Fundamental Engineering Research to Societal Benefits

Extraordinary Engineering Impacts
National Academy of Engineering Symposium
August 18, 2022

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University of California, Irvine

UCI University of California, Irvine

Professional Evolution

PhD Mentor

"Kalman Filter"

R. E. Kalman

- B. Tech. in Electrical Engineering, Indian Institute of Technology. Bombay, India
- MS in Math and PhD in Electrical Engineering, University of Florida
- Rising through the ranks at Universities of Florida, Minnesota, and Michigan

Evolution of Research Interests

- Control Systems Theory
- Manufacturing: Semiconductor, Reconfigurable
- Renewable Electricity Integration and Smart Grids
- Machine Learning and Control
- Funding from NSF, AFOSR, ARO, DARPA and the private sector
- Collaborations with industry: Honeywell, GE, SRC, Xerox, …

MICHIGAN ENGINEERING
NSF ERC FOR RECONFIGURABLE MANUFACTURING SYSTEMS

Professional Evolution: Leadership Roles

- EECS Department Chair at Michigan
- Dean of Engineering at Florida
- Vice Chancellor for Research at California, Irvine
- Head of Engineering Directorate at National Science Foundation
- Deputy Director of Technology ARPA-e


Michigan EECS


Weil Hall, UF

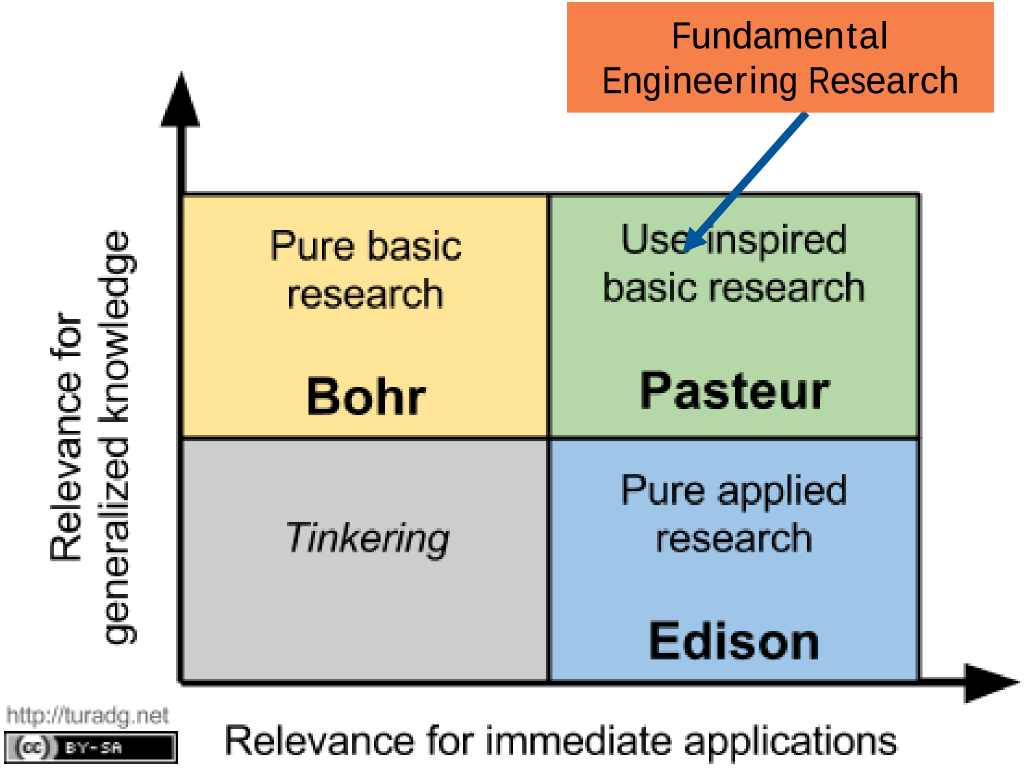

Aldrich Hall, UCI

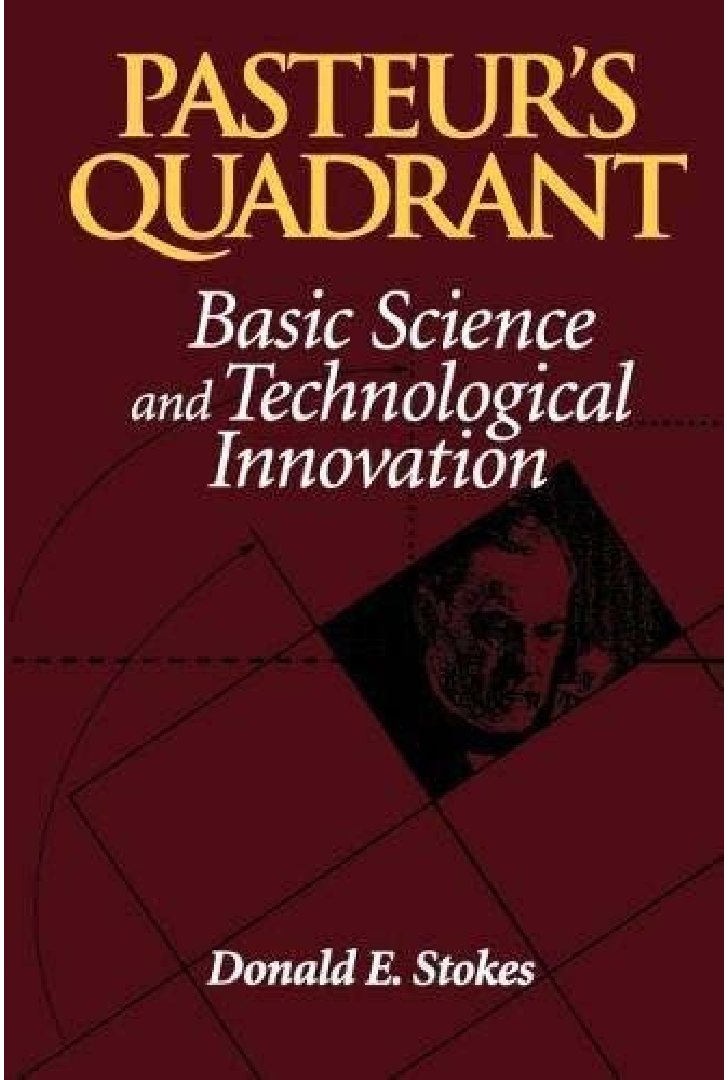
Advanced Research Projects Agency • ENERGY

