Operating Systems: Processes

CIS*3110: Operating Systems

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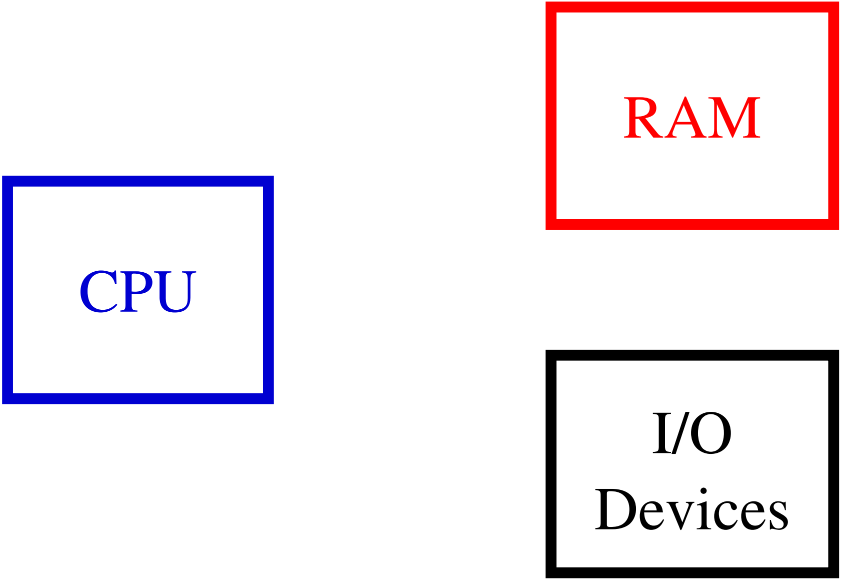
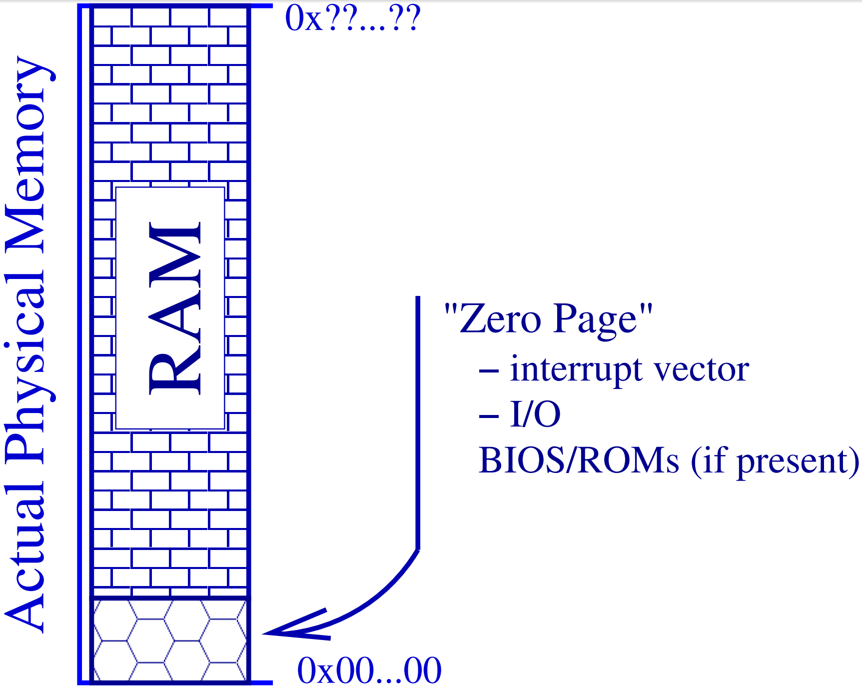
2024-12-01

