Distributed File Systems Issues

- Naming and transparency (location transparency versus location independence)
  - Host:local-name
  - Attach remote directories (mount)
  - Single global name structure
- Remote file access
  - Remote-service mechanism
    - Stateful vs. stateless
  - Caching and coherence
    - Cache update policy (write through vs. delayed write)
    - Client-initiated vs. server-initiated
- Reliability and file replication
  - Naming transparency
  - Availability vs. consistency

NFS (Network File System)

- Deals with heterogeneity using RPC/XDR
- Stateless – no open and close of files
- Interface transparent to user via VFS

The Andrew File System (AFS)

- Unified namespace (one /afs for everybody)
- One read-write copy
- Protection using access control lists (ACLs)
- Security using Kerberos 5 authentication

AFS: Namespace

- Managed by dedicated servers called “Vice”
- Local (root file system) and shared namespace with mounting similar to NFS
- Files partitioned into volumes
  - typically files of a single client
  - Possible migration and replication of volumes
- Clients run “Virtue” protocol

AFS: Security and Protection

- Security
  - Connection-based communication based on RPC
  - Encrypted
- Protection
  - Directories have access control lists
    - Allowed users or users not allowed
  - Regular UNIX bits for file protection

AFS: Caching and Coherence

- Caching of entire files
  - Callback mechanism to eliminate cached copies
  - One read-write copy

Google File System - Motivation

- Component failures are normal
  - Fault tolerance and automatic recovery are needed
- Huge files are common (Multi GB)
  - Revisited I/O and block size assumptions
- Record appends are prevalent than random writes
  - Appending is the focus of performance optimization and atomicity guarantees
- Co-designing applications and the file-system API for flexibility
  - Relaxed consistency model
  - Atomic append

Operating System Structure

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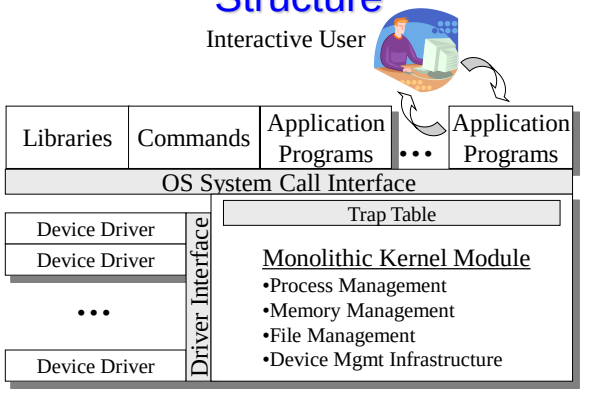
Operation System Architectures

- Monolithic architecture
- Microkernel architecture
- Layered architecture
- Virtual machines

OS Architecture: Monolithic Structure



Most modern OSes fall into this category!

Microkernel System Architecture

- Microkernel architecture:
  - Moves as much from the kernel into "*user*" space (still protected from normal users).
  - Communication takes place between user modules using message passing.
- What must be in the kernel and what can be in user space?
  - Mechanisms determine how to do something.
  - Policies decide what will be done.
- Benefits:
  - More reliable (less code is running in kernel mode)
  - More secure (less code is running in kernel mode)
- Disadvantage?

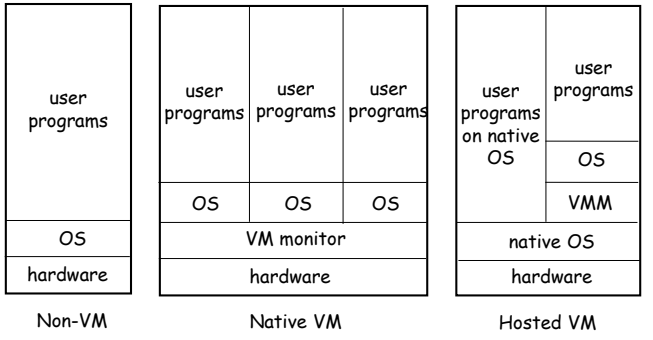
Layered Structure

- Layered structure
  - The operating system is divided into a number of layers (levels), each built on top of lower layers.
  - The bottom layer (layer 0), is the hardware.
  - The highest (layer N) is the user interface.
  - Decreased privileges for higher layers.
- Benefits:
  - more reliable
  - more secure
  - more flexibility, easier to extend
- Disadvantage?
  - Weak integration results in performance penalty (similar to the microkernel structure).

