Performance Research in the Boderc project

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world's fastest duplex digital printing system
250 duplex A4 or 132 duplex A3 per minute

Artist Meeting Bologna 22 May 2006

Boderc Project

Carrying Industrial Partner:

Period: October 2002-March 2007

15 fte/yr, 6 PhDs, 9 partners, 5.2 M€.

Aim: improve high-level design of mechatronic systems

Combine mechanics, electronics and software to allow:

- **multi-disciplinary design space exploration, focus on performance**
- **analysis of system-level decisions**
- **predict consequences of design decisions as early as possible**

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A Boderc Research Topic

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General business model:

- **Develop first high-end machine / system with over dimensioned HW**
- **In next versions this is optimized to increase performance and to reduce costs**
- **Questions:**
  - **what is most suitable hardware platform (currently typically PC + local nodes connected by CAN)?**
  - **how to distribute software (high-level management, UI, low-level motor control, etc.) on various processing nodes?**
  - **what is most optimal configuration for the processing nodes (scheduling strategies, memory management, caches sizes, ..)?**

➔ **research on performance modeling and analysis**

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Comparison of methods

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Continuation of the work on comparison of performance analysis methods by Marcel Verhoef

Uppaal, MPA, SymTA/S, and POOSL used on in-car radio-navigation system

Results have been improved and extended after Artist workshop at Leiden (November 2005)
http://www.ee.ethz.ch/~leiden05

Uppaal work and comparison presented at WPDRTS workshop International Parallel and Distributed Processing Symposium 2006.

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In-Car Radio Navigation System

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- Car radio with built-in navigation system
- User interface needs to be responsive
- Traffic messages must be processed in a timely way
- Several applications may execute concurrently

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System Overview – Change Volume

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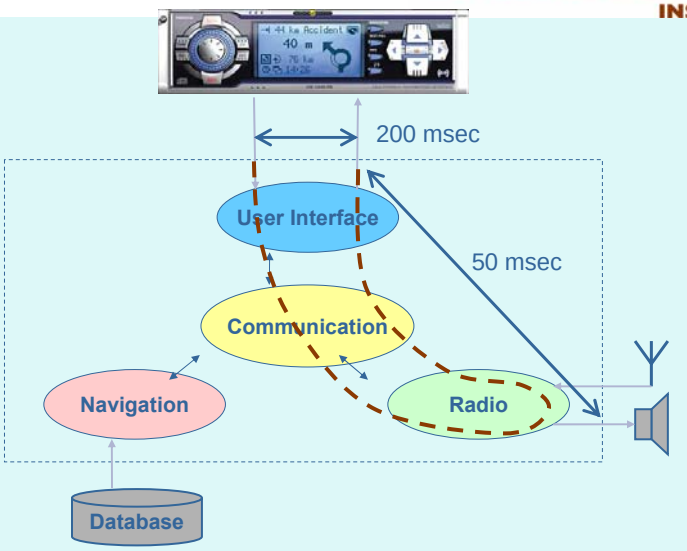

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System Overview – Handle TMC

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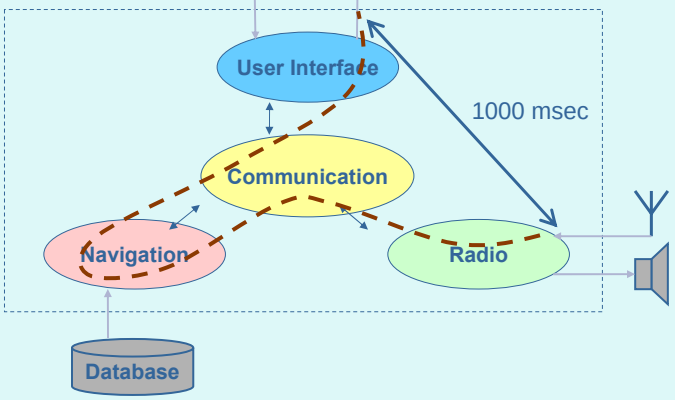

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Proposed Architecture Alternatives

