2012-01-04

Embedded Systems

Software Engineering in Embedded Systems

Stephan Heidinger

Seminar: Software Engineering
Fachbereich für Informatik und Informationssysteme
Universität Konstanz

19. January 2012

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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

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

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Embedded Systems

└ Motivation

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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Embedded Systems

└Outline

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Embedded Systems
└Embedded Systems Design
└Outline

Outline

Embedded Systems

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

Outline

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

Problems

- Problems in embedded Systems:

Problems

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

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  - deadlines
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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

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environment:

is unpredictable

embedded Software ⇒ must be concurrent

Problems

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

continuity:

embedded Software ⇒ does not normally terminate

software has to be reliable

may need update while operating

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Problems

- Problems in embedded Systems:
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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

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next thing:

not all are necessary, but most will be.

Embedded Systems Design - I

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

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Embedded Systems Design - I

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

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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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Example: radiation warning system

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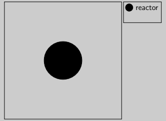

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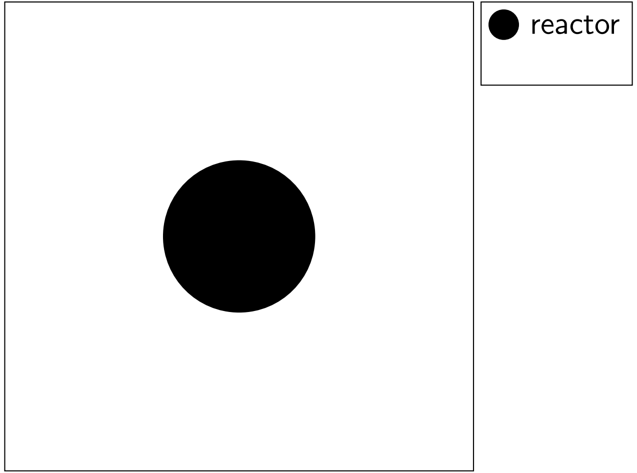

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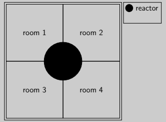

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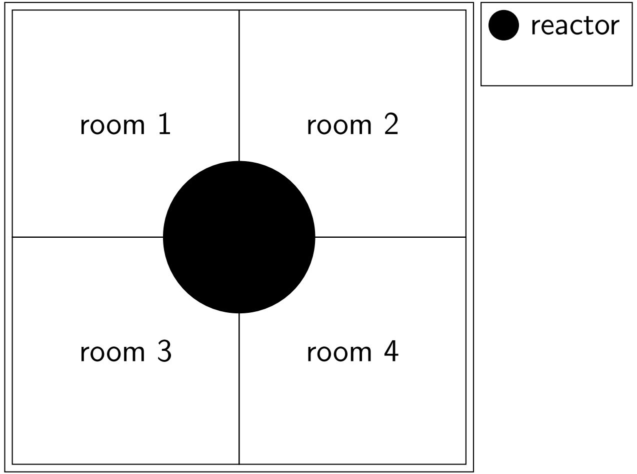

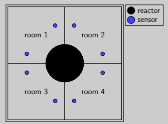

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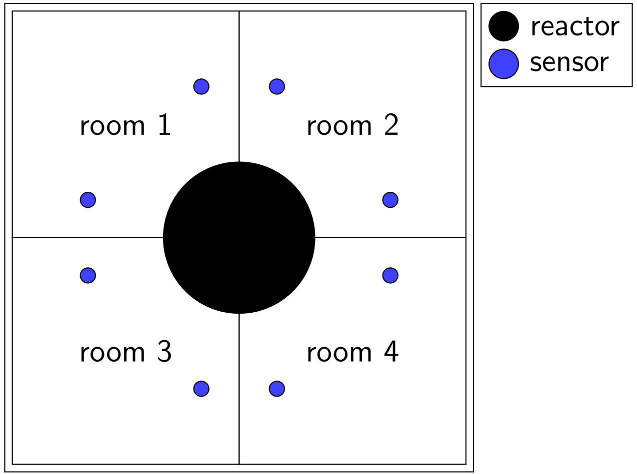

Example: Stimuli-List of a radiation warning system

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LAST CELL:

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└─Embedded Systems Design - II

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

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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 ⇒ design algorithm
especially important for computationally intensive tasks (signal processing)
Do we need to implement these in hardware?

Embedded Systems Design - II

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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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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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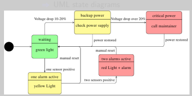
Embedded Systems
└Embedded Systems Design
└Embedded system modeling

Embedded system modeling

- Embedded Systems are often built as state machines.



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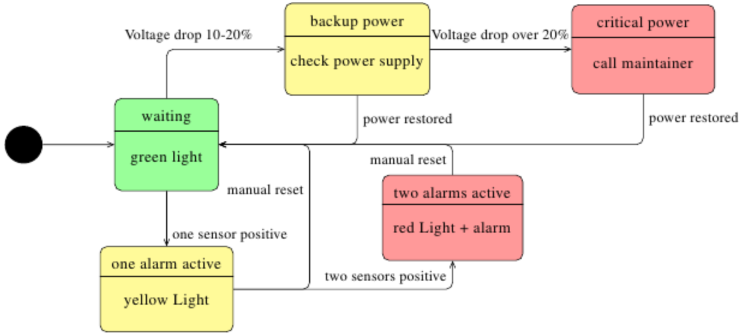
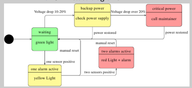
$\Rightarrow$ UML state diagrams





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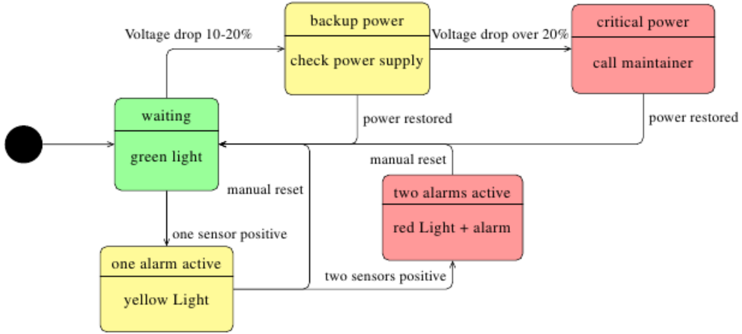
  ⇒ UML state diagrams



Embedded software programing

- 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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Embedded software programing

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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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Outline

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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

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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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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

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Observe and React

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

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monitoring:
as stated before

Observe and React

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

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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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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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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

Process Pipeline

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

- Process Pipeline
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  - 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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2012-01-04

Embedded Systems
└Timing analysis
└Outline

Outline

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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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:

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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voltage drop	switch to backup: 50ms
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turn on light	500ms

LAST CELL:

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Stimulus/Response	Timing requirements
voltage drop	switch to backup: 50ms
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turn on light	500ms
call maintainer	5000ms

Embedded Systems
Stephan Heidinger

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2012-01-04

Embedded Systems
└Real-time operating systems
└Outline

Outline

Embedded Systems

Stephan Heidinger

Outline

Real-time operating systems

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

normal operating systems:

too large, too bulky, too slow

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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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