Introduction

• Electronic systems are inherently *heterogeneous*
  • Perform a combination of signal processing, communications, and control algorithms
  • Implemented using a combination of digital signal processors (DSPs), microcontrollers, dedicated hardware, and configurable hardware
• No single design methodology is applicable to entire system
• *Embrace heterogeneity*: develop a formal consistent framework for specification, simulation, and synthesis
  • Integrate application-specific design methods (fast simulation, verification)
  • Integrate application-specific implementation technologies (DSPs, FPGAs)
• *Focus*: Automate the design of scalable software and hardware for image and video processing systems
  • Scalable hardware expands to a variable number of processors (Mercury)
  • Scalable software adapts to the available processors (Solaris, Windows NT)
• *Theme*: Decouple computational models from technologies for implementation (e.g., SPW, HP EEsof, and Ptolemy).
Hardware/Software Codesign for Video Codecs

- **Problem**: Rapid prototyping of audio/video codecs as a new standard being adopted each year since 1992, e.g.
  - MPEG-2 (1994): scalable (1-4 Mbps), surround sound, multiplexing
  - MPEG-4 (1999): scalable (0.01-4 Mbps), interactive, content-based

- **Goal**: Develop a formal system-level design methodology that includes H.261, H.263, H.263+, and MPEG 1, 2, and 4.

- **Solution**: Hierarchically combine multiple models of computation for reuse, fast cosimulation, and cosynthesis
Shape Coding for Multimedia Content and Retrieval

• **Problem**: Efficient object representation in video for compression/retrieval.

• **Goal**: Develop a scalable framework for lossy and lossless coding of shapes.

• **Solution**: Generalized predictive shape coding using polygonal representation (lossless) & approximation (lossy)
  
  • Contour segment coding: polygonal approximation and vertex coding
  • Contour motion estimation: shape motion estimation (temporal)
  
• One parameter $d_{\text{max}}$
  
  • Maximum distance between polygon and contour (0 for lossless coding)
  • Controls bitrate and distortion

Jong-il Kim
Scalable Software for Sonar Imaging Systems

• **Problem:** Real-time 3-D sonar systems are expensive to develop, manufacture & upgrade due to custom hardware

• **Goal:** Software beamformer on a desktop workstation

• **Solution:** CAD framework for scalable software that merges
  • symmetric multiprocessing on Unix workstations
  • lightweight POSIX threads (AIX, Irix, HP-UX, Linux, Solaris)
  • Process Network model (concurrency, determinism, boundedness)

• Real-time 4-GFLOP digital interpolation sonar front-end using 12 x 336 MHz UltraSPARC-IIIs: cascade of 1 vertical beamformer (80 staves, 10 sensors/stave, 100 kHz, 16 bits, 160 MB/s, 2.5 CPUs), 3 horizontal beamformers (each: 80 staves, 61 beams, 32-bit floats, 32 MB/s, 3 CPUs), and 3 shifters/decimators

• Reduces weight, volume, and development time by factor of two, and costs by:

<table>
<thead>
<tr>
<th></th>
<th>Front End</th>
<th>Manufacturing Costs</th>
<th>Development Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custom Hardware</td>
<td></td>
<td>$1,000,000</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Ultra-2 6000</td>
<td></td>
<td>$400,000</td>
<td>$300,000</td>
</tr>
</tbody>
</table>

• CAD tools can be deployed with the workstation

• Tutorial: [http://www.ece.utexas.edu/~allen/GuestLecture.html](http://www.ece.utexas.edu/~allen/GuestLecture.html)
Problem: Fast high-quality algorithms for halftoning for printers and inverse halftoning for scanned/printed images

Goal: Develop scalable algorithms that deliver high subjective image quality

Solution: Model halftoning as 2-D delta-sigma modulation

- Noise-shaped feedback coder ($\Delta-\Sigma$) has signal and noise transfer functions
- Objective measures of edge sharpening (proportional to quantizer gain) and shaped noise (noise transfer function) in halftoned images
- Objective measures of blurring and spatially-varying noise in inverse halftoned images
Hybrid Neural Network and Signal Processing Systems

- **Problem**: Develop a unified model of computation for mixed artificial neural network (ANN)/signal processing systems
  - Gamma Memory Model (add FIR filters on the inputs of the neurons)
  - Cellular Neural Network (CNN) detects impulsive noise in images which is removed by a median filter
- **Goal**: Find a unified model for simulation and synthesis
- **Solution**: Use dataflow models that support static schedules
  - ANNs during classification: Homogeneous Synchronous Dataflow (HSDF), except CNNs require BDF models (w/ static schedules)
  - ANNs during training: Boolean dataflow (BDF)

