# Real-Time Systems

## Course Introduction

Karl-Erik Årzén & Martina Maggio

16 January 2018

Lund University, Department of Automatic Control

www.control.lth.se/course/FRTN01

# Real-Time Systems

A *real-time system* is a computer system that has to respond to externally generated events or inputs within a finite and specified time period

All control systems are real-time systems

Most real-time systems are *embedded systems*, i.e, the computer is an embedded, integrated part of some equipment or machinery

# Embedded Systems

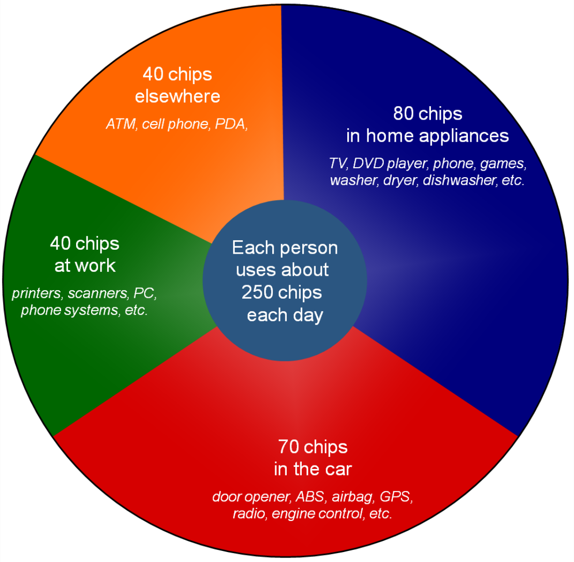
Embedded systems are by far the largest computer sector by volume

A large part of all embedded systems are control systems with hard/soft real-time constraints

- Vehicles
- Telecom
- Process & manufacturing industry
- Intelligent buildings
- ...

# Application Examples


# Embedded Systems




[Illustration courtesy of J. Sifakis]

# Example - Car Industry

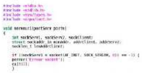
- A Volvo S80 contains $> 50$ computers (ECUs) and several communication networks
- Most of them for various control applications
- 25–30% of the price
- Software the largest part of the cost
- Strong connections between control and software
    - e.g., climate control system: 25,000 lines of C code