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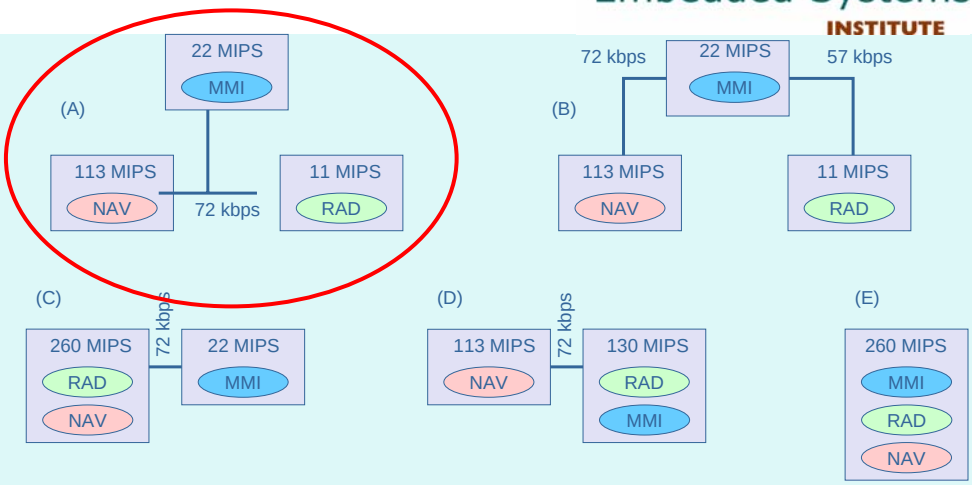

- kbps = kilo bit per second
- mips = 10^6 instructions per second
- assume no (protocol or scheduling) overhead (zero cost)
- inter task communication on same resource is instantaneous (zero cost)

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Method: Uppaal (1)

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- Model checker for timed automata
- Co-developed at Uppsala (S) and Aalborg (DK) by (Wang Yi, Kim Larsen et al)
- Integrated tool, graphical modeling interface
- Validation (simulation) and verification (model checking)
- Networks of timed automata
- Expressive and powerful language
- TA models prone to state space explosion problem

- http://www.uppaal.com

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Uppaal model (Martijn Hendriks)

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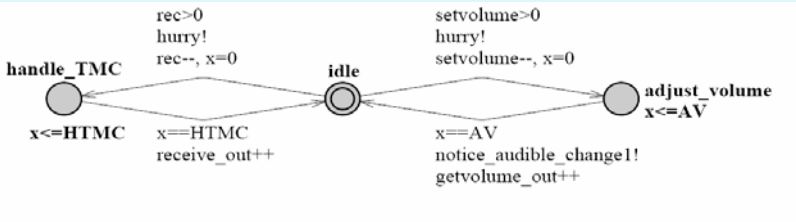

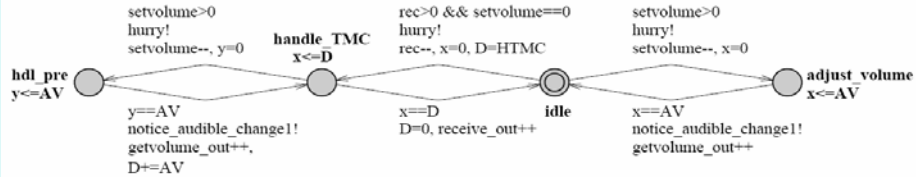

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Method: MPA (1)

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- Modular Performance Analysis
- Developed at ETH Zurich (Lothar Thiele et al)
- Performance networks analyzed with real-time calculus
- Analytic method, deterministic queuing theory
- Adaptation of Network Calculus (Boudec, Thiran)
- Describes event streams by interval bound functions
- Information is lost: $t \rightarrow \Delta t$
- Evaluation is very fast (no simulation)

- http://www.mpa.ethz.ch

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MPA model (Ernesto Wandeler)

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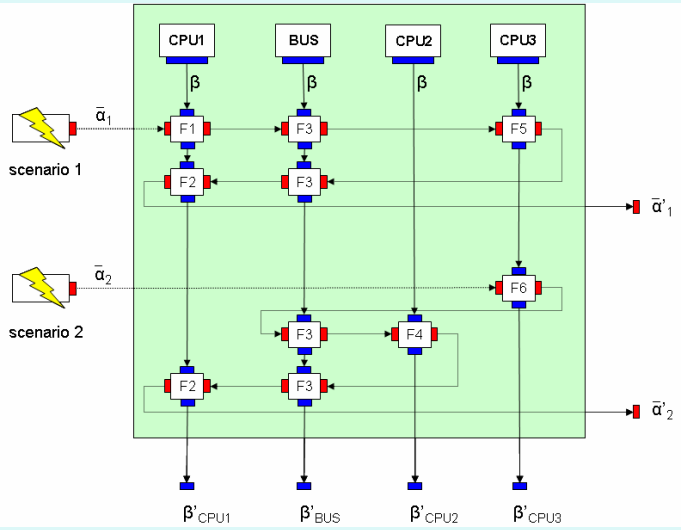

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Method: SymTA/S (1)

