OS Concepts and structure

Today

- OS services
- OS interface to programmers/users
- OS components & interconnects
- Structuring OSs

Next time

- Processes

OS Views

- Vantage points
  - OS as the services it provides
    - To users and applications
  - OS as its components and interactions
- OS provides a number of services
  - To users via a command interpreter/shell or GUI
  - To application programs via system calls
  - Some services are for convenience
    - Program execution, I/O operation, file system management, communication
  - Some to ensure efficient operation
    - Resource allocation, accounting, protection and security

Command interpreter (shell) & GUI

- Command interpreter
  - Handle (interpret and execute) user commands
  - Could be part of the OS: MS DOS, Apple II
  - Could be just a special program: UNIX, Windows XP
    - In this way, multiple options – shells – are possible
  - The command interpreter could
    - Implement all commands
    - Simply understand what program to invoke and how (UNIX)
- GUI
  - Friendlier, through a desktop metaphor, if sometimes limiting
  - Xerox PARK Alto >> Apple >> Windows >> Linux

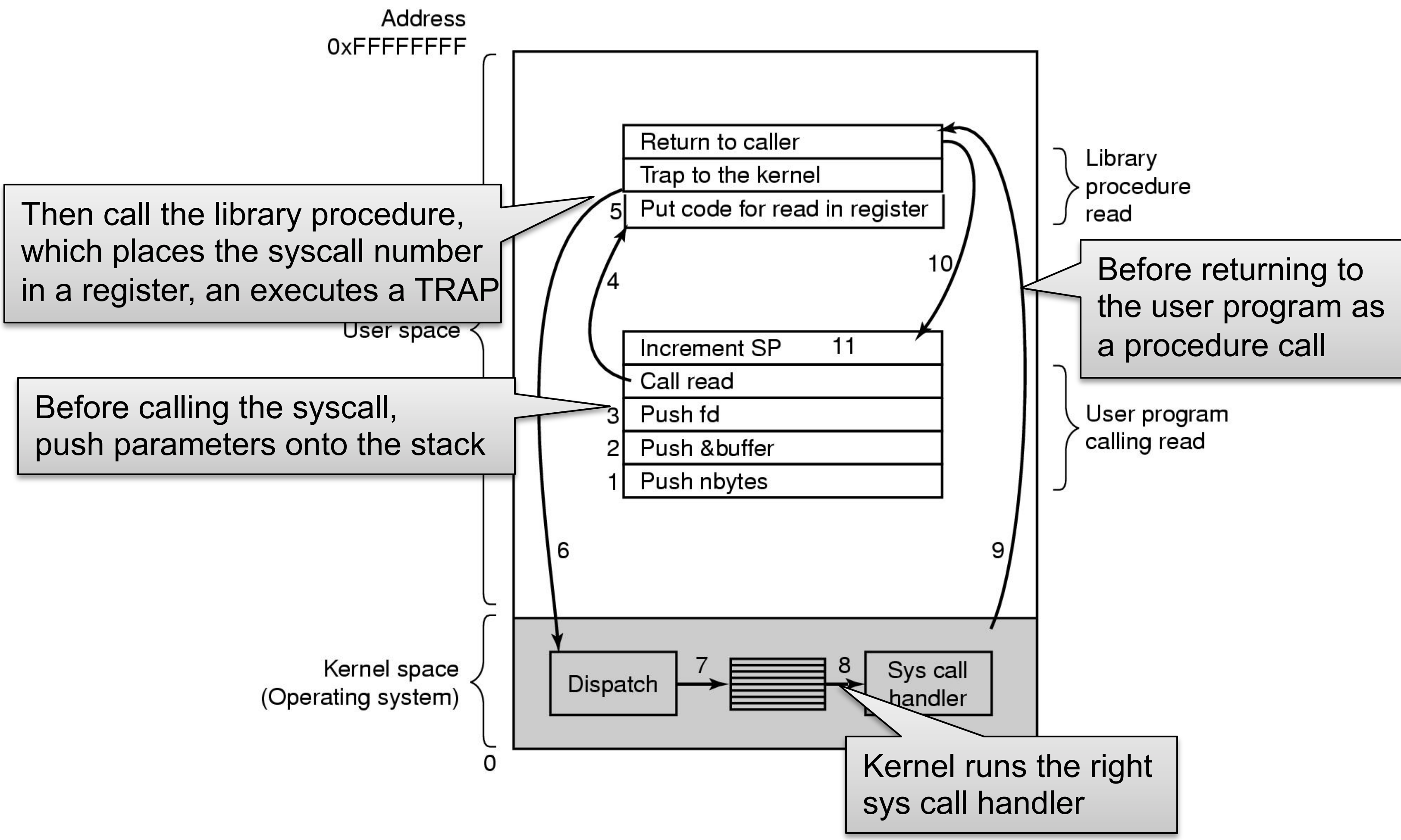
System calls

- Low-level interface to services for applications
- Higher-level requests get translated into sequence of system calls
- Writing `cp` – copy source to destination
  - Get file names
  - Open source
  - Create destination
  - Loop
    - Read from source
    - Copy to destination
  - Close destination
  - Report completion
  - Terminate

System calls

- The steps in making a read system call

```
read(fd, buffer, nbytes);
```



Major OS components & abstractions

- Processes
- Memory
- I/O
- Secondary storage
- File systems
- Protection
- Accounting
- Shells & GUI
- Networking

Processes

- A program in execution
  - Address space
  - Set of registers
- To get a better sense of it
  - What data do you need to (re-) start a suspended process?
  - Where do you keep this data?
  - What is the process abstraction I/F offered by the OS
    - Create, delete, suspend, resume & clone a process
    - Inter-process communication & synchronization
    - Create/delete a child process

Call	Description
pid = fork()	Create a child process identical to the parent
pid = waitpid(pid, &statloc, options)	Wait for a child to terminate
s = execve(name, argv, environp)	Replace a process' core image
exit(status)	Terminate process execution & return status

Memory management

- Main memory – the directly accessed storage for CPU
  – Programs must be stored in memory to execute
  – Memory access is fast (e.g., 60 ns to load/store)
