Teaching an Embedded Systems Software Course using Windows CE: An Experience Report

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Introduction

- Embedded systems are growing in importance, widespread deployment and complexity
- Software is becoming an important component of embedded systems
- Training manpower on the design and implementation of embedded software is becoming increasingly important

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Background

- Embedded systems courses are now being offered more frequently in universities
- Most courses concentrate on hardware
- Our course is designed especially for embedded systems software
  - Inherits ideas and topics from real-time systems, software development and software engineering

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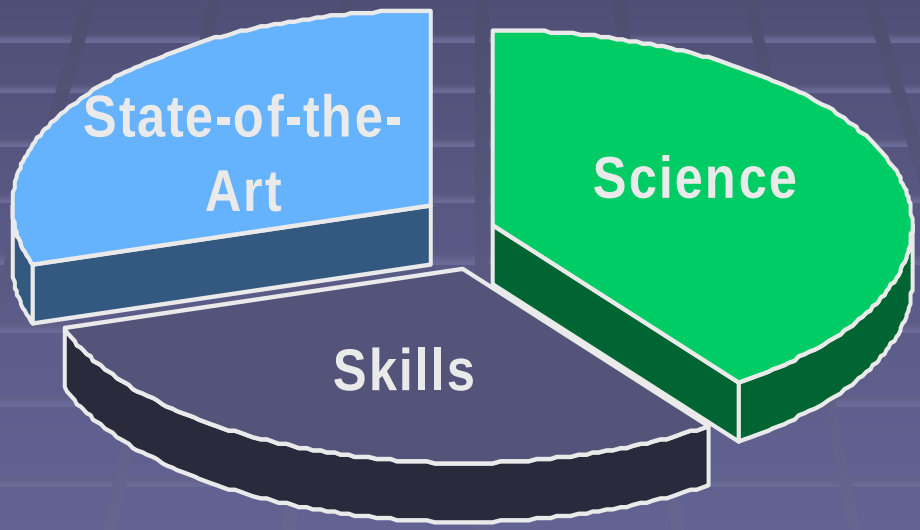
The Three "S"s of a Systems Course



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Course Topics and Structure

- Three major areas emphasized in the course:
  - Embedded software development
  - Real-time and embedded operating systems (RTOS)
  - Embedded software engineering
- Striking a good balance between theory and practice

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Course Topics and Structure

- Introduction
  - Introduction to Embedded Systems
  - Examples of Embedded Systems
  - Embedded System Characteristics
- Embedded Systems Architecture
  - Hardware Fundamentals: Processors, Memory, Bus, etc.
  - Software: OS, Application Software
- Embedded Software Development
  - Hosts and Targets
- Interrupts
  - Introduction to Interrupts
  - Interrupt Handlers and Interrupt Service Routines
- Embedded Software Architectures
- Real-Time Operating Systems (RTOS)
  - Review of Operating Systems Basics
    - Tasks, Processes and Threads
    - Task Scheduling: Rate Monotonic Scheduling, Priority Inversion
    - Task Synchronization and Coordination
    - Intertask Communication
    - Memory Management
  - Example RTOS: µC/OS-II, Windows CE,, Embedded Linux, J2ME
- Embedded Software Engineering
  - Basics of Software Engineering
  - Software Engineering Models
  - Unified Modeling Language (UML)
  - Software Testing
- Testing and Debugging Embedded Systems

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Textbooks and References

- Finding suitable textbook covering all the topics not straightforward:
  - Recent nature of the field
  - Too diverse set of topics
  - Material drawn from various textbooks from areas including real-time systems, software engineering, and embedded systems
  - Consulted the MSDN library for Windows CE related materials

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Hands-on Laboratory Exercises

- Major goals:
  - Introduce students to various IDEs and embedded environments
  - Give an overview of various techniques for embedded software development including aspects of RTOS
  - Preparing the students for course project

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Hands-on Laboratory Exercises

- Hands-on laboratory component concentrates mainly on the use of several real-time OS and integrated development environments
  - Mainly Windows CE, Platform Builder, Embedded Visual C++, Visual Studio 2005 based mobile development
  - Some labs on μC/OS-II, J2ME
  - General computer laboratory used
  - Dedicated embedded software laboratory being set up

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Hands-on Laboratory Exercises

