Early Developments: From *Difference Engine* to *IBM 701*

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Charles Babbage 1791-1871

Lucasian Professor of Mathematics, Cambridge University, 1827-1839

Charles Babbage

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Charles Babbage

- *Difference Engine* 1823
- *Analytic Engine* 1833
  - The forerunner of modern digital computer!

Application

- Mathematical Tables – Astronomy
- Nautical Tables – Navy

Background

- Any continuous function can be approximated by a polynomial --- *Weierstrass*

Technology

- mechanical - gears, Jacquard's loom, simple calculators

Difference Engine
A machine to compute mathematical tables

Weierstrass:

- Any continuous function can be approximated by a polynomial
- Any Polynomial can be computed from *difference* tables

An example

$$f(n) = n^2+n+41$$
$$d1(n) = f(n) - f(n-1) = 2n$$
$$d2(n) = d1(n) - d1(n-1) = 2$$

$$f(n) = f(n-1) + d1(n) = f(n-1) + (d1(n-1) + 2)$$

n	0	1	2	3	4 …
d2(n)			2	2	2
d1(n)		2	4	6	8
f(n)	41	43	47	53	61

all you need is an adder!

Difference Engine

1823

- Babbage's paper is published

1834

- The paper is read by Scheutz & his son in Sweden

1842

- Babbage gives up the idea of building it;he is onto Analytic Engine!

1855

- Scheutz displays his machine at the Paris World Fare
- Can compute any 6th degree polynomial
- *Speed:* 33 to 44 32-digit numbers per minute!

Now the machine is at the Smithsonian

Analytic Engine

1833: Babbage's paper was published

- *conceived during a hiatus in the development of the difference engine*

Inspiration: *Jacquard Looms*

- looms were controlled by punched cards
  - The set of cards with fixed punched holes dictated the pattern of weave ⇒ *program*
  - The same set of cards could be used with different colored threads ⇒ *numbers*

1871: Babbage dies

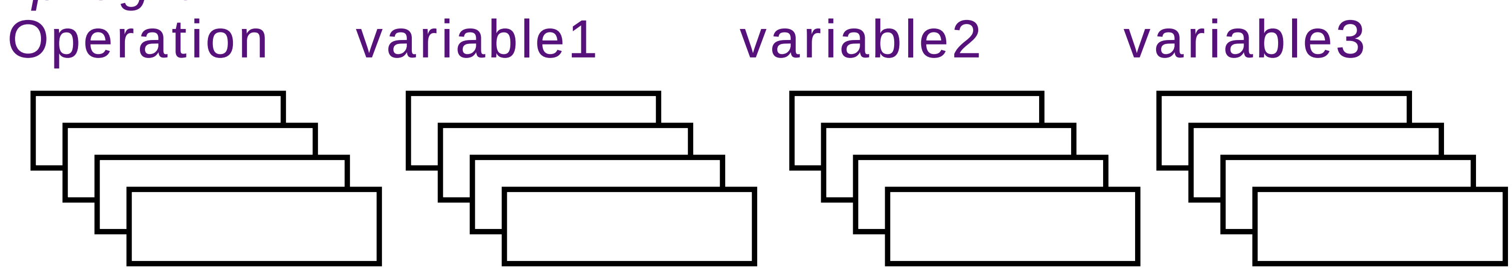
- The machine remains unrealized.

It is not clear if the analytic engine could be built even today using only mechanical technology

Analytic Engine
The first conception of a general purpose computer

1. The *store* in which all variables to be operated upon, as well as all those quantities which have arisen from the results of the operations are placed.
2. The *mill* into which the quantities about to be operated upon are always brought.

The *program*



An operation in the *mill* required feeding two punched cards and producing a new punched card for the *store.*

An operation to alter the sequence was also provided!

The first programmer
Ada Byron *aka* “Lady Lovelace” 1815-52

Ada Byron a.k.a "Lady Lovelace"
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Ada’s tutor was Babbage himself!

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Babbage's Influence

- Babbage's ideas had great influence later primarily because of
  - *Luigi Menabrea,* who published notes of Babbage's lectures in Italy
  - *Lady Lovelace,* who translated Menabrea's notes in English and thoroughly expanded them.
    "... Analytic Engine weaves *algebraic patterns*...."
- In the early twentieth century - the focus shifted to analog computers but
  - *Harvard Mark I built in 1944 is very close in spirit to the Analytic Engine.*

Harvard Mark I

- Built in 1944 in IBM Endicott laboratories
  - Howard Aiken – Professor of Physics at Harvard
  - Essentially mechanical but had some electro-magnetically controlled relays and gears
  - Weighed *5 tons* and had *750,000* components
  - A synchronizing clock that beat every *0.015* seconds

Performance:

0.3 seconds for addition
6 seconds for multiplication
1 minute for a sine calculation

Broke down once a week!

