The IT Innovation Ecosystem

Lessons from the “Tire Tracks Diagram”

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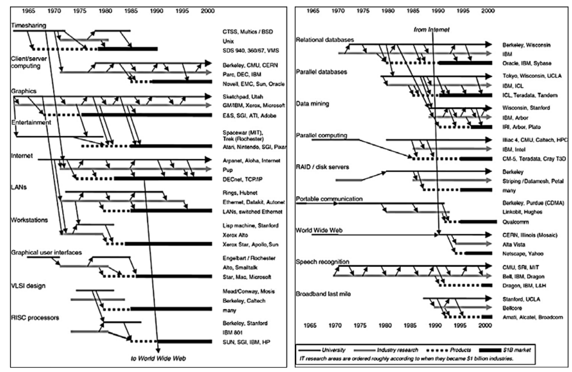
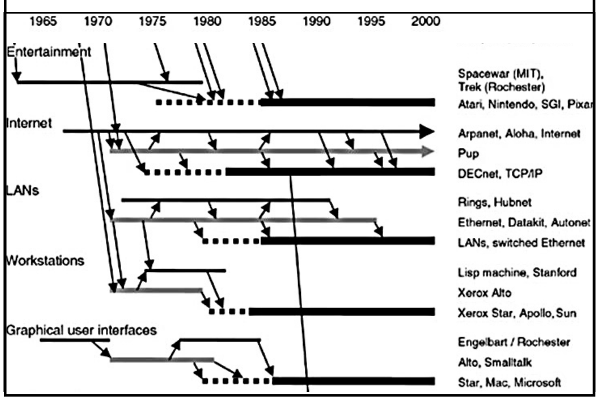
IT & Public Policy
Autumn 2004



National Research Council Computer Science & Telecommunications Board, 2003



Overview of “Tire Tracks Diagram”

- Shows 19 $1B (or larger) sub-sectors of IT
- Shows university research (federal funding), industry research (industry or federal funding), product introduction, $1B market
- Shows flows within sub-sectors, and between sub-sectors
- Shows a subset of the contributors, for illustrative purposes

Key concepts illustrated

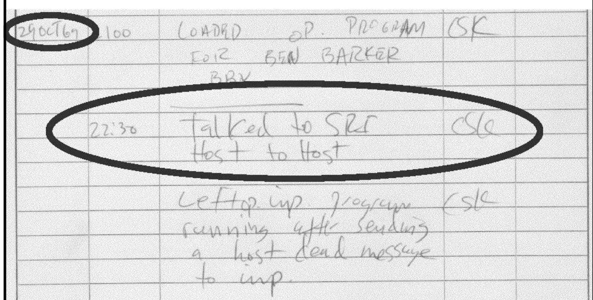
- Every major $1B IT sub-sector bears the stamp of federal research funding
- Every sub-sector shows a rich interplay between university and industry
- It’s not a “pipeline” – there’s lots of “back-and-forth”
- It typically takes 10-15 years from idea to $1B industry
- There are many research interactions across sub-fields

Key concepts not illustrated (but I’ll get to them)

- Unanticipated results are often as important as anticipated results
- It’s hard to predict the next “big hit”
- Research puts ideas in the storehouse for later use
- University research trains people
- University and industry research tend to be complementary
- Visionary and flexible program managers have played a critical role

The Internet

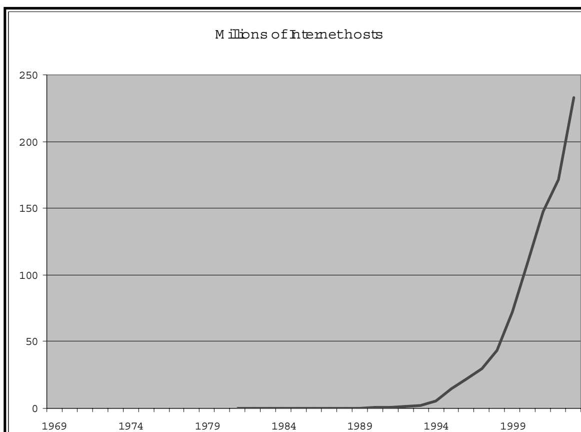
- 1966: First experiments in digital packet switched technology
- 1968: ARPA issues RFQ for IMPs
  - AT&T says it'll never work, and even if it does, no one will care
- 1969: ARPANET inaugurated with 4 hosts
  - Len Kleinrock's student/programmer Charley Kline attempts remote login from UCLA SDS Sigma 7 to SRI SDS 940
  - System crashed partway through – thus, the first message on the Internet was "lo"

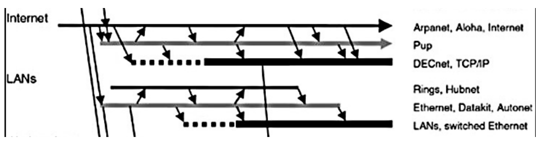


- 1975: ARPANET has 100 hosts
- 1977: Crufty internetworking demonstration
  - 4-network demonstration of ARPANET, SATNET, Ethernet, and PRnet – from a truck on 101 to England
- 1980: Design of TCP/IP completed
- 1983: Conversion to TCP/IP completed
  - Routers allowed full internetworking – "network of networks"
  - Roughly 500 hosts

- 1988: ARPANET becomes NSFNET
  - Regional networks established
  - Backbone speed 56kbps
  - Roughly 100,000 hosts and 200 networks
- 1989: CNRI interconnects MCImail to the Internet
  - Wise policy choice
- 1990: Backbone speed increased to 1.5Mbps by IBM and MCI
  - Roughly 250,000 hosts and 1,500 networks
  - Note: There still was "a backbone"!

