University of Twente
Enschede - The Netherlands

3TU.

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

The 3TU Embedded Systems master in the Netherlands

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Content

- Background
- What is special for Embedded Systems
- Admission and programme structure
- Individual programmes of the three involved universities
- Conclusion

Background (1)

- Master program ES of three technical universities
  - University of Twente
  - Technical university of Eindhoven
  - Technical university of Delft
- What is it
  - 2 year master program
  - Multidisciplinary master addressing Embedded Systems design
  - Closely connected to research expertise of groups
  - Started in 2007
- Why an ES master?
  - Knowledge gap between disciplines, e.g.:
    - EE students: lack skills in software abstractions
    - CS students: lack skills in continuous math and feeling for physical world
  - Understand language of other disciplines

Background (2)

- Why 3TU master ES?
  - Industry needs many ES engineers
  - Educate to a common knowledge level
  - Each individual university has its own research expertise
  - Students can select more specialization courses from 3TU research groups
  - Reuse course material of other universities
    - Experiments with tele-lectures

Background (3)

- 3TU is a federation of 3 TUs
- Supported by Dutch government to promote collaboration between 3 TUs
  - Research
    - CEDICT: Centre for Dependable ICT
    - 3 research labs (o.a. software dependability (Laquso))
  - Education
    - Joint master programs
      - Embedded Systems
      - Sustainable technology
  - Promote collaboration between various ES groups
    - STW NEST project (10 PhD students)

What is characteristic for ES

A. Systems approach
B. Multidisciplinary
C. Resource boundedness
D. Dependability

- Remark:
  - Goal ES master:
    - EE and CS engineers should be able to jointly design and implement embedded systems. Therefore, EE researchers should understand the language of CS researchers (and vice versa) and they should understand the language of application domain researchers.
  - it is not the intention (nor possible) of this master to ‘retrain’ CS Bachelors to EE masters, nor EE Bachelors to CS masters

Systems approach

- Interaction with the physical world
- Mix of functional and non-functional specs (like time, energy, size, …)
- Often domains lack the common background and technical language to interact efficiently
- Optimizations can only performed well when all relevant aspects of the system are modeled → holistic approach

- Requires fundamental changes in engineering education: from small scope to broad view

Multidisciplinary

- Embedded Systems touches many technical disciplines
  - computer science, electrical engineering, mechanical engineering, real-time computing, systems architecture, control engineering, signal processing, security and privacy, computer networking, mathematics, human machine interaction, sensors and actuators, …
- and many application domains
  - infotainment, transport and logistics,
  - health and wellness,
  - security and safety,
  - industrial control systems for copiers or wafer steppers,
  - energy management systems,
  - ….

Resource boundedness

- Key difference with standard CS masters
- Examples of resource bounds:
  - Time
  - Energy
  - Size
  - Data / program memory
  - Chip area
  - Development costs
  - ….
- Often a tradeoff / optimization has to be made

Dependability

- Embedded Systems often work in ‘life critical’ environments
  - Health monitoring of persons
  - Car control systems
  - ..
- Often no simple software updates possible after installation
  - But typical Embedded Systems are software dominated!
- Not possible / cost effective to have triple modular redundant systems

Admission to 3TU master

- Admission
  - Direct
    - Students with a completed bachelor CS or EE of UT, TU/e or TUD
  - Direct via Admission Committee
    - Students with bachelor CS or EE from elsewhere
  - Via Admission Committee with bridging program
    - Students with Polytechnic bachelor degree
    - Students with knowledge deficit
- Additional requirement
  - All lectures are in English → IELTS score (reading and writing) of > 6.5

General programme structure

- Pre-master (up to 30 EC)
  - Bridging courses 30 EC
- First year (60 EC)
  - Homologation courses ± 20 EC
  - Mandatory courses ± 20 EC
  - Elective courses ± 20 EC
- Second year (60 EC)
  - Internship or electives 20 EC
  - Master thesis 40 EC