Parts of a Computer

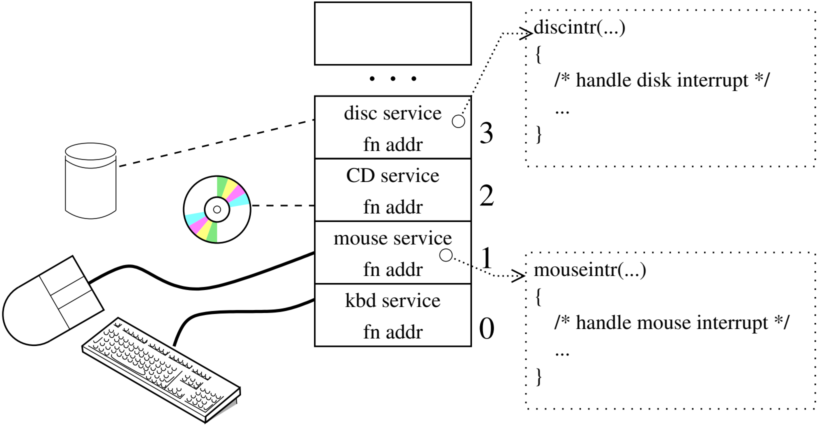



Actual Physical Memory
0x??...??
RAM
"Zero Page"
– interrupt vector
– I/O
BIOS/ROMs (if present)
0x00...00

Tools at the Hardware Architecture Level

- program counter (PC)
- stack pointer/frame pointer
- processor status register
- general purpose registers
- memory management unit (mapping, protection)
- kernel/user mode
- interrupts and interrupt vector

Interrupt vector links devices with service routines



- basic **instruction cycle** of the ALU of the CPU:

  1. fetch instruction pointed to by the PC
  2. increment PC
  3. execute instruction

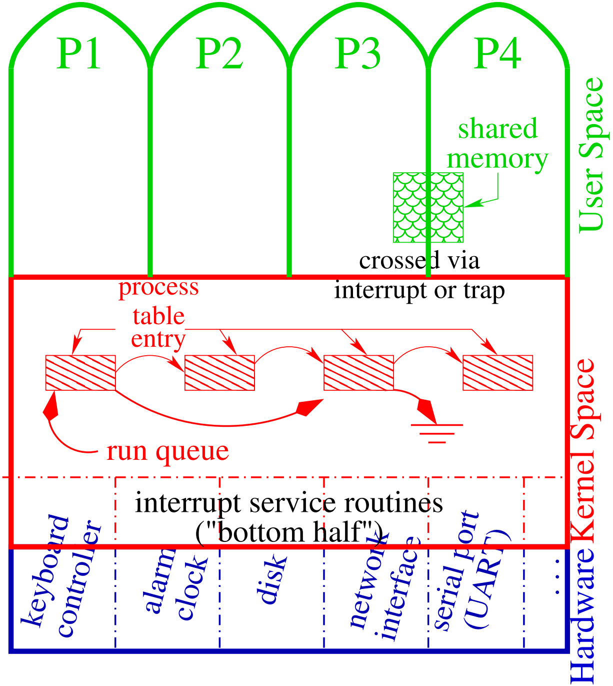
  over and over again

- **processor status** (usually a special register on each CPU)

  user mode – can execute **most** instructions (but no I/O)

  kernel mode – can execute **all** user instructions, PLUS access special instructions and registers that control I/O, memory access (also called **supervisor mode**)

- **interrupt vector** (special range of locations in RAM)
  - used to link hardware interrupts with … **interrupt service routines**


P1
P2
P3
P4
shared memory
User Space
crossed via interrupt or trap
process table entry
run queue
interrupt service routines ("bottom half")
Kernel Space
keyboard controller
alarm clock
disk
network interface
serial port (UART)
. . .
Hardware

Program on an Example Machine

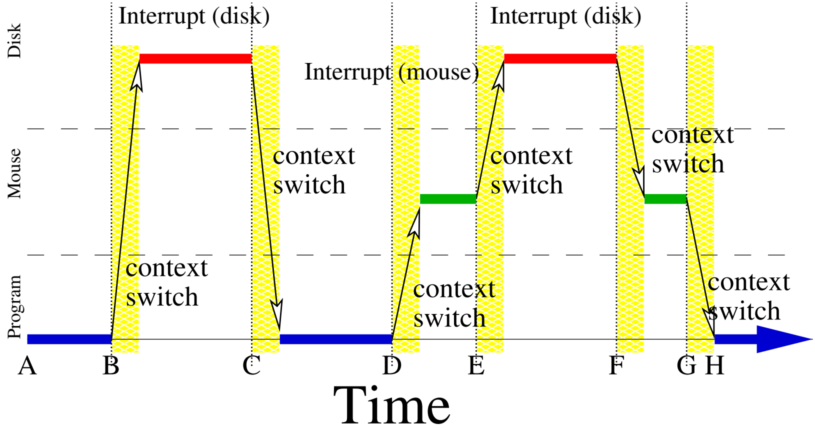
	Assembler		Mach Code	Virt Addr
	load	R1, 0xA2	0x11A2	0x10
int	incr	R1	0x3100	0x12
	store	R1, 0xA2	0x21A2	0x14
	jmp	xx	0x5026	0x16
yy:	decr	R2	0x4200	0x18
	...		...	
	rsb		0x7000	0x24
xx:	zero	R2	0x8200	0x26
	incr	R2	0x3200	0x28
	store	R2, 0xA0	0x22A0	0x2A
	jsr	yy	0x6018	0x2C
	incr	R2	0x3200	0x2E
	store	R2, 0xA2	0x22A0	0x30
	...		...	

