Progettazione di Sistemi Embedded
embedded systems design

Franco Fummi
University of Verona
Department of Computer Science
Italy

Laurea Magistrale in Ingegneria e Scienze Informatiche
Embedded Systems Design Course
Goals

• Techniques for the automatic design of embedded systems:
  – starting from their specification throughout:
    • validation / verification
    • automatic synthesis
    • testing

• This lecture is focused on:
  – most important design languages
  – most evolved tools for their manipulation
Embedded Systems: Where?
ES: Historical perspective

- From computer (’60-’80):
  - General purpose systems for solution of general problems

- To digital control systems (’80-’90):
  - Systems dedicated to control and automation

- To distributed systems (’90-’00):
  - General purpose systems and/or dedicated systems cooperating through the network

- To embedded systems (’00-)
  - Distributed systems integrated in non-computing objects and in the environment

- To cyber-physical systems (’10-):
  - Embedded systems integrated with physical processes
ES: History

- First computer Systems:
  - not showing the today characteristics, but devoted to the particular application of being programmable computers and embedded into a...
- The Apollo Guidance Computer is considered the world’s first modern Embedded System:
  - small size for a tremendous computational power, devoted to guide Apollo
- Mass production of Embedded Systems:
  - 1961 with the Autonetics D-17
- No stop…
ES Market

![Graph showing World Embedded Systems Revenue](image)

<table>
<thead>
<tr>
<th>Application</th>
<th>2004</th>
<th>2009</th>
<th>AAGR%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computers</td>
<td>10,000</td>
<td>15,000</td>
<td></td>
</tr>
<tr>
<td>Telecomm</td>
<td>20,000</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>Consumer</td>
<td>25,000</td>
<td>35,000</td>
<td></td>
</tr>
<tr>
<td>Automotive</td>
<td>15,000</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td>Medical/Office</td>
<td>5,000</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Industrial/Military</td>
<td>10,000</td>
<td>15,000</td>
<td></td>
</tr>
<tr>
<td>Total Revenues</td>
<td>45,873</td>
<td>88,144</td>
<td>14.0</td>
</tr>
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</table>
From ES to Smart Systems

- Miniaturized self-sufficient device that
  - Incorporates **functions** of sensing, actuation, and control
  - To describe and analyze a situation, and make **decisions** based on the available data
  - In a **predictive** or adaptive manner (smart actions)
  - Energy-**autonomous** and ubiquitously connected

Knowledge base separates smart systems from systems which, although they may be automated, remain purely reactive.
### Grow in smart system R&D

#### Number of R&D projects in 2016 compared with 2012

<table>
<thead>
<tr>
<th>Category</th>
<th>SME</th>
<th>Large organisation</th>
<th>Public research body</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;50% more</td>
<td></td>
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#### Employment in 2016 compared with 2012

<table>
<thead>
<tr>
<th>Category</th>
<th>SME</th>
<th>Large organisation</th>
<th>Public research body</th>
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</thead>
<tbody>
<tr>
<td>&gt;50% more</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>More</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>About the same</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>No opinion</td>
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<td></td>
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</table>

% predicting employment growth in Smart Systems

- 0%
- 20%
- 40%
- 60%

5 October '16  PSE
How Relevent (I)
How Relevant (II)

• & progetti europei completati e attivi:
  – Angel, Vertigo, Coconut, C4C, Complex, SMAC, Contrex

• 2 progetti europei in FP6
  – ANGEL (mobile gateway for sensors network)
  – VERTIGO (HW formal verification)

• 5 progetti europei in FP7
  – COCONUT (embedded systems design and verification)
    • best evaluation of the overall embedded systems track
  – C4C (control for coordination of distributed systems)
  – COMPLEX (platform-based design space exploration)
  – SMAC (smart systems design)
  – CONTREX (mixed-criticality systems)
ES: How to design?

