Resources, Services, and Interfaces

2A. OS Services, Layers and Mechanisms
2B. Service Interfcaes
2C. Standards and Stability
2D. Services and Abstract Resources

Services: Hardware Abstractions

- CPU/Memory abstractions
  - processes, threads, virtual machines
  - virtual address spaces, shared segments
  - signals (as execution exceptions)
- Persistent Storage abstractions
  - files and file systems, virtual LUNs
  - databases, key/value stores, object stores
- other I/O abstractions
  - virtual terminal sessions, windows
  - sockets, pipes, VPNs, signals (as interrupts)

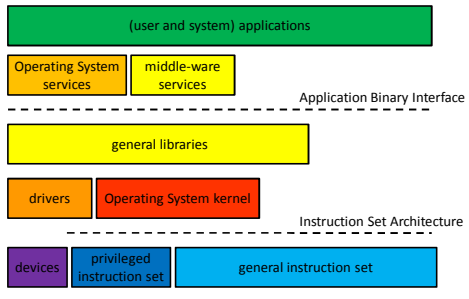
Services: Higher Level Abstractions

- cooperating parallel processes
  - locks, condition variables
  - distributed transactions, leases
- security
  - user authentication
  - secure sessions, at-rest encryption
- user interface
  - GUI widgetry, desktop and window management
  - multi-media

Services: under the covers

- enclosure management
  - hot-plug, power, fans, fault handling
- software updates and configuration registry
- dynamic resource allocation and scheduling
  - CPU, memory, bus resources, disk, network
- networks, protocols and domain services
  - USB, BlueTooth
  - TCP/IP, DHCP, LDAP, SNMP
  - iSCSI, CIFS, NFS

Software Layering



Service delivery via subroutines

- access services via direct subroutine calls
  - push parameters, jump to subroutine, return values in registers on on the stack
- advantages
  - extremely fast (nano-seconds)
  - DLLs enable run-time implementation binding
- disadvantages
  - all services implemented in same address space
  - limited ability to combine different languages
  - limited ability to change library functionality

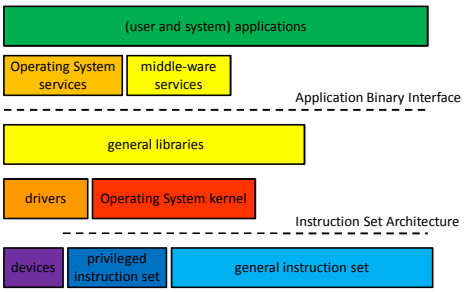
Layers: libraries

- convenient functions we use all the time
  - reusable code makes programming easier
  - a single well written/maintained copy
  - encapsulates complexity … better building blocks
- multiple bind-time options
  - static … include in load module at link time
  - shared … map into address space at exec time
  - dynamic … choose and load at run-time
- it is only code … it has no special privileges

Service delivery via system calls

- force an entry into the operating system
  - parameters/returns similar to subroutine
  - implementation is in shared/trusted kernel
- advantages
  - able to allocate/use new/privileged resources
  - able to share/communicate with other processes
- disadvantages
  - all implemented on the local node
  - 100x-1000x slower than subroutine calls
  - evolution is very slow and expensive

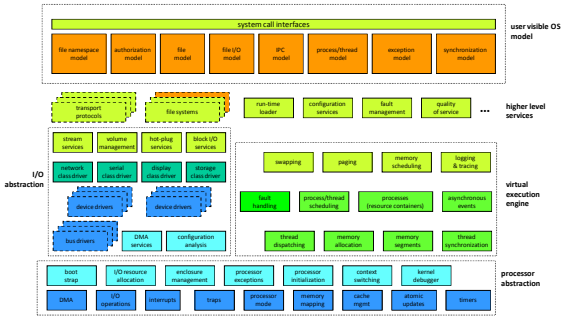
Software Layering



Layers: the kernel

- primarily functions that require privilege
  - privileged instructions (e.g. interrupts, I/O)
  - allocation of physical resources (e.g. memory)
  - ensuring process privacy and containment
  - ensuring the integrity of critical resources
- some operations may be out-sourced
  - system daemons, server processes
- some plug-ins may be less-trusted
  - device drivers, file systems, network protocols

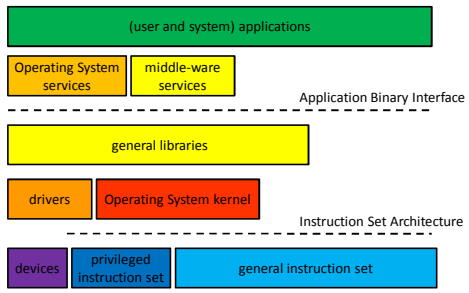
Kernel Structure (artists conception)



