Fundamental Engineering Research to Societal Benefits

Extraordinary Engineering Impacts
National Academy of Engineering Symposium
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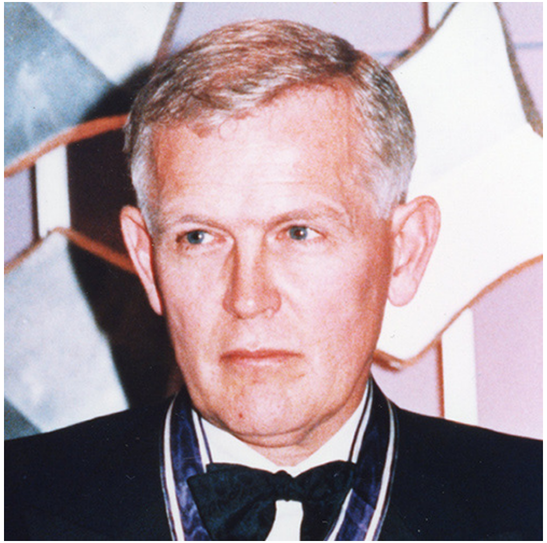
UCI University of California, Irvine

Professional Evolution

- 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 faculty ranks at Universities of Florida, Minnesota, and Michigan

“Kalman Filter”



PhD Mentor: R. E. Kalman

Evolution of Research Interests

- Control Systems Theory
- Manufacturing: Semiconductor, Reconfigurable
- Renewable Electricity Integration and Smart Power 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

