OPERATING SYSTEMS

Interprocess Communication

Operating Systems

School of Data & Computer Science
Sun Yat-sen University

Lecture Notes: os_sysu@163.com
Instructor: Guoyang Cai
email: isscgy@mail.sysu.edu.cn

中山大學
SUN YAT-SEN UNIVERSITY

Contents

Message-passing Systems

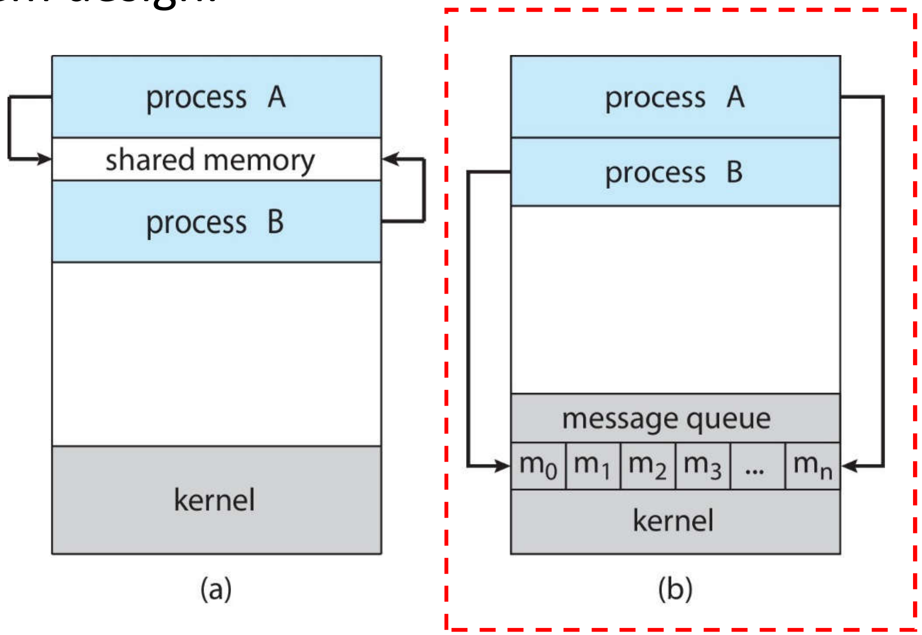
- Message-passing is a mechanism provided for the cooperating processes to communicate with each other and to synchronize their actions without resorting to shared variables.
  - Communication takes place by means of messages exchanged between cooperating processes.
  - useful for exchanging smaller amounts of data
  - typically implemented using system calls and thus require the more time-consuming task of kernel intervention
  - easier to implement in a distributed system than shared memory
  - particularly useful in a distributed environment, where the communicating processes may reside on different computers connected by a network.

Message-passing Systems

- A message-passing facility provides at least two *primitives* (原语):

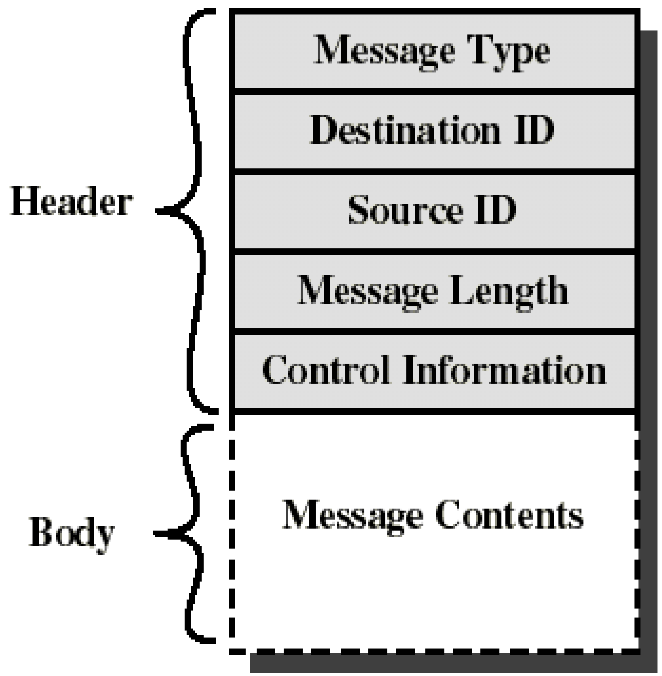
  send(destination, message) or send(message)
  receive(source, message) or receive(message)

- Message size is fixed or variable.
  - Variable-sized messages require a more complex system-level implementation, but the programming task becomes simpler.
    - This is a common kind of tradeoff seen throughout operating system design.



