual states can be disabled using the `cpupower idle-set` command. Typically one wants to disable the deepest sleep state, for example:

```
cpupower idle-set -d 4
```

But before making this change permanent by adding the corresponding command to a current `/etc/init.d/*` service file, check for performance or power impact.

11.3.2.3 Monitoring Kernel and Hardware Statistics with cpupower

The most powerful enhancement is the `monitor` subcommand. Use it to report processor topology, and monitor frequency and idle power state statistics over a certain period of time. The default interval is 1 second, but it can be changed with the `-i`. Independent processor sleep states and frequency counters are implemented in the tool—some retrieved from kernel statistics, others reading out hardware registers. The available monitors depend on the underlying hardware and the system. List them with `cpupower monitor -l`. For a description of the individual monitors, refer to the `cpupower-monitor man` page.
The **monitor** subcommand allows you to execute performance benchmarks and to compare Kernel statistics with hardware statistics for specific workloads.

### Example 11.4: Example cpupower monitor Output

| Mperf | | Idle_Stats |
|------| |-----------|
| CPU | C0 | Cx | Freq | POLL | C1 | C2 | C3 |
| 0   | 3.71 | 96.29 | 2833 | 0.00 | 0.00 | 0.02 | 96.32 |
| 1   | 100.0 | -0.00 | 2833 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2   | 9.06 | 90.94 | 1983 | 0.00 | 7.69 | 6.98 | 76.45 |
| 3   | 7.43 | 92.57 | 2039 | 0.00 | 2.60 | 12.62 | 77.52 |

1 Mperf shows the average frequency of a CPU, including boost frequencies, over a period of time. Additionally, it shows the percentage of time the CPU has been active (C0) or in any sleep state (Cx). The default sampling rate is 1 second and the values are read directly from the hardware registers. As the turbo states are managed by the BIOS, it is impossible to get the frequency values at a given instant. On modern processors with turbo features the Mperf monitor is the only way to find out about the frequency a certain CPU has been running in.

2 Idle_Stats shows the statistics of the cpuidle kernel subsystem. The kernel updates these values every time an idle state is entered or left. Therefore there can be some inaccuracy when cores are in an idle state for some time when the measure starts or ends.

Apart from the (general) monitors in the example above, other architecture-specific monitors are available. For detailed information, refer to the cpupower-monitor man page.

By comparing the values of the individual monitors, you can find correlations and dependencies and evaluate how well the power saving mechanism works for a certain workload. In Example 11.4 (page 142) you can see that CPU 0 is idle (the value of Cx is near to 100%), but runs at a very high frequency. Additionally, the CPUs 0 and 1 have the same frequency values which means that there is a dependency between them.

### 11.3.2.4 Modifying Current Settings with cpupower

Similar to cpufreq-set, you can use cpupower frequency-set command as root to modify current settings. It allows you to set values for the minimum or
maximum CPU frequency the governor may select or to create a new governor. With the `-c` option, you can also specify for which of the processors the settings should be modified. That makes it easy to use a consistent policy across all processors without adjusting the settings for each processor individually. For more details and the available options, refer to the `cpupower-frequency-set` man page or run `cpupower-frequency-set --help`.

### 11.3.3 Monitoring Power Consumption with powerTOP

Another useful tool for monitoring system power consumption is powerTOP. It helps you to identify the reasons for unnecessary high power consumption (for example, processes that are mainly responsible for waking up a processor from its idle state) and to optimize your system settings to avoid these. It supports both Intel and AMD processors. The `powertop` package is available from the SUSE Linux Enterprise SDK. For information on how to access the SDK, refer to About This Guide (page ix).

powerTOP combines various sources of information (analysis of programs, device drivers, kernel options, amounts and sources of interrupts waking up processors from sleep states) and shows them in one screen. Example 11.5, “Example powerTOP Output” (page 143) shows which information categories are available:

**Example 11.5: Example powerTOP Output**

<table>
<thead>
<tr>
<th>Cn</th>
<th>Avg residency</th>
<th>P-states</th>
<th>(frequencies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0 (cpu running)</td>
<td>11.6%</td>
<td>2.00 Ghz</td>
<td>0.1%</td>
</tr>
<tr>
<td>polling</td>
<td>0.0ms</td>
<td>(0.0%)</td>
<td>2.00 Ghz</td>
</tr>
<tr>
<td>C1</td>
<td>57.3%</td>
<td>1.87 Ghz</td>
<td>0.0%</td>
</tr>
<tr>
<td>C2</td>
<td>31.1%</td>
<td>1064 Mhz</td>
<td>99.9%</td>
</tr>
</tbody>
</table>

Wakeups-from-idle per second : 11.2 interval: 5.0s

no ACPI power usage estimate available

Top causes for wakeups:

- 96.2% (826.0) <interrupt> : extra timer interrupt
- 0.9% (8.0) <kernel core> : usb_hcd_poll_rh_status (rh_timer_func)
- 0.3% (2.4) <interrupt> : megasas
- 0.2% (2.0) <kernel core> : clocksource_watchdog (clocksource_watchdog)
- 0.2% (1.6) <interrupt> : eth1-TxRx-0
- 0.1% (1.0) <interrupt> : eth1-TxRx-4
Suggestion: Enable SATA ALPM link power management via:

```
echo min_power > /sys/class/scsi_host/host0/link_power_management_policy
```
or press the S key.

1. The column shows the C-states. When working, the CPU is in state 0, when resting it is in some state greater than 0, depending on which C-states are available and how deep the CPU is sleeping.
2. The column shows average time in milliseconds spent in the particular C-state.
3. The column shows the percentages of time spent in various C-states. For considerable power savings during idle, the CPU should be in deeper C-states most of the time. In addition, the longer the average time spent in these C-states, the more power is saved.
4. The column shows the frequencies the processor and kernel driver support on your system.
5. The column shows the amount of time the CPU cores stayed in different frequencies during the measuring period.
6. Shows how often the CPU is awoken per second (number of interrupts). The lower the number the better. The interval value is the powerTOP refresh interval which can be controlled with the -t option. The default time to gather data is 5 seconds.
7. When running powerTOP on a laptop, this line displays the ACPI information on how much power is currently being used and the estimated time until discharge of the battery. On servers, this information is not available.
8. Shows what is causing the system to be more active than needed. powerTOP displays the top items causing your CPU to awake during the sampling period.
9. Suggestions on how to improve power usage for this machine.

For more information, refer to the powerTOP project page at [http://www.lesswatts.org/projects/powertop/](http://www.lesswatts.org/projects/powertop/). It also provides tips and tricks and an informative FAQ section.

## 11.4 Special Tuning Options

The following sections highlight some of the most relevant settings that you might want to touch.
11.4.1 Tuning Options for P-States

The CPUfreq subsystem offers several tuning options for P-states: You can switch between the different governors, influence minimum or maximum CPU frequency to be used or change individual governor parameters.

To switch to another governor at runtime, use `cpupower frequency-set` (or `cpufreq-set`) with the `-g` option. For example, running the following command (as root) will activate the on-demand governor:

```bash
cpupower frequency-set -g ondemand
```

If you want the change in governor to persist also after a reboot or shutdown, use the pm-profile as described in Section 11.5, “Creating and Using Power Management Profiles” (page 147).

To set values for the minimum or maximum CPU frequency the governor may select, use the `-d` or `-u` option, respectively.

Apart from the governor settings that can be influenced with `cpupower` or `cpufreq*`, you can also tune further governor parameters manually, for example, Ignoring Nice Values in Processor Utilization (page 145).

**Procedure 11.1: Ignoring Nice Values in Processor Utilization**

One parameter you might want to change for the on-demand or conservative governor is `ignore_nice_load`.

Each process has a niceness value associated with it. This value is used by the kernel to determine which processes require more processor time than others. The higher the nice value, the lower the priority of the process. Or: the “nicer” a process, the less CPU it will try to take from other processes.

If the `ignore_nice_load` parameter for the on-demand or conservative governor is set to 1, any processes with a nice value will not be counted toward the overall processor utilization. When `ignore_nice_load` is set to 0 (default value), all processes are counted toward the utilization. Adjusting this parameter can be useful if you are running something that requires a lot of processor capacity but you do not care about the runtime.

1 Change to the subdirectory of the governor whose settings you want to modify, for example:

```bash
cd /sys/devices/system/cpu/cpu0/cpufreq/conservative/
```
2 Show the current value of `ignore_nice_load` with:
   
   ```
   cat ignore_nice_load
   ```

3 To set the value to 1, execute:
   
   ```
   echo 1 > ignore_nice_load
   ```

---

**TIP: Using the Same Value for All Cores**

When setting the `ignore_nice_load` value for `cpu0`, the same value is automatically used for all cores. In this case, you do not need to repeat the steps above for each of the processors where you want to modify this governor parameter.

---

Another parameter that significantly impacts the performance loss caused by dynamic frequency scaling is the sampling rate (rate at which the governor checks the current CPU load and adjusts the processor's frequency accordingly). Its default value depends on a BIOS value and it should be as low as possible. However, in modern systems, an appropriate sampling rate is set by default and does not need manual intervention.

### 11.4.2 Tuning Options for C-states

By default, SUSE Linux Enterprise Server uses C-states appropriately. The only parameter you might want to touch for optimization is the `sched_mc_power_savings` scheduler. Instead of distributing a work load across all cores with the effect that all cores are used only at a minimum level, the kernel can try to schedule processes on as few cores as possible so that the others can go idle. This helps to save power as it allows some processors to be idle for a longer time so they can reach a higher C-state. However, the actual savings depend on a number of factors, for example how many processors are available and which C-states are supported by them (especially deeper ones such as C3 to C6).

If `sched_mc_power_savings` is set to 0 (default value), no special scheduling is done. If it is set to 1, the scheduler tries to consolidate the work onto the fewest number of processors possible in the case that all processors are a little busy. To modify this parameter, proceed as follows:

**Procedure 11.2: Scheduling Processes on Cores**

1 Become root on a command line.
2 To view the current value of `sched_mc_power_savings`, use the following command:

    cpupower info -m

3 To set `sched_mc_power_savings` to 1, execute:

    cpupower set -m 1

11.5 Creating and Using Power Management Profiles

SUSE Linux Enterprise Server includes `pm-profiler`, intended for server use. It is a script infrastructure to enable or disable certain power management functions via configuration files. It allows you to define different profiles, each having a specific configuration file for defining different settings. A configuration template for new profiles can be found at `/usr/share/doc/packages/pm-profiler/config.template`. The template contains a number of parameters you can use for your profile, including comments on usage and links to further documentation. The individual profiles are stored in `/etc/pm-profiler/`. The profile that will be activated on system start, is defined in `/etc/pm-profiler.conf`.

Procedure 11.3: Creating and Switching Power Profiles

To create a new profile, proceed as follows:

1 Create a directory in `/etc/pm-profiler/`, containing the profile name, for example:

    mkdir /etc/pm-profiler/testprofile

2 To create the configuration file for the new profile, copy the profile template to the newly created directory:

    cp /usr/share/doc/packages/pm-profiler/config.template \
        /etc/pm-profiler/testprofile/config

3 Edit the settings in `/etc/pm-profiler/testprofile/config` and save the file. You can also remove variables that you do not need—they will be handled like empty variables, the settings will not be touched at all.
4 Edit /etc/pm-profiler.conf. The PM_PROFILER_PROFILE variable defines which profile will be activated on system start. If it has no value, the default system or kernel settings will be used. To set the newly created profile:

```
PM_PROFILER_PROFILE="testprofile"
```

The profile name you enter here must match the name you used in the path to the profile configuration file (/etc/pm-profiler/testprofile/config), not necessarily the NAME you used for the profile in the /etc/pm-profiler/testprofile/config.

5 To activate the profile, run

```
rcpm-profiler start
```

or

```
/usr/lib/pm-profiler/enable-profile testprofile
```

Though you have to manually create or modify a profile by editing the respective profile configuration file, you can use YaST to switch between different profiles. Start YaST and select *System > Power Management* to open the *Power Management Settings*. Alternatively, become root and execute `yast2 power-management` on a command line. The drop-down list shows the available profiles. Default means that the system default settings will be kept. Select the profile to use and click *Finish*.

### 11.6 Troubleshooting

**BIOS options enabled?**

In order to make use of C-states or P-states, check your BIOS options:

- To use C-states, make sure to enable CPU C State or similar options to benefit from power savings at idle.

