Digital Signal Processing: 
Road to the Future

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University of California, Santa Barbara
Digital Signal Processing

- Digital Signal Processing (DSP)
  - Roots in 17-th and 18-th century mathematics
  - An important modern tool in a multitude of fields of science and technology
Digital Signal Processing

- Techniques and Applications of DSP
  - As old as Newton and Gauss
  - As new as digital computers and integrated circuits

- What is digital signal processing?
  - It is concerned with the representation of signals as sequences of numbers and processing of these sequences
Purpose of Processing

- To estimate characteristic parameters of signals
- To transform a signal into a more desirable form
- Classical numerical analysis formulas, such as those designed for interpolation, integration, and differentiation, are certainly DSP algorithms
Purpose of Processing

- Availability of high-speed digital computers has fostered development of increasingly complex and sophisticated signal processing algorithms.

- Advances in VLSI technology have made possible economical implementations of very complex digital signal processing algorithms.
Advantages of DSP

- Absence of drift in the filter characteristics
  - Processing characteristics are fixed, e.g. by binary coefficients stored in memories
  - Thus, they are independent of the external environment and of parameters such as temperature
  - Aging has no effect
Advantages of DSP

- Improved quality level
  - Quality of processing limited only by economic considerations
  - Arbitrarily low degradations achieved with desired quality by increasing the number of bits in data/coefficient representation
  - An increase of 1 bit in the representation results in a 6 dB improvement in the SNR
Advantages of DSP

- Reproducibility
  - Component tolerances do not affect system performance with correct operation
  - No adjustments necessary during fabrication
  - No realignment needed over lifetime of equipment
Advantages of DSP

- Ease of new function development
  - Easy to develop and implement adaptive filters, programmable filters and complementary filters
  - Illustrates flexibility of digital techniques
Advantages of DSP

- **Multiplexing**
  - Same equipment can be shared between several signals, with obvious financial advantages for each function

- **Modularity**
  - Uses standard digital circuits for implementation
Advantages of DSP

- Total single chip implementation using VLSI technology
- No loading effect
Limitations of DSP

- Lesser Reliability
  - Digital systems are active devices, and thus use more power and are less reliable
  - Some compensation is obtained from the facility for automatic supervision and monitoring of digital systems
Limitations of DSP

- **Limited Frequency Range of Operation**
  - Frequency range technologically limited to values corresponding to maximum computing capacities that can be developed and exploited

- **Additional Complexity in the Processing of Analog Signals**
  - A/D and D/A converters must be introduced adding complexity to overall system
Early days:
- Computers primarily used in the implementations of signal processing algorithms
- Offered tremendous advantages in flexibility

Disadvantage:
- Processing could not always be done in real-time
DSP Evolution

- Early work:
  - Concerned with methods for programming a digital filter on a digital computer

- Goal:
  - Approximate an analog filter (A/D, filtering, D/A)
DSP algorithm development goal:
- “Approximate” or “simulate” analog signal processing systems
- Experimentation with sophisticated DSP algorithms
- Some new algorithms had no analog equivalents
DSP Evolution

- Examples of unique algorithms:
  - Cepstrum analysis and homomorphic filtering

- Implementation of these algorithms required precision and resolution not available with analog circuits
DSP Evolution

- Evolution of new view of DSP:
  - Accelerated by fast Fourier transform (FFT) algorithms developed in 1965
- FFT reduced the computation time of DFT by orders of magnitude
- Permitted implementation of sophisticated signal processing algorithms with processing times that allowed interaction with the system
DSP Evolution

- FFT algorithm:
  - Inherently a discrete-time concept
- Stimulated reformulation of many signal processing concepts and algorithms in terms of discrete-time mathematics
- These techniques then formed an exact set of relationships in the discrete-time domain
DSP Evolution

- Typical New Algorithms:
  - Adaptive digital filtering
  - Multirate digital signal processing
  - Mixed analog/digital signal processing
  - Nonlinear digital signal processing
# Decades of DSP