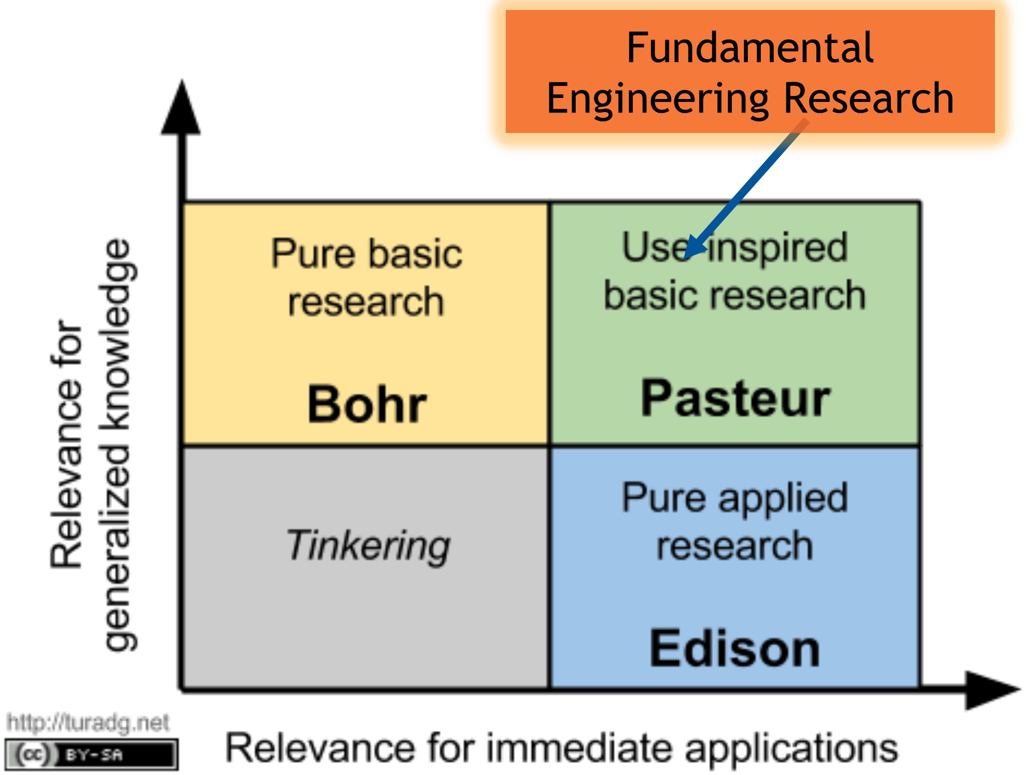
Michigan EECS

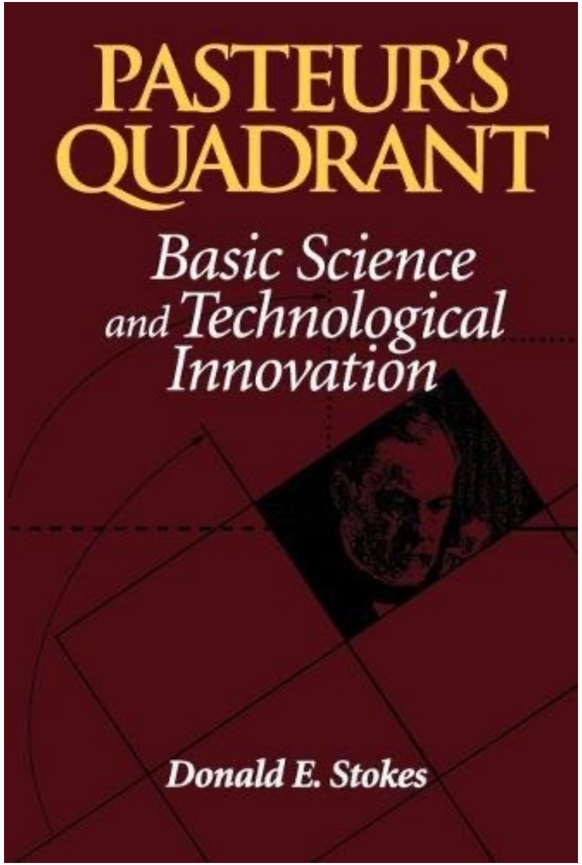
Weil Hall, UF

Aldrich Hall, UCI

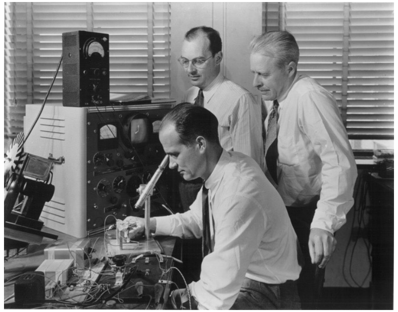
How does Fundamental Engineering Research lead to Societal Benefits?

Nature of Fundamental Engineering Research

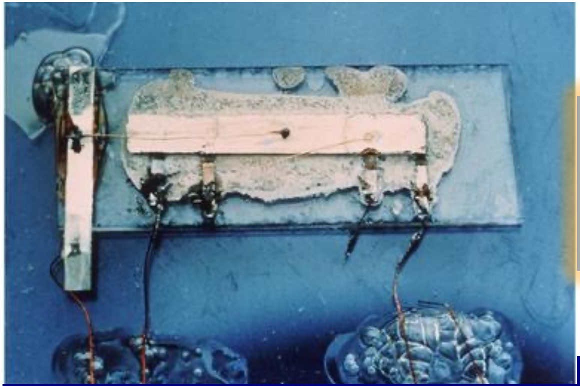




Example 1: Semiconductor Chips



Bell Labs
1947



Kilby's first integrated circuit

"for their researches on semiconductors and their discovery of the transistor effect"

The Nobel Prize in Physics 1956

William Bradford Shockley
Prize share: 1/3

John Bardeen
Prize share: 1/3

Walter Houser Brattain
Prize share: 1/3

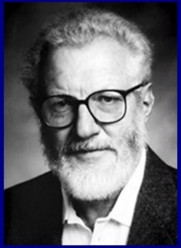
The Nobel Prize in Physics 2000

"for basic work on information and communication technology"

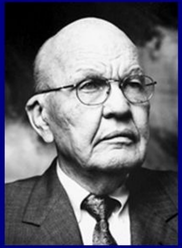
"for developing semiconductor heterostructures used in high-speed- and opto-electronics"

"for his part in the invention of the integrated circuit"