- 1992: NCSA Mosaic stimulates explosive growth of WWW
- 1995: Full commercialization, at 45Mbps
  - 6,000,000 hosts, 50,000 networks





Key concepts illustrated

- Bears the stamp of federal research funding
- Shows a rich interplay between university and industry
- Not a "pipeline" – there's lots of "back-and-forth"
- 10-15 years from idea to $1B industry

(D)ARPA I(P)TO

- JCR Licklider, 1962-64
- Ivan Sutherland, 1964-65
- Bob Taylor, 1965-69
- Larry Roberts, 1969-73
- Al Blue (acting), 1973-74
- JCR Licklider, 1974-75
- Dave Russell, 1975-79
- Bob Kahn, 1979-85
- Saul Amarel, 1985-87
- Jack Schwartz, 1987-89
- Barry Boehm, 1989-91
- Steve Squires, 1991-93
- John Toole (acting), 1993-94
- Howard Frank, 1994-97
- David Tennenhouse, 1997-99
- Shankar Sastry 1999-01
- Kathy McDonald (acting), 2001-02
- Ron Brachman, 2002-present

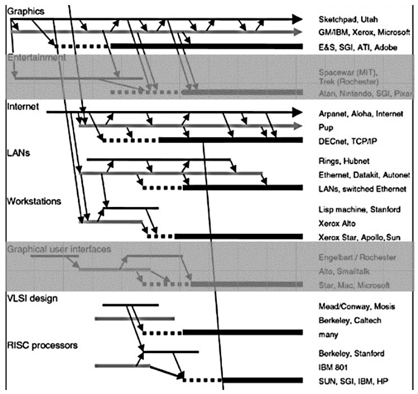
IPTO under Bob Kahn, 1979-85

- VLSI program
  - Mead-Conway methodology
  - MOSIS (Metal Oxide Silicon Implementation Service)
- Berkeley Unix
  - Needed Unix with virtual memory for the VLSI program (big designs) and the Image Understanding program (big images)
  - Also a Trojan horse for TCP/IP
  - And a common platform for much systems and application research

- SUN workstation
  - Baskett said no existing workstations could adequately handle VLSI designs (Bechtolsheim's frame buffer approach was unique)
  - Kahn insisted that it run Berkeley Unix
- Clear byproducts
  - Sun
  - SGI
  - RISC (MIPS, SPARC)
  - TCP/IP adoption
  - Internet routers (Cisco)

Additional key concepts illustrated

- Many research interactions across sub-fields
  - Graphics, workstations, VLSI, computer architecture, operating systems, and networking were being synergistically advanced!



- Visionary and flexible program managers have played a critical role

ISAT Study:

Impact of AI on DoD

August 2004

Co-Chairs: Ed Lazowska
Al McLaughlin

DARPA ISAT

Study Charter

- Review impact of AI technology on DoD
  - Major systems enabled by AI technology
  - Significant demonstrations and new capabilities
  - Spin-offs – DoD to civilian
  - "Spin-ons" – civilian to DoD

Phraselator

Phrase Translation Device for Military Use

- User speaks a phrase
- Automatic Speech Recognizer matches it to prerecorded translation
- Translation played through speaker
- Possible due to decades of ASR and systems research

Impact

Deployed in Operation Enduring Freedom and Iraqi Freedom

- Facilitated time-critical information exchange when interpreters not available
- Accepted by broad set of users
- Interaction with civilians – information on UXOs and weapons caches

Status

- Continued use in Iraq and Afghanistan
- Joint Forces Command fielding 800+ units
- SOCOM fielding 400 units
- Clearneed for 2-way voice machine translation (VMT)

TIDES+EARS: Automated processing of Arabic text & audio

Automated translation and classification of foreign language text and audio

- TIDES: Translation – foreign language text to English text, including document classification
- EARS: Transcription – converts Arabic and Chinese speech to text
- TIDES and EARS integration: Statistical learning – robust foreign language processing to extract intelligence from open sources.

Impact

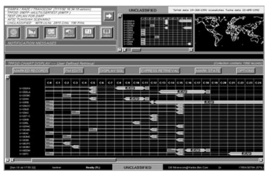
- CENTCOM using automated processing to pull intelligence from Arabic text and audio
- English-only operators can now form a picture in their mind of what is being discussed in Arabic source material
- 100's of documents from dozens of sources translated daily; 5-10 sent to NVTC for human translation
- Technology first used by US Forces Korea

Status

- Automatic speech recognition of English improved dramatically from 1984 to 1993. Now, equally dramatic improvement for Arabic ASR through EARS
- Text and audio processing of Arabic now possible end-to-end. Two deployment units to CENTCOM in 2004 for information exploitation from Arabic open source material

Planning Systems

Dynamic Analysis Replanning Tool (DART)



Rapid editing and analysis of force deployment databases

Intuitive graphical interface: generates English-like explanations

AI methods (search, scheduling, explanation) and GUI incorporated from Ascent Technology's commercial airline application

Built and fielded in 10 weeks during ODS

Endorsed by all CINCs as "a better way"

Impact	Status
An "80% solution" that provided a platform for incremental technology insertion Used by Gen McCarthy and then MG Zinni to plan deployment of VII Corps to SWA Immediate 20X decrease in analysis time PLUS new "what if-ing" capability and provably better schedules Led transition from JOPES to GCCS	Fielded to every CINCs J5 in FY92 Functionality lives on in GCCS Spawned new generation of scheduling algorithms and analysis models in daily use at USTRANSCOM and AMC Development methodology lives on in CPOF

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Robotic Systems

PackBot

Small intelligent robot for reconnaissance and explosive ordnance disposal

Behavior-based AI control systems enable small robots to operate intelligently – autonomously, or seamlessly with supervisory teleoperation

AI provides the low-level control of most recent robots

Impact	*Status*
Two versions in active use in Afghanistan and Iraq – PackBot Scouts for reconnaissance in caves, etc. – Packbot EODs for explosive ordnance disposal Keeps soldiers out of harm's way!	They are approximately 50 deployed PackBots in Afghanistan and Iraq carrying out more than 100 missions per day Will be a major component of Army's Future Combat Systems

