Programmation Systèmes
Cours 1 — Introduction

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Outline

1. What is system programming
2. UNIX concepts
3. System programming concepts
4. UNIX standards and implementations
5. About this course

Outline

Programming layered architectures

The architectures of modern computing systems are massively *layered*. When programming, we target specific layers.

E.g.:

n	virtual architectures / virtual machines. . .	
4	application level	(business-oriented, frameworks, 4GL, . . .)
3	system level	(system languages, system calls, 3GL, . . .)
2	assembly level	(assembly languages, interrupts, 2GL, . . .)
1	hardware level	(firmware, microcode, 1GL, . . .)

Each level is characterized by (or highly correlated with):

- mechanisms and APIs to interact with lower layers
- apt programming languages (and their generations)

Which layer to target

The choice of layer reveals important trade-offs.

1. Performances. Targeting a lower layer might grant better performances.

   Writing a performance critical routine in assembly might provide a several order of magnitude speed improvement when compared to programming higher layers.

   This technique is often used for performance critical code such as device drivers, multimedia, crytpo-code, etc.

Which layer to target (cont.)

The choice of layer reveals important trade-offs.

2. Portability. Targeting a higher layer usually guarantees better portability, in particular better than all lower layer equivalents that might be *generated* from the chosen layer.

   E.g.: a block of standard ISO C 99 code can be compiled using gcc to more than 70 different target processors.

Which layer to target (cont.)

The choice of layer reveals important trade-offs.

3. Maintainability. Targeting a higher layer usually makes writing code easier and the resulting code more maintainable than if it were written targeting lower layers.

   This is largely a consequence of the involved programming languages.

System programming

> *System programming is the art of writing system software.*
>
> *— Robert Love*

System software is “low level” software that interfaces *directly* with:

- the kernel of the operating system
- core system libraries (we’ll be more precise in a bit)

System software — examples

Some examples of system software you use daily:

- shell
- compiler
- interpreter
- debugger
- (text editor)

- system services
  - cron
  - print spool
  - power mgmt
  - session mgmt
  - backup
  - ...

- network services
  - HTTP server
  - MTA
  - DBMS
  - ...

Try:

```
$ ps -auxw
```

most of it is system-level software.

System programming — why bother?

- there are drawbacks in targeting the system level
    - performances, maintainability, portability, etc.
- recent years have witnessed a shift from system- to application programming
    - platforms such as Java and .NET, as well as 4GL and 5GL languages, hide the system level to the programmer, in the quest for the “run everywhere” mantra
    - many programmers spend most—if not all—of their time doing *application* programming

Why bother learning system programming?

?

Why system programming

1. legacy code—such as system utilities—is not going away any time soon; in some cases it is also basis for standardization (e.g. UNIX utilities)
    - in the Free Software world, the majority of *existing code* (50%+ of Debian) is system-level C code[1]

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[1] Gonzalez-Barahona et al. 2009, `http://dx.doi.org/10.1007/s10664-008-9100-x`

Why system programming (cont.)

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    - in the Free Software world, the majority of *existing code* (50%+ of Debian) is system-level C code[1]
2. new system-level tasks born on a regular basis, to cope with application-level evolution

Example

- an increasing number of new applications is written in JavaScript, for the Web, desktops (!), and mobiles (!!)
- *therefore* we need new and better JavaScript (JIT) compilers; most of their code is system-level code

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[1] Gonzalez-Barahona et al. 2009, `http://dx.doi.org/10.1007/s10664-008-9100-x`

Why system programming (cont.)

3. even application-level programming benefits a great deal from system programming knowledge
    - understanding system behavior and performance bottlenecks
    - deciding when to drop-down at the system level
    - debugging portability issues
    - ...

fluency in system programming will make you better application developers

UNIX system programming

This course is about UNIX system programming.

We address system programming in UNIX® systems as well as “UNIX-like” implementations (e.g. Linux, FreeBSD, etc.), following various UNIX-related standards.

This is not an introductory course about UNIX system programming

- prerequisites:
  - UNIX proficiency as a user
  - topics covered by course “Systèmes” L3
- we review today and in the first TDs *some* of that material:
  - UNIX concepts
  - UNIX syscalls for I/O
  - system programming concepts
- it’s up to you to catch up with the rest!

