Operating Systems Architecture

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Advanced Operating Systems
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Outline

- Part I
  - Organizing operating systems
  - Some microkernel examples
- Part II
  - New architectures for extensibility
  - 64-bit address space architectures

OS Organization

Motivating question:

What is the best way to organize/structure/design an operating system?

Question Assumptions

- at least one way to organize OS software
- more than one way to organize
- different ways can be effectively compared
  - requires comparison metric(s)
  - metrics must be valid for all subjects studied

OS Organization Issues

- Important OS software characteristics
- Typical OS components
- Component interactions
- Survey of OS organization structures used
  - description
  - pros/cons

Important OS Software Characteristics

- Correctness
- Simplicity
- Power & completeness
- Performance
- Extensibility & portability
- Suitability for distributed & parallel systems
- Compatibility with existing systems
- Security
- Fault tolerance

Typical OS Components

- Process/thread support
- Memory management
- I/O and device support
- Interprocess communications
- Security
- File system support
- Fault tolerance and recovery support

Putting the Pieces Together

- Many of these functions interact
- The totality of all these functions is highly complex
- How do we organize the overall operating system software to meet the goals?

Common OS Organizations

- Monolithic
- Virtual machine
- Layered designs
- Kernel designs
- Microkernels
- Object-Oriented

Note that individual OS components can be organized these ways

Monolithic OS Design

- Build OS as single combined module
  - Hopefully using data abstraction, compartmentalized function, etc.
- OS lives in its own, single address space
- Examples
  - DOS
  - early Unix systems
  - most VFS file systems

Pros/Cons of Monolithic OS Organization

+ Highly adaptable (at first . . .)
+ Little planning required
+ Potentially good performance
– Hard to extend and change
– Eventually becomes extremely complex
– Eventually performance becomes poor
– Highly prone to bugs

Virtual Machine Organizations

- A base operating system provides services in a very generic way
- One or more other operating systems live on top of the base system
  - Using the services it provides
  - To offer different views of system to users
- Examples - IBM’s VM/370, the Java interpreter

Pros/Cons of Virtual Machine Organizations

+ Allows multiple OS personalities on a single machine
+ Good OS development environment
+ Can provide good portability of applications
– Significant performance problems
– Especially if more than 2 layers
– Lacking in flexibility

Layered OS Design

- Design tiny innermost layer of software
- Next layer out provides more functionality
  – Using services provided by inner layer
- Continue adding layers until all functionality required has been provided
- Examples
  – Multics
  – Fluke
  – layered file systems and comm. protocols

Pros/Cons of Layered Organization

+ More structured and extensible
+ Easy model
– Layer crossing can be expensive
– In some cases, multiple layers unnecessary

Kernel OS Designs

- Similar to layers, but only two OS layers
  – Kernel OS services
  – Non-kernel OS services
- Move certain functionality outside kernel
  – file systems, libraries
- Unlike virtual machines, kernel doesn’t stand alone
- Examples - Most modern Unix systems

Pros/Cons of Kernel OS Organization

+ Many advantages of layering, without disadvantage of too many layers
+ Easier to demonstrate correctness
– Not as general as layering
– Offers no organizing principle for other parts of OS, user services
– Kernels tend to grow to monoliths

Microkernel OS Design

- Like kernels, only less so
- Try to include only small set of required services in the microkernel
- Moves even more out of innermost OS part
  – Like parts of VM, IPC, paging, etc.
- Examples - Mach, Amoeba, Plan 9, Windows NT, Chorus

Pros/Cons of Microkernel Organization

+ Those of kernels, plus:
+ Minimizes code for most important OS services
+ Offers model for entire system
– Microkernels tend to grow into kernels
– Requires very careful initial design choices
– Serious danger of bad performance

Object Oriented OS Design

- Design internals of OS as set of privileged objects, using OO methods
- Sometimes extended into application space
- Tends to lead to client/server style of computing
- Examples
  - Mach (internally)
  - Spring (totally)

Pros/Cons of Object Oriented OS Organization

+ Offers organizational model for entire system
+ Easily divides system into pieces
+ Good hooks for security
– Can be a limiting model
– Must watch for performance problems

Not widely used yet

Some Important Microkernel Designs

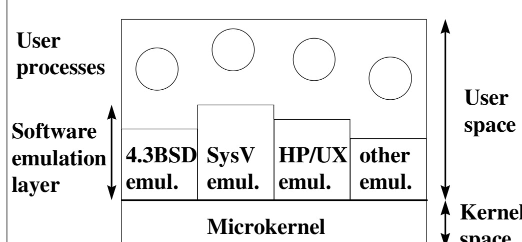
Micro-ness is in the eye of the beholder