    - but memory doesn't survive power failures
- OS must
  – Allocate memory space for programs (explicitly and implicitly)
  – Deallocate space when needed by rest of system
  – Maintain mappings from physical to virtual memory
    - e.g. through page tables
  – Decide how much memory to allocate to each process
  – Decide when to remove a process from memory

Call	**Description**
void *sbrk(intptr_t increment)	Increments program data space by 'increment' bytes

I/O

- A big chunk of the OS kernel deals with I/O
  - Hundreds of thousands of lines in NT
- The OS provides a standard interface between programs & devices
  - file system (disk), sockets (network), frame buffer (video)
- Device drivers are the routines that interact with specific device types
  - Encapsulates device-specific knowledge
    - e.g., how to initialize a device, request I/O, handle errors
  - Examples: SCSI device drivers, Ethernet card drivers, video card drivers, sound card drivers, …

Secondary storage

- Secondary storage (disk, tape) is persistent memory
  - Often magnetic media, survives power failures (hopefully)
- Routines that interact with disks are typically at a very low level in the OS
  - Used by many components (file system, VM, …)
  - Handle scheduling of disk operations, head movement, error handling, and often management of space on disks
- Usually independent of file system
  - Although there may be cooperation
  - File system knowledge of device details can help optimize performance
    - e.g., place related files close together on disk

File systems

- Secondary storage devices are hard to work with
- File system offers a convenient abstraction
  - Defines logical abstractions/objects like files & directories
  - As well as operations on these objects
- A file is the basic unit of long-term storage
- A directory is just a special kind of file
  - … containing names of other files & metadata
- Interface:
  - File/directory creation/deletion, manipulation, copy, lock
- Other higher level services: accounting & quotas, backup, indexing or search, versioning

Some I/O related system calls

Call	Description
open(s, flags)	Open a file with mode specified in flags
read(fd, buf, n)	Read n bytes from an open file into buf
write(fd,buf,n)	Write n bytes from an open file into fd
close(fd)	Release fd
dup(fd)	Duplicate fd
pipe(p)	Create a pipe and return fd's in p
chdir(s)	Change directory to directory s
mkdir(s)	Create a new directory s
mknod(s, major, minor)	Create a device file
fstat(fd)	Return info about an open file
link(s1, s2)	Create another name (s2) for the file s1
unlink(s)	Remove a name

