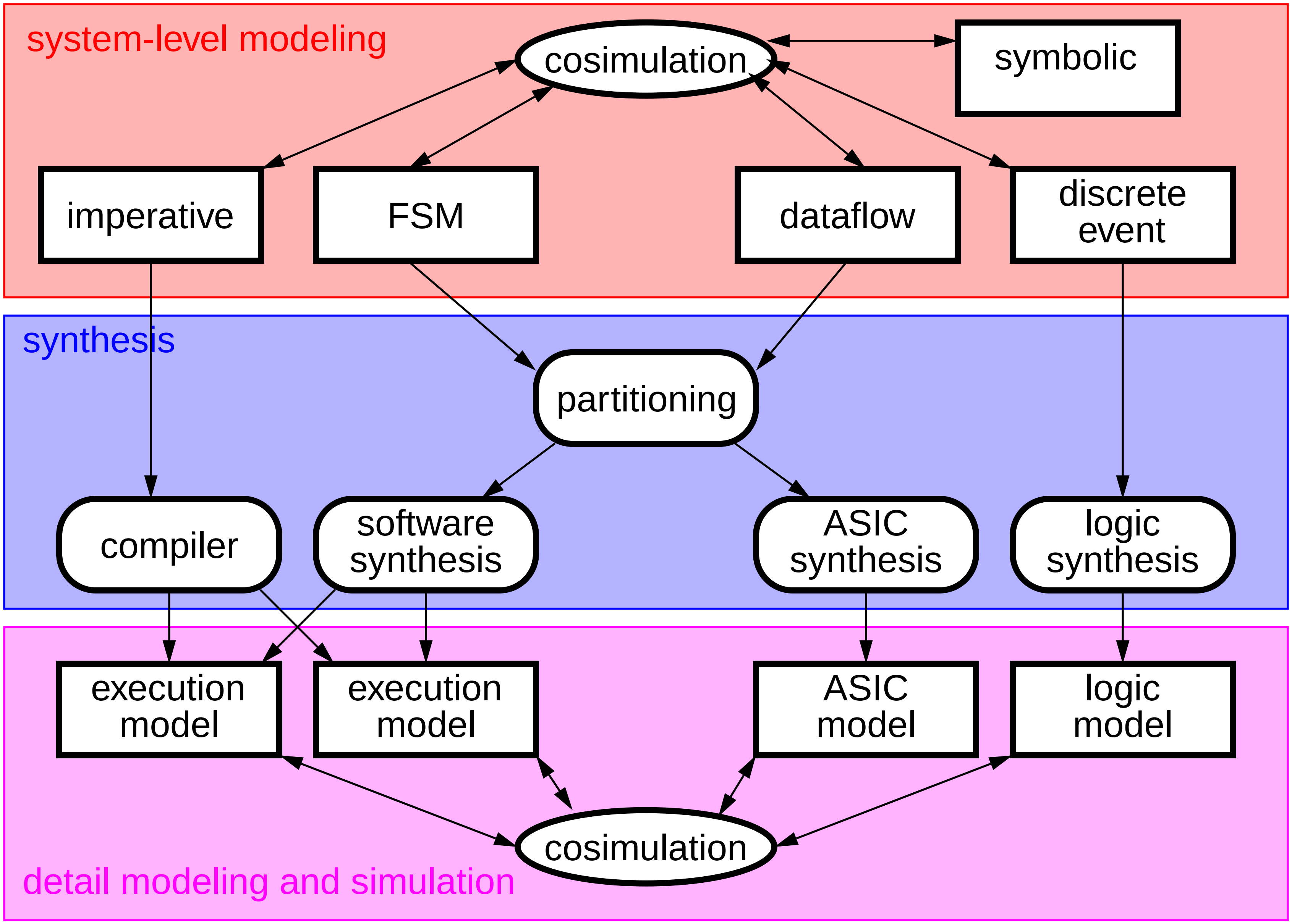
Introduction

- **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).**

Heterogeneity in System-Level Design

