Scuola Superiore Sant'Anna

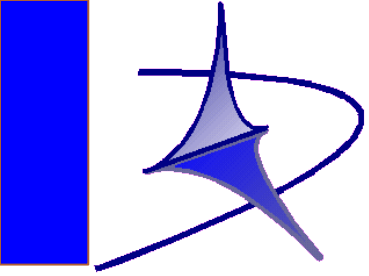
Real-Time Systems Laboratory

Laurea Specialistica in Ingegneria dell'Automazione – A.A. 2006-2007

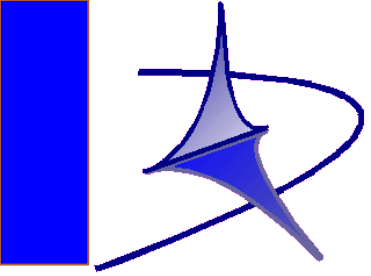
Sistemi in Tempo Reale

Giuseppe Lipari

Introduzione alla concorrenza - I

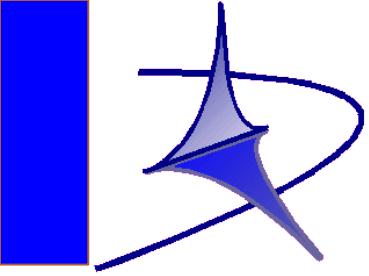


Processes



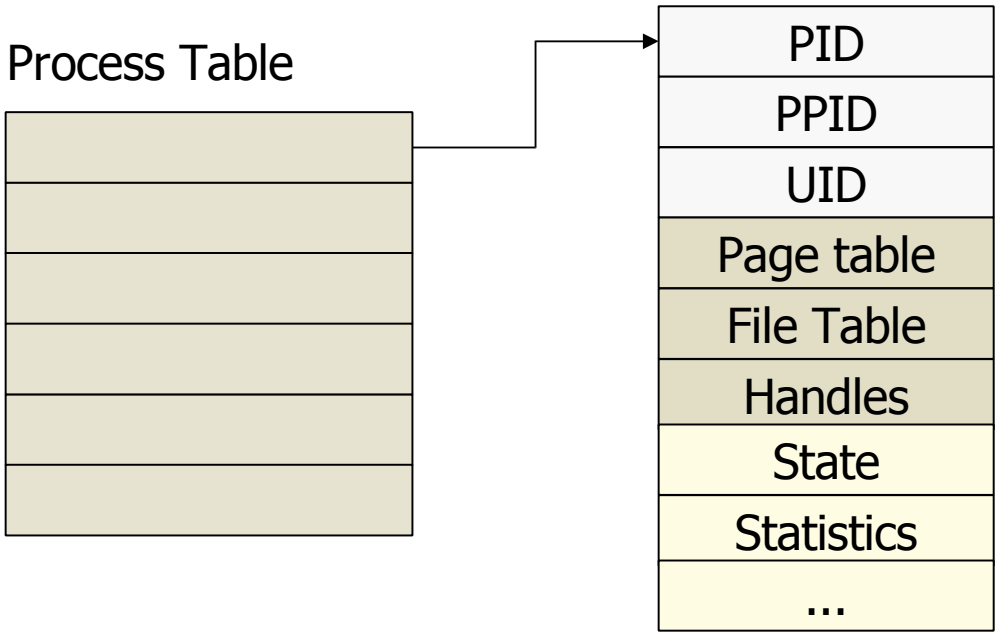
Process

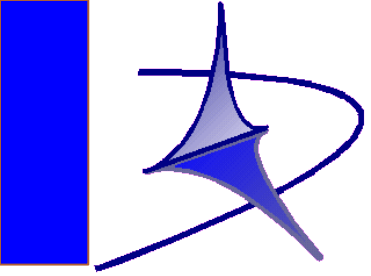
- The fundamental concept in any operating system is the “process”
  - A process is an executing program
  - An OS can execute many processes at the same time (concurrency)
  - Example: running a Text Editor and a Web Browser at the same time in the PC
- Processes have separate memory spaces
  - Each process is assigned a private memory space
  - One process is not allowed to read or write in the memory space of another process
  - If a process tries to access a memory location not in its space, an exception is raised (Segmentation fault), and the process is terminated
  - Two processes cannot directly share variables



Process Control Block

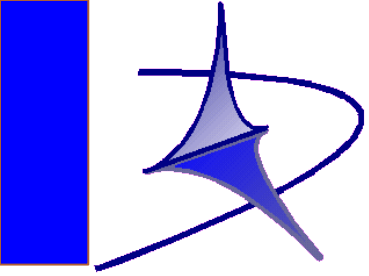
- It contains all the data concerning one process
- All PCBs are stored in the Process Table



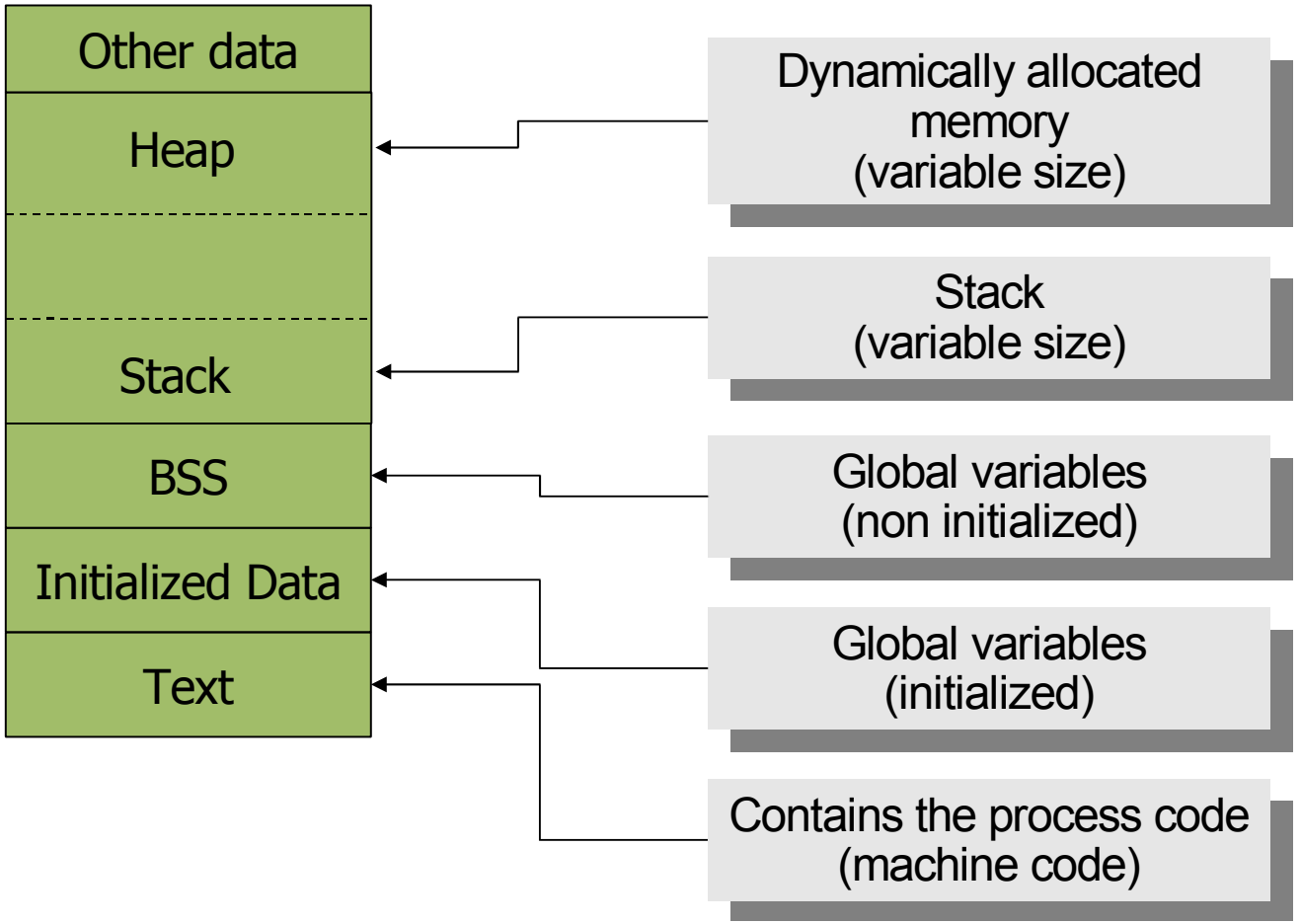


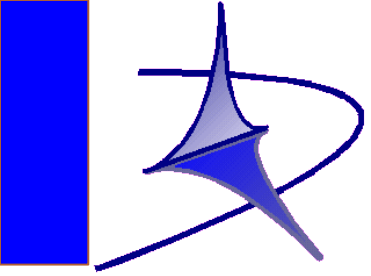
The role of PCB

- Virtually every routine in the OS will access the PCBs
  - The scheduler
  - The Virtual memory
  - The Virtual File System
  - Interrupt handlers (I/O devices)
  - ...
- It can only be accessed by the OS!
- The user can access some of the information in the PCB by using appropriate system calls
- The PCB is a critical point of any OS!