Registers: R0, R1, R2, R3, SP, PC

Op Codes	
load	0x1
store	0x2
incr	0x3
decr	0x4
jmp	0x5
jsr	0x6
rsb	0x7
zero	0x8

Context Switch

- change from one running program to another “on the fly”
- need to be able to change back later
- to do this, we must save the “program state”
  - program counter
  - general purpose registers
  - status register
  - stack pointer
- each program must be resident in different parts of memory


Disk
Mouse
Program
Interrupt (disk)
Interrupt (mouse)
Interrupt (disk)
context switch
context switch
context switch
context switch
context switch
context switch
A
B
C
D
E
F
G
H
Time

Interrupts

- a hardware generated jump to subroutine (JSR) requested by an external hardware device (not the CPU)
- defined through the **interrupt vector**
  - resides somewhere in physical memory
  - is effectively an array of **function pointers**
- may be delayed (*i.e.*; disabled, possibly temporarily) by **masking off**

Interrupt Steps

Interrupt $\rightarrow$

- save PC on stack
- switch CPU to kernel (supervisor) mode
- load PC from vector using hardware id (vector contains the start address of the interrupt service routine)
- save all registers
- continue execution

Return from Interrupt (RTI) $\leftarrow$

- restore registers
- restore saved PC value
- set CPU to previous mode

Critical Sections

- a **critical section** contains reference(s) to data shared between two or more “threads of control”
  - one may be an **interrupt**
  - this may be two or more **processes**
  - this may be two or more **threads**
- must manage the data so all parties can rely on its value
  - if we fail to do this, data may be wrong for one party, or even corrupted for all

i++;	$\longleftrightarrow$	`load R1, #i`
		`incr R1`
		`store R1, #i`

A Critical Example

```
c = 'A';
for (i = 0; i < MAX; i++) {
    a[i] = c++;
    if (c > 'E')
        c = 'B';
}
```

Interrupt Service Routine

```
set_to_a() {
    c = 'A';
}
```

Modern (UNIX-type) systems: 3 types of device drivers

BLOCK devices that read/write blocks (disc, tapes, SD-cards, CD-ROM/DVD, …)

NETWORK local area network (Ethernet, token ring), remote connection network interface (PPP, ISDN, …)

CHARACTER everything that does not fit the above two cases (serial ports, display/keyboard, mouse, joystick, touchscreen, …)

Device Driver Functions

Top Half: communicate with user, kernel

probe check for hardware at boot time

open called when a process does an open of a **device file** (*e.g.*, `/dev/mouse`, `/dev/disk0`, `/dev/null` *etc.*)

- mostly initializes variables and maybe hardware
- generates a file descriptor in user space

close called when a process does a `close()` of the file descriptor created from `open` (usually just marks the device closed)

read called when a process does a `read(fd)` — transfers data from device to process

write called when a process does a `write(fd)` — queues data for device to output

Bottom Half: event handling

interrupt service routine
called when device generates an interrupt and does the I/O on the hardware

```c
char get_keyb()
{
    while (???) {
    }

    return ???;
}

void keyb_intr()
{
        /* "magic" addresses for memory mapped I/O */
    char *keyb_reg = (char *) 0x2ff4200;
    char *keyb_status = (char *) 0x2ff4201;

    while (*keyb_status)
        ;

    ??? = *keyb_reg;

}
```

