CS631 - Advanced Programming in the UNIX Environment

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New Rules

Close your laptops!

New Rules

Close your laptops!

Open your eyes!
(Mind, too.)

So far, so good...

What questions do you have?

About this class

The class is called “Advanced Programming in the UNIX Environment”.

It is *not* called:

- “An Introduction to Unix”
- “An Introduction to Programming”
- “An introduction to C”

What is it?

https://www.bell-labs.com/usr/dmr/www/chist.html

In a nutshell: the ”what”

```
$ ls /bin
[           csh         ed          ls          pwd         sleep
cat         date        expr        mkdir       rcmd        stty
chio        dd          hostname    mt          rcp         sync
chmod       df          kill        mv          rm          systrace
cp          domainname  ksh         pax         rmdir       tar
cpio        echo        ln          ps          sh          test
$
```

See also:

`https://www.cs.stevens.edu/~jschauma/631/#source-code`

In a nutshell: the ”what”

```
$ grep "(int" /usr/include/sys/socket.h
int accept(int, struct sockaddr * __restrict, socklen_t * __restrict);
int bind(int, const struct sockaddr *, socklen_t);
int connect(int, const struct sockaddr *, socklen_t);
int getsockopt(int, int, int, void * __restrict, socklen_t * __restrict);
int listen(int, int);
ssize_t recv(int, void *, size_t, int);
ssize_t recvfrom(int, void * __restrict, size_t, int,
ssize_t recvmsg(int, struct msghdr *, int);
ssize_t send(int, const void *, size_t, int);
ssize_t sendto(int, const void *,
ssize_t sendmsg(int, const struct msghdr *, int);
int setsockopt(int, int, int, const void *, socklen_t);
int socket(int, int, int);
int socketpair(int, int, int, int *);
$
```

In a nutshell: the ”what”

- gain an understanding of the UNIX operating systems
- gain (systems) programming experience
- understand fundamental OS concepts (with focus on UNIX family):
  - multi-user concepts
  - basic and advanced I/O
  - process relationships
  - interprocess communication
  - basic network programming using a client/server model

In a nutshell

The ”why”:

- understanding how UNIX works gives you insights in other OS concepts
- system level programming experience is invaluable as it forms the basis for most other programming and even *use* of the system
- system level programming in C helps you understand general programming concepts
- most higher level programming languages (eventually) call (or implement themselves) standard C library functions

In a nutshell: the ”how”

```
static char dot[] = ".", *dotav[] = { dot, NULL };
struct winsize win;
int ch, fts_options;
int kflag = 0;
const char *p;

setprogname(argv[0]);
setlocale(LC_ALL, "");

/* Terminal defaults to -Cq, non-terminal defaults to -1. */
if (isatty(STDOUT_FILENO)) {
    if (ioctl(STDOUT_FILENO, TIOCGWINSZ, &win) == 0 &&
        win.ws_col > 0)
        termwidth = win.ws_col;
    f_column = f_nonprint = 1;
} else
    f_singlecol = 1;

/* Root is -A automatically. */
if (!getuid())
    f_listdot = 1;

fts_options = FTS_PHYSICAL;
while ((ch = getopt(argc, argv, "1ABCFLRSTWabcdfghiklmnopqrstuwx")) != -1) {
    switch (ch) {
    /*
     * The -1, -C, -l, -m and -x options all override each other so
     * shell aliasing works correctly.
     */
    case '1':
        f_singlecol = 1;
```

In a nutshell: the ”how”

```
$ $EDITOR cmd.c
```

Writing code

Writing code is *communication*.

Make sure your code is

- clearly structured
- well-formatted
- uses a consistent coding style (indentation, placement of braces, etc.)
- variables, functions etc. are sensibly named
- comments are used only when necessary, explaining the *why*, not the *what*

See `https://www.cs.stevens.edu/~jschauma/631/style`.

In a nutshell: the ”how”

Open your laptops!

Ignore Facebook, Twitter, Email, Tinder, ...

