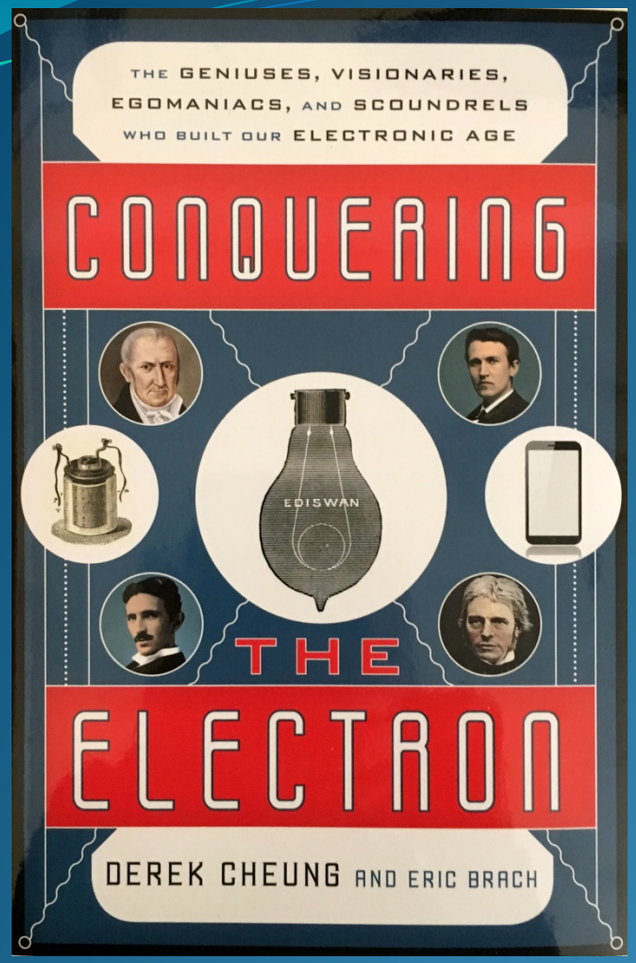
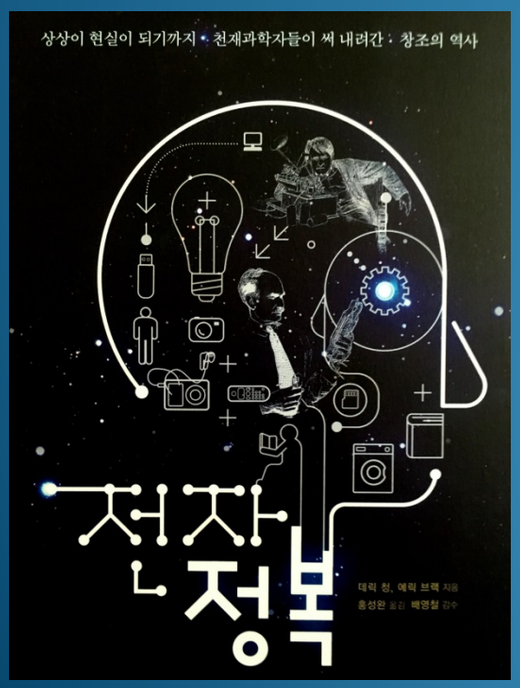
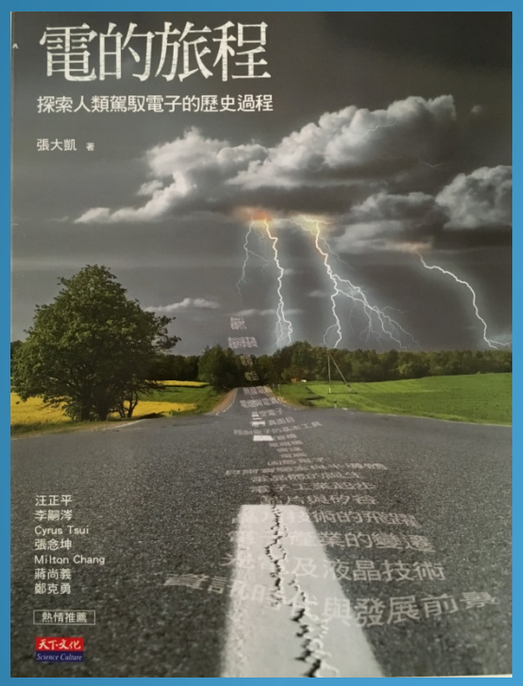


Conquering the Electron

200+ Years of Innovations & Inventions





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Outline

- Brief history
  - From a ***technology*** and ***business*** point of view
  - Focus on ***Communication*** and ***Information***
- Lessons learned
- Concluding thoughts

Early History (1000 BC to 1800 AD)



Amber ~1,000 BC



Magnet ~600 BC



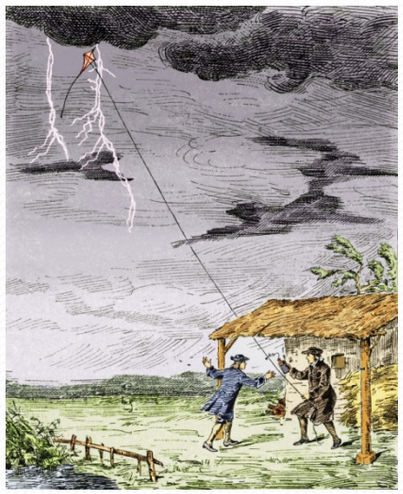
Compass ~220 BC



William Gilbert
1600 (Elektron)



