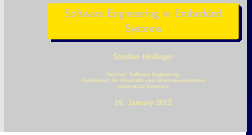
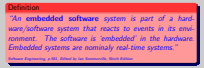


Software Engineering in Embedded Systems

Stephan Heidinger

Seminar: Software Engineering
Fachbereich für Informatik und Informationssysteme
Universität Konstanz

19. January 2012

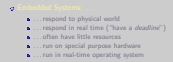


Embedded Systems - What's that? - I

Definition

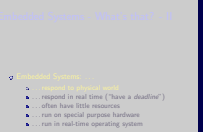
"An **embedded software** *system is part of a hardware/software system that reacts to events in its environment. The software is 'embedded' in the hardware. Embedded systems are nominaly real-time systems."*

Software Engineering, p.561, Edited by Ian Sommerville, Ninth Edition



Embedded Systems - What's that? - II

- Embedded Systems: ...
  - ... respond to physical world
  - ... respond in real time ("have a *deadline*")
  - ... often have little resources
  - ... run on special purpose hardware
  - ... run in real-time operating system



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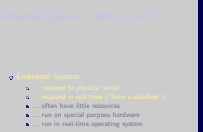

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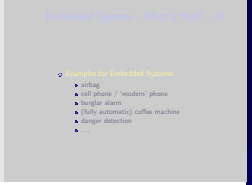

Embedded Systems - What's that? - III

- Examples for Embedded Systems:
  - airbag
  - cell phone / 'modern' phone
  - burglar alarm
  - (fully automatic) coffee machine
  - danger detection
  - ...

Embedded Systems - What's that? - III
Examples for Embedded Systems:
airbag
cell phone / 'modern' phone
burglar alarm
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danger detection
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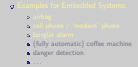

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Motivation

- We see:
  - Embedded Systems are everywhere!
  - There are probably more Embedded Systems than computers out there!
- We realize:
  - Man, they must be important.
  - There sure is some money in this.

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- We realize:
  - Man, they must be important.
  - There sure is some money in this.
  - I did an internship producing an embedded system.

Outline

Outline
Embedded Systems Design
Architectural patterns
Timing analysis
Real-time operating systems

Outline

Problems

- Problems in embedded Systems:
  - deadlines
  - environment
  - continuity
  - direct hardware interaction
  - safety & reliability

deadlines: every process has deadline until result must exist
hard systems: deadline not met, failure
soft system: deadline not met, bad results

Problems

- Problems in embedded Systems:
  - deadlines
  - environment
  - continuity
  - direct hardware interaction
  - safety & reliability

environment:
is unpredictable
embedded Software ⇒ must be concurrent

Problems

- Problems in embedded Systems:
  - deadlines
  - environment
  - continuity
  - direct hardware interaction
  - safety & reliability

continuity:
embedded Software ⇒ does not normally terminate
software has to be reliable
may need update while operating

Problems

- Problems in embedded Systems:
  - deadlines
  - environment
  - continuity
  - direct hardware interaction
  - safety & reliability

direct hardware interaction:
uncommon hardware (i.e. detonator in airbag)
speed issues (hardware is faster)

Problems

- Problems in embedded Systems:
  - deadlines
  - environment
  - continuity
  - direct hardware interaction
  - safety & reliability

safety & reliability:
cost of failure high
either economical or in human life

next thing:
Design steps
not all are necessary, but most will be.

Problems

- Problems in embedded Systems:
  - deadlines
  - environment
  - continuity
  - direct hardware interaction
  - safety & reliability

Embedded Systems Design - I

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
    1. periodic stimuli
    2. aperiodic stimuli

Platform selection:
what hardware?
Real-time operating system (later)
What is to be implemented in software, what in hardware
need to design special hardware?
power consumption (mobile device, backup)

Embedded Systems Design - I

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
    1. periodic stimuli
    2. aperiodic stimuli

special purpose hardware:
do we need special hardware?
design special hardware?
replace software by hardware?

