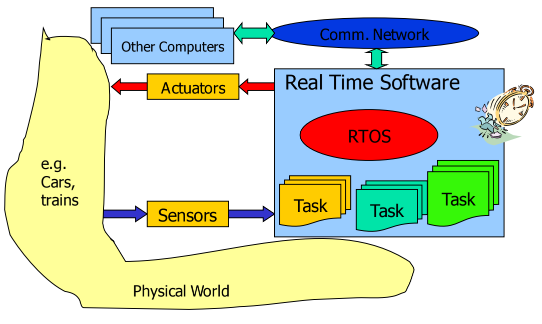
Course Outline

- Introduction
  - Characteristics of RTS
- Real Time Operating Systems (RTOS)
  - OS support: scheduling, resource handling
- Real Time Programming Languages
  - Language support, e.g. Ada tasking
- Scheduling and Timing Analysis of RT Software
  - Worst-case execution and response time analysis
- Design and Validation
  - Modeling, Verification and Testing
- Reliability and Fault-Tolerance
  - Fault tolerant, failure recovery, exception handling
- Distributed real time systems
  - Real Time Communication: CAN Bus

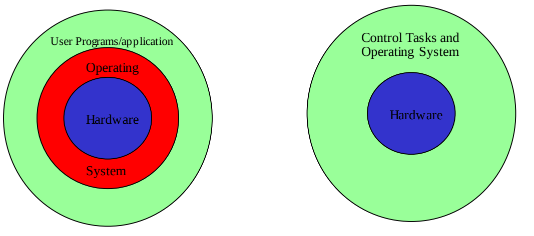
Overall Structure of RT Systems

- Hardware (CPU, I/O device etc)
  - a clock!
- A real time OS (function as standard OS, with predictable behavior and well-defined functionality)
- A collection of RT tasks/processes (share resourses, communicate/synchronize with each other and the environment)

Components of RT Systems



General-Purpose vs. Embedded RT Computer Systems



General-purpose computer systems

Typical Embedded Configuration

Characteristics of a RTS

- Large and complex — vary from a few hundred lines of assembler or C to 20 million lines of Ada estimated for the Space Station Freedom
- Concurrent control of separate system components — devices operate in parallel in the real-world; better to model this parallelism by concurrent entities in the program
- Facilities to interact with special purpose hardware — need to be able to program devices in a reliable and abstract way
- Mixture of Hardware/Software: some modules implemented in hardware, even whole systems, SoC

Characteristics of a RTS (ctn.)

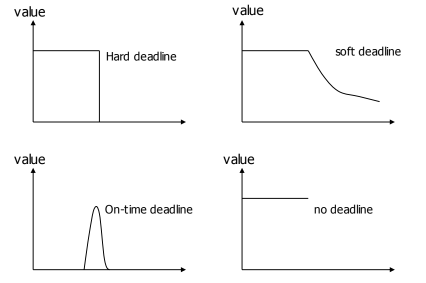
- Extreme reliability and safety — embedded systems typically control the environment in which they operate; failure to control can result in loss of life, damage to environment or economic loss
- Guaranteed response times — we need to be able to predict with confidence the worst case response times for systems; efficiency is important but predictability is essential

Classification of RTS's

- Hard real-time — systems where it is absolutely imperative that responses occur within the required deadline. E.g. Flight control systems, automotive systems, robotics etc.
- Soft real-time — systems where deadlines are important but which will still function correctly if deadlines are occasionally missed. E.g. Banking system, multimedia etc.

A single system may have both hard and soft real-time Subsystems. In reality many systems will have a cost function associated with missing each deadline.

Classification of RTS's



Example: a Car Controller

Activities of a car control system. Let

1. C= worst case execution time
2. T= (sampling) period
3. D= deadline

- Speed measurment: C=4ms, T=20ms, D=5ms
- ABS control: C=10ms,T=40ms, D=40ms
- Fuel injection: C=40ms, T=80ms,D=80ms
- Other software with soft deadlines e.g audio, air condition etc

Construct a controller meeting all the deadlines!