Now compile and run this program:

```
$ ftp https://www.cs.stevens.edu/~jschauma/631/welcome.c
$ cc welcome.c
$ ./a.out
$ echo "Hooray!"
Hooray!
$
```

In a nutshell: the ”how”

```
$ $EDITOR welcome.c
$ cc welcome.c
welcome.c: In function 'main':
welcome.c:5:81: warning: implicit declaration of function 'getlogin' [-Wimplicit-fu
  printf("Welcome to CS631 Advanced Programming in the UNIX Environment, %s!\n", ge
                                                                                 ^
welcome.c:6:1: error: expected ';' before '}' token
 }
 ^
$
```

In a nutshell: the ”how”

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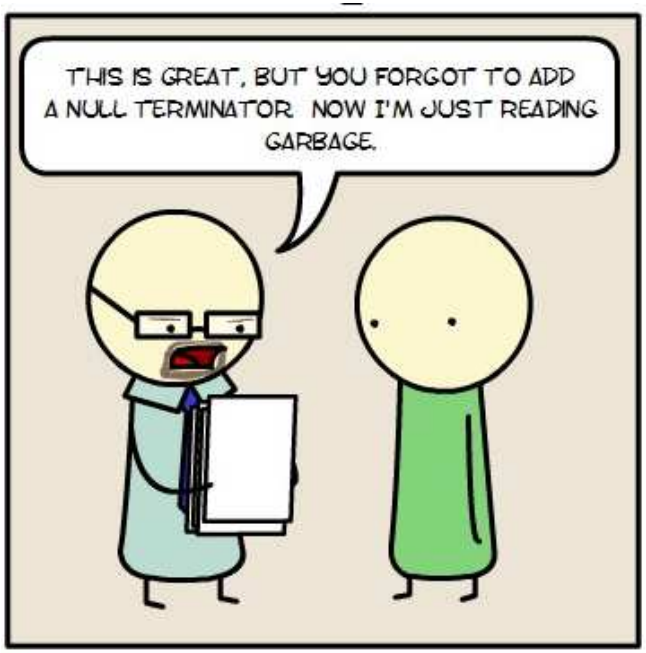
$ ./a.out
Memory fault (core dumped)
$
```

Programming



https://i.imgur.com/WnpMFjX.jpg
https://i.imgur.com/ZyeCO.jpg

In a nutshell: the ”how”

https://kristerw.blogspot.com/2017/09/useful-gcc-warning-options-not-enabled.html

