Mobile Embedded Computing: Applications & Beyond

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Two 2-threaded 64b VLIW cores
1.72 Billion transistors, 596 mm², 90nm
Generated clock frequency is a function of the measured voltage -- 3X gain in power consumption

- 16 bit Instr
- 32 bit datapath
- 4K*16 bit program
- 4K*8 bit data
- 1 GHz, 5-stage pipe
- Real-time scheduler
- Power control
- Temperature control

MicroController

Power Distribution at Fixed V/F

Power Range with Foxton
New Computing Nodes & Networks are no longer monolithic entities

- High-end processing migrating to mobile computing, sensor computing

Tremendous innovations in form and function
Over 90% all innovations in modern automobile are SW-

- **Processing**: 70-80 electronic control units (ECUs) supporting hundreds of features
  - ECUs delivered by multiple suppliers, with their own software chains

- **Networking**: separate, integrated networks for power train, chassis, security, MMI, multimedia, body/comfort functions
  - Increasing interaction beyond car’s boundaries with devices, networks

- **Software**: hardware independence, information interdependence among subsystems, system composition, validation.

- Highly complex, networked, and distributed
8oz to 2000 lb platforms: Computing is on the move

- Tremendous architectural variations on how these machines are built and deployed

- Silicon computational fabrics are getting to be intertwined with sensors, radios and multi-scale networks

- Opportunity for at-scale instrumentation of the physical world
  - Real-time embedded control software appearing everywhere

- Fundamental challenges of modeling, design, validation across all application domains.

▶ Mobile Computing = computing with time & space
Mobility is Inherent & Transformative

- Code can move to a new virtual location or to a new physical location
  - Different challenges: distributed computation, combat failure and disconnections

- It has a transformative effect on programming
  - The abstraction of just connecting things breaks down when considering Mobility
    - Whether networking (VL) or distributed computing (PL)
  - Mobility fundamentally changes the observables associated with computation
  - Observables are events or states that can in principle be detected.
New Observables and Hiddens

- Administrative Domains
- and new hiddens
  - Communication failure is no longer obvious
    - Lower bound on latencies, but no upper bound
    - Undetectable communication errors (as some long delay)
  - Failure recovery is now equivalent to occasional connectivity
Mobile Computing = Computing + Space + Time

- Location information is part of the computational infrastructure. Mobile device or mobile environments.
- Three broad classes:
Computing Efficiencies are rising to fundamental device limits

- **Watt nodes: Home, Office, Car**
  - Compute intensive platforms
  - Reaching 1 Tops in 5-10W: 100-200 Gops/W
  - 100-1000x more efficient than today’s PCs
  - Programmability must, innovation from domain knowledge

- **MilliWatt nodes: Converged devices**
  - Wireless intensive: radios, networks, protocols, applications
  - Multimedia evolution to Scalable video coding leading to 9-36x more CPU than H.264
  - 10-hour battery operation, 1W for 10-100 Gops: 10-100 Gops/W
  - Combination of scaling and duty cycling, computing models

- **MicroWatt nodes: Immortal devices, ad hoc networks**
  - < 100 microwatts for scavenging, 10 Mops: very high peak efficiencies
  - Approach limits on computation and communication
  - Aggressive duty cycling (<1%. 1bps-10kbps).
Intrinsic Power Efficiency of Silicon Substrates

At 130 nm nodes
- MPU: 100 MOPS/W
- FPGA: 1-2 GOPS/W
- ASIC: 10-20 GOPS/W

Computing Efficiency In the Near Term:
- We are within 10x of efficiency requirements for custom ASICs
- Perhaps a maximum of 25x of improvements in software performance possible on the same hardware through optimizations of embedded SW.

In the Far Term:
- But 500x behind when dealing with SW programmable systems
  - Unless, of course, notion of SW changes underneath..

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Problems we are focusing on

- **Adaptive and Reconfigurable Computing Fabrics**
  - Laboratory for experimentation with various computing fabrics: Coarse and fine-grain co-processing
    - Soft multiprocessor cores: with multithreading
    - Dynamically reconfigurable circuit fabrics: Sequential versus spatial processing
  - Capabilities: Fast prototyping, Synthesis, Modeling and Verification
    - Parallelizing High Level Synthesis, Architectural Modeling, Compositional methods

- **Cyber-Physical Systems (CPS)**
  - Combining processing and reasoning with both logical as well as physical variables
    - Time, Location/Place, Storage, Sensor observables
  - Model space and reason with spatial information
    - Time and Space as first order quantities in CPS models provide a starting point for this integration.