Virtual Machines

- Virtual machine architecture
  - Virtualization: A piece of software that provides an interface *identical* to the underlying bare hardware.
    - the upper-layer software has the illusion of running directly on hardware
    - the virtualization software is called virtual machine monitor
  - Multiplexing: It may provide several virtualized machines on top of a single piece of hardware.
    - resources of physical computer are shared among the virtual machines
    - each VM has the illusion of owning a complete machine
- Trust and privilege
  - the VM monitor does not trust VMs
  - only the VM monitor runs in full privilege
- Compared to an operating system
  - VM monitor is a resource manager, but not an extended machine

Virtual Machine Architecture



Multiprocessor Operating Systems

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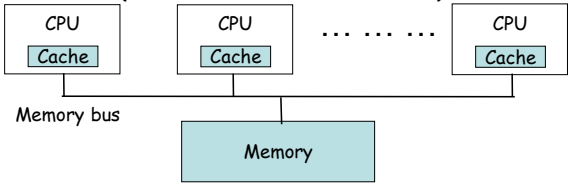
Multiprocessor Hardware

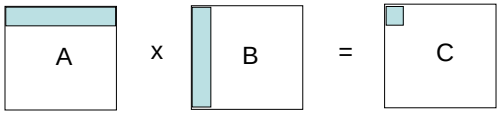
- A computer system in which two or more CPUs share full access to the main memory
- Each CPU might have its own cache and the coherence among multiple caches is maintained
  - write operation by a CPU is visible to all other CPUs
  - writes to the same location is seen in the same order by all CPUs (also called write serialization)



  - bus snooping and cache invalidation

Multiprocessor Applications

- Multiprogramming
  - Multiple regular applications running concurrently
- Concurrent servers
  - Web servers, … …
- Parallel programs
  - Utilizing multiple processors to complete one task (parallel matrix multiplication, Gaussian elimination)

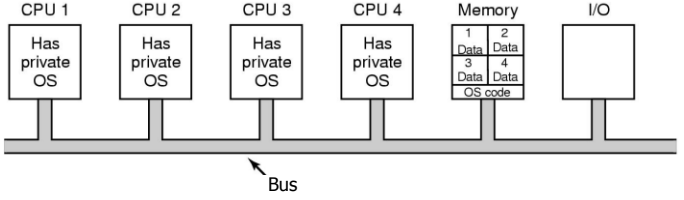


  - Strong synchronization

Single-processor OS vs. Multiprocessor OS

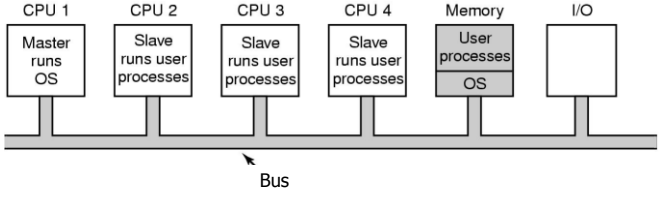
- Single-processor OS
  - easier to support kernel synchronization
    - coarse-grained locking vs. fine-grain locking
    - disabling interrupts to prevent concurrent executions
  - easier to perform scheduling
    - which to run, not where to run
- Multiprocessor OS
  - evolution of OS structure
  - synchronization
  - scheduling

Multiprocessor OS



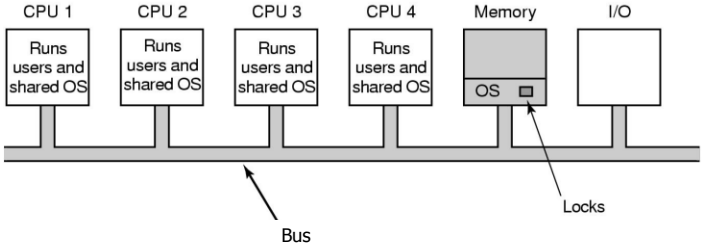
- Each CPU has its own operating system
  - quick to port from a single-processor OS
- Disadvantages
  - difficult to share things (processing cycles, memory, buffer cache)