Zhores I. **Alferov**
b. 1930



Herbert **Kroemer**
b. 1928

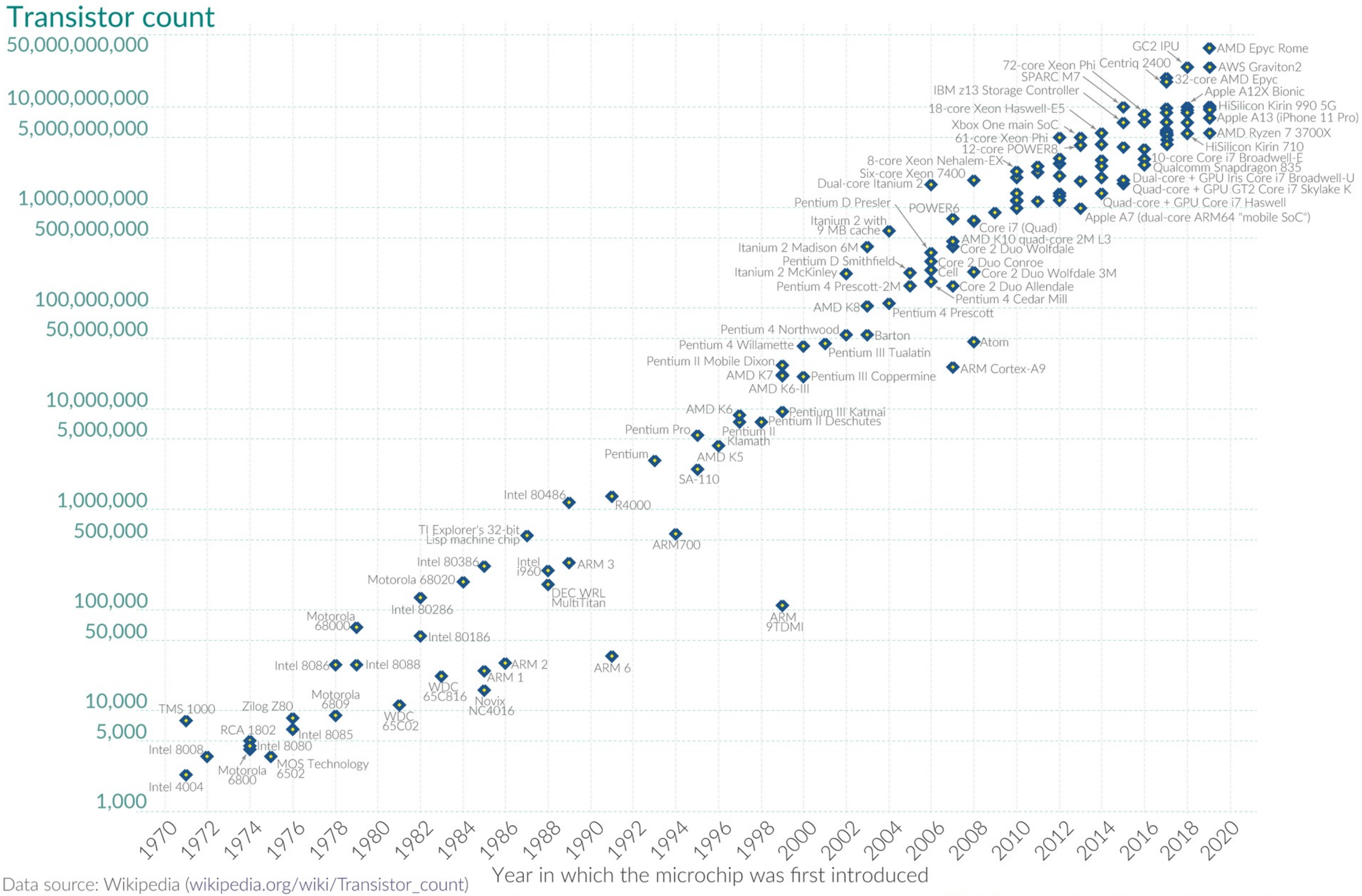


Jack S. **Kilby**
1923–2005

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

Our World in Data

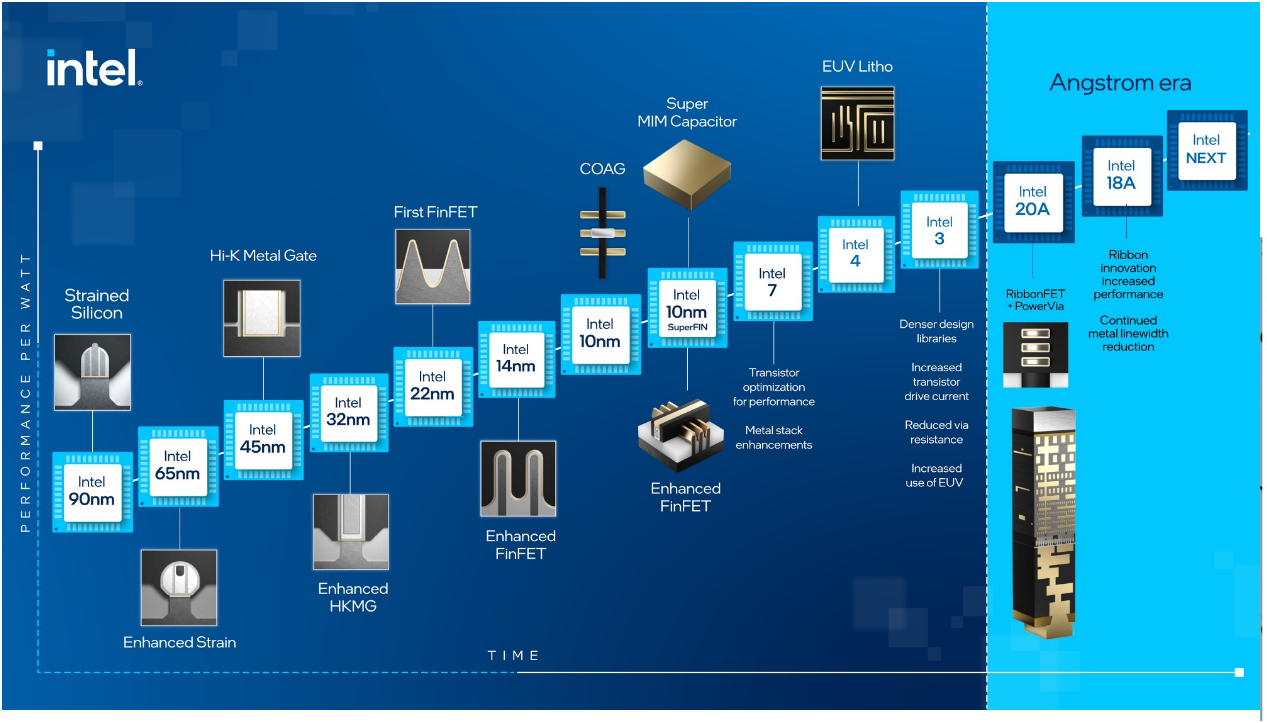
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.



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

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

Coherent Engineering Research Advances in Materials, Devices, Circuits, Architecture and Manufacturing