Leyden Jar
1745



Benjamin Franklin
1752



Alessandro Volta
1800

200+ Years of Cumulative Innovation & Invention



Volta's battery (1800)

I) Electromagnetics (1800~1900)

Battery, Electromagnet, EM theory

Telegraph, Telephone, Wireless Telegraph

Motor, Generator, Transformer

Tram, subway, elevator, pump, lighting, refrigerator

II) Vacuum Electronics (1900~1950)

Electron beam, Vacuum Triode

X-Ray, Radio, Television, Radar, Computer

III) Semiconductor Electronics (1950~ Present)

Transistor, Silicon chips, LCD, Fiber-Optics

Building blocks of Information Age



Smartphone (2007)

Inter-play of

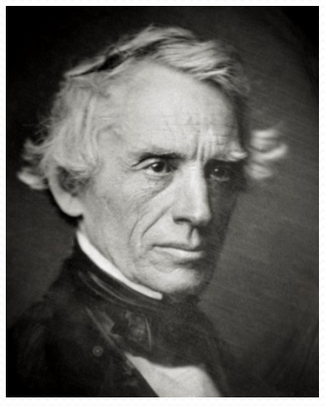
Technology

Application

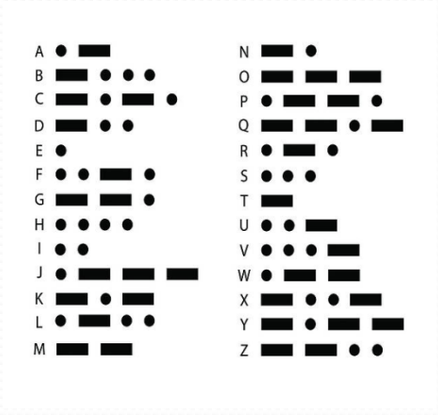
Science

The First "Electrical" Industry: Telegraph (1844)

- Cooke (GB) & Morse (US) both filed patent in 1837
- Cooke built first working system in 1839
- Morse demonstrated the Baltimore-Washington link in 1844
  - $30K funding from US Congress
- Morse system grew rapidly through licensing/franchising
  - Became de facto "standard" due to its ***simplicity***
- Cross Atlantic cable in 1858 ushered in global communication





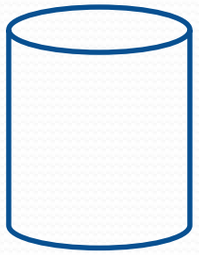






The Innovation & Invention (Innovention) Model





Building Blocks

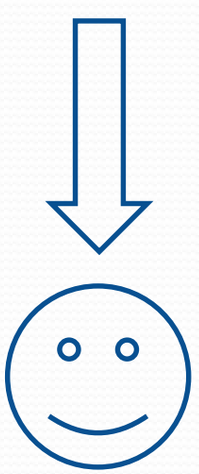
Existing Technologies

Market / Application



Product & Service

Features
Performance
Cost



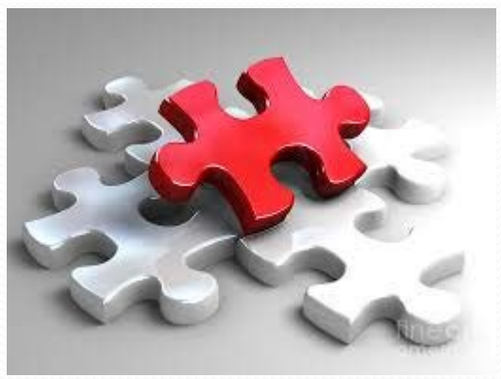
Creative Master Mind

Innovate



New Enablers

Invent

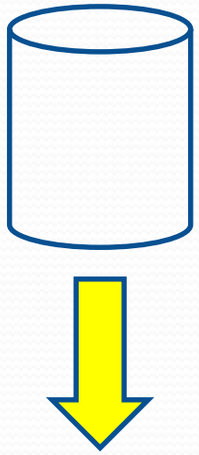


Innovention: The Apple Examples







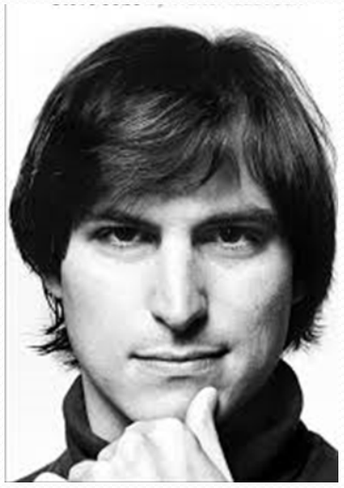


Building Block Technologies
Chips, CRT/LCD, battery, memory
System SW, Algorithms, Apps…..