<table>
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<tr>
<th>Decade</th>
<th>Characteristic</th>
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<td>Beyond</td>
<td>Expected Part of Daily Life</td>
<td>1¢ - 10¢</td>
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</table>

Courtesy: Texas Instruments
Three Major Areas of DSP

- Algorithms
- Implementation
  - Hardware and software
- Applications
DSP Performance Trend

Trend
MACs


Year

MegaMACs

1,000 3,000 10,000

100 300 1,000

30 10 3

1 1

Courtesy: Texas Instruments
DSP Price Finds New Applications

Courtesy: Texas Instruments
DSP Performance Enables New Applications

[Graph showing historical and future applications and performance milestones, including:
- Early DSP: Modem, HDD, Robotics, Answering Machine
- Present DSP: Audio, Digital Cellular, Multimedia, Video Phone, CD, DSP Radio, Engine Control, Noise Cancellation, Active Suspension, HDTV, Settop, Video Conferencing
- Single-Chip DSP: 3-D Graphics, Real-Time Imaging, Multi-Chip DSP
- Microcontroller: Motor Control

MOPS: 1, 10, 100, 1k, 10k


Courtesy: Texas Instruments]
DSP Drives Communication Equipment Trends

- **Cellular Phones**
  - AMPS: 5 MIPS
  - V.22: 300/1200
  - V.22bis: 2400
  - V.32: 9600
  - V.32bis: 14.4K
  - V.34: 28.8K
  - IS-54/136: 60 MIPS
  - Half Rate: 80-100 MIPS

- **Modems**
  - V.22: 300/1200
  - V.22bis: 2400
  - V.32: 9600
  - V.32bis: 14.4K
  - V.34: 28.8K
  - 30-40 MIPS

**Year**

*Courtesy: Texas Instruments*
Programmable DSP Market by Application

Communications: 56.1%

Consumer/Automotive: 10.69%

Military/Aero: 4.59%

Office Automation: 0.65%

Industrial: 3.31%

Computer: 21.16%

Instrumentation: 3.5%

Source: Forward Concepts

Courtesy: Texas Instruments
DSP Application Examples

- Acoustic Acquisition & Presentation
- Signal Coding & Compression
- Machine Synthesis of Signals
- Cellular Phone
- Discrete Multitone Transmission
- High Power RF Amplifier
- Digital Camera
- Digital Sound Synthesis
- Software Radio
Acoustic Acquisition & Presentation

Purpose:
- High quality, interference-free acquisition and presentation of acoustic signals, sounds, and speech

Technical Challenges:
- Control of echo, noise and reverberation
- Localization of sound
- Representation and reconstruction of acoustic field
- Enhancement of signals
Signal Coding & Compression

- **Purpose:**
  - Efficient digital representation of audio or visual signal for storage and transmission to provide maximum quality to the listener or viewer

- **Technology Challenges**
  - Dimensions
    - Low **Bit Rate**
    - Short **Processing Delay**
    - Low **Complexity & Cost**
    - High **Signal Quality and Robustness**
Signal Coding Applications

- Digital Telephony
  - Voice over IP;
  - Internet Telephony
  - Voice over ATM

- Audio Bridging & Conferencing
- Audio/Video Conferencing

- Audio Storage & Programming
- Digital Audio Broadcasting

- Internet Music
- Secure Voice
- Teleconferencing
- Sound Entertainment Systems

- Network Telephony
- Wireless & Messaging

- Home Theater
- Internet Telephony
- Voice over ATM

- Digital Telephony

Kbits/sec | Mbits/sec
1 | 1
2 | 2
4 | 8
8 | 16
16 | 32
32 | 64
64 | 128

Quality

1 2 4 8 16 32 64 128 1 2 8 32

Courtesy: Bell Laboratories
Machine Synthesis of Signals

- **Purpose:**
  - synthesis of intelligible, legible and natural signal such as speech, image, and video, given text, concept, or descriptive input