Energy-Efficient Computing: from Devices to Architectures (E2CDA)
A Joint Initiative between NSF and SRC

PROGRAM SOLICITATION
NSF 16-526

National Science Foundation

Directorate for Computer & Information Science & Engineering
Division of Computing and Communication Foundations

Directorate for Engineering
Division of Electrical, Communications and Cyber Systems

Semiconductor Research Corporation

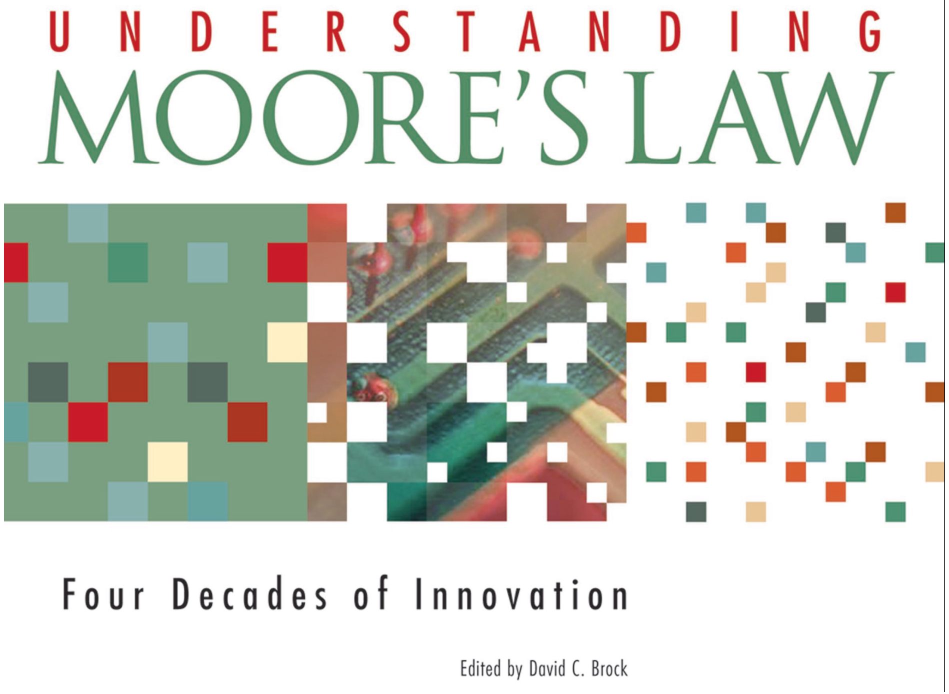
Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

