The telephone company

- Bell's patent in 1876
- Bell system started in 1878
  - Within 10 years assumed form of 20th century "Bell System"
- Originally point-to-point
- Then manual switchboard with operators to connect
- Then long distance switchboards
- 1882 Western Electric acquired to make all equipment
- 1925 Bell Laboratories organized to do research for Bell System
- Government ran telephone system in most countries
- Wires were strung overhead on large telephone poles with many arms
- Original amplifiers were a microphone connected to an earphone
- Signal quality became an issue on long circuits
  - "Loading" coils
    - Decreased dispersion
    - Placed a cutoff on frequency

Switching techniques

- Need to connect any subscriber to any other
- Labor intensive for operators
- Automatic switching systems installed to increase speed and decrease costs
- Call setup sequence
  - Request service
  - connect to operator
  - determine other number
  - select a path
  - test if not busy
  - if busy tell originator else ring destination
  - stop ringing when answered
  - determine when call is completed
  - tear down connection
  - (bill call)
- drops replaced with lights
- switchboards designed with multiple jacks and plugs for "trunks"

Automatic switching designs

- 1889, Strowger designed a mechanical switch that allowed fully automatic call connections
- Difficulty was that equipment was committed to call as successive digits dialed
  - No global planning of route
- Panel systems were designed that moved contacts over hundreds of contacts
  - Mechanical monstrosity
  - Noisy and poor quality connections
- Crossbar relays could connect any of 10 (or 20) inputs to any of 10 outputs simultaneously
- Crossbar offices would determine the destination without committing any resources and then globally plan a route through office
  - Common control circuits were called "markers"
  - Multiple markers could operate simultaneously in an office
- Electronic offices developed to use computer technology
  - Largest problems were to count dial pulses ("touch tone" receivers were simpler)
  - Generate ringing voltages with low-voltage electronic components
- Electronic offices (SS6, SS7 etc.) carried common control across the country
  - Routes are planned across the country
  - Changes in strategy can be implemented at a single point
    - "Mother's day"

Design

- progression
  - cord boards
  - step by step
  - crossbar
  - ess
  - electronic
  - digital voice
  - Digital network
- Was the largest distributed relay computer
  - originally mechanical replacement for operators
  - originally call committed equipment as it was dialed
  - common control developed
  - now a digital network of computers
- Reliability
  - Spec for phone office is 1/2 hour outage in 40 years
  - redundant circuits and alternate paths a way of living

Many telephone offices combined many different technologies

- #5 crossbar used special card punch to record error conditions
- #4A tandem crossbar used edge punched metallic cards to store routing information
  - read photoelectrically
- Many trunk circuits used radio / microwave links, vacuum tube amplifiers, transistor amplifiers
- Traveling wave tubes used to amplify wide band signals

Disruptive Technologies

- The Telephone Company assumed data was sent on dedicated links
- Cost of setting up connection high so short connection times discouraged
- Blindsided by data communication needs
- Telephone company view
  - Dumb terminals, smart connection network
  - Value add in services provided by (and controlled by) network
  - New features controlled by the network
  - Charges for network features on use basis
    - three-way calling, call forwarding, call interrupt etc.
- Internet view
  - Dumb network, no surprises, no value add
  - Smart terminals, all features controlled by terminals
  - New features deployed at terminals with no network changes
  - Value add is outside of network (google, amazon.com, ebay etc.)
  - Only value of network is forwarding packets
  - Charging model very different (and not sorted out yet, e.g., spam mail)

Feynman

- Los Almos - How the bomb calculations were done
- propagation of errors

Early Electronic Calculators

- edvac
- edsac
- apexc
- whirlwind
- seac
- Manchester machine
- maniac
- sage***
- LGP-30
  - Serial
  - Magnetic drum
  - 101 vacuum tubes
  - optimizing by placing data and instructions around the drum
- DEC
  - pdp8
  - pdp6/10
- IBM
  - 650
  - 701
  - 704***
    - FORTRAN
  - 709/7094
  - 1401
  - 1620
  - stretch/7030***
  - 360/370
- Univac
  - 1101
- GE
  - multics
- burroughs
  - 220
  - 5500
  - 6500
  - illiac IV
- CDC 1604
- CDC 6600/7600
- Amdahl
- minicomputers
  - nova
- microcomputers
  - national SC, motorola, signetics, Texas instruments
  - intel 4004 - pentium

