Advanced Programming in the UNIX Environment

Week 13, Segment 6:

Capabilities, Control Groups, Containers

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POSIX *Capabilities*

With so many things to try to restrict, one approach to more fine grained control are so-called *Capabilities*:

- `CAP_CHOWN` - the ability to chown files
- `CAP_SETUID` - allow setuid
- `CAP_LINUX_IMMUTABLE` - allow append-only or immutable flags
- `CAP_NET_BIND_SERVICE` - allow network sockets <1024
- `CAP_NET_ADMIN` - allow interface configuration, routing table manipulation, …
- `CAP_NET_RAW` - raw packets
- `CAP_SYS_ADMIN` - broad sysadmin privs (mounting file systems, setting hostname, handling swap, …)...

Note the difference in implementation (again); *e.g.,* POSIX, FreeBSD `capsicum(4)`, NetBSD/macOS `kauth(9)`, Linux `capabilities(7)`.

Linux Namespaces

Inspired by Bell Labs’ Plan 9 Operating System, Linux Namespaces partition kernel resources to expose them with granular visibility to processes and process groups:

- mnt — mount points
- pid — process ID visibility
- net — virtualized network stack
- ipc — System V IPC visibility
- uts — Unix Time Sharing (different host- and domain names)
- user — user-IDs and privileges
- time — system time
- cgroup — control groups

Linux Control Groups

Originally termed *process containers*, `cgroups` allow for:

- resource limiting (*e.g.*, memory limit)
- prioritization (*e.g.*, CPU utilization, disk I/O throughput)
- accounting
- control (*e.g.*, freezing, checkpointing, and restarting)

Linux Control Groups

cgroups provide the following controls:

- cpu - ability to schedule tasks
- cpuset - CPUs and memory nodes
- freezer - activity of control groups
- hugetlb - large page support (HugeTLB) usage
- io - block device I/O
- memory - memory, kernel memory, swap memory
- perf_event - ability to monitor threads
- pids - number of processes
- rdma - remote direct memory access

Linux Control Groups

cgroups are implemented as a virtual file system, often under /sys/fs/cgroup:

```
# create a new memory cgroup:
mkdir /sys/fs/cgroup/memory/group0
# move the current shell into the memory controller group:
echo $$ > /sys/fs/cgroup/memory/group0/tasks
# limit the shell’s memory usage:
echo 40M > /sys/fs/cgroup/memory/group0/memory.limit_in_bytes
```

See cgroups(7) for more details.