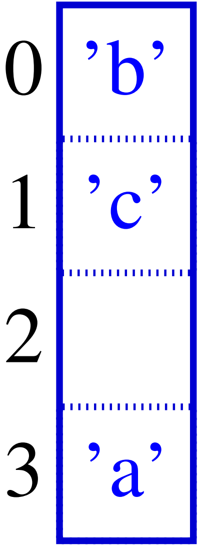
```
char Q[QSIZE];
int numQ, startQpos, endQpos;
numQ = startQpos = endQpos = 0;
```

Add into queue

```
Q[endQpos] = value;
endQpos = (endQpos + 1) % QSIZE;
numQ++;
```

Remove from queue

```
value = Q[startQpos];
startQpos = (startQpos + 1) % QSIZE;
numQ-;
```



Critical Sections in Device Driver

- interrupts can be masked off:

  `int state = spltty()` masks interrupt(s) to prevent a second interrupt from over-writing the first

  `int splx(int prevState)` returns the interrupt mask to the previous state

- process can be “put to sleep” until there is space in a buffer:

  `int tsleep(void *id, int flags, char *mesg, int timeo)` causes the current **thread** (program counter) to be **BLOCKED** until someone calls `wakeup()`

  `int wakeup(void *id)` un-blocks *all* **thread**s which are asleep and have the given **identifier**

Device Driver Skeleton – read

```
static char Q[QSIZE];
static int numQ = 0, startQpos = 0, endQpos = 0;
devread(char *ubuf) { /** read one character */
    int s;
    s = spltty();
    while (numQ == 0) {
        splx(s); /** can't sleep inside critical section */
        tsleep(devread, ...); /* sleep */
        s = spltty();
    }
    *ubuf = Q[ startQpos ];
    startQpos = (startQpos + 1) % QSIZE;
    numQ-;
    splx(s);
}
```

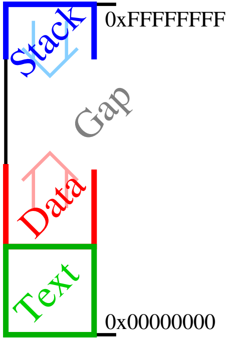
Device Driver Skeleton – intr

```
devintr() {
    int s;
    s = spltty();
    if (QSIZE == numQ) {
        /* queue is full . . . */
        splx(s); /* leave crit section before return */
        return;
    }
    Q[ endQpos ] = GET_CHAR_FROM_DEVICE();
    endQpos = (endQpos + 1) % QSIZE;
    numQ++;
    splx(s);
    wakeup(devread);
}
```

The **execution** of a **program** (an “image”) is a **process**.
The environment that the O/S provides for the execution of a program (*i.e.*; a process) is that of a **simplified** pseudo-computer.

UNIX/Mach process environment:

- **virtual** (simplified) address space
- **process context**
- no direct access to **I/O ports**



Process Table Entry (Process Context)

- the **process table** contains an entry for each current process
  - if a process has more than one **thread** there is usually one **process table entry** per thread (`ps(1)` may or may not show it this way)
- each **entry** holds all the information about a process:
  - process (thread) context
    - program counter
    - registers (general and special purpose)
    - stack pointer
    - virtual address space reference
  - scheduling information
    - BLOCKED *-vs-*RUNNABLE *-vs-*RUNNING
    - priority
    - time used

Process Status Listing

```
% ps auxw
USER       PID %CPU %MEM   VSZ  RSS TTY   STAT START TIME COMMAND
root         1  0.0  0.0  1368   84 ?     S    Jan11 0:04 init [3]
root         2  0.0  0.0     0    0 ?     SW   Jan11 0:00 [keventd]
root         4  0.0  0.0     0    0 ?     SWN  Jan11 0:00 [ksoftirqd_CPU0
root         9  0.0  0.0     0    0 ?     SW   Jan11 0:00 [bdflush]
root         5  0.0  0.0     0    0 ?     SW   Jan11 0:00 [kswapd]
root      1609  0.0  0.0  1368  144 ?     S    Jan11 0:00 klogd -x
root      1761  0.0  0.0  3508  480 ?     S    Jan11 0:00 /usr/sbin/sshd
root      1920  0.0  0.2  2320 1380 ?     S    Jan11 0:00 [login]
root      1921  0.0  0.0  1352   60 tty2  S    Jan11 0:00 /sbin/mingetty
andrew    8506  0.0  0.2  4692 1448 tty1  S    09:33 0:00 -csh
andrew    9373  0.0  0.5  8196 2980 pts/7 S    10:43 0:03 vim Processes.t
andrew    9795  0.0  0.2  4680 1428 pts/8 S    11:20 0:00 -bin/csh
andrew   10154  0.0  0.1  2728  780 pts/7 R    11:36 0:00 ps auxw
```

Synchronization Primitives

Shared data can also be used between **processes/threads**

$\rightarrow$ we need to manage critical sections at this level.

