Year 4 Review
Dresden, March 16th, 2012

Transversal Integration Activity

Achievements and Perspectives :

Design for Adaptivity

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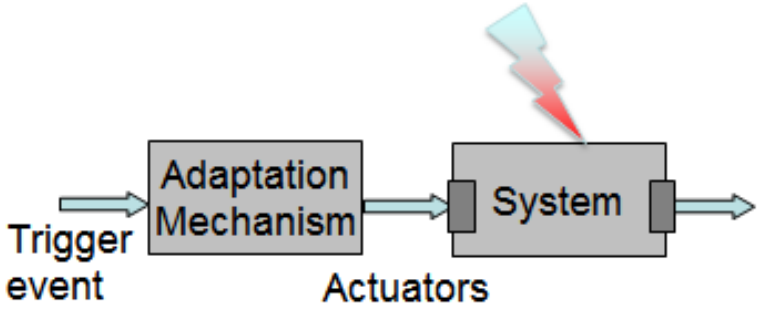
Overall High-Level Objectives and Vision

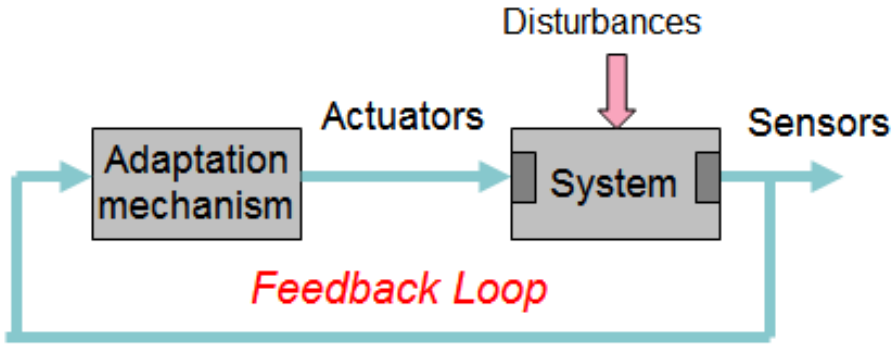
- Integrate the efforts and combine the competences related to adaptivity in embedded systems within ArtistDesign.
  - Adaptive performance, power, and/or thermal management
- Create suitable interfaces, meeting points, and research contacts between the partners and the communities.
- To develop the basic technology needed in order to meet the demands on adaptivity in embedded systems/CPS caused by
  - increasing complexity,
  - hardware development,
  - demands for resource efficiency,
  - increasing reliance on software and/or programmable approaches

Adaptation Mechanisms

- Feedforward
  - Requires perfect information (model)
  - No disturbances

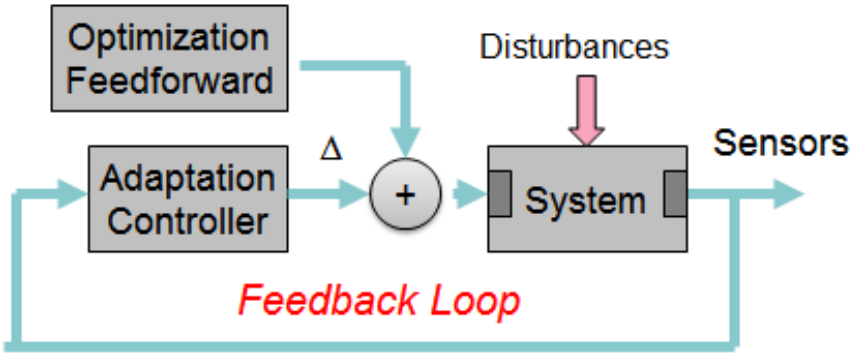


- Feedback
  - Requires sensors

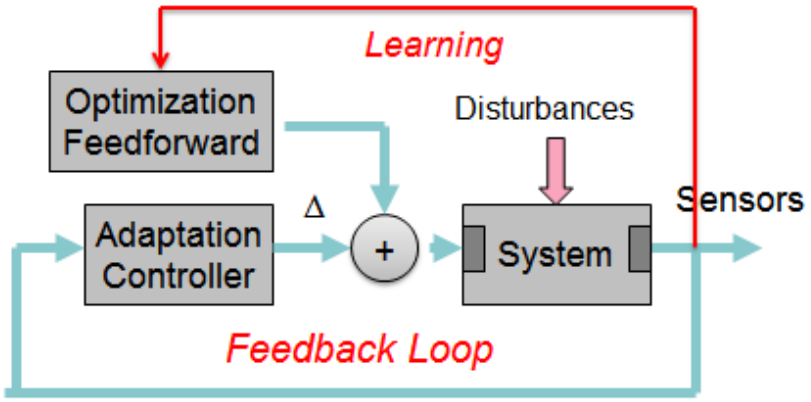


Adaptation Mechanisms

- Feedback + Feedforward
  - Feedback to adjust solution provided by feedforward



- Learning mechanism
  - Sensor-based updates of model
  - Longer time scale



Integration Achieved

- When ArtistDesign started Artist and Artist2 had already been running for 8 years
  - → the integration was already good
- Artist2 had a cluster on Control for Embedded System
- In ArtistDesign generalized to Adaptivity
- Currently
  - Large interest of and use of advanced control techniques in the embedded system community
  - Increasing awareness that embedded computing is a fruitful application area for control within the control community
    - Partly caused by CPS
- Integration has increased substantially

