Lecture 7 – Real Time Systems (Sommerville Ch. 13)

Karl R. Wilcox
K.R.Wilcox@reading.ac.uk

The University of Reading

Objectives

- To explain the concept of a real-time system and why these systems are usually implemented as concurrent processes
- To describe a design process for real-time systems
- To explain the role of a real-time executive
- To introduce generic architectures for monitoring and control and data acquisition systems

Real-time systems

- Systems which monitor and control their environment
- Inevitably associated with hardware devices
  - Sensors: Collect data from the system environment
  - Actuators: Change (in some way) the system's environment
- Time is critical. Real-time systems MUST respond within specified times

Definition

- A real-time system is a software system where the correct functioning of the system depends on the results produced by the system and the time at which these results are produced
- A ‘soft’ real-time system is a system whose operation is degraded if results are not produced according to the specified timing requirements
- A ‘hard’ real-time system is a system whose operation is incorrect if results are not produced according to the timing specification

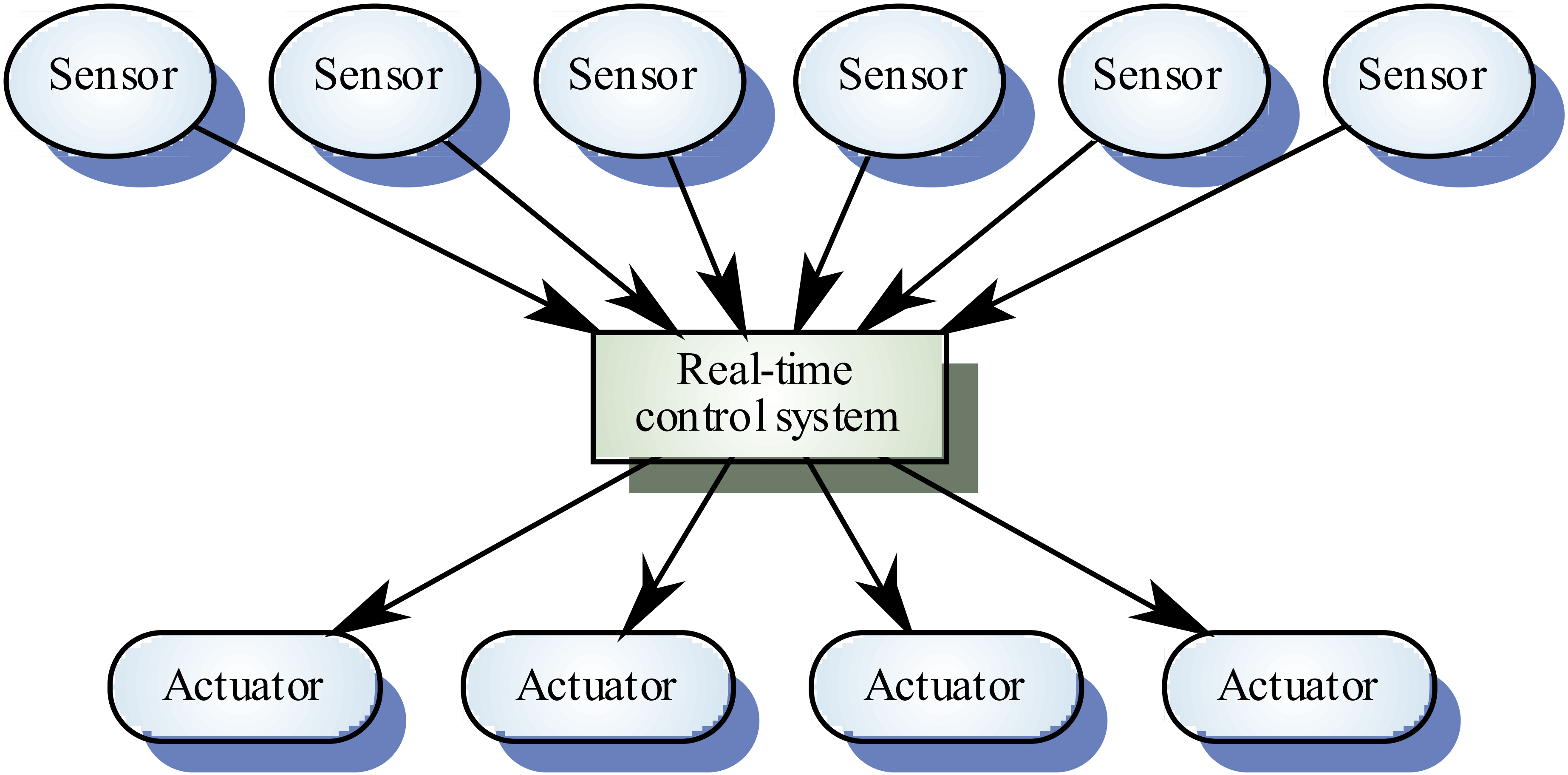