Embedded Systems Design - I

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
    1. periodic stimuli
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stimuli:
describe behavior of system by listing received stimuli and reactions
stimuli = signals

Embedded Systems Design - I

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
    1. periodic stimuli
    2. aperiodic stimuli

periodic stimuli:
occur at predictable intervals
predefined reaction per stimulus
i.e. polling

Embedded Systems Design - I

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
    1. periodic stimuli
    2. aperiodic stimuli

aperiodic stimuli:
occurr irregularly and unpredictably
often interrupts
i.e. alarms, failures, IO operation finished, etc**stimuli list:**
best practice: stimuli list with **all** stimuli.

example next slide

Embedded Systems Design - I

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
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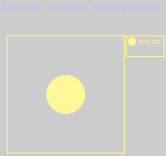
Example: radiation warning system



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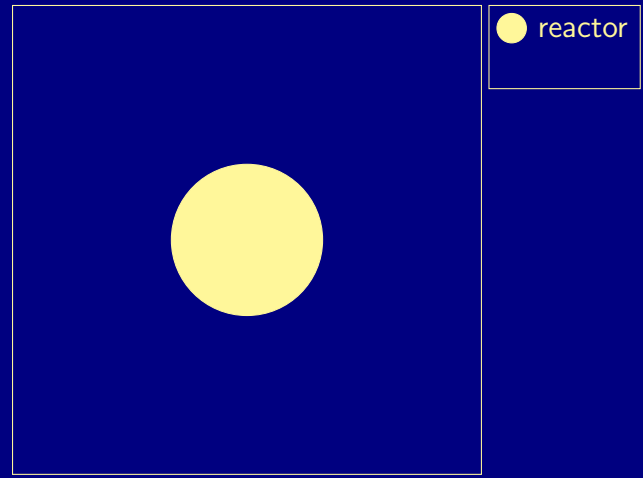

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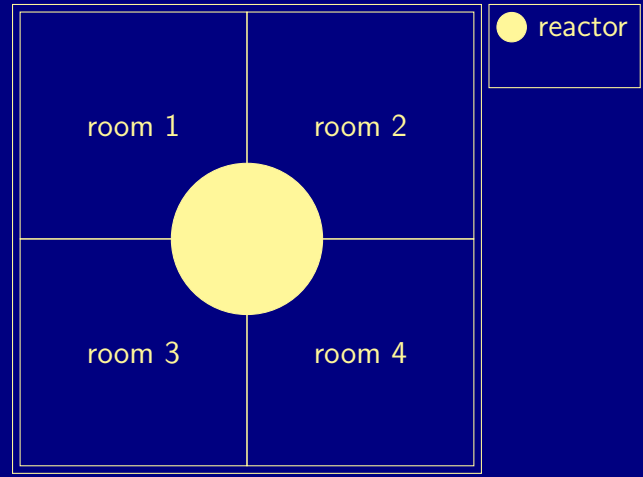

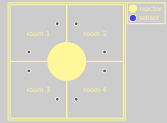

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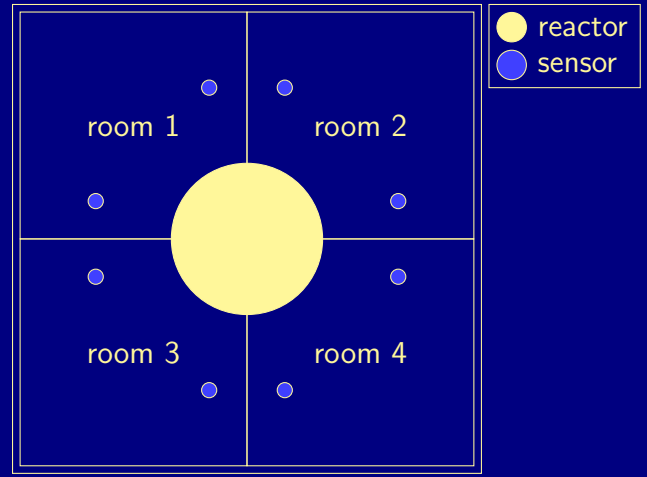

Example: Stimuli-List of a radiation warning system
Stimulus Response

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Stimulus	Response

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Embedded Systems Design - II

- design steps - continued
  - Timing analysis
  - Process design
  - Algorithm design
  - Data design
  - Process scheduling

Timing analysis:
For each stimulus and response ⇒ find timing constraints
timing constraints ⇒ deadlines

Embedded Systems Design - II

- design steps - continued
  - Timing analysis
  - Process design
  - Algorithm design
  - Data design
  - Process scheduling

Process design:
aggregate the stimuli & responses into concurrent processes
See Architectural design

Embedded Systems Design - II

- design steps - continued
  - Timing analysis
  - Process design
  - Algorithm design
  - Data design
  - Process scheduling

Algorithm design:
For each stimulus & response ⇒ design algorithm
especially important for computationally intensive tasks (signal processing)
Do we need to implement these in hardware?

