

Year 3 Review
Paris, December 14th, 2007

Control for Embedded Systems

Cluster Leader: Karl-Erik Årzén, Lund University

Outline

- Cluster Presentation
- Overview of achievements and status after Y3
- Four Scientific Highlights with demos
- Plans for Y4

Cluster Partners

Core partners:

- Lund University – Karl-Erik Årzén
- KTH – Martin Törngren
- UPVLC – Alfons Crespo
- CTU – Zdenek Hanzalek

Affiliated international partners:

- Lui Sha – Univ of Illinois
- Tarek Abdelzaher – Univ of Illinois



Cluster Partners

Affiliated industrial partners:

- dSpace (Joachim Stroop)
- ABB Automation Technology Products (Göran Arinder)
- Honeywell Prague Laboratory (Vladimir Havlena)
- Volvo Car Corporation (Jakob Axelsson)
- Volvo Technology Corporation (Magnus Hellring)
- Maquet Critical Care (Klas Engwall)
- Ericsson (Johan Eker)



Activities

Cluster Integration Activities:

- Control for Real-Time Computing – Karl-Erik Årzén
- RT Techniques in Control System Implementation – Alfons Crespo

Network Integration Activity:

- Adaptive RT, HRT and Control – Karl-Erik Årzén

Platform Activity:

- Design Tools for Embedded Control – Martin Törngren

Long-Term Scientific Objectives

*Development of methods, tools and theory that allow faster and more efficient development of **networked embedded control** systems that are **safer**, more **flexible**, more **predictable**, have higher degree of **resource** utilization, and better **performance** than what is possible today*

*Advance the state of the art in applying **control methods** for providing **flexibility** and **robustness** and manage **uncertainty in embedded computing and communication systems**.*

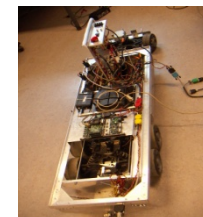
Design Tools for Embedded Control: Year 3

- **Objectives:**

- Long-Term: A platform of tools for tasks in the development process for resource-constrained embedded control systems
- Increased emphasis on model and tool integration

- **Focus in Year 3**

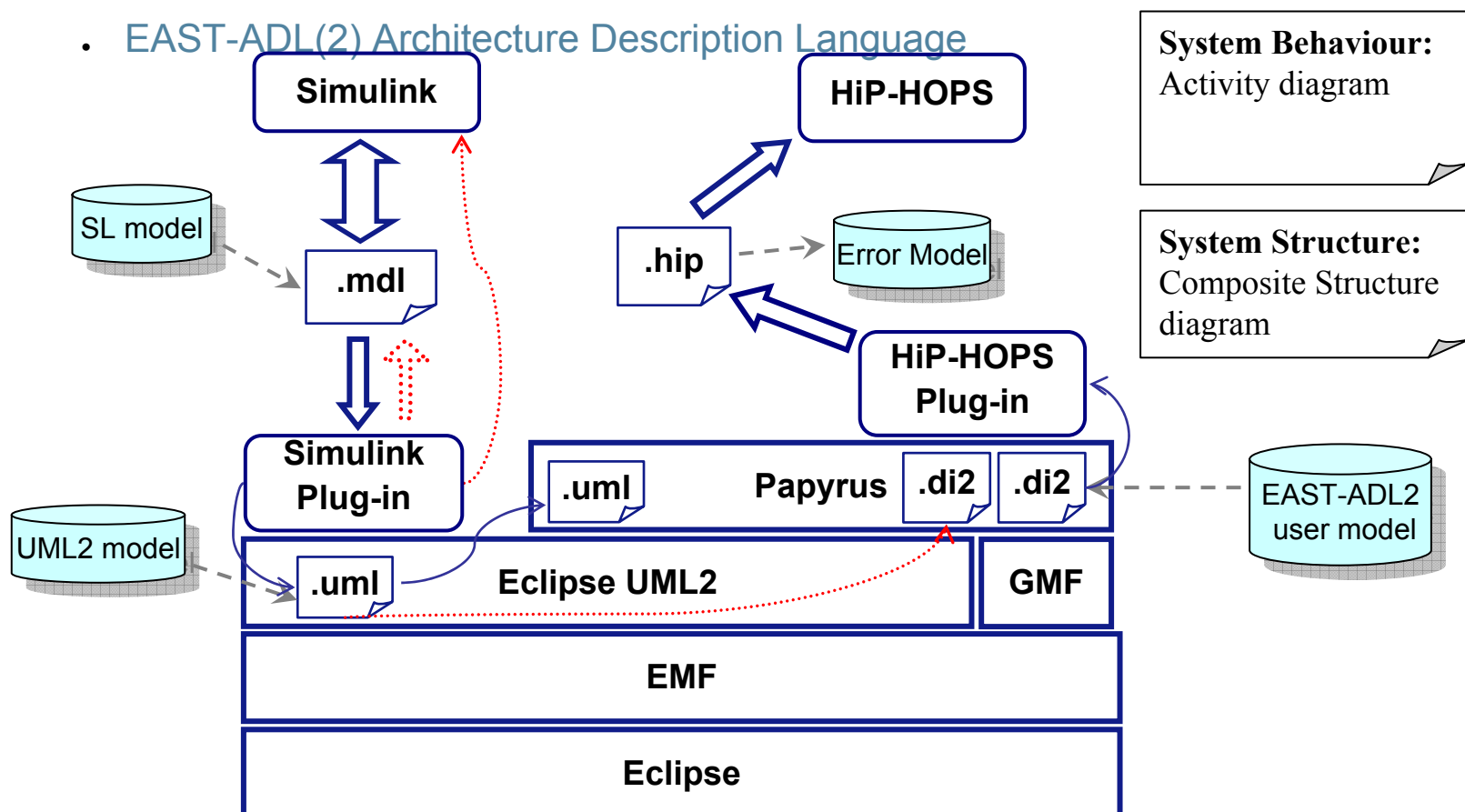
- Individual tool development, mainly Torsche (CTU) and **TrueTime** (Lund)
 - V1.5 released
 - Used by a large number of Artist2 partners and being ported to Modelica/Dymola within EUROSYSLIB
- Development of a demonstrator platform: The Saint truck (KTH, Scania)
 - Light weight Autosar middleware, distributed control systems, CAN, location alloc
- Cross-cluster integration with RTC
 - Co-organized two workshops (DATE and CAV)