```
$ export CFLAGS="-ansi -g -Wall -Werror -Wextra -Wformat=2 -Wjump-misses-init \
                 -Wlogical-op -Wpedantic -Wshadow"
$ cc $CFLAGS welcome.c
welcome.c: In function 'main':
welcome.c:5:81: error: implicit declaration of function 'getlogin' [-Werror=implicit-function-declaration]
  printf("Welcome to CS631 Advanced Programming in the UNIX Environment, %s!\n", getlogin());
                                                                                 ^
welcome.c:5:9: error: format '%s' expects argument of type 'char *', but argument 2 has type 'int' [-Werror=format=]
  printf("Welcome to CS631 Advanced Programming in the UNIX Environment, %s!\n", getlogin());
         ^
welcome.c:5:9: error: format '%s' expects argument of type 'char *', but argument 2 has type 'int' [-Werror=format=]
welcome.c:4:10: error: unused parameter 'argc' [-Werror=unused-parameter]
 main(int argc, char **argv) {
          ^
welcome.c:4:23: error: unused parameter 'argv' [-Werror=unused-parameter]
 main(int argc, char **argv) {
                       ^
welcome.c:6:1: error: control reaches end of non-void function [-Werror=return-type]
 }
 ^
cc1: all warnings being treated as errors
$ $EDITOR welcome.c
$ cc $CFLAGS welcome.c
$ ./a.out
Welcome to CS631 Advanced Programming in the UNIX Environment, jschauma!
```

About this class

Textbook:

- "Advanced Programming in the UNIX Environment", by W. Richard Stevens, Stephen A. Rago (3rd Edition)

Grading:

- course participation, course notes: 50 points
- 2 homework assignments, worth 25 points each
- 1 midterm project, worth 100 points
- 1 final project (group work), worth 200 points
- 1 final programming assignment (individual), worth 100 points
- *no curve*
- *no late submissions*
- *no extra credit*
- *no make-up assignments*

Course Notes

- create a git repository with a single text file for each lecture
- before each lecture, note:
  - what you read
  - what questions you have
- after each lecture:
  - answers you've found, or especially interesting new things you learned
  - what questions remain
  - what new questions arose
  - what additional reading might be relevant
- follow up on unanswered questions in class or on the mailing list
- at the end of the semester, submit all your notes

`https://www.cs.stevens.edu/~jschauma/631/course-notes.html`

Syllabus

- Introduction, UNIX history, UNIX Programming Basics
- File I/O, File Sharing
- Files and Directories
- Filesystems, System Data Files, Time & Date
- UNIX tools: make(1), gdb(1), revision control, etc.
- Process Environment, Process Control
- Process Groups, Sessions, Signals
- Interprocess Communication
- Daemon Processes, shared libraries
- Advanced I/O: Nonblocking I/O, Polling, and Record Locking
- Encryption
- Code reading, coding style, best practices
- Review

So far, so good...

What questions do you have?

Hooray!

5 Minute Break

UNIX History

UNIX history

`http://www.unix.org/what_is_unix/history_timeline.html`

- Originally developed in 1969 at Bell Labs by Ken Thompson and Dennis Ritchie.
- 1973, Rewritten in C. This made it portable and changed the history of OS
- 1974: Thompson, Joy, Haley and students at Berkeley develop the Berkeley Software Distribution (BSD) of UNIX
- two main directions emerge: BSD and what was to become “System V”