![HSDF Hopfield ANN](image)

Cellular Neural Network for Edge Detection

Demonstration in Ptolemy 0.7.1

Biao Lu
• Introduced undergraduate course that covers
  • Digital signal processing (DSP): signals, sampling, filters, difference equations, z-transforms, quantization
  • Digital communications: modulation, pulse shaping, pseudo random sequences, timing recovery, modems
  • DSP architectures: Harvard architecture, special addressing modes, parallel instructions, real-time programming, modern trends in DSP architectures
• Students build a 4800 baud modem using DSP processor
• Integrating research and education through guest lecturers:
  • Dr. Sayfe Kiaei, Motorola, “Asymmetric Digital Subscriber Line (ADSL) Modem Design and Implementation,” about CopperGold ADSL chip
  • Mr. Jeff Michalski, Concur Systems, “Mini-Web Servers for Real-time Data Acquisition” using DSPs
  • Mr. Thomas Kite, UT, “Sigma-Delta Modulation”
• In-class multimedia demonstrations
• Lectures on-line: http://www.ece.utexas.edu/~bevans/courses/realtime/
Embedded Software Systems Course

• Introduced graduate course that covers
  • Models of computation based on formal methods (with mathematical basis)
  • Specifying algorithms, simulating systems, and mapping specifications onto embedded systems using models of computation.
  • Management of heterogeneity in system-level CAD frameworks, esp. composition of formal models to form complex systems

• Integrating research and education
  • Hands-on experience with modifying/using system-level CAD tool Ptolemy
  • Projects require a literature survey and a computer implementation
  • Half of student projects published in IEEE publications

• Lectures on-line: http://www.ece.utexas.edu/~bevans/courses/ee382c/
Multidimensional Digital Signal Processing Course

• Introduced graduate course that covers
  - Theory and algorithms of multidimensional systems: signals, systems, Fourier analysis, discrete cosine transforms, linear filters, resampling
  - Applications: sonar beamforming, seismic data processing, tomography, image halftoning, image restoration, video coding

• Curriculum development is impacting

• Integrating research and education
  - Eight guest lecturers on current research topics in eight different application areas
  - Projects require a literature survey and a computer implementation
  - One-third of student projects published in IEEE publications

• Lectures on-line: [http://www.ece.utexas.edu/~bevans/courses/ee381k/](http://www.ece.utexas.edu/~bevans/courses/ee381k/)
# Selected Journal Papers Citing NSF Support

## Accepted/Published (6 total)

## Submitted/In Revision (5 total)
Other Deliverables

- Ph.D. students graduated
  - *Thomas D. Kite*: now DSP Engineer, Audio Precision, Portland, OR
  - *Dong Wei*: now Assistant Professor, Drexel University, Philadelphia, PA

- Software releases funded by NSF support
  - *Filter Optimization Packages for Matlab and Mathematica*: joint optimization of several characteristics of all-pole analog infinite impulse response filters
  - *Web-Enabled Simulation*: extensible framework for Web interfaces to simulators and debuggers for microcontrollers and digital signal processors

- Sponsored/supervised 15 Senior Design Projects, with more than half involving industrial partners:
  - *Concur Systems*: mini-Web servers for real-time data acquisition
  - *Motorola*: ADSL POTS splitter, phase locked loop design, Web-based tools
  - *Texas Instruments*: TMS320C30 DSP simulator, Web-based tools

- Initiated bi-weekly Signal and Image Processing Seminar

- Curriculum: successfully advocated moving signals and systems to sophomore year and introduced 3 new courses
Conclusion

• Third year of Career Award
• Founded Embedded Signal Processing Laboratory
  • Ph. D. Students: Gregory E. Allen, Guner Arslan, Srikanth Gummadi, Jong-il Kim, Biao Lu, Wade C. Schwartzkopf, K. Clint Slatton, and Murat Torlak
  • M.S. Students: David M. Brunke, Niranjan Damera-Venkata, and Magesh Valliappan
  • Web site: http://signal.ece.utexas.edu/
• Part of independent research unit Center for Vision and Image Sciences which includes 3 EE, 1 CS, and 5 Psychology professors
• Future Directions
  • Computational vision: incorporating linear and nonlinear models of the human visual system in image quality assessment for system optimization, ranking compression techniques, coding gain, and blind quality assessment
  • Next-generation fax machines: lossy bilevel image compression (JBIG-2)
  • Printers and scanners: halftoning, interpolated halftoning, and rehalftoning
  • Remote sensing: embedded systems for synthetic aperture radar imaging