Design Tools for Embedded Control: Year 3

- Model and tool integration considering how UML and safety models can be connected to control system models/tools (KTH, Volvo, CEA - ATESSST)

- EAST-ADL(2) Architecture Description Language



Control for Real-Time Computing : Year 3

- **Objectives:**

- Advance state of the art in applying control methods in embedded computing and communication systems
- Applications in control of web server systems, feedback-based reservation management in embedded real-time systems, feedback scheduling of control systems, and control of communication and sensor networks

- **Status:**

- Technical work involving one or several partners:
 - Control of server systems (Lund, UIUC)
 - Feedback-Based Resource management in cellular phones (Ericsson, Lund)
 - Control of communications and sensor networks (KTH, Ericsson , ABB, Lund)
 - Dynamically configurable automotive systems (KTH, Volvo)
- Artist2 Poster Session at IEEE FeBID 2007 (Int Workshop on Feedback Control Implementation and Design in Computing Systems and Networks), Munich, May 2007

Real-Time Tech. in Control System Impl. : Year 3

- **Objectives:**

- Advance the state of the art in applying real-time system methodology for embedded control system implementation
- Develop a common framework of control parameters and real time operating systems criteria

- **Status:**

- Common framework activities proceed
- Technical work on
 - operating system and language support (e.g. **Real-Time Java** (LUND, ABB, Sun), **control kernel middleware** (UPVLC))
 - Scheduling and control co-design: UPVLC, KTH and LUND (event-based control) CTU (FPGA scheduling)
 - Wireless embedded control within RUNES and Socrades (KTH, LUND, ABB, Ericsson)
 - Case studies (UPVLC, KTH, CTU)
 - Mobile robot, helicopter, truck

Adaptive RT, HRT and Control : Year 3

- **Objectives:**

- The union of the objectives for the cluster activities, but on a network-wide level involving the ART and RTC clusters

- **Status:**

- Several joint research projects between the Control and the ART cluster
 - Lund/SSSA, TUKL/Lund, UPC/Aveiro, CTU/Porto, UPC/Lund,
 - FP7 STREP ACTORS (Ericsson, Lund, TUKL, SSSA, Evidenc
- Interaction with RTC
 - Modeling and Tools (KTH/CEA)
 - Jointly organized CDC session (INRIA/Lund)
 - Internal RTC activities on control-related issues related to LTTA
- **2nd International Artist2 Workshop on Control for Embedded Systems**
 - Urbana-Champaign, 31 May – 1 June



Additional Comments on Year 3

- Artist2 Embedded Control Graduate School (Lund, UPVLC, CTU, KTH)
 - Lund, 10-14 May 2007
- The Bridgit embedded control benchmark repository (CTU)
 - Control design and real-time implementation
 - <http://dce.felk.cvut.cz/hanzalek/bridgit/>
 - Will be more populated during Y4
- Joint textbook development between KTH and Lund



Overall Assessment and Vision at Y0+3

- Partners well positioned in the control, embedded systems, networked systems, and hybrid system communities
- The collaboration within the cluster and with other Artist partners continues to develop well
 - E.g. 24 joint publications
 - The number of organized events is large (next slide)
- Increased collaboration with industrial affiliates
 - Volvo, Ericsson, ABB,
- Large participation in FP6 and FP7 embedded systems/control projects (ACTORS, ATESSST, Socrades, FRESCOR, SENSE, DYSCAS, SMERobot, EUROSYSLIB (ITEA2), RUNES)

Events

- Graduate School on Embedded Control Systems, Lund
- International Workshop at Urbana-Champaign
- Artist2 poster session at FeBID, Munich
- Invited session on Co-Design Tools at IEEE CACSD Conf, Munich
- KTH/Industry Embedded Systems seminar, Stockholm
- Towards a Systematic Approach to Embedded Systems Design, Workshop at DATE 2007
- Tool Platforms for ES Modelling, Analysis and Verification, Satellite event of CAV 2007
- Tool exhibition within the Real-Time in Sweden Symposium
- Embedded Systems Colloquium, Prague
- Embedded RTLinux Intro, Summer School, Prague
- Design of Embedded Real-Time Systems, Graduate Course, KTH
- Embedded Control, One week graduate school, UNED Madrid
- Embedded Control – Controller Implementation with Resource Constraints, Aalborg, Denmark
- EU/China Summer School, Suzhou, China
- Between Control and Software Workshop, Grenoble
- Dagstuhl seminar: Model based engineering of embedded systems

Plenaries and Keynotes

- Real-time Aspects in Control, ANIPLA, Rome (Årzén)
- Embedded Systems: From Design to Implementation, IFAC Symp. On Cost Oriented Automation, Havana Cuba (Crespo, Albertos)
- New Control Challenges in the Design of Embedded Systems, IEEE Systems and Control, Singapore (Albertos, Crespo)
- Wireless Control Systems: Scientific Challenges and Emerging Applications, 15th Med. Conf on Control and Automation, Athens (Johansson)
- Simulation of Networked Control Systems using TrueTime, Int Workshop on Networked Control Systems Tolerant to Faults, Nancy (Cervin)
- Jitterbug and TrueTime: MATLAB Tools for Analysis and Simulation of Controller Timing, Mexican National Congress of Automatic Control, Mexico City (Cervin)
- Challenges for Automotive Embedded Systems, Enea Automotive Systems Meeting, Stockholm (Törngren)
- Model-based development of Automotive Embedded Systems, Electronics in

Some Scientific Highlights

1. Robot Control in Java
 - Lund, ABB, Sun Labs
2. International Workshop in U-C
 - U Illinois, Lund, UPVLC, KTH,
3. Control Kernel Developments
 - UPVLC
4. Development of TrueTime for Sensor Network & MANET Simulations
 - Lund, Ericsson, KTH