- **Technology Challenges:**
  - Natural sounding speech synthesis from unrestricted text
  - Message to speech; concept to speech
  - Personalization of synthetic speech; talker transformation
  - Text to image synthesis; virtual reality; image rendering
  - Text to video synthesis
Speech/Speaker Recognition Technology

Vocabulary Size

- Spontaneous Speech
- Fluent Speech
- Read Speech
- Connected Speech
- Isolated Words

Speaking Style

- Word spotting
- Digit strings
- System driven dialog
- Name dialing
- Form fill by voice
- Speaker verification
- Directory assistance
- 2-way dialog
- Network agent & intelligent messaging
- Transcription
- Office dictation
- Natural conversation
- 2-way dialog
- Natural conversation
- Two-way dialog

1980
1990
1998
200X

Vocabulary Size

Courtesy: Bell Laboratories
Cellular Phone

Digital Cellular Market


Units 48M 86M 153M 200M 300M 2B 4.6B

Courtesy: Texas Instruments
Cellular Phone Block Diagram

Audio Interface

DSP Core

ARM RISC Core

ASIC Backplane

S/W

RF Interface

Op Amps

Switches

Regulators

Touch Screen

RF SECTION

Receiver
Synthesizer
Modulator
Driver

Power Amp

Op Amps

Switches

Regulators

Speaker
Mic

User Display
Keyboard

SIM Card

SINGLE CHIP DIGITAL BASEBAND

Courtesy: Texas Instruments
Cellular Phone Baseband System on a Chip

- 100-200 MHz DSP + MCU
- ASIC Logic
- Dense Memory
- Analog

Courtesy: Texas Instruments
Discrete Multitone Transmission (DMT)

- Core technology in the implementation of the asymmetric digital subscriber line (ADSL) and very-high-rate digital subscriber line (VDSL)
- Closely related to: Orthogonal frequency-division multiplexing (OFDM)
ADSL

- A local transmission system designed to simultaneously support three services on a single twisted-wire pair:
  - Data transmission downstream (toward the subscriber) at bit rates of up to 9 Mb/s
  - Data transmission upstream (away from the subscriber) at bit rates of up to 1 Mb/s
  - Plain old telephone service (POTS)
Band-allocations for an FDM-based ADSL system
ADSL

- Asymmetry in the frequency band allocation:
  - to bring movies, television, video catalogs, remote CD-ROMs, corporate LANs, and the Internet into homes and small businesses
VDSSL

- Optical network emanating from twisted pair provides data rates of 13 to 26 Mb/s downstream and 2 to 3 Mb/s upstream over short distances less than about 1 km

- Allows the delivery of digital TV, super-fast Web surfing and file transfer, and virtual offices at home
Discrete Multitone Transmission

Block diagram

- Binary data input
- Demultiplexer
- Constellation encoder
- IDFT
- Parallel-to-serial converter
- D/A converter
- Reconstruction filter
- Channel
- Estimate of the original binary data input
- Multiplexer
- Decoder
- DFT
- Serial-to-parallel converter
- A/D converter
- Anti-aliasing filter
Discrete Multitone Transmission

- Advantages in using DMT for ADSL and VDSL
  - The ability to maximize the transmitted bit rate
  - Adaptivity to changing line conditions
  - Reduced sensitivity to line conditions
OFDM

- Applications:
  - Wireless communications - an effective technique to combat multipath fading
  - Digital audio broadcasting

- Uses a fixed number of bits per subchannel while DMT uses loading for bit allocation
OFDM

Basic differences with DMT architecture

– Signal constellation encoder does not include a loading algorithm for bit allocation
– In the transmitter, an upconverter included after the D/A converter to translate the transmitted frequency
– In the receiver, a downconverter included before the A/D converter to undo the frequency translation
High Power RF Amplifier Technology

- High power RF amplifiers significant part of cellular and PCS base stations
  - 50% of base station costs
  - Large % of base station power

Courtesy: Fujant Corporation
High Power RF Amplifier Technology

- Industry driven to improve linearity and efficiency
  - Introduction of spectrally efficient waveforms requires linear high power amplifier
  - Efficient DC to RF conversion reduces base station operating costs