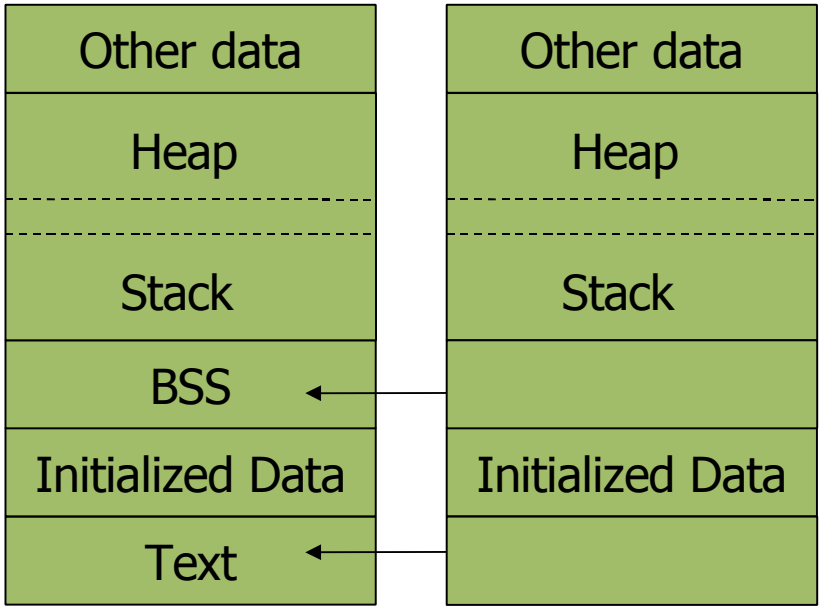
Memory layout of a Process

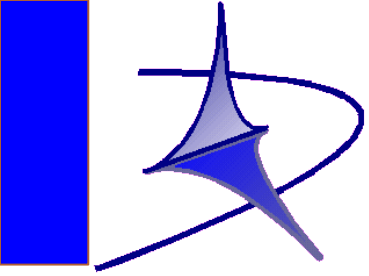




Memory protection

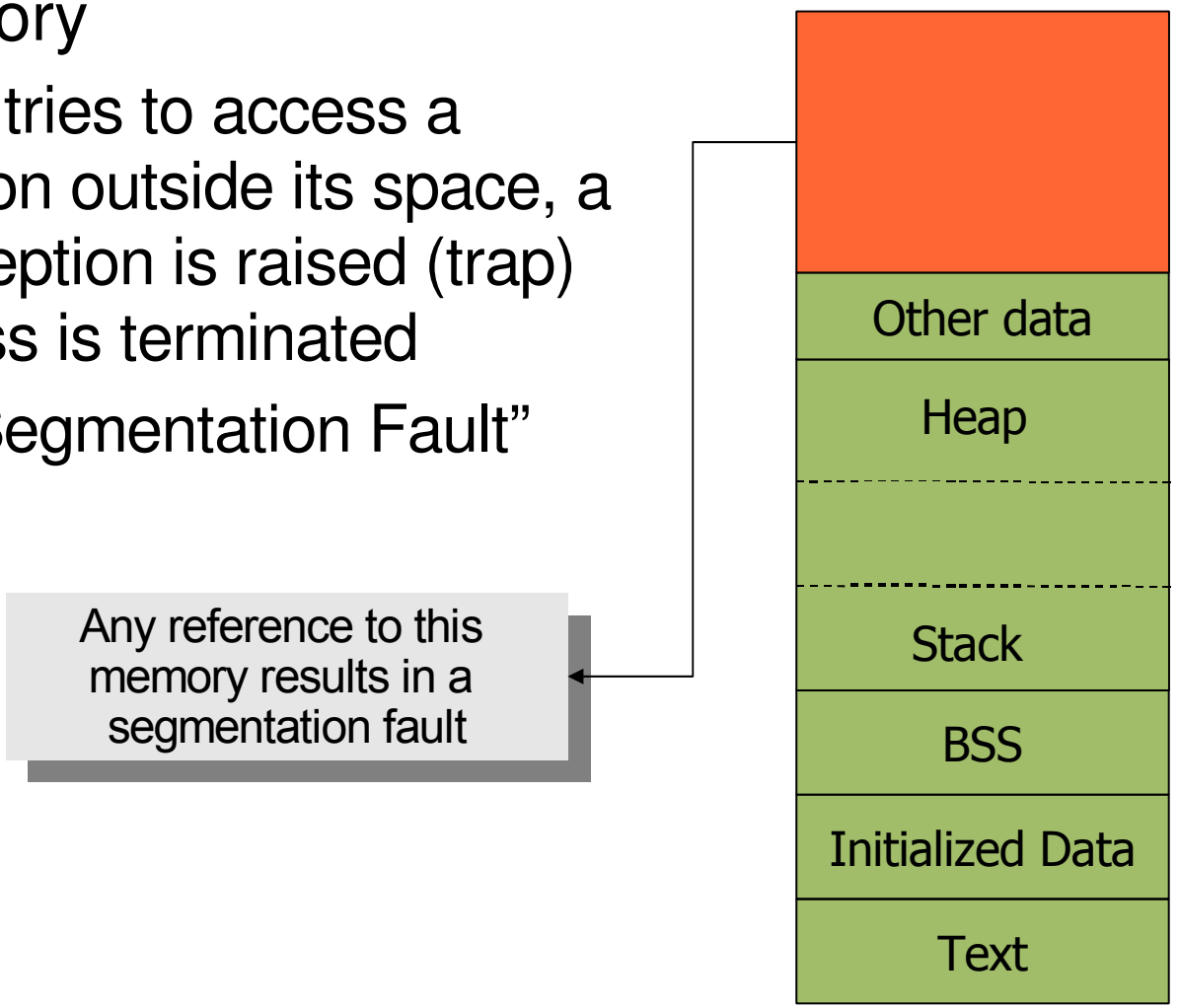
- Every process has its own memory space
  - Part of it is “private to the process”
  - Part of it can be shared with other processes
  - For examples: two processes that are instances of the same program will probably share the TEXT part
  - If two processes want to communicate by shared memory, they can share a portion of the data segment

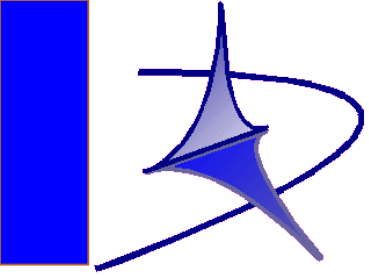




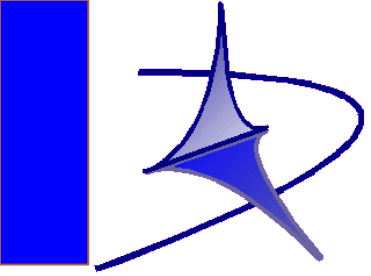
Memory Protection

- By default, two processes cannot share their memory
  - If one process tries to access a memory location outside its space, a processor exception is raised (trap) and the process is terminated
  - The famous “Segmentation Fault” error!!