Outline

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Operating systems in a nutshell

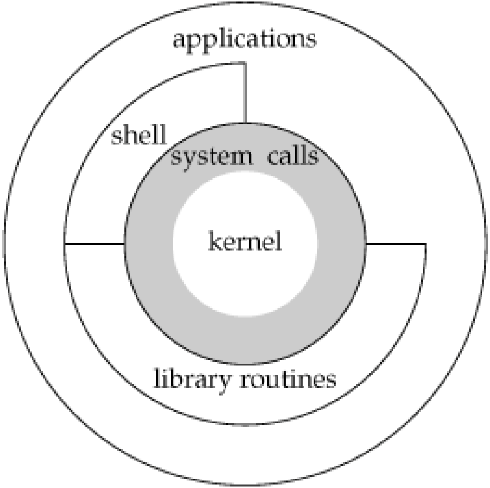
An operating system is the software environment that provides services needed to run final user programs. E.g.:

- program execution
- hardware access (e.g. read from disk, play a sound)
- file system access (e.g. open, close, read, write a file)
- memory access (e.g. allocation, memory mapping)
- network access (e.g. connect to a server, wait for connections)

> The kernel of an operating system is the software layer that *control the hardware* and create the *environment* in which programs can run.

The kernel layer is usually thin—when compared to an entire operating system—and self-contained.

UNIX architecture



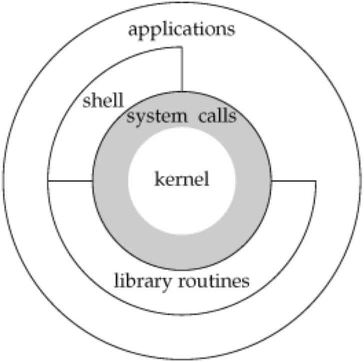
APUE, Figure 1.1

- layered architecture, with a UNIX kernel at its core
- not all layers are strictly encapsulated

UNIX architecture — some details

System calls (or "syscalls" for short) provide the interface (API) for programs to access kernel services.

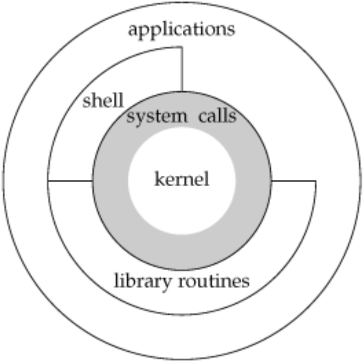
- operating systems before UNIX used to define the system call API in assembly, UNIX started doing so in C
- the *implementation* of system calls is part of the kernel code (AKA "kernel-space code")
  - for now, we assume that we can invoke system calls as if they were ordinary C functions



UNIX architecture — some details (cont.)

The standard C library ("library routines" in figure) implement basic functionalities needed by almost all programs.

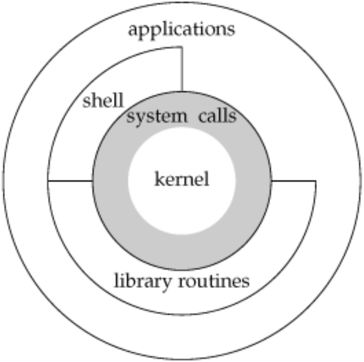
- E.g.:
  - buffered I/O
  - fine-grained memory allocation
  - time management
- those functionalities are usually implemented "lifting" system call API to richer interfaces
- the implementation is *not* part of the kernel code (AKA "user-space code") and hence can be replaced more easily (but still. . .)



UNIX architecture — some details (cont.)

The shell is a specific application used interactively by system users to start and control programs.

- historically, shells have been—and still are, for power users—an interactive equivalent of the system call API
- the advent of higher-level wrappers to start applications (e.g. desktop environments) have partially replaced shells.
  Arguably they are just a different kind of shells

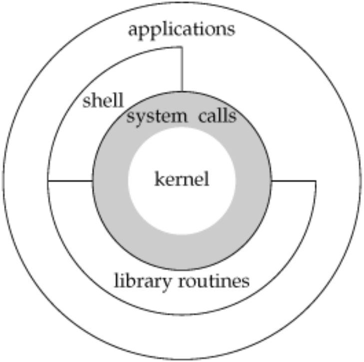


UNIX architecture — some details (cont.)

Applications are the programs typically used for the productivity of the final user.

Note how applications can be built accessing various layers of what's under them:

- kernel services (via the system call API)
- the shell
- standard C library
- other intermediate libraries (not shown)



Filesystem

UNIX directory structure (excerpt):

```
/
        /bin
        /sbin
        /etc
        /dev
        /home
        /mnt
        /lib
        /root
        /tmp

        /usr
              /usr/bin
              /usr/include
              /usr/lib
              /usr/local

        /var
              /var/log
              /var/mail
              /var/spool
              /var/tmp
        /proc
        /opt
        /media
        /srv
        /boot
        /sys
```

- hierarchical file system with a single root
- "*everything is a file*" mantra
  - directory are files mapping file names to (nameless) files
- (regular) file = data + metadata:
  - type
  - permissions
  - size
  - owner
  - ...