Stimulus/Response Systems

- Given a stimulus, the system must produce a response within a specified time
- Periodic stimuli. Stimuli which occur at predictable time intervals
  - For example, a temperature sensor may be polled 10 times per second
- Aperiodic stimuli. Stimuli which occur at unpredictable times
  - For example, a system power failure may trigger an interrupt which must be processed by the system

Architectural considerations

- Because of the need to respond to timing demands made by different stimuli/responses, the system architecture must allow for fast switching between stimulus handlers
- Timing demands of different stimuli are different so a simple sequential loop is not usually adequate
- Real-time systems are usually designed as cooperating processes with a real-time executive controlling these processes

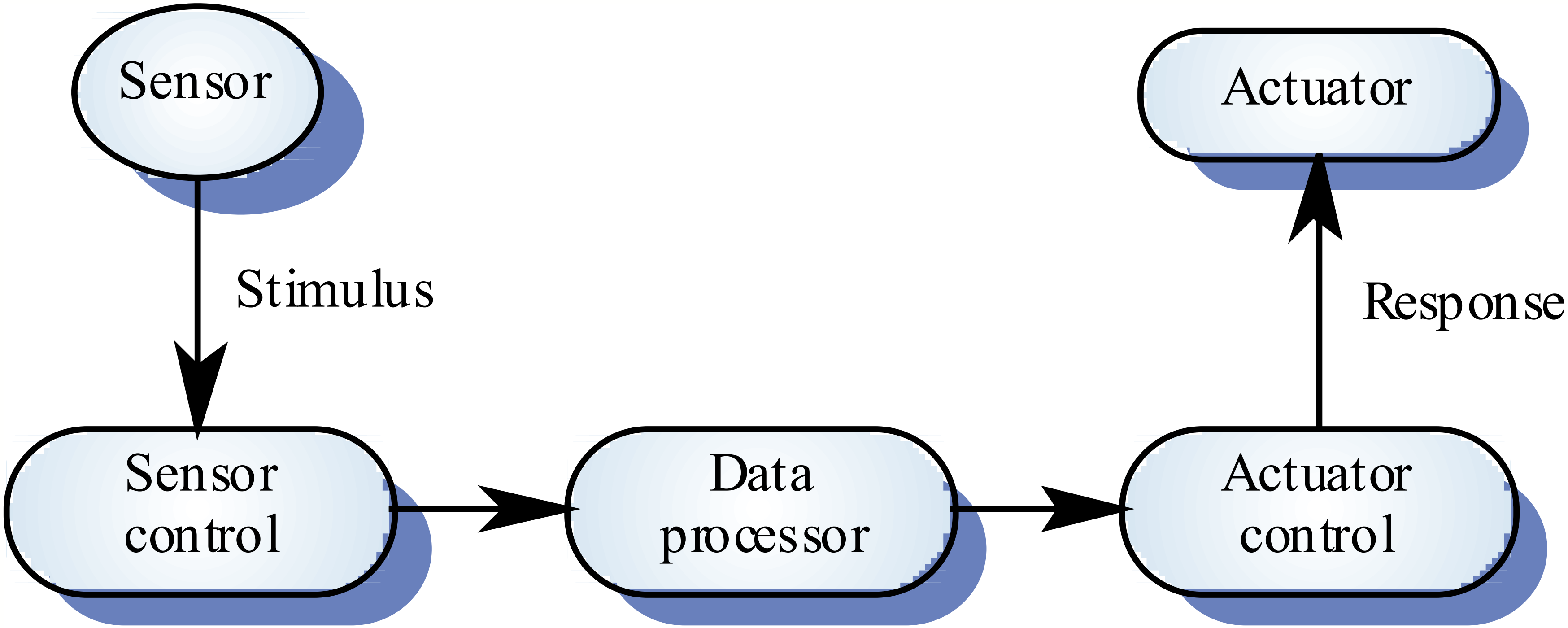
A real-time system model



System elements

- Sensors control processes
  - Collect information from sensors. May buffer information collected in response to a sensor stimulus
- Data processor
  - Carries out processing of collected information and computes the system response
- Actuator control
  - Generates control signals for the actuator