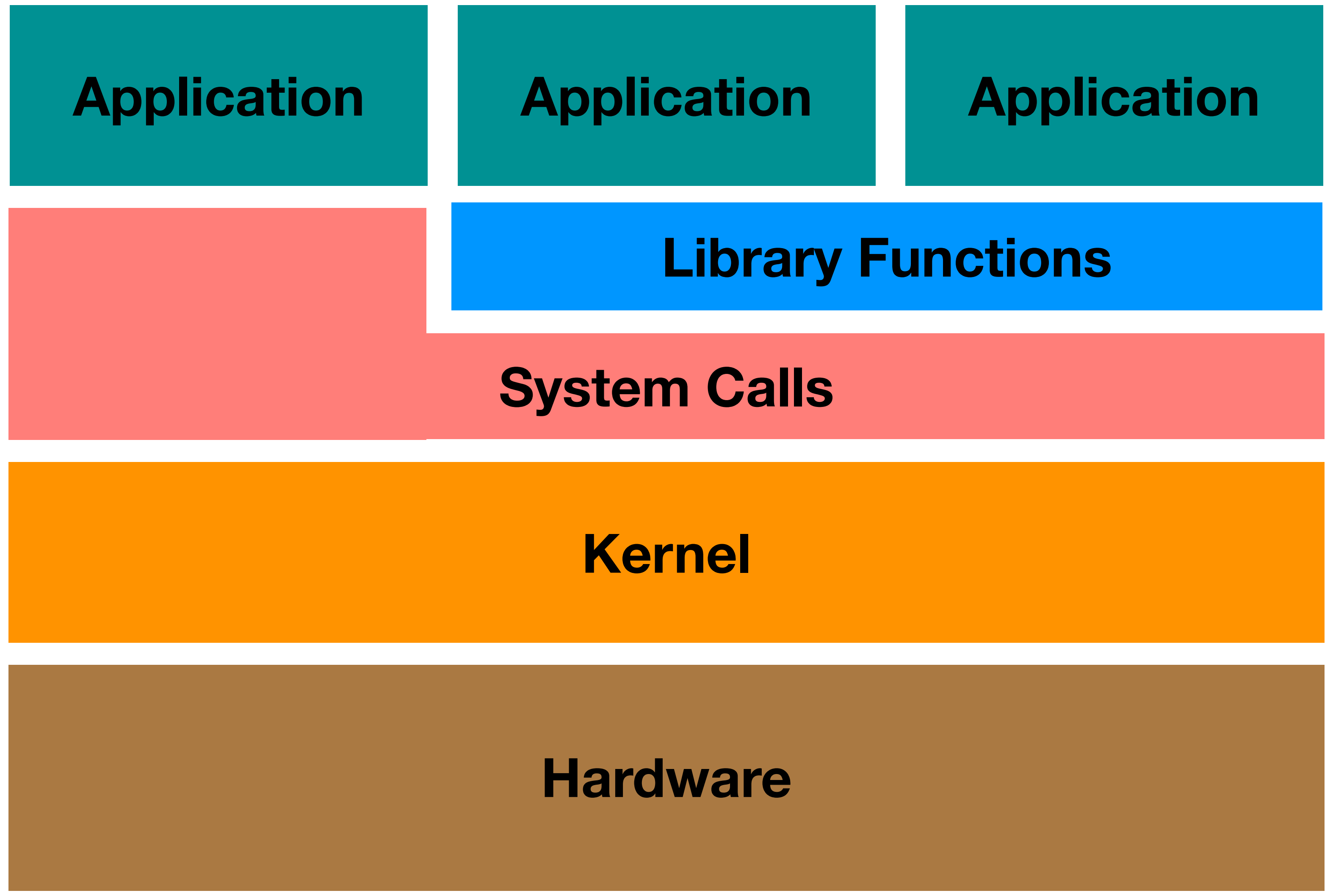
Containers

A *container* is an isolated execution environment providing a form of lightweight virtualization:

- use null and union mounts to provide the right environment
- restrict processes in their utilization
- restrict filesystem views
- restrict processes from what they can see
- restrict processes from what they can do