Building Excellence

- The activity has contributed to building excellence by
  - Developing theory, technology, and methodology relevant for achieving adaptivity in embedded systems
  - Organized workshops, technical meetings, and special sessions of relevance to adaptivity, e.g.,
    - APRES Workshops
    - FeBID Workshops
    - WARM workshop
  - Contributed to graduate schools
  - Formed a research network on adaptivity that will continue to evolve

Active Projects during Y4

- Adaptive Resource Scheduling
  - Incl modeling and analysis
  - 21 projects/activities (7 joint)
- Adaptive Networking
  - Wireless networks and distributed systems
  - 5 projects/activities (2 joint)
- Hardware-Based Adaptivity
  - 1 project/activities

Y4 Projects: Adaptive Resource Scheduling

Adaptive and feedback-based resource management (SSSA, ULUND, TUKL, Evidence, Ericsson)

Feedback Control of Computing Systems (ULUND, UIUC, Ericsson)

Theory of distributed performance analysis (TU Braunschweig)

In-system Sensitivity Analysis for Real-Time Systems (TU Braunschweig)

Contract-based Dynamic Task Management for Real-Time Systems (TU Braunschweig)

Analysis of Mode-Changes in Real-Time Systems (TU Braunschweig)

Parametric WCET Analysis (MDH)

Mode Transitions with Mode Independent Tasks in Multicore Systems (IPPorto)

Y4 Projects: Adaptive Resource Scheduling

Comparing schedulers and energy management strategies (IPPorto)

Code offloading in adaptive real-time distributed systems (IPPorto)

Dynamic behavior of embedded systems (IMEC)

Adaptive control of MPEG-4 decoding (TUKL, ULUND)

Improving real-time BIP (Verimag)

Modelling of extra-functional properties (UPM)

Adaptation in service-oriented architectures (UPM)

Y4 Projects: Adaptive Resource Scheduling

Adaptive Temperature Management (ETH Zurich)

Adaptive Timing Management (ETH Zurich, UIUC)

Adaptive Power Management (ETH Zurich, SSSA)

Sampling mechanisms for event-driven control systems (UPC, SSSA)

Optimal online sampling period assignment (ULUND, UPC)

Variability aware allocation and scheduling (UNIBO, STM)

Mode management and architecture for automotive embedded systems (KTH)

Y4 Projects: Adaptive Networking

Online adaptation of QoS in video transmission over Ethernet (UPorto, Aveiro, Valencia)

Dynamic adaptation of virtual channels within hierarchical frameworks (Aveiro, UPorto, MdH)

QoS adaptation in service-oriented architectures (UPorto)

Adaptation of the beacon rate in tracking with cluster-based wireless sensor networks (UPorto, Zhejiang University)

Fault Tolerant and Reliable Communication Platforms (KTH)

Y4 Projects: Hardware-Based Adaptivity

eDNA: Reconfigurable self-organising and self-healing hardware platform (DTU)

Observations

- The majority of the activities concern multi/many-core systems
- Several joint activities involve partners from multiple thematic clusters

Selected Technical Highlights

- Scheduling:
  - Analysis for dynamically changing task sets (UYork)
    - Maximise the utilisation of the available resources by adapting near optimal algorithms
  - Task allocation strategies that are robust to changes (UYork)
    - Minimizes the amount of change that has to be done to the system
  - Mode change protocols for bandwidth servers (SSSA, ETHZ)
    - Maintain schedulability and temporal isolation for CBS bandwidth servers when the server parameters change
  - Mode transitions with mode independent tasks in multicore systems (IPPorto)
    - Analysis for mode changes in multicore systems using global
    - Mode independent (MI) tasks and mode specific (MS) tasks (to be replaced)