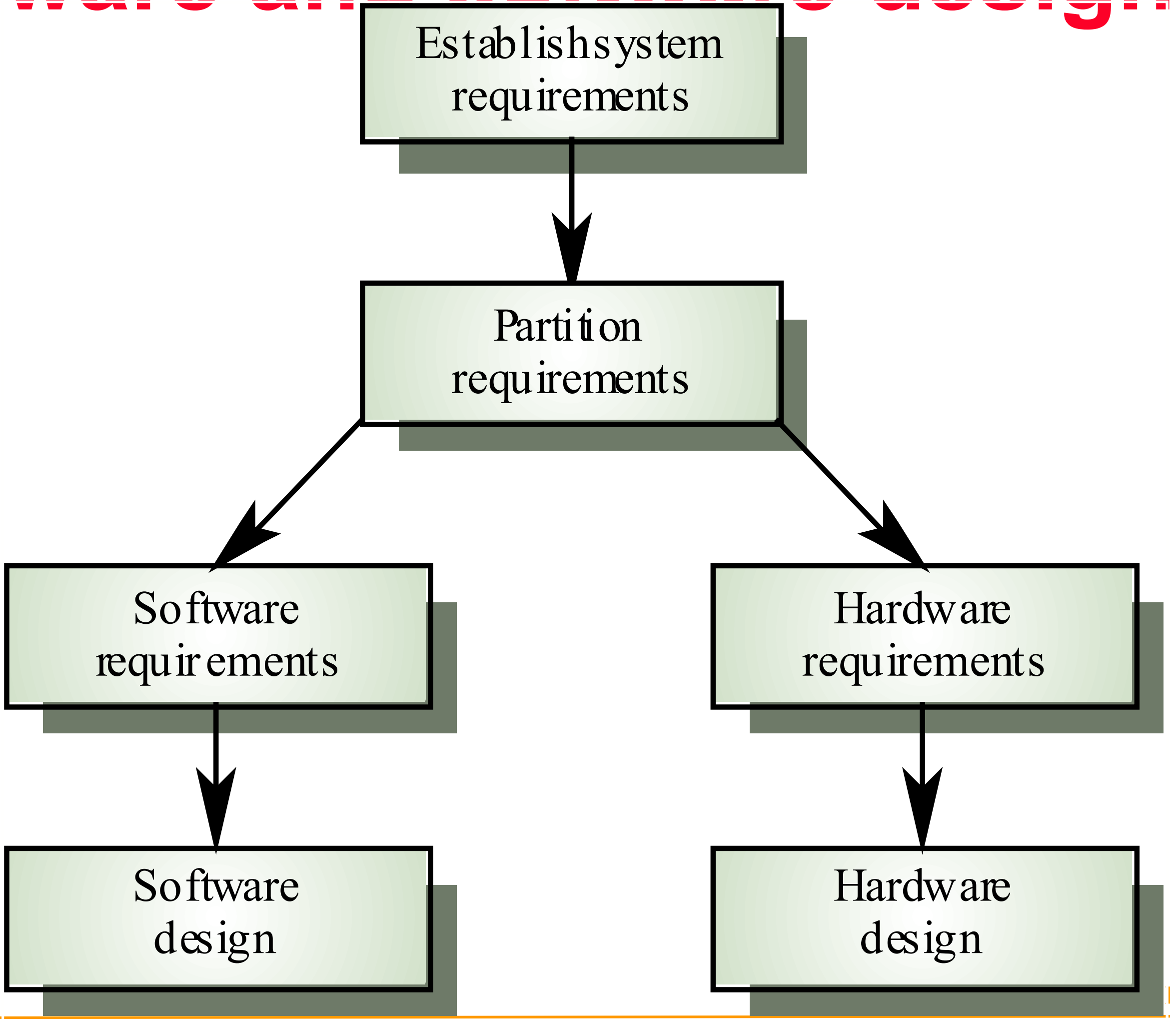
Sensor/actuator processes



System design

- Design both the hardware and the software associated with system. Partition functions to either hardware or software
- Design decisions should be made on the basis on non-functional system requirements
- Hardware delivers better performance but potentially longer development and less scope for change

Hardware and software design



R-T systems design process

- Identify the stimuli to be processed and the required responses to these stimuli
- For each stimulus and response, identify the timing constraints
- Aggregate the stimulus and response processing into concurrent processes. A process may be associated with each class of stimulus and response