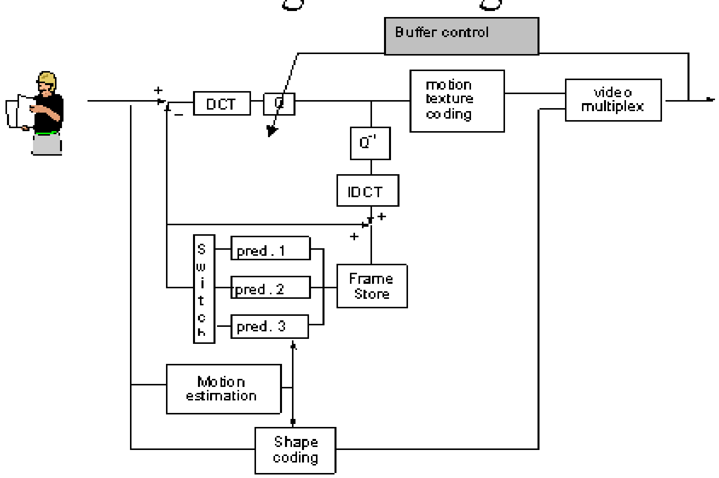


Slide by Prof. Edward A. Lee, UC Berkeley. Used with permission

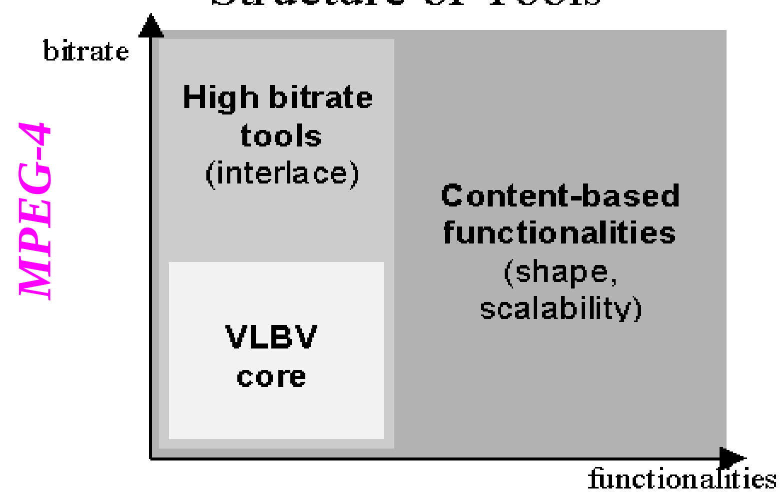
Hardware/Software Codesign for Video Codecs

