EE249: Embedded-System Design

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Outline

- Part 2: Design Methodology
- Part 3: Models of Computation
- Part 4: The Ptolemy and POLIS Systems
- Part 5: Verification and Synthesis, Hardware and Software
- Part 6: Interface-based Design
Plan

- We are on the edge of a revolution in the way electronics products are designed
- System design is the key
  - Start with the highest possible level of abstraction (e.g., control algorithms)
  - Establish properties at the right level
  - Use formal models
  - Leverage multiple “scientific” disciplines
- Establish horizontal and vertical “supplier-chain” like partnerships
- Need change in education

Outline

- Scenario and Characteristics of Future Information Technology
- Embedded Systems: Automotive, Home Networks, Smart Dusts, Universal Radios
- What is Needed at the Infrastructure Level
- High-Leverage System Design Paradigms:
  - Communication-based Design
  - Architecture-Function Co-design
- Platform-based Design as Implementation Technology
Information Technology Scenario

- According to the International Data Corporation
  - 96% of all Internet-access devices shipped in the United States in 1997 were PCs.
  - By 2002, nearly 50% will not be PCs. Instead, they will be digital set-top boxes, Web-enabled phones, and personal digital assistants, to name just a few.
  - By 2004, the unit shipments of such appliances will exceed those of the PC.

Historic Perspective

- Technology discontinuities drive new computing paradigms and applications
- E.g., Xerox Alto
  - 3Ms--1 mips, 1 megapixel, 1 mbps
  - Fourth M: 1 megabyte of memory
  - From time sharing to client-server with display intensive applications
- What will drive the next discontinuity? What are the new metrics of system capability?
What’s Important: Shifts in Technology Metrics

- Display (human-computer interface)
  - More ubiquitous I/Os (e.g., MEMS sensors & actuators) and modalities (speech, vision, image)
  - How to Quantify?

- Connectivity (computer-computer interface)
  - Not bandwidth but “scaled ubiquity”
  - Million accesses (wired and wireless) per day

- Computing (processing capacity)
  - Unbounded capacity & utility functionality (very high mean time to unavailable, gracefully degraded capability acceptable)

What’s Important: Shifts in User/Applications Metrics

- Cost: Human Effort
  - Save time
  - Reduce effort

- The Next Power Tools
  - Leveraging other peoples’ effort/expertise
    - e.g., “What did Dave read about disk prices?”
    - e.g., “What did people who buy this book also buy?”
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Modern Vehicles, an Electronic System

IVHS Infrastructure

- Cellular Phone
- Navigation
- Info/Comms/AV Bus
- GPS

Multiplexed Systems

- Vehicle CAN Bus
- Suspension
- Display

Wireless Communications/Data
Global Positioning

Electronic Toll Collection
Collision Avoidance
Vehicle ID Tracking

SW Architecture
Network Design/Analysis
Supplier Chain Integration

Performance Modelling
Function / Protocol Validation
Wireless Communication in the Car

- Wireless communication is a must in car
- Wireless communication to leverage entertainment system and auto PC
  - Same input-output devices, e.g., voice activation, loudspeakers, automatic sound re-direction
- IC providers likely to play major role in producing single chip solutions to be integrated in local network of car electronics
- IP providers for protocol layers (GSM, Wide-band CDMA)
- Major role of system integrators to provide global solution
Home Networking: Application (Subnet) Clusters

Cameras Everywhere!

CMOS Camera

CCD Camera

Source: Dr. K. Pister, UC Berkeley

Chips that Fly?

SmartPen
Smart Dust

Goal:
- Distributed sensor networks
- Sensor nodes:
  - Autonomous
  - 1 mm³

Challenges:
- 1 Joule
- 1 kilometer
- 1 piece

Smart Dust Components

- Laser diode
  - III-V process
- Active beam steering laser comm.
  - MEMS/optical quality polysilicon
- Analog I/O, DSP, Control
- COTS CMOS
- Power capacitor
- Multi-layer ceramic
- Solar cell
- CMOS or III-V
- Thick film battery
- Sol/gel V₂O₅

Sensor
- MEMS/bulk, surface, ...