R-T systems design process

- Design algorithms to process each class of stimulus and response. These must meet the given timing requirements
- Design a scheduling system which will ensure that processes are started in time to meet their deadlines
- Integrate using a real-time executive or operating system

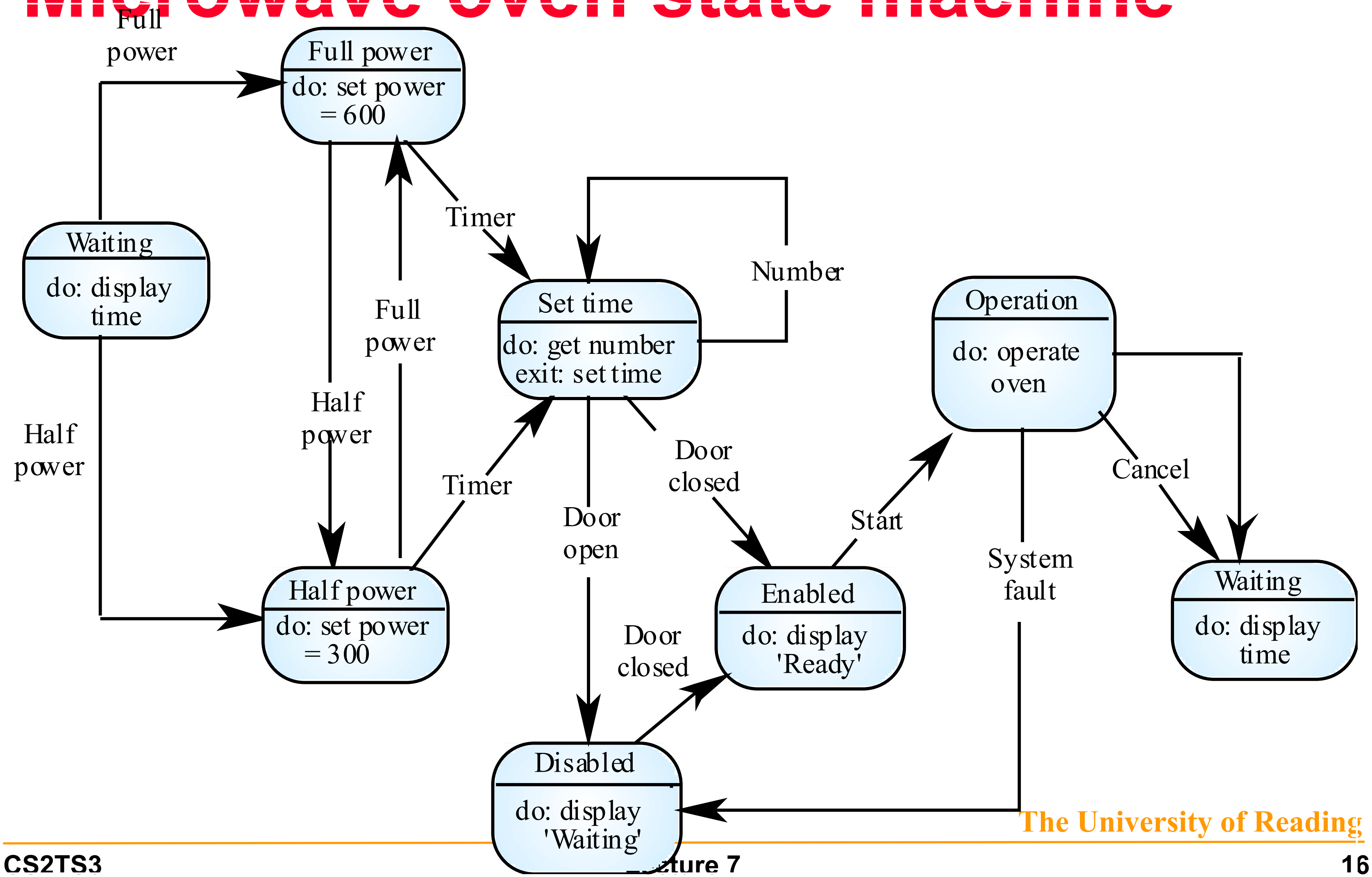
Timing constraints

- May require extensive simulation and experiment to ensure that these are met by the system
- May mean that certain design strategies such as object-oriented design cannot be used because of the additional overhead involved
- May mean that low-level programming language features have to be used for performance reasons

State machine modelling

- The effect of a stimulus in a real-time system may trigger a transition from one state to another.
- Finite state machines can be used for modelling real-time systems.
- However, FSM models lack structure. Even simple systems can have a complex model.
- The UML includes notations for defining state machine models
- See also Chapter 7.