March 28, 2016

Transistor Innovations over Time

Source: Moore's Law – Now and in the Future, Intel, 2022

Moore's Law: Fundamental Research Intertwined with Technological Progress

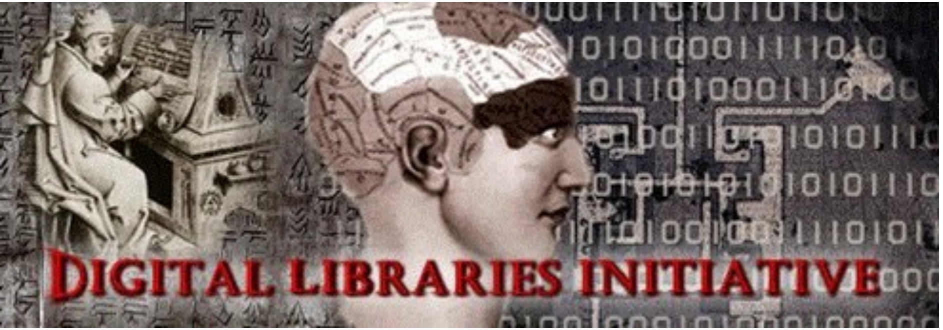


"Indeed, the technology led the science in a sort of inverse linear model ..."

Gordon Moore

Source: Understanding Moore's Law, Ed. D. C. Brock, 2006

Example 2: 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."

Continuing Innovation in Information Technology

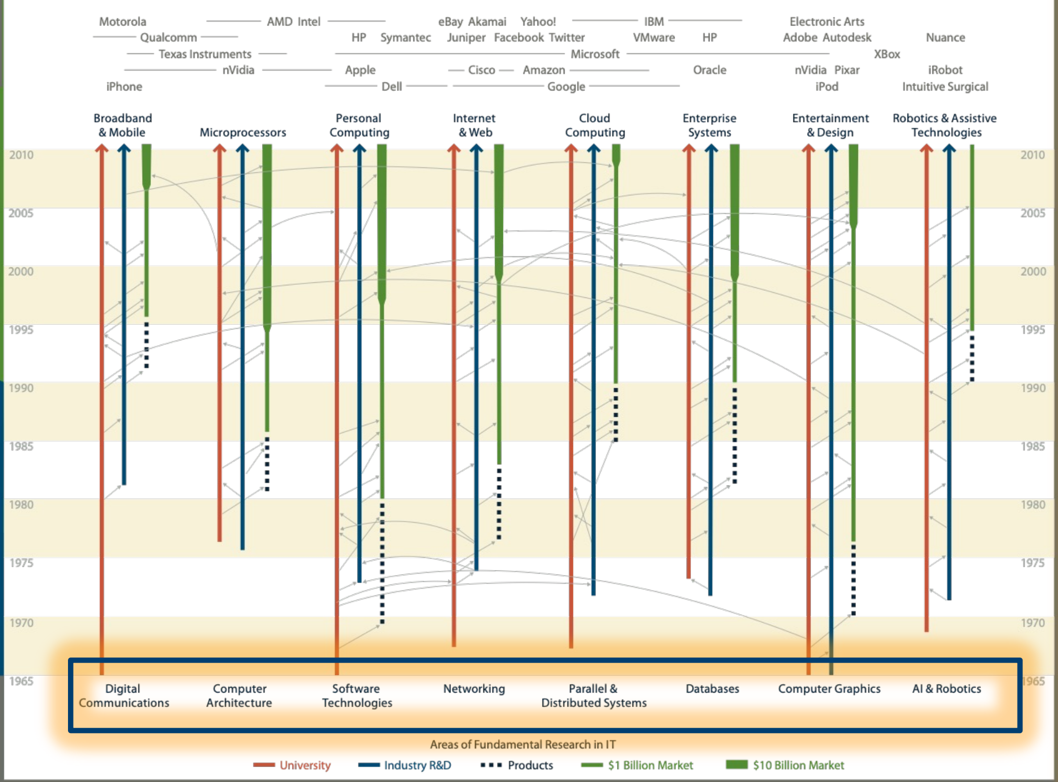
Fundamental research in IT underpins the creation of billion-dollar-plus IT market segments and a vital U.S. IT industry through a complex partnership between universities, industry, and government.

