The Duality of Memory and Communication in the Implementation of a Multiprocessor Operating System

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Agenda

- Introduction
- Key Ideas
- Monolithic vs Microkernel
- Primitive abstractions
- Implementation Details
- Issues with External Memory Management
- Benefits of Duality
- Conclusion

Introduction

- Mach OS project started in 1985. Continued till 1994.
- Successor to Accent OS developed at CMU
- MACH ⟹ NeXTSTEP ⟹ OPENSTEP ⟹ Mac OS X
- Mach OS kernel – mainly designed to support multiprocessors.
- Microkernel - a small, efficient kernel providing basic services such as process control and communication

Design goals

- Object oriented interface with small number of basic system objects
- Support for distributed and multiprocessing
- Portability to different multiprocessor and uniprocessor architectures
- Compatibility with BSD UNIX
- Performance comparable to commercial UNIX distributions

Key ideas

- Communication and virtual memory can play complementary roles in OS kernel
  - Increased flexibility in memory management
  - Support for multiprocessors
  - Improved performance
  - Easier task migration
- Memory represented as abstract objects called memory objects
- Single level store implementation

Key ideas (contd.)

- Virtual memory implementation using memory objects
- External memory management – Structure for secondary storage management

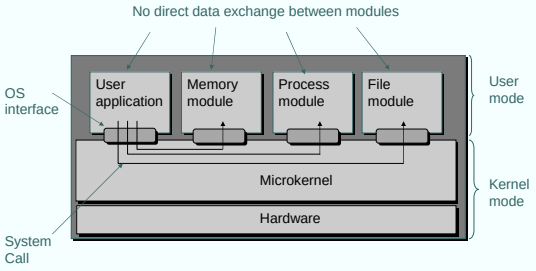
Microkernel vs Monolithic

- Monolithic kernel
  - Kernel interacts directly with the hardware
  - Kernel can be optimized for a particular hardware architecture
  - Kernel is not very portable
- Microkernel
  - Kernel is very small
  - Most OS services are not part of the kernel and run at a layer above it
  - Very easily portable to other systems

Examples

- Microkernel
  - Amoeba, Minix, Chorus, Mach, GNU Hurd, NeXTSTEP, Mac OS X, Windows NT
- Monolithic kernel
  - Traditional UNIX kernels, such as BSD, Linux, Solaris, Agnix

Architecture



*source *Distributed systems – Principles and Paradigms*, Andrew Tannembaum, Maarten van Steen

Primitive abstractions in Mach OS

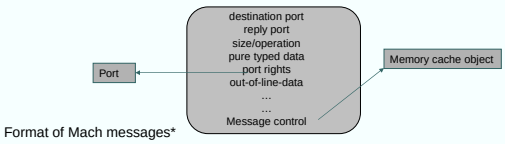
- Four basic abstractions from Accent
  - Task, Threads, Ports, Messages
  - Port set
- Fifth abstraction introduced in Mach
  - Memory Objects
- Tasks and Threads – Execution control primitives
- Ports and Messages - Interprocess communication

Interprocess communication

- Two components of Mach IPC – ports and messages
- Ports
  - Communication channel
  - Provides finite length queue
  - Protected bounded queue within the kernel
- Messages
  - Fixed length header and variable size collection of typed data objects

IPC (contd.)

- One receiver, multiple sender
- Tasks allocate ports to perform communication
- Task can deallocate rights to a port



Format of Mach messages*

*source *Operating System Concepts*, Sixth Edition by Avi Silberschatz, Peter Baer, Galvin Greg Gagne

Memory Management

- Virtual memory – level of abstraction between process memory requests and physical memory
- Continuous address space
- Demand Paging
- Transparent relocation of running programs in memory
- Page and Page frame
- VM -> RAM – page global directory, page table, offset

Virtual Memory Management in microkernel

- Each task has its own virtual address space
- Restriction – virtual address space must be aligned with the system page boundaries
- Supports read/write sharing of memory among tasks of common ancestry through inheritance
- API provided for operation on VM

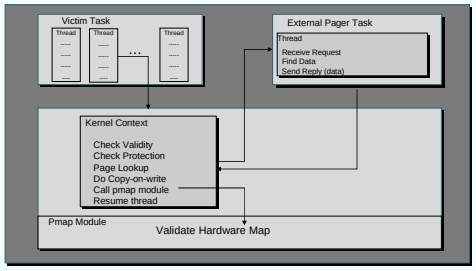
External Memory Management (EMM)

- External memory management interface based on memory object
- Memory object – abstract collection of data bytes with operations defined on them
- Memory object represented by a port
- Secondary storage objects available using message passing (data managers)
- Mach kernel as cache manager for contents of memory object

External Memory Management (contd.)