U.S. DEPARTMENT OF ENERGY

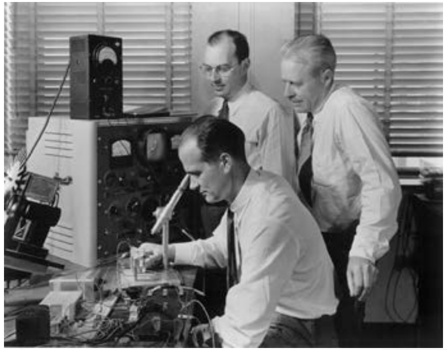
How does Fundamental Engineering Research lead to Societal Benefits?

Pasteur’s Quadrant

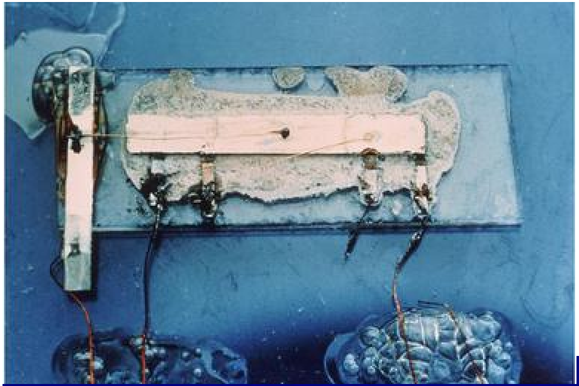




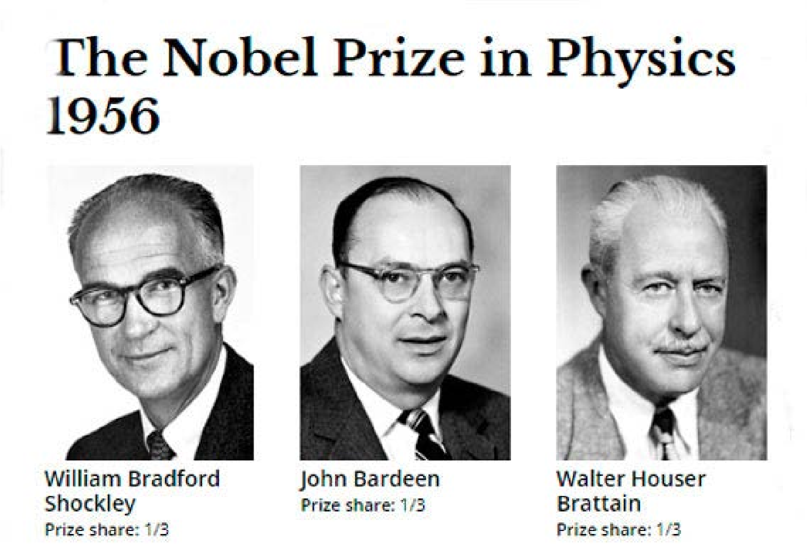
Example 1: Semiconductor Chips

