Technische Universität Braunschweig

Course: Energy Efficiency in Embedded Systems

A System-Level Perspective for Computer Scientists

Ulf Kulau, EWME 2018-09-25

TU Braunschweig

Motivation

A typical situation at university....

- A simple task assignement for some CS students
  - Implement an embedded system that samples a temperature value each 5s
  - Please be aware of energy efficiency!

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... after a little while

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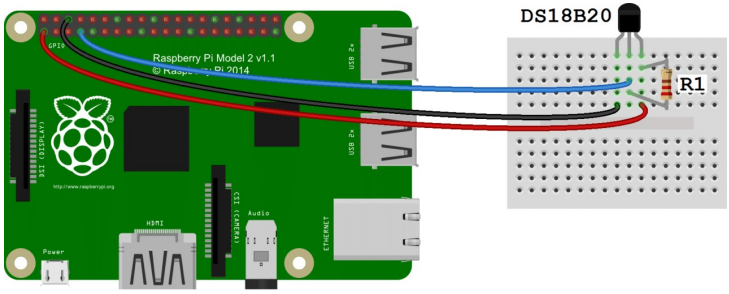
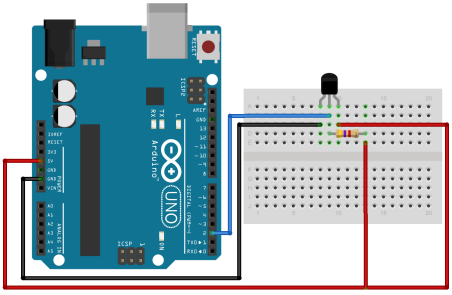


Maybe a bit overkill for this application...

Motivation



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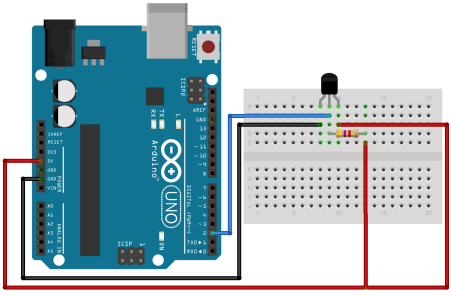
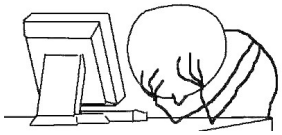


```
void loop(void){
…

 Serial.print("Temperature is: ");
 Serial.print(sensors.getTempCByIndex(0));
 Delay(5000);
}
```



We need to talk...

Motivation

Reasons to establish a course on energy efficiency for computer scientists

- Low power has been the focus of hardware designers for decades with great advances have been made in low power designs
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Software controls the Hardware!

- Energy efficiency can not be ignored when developing software
- But, most software developers are blissfully unaware of the impact their decisions have on energy consumption

Challenge

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"If you want an ultimate low-power system, then you have to worry about energy usage at every level in the system design, and you have to get it right from top to bottom, because any level at which you get it wrong is going to lose you perhaps an order of magnitude in terms of power efficiency."

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Overall goal: Close the skills gap between low-level hardware and high level system stack

Structure of the course

General Structure

- Lecture
  → Currently 9 classical lectures of about 90min each

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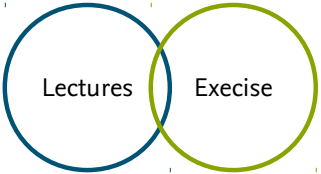

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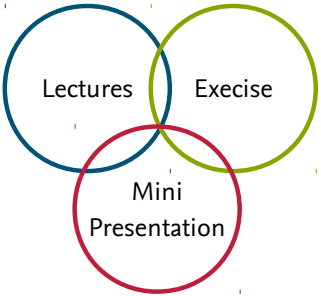
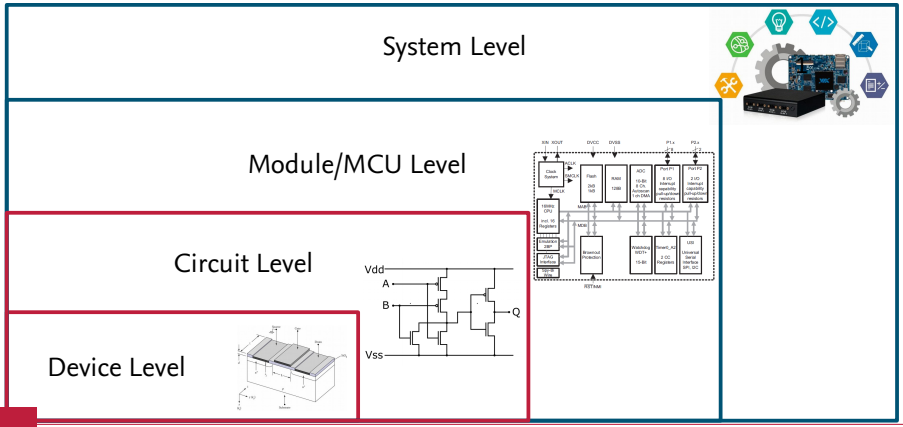