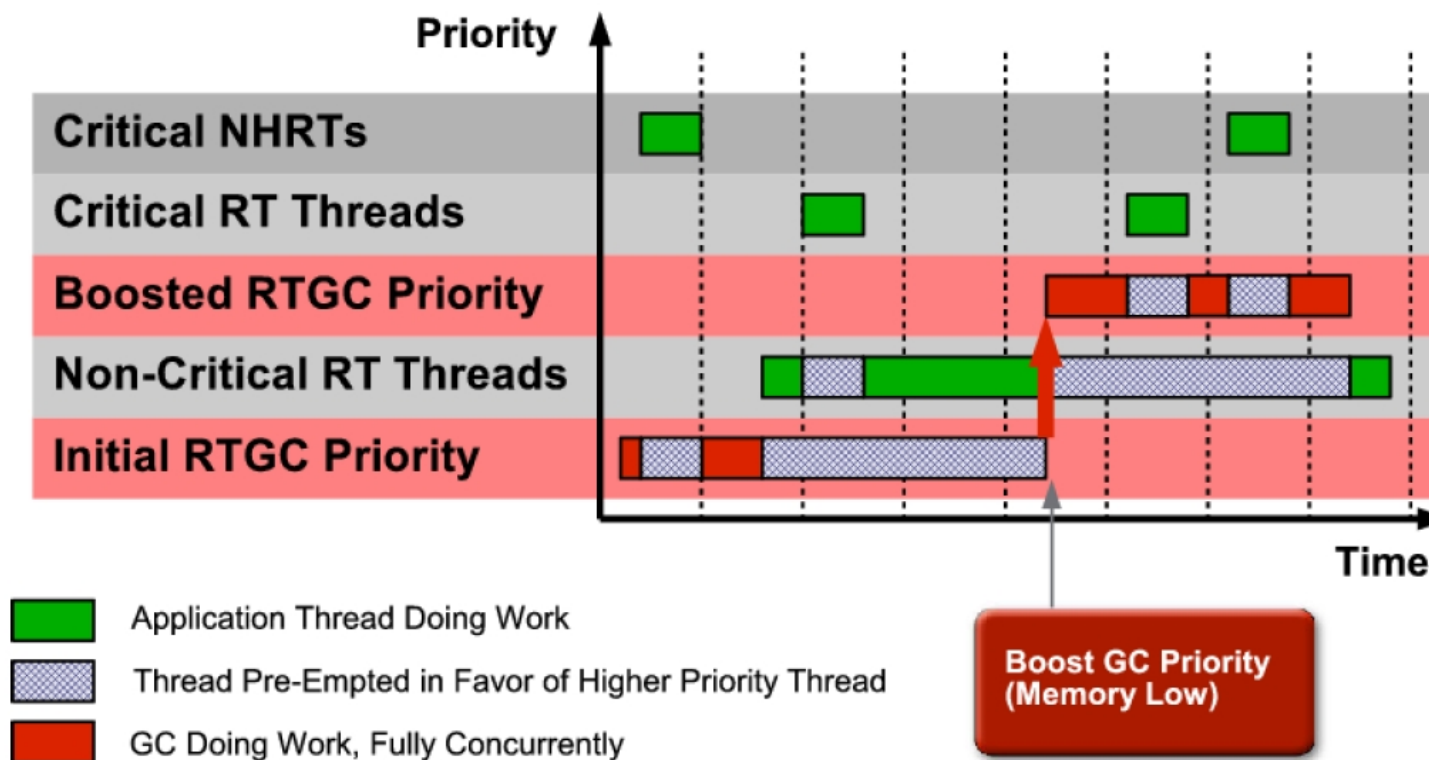
Scientific Highlights 1: Robot Control in Java

- Sun Java Real-Time System 2.0
 - May 2007 at JavaOne
- Joint project between Lund, Sun, and ABB.
- Incorporates real-time garbage collection techniques from Lund
 - Lund / CS
- Implements time and safety-critical robot control application
 - Lund / Control + CS, ABB

RTSJ Problems

- The different memory models and access rules make RTSJ complicated to use
- The RTGC technology from Lund:
 - Latency and jitter for critical tasks are minimized
 - Fully preemptible GC running as a thread at lower priority than critical (high-priority) application threads
 - Ensures that allocations by critical threads succeed
 - Pre-allocate memory
 - RealtimeThreads rather than NHRTs
 - Use the same reference space (the ordinary heap) as the non-critical threads

Sun JRTS 2.0 RTGC



Robot Control in Java

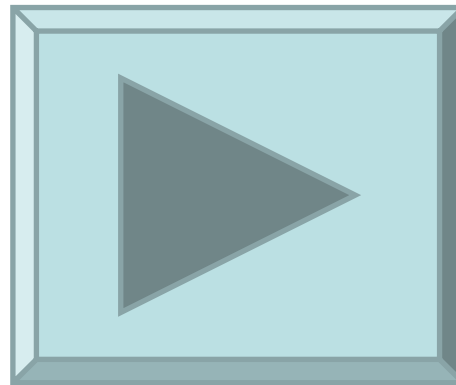
- Robot Motion Control in RT Java
 - Safe object-oriented language for implementing the entire robot system (incl 1 kHz motor control feedback loops)
- Robot system using COTS components
 - Manipulator from ABB (Flexpicker without ABB control and drive electronics)
 - Off the shelf servo drives from Beckhoff
 - Standard PC and OS (Solaris)
 - EtherCAT field bus

Main Benefits

- Critical tasks can allocate memory dynamically in a "safe" way
 - However, this is not the key point
 - Control loops running in steady state typically do not allocate much memory dynamically
 - In order for the allocations to be "safe", static analysis is required of worst-case memory allocations, similar to WCET analysis
- Critical tasks can refer to the same objects on the heap as non-critical tasks
 - Simplifies development greatly



Demo from JavaOne 2007

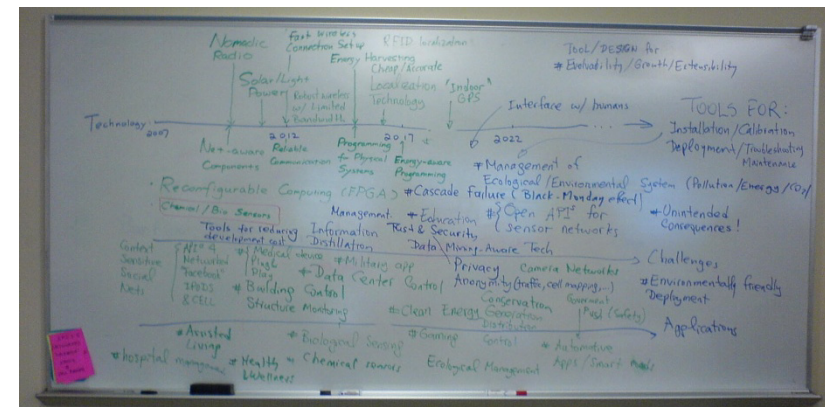


Scientific Highlight 2: International Workshop

- 2nd International Artist2 Workshop on Control for Embedded Systems
- Urbana-Champaign, 31 May – 1 June
- Hosted by Tarek Abdelzaher and Lui Sha
- 18 participants from US and European control and embedded/real-time communities
 - E.g. Tarek Abdelzaher, Lui Sha, Bruce Krogh, Geir Dullerud, Michael Lemmon, P.R. Kumar, Chenyang Lu, Marco Caccamo
 - Six Artist2 core participants from Lund, UPVLC and KTH
 - Industrials from Microsoft and PARC