Courtesy: Fujant Corporation
High Power RF Amplifier Technology

- Today’s amplifiers employ analog processing
- New application area for DSP
- Advanced DSP algorithms enable amplifiers to operate in the nonlinear region
- Greater power efficiency without significant distortion of the transmitted communication signal
LINC Amplifier Concept

Amplitude Reconstruction or LINC Amplifier

Reconstruction Signal Modulator

Saturated HPA

Σ

Courtesy: Fujant Corporation
LINC Amplifier Concept

Basic Idea

- Input signal decomposed into two constant amplitude waveforms
- LINC channel signals amplified constant amplitude waveforms
- LINC channel signals recombined to reconstruct original input waveform

Courtesy: Fujant Corporation
Typical LINC Amplifier Subsystems

Input Signal

Low Power RF Subsystem
- Down Converter
- Down Converter
- Real Time Digital Processor
- DSP
- Up Converter

Feedback Signal

High Power RF Subsystem
- HPA
- HPA
- Combiner & Load

Output Signal

Courtesy: Fujant Corporation
Digital Camera

- **CMOS Imaging Sensor**
  - Increasingly being used in digital cameras
  - Single chip integration of sensor and other image processing algorithms needed to generate final image
  - Can be manufactured at low cost
  - Less expensive cameras use single sensor with individual pixels in the sensor covered with either a red, a green, or a blue optical filter
Digital Camera

- Image Processing Algorithms
  - Bad pixel detection and masking
  - Color interpolation
  - Color balancing
  - Contrast enhancement
  - False color detection and masking
  - Image and video compression
Digital Camera

- Bad Pixel Detection and Masking
Digital Camera

- Color Interpolation and Balancing
Digital Sound Synthesis

- Four methods for the synthesis of musical sound:
  - Wavetable Synthesis
  - Spectral Synthesis
  - Nonlinear Synthesis
  - Synthesis by Physical Modeling
Digital Sound Synthesis

- Wavetable Synthesis
  - Recorded or synthesized musical events stored in internal memory and played back on demand
  - Playback tools consists of various techniques for sound variation during reproduction such as pitch shifting, looping, enveloping and filtering
  - Example: Giga Sampler
Digital Sound Synthesis

- Spectral Synthesis
  - Produces sounds from frequency domain models
  - Signal represented as a superposition of basis functions with time-varying amplitudes
  - Practical implementation usually consist of a combination of additive synthesis, subtractive synthesis and granular synthesis
  - Example: Kawaii K500 Demo
Digital Sound Synthesis

- **Nonlinear Synthesis**
  - **Frequency modulation method**: Time-dependent phase terms in the sinusoidal basis functions
  - An inexpensive method frequently used in synthesizers and in sound cards for PC
  - **Example**: Variation modulation index complex algorithm (Pulsar)
Digital Sound Synthesis

- **Physical Modeling**
  - Models the sound production method
  - Physical description of the main vibrating structures by partial differential equations
  - Most methods based on wave equation describing the wave propagation in solids and in air
  - Examples: (CCRMA, Stanford)
    - Guitar with nylon strings
    - Marimba
    - Tenor saxophone
Future Trends in DSP

- Defined by market trends
- Defined by particular implementations of specific products
- What products will dominate in the future?
Future Trends in DSP

- Future products dominating the market: Computers and cellular phones
- Difficult to separate between these two products
- Cellular phones will have computing power
- Computers will need mobility and mobile Internet access
Future Trends in DSP

What we need:

- Handsets with computing capabilities and mobile connection to the Internet
- Multimedia services instead of simple phone calls
- Global mobility with multistandard capabilities
- Flexibility of terminals, up to configurability in real time by the networks
Future Trends in DSP

- Development and optimization of algorithms for
  - audio and video compression
  - adaptive and efficient channel coding
  - adaptive/multimode modulations
  - reconfigurable radio interface and adaptive antenna
  - real time software download in terminals