- *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**

Video/Image Coding Scheme

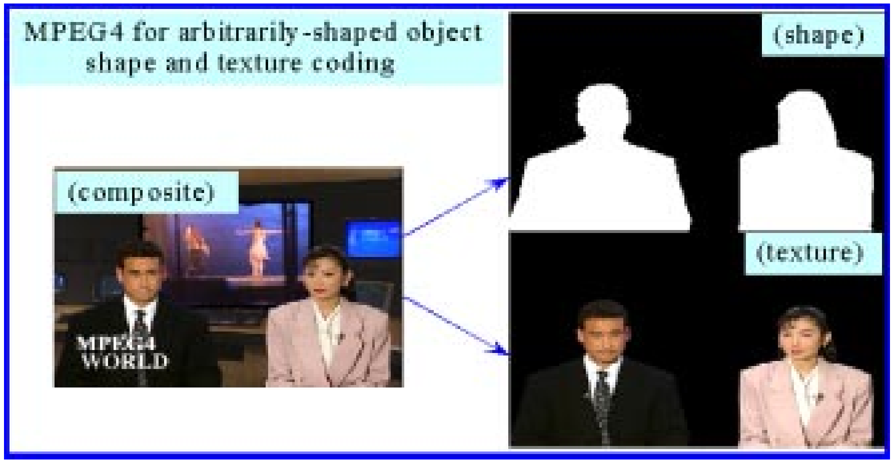


Structure of Tools

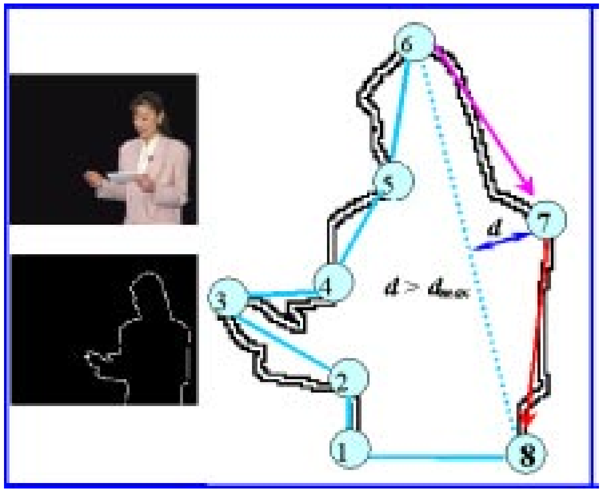


Shape Coding for Multimedia Content and Retrieval

- *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_{max}
  - Maximum distance between polygon and contour (0 for lossless coding)
  - Controls bitrate and distortion



Scalable Software for Sonar Imaging Systems

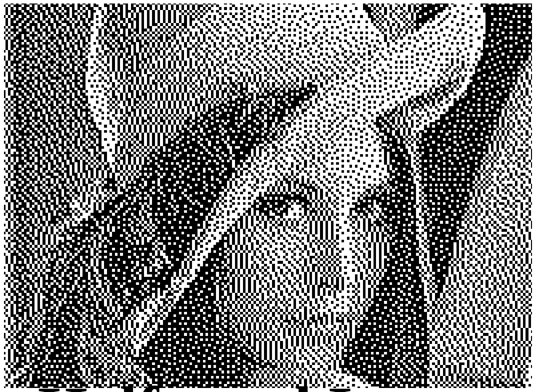
- *Problem*: Real-time 3-D sonar systems are expensive to develop, manufacture & upgrade due to custom hardware
- *Goal*: Software beamformer on a desktop workstation
- *Solution*: CAD framework for scalable software that merges
  - symmetric multiprocessing on Unix workstations
  - lightweight POSIX 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-IIs: 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:
- CAD tools can be deployed with the workstation

Front End	Manufacturing Costs	Development Costs
Custom Hardware	$1,000,000	$3,000,000
Ultra-2 6000	$400,000	$300,000

- Tutorial: http://www.ece.utexas.edu/~allen/GuestLecture.html

Embedded Software for Scanning and Printing

- *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 (Δ-Σ) 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**