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.

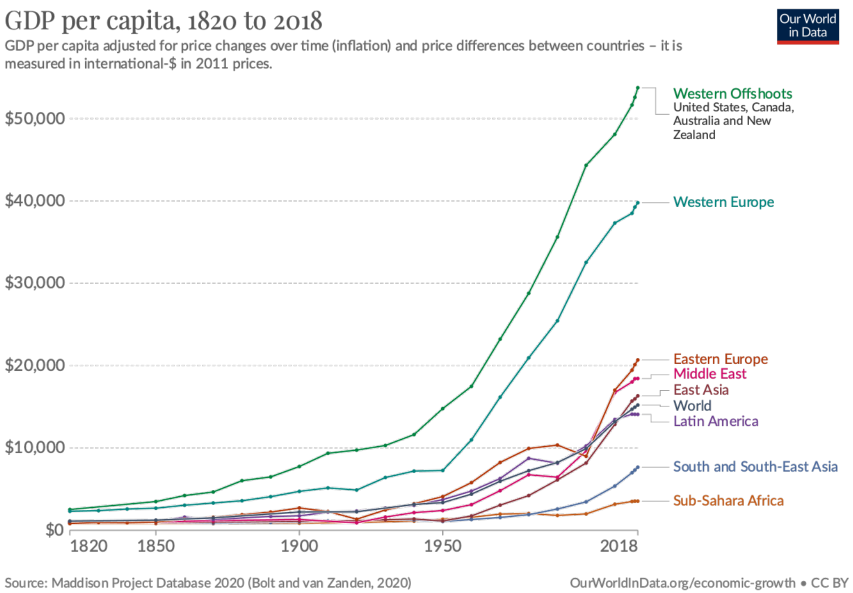
Fundamental Research in

- Digital Communications
- Computer Architecture
- Software
- Networking
- Distributed Systems
- Database Systems
- Computer Graphics
- AI & Robotics

Cumulative Benefit of Technological Innovation fueled by Engineering Advances

Technological revolution	Popular name for the period	Big-bang initiating the revolution	Year	Core country or countries
First	The Industrial Revolution	Arkwright's mill opens in Cromford	1771	Britain
Second	Age of Steam and Railways	Test of the *Rocket* steam engine for the Liverpool–Manchester railway	1829	Britain (spreading to Europe and USA)
Third	Age of Steel, Electricity and Heavy Engineering	The Carnegie Bessemer steel plant opens in Pittsburgh, PA	1875	USA and Germany forging ahead and overtaking Britain
Fourth	Age of Oil, the Automobile and Mass Production	First Model-T comes out of the Ford plant in Detroit, MI	1908	USA (with Germany at first vying for world leadership), later spreading to Europe
Fifth	Age of Information and Telecommunications	The Intel microprocessor is announced in Santa Clara, CA	1971	USA (spreading to Europe and Asia)

Source: Perez (2002).



Source: [C. Perez, 2002]

Example 3: Origins of 3D Printing

*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).*

Source: Bullock Museum, Ausitn, TX

'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.