- Laboratory Set-up:
  - Standard PCs running WinXP used as development hosts
  - Windows CE .NET Platform Builder used as the development environment
  - Embedded VC++ and Visual Studio 2005 used for application development
  - Most initial training using Emulator and CEPC setup

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Hands-on Laboratory Exercises

- Specialized equipment for embedded laboratory:
  - Ebox-II from ICOPtech

  - Intel PXA255 based embedded development boards from Emdoor Inc., Shenzhen

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Hands-on Laboratory Exercises

- Typical set of laboratory exercises include:
  - Introduction to Platform Builder
  - Advanced PB and debugging features
  - Application development using eVC++ and VS 2005
  - Threads and thread synchronization in Win32 API
  - Interprocess communication using message queues, MSMQ, events
  - Priority scheduling and priority inversion issues
  - Memory leaks and detection

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Course Project

- Team project with teams of up to 3 students
- Main emphasis on demonstrating the use of techniques learnt in the course
- Diverse range of topics last year:
  - Positioning system using bluetooth on pocket pc
  - Several J2ME based projects:
    - Multi-player paper, rock, scissors game
    - Integrated Multimedia environment including audio player and image manager
    - Chat room and instant messaging system
  - Implementing priority inheritance protocol in μC/OS-II
- This year more emphasis on WinCE based projects with the availability of Ebox-II

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Reflections

- Topics covered in the course:
  - Embedded software development:
    - Both theoretical and practical aspects
    - Emphasis on cross-platform development and cross-compilation
  - Real-time OS
    - Review of general OS related topics
    - Emphasis on RTOS issues including scheduling and synchronization
    - Possible overlap with existing OS, real-time courses

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Reflections

- Topics covered in the course:
  - Embedded Software Engineering:
    - Difficult to do good justice to this area
    - Lack of suitable large-scale case studies
    - UML extensions for real-time just now appearing and most in research stage
    - UML coverage hampered due to lack of good application examples

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Reflections: Some Questions

- What is so special about embedded software?
- Does this conglomeration of diverse topics deserve a special course?
  - Why not cover the related topics in the courses dealing with those specific topics?
  - How do we address the overlap of topics with the other courses?
  - Why not make embedded a point of emphasis in these other courses?

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Reflections: Some Questions

- Where do we draw the balance between theory and practice?
  - Perhaps Undergraduate courses should place more emphasis on practical skills!
  - Leave the esoteric theory to graduate courses?
  - Lack of generic approaches makes it imperative to put greater emphasis on specific platforms and solutions in the interim

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Reflections: Some Questions

- Should we use a single platform, or present different platforms?
  - Windows? Embedded Linux? VxWorks?
- How much hardware coverage?
  - Emphasis on the software aspects, but cannot do so divorced from the underlying hardware
  - Generic hardware concepts
  - Device drivers and interfacing?
  - Complete isolation from the underlying hardware is neither feasible nor desirable

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Student Background

- A good mix of students in their junior and senior year of undergraduate studies
- Students from both computer engineering and computer science streams
- Background includes courses on:
  - Computer programming including OO
  - Computer architecture and organization
  - Operating Systems

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Student Feedback from Last Year

- More hands-on labs, experience with dedicated hardware and embedded development platforms, rather than the general purpose PC
- Most popular: embedded development, and RTOS
- Least popular: software engineering
- More in-depth coverage of only two or three major RTOS
- More coverage on interfacing, especially with emphasis on device-driver development
- Overlap with other courses should be minimized
- UML not well appreciated: lack of suitable case-studies

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Conclusions

- Embedded systems software is an interesting topic deserving a dedicated course
- Our experience is only one point of reference
  - More expeirence sharing needed
- Greater consensus on embedded systems and software curricula:
  - Where do different courses fit in the overall picture?
  - What are the suitable set of courses?

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Further Information

- **J. K. Muppala**, Experience with an Embedded Systems Software Course, *ACM SIGBED Review Special Issue on the First Workshop on Embedded Systems Education (WESE 2005)*, Vol. 2, No. 5, Oct. 2005, pp. 29-33.
- Course website: http://www.cs.ust.hk/~muppala/comp355/

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The Second International Workshop on Embedded Systems Education 2006 (WESE 2006)

- October 2006
- Seoul, South Korea
- Details at http://www.emsoft.org/ under workshops
- CFP to be issued soon

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