Programme UT

- Homologation (20 EC)
  - For CS students
    - (156081) Systems and Transformation (5 EC)
    - (121000) Instrumentation of Embedded Systems (5 EC)
    - (121044) Control Theory (5 EC)
    - (121034) Physical modeling of Embedded Systems (5 EC)
  - For EE students
    - (213505) Programming (5 EC)
    - (214012) System validation (5 EC)
    - (213510) Software Engineering Models (5 EC)
    - (211045) Operating systems (5 EC)
- Mandatory courses (20 EC)
  - (21302) Embedded Computer Architectures I (5 EC)
  - (213050) Quantitative Evaluation of Embedded Systems (5 EC)
  - (121165) Multi-disciplinary design project (10 EC)
- Elective courses (20 EC)
  - Coherent set of courses from list of EE/CS master courses
- Internship or electives (20 EC)
- Master thesis (40 EC)
  - Individual project (10 EC)
  - Final project (30 EC)

Course descriptions UT

Homologation for CS students (1)

- (121000) Instrumentation of Embedded Systems (5 EC)
  - Topics: properties of electronic measurement systems, signal description in both time- and frequency domain, complex transfer functions, impedances, Bode plots, semiconductor diodes, photodiodes, LEDs. Operational amplifiers. Passive and active filters. Sensors. AD and DA converters. Virtual instrumentation.
- (121034) Physical modeling of Embedded Systems (5 EC)
  - The aim of the course is to learn to model and analyze the dynamic behavior of engineering systems, in which multiple physical domains may be present (e.g. a loudspeaker, an electronically driven fluid-pump, a gear-box and an electric motor). Bond graphs are used as a modeling language: the system is represented, independent of the physical domain(s), in elementary behaviors with their mutual relations.

Course descriptions UT

Homologation for CS students (2)

- (156081) Systems and Transformation (5 EC)
  - In this course we give an introduction in the theory of signals and transformations. We introduce standard signals such as the unit-step and the delta puls. Furthermore, we introduce the Fourier series as the transform for periodic signals, the Fourier integral as the transform for bounded signals , and the Laplace transform for causal signals. We illustrate the usefulness of these transformations by different applications; e.g. filter design, Shannon's sampling theorem, and solving ordinary differential equations.
- (121044) Control Theory
  - Contents: Description of dynamical systems in the s-domain, the frequency domain and with state-space models. Step responses. Block diagrams, signal flow graphs, sensitivity and stability. Design cycle of a control system, design of control systems in the s-domain (root locus) and frequency domain (Bode plots). Introductory treatment of state feedback, non-linear systems and digital control systems.

Course descriptions UT

Mandatory courses

- (21302) Embedded Computer Architectures I (5 EC)
  - In this course we study hardware architectures for embedded systems. The following architectures will be evaluated: super scalar, VLIW, EPIC, parallel architectures MIMD, SIMD, NUMA, UMA, SoC with networks on-chip, streaming architectures, coarse-grain reconfigurable architectures, fine-grain FPGA.
- (213050) Quantitative Evaluation of Embedded Systems (5 EC)
  - In this lecture we study analytical and numerical techniques that help in evaluating extra-functional system properties at design time. Next to these techniques, also techniques originating from the area of real-time scheduling, real-time calculus and worst-case execution times will be presented. Extra-functional systems properties to be evaluated include performance, reliability, availability, and power-usage.
- (121165) Multi-disciplinary design project (MDDP) (10 EC)
  - MDDP is cooperative design project. All the design cycles (specification, design, realization, and testing/validation) are addressed. MDDP is strictly planned, with a project plan and a project presentation after 1/3rd of the time. Also a final report and presentation must be presented. The topics of MDDP are typical for the research of the group hosting it.

Programme TU/e

- Homologation
  - For EE students
    - 2IP25 Software engineering (3 EC)
    - 2IL05 Data structures (6 EC)
    - 5HH00 Electronics for embedded systems (3 EC)
  - For CS students
    - 5DD17 Circuit analysis (3 EC)
    - 5DD30 Signals (5 EC)
    - 5HH00 Electronics for embedded systems (3 EC)
- Mandatory courses (45 EC)
  - 2II45 Architecture of distributed systems (5 EC)
  - 2IN25 Real-time architectures (5 EC)
  - 2IW25 Requirement analysis, design and verification (5 EC)
  - 5KK60 Systems on Silicon (5 EC)
  - 5KK70 Platform-based design (5 EC)
  - 2IW15 Automated reasoning (5 EC)
  - 4C390 Performance analysis of embedded systems (5EC)
  - 5KK03 Embedded systems laboratory (5 EC)
  - 5KK80 Multiprocessors (5 EC)
- Elective courses (45 EC)
  - Internship (optional) (15 EC)
- Master thesis (30 EC)

