Software Engineering in Embedded Systems
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Seminar: Software Engineering
Fachbereich für Informatik und Informationssysteme
Universtität Konstanz
19. January 2012

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Embedded Systems

└─Embedded Systems - What's that? - I

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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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"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 - 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

respond to physical world

Embedded Systems - What's that? - II

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Embedded Systems - What's that? - II

resüpm om real time
("have a deadline") → time in which the result is produced

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often have litte resources
i.e. not 'computers'

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run in real time operating systems

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└Embedded Systems - What's that? - III

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- Examples for Embedded Systems:

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
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  - danger detection

airbag:

strict deadline

catastrophic result on failure

Embedded Systems - What's that? - III

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Embedded Systems - What's that? - III

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cell phone:

phone must be answered before call quit vom other side

Embedded Systems - What's that? - III

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burglar alarm:

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coffee machine:

dont want to have coffee, when its cold...

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danger detection:

earthquake, toxins, . . .

depending on the kind of danger, absolutely no time to spare.

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One can produce more examples on a whim especially in cars

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We see:

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 skillsand i did an internship producing an embedded system at PSI

monitoring device for the detector of an particle accelerator

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

this is the structure of my talk:
embedded systems DESIGN
architectural patterns
timing analysis
real-time operating systems

Outline

2012-01-15

Embedded Systems
└Embedded Systems Design
└Outline

Outline

Outline

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

several problems in emb-systems that are not in “normal” systems

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2012-01-15

Problems
- Problems in embedded Systems:
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  - 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

Problems
- Problems in embedded Systems:
  - deadlines
  - environment

environment:

is unpredictable

embedded Software $\Rightarrow$ must be concurrent

Problems

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

continuity:

embedded Software $\Rightarrow$ does not normally terminate

software has to be reliable

may need update while operating

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Problems
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direct hardware interaction:

uncommon hardware (i.e. detonator in airbag)

speed issues (hardware is faster than software)

Problems

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Problems

- Problems in embedded Systems:
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  - safety & reliability

safety & reliability:

cost of failure high

either economical or in human life

Problems

- Problems in embedded Systems:
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design steps

not all are necessary, but most will be.

no definite order

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?

choice of Real-time operating system (later)

power consumption (mobile device, backup)

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special purpose hardware:

What is to be implemented in software, what in hardware

do we need uncommon hardware?

design special hardware?

replace software by hardware?

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think about **stimuli:**
describe behavior of system by listing received stimuli and reactions
stimuli = signals
often: stimulus *Rightarrow* defined response

example AFTER THIS SLIDE

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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 AFTER THIS SLIDE

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Timing analysis:

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

timing constraints $\Rightarrow$ deadlines

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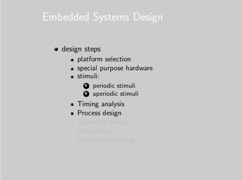

Process design:
aggregate the stimuli & responses into concurrent processes
SEE Architectural patterns

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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? (i.e. control systems)

Embedded Systems Design

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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

- design steps
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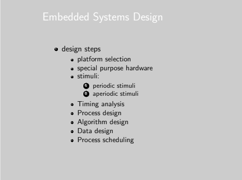

Process scheduling:
ensure, that processes meet their deadline

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

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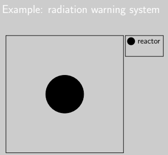
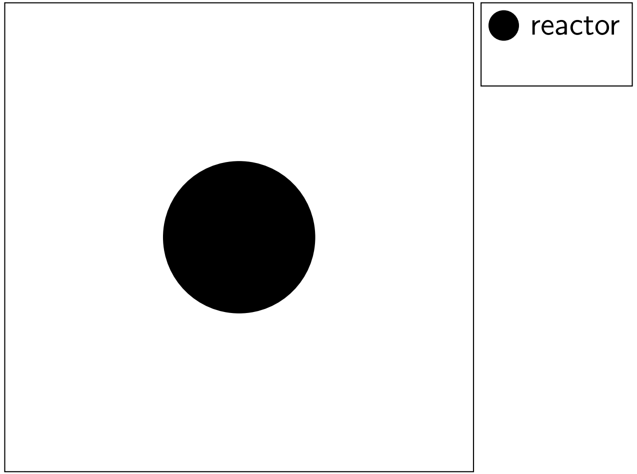
Now for the examples for stimuli:

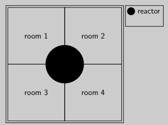
Example: radiation warning system



we have this room with an reactor inside

Example: radiation warning system

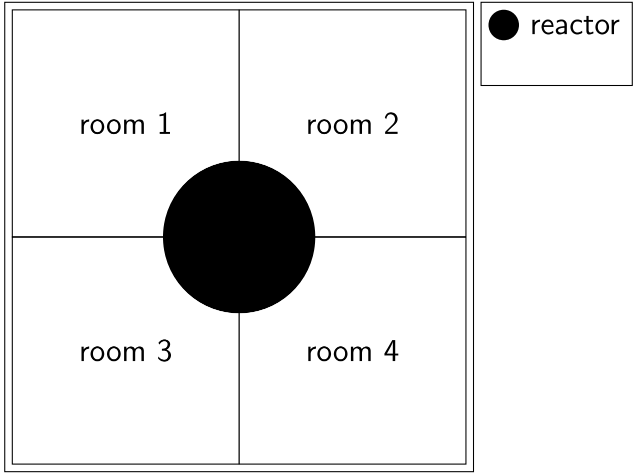


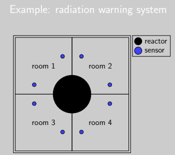


because several people work here, we put several rooms around the reactor

walls are shielded

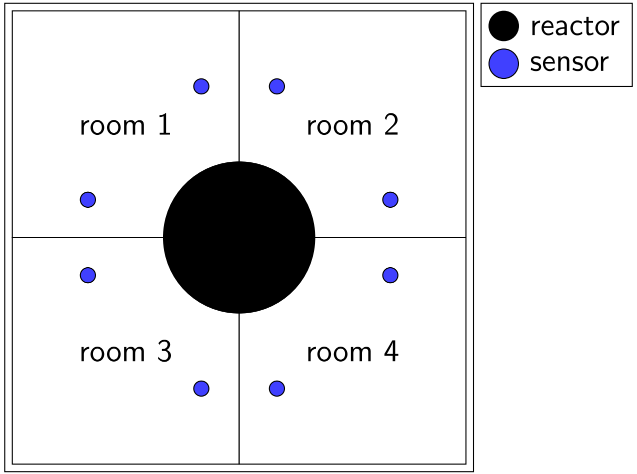
Example: radiation warning system





because people work here, we need some sensors to detect radiation leaks

Example: radiation warning system



Example: Stimuli-List of a radiation warning system

Stimulus	Response

Now we built a list of stimuli and responses

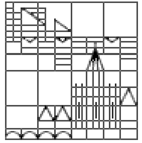
Example: Stimuli-List of a radiation warning system

Stimulus	Response

Example: Stimuli-List of a radiation warning system

Stimulus	Response
single sensor positive	flash yellow light around sensor

single sensor positive
want to warn people, that there is something
flash a yellow light around the sensor



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

Example: Stimuli-List of a radiation warning system

Stimulus	Response
single sensor positive	flash yellow light around sensor

two sensors in one are positive
something is really wrong
flash red light in are
sound alarm

Example: Stimuli-List of a radiation warning system

Stimulus	Response
single sensor positive	flash yellow light around sensor
both sensors in one area positive	flash red light in area, sound acoustic alarm in area

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Stimulus	Response
single sensor positive	flash yellow light around sensor
both sensors in one area positive	flash red light in area, sound acoustic alarm in area
Voltage drop of 10-20%	switch to backup power; run power supply test

small voltage drop
probably nothing bad
switch to backup power
run power supply test

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 technician

big voltage drop
do the same as on small drop
call technician
LAST CELL:

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

Embedded Systems ⇒ often build as state machines

Embedded system modeling

- Embedded Systems are often built as state machines.

  ⇒ UML state diagrams

Embedded system modeling
- Embedded Systems are often built as state machines.
  $\Rightarrow$ UML state diagrams

of course $\Rightarrow$ UML state diagrams
very good for understanding the workings of the system
something like thismodelled stimuli+responses into states
here i modelled two sensor as a result of one sensor $\Rightarrow$ may be done differently

Embedded system modeling

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  $\Rightarrow$ UML state diagrams

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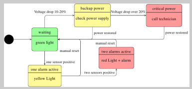
Embedded Systems

Embedded Systems Design

Embedded system modeling



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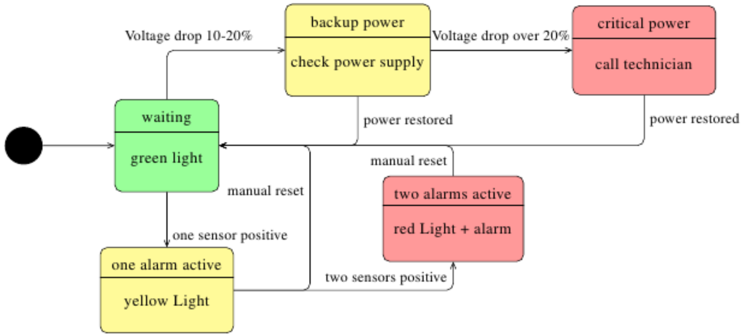

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Embedded Systems
└ Embedded Systems Design
  └ Programming language

Programming language

- program has to be. . . the programming language several things need to be taken into account

  program has to be

Programming language

- program has to be. . . the programming language several things need to be taken into account

  program has to be
  - . . . fast (i.e. C, Asssembler)
  - . . . concurrent (i.e. C++, real time Java, . . .)
- speed looses importance
- it's up to you in the end . . .

fast: C, Assembler:

No concurrency

no built-in system for shared resources

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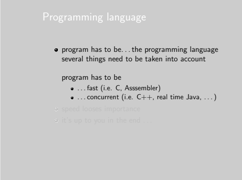

concurrent:
and manage shared resources

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, . . .

still there are some areas, where you need C & assembler. . .