Simulation/Training

TacAir-Soar

Intelligent adversaries for tactical air combat training

- Fully autonomous intelligent agent system that provides high-fidelity, realistic, entity-level behaviors for a wide range of aircraft and missions (friendly and enemy)
- Used in interactive simulations (mix of real and computer-generated pilots)
  - Aware: Maintains sophisticated situation interpretation
  - Smart: Makes intelligent decisions
  - Fast: Operates effectively, in real time, in a highly dynamic environment
  - Social: Interacts naturally with humans

Impact	Status
• Allows exercises to expand significantly (greater numbers of players) by providing synthetic enemy and friendly aircraft that seamlessly interact with real pilots, controllers, ground defenses, etc. Examples: STOW-97, Roadrunner, Distributed Mission Training, Enduring Freedom Reconstruction, Millennium Challenge '02, Automated Wingman (Army helicopter), others	• Most sophisticated synthetic force model currently available • Autonomous behavior ⇒ reduced manpower requirements • Full implementation of coordinated behavior • Not "black box" behavior – knowledge and reasoning are explicit • Behaviors are distinct from the underlying simulation platform and physical models

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Image/Signal Understanding

Image Understanding: BCAMS

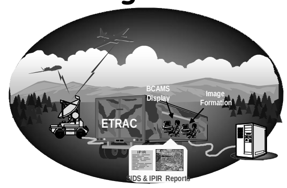


Image analysis for change detection

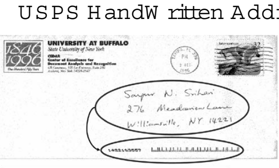
AI techniques extract meaning from single images or image sequences

- Motion detection, optical flow, and tracking
- Stereo to recover depth
- Object-specific recognition algorithms

Impact	*Status*
Operational systems – e.g., Bosnian Cantonment Monitoring System (BCAMS) for Dayton Peace Accords: - Significantly reduced the number of photo analysts in the field - Produced more accurate information - Produced it 5X faster - Quicker response to unfolding events	Many techniques have been developed Many commercial and military systems use these techniques Still a long way to go to get to all the capabilities of humans

Spin-Offs

USPS HandWritten Address Interpretation System



Automatically add Postnet Bar Code

Automatically adds Postnet BarCode to >83% of all handwritten US Mail with <2% error rate

An application of machine learning and knowledge-guided interpretation

Impact	Status
$100M labor costs saved in first deployed year (1997) Over $1B cumulative savings since adoption	Over 83% of all handwritten USPS mail sorted automatically (55M pieces/day) Above 98% accuracy Adopted now in other countries New direction: writer identification

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Spin-Offs

Image Guided Surgery

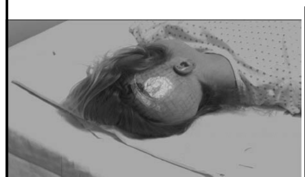


Image analysis for pre-op planning and in-op guidance

Data from multiple types of scan are segmented, aligned, and correlated to position of patient

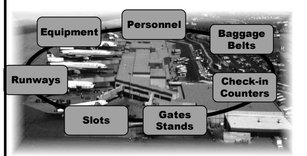
Lets surgeon do detailed pre-op planning and analysis

Provides real-time feedback during surgery on where structures are

Impact	*Status*
Surgery is faster than before, lessening possible complications Surgeries that were not previously possible are now routine Surgeons have better feedback and so can be more precise	System is used almost every day in brain surgery at Brigham and Women's hospital in Boston New diagnosis techniques are being tested for neurology, orthopedics, and internal medicine

Spin-Ons

Commercial Airport Operations



Resource planning, allocation, and scheduling for airport operations

- English-like rule (constraint) statements
- Constraint-directed search
- Blackboard architecture
- Visualization of plans and schedules

Impact

- Dynamic, fast rescheduling
  almost instantaneous generation of new schedules in response to changing conditions
- Intuitive, "easy to understand" results
- Saves money
  e.g., recent $20K mod for minimal ramp paths saved one airline $100K/day at one US airport
- Adapted for DART during ODS

Status

- Many deployed knowledge-intensive applications including airline and airport resource management, operations, maintenance scheduling, personnel
- Installed at 20 airports
- In regular use by 5 airlines

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Impact of AI on DoD: Observations

- AI technology is having significant impact on DoD. Metrics include:
  - saving lives: CPOF
  - expediting planning and logistics: DART
  - keeping troops from harm's way: PackBot
  - large operational cost savings: ASF
  - improved intelligence: TIDES/EARS
  - reduced training costs/manpower: TacAir-Soar
  - more effective surveillance/monitoring: BCAMS

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- AI yields new capabilities:
  - speech recognition: Phraselator
  - automated language translation: TIDES
  - planning: DART
  - decision support: CPOF
  - simulation/training: TacAir-Soar
  - image understanding: BCAMS
  - robotics: PackBot

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- Some of the specific systems were quickly engineered in response to DoD/wartime needs – e.g., DART, ACPT, Phraselator
- All systems were built upon three or more decades of sustained DARPA investments in AI and other technologies
  - technologies, prototypes
  - trained people, synergistic interactions
  - ability for quick reaction response

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"Ideas in the storehouse"

- Electronic commerce draws upon:
  - Internet
  - Web browsers
  - Public key cryptography
  - Databases and transaction processing
  - Search

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Unanticipated results are often as important as anticipated results

- The development of timesharing in the 1960s (in Tenex, Multics, CalTSS) gave us electronic mail and instant messaging

