Kernel and System Calls

Advanced Systems Programming in C/Rust

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Topics

1. What is an operating systems' **kernel**?
2. How do applications interact with the kernel?

Kernel

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- manages resources (memory, threads, I/O devices, etc. . .)
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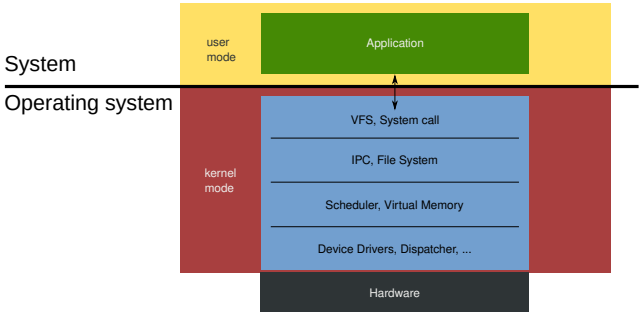
Various kernel designs define the boundary between privileged/unprivileged modes.

Monolithic Kernels

All OS services live in the kernel, in a single address space.
Single binary, modules can be added at run time.



Pros:

- *Performance*: mode switches are relatively rare

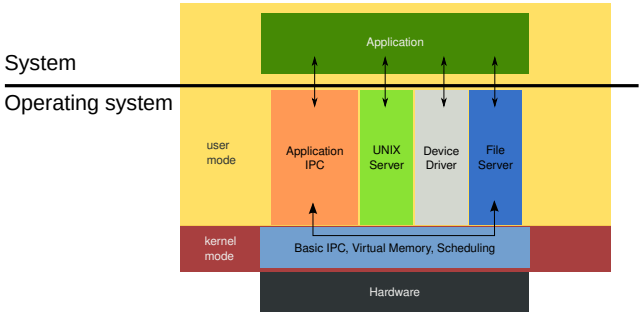
Cons:

- *Reliability*: failure of a kernel service crashes the system

Examples: Linux, *BSD, MS-DOS, . . .

Micro Kernels

Minimal services live in the kernel. Non essential services run in user mode.
If a user service crashes, it can be restarted without crashing the system.



Pros:

- *Reliability*: services can crash and restart
- *Safety*: easier to formalise

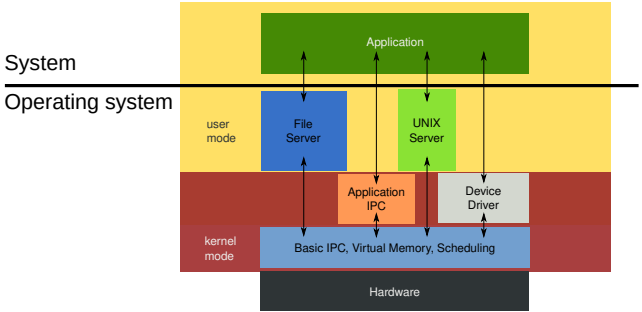
Cons:

- *Performance*: lots of mode switches and communication

Examples: MINIX, Mach, ...

Hybrid Kernels

Between monolithic and micro kernels.
Performance-critical services live in the kernel, others run in user mode.

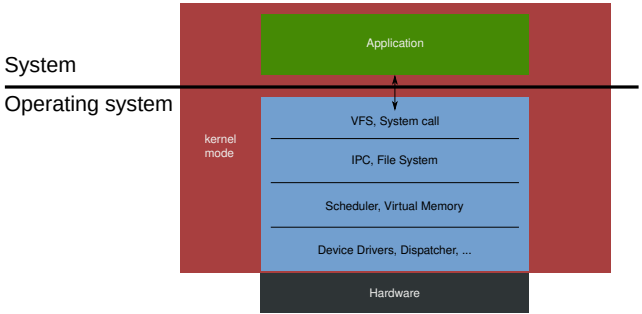


Depending on how *monolithic* or *micro* the kernel is, performance and reliability are on a spectrum between both designs.

Examples: NT, XNU, ReactOS, ...

UniKernels

Everything lives in the kernel, even applications.
Usually tailored for a particular application.