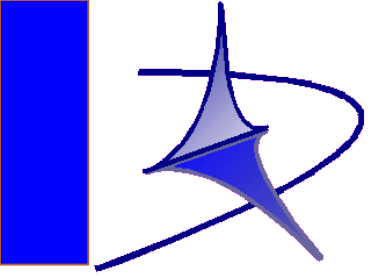


Processes and Threads



Processes

- We can distinguish two aspects in a process
- Resource Ownership
  - A process includes a virtual address space, a process image (code + data)
  - It is allocated a set of resources, like file descriptors, I/O channels, etc
- Scheduling/Execution
  - The execution of a process follows an ececution path, and generates a trace (sequence of internal states)
  - It has a state (ready, Running, etc.)
  - And scheduling parameters (priority, time left in the round, etc.)

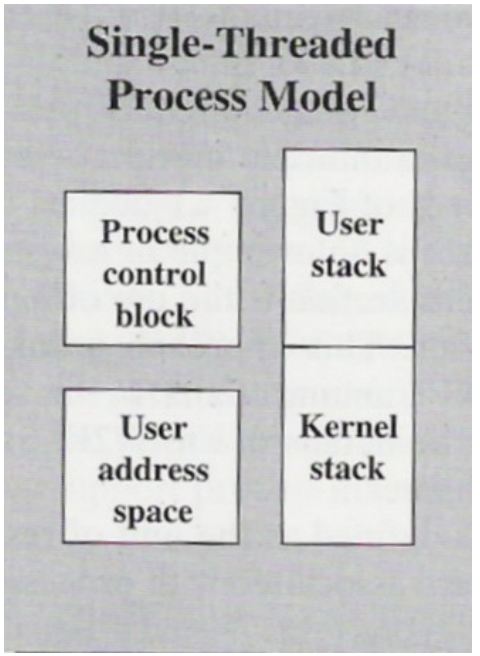


Multi-threading

- Many OS separate these aspects, by providing the concept of thread
- The process is the “resource owner”
- The thread is the “scheduling entity”
  - One process can consists of one or more *threads*
  - Threads are sometime called (improperly) lightweight processes
  - Therefore, on process can have many different (and concurrent) traces of execution!

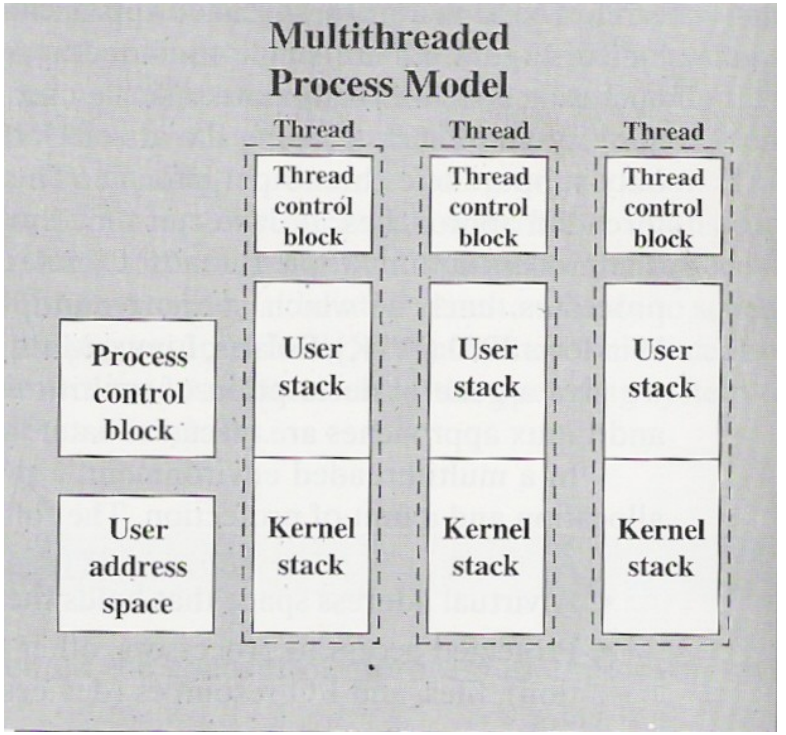
Single threaded Process Model

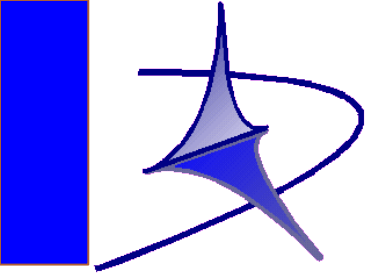
- In the single-threaded process model one process has only one thread
  - One address space
  - One stack
  - One PCB only



Multi-threaded process model

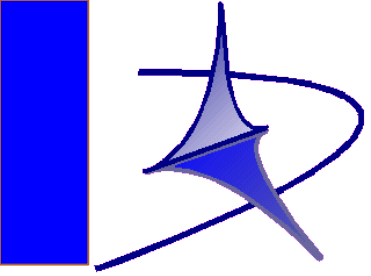
- In the multi-threaded process model each process can have many threads
  - One address space
  - One PCB
  - Many stacks
  - Many TCB (Thread Control blocks)
  - The threads are scheduled directly by the global scheduler





Threads

- Generally, processes do not share memory
  - To communicate between process, it is necessary to user OS primitives
  - Process switch is more complex because we have to change address space
- Two threads in the same process share the same address space
  - They can access the same variables in memory
  - Communication between threads is simpler
  - Thread switch has less overhead

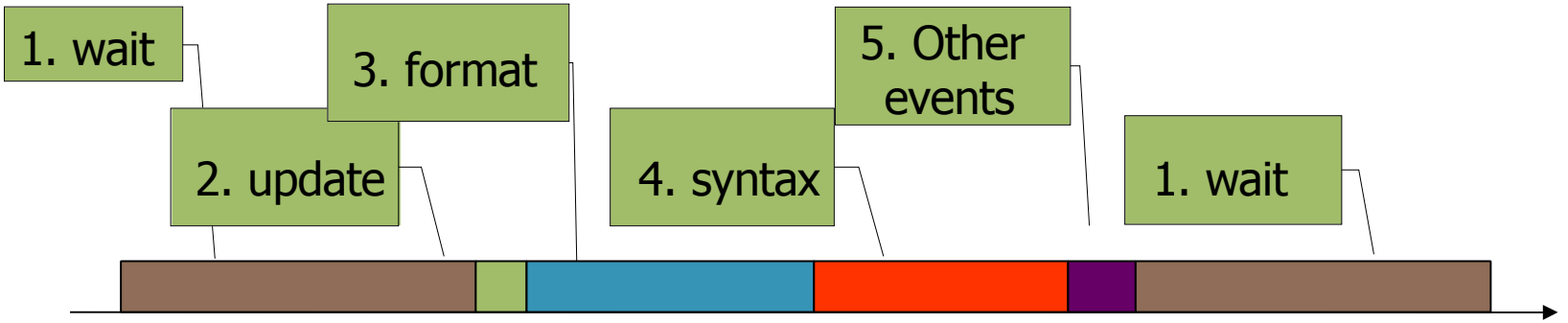


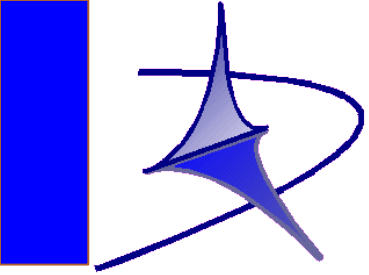
Processes vs. Threads

- Processes are mainly used to compete for some resource
  - For example, two different users run two separate applications that need to print a file
  - The printer is a shared resource, the two processes compete for the printer
- Threads are mainly used to collaborate to some goal
  - For example, one complex calculation can be split in two parallel phases, each thread does one phase
  - In a multi-processor machine the two threads go in parallel and the calculation becomes faster

Example - I

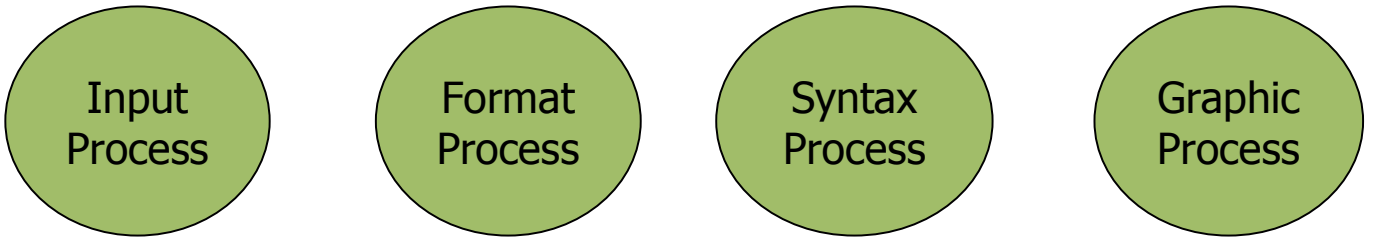
- Consider a Word Processor application
- Main cycle
  1. Wait for input from the keyboard
  2. Update the document
  3. Format the document
  4. Check for syntax errors
  5. Check for other events (i.e. temporary save)
  6. Return to 1
- One single process would be a waste of time!