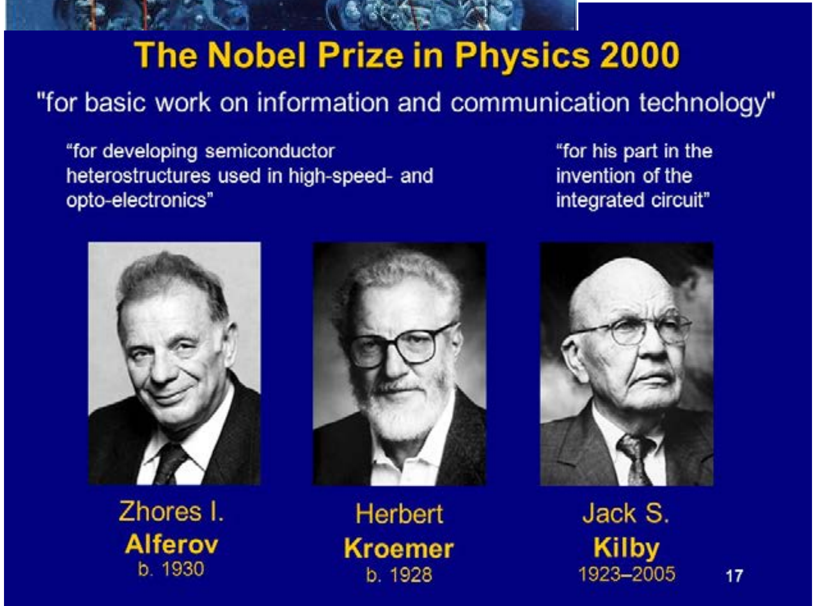


Bell Labs
1947



Kilby's first integrated circuit

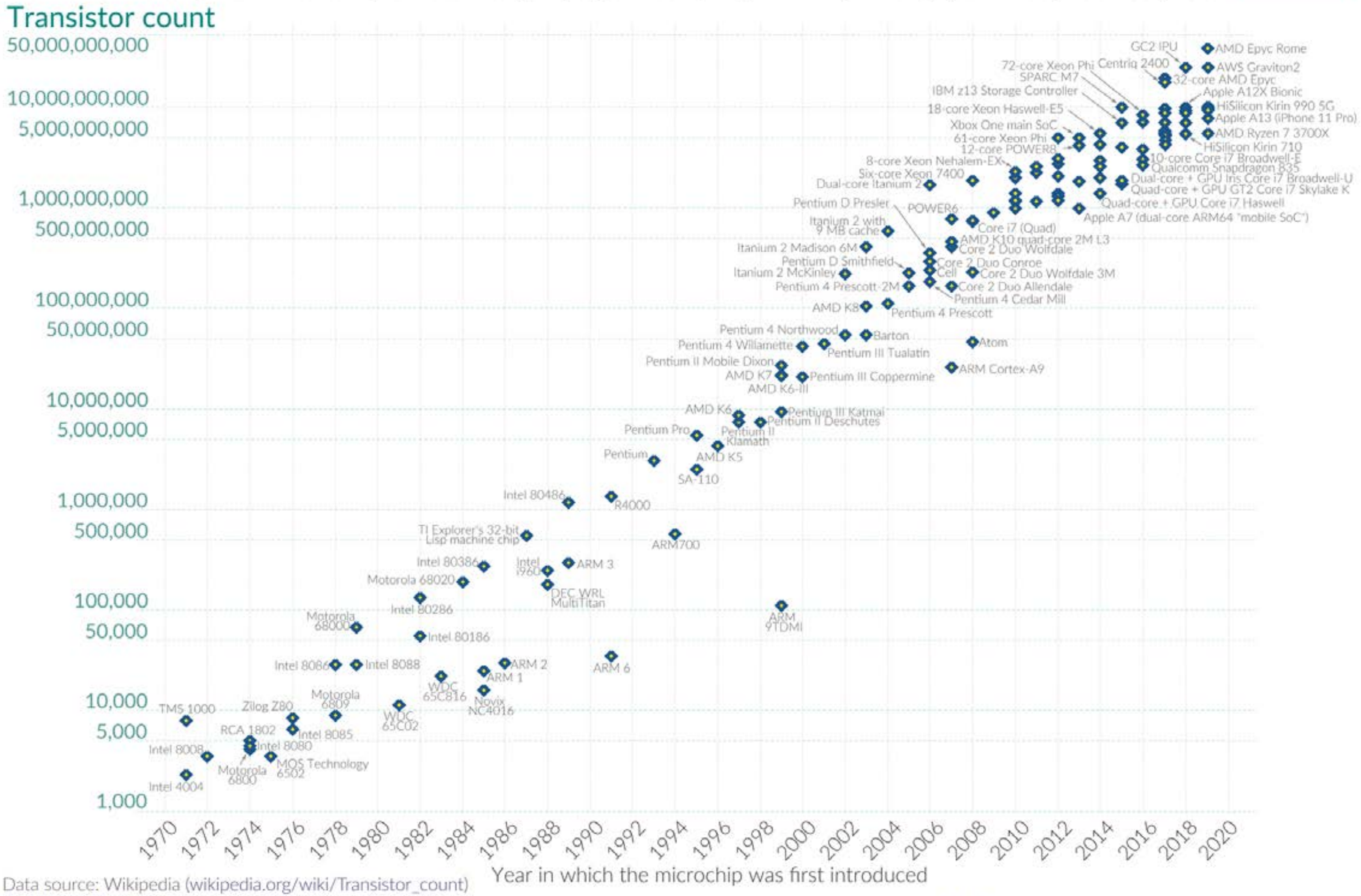




Moore's Law: The number of transistors on microchips doubles every two years

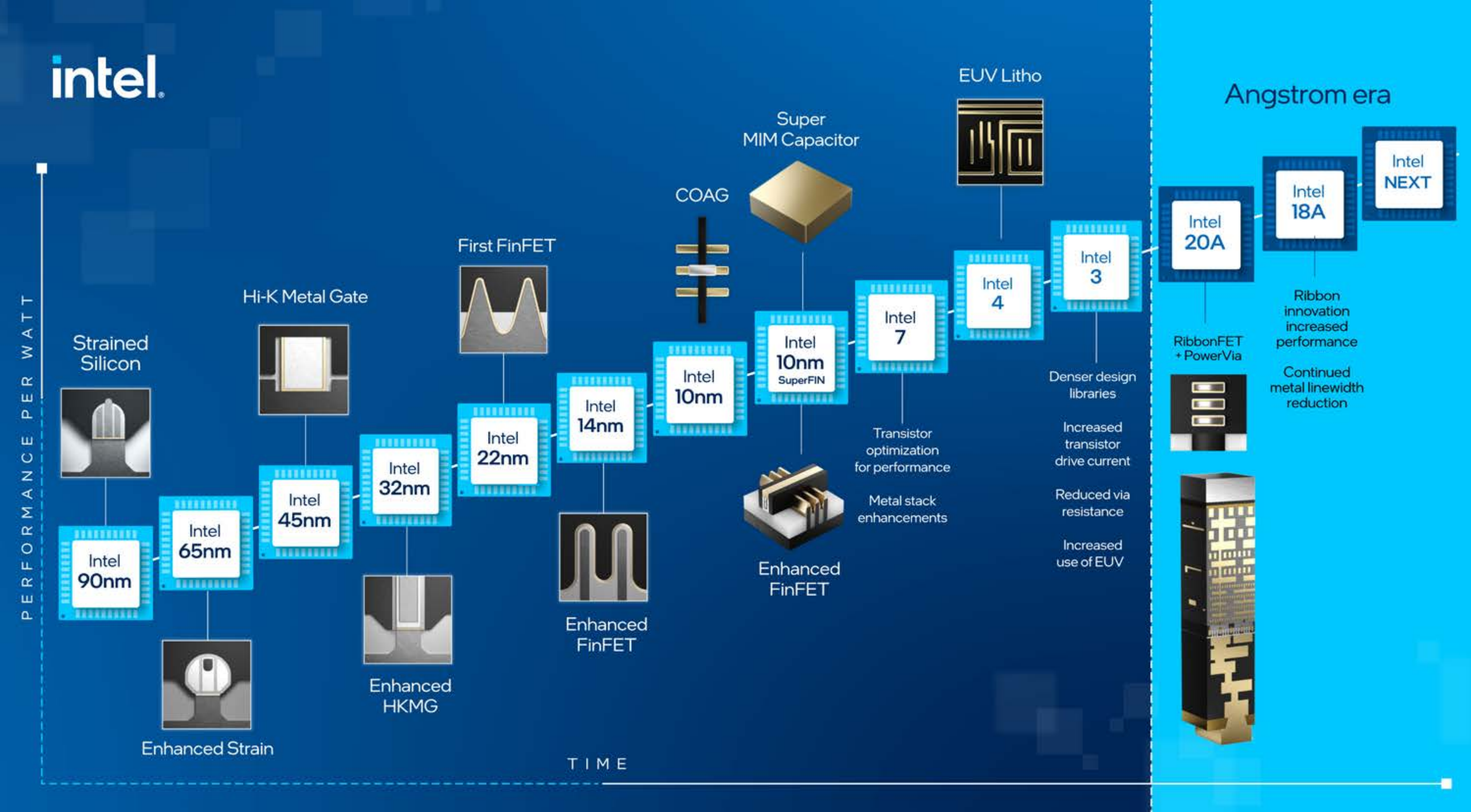
Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.



Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)

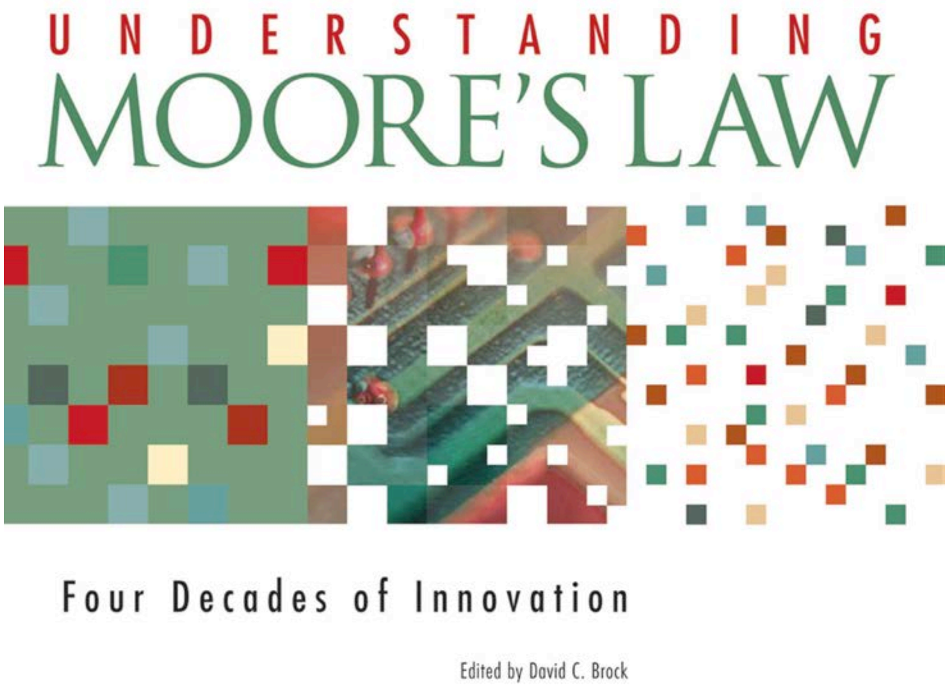
OurWorldinData.org – Research and data to make progress against the world's largest problems.