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it's up to you in the end. . .
evaluate the needs and decide. . .

Programming language

- program has to be. . . the programming language
  several things need to be taken into account

  program has to be
  - . . . fast (i.e. C, Asssembler)
  - . . . concurrent (i.e. C++, real time Java, . . .)
- speed looses importance
- it's up to you in the end . . .

2012-01-15

Embedded Systems
└Architectural patterns
└Outline

Outline

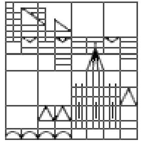
1. Embedded Systems Design
2. Architectural patterns
3. Timing analysis
4. Real-time operating systems

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 the 3 patterns:
The summerville book describes three rough design pattern
there are finer patterns that will lead to more exact design



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Architectural patterns

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  - Observe and react

Observe and React:
set of monitored sensors
Something exeptional happens $\Rightarrow$ we do something
i.e. monitoring, incoming phone call

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Environmental Control:

set of sensors and actuators

can change environment

i.e. flash light, when sensor fires

i.e. control water level in a tank

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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 ⇒ only for understanding system

Architectural patterns

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Observer & React

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:

monitor the system with a set of sensors

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display:

monitoring screen

on exceptional behaviour: alarms, shutdown

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primarly in **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

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

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.

monitor sytem and react to any changes

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no required user interaction

examples:

cruise control

water level

pressure control

. . .

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no time for user interaction

examples:

break assist

airbag

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no way for user interaction

example:

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

self desctruct of military/sensitive equipment

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too much information for users

example:

Nuclear Power Plant

Airplane

Car

virtually any big system with many subsystems

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2012-01-15

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

transform data

examples:

signal processing from sensors in other systems

optical sensor

convert digital data to audio

Process Pipeline

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  - 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

huge amount in real time:

concurrency + multicore is the key

Process Pipeline

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Process Pipeline

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  - data aquisition system: storing of data may need to be fast

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

Process Pipeline

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2012-01-15

Embedded Systems
└Timing analysis
└Outline

Outline

Outline

timing analysis

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

Timing Analysis - I

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  - aperiodic stimuly $\Rightarrow$ make assumptions

not only result, also time is important
soft and hard systems

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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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aperiodic stimuli:
make assumptions
vspace*1em **fast systems:**
use only periodic stimuli
poll frequently for aperiodic stimuli

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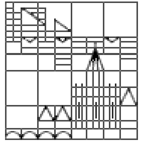
Timing analysis must consider:



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
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  - execution time

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

We list stimuli and response
then think about how fast this needs to work

Stimulus/Response Timing requirements

voltage drop ⇒ 50ms

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

Stimulus/Response	Timing requirements
voltage drop	switch to backup: 50ms
sensor reaction	poll twice a second

sensor reaction ⇒ poll twice a second

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Stimulus/Response | Timing requirements
voltage drop | switch to backup: 50ms
sensor reaction | poll twice a second
turn on light | 500ms

turn on light ⇒ 500ms

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Stimulus/Response	Timing requirements
voltage drop	switch to backup: 50ms
sensor reaction	poll twice a second
turn on light	500ms
call technician	5000ms

call technician ⇒ 5000ms
may take longer, as technician reaction time is low anyways**LAST CELL:**

Stimulus/Response	Timing requirements
voltage drop	switch to backup: 50ms
sensor reaction	poll twice a second
turn on light	500ms
call technician	5000ms

2012-01-15

Embedded Systems
Real-time operating systems
Outline

Outline

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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normal operating systems not feasible
special "real-time operating systems" exist
real-time clock
interrupt handler
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dispatcher

real-time operating systems:

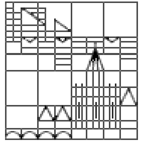
Windows/CE

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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Embedded Systems Design
Architectural patterns
Timing analysis
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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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nearly done

important stuff in short

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 reacting to stimuli
  - State models help understanding the System.
  - Architectural patterns can be used to help in designing the system.
  - Always do timing analysis in (hard) Embedded Systems.

Embedded Systems
react to events in real time

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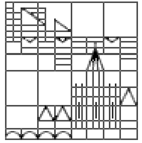
Embedded Systems
react to events in real time
are a set of processes reacting to stimuli
state models
help understanding the system**Architectural patterns**
help designing the system especially first steps



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