- Software Radio
Software Radio

- **Aim**
  - Build a flexible multiservice, multiband, multistandard radio system that is reconfigurable and reprogrammable by software

- Reconfigurability provided by the DSP engine reprogrammability
Software Radio

Two main goals must be met:

- Move the border between the analog and digital worlds toward radio frequency (RF)
- Adopt analog-to-digital (A/D) and digital-to-analog (D/A) wideband converters as close as possible to the antenna
- Replace ASICs with DSPs for baseband signal processing to define as many radio functionalities as possible in software (SW)
Software Radio

- Replacement of ASIC technology with DSP technology enables
  - SW implementation of baseband functions, such as coding, modulation, equalization, and pulse shaping
  - reprogrammability of the system to guarantee multistandard operation
Software Radio

- Hardware platform of a software radio receiver

Diagram:
- RF/analog front-end
- A/D
- Compute engine
  - DSP (software)
  - Accelerators
- D/A
- Digital output
- Analog output
- Common master crystal
Software Radio

- The Digital Compute Engine
  - Certain DSP algorithms too demanding for conventional DSP to achieve cost-effective solution
  - Such “number-crunching” functions are realized by dedicated hardware called accelerators
Software Radio

Examples of Accelerators

- The digital down-conversion (DDC) of a received signal, performed directly after the A/D conversion, and thus at a relatively high sample rate

- Other examples include Viterbi equalization, despreading/spreading, digital filtering (at high sample rates), digital down/up-conversion, etc.
Unsolved Problems

- Robust object extraction algorithm
  - MPEG-4 core profile encoders ask for object extraction from video
  - Existing algorithms are not robust and work well only under certain conditions
  - Develop simplified and robust algorithm for object extraction
Unsolved Problems

- Co-channel signal separation for wireless communications
  - Since multiple users occupy the same channel, signal processing algorithms are needed to separate and demodulate the user signals, preferably with low complexity and low noise enhancement
  - These techniques needed for both TDMA and CDMA signal formats
Unsolved Problems

- Blind adaptive beamforming or space-time array processing
  - Adaptive antennas are capable of nulling signals (interferers) without the use of training or pilot signals
  - They can be used in wireless communications and for GPS (global position system) applications
Unsolved Problems

- Channel equalization
  - Adaptive equalization has been applied to wireline and wireless communication systems since 1960s
  - Current applications include next-generation multimedia wireless networks, as well as cable and digital subscriber lines (DSLs)
Unsolved Problems

- Filter banks for source coding
  - Have been studied extensively in the past
  - There are still important applications - especially involving nonstationary signals such as video and motion pictures
  - Compression is used in motion picture signals in editing systems so that films can be edited digitally without requiring massive amounts of data storage
DSP Chips for the Future

- Very low power consumption
- High speed operation
- Reconfigurable processor
- Customizable processor
- DSP chip with multiple integer and floating-point MACs
Reconfigurable Processors

- Reconfigurable MAC array with embedded memory for high-speed processing for vision/video processing

- As many DSP algorithms are dominated by fairly well structured inner loops, this approach has the potential to combine the flexibility of a conventional processor with the efficiency of custom hardware
Customizable Processors

- These processors are not field reconfigurable, but can be customized by the system (or SoC) designer to better meet the needs of the application.

- Can be very effective for certain DSP applications.
DSP Chip with Multiple Integer and Floating-point MACs

- Multiple ALUs allow simultaneous dispatch of many operations per clock cycle
- Examples - Equator MAP and Sun MAJC
  - These DSP chips are basically fast RISC processors with DSP instructions added to their general purpose instruction set
Major Bottlenecks