The two most popular **synchronization primitives** are:

mutex: bracket critical section so only 1 process allowed at a time:

```
critical_begin();
```

... code in critical section ...

```
critical_end();
```

semaphores: allow *N*-at-a-time

Co-operating sequential processes can be envisioned as a separate, dedicated processor for each – with no guarantee which runs first/faster *etc*.

Mutex Synchronization: Producer

```
void add_queue(char aNewChar) {
    int oldsize;

    do { /** wait until not full */
        critical_begin();
        oldsize = numQ;
        critical_end();
    } while (oldsize == QSIZE);

    critical_begin();
    Q[ endQpos ] = aNewChar;
    endQpos = (endQpos + 1) % QSIZE;
    numQ++;
    critical_end();
```

Mutex Synchronization: Consumer

```
void del_queue(char aNewChar) {
    int oldsize, tmpBuf;

    do { /** wait until not empty */
        critical_begin();
        oldsize = numQ;
        critical_end();
    } while (oldsize == 0);

    critical_begin();
    tmpBuf = Q[ startQpos ];
    startQpos = (startQpos + 1) % QSIZE;
    numQ-;
    critical_end();
    return tmpBuf;
```

Implementing Mutual Exclusion (in Hardware)

```
static mutexFlag = 0;

critical_begin() {
    int oldFlag;

    do {
        /** does oldflag = flag, flag = 1 */
        TEST_AND_SET(&oldFlag, &mutexFlag);
        /** as one indivisible operation */
    } while (oldFlag);
}

critical_end() {
    mutexFlag = 0;
}
```

Dekker's Algorithm (2 processes)

```
int need[2] = {0, 0};
int turn;

critical_begin(int who) {
    need[ who ] = 1;
    turn = !who;

    while (need[ !who ] && turn != who)
        ;
}

critical_end(int who) {
    need[ who ] = 0;
}
```

Semaphores

A **semaphore** is a synchronization primitive which has an internal integer counter the following operations:

signal
: increments the internal counter

wait
: until the internal counter > 0 ... *only then* decrement the counter

Semaphore Implementation - Using Mutexes

```
SEM_WAIT(semaphore_t *s) {
    semaphore_t oldsem;

    /** wait until sem > 0 */
    do {
        critical_begin();
        oldsem = *s;
        if (*s > 0)
            *s = *s - 1;
        critical_end();
    } while (oldsem == 0);
```

```
SEM_SIGNAL(semaphore_t *s) {
    critical_begin();
    *s = *s + 1;
    critical_end();
}
```

- commercial/professional implementations use `tsleep()` to block the process instead of a busy-loop

Semaphore Producer/Consumer

```
available_sem = QSIZE;
used_sem = 0;
critical_sem = 1;

void add_queue(char aNewChar) {
   SEM_WAIT( &available_sem );
   SEM_WAIT( &critical_sem );
   Q[ endQpos ] = aNewChar;
   endQpos = (endQpos + 1) % QSIZE;
   SEM_SIGNAL( &critical_sem );
   SEM_SIGNAL( &used_sem );
}
```

```
void del_queue(char aNewChar) {
   int tmpBuf;
   SEM_WAIT( &used_sem );
   SEM_WAIT( &critical_sem );

   tmpBuf = Q[ startQpos ];
   startQpos = (startQpos + 1)
        % QSIZE;

   SEM_SIGNAL( &critical_sem );
   SEM_SIGNAL( &available_sem );

   return tmpBuf;
}
```

Co-Operating Sequential Processes – Examples

```
semaphore_t U = 1;    semaphore_t D = 0;    int sharedch = 'a';
```

```
up() {
  while (1) {


    printf("U-%c ", sharedch);
    if(++sharedch > 'z')
      sharedch = 'a';


  }
}
```

```
down() {
  while (1) {


    printf("D-%c ", sharedch);
    if(-sharedch < 'a')
      sharedch = 'a';


  }
}
```