- To use P-states and the CPUfreq governors, make sure to enable Processor Performance States options or similar.

In case of a CPU upgrade, make sure to upgrade your BIOS, too. The BIOS needs to know the new CPU and its valid frequencies steps in order to pass this information on to the operating system.
CPUfreq subsystem enabled?
In SUSE Linux Enterprise Server, the CPUfreq subsystem is enabled by default. To find out if the subsystem is currently enabled, check for the following path in your system: /sys/devices/system/cpu/cpufreq (or /sys/devices/system/cpu/cpu*/cpufreq for machines with multiple cores). If the cpufreq subdirectory exists, the subsystem is enabled.

Log file information?
Check syslog (usually /var/log/messages) for any output regrading the CPUfreq subsystem. Only severe errors are reported there.

If you suspect problems with the CPUfreq subsystem on your machine, you can also enable additional debug output. To do so, either use cpufreq.debug=7 as boot parameter or execute the following command as root:

echo 7 > /sys/module/cpufreq/parameters/debug

This will cause CPUfreq to log more information to dmesg on state transitions, which is useful for diagnosis. But as this additional output of kernel messages can be rather comprehensive, use it only if you are fairly sure that a problem exists.

11.7 For More Information

- A threepart, comprehensive article about tuning components with regards to power efficiency is available at the following URLs:


• The LessWatts.org project deals with how to save power, reduce costs and increase efficiency on Linux systems. Find the project home page at http://www.lesswatts.org/. The project page also holds an informative FAQs section at http://www.lesswatts.org/documentation/faq/index.php and provides useful tips and tricks. For tips dealing with the CPU level, refer to http://www.lesswatts.org/tips/cpu.php. For more information about powerTOP, refer to http://www.lesswatts.org/projects/powertop/.

• Platforms with a Baseboard Management Controller (BMC) may have additional power management configuration options accessible via the service processor. These configurations are vendor specific and therefore not subject of this guide. For more information, refer to the manuals provided by your vendor. For example, HP ProLiant Server Power Management on SUSE Linux Enterprise Server 11—Integration Note provides detailed information how the HP platform specific power management features interact with the Linux Kernel. The paper is available from http://h18004.www1.hp.com/products/servers/technology/whitepapers/os-techwp.html.
Part V. Kernel Tuning
Installing Multiple Kernel Versions

SUSE Linux Enterprise Server supports the parallel installation of multiple kernel versions. When installing a second kernel, a boot entry and an initrd are automatically created, so no further manual configuration is needed. When rebooting the machine, the newly added kernel is available as an additional boot option.

Using this functionality, you can safely test kernel updates while being able to always fall back to the proven former kernel. To do so, do not use the update tools (such as the YaST Online Update or the updater applet), but instead follow the process described in this chapter.

WARNING: Support Entitlement

Please be aware that you lose your entire support entitlement for the machine when installing a self-compiled or a third-party kernel. Only kernels shipped with SUSE Linux Enterprise Server and kernels delivered via the official update channels for SUSE Linux Enterprise Server are supported.

TIP: Check Your Bootloader Configuration Kernel

It is recommended to check your boot loader config after having installed another kernel in order to set the default boot entry of your choice. See Section “Configuring the Boot Loader with YaST” (Chapter 11, The Boot Loader GRUB, Administration Guide) for more information. To change the default append line for new kernel installations, adjust /etc/sysconfig/bootloader prior to installing a new kernel. For more information re-
12.1 Enabling and Configuring Multiversion Support

Installing multiple versions of a software package (multiversion support) is not enabled by default. To enable this feature, proceed as follows:

1. Open `/etc/zypp/zypp.conf` with the editor of your choice as root.

2. Search for the string `multiversion`. To enable multiversion for all kernel packages capable of this feature, uncomment the following line:
   ```
   # multiversion = provides:multiversion(kernel)
   ```

3. To restrict multiversion support to certain kernel flavors, add the package names as a comma-separated list, to the `multiversion` option in `/etc/zypp/zypp.conf`—for example:
   ```
   multiversion = kernel-default,kernel-default-base,kernel-source
   ```

4. Save your changes.

12.1.1 Automatically Deleting Unused Kernels

When frequently testing new kernels with multiversion support enabled, the boot menu quickly becomes confusing. Since a `/boot` usually has got limited space you also might run into trouble with `/boot` overflowing. While you may delete unused kernel versions manually with YaST or Zyppe (as described below), you can also configure `libzypp` to automatically delete kernels no longer used. By default no kernels are deleted.

1. Open `/etc/zypp/zypp.conf` with the editor of your choice as root.

2. Search for the string `multiversion.kernels` and activate this option by uncommenting the line. This option takes a comma separated list of the following values.
2.6.32.12-0.7: keep the kernel with the specified version number

**latest:** keep the kernel with the highest version number

**latest-N:** keep the kernel with the Nth highest version number

**running** keep the running kernel

**oldest** keep the kernel with the lowest version number (the one that was originally shipped with SUSE Linux Enterprise Server)

**oldest+N** keep the kernel with the Nth lowest version number

Here are some examples

```
multiversion.kernels = latest,running
```
Keep the latest kernel and the one currently running one. This is similar to not enabling the multiversion feature at all, except that the old kernel is removed *after the next reboot* and not immediately after the installation.

```
multiversion.kernels = latest,latest-1,running
```
Keep the last two kernels and the one currently running.

```
multiversion.kernels = latest,running,3.0.rc7-test
```
Keep the latest kernel, the one currently running and 3.0.rc7-test.

---

**TIP: Keep the running Kernel**

Unless using special setups, you probably always want to keep the running kernel.

---

### 12.2 Installing/Removing Multiple Kernel Versions with YaST

1. Start YaST and open the software manager via *Software > Software Management*.

2. List all packages capable of providing multiple versions by choosing *View > Package Groups > Multiversion Packages*.
3 Select a package and open its Version tab in the bottom pane on the left.

4 To install a package, click its check box. A green check mark indicates it is selected for installation.

To remove an already installed package (marked with a white check mark), click its check box until a red X indicates it is selected for removal.

5 Click Accept to start the installation.

12.3 Installing/Removing Multiple Kernel Versions with zypper

1 Use the command `zypper se -s 'kernel*'` to display a list of all kernel packages available:
2 Specify the exact version when installing:

zypper in kernel-default-2.6.32.10-0.4.1

3 When uninstalling a kernel, use the commands `zypper se -si 'kernel*'
   to list all kernels installed and `zypper rm PACKAGENAME-VERSION` to re-
   move the package.
Tuning I/O Performance

I/O scheduling controls how input/output operations will be submitted to storage. SUSE Linux Enterprise Server offers various I/O algorithms—called elevators—suiting different workloads. Elevators can help to reduce seek operations, can prioritize I/O requests, or make sure, and I/O request is carried out before a given deadline.

Choosing the best suited I/O elevator not only depends on the workload, but on the hardware, too. Single ATA disk systems, SSDs, RAID arrays, or network storage systems, for example, each require different tuning strategies.

13.1 Switching I/O Scheduling

SUSE Linux Enterprise Server lets you set a default I/O scheduler at boot-time, which can be changed on the fly per block device. This makes it possible to set different algorithms for e.g. the device hosting the system partition and the device hosting a database.

By default the CFQ (Completely Fair Queuing) scheduler is used. Change this default by entering the boot parameter

elevator=SCHEDULER

where SCHEDULER is one of cfq, noop, or deadline. See Section 13.2, “Available I/O Elevators” (page 160) for details.

To change the elevator for a specific device in the running system, run the following command:
**NOTE: Default Scheduler on IBM System z**

On IBM System z the default I/O scheduler for a storage device is set by the device driver.

### 13.2 Available I/O Elevators

In the following elevators available on SUSE Linux Enterprise Server are listed. Each elevator has a set of tunable parameters, which can be set with the following command:

```
echo VALUE > /sys/block/<DEVICE>/queue/iosched/TUNABLE
```

where `VALUE` is the desired value for the `TUNABLE` and `DEVICE` the block device.

To find out which elevator is the current default, run the following command. The currently selected scheduler is listed in brackets:

```
jupiter:~ # cat /sys/block/sda/queue/scheduler
noop deadline [cfq]
```

#### 13.2.1 CFQ (Completely Fair Queuing)

CFQ is a fairness-oriented scheduler and is used by default on SUSE Linux Enterprise Server. The algorithm assigns each thread a time slice in which it is allowed to submit I/O to disk. This way each thread gets a fair share of I/O throughput. It also allows assigning tasks I/O priorities which are taken into account during scheduling decisions (see `man 1 ionice`). The CFQ scheduler has the following tunable parameters:

```
/sys/block/<device>/queue/iosched/slice_idle
```

When a task has no more I/O to submit in its time slice, the I/O scheduler waits for a while before scheduling the next thread to improve locality of I/O. For media where locality does not play a big role (SSDs, SANs with lots of disks) setting `/sys/block/<device>/queue/iosched/slice_idle` to 0 can improve the throughput considerably.
This option limits the maximum number of requests that are being processed by the device at once. The default value is 4. For a storage with several disks, this setting can unnecessarily limit parallel processing of requests. Therefore, increasing the value can improve performance although this can cause that the latency of some I/O may be increased due to more requests being buffered inside the storage. When changing this value, you can also consider tuning `/sys/block/<device>/queue/iosched/slice_async_rq` (the default value is 2) which limits the maximum number of asynchronous requests—usually writing requests—that are submitted in one time slice.

For workloads where the latency of I/O is crucial, setting `/sys/block/<device>/queue/iosched/low_latency` to 1 can help.

### 13.2.2 NOOP

A trivial scheduler that just passes down the I/O that comes to it. Useful for checking whether complex I/O scheduling decisions of other schedulers are not causing I/O performance regressions.

In some cases it can be helpful for devices that do I/O scheduling themselves, as intelligent storage, or devices that do not depend on mechanical movement, like SSDs. Usually, the DEADLINE I/O scheduler is a better choice for these devices, but due to less overhead NOOP may produce better performance on certain workloads.

### 13.2.3 DEADLINE

DEADLINE is a latency-oriented I/O scheduler. Each I/O request has got a deadline assigned. Usually, requests are stored in queues (read and write) sorted by sector numbers. The DEADLINE algorithm maintains two additional queues (read and write) where the requests are sorted by deadline. As long as no request has timed out, the “sector” queue is used. If timeouts occur, requests from the “deadline” queue are served until there are no more expired requests. Generally, the algorithm prefers reads over writes.

This scheduler can provide a superior throughput over the CFQ I/O scheduler in cases where several threads read and write and fairness is not an issue. For example, for
several parallel readers from a SAN and for databases (especially when using “TCQ” disks). The **DEADLINE** scheduler has the following tunable parameters:

```
/sys/block/<device>/queue/iosched/writes_starved
Controls how many reads can be sent to disk before it is possible to send writes. A value of 3 means, that three read operations are carried out for one write operation.

/sys/block/<device>/queue/iosched/read_expire
Sets the deadline (current time plus the read_expire value) for read operations in milliseconds. The default is 500.

/sys/block/<device>/queue/iosched/write_expire
```

13.3 I/O Barrier Tuning

Most file systems (XFS, ext3, ext4, reiserfs) send write barriers to disk after fsync or during transaction commits. Write barriers enforce proper ordering of writes, making volatile disk write caches safe to use (at some performance penalty). If your disks are battery-backed in one way or another, disabling barriers may safely improve performance.

Sending write barriers can be disabled using the `barrier=0` mount option (for ext3, ext4, and reiserfs), or using the `nobarrier` mount option (for XFS).

---

**WARNING**

Disabling barriers when disks cannot guarantee caches are properly written in case of power failure can lead to severe file system corruption and data loss.
14 Tuning the Task Scheduler

Modern operating systems, such as SUSE® Linux Enterprise Server, normally run many different tasks at the same time. For example, you can be searching in a text file while receiving an e-mail and copying a big file to an external hard drive. These simple tasks require many additional processes to be run by the system. To provide each task with its required system resources, the Linux kernel needs a tool to distribute available system resources to individual tasks. And this is exactly what the task scheduler does.

The following sections explain the most important terms related to a process scheduling. They also introduce information about the task scheduler policy, scheduling algorithm, description of the task scheduler used by SUSE Linux Enterprise Server, and references to other sources of relevant information.