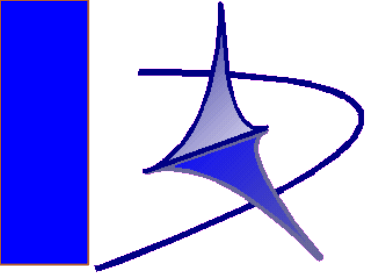




Example - II

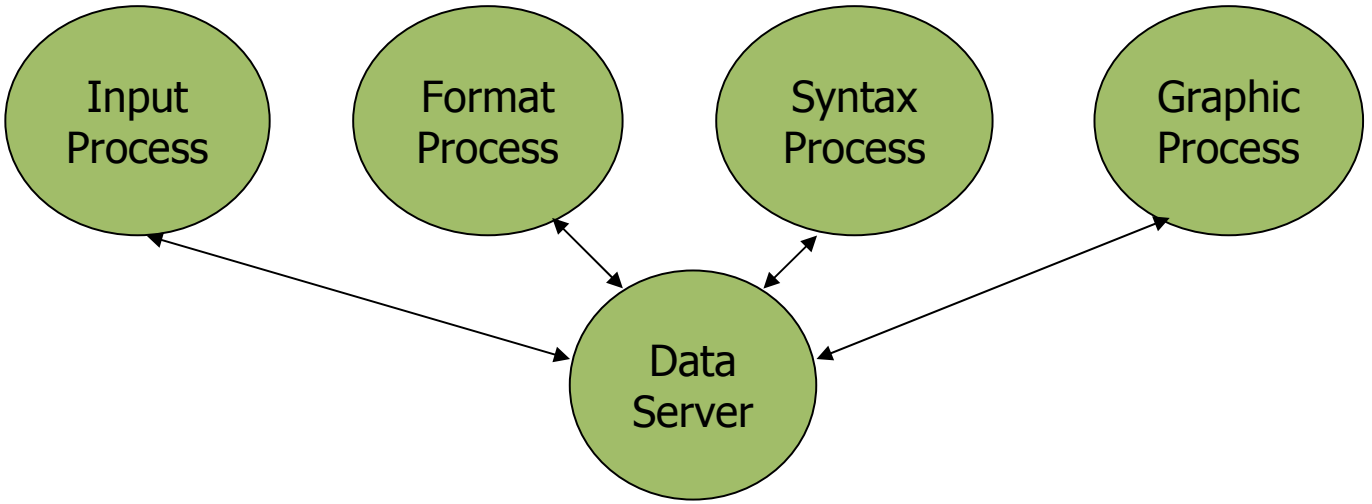
- Problems
  - Most of the time, the program waits for input
    - Idea, while waiting we could perform some other task
  - Activities 3 and 4 (formatting and syntax checking) are very time consuming
    - Idea: let's do them while waiting for input
- Solution with multiple processes
  - One process waits for input
  - Another process periodically formats the document
  - A third process periodically performs a syntax checking
  - A fourth process visualize the document

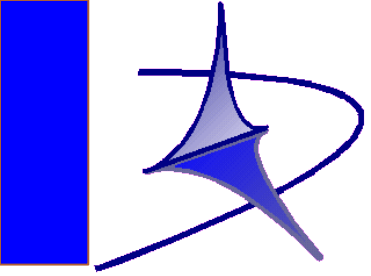




Example - III

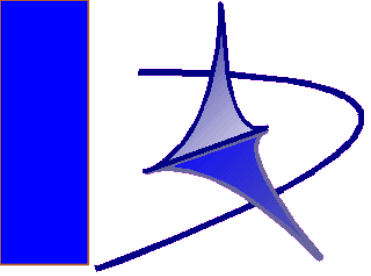
- Problem with multiple processes
  - All processes needs to access the same data structure, the document
  - Which process holds the data structure?
  - Solution 1: message passing
    - A dedicated process holds the data, all the others communicate with it to read/update the data
    - Very inefficient!





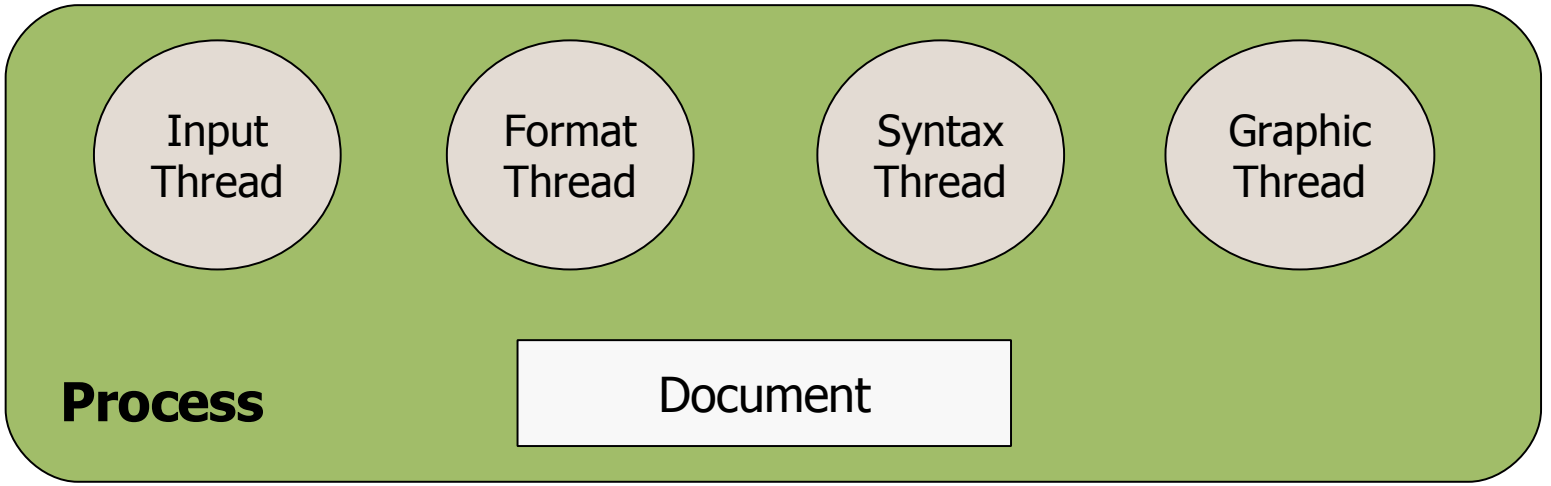
Example - IV

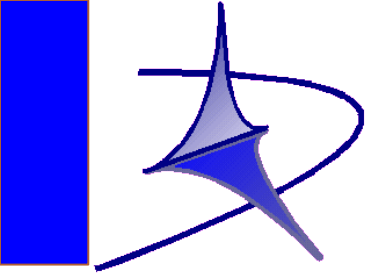
- Another solution...
  - Solution 2: shared memory
    - One process holds the data and makes that part of its memory shareable with the others
  - Still not very efficient:
    - We have a lot of process switches
    - Memory handling becomes very complex



Why using threads

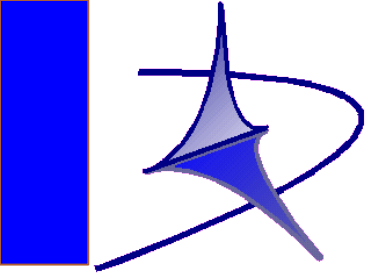
- Speed of creation
  - Creating a thread takes far less time than creating a process
- Speed of switching
  - Thread switch is faster than process switch
- Shared memory
  - Threads of the same process run in the same memory space
  - They can naturally access the same data!