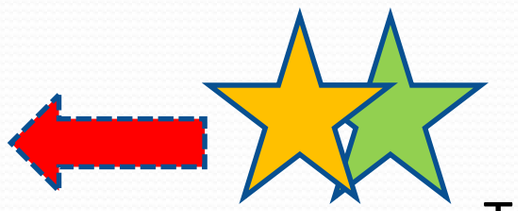
Market

Products

Features
Performance
Cost



Master Mind
(Innovator)



The Enablers
GUI / Mouse **(Mac)**
1.8” drive **(iPod)**
Touch Screen **(iPhone)**

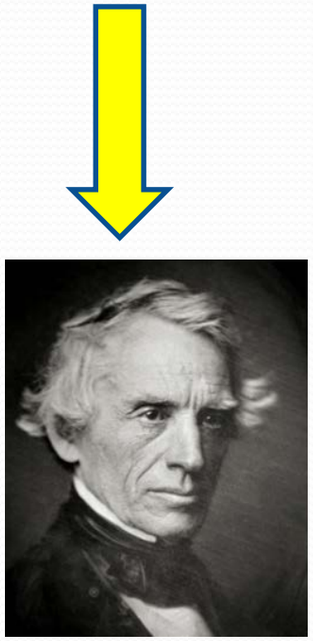
The Innovention of Telegraph



“Killer App”
(Railroad dispatch)

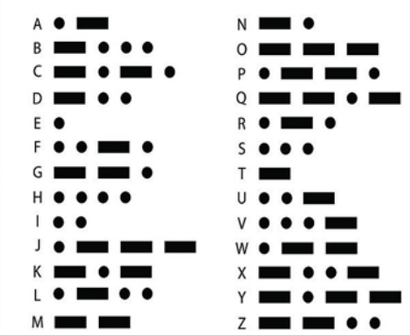
Telegraph

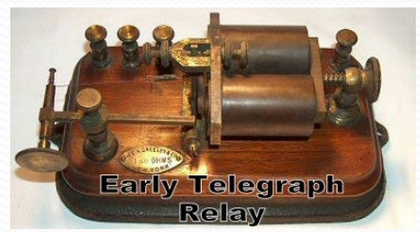
Building Blocks
Wires
Battery
Switch
Electromagnet



Morse

New Enablers
Morse Code (Alfred Vail?)
Relay (Joseph. Henry)

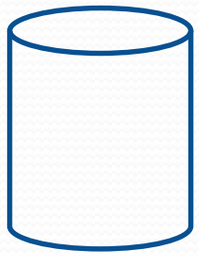




(Digital)

The Accidental invention: Telephone (1876)