Source: Austin American Statesman

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

Fundamental Engineering 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.

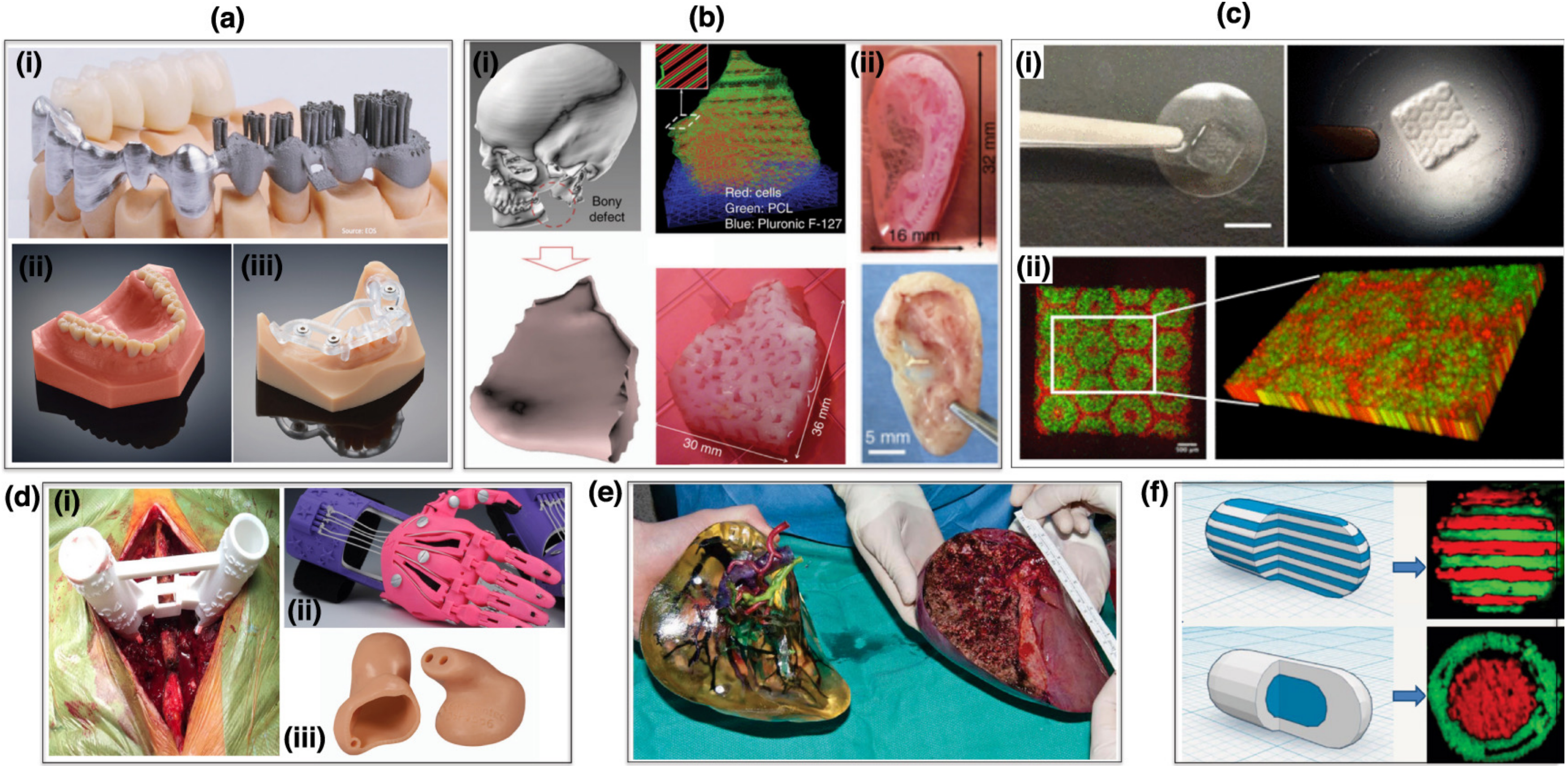
DISSERTATION

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]

Big Challenge and Aspirational Goal

Accelerate and optimize
the engineering research to innovation to
technology to society interconnected system to
assist people and society to flourish.

Thank you!

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