Scientific Highlight 2: International Workshop

- Four topics:
 - Real-time and Control in Sensor/Actuator Networks
 - RT and Control issues in Cyber-Physical Systems
 - Event-Based Control and Computing
 - Control of Software Errors
- Plenary and shorter position presentations
- Extensive discussions
- Material and summary on the Artist2 web



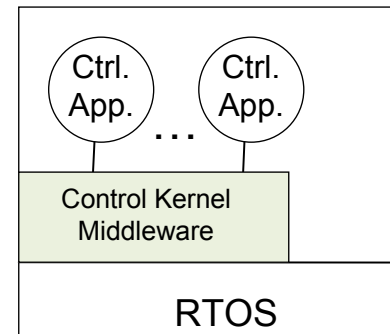
Scientific Highlight 3: Control Kernel Development

- **New version of RTLinux (Partikle core)** completed by UPVLC
 - POSIX Compliant
 - Control Kernel support
- Can be **deployed** for three targets:
 - Linux process
 - Stand-alone (bare machine)
 - XtratuM domain (system partition with temporal and spatial isolation)
 - ARM

Control Kernel

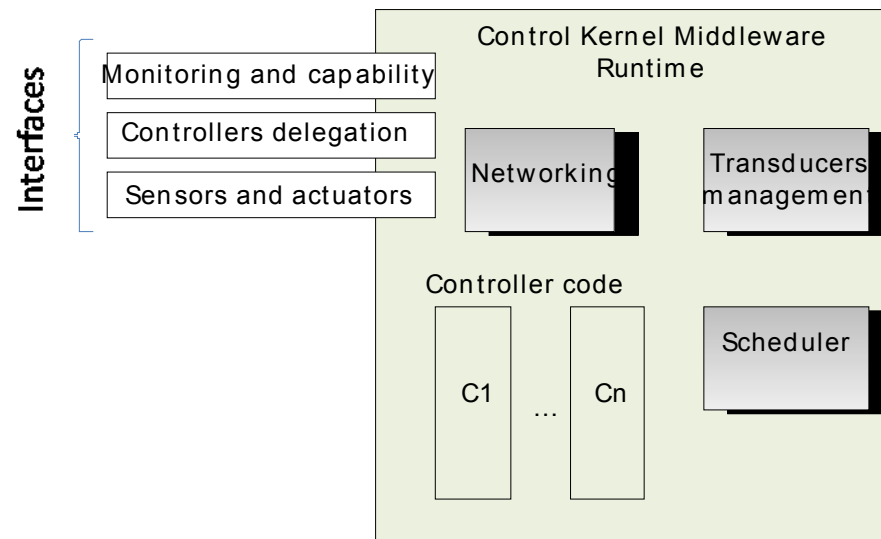
- Different nodes can be defined:
 - Service node: Small node with reduced capabilities

