Unit 14: The Mach Operating System

14.1. Mach Overview and System Concepts

The Mach Operating System

- Research project at Carnegie Mellon University (CMU)
- based on a simple communication-oriented kernel
- designed to support distributed and parallel computation
- provides UNIX 4.3BSD compatibility

- small, extensible system kernel provides:
  - Processor scheduling
  - Management of virtual memory
  - Interprocess communication

History of Mach

- RIG (Rochester Intelligent Gateway)
  - Research OS for 16-bit Data General minicomputer (Eclipse)
  - University of Rochester, Richard Rashid et al., 1975
  - Demonstrate modular structuring of an OS
  - Message-passing communication
- Accent
  - Message-passing OS at Carnegie Mellon University (Rashid moved to CMU in 1979)
  - PERQ machine with bitmapped screen, mouse, network
  - Protection, transparent networking and 32-bit virtual memory manag.
  - Operational by 1981
  - Accent was running on 150 PERQs by 1984

History of Mach (contd.)

- Mach
  - Third-generation OS
  - Compatible with UNIX
  - Many improvements over Accent
  - threads, better interprocess communication, multiprocessor support, novel virtual memory system
- DARPA Strategic Computing Initiative
  - U.S. Department of Defense‘s Advanced Research Projects Agency was searching for a multiprocessor operating system
  - CMU was selected, substantial DARPA funding
  - Mach was combined with 4.2/4.3BSD code
  - Large kernel but absolute compatibility with Berkeley UNIX (DARPA requirement)

History of Mach (contd.)

- Mach 2 was released
  - VAX 11/784 version (4 CPU multiprocessor) in 1986
  - Ports to IBM PC/RT and Sun3 in 1987
  - Versions for Encore and Sequent multiprocessors available in 1987
- OSF/1
  - Open Software Foundation (consortium of vendors; IBM, DEC, HP,...) selected Mach 2.5 as basis for OSF/1
  - Alliance against AT&T and Sun Microsystem‘s UNIX System V.4
  - Large and monolithic kernel
- Mach 3 microkernel OS
  - CMU removed all BSD code from kernel and put it in user space
  - User-level OS emulator for BSD UNIX in 1988.

Mach Components

- Kernel exports a small number of abstractions through an integrated interface.
- Operating system support environments provide:
  - distributed file access
  - transparent network interprocess communication
  - remote execution facilities
  - UNIX 4.3BSD emulation
- Many traditional operating system functions can be implemented by user programs or servers outside the kernel.

Mach provides features not found in UNIX 4.3BSD:

- Multiple tasks, each with a large, paged virtual memory space
- Multiple threads of execution within each task, with a flexible scheduling facility
- Flexible sharing of memory between tasks
- Efficient and consistent message-based interprocess communication
- Memory-mapped files
- Transparent network extensibility
- A flexible, capability-based approach to security and protection
- Support for multiprocessor scheduling

Tasks and Threads

- Mach splits the notion of a process into two abstractions,
  the task and the thread:
- **Task**
  - environment for program execution
  - basic unit of protection
  - basic unit of resource allocation, including
    - paged virtual address space
    - port rights that protect access to system resources
  - The task itself performs no computation; it is a framework for running threads.

Tasks and Threads (contd.)

- **Thread**
  - basic unit of execution
  - lightweight process executing within a task – defined by processor state
  - executes within the context of a single task
  - each task may contain more than one thread
  - All threads within a task share
    - the virtual memory address space and
    - communication rights of that task.
  - basic unit of scheduling
  - multiple threads from one task may be executing simultaneously.

