Embedded Systems

Jian-Jia Chen
(slides are based on
Peter Marwedel)
TU Dortmund,
Informatik 12

2016年 10月 18 日
Structure of the course

Course organizations

- OH 14, E23, Tuesday 10:15-11:45 and Wednesday 10:15 – 11:45
  - 18 sessions of lectures, including today
  - 7 sessions of on-site exercises with *interactions*
    - The exercises will be available one week before the session in the website. *Bring/print the assignment yourself!*
    - The on-site (theoretical) exercises will not be graded
- Tuesday, Wednesday, and Friday
  - 12 hand-on lab sessions (starting next week) *Register is needed*
  - Two blocks 7 sessions + 5 sessions
  - 50% performance of each block for the admission to the final exam
  - You should expect certain points (in final exam) are *directly* related to the topics assigned in the labs
- Material
  - Course website. You are expected to find it yourself
What is an embedded system?
Motivation for course (1)

According to forecasts, future of IT characterized by terms such as

- Post-PC era,
- Disappearing computer,
- Ubiquitous computing,
- Pervasive computing,
- Ambient intelligence,
- Cyber-physical systems.
- Internet of Things (IoT)

Basic technologies:

- *Embedded System technologies*
- Communication technologies
Motivation for Course (2)

National Research Council Report (US) 
Embedded Everywhere, 2001:

“Information technology (IT) is on the verge of another revolution. …..

networked systems of embedded computers ... have the potential to change radically the way people interact with their environment by linking together a range of devices and sensors that will allow information to be collected, shared, and processed in unprecedented ways. ...
The use … throughout society could well dwarf previous milestones in the information revolution.”
The future is embedded, embedded is the future
Textbook(s)

Several editions/translations:

- 1st edition
  - English
    - Original hardcover version
    - Reprint, soft cover, 2006
  - German, 2007
  - Chinese, 2006
  - Macedonian, 2010

- 2nd edition, with CPS
Concept of CPS & ES Education at Dortmund

- Integrated as a specialization into CS curriculum

- Programming
- Algorithms
- Computer organization
- OS & networks
- Math education
- EE fundamentals

Lab

first course on embedded & CP systems

+ courses for minor degree

control systems
DSP
machine vision
real-time systems
middleware
applications

Lego, μC, OS

undergraduate

graduate level

Lab

thesis

project

Lab
## Structure of the CS curriculum at Dortmund

- **3 year bachelor program**

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Programming &amp; semantics</th>
<th>Math education</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer organization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Circuits &amp; communication</td>
<td>OS</td>
<td>Algorithms</td>
</tr>
<tr>
<td>3</td>
<td>HW lab</td>
<td>Networks</td>
<td>SW lab</td>
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<tr>
<td>4</td>
<td></td>
<td>Databases</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Embedded systems fundamentals</td>
<td>Software engineering</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bachelor project + Thesis</td>
<td></td>
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</tbody>
</table>

*All dependences met*
Broad set of topics

1. Introduction

2. Specification and modeling

3. CPS/ES hardware

4. CPS/ES system software

5. Evaluation

6. Mapping of applications to execution platforms

7. Optimizations

8. Test
# Schedule (1)

<table>
<thead>
<tr>
<th>Date</th>
<th>Book</th>
<th>Topic</th>
<th>Lecturer</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct. 18th</td>
<td>Preface, 1.1-2</td>
<td>Intro, definitions, area, characteristics</td>
<td>Chen</td>
<td>1</td>
</tr>
<tr>
<td>Oct. 19th</td>
<td>1.3-2.2</td>
<td>Design flows, MoC</td>
<td>Chen</td>
<td>2</td>
</tr>
<tr>
<td>Oct. 25th</td>
<td>2.1-2.4.3</td>
<td>Early phases, statecharts, timed automata, synchronous languages</td>
<td>Chen</td>
<td>3</td>
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<tr>
<td>Oct. 26th</td>
<td>2.4.4-2.5.3</td>
<td>SDL, data flow, SDF, Kahn process netw.</td>
<td>Chen</td>
<td>4</td>
</tr>
<tr>
<td>Nov. 2nd</td>
<td>(Sessions 1-3)</td>
<td>Exercise 1</td>
<td>Ingo</td>
<td>A</td>
</tr>
<tr>
<td>Nov. 8th</td>
<td>2.6-2.7</td>
<td>Petri nets, Discrete event model</td>
<td>Chen</td>
<td>5</td>
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<tr>
<td>Nov. 9th</td>
<td>2.8, 2.10</td>
<td>Imperative model, comparison of MoCs</td>
<td>Chen</td>
<td>6</td>
</tr>
<tr>
<td>Nov. 15th</td>
<td>3.1-3.2</td>
<td>Sensors &amp; sampling</td>
<td>Chen</td>
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</table>
## Schedule (2)