- Projects that seek to use and contribute to improving technological and societal infrastructure.
Location & Location Infrastructure

- Current GPS infrastructure primarily used for transportation purposes in civilian use
  - Recreational, Navigational: 3m-10m
  - Resource mapping: 1m-5m
  - Precision increase through augmentation over GPS
- Many levels and sources of augmentation
  - All the way to survey type applications
1cm-1dm ‘real-time’ GPS

- Assisted by reference stations, rowers and cooperative infrastructure
  - DGPS: L1 corrections, range: 200-400km, meter level accuracy, few seconds, continental coverage
  - RTK – single base-station: L1 code, L1/L2 carrier corrections, range: 10-15 km, cm level accuracy, < 1 second delay, regional and local coverage.

- dm real-time positioning capability is on the horizon
  - Augment NDGPS and WAAS
  - National Spatial Reference System: collect CORS measurements and stream over the internet

- Many other advances in ‘localization’ techniques other than the GPS.
Continuously Operating Reference Stations
Adding real-time

- Dm accuracy in real-time can be used for
  - Land surveying
  - Remote sensing
  - Hydrography
  - Machine control (precision agriculture)
  - Emergency response
  - Asset inventory
  - Structural integrity monitoring
  - Atmospheric monitoring, weather forecasting
  - Tsunami and volcanic warning systems.
New Computing Paradigms with time and space observables

- **RT computing at the intersection of two different time topologies**
  - Absolute and relative delays
    - Delays as uninterruptible actions
    - Timeouts, timed procedure calls, wait selects
  - Location-specific computing
    - Need models that capture location
    - Need methods including operations on these models.

These two together lay the foundation for a new vocabulary in engineering systems.
Location awareness

- Programming with spatial references
- Infrastructural support for location
  - Transparent location updates
  - Monitor resources in their environment
    - Virtual resource naming, that is, resources referred to based on their expected location
    - Reactive to changes in the resource availability
    - Control resource usage: access timeouts.
- Spatial Programming
  - Using Reactive Mobile Concurrent Processes (RMCP)
  - Define ‘observables’ across computing entities and methods to communicate these.
  - Define new methods “match_ontology” to reason with spatial constructs.
Embedded Systems in Societal Context

While Embedded Systems continue to proliferate their impact on societal infrastructure in a meaningful way is yet to be seen
- Intelligent transportation networks
- Power distribution and delivery
- Healthcare
- Emergency response

Challenges
- Highly distributed, complex ‘systems of systems’
- Societal integration challenges: legacy, scalability, policy goals

Goal:
- Combat fragility, devise robust and adaptable solutions to societal applications.
A Team Effort

- Partnership between researchers drawn from
  - Technology areas
  - Social and Technology policy
  - Industry and Standards bodies

- Deeply integrated with engineering education
  - Embedded Real-Time Systems, Structural Dynamics, Distributed Control, Data Management, Communications & Networking

- Institutional Engagement and Support
  - CalIT2
  - Center for Embedded Computer Systems, UC Irvine
  - UCSD/LANL Engineering Institute
  - MIND Laboratory, University of Maryland
  - GM-CMU Collaborative Laboratory at CMU
  - IIT Delhi, IIT Bombay, Univ. of Bologna
  - C. A. R., Sona Koyo Testing Facilities in Gurgaon
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On going Activities

- Application focii
  - Energy and Power Distribution Networks
  - Automotive and Transportation Networks
- Multiple technical efforts seeded
  - PCES: Engineering of Physically-Coupled Distributed Embedded Systems for Societal Scale Applications
  - CAESERS: Advanced Embedded Systems for Robust Societal Scale Applications
  - ACCESS: Adaptable Cyber-Coupled Engineering Systems for Autonomous Response to Unexpected Events
  - SHM: Structural Health Monitoring for Damage Prognosis
- Community building
  - ASWD: Automotive Software Workshop at San Diego, March 2006
  - ESLD: System-level Design Workshop at IIT Delhi, February 2007
  - CPS: Multiple and Broader Community building on Cyber-Physical Systems, July, October, 2006
Adaptable Cyber-Coupled Engineering Systems for Autonomous Response to Unexpected Events (ACCESS)

**Grand Challenge:** Models and methods to build coupled cyber-physical systems that are able to autonomously respond to unexpected events through highly available IT infrastructure, accurate and timely situational awareness and key reconfigurabilities for resource repurposing.

**Research Components**
1. Provably correct composable models of CP components
2. Situational awareness through continuous structural monitoring for dynamic decision support
3. Automatic synthesis of adaptive and reflective middleware for dynamic resource management

**Impact & Testbed**

MetaSim: simulation environment for crisis response situations.

**Awareness Applications**

Distributed Embedded Systems, Storage & Data Architecture, Structural Health Monitoring, Resource Planning
Summary

- Cal-IT2 is the hub of a community of shared interests
  - Technical: Deeply-coupled Cyber-physical systems
  - Educational: Embedded systems, software engineering, sensor networks, data engineering, predictive modeling and hazard mitigation
  - Wholesome and Holistic: societal-scale applications and implications for technology and social policy

- We have assembled a strong team to address deep technical challenges
  - And capability to transition research success to meaningful societal contributions
  - And always looking for the driven few…!