That is, the basis of many container technologies, such as CoreOS, LXC, or Docker, are `cgroups`, *namespaces*, and the application of all the various concepts discussed in this series.

Basic OS


Application
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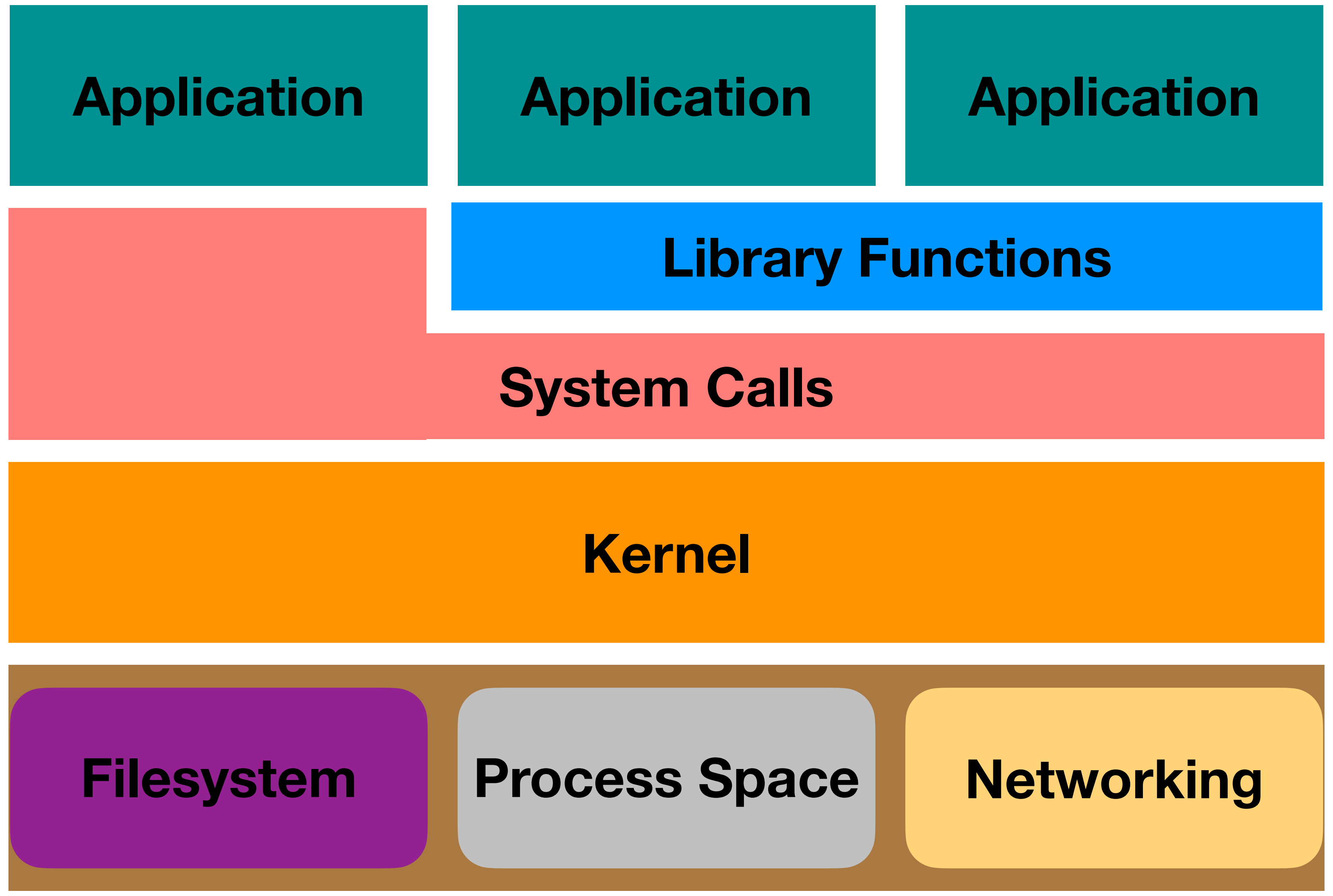
Application
Library Functions
System Calls
Kernel
Hardware