- Interface between kernel and data manager consists of 3 parts:
  - Calls made by application program to cause object to be mapped into its address space
  - Calls made by the kernel on the data manager
  - Calls made by the data manager on the Mach kernel to control use of its memory object

Fault Handling



Minimal Filesystem

```
Char * file_data;
int i, file_size;
extern float rand();

fs_read_file("filename", &file_data,
file_size);
.....
.....
fs_write_file("filename", file_data,
file_size/2);
vm_deallocate(task_self(), file data,
file_size);
```

Call from the application

```
return_t fs_read_file( name, data, size)
 {

//Allocate memory object (a port) and
accept request
port_allocate(t...);
port_enable(...);
.....
//perform file lookup. Find current file
size
.....
//Map the memory object into client
address space
vm_allocate_with_pager(...);
return (success);
}
```

Minimal Filesystem (contd.)

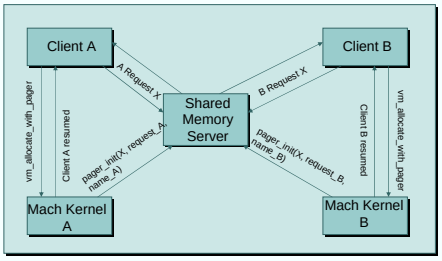
```
void pager_data_request(
memory_object, pager_request, offset,
size, access)
{
//Allocate disk buffer
vm_allocate (…);
//Lookup memory object and read disk
data
disk_read(…);
//Return the data without any lock
pager_data_povided(…);
//Deallocate disk buffer
vm_deallocate(…);
}
```

File retrieval for the application

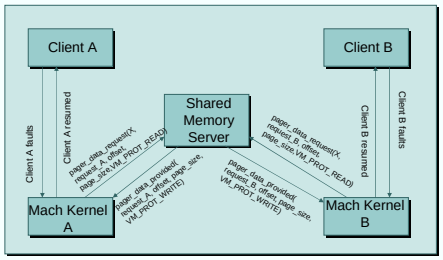
```
void port_death (request_port)
{
//find associated memory object with the
port
lookup_by_request_port(…);
//Release resources
port_deallocate(…);
vm_deallocate(…);
}
```

Release filesystem resources after application deallocates its resources

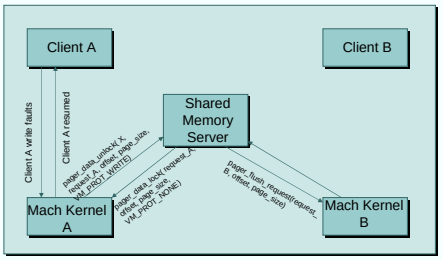
Consistent Network Shared Memory (Initialization)



Consistent Network Shared Memory (Read)



Consistent Network Shared Memory (Write)



Implementation Details

- Four basic data structures used to implement EMM
  - Address Map -Two level map
    - Top level – protection and inheritance information, link to second level
    - Second level – Map to memory object structures
  - Virtual Memory Object structures
  - Resident Memory Structures
  - Page replacement queues

External Memory Management Issues

- Types of Memory failure – Data manager
  - doesn't return data
  - fails to free flushed data
  - floods the cache
  - changes its own data
  - backs up its own data
- Handling Memory failure
  - Timeout, notification, wait, abort
  - Default pager
  - Reserved memory pool

Benefits of duality

- Multiprocessor support for UMA, NUMA, and NORMA architectures
- The programmer has the option to choose between shared memory and message-based communication
- Emulation of operating system environment such as UNIX achieved on Mach
- Generic UNIX system calls can be implemented outside Mach kernel
- Other features supported are transaction and database facilities, task migration, and AI knowledge bases

Conclusion

- Significant contribution to the operating system research
- No experimental to support performance claim
- More information could be presented in the implementation
- Drawbacks
  - Frequent message passing may cause degradation in performance
  - Continuous monitoring of external services

Current Trend

- Pure microkernel architecture not common
- Most OS kernels are hybrid models of monolithic and microkernel, e.g., Windows XP, Windows 2000

Questions?