Grain Size	Description	Synchronization Interval (Instructions)
Fine	Parallelism inherent in a single instruction stream.	<20
Medium	Parallel processing or multitasking within a single application	20-200
Coarse	Multiprocessing of concurrent processes in a multiprogramming environment	200-2000
Very Coarse	Distributed processing across network nodes to form a single computing environment	2000-1M
Independent	Multiple unrelated processes	not applicable

Synchronization Granularity and Processes

Fine-Grained Parallelism

- Represents a much more complex use of parallelism than is found in the use of threads
- Is a specialized and fragmented area with many different approaches

Master/Slave Architecture

- Key kernel functions always run on a particular processor
- Master is responsible for scheduling
- Slave sends service request to the master
- Is simple and requires little enhancement to a uniprocessor multiprogramming operating system
- Conflict resolution is simplified because one processor has control of all memory and I/O resources

Disadvantages:

- failure of master brings down whole system
- master can become a performance bottleneck

Thread Scheduling

- Thread execution is separated from the rest of the definition of a process
- An application can be a set of threads that cooperate and execute concurrently in the same address space
- On a uniprocessor, threads can be used as a program structuring aid and to overlap I/O with processing
- In a multiprocessor system threads can be used to exploit true parallelism in an application
- Dramatic gains in performance are possible in multi-processor systems
- Small differences in thread management and scheduling can have an impact on applications that require significant interaction among threads

Gang Scheduling

- Simultaneous scheduling of the threads that make up a single process

Benefits:
• synchronization blocking may be reduced, less process switching may be necessary, and performance will increase • scheduling overhead may be reduced

- Useful for medium-grained to fine-grained parallel applications whose performance severely degrades when any part of the application is not running while other parts are ready to run
- Also beneficial for any parallel application

Dynamic Scheduling

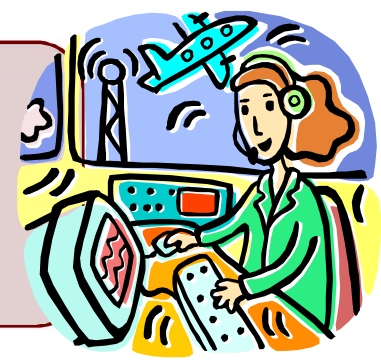
- For some applications it is possible to provide language and system tools that permit the number of threads in the process to be altered dynamically
  - this would allow the operating system to adjust the load to improve utilization
- Both the operating system and the application are involved in making scheduling decisions
- The scheduling responsibility of the operating system is primarily limited to processor allocation
- This approach is superior to gang scheduling or dedicated processor assignment for applications that can take advantage of it

Real-Time Systems

- The operating system, and in particular the scheduler, is perhaps the most important component

Examples:

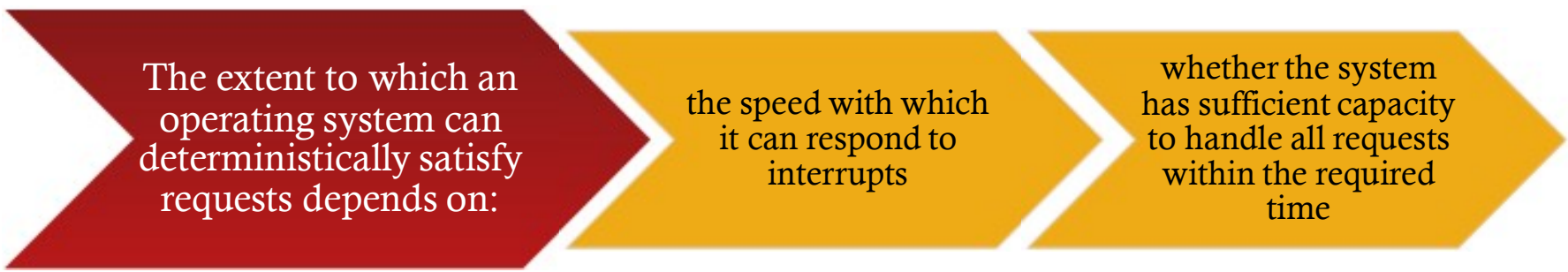
- control of laboratory experiments
- process control in industrial plants
- robotics
- air traffic control
- telecommunications
- military command and control systems



- Correctness of the system depends not only on the logical result of the computation but also on the time at which the results are produced
- Tasks or processes attempt to control or react to events that take place in the outside world
- These events occur in “real time” and tasks must be able to keep up with them

Determinism

- Concerned with how long an operating system delays before acknowledging an interrupt
- Operations are performed at fixed, predetermined times or within predetermined time intervals
  - when multiple processes are competing for resources and processor time, no system will be fully deterministic



Fail-Soft Operation

- A characteristic that refers to the ability of a system to fail in such a way as to preserve as much capability and data as possible
- Important aspect is stability
  - a real-time system is stable if the system will meet the deadlines of its most critical, highest-priority tasks even if some less critical task deadlines are not always met

Deadline Scheduling

- Real-time operating systems are designed with the objective of starting real-time tasks as rapidly as possible and emphasize rapid interrupt handling and task dispatching
- Real-time applications are generally not concerned with sheer speed but rather with completing (or starting) tasks at the most valuable times
- Priorities provide a crude tool and do not capture the requirement of completion (or initiation) at the most valuable time

Execution Profile of Five Aperiodic Tasks

Process	Arrival Time	Execution Time	Starting Deadline
A	10	20	110
B	20	20	20
C	40	20	50
D	50	20	90
E	60	20	70

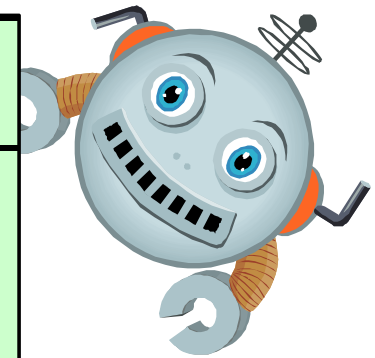
How to schedule these tasks such that start deadlines are met (or alternatively, the fewest deadlines are missed)?

- Using pre-emption?
- FCFS?
- Earliest deadline?
- Others?

Value of the RMS Upper Bound

If rate sum less than or equal upper bound, tasks are schedulable

n	$n(2^{1/n} - 1)$
1	1.0
2	0.828
3	0.779
4	0.756
5	0.743
6	0.734
•	•
•	•
•	•
∞	$\ln 2 \approx 0.693$



Earliest deadline first has upper bound of 1

RMS is still popular – why?