relevant syscalls: `stat`

File and path names

- *within directories*, files are associated to filenames
    - i.e. filenames are local to a specific directory and contain no “/”
    - special values: “.” (current dir), “..” (parent dir)
- pathnames are used to identify files filesystem-wide
    - pathnames do contain “/”

File and path names

- *within directories*, files are associated to filenames
  - i.e. filenames are local to a specific directory and contain no "/"
  - special values: "." (current dir), ".." (parent dir)
- pathnames are used to identify files filesystem-wide
  - pathnames do contain "/"

Path resolution (OCaml-like pseudocode)

```
List.fold_left
  (fun cur_file name ->
    if not (is_dir cur_file) then raise Invalid_path;
    try
      List.assoc name (dir_content (opendir cur_file))
    with Not_found -> raise File_not_found)
  root_dir    (* needed to bootstrap; known by the kernel *)
  path    (* e.g. ["usr";"lib";"ocaml";"pcre";"pcre.mli"] *)
```

- path resolution is performed implicitly by the kernel
  - can be performed explicitly via syscalls, e.g. `opendir`

File descriptors

Definition (file descriptor)

A file descriptor (fd) is a small non-negative integer used by the kernel to reference a file used by a running program.

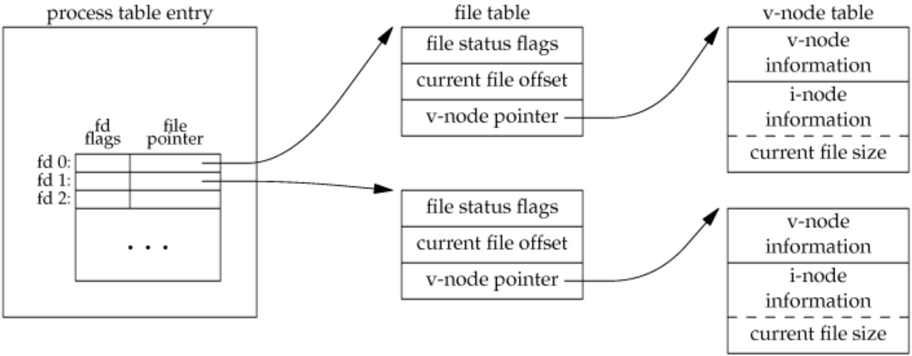
- fd are unique only within a process
- ⟨fd, process⟩ pairs act as keys to reference internal kernel data structures

Typical file descriptor "protocol"

1. each time the kernel opens/creates a file for a process, it returns a file descriptor to it
2. subsequent actions on that file requires that the process passes the corresponding file descriptor back to the kernel

According to the "everything is a file" UNIX mantra, this protocol is used for way more than regular file manipulations

Open files and the kernel



APUE, Figure 3.6

- each process file descriptor points to an in-kernel file table entry
- each file table entry points to in-kernel equivalent of on-filesystem file information and associated metadata
  - in particular: the current file offset

Standard file descriptors

Due to how process creation works on UNIX, shells are de facto responsible to setup part of the initial environment of new processes. To that end, shells conventionally open 3 file descriptors at process creation:

standard input default fd where to read input from

standard output default fd where to write output to

standard error default fd where to write error output to

Typical values for standard file descriptors are given in `<unistd.h>`:

```
/* Standard file descriptors.  */
#define STDIN_FILENO    0  /* Standard input.  */
#define STDOUT_FILENO   1  /* Standard output.  */
#define STDERR_FILENO   2  /* Standard error output.  */
```

File descriptors — syscalls

- file opening: `open`
- new file creation: `creat`
- fd closing: `close`
- fd manipulation: `dup`, `dup2`, `fcntl`, ...

Unbuffered I/O

syscalls are available for basic, unbuffered,[1] I/O:

- read content from file to memory: `read`
- write content from memory to file: `write`

Read and write operations are chunked.

Every operation implicitly move the file offset by the amount of data read/written.
Explicit displacement of the file offset is provided by the `lseek` syscall.