14.1 Introduction

The Linux kernel controls the way tasks (or processes) are managed in the running system. The task scheduler, sometimes called process scheduler, is the part of the kernel that decides which task to run next. It is one of the core components of a multitasking operating system (such as Linux), being responsible for best utilizing system resources to guarantee that multiple tasks are being executed simultaneously.
14.1.1 Preemption

The theory behind task scheduling is very simple. If there are runnable processes in a system, at least one process must always be running. If there are more runnable processes than processors in a system, not all the processes can be running all the time.

Therefore, some processes need to be stopped temporarily, or suspended, so that others can be running again. The scheduler decides what process in the queue will run next.

As already mentioned, Linux, like all other Unix variants, is a multitasking operating system. That means that several tasks can be running at the same time. Linux provides a so called preemptive multitasking, where the scheduler decides when a process is suspended. This forced suspension is called preemption. All Unix flavors have been providing preemptive multitasking since the beginning.

14.1.2 Timeslice

The time period for which a process will be running before it is preempted is defined in advance. It is called a process' timeslice and represents the amount of processor time that is provided to each process. By assigning timeslices, the scheduler makes global decisions for the running system, and prevents individual processes from dominating over the processor resources.

14.1.3 Process Priority

The scheduler evaluates processes based on their priority. To calculate the current priority of a process, the task scheduler uses complex algorithms. As a result, each process is given a value according to which it is “allowed” to run on a processor.

14.2 Process Classification

Processes are usually classified according to their purpose and behavior. Although the borderline is not always clearly distinct, generally two criteria are used to sort them. These criteria are independent and do not exclude each other.

One approach is to classify a process either I/O-bound or processor-bound.
I/O-bound

I/O stands for Input/Output devices, such as keyboards, mice, or optical and hard disks. *I/O-bound processes* spend the majority of time submitting and waiting for requests. They are run very frequently, but for short time intervals, not to block other processes waiting for I/O requests.

Processor-bound

On the other hand, *processor-bound* tasks use their time to execute a code, and usually run until they are preempted by the scheduler. They do not block processes waiting for I/O requests, and, therefore, can be run less frequently but for longer time intervals.

Another approach is to divide processes by either being *interactive*, *batch*, or *real-time* ones.

- **Interactive** processes spend a lot of time waiting for I/O requests, such as keyboard or mouse operations. The scheduler must wake up such process quickly on user request, or the user will find the environment unresponsive. The typical delay is approximately 100 ms. Office applications, text editors or image manipulation programs represent typical interactive processes.

- **Batch** processes often run in the background and do not need to be responsive. They usually receive lower priority from the scheduler. Multimedia converters, database search engines, or log files analyzers are typical examples of batch processes.

- **Real-time** processes must never be blocked by low-priority processes, and the scheduler guarantees a short response time to them. Applications for editing multimedia content are a good example here.

### 14.3 O(1) Scheduler

The Linux kernel version 2.6 introduced a new task scheduler, called O(1) scheduler (see Big O notation [http://en.wikipedia.org/wiki/Big_O_notation]), It was used as the default scheduler up to Kernel version 2.6.22. Its main task is to schedule tasks within a fixed amount of time, no matter how many runnable processes there are in the system.

The scheduler calculates the timeslices dynamically. However, to determine the appropriate timeslice is a complex task: Too long timeslices cause the system to be less inter-
active and responsive, while too short ones make the processor waste a lot of time on the overhead of switching the processes too frequently. The default timeslice is usually rather low, for example 20ms. The scheduler determines the timeslice based on priority of a process, which allows the processes with higher priority to run more often and for a longer time.

A process does not have to use all its timeslice at once. For instance, a process with a timeslice of 150ms does not have to be running for 150ms in one go. It can be running in five different schedule slots for 30ms instead. Interactive tasks typically benefit from this approach because they do not need such a large timeslice at once while they need to be responsive as long as possible.

The scheduler also assigns process priorities dynamically. It monitors the processes' behavior and, if needed, adjusts its priority. For example, a process which is being suspended for a long time is brought up by increasing its priority.

### 14.4 Completely Fair Scheduler

Since the Linux kernel version 2.6.23, a new approach has been taken to the scheduling of runnable processes. Completely Fair Scheduler (CFS) became the default Linux kernel scheduler. Since then, important changes and improvements have been made. The information in this chapter applies to SUSE Linux Enterprise Server with kernel version 2.6.32 and higher (including 3.x kernels). The scheduler environment was divided into several parts, and three main new features were introduced:

**Modular Scheduler Core**

The core of the scheduler was enhanced with *scheduling classes*. These classes are modular and represent scheduling policies.

**Completely Fair Scheduler**

Introduced in kernel 2.6.23 and extended in 2.6.24, CFS tries to assure that each process obtains its “fair” share of the processor time.

**Group Scheduling**

For example, if you split processes into groups according to which user is running them, CFS tries to provide each of these groups with the same amount of processor time.

As a result, CFS brings more optimized scheduling for both servers and desktops.
14.4.1 How CFS Works

CFS tries to guarantee a fair approach to each runnable task. To find the most balanced way of task scheduling, it uses the concept of red-black tree. A red-black tree is a type of self-balancing data search tree which provides inserting and removing entries in a reasonable way so that it remains well balanced. For more information, see the wiki pages of Red-black tree [http://en.wikipedia.org/wiki/Red_black_tree](http://en.wikipedia.org/wiki/Red_black_tree).

When a task enters into the run queue (a planned time line of processes to be executed next), the scheduler records the current time. While the process waits for processor time, its “wait” value gets incremented by an amount derived from the total number of tasks currently in the run queue and the process priority. As soon as the processor runs the task, its “wait” value gets decremented. If the value drops below a certain level, the task is preempted by the scheduler and other tasks get closer to the processor. By this algorithm, CFS tries to reach the ideal state where the “wait” value is always zero.

14.4.2 Grouping Processes

Since the Linux kernel version 2.6.24, CFS can be tuned to be fair to users or groups rather than to tasks only. Runnable tasks are then grouped to form entities, and CFS tries to be fair to these entities instead of individual runnable tasks. The scheduler also tries to be fair to individual tasks within these entities.

Tasks can be grouped in two mutually exclusive ways:

- By user IDs
- By kernel control groups.

The way the kernel scheduler lets you group the runnable tasks depends on setting the kernel compile-time options CONFIG_FAIR_USER_SCHED and CONFIG_FAIR_CGROUP_SCHED. The default setting in SUSE® Linux Enterprise Server 11 SP4 is to use control groups, which lets you create groups as needed. For more information, see Chapter 10, Kernel Control Groups (page 119).

14.4.3 Kernel Configuration Options

Basic aspects of the task scheduler behavior can be set through the kernel configuration options. Setting these options is part of the kernel compilation process. Because kernel
compilation process is a complex task and out of this document’s scope, refer to relevant source of information.

---

**WARNING: Kernel Compilation**

If you run SUSE Linux Enterprise Server on a kernel that was not shipped with it, for example on a self-compiled kernel, you loose the entire support entitlement.

---

### 14.4.4 Terminology

Documents regarding task scheduling policy often use several technical terms which you need to know to understand the information correctly. Here are some of them:

**Latency**
Delay between the time a process is scheduled to run and the actual process execution.

**Granularity**
The relation between granularity and latency can be expressed by the following equation:

\[
\text{gran} = \left( \frac{\text{lat}}{\text{rtasks}} \right) - \left( \frac{\text{lat}}{\text{rtasks} \cdot \text{rtasks}} \right)
\]

where `gran` stands for granularity, `lat` stand for latency, and `rtasks` is the number of running tasks.

### 14.4.4.1 Scheduling Policies

The Linux kernel supports the following scheduling policies:

**SCHED_FIFO**
Scheduling policy designed for special time-critical applications. It uses the First In-First Out scheduling algorithm.

**SCHED_BATCH**
Scheduling policy designed for CPU-intensive tasks.

**SCHED_IDLE**
Scheduling policy intended for very low prioritized tasks.

**SCHED_OTHER**
Default Linux time-sharing scheduling policy used by the majority of processes.
SCHED_RR
Similar to SCHED_FIFO, but uses the Round Robin scheduling algorithm.

14.4.5 Changing Real-time Attributes of Processes with chrt

The chrt command sets or retrieves the real-time scheduling attributes of a running process, or runs a command with the specified attributes. You can get or retrieve both the scheduling policy and priority of a process.

In the following examples, a process whose PID is 16244 is used.

To retrieve the real-time attributes of an existing task:

```
saturn.example.com:~ # chrt -p 16244
pid 16244's current scheduling policy: SCHED_OTHER
pid 16244's current scheduling priority: 0
```

Before setting a new scheduling policy on the process, you need to find out the minimum and maximum valid priorities for each scheduling algorithm:

```
saturn.example.com:~ # chrt -m
SCHED_OTHER min/max priority : 0/0
SCHED_FIFO min/max priority : 1/99
SCHED_RR min/max priority : 1/99
SCHED_BATCH min/max priority : 0/0
SCHED_IDLE min/max priority : 0/0
```

In the above example, SCHED_OTHER, SCHED_BATCH, SCHED_IDLE polices only allow for priority 0, while that of SCHED_FIFO and SCHED_RR can range from 1 to 99.

To set SCHED_BATCH scheduling policy:

```
saturn.example.com:~ # chrt -b -p 0 16244
saturn.example.com:~ # chrt -p 16244
pid 16244's current scheduling policy: SCHED_BATCH
pid 16244's current scheduling priority: 0
```

For more information on chrt, see its man page (man 1 chrt).

14.4.6 Runtime Tuning with sysctl

The sysctl interface for examining and changing kernel parameters at runtime introduces important variables by means of which you can change the default behavior
of the task scheduler. The syntax of the `sysctl` is simple, and all the following commands must be entered on the command line as `root`.

To read a value from a kernel variable, enter

```
sysctl variable
```

To assign a value, enter

```
sysctl variable=value
```

To get a list of all scheduler related `sysctl` variables, enter

```
sysctl -A | grep "sched" | grep -v "domain"
saturn.example.com:~ # sysctl -A | grep "sched" | grep -v "domain"
kernel.sched_child_runs_first = 0
kernel.sched_min_granularity_ns = 1000000
kernel.sched_latency_ns = 5000000
kernel.sched_wakeup_granularity_ns = 1000000
kernel.sched_shares_ratelimit = 250000
kernel.sched_tunable_scaling = 1
kernel.sched_shares_thresh = 4
kernel.sched_features = 15834238
kernel.sched_migration_cost = 500000
kernel.sched_nr_migrate = 32
kernel.sched_time_avg = 1000
kernel.sched_rt_period_us = 1000000
kernel.sched_rt_runtime_us = 950000
kernel.sched_compat_yield = 0
```

Note that variables ending with “_ns” and “_us” accept values in nanoseconds and microseconds, respectively.

A list of the most important task scheduler `sysctl` tuning variables (located at `/proc/sys/kernel/`) with a short description follows:

- **sched_child_runs_first**
  A freshly forked child runs before the parent continues execution. Setting this parameter to 1 is beneficial for an application in which the child performs an execution after fork. For example `make -j<NO_CPUS>` performs better when `sched_child_runs_first` is turned off. The default value is 0.

- **sched_compat_yield**
  Enables the aggressive yield behavior of the old 0(1) scheduler. Java applications that use synchronization extensively perform better with this value set to 1. Only use it when you see a drop in performance. The default value is 0.
Expect applications that depend on the sched_yield() syscall behavior to perform better with the value set to 1.

**sched_migration_cost**
Amount of time after the last execution that a task is considered to be “cache hot” in migration decisions. A “hot” task is less likely to be migrated, so increasing this variable reduces task migrations. The default value is 500000 (ns).

If the CPU idle time is higher than expected when there are runnable processes, try reducing this value. If tasks bounce between CPUs or nodes too often, try increasing it.

**sched_latency_ns**
Targeted preemption latency for CPU bound tasks. Increasing this variable increases a CPU bound task's timeslice. A task's timeslice is its weighted fair share of the scheduling period:

\[
timeslice = \text{scheduling period} \times \left( \text{task's weight/total weight of tasks in the run queue} \right)
\]

The task's weight depends on the task's nice level and the scheduling policy. Minimum task weight for a SCHED_OTHER task is 15, corresponding to nice 19. The maximum task weight is 88761, corresponding to nice -20.