Basic OS


Application
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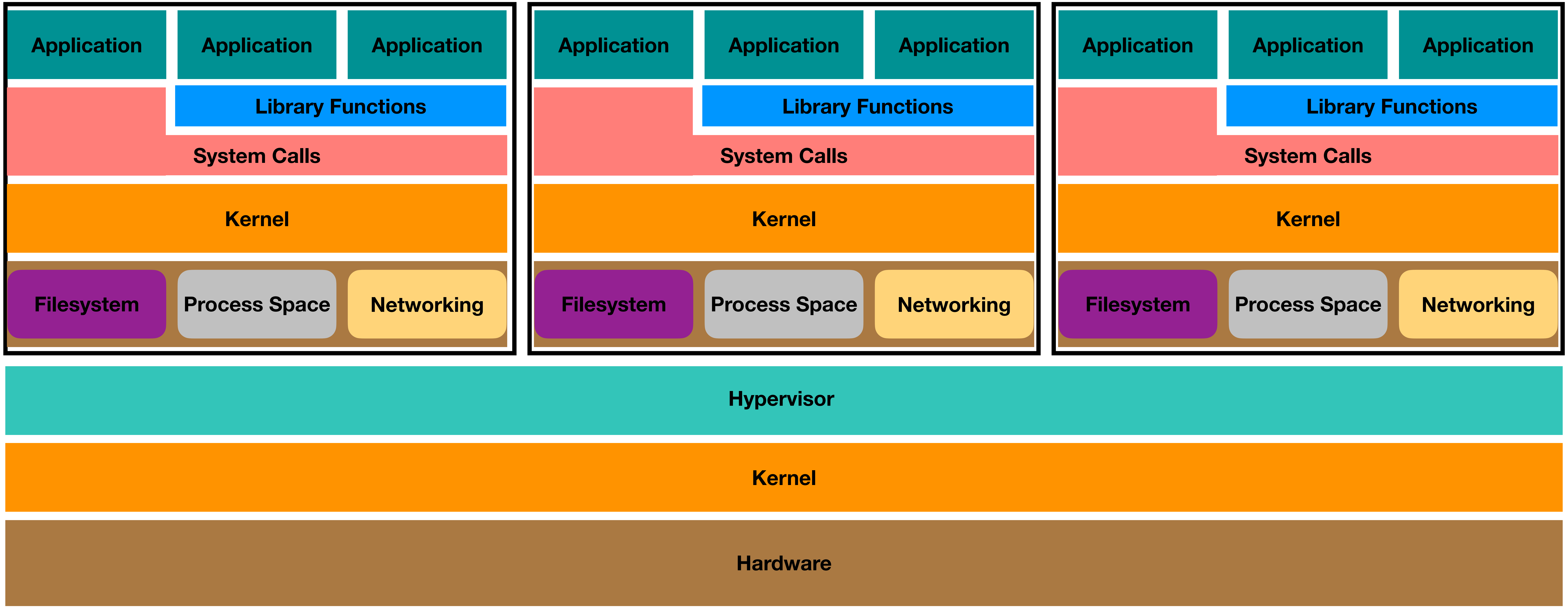
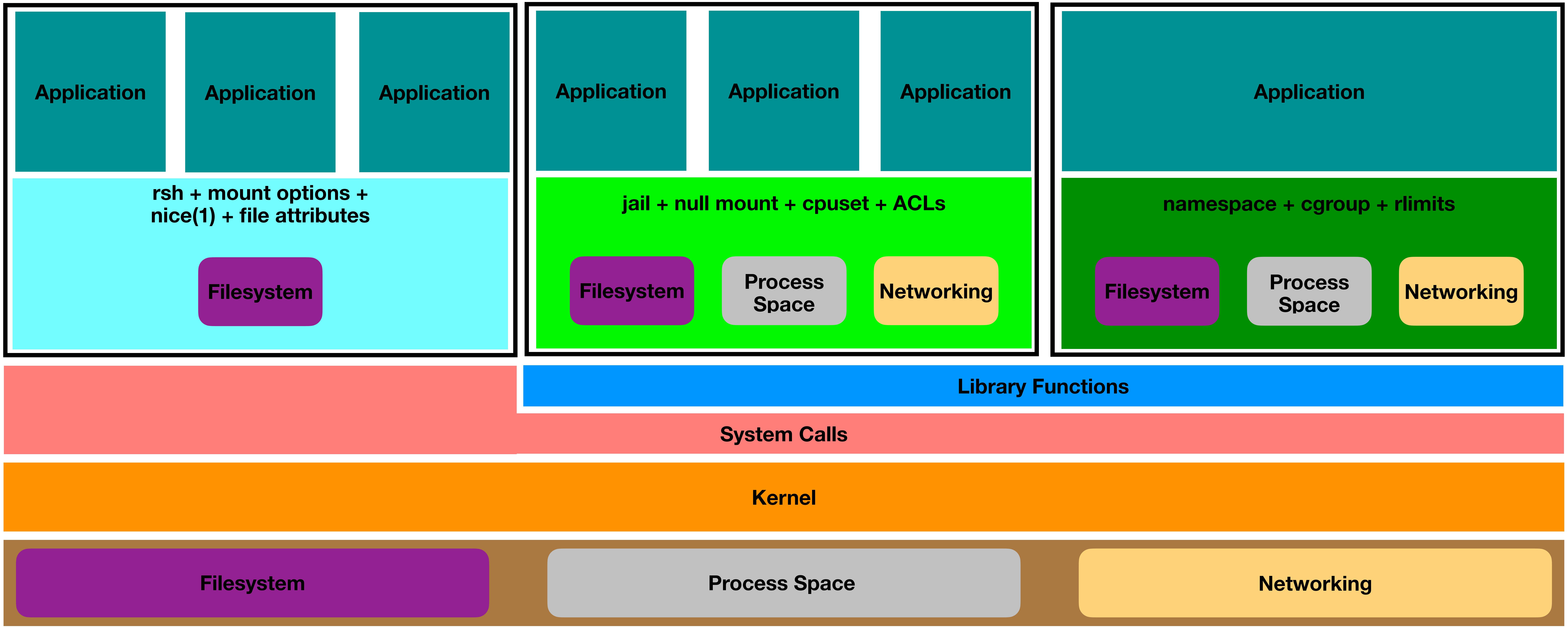
Library Functions
System Calls
Kernel
Filesystem
Process Space
Networking

Virtualization



From restricted processes to containers



Additional Reading

- Capabilities: https://wiki.gentoo.org/wiki/Hardened/Overview_of_POSIX_capabilities
- NetBSD `kauth(9)`: https://man.netbsd.org/kauth.9
- macOS: https://developer.apple.com/library/archive/technotes/tn2127/_index.html
- Linux `capabilities(7)`: https://man7.org/linux/man-pages/man7/capabilities.7.html
- FreeBSD Capsicum: https://wiki.freebsd.org/Capsicum
- Linux Control Groups: https://www.kernel.org/doc/Documentation/cgroup-v2.txt
- Linux Namespaces: https://medium.com/@teddyking/linux-namespaces-850489d3ccf