intel.
Angstrom era
Strained Silicon
Intel 90nm
Intel 65nm
Enhanced Strain
Hi-K Metal Gate
Intel 45nm
Intel 32nm
Enhanced HKMG
First FinFET
Intel 22nm
Intel 14nm
Enhanced FinFET
COAG
Intel 10nm
Super MIM Capacitor
Intel 10nm SuperFIN
Enhanced FinFET
Intel 7
Transistor optimization for performance
Metal stack enhancements
EUV Litho
Intel 4
Intel 3
Denser design libraries
Increased transistor drive current
Reduced via resistance
Increased use of EUV
Intel 20A
RibbonFET + PowerVia
Intel 18A
Ribbon innovation increased performance
Continued metal linewidth reduction
Intel NEXT
PERFORMANCE PER WATT
TIME

Source:

Moore's Law: Fundamental Research Intertwined with Technological Progress



"Indeed, the technology led the science in a sort of inverse linear model …"

Gordon Moore

Continuing Innovation in Information Technology

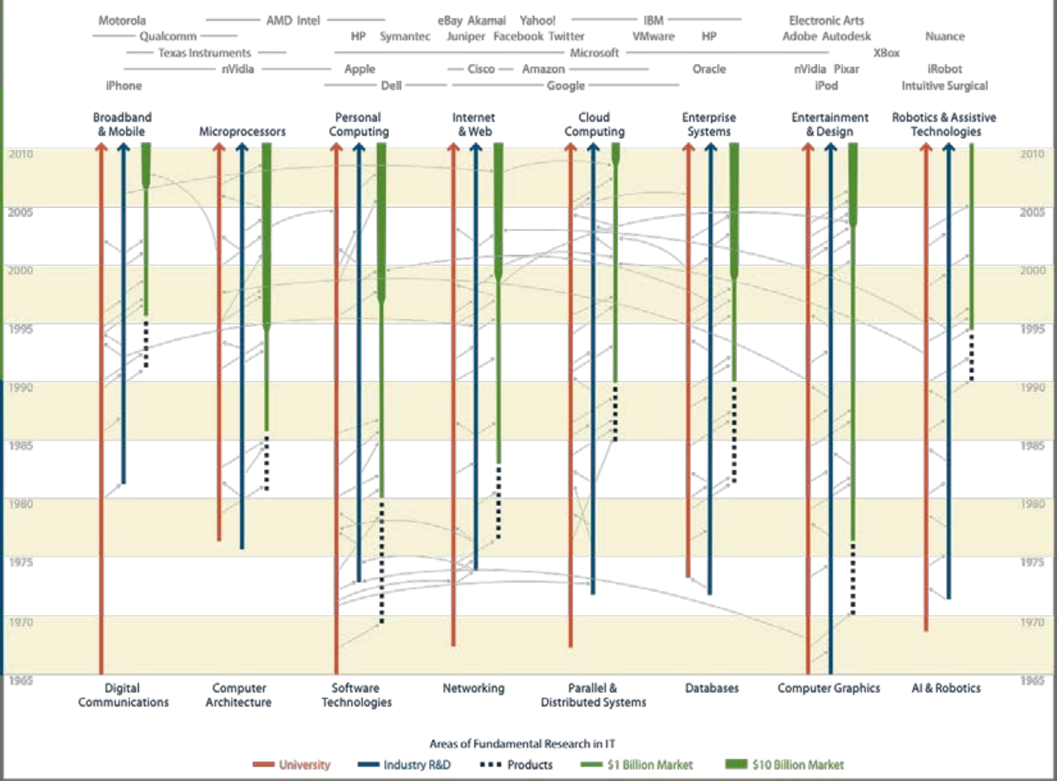
Fundamental research in IT underpins the creation of billion-dollar-plus IT market segments and a vital U.S. IT industry through a complex partnership between universities, industry, and government.

The first version of this figure was published in the 1995 report *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*. The original figure, which was updated in 2002 and 2003, dispelled the assumption that the commercially successful IT industry is self-sufficient. It underscored the extent to which industry instead builds on government-funded university research—sometimes through long incubation periods of years and even decades.

As illustrated in this figure from the 2012 report *Continuing Innovation in Information Technology*, computing research and its impacts have since continued to evolve and blossom. The figure illustrates how fundamental research in IT, conducted in industry and universities, has led to the introduction of entirely new product categories that ultimately became billion-dollar industries. It reflects a complex research environment in which concurrent advances in multiple subfields have been mutually reinforcing, stimulating and enabling one another and leading to vibrant, innovative industries exemplified by top-performing U.S. firms. Such research often starts as a search for fundamental knowledge but time and again produces practical technologies that enable significant economic impact.

The gray lines illustrate the rich interplay between academic research, industry research, and products and indicate the cross-fertilization resulting from multi-directional flows of ideas, technologies, and people.

IT Sectors with Large Economic Impact



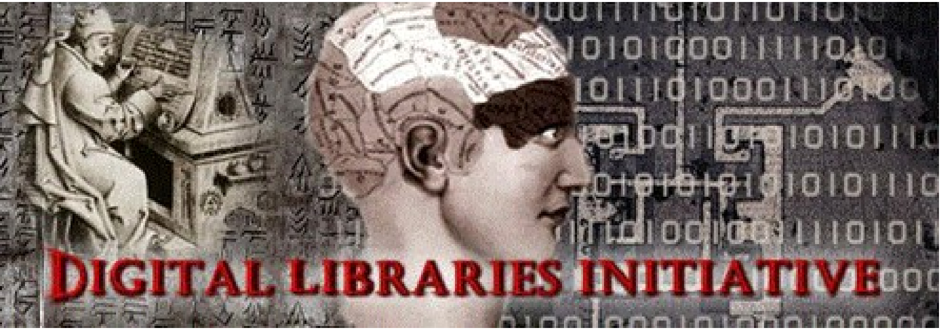
THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

The full report featuring this figure is available at **www.nap.edu**.