Timeslices become smaller as the load increases. When the number of runnable tasks exceeds \( \text{sched_latency_ns} / \text{sched_min_granularity_ns} \), the slice becomes \( \text{number_of_running_tasks} \times \text{sched_min_granularity_ns} \). Prior to that, the slice is equal to \( \text{sched_latency_ns} \).

This value also specifies the maximum amount of time during which a sleeping task is considered to be running for entitlement calculations. Increasing this variable increases the amount of time a waking task may consume before being pre-empted, thus increasing scheduler latency for CPU bound tasks. The default value is 20000000 (ns).

**sched_min_granularity_ns**
Minimal preemption granularity for CPU bound tasks. See sched_latency_ns for details. The default value is 4000000 (ns).

**sched_wakeup_granularity_ns**
The wake-up preemption granularity. Increasing this variable reduces wake-up preemption, reducing disturbance of compute bound tasks. Lowering it improves
wake-up latency and throughput for latency critical tasks, particularly when a short duty cycle load component must compete with CPU bound components. The default value is \(5000000\) (ns).

**WARNING**

Settings larger than half of \(\text{sched\_latency\_ns}\) will result in zero wake-up preemption and short duty cycle tasks will be unable to compete with CPU hogs effectively.

\[\text{sched\_rt\_period\_us}\]
Period over which real-time task bandwidth enforcement is measured. The default value is \(1000000\) (µs).

\[\text{sched\_rt\_runtime\_us}\]
Quantum allocated to real-time tasks during \(\text{sched\_rt\_period\_us}\). Setting to -1 disables RT bandwidth enforcement. By default, RT tasks may consume 95%CPU/sec, thus leaving 5%CPU/sec or 0.05s to be used by \text{SCHED\_OTHER} tasks.

\[\text{sched\_features}\]
Provides information about specific debugging features.

\[\text{sched\_stat\_granularity\_ns}\]
Specifies the granularity for collecting task scheduler statistics.

\[\text{sched\_nr\_migrate}\]
Controls how many tasks can be moved across processors through migration software interrupts (softirq). If a large number of tasks is created by \text{SCHED\_OTHER} policy, they will all be run on the same processor. The default value is 32. Increasing this value gives a performance boost to large \text{SCHED\_OTHER} threads at the expense of increased latencies for real-time tasks.

### 14.4.7 Debugging Interface and Scheduler Statistics

CFS comes with a new improved debugging interface, and provides runtime statistics information. Relevant files were added to the \(/\text{proc}\) file system, which can be examined simply with the `cat` or `less` command. A list of the related \(/\text{proc}\) files follows with their short description:
/proc/sched_debug
Contains the current values of all tunable variables (see Section 14.4.6, “Runtime Tuning with sysctl” (page 169)) that affect the task scheduler behavior, CFS statistics, and information about the run queue on all available processors.

saturn.example.com:~ # less /proc/sched_debug
Sched Debug Version: v0.09, 2.6.32.8-0.3-default #1
now at 2413026096.408222 msecs
...jiffies : 4898148820
.sysctl_sched_latency : 5.000000
.sysctl_sched_min_granularity : 1.000000
.sysctl_sched_wakeup_granularity : 1.000000
.sysctl_sched_child_runs_first : 0.000000
.sysctl_sched_features : 15834238
.sysctl_sched_tunable_scaling : 1 (logartmic)
cpu#0, 1864.411 MHz
.nr_running : 1
.load : 1024
.nr_switches : 37539000
.nr_load_updates : 22950725
...]
cfs_rq[0]/:
.exec_clock : 52940326.803842
.MIN_vruntime : 54410632.307072
.min_vruntime : 54410632.307072
.max_vruntime : 0.000001
...
rt_rq[0]/:
.rt_nr_running : 0
.rt_throttled : 0
.rt_time : 0.000000
.rt_runtime : 950.000000

runnable tasks:
...task PID tree-key switches prio exec-runtime sum-exec sum-sleep
R cat 16884 54410632.307072 0 120 54410632.307072 13.836804 0.000000

/proc/schedstat
Displays statistics relevant to the current run queue. Also domain-specific statistics for SMP systems are displayed for all connected processors. Because the output format is not user-friendly, read the contents of /usr/src/linux/Documentation/scheduler/sched-stats.txt for more information.

/proc/PID/sched
Displays scheduling information on the process with id PID.
14.5 For More Information

To get a compact knowledge about Linux kernel task scheduling, you need to explore several information sources. Here are some of them:

- For task scheduler System Calls description, see the relevant manual page (for example `man 2 sched_setaffinity`).

- General information on scheduling is described in Scheduling [http://en.wikipedia.org/wiki/Scheduling_(computing)] wiki page.

- General information on Linux task scheduling is described in Inside the Linux scheduler [http://www.ibm.com/developerworks/linux/library/l-scheduler/].

- Information specific to Completely Fair Scheduler is available in Multiprocessing with the Completely Fair Scheduler [http://www.ibm.com/developerworks/linux/library/l-cfs/?ca=dgr-lnxw06CFC4Linux]

- Information specific to tuning Completely Fair Scheduler is available in Tuning the Linux Kernel’s Completely Fair Scheduler [http://www.hotaboutlinux.com/2010/01/tuning-the-linux-kernels-completely-fair-scheduler/]

- A useful lecture on Linux scheduler policy and algorithm is available in [http://www.inf.fu-berlin.de/lehre/SS01/OS/Lectures/Lecture08.pdf].

• A very comprehensive overview of the Linux kernel internals is given in *Understanding the Linux Kernel* by Daniel P. Bovet and Marco Cesati (ISBN 978-0-596-00565-8).

• Technical information about task scheduler is covered in files under `/usr/src/linux/Documentation/scheduler`. 
Tuning the Memory Management Subsystem

In order to understand and tune the memory management behavior of the kernel, it is important to first have an overview of how it works and cooperates with other subsystems.

The memory management subsystem, also called the virtual memory manager, will subsequently be referred to as “VM”. The role of the VM is to manage the allocation of physical memory (RAM) for the entire kernel and user programs. It is also responsible for providing a virtual memory environment for user processes (managed via POSIX APIs with Linux extensions). Finally, the VM is responsible for freeing up RAM when there is a shortage, either by trimming caches or swapping out “anonymous” memory.

The most important thing to understand when examining and tuning VM is how its caches are managed. The basic goal of the VM’s caches is to minimize the cost of I/O as generated by swapping and file system operations (including network file systems). This is achieved by avoiding I/O completely, or by submitting I/O in better patterns.

Free memory will be used and filled up by these caches as required. The more memory is available for caches and anonymous memory, the more effectively caches and swapping will operate. However, if a memory shortage is encountered, caches will be trimmed or memory will be swapped out.

For a particular workload, the first thing that can be done to improve performance is to increase memory and reduce the frequency that memory must be trimmed or swapped. The second thing is to change the way caches are managed by changing kernel parameters.
Finally, the workload itself should be examined and tuned as well. If an application is allowed to run more processes or threads, effectiveness of VM caches can be reduced, if each process is operating in its own area of the file system. Memory overheads are also increased. If applications allocate their own buffers or caches, larger caches will mean that less memory is available for VM caches. However, more processes and threads can mean more opportunity to overlap and pipeline I/O, and may take better advantage of multiple cores. Experimentation will be required for the best results.

15.1 Memory Usage

Memory allocations in general can be characterized as “pinned” (also known as “unreclaimable”), “reclaimable” or “swappable”.

15.1.1 Anonymous Memory

Anonymous memory tends to be program heap and stack memory (for example, malloc()). It is reclaimable, except in special cases such as mlock or if there is no available swap space. Anonymous memory must be written to swap before it can be reclaimed. Swap I/O (both swapping in and swapping out pages) tends to be less efficient than pagecache I/O, due to allocation and access patterns.

15.1.2 Pagecache

A cache of file data. When a file is read from disk or network, the contents are stored in pagecache. No disk or network access is required, if the contents are up-to-date in pagecache. tmpfs and shared memory segments count toward pagecache.

When a file is written to, the new data is stored in pagecache before being written back to a disk or the network (making it a write-back cache). When a page has new data not written back yet, it is called “dirty”. Pages not classified as dirty are “clean”. Clean pagecache pages can be reclaimed if there is a memory shortage by simply freeing them. Dirty pages must first be made clean before being reclaimed.
15.1.3 Buffercache

This is a type of pagecache for block devices (for example, /dev/sda). A file system typically uses the buffercache when accessing its on-disk “meta-data” structures such as inode tables, allocation bitmaps, and so forth. Buffercache can be reclaimed similarly to pagecache.

15.1.4 Buffer Heads

Buffer heads are small auxiliary structures that tend to be allocated upon pagecache access. They can generally be reclaimed easily when the pagecache or buffercache pages are clean.

15.1.5 Writeback

As applications write to files, the pagecache (and buffercache) becomes dirty. When pages have been dirty for a given amount of time, or when the amount of dirty memory reaches a particular percentage of RAM, the kernel begins writeback. Flusher threads perform writeback in the background and allow applications to continue running. If the I/O cannot keep up with applications dirtying pagecache, and dirty data reaches a critical percentage of RAM, then applications begin to be throttled to prevent dirty data exceeding this threshold.

15.1.6 Readahead

The VM monitors file access patterns and may attempt to perform readahead. Readahead reads pages into the pagecache from the file system that have not been requested yet. It is done in order to allow fewer, larger I/O requests to be submitted (more efficient). And for I/O to be pipelined (I/O performed at the same time as the application is running).

15.1.7 VFS caches
15.1.7.1 Inode Cache

This is an in-memory cache of the inode structures for each file system. These contain attributes such as the file size, permissions and ownership, and pointers to the file data.

15.1.7.2 Directory Entry Cache

This is an in-memory cache of the directory entries in the system. These contain a name (the name of a file), the inode which it refers to, and children entries. This cache is used when traversing the directory structure and accessing a file by name.

15.2 Reducing Memory Usage

15.2.1 Reducing malloc (Anonymous) Usage

Applications running on SUSE Linux Enterprise Server 11 SP4 can allocate more memory compared to SUSE Linux Enterprise Server 10. This is due to glibc changing its default behavior while allocating userspace memory. Please see http://www.gnu.org/s/libc/manual/html_node/Malloc-Tunable-Parameters.html for explanation of these parameters.

To restore a SUSE Linux Enterprise Server 10-like behavior, M_MMAP_THRESHOLD should be set to 128*1024. This can be done with malloc() call from the application, or via setting MALLOC_MMAP_THRESHOLD environment variable before running the application.

15.2.2 Reducing Kernel Memory Overheads

Kernel memory that is reclaimable (caches, described above) will be trimmed automatically during memory shortages. Most other kernel memory cannot be easily reduced but is a property of the workload given to the kernel.
Reducing the requirements of the userspace workload will reduce the kernel memory usage (fewer processes, fewer open files and sockets, etc.)

15.2.3 Memory Controller (Memory Cgroups)

If the memory cgroups feature is not needed, it can be switched off by passing cgroup_disable=memory on the kernel command line, reducing memory consumption of the kernel a bit.

15.3 Virtual Memory Manager (VM) Tunable Parameters

When tuning the VM it should be understood that some of the changes will take time to affect the workload and take full effect. If the workload changes throughout the day, it may behave very differently at different times. A change that increases throughput under some conditions may decrease it under other conditions.

15.3.1 Reclaim Ratios

/proc/sys/vm/swappiness

This control is used to define how aggressively the kernel swaps out anonymous memory relative to pagecache and other caches. Increasing the value increases the amount of swapping. The default value is 60.

Swap I/O tends to be much less efficient than other I/O. However, some pagecache pages will be accessed much more frequently than less used anonymous memory. The right balance should be found here.

If swap activity is observed during slowdowns, it may be worth reducing this parameter. If there is a lot of I/O activity and the amount of pagecache in the system is rather small, or if there are large dormant applications running, increasing this value might improve performance.

Note that the more data is swapped out, the longer the system will take to swap data back in when it is needed.
/proc/sys/vm/vfs_cache_pressure
This variable controls the tendency of the kernel to reclaim the memory which is used for caching of VFS caches, versus pagecache and swap. Increasing this value increases the rate at which VFS caches are reclaimed.

It is difficult to know when this should be changed, other than by experimentation. The slabtop command (part of the package procps) shows top memory objects used by the kernel. The vfs caches are the "dentry" and the "*_inode_cache" objects. If these are consuming a large amount of memory in relation to pagecache, it may be worth trying to increase pressure. Could also help to reduce swapping. The default value is 100.

