Advanced Operating Systems
Through tracing, analysis, and experimentation

ACS/Part III L41: Advanced Operating Systems
Part II: Advanced Operating Systems

Lecture 1, Part 1: What is an Operating System?
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MPhil/Part III L41 vs. Part II AdvOpSys

• These lectures are shared by two separate courses:
  • ACS / Part III L41: Advanced Operating Systems
  • Part II: Advanced Operating Systems (AdvOpSys)

• The two courses also share an online lab framework based on the RPi4, DTrace, and HWPMC

• But there are some important differences:
  • Key difference 1: Assessed coursework
    • L41 has 3x independently written lab reports
    • Part II has 2x short answer lab assignments (+ 1x optional)
  • Key difference 2: Assigned readings
    • L41 assigns additional research readings

• Please be sure to use the right material for your course!
Taught online for the first time ... please bear with us!

- Due to the pandemic, this material is being taught fully online for the first time
- We have had to make large changes to lab structures:
  - Previously used take-home BBB boards ...
  - ... now we have 50 RPi4 boards in a rack
  - Previously involved several hours of in-person lab time ...
  - ... now we will provide support online via Slack, etc.

- We’ve wanted to move to the RPi for years, but ...
- ... There will probably be some bumpiness as a result
  - You might well encounter bugs with the material
  - Contact us rather than spending hours figuring it out
  - Let us know how we can improve the course
Getting started

• What is an operating system?

• About the module

• Systems research

• Lab assignments / reports

• Readings for next lecture

Lecture 1, Part 1

Lecture 1, Part 2
What is an operating system?

[An OS is] low-level software that supports a computer’s basic functions, such as scheduling tasks and controlling peripherals.

- Google hive mind
What is an operating system?

But that is basically the 1970s definition, and not at all a contemporary one.

Today’s general-purpose operating systems consist of GB of binaries and hundreds of millions of LoC.

Further, when you select an operating system, you select hardware and software ecosystems.
What is an operating system?

Access control?

Local file systems?

User authentication?

Distributed file-system clients and servers?

Kernel and userspace?

Remote management?

Virtual machines?

Multimedia?

Threads and processes?

Networking and WiFi?

Debug and trace?

Application packaging?

Web browser?

Device drivers?

Class libraries?

System libraries?

Remote access?

Language runtimes?

Shell and command-line tools?

Run-time linker?

System libraries?

Remote access?

Language runtimes?

Class libraries?

Device drivers?

Application packaging?

Debug and trace?

Networking and WiFi?

Threads and processes?

Access control?

Local file systems?

User authentication?

Distributed file-system clients and servers?

Kernel and userspace?

Remote management?

Virtual machines?

Multimedia?

.. And surely lots more

Payment services?

Software updates?

Window system?

Profile and optimization?
General-purpose operating systems

... are for **general-purpose computers**:  
- Servers, workstations, mobile devices  
- Run **applications** – i.e., software unknown at OS design time  
- Abstract the hardware, provide services, ‘class libraries’  
- E.g., Windows, Mac OS X, Android, iOS, Linux, BSD, ...

| Userspace | Local and remote shells, GUI, management tools, daemons  
| Run-time linker, system libraries, logging and tracing facilities |
|---|---|
| Kernel | System calls, hypercalls, remote procedure call (RPC)*  
| Processes, filesystems, IPC, sockets, management  
| Drivers, packets/blocks, protocols, tracing, virtualisation  
| VM, malloc, linker, scheduler, threads, timers, tasks, locks |

* Continuing disagreement on whether distributed-filesystem servers and window systems ‘belong’ in userspace or the kernel
Specialise the OS for a specific application or environment:

- **Embedded, real-time operating systems**
  - Serve a single application in a specific context
    - E.g., WiFi access points, medical devices, washing machines, cars
  - Small code footprint, real-time scheduling
  - Might have virtual memory / process model
  - Microkernels or single-address space: VxWorks, RTEMS, L4
  - Now also: Linux, BSD (sometimes over a real-time kernel), etc.

- **Appliance operating systems**
  - Apply embedded model to higher-level devices/applications
  - File storage appliances, routers, firewalls, ...
    - E.g., Juniper JunOS, Cisco IOS, NetApp OnTap, EMC/Isilon
  - Under the hood, almost always Linux, BSD, etc.

Key concept: **Operating system as a reusable component**
Other kinds of operating systems? (2/3)

What if we rearrange the boxes?

• **Microkernels, library operating systems, unikernels**
  • Shift code from kernel into userspace to reduce Trusted Computing Base (TCB); improve robustness/flexibility; ‘bare-metal’ apps
  • Early 1990s: Microkernels are king!
  • Late 1990s: Microkernels are too slow!
    • (But ideas about OS modularity dating from this period are widespread)
  • 2000s/2010s: Microkernels are back! But now ‘hypervisors’
  • Sometimes: programming-language runtime as OS
Other kinds of operating systems? (3/3)

• **Hypervisors**
  • Kernels host processes; hypervisors host virtual machines
    • Type-1: Standalone hypervisors (e.g., Xen)
    • Type-2: Integrated with OS kernel (e.g., KVM)
  • Virtualised hardware interface rather than POSIX APIs
  • Paravirtualisation reintroduces OS-like APIs for performance
  • E.g., System/370, VMware, Xen, KVM, VirtualBox, bhyve, Hafnium, ...
  • Many microkernel ideas have found a home here

• **Containers**
  • Hosts multiple userspace instances over a common kernel
  • Controlled namespaces prevent inappropriate accesses
  • Really more about code/ABI (Application Binary Interface) distribution and maintenance
What does an operating system do?

• Key hardware-software surface (w/compiler toolchain)
• Low-level abstractions and services
  • **Operational model**: bootstrap, shutdown, watchdogs
  • **Process model, IPC**: processes, threads, IPC, program model
  • **Resource sharing**: scheduling, multiplexing, virtualisation
  • **I/O**: drivers, local/distributed filesystems, network stack
  • **Security**: authentication, encryption, ACLs, MAC, audit
  • **Local or remote access**: console, window system, SSH
  • **Libraries**: math, protocols, RPC, crypto, UI, multimedia
  • **Monitoring/debugging**: logs, profiling, tracing, debugging

Compiler? Text editor? E-mail package? Web browser?
Can an operating system be “distributed”??