Halftoned Image

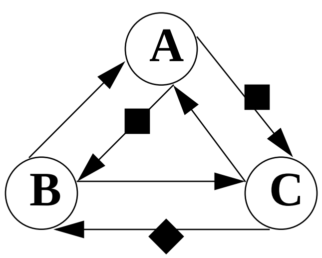
Original Image

Inverse Halftone

Thomas Kite and Niranjan Damera-Venkata

Hybrid Neural Network and Signal Processing Systems

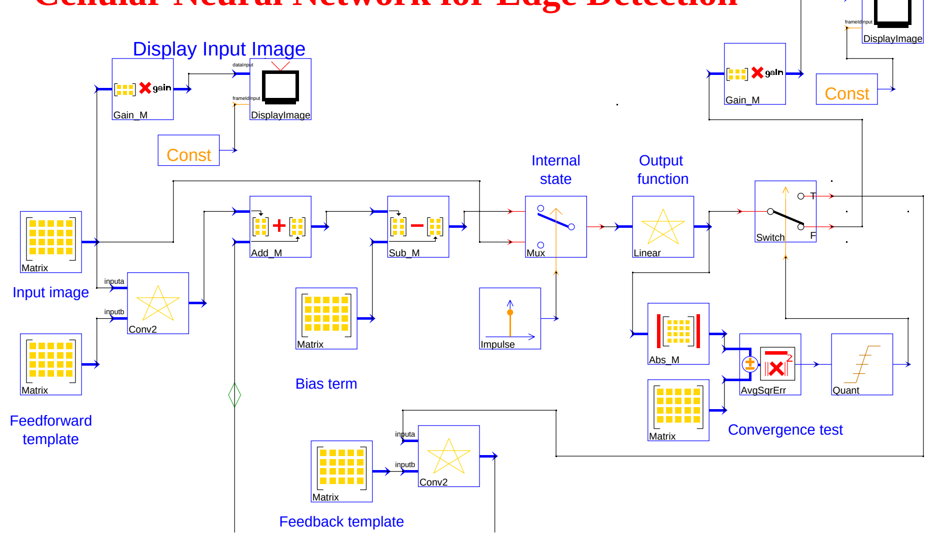
- ***Problem*: Develop a unified model of computation for mixed artificial neural network (ANN)/signal processing systems**
  - **Gamma Memory Model (add FIR filters on the inputs of the neurons)**
  - **Cellular Neural Network (CNN) detects impulsive noise in images which is removed by a median filter**
- ***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

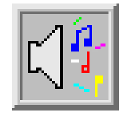
Demonstration in Ptolemy 0.7.1

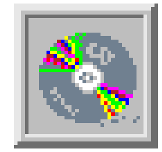
Cellular Neural Network for Edge Detection



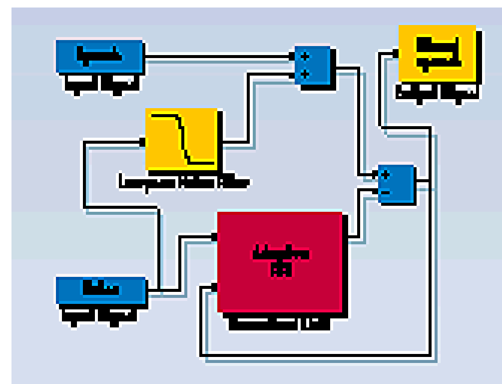
Real-Time Digital Signal Processing Laboratory Course

- **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**





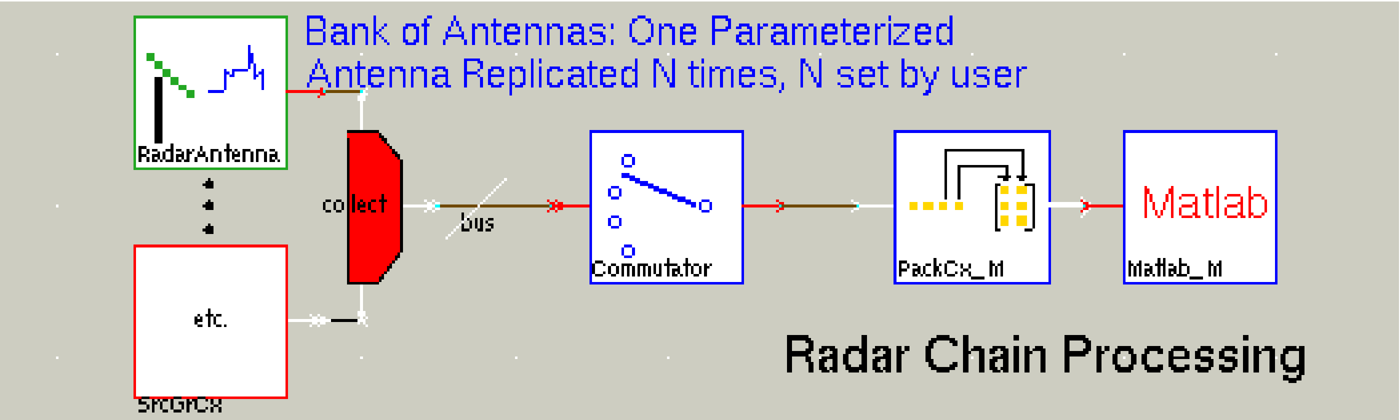
- **Students build a 4800 baud modem using DSP processor**
- **Integrating research and education through guest lecturers:**
  - **Dr. Sayfe Kiaei, Motorola, "Asymmetric Digital Subscriber Line (ADSL) Modem Design and Implementation," about CopperGold ADSL chip**
  - **Mr. Jeff Michalski, Concur Systems, "Mini-Web Servers for Real-time Data Acquistion" 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