/proc/sys/vm/min_free_kbytes
This controls the amount of memory that is kept free for use by special reserves including "atomic" allocations (those which cannot wait for reclaim). This should not normally be lowered unless the system is being very carefully tuned for memory usage (normally useful for embedded rather than server applications). If "page allocation failure" messages and stack traces are frequently seen in logs, min_free_kbytes could be increased until the errors disappear. There is no need for concern, if these messages are very infrequent. The default value depends on the amount of RAM.

15.3.2 Writeback Parameters

One important change in writeback behavior since SUSE Linux Enterprise Server 10 is that modification to file-backed mmap() memory is accounted immediately as dirty memory (and subject to writeback). Whereas previously it would only be subject to writeback after it was unmapped, upon an msync() system call, or under heavy memory pressure.

Some applications do not expect mmap modifications to be subject to such writeback behavior, and performance can be reduced. Berkeley DB (and applications using it) is one known example that can cause problems. Increasing writeback ratios and times can improve this type of slowdown.

/proc/sys/vm/dirty_background_ratio
This is the percentage of the total amount of free and reclaimable memory. When the amount of dirty pagecache exceeds this percentage, writeback threads start writing back dirty memory. The default value is 10 (%).
/proc/sys/vm/dirty_ratio

Similar percentage value as above. When this is exceeded, applications that want to write to the pagecache are blocked and start performing writeback as well. The default value is 40 (%).

These two values together determine the pagecache writeback behavior. If these values are increased, more dirty memory is kept in the system for a longer time. With more dirty memory allowed in the system, the chance to improve throughput by avoiding writeback I/O and to submitting more optimal I/O patterns increases. However, more dirty memory can either harm latency when memory needs to be reclaimed or at data integrity (sync) points when it needs to be written back to disk.

15.3.3 Readahead parameters

/sys/block/<bdev>/queue/read_ahead_kb

If one or more processes are sequentially reading a file, the kernel reads some data in advance (ahead) in order to reduce the amount of time that processes have to wait for data to be available. The actual amount of data being read in advance is computed dynamically, based on how much "sequential" the I/O seems to be. This parameter sets the maximum amount of data that the kernel reads ahead for a single file. If you observe that large sequential reads from a file are not fast enough, you can try increasing this value. Increasing it too far may result in readahead thrashing where pagecache used for readahead is reclaimed before it can be used, or slowdowns due to a large amount of useless I/O. The default value is 512 (kb).

15.3.4 Further VM Parameters

For the complete list of the VM tunable parameters, see /usr/src/linux/Documentation/sysctl/vm.txt (available after having installed the kernel-source package).

15.4 Non-Uniform Memory Access (NUMA)

Another increasingly important role of the VM is to provide good NUMA allocation strategies. NUMA stands for non-uniform memory access, and most of today's mul-
ti-socket servers are NUMA machines. NUMA is a secondary concern to managing swapping and caches in terms of performance, and there are lots of documents about improving NUMA memory allocations. One particular parameter interacts with page reclaim:

/proc/sys/vm/zone_reclaim_mode

This parameter controls whether memory reclaim is performed on a local NUMA node even if there is plenty of memory free on other nodes. This parameter is automatically turned on on machines with more pronounced NUMA characteristics.

If the VM caches are not being allowed to fill all of memory on a NUMA machine, it could be due to zone_reclaim_mode being set. Setting to 0 will disable this behavior.

### 15.5 Monitoring VM Behavior

Some simple tools that can help monitor VM behavior:

1. **vmstat**: This tool gives a good overview of what the VM is doing. See Section 2.1.1, “vmstat” (page 10) for details.

2. **/proc/meminfo**: This file gives a detailed breakdown of where memory is being used. See Section 2.4.2, “Detailed Memory Usage: /proc/meminfo” (page 29) for details.

3. **slabtop**: This tool provides detailed information about kernel slab memory usage. buffer_head, dentry, inode_cache, ext3_inode_cache, etc. are the major caches. This command is available with the package procps.
Tuning the Network

The network subsystem is rather complex and its tuning highly depends on the system use scenario and also on external factors such as software clients or hardware components (switches, routers, or gateways) in your network. The Linux kernel aims more at reliability and low latency than low overhead and high throughput. Other settings can mean less security, but better performance.

16.1 Configurable Kernel Socket Buffers

Networking is largely based on the TCP/IP protocol and a socket interface for communication; for more information about TCP/IP, see Chapter 22, Basic Networking (↑Administration Guide). The Linux kernel handles data it receives or sends via the socket interface in socket buffers. These kernel socket buffers are tunable.

**IMPORTANT: TCP Autotuning**

Since kernel version 2.6.17 full autotuning with 4 MB maximum buffer size exists. This means that manual tuning in most cases will not improve networking performance considerably. It is often the best not to touch the following variables, or, at least, to check the outcome of tuning efforts carefully.

If you update from an older kernel, it is recommended to remove manual TCP tunings in favor of the autotuning feature.
The special files in the `/proc` file system can modify the size and behavior of kernel socket buffers; for general information about the `/proc` file system, see Section 2.6, “The `/proc` File System” (page 35). Find networking related files in:

```
/proc/sys/net/core
/proc/sys/net/ipv4
/proc/sys/net/ipv6
```


In the `/proc` file system, for example, it is possible to either set the Maximum Socket Receive Buffer and Maximum Socket Send Buffer for all protocols, or both these options for the TCP protocol only (in `ipv4`) and thus overriding the setting for all protocols (in `core`).

```
/proc/sys/net/ipv4/tcp_moderate_rcvbuf
   If `/proc/sys/net/ipv4/tcp_moderate_rcvbuf` is set to 1, autotuning is active and buffer size is adjusted dynamically.

/proc/sys/net/ipv4/tcp_rmem
   The three values setting the minimum, initial, and maximum size of the Memory Receive Buffer per connection. They define the actual memory usage, not just TCP window size.

/proc/sys/net/ipv4/tcp_wmem
   The same as `tcp_rmem`, but just for Memory Send Buffer per connection.

/proc/sys/net/core/rmem_max
   Set to limit the maximum receive buffer size that applications can request.

/proc/sys/net/core/wmem_max
   Set to limit the maximum send buffer size that applications can request.
```

Via `/proc` it is possible to disable TCP features that you do not need (all TCP features are switched on by default). For example, check the following files:

```
/proc/sys/net/ipv4/tcp_timestamps
   TCP timestamps are defined in RFC1323.

/proc/sys/net/ipv4/tcp_window_scaling
   TCP window scaling is also defined in RFC1323.
```
/proc/sys/net/ipv4/tcp_sack
   Select acknowledgments (SACKS).

Use `sysctl` to read or write variables of the /proc file system. `sysctl` is preferable to `cat` (for reading) and `echo` (for writing), because it also reads settings from /etc/sysctl.conf and, thus, those settings survive reboots reliably. With `sysctl` you can read all variables and their values easily; as `root` use the following command to list TCP related settings:
   
   `sysctl -a | grep tcp`

---

**NOTE: Side-Effects of Tuning Network Variables**

Tuning network variables can affect other system resources such as CPU or memory use.

---

**16.2 Detecting Network Bottlenecks and Analyzing Network Traffic**

Before starting with network tuning, it is important to isolate network bottlenecks and network traffic patterns. There are some tools that can help you with detecting those bottlenecks.

The following tools can help analyzing your network traffic: `netstat`, `tcpdump`, and `wireshark`. Wireshark is a network traffic analyzer.

---

**16.3 Netfilter**

The Linux firewall and masquerading features are provided by the Netfilter kernel modules. This is a highly configurable rule based framework. If a rule matches a packet, Netfilter accepts or denies it or takes special action (“target”) as defined by rules such as address translation.

There are quite some properties, Netfilter is able to take into account. Thus, the more rules are defined, the longer packet processing may last. Also advanced connection tracking could be rather expensive and, thus, slowing down overall networking.

When the kernel queue becomes full, all new packets are dropped, causing existing connections to fail. The ‘fail-open’ feature, available since SUSE Linux En-
terprise Server 11 SP3, allows a user to temporarily disable the packet inspection and maintain the connectivity under heavy network traffic. For reference, see https://home.regit.org/netfilter-en/using-nfqueue-and-libnetfilter_queue/.

For more information, see the home page of the Netfilter and iptables project, http://www.netfilter.org

16.4 Improving the Network Performance with Receive Packet Steering (RPS)

Modern network interface devices can move so many packets that the host can become the limiting factor for achieving maximum performance. In order to keep up, the system must be able to distribute the work across multiple CPU cores.

Some modern network interfaces can help distribute the work to multiple CPU cores through the implementation of multiple transmission and multiple receive queues in hardware. However, others are only equipped with a single queue and the driver must deal with all incoming packets in a single, serialized stream. To work around this issue, the operating system must "parallelize" the stream to distribute the work across multiple CPUs. On SUSE Linux Enterprise Server this is done via Receive Packet Steering (RPS). RPS can also be used in virtual environments.

RPS creates a unique hash for each data stream using IP addresses and port numbers. The use of this hash ensures that packets for the same data stream are sent to the same CPU, which helps to increase performance.

RPS is configured per network device receive queue and interface. The configuration file names match the following scheme:
/sys/class/net/<device>/queues/<rx-queue>/rps_cpus

where <device> is the network device, such as eth0, eth1, and <rx-queue> is the receive queue, such as rx-0, rx-1.

If the network interface hardware only supports a single receive queue, only rx-0 will exist. If it supports multiple receive queues, there will be an rx-N directory for each receive queue.
These configuration files contain a comma-delimited list of CPU bitmaps. By default, all bits are set to 0. With this setting RPS is disabled and therefore the CPU which handles the interrupt will also process the packet queue.

To enable RPS and enable specific CPUs to process packets for the receive queue of the interface, set the value of their positions in the bitmap to 1. For example, to enable CPUs 0-3 to process packets for the first receive queue for eth0, you would need to set bit positions 0-3 to 1 in binary, this value is 00001111. It needs to be converted to hex—which results in F in this case. Set this hex value with the following command:

```
echo "f" > /sys/class/net/eth0/queues/rx-0/rps_cpus
```

If you wanted to enable CPUs 8-15:

```
1111 1111 0000 0000 (binary)
15 15 0 0 (decimal)
F F 0 0 (hex)
```

The command to set the hex value of ff00 would be:

```
echo "ff00" > /sys/class/net/eth0/queues/rx-0/rps_cpus
```

On NUMA machines, best performance can be achieved by configuring RPS to use the CPUs on the same NUMA node as the interrupt for the interface's receive queue.

On non-NUMA machines, all CPUs can be used. If the interrupt rate is very high, excluding the CPU handling the network interface can boost performance. The CPU being used for the network interface can be determined from /proc/interrupts. For example:

```
root # cat /proc/interrupts

CPU0       CPU1       CPU2       CPU3
...[omitted]
51:   113915241          0          0          0      Phys-fasteoi  eth0
...[omitted]
```

In this case, CPU 0, is the only CPU processing interrupts for eth0, since only CPU0 contains a non-zero value.

On i586 and x86_64 platforms, irqbalance can be used to distribute hardware interrupts across CPUs. See man 1 irqbalance for more details.

### 16.5 For More Information

• John Heffner, Matt Mathis: “Tuning TCP for Linux 2.4 and 2.6” (2006): http://www.psc.edu/networking/projects/tcptune/#Linux
Part VI. Handling System Dumps
SUSE Linux Enterprise Server comes with a number of tools that help you obtain useful information about your system. You can use the information for various purposes, for example, to debug and find problems in your program, to discover places causing performance drops, or to trace a running process to find out what system resources it uses. The tools are mostly part of the installation media, otherwise you can install them from the downloadable SUSE Software Development Kit.

**NOTE: Tracing and Impact on Performance**

While a running process is being monitored for system or library calls, the performance of the process is heavily reduced. You are advised to use tracing tools only for the time you need to collect the data.