Visit **www.cstb.org** for details on the Computer Science and Telecommunications Board (CSTB), a unit of the National Research Council of the National Academies.

The study was supported by the National Science Foundation. Any opinions, findings, conclusions, or recommendations expressed in the report are those of the authors and do not necessarily reflect the views of the agency that provided support for the project.

Origins of Google



NSF Digital Libraries Initiative, 1994

S. Brin and L. Page

Award Abstract # 9411306

The Stanford Integrated Digital Library Project

NSF Org:	IIS Div Of Information & Intelligent Systems
Awardee:	
Initial Amendment Date:	September 16, 1994

PI: H. Molina-Garcia and T. Winograd

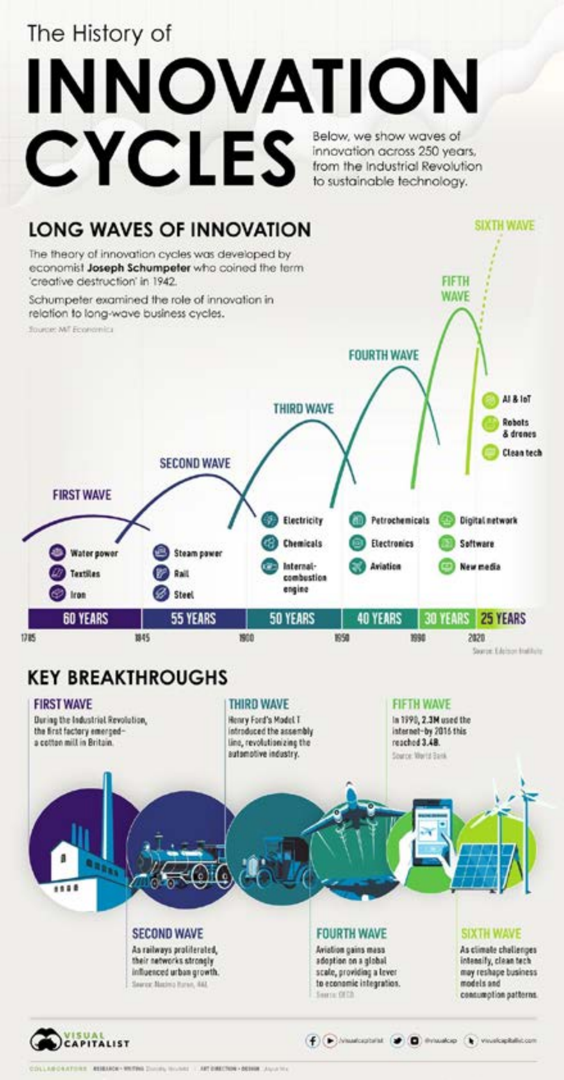
PageRank Algorithm

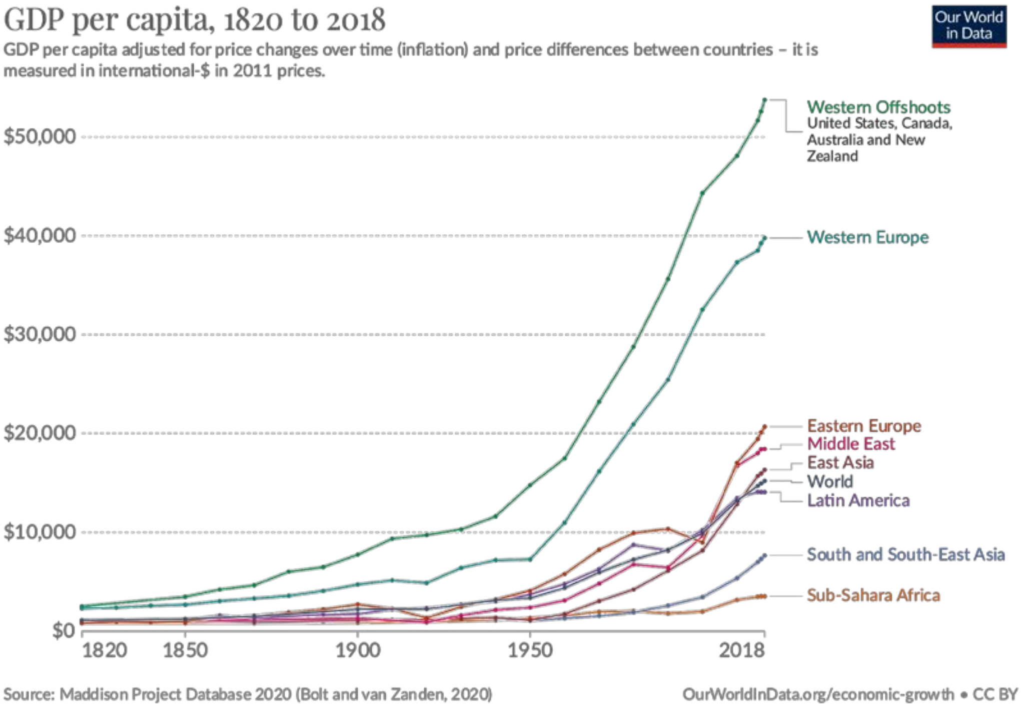
The PageRank Citation Ranking: Bringing Order to the Web.