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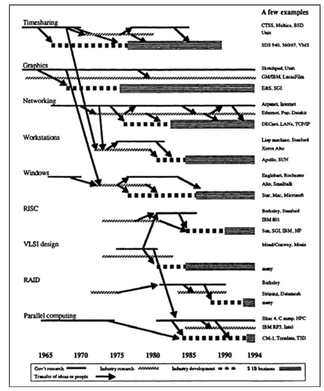
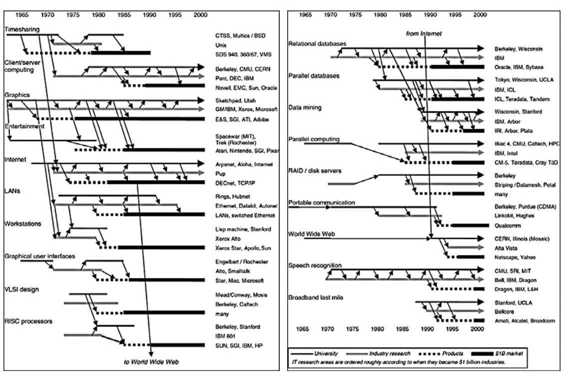
It's hard to predict the next "big hit"

- "Tire Tracks Diagram," 1995 vs. 2003



National Research Council Computer Science & Telecommunications Board, 1995



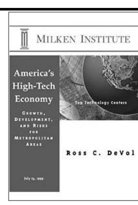
National Research Council Computer Science & Telecommunications Board, 2003

- In our despondency in 1995, we failed to foresee …
  - Client/Server computing
  - Entertainment technology
  - Data mining
  - Portable communication
  - World Wide Web
  - Speech recognition
  - Broadband last mile

Table 2
High-Tech Development Factors

	Inception	Growth	Fortification
Public Policy			
Tax Incentives	• • •	•	
Public Investment	•	• •	
Commercialization of Ideas	•	• •	• •
Comparative Location Benchmarking			
Cost Factors	• • •		
Research Institutions	• • •	• • •	• • •
Skilled or Educated Labor Force	• •	• • •	• • •
Transportation Center	•		
Proximity to Supplies & Markets	• •	•	•
Social Infrastructure Developments			
Attending Changing Needs		• •	• • •
Re-education & Training Facilities		• • •	•
Establishing Trade Groups, & Affiliations		• • •	• • •
Housing, Zoning, & Quality of Life	• •	• •	• • •

••• *Critical*
•• *Very Important*
• *Important*



Research centers and institutions are undisputedly the most important factor in incubating high-tech industries.

Research institutions come in many different shapes and sizes

The correlation between high-tech success and top universities is clear

- Boston: MIT, Harvard
- Research Triangle Park: Duke, UNC, NC State
- Austin: University of Texas
- So. California: UCSD, UCLA, Caltech
- No. California: Stanford, Berkeley, UCSF
- Puget Sound region: University of Washington

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Why?

- Education
- Technology attraction
- Company attraction
- Innovation (technology creation)
- Entrepreneurship (company creation)
- Leadership and intangibles

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"Competitive advantages" of universities

- Students
- Long-term research, not tied to today's products
- Inherently multi-disciplinary
- Neutral meeting ground
- "Open"

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TERANODE
The Graw Group
GraniteEdge
ALDUS
Dialogic
DIGITAL RESEARCH
Impinj
IC DESIGNS
metacrawler
netbot
Nimble Technology
WebCrawler "It's that Simple."
adrelevance
Simultaneous Multithreading
consystant EMBEDDING CONFIDENCE
Numinous Technologies
Inklination
APPLIANT managing the web
Safeware Engineering Corporation
Etch
asta networks
VISIO
PERFORMANT
PIXAR ANIMATION STUDIOS

The nature of industry R&D

- *Entirely appropriately*, industry R&D (at least in IT) is heavily focused on D – product and process development
- Microsoft's investment in Microsoft Research – unquestionably one of the world's great IT research enterprises – is nearly unique
  - 30 years ago, IBM, Xerox, and AT&T represented a huge proportion of the "IT pie"
  - Each had a great research laboratory focused more than 18 months out

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- Today, the "IT pie" is far larger
- And the industry's investment in R&D is far greater (all technology companies do R&D)
- But of the newer companies – the ones that have grown the pie – *Microsoft stands almost alone* in its investment in fundamental research
  - Dell? Oracle? Cisco? Nada!
- Microsoft began this investment in 1991 – when it was a far-from-dominant $1B company – Microsoft (particularly Gates and Myhrvold) should receive enormous credit for taking this step

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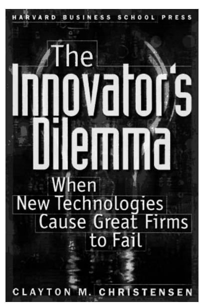
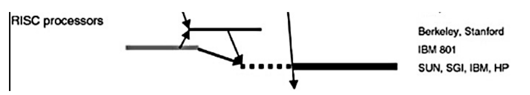
- So, how much of Microsoft's $7B in R&D (>15% of revenues) is "research"?
  - Microsoft Research – the part of Microsoft's R&D enterprise that's looking more than 18 months ahead – is about 700 heads, <5% of this total
  - This is extraordinary by the standards of other companies … but don't confuse Microsoft's R&D expenditures – much less the rest of the industry's R&D expenditures – with an investment in fundamental research!

- Why might companies be reluctant to invest in R&D that looks ahead more than one product cycle?

- Established companies generally don't capitalize on innovations
- The culprit is good management (and shareholder behavior), not bad management
- *Evolutionary* vs. *disruptive* innovation
- "It's a zero billion dollar market"



- Example: RISC (Reduced Instruction Set Computer) processors



- (One can argue that innovations tend to arise from universities or established companies, and tend to be brought to market by startups.)