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Linear Equation Solver
John Atanasoff, Iowa State University

1930's:
- Atanasoff built the Linear Equation Solver.
- It had 300 tubes!

Application:
- Linear and Integral differential equations

Background:
- Vannevar Bush's Differential Analyzer
  --- *an analog computer*

Technology:
- Tubes and Electromechanical relays

Atanasoff decided that the correct mode of computation was by electronic digital means.

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Electronic Numerical Integrator and Computer (ENIAC)

- Inspired by Atanasoff and Berry, Eckert and Mauchly designed and built ENIAC (1943-45) at the University of Pennsylvania
- The first, completely electronic, operational, general-purpose analytical calculator!
  - 30 tons, 72 square meters, 200KW
- Performance
  - Read in 120 cards per minute
  - Addition took 200 μs, Division 6 ms
  - 1000 times faster than Mark I
- Not very reliable!

Application: Ballistic calculations

angle = f (location, tail wind, cross wind,
air density, temperature, weight of shell,
propellant charge, ...)

Electronic Discrete Variable Automatic Computer (EDVAC)

- ENIAC's programming system was external
  - Sequences of instructions were executed independently of the results of the calculation
  - Human intervention required to take instructions "out of order"
- Eckert, Mauchly, John von Neumann and others designed EDVAC (1944) to solve this problem
  - Solution was the *stored program computer*

    ⇒ "*program can be manipulated as data*"
- *First Draft of a report on EDVAC* was published in 1945, but just had von Neumann's signature!
  - In 1973 the court of Minneapolis attributed the honor of *inventing the computer* to John Atanasoff

Stored Program Computer

Program = A sequence of instructions

How to control instruction sequencing?

manual control	calculators
automatic control	
external (paper tape)	Harvard Mark I , 1944 Zuse's Z1, WW2
internal	
plug board	ENIAC 1946
read-only memory	ENIAC 1948
read-write memory	EDVAC 1947 *(concept)*

- The same storage can be used to store program and data

EDSAC	1950	Maurice Wilkes

Technology Issues

ENIAC $\Rightarrow$ EDVAC

ENIAC	EDVAC
18,000 tubes	4,000 tubes
20 10-digit numbers	2000 word storage
	mercury delay lines

ENIAC had many asynchronous parallel units but only one was active at a time

BINAC : Two processors that checked each other for reliability.

Didn't work well because processors never agreed

The Spread of Ideas

ENIAC & EDVAC had immediate impact

brilliant engineering: Eckert & Mauchley
lucid paper: Burks, Goldstein & von Neumann

IAS	Princeton	46-52	Bigelow
EDSAC	Cambridge	46-50	Wilkes
MANIAC	Los Alamos	49-52	Metropolis
JOHNIAC	Rand	50-53	
ILLIAC	Illinois	49-52	
	Argonne	49-53	
SWAC	UCLA-NBS		

UNIVAC - the first commercial computer, 1951

Alan Turing's direct influence on these developments is still being debated by historians.

Dominant Problem: *Reliability*

Mean time between failures (MTBF)

MIT's Whirlwind with an MTBF of 20 min. was perhaps the most reliable machine !

Reasons for unreliability:

1. Vacuum Tubes

2. Storage medium
   - acoustic delay lines
   - mercury delay lines
   - Williams tubes
   - Selections

CORE	J. Forrester	1954

Commercial Activity: 1948-52

IBM's SSEC

Selective Sequence Electronic Calculator

- 150 word store.
- Instructions, constraints, and tables of data were read from paper tapes.
- 66 Tape reading stations!
- Tapes could be glued together to form a loop!
- Data could be output in one phase of computation and read in the next phase of computation.

And then there was IBM 701

IBM 701 -- 30 machines were sold in 1953-54

IBM 650 -- a cheaper, drum based machine,
more than 120 were sold in 1954
and there were orders for 750 more!

Users stopped building their own machines.

Why was IBM late getting into computer technology?

IBM was making too much money!
Even without computers, IBM revenues were doubling every 4 to 5 years in 40's and 50's.

Software Developments

up to 1955 Libraries of numerical routines

- Floating point operations
- Transcendental functions
- Matrix manipulation, equation solvers, . . .