Notable dates in UNIX history

- 1984 4.2BSD released (TCP/IP)
- 1986 4.3BSD released (NFS)
- 1991 Linus Torvalds starts working on the Linux kernel
- 1993 Settlement of USL vs. BSDi; NetBSD, then FreeBSD are created
- 1994 Single UNIX Specification introduced
- 1995 4.4BSD-Lite Release 2 (last CSRG release); OpenBSD forked off NetBSD
- 2000 Darwin created (derived from NeXT, FreeBSD, NetBSD)
- 2003 Xen; SELinux
- 2005 Hadoop; DTrace; ZFS; Solaris Containers
- 2006 AWS (”Cloud Computing” comes full circle)
- 2007 iOS; KVM appears in Linux
- 2008 Android; Solaris open sourced as OpenSolaris

Some UNIX versions

More UNIX (some generic, some trademark, some just unix-like):

1BSD	2BSD	3BSD	4BSD	4.4BSD Lite 1
4.4BSD Lite 2	386 BSD	A/UX	Acorn RISC iX	AIX
AIX PS/2	AIX/370	AIX/6000	AIX/ESA	AIX/RT
AMiX	AOS Lite	AOS Reno	ArchBSD	ASV
Atari Unix	BOS	BRL Unix	BSD Net/1	BSD Net/2
BSD/386	BSD/OS	CB Unix	Chorus	Chorus/MiX
Coherent	CTIX	Darwin	Debian GNU/Hurd	DEC OSF/1 ACP
Digital Unix	DragonFly BSD	Dynix	Dynix/ptx	ekkoBSD
FreeBSD	GNU	GNU-Darwin	HPBSD	HP-UX
HP-UX BLS	IBM AOS	IBM IX/370	Interactive 386/ix	Interactive IS
IRIX	Linux	Lites	LSX	Mac OS X
Mac OS X Server	Mach	MERT	MicroBSD	Mini Unix
Minix	Minix-VMD	MIPS OS	MirBSD	Mk Linux
Monterey	more/BSD	mt Xinu	MVS/ESA OpenEdition	NetBSD
NeXTSTEP	NonStop-UX	Open Desktop	Open UNIX	OpenBSD
OpenServer	OPENSTEP	OS/390 OpenEdition	OS/390 Unix	OSF/1
PC/IX	Plan 9	PWB	PWB/UNIX	QNX
QNX RTOS	QNX/Neutrino	QUNIX	ReliantUnix	Rhapsody
RISC iX	RT	SCO UNIX	SCO UnixWare	SCO Xenix
SCO Xenix System V/386	Security-Enhanced Linux	Sinix	Sinix ReliantUnix	Solaris
SPIX	SunOS	Tru64 Unix	Trusted IRIX/B	Trusted Solaris
Trusted Xenix	TS	UCLA Locus	UCLA Secure Unix	Ultrix
Ultrix 32M	Ultrix-11	Unicos	Unicos/mk	Unicox-max
UNICS	UNIX 32V	UNIX Interactive	UNIX System III	UNIX System IV
UNIX System V	UNIX System V Release 2	UNIX System V Release 3	UNIX System V Release 4	UNIX System V/286
UNIX System V/386	UNIX Time-Sharing System	UnixWare	UNSW	USG
Venix	Wollogong	Xenix OS	Xinu	xMach

UNIX Timeline

unix.png : https://www.levenez.com/unix/
linux.png : http://futurist.se/gldt/

UNIX Everywhere

Today, your desktop, server, cloud, TV, phone, watch, stereo, car navigation system, thermostat, door lock, etc. all run a Unix-like OS...

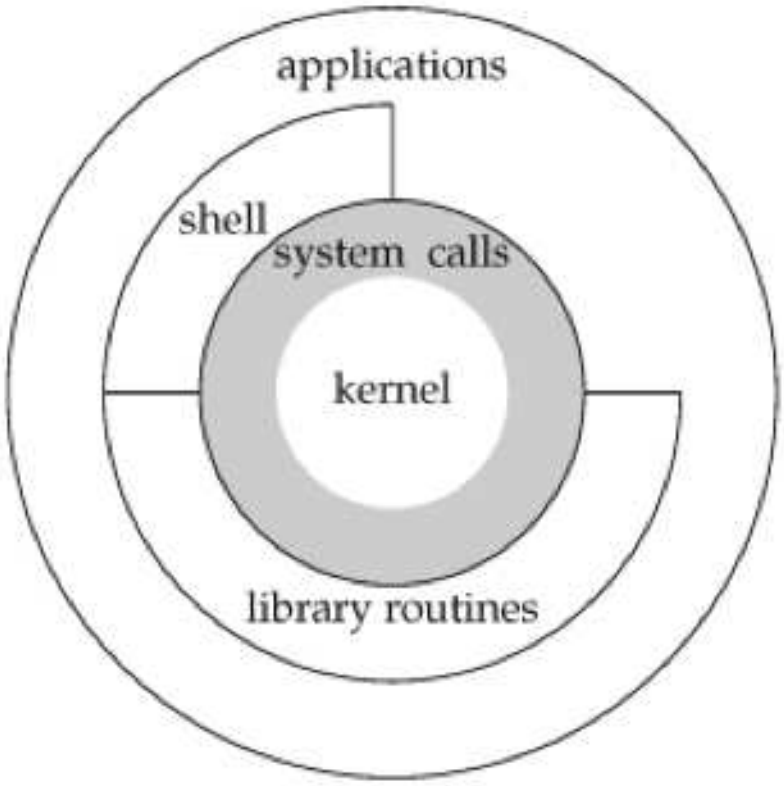
UNIX Everywhere

Today, your desktop, server, cloud, TV, phone, watch, stereo, car navigation system, thermostat, door lock, etc. all run a Unix-like OS...

...with all the risks that entails.

UNIX Basics

UNIX Basics: Architecture



System Calls and Library Functions, Standards

System Calls and Library Functions

- *System calls* are entry points into kernel code where their functions are implemented. Documented in section 2 of the manual (e.g. `write(2)`).
- *Library calls* are transfers to user code which performs the desired functions. Documented in section 3 of the manual (e.g. `printf(3)`).

Standards

- ANSI C (X3.159-1989) C89, C9X/C99 (ISO/IEC 9899), C11 (ISO/IEC 9899:2011)
- IEEE POSIX (1003.1-2008) / SUSv4

Important ANSI C Features, Error Handling

- Important ANSI C Features:
  - function prototypes
  - generic pointers (`void *`)
  - abstract data types (e.g. `pid_t`, `size_t`)
- Error Handling:
  - meaningful return values
  - `errno` variable
  - look up constant error values via two functions:

```
#include <string.h>
char *strerror(int errnum)
```

Returns: pointer to message string

```
#include <stdio.h>
void perror(const char *msg)
```

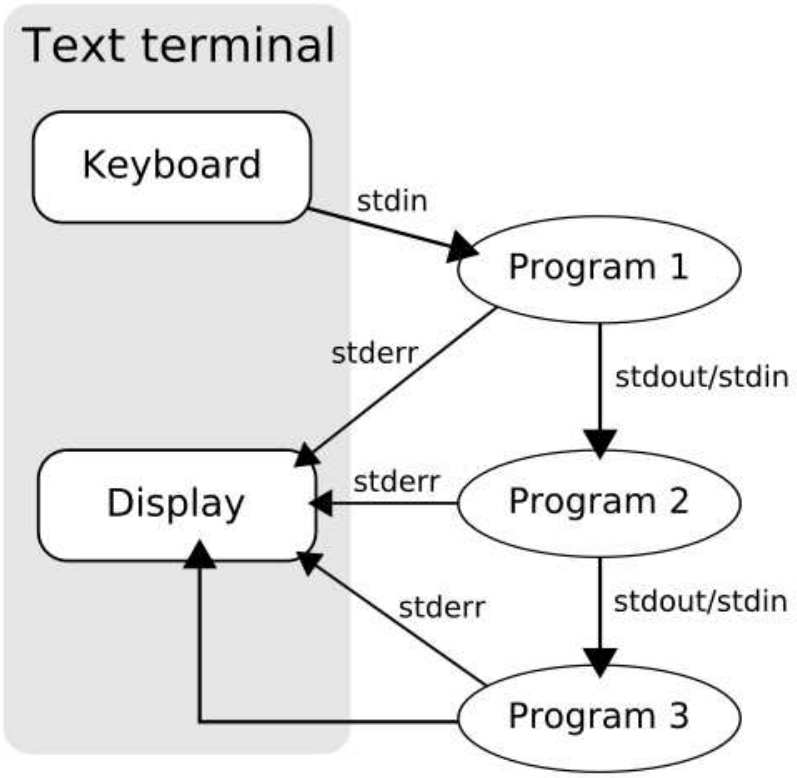
UNIX Basics: Pipelines

What is the longest word found on the ten most frequently retrieved English Wikipedia pages?

```
for f in $(curl -L https://is.gd/c6F2fs | zgrep -i "^en " |
        sort -k3 -n | tail -10 |
        sed -e 's/en \(.*\) [0-9]* [0-9]*/\1/'); do
        links -dump https://en.wikipedia.org/wiki/${f}
done |
tr '[:punct:]' ' ' |
tr '[:space:]' '\n' |
tr '[:upper:]' '[:lower:]' |
egrep '^[a-z]+$' |
awk '{ print length() " " $0; }' |
sort |
uniq |
sort -n |
tail -1
```

UNIX Basics: Pipelines

Say ”Thank you, Douglas McIlroy!”



https://is.gd/vGH09J

Program Design

”Consistency underlies all principles of quality.”
Frederick P. Brooks, Jr

Program Design

`https://en.wikipedia.org/wiki/Unix_philosophy`

UNIX programs...

- ...are simple
- ...follow the element of least surprise
- ...accept input from `stdin`
- ...generate output to `stdout`
- ...generate meaningful error messages to `stderr`
- ...have meaningful exit codes
- ...have a manual page

Boot/Login process

```
[...]
total memory = 1023 MB
avail memory = 971 MB
timecounter: Timecounters tick every 10.000 msec
mainbus0 (root)
[...]
boot device: wd0
root on wd0a dumps on wd0b
root file system type: ffs
[...]
Starting local daemons:.
Starting sendmail.
Starting sshd.
Starting snmpd.
Starting cron.

NetBSD/amd64 (apue) (console)

login: jschauma
```

Boot/Login process

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NetBSD/amd64 (apue) (console)

login: jschauma
Password:
Last login: Mon Aug 27 01:57:11 2018 from 10.0.2.2
NetBSD 8.0 (GENERIC) #0: Tue Jul 17 14:59:51 UTC 2018

Welcome to NetBSD!

apue$
```

Soooo... what exactly is a ”shell”?

```
$ ftp https://www.cs.stevens.edu/~jschauma/631/simple-shell.c
$ more simple-shell.c
$ cc $CFLAGS -o mysh simple-shell.c
$ ./mysh
$$ /bin/ls
[...]
$$ ^D
$
```

Files and Directories

- The UNIX **filesystem** is a tree structure, with all partitions mounted under the root (/). File names may consist of any character except / and NUL as pathnames are a sequence of zero or more filenames separated by /'s.