Federal support of science

- Old history
  - NIH (National Institutes of Health) as a small unit of the Public Health Service since the late 1800s
  - Army Ballistic Missile Laboratory supported ENIAC at Penn
- 1945: Vannevar Bush, *Science: The Endless Frontier*
- 1947: ONR (Office of Naval Research) established

- 1950: NSF (National Science Foundation) established
  - Bush had advocated one agency, but got 3+
    - Civilian natural and physical sciences: NSF
    - Civilian life sciences: NIH
    - Defense sciences: ONR, etc.
- 1957: Sputnik
- 1958: (D)ARPA ((Defense) Advanced Research Projects Agency) established
  - 1958: ARPA / 1972: DARPA / 1993: ARPA / 1996: DARPA

- 1962: I(P)TO (Information (Processing) Techniques/Technology Office) established within DARPA
  - More on DARPA IPTO shortly

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Recent history in IT specifically

- 1985-86: NSF Supercomputer Centers established
- 1986: NSF CISE Directorate established
- HPC (High Performance Computing) Act of 1991 (the "Al Gore created the Internet" Act)
  - Multi-agency coordination
  - Presidential advisory committee
- 1992: NCO/HPCC (National Coordination Office for High Performance Computing & Communication) established

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- 1997: PITAC (President's Information Technology Advisory Committee) established
  - 1998: PITAC interim report
  - 1999: PITAC final report

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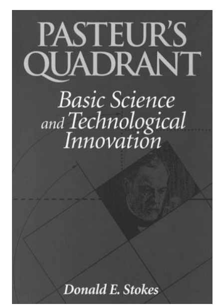
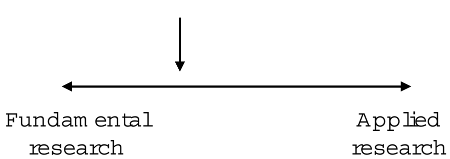
Characterizing research

- "Fundamental research" and "application-motivated research" are compatible



Traditional view



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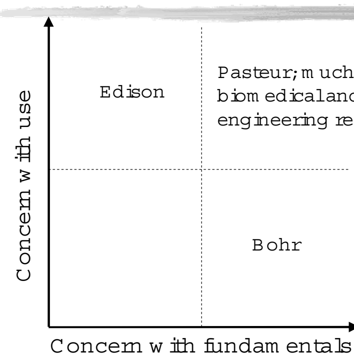
Alternative view



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Trends in federal research funding

- How has the federal research investment (basic and applied) fared over the years?
  - It's increasing significantly, in constant dollars – a factor of more than 2 in less than 20 years
    [NSF data analyzed by AAAS, 2003]

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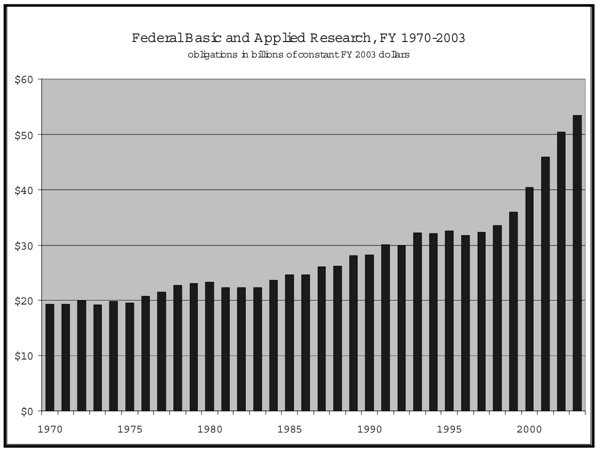

- What's the balance of the nation's research portfolio?
  - A dramatic shift towards the biomedical sciences in the past 20 years, accelerating in the past 5 years
    - Biomedical research is important
    - But it relies critically on advances in other fields, such as physics, engineering, and information technology
  - There is broad agreement that the nation's R&D portfolio has become unbalanced
    [NSF data analyzed by AAAS, 2003]

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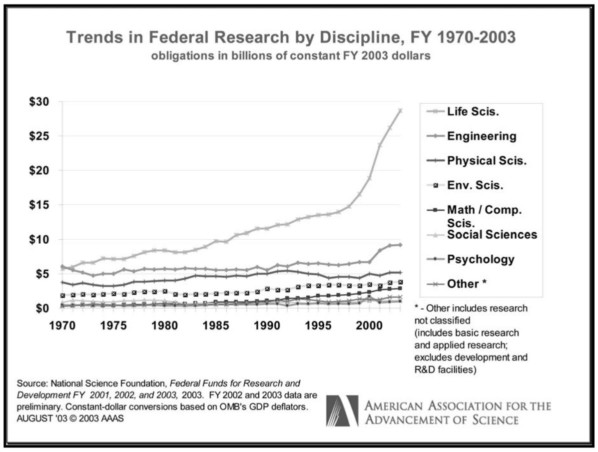

- How does support for computing research stack up against the recommendations of PITAC?
  - It's fallen off the train

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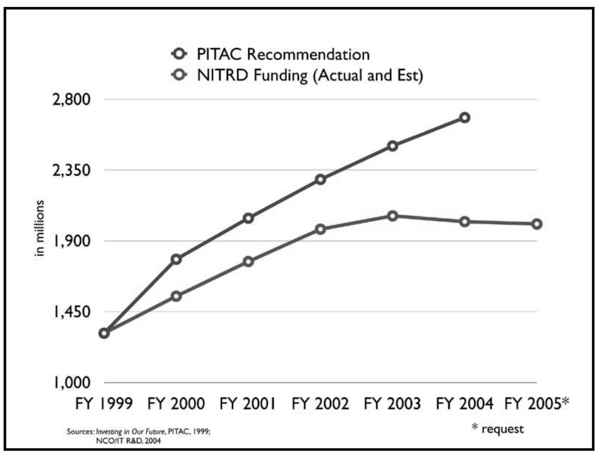

- Research investments are closely linked to creation of the nation's Science & Technology workforce
  - So, in what fields are the nation's Science & Technology jobs?
    - [John Sargent, U.S. Department of Commerce, 2004]
      - [First chart: employment growth, 1996-2000]
      - [Second chart: projected employment growth, 2002-2012]
      - [Third chart: total projected job openings, 2002-2012]
      - [Fourth chart: projected degree production vs. projected job openings, 2002-2012, annualized]