Computer Logic

- mechanical
- relays
- vacuum tubes
- diodes
- cores (magnetic logic)
- transistors
- integrated circuits
  - bipolar
  - FET

Computer Memory

- card punch equipment
  - hollerith
    - census
  - code
  - keypunch
  - verifiers
  - plug board programming
  - IBM
    - sorters
    - 407 accounting machines
    - workflow by moving decks of cards
    - cards in mail for subscriptions, billing
  - relays
  - mercury delay lines
  - Williamson tubes
  - drums
  - core
  - mag tape
  - disks
  - RAMAC 305
  - integrated circuits
- Mag tape
  - IBM 7-track - 9-track - high-density
  - linc tapes / dec tapes
  - cartridge tapes (gigabytes)

Themes in History of Computers

- Many lessons from the history of computers and technology
- Some of these lessons need to be learned many times
- It is difficult to predict the future and future lessons
- The past can be a guide to the future
  - "Those who do not know history are doomed to repeat it"

Cost and Size of

- Logic
  - Originally very expensive - now virtually free
- Memory
  - Originally very expensive - now virtually free
- Speed
  - Mechanical - seconds
  - Relay - tenths of seconds
  - Drums - milliseconds
  - Tubes/core - microseconds
  - Today - nanoseconds
  - Speed of light is now an issue
    - 1 foot per nanosecond (10^{-9} second)
- Connections
  - Originally not an issue
  - Now connections dominate area in computers
- Communications

Expensive vs Free

- Memory
- Bandwidth
- Cycles
- Computers
- Communication

Digital vs analog

- Digital is indistinguishable from analog if fine enough quantization
- Quantitize space and time
- Packets are now fast enough to be considered a continuous stream
  - Xerox call center volume of calls so big that was controlled like a pipeline

Serial vs Parallel

- Serial simpler but slower
- Parallel more complicated but faster
- Serial will win if high enough speed

Control vs Individuality

- Who is in charge?
  - Computer
  - Company
  - Government
  - Individual
- Peripherals
  - Originally for convenience of computer
  - Now designed for humans or application
  - Example - Displays
    - Terminals
    - Teletypes
    - 2741
    - IO Devices
    - Vector Graphics
    - 24 X 80
    - Bit-Mapped Graphics

Hardware vs Software

- Last century products were designed in hardware
- Now features, interfaces etc. designed in software

Turn Around Time

- Do it myself vs using tools vs special "coders"
  - Electrical engineering vs mathematicians
  - Assembly
  - Compilers
  - Libraries lapack linpack
- Leveraging work of others always wins over "ego of doing it myself"

Fixed vs Floating-Point Computations

- Early computers generally fixed-point
- Decision was which one - too expensive for both
- Floating-point looked down on because of harder error analysis
- IEEE standard and previous implementations

Precision vs Speed

- Some early computers had short word lengths
  - Cost of memory
- Round-off errors accumulate depending on the length and stability of the computation
- Faster, bigger machines did more floating-point operations so needed more precision to have any significance in the final answer
- Early computer users knew numerical analysis (from calculator days)
- Modern user puts in data and assumes computer is mathematically right
- Exponent fields also growing increasing range of floating-point numbers

Change In Computer Applications

- Originally, computers solved engineering problems about real numbers and continuous curves
- Then commercial problems were the driver
  - Banks
  - Insurance
  - Inventory control
  - Linear programming
- Gradually, discrete problems were attacked
  - List processing
  - Compilers

Networking

- Communications
- Arpanet
- Internet
- "The Web"

"Point-In-Time" Optimizations

- Good at the time
  - Not generalizable
  - Not flexible
- Eventually more general methods displace
  - Optimization no longer important
  - Other considerations become more important