703013 PS Operating Systems (Betriebssysteme)
A Short Introduction to Linux/Unix

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* based on material by Stefan Podlipnig and many others

General Information on UNIX

- Multi-user OS developed in the 1970s
- Many derivatives and UNIX-like operating systems
  - Linux!
- Many significant properties
  - hierarchical file systems
  - single interface for data, device and inter-process communication
  - background processes
  - synchronous and asynchronous operation
  - filter programs (cut, grep, sed, …)
  - highly portable

Once Upon a Time…

- First UNIX version developed 1969 by AT&T (Bell Labs)
  - Ken Thompson, Dennis Ritchie, Brian Kernighan, Douglas McIlroy, Joe Ossanna
  - written in assembler code
- Over time, many different variants formed
  - BSD-Systems (Univ. California), HP-UX (Hewlett Packard), DG/UX (Data General), AIX (IBM), IRIX (Silicon Graphics), Solaris (Oracle), Mac OS X (Apple), …
- Standardization was inevitable

Standardization in and around UNIX

- ISO C
  - American National Standards Institute (ANSI)
  - Standard for C Programming Language
- Portable Operating System Interface (POSIX)
  - Institute of Electrical and Electronics Engineers (IEEE)
  - Family of standards (system interfaces, threads, shells, …)
  - POSIX is based on UNIX but not limited to it
    - POSIX also supported by other operating systems
- Single UNIX Specification
  - required to use “UNIX” trademark, built around POSIX
  - but very few BSD or LINUX systems submitted for compliance

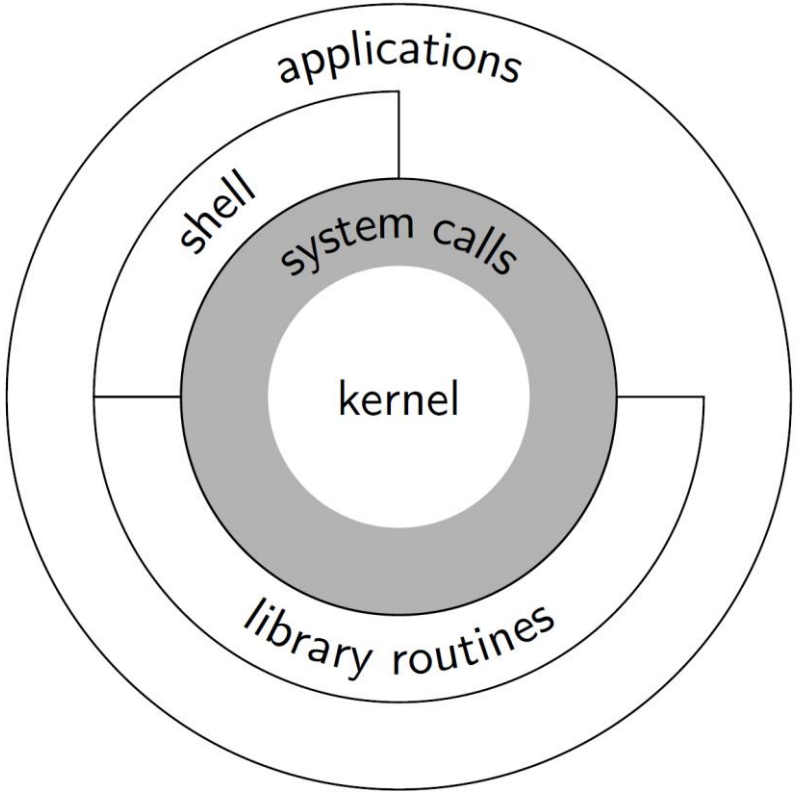
UNIX Implementations

- Mostly done by companies

- Three major players
  - System V Release 4 (SVR 4)
    - Unix System Laboratories (USL), AT&T
    - SVR 4 meets POSIX standard requirements
    - Covers large class of UNIX derivatives (e.g. Solaris)
  - Berkley Software Distribution (BSD)
    - University of California at Berkeley (UCB)
    - Covers large class of UNIX derivatives (e.g. FreeBSD, Mac OS X)
  - Linux
    - public domain (GNU license)
    - Holds features of SVR 4, POSIX and BSD family

UNIX Architecture

- System core
  - interface for direct hardware access (e.g. peripheral devices, memory, CPU)
- System calls
  - interface to the core
- Library calls
  - frequently-used features (e.g. printf in stdio.h of libc)
- Shell
  - interface for executing applications
- Applications



UNIX Shell

- Main interface to the system
- Is an interpreter
  - takes a command
  - interprets it
  - executes it
  - waits for the next command
- Standard composition of commands
  - command [flags…] [files…]
  - e.g. `ls -l start1.txt start2.txt`
  - e.g. `cd /tmp`
  - e.g. `pwd`