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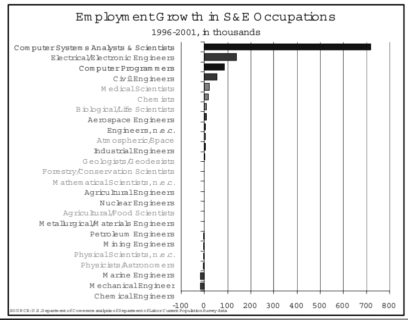
Recent Occupational Growth
Growth in Numbers



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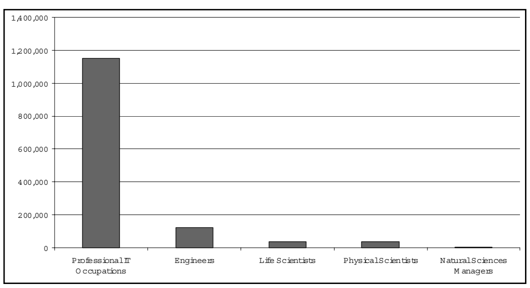
IT, Science and Engineering Occupational Projections, 2002-2012

Employment Growth: Numbers



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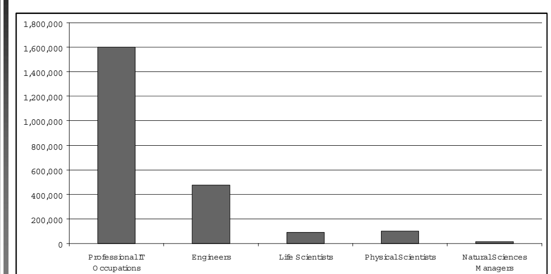
IT, Science and Engineering Occupational Projections, 2002-2012

Total Job Openings



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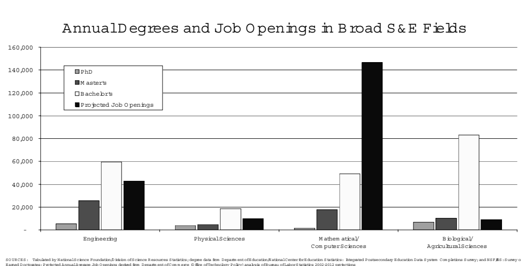
The Market Perspective
Degree Production vs. Projected Job Openings



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NSF CISE Cyber Trust program

- FY04 awards announced 9/21/2004
  - Funded **8.2%** of proposals
    - 32 of 390 proposals
      - 2 of 25 Center proposals
      - 12 of 135 Team proposals
      - 18 of 230 Small Group proposals
  - Awarded **6.2%** of requested funds
    - $31.5M of $510M

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Department of Homeland Security FY05 budget request

- $1,069M Science & Technology budget request
- $17.8M for Cyber Security – **1.67%**
- *One is led to conclude that DHS simply* ***does not care*** *about Cyber Security*
- (Also, 90% of the DHS S&T budget goes to Development/Deployment rather than Research – fails to prepare us for the future)

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DARPA Cyber Security research

- DARPA's new Cyber Security research programs have been classified
- Let's assume there are good reasons. There still are two major negative consequences:
  - Many of the nation's leading cyber security researchers (namely, those at universities) are excluded from participation
  - The results may not rapidly impact commercial networks and systems – *upon which much of the government, and much of the nation's critical infrastructure, rely*

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21st century vs. 19th century industries

- In 2003, the US government spent:
  - $5B on basic research in the physical science and engineering
  - $25B on direct agricultural subsidies

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- Recap:
  - About $55B of the nation's $2,319B budget goes to basic and applied research
  - More than half of this goes to the life sciences (IT is less than 4%)
  - IT research funding is actually decreasing
  - More than 80% of the employment growth in all of S&T in the next decade will be in IT – and more than 70% of all job openings (including those due to retirements)
  - Recent news provides little encouragement!

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- "What the hell were you thinking?"

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The federal budget: How the sausage is made

- Most of the budget is mandatory
- Half of what's discretionary is defense
- The rest involves dozens of agencies
- They are grouped irrationally, and tradeoffs must be made within those groups
- "Balancing the budget" is a foreign concept