Embedded Systems Design - II

- design steps - continued
  - Timing analysis
  - Process design
  - Algorithm design
  - Data design
  - Process scheduling

Data design:
How to store data, that will be exchanged
semaphore & critical regions & monitors & ...
circular buffer: producer & consumer may run at different speeds

Embedded Systems Design - II

- design steps - continued
  - Timing analysis
  - Process design
  - Algorithm design
  - Data design
  - Process scheduling

Process scheduling:
ensure, that processes meet their deadline
probably among the hardest (own opionion)
all shown:
not all need to be done, but most probably will
which & order depends on what we design

after this design steps:
make sure system can meet deadlines
static analysis
simulation

Embedded Systems Design - II

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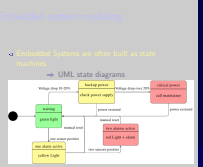
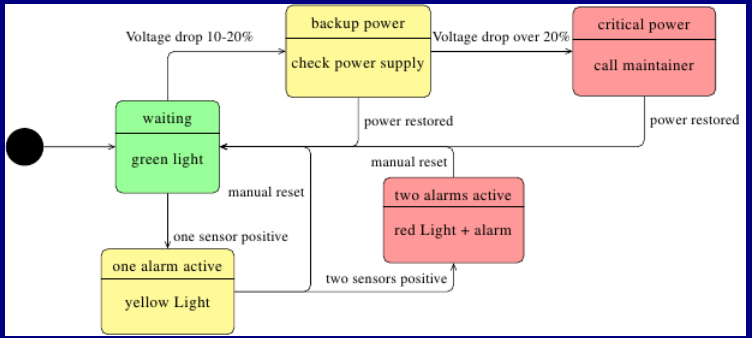


Embedded system modeling

- Embedded Systems are often built as state machines.

  ⇒ UML state diagrams



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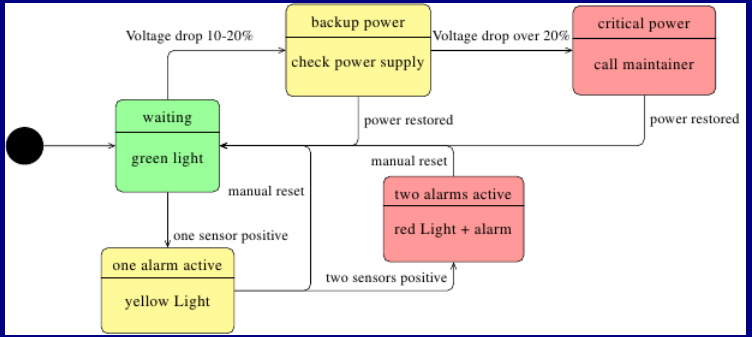

Embedded software programing

- programm has to be...
  - ...fast (i.e. C, Asssembler)
  - ...concurrent (i.e. C++, real time Java, ...)
- speed looses importance

C, Assembler:
No concurrency
no built-in system for shared resources

Embedded software programing

- programm has to be...
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concurrent:
and manage shared resources

concurrent or speed??:
depends on what is more important
simulate concurrency with frequent polling
do something yourself about shared resources

Embedded software programing

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  - ...fast (i.e. C, Asssembler)
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speed:
due to faster hardware
ie monitoring device written in C++
ie cell phones in java, objective C, ...

Embedded software programing

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Outline
Embedded Systems Design
Architectural patterns
Timing analysis
Real-time operating systems

Outline

Architectural patterns
Architectural patterns are used to describe a system in an abstract way and help to understand the architecture.
Observe and react
Environmental Control
Process Pipeline

note on 3:
The source described three rough design pattern there are finer patterns

Architectural patterns

- Architectural patterns are used to describe a system in an abstract way and help to understand the architecture.
  - Observe and react
  - Environmental Control
  - Process Pipeline

Observe and React:
set of monitored sensors
Something happens *Rightarrow* we do something
ie incoming phone call

Architectural patterns

- Architectural patterns are used to describe a system in an abstract way and help to understand the architecture.
  - Observe and react
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Environmental Control:
set of sensors and actuators
can change environment
ie flash light, when sensor fires

Architectural patterns

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Process Pipeline:
data transformation
series of processing steps
preferably concurrent
all of those: can be combined
often more than one pattern in the system
ie monitor the actuators **design patterns:** will lead to inefficient system *Rightarrow* only for understanding system

Architectural patterns

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Observe and React
5 Observe and React
- monitor the system with a set of sensors
- display something
- primarily used in: Monitoring systems

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monitoring:
as stated before

Observe and React

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display:
monitoring screen
on exceptional behaviour: alarms, shutdown

Observe and React

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  - display something
  - primarly used in: Monitoring systems

monitoring systems:
often consist of more than one O&R patterns, one for each sensor
optimisation: combine something, ie display on one monitor

Observe and React

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  - monitor the system with a set of sensors
  - display something
  - primarly used in: Monitoring systems

Environmental Control
Environmental Control
monitor the system and react to any changes
Used when there is no requirement for user interaction...
...or no time for the user to interact ...
...no way a user can interact ...
...or there is too much information for users to process.