• We cannot design embedded systems like general purpose systems
  – Different design constraints, different goals
  – Embedded design is about the system, not about the computer

• E.g.
  – In general purpose computing, design often focuses on building the fastest CPU
  – In embedded systems the CPU simply exists as a way to implement control algorithms communicating with sensors and actuators
ES: Design constraints

• Size and weight
  – Hand-held electronics
  – Weight costs money in transportation
  – Human body cannot eat desktops

• Power
  – Buttery power instead of AC

• Harsh environment
  – Power fluctuation, RF interferences, heat, vibration, water, …

• Safety critical and real time operations

• Low costs
ES: Designer knowledge

- HW architecture alternatives
  - for a correct HW/SW trade-off
- SW design skills
  - lots of languages continuously extending
- HW/SW interaction mechanisms
  - O.S., MW, HdS for efficient SW development
- Network infrastructure
  - all ES are now networked embedded systems
- Computation effort estimation
  - theory is important when used in practice
- Join 3C: computation, control & communication
Course Structure

• 34 lectures:
  – 32 theory hours
    • 22 lectures
  – 24 practical hours
    • 12 lectures

• People:
  – Franco Fummi (theory)
  – Michele Lora (laboratory class)
  – … for practical elaborations

6 credits
Modalità di Esame (I)

- Teoria + lab. + opzioni:
  - teoria
    - scritto con votazione /30
  - relazione laboratorio
    - +3 punti max
  - on demand
    - elaborato 0 +∞
    - (orale) +3 -∞

- Regole generali:
  - relazione dura 1 anno accademico
  - consegna in date stabilite
Modalità di Esame (II)

- Alternative:
  - Elaborato personale
    - stage aziendale
    - tesi
  - Teoria
    - no way :-)  

- Design&Reuse:
  - tesi
  - stage pre-tesi
Pre/post Condizioni

• Precedenze Indispensabili:
  – Architettura degli Elaboratori
  – Programmazione
  – Linguaggi ...
  – Sistemi (Metodi di specifica)

• Fondamentale per
  – Curriculum sistemì embeddèd (magistrale in Ingegneria)
    • Sistemi operativi avanzati, Architetture avanzate, Software per Sistemi Embedded, Sistemi Embedded Multimediali, Sistemi Embedded di Rete…
Benchmark and Labs.

• Smart devices:
  – The Open Source Test Case (SMAC project)

• Laboratorio Ciberfisico:
  – Secondo piano CV

• Lab. NES/Parco
2016 News

Semiformal Assertion Based Verification of Hardware/Software Systems in a ModelDriven Design Framework

Pravadelli, G., Quaglia, D., Vinco, S., Fummi, F.
<table>
<thead>
<tr>
<th>week</th>
<th>data</th>
<th>day</th>
<th>lecture</th>
<th>lab.</th>
<th>topic</th>
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<tbody>
<tr>
<td>1</td>
<td>5-Oct</td>
<td>Wed.</td>
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<td>Course introduction; Embedded systems modeling</td>
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<td>7-Oct</td>
<td>Fri.</td>
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<td>Embedded systems modeling II; SystemC-based design</td>
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<td>Platform-based design; Transactional-based design; TLM 2.0 standard</td>
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<td>TLM 2.0 standard II; SystemC/AMS support</td>
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<td>Platform, testbench and device driver (OSTC)</td>
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<td>Software embedded synthesis; Model-based design (MBD) of embedded software; IoT and Cloud</td>
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<td>Cyber-physical systems: models of computations</td>
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<td>Model-based design: Matlab/Simulink/FMI</td>
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<td>VHDL introduction; VHDL syntax</td>
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<td>16-Dec</td>
<td>Fri.</td>
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<td>Wed.</td>
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<tr>
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<td>Networked embedded systems (NES); Smart systems</td>
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<td>Introduction to embedded systems verification; Introduction to embedded systems testing</td>
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<td>Wed.</td>
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<td>final report preparation</td>
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<td>Fri.</td>
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<td>IoT and Cloud architectures; GPGPU: design problems and opportunities</td>
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<tr>
<td>hours</td>
<td>56</td>
<td></td>
<td>32</td>
<td>24</td>
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<tr>
<td>credits</td>
<td>6,0</td>
<td></td>
<td>4,0</td>
<td>2,0</td>
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</table>
Topics (theory)

