Operating Systems

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What is an Operating System

- **Operating System handles**
  - **Memory Addressing & Management**
  - **Interrupt & Exception Handling**
  - **Process & Task Management**
  - **File System**
  - **Timing**
  - **Process Scheduling & Synchronization**
- **Examples of Operating Systems**
  - **RTOS – Real-Time Operating System**
  - **Single-user, Single-task: example PalmOS**
  - **Single-user, Multi-task: MS Windows and MacOS**
  - **Multi-user, Multi-task: UNIX**

Real-Time Operating Systems

- **Operating systems come in two flavors, real-time versus non real-time**
- **The difference between the two is characterized by the consequences which result if functional correctness and timing parameters are not met in the case of real-time operating systems**
- **Real-time operating systems themselves have two varieties, *soft real-time* systems and *hard real-time* systems**
- **Examples of real-time systems:**
  - **Food processing**
  - **Engine Controls**
  - **Anti-lock breaking systems**

Soft versus Hard Real-Time

- In a ***soft real-time*** **system, tasks are completed as fast as possible without having to be completed within a specified timeframe**
- **In a** ***hard real-time*** **operating system however, not only must tasks be completed within the specified timeframe, but they must also be completed correctly**

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Foreground/Background Systems

- **The simplest forms of a non real-time operating systems are comprised of** ***super-loops*** **and are called** ***foreground/background*** **systems**
- **Essentially this is an application consisting of an infinite loop which calls functions as may be necessary to perform various tasks**
- **The functions which are called to perform these tasks are** ***background functions*****, and are executed at the** ***task-level*** **of the operating system**

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F/B Systems

- **On the other hand, processes which must be handled in a timely fashion such as interrupts are** ***foreground processes*** **and are executed at** ***interrupt-level***
- **Most microcontroller based embedded systems, such as microwaves and washing machines are foreground/background systems**

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Definitions

- The *Critical Section* of a code is code which needs to be executed indivisibly and without interruption. The operating system usually disables interrupts before entering a critical section, and enables them again after its completion
- A *resource* is any object used by a task. It can be anything from an I/O pin to a data structure
- *Shared resources* are resources that can be used by more than one task. However, to prevent data corruption, each task needs to obtain exclusive access to the shared resource through a mechanism called *mutual exclusion*

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Definitions

- A *task*, also referred to as a *thread*, is an independent section of a program complete with its own stack and CPU register space
- Each task is assigned a priority, and is always placed in one of *dormant, ready, running, waiting,* or *ISR* states
- A *dormant* task is a task which is available in memory but is not submitted to the kernel for execution

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Definitions

- A task is deemed *ready* when it is available for execution but its priority is less than the current task priority of the system
- Consequently, a task is *running* when its current priority is met and the CPU starts to execute it
- A task is considered in *wait* mode when it is waiting for a resource to become available

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Definitions

- And finally a task is considered *interrupted* when the CPU is in the process of servicing an interrupt
- If a task needs to be put on hold so that another task can execute, a context switch or a task switch occurs
- In this event, the processor saves the task's context (CPU registers) usually into a secondary storage area, and loads the new task's context from the same

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Kernels

- The engine within the operating system which is in charge of handling tasks and communications between them is called the *kernel*
- A real-time kernel for instance manages breaking up an application into a series of tasks to be performed in a *multi-tasking* fashion
- Multitasking systems maximize the usage of a CPU and allow programmers to easily manage the complexities associated with real-time systems

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Kernels

- Kernels come in two flavors, *pre-emptive* kernels, and *non pre-emptive* kernels
- *Pre-emptive kernels* are used when system response times are of critical concern, and as such most real-time operating systems are pre-emptive in nature
- Non pre-emptive kernels require that the tasks themselves give up using the CPU, and therefore this is a process which must be performed frequently

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Non Pre-emptive Kernels

- One advantage of using a non-pre-emptive system is that interrupt latencies are low
- Another advantage is that programmers can use non re-entrant functions within their code
- This is because each task runs to completion before another task executes
- By the same token, there is less headache associated with the management of shared resources

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Non Pre-emptive Kernels

- The biggest disadvantage of a non pre-emptive kernel is task responsiveness. This is because a high priority task is made to wait until the current task (even if of a lower priority) has finished execution
- Interrupts can preempt a task, however even if a higher priority task is scheduled within an interrupt service routine, it still cannot run until the CPU operation is relinquished by the current task

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Pre-emptive Kernels

- As mentioned earlier, most real-time operating systems are pre-emptive
- This is because the execution of a higher priority task is deterministic
- However, programs written to run on a pre-emptive system must only use re-entrant functions in order to guarantee that both a low and a high priority task can use the same function without fear of data corruption

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Pre-emptive Kernels

- One important difference between pre-emptive and non pre-emptive systems is that upon executing an interrupt service routine, the pre-emptive system always runs the highest ready task (not necessarily the task which was interrupted), whereas a non pre-emptive system returns to the task which was interrupted

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Reentrancy

- Not just a dirty word!
- *Reentrant functions* are critical to the proper operation of a preemptive OS
- A reentrant function can be used by more than one task without fear of data corruption
- Also, a reentrant function can be interrupted at any point and restarted at a different time without loss of data
- Reentrancy is achieved by using local data, or by protecting global data

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Priority

- Tasks need a mechanism by which they can be prioritized
- This is done at the kernel level and at compile time by the programmer
- Task priorities can be *static*, in that the priority of a task does not change for the duration of the application's execution
- On the other hand, priorities are deemed *dynamic* if task priorities can be changed at runtime

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Priority

- The advantage to being able to change priority during runtime is that one can avoid occurrence of what is known as Priority Inversion
- *Priority inversion* occurs when the priority of a higher priority task is virtually reduced to the priority of a lower priority task
- This happens specially when the higher priority task is waiting for a resource which is in use by a lower priority task