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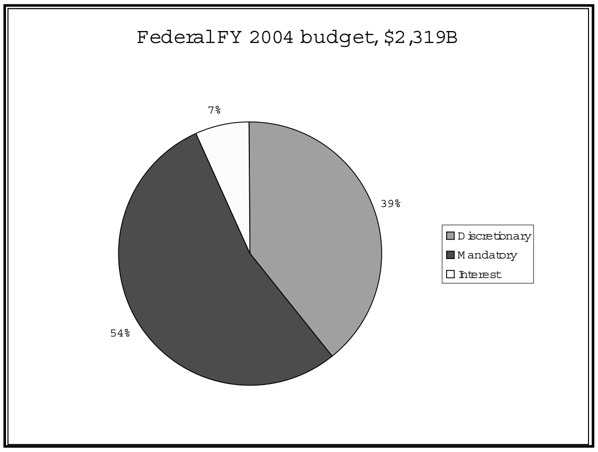
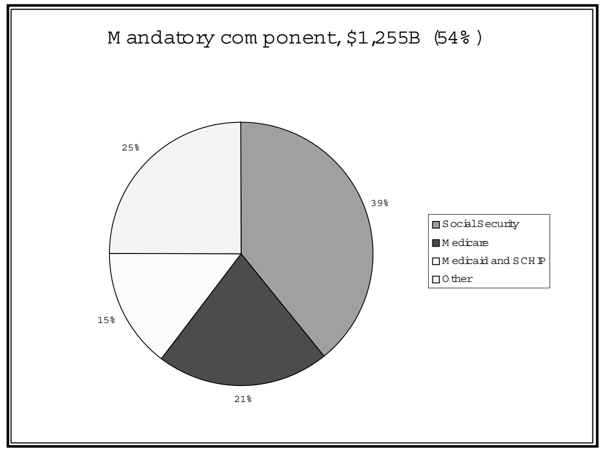
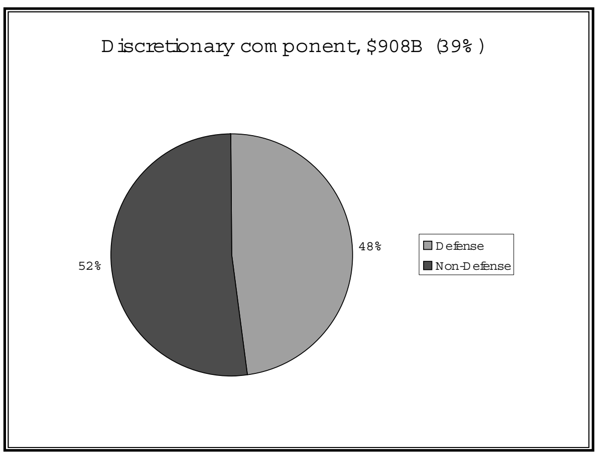
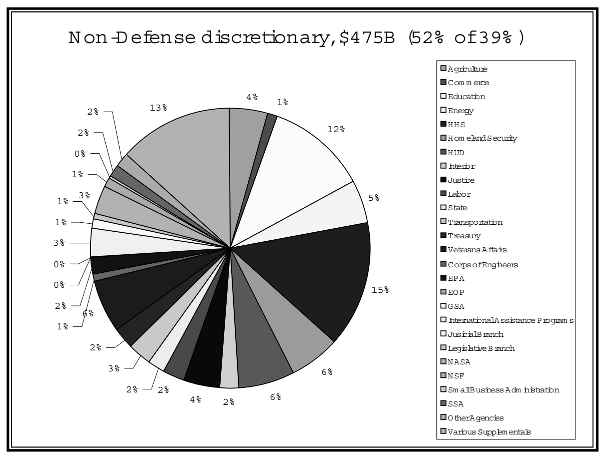
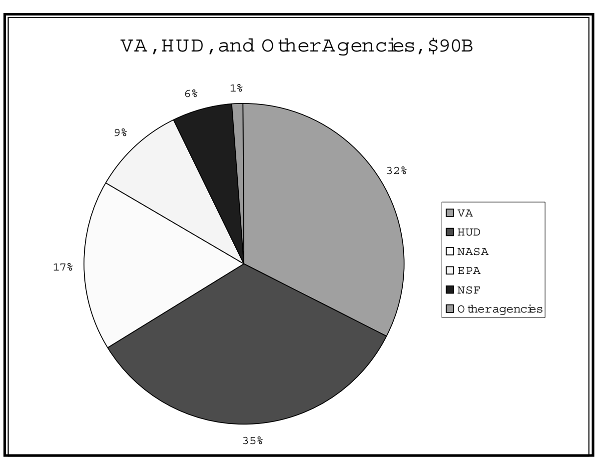
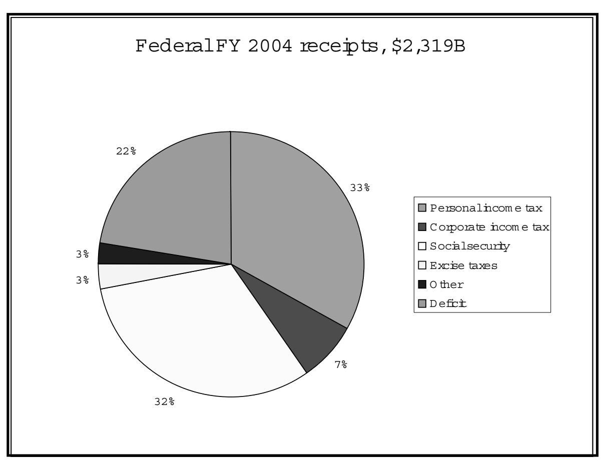

Federal FY 2004 budget, $2,319B
7%
39%
54%
Discretionary
Mandatory
Interest


Mandatory component, $1,255B (54%)
25%
39%
15%
21%
Social Security
Medicare
Medicaid and SCHIP
Other


Discretionary component, $908B (39%)
52%
48%
Defense
Non-Defense


Non-Defense discretionary, $475B (52% of 39%)
Agriculture
Commerce
Education
Energy
HHS
Homeland Security
HUD
Interior
Justice
Labor
State
Transportation
Treasury
Veterans Affairs
Corps of Engineers
EPA
EOP
GSA
International Assistance Programs
Jusicial Branch
Legislative Branch
NASA
NSF
Small Business Administration
SSA
Other Agencies
Various Supplementals


VA, HUD, and Other Agencies, $90B
6%
1%
9%
32%
17%
35%
VA
HUD
NASA
EPA
NSF
Other agencies


Federal FY 2004 receipts, $2,319B
22%
33%
3%
3%
7%
32%
Personal income tax
Corporate income tax
Social security
Excise taxes
Other
Deficit

IT, economic growth, and productivity

- "Advances in information technology are changing our lives, driving our economy, and transforming the conduct of science."
  - Computing Research Association

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Economic Growth can Derive from:

- Increased levels of inputs
  - Labor, IT, other capital
  - Capital deepening and labor productivity
- Improved quality of inputs
- Increased multifactor productivity
  - Improved production methods

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Productivity

- In the US, our wages are high, so our productivity needs to be high, or we're SOL
  - A US worker who is twice as productive can compete with a foreign worker who makes half as much

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The productivity paradox

- We all "believe" that IT increases productivity
- There have been continuous investments in the application of IT for more than 40 years
- But there were at most *very* modest signs of any increase in organizational productivity from 1975-1995
- "Computers show up everywhere except in the productivity statistics"
  - – Robert Solow, Nobel prize winning Economist, 1987

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Between 1995 and 2000

- A huge surge in economic growth, driven by dramatic increases in productivity (double the average pace of the preceding 25 years), attributed almost entirely to IT!
- "We are now living through a pivotal period in American economic history … It is the growing use of information technology that makes the current period unique."
  - Alan Greenspan, Chairman of the Fed, 2000

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So, what happened?