Passive CCR comm.
- MEMS/polysilicon

1-2 mm
Airborne Dust

Mapleseed solar cell
MEMS/Hexsil/SOI

1-5 cm

Rocket dust
MEMS/Hexsil/SOI

Controlled auto-rotator
MEMS/Hexsil/SOI

Synthetic Insects
R. Yeh, K. Pister, UCB/BSAC
The Berkeley Wireless Research Center (BWRC)

- Brodersen, Rabaey, Gray, Meyer, Katz, ASV, Tse and students
- Cadence, Ericsson, HP, Intel, Lucent, ST, TI
- Next Generation Wireless systems:
  - Circuits
  - Architectures
  - Protocols
  - Design Methodologies

The “Universal” Radio (BWRC)

Fourth-generation radio providing following features

- Focus on the wireless services with minimal constraints on how the link is provided
- Allows for uncoordinated co-existence of service providers (assuming they provide compatible services)
- Provides evolving functionality
  - Adapts to provide requested service given type of service, location, and dynamic variations in environment (i.e. number of users)
  - Allows for to continuously upgrade to support new services as well as advances in communication engineering and implementation technologies

Presents an architectural vision to the multi-user, multi-service problem!

- This is in contrast with current approach where standards are the input and architecture the result - leading to spectral
Ultra Low-Power PicoRadio

- Dedicated radio’s for ubiquitous wireless data acquisition and display.
  Energy dissipation and footprint are of uttermost importance
- Goal: $P < 1 \text{ mW}$ enabling energy scavenging and self-powering
- Challenges:
  - System architecture: self-configuring and fool-proof
  - Ultra-low-power design
  - Automated generation of application-specific radio modules making extensive use of parameterizable module generators and reusable components

Integrated CMOS Radio

Integrate within the same chip very diverse system functions like: wireless channel control, signal processing, codec algorithms, radio modems, RF transceivers… and implement them using a heterogeneous architecture
Communication versus Computation

  (assuming continued scaling)
- Communication cost (minimum):
  - 100 m distance: 20 nJ/bit @ 1.5 GHz
  - 10 m distance: 2 pJ/bit @ 1.5 GHz
- Computation versus Communications
  - 100 m distance: 300 operations ≈ 1 bit
  - 10 m distance: 0.03 operation ≈ 1 bit

Computation/Communication requirements vary with distance, data type, and environment

Energy-efficient Programmable Implementation Platform

“Software-defined Radio”

- Embedded Microprocessor/DSP System
- Configurable Arithmetic and Logic Processors
- Programmable Logic
- Dedicated Modules
- Analog RF
- Protocol Processing
- Communication Channel
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What's Needed:
(Endeavor Expedition, Berkeley Oxygen, MIT)

- Automatic Self-Configuration
  - Personalization on a Vast Scale
  - Plug-and-Play
- The OS of the Planet
  - New management concerns: protection, information utility, not scheduling the processor
  - What is the OS of the Internet? TCP plus queue scheduling in routers
- Adapts to You
  - Protection, Organization, Preferences by Example
Technology Changes & Architectural Implications

- Zillions of Tiny Devices
  - Proliferation of information appliances, MEMS, etc.
- “Of course it’s connected!”
  - Cheap, ample bandwidth
  - “Always on” networking
- Vast (Technical) Capacity
  - Scalable computing in the infrastructure
  - Rapid decline in processing, memory, & storage cost
- Adaptive Self-Configuration
- Loosely Organized
- “Good Enough” Reliability and Availability
- Any-to-Any Transducers
  (dealing with heterogeneity, over time--legacy--and space)
- Communities (sharing)

Adaptive Self-Configuration

- Plug-and-Play Networking
  - No single protocol/API: standardization processes too slow and stifle innovation
  - Devices probe local environment and configure to inter-operate in that environment
  - “Computer” not defined by the physical box: portals and ensembles

- Local Storage is a Cache
  - Invoke software and apps migrate to local disk

- System Learns Preferences by Observation
  - E.g., “Privacy by Example:” owner intervention on first access, observe and learn classification, reduce28
Loose Organization

- Loosely Structured Information
  - Large volume, easily shared: supports communities

- Self-Organized
  - Too time consuming to do yourself: Organize by example
  - Individualized & context-dependent filtering

- Incremental Access, Eventually exact
  - Query by concept: “What did Dave read about storage prices?”
    - “A close answer quickly is better than a precise answer in the far future”;
    - Probabilistic access is often “good enough”

Any-to-Any Transducers

- No need for agreed upon/standardized APIs (though standard data types are useful)
  - If applications cannot adapt, then generate transducers in the infrastructure automatically
  - Exploits compiler technology
  - Enhance plug-and-play to the application level

- Legacy Support
  - Old file types and applications retained in the infrastructure
Next-Generation Operating Environments

- Advances in hardware and networking will enable an entirely new kind of operating system, which will raise the level of abstraction significantly for users and developers.

- Such systems will enforce extreme location transparency
  - Any code fragment runs anywhere
  - Any data object might live anywhere
  - System manages locality, replication, and migration of computation and data

- Self-configuring, self-monitoring, self-tuning, scaleable and secure

Adapted from Microsoft “Millenium” White Paper
http://www.research.microsoft.com