The Single Most Important Command: man

- Offers access to the manpages (documentation for each command and its options)
- man <command>
  - Examples
    - `man ls` – shows the documentation for the command `ls` (in section 1)
    - `man 5 config-file` – shows the documentation for `config-file` in section 5
    - `man -k query` – lists the manpages that contain `query`
    - `man man` – shows the manpage for man
    - `man intro` – shows an introduction to user commands
- A manpage usually exceeds the available space on the screen
  - navigation keys plus shortcuts: **d** (half page down), **u** (half page up), ...
  - hit **/** to search within the man page, use **n** and **N** to navigate between results
  - hit **q** to quit the man page

My $HOME is my Castle

- When starting a shell, the current directory is the home directory
- pwd – prints the current working directory
  - e.g. /home/foo
- Differences with regard to Windows
  - directories are separated by a slash (/), not a backslash (\)
  - there are no drive letters, everything is located in the root directory /
  - Linux/UNIX is case sensitive
  - file endings (e.g. .txt, .pdf) are often omitted
    - e.g. `.gitignore`, `filewithnoending`
    - use `file <filename>` command to determine its type based on its contents
  - executable files often have no ending

UNIX File System (1/2)

- Hierarchical tree structure
- The root is simply /
- Individual file path components are separated by /
- Each component is a directory (or at the end a file)
  - e.g. `/usr/sbin/bzip2`
  - where usr and sbin are directories and bzip2 is a file
- Access is controlled via permissions
  - read
  - write
  - execute

UNIX File System (2/2)

- Important commands
  - `pwd` – show the current working directory
  - `cd` – change directory (if no argument given ➔ changes to $HOME)
  - `mkdir`, `rmdir` – make or remove directories
- Absolute and relative paths are possible
  - absolute paths start with / and start from the root
    - `cd /etc/init.d`
  - relative paths do not start with / and start from the current directory
    - `cd foo/bar`
- Special placeholders
  - `.` is the current directory
  - `..` is the parent directory
  - $HOME or ~ is the home directory of the current user

Working With Files (1/3)

- `ls` – list the contents of a directory
- `ls -l` – list the contents using the “long” format (including permissions)
- `file` – show type information regarding a file

- Wildcards
  - `?` represents a single character
  - `*` represents 0 or multiple characters
  - `[b-d]` represents b, c, or d
  - `{conf,loc}` represents either `conf` or `loc`
  - note: wildcards are interpreted by the shell, not the command (e.g. executable) itself

Working With Files (2/3): Wildcard Examples

- Examples
  - files in the current directory:

```
date, out1, out2, out3, outer, prog.f, prog.o
```

Pattern	Match
`out?`	`out1, out2, out3`
`prog.[fo]`	`prog.f, prog.o`
`*`	`date, out1, out2, out3, outer, prog.f, prog.o`
`*.f`	`prog.f`
`out*`	`out1, out2, out3, outer`

Working With Files (3/3)

- `cat` – print the contents of a file on the screen
- `less` – does the same, but page by page
- Editors
  - `nano`
  - `vi`, `vim`
  - `emacs`
  - `kate`
  - `gedit`
  - …
- Display strings directly via `echo`
  - e.g. `echo “Hello World“`

Input, Output, and Redirections

- `stdin` – standard input (your keyboard, by default)
- `stdout` – standard output (your screen, by default)
- `stderr` – standard error (your screen, by default)
- Redirection
  - `>, <, 2>` redirects `stdout`, `stdin`, and `stderr` respectively (to a file)
  - `2>&1` redirects `stderr` to `stdout`
  - `A | B` redirects `stdout` of `A` to `stdin` of `B` (unnamed pipe)
- Examples
  - `ls -l > ls.txt` (redirects `ls -l` to `ls.txt` – will overwrite if present)
  - `ls -l >> ls.txt` (redirects `ls -l` to `ls.txt` – will append if present)
  - `ls ~/nope 2> err.txt` (redirects error messages)
  - `ls test1.txt nope > out.txt 2>&1` (`test1` exists, `nope` does not exist, but output is in `out.txt`)
  - `ls -l | grep txt` (output of `ls` handed to `grep`, only shows entries containing `txt`)

Copy, Move, Rename, and Delete Files

- `cp` – copies files
  - `cp -r` also copies directories
- `rm` – removes files
  - Note: `rm -r` removes files recursively (e.g. a directory and its contents)
  - Note: `rm -rf` removes files recursively **without asking** – pay attention!
- `touch filename`
  - if `filename` does not exist, create it (will be empty)
  - if `filename` does exist, update its timestamp
- `mv` – moves or renames files