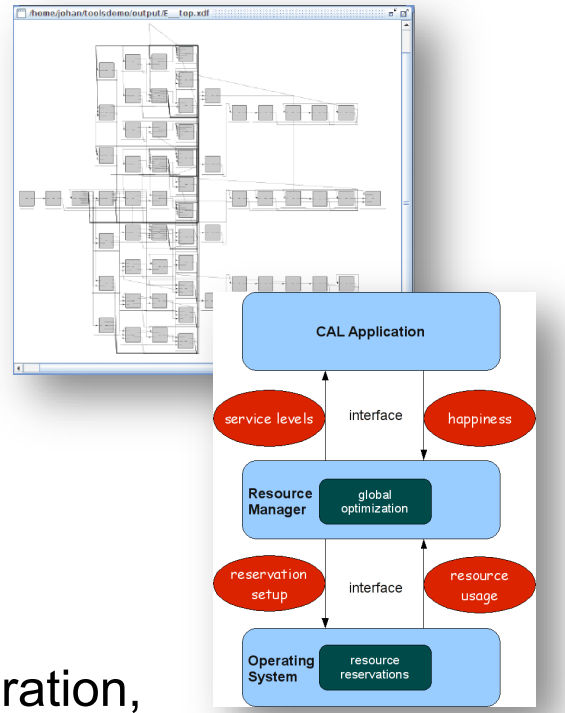
Selected Technical Highlights

- A new allocation and scheduling approach for parallel tasks in a soft-real time media processing systems (UNIBO)
  - In the presence of variability on a multi-core platform.
  - Efficient online policy for meeting timing constraints with minimum energy.

- Memory:
  - Run-time adaptivity of the memory hierarchy within NoC architectures (UYork)
    - Real-time guarantees in dynamic systems
    - Reduce memory requirements and energy costs

Selected Technical Highlights

- Run-Time Resource Management:
  - ACTORS (SSSA, TUKL, ULUND, Ericsson)
    - Homogeneous multicore systems
    - Virtualization through CBS servers
    - Optimization (ILP) and control
    - New Linux scheduling classes
    - Media processing and control applications implemented in the CAL dataflow language
    - Complete tool chain including design space exploration, simulation, model transformation, automatic code generation, profiling
    - X86, ARM11, ST-Ericsson dev board (Android)
    - The work on the resource manager continued by ULUND and TUKL using ArtistDesign funding during 2011
      - Increased functionality incl. DPM
      - Open source



Selected Technical Highlights

- Run-Time Resource Management:
  - Adaptive resource management for distributed multimedia systems (IMEC, BARCO)
    - Video clusters
    - BARCO reported a factor 3 reduction in average power consumption, a factor 5 reduction in hardware cost, and more than a factor 10 in system size as compared to their current solution.
  - Adaptive resource management (VERIMAG)
    - Multimedia applications with multiple quality levels that impacts the quality of service (QoS) and the execution times
    - Optimal quality levels computed online
    - Controller that is constantly adapting the chosen quality levels depending on the actual time and on a combination of average and worst-case estimates of the execution times

Selected Technical Highlights

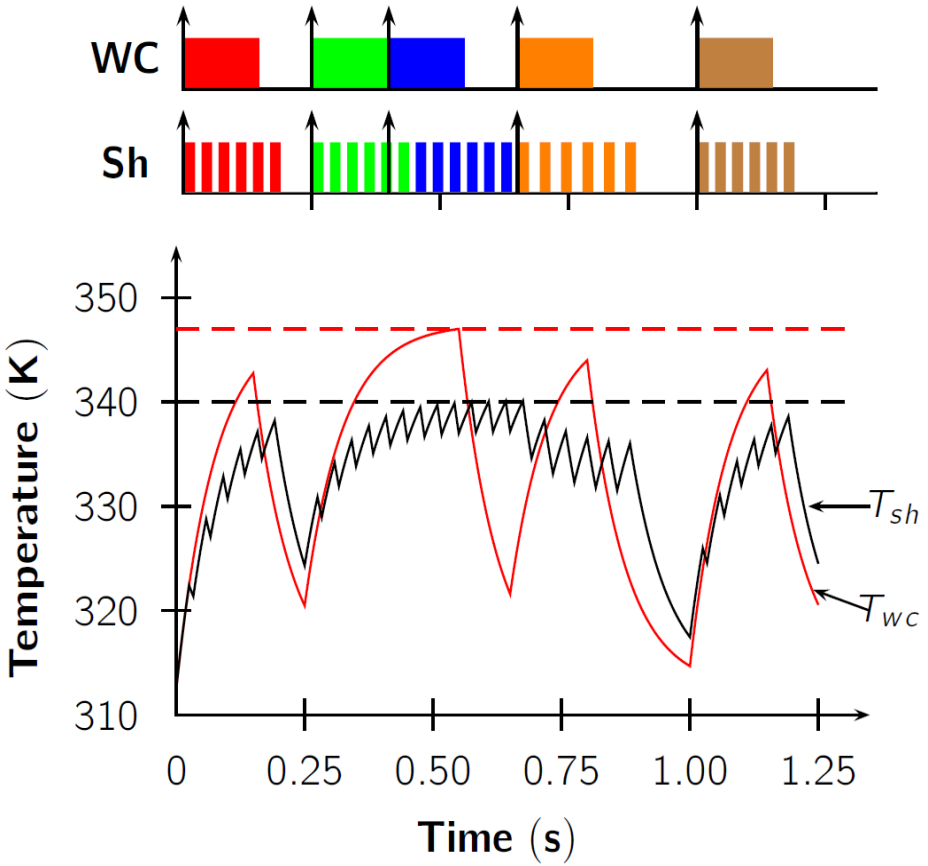
- Run-Time Resource Management:
  - Compile-time and run-time adaptivity for energy and variability (UYork)
    - Compiled code includes potential for OS to vary applications behaviour at run-time for achieving better performance
  - Adaptive Service Management (UPM)
    - Adaptation of service request handling behaviour to the specific requirements of the services
    - CPU contracts to ensure sufficient computation time (modified Linux)
    - Quality compositions of services at run-time