Building Blocks

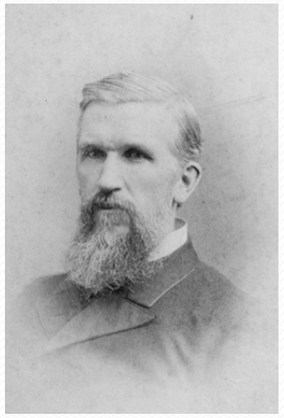
Wires

Battery

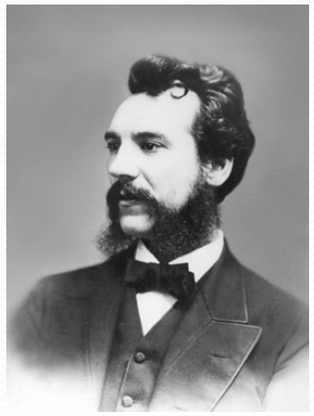
Switch

Electromagnet

Gray



Bell



New Enablers

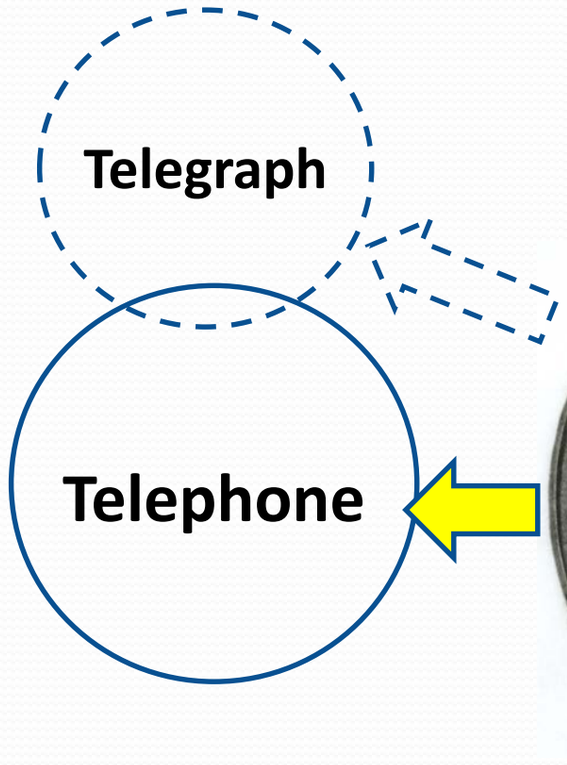


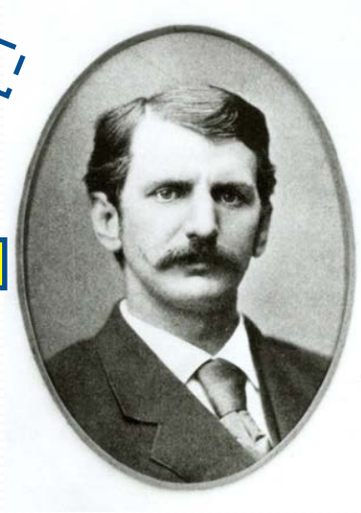


Harmonic Telegraph concept

Voice/Current Transducers

Analog

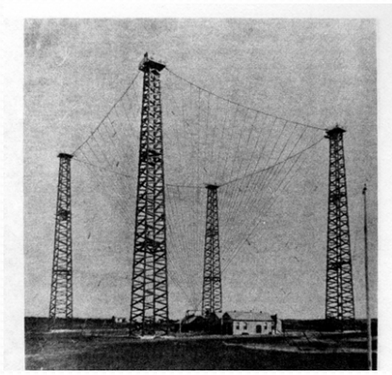




Ted Vail

Wireless Telegraphy (1896)

A classic case of building a new business from science





Building Blocks
Coherer (Valve)
Morse Code
Kite



Shrewd market focus

New Enablers

Wireless Telegraphy



Marconi

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$$
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$
$$\nabla \cdot \vec{B} = 0$$
$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

Maxwell



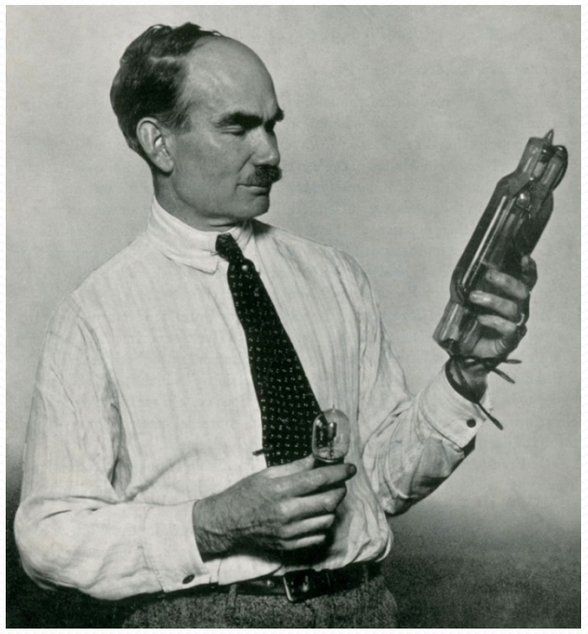
Herz

Technology Bottlenecks @ End of 19th Century

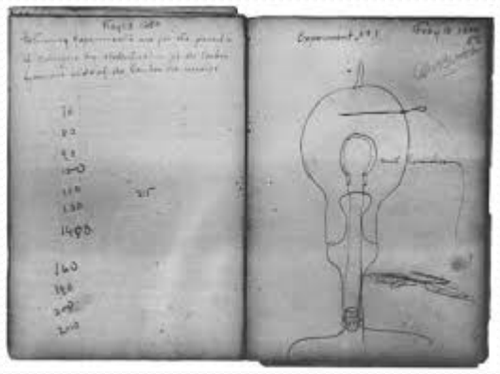
- **How to**
  - Build a coast-to-coast ***long distance telephone*** system?
  - Transmit ***voice*** and ***music*** over wireless signals?
  - Switch telephone calls quickly over a large network?
  - Vary volume of phonograph playback?
- The ***Dream Solution*** was to have a:

>> High sensitivity amplifier and a fast switch

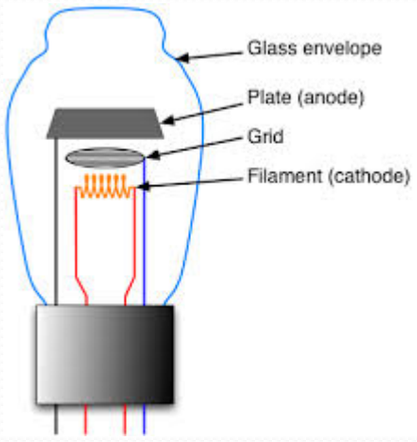
“The Answer is here!” --- Vacuum Triode

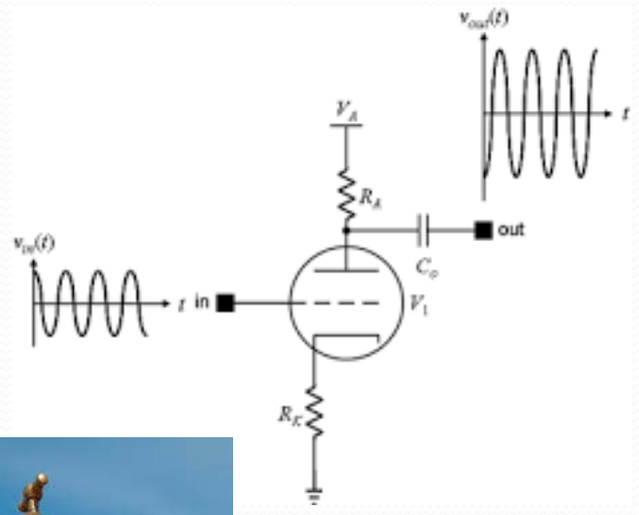


- The Edison Effect (1882)
- The Flaming valve (vacuum diode) (1904)
- Lee De Forest’s 3rd electrode (1906)
  - **“Out-of-Box” thinking**
  - **A monumental, yet obscure historical event**
- The triode is an **amplifier** and a **switch**