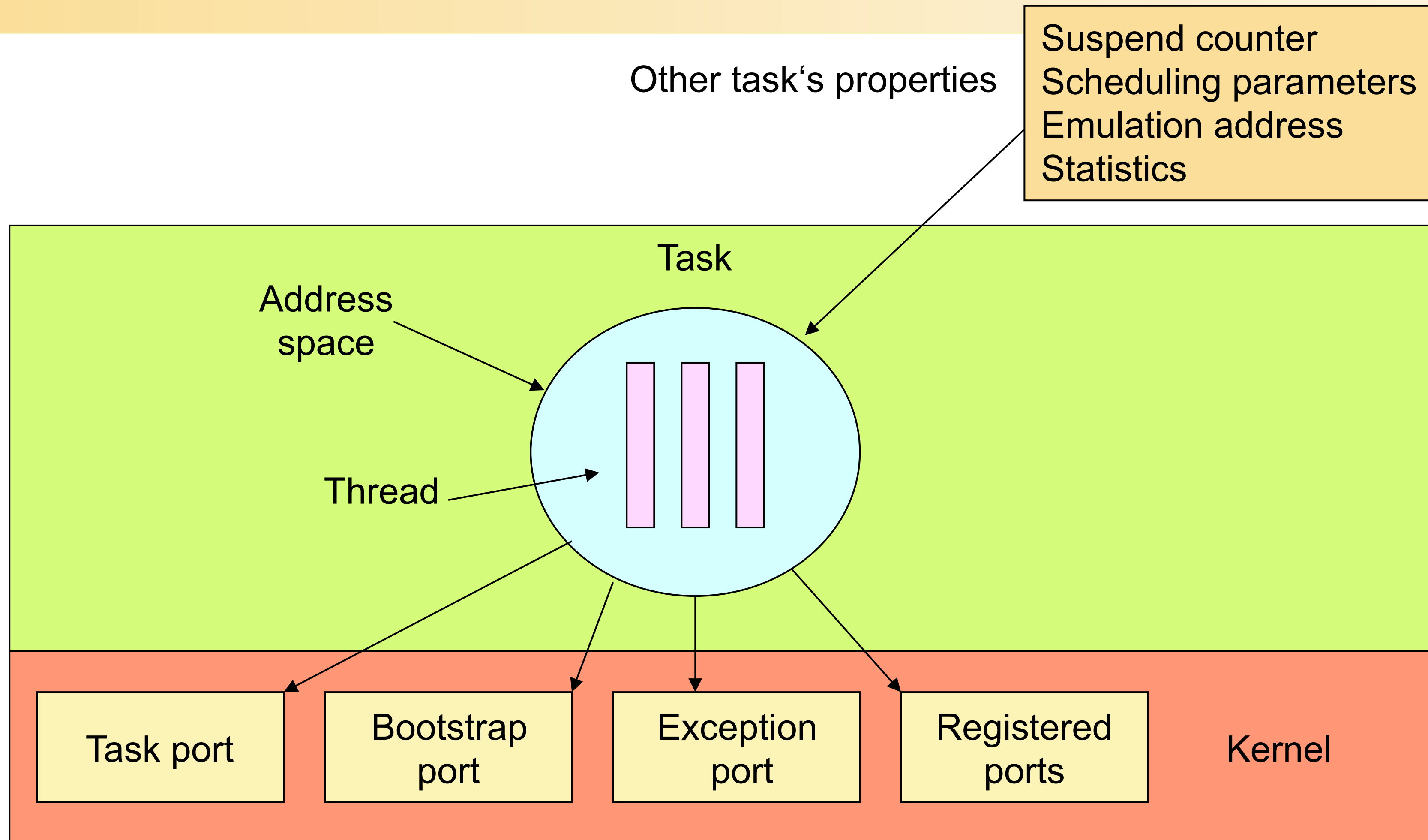
Task and Thread Ports

- Tasks and threads are represented by ports (message queues).
- Task port and thread port tell the kernel which task or thread is executing a function call.
  - task_self() and thread_self() return task and thread ports of the currently executing thread.
- Tasks can have access to the task and thread ports of other tasks and threads.
  - creator gets access to a new task port or thread port
  - any thread can pass access to ports in a message to other threads

Task and Thread Ports (contd.)

- Access rights to a task or thread port allow
  - to act on behalf of that task or thread
  - to perform Mach function calls
- Access to a task's port indirectly permits access to all threads within that task.
- The task port and thread port are often called kernel ports.
- Tasks and threads have a number of special ports associated with them.
  - Notify port, Exception port, Bootstrap port.