- Mach
- Amoeba
- Plan 9
- Windows NT

Mach

- Mach didn't start life as a microkernel
  - became one in Mach 3.0
- Object-oriented internally
  - doesn't force OO at higher levels
- Microkernel focus is on communications facilities
- Much concern with parallel/distributed systems

Mach Model



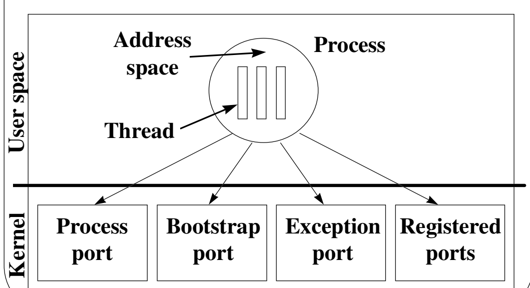
What's In the Mach Microkernel?

- Tasks & Threads
- Ports and Port Sets
- Messages
- Memory Objects
- Device Support
- Multiprocessor/Distributed Support

Mach Tasks

- An execution environment providing basic unit of resource allocation
- Contains
  - Virtual address space
  - Port set
  - One or more threads

Mach Task Model



Mach Threads

- Basic unit of Mach execution
- Runs in context of one task
- All threads in one task share its resources
- Unix process similar to Mach task with single thread

Task and Thread Scheduling

- Very flexible
- Controllable by kernel or user-level programs
- Threads of single task can execute in parallel
  - on single processor
  - multiple processors
- User-level scheduling can extend to multiprocessor scheduling

Mach Ports

- Basic Mach object reference mechanism
  - kernel-protected communication channel
- Tasks communicate by sending messages to ports
- Threads in receiving tasks pull messages off a queue
- Ports are location independent
- Port queues protected by kernel; bounded

Mach Messages

- Typed collection of data objects
  - Unlimited size
- Sent to particular port
- May contain actual data or pointer to data
- Port rights may be passed in a message
- Kernel inspects messages for particular data types (like port rights)

Mach Memory Objects

- A source of memory accessible by tasks
- May be managed by user-mode external memory manager
  - a file managed by a file server
- Accessed by messages through a port
- Kernel manages physical memory as cache of contents of memory objects

Mach Device Support

- Devices represented by ports
- Messages control the device and its data transfer
- Actual device driver outside the kernel in an external object

Mach Multiprocessor and Distributed System Support

- Messages and ports can extend across processor/machine boundaries
  - Location transparent entities
- Kernel manages distributed hardware
- Per-processor data structures, but also structures shared across the processors
- Intermachine messages handled by a server that knows about network details

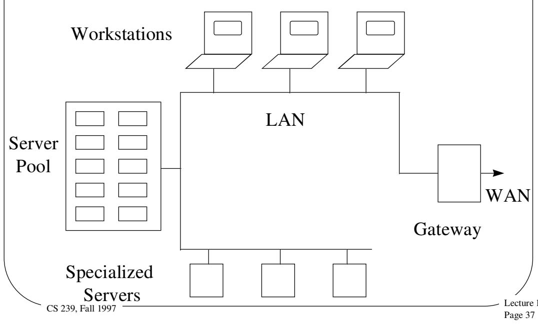
Mach and User Interfaces

- Mach was built largely for the community that uses Unix
- Unix programs don't know about ports, messages, threads, and tasks
- So how do Unix programs run under Mach?
- Mach typically runs a user-level server that offers Unix emulation
- Either provides Unix system call semantics internally or translates it to Mach primitives

Amoeba

- Amoeba presents transparent distributed computing environment (a la timesharing)
- Major components
  - processor pools
  - server machines
  - X-terminals
  - gateway servers for off-LAN communications
- Microkernel runs everywhere

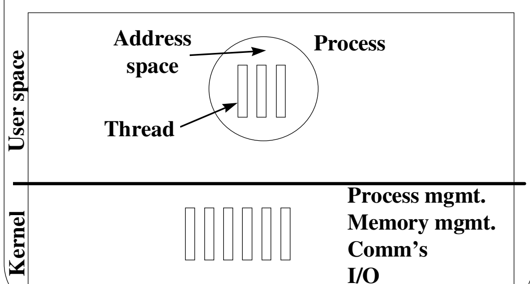
Amoeba Diagram



Amoeba's Basic Primitives

- Processes
- Threads
- Low level memory management
- RPC
- I/O

Amoeba Software Model



Amoeba Processes

- Similar to Mach processes
- Process has multiple threads
  - But a single shared address space
- Thread scheduling by microkernel

Amoeba Memory Management

- Amoeba microkernel supports concept of *segments*
- A segment is a set of memory blocks
- Segments can be mapped in/out of address spaces

Remote Procedure Call

- Fundamental Amoeba IPC mechanism
- Amoeba RPC is thread-to-thread
- Microkernel handles on/off machine invocation of RPC