Service delivery via messages

- exchange messages with a server (via syscalls)
  - parameters in request, returns in response
- advantages:
  - server can be anywhere on earth
  - service can be highly scalable and available
  - service can be implemented in user-mode code
- disadvantages:
  - 1,000x-100,000x slower than subroutine
  - limited ability to operate on process resources

Software Layering



Layers: system services

- not all trusted code must be in the kernel
  - it may not need to access kernel data structures
  - it may not need to execute privileged instructions
- some are actually privileged processes
  - login can create/set user credentials
  - some can directly execute I/O operations
- some are merely trusted
  - sendmail is trusted to properly label messages
  - NFS server is trusted to honor access control data

Layers: middle-ware

- Software that is a key part of the application or service platform, but not part of the OS
  - database, pub/sub messaging system
  - Apache, Nginx
  - Hadoop, Zookeeper, Beowulf, OpenStack
  - Cassandra, RAMCloud, Ceph, Gluster
- Kernel code is very expensive and dangerous
  - user-mode code is easier to build, test and debug
  - user-mode code is much more portable
  - user-mode code can crash and be restarted

Where to implement a service

- How many different applications use it?
- How frequently is it used?
- How performance critical are the operations?
- How stable/standard is the functionality?
- How complex is the implementation?
- Are there issues of privilege or trust?
- Is the service to be local or distributed?
- Are there to be competing implementations?

Is it faster if it is in the OS?

- OS is no faster than a user-mode process
  - CPU, instruction set, cache are the same
- some services involve expensive operations
  - servicing interrupts … faster in the kernel
  - making system calls … unnecessary in kernel
  - process switches … faster/less often in kernel
- but kernel code is very expensive
  - difficult to build and test
  - long delivery schedules, difficult to change

Why Do Interfaces Matter?

- primary value of OS is the apps it can run
  - it must provide all services those apps need
  - via the interfaces those apps expect
- correct application behavior depends on
  - OS correctly implements all required services
  - application uses services only in supported ways
- there are numerous apps and OS platforms
  - it is not possible to test all combinations
  - rather, we specify and test interface compliance

Application Programming Interfaces

- a source level interface, specifying
  - include files
  - data types, data structures, constants
  - macros, routines, parameters, return values
- a basis for software portability
  - recompile program for the desired ISA
  - linkage edit with OS-specific libraries
  - resulting binary runs on that ISA and OS
- they are (by definition) language specific
  - but an API can be offered in many languages

Application Binary Interfaces

- a binary interface, specifying
  - load module, object module, library formats
    - what makes a blob of ones and zeroes a program
  - data formats (types, sizes, alignment, byte order)
  - calling sequences, linkage conventions
    - it is independent of particular routine semantics
- a basis for binary compatibility
  - one binary will run on any ABI compliant system
    - e.g. all x86 Linux/BSD/OSx/Solaris/…
    - may even run on windows platforms

Other interoperability interfaces

- Data formats and information encodings
  - multi-media content (e.g. MP3, JPG)
  - archival (e.g. tar, gzip)
  - file systems (e.g. DOS/FAT, ISO 9660)
- Protocols
  - networking (e.g. ethernet, WLAN, TCP/IP)
  - domain services (e.g. IMAP, LPD)
  - system management (e.g. DHCP, SNMP, LDAP)
  - remote data access (e.g. FTP, HTTP, CIFS, S3)

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Interoperability requires Completeness

- Interface specification must be complete
  - all input parameters
  - all output values
  - all input/output behaviors
  - all internal state or side-effects
- All specifications should be explicit
  - no undocumented features
  - not defined by an implementation's behavior

Interoperability requires compliance

- Complete interoperability testing impossible
  - cannot test all applications on all platforms
  - cannot test interoperability of all implementations
  - new apps and platforms are added continuously
- Rather, we focus on the interfaces
  - interfaces are completely and rigorously specified
  - standards bodies manage the interface definitions
  - compliance suites validate the implementations
- and hope that sampled testing will suffice

Interoperability requires stability

- no program is an island
  - programs use system calls
  - programs call library routines
  - programs operate on external files
  - programs exchange messages with other software
- API requirements are frozen at compile time
  - execution platform must support those interfaces
  - all partners/services must support those protocols
  - all future upgrades must support older interfaces