Explosion of Innoventions Enabled by Triode

Armstrong's **oscillator circuit**





NYC-SF Phone Line
1914 (Repeaters)



Refined and Mass Produced by AT&T

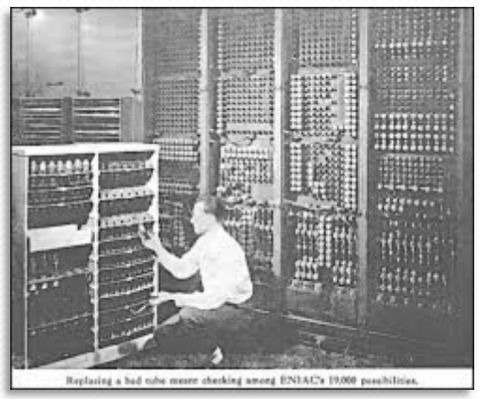
Radio 1915



Television 1927

Radar 1939
(Watson-Watt)

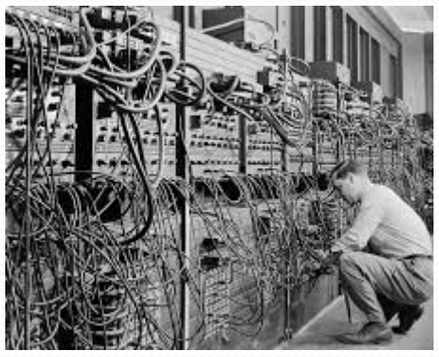




Computer 1946

First Digital Computer: ENIAC (1946)



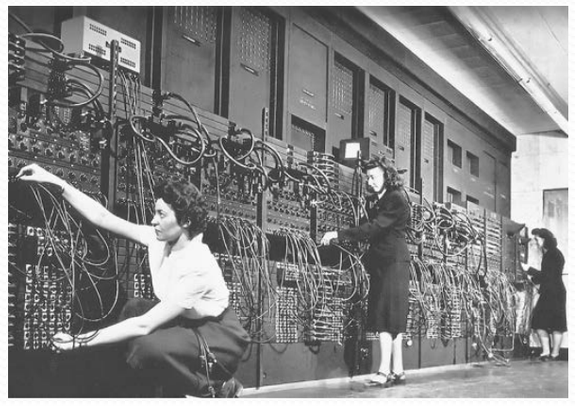




- Mauchly, Eckert (Atanasoff, von Neumann)
- US Army funded @ U. of Penn (~$0.5M)
- ENIAC
  - 17,468 triodes, 5,000,000 soldering joints
  - 160 KW power
  - >60,000 pounds
  - >5,000 operations per second
  - MTF ~ 36 seconds
- Precursor to other computers (Colossus*)







Colossus (1941)



Flowers





The Holy Grail:
A Replacement for Vacuum Triode?

- Mervin Kelly & Bell Labs
- Kelly's vision
- Kelly's action





Kelly



Braun (1874)



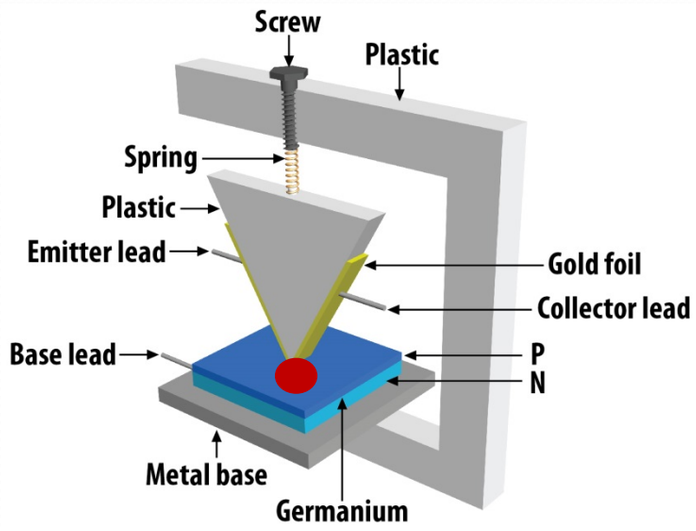
Point contact rectifier

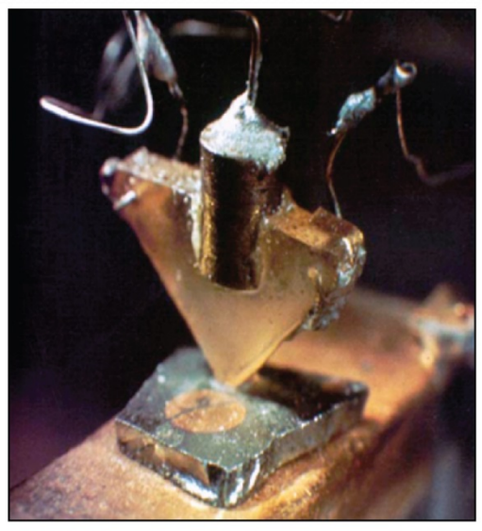
?
=



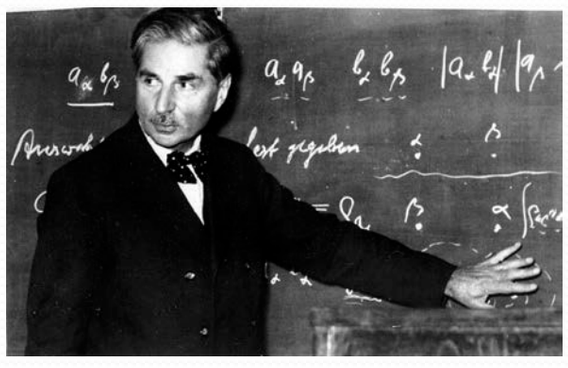
Vacuum diode rectifier

The ultimate building block: Transistor (1947)