Plan 9

- Everything in Plan 9 is a file system (almost)
  - Processes
  - Files
  - IPC
  - Devices
- Only a few operations are required for files
- Text-based interface

Plan 9 Basic Primitives

- Terminals
- CPU servers
- File systems
- Channels

File Systems in Plan 9

- File systems consist of a hierarchical tree
- Can be persistent or temporary
- Can represent simple or complex entities
- Can be implemented:
  - in the kernel as a driver
  - as a user level process
  - by remote servers

Sample Plan 9 File Systems

- Device file systems - Directory containing `data` and `ctl` file
- Process file systems - Directory containing files for memory, text, control, etc.
- Network interface file systems

Plan 9 Channels and Mounting

- A channel is a file descriptor
  - since a file can be anything, a channel is a general pointer to anything
- Plan 9 provides 9 primitives on channels
- Mounting is used to bring resources into a user's name space
- Users start with minimal name space, build it up as they go along

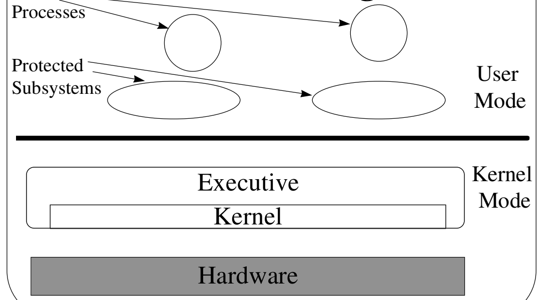
Typical User Operation in Plan 9

- User logs in to a terminal
  - provides bitmap display and input
- Minimal name space is set up on login
- Mounts used to build space
- Pooled CPU servers used for compute tasks
- Substantial caching used to make required files local

Windows NT

- More layered than some microkernel designs
- NT Microkernel provides base services
- Executive builds on base services to provide user-level services
- User-level services used by
  - privileged subsystems (parts of OS)
  - true user programs

Windows NT Diagram



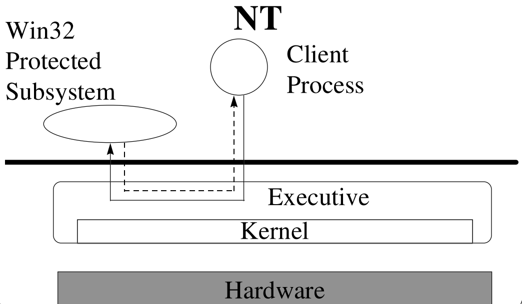
The Windows NT Executive

- Typical microkernel approach to building total OS
- Offers higher level services than the kernel
- Runs in kernel mode
  - but separate from the kernel
  - ease of change and expansion
- Built of independent modules

Windows NT Executive Modules

- Object manager
- Security reference monitor
- Process manager
- Local procedure call facility
- Virtual memory manager
- I/O manager

Typical Activity in Windows NT



Windows NT Threads

- Executable entity running in an address space
- Scheduled by kernel
- Handled by kernel's dispatcher
- Kernel works with stripped-down view of thread - *kernel thread object*

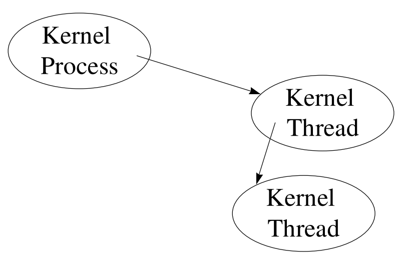
Kernel Process Objects

- Basically a kernel proxy for the real process
- The kernel's interface to the real process
- Contains pointers to the various resources owned by the process
  – e.g., threads and address spaces
- Alterable only by kernel calls

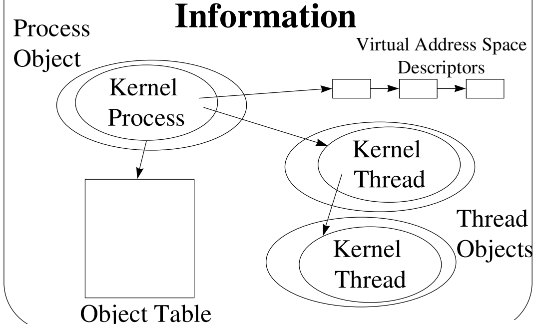
Kernel Thread Objects

- As kernel process objects are proxies for the real object, kernel thread objects are proxies for the real thread
  – one per thread
- Contains minimal information about thread
  – Priorities, dispatching state
- Used by the kernel for dispatching

Kernel Process and Thread Object Diagram



Other Kernel Process Information



More On Microkernels

- Microkernels were *the* research architecture of the 80s
- But few commercial systems of the 90s really use microkernels
- To some extent, "microkernel" is a dirty word in OS design
- Why?