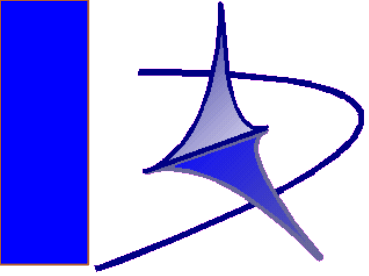
Threads support in OS

- Different OS implement threads in different ways
  - Some OS supports directly only processes
    - Threads are implemented as “special processes”
  - Some OS supports only threads
    - Processes are threads’ groups
  - Some OS natively supports both concepts
    - For example Windows NT
- In Real-Time Operating Systems
  - Depending on the size and type of system we can have both threads and processes or only threads
  - For efficiency reasons, most RTOS only support
    - 1 process
    - Many threads inside the process
    - All threads share the same memory
  - Examples are RTAI, RT-Linux, Shark, some version of VxWorks, QNX, etc.

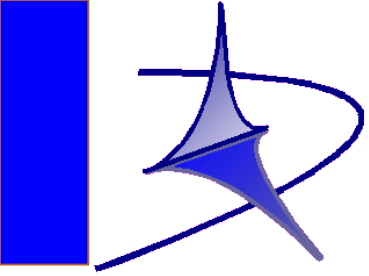


Summary

- Important concepts
  - Process: provides the abstraction of memory space
  - Threads: provide the abstraction of execution trace
  - The scheduler manages threads!
- Processes do not normally share memory
- Two threads of the same process share memory
- We need to explore all the different ways in which two threads can communicate
  - Shared memory
  - Message passing
- In the next section we will only refer to threads

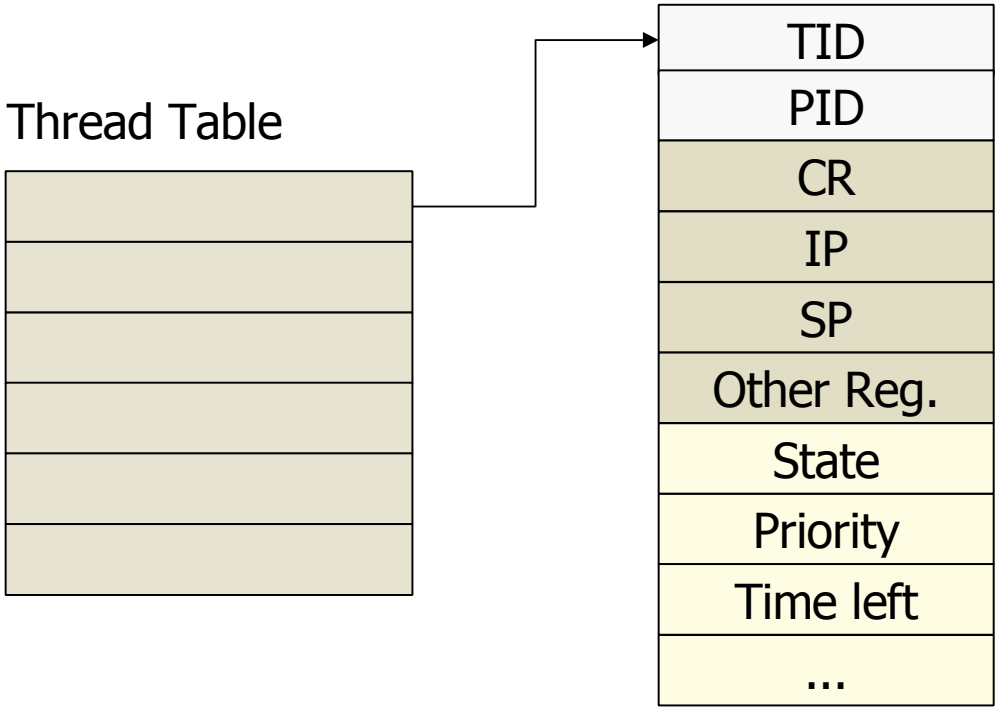


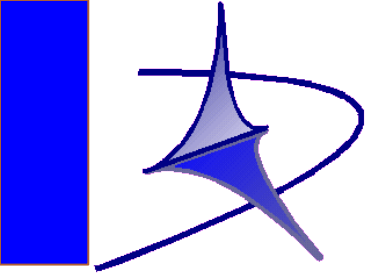
Scheduling and context switch



The thread control block

- In a OS that supports threads
  - Each thread is assigned a TCB (Thread Control Block)
  - The PCB holds mainly information about memory
  - The TCB holds information about the state of the thread





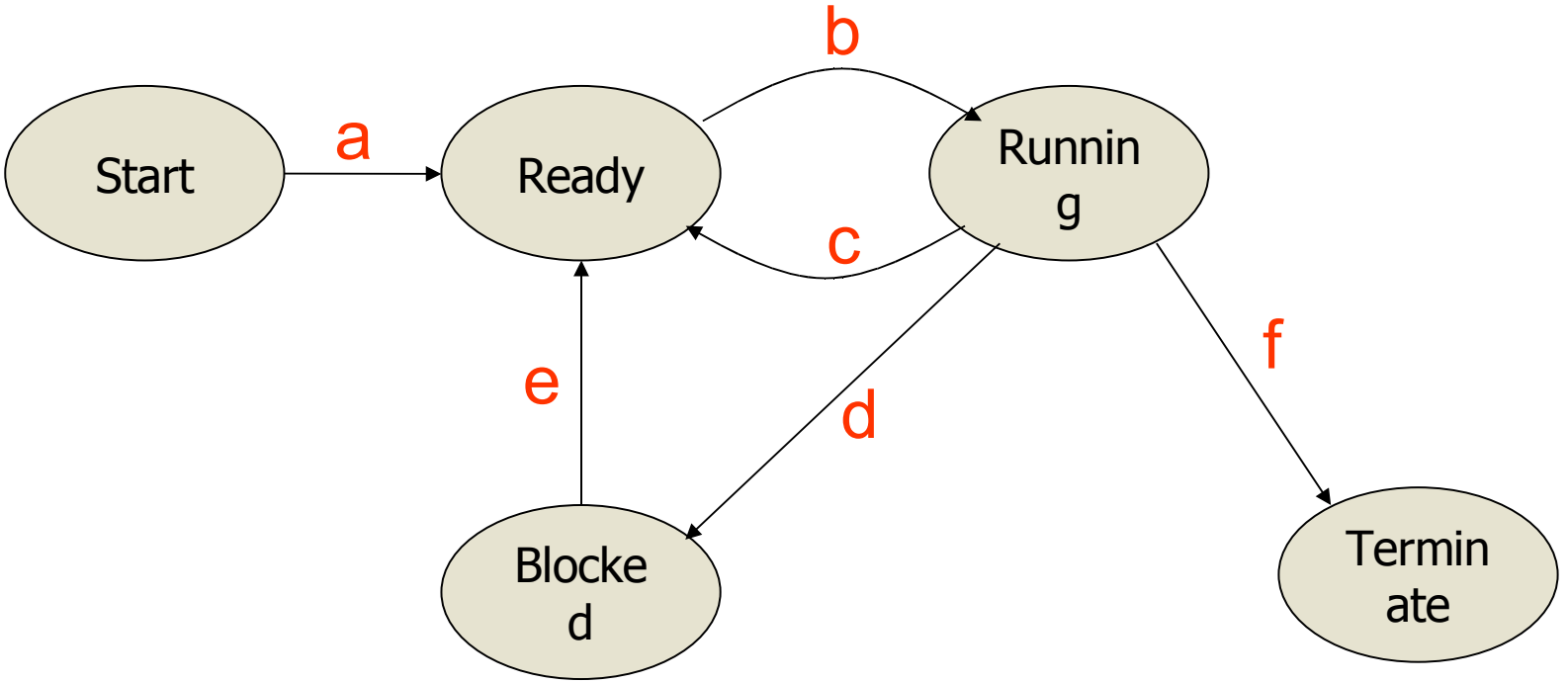
Thread states

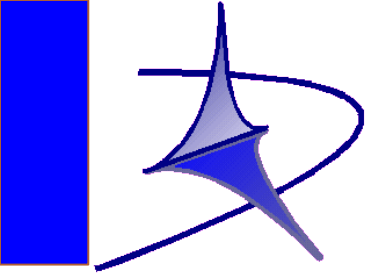
- The OS can execute many threads at the same time