---

[1] actually, there is *some* buffering, but it happens in kernel-space; this kind of I/O is better defined "user-space unbuffered"

Unbuffered I/O — example: cat

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

#define BUFFSIZE        4096

int main(void) {
        int     n;
        char    buf[BUFFSIZE];
        while ((n = read(STDIN_FILENO, buf, BUFFSIZE)) > 0)
                if (write(STDOUT_FILENO, buf, n) != n) {
                        perror("write error");
                        exit(EXIT_FAILURE);
                }
        if (n < 0) {
                perror("read error");
                exit(EXIT_FAILURE);
        }
        exit(EXIT_SUCCESS);
}
```

Unbuffered I/O — example: cat (cont.)

- chunking forces us to loop and fix a buffer size
- thanks to implicit moves, no explicit file offset accounting is needed
- data is copied to/from user/kernel-space at each read/write

Programs and processes

Definition (programs and processes)

- a program is an executable file residing on the filesystem
- a process is an instance of a program in execution

Note: several different process instances of the same program might exist in memory at the same time.

- each process is associated to:
  - a numeric process ID
  - an address space (. . .)
  - a thread of control (or more. . .)
- program execution—resulting in a new process—is requested to the kernel using the `fork`/`exec` (family of) syscalls

We will get back to this in lecture "process management".

Programs and processes — demo

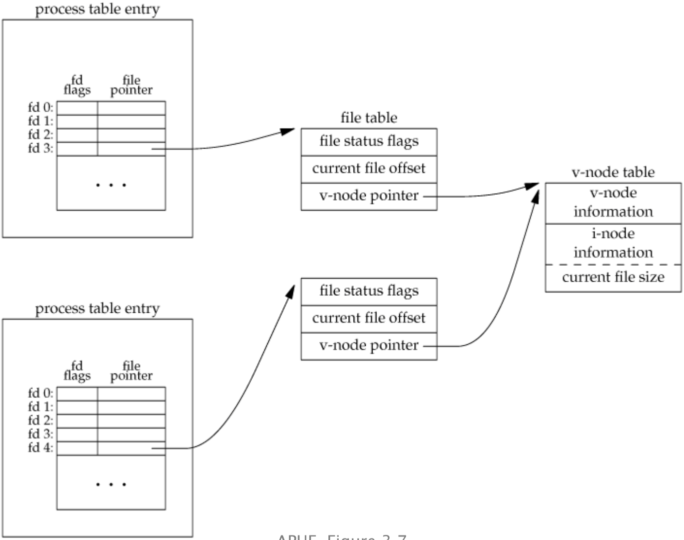
```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main(int argc, char **argv) {
        printf("hello, world from process %d\n", getpid());
        exit(EXIT_SUCCESS);
}
```

```
$ gcc -Wall -o hello-pid hello-pid.c
$ ./hello-pid
hello, world from process 21195
$ ./hello-pid
hello, world from process 21196
$ ./hello-pid
hello, world from process 21199
```

Multi-process I/O — file sharing

What happens when *independent* processes act on the same file?



APUE, Figure 3.7

Sharing resources among processes

It seems processes can share resources, such as the v-node table in the previous (degenerate) example.

Can they share more?

Sharing resources among processes

It seems processes can share resources, such as the v-node table in the previous (degenerate) example.

Can they share more?
Yes.

E.g.:

- related processes can share file table entries
- processes can share specific memory regions of their own address space (e.g. memory mapping, shared memory)
- pushing it to the extreme, multiple "processes" can share by default their entire address space by the means of threads

Threads

By default, each process has only one thread of control (or “thread”), i.e. only one set of instructions being executed at any given time.

Additional threads can be added at runtime.

All threads within a process share:

- address space
- file descriptors
- stacks (note the plural)

Each thread has its own:

- thread ID (unique only within the owning process)
- stack (but others’ stacks can be *accessed* !)
- processor status
- instruction pointer
- thread-local storage (to be requested explicitly)

Threads (cont.)

pro	concurrent work on common data, without having to pass data around or setup shared memory regions; all data is "shared by default"
pro	different threads can run in parallel on multiprocessor / multicore systems
con	synchronization issues to avoid memory corruption; they might get very intricated (in non- purely-functional programming paradigms)

We will get back to this in lecture "pthreads".

Outline

System calls

Definition (system call)

A system call is a controlled entry point into the kernel, used by programs to request a service.

- during syscall execution, the processor state changes from user mode to kernel mode → so that protected kernel memory can be used
- the set of available system calls is fixed for a given platform; each syscall is identified by a unique number
- each system call accepts arguments and possibly return values, bridging user space and kernel space

. . . but syscall code (in the kernel) is not linked directly with user programs. How can they invoke syscalls then?

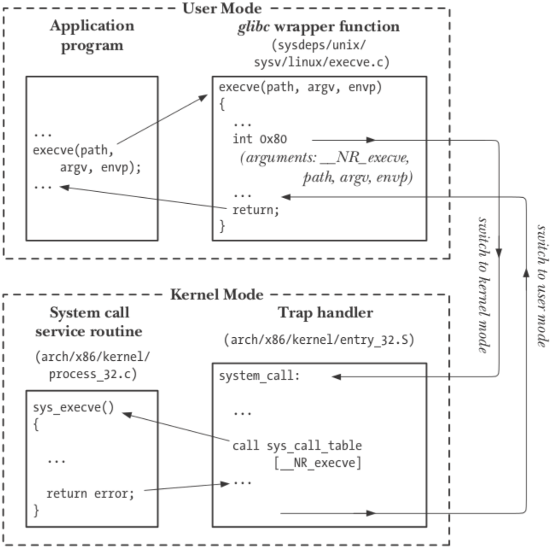
System call invocation

1. programs trigger syscalls by invoking wrapper functions provided by the standard C library (with which they can link)
2. before actual syscall invocation, arguments shall be put in specific registers; the wrapper fill those registers copying from user space
3. the wrapper fills a predefined register with the syscall number
    - %eax on x86-32 architectures
4. the wrapper executes a trap machine instruction
    - 0x80 on x86-32
5. the kernel invoke its syscall dispatcher routine

System call invocation (cont.)

6. the syscall dispatcher:
   1. saves processor status on the kernel stack
   2. looks up the syscall code in its syscall table
   3. executes the syscall code, passing and returning arguments via the kernel stack
   4. restore processor status
   5. put on the *process* stack the syscall return value
   6. return to the wrapper function
7. if the return value of the syscall dispatcher indicates an error, the wrapper function sets `errno` to the error value

System call invocation — example



TLPI, Figure 3-1

System call invocation — putting it all together

"All this seems pretty complicated."
When developing and debugging how can we know which is which?

E.g.: is `foo(42)`

- a syscall?
- a wrapper from the standard C library?
- another user-space library function?

strace

To understand the interaction among user- and kernel-level code, and the role played by system calls, *experimenting with existing programs* is invaluable.

strace allows to trace syscall invocations.

From the `strace(1)` manpage:

> strace - trace system calls and signals
>
> `strace [ command [ arg... ] ]`
>
> [. . .] strace runs the specified command until it exits. It intercepts and records the system calls which are called by a process [. . .]. The name of each system call, its arguments and its return value are printed on standard error [. . .].
>
> strace is a useful diagnostic, instructional, and debugging tool. [. . .] Students, hackers and the overly-curious will find that a great deal can be learned about a system and its system calls by tracing even ordinary programs. [. . .]

A “Hello, World!” journey