A Mach Task



Mach Ports and Messages

- Communication among operating system objects is achieved through messages.
- Mach messaging is implemented by three kernel abstractions:
- **Port**
  - protected communication channel
  - implemented as a finite-length message queue)
  - basic object reference mechanism in Mach
  - similar to that of object references in an object-oriented system
- Operations are requested by sending messages to and from the ports that represent objects.
- When a task is created, a port that represents the task is simultaneously created.
- When the task is destroyed, its port is also destroyed.

Mach Ports and Messages (contd.)

- **Port set**
  - group of ports, combining the message queues of the constituent ports.
  - may be used to receive a message sent to any of several ports.
- **Messages**
  - Used to communicate between objects;
  - data stream consisting of two parts:
    - fixed-length header
    - variable-length message body -- typed data objects
  - header contains information about:
    - size of the message, its type, and its destination
  - body contains the content (or a pointer to the content) of the message
  - Messages may be of any size, may contain:
  - in-line data, pointers to data, and capabilities for ports.
- A single message may transfer the entire address space of a task.

Port Access Rights

- Communication between objects is protected by a system of port access rights (Capabilities).
- Send access to a port
  - Implies that a message can be sent to that port.
- Receive access to a port
  - Allows a message to be de-queued from that port.
  - Only one task may have receive access for a given port at a time;
  - more than one thread within that task may concurrently attempt to receive messages
  - receive access implies send rights.
- Multiple tasks may hold send rights to the same port, but
  - only one task at a time may hold receive rights to a port.
- Port access rights can be passed in messages.

Port Sets

- Port sets are
  - a bag holding zero or more receive rights.
  - a mechanism to allow a thread to block while waiting for a message sent to any of several ports.
- A port may be a member of no more than one port set at any time, and a task can have only one port set.
  - port_set_allocate(), port_set_add(),
  - port_set_remove(), port_set_status(), port_set_deallocate().
- Unlike port rights, a port set right can't be passed in messages.