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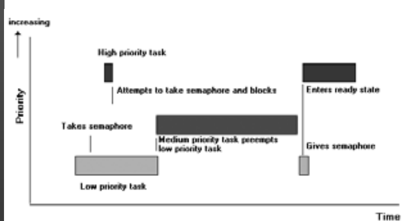
Priority Inversion



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Mutual Exclusion (mutex)

- The easiest way for tasks to communicate between each other is through shared data structures
- However, while exchanging data through shared resources makes communication easy, it poses a special challenge when more than one process may change a shared resource at the same time
- Therefore it is critical to ensure that a task has exclusive access to a shared resource before it changes any data
- **Mutex**

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Mutex

- **The most important mechanism which must be provided at the CPU level in order to achieve mutual exclusivity is a *test-and-set-lock* (TSL) instruction**
- **Test-and-set-lock instructions come in various mnemonics and operations, but they all perform a single critical task: to allow an atomic operation which both tests (checks) a resource and sets (switches) its value in one operation**

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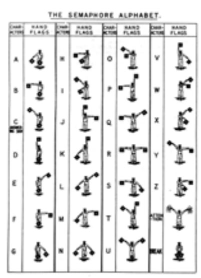
Semaphores

- **There are other operations which can also be employed, such as disabling interrupts, disabling scheduling, and using semaphores**
- **Semaphores are of great use in real-time kernels. They allow operations on shared resources, and allow tasks to synchronize their operations**



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Semaphores

- **A semaphore is basically a flag which signals the right to use a shared resource**
- **A *binary semaphore* is either set or not set which then allows a task to use or have to wait to use a shared resource**
- **A *counting semaphore* on the other hand allows for more complex scenarios**

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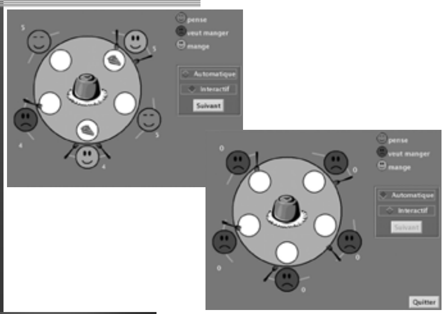
Dining Philosopher Problem



Scheduling

- A central piece of an operating system is the scheduler
- The scheduler maintains an overview of all tasks which are running or pending and decides which one to execute next
- There are many algorithms to determine which task to run next ranging from the simple *first-in-first-out* and *shortest-job-first*, to more complex priority-based algorithms found on real-time operating systems

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Scheduling

- The oldest, simplest, fairest, and most widely used scheduling algorithm is round robin, where each process is assigned a time interval during which it is allowed to run
- Round robin scheduling makes the implicit assumption that all tasks are of the same priority.
- Priority based scheduling on the other hand takes the different priorities of tasks into account during scheduling, and changes them dynamically as may be necessary to increase system throughput

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Deadlocks

- Since tasks share resources, a *deadlock* can occur if there is an interdependency between two tasks and their respectively locked resources
- Four conditions must be met for a deadlock to occur:
  - Mutual exclusion – a resource is already assigned
  - Hold and Wait – a process which has already been granted resources can seek new ones
  - No preemptive condition – resources previously granted cannot be forcibly taken away
  - Circular wait condition – there is a circular condition of at least two processes, each waiting for a resource held by the other one

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Deadlock Recovery

- There are various means to recover from deadlocks
  - Recover by preemption: temporarily take away a resource from its current owner so that another process can continue executing. Not easy to do.
  - Recover through rollback: processes which hold the required resource are rolled back to a point in time before it requested the resource. All work done since the last *checkpoint* is lost.
  - Recover through killing the process: the simplest and crudest way of recovery

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Interrupts

- Interrupts are primarily hardware mechanisms used to notify the processor that an asynchronous even has occurred
- When an interrupt occurs, the CPU saves the current context and jumps to the Interrupt Service Routine (ISR)
- Microprocessors can individually enable or disable interrupts, and assign different interrupt priorities to individual interrupt sources
- On a real-time system, interrupts should be disabled for as little as possible

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Interrupt Latency

- By far one of the most important characteristics of a real-time kernel is the amount of time for which interrupts are disabled
- The longer interrupts are disabled, the longer the *interrupt latency* of the system
- Interrupt latency is the maximum time interrupts are disabled, plus the time it takes to start executing the first instruction of the ISR

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Memory Management

- Parkinson's Law:

  Programs expand to fill the memory available to hold them!
- The part of the operating system which handles memory management is referred to as the *Memory Manager*
- The section of the processor which handles memory management is referred to as the *Memory Management Unit (MMU)*

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Memory Management

- The memory management system is designed to make memory resources available to processes safely and efficiently
- The term *memory management* refers to the rules that govern mappings between the physical and virtual memory
- We are primarily concerned with two types of Memory Management:
  - Memory management over the *Logical* (virtual) address space
  - Memory management over the *Physical* address space (main memory)

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Memory Management

- The memory management system is designed to make memory resources available safely and efficiently among threads and processes:
- It provides a complete address space for each process, protected from all other processes.
- It enables program size to be larger than physical memory.
- It allows efficient sharing of memory between processes.

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Relocation

- Programs are *relocatable*, meaning that at run time the operating system will assign physical addresses to your program (relocate it) prior to loading it into the physical memory
- This also allows the operating system to swap the program out of memory and reload it at a different location at a later time
- Virtual Memory is essentially a technique which allows execution of a program which may not fit into the physical memory

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Relocation

- Therefore the Operating System fakes a program into thinking that there is more memory space than is physically available to it, and Virtual Address is translated into Physical address

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