- Each thread, during its lifetime can be in one of the following states
  - Starting (the thread is being created)
  - Ready (the thread is ready to be executed)
  - Executing (the thread is executing)
  - Blocked (the thread is waiting on a condition)
  - Terminating (the thread is about to terminate)

Thread states

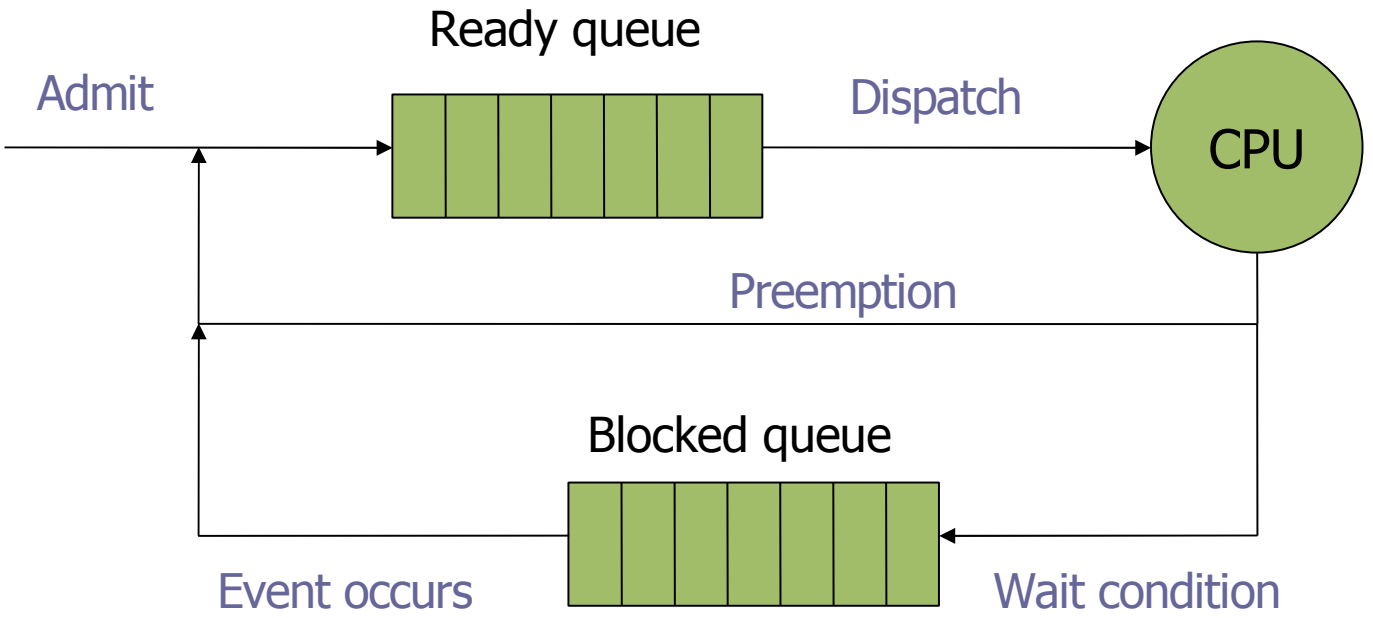
a)	Creation	The thread is created
b)	Dispatch	The thread is selected to execute
c)	Preemption	The thread leaves the processor
d)	Wait on condition	The thread is blocked on a condition
e)	Condition true	The thread is unblocked
f)	Exit	The thread terminates



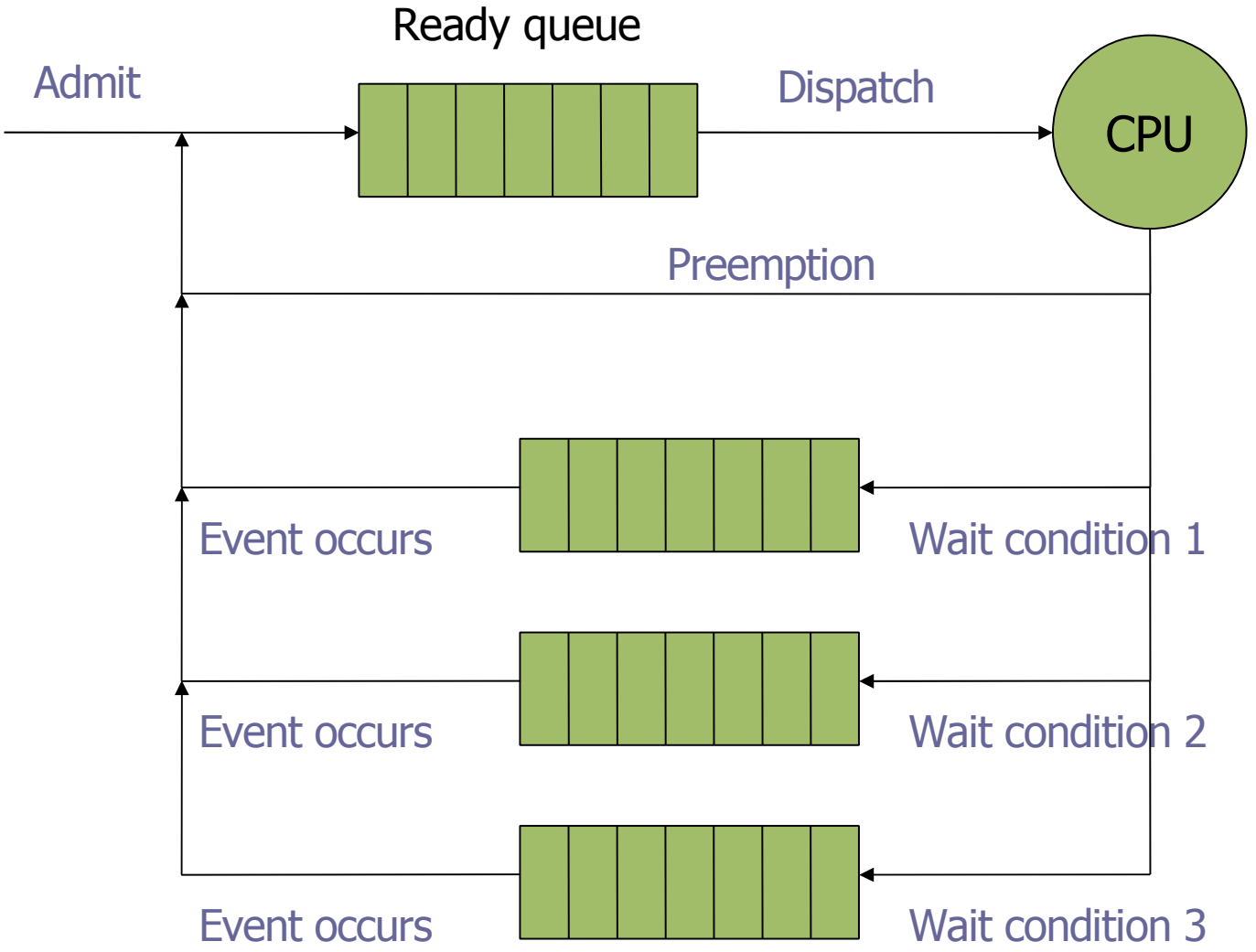


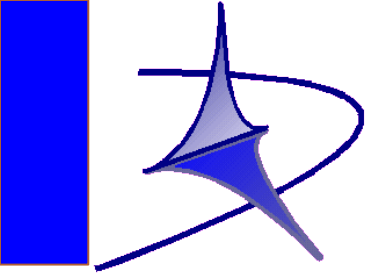
Thread queues

- Single processor



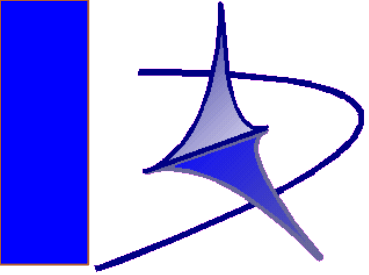
Multiple blocking queues





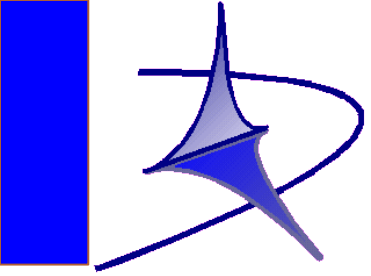
Modes of operation (revised)