1955-60 *High level Languages* - Fortran 1956
Operating Systems -

- Assemblers, Loaders, Linkers, Compilers
- Accounting programs to keep track of usage and charges

Machines required *experienced operators*

⇒ Most users could not be expected to understand these programs, much less write them

⇒ Machines had to be sold with a lot of resident software

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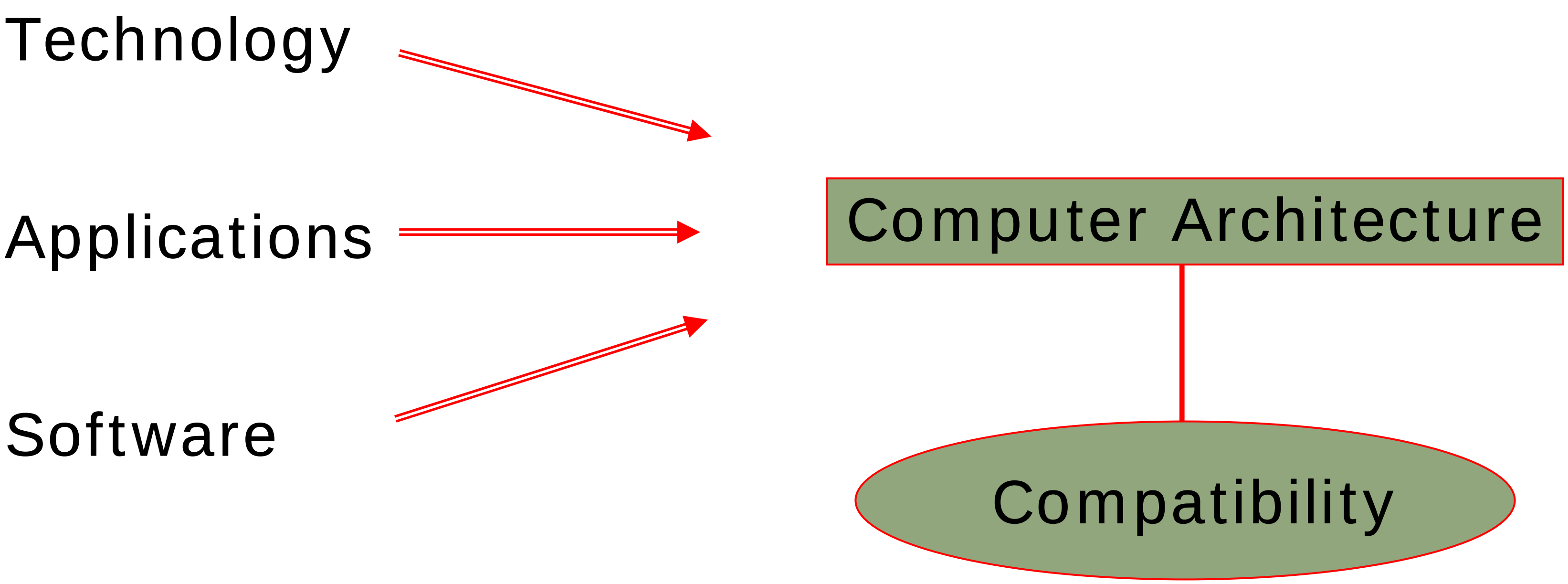
Factors that Influence Computer Architecture



Software played almost no role in defining an architecture before mid fifties.

special-purpose *versus* general-purpose machines

Microprocessors Economics *since 1990's*

- Huge teams design state-of-the-art microprocessors

  PentiumPro ~ 500 engineers
  Itanium ~ 1000 engineers

- Huge investments in fabrication lines and technology

  ⇒ to improve clock-speeds and yields
  ⇒ to build new peripheral chips (memory controllers, ...)

- Economics

  ⇒ price drops to one tenth in 2-3 years
  ⇒ need to sell 2 to 4 million units to breakeven

The cost of launching a new ISA is prohibitive and the advantage is dubious!

Compatibility

Essential for *portability* and *competition*

Its importance increases with the market size

but it is also the most *regressive* force

What does compatibility mean?

Instruction Set Architecture (ISA) compatibility

The same assembly program can run on an upward compatible model

then IBM 360/370 ... *now* Intel x86 (IA32), IA64

System and application software developers expect more than ISA compatibility *(API's)*

applications
operating system
proc + mem + I/O

Java?

Wintel

Perpetual tension

Language/ Compiler/ System software designer		*Architect/Hardware designer*
Need mechanisms to support important abstractions	⇒	Decompose each mechanism into essential micro-mechanisms and determine its feasibility and cost effectiveness
Determine compilation strategy; new language abstractions	⇐	Propose mechanisms and features for performance

Architects main concerns are performance (both absolute and MIPs/$), and power (both absolute and MIPs/watt) in supporting a broad class of software systems.