- High level language
- Efficient compiler
## Two Decades of DSP Integration

<table>
<thead>
<tr>
<th>Die size</th>
<th>Technology size</th>
<th>MIPS</th>
<th>MHz</th>
<th>RAM</th>
<th>ROM</th>
<th>Price</th>
<th>Power dissipation</th>
<th>Transistors</th>
<th>Wafer size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical 1982 DSP</td>
<td>50 mm</td>
<td>3μ</td>
<td>5 MIPS</td>
<td>20 MHz</td>
<td>144 Words</td>
<td>1.5K Words</td>
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<td>250 mW/MIPS</td>
<td>50K Transistors</td>
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<td>40 MIPS (150)</td>
<td>80 MHz (300)</td>
<td>1K Words</td>
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<td>12.5 mW/MIPS (.1)</td>
<td>500K Transistors</td>
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<td>Typical 2002 DSP</td>
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<td>2000 MIPS</td>
<td>500 MHz</td>
<td>16K Words</td>
<td>64K Words</td>
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<td>0.1 mW/MIPS</td>
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Courtesy: Texas Instruments
## DSP Integration Through the Years

### Typical Device capabilities

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<th>1980</th>
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<th>2000</th>
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<td>6&quot;</td>
<td>12&quot;</td>
<td>12&quot;</td>
</tr>
</tbody>
</table>

*Courtesy: Texas Instruments*
Power Dissipation Trends

Courtesy: Texas Instruments
DSP is impacting the way we

- **Work**: Computers, software, modems, cellular phones, pagers, palm top computers, video phones
- **Live**: Medical electronics, security systems, robots, intelligent appliances
- **Learn**: Electronic learning, computers
- **Keep information**: HDD, CDs, DVD
- **Play**: Games, internet, optimally designed equipment
- **Travel**: Automatic Cruise Control, GPS, collision avoidance
- **Socialize**: Internet, personal computers, cellular phones
Future Device Trends

- Quantum-Dot Cellular Automata (QCA)
- Nanotubes
- Quantum Computing
- Evolvable Hardware (EHW)
Quantum-Dot Cellular Automata

- A nano-structure-compatible computation paradigm
  - Uses arrays of quantum-dot cells to implement logic functions
  - A three-input majority logic gate based on QCA has been reported
  - The majority gate can be programmed to act as an OR gate or an AND gate

Source: Science, 9 April 1999
Quantum-Dot Cellular Automata

Information transfer procedure:
- Use of currents, that is, transfer of charge in conventional digital circuits
- By the propagation of a polarization state from one cell-like structure to the next in QCA (proposed in 1994)
Quantum-Dot Cellular Automata

- **Advantages:**
  - Offers a fast switching and low-power computing architecture
  - Architecture, in theory, can be shrunk down to the molecular scale

- **Disadvantages:**
  - Current device only work at 0.1 K (−273.15°C)
  - Smaller cells should allow an increase in the temperature of operation
Magnetic Quantum-Dot Cellular Automata

- A promising approach to quantum computing
- A universal logic gate has been built based on magnetic nanostructures
- Makes use of spintronic built on classical ferromagnets

Science, 13 January 2006
Magnetic Quantum-Dot Cellular Automata

- Magnetic QCA has been built from simple, identical, bistable units.
- The units are locally connected to each other solely by electromagnetic forces.
- Thus, the signal processing function is defined by the physical placement of the building blocks.
Magnetic Quantum-Dot Cellular Automata

- The nanomagnets are arranged in two intersecting lines.
- The dipole coupling of the nanomagnets produces ferromagnetic ordering along the vertical line and antiferromagnetic coupling along the horizontal line.
Magnetic Quantum-Dot Cellular Automata

- The central nanomagnet is surrounded by four others.
- Three of the neighbors can be used as inputs driven by additional driver nanomagnets oriented in the horizontal direction, along the clock-field.
- The fourth neighbor to the right of the central magnet is the output.
Magnetic Quantum-Dot Cellular Automata

- The gate has been constructed so that the ferromagnetic and antiferromagnetic coupling to the central dot have the same strength.
- Therefore it switches to the state to which the majority of the inputs force it.
- The input logic combinations are obtained by varying driver nanomagnet positions.
Magnetic Quantum-Dot Cellular Automata