• Specification:
  – Embedded systems modeling
  – SystemC-based design
  – TLM design introduction
  – AMS modeling
  – VHDL modeling, syntax
  – Networked ES (NES)
  – Smart systems

• HW synthesis:
  – Introduction to TLM design
  – High-level synthesis
  – Automatic VHDL synthesis

• SW synthesis:
  – Embedded software generation
  – Automatic device driver generation
  – Model-based design
  – IoT and Cloud

• Verification & testing:
  – Introduction to verification
  – Introduction to testing
  – VHDL timing simulation
  – FMI/FMU simulink
Topics (lab.)

• **Specification:**
  - Compiling / executing /debugging SystemC
  - Modeling SystemC TLM
  - Modeling SystemC RTL
  - Timing evolution in SystemC
  - Analog modeling in SystemC/AMS
  - Platforms and IP-Xact
  - Mixed modeling RTL/TLM/AMS
  - Timing modeling in VHDL

• **Hardware synthesis:**
  - Automatic synthesis from TLM
  - VHDL modeling at RT
  - Automatic synthesis from RTL VHDL

• **Software synthesis:**
  - Testbench and device driver
  - Embedded software design
  - FMI/FMU cosimulation
Teaching supports (I)

- Course web page
  - Detailed program
  - Complete program
- E-learning web page
  - Slides
  - Laboratory instructions
  - Questions/answers
- Book
  - Ongoing
- Seminars
  - Indications during the course
Teaching supports (II)

- Theory slides:
  - 0. Course Introduction
  - 1. Embedded Systems Modeling
  - 2. System C Based Design Flow
  - 3. Platform Based Design
  - 4. TLM Based Design
  - 5. SystemC/AMS
  - 6. High Level Synthesis
  - 7. Embedded Software
  - 8. Model Based Design

- Theory slides:
  - 9. VHDL Design Introduction
  - 10. VHDL Syntax
  - 11. VHDL Specification
  - 12. VHDL Simulation
  - 13. VHDL Synthesis
  - 14. NES Design
  - 15. Smart Systems
  - 16. Verification And Testing
More information

http://www.di.univr.it/~fummi

Laurea magistrale in Ingegneria e scienze informatiche

Progettazione di sistemi embedded (2016/2017)

CODICE INSEGNAMENTO 450291
DOCENTE Franco Fummi
CREDITI 6
SETTORE DISCIPLINARE ING-INF/05 - SISTEMI DI ELABORAZIONE DELLE INFORMAZIONI
LINGUA DI EROGAZIONE Italiano

Orario lezioni

<table>
<thead>
<tr>
<th>SEM.</th>
<th>GIORNO</th>
<th>ORA</th>
<th>TIPO</th>
<th>LUGO</th>
<th>NOTE</th>
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<tr>
<td></td>
<td>mercoledi</td>
<td>13.30 - 15.30</td>
<td>laboratorio</td>
<td>Laboratory didattico Laboratorio Ciberfisico</td>
<td>dal 10-ott-2016 al 31-gen-2017</td>
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<tr>
<td></td>
<td>venerdì</td>
<td>8.30 - 11.30</td>
<td>lezione</td>
<td>Aula 1</td>
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Obiettivi formativi

Tecniche per la progettazione automatica di sistemi embedded a partire dalla loro specifica per passare attraverso la verifica, la sintesi automatica e il collevo. Il corso presenta i principali linguaggi per affrontare questo progetto e i più avanzati strumenti automatici per la loro maniopulazione.

Programma

Introduzione ai sistemi embedded: definizione dei campi di applicazione, caratteristiche generali, caratteristica comuni.

Modellizzazione dei sistemi embedded: problematiche generali della modellazione dei sistemi embedded. Linguaggi per la descrizione dei sistemi embedded.
For the stronger ...

7994

Tuesday
8:30 – 10:30

In the corridors...
running

franco.fummi@univr.it
For the strongest...

7048

michele.lora@univr.it

Monday
10.00 – 11.00

On the e-learning

5 October '16

PSE

28