<table>
<thead>
<tr>
<th>Date</th>
<th>Book</th>
<th>Topic</th>
<th>Lecturer</th>
<th>Session</th>
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</thead>
<tbody>
<tr>
<td>Nov. 16th</td>
<td>(Sessions 4-6)</td>
<td>Exercise</td>
<td>Chen</td>
<td>B</td>
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<tr>
<td>Nov. 22nd</td>
<td>3.3.3.3-3.4</td>
<td>Execution platforms</td>
<td>Chen</td>
<td>8</td>
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<tr>
<td>Nov. 23rd</td>
<td>3.5-3.7</td>
<td>Communication, sampling theorem</td>
<td>Chen</td>
<td>9</td>
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<tr>
<td>Nov. 29th</td>
<td>4.1</td>
<td>System SW, RTOS</td>
<td>Ingo</td>
<td>10</td>
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<tr>
<td>Nov. 30th</td>
<td>(Sessions 7-8)</td>
<td>Exercise</td>
<td>Ingo</td>
<td>C</td>
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<tr>
<td>Dec. 6th</td>
<td>6.1-6.2.3</td>
<td>Aperiodic Scheduling</td>
<td>Chen</td>
<td>11</td>
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<tr>
<td>Dec. 7th</td>
<td>6.2.4-6.3</td>
<td>Periodic Scheduling</td>
<td>Chen</td>
<td>12</td>
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<tr>
<td>Dec. 13th</td>
<td>4.1</td>
<td>Priority Inheritance</td>
<td>Chen</td>
<td>13</td>
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<tr>
<td>Dec. 14th</td>
<td>(Sessions 9-11)</td>
<td>Exercise</td>
<td>Chen</td>
<td>D</td>
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<tr>
<td>Date</td>
<td>Book</td>
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<tr>
<td>Jan. 10th</td>
<td>4.2-4.5</td>
<td>Evaluation, Pareto optimality, Integer Linear Programming</td>
<td>Chen</td>
<td>14</td>
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<tr>
<td>Jan. 11th</td>
<td>5.1-5.2.3</td>
<td>WCET, Real-Time Calculus</td>
<td>Chen</td>
<td>15</td>
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<tr>
<td>Jan. 17th</td>
<td>(Sessions 12-13)</td>
<td>Exercise</td>
<td>Chen</td>
<td>E</td>
</tr>
<tr>
<td>Jan. 18th</td>
<td>5.3-5.8</td>
<td>Energy and power models, thermal models, dependability</td>
<td>Chen</td>
<td>16</td>
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<tr>
<td>Jan. 24th</td>
<td>(Sessions 14-15)</td>
<td>Exercise</td>
<td>Chen</td>
<td>F</td>
</tr>
<tr>
<td>Jan. 25th</td>
<td>6.3.2, 6.4</td>
<td>Hardware/Software Partitioning, Mapping</td>
<td>Chen</td>
<td>17</td>
</tr>
<tr>
<td>Jan. 31rd</td>
<td>7</td>
<td>Overview of optimizations and Real-Time Communication</td>
<td>Chen</td>
<td>18</td>
</tr>
<tr>
<td>Feb. 1st</td>
<td>(Sessions 16-18)</td>
<td>Exercise</td>
<td>Chen</td>
<td>G</td>
</tr>
</tbody>
</table>
Exams

Test exam (only for you to understand the style of the exam)

- Tue., 07.02.2017, OH14, E23

There are two final exams in March.

- You need to get the admission (50% in lab)
- 1. Mi, 01.03.2017, 10:30-12:00
- 2. Di, 11.04.2017, 08:30-10:00
- Remember to register at least 14 days before the exam

Lehramt Studenten

- Oral exam is by appointments.
Slides

- Slides are available at the course web site
- Master format: (mostly) Powerpoint (2010 –new-);
- Derived format: PDF
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Introduction of Embedded Systems

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(slides are based on Peter Marwedel)
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Informatik 12

2016年 10 月 18 日
Embedded Systems & Cyber-Physical Systems

“Dortmund” Definition: [Peter Marwedel]

Embedded systems are information processing systems embedded into a larger product

Berkeley: [Edward A. Lee]:
Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.

Cyber-Physical (cy-phy) Systems (CPS) are integrations of computation with physical processes [Edward Lee, 2006].

Cyber-physical system (CPS) = Embedded System (ES) + physical environment
Cyber-physical systems and embedded systems

CPS = ES + physical environment

Cyber-physical systems

Embedded systems ("small computers")

Embedded systems ("computers in physical environments")
What is a Cyber-Physical System?