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- Directories are special "files" that contain mappings between *inodes* and *filenames*, called directory entries.
- All processes have a current working directory from which all relative paths are specified. (Absolute paths begin with a slash, relative paths do not.)

Listing files in a directory

```
$ ftp https://www.cs.stevens.edu/~jschauma/631/simple-ls.c
$ more simple-ls.c
$ cc $CFLAGS -o myls simple-ls.c
$ ./myls .
[...]
$
```

User Identification

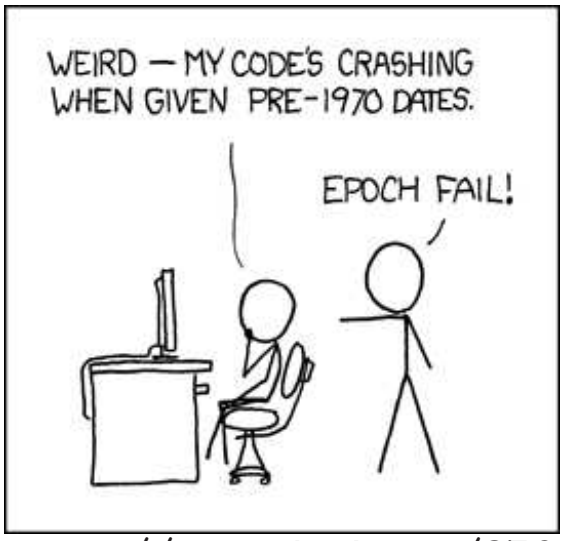
- *User ID*s and *group ID*s are numeric values used to identify users on the system and grant permissions appropriate to them.
- *Group ID*s come in two types; *primary* and *secondary*.

```
$ id
```

Unix Time Values

Calendar time: measured in seconds since the UNIX epoch (Jan 1, 00:00:00, 1970, GMT). Stored in a variable of type `time_t`.

```
$ date +%s
```



https://www.xkcd.com/376/

https://en.wikipedia.org/wiki/Year_2038_problem

Unix Time Values

Process time: central processor resources used by a process. Measured in *clock ticks* (`clock_t`). Three values:

- clock time
- user CPU time
- system CPU time

```
$ time grep -r _POSIX_SOURCE /usr/include >/dev/null
```

Standard I/O

- Standard I/O:
  - **file descriptors**: Small, non-negative integers which identify a file to the kernel. The shell can redirect any file descriptor.
  - kernel provides **unbuffered** I/O through e.g. `open read write lseek close`
  - kernel provides **buffered** I/O through e.g. `fopen fread fwrite getc putc`

```
$ ftp https://www.cs.stevens.edu/~jschauma/631/simple-cat.c
$ ftp https://www.cs.stevens.edu/~jschauma/631/simple-cat2.c
$ diff -bu simple-cat*.c
[...]
$
```

Processes

Programs executing in memory are called *processes*.

- Programs are brought into memory via one of the six `exec(3)` functions. Each process is identified by a guaranteed unique non-negative integer called the *processes ID*. New processes can **only** be created via the `fork(2)` system call.
- **process control** is performed mainly by the `fork(2)`, `exec(3)` and `waitpid(2)` functions.

```
$ ftp https://www.cs.stevens.edu/~jschauma/631/pid.c
$ more pid.c
$ cc $CFLAGS -o mypid pid.c
$ ./mypid .
[...]
$ echo $$
[...]
```