Pros:

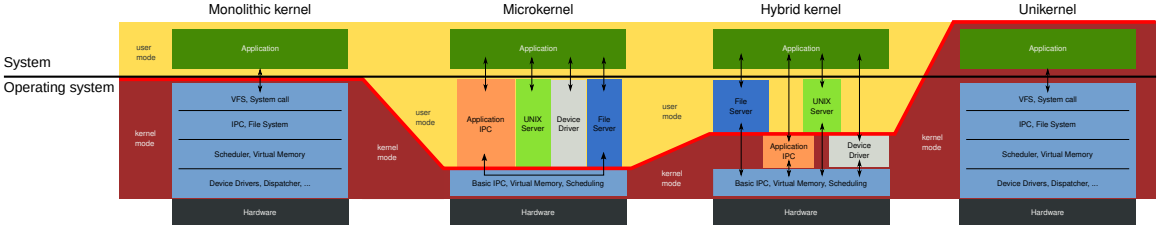
- *Performance*: No mode switches, tailored to application.

Cons:

- *Usability*: Hard to create, single purpose.

Examples: ClickOS, MirageOS, Graphene ...

~~Fifty~~ Four Shades of Kernel



Privilege Levels

The privilege level determines what a piece of code can do on the system.

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  $\Rightarrow$ Used by applications
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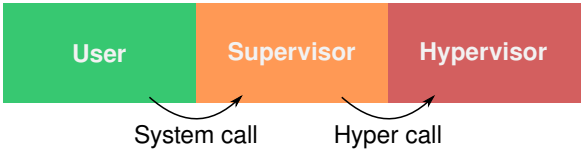
Switching between privilege levels requires specific instructions.



System Calls

System calls allow applications to execute privileged code to perform certain tasks:

- I/Os (disk, network)
- resource management (memory, threads)
- communication (signals, IPCs)
- access to specific hardware

They are the API of the kernel for user applications.
We'll only focus on **Linux** system calls here.

System Call Wrappers

Programmers rarely directly use system calls. They usually use `libc` functions that perform system calls.

Example: The `ssize_t write(int, void*, size_t)` function is **not** an actual system call, but a wrapper from the `libc`.

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Example: The `ssize_t write(int, void*, size_t)` function is **not** an actual system call, but a wrapper from the `libc`.

Wrappers can make some argument checks and error handling (i.e. `errno`).

Some wrappers may do more (e.g. memory allocation can reuse previously freed memory without going through the kernel)

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int 0x80
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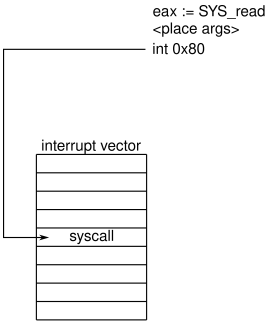

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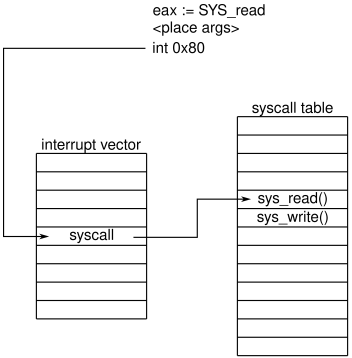

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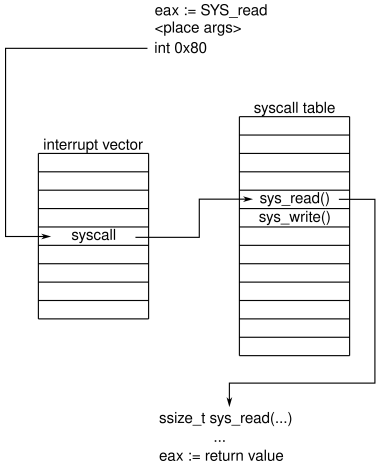

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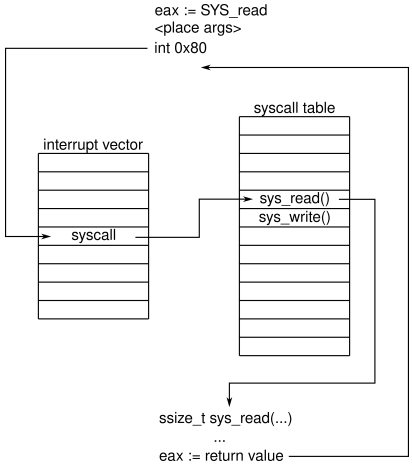