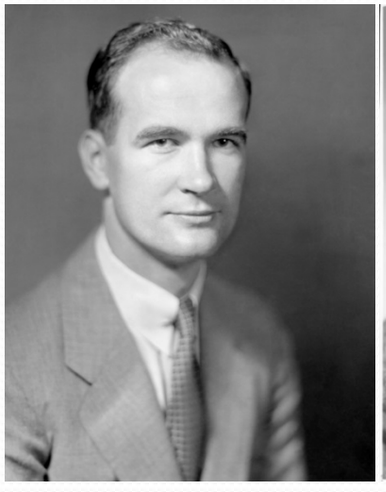




- > 10 years (1937-1948)
- Brilliant individuals
- Multidisciplinary teams
- Triumph for physics & chemistry



Schottky



Shockley



Brattain



Bardeen



Teal



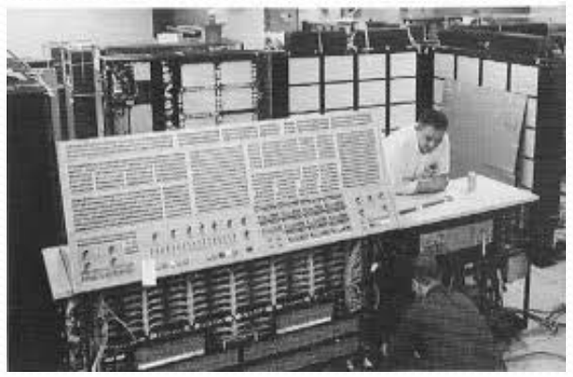
Pfann

Launching a New Industry

- AT&T ‘s decision to license the technology (1954)
- Licensees:
  - IBM, GE, Westinghouse, Philco, Raytheon, RCA, Sylvania..
  - TI, Motorola, TTK,….
- Early impact:
  - Improved existing products
  - Enabled new products



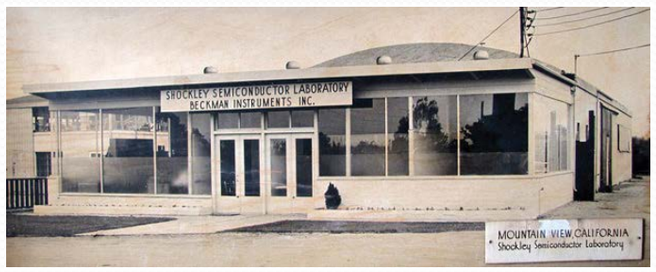






The Birth of Silicon Valley

- Shockley's home coming (1955)
- Nation-wide talent recruitment
- Spreading the seed
  - The folklore of Shockley and the Traitorous Eight
  - The unique Fairchild Spin-off Phenomenon