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- Symbolic Timing Analysis for Systems
- Developed at TU Braunschweich (Rolf Ernst et al)
- Classical (formal) scheduling analysis techniques
- Symbolic simulation
- Calculate resource local optima
- Optimize system level by iteration over local optima
- Heterogeneous architectures
- Complex task dependencies, context aware analysis
- Rapid design space exploration by sensitivity analysis

- http://www.symtavision.com

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SymTA/S model (Kai Richter)

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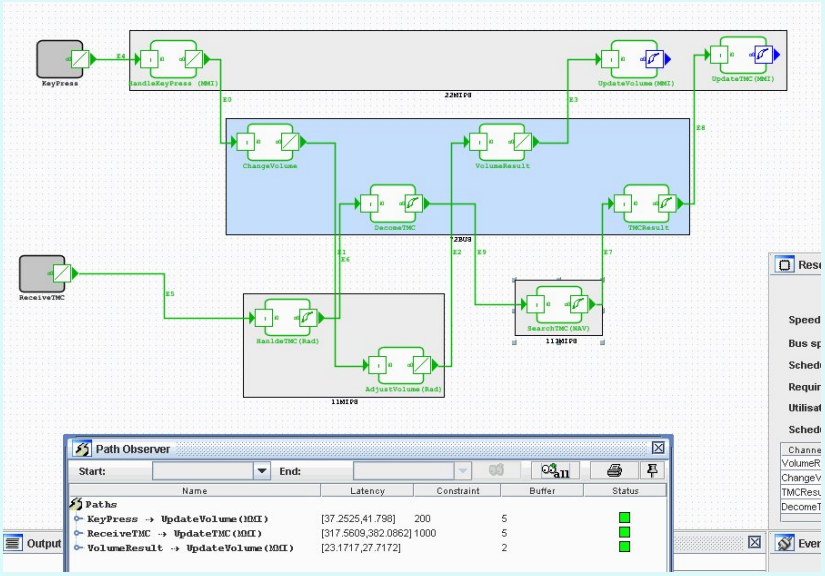

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Method: POOSL (1)

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- Parallel Object-Oriented Specification Language
- Languages combines primitives for specifying data manipulations, concurrency and timing
- SHE method: Software / Hardware Engineering
- SheSIM tool for model construction and simulation
- Rotalumis for high-speed batch-oriented simulation
- Formal semantics based on probabilistic timed labeled transition systems
- Symbolic execution

- http://www.es.ele.tue.nl/poosl/

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POOSL model (Menno de Hoon)

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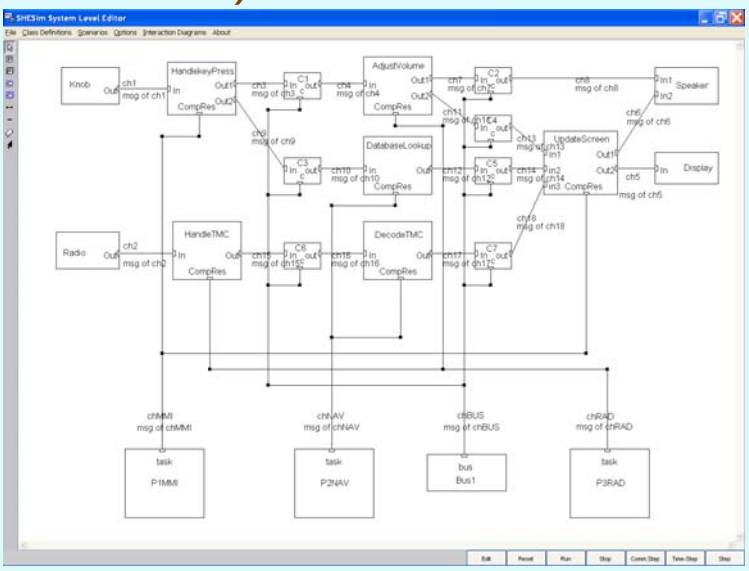

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Analysis

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- **Played with many environment models**
  - Pure periodic with zero offset (synchronous)
  - Pure periodic with fixed offset (synchronous)
  - Pure periodic with unknown offset (asynchronous)
  - Periodic with jitter (j ≤ p)
  - Periodic with bursts (j = 2p, d = 0)
  - Sporadic (periodic with only upper bound to period)
- **Some results easy to verify by hand**
  - AddressLookup is fully independent and has highest priority
  - ChangeVolume is only dependent on itself

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Results

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Table 1. Uppaal worst-case response time analysis results (in milliseconds)