Extreme view:

Digital Controls Systems, ca. 1980

Cyber-Physical Systems, 2010+!
Definition according to National Science Foundation (US)

Cyber-physical systems (CPS) are engineered systems that are built from and depend upon the synergy of computational and physical components. Emerging CPS will be coordinated, distributed, and connected, and must be robust and responsive. The CPS of tomorrow will need to far exceed the systems of today in capability, adaptability, resiliency, safety, security, and usability.

Examples of the many CPS application areas include the smart electric grid, smart transportation, smart buildings, smart medical technologies, next-generation air traffic management, and advanced manufacturing.
CPS: Integration of Cyber and Physics

Cyber

Physics

CPS
Definition according to akatech

The physical world and the virtual world – or cyber-space – are merging; cyber-physical systems are developing. Future cyber-physical systems will contribute to security, efficiency, comfort and health systems as never before, and as a result, they will contribute to solving key challenges of our society, such as the aging population, limited resources, mobility, or energy transition.

Extending the motivation: Embedded systems and ubiquitous computing

Ubiquitous computing: Information anytime, anywhere. Embedded systems provide fundamental technology.

Communication Technology
- Optical networking
- Network management
- Distributed applications
- Service provision
- UMTS, DECT, Hiperlan, ATM

Embedded Systems Techn.:
- Robots
- Control systems
- Feature extraction and recognition
- Sensors/actuators
- A/D-converters

Pervasive/Ubiquitous computing
- Distributed systems
- Embedded web systems
Growing importance of CPS and ES

- 49.7% of Americans own smartphones
  [www.itfacts.biz, March 31, 2012]
- …, the market for remote home health monitoring is expected to generate $225 mln revenue in 2011, up from less than $70 mln in 2006, according to Parks Associates. [www.itfacts.biz, Sep. 4th, 2007]
- Funding in the 7th European Framework
- Funding in Horizon 2020
- Creation of the ARTEMIS Joint Undertaking in Europe
- Funding of CPS research in the US
- Joint education effort of Taiwanese Universities
- …
Growing importance of cyber-physical & embedded systems (2)

- *.. but embedded chips form the backbone of the electronics driven world in which we live ... they are part of almost everything that runs on electricity* [Ryan, EEDesign, 1995]

- Foundation for the “post PC era“

- CPS & ES hardly discussed in other courses

- CPS & ES important for TU Dortmund

- CPS & ES important for many industries

- Scope: sets context for specialized courses
Application areas and examples
Application area avionics: also cyber-physical

- Flight control systems,
- anti-collision systems,
- pilot information systems,
- power supply system,
- flap control system,
- entertainment system,
- …

Dependability is of outmost importance.
More application areas:

- railroad

- water ways

Dependability is of outmost importance.
Logistics

Applications of embedded/cyber-physical system technology to logistics:

- Radio frequency identification (RFID) technology provides easy identification of each and every object, worldwide.
- Mobile communication allows unprecedented interaction.
- The need of meeting real-time constraints and scheduling are linking embedded systems and logistics.
- The same is true of energy minimization issues.
Internet of Things

Internet of things and services

Energy Harvesting, 400lx Solar cell

Energy storage
7,000 Telegrams without re-charging

ePaper-Grafik-Display

32 Bit μProcessor
<=25 MHz, 512kRAM

256bit Crypto processor

Innovationspartner:
Würth Industrie Services GmbH
Debrunner Koenig Management AG

© Fraunhofer IML, Dortmund
Fabrication

Production resources are self-configuring and distributed *social machines*

Industry 4.0

© Fraunhofer IML, Dortmund
Structural safety

Sensors + data analysis

Möhne lake dam

Kilauea, Hawaii

Bridge at Vancouver

Taipeh 101

© Photos: P. Marwedel
Smart Home

- Zero energy building, generates as much energy as it consumes
- Provides safety and security
- Supports owners
- Provides maximum comfort
- Ambient assisted living

© P. Marwedel
Integration of Physics and Cyber in Physical Experiments
More application areas

- Telecommunication
- Consumer electronics
- Robotics
- Public safety
- Military systems

Mostly cyber-physical
Connecting previously isolated systems
Scope avoids problems with narrow perspectives reported by ARTIST


“The lack of maturity of the domain results in a large variety of industrial practices, often due to cultural habits”

“curricula … concentrate on one technique and do not present a sufficiently wide perspective.”

“As a result, industry has difficulty finding adequately trained engineers, fully aware of design choices.”
"The development of ES cannot ignore the underlying HW characteristics. Timing, memory usage, power consumption, and physical failures are important."

\[ \int P \, dt \]

"It seems that fundamental bases are really difficult to acquire during continuous training if they haven’t been initially learned, and we must focus on them."
Summary

- A look at the future of IT
- Definition: embedded & cyber-physical (cy-phy) systems
- Growing importance of embedded & cy-phy systems
- Application areas & examples