Message Format

- Header and Body
- Control Information
  - what to do if run out of buffer space
  - sequence numbers
  - priority
- Queuing discipline: usually FIFO but can also include priorities.

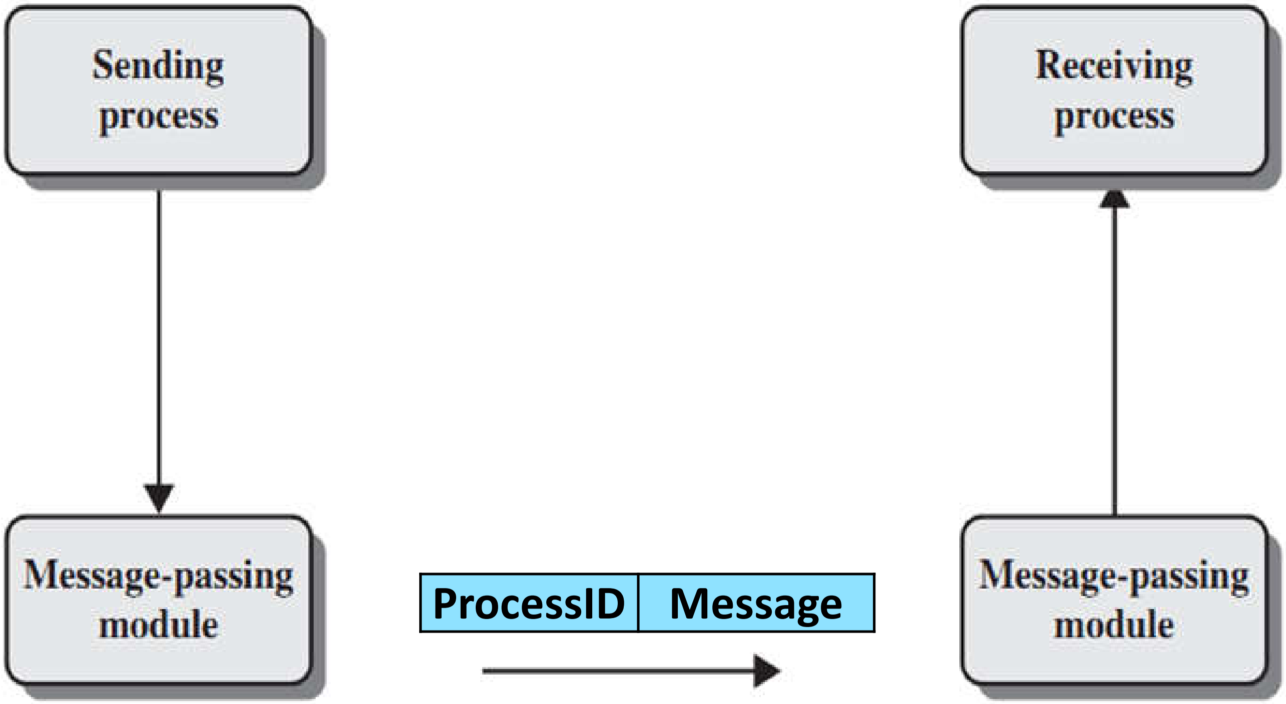


Message Format

- Linux Message Structure

```
struct msg_st {
    long int msg_type;
    char mtext[TEXT_SIZE];
};
```

Basic Message-passing Primitives



Logical Communication Link

- A *communication link* must exist between two processes if they want to communicate, send messages to and receive messages from each other.
- A communication link can be implemented in a variety of ways.
  - We are concerned here not with the link's physical implementation but rather with its logical implementation.
- Several methods for logically implementing a link and the send/receive operations:
  - *Direct* or *indirect* communication
  - *Synchronous* or *asynchronous* communication
  - *Automatic* or *explicit* buffering.

Direct Communication

- Processes of both sides explicitly *name* the recipient or sender of the communication symmetrically:

  send(destination_process_name, message)
  receive(source_process_name, message)

  or asymmetrically: The receiver is not required to name the sender. The variable id is set to the name of the process message received from.

  send(destination_process_name, message)
  receive(id, message)

- Properties
  - A link is established automatically between every pair of processes that want to communicate. The processes need to know only each other’s identity to communicate.
  - A link is associated with exactly two processes.
  - Between each pair of processes, there exists exactly one link.

