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

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*Arvind*
Computer Science & Artificial Intelligence Lab
M.I.T.

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*Based on the material prepared by Arvind and Krste Asanovic*

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# Charles Babbage 1791-1871

## Lucasian Professor of Mathematics, Cambridge University, 1827-1839

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**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

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# 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!*



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# 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*



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# 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*



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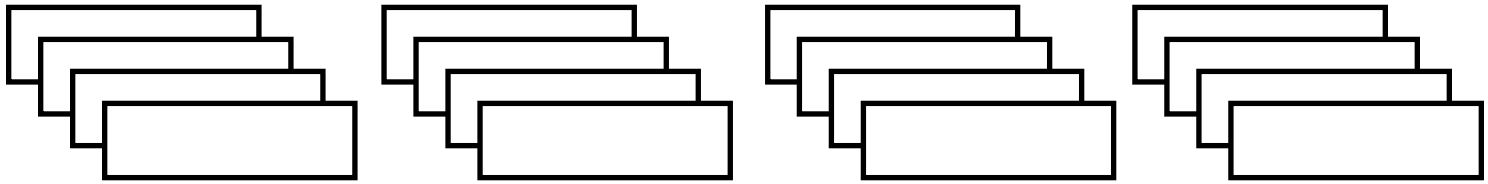
# Analytic Engine
## The first conception of a general purpose computer

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.

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The *program*

Operation variable1 variable2 variable3



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!*



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# 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.*



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# 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

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Performance:

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

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*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, ... )

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# 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*

    $\Rightarrow$ "*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



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# 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 |



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# Technology Issues

ENIAC ⇒ EDVAC

18,000 tubes
20 10-digit numbers

4,000 tubes
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*



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# 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.*



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# 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

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| CORE | J. Forrester | 1954 |
|---|---|---|



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# 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.

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# 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!

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*Users stopped building their own machines.*

Why was IBM late getting into computer technology?

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*IBM was making too much money!*

Even without computers, IBM revenues were doubling every 4 to 5 years in 40's and 50's.



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# 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*

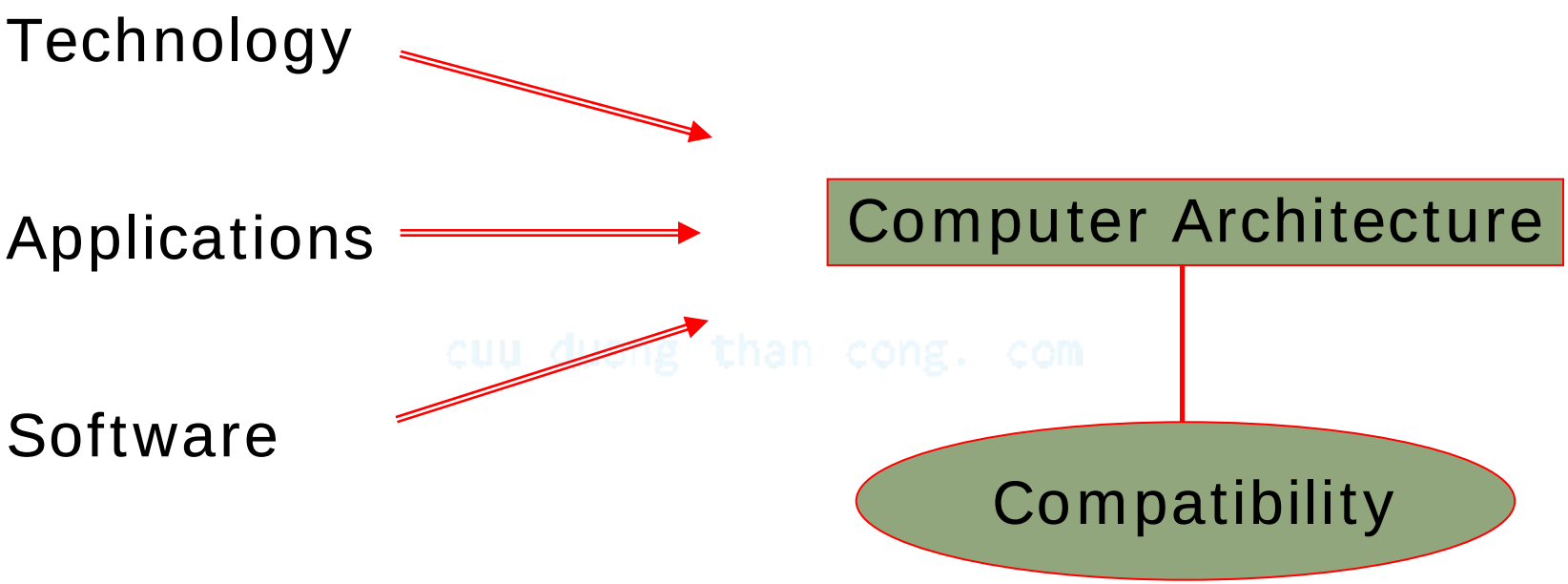
⇒ Most users could not be expected to understand these programs, much less write them

⇒ 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



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# 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!*



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# 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?*

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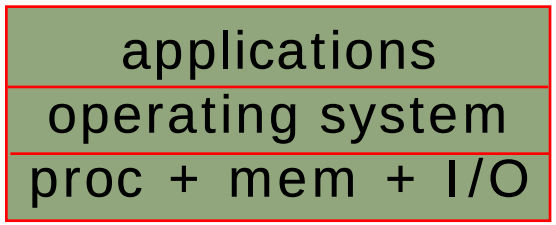
Instruction Set Architecture (ISA) compatibility

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)*

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*Java?*

*Wintel*



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# 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.*



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