- Logic state of central nanomagnet is determined by the logical majority vote of its three neighbors.
- Logic state of central nanomagnet is written inverted to output nanomagnet by antiferromagnetic coupling.
Magnetic Quantum-Dot Cellular Automata

- The three-input majority gate can be viewed as a programmable two-input NAND or NOR gate, depending on the state of any one of the three input nanomagnets and accounting for inversion at the output nanomagnet.
Nanotubes

- Carbon nanotubes discovered in 1991
- Roughly one-billionth of a meter in diameter
- Five hundred times smaller than today’s transistors
- Potential use in nanoelectronic devices
Nanotubes

- Field-Effect Transistor
  - Based on a single carbon nanotube
  - Consists of one single-wall carbon nanotube connected to two metal electrodes
  - By applying a voltage to a crossing tube, the nanotube can be switched from a conducting to an insulating state
  - Operates at room temperature

Source: Nature, 7 May 1998
Nanotubes

- **What is needed?**
  - An inexpensive approach for densely packing nanotubes onto silicon wafers

- **Basic difficulty**
  - When deposited onto a silicon substrate, result is a dense tangle of both semiconducting nanotubes and metallic nanotubes
  - To build devices, the metallic nanotubes need to be eliminated and manipulate only the semiconducting nanotubes
Nanotubes

- Promising approach
  - Disperse a tangle of nanotubes on silicon and fabricate electrodes on top
  - Using the electrodes switch off all semiconducting tubes so that they cannot carry a current
  - Selectively shatter the metallic tubes by applying a voltage

Source: Science, April 27, 2001
Nanotubes

- A single electron transistor (SET) comprises a small island of discrete energy levels (a quantum dot or a molecular structure) connected to metallic leads by tunnel junctions.

- A room temperature SET has been reported.

Source: Science, July 6, 2001
A scanning probe was used to form kinks in a metallic carbon nanotube in two places to create the island bracketed by two junctions.
Quantum Computing

- Process information at the scale of individual atoms and photons
- Operate by mapping the quanta of information - the bits - into quanta of energy and angular momentum
- Information processed by transforming the physical quanta
Quantum Computing

- Quantum systems such as photons and electrons can occupy several places at once.
- Quantum bits (qubits) can therefore "register" 0 and 1 at the same time.
- Quantum computing exploits this quantum weirdness to perform many computations at the same time.
- Phenomenon called quantum parallelism.
Quantum Computing

- Usually performed by taking quantum systems such as atoms or molecules, and addressing them with electromagnetic waves.
- Zapping quantum systems with lasers or microwaves is a highly effective way of performing elementary quantum logic operations.
Evolvable Hardware

- Evolve and learn to improve itself using trial-and-error experiences
- Seeks solutions through trying billions of different possibilities
- Continually crops and refines its search algorithm
- Selects the best each time and tries that
- Does all this on its own accord
Evolvable Hardware

- Requires reconfigurable hardware
- Trick lies in creating a device that knows how to make the correct structural adaptation at the correct time
- Makes use of “genetic algorithm” invented over 40 years ago
EHW Design Steps

- Generate a set of random blueprints which are used, one by one, to configure the device
- After each reconfiguration, the device is tested to see how well it carries out the required task
- Highest-scoring designs are retained as guidelines ("parents") for new generation of designs
EHW Design Steps

- The “offspring” designs are created by swapping portions of the parent’s blueprints with one another, or making some random changes.
- The marginally improved population of designs then undergoes further testing.
- Cycle repeats itself until the device achieves an optimal level of performance.
Evolvable Hardware

- Entire genetic algorithm - blueprint creation, fitness evaluation and reconfiguration - can be contained within a single microchip

- Run thousands of evolutionary trials in a fraction of a second
Evolvable Hardware

- Genetic algorithms originally have been run in software placing a large and often prohibitive burden on the processor’s time.

- EHW avoids this problem by running its genetic algorithms in hardware.

- Most notable application of EHW so far is in the design of analog circuits.
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The End