EE249: Embedded-System Design

Alberto Sangiovanni Vincentelli
Department of EECS
University of California at Berkeley
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
- Stereo/CD
- GPS
- Display

Multiplexed Systems
- Body Control
- Suspension
- ECU
- Abs
- Vehicle CAN Bus
- Transmission

Wireless Communications/Data
- Global Positioning

Electronic Toll Collection
- Collision Avoidance
- Vehicle ID Tracking

SW Architecture
- Performance Modelling
- Network Design/Analysis
- Function / Protocol Validation
- Supplier Chain Integration
Vehicles, a Consumer Electronic System

**Challenges**
- Minimum Technology to Satisfy User Requirement
- Usability
- Integrate with Other Vehicle Systems
- Add the Function Without Adding the Cost

**Vehicle Web Site Technology**

- **Comms**
  - GSM/PCS
  - CDMA, Paging
  - Compression

- **S/W Shell**
  - Windows CE, NT, MAC, BIOS

- **Output & I/F**
  - Serial, Ethernet
  - Diagnostics

- **User I/F**
  - Voice Synthesis
  - Voice Control
  - Stylus, ETC

- **Processor**
  - RISC, PowerPC
  - X86, Hitachi RISC

- **Display**
  - Heads Up,
  - Flat Panel
  - Graphics

- **S/W Apps**
  - Browser, Comms, User Apps

**Info/Comms/AV Bus**

- Cellular Phone
- GPS
- Navigation
- Stereo/CD
- Display
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

PC/Data Based
- PC-1
- Internet Access
- PC-2
- Printer
- Laptop

Entertainment Based
- Stereo
- TV
- Cam Corder
- Still Camera
- DVD Player
- VCR
- Video Game
- Web-TV STB

Appliance Based
- Sprinklers
- Toasters
- Toasters
- Ovens
- Clocks
- Utility Customization
- Climate Control

Security Based
- Door Sensors
- Motion Detectors
- Video Surveillance
- Window Sensors
- Audio Alarms
- Light Control
- Smoke Detectors

Telecom Based
- PDA
- Intercom
- Voice Phone
- Video Phone

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
- 1mm$^3$

**Challenges:**
- 1 Joule
- 1 kilometer
- 1 piece

**Components:**
- Sensor
- Interface
- Power: battery, solar, cap.
- Comm: LOS Optical (CCR, Laser)
Smart Dust Components

- Laser diode
  - III-V process
- Passive CCR comm.
  - MEMS/polysilicon
- Active beam steering laser comm.
  - MEMS/optical quality polysilicon
- Sensor
  - MEMS/bulk, surface, ...
- Analog I/O, DSP, Control
  - COTS CMOS
- Power capacitor
  - Multi-layer ceramic
- Solar cell
  - CMOS or III-V
- Thick film battery
  - Sol/gel $V_2O_5$

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
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

- Computation cost (2004): 60 pJ/operation (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 == 1bit
  - 10 m distance: 0.03 operation == 1bit

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

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, reduce explicit intervention over time
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