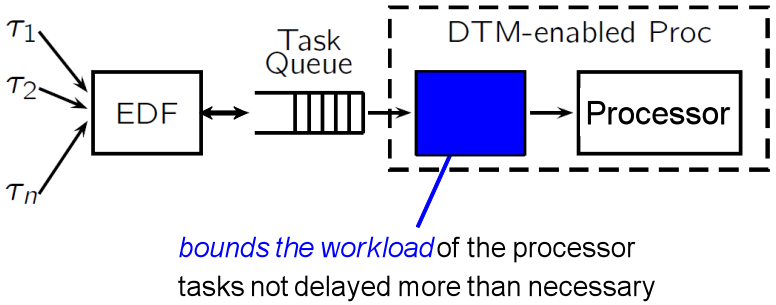
Selected Technical Highlights

- Run-Time Analysis:
  - Distributed run-time analysis of embedded systems (TUBraunschweig)
    - An existing analysis engine has been complemented by a framework that enables access control and runtime-optimization.
    - Extended with distributed algorithms that allow the usage of self-configuration services for self-protecting real-time systems.

Selected Technical Highlights

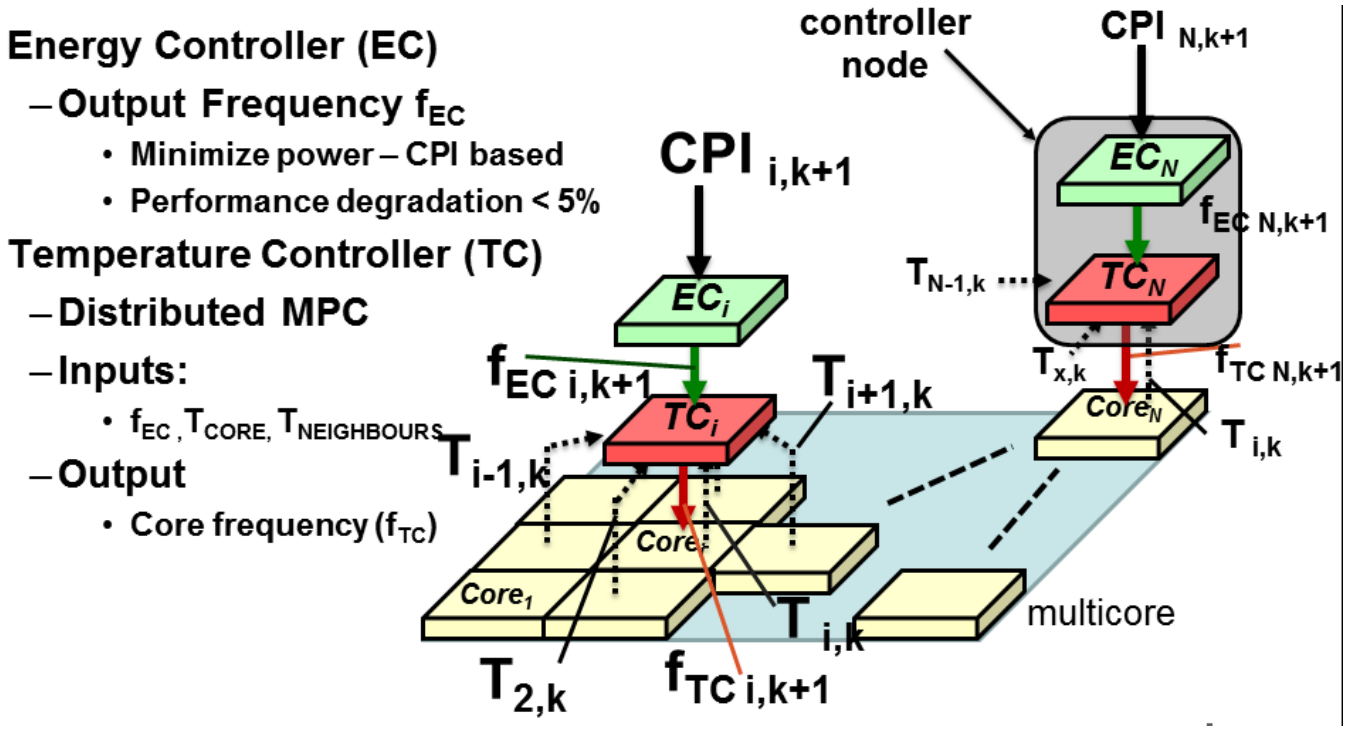
- Power and Thermal Management:
  - Task shaping to obtain thermal guarantees (ETHZ)
    - Just Sufficient Throttling (JUST)