```c
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char **argv) {
        printf("hello, world\n");
        exit(EXIT_SUCCESS);
}
```

- which system calls are invoked by the most famous C code example?
- what are the respective roles of user- and kernel-level code?

A “Hello, World!” journey

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}
```

- which system calls are invoked by the most famous C code example?
- what are the respective roles of user- and kernel-level code?

Let’s strace it. . .

A “Hello, World!” journey (cont.)

```
$ strace ./hello
execve("./hello", ["./hello"], [/* 51 vars */]) = 0
brk(0)                                  = 0x1c25000
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
mmap(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f734db26000
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
open("/etc/ld.so.cache", O_RDONLY)      = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=143995, ...}) = 0
mmap(NULL, 143995, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f734db02000
close(3)                                = 0
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
open("/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY) = 3
read(3, "\177ELF\2\1\1\0\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\300\357\1\0\0\0\0\0"..., 832) = 832
fstat(3, {st_mode=S_IFREG|0755, st_size=1570832, ...}) = 0
mmap(NULL, 3684440, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x7f734d585000
mprotect(0x7f734d6ff000, 2097152, PROT_NONE) = 0
mmap(0x7f734d8ff000, 20480, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x17a0
mmap(0x7f734d904000, 18520, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) =
close(3)                                = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f734db01000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f734db00000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f734daff000
arch_prctl(ARCH_SET_FS, 0x7f734db00700) = 0
mprotect(0x7f734d8ff000, 16384, PROT_READ) = 0
mprotect(0x7f734db28000, 4096, PROT_READ) = 0
munmap(0x7f734db02000, 143995)          = 0
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 5), ...}) = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f734db25000
write(1, "hello, world\n", 13)          = 13
exit_group(0)                           = ?
```

A “Hello, World!” journey (cont.)

Here is a tiny part of the journey, annotated with actors:

- a new process, created by the shell uses the execve syscall to execute our program
- the kernel reads the object code from the “hello” binary program and start executing it

...

- the “hello” process invokes the `printf` function from the standard C library (libc)
- the libc invokes the `write` syscall to print on the screen
- the kernel prints on the console

...

- (process) invokes `exit`
- (libc) invokes the `exit_group` syscall
- (kernel) terminates the process

Manual sections help too

When looking at *code*, help to understand where specific functions are implemented might come from sections of the UNIX programming manual.