Direct Communication

- Disadvantage of direct communication
  - Direct communication uses a specific process identifier for source/destination. But it might be impossible to specify the source ahead of time.
  - Another disadvantage in both symmetric and asymmetric schemes is the limited modularity of the resulting process definitions.
    - Changing the identifier of a process may necessitate examining all other process definitions.
    - All references to the old identifier must be found, so that they can be modified to the new identifier.
    - In general, any such *hard-coding* (硬编码) techniques, where identifiers must be explicitly stated, are less desirable than techniques involving indirection, as described next.

Indirect Communication

- The messages are sent to and received from *mailboxes*, or *ports*.
- A mailbox can be viewed abstractly as an object that
  - Processes can place messages into, and
  - Processes can receive and remove messages from.
- Each mailbox has a unique identification.
  - E.g., POSIX message queues use an integer value to identify a mailbox. A process can communicate with another process via a number of different mailboxes, but two processes can communicate only if they have a shared mailbox ID.

```
send(mailbox_A, message)
receive(mailbox_A, message)
```

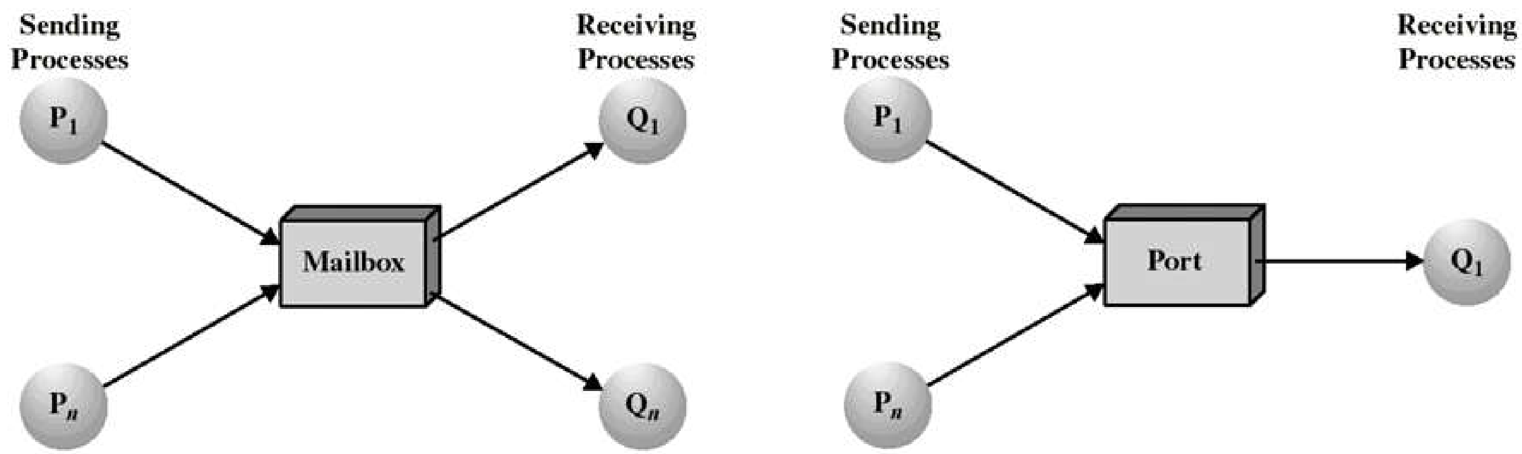
- Properties
  - A link is established between a pair of processes only if both members of the pair have a shared mailbox.
  - One link may be associated with more than two processes.
  - Between each pair of communicating processes, a number of different links may exist, with each link corresponding to one mailbox.

Indirect Communication

- Suppose that processes P_1, P_2, and P_3 all share mailbox A. Process P_1 sends a message to A, while both P_2 and P_3 execute a receive() (and *delete* the received message) from A. Which process will receive the message sent by P_1? The answer depends on which of the following methods we choose:
  - Allow a link to be associated with two processes at most.
  - Allow at most one process at a time to execute a receive() operation.
  - Allow the system to select arbitrarily which process will receive the message (that is, either P_2 or P_3, but not both, will receive the message). The system may define an algorithm for selecting which process will receive the message.
    - E.g, *Round-Robin*, where processes take turns receiving messages.
  - The system may identify the receiver to the sender.
- A mailbox may be owned either by a process or by the operating system. The ownership and receiving privilege of a mailbox must be considered.