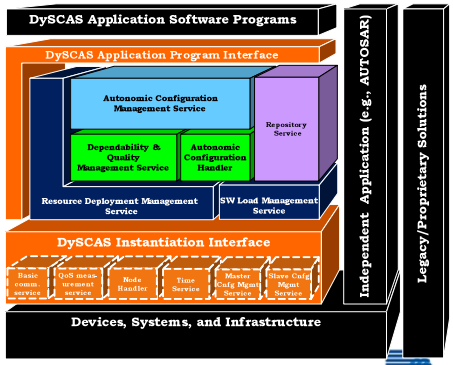
Selected Technical Highlights

- Power and Thermal Management:
  - Integrated energy and thermal control (UNIBO)
    - Cascaded control structure
    - Model-Predictive Control



Selected Technical Highlights

- Frameworks and Reference Architectures:
  - Adaptable Collaboration Framework (IPPorto)
    - Networked embedded systems
    - Allows constrained devices to collaborate with more powerful or less congested peers
    - Trade-off computation time and resource usage against quality
  - DySCAS - Dynamically Self-Configuring Automotive Systems (KTH, ++)
    - A reference middleware architecture for automotive embedded systems
    - Run-time support for the fusion of monitored context data, the resolution of conflicts and configuration variations, and the execution of dynamic adaptations (QoS changes and migrations)

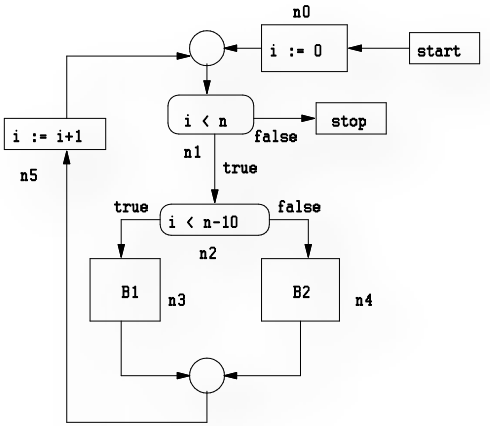


Selected Technical Highlights

- Sensor Networks:
  - Adaptive energy management (ETHZ, UNIBO)
    - Sensor networks with solar cell-based energy harvesting
    - Adaptation of application parameters based on a prediction of future energy availability
    - Optimization problem solved using multiparametric programming
    - Optimal task scheduling using both time and energy constraints
- Adaptive Networking:
  - Communication channel adaptation (UPorto)
    - Virtual channels with adaptable bandwidth and latency through the Flexible Time-Triggered (FTT) approach over switched Ethernet
    - Adaptive TDMA that adapts its phase to escape interfering traffic

Selected Technical Highlights

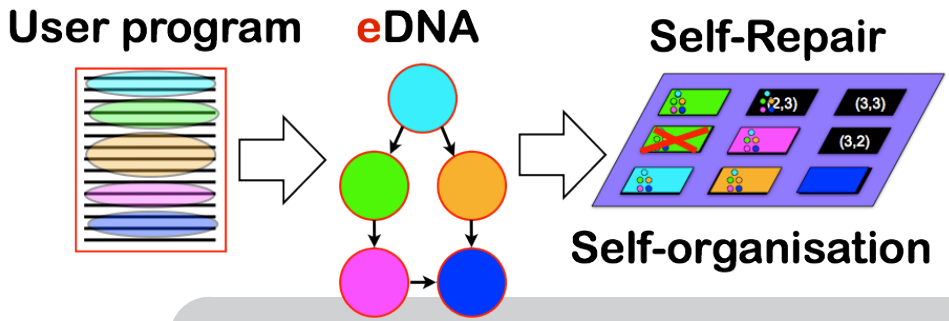
- Control Techniques:
  - Optimization of the timing parameters of real-time control tasks (SSSA)
  - New feedback scheduling techniques (UPC)
  - New event-based control techniques (ULUND, UPC)
- WCET Analysis:
  - Parametric WCET analysis (MDH)
    - Bounds as a function of input values
    - To be used in adaptive real-time systems where the task scheduling adapts to external factors
    - Analysis packaged in the SWEET tool