Processes

```
$ pstree | more
```

Processes

```
[...]
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mainbus0 (root)
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Password:
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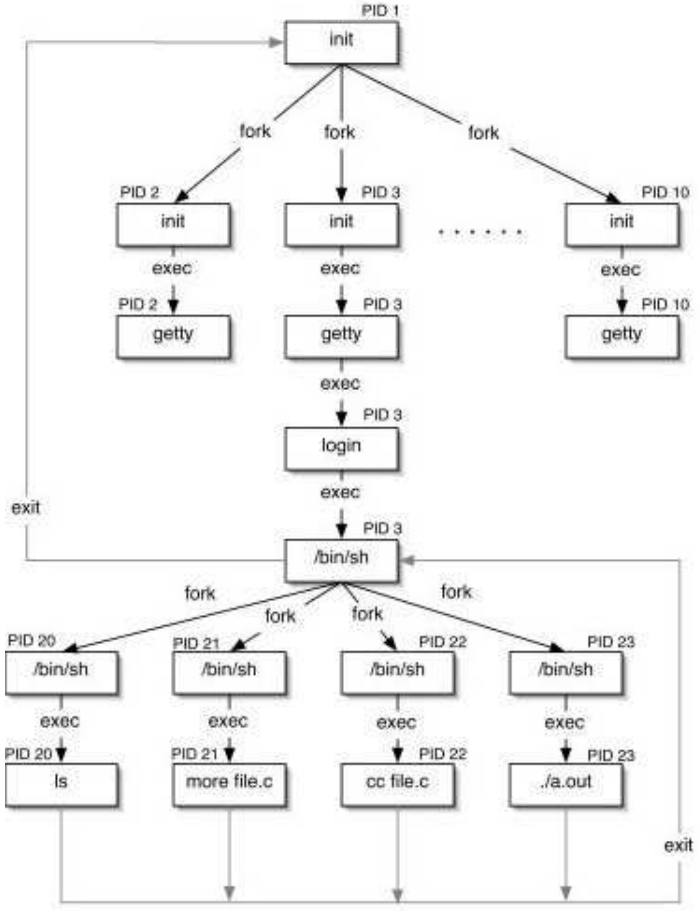
Processes


PID 1
init
fork
fork
fork
PID 2
init
PID 3
init
PID 10
init
exec
exec
exec
PID 2
getty
PID 3
getty
PID 10
getty
exec
PID 3
login
exec
exit
PID 3
/bin/sh
fork
fork
fork
fork
PID 20
/bin/sh
PID 21
/bin/sh
PID 22
/bin/sh
PID 23
/bin/sh
exec
exec
exec
exec
PID 20
ls
PID 21
more file.c
PID 22
cc file.c
PID 23
./a.out
exit

Signals

- **Signals** notify a *process* that a condition has occured. Signals may be
  - ignored
  - allowed to cause the default action
  - caught and control transferred to a user defined function

```
$ ftp https://www.cs.stevens.edu/~jschauma/631/simple-shell2.c
$ more simple-shell2.c
$ cc $CFLAGS -o mysh simple-shell2.c
$ ./mysh
$$ /bin/ls
[...]
$$ ^C
Caught SIGINT!
```

Code requirements

For *all* code assignments, create a plain ASCII file named `checklist`. In it, answer the following questions:

- Did I write all the code myself?
- Does my code follow the style guide?
- Does my code compile without warnings or errors on a NetBSD 8.x system?
- Did I provide a `Makefile` and a `README` to explain any problems or issues I encountered?
- Did I check the return value of all function calls?
- Did I send error messages to `stderr`?
- Did I use only *meaningful* and *necessary* comments?
- Does my program return zero on success, non-zero otherwise?
- Did I make sure that my `.h` files only include function forward declarations, macros, etc.?

`https://www.cs.stevens.edu/~jschauma/631/checklist`

Homework

Before every lecture:

- re-read the previous week's slides and notes
- follow up with questions on the course mailing list or in class
- prepare for class by reading the assigned chapters and slides
- come to class prepared with questions
- update your class notes

After every lecture:

- run all examples from the lecture
- update your class notes

Homework

This week:

- set up your class notes
- read `intro(2)`, Stevens 1 & 2
- bookmark these websites:
  - `https://www.cs.stevens.edu/~jschauma/631/`
  - `http://pubs.opengroup.org/onlinepubs/9699919799/`
- ensure you are subscribed to the class mailing list:
  `https://lists.stevens.edu/cgi-bin/mailman/listinfo/cs631apue`
- ensure you have access to a NetBSD system
  `https://www.cs.stevens.edu/~jschauma/631/netbsd.html`

Just one more thing...

What questions do you have?