Software Engineering in Embedded Systems

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Seminar: Software Engineering
Fachbereich für Informatik und Informationssysteme
Universität Konstanz

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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? - I

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*"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."*

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

Embedded Systems - What's that? - III

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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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some money:

C-programing

special skills

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Outline
1. Embedded Systems Design
2. Architectural patterns
3. Timing analysis
4. Real-time operating systems

Outline

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Embedded Systems
└ Embedded Systems Design
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Embedded Systems
└ Embedded Systems Design
  └ Problems

Problems

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

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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 $\Rightarrow$ must be concurrent

Problems

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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)

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safety & reliability:

cost of failure high

either economical or in human life

Problems

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

- Problems in embedded Systems:
  - deadlines
  - environment
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  - direct hardware interaction
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next thing:
not all are necessary, but most will be.

Embedded Systems Design

- design steps
  - platform selection
  - special purpose hardware
  - stimuli:
    1. periodic stimuli
    2. aperiodic stimuli
  - Timing analysis
  - Process design
  - Algorithm design
  - Data design
  - Process scheduling

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)

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

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stimuli:

describe behavior of system by listing received stimuli and reactions

stimuli = signals

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

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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

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Timing analysis:

For each stimulus and response $\Rightarrow$ find timing constraints

timing constraints $\Rightarrow$ deadlines

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

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Algorithm design:

For each stimulus & response $\Rightarrow$ design algorithm

especially important for computationally intensive tasks (signal processing)

Do we need to implement these in hardware?

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

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stimuli:
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aperiodic stimuli
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

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└Example: radiation warning system

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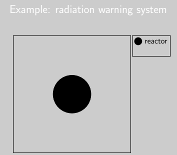

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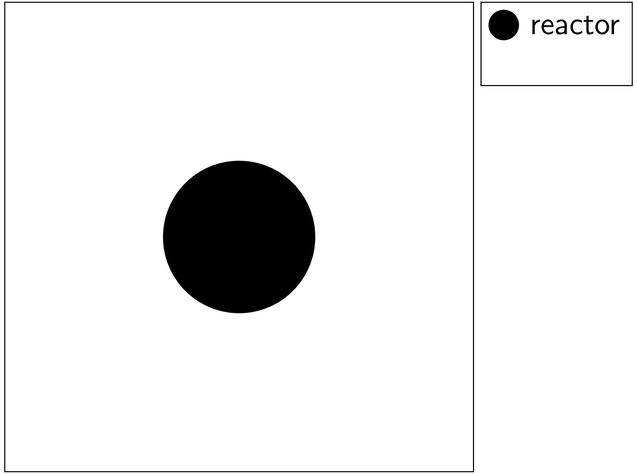

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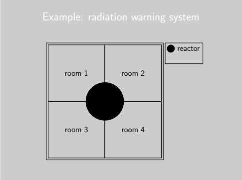

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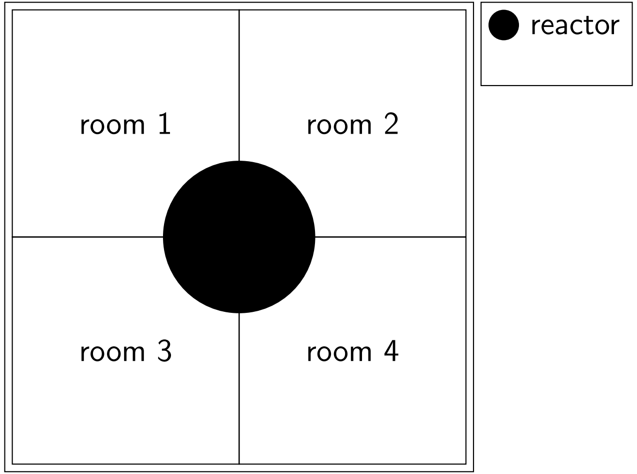

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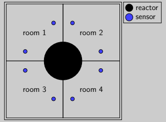