Co-Operating Sequential Processes – Example #1

```
semaphore_t U = 1;    semaphore_t D = 0;    int sharedch = 'a';
```

```
up() {
  while (1) {
    SEM_WAIT( &U );

    printf("U-%c ", sharedch);
    if(++sharedch > 'z')
      sharedch = 'a';
    SEM_SIGNAL( &D );

  }
}
```

```
down() {
  while (1) {
    SEM_WAIT( &D );

    printf("D-%c ", sharedch);
    if(-sharedch < 'a')
      sharedch = 'a';
    SEM_SIGNAL( &U );

  }
}
```

Output: U-a D-b U-a D-b U-a . . .

Co-Operating Sequential Processes – Example #2

```
semaphore_t U = 2;    semaphore_t D = 0;    int sharedch = 'a';
```

```
up() {
  while (1) {
    SEM_WAIT( &U );

    printf("U-%c ", sharedch);
    if(++sharedch > 'z')
      sharedch = 'a';
    SEM_SIGNAL( &D );

  }
}
```

```
down() {
  while (1) {
    SEM_WAIT( &D );
    SEM_WAIT( &D );
    printf("D-%c ", sharedch);
    if(-sharedch < 'a')
      sharedch = 'a';
    SEM_SIGNAL( &U );
    SEM_SIGNAL( &U );
  }
}
```

Output: U-a U-b D-c U-~~d~~ U-d D-e U-d U-e D-f U-e U-f D-g U-f ...

b

Co-Operating Sequential Processes – Example #3

```
semaphore_t U = 0;    semaphore_t D = 2;    int sharedch = 'a';
```

```
up() {
  while (1) {
    SEM_WAIT( &U );
    printf("U-%c ", sharedch);
    if(++sharedch > 'z')
      sharedch = 'a';
    SEM_SIGNAL( &D );
  }
}
```

```
down() {
  while (1) {
    SEM_WAIT( &D );
    SEM_WAIT( &D );
    printf("D-%c ", sharedch);
    if(-sharedch < 'a')
      sharedch = 'a';
    SEM_SIGNAL( &U );
    SEM_SIGNAL( &U );
  }
}
```

Output: D-a U-a U-b D-c U-~~c~~ U-d D-e U-d U-e D-f U-e U-f D-g ...

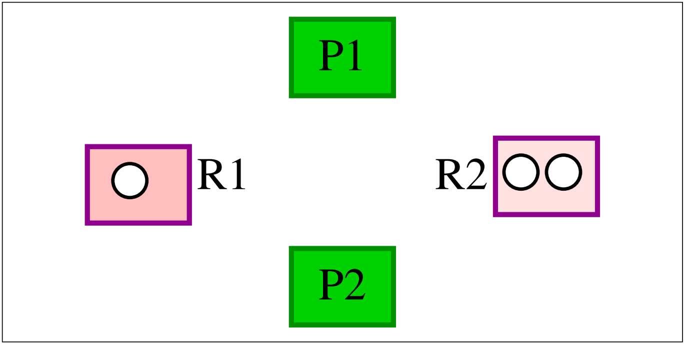
b

Semaphore Hints:

- all semaphores must be properly initialized
- always work from the definition of `wait_sem()` and `signal_sem()`
- normally, there will be a `wait_sem` with a corresponding `signal_sem()` on the same semaphore
- the order of `wait_sem()` operations is quite important; the order of **signal** less so

Deadlock

- deadlock occurs when processes *hold* resources and they *require* resources that other processes already hold
- shown by the presence of a cycle in the request allocation graph



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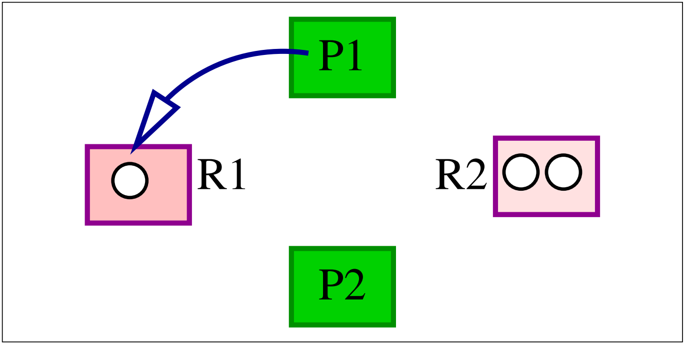