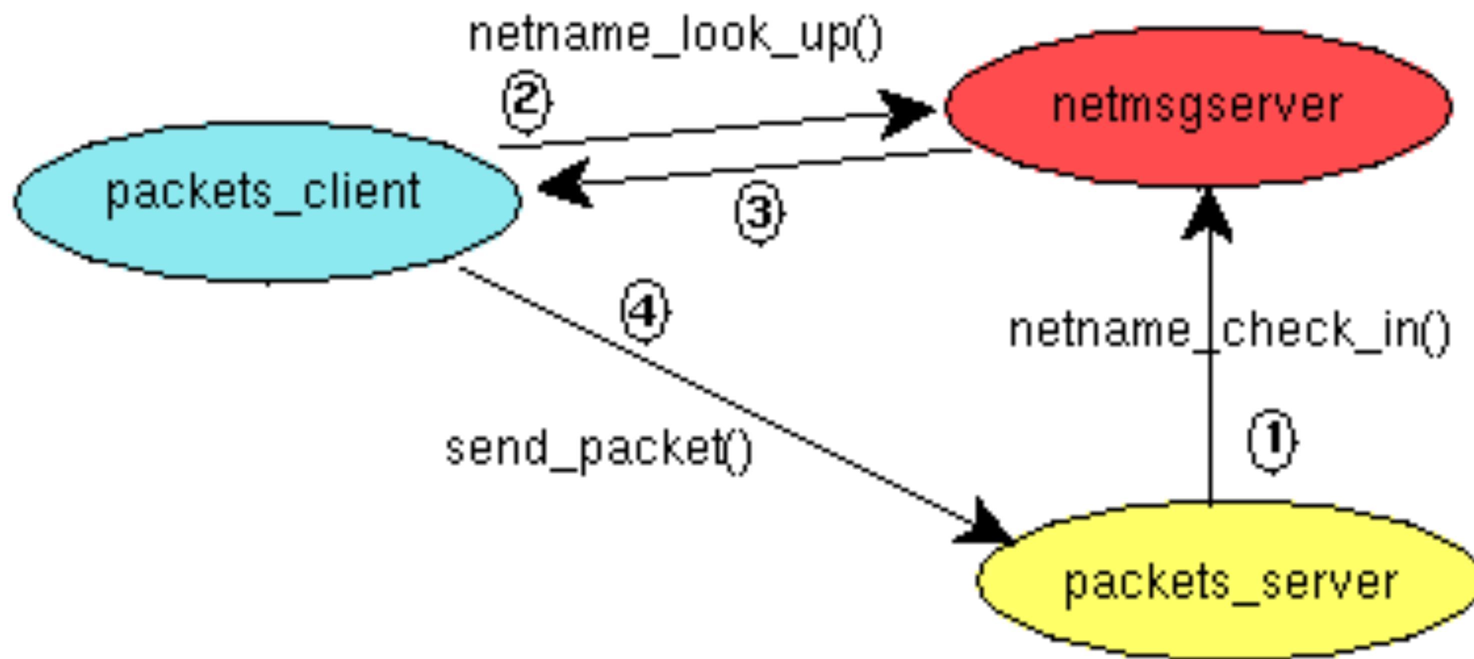
Port Names

- Every task has its own port name space, used for port and port set names.
  - For example, one task with receive rights for a port may know the port by the name 13,
  - while another task with send rights for the same port may know it by the name 17.
- A task has only one name for a port.
- Typically, these names are small integers, but this is implementation dependent.
  - port_rename() call can be used to change a task's name for a port.

Port Queues

- Messages that are sent to a port are held there until removed by a thread.
  - The queue associated with a port is of finite length and may become full.
- A thread sending to a filled queue has a choice of three alternatives:
  - By default, the sender is suspended until it can successfully transmit the message.
  - The sender can have the kernel hold the message for later transmission.
  - If the sender selects this action, it can't transmit further messages to the port until the kernel notifies it that the port has received the initial message.
- The attempt to send a message to a full port can be reported to the sender as an error.

Client/Server Setup



Programming with Ports (IPC)

- **Allocating a port**

```
# include <mach/mach.h>
# include <mach/port.h>

int allocate_port(port_name_t* port) {
        /* allocate a new port */
        kern_return_t ret;
        ret = port_allocate( task_self(), port );
        if (ret != KERN_SUCCESS) {
                mach_error("port_allocate:", ret );
                return -1;
        }
        return 0;
}
```

Registering with the Name Service

```
# include <mach/mach.h>
# include <servers/netname.h>
# include <mach/message.h>
# include <mach/port.h>

int allocate_and_check_in_port(char* name,port_name_t* port) {
/* allocate a new port and check the name in with netmsgserver*/
        kern_return_t ret;
        netname_name_t n_name;
        ret = port_allocate( task_self(), port );
        if (ret != NETNAME_SUCCESS) return -1;
        strncpy(n_name, name, sizeof(n_name));
        ret = netname_check_in( name_server_port, n_name,
                                task_self(), *port );
        if (ret != NETNAME_SUCCESS) return -2;
        return 0;
}
```

Looking up a Port

```
int lookup_port( char * name, port_name_t * port ) {
        /* lookup a port registered with netmsgserver   */
        kern_return_t ret;
        netname_name_t n_name;

        strncpy(n_name, name, sizeof(n_name));
         /*the pseudo name "*" initiates a broadcast on the net*/
        if ((ret = netname_look_up(name_server_port, "*",
                            n_name, port)) != NETNAME_SUCCESS) {
                mach_error("netname_lookup", ret);
                return -1;
        }
        return 0;
}
```