Protection

- Protection is a general mechanism used throughout the OS
  - All resources needed to be protected
    - memory
    - processes
    - files
    - devices
    - …
- Protection mechanisms help to detect and contain errors, as well as preventing malicious destruction

OS structure

- OS made of number of components
  - Process & memory management, file system, …
  - and system programs
    - e.g., bootstrap code, the init program, …
- Major design issue
  - How do we organize all this?
  - What are the modules, and where do they exist?
  - How do they interact?
- Massive software engineering
  - Design a large, complex program that:
    - performs well, is reliable, is extensible, is backwards compatible, …

OS design & implementation

- *User* goals and *System* goals
  - User – convenient to use, easy to learn, reliable, safe, fast
  - System – easy to design, implement, & maintain, also flexible, reliable, error-free & efficient
- Affected by choice of hardware, type of system
- Clearly conflicting goals, no unique solution
- Some other issues complicating this
  - Size: Windows XP ~40G SLOC, RH 7.1 17G SLOC
  - Concurrency – multiple users and multiple devices
  - Potentially hostile users, but some users want to collaborate
  - Long expected lives & no clear ideas on future needs
  - Portability and support to thousands of device drivers
  - Backward compatibility

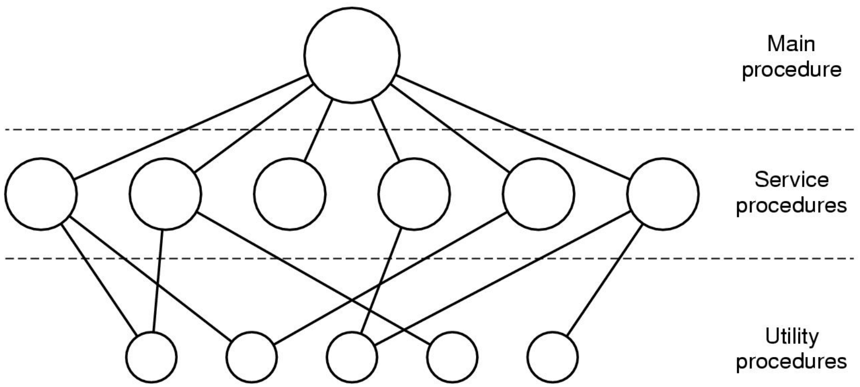
OS design & implementation

- A software engineering principle – separate policy & mechanism
  - Policy: What will be done?
  - Mechanism: How to do it?
  - Why do you care? Max flexibility, easier to change policies
- Implementation on high-level language
  - Early on – assembly (e.g. MS-DOS – 8088), later Algol (MCP), PL/1 (MULTICS), C (Unix, …)
  - Advantages – faster to write, more compact, easier to maintain & debug, easier to port
  - Cost – Size, speed?, but who cares?!

> Early versions … were written in assembly language, but during the summer of 1973, it was rewritten in C. The size of the new system is about one third greater than the old. … much easier to understand and to modify but also includes many functional improvements … we considered this increase in size quite acceptable.
>
> *D. Ritchie and K. Thompson,* The UNIX time-sharing system, *CACM 17(7),1974*

Monolithic design

- Major advantage:
  - Cost of module interactions is low (procedure call)



- Disadvantages:
  - Hard to understand
  - Hard to modify
  - Unreliable (no isolation between system modules)
  - Hard to maintain
- Alternative?
  - How to organize the OS in order to simplify its design and implementation?