- Light Node: Node including more services
 - Code mobility
 - Monitoring
 -

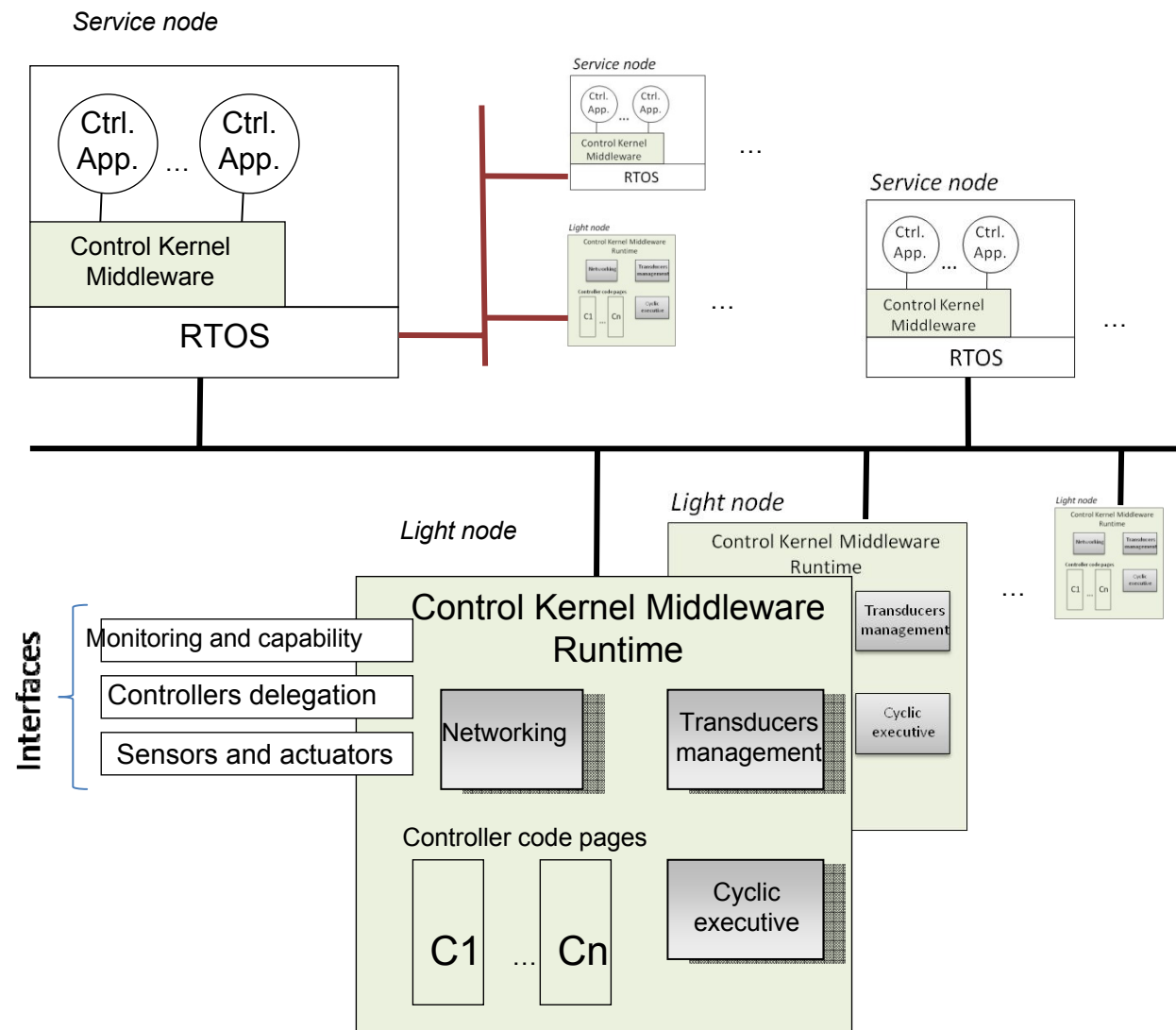


Service node

Light node

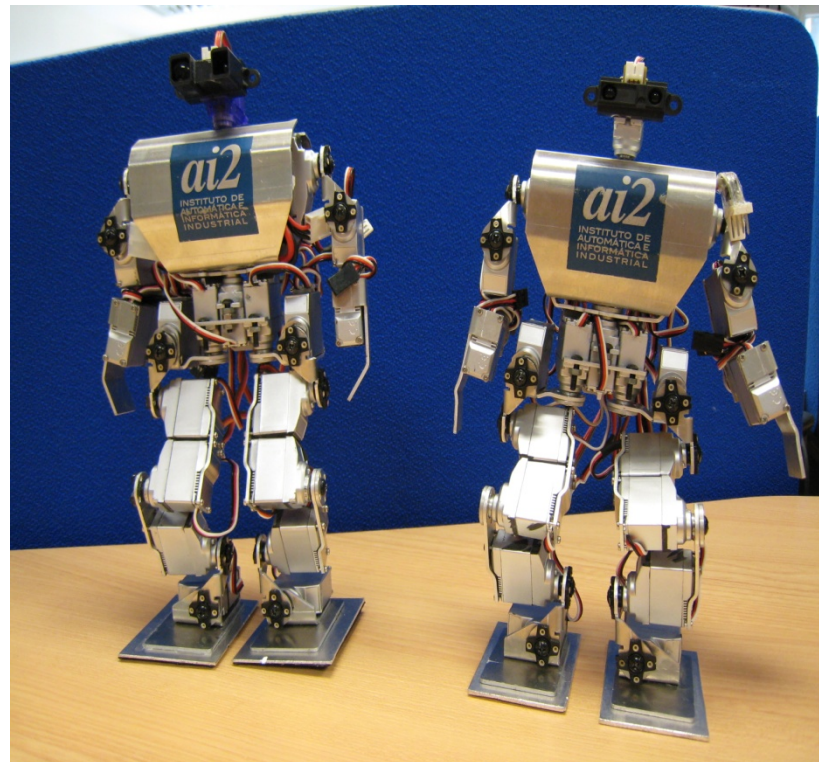
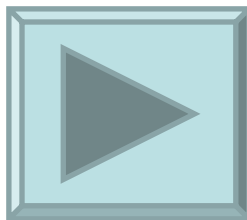


Application architecture



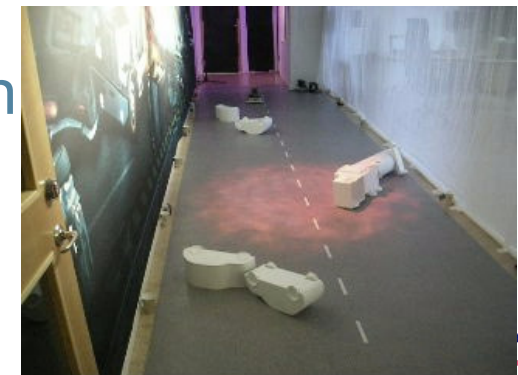
Real-Time Control Techniques (cont.)

- Walking Robot (UPVLC)
 - Embedded networked system
 - Control kernel middleware
 - PartiKle OS



Scientific Highlight 4: Sensor Networks with TrueTime

- Tunnel road safety scenario in RUNES
- Stationary sensor network in a road tunnel
- Mobile robots as mobile gateways for restoring connectivity among isolated sub-islands of the network
- Mobile robot tasks:
 - Localization (ultrasound), navigation, collision avoidance, obstacle avoidance, power control
- TrueTime used for developing a simulation demo in parallel with the real physical demo (@ Ericsson, Kista, July 2007)

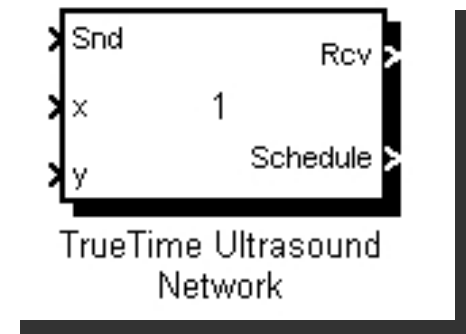


The Need for Simulation

- The behaviour of sensor network and MANET applications crucially depend on their **dynamic interaction with the external environment** and on **efficient resource management** (CPU time, bandwidth, power, ...)
- Holistic co-simulation of:
 - computations inside the nodes
 - tasks and interrupt handlers written in C code
 - wireless and wired communication between nodes
 - dynamics of the environment and of physical plants
 - sensor and actuator dynamics
 - mobile robot dynamics
 - the power consumption in the nodes
- TrueTime is one of the few simulation tools that allow the

TrueTime Features for Sensor Networks

- Support for IEEE 802.15.4 and 802.11b/g
- AODV - Ad-hoc On-Demand Distance Vector Routing
- Ultrasound Block
 - A version of the wireless network block that models the propagation delay of ultrasound in air