> *The table below shows the section numbers of the manual followed by the types of pages they contain.*
>
> 1. *Executable programs or shell commands*
> 2. *System calls (functions provided by the kernel)*
> 3. *Library calls (functions within program libraries)*
> 4. *Special files*
> 5. *File formats and conventions*
> 6. *Games*
> 7. *Miscellaneous*
> 8. *System administration commands*
> 9. *Kernel routines [Non standard]*
>
> — *man(1)*

Interlude — Error handling

Error checking mantra

Thou shalt always check the return code of system calls for error.

Usually, when such an error occurs the following happens:

1. the syscall wrapper function returns a negative value
    - or NULL, for functions returning pointers
2. `errno` is set to further *explain* the error (why?)

Interlude — Error handling

Error checking mantra

Thou shalt always check the return code of system calls for error.

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Example

`open` returns -1 upon failure, but there are about 15 possible different reasons for the failure.
`errno` discriminates among them.

`errno`

`<errno.h>` defines:

- the `errno` symbol
- constants (all starting with 'E') corresponding to error classes, which can be compared with `errno` for equality

Some examples from `errno(3)`:

EACCES	permission denied
EAGAIN	resource temporarily unavailable
EBUSY	device or resource busy
EINTR	interrupted function call
EINVAL	invalid argument
ENOENT	no such file or directory
ENOSPC	no space left on device
EPRM	operation not permitted
EPIPE	broken pipe

sounds familiar?

`errno` — tips and pitfalls

- `errno` is usually believed to be global and unique, but it's actually thread local for multi-threaded processes
  - allow to have thread-local error contexts
- `errno` is *not* cleared by functions that do *not fail*; the previous value, possibly erroneous, remains
  - you should check `errno` *only if an error has actually occurred*

errno — tips and pitfalls (cont.)

- the following code is b0rked:

```
if (somecall() == -1) {
        printf("somecall() failed\n");
        if (errno == ENOENT) { ... }
}
```

Why?

errno — tips and pitfalls (cont.)

- the following code is b0rked:

```
if (somecall() == -1) {
        printf("somecall() failed\n");
        if (errno == ENOENT) { ... }
}
```

Many functions set errno upon failure, so we might be checking the `errno` of someone else than `somecall()`.
The fix (if you really have to print before testing `errno`) is to "backup" `errno` to a separate variable and *test the saved value* against `<errno.h>` constants:

```
if (somecall() == -1) {
        int errsv = errno;
        printf("somecall() failed\n");
        if (errsv == ENOENT) { ... }
}
```

Interlude — helper functions

To keep examples short, we'll introduce various helper functions (or "helpers"). Here is the first one:

```
#include <stdio.h>
#include <stdlib.h>

void err_sys(const char *msg) {
        perror(msg);
        exit(EXIT_FAILURE);
}
```

- `perror` print a given error message together with a human readable version of `errno` (message + ": " + errno description)
  - this is why `errno` descriptions sounded familiar...

We will **#include** "helpers.h" in code examples when using helpers.

Interlude — helper functions (cont.)

A couple more helpers...

```
#include <stdio.h>
#include <stdlib.h>

void err_msg(const char *msg) {
        perror(msg);
}

void err_quit(const char *msg) {
        printf("%s\n", msg);
        exit(EXIT_FAILURE);
}
```

Helper functions — example

```
#include <unistd.h>
#include "helpers.h"

#define BUFFSIZE        4096

int main(void) {
        int     n;
        char    buf[BUFFSIZE];

        while ((n = read(STDIN_FILENO, buf, BUFFSIZE)) > 0)
                if (write(STDOUT_FILENO, buf, n) != n)
                        err_sys("write error");
        if (n < 0)
                err_sys("read error");

        exit(EXIT_SUCCESS);
}
```

The standard C library

We've seen that the standard C library ("libc" for short) contains syscall wrappers. It contains much more than that.

- many libc functions do not use syscalls at all
- some libc functions just lift syscalls API to handier APIs
  - e.g.: time and timezone management
- some libc functions performs substantial extra work
  - memory allocation
    - syscall-level: `sbrk` (it just *moves* address space boundary)
    - libc-level: `malloc`/`free` (bookkeeping of allocated blocks)
  - standard I/O: buffering, higher-level operations (e.g. read a *line*)

Standard I/O — example

Same example, with C (buffered) standard I/O:

```
#include "helpers.h"
#define BUFFSIZE 4096

int main(void) {
        char buf[BUFFSIZE];

        while (fgets(buf, BUFFSIZE, stdin))
                if (fputs(buf, stdout) == EOF)
                        err_sys("fputs error");
        exit(EXIT_SUCCESS);
}
```

note the double copy phenomenon:

1. at each loop iteration data is copied to/from internal buffers of the C standard library implementation
2. upon buffer flushing, `read`/`write` are used

Which libc am I using?