Requirement \ *Event model*	*po* ($F = 0$)	*pno*	*sp*	*pj* ($J = P$)	*bur* ($J = 2P, D = 0$)
HandleTMC (+ ChangeVolume)	357.133	381.632	382.076	> 400.000 (df)	> 500.000 (rdf)
HandleTMC (+ AddressLookup)	172.106	239.080	239.080	329.989	420.898
K2A (ChangeVolume + HandleTMC)	27.716	27.716	27.716	> 27.715 (bf)	> 27.715 (bf)
A2V (ChangeVolume + HandleTMC)	41.796	41.796	41.796	> 41.795 (bf)	> 41.795 (bf)
AddressLookup (+ HandleTMC)	79.075	79.075	79.075	79.075	79.075

Table 2. Worst-case response time results – comparison with other tools

Requirement \ *Tool*	*Uppaal (po)*	*Uppaal (pno)*	*POOSL (pno)*	*SymTA/S (pno)*	*MPA (pno)*
HandleTMC (+ ChangeVolume)	357.133	381.632	~~266.94~~	382.086	390.0862
HandleTMC (+ AddressLookup)	172.106	239.080	~~244.26~~	253.304	265.8491
K2A (ChangeVolume + HandleTMC)	27.716	27.716	27.7067	27.717	28.1616
A2V (ChangeVolume + HandleTMC)	41.796	41.796	41.7771	41.798	42.2424
AddressLookup (+ HandleTMC)	79.075	79.075	78.8989	79.076	84.066

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Observations & lessons learnt

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- **Comparing results is as hard as getting the results**
  - Did we ***really*** model the same thing?
  - Simulation / computation effects or true "problem"?
  - Interaction with method experts is needed to make comparison!
- **Methods are typically**
  - Either biased towards application domain; can cause mismatch
  - Or very generic; can cause huge modeling effort
- **Methods can be used complementary**
  - Provide answers to different types of questions
  - Model validation by moving to another paradigm

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SymTA/S Evaluation

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SymTA/S used at Océ (Hennie Freriks) to model data path

- **Nice modeling tool, after understanding theoretical background, model made in less than a day by industrial engineer**
- **Modeling itself (and collecting data for it) very useful and provided useful insight**
- **Not is so useful for analysis of data path because, e.g.,**
  - time-dependency between use case scenarios could not be modeled (and hence result were far too pessimistic)
  - finite event streams cannot be modeled
- **Usability of tool improved a lot during evaluation period (Jan/Feb 2006)**

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Performance analysis

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Industrial practice:
start with distributed solution, next try to reduce costs by combining more functionality on single node

Question: does it fit, which hardware is suitable?

➔work on performance measurements and models (Peter van den Bosch, Océ)

Aim: method to help embedded control engineer to make well-founded choice for hardware platform

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Performance models

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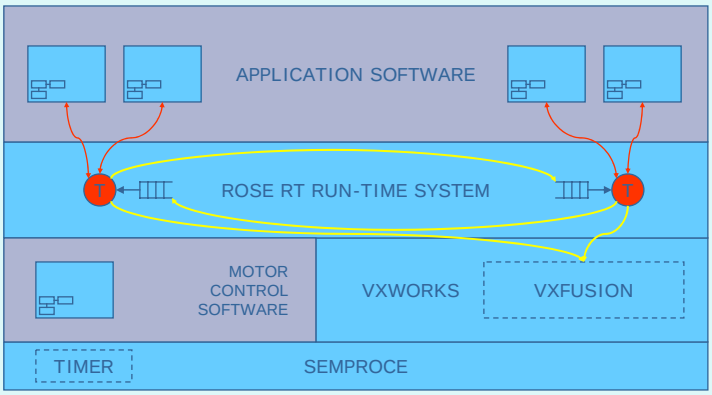
SW development based on UML in Rose RealTime



How to relate performance of underlying HW platform to high-level SW model and requirements?

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Performance Measurements

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Measurements have been done on existing platform
(ARM9, 200 MHz, 5-stage instruction pipeline,
100 MHz 32-bit memory bus SDRAM, 8k data, 8k instruction cache)
and SW with soft real-time (action planning) and hard-real time tasks

- insight in caching behavior, memory latencies, modeling overhead (Rose RT)
- large variation on lowest level, but less at high-level application
- formulas and graphics have been derived, also based on characteristics of SW (# cache misses, # interrupts, …)

Unclear: general method/approach and/or suitable models & tools
to decide fast and with some accuracy about suitable HW platform
and best configuration choices given certain characteristics of SW
➔ for the moment, focus in examples, later try to generalize

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Concluding Remarks

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Several results of the Boderc project are used at Océ, e.g.

- Matlab-based visualization of paper path
- event-based scheduling

Important spin-off: increase awareness at Océ about

- usefulness of modeling and
- benefits of multi-disciplinary collaboration

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