Layering

- The traditional approach
  – Implement OS as a set of layers
  – Each layer shows an enhanced ‘virtual mach’ to layer above
- Each layer can be tested and verified independently

Layer	Description
5: Job managers	Execute users’ programs
4: Device managers	Handle device & provide buffering
3: Console manager	Implements virtual consoles
2: Page manager	Implements virtual memory for each process
1: Kernel	Implements a virtual processor for each process
0: Hardware	

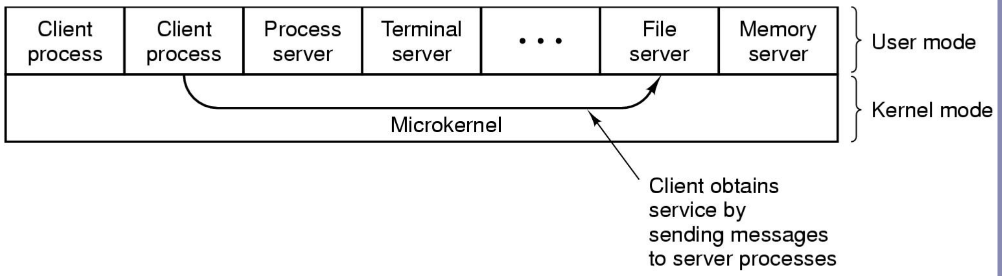
Dijkstra’s THE system

Problems with layering

- Imposes hierarchical structure
  - but real systems have complex interactions
  - Strict layering isn't flexible enough
- Poor performance
  - Each layer crossing implies overhead
- Disjunction between model and reality
  - Systems modelled as layers, but not built that way

Microkernels

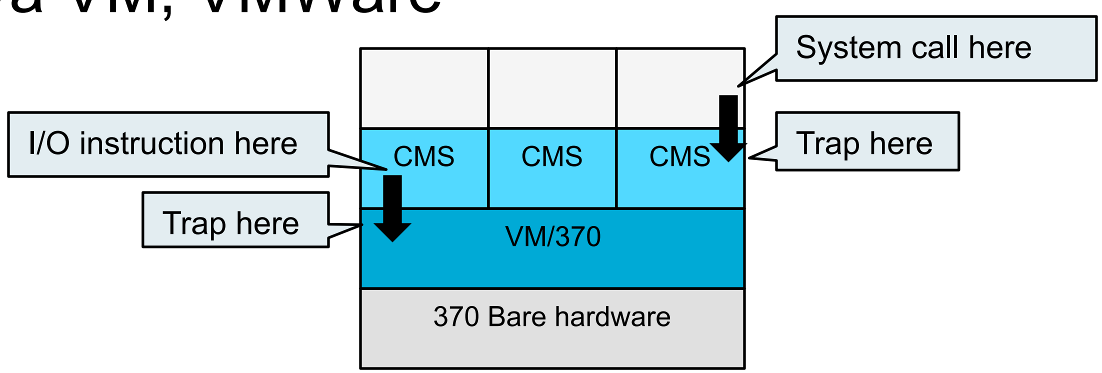
- Popular in the late 80's, early 90's
  - Recent resurgence
- Goal
  - Minimize what goes in kernel
  - Organize rest of OS as user-level processes



- This results in
  - Better reliability (isolation between components)
  - Ease of extension and customization
  - Poor performance (user/kernel boundary crossings)
- First microkernel system was Hydra (CMU, 1970)
  - … Mach (CMU), Chorus (French UNIX-like OS), OS X (Apple), in some ways NT (Microsoft), L4 (Karlsruhe), …

