Introduction to Real-Time Systems

Frank Singhoff

Office C-202

University of Brest, France

singhoff@univ-brest.fr

Summary

1. Some definitions.
2. Example of real-time systems.
3. Real-Time systems require specific analysis and programming methods.
4. Summary, further readings, planning of the week.
5. References.

Real-time systems (1)

- "**Real-time systems** are defined as those systems in which the correctness of the system depends not only on the logical result of computation, but **also on the time** at which the results are produced" [STA 88].

- **Properties we look for** :
  - **Functions must be predictable** : the same data input will produce the same data output.
  - **Timing behavior must be predictable** : must meet temporal constraints (e.g. deadline, response time).

$\Longrightarrow$ Predictable means ... we can **compute** the system temporal behavior **before** execution time.

Real-time systems (2)

- **A real time system is NOT a system that runs quickly ... this is a system that has temporal constraints to meet.**

- **Examples of temporal constraints[DOR 91, DEM 99]:**

  - **Few milliseconds** for radar systems.
  - **One second** for machine-man interfaces (in an aircraft for example).
  - **Hours** for some chemical reactions.
  - **24 hours** for weather forecast.
  - **Several months or years** for some spacecrafts (Mars Express, Voyager, ...).

Real-time systems (3)

- **Different types of real-time systems :**
  - **Hard (or critical) real-time systems:** temporal constraints MUST be met, otherwise defects could have a dramatic impact on human life, on the environment, on the system, ...
  - **Soft (or non critical) real-time systems:** temporal constraints cannot (sometimes) be met without any dramatic impact.
  - **Opened or closed real-time systems:** tasks/functions can be launched/created at execution time?

Real-time systems (4)

- **Different types of real-time systems :**

- **Embedded systems**: *An embedded system is a computer system designed for specific control functions within a larger system. Often with real-time computing constraints. It is embedded as part of a complete device often including hardware and mechanical parts (e.g. mobile phone, aircraft, automotive, ...)*

- **Distributed systems**: "*A distributed system consists of a collection of autonomous computers, connected through a network which enables computers to coordinate their activities and to share resources." Coulouris et al. [COU 94].*

- **Distributed systems are required:**
  - For dependability (redundancy).
  - Due to physical constraints.
  - For efficiency (resource sharing).

Real-time systems (5)

- **Problems raised by embedded systems:**
  - Difficult to update/correct when a software failure is discovered (e.g. mobile phone, spacecraft).

- **Problems raised by distributed systems:**
  - Heterogeneity.
  - Timing behavior.
  - Have many different resources.

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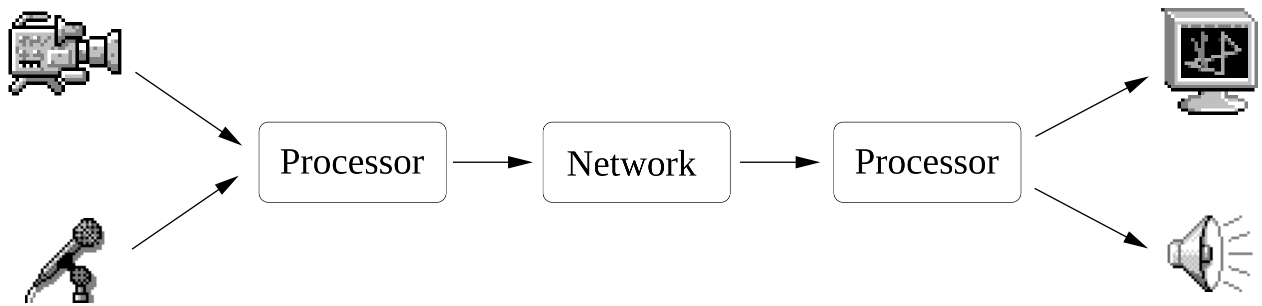
Example 1: aircraft

- **Hard and closed real-time systems:**
  - Temporal constraints: worst case response time, deadline, ... Strong requirements to meet temporal constraints.
  - Resource reservation on the worst case: to be sure that resources are available when they are required.
  - Closed systems : all tasks are known at design time and are launched at system's switch on. Resource requirements are easy to estimate.
  - Use of software and hardware redundancy.
  - Use of dedicated software and hardware components : Real-time operating system (e.g. RTEMS), embedded processor (e. g. Leon Sparc processor).