Several libc implementations are available, popular ones:

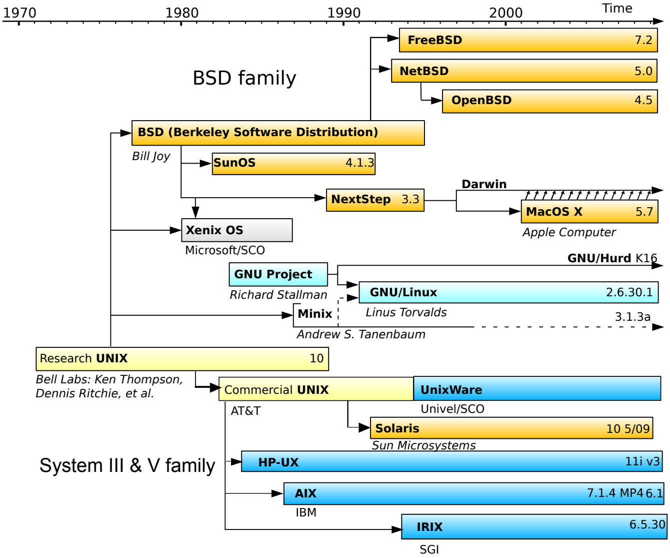
- glibc — the GNU C library — `www.gnu.org/software/libc/`
- eglibc — the Embedded GLIBC — `www.eglibc.org`

```
$ ldd `which ls` | grep libc
   libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007fb406fbc000)

$ /lib/x86_64-linux-gnu/libc.so.6
GNU C Library (Debian EGLIBC 2.13-21) stable release version 2.13,
by Roland McGrath et al.
Copyright (C) 2011 Free Software Foundation, Inc.
This is free software; see the source for copying conditions.
There is NO warranty; not even for MERCHANTABILITY or FITNESS FOR A
PARTICULAR PURPOSE.
Compiled by GNU CC version 4.4.6.
Compiled on a Linux 3.0.0 system on 2011-09-13.
Available extensions:
    crypt add-on version 2.1 by Michael Glad and others
    GNU Libidn by Simon Josefsson
    Native POSIX Threads Library by Ulrich Drepper et al
    BIND-8.2.3-T5B
libc ABIs: UNIQUE IFUNC
For bug reporting instructions, please see: <http://www.debian.org/Bugs/>.
```

Outline

UNIX genealogy



`http://en.wikipedia.org/wiki/File:Unix_history.svg`

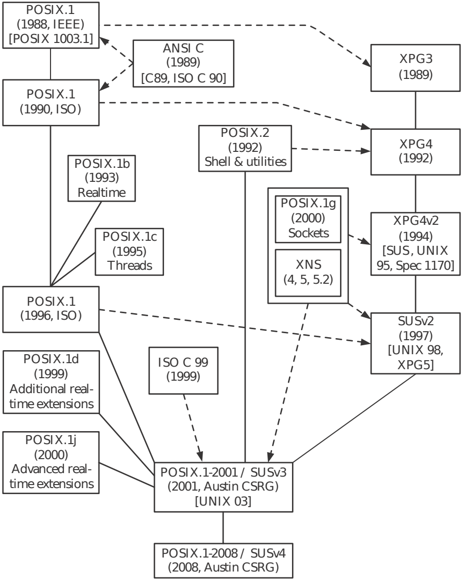
UNIX standardization

Originally, portability across UNIX-es has been quite good.
During the UNIX wars of the 80s, the situation started getting worse.

Due to that, many high-profile users—including the US government—started pushing for UNIX standardization.

Many (competing) standards ensued.

UNIX standardization



POSIX.1
(1988, IEEE)
[POSIX 1003.1]

ANSI C
(1989)
[C89, ISO C 90]

XPG3
(1989)

POSIX.1
(1990, ISO)

POSIX.2
(1992)
Shell & utilities

XPG4
(1992)

POSIX.1b
(1993)
Realtime

POSIX.1g
(2000)
Sockets

XNS
(4, 5, 5.2)

XPG4v2
(1994)
[SUS, UNIX 95, Spec 1170]

POSIX.1c
(1995)
Threads

POSIX.1
(1996, ISO)

SUSv2
(1997)
[UNIX 98, XPG5]

POSIX.1d
(1999)
Additional real-time extensions

ISO C 99
(1999)

POSIX.1j
(2000)
Advanced real-time extensions

POSIX.1-2001 / SUSv3
(2001, Austin CSRG)
[UNIX 03]

POSIX.1-2008 / SUSv4
(2008, Austin CSRG)

TLPI, Figure 1-1

ISO C

The C standard defines:

- syntax and semantics of the C language
- the C standard library

Relevant timeline:

1989 approved by ANSI (“ANSI C”)

1990 approved by ISO, unchanged

1999 updated by ISO (“C99”)

- new keyword `restrict` for pointer declarations. Inform the compiler that the object referenced by a pointer is accessible *only via that pointer* within the containing scope (i.e. no pointer aliasing)
- not yet fully supported by compilers

2011 updated by ISO (“C11”)

- type-generic macros, thread local storage, unicode, anonymous structs/unions, . . .
- more optional features, to ease compliance (. . .)