- Lecture
  → Currently 9 classical lectures of about 90min each
- Exercises
  → Currently 6 exercises (mainly calculation tasks)
- Mini-Presentations
  → Students are encouraged to prepare a mini presentation on recent research

Content

4 levels to get the link between Hard- and Software in terms of Energy Efficiency



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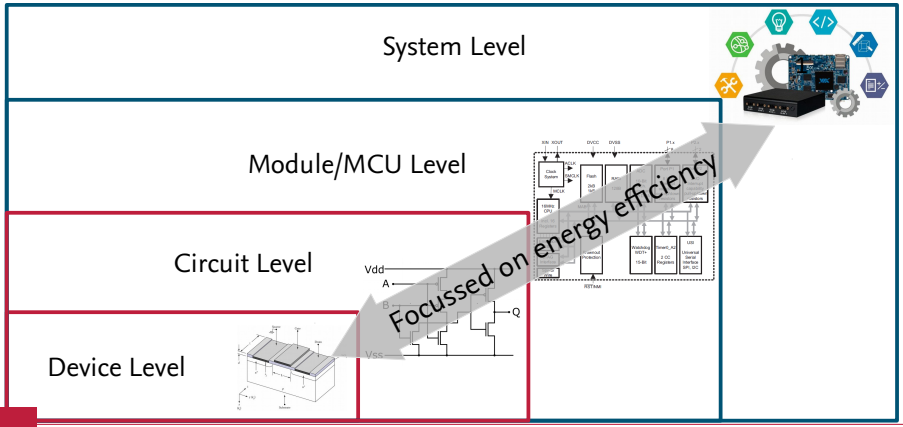

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Device Level

- Basics and the power dissipation of semiconductors / processing elements
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- Energy consumption of different circuit technologies
  - TTL vs. RTL vs. CMOS
- Extensive review of CMOS power dissipation (of course)

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- Energy consumption of different circuit technologies
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→ CS students usually not control these levels
→ Fundamentals are highly important to understand connections and dependencies

Content levels

Module/MCU Level

- Energy management mechanisms and their limitations (drawbacks and overhead)
  - sleep states (clock- and power gating), frequency and voltage scaling, DMA, undervolting schemes
- Online and offline scheduling mechanisms

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System Level

- General system design
  - Voltage conversion and the selection and dimension of components/devices
- Efficient application software
- Energy Harvesting, Energy Neutral Computing and Transiently Powered Computing

Content overview

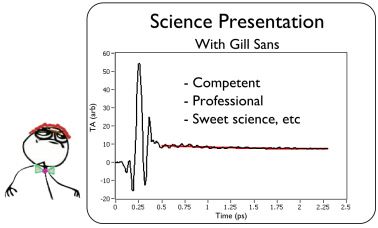
Lecture	Exercise
00 Organization and Topics	Exercise 1:
01 Motivation and Power Dissipation	
02 Digital Circuits	Exercise 2
03 Sleep Modes (Power- and Clock Gating)	Exercise 3
04 Frequency and Voltage Scaling	Exercise 4
05 Undervolting (active)	Exercise 5
06 Undervolting (passive)	
07 Energy Harvesting and TPC	Exercise 6
08 Recent Research and Application Layer Optimization	-

- Lectures and exercises are discussed in the paper extensively!

Mini-Presentations

Idea

- Create a more interactive course
- Enforcing students to discuss on the lecture's topics



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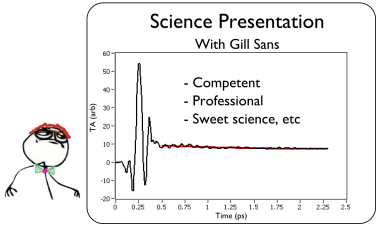

Workflow

1. A paper of a recent conference is assigned to each student
   - Of course, conferences related to the course, e.g. ISLPED, ENSYS, IoNET, ...
2. Preparation of a short presentation (10-15min)
   - *content*, the *concepts* and the *connection to the course*
3. Critical examination / discussion together with all students

Evaluation of the course

First course was held this summer term 2018

- 15 participants (2/3 CS students)
- Educational evaluation (Questionnaire)

→ Overall Rating:	1.4 (1='verry good', 5='verry poor')
→ Comparison against other courses:	1.6 (1='better', 5='worse')
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Critics

- Course was held for the first time → missing literature list at the beginning
  - This EWME paper contains the majority of used references

Future Extensions

Currently the course is still heavy on hardware related topics...

- Extension by one or two lectures on pure software related approaches
  - Analysis and profiling tools
  - Modeling and energy estimation
  - Frameworks and tools for energy efficient coding

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Practical course

- Next winter term 2018/19 we start a practical course
- Programming and implementation of simple tasks on a solar-energy harvesting platform
  - e.g. how to implement an energy neutral temperature logger

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Evaluation and future extension

- Positive evaluation and helpful feedback
- Extension (more software approaches) and practical course

Fin

Thank you for your attention!

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