Example 2: multimedia on the Web

- **Soft and opened real-time systems:**



- Temporal constraints: worst case response time but also jitter, end to end delay, intra-flow and inter-flow synchronization.
- General purpose execution environment (e.g. PC with a windows operating system).
- Resource requirements difficult to estimate : number of flow, bandwidth of each flow (e.g. MPEG encoder).
- Can not perform worst case resource reservation.

Others examples

- **From a book on real-time systems programming :**

"*This book is about real-world programming ... So real-world programs (and real-world programmers) are all around us. What characterizes all of these real-world applications is a critical dependence on time."* [GAL 95]

- Transportations (train, aircraft, automotive, underground, ...).
- Satellite TV decoder.
- Mobile phones, MPEG3 players, cameras, ...
- Monitoring services (e.g. health devices).
- Robotic systems
- Nuclear power plant.
- ...

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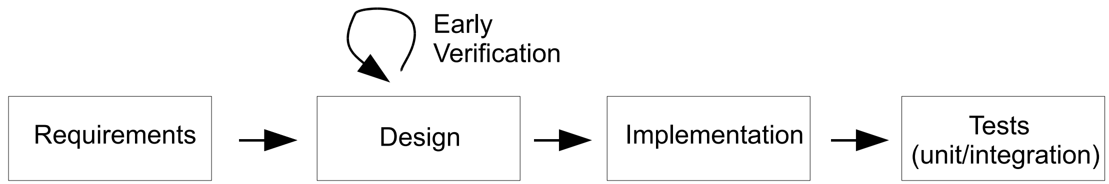
Hard real-time system specific practices

- **Real-time critical (hard) systems:**
  - Are concurrent and synchronized applications. Need to handle time.
  - Have high implementation cost : temporal constraints verification, safety, certification, dedicated software development kits/environments.
  - Do not allow software maintenance: e.g. spacecrafts, mobile phones $\Longrightarrow$ we cannot correct erroneous software (bugs).
  - May have dramatic impact on human life, on the environment, on the system, ...

- **Specific software engineering:** methods, models and tools to master software quality and development cost.
- **Specific programming tools:** languages, cross-compilers, operating systems.

Specific Software Engineering (1)



- **Typical software engineering process:**
  - Requirements = What ? Are they consistent?
  - Design software architecture = How ? Verification of the timing/logical constraints. Does the architecture provide the right answer?
  - Implementation = write software components.
  - Tests: check correctness of the software.

Specific software Engineering (2)

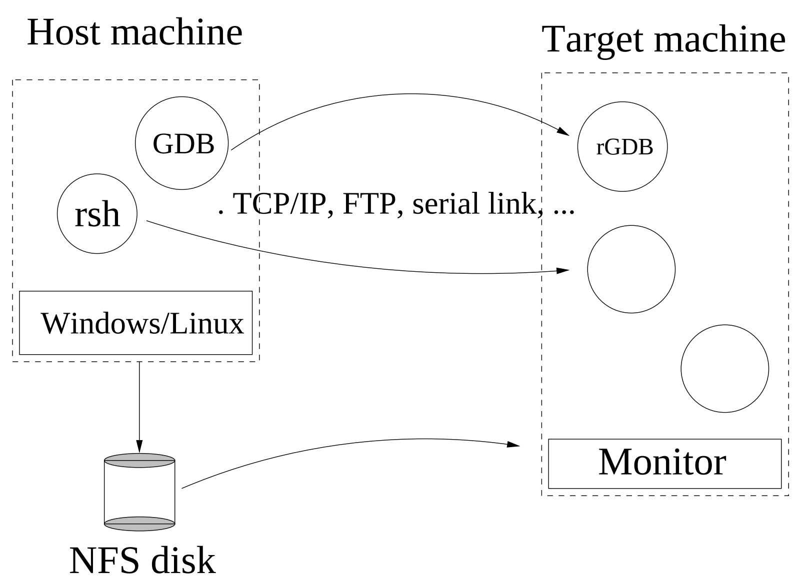
- **Software engineering specific practices for real-time software:**
  - **To reduce costs:** do early verification each time we can => design step.
  - **Use of Models** and tools that automatically handle those models.
  - **Analysis methods:**
    - Simulation.
    - Model checking. Formal methods for real-time systems: Petri nets, timed automata, synchronous languages, ...
    - Analytical approaches: real-time scheduling analysis.