IEEE POSIX

"Portable Operating System Interface"

- family of UNIX-related standards by IEEE, updated overtime
- notion of "POSIX compliance", which has worked pretty well

Relevant timeline:

1988	IEEE 1003.1 — syscall API
1990	approved by ISO with the name "POSIX.1", unchanged
1993–2000	updated by IEEE, real-time extensions
1996	updated by ISO, includes pthreads ("POSIX threads")
2001	great merger, combines several standards • ISO/IEEE POSIX branches • shell and utilities • ISO C standard library

Single UNIX Specification (SUS)

Initially a superset of POSIX.1, specifying additional *optional* interfaces known as X/Open System Interface (XSI). E.g.:

- encryption
- real-time threads
- XSI STREAMS
- ...

SUS defines extra interfaces and also “annotates” all POSIX.1 interfaces as either mandatory or optional for XSI conformance.

The UNIX® trademark

The UNIX trademark, owned by Open Group, uses SUS as a criteria to define “UNIX systems”. To be called “UNIX system”, a system must pass XSI conformance.

Some UNIX(-like) implementations

- **UNIX System V** (SysV) proprietary UNIX by AT&T (now SCO)
  - release 4 conformed to both POSIX 1003.1 and SUS
- **BSD** (Berkeley Software Distribution)
  - now evolved into FreeBSD / NetBSD / OpenBSD
  - origin of the liberal licensing movement
- **Linux**, started in 1991 by Linus Torvalds
  - nowadays the most popular UNIX-like system
  - considered to be both POSIX.1 and SUSv4 compliant
    - no formal conformance though, due to the distribution model
- **Mac OS X** mixture of Mach kernel and FreeBSD
- **Solaris** UNIX system by Sun Microsystems (now Oracle)
  - historically proprietary, mixed fortune in open sourcing

Outline

1. What is system programming

2. UNIX concepts

3. System programming concepts

4. UNIX standards and implementations

5. About this course

Objectives

Learn UNIX system programming concepts and core APIs.
Learn how to learn more.

Specific topics:

- process management
- inter process communication (IPC)
  - signal handling
  - pipes
  - FIFOs
  - (UNIX domain sockets)
  - shared memory
  - synchronization
  - ~~System V~~ POSIX IPC
  - (D-Bus)
- threads

General info

Équipe pédagogique

- chargé de cours: Stefano Zacchiroli
- chargé de TD et projet: Juliusz Chroboczek

Horaires

- jeudi 13h30-15h30, cours magistral, amphi 3BD
- lundi 13h30-15h30, TD (groupe A), salle 2032
- vendredi 13h30-15h30, TD (groupe B), salles 2032

Calendrier

- 16 septembre 2013 - début de cours
- 23 septembre 2013 - début de TD

Homepage

`http://upsilon.cc/zack/teaching/1314/progsyst/`

Mailing list

Tous les étudiants doivent s'abonner à la liste de diffusion `m1progsyst`:

https://listes.sc.univ-paris-diderot.fr/sympa/info/m1progsyst

- toute annonce concernant le cours sera envoyée à cette liste
- toute question concernant le cours doit être envoyée à cette liste

Validation

Le cours sera évalué:

- pour 50% par un projet[2]
- pour 50% par un examen

Le projet consistera à développer un logiciel, en utilisant les concepts et les techniques de programmation systèmes que nous découvrirons.

---

[2] qui n'est pas du contrôle continu donc obligatoire

Bibliography

W. Richard Stevens and Stephen A. Rago
Advanced Programming in the UNIX® Environment. ("APUE")
Addison-Wesley Professional, 2nd edition, 2005.

- the great classic of UNIX system programming
- undying textbook for any UNIX programming course

Michael Kerisk
The Linux Programming Interface. ("TLPI")
No Starch Press, 2010.

- more recent (past POSIX.1-2008), more in-depth
- more Linux-specific, but still with an eye on standards

Robert Love
Linux System Programming.
O'Reilly Media, 2007.

- Linux-specific, does not cover IPC
- full of kernel-level insights, useful to any UNIX programmer