Connecting and Reusing Commands (1/2)

- Commands can be successful, or they can fail
  - Successful commands return **exit code** = 0
  - Failed commends return exit code != 0
- Multiple commands can be issued at once
  - `A ; B` will first execute A and then B (always)
  - `A && B` will first execute A and then B if A was executed successfully
  - `A || B` will first execute A and then B if A was **not** executed successfully
  - `{ ... }` groups multiple commands, returns exit status of last command
    - `{ A || B; } && C` vs
    - `A || { B && C; }` (note the required trailing semicolon)

Connecting and Reusing Commands (2/2)

- Shell allows access to history of commands
  - `history` – shows a log of all commands, numbered
  - `!!` – re-executes the last command
  - `!-2` – re-executes the second last command
  - `!<number>` – re-executes the x-th last command
  - `!xt` – re-executes the last command that starts with xt

Additional Commands

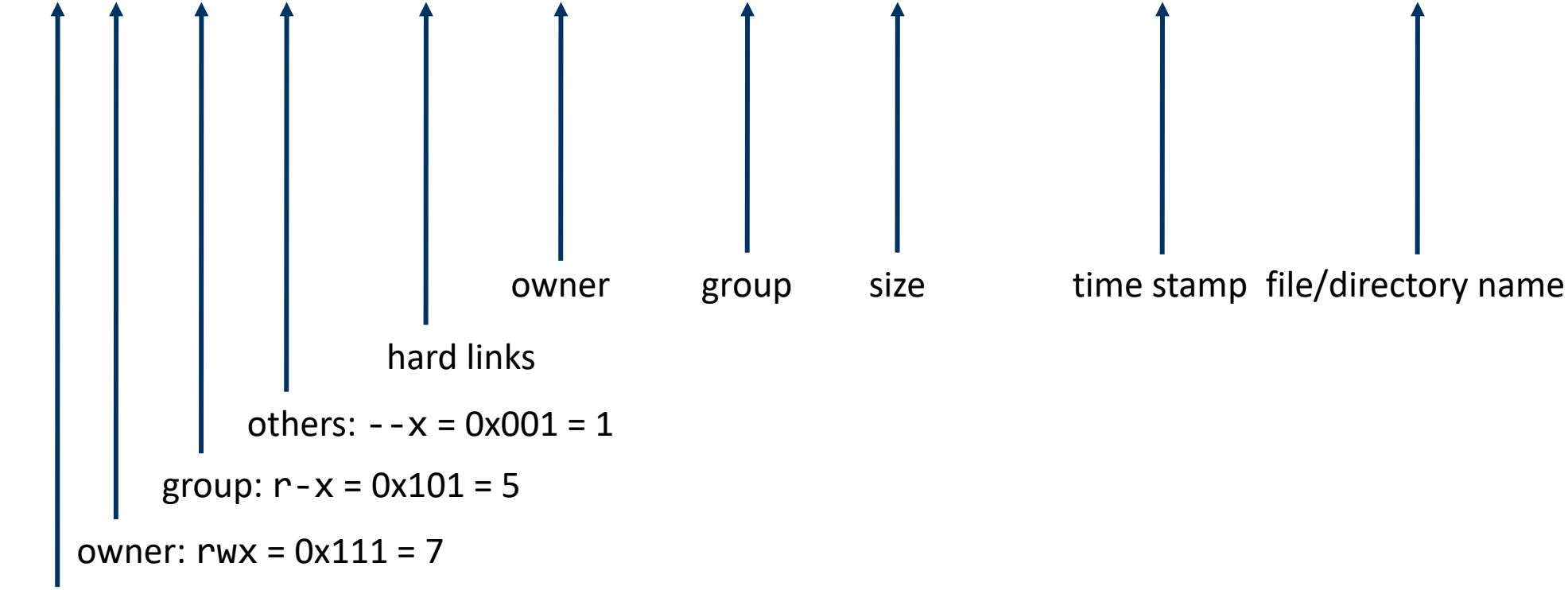
- `info` – similar to man but with cross-references
- `apropos` – search manpage names and descriptions
- `find` – search for files
- `head`, `tail` – show the first or last few lines of a file
- `sort` – sort lines
- `grep` – show or hide lines matching a pattern
- `date` – set/show the system date and time
- `hostname` – set/show the name of the computer
- `wc` – count lines, words and bytes
- `xargs` – build and execute commands from standard input