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syscall
```

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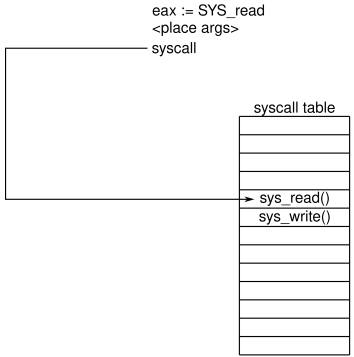

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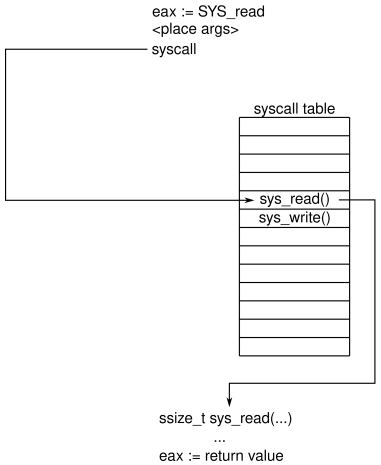

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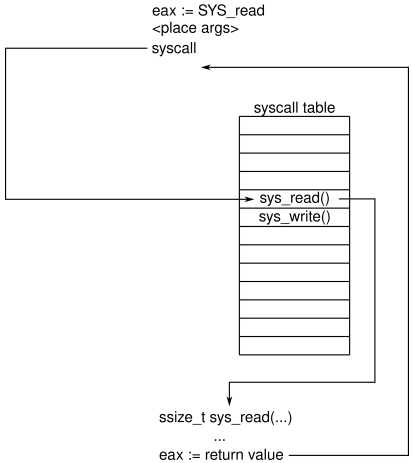

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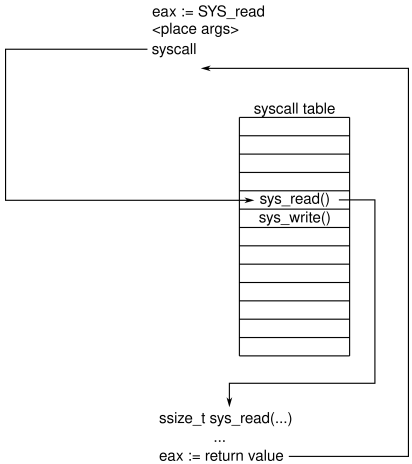
One level of indirection is bypassed.



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Arch	syscall#	retval	arg1	arg2	arg3	arg4	arg5	arg6	arg7
arm EABI	r7	r0	r0	r1	r2	r3	r4	r5	r6
arm64	w8	x0	x0	x1	x2	x3	x4	x5	–
mips	v0	v0	a0	a1	a2	a3	a4	a5	–
riscv	a7	a0	a0	a1	a2	a3	a4	a5	–
x86-64	rax	rax	rdi	rsi	rdx	r10	r8	r9	–

Note: Linux allows at most 6 arguments for system calls. More examples at `man syscall`.

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x86-64	rax	rax	rdi	rsi	rdx	r10	r8	r9	–

Note: Linux allows at most 6 arguments for system calls. More examples at `man syscall`.
Note 2: Conforming to the ABI is the job of the `long syscall(long nr, ...)` function from the `libc`.

This Week's Tasks

Training exercises:

- Invoke a system call with the `syscall` libc function
- Invoke a system call in assembly

Main exercise:

- Implement a system call tracer

Going further (not graded):

- Implement a new system call in the Linux kernel

Hijacking System Calls (sort of . . .)

For the training exercises

System calls wrappers (`libc`) are usually provided through a shared library.

```
redha@tum:~$ ldd /usr/bin/echo
linux-vdso.so.1 (0x00007ffd71f08000)
libc.so.6 => /usr/lib/libc.so.6 (0x00007f1af627a000)
/lib64/ld-linux-x86-64.so.2 => /usr/lib64/ld-linux-x86-64.so.2 (0x00007f1af6475000)
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You can override a system shared library with your version with the `LD_PRELOAD` environment variable.

Tracing System Calls with `strace`

For the main exercise

`strace` is a tool used to trace system calls and signals. It relies on the `ptrace()` system call.

```
redha@tum:~$ strace -e execve,brk,open,read,write echo foo bar > /tmp/toto
execve("/usr/bin/echo", ["echo", "foo", "bar"], 0x7fff7460ee10 /* 48 vars */) = 0
brk(NULL)                               = 0x55d47d60c000
read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0`|\2\0\0\0\0\0"..., 832) = 832
brk(NULL)                               = 0x55d47d60c000
brk(0x55d47d62d000)                     = 0x55d47d62d000
write(1, "foo bar\n", 8)                = 8
+++ exited with 0 +++

redha@tum:~$
```

See you at the Q&A on Thursday!