WCET(n) ≤ if n ≥ 11: 190n - 530
if 0 < n ≤ 10: 140n - 20
otherwise: 20

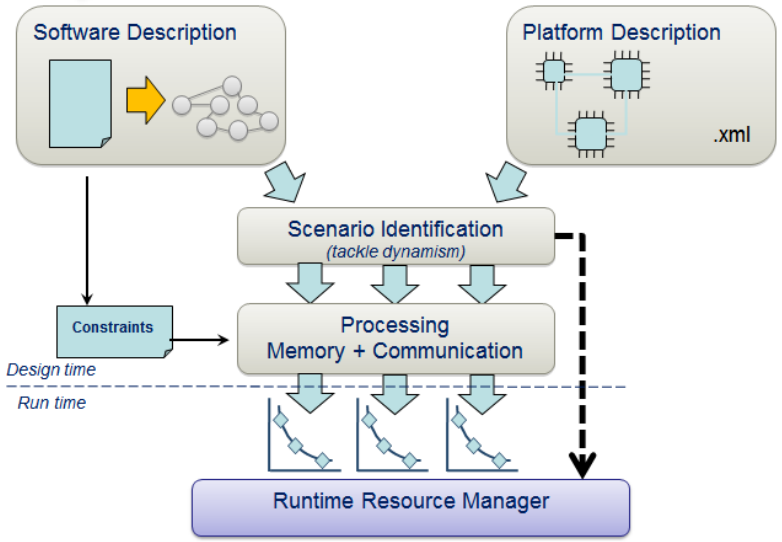
Selected Technical Highlights

- Programmable Hardware:
  - eDNA architecture (DTU)
    - Ultra fault-tolerant FPGA
    - Multiple processors (cells) connected through NoC
    - Programmed via eDNA (electronic DNA), a behavioural spec of the user algorithm encoded in a binary format
    - Cells self-organize by translating the eDNA into tasks and maps them
    - In case of faults the self-organization algorithm is re-run
    - NASA JPL collaboration
    - Commercialized through spin-off company



Selected Technical Highlights

- Tool Chains:
  - Tool chain for multimedia applications modeled with dataflow techniques for multicore platforms (ACTORS project)
  - OptiMMA tool chain (IMEC)



Insights Gained

Adaptivity in embedded systems covers a wide range of subjects.

Hence, to develop a common theoretical basis for adaptivity in embedded systems is extremely challenging.

The work performed within ArtistDesign can merely be considered as a starting point for this.

Insights Gained

In order to move adaptivity from the research community to industrial practice it is essential that adequate support for adaptivity is included in COTS software and hardware, including OS and middleware. This include

- *sensing and actuation mechanisms.*
- *models (thermal, battery, power, …) with correct parameters*
- *adaptivity API between applications and OS/middleware*

Insights Gained

There is a fundamental trade off between adaptivity and predictability. Hence, for applications with severe requirements on predictability, adaptive mechanisms are less suitable.

Furthermore, adaptivity makes formal verification more difficult

→So maybe it is not suitable for hard RT, time-critical systems?

Or?

As soon as fault tolerance and reconfigurability becomes design requirements we have in essence adaptivity

Insights Gained

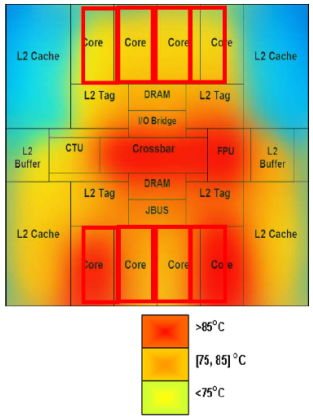
1) The adaptation mechanisms must be very resource efficient.

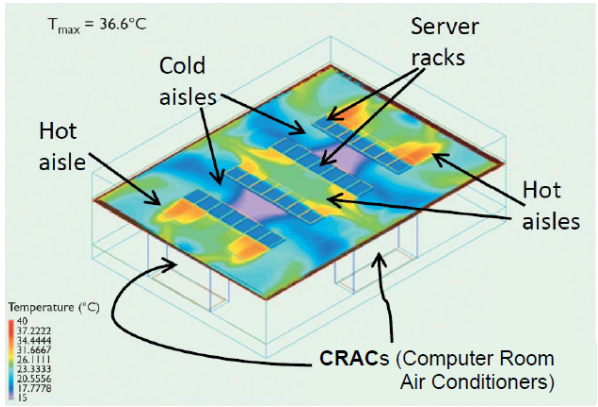
2) The requirements which they pose on the applications and the knowledge they require about the applications must be small.

The adaptation mechanisms must be quite simple in order to be practically useful.

Insights Gained

The thermal control, power control, and performance control needed in multi/many-core embedded systems have very strong relationships with the same problems in data centers.