Specific programming tools (1)

- **Use of monitors:**
  - Small software size. Very deterministic systems. Small memory footprint.
  - No system calls and no separate address spaces : set of functions built as an unique executable.
  - Sometimes no scheduler (high critical).
  - Cross compilers.

Specific programming tools (2)

- **Cross-compiling:**



- **Why cross-compiling** : because target has a limited amount of resource, is composed of specific hardware/software (timing behavior).
- **Host :** where we compile the program.
- **Target :** where we run the program.

Specific programming tools (3)

- **High level versus low level programming languages:**
  - Low level languages : C or assembly languages.
  - High level languages: Esterel or Ada languages.

Specific programming tools (4)

- **An example of low level language: C**
  - Largely known.
  - Direct access to hardware components.
  - But must be used with libraries for concurrency/synchronization/timing/scheduling.
  - Use of language subsets (e.g. dynamic allocation).
  - Low portability.
  - Well suited for small real-time applications.

Specific programming tools (5)

- **An example of high level language: Ada**
  - Contains real-time abstractions: timing/concurrency/synchronization/scheduling.
  - Standard : semantics is well defined $\Longrightarrow$ portability.
  - Separate compilation.
  - Safety programming (strong typing, static analysis).
  - Complex language which is difficult to use. Few programmers.
  - Well suited for large real-time applications.

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Summary and further readings (1)

- **Real-time systems:** systems with timing constraints to meet. Are usually concurrent systems (tasks and synchronization).
- **Embedded systems and distributed systems.**
- **Specific development process and programming technologies:** modeling and early verifications (e.g. real-time scheduling analysis), specific operating systems and programming languages (cross-compiler, real-time features).

Summary and further readings (2)

- **About real-time scheduling theory:**
  - *Scheduling in Real Time Systems*. F. Cottet and J. Delacroix and C. Kaiser and Z. Mammeri. 2002, John Wiley and Sons Ltd editors.
- **Real-time scheduling facilities with POSIX 1003:**
  - *POSIX 4 : Programming for the Real World* . B. O. Gallmeister. O'Reilly and Associates, January 1995.
- **Real-time scheduling facilities with Ada:**
  - *Concurrent and Real Time programming in Ada.* A. Burns and A. Wellings. 2007, Cambridge University Press.
  - *Building Parallel, Embedded, and Real-Time Applications with Ada.* J. W. McCormick, F. Singhoff, J. Hugues. Cambridge University Press, July 2010.

Summary and further readings (3)

- **Other books on real-time systems:**
  - *Real-Time Systems and Programming Languages*. A. Burns. 2009, Addison Wesley; 4th Revised edition.
  - *Real-Time Systems Design and Analysis*. Phillip A. Laplante. 1994, Wiley-IEEE Press.

Planning of the week

1. Monday:
   - Lecture: introduction, real-time scheduling (fixed priority scheduling, EDF, shared resources).
   - Exercise: real-time scheduling analysis.
2. Tuesday:
   - Lecture: real-time programming ; C programming with POSIX/RTEMS.
   - Exercise: real-time scheduling (cont).
   - Lab: real-time programming ; C with POSIX/RTEMS.
3. Wednesday:
   - Lecture: real-time programming ; Ada programming with RTEMS.
   - Lab: real-time programming ; C with POSIX/RTEMS (cont) ; Ada RTEMS.
4. Thursday:
   - Lecture: real-time programming ; Ada programming with RTEMS (cont).
   - Lab: real-time programming ; Ada with RTEMS (cont).
5. Friday:
   - Lecture: real-time scheduling (architecture description languages, multi-core/distributed systems).
   - Lab: real-time programming ; Ada with RTEMS (cont).

References

[COU 94] G. Coulouris, J. Dollimore, and T. Kindberg. *Distributed Systems—Concepts and Design, 2nd Ed.* Addison-Wesley Publishers Ltd., 1994.

[DEM 99] I. Demeure and C. Bonnet. *Introduction aux systèmes temps réel*. Collection pédagogique de télécommunications, Hermès, septembre 1999.

[DOR 91] A. Dorseuil and P. Pillot. *Le temps réel en millieu industriel*. Edition DUNOD, Collection Informatique Industrielle, 1991.

[GAL 95] B. O. Gallmeister. *POSIX 4 : Programming for the Real World* . O'Reilly and Associates, January 1995.

[STA 88] John Stankovic. « Misconceptions about real-time computing ». *IEEE Computer*, October 1988.