Programme TU Delft

- Homologation courses
  - For EE students
    - ET4174 System Programming in C (3 EC)
    - IN2305-B Embedded Programming (4 EC)
    - IN2611WI Software Engineering (6 EC)
    - IN3205 Software Testing and Quality (4 EC)
  - For CS students
    - IN2405-I Signal Processing (4 EC)
    - SC4180ES Modeling and Control (6 EC)
- Mandatory courses
  - ET4165 Embedded Computer Architecture (6 EC)
  - ET4367 Performance Analysis of Communications Networks and Systems (6 EC)
  - IN4024 Real-Time Systems (6 EC)
  - IN4073 Embedded Real-Time Systems (6 EC)
  - IN4087 System Validation (4 EC)
- Elective courses (34 – 42 EC)
  - From a list of electives
- Master thesis (40 EC)
  - Individual research project (10 EC)
  - Final project (30 EC)

Implementation Systems Approach

- TU/e
  - Architecture of distributed systems
  - Requirement analysis, design and verification
  - Multiprocessors
- UT
  - Quantitative Evaluation of Embedded Systems
  - Control Theory
  - Systems and Transformation
  - Physical modelling of Embedded Systems
- TU Delft
  - Embedded real-time systems
  - Modeling and control

Multidisciplinary approach

- TU/e
  - Embedded systems laboratory
  - Requirement analysis, design and verification
  - Platform based design
- UT
  - Multidisciplinary design project
  - Physical modeling of Embedded Systems
  - Instrumentation of Embedded Systems
- TU Delft
  - System validation
  - Embedded real-time systems

Resource boundedness

- TU/e
  - Performance analysis of embedded systems
  - Real-time architectures
- UT
  - Quantitative Evaluation of Embedded Systems
  - Embedded Computer Architectures I
  - Energy-efficient Embedded Systems
  - Real-time systems I and II
- TU Delft
  - Embedded Computer Architecture
  - Real-time Systems
  - Performance analysis of Communication
  - Networks and Systems
  - Embedded real-time systems

Dependability

- TU/e
  - Automated reasoning
  - Requirement analysis, design and verification
- UT
  - Quantitative Evaluation of Embedded Systems
  - Reliability Engineering
  - Fault tolerant digital systems
- TU Delft
  - System validation
  - Software testing and Quality

	TU/e	UT	TU Delft
SYSTEMS APPROACH	• Architecture of distributed systems • Requirement analysis, design and verification • Multiprocessors	• Quantitative Evaluation of Embedded Systems • Control Theory, Systems and Transformation and Physical modelling of Embedded Systems. • Multi-disciplinary design project	• Embedded real-time systems • Modelling and control
MULTIDIS-CIPLINARY APPROACH	• Embedded systems laboratory • Requirement analysis, design and verification • Platform based design	• Multidisciplinary design project • Physical modelling of Embedded Systems and Instrumentation of Embedded Systems;	• System validation • Embedded real-time systems
RESOURCE BOUNDED-NESS	• Performance analysis of embedded systems • Real-time architectures	• Quantitative Evaluation of Embedded Systems • Embedded Computer Architectures I • Energy-efficient Embedded Systems • Real-time systems I and II	• Embedded Computer Architecture • Real-time Systems • Performance analysis of Commu-nication Networks and Systems • Embedded real-time systems
DEPENDABI-LITY	• Automated reasoning • Requirement analysis, design and verification	• Quantitative Evaluation of Embedded Systems • Reliability Engineering • Fault tolerant digital systems	• System validation • Software testing and Quality

Conclusion

- Presented the overall structure of the 3TU master on Embedded Systems
- 4 qualities of Embedded Systems
  - Systems approach
  - Multi-disciplinary approach
  - Resource boundedness
  - Dependability
- Programme of the three universities

Thank you
More information?

www.utwente.nl
www.tue.nl
www.tudelft.nl
www.3tu.nl/en