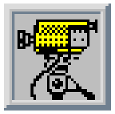
- **Introduced graduate course that covers**
  - **Models of computation based on formal methods (with mathematical basis)**
  - **Specifying algorithms, simulating systems, and mapping specifications onto embedded systems using models of computation.**
  - **Management of heterogeneity in system-level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



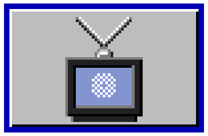
  - **Projects require a literature survey *and* a computer implementation**
  - **Half of student projects published in IEEE publications**
- **Lectures on-line: http://www.ece.utexas.edu/~bevans/courses/ee382c/**

Multidimensional Digital Signal Processing Course

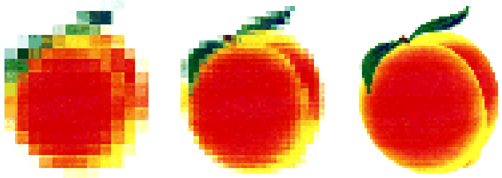
- **Introduced graduate course that covers**
  - **Theory and algorithms of multidimensional systems: signals, systems, Fourier analysis, discrete cosine transforms, linear filters, resampling**



  - **Applications: sonar beamforming, seismic data processing, tomography, image halftoning, image restoration, video coding**



- **Curriculum development is impacting**
  - **R. M. Mersereau, D. E. Dudgeon, and B. L. Evans, *Multidimensional Digital Signal Processing*, 2nd edition, Prentice-Hall, in progress.**
- **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/**

Selected Journal Papers Citing NSF Support

- **Accepted/Published (6 total)**
  - N. Damera-Venkata and B. L. Evans, “An Automated Framework for Multi-criteria Optimization of Analog Filter Designs,” *IEEE Trans. on Circuits and Systems II: Analog and Digital Signal Processing*.
  - J.-I. Kim, B. L. Evans, and A. C. Bovik, “Generalized Predictive Binary Shape Coding Using Polygon Approximations,” *Signal Processing: Image Communication*.
  - B. L. Evans, “Designing Commutative Cascades of Multidimensional Upsamplers and Downsamplers,” *IEEE Signal Processing Letters*, vol. 4, no. 11, pp. 313-6, 1997.
  - D. Wei, B. L. Evans, and A. C. Bovik, “Loss of Perfect Reconstruction in Multidimensional Filter Banks and Wavelets Designed by Extended McClellan Transformations,” *IEEE Signal Processing Letters*, vol. 4, no. 10, pp. 295-7, 1997.
- **Submitted/In Revision (5 total)**
  - T. D. Kite, B. L. Evans, and A. C. Bovik, “Modeling and Quality Assessment of Halftoning by Error Diffusion,” *IEEE Trans. on Image Processing*, in revision.
  - R. Bhargava, L. K. John, B. L. Evans, and R. Radhakrishnan, “Evaluating Native Signal Processing on General Purpose Processors,” *IEEE Trans. on Computers*.
  - T. D. Kite, B. L. Evans, and A. C. Bovik, “Design and Quality Assessment of a Fast Inverse Halftoning Algorithm for Error Diffused Halftones,” *IEEE Trans. on Image Processing*.

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**