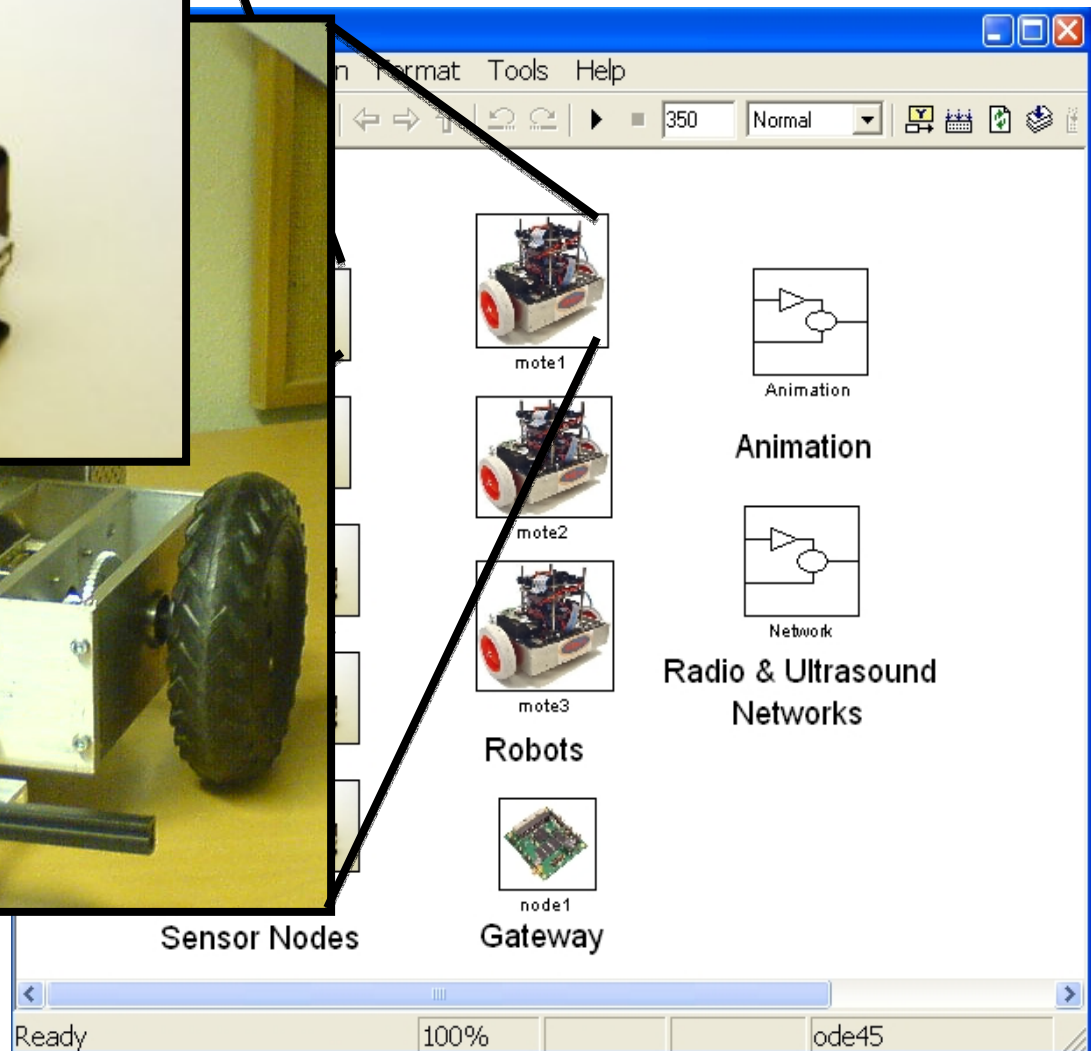
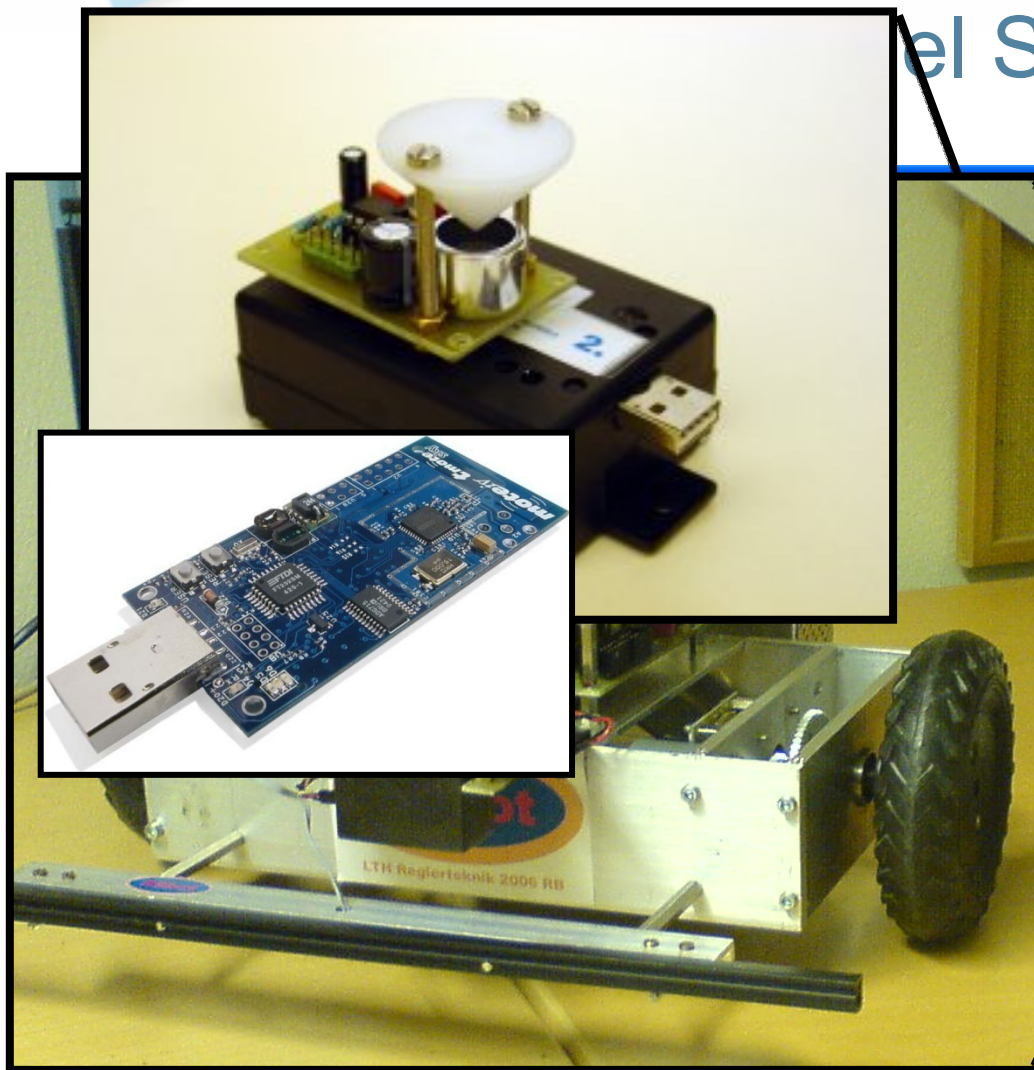
Localization Overview

- Ultrasound-based
 - Active mobile robots
 - Passive stationary nodes
- Robot broadcasts radio packet and ultrasound pulse simultaneously
- Difference in time-of-arrival allows each reachable node to calculate its distance to the robot, which is then sent back to the robot

Localization Overview cont.