# Example - Car Industry 2

## 2014 Mercedes S-class complexity

ECUs and Networks
- 10 FlexRay
- 73 CAN
- 61 LIN

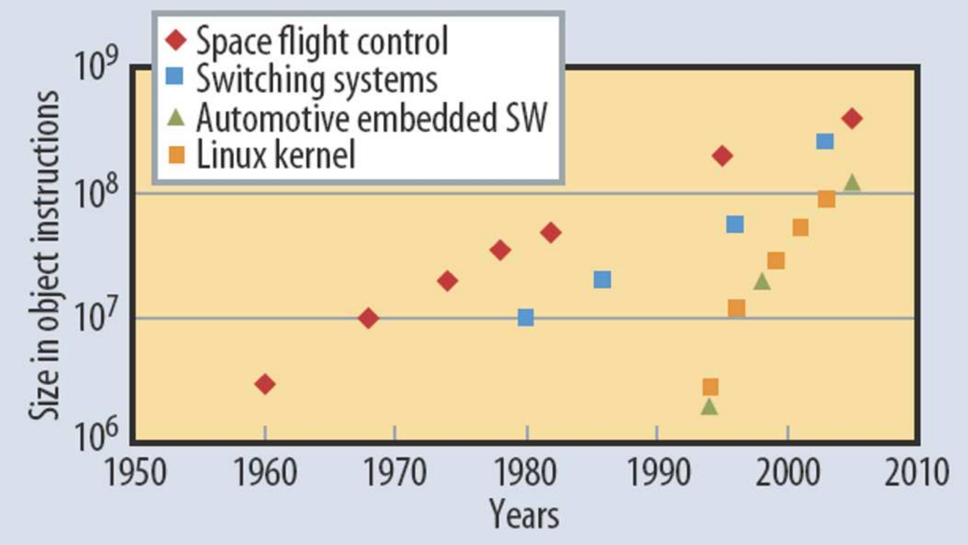
200 microprocessors



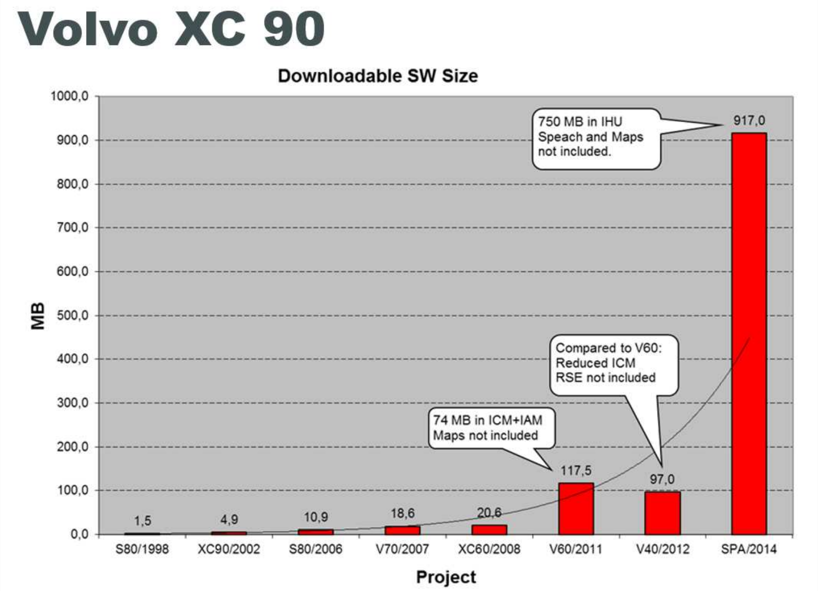
65 million lines of code
- 30 million lines in multimedia system
- > $10 per line of code


http://spectrum.ieee.org/transportation/systems/this-car-runs-on-code

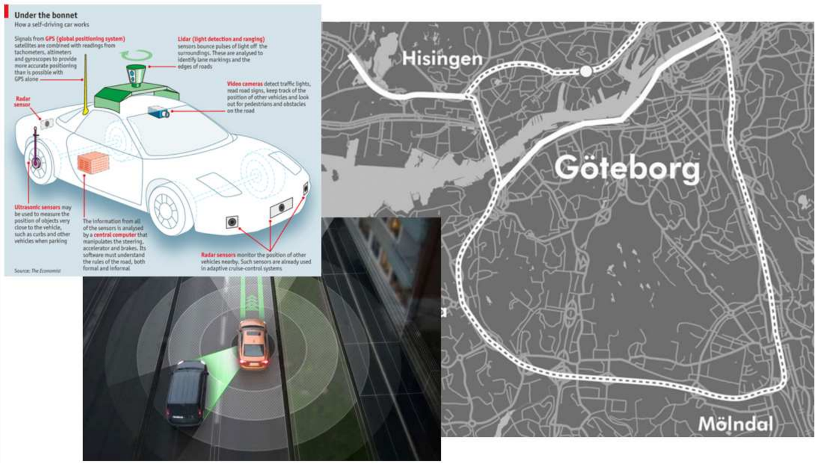
# Software Size



# Software Size - Car Industry



# Autonomous Cars




2017 Volvo started running self-driving cars around Gothenburg in the DriveMe project (currently only two and still only in data collection/training mode)