Indirect Communication

- Mailboxes vs. Ports
  - A mailbox can be private to one sender/receiver pair.
  - The same mailbox can be shared among several senders and receivers:
    - The OS may then allow the use of message types (for selection).
  - A Port is a mailbox associated with one receiver and multiple senders.
    - used for client/server applications - the receiver is the server



Indirect Communication

- Mailboxes vs. Ports
  - Ownership of mailboxes
    - OS creates a mailbox on behalf of a process (which becomes the owner).
    - The mailbox is destroyed at the owner’s request or when the owner terminates.
  - Ownership of ports
    - A port is usually created and own by the receiving process.
    - The port is destroyed when the receiver terminates.

Synchronization in Message-passing Systems

- There are different design options for implementing the two primitives send() and receive().
- Message passing may be either *blocking* or *non-blocking*. Blocking is considered synchronous, and non-blocking is considered asynchronous.
  - *Blocking send*
    - The sending process blocks until the message is received by the receiving process or by the mailbox.
  - *Blocking receive*
    - The receiver blocks until a message is available.
  - *Non-blocking send*
    - The sending process sends the message and resumes.
  - *Non-blocking receive*
    - The receiver retrieves a valid message or a null.

Synchronization in Message-passing Systems

- For the sender
  - It is more natural not to be blocked after issuing send:
    - The sender can send several messages to multiple destinations.
    - Senders usually expect acknowledgment of message receipt.
      - in case receiver fails
- For the receiver
  - It is more natural to be blocked after issuing receive request.
    - The receiver usually needs the information before proceeding, but it could be blocked indefinitely (无限期堵塞) if sender process fails before send.

Synchronization in Message-passing Systems

- There are really three combinations here that make sense:
  - Blocking send, Blocking receive
    - have a rendezvous (汇聚点) between the sender and the receiver
    - both are blocked until the message is received
    - occurs when the communication link is unbuffered (no message queue)
    - provides tight synchronization (*rendezvous*).
  - Non-blocking send, Non-blocking receive
    - used in purpose
  - Non-blocking send, Blocking receive
    - Server process provides services/resources to other processes. It will need the expected information before proceeding.
    - most popular
- We will discuss the synchronization problem in detail later.

- **Buffering**
  - Whether communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue. Basically, such queues can be implemented in three ways:
    - Zero capacity
      - a message system with no buffering
      - The link cannot have any messages waiting in it.
      - Sender must wait until the recipient receives the message (rendezvous).
    - Bounded capacity
      - The queue has a finite length *n*.
      - Sender must wait if link full.
    - Unbounded capacity
      - The queue's length is potentially infinite.
      - Sender never waits.

Linux: Message-passing

- Linux IPCs Limits
  - The kernel level limits can be redefined in /etc/sysctl.conf

```
isscgy@ubuntu:/mnt/hgfs/VM-Shared/OS-test$ ipcs -l

------ Messages Limits --------
max queues system wide = 32000
max size of message (bytes) = 8192
default max size of queue (bytes) = 16384

------ Shared Memory Limits --------
max number of segments = 4096
max seg size (kbytes) = 18014398509465599
max total shared memory (kbytes) = 18014398509481980
min seg size (bytes) = 1

------ Semaphore Limits --------
max number of arrays = 32000
max semaphores per array = 32000
max semaphores system wide = 1024000000
max ops per semop call = 500
semaphore max value = 32767

isscgy@ubuntu:/mnt/hgfs/VM-Shared/OS-test$
```

Linux: Message-passing

Message structure

```
struct msg_struct {
    long int msg_type;
    char mtext[TEXT_SIZE];
};

struct msqid_ds { /* linux/msg.h */
    struct ipc_perm msg_perm;
    time_t msg_stime;    /* Last msgsnd time */
    time_t msg_rtime;    /* Last msgrcv time */
    time_t msg_ctime;    /* Last change time */
    msgqnum_t msg_qnum;  /* Current number of messages in queue */
    msglen_t msg_qbytes; /* Maximum number of bytes allowed in queue */
    pid_t msg_lspid;     /* PID of last msgsnd */
    pid_t msg_lrpid;     /* PID of last msgrcv */
};
```