Microwave oven state machine



Real-time programming

- Hard-real time systems may have to programmed in assembly language to ensure that deadlines are met
- Languages such as C allow efficient programs to be written but do not have constructs to support concurrency or shared resource management
- Ada as a language designed to support real-time systems design so includes a general purpose concurrency mechanism

Java as a real-time language

- Java supports lightweight concurrency (threads and synchonized methods) and can be used for some soft real-time systems
- Java 2.0 is not suitable for hard RT programming or programming where precise control of timing is required
  - Not possible to specify thread execution time
  - Uncontrollable garbage collection
  - Not possible to discover queue sizes for shared resources
  - Variable virtual machine implementation
  - Not possible to do space or timing analysis

Real-time executives

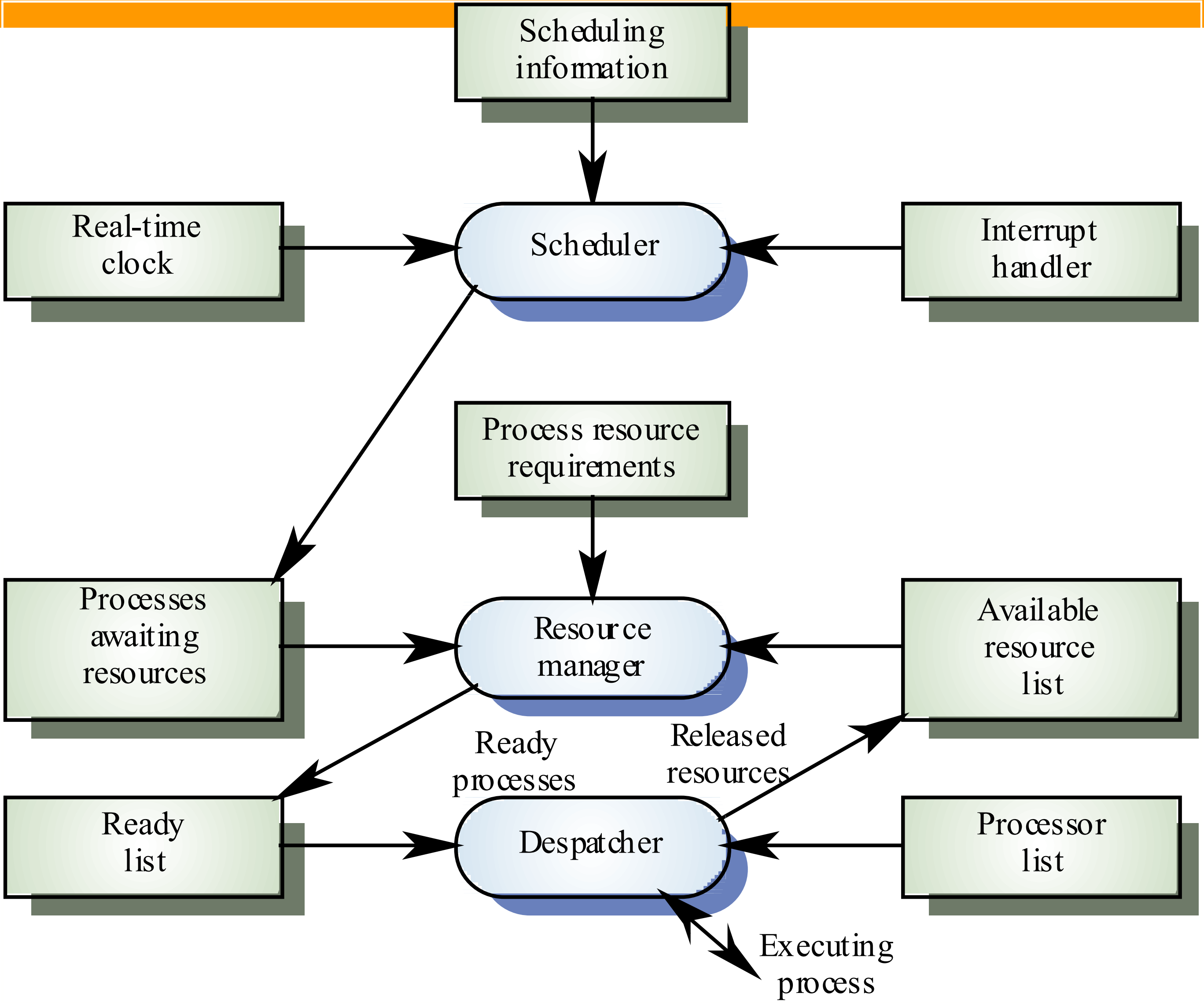
- Real-time executives are specialised operating systems which manage the processes in the RTS
- Responsible for process management and resource (processor and memory) allocation
- May be based on a standard RTE kernel which is used unchanged or modified for a particular application
- Does not include facilities such as file management

