Experimental Research

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Overview

- Experimental research is an essential component of CHESS
  - Feedback on approach
  - Inspiration for new theory
  - Impact
- Wide range
  - Industrial cases
    - Automotive (safety-critical distributed systems)
    - System-on-Chip (high-complexity platforms)
  - Internal experimental test benches
    - Wireless Sensor Networks (security, low power)
    - UAVs (complex control, sensor integration)
- New domains:
  - Soft walls
  - Biological Systems
Disaggregation:
Electronic Systems Design Chain

Wiring Harness S-Class 1998

Powertrain - Suspension - Displays - Comfort - Diagnosis - Braking
Active & Passive Safety - Telematic - Anti-Theft Systems - ...
Motivation: Complexity - From 1986 to 1998

- 1986:
  - Single systems
  - Wiring Harness:
    - weight 37 kg, length 2.4 km, 1200 wires, 2400 wrap connections
    - < 6 ECUs

- 1998:
  - Networked systems
  - Wiring Harness:
    - weight 39 kg, length 2.2 km, 1900 wires, 3800 wrap connections
    - 60 ECUs
    - 113 electric motors

CAN - Networking, e.g. Mercedes-Benz, BMW, Audi:

Design Chain Segmentation: Integration effort

More than 50% of the development effort is in validation
Complexity, Quality, Time-to-Market: TODAY

<table>
<thead>
<tr>
<th>PWT UNIT</th>
<th>BODY GATEWAY</th>
<th>INSTRUMENT CLUSTER</th>
<th>TELEMATIC UNIT</th>
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<tbody>
<tr>
<td>MEMORY</td>
<td>256 KB</td>
<td>128 KB</td>
<td>184 KB</td>
</tr>
<tr>
<td>LINES OF CODE</td>
<td>50.000</td>
<td>30.000</td>
<td>45.000</td>
</tr>
<tr>
<td>PRODUCTIVITY</td>
<td>6 LINES/DAY</td>
<td>10 LINES/DAY</td>
<td>6 LINES/DAY</td>
</tr>
<tr>
<td>RESIDUAL DEFECT RATE @ END OF DEV</td>
<td>3000 PPM</td>
<td>2500 PPM</td>
<td>2000PPM</td>
</tr>
<tr>
<td>CHANGING RATE</td>
<td>3 YEARS</td>
<td>2 YEARS</td>
<td>1 YEAR</td>
</tr>
<tr>
<td>DEV. EFFORT</td>
<td>40 MAN-YEAR</td>
<td>12 MAN-YEAR</td>
<td>30 MAN-YEAR</td>
</tr>
<tr>
<td>VALIDATION TIME</td>
<td>5 MONTHS</td>
<td>1 MONTH</td>
<td>2 MONTHS</td>
</tr>
<tr>
<td>TIME TO MARKET</td>
<td>24 MONTHS</td>
<td>18 MONTHS</td>
<td>12 MONTHS</td>
</tr>
</tbody>
</table>

* C++ CODE

FABIO ROMEO, Magneti-Marelli
Design Automation Conference, Las Vegas, June 20th, 2001

Design Flow

Algorithm Specifications

Requirement Specification

Algorithm Analysis

Algorithm Design

Environment - Test Bench Modeling

Virtual Prototyping

Behavioral Modeling

Architectural Modeling

Architecture IP Authoring

Distributed Architecture Analysis

ECU Scheduling Analysis

Algorithm Performance

System Mode

Synthesis Export

Physical Prototyping

Performance Simulation

Compile/Link/Load

Load
GM Steer-By-Wire System Architecture Exploration

- 36 architectures explored within different dimensions
  - Time-triggered and event-triggered software architectures
  - Sensor/actuator interconnections
  - Network architectures
  - Computing architectures
- Quantitative and qualitative evaluation of architectures in terms of performance, reusability, composability, dependability and modifiability derived.

Single Cylinder Hybrid Model

\[ T(i) = \lambda_4 (s_i, \varphi(i)) \]
**Giotto Applications (TAH):**
*Drive-by-Wire Throttle*

- BMW Throttle Control
- OSEKWorks RTOS
- PID Controller
- Motorola MPC555 40Mhz

**Methodology:**
from a Matlab/Simulink Model of the Controller:

a) Timing Code (Giotto):
generated via S/G Translator (University of Salzburg)
b) Functionality Code (C):
via Real-Time workshop.

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**Outline**

- **Industrial cases**
  - Automotive (safety-critical distributed systems)
  - System-on-Chip (high-complexity platforms) (ASV, K. Keutzer)

- **Internal experimental test benches**
  - Wireless Sensor Networks (security, low power)
  - UAVs (complex control, sensor integration)

- **New domains:**
  - Soft walls
  - Biological Systems
Typical Application: Intel PXA800F

Industry's First Complete GSM/GPRS Class solution

- Intel® XScale™ Core
- Intel® Micro Signal Architecture
- Intel® On-Chip Flash Memory
- GSM/GPRS Communications Stack, RTOS and applications code for a single-chip mobile solution

Typical Problem: Next Generation PXA800F

Design Improved IP Block Interconnection Module for Increased Performance

Employ Metropolis QUANTITIES for POWER ESTIMATION of the new design
Typical Application: The Intel MXP5800

- Complete Solution for high performance Digital Imaging Applications
  - Multifunction Printers
  - High End scanners

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Networks of Embedded Systems (SS)

- Pursuit Evasion Game Demo with 100 sensor motes performed in July 2003
- $10^4$ mote scaling issues being discussed for oil pipeline surveillance and protection. For conceptual issues see Franceschetti and Bollobas talks to follow
- Drop experiment planned with 40 motes at China Lake in February 2003
- Infrastructure Protection using secure networks of embedded systems is a new direction.