Page, Lawrence and Brin, Sergey and Motwani, Rajeev and Winograd, Terry (1999) *The PageRank Citation Ranking: Bringing Order to the Web*. Technical Report. Stanford InfoLab.

The importance of a Web page is an inherently subjective matter, which depends on the readers interests, knowledge and attitudes. But there is still much that can be said objectively about the relative importance of Web pages. This paper describes PageRank, a method for rating Web pages objectively and mechanically, effectively measuring the human interest and attention devoted to them.

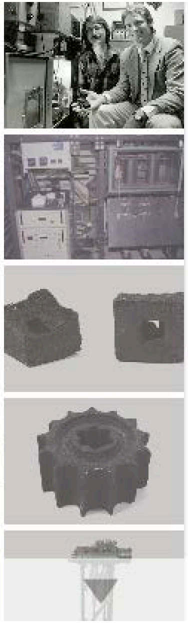
We compare PageRank to an idealized random Web surfer. We show how to efficiently compute PageRank for large numbers of pages. And, we show how to apply PageRank to search and to user navigation.


The History of
INNOVATION CYCLES
Below, we show waves of innovation across 250 years, from the Industrial Revolution to sustainable technology.
LONG WAVES OF INNOVATION
The theory of innovation cycles was developed by economist Joseph Schumpeter who coined the term 'creative destruction' in 1942.
Schumpeter examined the role of innovation in relation to long-wave business cycles.
FIRST WAVE
SECOND WAVE
THIRD WAVE
FOURTH WAVE
FIFTH WAVE
SIXTH WAVE
Water power
Textiles
Iron
Steam power
Rail
Steel
Electricity
Chemicals
Internal-combustion engine
Petrochemicals
Electronics
Aviation
Digital network
Software
New media
AI & IoT
Robots & drones
Clean tech
60 YEARS
55 YEARS
50 YEARS
40 YEARS
30 YEARS
25 YEARS
1785
1845
1900
1950
1990
2020
KEY BREAKTHROUGHS
FIRST WAVE
During the Industrial Revolution, the first factory emerged—a cotton mill in Britain.
THIRD WAVE
Henry Ford's Model T introduced the assembly line, revolutionizing the automotive industry.
FIFTH WAVE
In 1990, 2.3M used the internet—by 2016 this reached 3.4B.
SECOND WAVE
As railways proliferated, their networks strongly influenced urban growth.
FOURTH WAVE
Aviation gains mass adoption on a global scale, providing a lever to economic integration.
SIXTH WAVE
As climate challenges intensify, clean tech may reshape business models and consumption patterns.
VISUAL CAPITALIST


GDP per capita, 1820 to 2018
GDP per capita adjusted for price changes over time (inflation) and price differences between countries – it is measured in international-$ in 2011 prices.
Our World in Data
$50,000
$40,000
$30,000
$20,000
$10,000
$0
1820
1850
1900
1950
2018
Western Offshoots
United States, Canada, Australia and New Zealand
Western Europe
Eastern Europe
Middle East
East Asia
World
Latin America
South and South-East Asia
Sub-Sahara Africa
Source: Maddison Project Database 2020 (Bolt and van Zanden, 2020)
OurWorldInData.org/economic-growth • CC BY

Example 2: Origins of 3D Printing in the 80’s

1 of 8: **Dr. Joe Beaman and Carl Deckard, ca. 1989.** *In the 1980s, student Carl Deckard and his advisor Dr. Joe Beaman developed and patented a type of additive manufacturing called selective laser sintering (SLS).*



‘Revolutionary’

Machine makes 3-D objects from drawings

By Kathleen Sullivan
American-Statesman Staff

Wedged into the corner of an unused photo lab at the University of Texas is an ungainly machine that can transform a computer drawing into a three-dimensional model at the touch of a button.

Sometime next year, the machine, which was developed by a UT graduate student, will make its way out of the lab and into the commercial arena. It will leave with the blessing of the UT Board of Regents, which Thursday gave an Austin company exclusive licensing rights to the "revolutionary" new technology embodied in the machine.

The licensing pact paves the way for the first transfer of technology from the University of Texas at Austin to a commercial venture.

The company that won the right to market the invention is Nova Automation Corp., whose principal shareholders are an Austin consulting engineer and Nova Graphics International Corp., an Austin-based computer graphics software firm.

The agreement represents a "hard fought" victory for UT's fledgling Center for Technology Development and Transfer, said Meg Wilson, coordinator of the center, which was given life during the last Texas Legislature and got

See Inventor, A11

Staff photo by Ralph Barrera

Associate Professor Joe Beaman shows some three-dimensional plastic models made by the 'selective laser centering' device developed by Carl Deckard, left.

United States Patent [19]

Deckard

[54] **METHOD AND APPARATUS FOR PRODUCING PARTS BY SELECTIVE SINTERING**

[75] Inventor: **Carl R. Deckard**, Austin, Tex.

[73] Assignee: **Board of Regents, The University of Texas System**, Austin, Tex.

[21] Appl. No.: **920,580**

[22] Filed: **Oct. 17, 1986**

NSF Role in 3D Printing

“NSF funded precursors of AM technologies in the 1970s (development of computer numerical controlled machining and solid modeling tools) and turned early AM patents in the 1980s into proof-of-concept and prototype machines in two major commercial technology areas (binder jetting and laser sintering).”