Multiprocessor OS – Master/Slave



- All operating system functionality goes to one CPU
  - no multiprocessor concurrency in the kernel
- Disadvantage
  - OS CPU consumption may be large so the OS CPU becomes the bottleneck (especially in a machine with many CPUs)

Multiprocessor OS – Shared OS



- A single OS instance may run on all CPUs
- The OS itself must handle multiprocessor synchronization
  - multiple OS instances from multiple CPUs may access shared data structure

Preemptive Scheduling

- Use timer interrupts or signals to trigger involuntary yields
- Protect scheduler data structures by locking ready list, disabling/reenabling prior to/after rescheduling

yield:

disable_signals
enqueue(ready_list, current)
reschedule
re-enable_signals

Synchronization (Fine/Coarse-Grain Locking)

- Fine-grain locking – lock only what is necessary for critical section
- Coarse-grain locking – locking large piece of code, much of which is unnecessary
  - simplicity, robustness
  - prevent simultaneous execution

Simultaneous execution is not possible on uniprocessor anyway

Anderson et al. 1989 (IEEE TOCS)

- Raises issues of
  - Locality (per-processor data structures)
  - Granularity of scheduling tasks
  - Lock overhead
  - Tradeoff between throughput and latency
    - Large critical sections are good for best-case latency (low locking overhead) but bad for throughput (low parallelism)

Performance Measures

- Latency
  - Cost of thread management under the best case assumption of no contention for locks
- Throughput
  - Rate at which threads can be created, started, and finished when there is contention

Optimizations

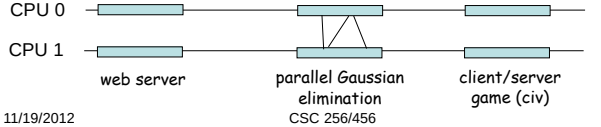
- Allocate stacks lazily
- Store deallocated control blocks and stacks in free lists
- Create per-processor ready lists
- Create local free lists for locality
- Queue of idle processors (in addition to queue of waiting threads)

Ready List Management

- Single lock for all data structures
- Multiple locks, one per data structure
- Local freelists for control blocks and stacks, single shared locked ready list
- Queue of idle processors with preallocated control block and stack waiting for work
- Local ready list per processor, each with its own lock

Multiprocessor Scheduling

- Timesharing
  - similar to uni-processor scheduling – one queue of ready tasks (protected by synchronization), a task is dequeued and executed when a processor is available
- Space sharing
- cache affinity
  - affinity-based scheduling – try to run each process on the processor that it last ran on
- cache sharing and synchronization of parallel/concurrent applications
  - gang/cohort scheduling – utilize all CPUs for one parallel/concurrent application at a time



SMP-CMP-SMT Multiprocessor

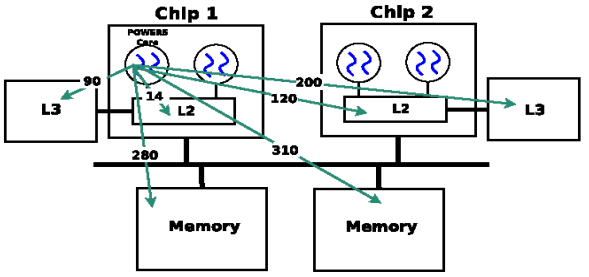


Image from http://www.eecg.toronto.edu/~tamda/papers/threadclustering.pdf

Resource Contention-Aware Scheduling I

- Hardware resource sharing/contention in multi-processors
  - SMP processors share memory bus bandwidths
  - Multi-core processors share L2 cache
  - SMT processors share a lot more stuff
- An example: on an SMP machine
  - a web server benchmark delivers around 6300 reqs/sec on one processor, but only around 9500 reqs/sec on an SMP with 4 processors
- Contention-reduction scheduling
  - co-scheduling tasks with complementary resource needs (a computation-heavy task and a memory access-heavy task)
  - In [Fedorova et al. USENIX2005], IPC is used to distinguish computation-heavy tasks from memory access-heavy tasks

Resource Contention-Aware Scheduling II

- What if contention on a resource is unavoidable?
- Two evils of contention
  - high contention ⇒ performance slowdown
  - fluctuating contention ⇒ uneven application progress over the same amount of time ⇒ poor fairness
- [Zhang et al. HotOS2007] Scheduling so that:
  - very high contention is avoided
  - the resource contention is kept stable