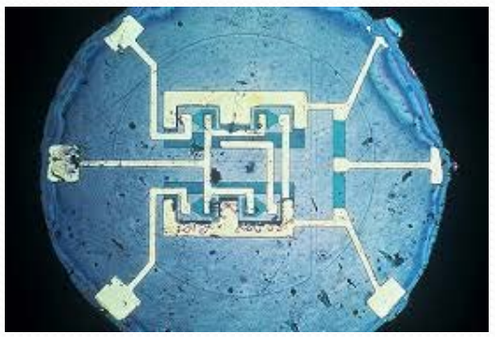


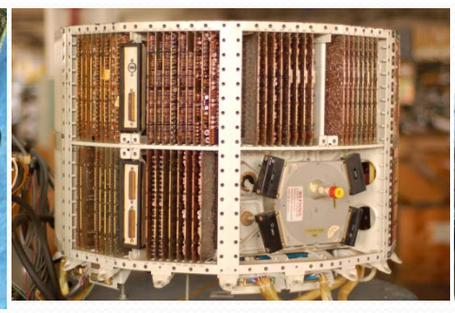


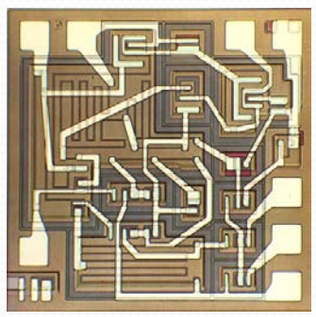


Aggregation of Transistors on a Chip ~1960

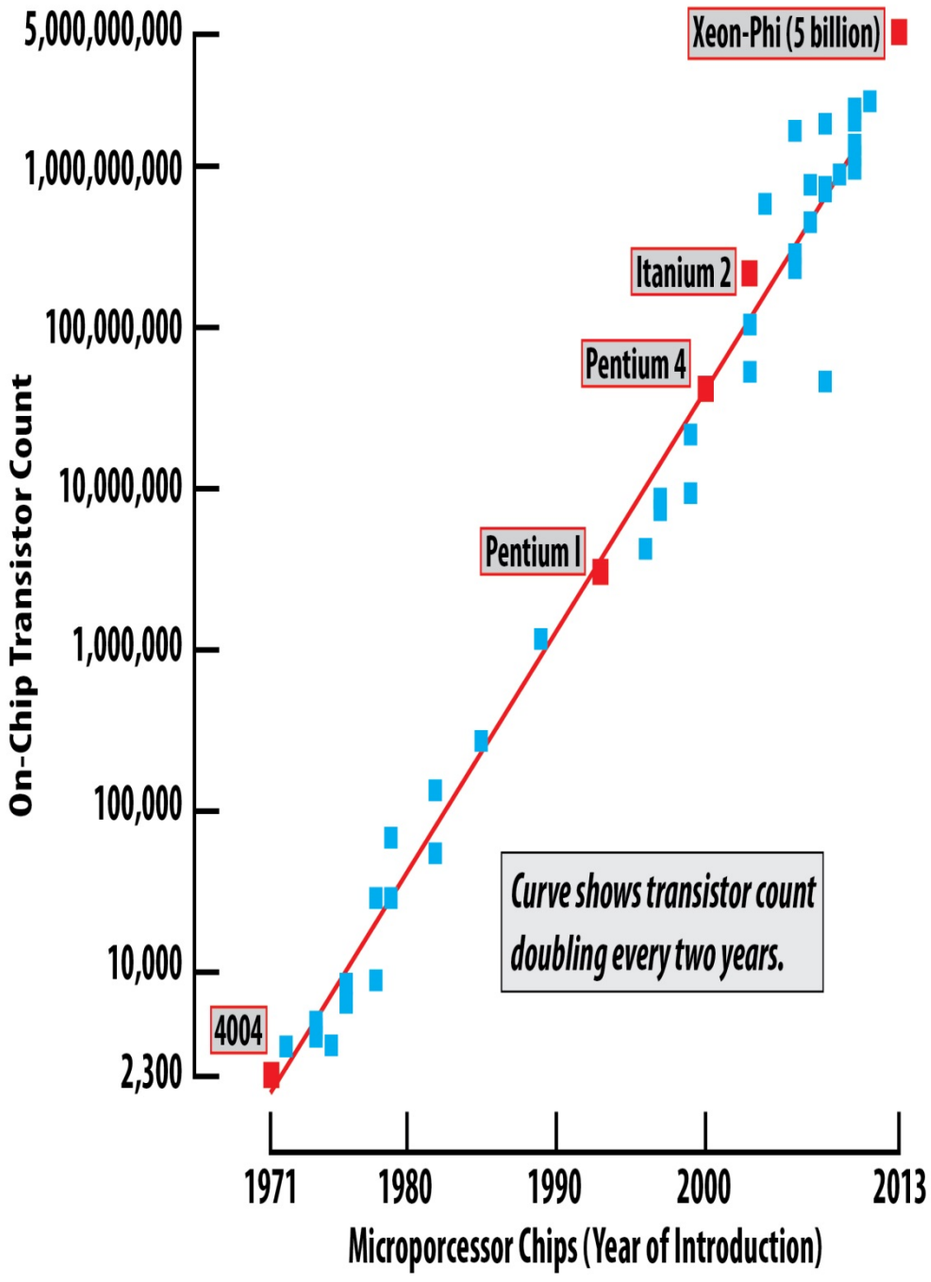
- Kilby (TI) & Noyce (Fairchild)
- Early days of Chip market
  - Skepticism on cost, reliability
  - Aerospace & Defense funding nurtured the young industry
- Recognizing the advantages of scaling down chip features
  - Performance ↑ , Unit Cost ↓





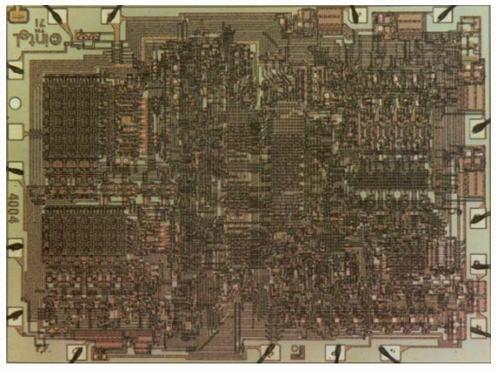
Moore's Law & Its Impact
-- 50 years of exponential growth



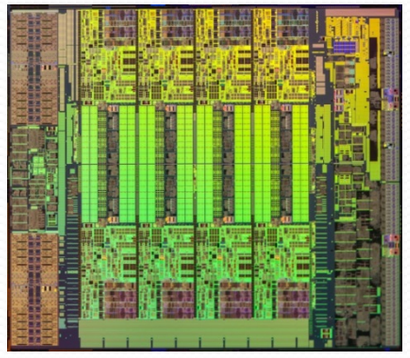
- Transistors on a chip 2x in every ~18-24 months
- Drives other technologies, e.g. LCD, hard discs.