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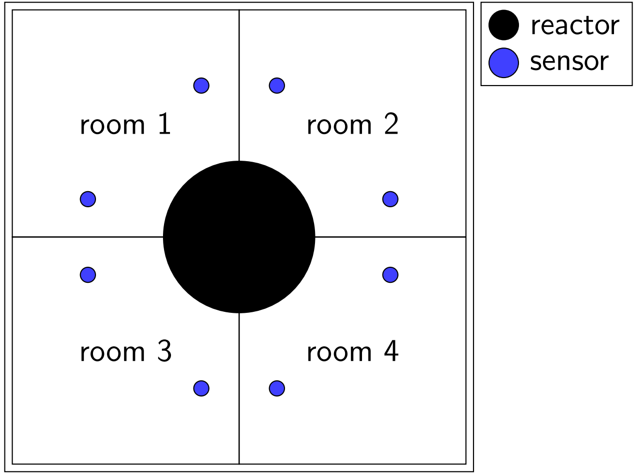

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└Example: Stimuli-List of a radiation warning system

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Voltage drop of more than 20%	switch to backup; run power supply test; call maintainer

LAST CELL:

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  └ Embedded system modeling

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- Embedded Systems are often built as state machines.
  ⇒ UML state diagrams

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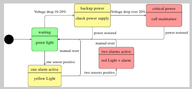

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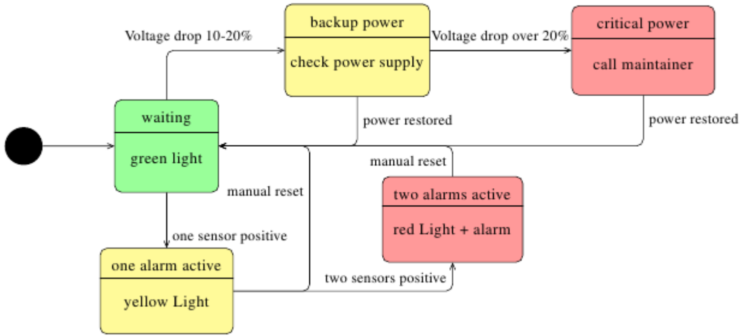
  $\Rightarrow$ UML state diagrams



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Embedded Systems

Embedded Systems Design

Embedded software programing

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

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C, Assembler:

No concurrency

no built-in system for shared resources

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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

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speed:

due to faster hardware

ie monitoring device written in C++

ie cell phones in java, objective C, . . .

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Embedded Systems
└Architectural patterns
└Outline

Outline

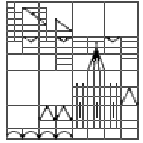
- Embedded Systems Design
- Architectural patterns
- Timing analysis
- Real-time operating systems

Outline

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



Architectural patterns

- Architectural patterns are used to describe a system in an abstract way and help to understand the architecture.
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Observe and React:
set of monitored sensors
Something happens *Rightarrow* we do something
ie incoming phone call

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Architectural patterns
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  - Observe and react
  - Environmental Control

Environmental Control:
set of sensors and actuators
can change environment
ie flash light, when sensor fires

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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

- 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

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

monitoring:
as stated before

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display:

monitoring screen

on exceptional behaviour: alarms, shutdown

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

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Embedded Systems
└ Architectural patterns
  └ Environmental Control

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.

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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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Embedded Systems
└─ Architectural patterns
  └─ Process Pipeline

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

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huge amount:

concurrency + multicore is the key

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example:

particle accelerator

chemical reactions

...

if storing not fast, data will be lost

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2012-01-15

Embedded Systems
└Timing analysis
  └Outline

Outline

1. Embedded Systems Design
2. Architectural patterns
3. Timing analysis
4. Real-time operating systems

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Embedded Systems
└ Timing analysis
  └ Timing Analysis - I

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  - aperiodic stimuly $\Rightarrow$ make assumptions

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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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Embedded Systems
Timing analysis
Timing Analysis - II

Timing Analysis - II

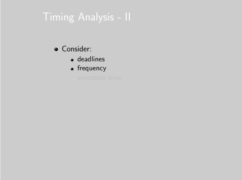
- Consider:
  - deadlines
  - frequency
  - execution time

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

- Consider:
  - deadlines
  - frequency
  - execution time

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

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LAST CELL:

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

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Embedded Systems

└Real-time operating systems

└Outline

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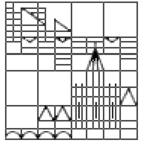

Embedded Systems Design

Architectural patterns

Timing analysis

Real-time operating systems

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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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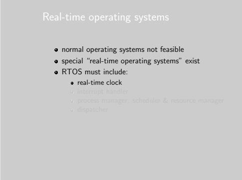

real-time clock:

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:

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  - 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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