# Lines of Code Comparisons

| | |
|---|---|
| **Pacemaker** | 80k |
| **Space Shuttle** | 400k |
| Windows 3.1 (1992) | 2.5M |
| **US military drone** | 3.5M |
| **Mars Rover** | 5M |
| Google Chrome | 6M |
| Firefox | 9M |
| Android | 12M |
| **Boeing 787** | 14M |
| Linux 3.1 | 15M |
| **F-35 fighter jet** | 24M |
| Microsoft Office 2013 | 44M |
| Facebook | 61M |
| **High-end car** | 100M |
| Mouse genome | 120M |
| Human genome | 3,300B |

Source:
www.informationisbeautiful.net/visualization/million-lines-of-code/

1M LOC = 18,000 pages of printed text

# Example - Process Automation

- “Industrial IT” buzzword used by ABB
- Integration of automation and IT
  - software, distributed systems, WWW, e-commerce
- Focus on software rather than hardware

# Real-Time Systems in Sweden

Real-Time and Embedded Systems have a very strong position in Sweden and in Lund

Research:

- LUCAS: Center for Applied Software Research at LTH
  - Computer Science and Automatic Control
- EASE: Industrial Excellence Center for Embedded Applications Software Engineering
- ELLIIT: The Lund-Linköping Initiative on IT and Mobile Communications
- WASP: Wallenberg Autonomous Systems and Software Program

Industry:

- embedded systems and embedded control systems of vital importance to Swedish industry (Ericsson, ABB, Volvo, Scania, SAAB, ...)

# Course Aims

Study methods for design and implementation of computer control systems.

Focused on embedded control systems.

Two parts:

1. Real-time programming
2. Design and Implementation of Digital Control Systems

# Programming Languages

Java as the main programming language.

However, not a Java course.

We assume basic knowledge of

- Java
- object-oriented programming concepts

Code examples written Modula 2 (very similar to C, Pascal) will be shown.

One laboratory session and some of the projects will use C

# Relation to EDA040 Concurrent Programming

The students who have taken the Concurrent/Real-Time Programming course at Computer Science will recognize some parts of the first lectures

During the lectures we will also describe how real-time programming is performed with a conventional real-time programming language (Modula-2) and how a conventional real-time kernel (Stork) is implemented. (You do not have to program in Modula-2)

Deeper understanding and repetition

Students who have taken the Concurrent Programming course will do a special version of Lab 1 in which LJRT is used

Students that have taken the Concurrent Programming course must do a control-oriented project.

# Staff


**Karl-Erik Årzén**
Course responsible
and lecturer

karlerik@control.lth.se
046-222 87 82

**Martina Maggio**
Course responsible
and lecturer

martina@control.lth.se
046-222 87 77

**Mika Nishimura**
Course administrator

mika@control.lth.se
046-222 87 85

# Staff

**Tommi Nylander**
Teaching assistant

tommi@control.lth.se

**Marcus Thelander Andrén**
Teaching assistant

marcus.thelander_andren@control.lth.se

**Victor Millnert**
Teaching assistant

victor@control.lth.se

# Lectures

| Lecture | Date | Time | Room | Topic | Lecturer |
|---|---|---|---|---|---|
| L1 | Jan 16 | 10-12 | M:D | Introduction | Both |
| LX | Jan 17 | 15-17 | M:2112b | Extra: Introduction to Java | Martina |
| L2 | Jan 18 | 10-12 | M:D | Concurrent programming | Martina |
| L3 | Jan 19 | 10-12 | M:D | Process communication 1 | Martina |
| L4 | Jan 23 | 10-12 | M:D | Process communication 2 | Martina |
| L5 | Jan 24 | 10-12 | E:C | Interrupts and time | Martina |
| L6 | Jan 26 | 10-12 | M:D | Sampling of linear systems | Martina |
| L7 | Jan 30 | 10-12 | M:D | Input-output models | Karl-Erik |
| L8 | Feb 1 | 10-12 | M:D | Approx. of analog controllers, PID | Karl-Erik |
| L9 | Feb 6 | 10-12 | M:D | State feedback and observers | Karl-Erik |
| L10 | Feb 8 | 10-12 | M:D | Feedforward design | Karl-Erik |
| L11 | Feb 13 | 10-12 | M:D | Implementation aspects | Martina |
| L12 | Feb 15 | 10-12 | M:D | Scheduling theory | Martina |
| L13 | Feb 20 | 10-12 | M:D | Project specifications | Both |
| L14 | Mar 1 | 10-12 | M:B | Discrete-event control | Karl-Erik |
| L15 | Mar 22 | 15-17 | M:E | Real-time networks | Karl-Erik |
| LY | Mar 28 | 15-17 | M:2112b | Extra: Repetition lecture | Both |
| L16 | Mar 29 | 15-17 | M:E | Hot research topics | Both |
| L17 | May 14 | 15-17 | M:E | Project demos & oral presentations | - |