Linux: Message-passing

Functions

```
key_t ftok(char *pathname, char proj_id)

int msgget(key_t key, int msgflg)

int msgsnd(int msqid, void *msgp, size_t msgsz, int msgflg)

ssize_t msgrcv(int msqid, const void *msgp, size_t msgsz, long msgtyp,
int msgflg)

int msgctl(int msqid, int cmd, struct msqid_ds *buf)
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-0: msgdata.h

```
#define TEXT_SIZE 512
/* considering
------ Messages Limits --------
max queues system wide = 32000
max size of message (bytes) = 8192
default max size of queue (bytes) = 16384
------------------------------------------
The size of message is set to be 512, the total number of messages is 16384/512 = 32
If we take the max size 8192, the number would be 16384/8192 = 2. It is not reasonable
*/

/* message structure */
struct msg_struct {
    long int msg_type;
    char mtext[TEXT_SIZE]; /* binary data */
};

#define PERM S_IRUSR|S_IWUSR|IPC_CREAT

#define ERR_EXIT(m) \
    do { \
        perror(m); \
        exit(EXIT_FAILURE); \
    } while(0)
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-1: msgsnd.c (1)

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/msg.h>
#include <sys/stat.h>
#include <fcntl.h>

#include “alg.9-0-msgdata.h”
```

```
int main(int argc, char *argv[])
{
    struct msg_struct data;

    long int msg_type;
    char buffer[TEXT_SIZE], pathname[80];