Programming the car controller (1)

Process Speed: Loop read sensor,compute,display... sleep (0.02) /*period*/ End loop	Process ABS Loop Read sensor, compute, react sleep(0.04) End loop
Process Fuel Loop read data, compute, inject ... sleep(0.08) End loop	Soft RT Processes Loop read temperature el hiss, stereo .... End loop

Any problem?

- We forgot the execution times …

e.g. Process speed:

20ms = execution time + sleep(X)

Programming the car controller (2)

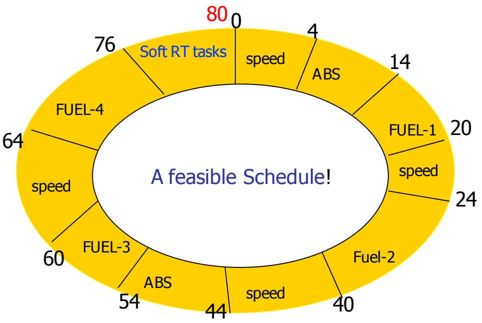
Process Speed: Loop next := get-time + 0.02 read sensor,compute,display... sleep until next End loop	Process ABS Loop next:=get-time + 0.04 Read sensor, compute, react sleep until next End loop
Process Fuel Loop next:=get-time + 0.08 read data, compute, inject ... sleep until next End loop	Soft RT Processes Loop read temperature elevator, stereo .... End loop

What is the problem now?

We don't know if the deadlines are met!

- We need to know the execution times
- We need to do schedulability analysis
- We need to construct a schedule
- We need to implement/buy an RT OS kernel

Programming the car controller (3)



Design and Implementation of RT Systems

- Specification and Analysis
  - Requirement Specs
  - Design Specs
- Implementation
  - Hardware platform
  - OS kernel
  - Design/Programming Languages
  - Code generation vs. coding
- Validation
  - Verification
  - Testing

Real-time Programming Languages

- Assembly languages
- Sequential programming languages — e.g. Pascal, C.
  - Both normally require operating system support.
- High-level concurrent languages e.g. Concurrent Pascal, Ada, Modula-2, RT Java.
  - No/less operating system support!
- Other (design/prog) languages: Esterel, Lustre, SystemC, UML (modeling and Code generation)
- We will consider:
  - Ada 95 and C

Challenges in RT Systems Design

- Predictability: able to predict the future consequences of current actions
- Testability: easy to test if the system can meet all the deadlines
- Cost optimality: e.g. Energy consumption, memory blocks etc

Main desirable properties of RT Systems (2)

- Maintainability: modular structure to ease system modification
- Robustness: must not collapse when subject to peak load, exception, manage all possible scenarios
- Fault tolerance: hardware and software failures should not cause the system to crash - function down-grading

Predictability: the most important one

- The system behaviour is known before it is put into operation!
  e.g. Response times, deadlock freedom etc

Difficult (impossible?) to achieve!

Difficult to achieve predictability: Hardware & RTOS

- Cache sharing, processor pipelines, DMA ...
- Interrupt handling may introduce unbounded delays
- Priority inversion (low-prority tasks blocking high-prior taskts)
- Memory management (static allocation may not be enough, dynamic data structures e.g. Queue), no virtual memory
- Communication delays in a distributed environment

Difficult to achieve predictability: RT Tasks:

- Difficult to calculate the worst case execution time for tasks (theoretically impossible, halting problem)
  - Avoid dynamic data structures
  - Avoid recursion
  - Bounded loops e.g. For-loops only
- Complex synchronization patterns between tasks: potential deadlocks (formal verification)
- Multi-tasking, tasks that share resources

Problems to solve ...

- Missing deadlines (!)
- Deadlocks/livelocks
- Uncontrolled exception (ARIAN 5)
- Priority inversion (the Mars project)
- Uncontrolled code size, cost, ...
- Non-determinism and/or Race condition
- Overloaded

Problems to solve ...

- Missing deadlines (!)
- Deadlocks/livelocks
- Uncontrolled exception (ARIAN 5)
- Clock jitter (the golf war, Scud missile)
  - 57micro sec/min, 343ms/100 hours
  - 687 meters
- Priority inversion (the Mars project)
- Uncontrolled code size, cost, ...
- Non-determinism and/or Race condition
- Overloaded