- Every modern processor supports at least 2 modes of operation
  - User
  - Supervisor
  - The Control Register (CR) contains one bit that tells us in which mode the processor is running
- Operating system routines run in supervisor mode
  - They need to operate freely on every part of the hardware with no restriction
  - User code runs into user mode
- Mode switch
  - Every time we go from user to supervisor mode or viceversa



Mode switch

- It can happen in one of the following cases
  - Interrupts or traps
    - In this case, before calling the interrupt handler, the processor goes in supervisor mode and disables interrupts
    - Traps are interrupts that are raised when a critical error occurs (for example, division by zero, or page fault)
    - Returning from the interrupt restores the previous mode
  - Invoking a special instruction
    - In the Intel family, it is the INT instruction
    - This instruction is similar to an interrupt
    - It takes a number that identifies a “service”
    - All OS calls are invoked by calling INT
    - Returning from the handler restores the previous mode



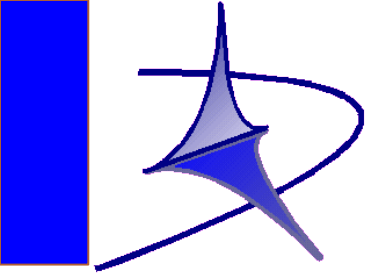
Example of system call

```
int fd,n;
char buff[100];

fd = open("Dummy.txt", O_RDONLY);
n =  read(fd, buff, 100);
```

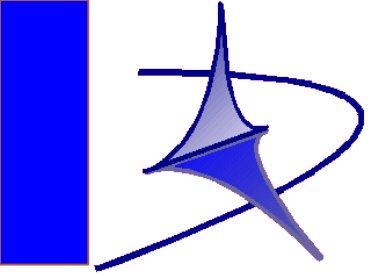
- The "open" system call can potentially block the thread!
- In that case we have a "context switch"

- Saves parameters on the stack
- Executes INT 20h
  1. Change to supervisor mode
  2. Save context
  3. Execute the function open
  4. Restores the context
  5. IRET
- Back to user mode
- Delete parameters from the stack



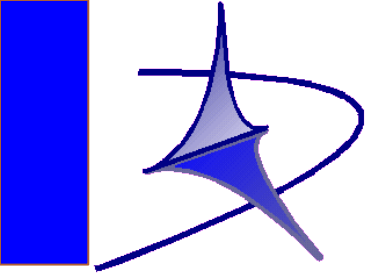
Context switch

- It happens when
  - The thread has been “preempted” by another higher priority thread
  - The thread blocks on some condition
  - In time-sharing systems, the thread has completed its “round” and it is the turn of some other thread
- We must be able to restore the thread later
  - Therefore we must save its state before switching to another thread



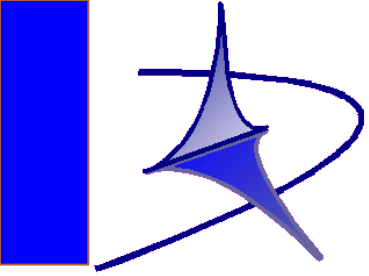
The “exec” pointer

- Every OS has one pointer (“exec”) to the TCB of the running thread
  - The status of the “exec” thread is RUNNING
- When a context switch occurs,
  - The status of the “exec” thread is changed to BLOCKING or READY
  - The scheduler is called
  - The scheduler selects another “exec” from the ready queue

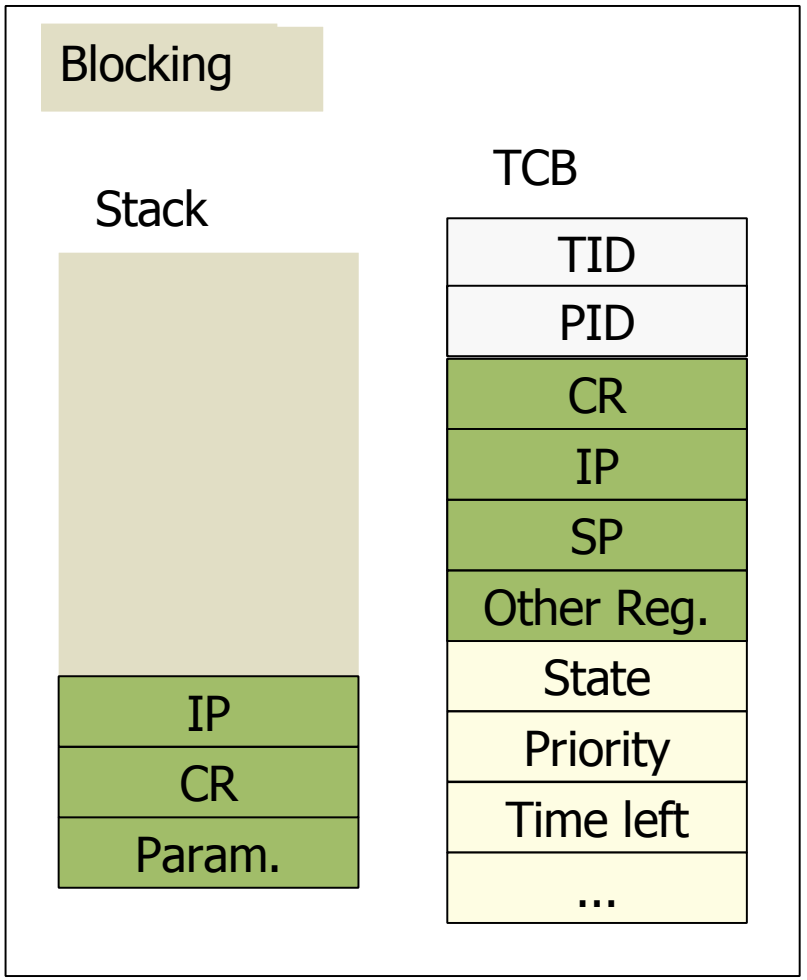


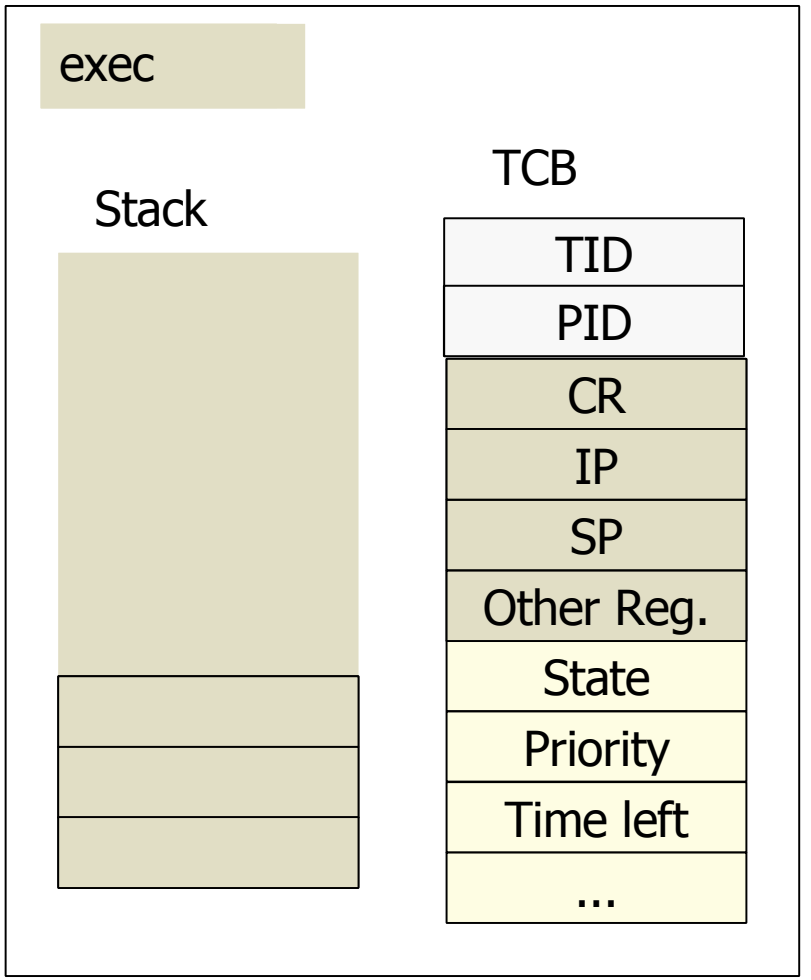
System call with context switch

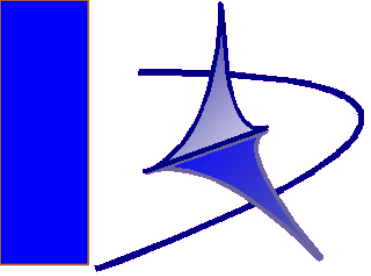
- Saves parameters on stack
- INT 20h
  - Change to supervisor mode
  - Save context in the TCB of “exec” (including SP)
  - Execute the code
    - The thread change status and goes into BLOCKING mode
  - Calls the scheduler
    - Moves “exec” into the blocking queue
    - Selects another thread to go into RUNNING mode
    - Now exec points to the new process
  - Restores the context of “exec” (including SP)
    - This changes the stack
  - IRET
    - Returns to where the new thread was interrupted