Compatibility Taxonomy

- upwards compatible (with …)
  - new version still supports previous interfaces
- backwards compatible (with …)
  - will correctly interact with old protocol versions
- versioned interface, version negotiation
  - parties negotiate a mutually acceptable version
- compatibility layer
  - a cross-version translator
- non-disruptive upgrade
  - update components one-at-a-time w/o down-time

Services: an object-oriented view

- my execution platform implements objects
  - they may be bytes, longs and strings
  - they may be processes, files, and sessions
- an object is defined by
  - its properties, methods, and their semantics
- what makes a particular set of objects good
  - they are powerful enough to do what I need
  - they don't force me to do a lot of extra work
  - they are simple enough for me to understand

Better Objects and Operations

- easier to use than the original resources
  - disk I/O without DMA, interrupts and errors
- compartmentalize/encapsulate complexity
  - a securely authenticated/encrypted channel
- eliminate behavior that is irrelevant to user
  - hide the slow erase cycle of flash memory
- create more convenient behavior
  - highly reliable/available storage from anywhere

Simplifying Abstractions

- hardware is fast, but complex and limited
  - using it correctly is extremely complex
  - it may not support the desired functionality
  - it is not a solution, but merely a building block
- encapsulate implementation details
  - error handling, performance optimization
  - eliminate behavior that is irrelevant to the user
- more convenient or powerful behavior
  - operations better suited to user needs

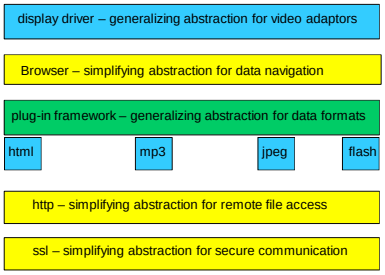
Generalizing Abstractions

- make many different things appear the same
  - applications can all deal with a single class
  - often Lowest Common Denominator + sub-classes
- requires a common/unifying model
  - *portable document format* for printed output
  - SCSI/SATA/SAS standard for disks, CDs, SSDs
- usually involves a federation framework
  - device-specific drivers
  - browser plug-ins to handle multi-media data

Federation Frameworks

- A structure that allows many similar, but somewhat different things to be treated uniformly
- By creating one interface that all must meet
- Then plugging in implementations for the particular things you have
- E.g., make all hard disk drives accept the same commands
  - Even though you have 5 different models installed

Layers of Abstraction: a browser



Building Blocks and World Views

- An OS is a general purpose platform
  - it must support a wide range of applications
  - including those to be designed in the future
- OS services are software building blocks
  - not solutions, but pieces for building solutions
- OS abstractions represent a world view
  - concepts that encompass all possible s/w
  - interaction rules to govern their combinations
  - frame (guide/constrain) all future discussions

Virtualizing Physical Resources

- serially reusable (temporal multiplexing)
  - used by multiple clients, one at a time
  - requires access control to ensure exclusive access
- partitionable resources (spatial multiplexing)
  - different clients use different parts at same time
  - requires access control for containment/privacy
- sharable (no apparent partitioning or turns)
  - often involves mediated access
  - often involves under-the-covers multiplexing

Serially Reusable Resources

- Used by multiple clients ... one at a time
  - temporal multiplexing
- Require access control to ensure exclusivity
  - while A has resource, nobody else can use it
- Require graceful transitions between users
  - B will not start until A finishes
  - B receives resource in like-new condition
- Examples: printers, bathroom stalls

Partitionable Resources

- Divided into disjoint pieces for multiple clients
  - Spatial multiplexing
- Needs access control to ensure:
  - Containment: *you cannot access resources outside of your partition*
  - Privacy: *nobody else can access resources in your partition*
- Examples: RAM, hotel rooms

Shareable Resources

- Usable by multiple concurrent clients
  - Clients do not have to "wait" for access to resource
  - Clients don't "own" a particular subset of resource
- May involve (effectively) limitless resources
  - Air in a room, shared by occupants
  - Copy of the operating system, shared by processes
- May involve under-the-covers multiplexing
  - Cell-phone channel (time and frequency multiplexed)
  - Shared network interface (time multiplexed)

Assignments

- Projects
  - get started on Project 0
  - order your Edison and Grove sensor kit
- Reading for next Lecture
  - linking and libraries
  - linkage conventions
  - A-D C3 … introduction to processes
  - A-D C4 … processes
  - A-D C5 … process APIs
  - A-D C6 … process implementation
  - kill(2), signal(2) … Unix signals/exceptions