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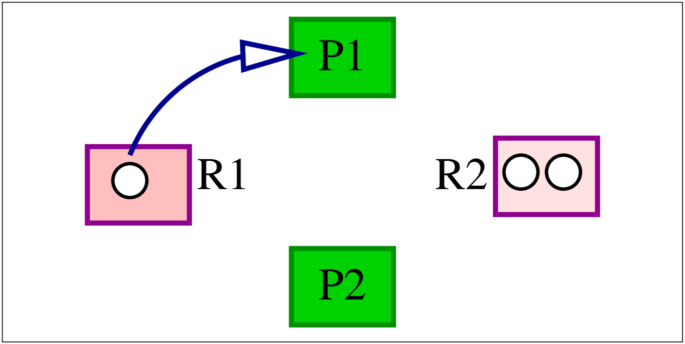

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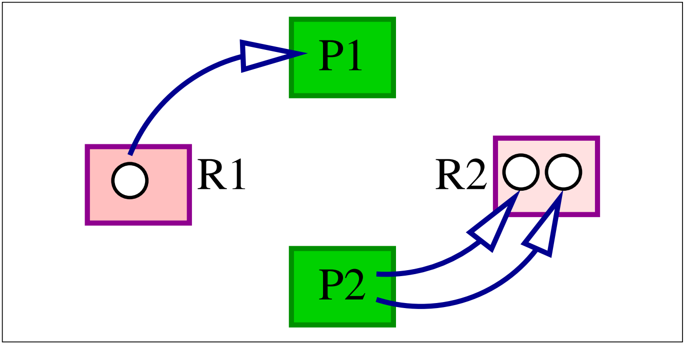

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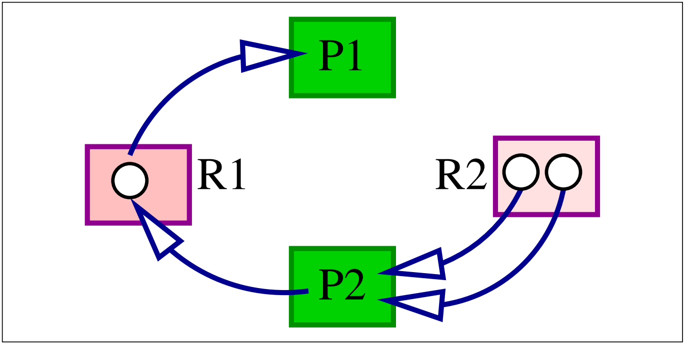

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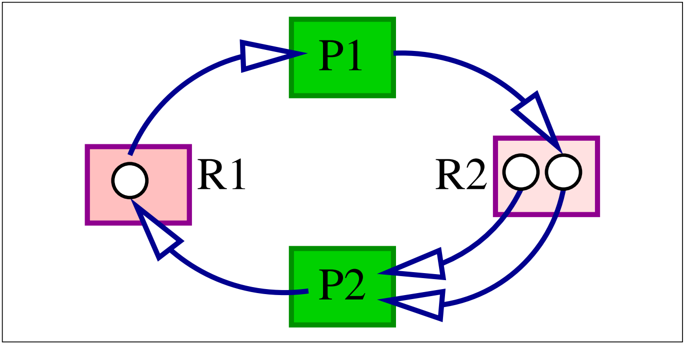


Java `synchronized` keyword

- The `synchronized` keyword can be used on a whole method or a block to provide a critical section
- method locking:

```
public class SyncCount {
    private int count = 0;
    public synchronized void increment() { count++; };
    public synchronized int getValue() { return count; };
}
```

- block locking:

```
    public void someMethod() {
        while(keepGoing()) {
            synchronized(someObject) {
                count++;
            }
        }
    }
```

IPC in General

Shared Memory blocks of shared process image

Semaphores/Mutexes integer data values for flow control

Signals a software “interrupt”

Pipes an imitation file shared by two processes

Signals

- used to indicate that some important event has happened
- sequence of events
  - process A is running and performing some task
  - process B sends a signal to process A
  - process A interrupts whatever it is doing ...
  - call a signal handler (a function) ...
  - returns to whatever it was doing before
- there is no direct notification to process B that anything has been done