### 17.1 Tracing System Calls with `strace`

The `strace` command traces system calls of a process and signals received by the process. `strace` can either run a new command and trace its system calls, or you can attach `strace` to an already running command. Each line of the command's output contains the system call name, followed by its arguments in parenthesis and its return value.
To run a new command and start tracing its system calls, enter the command to be monitored as you normally do, and add `strace` at the beginning of the command line:

```
tux@mercury:~> strace ls
execve("/bin/ls", ["ls"], [/* 52 vars */]) = 0
brk(0) = 0x618000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) \
   = 0x7f9848667000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) \
   = 0x7f9848666000
access("/etc/ld.so.preload", R_OK) = -1 ENOENT \n(No such file or directory)
open("/etc/ld.so.cache", O_RDONLY) = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=200411, ...}) = 0
mmap(NULL, 200411, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f9848635000
close(3) = 0
open("/lib64/librt.so.1", O_RDONLY) = 3
[...
```

To attach `strace` to an already running process, you need to specify the `-p` with the process ID (PID) of the process that you want to monitor:

```
tux@mercury:~> strace -p `pidof mysqld`
Process 2868 attached - interrupt to quit
select(15, [13 14], NULL, NULL, NULL) = 1 (in [14])
fcntl(14, F_SETFL, O_RDWR|O_NONBLOCK) = 0
accept(14, {sa_family=AF_FILE, NULL}, [2]) = 31
fcntl(14, F_SETFL, O_RDWR) = 0
getsockname(31, {sa_family=AF_FILE, path="/var/run/mysql"}, [28]) = 0
fcntl(31, F_SETFL, O_RDWR|O_NONBLOCK) = 0
fcntl(31, F_GETFL) = 0x2 (flags O_RDWR)
[...
```
The `-e` option understands several sub-options and arguments. For example, to trace all attempts to open or write to a particular file, use the following:

```bash
strace -e trace=open,write ls -
```

```bash
open("/etc/ld.so.cache", O_RDONLY) = 3
open("/lib64/librt.so.1", O_RDONLY) = 3
open("/lib64/libselinux.so.1", O_RDONLY) = 3
open("/lib64/libacl.so.1", O_RDONLY) = 3
open("/lib64/libc.so.6", O_RDONLY) = 3
open("/lib64/libpthread.so.0", O_RDONLY) = 3
open("/usr/lib/locale/cs_CZ.utf8/LC_CTYPE", O_RDONLY) = 3
open(".", O_RDONLY|O_NONBLOCK|O_DIRECTORY|O_CLOEXEC) = 3
write(1, "addressbook.db.bak\nbinbox\ncxoffice\n"..., 311) = 311
```

To trace only network related system calls, use `-e trace=network`:

```bash
strace -e trace=network -p 26520
```

```bash
socket(PF_NETLINK, SOCK_RAW, 0) = 50
bind(50, {sa_family=AF_NETLINK, pid=0, groups=00000000}, 12) = 0
getsockname(50, {sa_family=AF_NETLINK, pid=26520, groups=00000000}, \
[12]) = 0
sendto(50, "\24\0\0\0\26\0\1\3~p\315K\0\0\0\0\0\0\0\0", 20, 0, \
{sa_family=AF_NETLINK, pid=0, groups=00000000}, 12) = 20
[...]```

The `-c` calculates the time the kernel spent on each system call:

```bash
strace -c find /etc -name xorg.conf
```

```
% time  seconds  usecs/call   calls   errors syscalls
------ ----------- ----------- --------- --------- ----------------
    32.38  0.000181     181        1   execve
    22.00  0.000123      0        576   getdents64
    19.50  0.000109      0        917 31 open
    19.14  0.000107      0        888   close
    4.11   0.000023      2        10   mprotect
    0.00   0.000000      0        1   write
[...]    0.00   0.000000      0        1  getrlimit
    0.00   0.000000      0        1  arch_prctl
    0.00   0.000000      0        3 1 futex
    0.00   0.000000      0        1 set_tid_address
    0.00   0.000000      0        4  fadvise64
    0.00   0.000000      0        1 set_robust_list
------ ----------- ----------- --------- --------- ----------------
    100.00 0.000559 3633 33 total
```

To trace all child processes of a process, use `-f`:

```bash
strace -f rcapache2 status
```

```bash
execve("/usr/sbin/rcapache2", ["rcapache2", "status"], [/* 81 vars */]) = 0
```
If you need to analyze the output of `strace` and the output messages are too long to be inspected directly in the console window, use `-o`. In that case, unnecessary messages, such as information about attaching and detaching processes, are suppressed. You can also suppress these messages (normally printed on the standard output) with `-q`. To optionally prepend timestamps to each line with a system call, use `-t`:

```
tux@mercury:~> strace -t -o strace_sleep.txt sleep 1; more strace_sleep.txt
08:44:06 execve("/bin/sleep", ["sleep", "1"], [/* 81 vars */]) = 0
08:44:06 brk(0) = 0x60600
08:44:06 mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, 
-1, 0) = 0x7fb1fff1000
08:44:06 close(3) = 0
08:44:06 nanosleep({1, 0}, NULL) = 0
08:44:07 close(1) = 0
08:44:07 close(2) = 0
08:44:07 exit_group(0) = ?
```

The behavior and output format of `strace` can be largely controlled. For more information, see the relevant manual page (man 1 strace).
17.2 Tracing Library Calls with ltrace

ltrace traces dynamic library calls of a process. It is used in a similar way to strace, and most of their parameters have a very similar or identical meaning. By default, ltrace uses /etc/ltrace.conf or ~/.ltrace.conf configuration files. You can, however, specify an alternative one with the -F config_file option.

In addition to library calls, ltrace with the -S option can trace system calls as well:

tux@mercury:~> ltrace -S -o ltrace_find.txt find /etc -name xorg.conf; more ltrace_find.txt

SYS_brk(NULL)                                              = 0x00628000
SYS_mmap(0, 4096, 3, 34, 0xffffffff)                       = 0x7f1327ea1000
SYS_mmap(0, 4096, 3, 34, 0xffffffff)                       = 0x7f1327ea0000
[[...]]
fnmatch("xorg.conf", "xorg.conf", 0)                       = 0
free(0x0062db80)                                           = <void>
__errno_location()                                         = 0x7f1327e5d698
__ctype_get_mb_cur_max(0x7fff25227af0, 8192, 0x62e020, -1, 0) = 6
__ctype_get_mb_cur_max(0x7fff25227af0, 18, 0x7f1327e5d6f0, 0x7fff25227af0, 0x62e031) = 6
__fprintf_chk(0x7f1327821780, 1, 0x420cf7, 0x7fff25227af0, 0x62e031
<unfinished ...>
SYS_fstat(1, 0x7fff25227230)                               = 0
SYS_mmap(0, 4096, 3, 34, 0xffffffff)                       = 0x7f1327e72000
SYS_write(1, "/etc/X11/xorg.conf
", 19)                   = 19
[[...]]

You can change the type of traced events with the -e option. The following example prints library calls related to fnmatch and strlen functions:

tux@mercury:~> ltrace -e fnmatch,strlen find /etc -name xorg.conf

[[...]]
fnmatch("xorg.conf", "xorg.conf", 0)             = 0
strlen("Xresources")                             = 10
strlen("Xresources")                             = 10
strlen("Xresources")                             = 10
fnmatch("xorg.conf", "Xresources", 0)            = 1
strlen("xorg.conf.install")                      = 17
[[...]]

To display only the symbols included in a specific library, use -l /path/to/library:

tux@mercury:~> ltrace -l /lib64/librt.so.1 sleep 1
clock_gettime(1, 0x7fff4b5c34d0, 0, 0, 0) = 0
clock_gettime(1, 0x7fff4b5c34c0, 0xffffffff600180, -1, 0) = 0
+++ exited (status 0) +++

You can make the output more readable by indenting each nested call by the specified number of space with the \(-n\) num_of_spaces.

17.3 Debugging and Profiling with Valgrind

Valgrind is a set of tools to debug and profile your programs so that they can run faster and with less errors. Valgrind can detect problems related to memory management and threading, or can also serve as a framework for building new debugging tools.

17.3.1 Installation

Valgrind is not shipped with standard SUSE Linux Enterprise Server distribution. To install it on your system, you need to obtain SUSE Software Development Kit, and either install it as an Add-On product and run

\texttt{zypper install valgrind}

or browse through the SUSE Software Development Kit directory tree, locate the Valgrind package and install it with

\texttt{rpm -i valgrind\textasciitilde version\_architecture.rpm}

17.3.2 Supported Architectures

Valgrind runs on the following architectures:

- i386
- x86\_64 (AMD-64)
- ppc
• ppc64
• System z

17.3.3 General Information

The main advantage of Valgrind is that it works with existing compiled executables. You do not have to recompile or modify your programs to make use of it. Run Valgrind like this:

```
valgrind valgrind_options your-prog your-program-options
```

Valgrind consists of several tools, and each provides specific functionality. Information in this section is general and valid regardless of the used tool. The most important configuration option is --tool. This option tells Valgrind which tool to run. If you omit this option, memcheck is selected by default. For example, if you want to run find ~ -name .bashrc with Valgrind's memcheck tools, enter the following in the command line:

```
valgrind --tool=memcheck find ~ -name .bashrc
```

A list of standard Valgrind tools with a brief description follows:

**memcheck**
- Detects memory errors. It helps you tune your programs to behave correctly.

**cachegrind**
- Profiles cache prediction. It helps you tune your programs to run faster.

**callgrind**
- Works in a similar way to cachegrind but also gathers additional cache-profiling information.

**exp-drd**
- Detects thread errors. It helps you tune your multi-threaded programs to behave correctly.

**helgrind**
- Another thread error detector. Similar to exp-drd but uses different techniques for problem analysis.
massif
A heap profiler. Heap is an area of memory used for dynamic memory allocation. This tool helps you tune your program to use less memory.

lackey
An example tool showing instrumentation basics.

17.3.4 Default Options
Valgrind can read options at start-up. There are three places which Valgrind checks:

1. The file `.valgrindrc` in the home directory of the user who runs Valgrind.

2. The environment variable `$VALGRIND_OPTS`

3. The file `.valgrindrc` in the current directory where Valgrind is run from.

These resources are parsed exactly in this order, while later given options take precedence over earlier processed options. Options specific to a particular Valgrind tool must be prefixed with the tool name and a colon. For example, if you want cachegrind to always write profile data to the `/tmp/cachegrind_PID.log`, add the following line to the `.valgrindrc` file in your home directory:

```
--cachegrind:cachegrind-out-file=/tmp/cachegrind_%p.log
```

17.3.5 How Valgrind Works
Valgrind takes control of your executable before it starts. It reads debugging information from the executable and related shared libraries. The executable's code is redirected to the selected Valgrind tool, and the tool adds its own code to handle its debugging. Then the code is handed back to the Valgrind core and the execution continues.

For example, memcheck adds its code, which checks every memory access. As a consequence, the program runs much slower than in the native execution environment.

Valgrind simulates every instruction of your program. Therefore, it not only checks the code of your program, but also all related libraries (including the C library), libraries used for graphical environment, and so on. If you try to detect errors with Valgrind, it also detects errors in associated libraries (like C, X11, or Gtk libraries). Because you
probably do not need these errors, Valgrind can selectively, suppress these error mes-
sages to suppression files. The --gen-suppressions=yes tells Valgrind to re-
port these suppressions which you can copy to a file.

Note that you should supply a real executable (machine code) as an Valgrind argument. 
Therefore, if your application is run, for example, from a shell or a Perl script you will 
by mistake get error reports related to /bin/sh (or /usr/bin/perl). In such 
case, you can use --trace-children=yes or, which is better, supply a real exe-
cutable to avoid any processing confusion.

17.3.6 Messages

During its runtime, Valgrind reports messages with detailed errors and important 
events. The following example explains the messages:

tux@mercury:~> valgrind --tool=memcheck find ~ -name .bashrc 
[...] ==6558== Conditional jump or move depends on uninitialised value(s) 
==6558== at 0x400AE79: _dl_relocate_object (in /lib64/ld-2.11.1.so) 
==6558== by 0x4003868: dl_main (in /lib64/ld-2.11.1.so) 
[...] ==6558== Conditional jump or move depends on uninitialised value(s) 
==6558== at 0x400AE82: _dl_relocate_object (in /lib64/ld-2.11.1.so) 
==6558== by 0x4003868: dl_main (in /lib64/ld-2.11.1.so) 
[...] ==6558== ERROR SUMMARY: 2 errors from 2 contexts (suppressed: 0 from 0) 
==6558== malloc/free: in use at exit: 2,228 bytes in 8 blocks. 
==6558== malloc/free: 235 allocs, 227 frees, 489,675 bytes allocated. 
==6558== For counts of detected errors, rerun with: -v 
==6558== searching for pointers to 8 not-freed blocks. 
==6558== checked 122,584 bytes. 
==6558== 
==6558== LEAK SUMMARY: 
==6558== definitely lost: 0 bytes in 0 blocks. 
==6558== possibly lost: 0 bytes in 0 blocks. 
==6558== still reachable: 2,228 bytes in 8 blocks. 
==6558== suppressed: 0 bytes in 0 blocks. 
==6558== Rerun with --leak-check=full to see details of leaked memory.

The ==6558== introduces Valgrind's messages and contains the process ID number
(PID). You can easily distinguish Valgrind's messages from the output of the program
itself, and decide which messages belong to a particular process.

To make Valgrind's messages more detailed, use -v or even -v -v.

Basically, you can make Valgrind send its messages to three different places:
1. By default, Valgrind sends its messages to the file descriptor 2, which is the standard error output. You can tell Valgrind to send its messages to any other file descriptor with the --log-fd=file_descriptor_number option.

2. The second and probably more useful way is to send Valgrind's messages to a file with --log-file=filename. This option accepts several variables, for example, %p gets replaced with the PID of the currently profiled process. This way you can send messages to different files based on their PID. %q{env_var} is replaced with the value of the related env_var environment variable.

The following example checks for possible memory errors during the Apache Web server restart, while following children processes and writing detailed Valgrind's messages to separate files distinguished by the current process PID:

```bash
tux@mercury:~> valgrind -v --tool=memcheck --trace-children=yes \
--log-file=valgrind_pid_%p.log rcapache2 restart
```

This process created 52 log files in the testing system, and took 75 seconds instead of the usual 7 seconds needed to run rcapache2 restart without Valgrind, which is approximately 10 times more.