Stacks

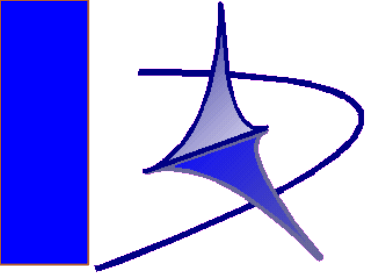

Blocking
Stack
TCB
TID
PID
CR
IP
SP
Other Reg.
State
Priority
Time left
...
IP
CR
Param.


exec
Stack
TCB
TID
PID
CR
IP
SP
Other Reg.
State
Priority
Time left
...



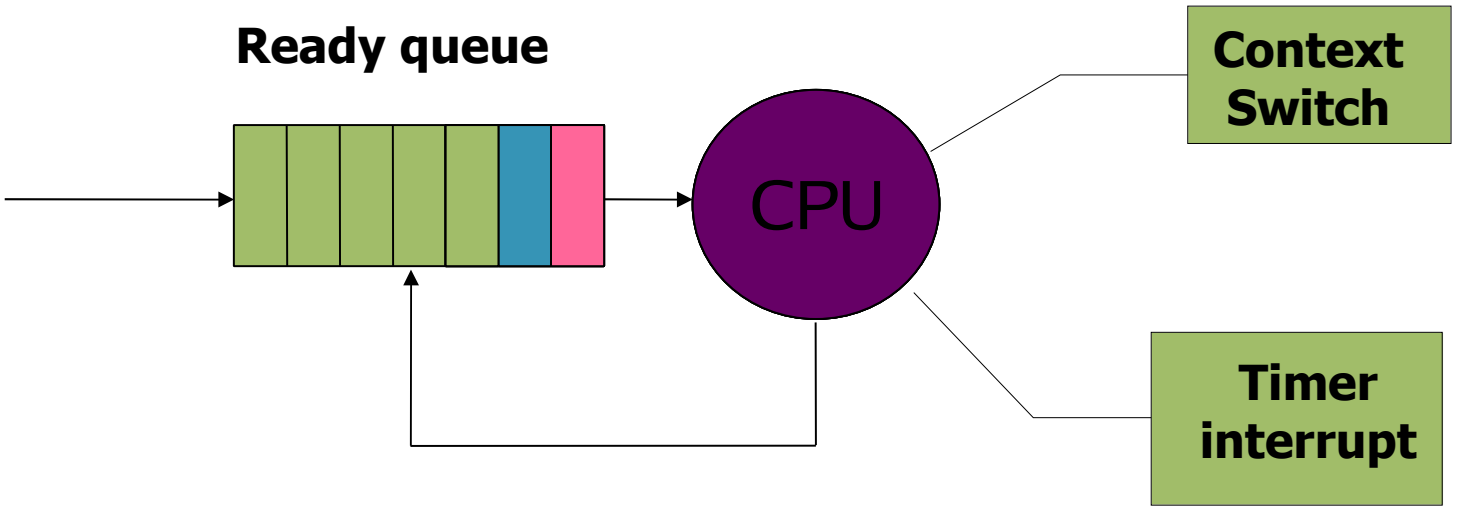
Context switch

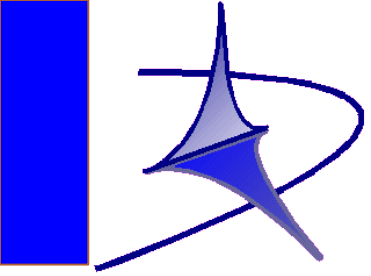
- This is only an example
  - Every OS has little variations on the same theme
  - For example, in most cases, registers are saved on the stack, not on the TCB
- You can try to look into some real OS
  - Linux
  - Free BSD
  - Shark (http://shark.sssup.it)
  - Every OS is different!



Time sharing systems

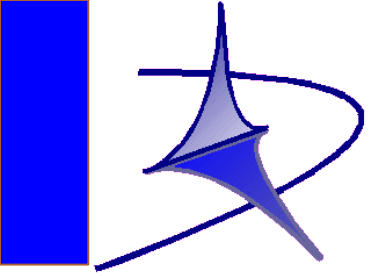
- In time sharing systems,
  - Every thread can execute for maximum one round
    - For example, 10msec
  - At the end of the round, the processor is given to another thread





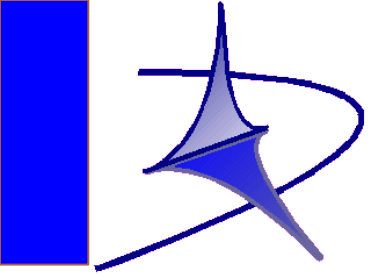
Interrupt with context switch

- It is very similar to the INT with context switch
  - An interrupt arrives
  - Change to supervisor mode
  - Save CR and IP
  - Save processor context
  - Execute the interrupt handler
  - Call the scheduler
    - This may change the “exec” pointer
  - IRET



Causes for a context switch

- A context switch can be
  - Voluntary: the thread calls a blocking primitive, i.e. it executes an INT
    - For example, by calling a read() on a blocking device
  - Non-voluntary: an interrupt arrives that causes the context switch
    - It can be the timer interrupt , in time-sharing systems
    - It can be an I/O device which unblocks a blocked process with a higher priority
- Context switch and mode switch
  - Every context switch implies a mode switch
  - Not every mode switch implies a context switch



Esercizio

- Considerate il seguente task

```
void *threadA(void *arg)
{
        int i;
        double s = *((double *) arg);
        double vect[3];
        for (i=0; i<3; i++) vect[i] = 0;
        while (1) {
                multiply(vect);
                if (length(vect) >s)
                        normalize(vect);
                task_endcycle();
        }
}
```

Ipotesi di lavoro

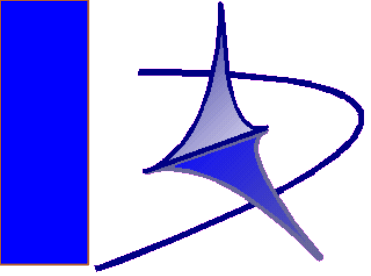
- processore a 32 bit
- Int = 4 bytes
- Double = 8 bytes
- Char = 1 byte

```
double mat[3][3];

void multiply(double v[])
{
    int i,j;
    double ris[3];
    for(i=0; i<3; i++) {
        ris[i] = 0;
        for (j=0; j<3; j++) ris[i] += mat[i][j] * v[i];
    }
    for (i=0; i<3; i++) v[i] = ris[i];
    return;
}

double length(double v[])
{
   return sqrt(v[0]*v[0] + v[1]*v[1] + v[2]*v[2]);
}

void normalize(double v[])
{
    int i;
    double l = length(v);
    for (i=0; i<3; i++) v[i] /= l;
    return;
}
```



Esercizio

- Domande:
  - Disegnare la struttura dello stack e calcolare la sua dimensione in byte
  - Descrivere cosa succede quando arriva una interruzione
  - In un sistema time sharing, descrivere cosa succede quando il quanto di esecuzione del thread è terminato