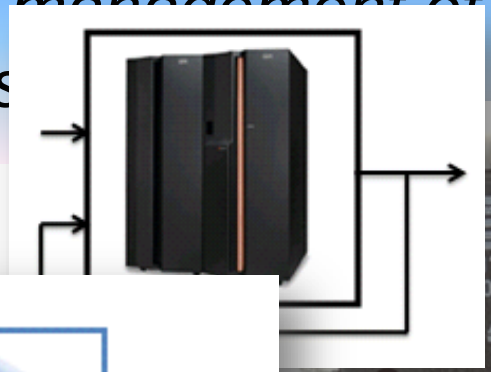


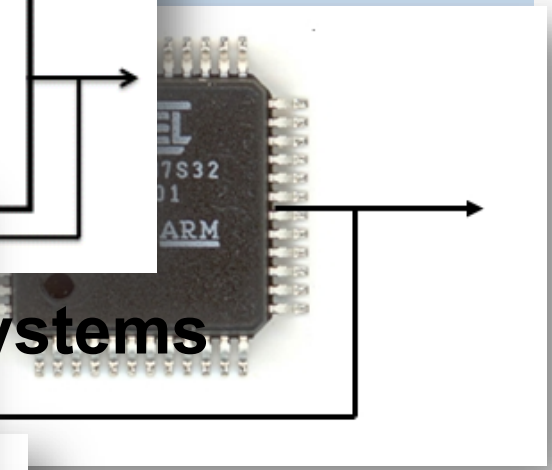


Insights Gained

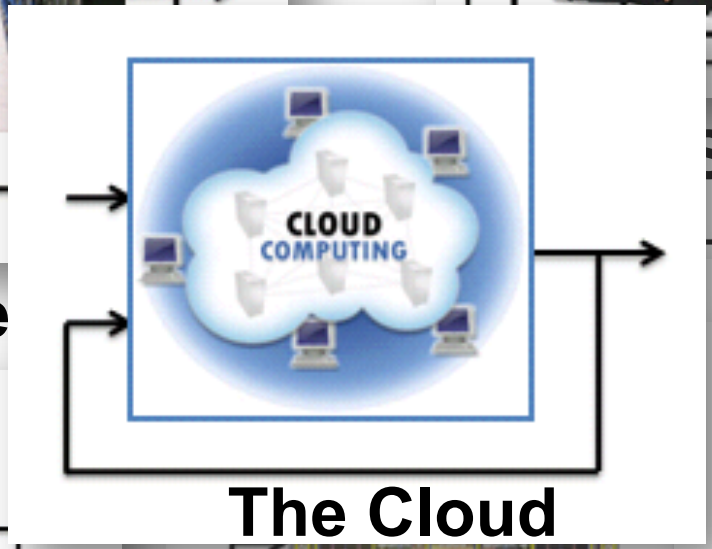
A unified approach to resource management of computing

Data Ce





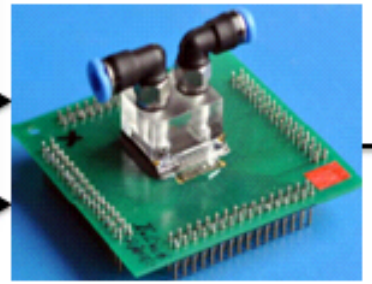
Systems



The Cloud

Desktop Systems

MPSoCs



3D Liquid Cooling

Joint Activities

- LCCC/Artist Workshop on Control of Computing Systems
  - Lund, Dec 5-7, 2011
  - 55 participants, incl 27 invited speakers
  - From Artist Design (UNIBO, TUKL, SSSA, Ericsson, KTH, MDH, UIUC, ULinköping)
  - From industry (IBM, Ericsson, Microsoft, HP Labs, VmWare, Advertising.com Group)
  - Adaptive performance and resource management stretching from embedded systems to the cloud

Joint Activities

- APRES 2011 Workshop
  - CPSWEEK, Chicago
- Workshop on Reconfigurable and Communication-Centric SoC (ReCoSoC), Montpellier, France, June 20-22
  - Indrusiak (UYork) program chair
- FeBID - Sixth International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks
  - Kihl (ULUND) co-chair
  - From 2012 FeBID will be renamed ”Feedback Computing”
- ECRTS – 23rd Euromicro Conference on Real-Time Systems, Porto, July 6-8, 2011
  - Årzén (ULUND) program chair
- RTSS – Real-Time Systems Symposium, Vienna, Nov 30 – Dec 2, 2011
  - Årzén program co-chair for CPS track