```bash
tux@mercury:~> ls -1 valgrind_pid_*log
valgrind_pid_11780.log
valgrind_pid_11782.log
valgrind_pid_11783.log
[...]
valgrind_pid_11860.log
valgrind_pid_11862.log
valgrind_pid_11863.log
```

3. You may also prefer to send the Valgrind's messages over the network. You need to specify the aa.bb.cc.dd IP address and port_num port number of the network socket with the --log-socket=aa.bb.cc.dd:port_num option. If you omit the port number, 1500 will be used.

It is useless to send Valgrind's messages to a network socket if no application is capable of receiving them on the remote machine. That is why valgrind-listener, a simple listener, is shipped together with Valgrind. It accepts connections on the specified port and copies everything it receives to the standard output.

### 17.3.7 Error Messages

Valgrind remembers all error messages, and if it detects a new error, the error is compared against old error messages. This way Valgrind checks for duplicate error mes-
sages. In case of a duplicate error, it is recorded but no message is shown. This mechanism prevents you from being overwhelmed by millions of duplicate errors.

The `-v` option will add a summary of all reports (sorted by their total count) to the end of the Valgrind's execution output. Moreover, Valgrind stops collecting errors if it detects either 1000 different errors, or 10 000 000 errors in total. If you want to suppress this limit and wish to see all error messages, use `--error-limit=no`.

Some errors usually cause other ones. Therefore, fix errors in the same order as they appear and re-check the program continuously.

### 17.4 For More Information

- For a complete list of options related to the described tracing tools, see the corresponding man page (man 1 strace, man 1 ltrace, and man 1 valgrind).

- To describe advanced usage of Valgrind is beyond the scope of this document. It is very well documented, see Valgrind User Manual [http://valgrind.org/docs/manual/manual.html]. These pages are indispensable if you need more advanced information on Valgrind or the usage and purpose of its standard tools.
kexec and kdump

kexec is a tool to boot to another kernel from the currently running one. You can perform faster system reboots without any hardware initialization. You can also prepare the system to boot to another kernel if the system crashes.

18.1 Introduction

With kexec, you can replace the running kernel with another one without a hard reboot. The tool is useful for several reasons:

- Faster system rebooting
  
  If you need to reboot the system frequently, kexec can save you significant time.

- Avoiding unreliable firmware and hardware

  Computer hardware is complex and serious problems may occur during the system start-up. You cannot always replace unreliable hardware immediately. kexec boots the kernel to a controlled environment with the hardware already initialized. The risk of unsuccessful system start is then minimized.

- Saving the dump of a crashed kernel

  kexec preserves the contents of the physical memory. After the *production* kernel fails, the *capture* kernel (an additional kernel running in a reserved memory range) saves the state of the failed kernel. The saved image can help you with the subsequent analysis.
• Booting without GRUB or LILO configuration

When the system boots a kernel with kexec, it skips the boot loader stage. Normal booting procedure can fail due to an error in the boot loader configuration. With kexec, you do not depend on a working boot loader configuration.

18.2 Required Packages

If you intend to use kexec on SUSE® Linux Enterprise Server to speed up reboots or avoid potential hardware problems, you need to install the kexec-tools package. It contains a script called kexec-bootloader, which reads the boot loader configuration and runs kexec with the same kernel options as the normal boot loader does. kexec-bootloader -h gives you the list of possible options.

To set up an environment that helps you obtain useful debug information in case of a kernel crash, you need to install makedumpfile in addition.

The preferred method to use kdump in SUSE Linux Enterprise Server is through the YaST kdump module. Install the package yast2-kdump by entering zypper install yast2-kdump in the command line as root.

18.3 kexec Internals

The most important component of kexec is the /sbin/kexec command. You can load a kernel with kexec in two different ways:

• kexec -l kernel_image loads the kernel to the address space of a production kernel for a regular reboot. You can later boot to this kernel with kexec -e.

• kexec -p kernel_image loads the kernel to a reserved area of memory. This kernel will be booted automatically when the system crashes.

If you want to boot another kernel and preserve the data of the production kernel when the system crashes, you need to reserve a dedicated area of the system memory. The production kernel never loads to this area because it must be always available. It is used for the capture kernel so that the memory pages of the production kernel can be preserved. You reserve the area with crashkernel = size@offset as a command line parameter of the production kernel. Note that this is not a parameter of the capture kernel. The capture kernel does not use kexec at all.
The capture kernel is loaded to the reserved area and waits for the kernel to crash. Then kdump tries to invoke the capture kernel because the production kernel is no longer reliable at this stage. This means that even kdump can fail.

To load the capture kernel, you need to include the kernel boot parameters. Usually, the initial RAM file system is used for booting. You can specify it with --initrd = filename. With --append = cmdline, you append options to the command line of the kernel to boot. It is helpful to include the command line of the production kernel if these options are necessary for the kernel to boot. You can simply copy the command line with --append = "$(cat /proc/cmdline)" or add more options with --append = "$(cat /proc/cmdline) more_options".

You can always unload the previously loaded kernel. To unload a kernel that was loaded with the -l option, use the kexec -u command. To unload a crash kernel loaded with the -p option, use kexec -p -u command.

## 18.4 Basic kexec Usage

To verify if your kexec environment works properly, follow these steps:

1. Make sure no users are currently logged in and no important services are running on the system.
2. Log in as root.
3. Switch to runlevel 1 with telinit 1
4. Load the new kernel to the address space of the production kernel with the following command:

   `kexec -l /boot/vmlinuz --append="$(cat /proc/cmdline)" --initrd=/boot/initrd`

5. Unmount all mounted file systems except the root file system with umount -a

---

**IMPORTANT: Unmounting Root Filesystem**

Unmounting all file systems will most likely produce a device is busy warning message. The root file system cannot be unmounted if the system is running. Ignore the warning.
6 Remount the root file system in read-only mode:

   mount -o remount,ro /

7 Initiate the reboot of the kernel that you loaded in Step 4 (page 207) with kexec -e

It is important to unmount the previously mounted disk volumes in read-write mode. The reboot system call acts immediately upon calling. Hard drive volumes mounted in read-write mode neither synchronize nor unmount automatically. The new kernel may find them “dirty”. Read-only disk volumes and virtual file systems do not need to be unmounted. Refer to /etc/mtab to determine which file systems you need to unmount.

The new kernel previously loaded to the address space of the older kernel rewrites it and takes control immediately. It displays the usual start-up messages. When the new kernel boots, it skips all hardware and firmware checks. Make sure no warning messages appear. All the file systems are supposed to be clean if they had been unmounted.

18.5 How to Configure kexec for Routine Reboots

kexec is often used for frequent reboots. For example, if it takes a long time to run through the hardware detection routines or if the start-up is not reliable.

---

**NOTE: Rebooting with kexec**

In previous versions of SUSE® Linux Enterprise Server, you had to manually edit the configuration file /etc/sysconfig/shutdown and the init script /etc/init.d/halt to use kexec to reboot the system. You no longer need to edit any system files, since version 11 is already configured for kexec reboots.

Note that firmware as well as the boot loader are not used when the system reboots with kexec. Any changes you make to the boot loader configuration will be ignored until the computer performs a hard reboot.
18.6 Basic kdump Configuration

You can use kdump to save kernel dumps. If the kernel crashes, it is useful to copy the memory image of the crashed environment to the file system. You can then debug the dump file to find the cause of the kernel crash. This is called “core dump”.

kdump works similar to kexec (see Chapter 18, kexec and kdump (page 205)). The capture kernel is executed after the running production kernel crashes. The difference is that kexec replaces the production kernel with the capture kernel. With kdump, you still have access to the memory space of the crashed production kernel. You can save the memory snapshot of the crashed kernel in the environment of the kdump kernel.

---

**TIP: Dumps over Network**

In environments with limited local storage, you need to set up kernel dumps over the network. kdump supports configuring the specified network interface and bringing it up via initrd. Both LAN and VLAN interfaces are supported. You have to specify the network interface and the mode (dhcp or static) either with YaST, or using the KDUMP_NETCONFIG option in the /etc/sysconfig/kdump file. The third way is to build initrd manually, for example with