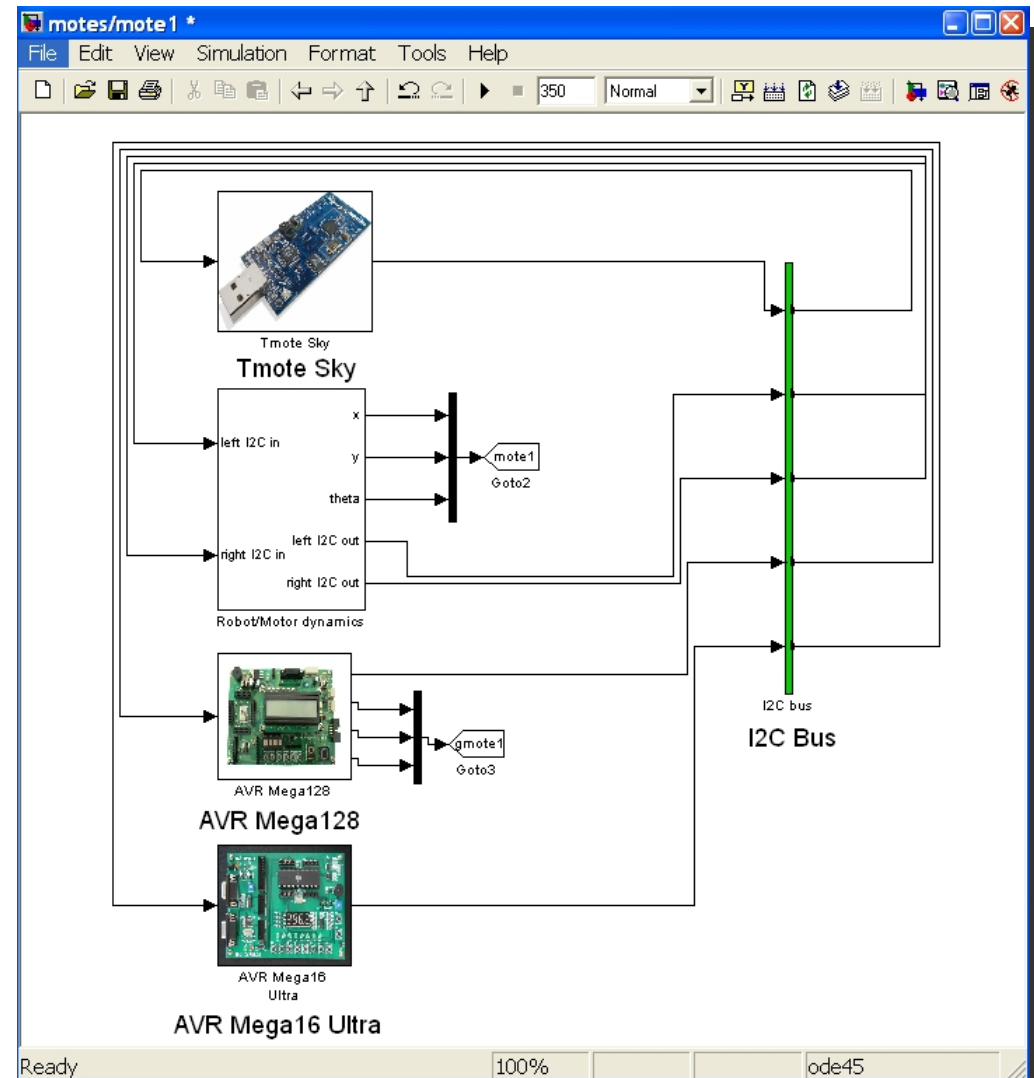
- The robot combines together the distance measurements using an Extended Kalman Filter (EKF)
 - In the update part of the EKF
- The robot combines the distance measurements with the measured wheel positions (dead reckoning)
 - In the predictor part of the EKF
- The EKF provides estimates of the
 - x & y positions
 - orientation

Model Scenario Model

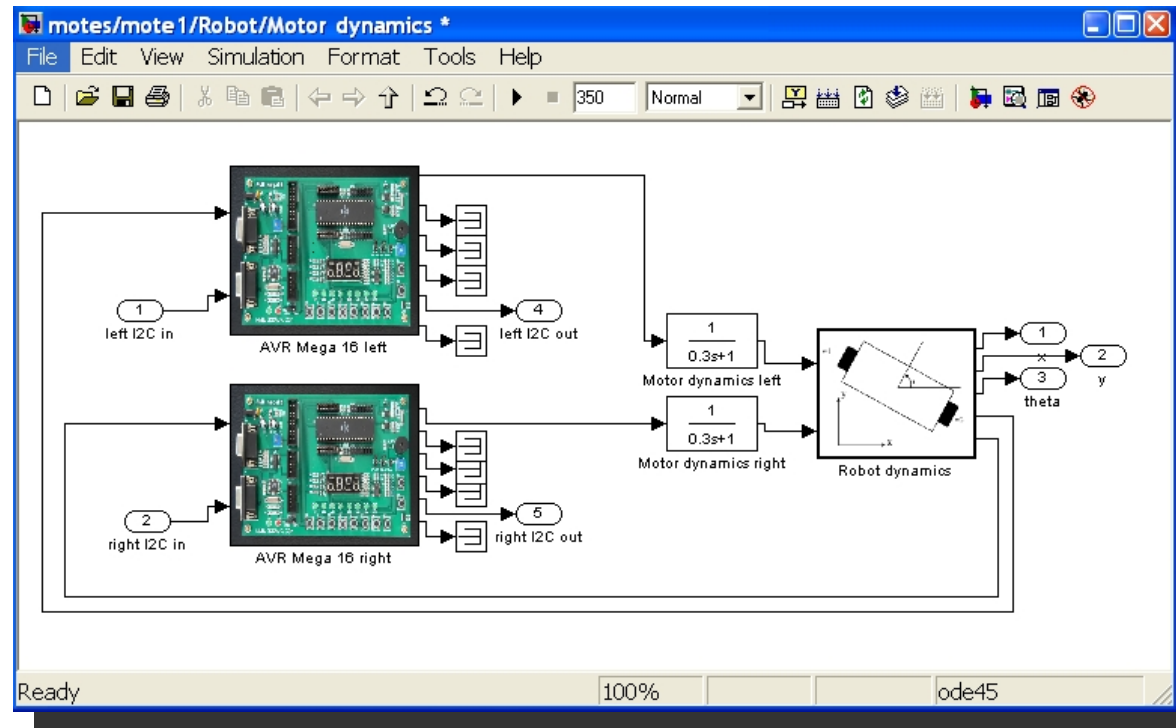


Robot Submodel

- Tmote Sky
 - Radio interface & bus master
 - Robot controller
- AVR Mega128
 - Compute engine
 - IR interface
 - EKF, navigation, and obstacle avoidance
- AVR Mega16
 - Ultrasound interface
- I2C bus
- Wheel and motor submodel