Environmental Control

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  - monitor the system and react to any changes
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examples:
cruise control
water level
pressure control
. . .

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examples:
break assist
airbag

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example:

CYPRES (parachute, Möllemann did not activate his in 2003)

self desctruct of military/sensitive equipment

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example:
Nuclear Power Plant
Airplane
Car
virtually any big system with many subsystems

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Process Pipeline
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transform data
often huge amounts of data to be converted in real time
data aquisition system: storing of data may need to be fast

Process Pipeline

- Process Pipeline
  - transform data
  - often huge amounts of data to be converted in real time
  - data aquisition system: storing of data may need to be fast

examples:
signal processing from sensors in other systems
optical sensor
convert digital data to audio

Process Pipeline

- Process Pipeline
  - transform data
  - often huge amounts of data to be converted in real time
  - data aquisition system: storing of data may need to be fast

huge amount:
concurrency + multicore is the key

Process Pipeline

- Process Pipeline
  - transform data
  - often huge amounts of data to be converted in real time
  - data aquisition system: storing of data may need to be fast

example:
particle accelerator
chemical reactions
...
if storing not fast, data will be lost

Process Pipeline

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  - often huge amounts of data to be converted in real time
  - data aquisition system: storing of data may need to be fast

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Outline

Timing Analysis - I

- timing analysis
  - Correctness of systems depends not only on result, but also on the time at which the result is produced.
  - How often does each process need to be executed?
  - aperiodic stimuly ⇒ make assumptions

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Timing Analysis - I

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  - Correctness of systems depends not only on result, but also on the time at which the result is produced.
  - How often does each process need to be executed?
  - aperiodic stimuly ⇒ make assumptions

how often?:
then we check, if our system can deliver this
this can be quite hard, when *mixture of aperiodic and periodic stimuli* or *many aperiodic stimuli* are expected

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fast systems:
use only periodic stimuli
poll frequently for aperiodic stimuli

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Timing Analysis - II

- Consider:
  - deadlines
  - frequency
  - execution time

deadlines:
By which time must the process have ended.

Timing Analysis - II

- Consider:
  - deadlines
  - frequency
  - execution time

frequency:
The number of times a process must be executed in a given span, so that the *system* meets all deadlines

Timing Analysis - II

- Consider:
  - deadlines
  - frequency
  - execution time

execution time:
How long does each single process take (average & worst case)
hard: conditional execution, delays waiting, ...
hard systems: always worst case

Timing Analysis - II

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Stimulus/Response	Timing requirements
voltage drop	switch to backup: 50ms

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call maintainer	5000ms

Embedded Systems

Stephan Heidinger

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Outline

Embedded Systems Design
Architectural patterns
Timing analysis
Real-time operating systems

Outline

normal operating systems:
too large, too bulky, too slow

Real-time operating systems
normal operating systems not feasible
special "real-time operating systems" exist
RTOS must include:
real-time clock
interrupt handler
process manager: scheduler & resource manager
dispatcher

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real-time operating systems:
Windows/CE
Vxworks
RTLinux
emdebian

they are small and damn fast

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real-time clock:
provides information required to schedule processes

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interrupt handler:
manages aperiodic requests for service
may be inside process manager
at least **2 levels:**
interrupt for processes with fast response time & *clock level* fore regular processes
often also background processes with low priority (self checks etc)

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scheduler
examines processes and chooses one for execution
processes need enough processor time to *finish before their deadline*
commonly used:
non-pre-emptive & pre-emtive (execution of processes may be stopped)
round robin
rate monolithic scheduling (SJF)
shortes deadline first (HPF) **resource manager:**
allocates memory and processor resources scheduled for execution

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dispatcher:
starts execution of processes

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30 minutes in short

- What you should (at least)remember:
  - Embedded Systems react to events in real time.
  - Embedded Systems are a set of processes reating to stimuli
  - State models help understanding the System.
  - Architectural patterns can be used to help in designing the system.
  - Always to timing analysis in (hard) Embedded Systems.

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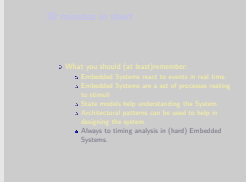

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