VisualSense: Modeling and Simulation of Wireless Sensor Nets Based on Ptolemy II

VisualSense extends the Ptolemy II discrete-event domain with communication between actors representing sensor nodes being mediated by a channel, which is another actor.

The example at the left shows a grid of nodes that relay messages from an initiator (center) via a custom channel that models a low (but non-zero) probability of long range links being viable.
Picoradio Sensor Networks (BWRC, J. Rabaey and ASV)

- Control Environmental parameters (temperature, humidity...)
- Minimize Power consumption
- Cheap (<0.5$) and small (< 1 cm³)
- Large numbers of nodes between 0.05 and 1 nodes/m²
- Limited operation range of network maximum 50-100m
- Low data rates per node 1-10 bits/sec average
- Low mobility (at least 90% of the nodes stationary)

Key challenges
- Satisfy tight performance and cost constraints (especially power consumption)
- Identify Layers of Abstraction (Protocol Stack)
- Develop distributed algorithms (e.g. locationing, routing) for ubiquitous computing applications
- Design Embedded System Platform to implement Protocol Stack efficiently

Wireless Sensor Networks: Applications

The present

The future

But also ...
Wireless Sensor Networks

- Use of commercially available platforms
  - Test validity of algorithms
  - Verify Networking properties
  - Implement Network Platform abstraction

- Nodes are getting cheaper and cheaper!
  - More companies are interested in joint projects
    (Johnson Controls, Pirelli, ST, Levoni Prosciutto, COMAU,...)
  - Volumes expected to be even higher
  - Building temperature and humidity control are the main drivers

Acoustic Localization Experiments
(K. Frampton, Vanderbilt)

**Goal:** To test the composition, synthesis and verification techniques on real-world networked embedded system applications using a highly resource constrained platform

- **Applications**
  - Active acoustic sensor self localization
  - Acoustic event localization
    - TDOA, AOA or TOA based methods
    - 1 m 3D accuracy, 2 sec latency
  - Acoustic signal recorder
    - Raw signal or zero crossing encoded
    - 5 Kbs short term buffer, 512Kbs long term buffer

- **Middleware services developed**
  - Time synchronization
    - 20 usec per hop accuracy, 1 msg per node per min
  - Message routing framework
    - Directed flooding, interchangeable flooding policy
  - Broadcast, convergecast, fat spanning treecast
  - Time-slot negotiation (graph coloring)
    - TDMA for acoustic measurements
  - Remote command
    - Reconfiguration, health monitoring

- **Field experiments**
  - ~50-100 nodes, ~4000 m², 8-hop diameter, cluttered environment

- **Collaborators**
  - Akos Ledeczi and Miklos Maroti, ISIS
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The Legacy of Success in UAV Research at BErkeley AeRobotics

- Pursuit-evasion games 2000- to date
- Architecture for multi-level rotorcraft UAVs 1996- to date
- Landing autonomously using vision on pitching decks 2001- to date
- Multi-target tracking 2001- to date
- Formation flying and formation change 2002, 2003
- Conflict resolution with model predictive control/ stochastic hybrid systems, 2003
- Airspace Management and personal aviation, 2004?
Platform Based Design for UAVs

- **Device Platform**
  - Isolates details of sensor/actuators from embedded control programs
  - Communicates with each sensor/actuator according to its own data format, context, and timing requirements
  - Presents an API to embedded control programs for accessing sensors/actuators

- **Language Platform**
  - Provides an environment in which synchronous control programs can be scheduled and run
  - Assumes the use of generic data formats for sensors/actuators made possible by the Device Platform

**Sensors:** INS, GPS
**Actuators:** Servo Interface
**Vehicles:** Yamaha R-50/R-Max

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**Giotto Applications:**
Unmanned Helicopter Control Systems

**RMAX UC Berkeley Helicopter (BEAR):**
- RTOS: VxWorks
- Control: Model Predictive
- Navigation: GPS & INS & Vision based
- Hardware-in-the-Loop Simulation

**Swiss Federal Institute of Technology Zurich Helicopter (OLGA):**
- RTOS: Customized HelyOS
- Control: LQR based
- Navigation: GPS & INS (EKF)
- Processor: StrongARM 200Mhz
Experimental Test Bed (G. Biswas, Vanderbilt): Fuel Transfer System

- Always have adequate flow to engines
- Avoid imbalances that affect center of gravity of system
- Two primary subsystems, left and right symmetric
  - Engine feed system
  - Transfer system
- Engine Feed System
  - Feed tanks with level control valves, Boost pump, interconnect valve, pipes
- Transfer System
  - Fuselage and Wing Tanks, Redundant pump system, Transfer manifold, pipes

Number of sensors: pressure transducers, flow meters, temperature gauges

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### Challenges of Systems (SS) (post genomic biology)

- Hybrid Systems Models for Intracellular functioning: stochastic hybrid systems (see talk by Abate)
- Hybrid Systems tools for ensembles of cells: group behavior of complex networked systems
- Biologically complex networks are an exemplar of how networked embedded systems could evolve, self-organize and reprogram themselves (network programming?) See talk by Franceschetti

### Concluding Remarks

- Applications are critical to drive research and to test quality of results
- Safety-critical Real Time and secure system emphasis
- Industrial and Experimental Test Benches
- Rigorous methodology for hybrid distributed systems
Embedded Software: Today

Embedded Software: Future?