```
/sbin/mkinitrd -D vlan0
```

for a dhcp VLAN interface, or

```
/sbin/mkinitrd -I eth0
```

for a static LAN interface.

---

You can either configure kdump manually or with YaST.

---

**IMPORTANT: Target Filesystem for kdump Must Be Mounted During Configuration**

When configuring kdump, you can specify a location to which the dumped images will be saved (default: /var/crash). This location must be mounted when configuring kdump, otherwise the configuration will fail.
18.6.1 Manualkdump Configuration

kdump reads its configuration from the `/etc/sysconfig/kdump` file. To make sure that kdump works on your system, its default configuration is sufficient. To use kdump with the default settings, follow these steps:

1. Append the following kernel command line option to your boot loader configuration, and reboot the system:

   ```
   crashkernel=size@offset
   ```

   You can find the corresponding values for `size` and `offset` in the following table:

   **Table 18.1: Recommended Values for Additional Kernel Command Line Parameters**

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Recommended value</th>
</tr>
</thead>
</table>
   | i386 and x86-64 | crashkernel=256M for 0 - 12 GB memory  
   |               | crashkernel=512M for 13 - 48 GB memory  
   |               | crashkernel=768M for more than 48 GB memory |
   | IA64 | crashkernel=256M (small systems)  
   |       | or crashkernel=512M (larger systems) |
   | ppc64 | crashkernel=128M@4M or  
   |       | crashkernel=256M@4M (larger systems) |
   | s390x | crashkernel=128M (small systems)  
   |       | or crashkernel=256M (larger systems) |

2. Enable kdump init script:
chkconfig boot.kdump on

3 You can edit the options in /etc/sysconfig/kdump. Reading the comments will help you understand the meaning of individual options.

4 Execute the init script once with rchkdump start, or reboot the system.

After configuring kdump with the default values, check if it works as expected. Make sure that no users are currently logged in and no important services are running on your system. Then follow these steps:

1 Switch to runlevel 1 with telinit 1

2 Unmount all the disk file systems except the root file system with umount -a

3 Remount the root file system in read-only mode: mount -o remount,ro /

4 Invoke “kernel panic” with the procfs interface to Magic SysRq keys:

   echo c >/proc/sysrq-trigger

---

**IMPORTANT: The Size of Kernel Dumps**

The KDUMP_KEEP_OLD_DUMPS option controls the number of preserved kernel dumps (default is 5). Without compression, the size of the dump can take up to the size of the physical RAM memory. Make sure you have sufficient space on the /var partition.

The capture kernel boots and the crashed kernel memory snapshot is saved to the file system. The save path is given by the KDUMP_SAVEDIR option and it defaults to /var/crash. If KDUMP_IMMEDIATE_REBOOT is set to yes, the system automatically reboots the production kernel. Log in and check that the dump has been created under /var/crash.

---

**WARNING: Screen Freezes in X11 Session**

When kdump takes control and you are logged in an X11 session, the screen will freeze without any notice. Some kdump activity can be still visible (for example, deformed messages of a booting kernel on the screen).
Do not reset the computer because kdump always needs some time to complete its task.

18.6.2 YaST Configuration

In order to configure kdump with YaST, you need to install the \texttt{yast2-kdump} package. Then either start the \textit{Kernel Kdump} module in the \textit{System} category of YaST Control Center, or enter \texttt{yast2 kdump} in the command line as \texttt{root}.

\textbf{Figure 18.1: YaST2 Kdump Module - Start-Up Page}

In the \textit{Start-Up} window, select \textit{Enable Kdump}. The default value for kdump memory is sufficient on most systems.

Click \textit{Dump Filtering} in the left pane, and check what pages to include in the dump. You do not need to include the following memory content to be able to debug kernel problems:

- Pages filled with zero
- Cache pages
- User data pages
- Free pages
In the *Dump Target* window, select the type of the dump target and the URL where you want to save the dump. If you selected a network protocol, such as FTP or SSH, you need to enter relevant access information as well.

Fill the *Email Notification* window information if you want kdump to inform you about its events via E-mail and confirm your changes with *OK* after fine tuning kdump in the *Expert Settings* window. kdump is now configured.

## 18.7 Analyzing the Crash Dump

After you obtain the dump, it is time to analyze it. There are several options.

The original tool to analyze the dumps is GDB. You can even use it in the latest environments, although it has several disadvantages and limitations:

- GDB was not specifically designed to debug kernel dumps.
- GDB does not support ELF64 binaries on 32-bit platforms.
- GDB does not understand other formats than ELF dumps (it cannot debug compressed dumps).

That is why the *crash* utility was implemented. It analyzes crash dumps and debugs the running system as well. It provides functionality specific to debugging the Linux kernel and is much more suitable for advanced debugging.

If you want to debug the Linux kernel, you need to install its debugging information package in addition. Check if the package is installed on your system with `zypper se kernel | grep debug`.

### IMPORTANT: Repository for Packages with Debugging Information

If you subscribed your system for online updates, you can find “debuginfo” packages in the `*-Debuginfo-Updates` online installation repository relevant for SUSE Linux Enterprise Server 11 SP4. Use YaST to enable the repository.

To open the captured dump in *crash* on the machine that produced the dump, use a command like this:

```
crash /boot/vmlinux-2.6.32.8-0.1-default.gz /var/crash/2010-04-23-11:17/vmcore
```
The first parameter represents the kernel image. The second parameter is the dump file captured by kdump. You can find this file under /var/crash by default.

18.7.1 Kernel Binary Formats

The Linux kernel comes in Executable and Linkable Format (ELF). This file is usually called vmlinux and is directly generated in the compilation process. Not all boot loaders, especially on x86 (i386 and x86_64) architecture, support ELF binaries. The following solutions exist on different architectures supported by SUSE® Linux Enterprise Server.

18.7.1.1 x86 (i386 and x86_64)

Mostly for historic reasons, the Linux kernel consists of two parts: the Linux kernel itself (vmlinux) and the setup code run by the boot loader.

These two parts are linked together in a file called bzImage, which can be found in the kernel source tree. The file is now called vmlinux (note z vs. x) in the kernel package.

The ELF image is never directly used on x86. Therefore, the main kernel package contains the vmlinux file in compressed form called vmlinux.gz.

To sum it up, an x86 SUSE kernel package has two kernel files:

- vmlinuz which is executed by the boot loader.
- vmlinux.gz, the compressed ELF image that is required by crash and GDB.

18.7.1.2 IA64

The elilo boot loader, which boots the Linux kernel on the IA64 architecture, supports loading ELF images (even compressed ones) out of the box. The IA64 kernel package contains only one file called vmlinux. It is a compressed ELF image. vmlinuz on IA64 is the same as vmlinux.gz on x86.

18.7.1.3 PPC and PPC64

The yaboot boot loader on PPC also supports loading ELF images, but not compressed ones. In the PPC kernel package, there is an ELF Linux kernel file vmlinux. Considering crash, this is the easiest architecture.
If you decide to analyze the dump on another machine, you must check both the architecture of the computer and the files necessary for debugging.

You can analyze the dump on another computer only if it runs a Linux system of the same architecture. To check the compatibility, use the command `uname -i` on both computers and compare the outputs.

If you are going to analyze the dump on another computer, you also need the appropriate files from the kernel and kernel debug packages.

1. Put the kernel dump, the kernel image from `/boot`, and its associated debugging info file from `/usr/lib/debug/boot` into a single empty directory.

2. Additionally, copy the kernel modules from `/lib/modules/$(uname -r)/kernel/` and the associated debug info files from `/usr/lib/debug/lib/modules/$(uname -r)/kernel/` into a subdirectory named `modules`.

3. In the directory with the dump, the kernel image, its debug info file, and the `modules` subdirectory, launch the crash utility: `crash vmlinux-version vmcore`.

**NOTE: Support for Kernel Images**

Compressed kernel images (gzip, not the bzImage file) are supported by SUSE packages of crash since SUSE® Linux Enterprise Server 11. For older versions, you have to extract the `vmlinux.gz` (x86) or the `vmlinuz` (IA64) to `vmlinux`.

Regardless of the computer on which you analyze the dump, the crash utility will produce an output similar to this:

```
tux@mercury:~> crash /boot/vmlinux-2.6.32.8-0.1-default.gz
/var/crash/2010-04-23-11:17/vmcore

crash 4.0-7.6
Copyright (C) 2004, 2005, 2006 IBM Corporation
Copyright (C) 1999-2006 Hewlett-Packard Co
Copyright (C) 2005, 2006 Fujitsu Limited
Copyright (C) 2006, 2007 VA Linux Systems Japan K.K.
Copyright (C) 2005 NEC Corporation
This program is free software, covered by the GNU General Public License,
and you are welcome to change it and/or distribute copies of it under
```
certain conditions. Enter "help copying" to see the conditions.
This program has absolutely no warranty. Enter "help warranty" for details.

GNU gdb 6.1
Copyright 2004 Free Software Foundation, Inc.
GDB is free software, covered by the GNU General Public License, and you are
welcome to change it and/or distribute copies of it under certain
conditions.
Type "show copying" to see the conditions.
There is absolutely no warranty for GDB. Type "show warranty" for details.
This GDB was configured as "x86_64-unknown-linux-gnu"...

KERNEL: /boot/vmlinux-2.6.32.8-0.1-default.gz
DEBUGINFO: /usr/lib/debug/boot/vmlinux-2.6.32.8-0.1-default.debug
CPUS: 2
DATE: Thu Apr 23 13:17:01 2010
UPTIME: 00:10:41
LOAD AVERAGE: 0.01, 0.09, 0.09
TASKS: 42
NODENAME: eros
RELEASE: 2.6.32.8-0.1-default
VERSION: #1 SMP 2010-03-31 14:50:44 +0200
MACHINE: x86_64 (2999 Mhz)
MEMORY: 1 GB
PANIC: "SysRq : Trigger a crashdump"
PID: 9446
COMMAND: "bash"

The command output prints first useful data: There were 42 tasks running at the mo-
ment of the kernel crash. The cause of the crash was a SysRq trigger invoked by the
task with PID 9446. It was a Bash process because the `echo` that has been used is an
internal command of the Bash shell.

The `crash` utility builds upon GDB and provides many useful additional commands. If
you enter `bt` without any parameters, the backtrace of the task running at the moment
of the crash is printed:

```
crash> bt
PID: 9446   TASK: ffff88003a57c3c0   CPU: 1   COMMAND: "bash"
#0 [fff880037169db0] crash_kexec at ffffffff80268fd6
#1 [fff880037169e80] __handle_sysrq at ffffffff803d50ed
#2 [fff880037169ec0] write_sysrq_trigger at ffffffff802f6fc5
#3 [fff880037169ed0] proc_reg_write at ffffffff802f68b
#4 [fff880037169f10] vfs_write at ffffffff802b1aba
#5 [fff880037169f40] sys_write at ffffffff802b1c1f
```
Now it is clear what happened: The internal `echo` command of Bash shell sent a character to `/proc/sysrq-trigger`. After the corresponding handler recognized this character, it invoked the `crash_kexec()` function. This function called `panic()` and kdump saved a dump.

In addition to the basic GDB commands and the extended version of `bt`, the crash utility defines many other commands related to the structure of the Linux kernel. These commands understand the internal data structures of the Linux kernel and present their contents in a human readable format. For example, you can list the tasks running at the moment of the crash with `ps`. With `sym`, you can list all the kernel symbols with the corresponding addresses, or inquire an individual symbol for its value. With `files`, you can display all the open file descriptors of a process. With `kmem`, you can display details about the kernel memory usage. With `vm`, you can inspect the virtual memory of a process, even at the level of individual page mappings. The list of useful commands is very long and many of these accept a wide range of options.

The commands that we mentioned reflect the functionality of the common Linux commands, such as `ps` and `lsof`. If you would like to find out the exact sequence of events with the debugger, you need to know how to use GDB and to have strong debugging skills. Both of these are out of the scope of this document. In addition, you need to understand the Linux kernel. Several useful reference information sources are given at the end of this document.

### 18.8 Advanced kdump Configuration

The configuration for kdump is stored in `/etc/sysconfig/kdump`. You can also use YaST to configure it. kdump configuration options are available under `System > Kernel Kdump` in YaST Control Center. The following kdump options may be useful for you:
You can change the directory for the kernel dumps with the **KDUMP_SAVEDIR** option. Keep in mind that the size of kernel dumps can be very large. kdump will refuse to save the dump if the free disk space, subtracted by the estimated dump size, drops below the value specified by the **KDUMP_FREE_DISK_SIZE** option. Note that KDUMP_SAVEDIR understands URL format `protocol://specification`, where `protocol` is one of file, ftp, sftp, nfs or cifs, and `specification` varies for each protocol. For example, to save kernel dump on an FTP server, use the following URL as a template: `ftp://username:password@ftp.example.com:123/var/crash`.

Kernel dumps are usually huge and contain many pages that are not necessary for analysis. With **KDUMP_DUMPLEVEL** option, you can omit such pages. The option understands numeric value between 0 and 31. If you specify 0, the dump size will be largest. If you specify 31, it will produce the smallest dump. For a complete table of possible values, see the manual page of `kdump` (`man 7 kdump`).

Sometimes it is very useful to make the size of the kernel dump smaller. For example, if you want to transfer the dump over the network, or if you need to save some disk space in the dump directory. This can be done with **KDUMP_DUMPFORMAT** set to `compressed`. The `crash` utility supports dynamic decompression of the compressed dumps.

---

**IMPORTANT: Changes to kdump Configuration File**

You always need to execute `rckdump restart` after you make manual changes to `/etc/sysconfig/kdump`. Otherwise these changes will take effect next time you reboot the system.

---

**18.9 For More Information**

Since there is no single comprehensive reference to kexec and kdump usage, you have to explore several resources to get the information you need. Here are some of them:

- For the kexec utility usage, see the manual page of `kexec` (`man 8 kexec`).

• For more details on kdump specific to SUSE Linux, see http://ftp.suse.com/pub/people/tiwaitiwaikdump-training/kdump-training.pdf.


For more details on crash dump analysis and debugging tools, use the following resources:

• In addition to the info page of GDB (info gdb), you might want to read the printable guides at http://sourceware.org/gdb/documentation/.

• A white paper with a comprehensive description of the crash utility usage can be found at http://people.redhat.com/andersson/crash_whitepaper/.

• The crash utility also features a comprehensive online help. Just write help command to display the online help for command.

• If you have the necessary Perl skills, you can use Alicia to make the debugging easier. This Perl-based front end to the crash utility can be found at http://alicia.sourceforge.net/.

• If you prefer Python instead, you may want to install Pykdump. This package helps you control GDB through Python scripts and can be downloaded from http://sf.net/projects/pykdump.

• A very comprehensive overview of the Linux kernel internals is given in Understanding the Linux Kernel by Daniel P. Bovet and Marco Cesati (ISBN 978-0-596-00565-8).
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