Signal Values

Signals are simply integer valued actions, similar to interrupts. Some common signals are:

1	HUP	hangup	BUS	bus error
2	INT	interrupt	SEGV	segmentation violation
3	QUIT	quit	PWR	power failure
4	ILL	illegal instruction	TERM	terminate process
5	TRAP	trace trap	USR1	user defined #1
9	KILL	kill process	USR2	user defined #2

Signal Example

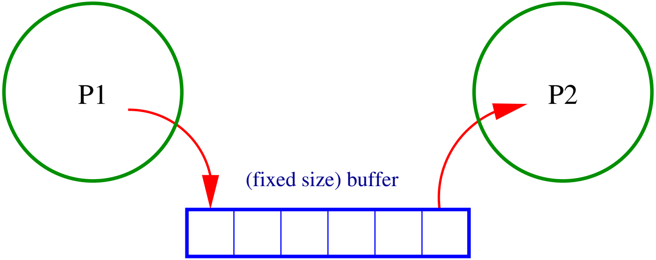
```
#include <signal.h>

void signalHandler(int code)
{
    fprintf(stderr,
            "Interrupt caught -- cleaning up\n");
    performCleanup();
    exit(1);
}

void main()
{
    signal(SIGINT, signalHandler);

⋮
```

A **pipe** is a file descriptor pair shared between processes, attached to a buffer common to both processes. The buffer is not stored anywhere in a filesystem, only in memory.



Scheduling

Basic process scheduler loop:

- when a process can no longer run (exits, waiting for I/O or time-slice used up)
  - mark process RUNNABLE or blocked (and why – blocked status)
  - save process context in process table entry
- search process table for another RUNNABLE process
  - mark this process running
  - restore process context for this process
- the system now runs this process, picking up where it left off (just as with a hardware interrupt)

Scheduling Algorithm or “Queuing Discipline”

FIFO

- if jobs/processes/...repeatedly join the queue this is typically called “round robin.”
- typically, round robin is preemptive

SJF

- shortest job first
- allow the job with the shortest running time to go next (jump to the head of the queue)
- not preemptive

A preemptive discipline permits a job to be preempted before it completes

Scheduling Algorithms/Queuing Disciplines

- FIFO and round robin are generally considered to be **fair**, as jobs cannot be stuck waiting forever
- SJF is optimal w.r.t. throughput:
  - *iff* you always run the job that will finish in the shortest time.
  - will always finish more jobs in a given elapsed time than any other ordering
  - it is **unfair**, and impractical for processes (can be approximated)

Scheduling Algorithms/Queuing Disciplines

In general:

- preemptive schedulers will perform better (*i.e.*; smoother response) than non-preemptive schedulers and are **required** for interactive systems
- schedulers will normally bias towards short jobs, such as updating an editor after a keystroke
- operators/users will be able to set/adjust priorities for jobs, *see* nice(1)
  - dynamic priority is updated during context switch based on last run time
- there will always be a trade-off between coarse -*vs*-fine granularity of the time-slices:

  coarse : low overhead/poor interactive response

  fine : higher overhead/better interactive response

Scheduling Algorithms/Queuing Disciplines

- if preemption occurs extremely frequently such that each job gets an infinitesimally small time each time it runs, the discipline is called “processor sharing”

- whereas, if the preemption time is infinitely large, the discipline is called FIFO

Scheduling Algorithms/Types of Tasks

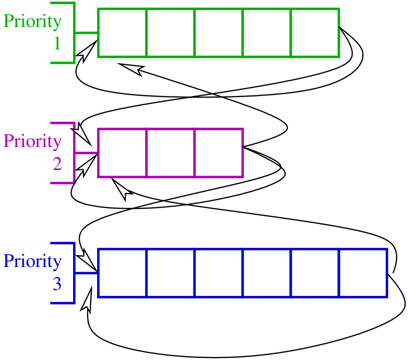
batch insensitive to gaps in runtime; get overall task done

interactive sensitive to runtime gaps; typically lots of I/O

real-time critically sensitive to runtime gaps

- demand fixed fraction of CPU/unit time

Priority Queues (VMS/Windows)



Some systems vary the priority dynamically, others do not