# Computer Exercises

- Five computer exercises (C1–C5)
    - Jan 23, 13-15, 15-17 - Jan 24, 8-10
    - Jan 30, 13-15, 15-17 - Jan 31, 10-12
    - Feb 6, 13-15, 15-17 - Feb 7, 10-12
    - Feb 13, 13-15, 15-17 - Feb 14, 10-12
    - Feb 20, 13-15, 15-17 - Feb 21, 10-12
- One extra Java exercise (C0)
    - Jan 19, 15-17

All exercises are held in Department of Automatic Control, Lab A

# Problem Solving Exercises

- Six problem-solving exercises (P1–P6)
    - Jan 31, 8-10 - Feb 1, 8-10 - Feb 2, 10-12
    - Feb 7, 8-10 - Feb 8, 8-10 - Feb 9, 10-12
    - Feb 14, 8-10 - Feb 15, 8-10 - Feb 16, 10-12
    - Feb 21, 8-10 - Feb 22, 8-10 - Feb 23, 8-10
    - Mar 20, 13-15 - Mar 22, 8-10
    - Mar 27, 13-15 - Mar 29, 8-10
- One extra Matlab exercise (P0)
    - Jan 26, 15-17

All exercises are held in Department of Automatic Control, Lab A

# Exercise Groups: Study Period 3

| Computer Exercises: | Teaching Assistant |
|---|---|
| Tuesdays 13-15 | Victor Millnert |
| Tuesdays 15-17 | Marcus Thelander Andrén |
| Wednesdays 8-10 and 10-12 | Tommi Nylander |

| Problem-Solving Exercises: | Teaching Assistant |
|---|---|
| Wednesdays 8-10 | Marcus Thelander Andrén |
| Thursdays 8-10 | Victor Millnert |
| Fridays 8-10 and 10-12 | Tommi Nylander |

The last two problem solving exercise only have two sessions.

In order to balance the load on the exercise groups you must register for the group that you would like to follow. Done via the course home page earliest on Thursday 18 January.

# Exercise Schedule

| Exercise | Dates | Topic |
|---|---|---|
| C0 | Jan 19 | Extra: Introduction to Java |
| C1 | Jan 23-24 | Threads |
| P0 | Jan 26 | Extra: Control in Matlab |
| C2 | Jan 30-31 | Synchronization |
| P1 | Jan 31-Feb 1-2 | Sampling of systems |
| C3 | Feb 6-7 | Controller implementation |
| P2 | Feb 7-8-9 | Input-output models |
| C4 | Feb 13-14 | Graphical user interface |
| P3 | Feb 14-15-16 | State feedback and observers |
| C5 | Feb 20-21 | Prepare Lab 1 |
| P4 | Feb 21-22-23 | Discrete approximation, PID |
| P5 | Mar 20-22 | Fixed-point implementation |
| P6 | Mar 27-29 | Scheduling theory |