    int msqid, ret, count = 0;
    key_t key;
    FILE *fp;
    struct stat fileattr;

    if(argc < 2) {
        printf("Usage: ./a.out pathname\n");
        return EXIT_FAILURE;
    }
    strcpy(pathname, argv[1]);

    if(stat(pathname, &fileattr) == -1) {
        ret = creat(pathname, O_RDWR);
        if (ret == -1) {
            ERR_EXIT("creat()");
        }
        printf("shared file object created\n");
    }
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-1: msgsnd.c (2)

```
    key = ftok(pathname, 0x27); /* project_id can be any nonzero integer */
    if(key < 0) {
        ERR_EXIT("ftok()");
    }

    printf("\nIPC key = 0x%x\n", key);

    msqid = msgget((key_t)key, 0666 | IPC_CREAT);
    if(msqid == -1) {
        ERR_EXIT("msgget()");
    }

    fp = fopen("./msgsnd.txt", "rb");
    if(!fp) {
        ERR_EXIT("source data file: ./msgsnd.txt fopen()");
    }

    struct msqid_ds msqattr;
    ret = msgctl(msqid, IPC_STAT, &msqattr);
    printf("number of messages remainded = %ld, empty slots = %ld\n", msqattr.msg_qnum,
16384/TEXT_SIZE-msqattr.msg_qnum);
    printf("Blocking Sending ... \n");
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-1: msgsnd.c (3)

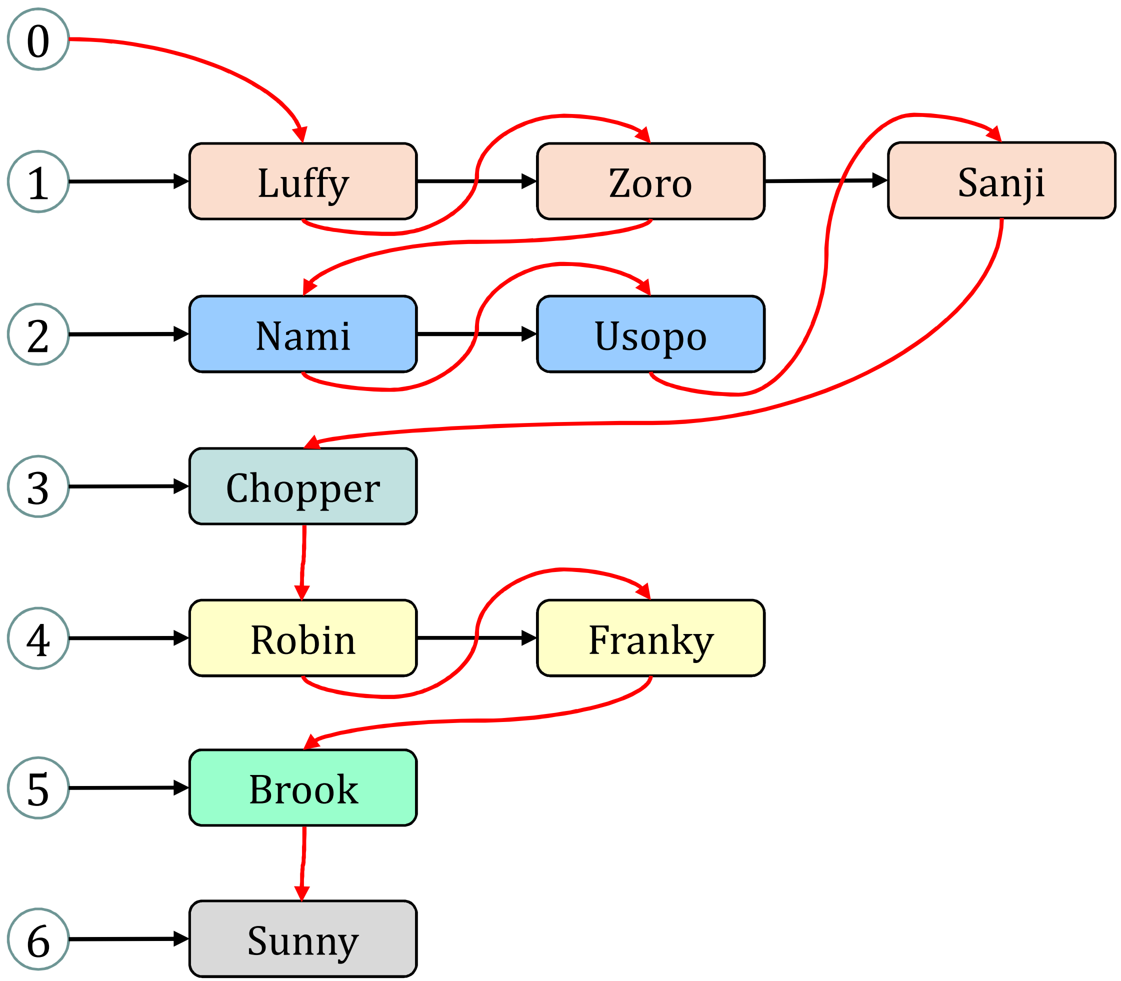
```
    while (!feof(fp)) {
        ret = fscanf(fp, "%ld %s", &msg_type, buffer);
        if (ret == EOF) break;
        printf("%ld %s\n", msg_type, buffer);