Programming with Mach IPC

- Interface definition file packets.defs - Mach 3

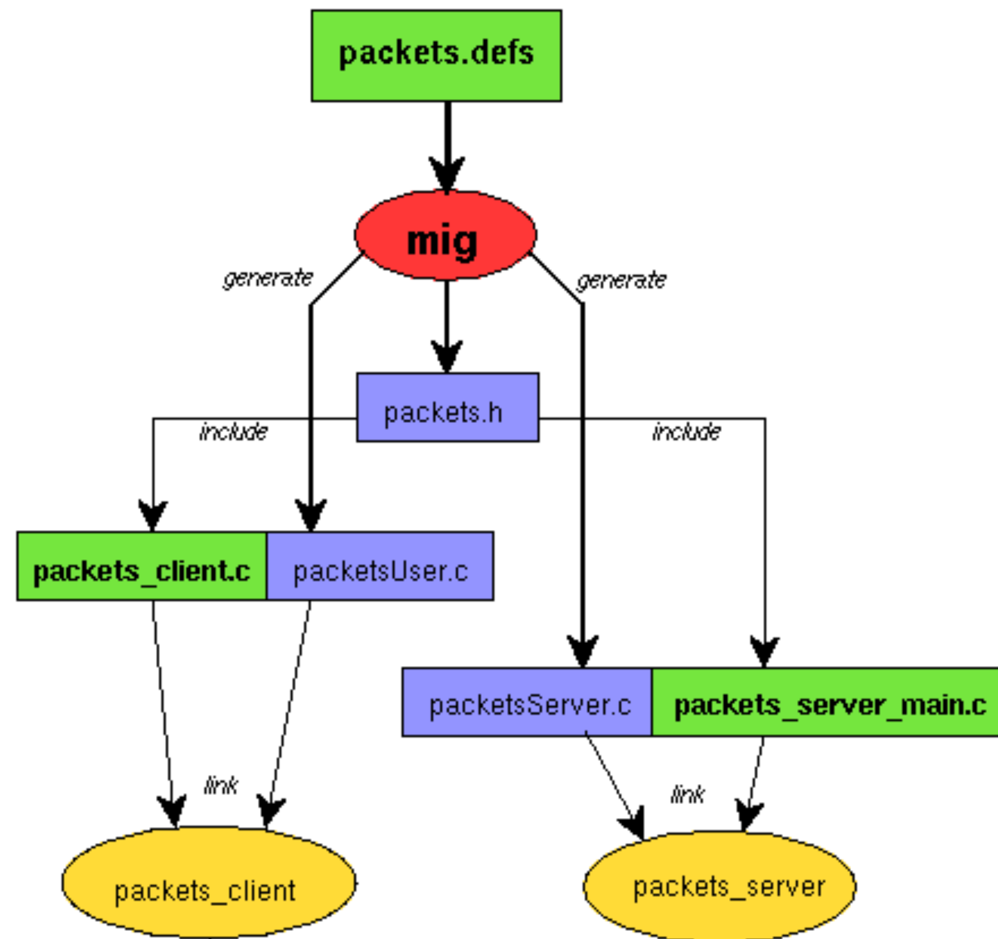
```
subsystem packets 0;
ServerPrefix Serv_;

# include <mach/mach_types.defs>

routine send_packet(
        RequestPort server: mach_port_t;
        in          count:      int
);

simpleroutine server_exit(
        RequestPort server: mach_port_t
);
```

Mach Interface Generator (MIG)



MIG Operations

	Nachricht senden	Antwort empfangen	Fehlermeldung zurück	Rückgabewert
simpleroutine	✓		✓	
routine	✓	✓	✓	
simpleprocedure	✓			
procedure	✓	✓		
function	✓	✓		✓

MIG Declarations - EBNF

operation	::=	operation-type op-name (parameter-list); | function op-name (parameter-list) : func-type;.
operation-type	::=	simpleroutine | routine | simpleprocedure | procedure.
parameter-list	::=	parameter { ; parameter }.
parameter	::=	[specification] var-name : type [, dealloc-flag].
specification	::=	in | out | inout | RequestPort | ReplyPort | WaitTime | MsgType.

Network-transparent IPC

- netmsgserver extends reach of local IPC
  - uses TCP/IP to transmit IPC messages to remote sites
  - provides a network-wide name service for port lookup