>> A major driving force for economic growth

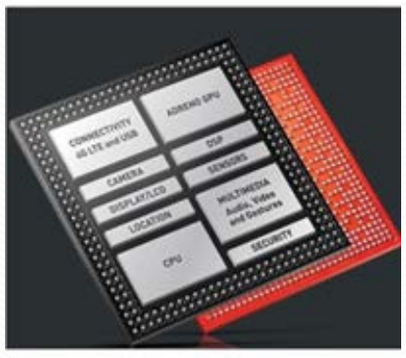
- Examples
  - Intel 4004 CPU (1971) vs ENIAC (1946)
  - Noyce flip-flop (1961) to Intel Xenon (2015)
    - 4 to 5.5 billion transistors
  - Multi-functions: Systems-on-a-Chip (SoC)



4004 (1971)
0.3 x 0.4 cm



Xenon ('2015)



Qualcomm
Snapdragon (2016)

How will Innovention evolve?

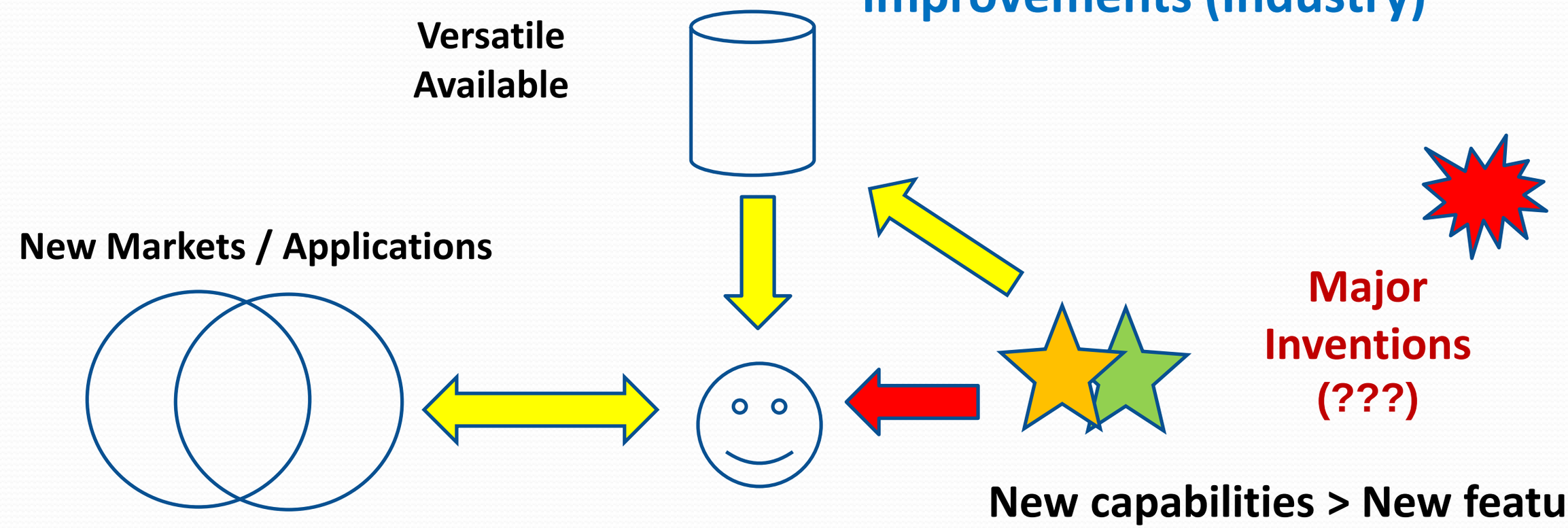
Building Blocks

Powerful

Versatile

Available

Continuous incremental improvements (Industry)



New capabilities > New features

>10X in cost/perf. improvements

Innovators

(Industry, VC…)

On Major Inventions

- All from ***individual minds***; sometimes as ***teams***.
- Different ***styles*** (separate talk)
  - The geniuses
  - The dot-connectors (association)
  - The tinkerers (serendipity)
  - The one-track minders (extreme conviction)
- Challenge is to
  - Create the ***right environment***
  - Develop the ***right metrics*** to measure success
    - Outside of ROI paradigm
  - Deal with invention-to-commercialization ***gap***

Lessons from Bell Labs & Fairchild

Bell Labs (1930-1970's)

Accomplishments

- Transistors, solar cells, lasers
- Information theory, DSP, "C", Unix
- Cellular, satellite, digital network

Reasons for success

- Prestige
- Critical mass
- Stable funding
- **Domain focus**
- **Dynamic turn-over**
- "Non-competing"
- Dispersion of knowledge

Fairchild (1960's)

Role

- Cradle of IC technology
  - Failed as a business
  - But key to the success of US semiconductor industry

Reason for impact

- Top quality technologists
- Entrepreneurial culture
- "Loosely" managed

Create labs for discovery research in ***health, biotech, energy, environment*** ?

Concluding thoughts

- **200+ years of cumulative innovations & inventions**
  - One of the greatest achievements by Human Race

- **The inter-play of science-technology-application**
  - Convoluted, Non-linear, and Dynamic; all essential

- **Moore's law coming to an end**
  - What is next? Anticipate a ***"New norm".***

(http://www.economist.com/technology-quarterly/2016-03-12/after-moores-law)