Access Permissions

- Bitmask with 9 bits
- 3 bits each for access permissions (read, write, execute) for each of the three user classes (owner, group, others)
- 3 types of permissions, applicable to both files and directories
  - **read (r):** file: may be read; directory: content may be listed but not the access permissions
  - **write (w):** file: may be written; directory: may create, move, and remove files and directories within
  - **execute (x):** file: may be executed; directory: may change into this directory
- Additionally: special permissions
- Important commands
  - `chmod` – change access permissions
  - `chown` – change ownership

Output of `ls -l`

```
-rw-r--r--. 1 philipp dps    0 Mar 18 20:58 bar
drwxr-x--x. 2 philipp dps 4096 Mar 18 20:58 foo
```



Processes

- Programs consist of one or more processes (usually one)
- Each process gets a unique ID upon start (called a PID)
- `ps` – shows a selection of currently present processes
  - `ps -e` – shows all processes
  - `ps aux` – shows all processes with additional information (who executes it, CPU time thus far, …)
- `pstree` – shows process hierarchy (parents and children – tree structure)
  - root is called `init`, started upon boot up
- `top` – same information as `ps`, but interactive
- `htop` – modern version of top

Processes in the Shell

- `&` – starts process in the background
- `Ctrl-Z` – suspend the current foreground process
- `fg` – resume job in the foreground
- `bg` – resume suspended job in the background
- `jobs` – show all suspended and background processes
- `Ctrl-C` – stop the current foreground process (`SIGINT` signal)
- `nice` – set process priorities

Stopping and Killing Processes

- `kill` – sends a signal to a process
  - `kill -TERM 3333` – stops process with PID 3333 with SIGTERM
  - `kill -9 3333` – kills process with SIGKILL (cannot be caught by process)
  - `kill -9 -1` – kill all processes
  - `kill -l` – shows all signals

System Status

- `df` – shows disk space usage
- `du` – shows file/directory space usage
- `vmstat` – shows system statistics
  - `vmstat 1` – continuously shows current state every second
- `/proc` – holds files that report system state and information
  - e.g. `cat /proc/cpuinfo` – holds CPU model information
  - e.g. `cat /proc/[PID]` – holds information about process `[PID]`

Shell Variables

- Shell supports variables
- Values can be assigned and tested for arbitrarily
- **No type system!**
- Example
  - `HELLO_VAR="Hello World"` – set `HELLO_VAR` to value "`Hello World`"
  - `export HELLO_VAR` – make `HELLO_VAR` available to subsequently executed processes
  - `echo $HELLO_VAR` – print the content of `HELLO_VAR`
- Variable names can contain letters (case sensitive!), numbers and underscore, but must start with a letter
- `unset` – deletes variables (undo `export`)

Special Shell Variables

- `$HOME` – home directory
- `$PATH` – executable search path
  (e.g., call `bash` directly instead of `/usr/bin/bash`)
- `$PWD` – current directory
- `$USER` – current user name
- `$SHELL` – current shell
- `$$` – process number of the current shell
- `$?` – exit status of the last command

Quoting

- Shell can interpret many special characters
  - e.g. *, ?, !, [,], &, …
- They can also be used as normal characters (= will not be interpreted) if quoted or escaped properly
  - ‘ – single quote, will escape everything until next ‘
  - “ – double quote, will escape everything until next “ except for \, $ and ` (back ticks)
  - \ - will escape the subsequent character

Special Characters Summary

- `;` – separator for multiple commands
- `&` – start process in the background
- `( )` – group a command and create a sub-shell
- `|` – pipe (for streaming/redirection)
- `< > &` – redirection symbols
- `* ? [ ] ~ + - @ !` – meta characters for file names
- `` `pwd` `` – back ticks (pwd will be executed and substituted for result)
- `$` – variable substitution
- `[newline] [space] [tab]` – word separators

Command Substitution

- `` `...` `` – back tick/accent grave/grave accent – NOT a single quote
  - e.g. `` `pwd` ``
- `$(...)` – equivalent (and **preferred**!) way of doing it
- command in between will be executed
- `stdout` of command will be returned
- Examples
  - VAR=pwd – assigns the string (!) value “pwd” to variable VAR
  - `echo $VAR` ➔ “pwd”
  - VAR=$(pwd) – assigns the string value of the current directory to variable VAR
  - `echo $VAR` ➔ `/home/...`

Concluding Advice

- Check man pages and tutorials/explanations on the Internet – there are tons of really good ones (e.g. StackOverflow)
- Ensure proper quoting / escaping when using special characters
- Be exact and consider special cases
  - e.g. `rm -rf /$VARIABLE` – if `$VARIABLE` is empty, this is equal to `rm -rf /`
  - e.g. `rm -rf /usr /lib/nvidia-current/xorg/xorg`

- `Further reading:`
  `https://github.com/ketancmaheshwari/lisa19`