# Laboratory Sessions

- Three manadatory laboratory sessions, 4 hours each
- The preparatory assigments will be checked at the beginning of each lab
- Room: Department of Automatic Control Lab A

| **Lab** | **Approx. dates** | **Topic** | **Responsible** |
|---|---|---|---|
| Lab 1 | Feb 21–Mar 2 | Control of ball and beam | Victor Millnert |
| Lab 2 | Mar 5–9 | Sequence control of bead sorter | Marcus Thelander Andrén |
| Lab 3 | Mar 19–30 | Embedded control of rotating servo | Tommi Nylander |

# Lab 1

Implementation of a control system for the ball & beam process

- Cascaded PID controllers
- Java or Java/LJRT with Swing-based GUI
- Prepared during the computer exercises

# Lab 2

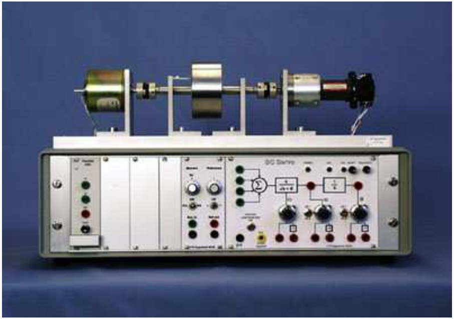
Sequence control of a bead-sorter process

- Discrete-event controller
- JGrafchart – a Java-based Grafcet editor and run-time system

# Lab 3

Fixed-point implementation of a DC-servo controller

- State feedback controllers
- C on ATMEL AVR Mega16



# Project

Projects are performed as team works with four persons per team (in special cases it is OK with smaller project teams).

Around 30 different projects to chose among:

- control of ball and beam process
- control of inverted pendulum
- control of helicopter process
- real-time kernel projects
- embedded system projects using ATMEL AVR and C
- Lego Mindstorm NXT projects
- etc.

If you are following the Predictive Control course it will be possible to do a joint project between the courses.

Students that have taken EDA040 Concurrent Programming course must do a control-oriented project

# Project

Important dates:

- Feb 20, at Lecture 15: Presentation of available projects
- TBD: Deadline for team formation and project selection
- TBD: Deadline for suggested solution
- TBD: Deadline for project report (10–15 pages, English/Swedish)
- May 14, at Lecture 18: Project demos (mandatory)
- May 14: Oral presentations (mandatory)

# Literature

- K.-E. Årzén, "Real-Time Control Systems", 2015. KFS.
- B. Wittenmark, K.J. Åström, K-E Årzén, "Computer-Control: An Overview", Educational version 2016. KFS.
- "Real-Time Systems – Problem Solving Exercises", 2015. KFS.
- "Real-Time Systems Formula Sheet". Online.

The 2014 versions are very similar and also possible to use.

# Examination

Mandatory parts: Three laboratory sessions, project, written exam (5 hours).

The exam consists of 25 points and gives the grade Fail, 3, 4, or 5.

Accepted aid: The textbooks “Real-Time Control Systems” and “Computer Control: An Overview ”, standard mathematical tables and authorized “Real-Time Systems Formula Sheet”; pocket calculator.

Exam opportunities:

- Wednesday, April 11, 14:00 -19:00, Victoriastadion 1A-1B
- Thursday, May 31. 8:00 - 13:00, Sparta D
- Saturday, September 1, 8:00 - 13:00, MA 9A

# Course History

**-71-72** Control of LKAB iron ore crusher over modem, PDP 15

**-73** "Computers in Control Systems", PDP 15, assembler

**-79** "Computers in Control Systems 2", LSI-11, Concurrent Pascal

**-81** Pascal + real-time kernel

**-83** "Applied Real-Time Programming", IBM PC, Modula 2

**-86-87** CS course on real-time programming. Focus on robotics.

**-89** "Computer Implementation of Control Systems", VME 68020

**-93** "Real-Time Systems". CS course no longer a prerequisite.

**-96** Windows NT, Pentium, InTouch

**-98** PowerPC, Migration to Java started

**-00** Java, Linux, PC

**-03** ATMEL AVR microprocessors introduced

**-07** More focus on digital control and embedded systems