Executive components

- Real-time clock
  - Provides information for process scheduling.
- Interrupt handler
  - Manages aperiodic requests for service.
- Scheduler
  - Chooses the next process to be run.
- Resource manager
  - Allocates memory and processor resources.
- Despatcher
  - Starts process execution.

Non-stop system components

- Configuration manager
  - Responsible for the dynamic reconfiguration of the system software and hardware. Hardware modules may be replaced and software upgraded without stopping the systems
- Fault manager
  - Responsible for detecting software and hardware faults and taking appropriate actions (e.g. switching to backup disks) to ensure that the system continues in operation



Real-time executive components

Process priority

- The processing of some types of stimuli must sometimes take priority
- Interrupt level priority. Highest priority which is allocated to processes requiring a very fast response
- Clock level priority. Allocated to periodic processes
- Within these, further levels of priority may be assigned

Interrupt servicing

- Control is transferred automatically to a pre-determined memory location
- This location contains an instruction to jump to an interrupt service routine
- Further interrupts are disabled, the interrupt serviced and control returned to the interrupted process
- Interrupt service routines MUST be short, simple and fast

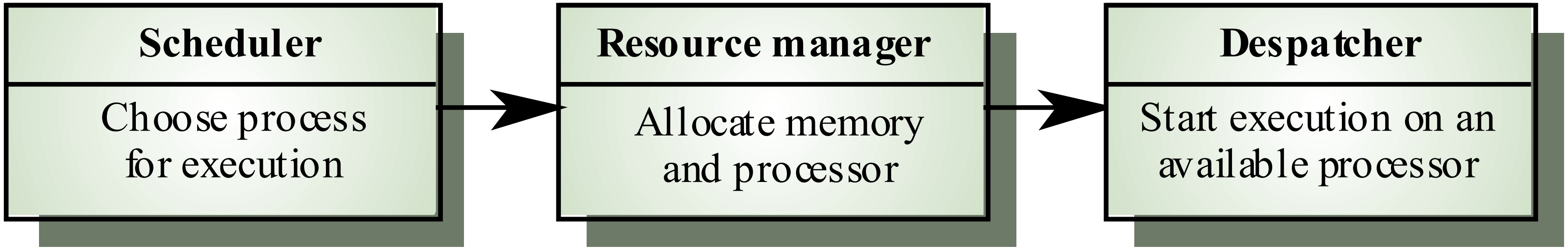
Periodic process servicing

- In most real-time systems, there will be several classes of periodic process, each with different periods (the time between executions), execution times and deadlines (the time by which processing must be completed)
- The real-time clock ticks periodically and each tick causes an interrupt which schedules the process manager for periodic processes
- The process manager selects a process which is ready for execution

Process management

- Concerned with managing the set of concurrent processes
- Periodic processes are executed at pre-specified time intervals
- The executive uses the real-time clock to determine when to execute a process
- Process period - time between executions
- Process deadline - the time by which processing must be complete

RTE process management



Process switching

- The scheduler chooses the next process to be executed by the processor. This depends on a scheduling strategy which may take the process priority into account
- The resource manager allocates memory and a processor for the process to be executed
- The despatcher takes the process from ready list, loads it onto a processor and starts execution

Scheduling strategies

- Non pre-emptive scheduling
  - Once a process has been scheduled for execution, it runs to completion or until it is blocked for some reason (e.g. waiting for I/O)
- Pre-emptive scheduling
  - The execution of an executing processes may be stopped if a higher priority process requires service
- Scheduling algorithms
  - Round-robin
  - Rate monotonic
  - Shortest deadline first

Key points

- Real-time system correctness depends not just on what the system does but also on how fast it reacts
- A general RT system model involves associating processes with sensors and actuators
- Real-time systems architectures are usually designed as a number of concurrent processes

Key points

- Real-time executives are responsible for process and resource management.
- Monitoring and control systems poll sensors and send control signal to actuators
- Data acquisition systems are usually organised according to a producer consumer model
- Java has facilities for supporting concurrency but is not suitable for the development of time-critical systems