        data.msg_type = msg_type;
        strcpy(data.mtext, buffer);

        ret = msgsnd(msqid, (void *)&data, TEXT_SIZE, 0);
            /* 0: blocking send, waiting when msg queue is full */
        if(ret == -1) {
            ERR_EXIT("msgsnd()");
        }
        count++;
    }

    printf("number of sent messages = %d\n", count);

    fclose(fp);
    system("ipcs -q");
    exit(EXIT_SUCCESS);
}
```

Examples


```
isscgy@ubuntu:/mnt/os-2020$ gcc alg.9-1-msgsnd.c
isscgy@ubuntu:/mnt/os-2020$ ./a.out /home/isscgy/myshm

IPC key = 0x27011c6c
number of messages remainded = 0, empty slots = 32
Blocking Sending ...
1 Luffy
1 Zoro
2 Nami
2 Usopo
1 Sanji
3 Chopper
4 Robin
4 Franky
5 Brook
6 Sunny
number of sent messages = 10

------ Message Queues --------
key        msqid      owner      perms      used-bytes   messages
0x27011c9e 1          isscgy     666        0            0
0x27011c6c 4          isscgy     666        5120         10

isscgy@ubuntu:/mnt/os-2020$
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - The message queues.



Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-2: msgrcv.c (1)

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/msg.h>
#include <sys/stat.h>

#include "alg.9-0-msgdata.h"
```

```
    /* Usage: ./b.out pathname msg_type */
int main(int argc, char *argv[])
{
    key_t key;
    struct stat fileattr;
    char pathname[80];
    int msqid, ret, count = 0;
    struct msg_struct data;
    long int msgtype = 0;   /* 0 - type of any messages */

    if(argc < 2) {
        printf("Usage: ./b.out pathname msg_type\n");
        return EXIT_FAILURE;
    }
    strcpy(pathname, argv[1]);
    if(stat(pathname, &fileattr) == -1) {
        ERR_EXIT("shared file object stat error");
    }
    if((key = ftok(pathname, 0x27)) < 0) {
        ERR_EXIT("ftok()");
    }
    printf("\nIPC key = 0x%x\n", key);
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-2: msgrcv.c (2)

```
msqid = msgget((key_t)key, 0666); /* do not create a new msg queue */
if(msqid == -1) {
    ERR_EXIT("msgget()");
}

if(argc < 3)
    msgtype = 0;
else {
    msgtype = atol(argv[2]);
    if (msgtype < 0)
        msgtype = 0;
}    /* determin msgtype (class number) */
printf("Selected message type = %ld\n", msgtype);

while (1) {
    ret = msgrcv(msqid, (void *)&data, TEXT_SIZE, msgtype, IPC_NOWAIT);
        /* Non_blocking receive */
    if(ret == -1) { /* end of this msgtype */
        printf("number of received messages = %d\n", count);
        break;
    }

    printf("%ld %s\n", data.msg_type, data.mtext);
    count++;
}
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-2: msgrcv.c (3)

```
    struct msqid_ds msqattr;
    ret = msgctl(msqid, IPC_STAT, &msqattr);
    printf("number of messages remainding = %ld\n", msqattr.msg_qnum);

    if(msqattr.msg_qnum == 0) {
        printf("do you want to delete this msg queue?(y/n)");
        if (getchar() == 'y') {
            if(msgctl(msqid, IPC_RMID, 0) == -1)
                perror("msgctl(IPC_RMID)");
        }
    }

    system("ipcs -q");
    exit(EXIT_SUCCESS);
}
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.
  - Algorithm 9-2: msgrcv.c (3)

```
struct msqid_ds msqattr;
```

```
isscgy@ubuntu:/mnt/os-2020$ gcc -o b.out alg.9-2-msgrcv.c
isscgy@ubuntu:/mnt/os-2020$ ./b.out /home/isscgy/mysh
shared file object stat error: No such file or directory
isscgy@ubuntu:/mnt/os-2020$ ./b.out /home/isscgy/myshm 2

IPC key = 0x27011c6c
Selected message type = 2
2 Nami
2 Usopo
number of received messages = 2
number of messages remainding = 8

------ Message Queues --------
key        msqid      owner      perms      used-bytes   messages
0x27011c9e 1          isscgy     666        0            0
0x27011c6c 5          isscgy     666        4096         8

isscgy@ubuntu:/mnt/os-2020$
```

Linux: Message-passing

- Sending & Receiving process illustrating Linux message-passing API.

```
isscgy@ubuntu:/mnt/os-2020$ ./b.out /home/isscgy/myshm 0

IPC key = 0x27011c6c
Selected message type = 0
1 Luffy
1 Zoro
1 Sanji
3 Chopper
4 Robin
4 Franky
5 Brook
6 Sunny
number of received messages = 8
number of messages remainding = 0
do you want to delete this msg queue?(y/n)y

------ Message Queues --------
key        msqid      owner      perms      used-bytes   messages
0x27011c9e 1          isscgy     666        0            0

isscgy@ubuntu:/mnt/os-2020$ 
```

POSIX: Message-passing

```
#include <mqueue.h>
```

- Open, Close and Unlink

```
mqd_t mq_open(const char *name, int oflag, mode_t mode, struct
mq_attr *attr ); /* return the mqdes, or -1 if failed */
mqd_t mqID;
mqID = mq_open("/anonymQueue", O_RDWR | O_CREAT, 0666, NULL);

mqd_t mq_close(mqd_t mqdes);
mqd_t mq_unlink(const char *name); /* return -1 if failed */
```

- Send and Receive

```
mqd_t mq_send(mqd_t mqdes, const char *msg_ptr, size_t msg_len,
unsigned msg_prio); /* return 0, or -1 if failed */
mq_send(mqID, msg, sizeof(msg), i)
mqd_t mq_receive(mqd_t mqdes, char *msg_ptr, size_t msg_len,
unsigned *msg_prio); /* return the number of char received, or -1
if failed */
mq_attr mqAttr;
mq_getattr(mqID, &mqAttr);
mq_receive(mqID, buf, mqAttr.mq_msgsize, NULL)
```

Windows XP: Message-passing

- Local Procedure Calls in Windows XP