Award Abstract # 8707871

Part Generation by Layerwise Selective Sintering

NSF Org:	CMMI Div Of Civil, Mechanical, & Manufact Inn
Awardee:	UNIVERSITY OF TEXAS AT AUSTIN
Initial Amendment Date:	March 6, 1987
Latest Amendment Date:	March 6, 1987

Source: Weber et al, IDA Paper P-5091

Foundational Research

IEEE Computer, 1977

Geometric Modeling of Mechanical Parts and Processes

Herbert B. Voelcker and Aristides A. G. Requicha
University of Rochester

Acknowledgments

The work reported in this paper was supported primarily by the National Science Foundation under grants GI-34274X and APR76-01034.

SELECTIVE LASER SINTERING

by

CARL ROBERT DECKARD, M.S.M.E., B.S.M.E.

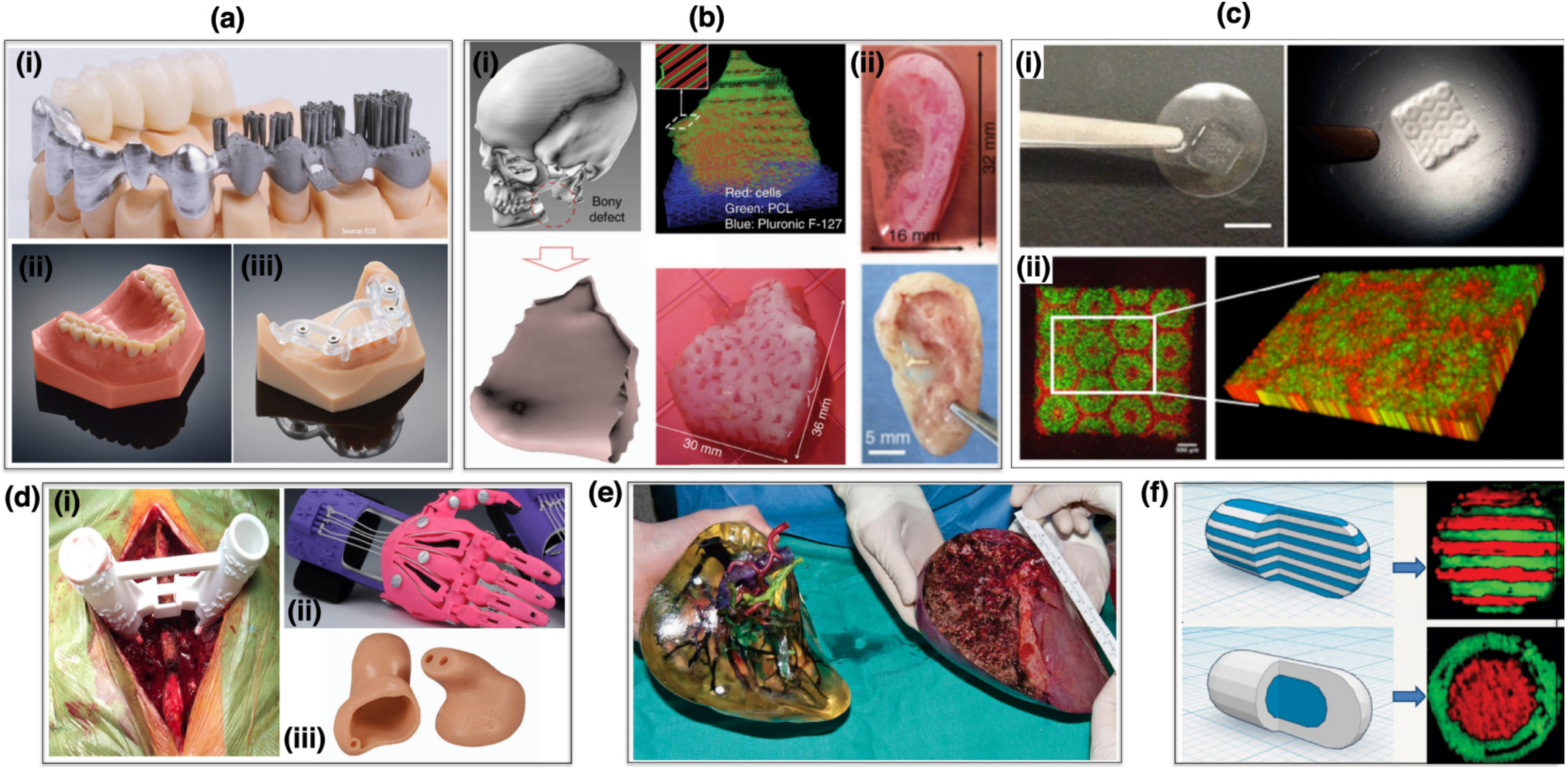
DISSERTATION

Presented to the Faculty of the Graduate School of The University of Texas at Austin in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Mechanical Engineering

THE UNIVERSITY OF TEXAS AT AUSTIN

December, 1988.

Societal Impact of 3D Printing: Medical Applications



Source: C.Y. Liaw and M. Guvendiren, Biofabrication, 2017

We aspire to accelerate and optimize
the engineering research to innovation to
technology cycle to assist
people and society to flourish.

Comments

Ideas

Questions?

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http://faculty.sites.uci.edu/khargonekar/