Virtual machines

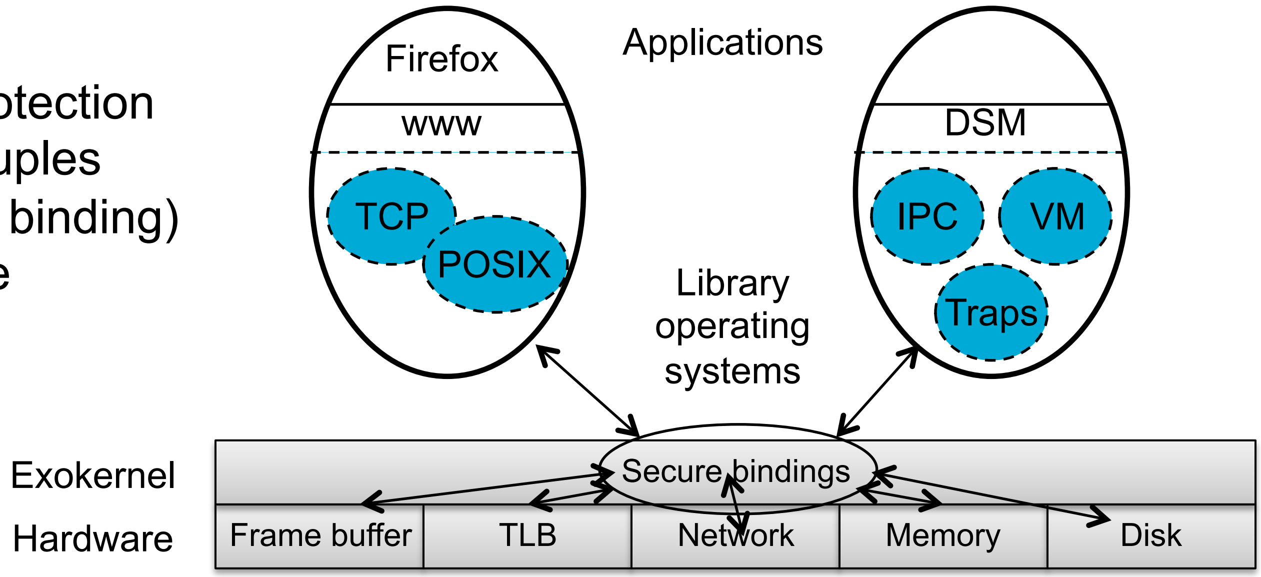
- Initial release of OS/360 were strictly batch but users wanted timesharing
  - IBM CP/CMS, later renamed VM/370 (‘79)
- Note that timesharing systems provides (1) multiprogramming & (2) extended (virtual) machine
- Essence of VM/370 – separate the two
  - Heart of the system (VMM) does multiprogramming & provides to next layer up multiple exact copies of bare HW
  - Each VM can run any OS
- Nowadays – Java VM, VMWare



Exokernels

- OS, typically securely multiplexes & *abstract* physical resources
- But no OS abstractions fits all!
- Exokernel
  - A minimal OS securely multiplexes resources
  - Library OSes implement higher-level abstractions

Secure binding – a protection mechanism that decouples authorization (done at binding) from use of a resource



Summary & preview

- Today
  - The mess under the carpet
  - Basic concepts in OS
  - OS design has been an evolutionary process
  - Structuring OS - a few alternatives, not a clear winner
- Next …
  - Process – the central concept in OS
    - Process model and implementation
    - What it is, what it does and how it does it

System boot

How does the OS gets started?

- Booting: starting a computer by loading the kernel
- Instruction register loaded with predefined memory location – bootstrap loader (ROM)
  - Why not just put the OS in ROM? Cell phones & PDAs
- Bootstrap loader
  - Run diagnostics
  - Initialize registers & controllers
  - Fetch second bootstrap program form disk
    - Why do you need a second bootstrap loader?
- Second bootstrap program loads OS & gets it going
  - A disk with a boot partition – boot/system disk

System calls

File management

Call	Description
fd = open(file, how, …)	Open a file for reading, writing or both.
s = close(fd)	Close an open file
n = read(fd, buffer, nbytes)	Read data from a file into a buffer
n = write(fd, buffer, nbytes)	Write data from a buffer into a file
pos = lseek(fd, offest, whence)	Move the file pointer
s = stat(name,&buf)	Get a file's status info

Directory & file system management

Call	Description
s = mkdir(name, mode)	Create a new directory
s = rmdir(name)	Remove an empty directory
s = link(name1, name2)	Create a new entry, name2, pointing to name1
s = unlink(name)	Remove a directory entry
s = mount(special, name, flag)	Mount a file system
s = unmount(special)	Unmount a file system

Operating system generation

- OS design for a class of machines; need to configure it for yours - SYSGEN
- SYSGEN program gets info on specific configuration
  - CPU(s), memory, devices, other parameters
    - Either asking the user or probing the hardware
- Once you got it you could
  - Modify source code & recompile kernel
  - Modify tables and select precompiled modules
  - Modify tables but everything is there & selection is at run time

  Trading size & generality for ease of modification