Joint Activities

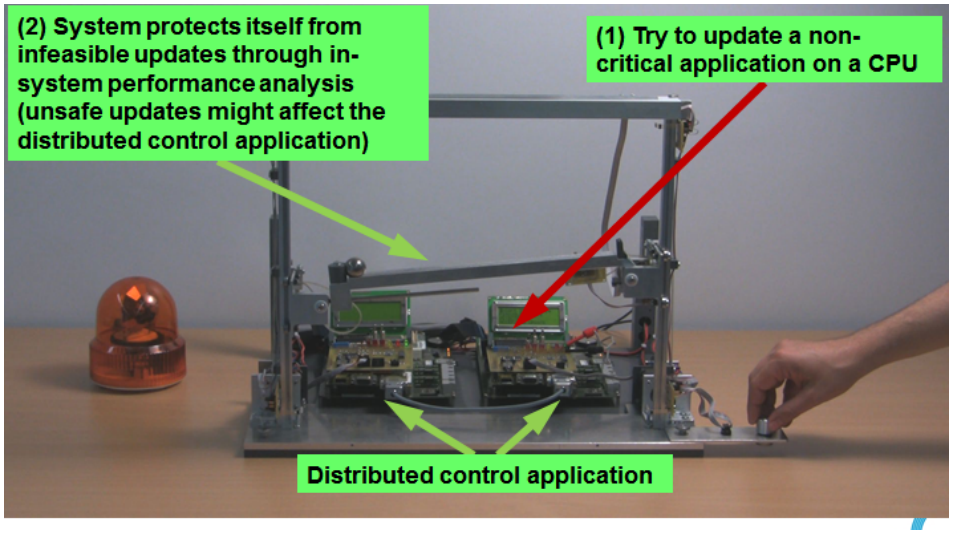
- **Meeting:** Continuation of the ACTORS resource management framework, Kaiserslautern, May 10-11
  Participants: ULUND, TUKL
- **Meeting**: Discussions on joint project in adaptive resource management for telecommunication systems, Kista, Sweden, Oct 6
  Participants: Ericsson, ULUND, UIUC
- **Meeting**: Discussions on joint project in adaptive resource management for telecommunication systems, Lund, Sweden, Nov 22. 2011
  Participants: Ericsson, UIUC, ULUND
- Participated in the Summer Schools in Europe and China, 2011

Special Issue

- Special issue on adaptive embedded systems for RTSJ in the pipeline
- 8 submissions
  - Several from Artist partners
- 2-3 will be accepted
  - Announced shortly

Tools and Platforms

- **SWEET (SWEdish Execution Time tool)**
  - Parametric WCET analysis
  - Mälardalen, Usaarland, TUVienna
- **Hardware setup**
  - Demonstrate self-protection and adaptability of embedded Real-Time Systems
  - TUBraunschweig, UErlangen, Symtavision



Tools and Platforms

- **TrueTime Simulator**
  - Networked embedded control simulation in Simulink
  - ULUND + several Artist partners as users
  - Support for slot-shifting in time-triggered systems (TUKL)
  - Support for WirelessHART (ABB Corporate Research)
  - Port TrueTime to Modelica
    - Replace Simulink S-functions with FMI
    - Vanderbilt University and ULUND
    - TrueTime will be part of the META-2 tool chain for model-based development of cyber-physical systems, developed in the DARPA project AVM (Adaptive Vehicle Make)
    - Connections to Dassault Systèmes and Modelon on related issues

Tools and Platforms

- **Fault Tolerant Nostrum (KTH)**
  - KTH Network-on-Chip platform has been developed into a complete fault tolerant platform, based on adaptive routing
  - Tolerate transient, intermittent, and permanent faults with a combination of techniques at the link, the network and the transport layer.
- **SPARTS: Comparing Schedulers and Power Management Strategies (IPPorto)**
  - A framework for simulating scheduling mechanisms and power management strategies on a generic real-time device.

Observation

- The individual tool address quite different aspects of adaptivity.
- No clear gain in attempting to integrate them

Lasting Impacts

Future interaction beyond the end of the NoE

- The OS and Networks cluster partners will continue their activities, incl adaptivity, within, e.g., ADSIG
- The workshops will continue, e.g., APRES 2012 in Beijing, April 16
- TUKL and ULUND will continue their joint work on adaptive resource management
- SSSA and ULUND will continue their collaboration (Enrico Bini from SSSA will spend two year at ULUND as a Marie Curie Fellow)
- The collaboration between Ericsson, UIUC and ULUND on resource management in telecommunication systems continues
  - Tarek Abdelzaher, UIUC spent Fall 2011 at ULUND
- MDH and Tidorum will continue their collaboration
- Several other collaborations will continue

Final Overall Assessment

What worked well:

- The scientific part - significant advances have been made in adaptive resource management by the partners in joint and individiual projects
- The integrated research network established
- Large number of workshops and technical meetings organized
- The ArtistDesign organization
- Industrial connections, although they were mainly at the partner level

Quantitative Metrics

Over the four years:

- 133 individual publications
- 45 joint publications
- 19 workshops or technical meetings organized
- 8 educational events

Final Overall Assessment

What went less well:

- In the beginning we envisioned that a Wiki could be used as a platform for collaborative work
- We did not succeed in writing a joint white paper/survey on adaptivity in embedded systems

For the future:

- ADSIG within EDAA
- The current momentum guarantees a successful continuation