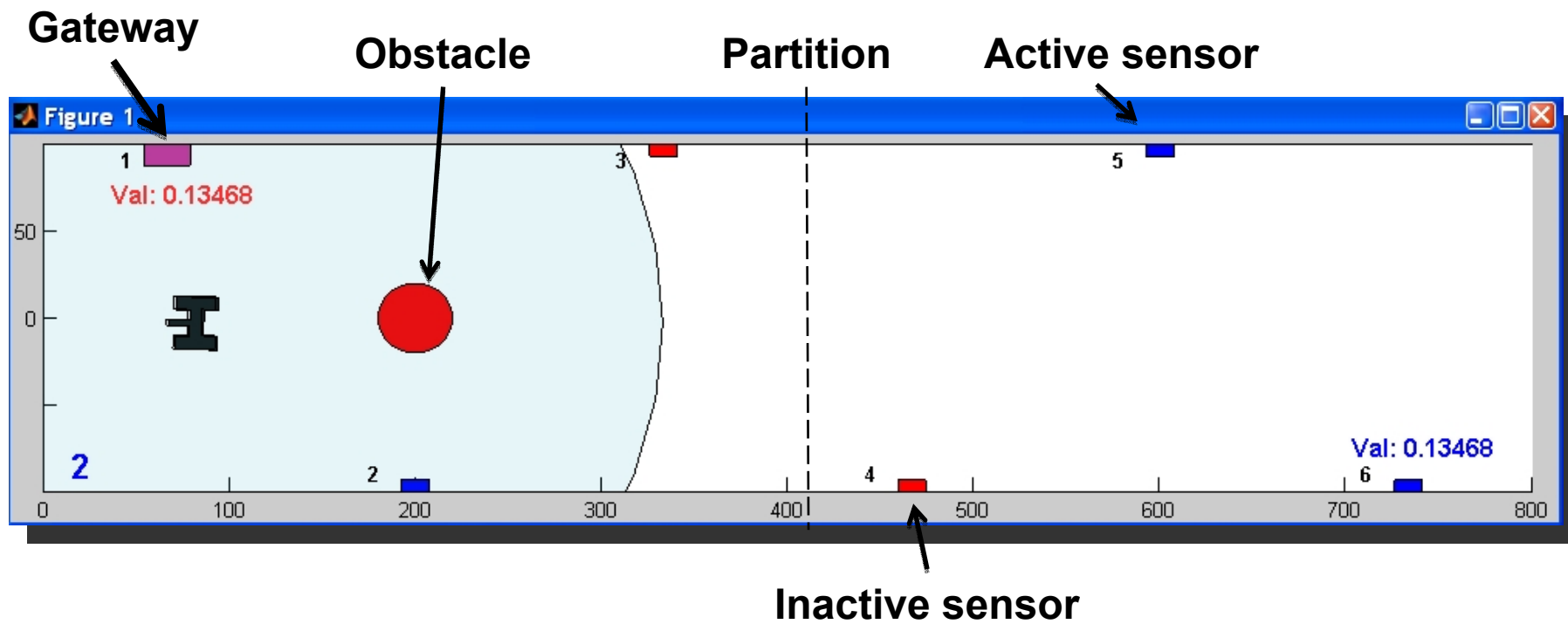


Wheel and Motor Submodel

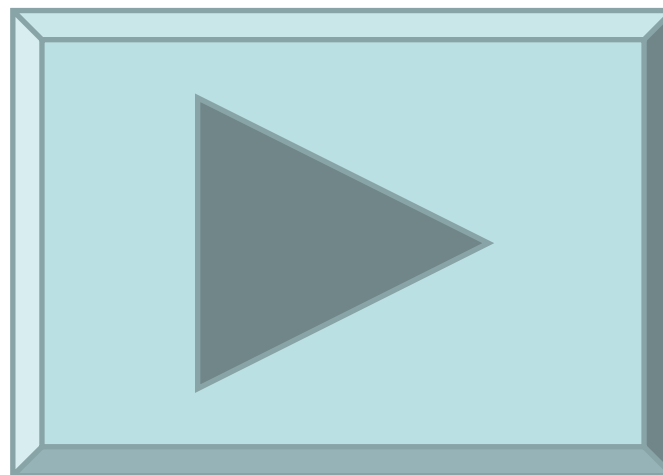


- One AVR Mega16 for each wheel/motor
- Simple motor models
- Dual-drive unicycle robot dynamics model

Animation



Demo



Plans for Year 4

- Continued joint and individual research according to the roadmaps derived in Year 1
- Focus on dissemination of results
 - Joint journal submissions summarizing the achievements of the cluster in Artist2
- Meetings Planned:
 - Cluster telephone conf, Nov 26
 - Cluster telephone conf, Jan 18
 - Meeting with ART partners to plan the interface to ACTORS, Lausanne, Jan 23-24
 - Cluster Meeting, Valencia, Feb 18-19
 - Organize dissemination activities

Plans for Year 4

- 4th Artist Graduate Course on Embedded Control, KTH, May 26-30
 - Cluster meeting
- IFAC World Congress, Seoul, July
 - Workshops on embedded control proposed by the cluster alone and in collaboration with HYCON + Cluster meeting
- ECRTS '08 (“Euromicro”) , Prague, July (Hanzalek as general chair)
- Meeting between ART, Control and RTC in connection with ArtistDesign meeting on “Design for Adaptivity”
- Industrial workshop on adaptivity and resource management aimed at the mobile telecom and consumer electronics sectors
- Joint (RTC + Control) invited session to CDC 2008
- Contribute to centrally arranged Artist2 dissemination events / schools.

Links to ArtistDesign

- Many of the activities will continue within the ArtistDesign FP7 NoE
 - In the “Design for Adaptivity” activity
 - In the “Operating Systems and Networks” thematic cluster
- The core partners of this cluster are all either core or affiliated partners in ArtistDesign

Q & A ?