- Not clear the economic data was capturing the right things
- Also, it was measuring entire industries, not individual firms (accounting for quality differences)
- Changes in processes, stimulated by changes in technology, take time to show impact

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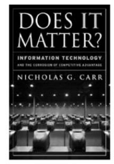
Impact of IT on the economy, 2004

- "We have completed our program of attributing US economic growth to its sources at the industry level. … Our first conclusion is that many of the concepts used in earlier industry-level growth accounting should be replaced … investments in information technology and higher education stand out as the most important sources of growth at both industry and economy-wide levels … the restructuring of the American economy in response to the progress of information technology has been massive and continuous …"
  - Dale W. Jorgenson, Harvard, Mun S. Ho, Resources for the Future, and Kevin J. Stiroh, Federal Reserve Bank of NY, "Growth of US Industries and Investments in Information Technology and Higher Education"

Does IT Provide Competitive Advantage?



"As availability increases and cost decreases ... [technologies] become commodity inputs. From a strategic standpoint, they become invisible; they no longer matter …

"Executives need to shift their attention from IT opportunities to IT risks — from offense to defense."

- Nicholas Carr

What Does All This Mean?

- Continuing IT innovation will continue to provide opportunities for firms to raise productivity
- Back to the basics – understand and leverage the role of IT in key business processes
- Investments in IT capital must be complemented with corresponding investments in organizational capital

Education for the "innovation economy"

- Once upon a time, the "content" of the goods we produced was largely physical

- Then we transitioned to goods whose "content" was a balance of physical and intellectual

- In the "innovation economy," the content of goods is almost entirely intellectual rather than physical

- Every state *consumes* "innovation economy" goods
  - Information technology, biotechnology, telecommunications, …
- We *produce* these goods!
  - Over the past 20 years, the Puget Sound region has had the fastest pro-rata growth in the nation in the "high tech services" sector

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What kind of education is needed to produce "innovation economy" goods?

- National and regional studies conclude the 3/4ths of the jobs in software require a Bachelors degree or greater (and it's highly competitive among those with this credential!)

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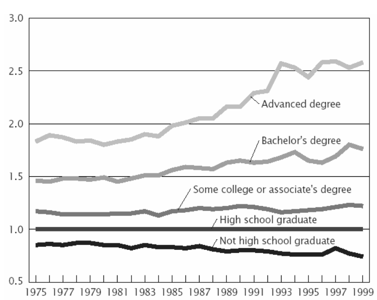
Average Earnings as a Proportion of High School Graduates' Earnings, 1975 to 1999



Source: U.S. Census Bureau, Current Population Surveys, March 1976-2000.

- In Washington State:
  - We rank **48th out of the 50 states** in the participation rate in public 4-year higher education (1997 federal data presented by OFM)
    - We rank 41st in upper-division enrollment – "Bachelors degree granting capacity" – still in the bottom 20% of states
    - We rank 4th in community college participation
  - Washington's public higher education system is structured for a manufacturing economy, not an innovation economy!

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- On a per capita basis, Washington ranks **32nd** among the states in the number of Bachelors degrees granted by *all* colleges and universities, public and private, and **35th** in the percentage of our Bachelors degrees that are granted in science and engineering (1997-98 data, Dept. of Ed.)
- Private institutions are not filling the gap

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- We rank **43rd** in graduate and professional participation rate at public institutions (1997 federal data presented by OFM)
- We rank **41st** in the number of students pursuing graduate degrees in science and engineering at all institutions, public and private (1999 data, NSF)
- At the graduate level, things are just as grim

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- We rank 5^{th} in the nation in the percentage of our workforce with a recent Bachelors degree in science or engineering, and 6^{th} in the percentage of our workforce with a recent Masters degree in science or engineering (1999 data, NSF; "recent degree" = 1990-98)
- We are creating the jobs – and we are importing young people from elsewhere to fill them!

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- UW's state funding *per student* is **~25% below the average of its Olympia-defined "peers"** (22% behind 24 HECB peers, 26% behind 8 OFM peers) (1999-2000 data, IPEDS)
- In 1976, Washington spent $14.35 on higher education per $1,000 of personal income; by 2001, that number had **dropped by nearly a factor of two** – to $7.65 (Postsecondary Educational Opportunity #115)
- We under-fund the relatively few student places we have. And it's getting worse

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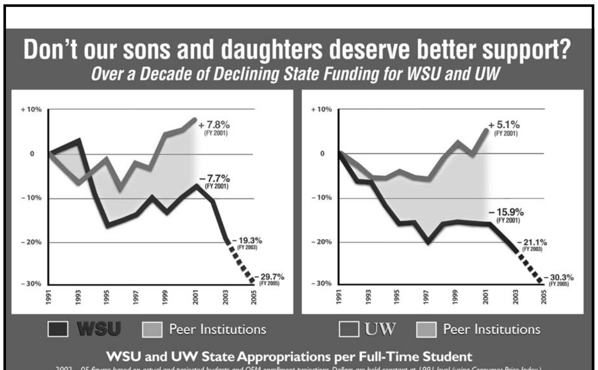

WSU and UW State Funding, Per Student, Relative to Olympia-Defined "Peers"

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- Washington ranks **46^{th} out of the 50 states** in state support for research
- This is the relatively modest "seed corn" from which large-scale federally-funded research programs grow

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- Washington is all geared up to fight the last war!

More broadly (some data is not current, but nothing much has changed)

- Bachelors degrees, nationwide, 1997:
  - 222,000 in business
  - 125,000 in the social sciences
  - 105,000 in education
  - **63,000** in all of engineering
  - **25,000** in computer science

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- China granted only 1/4 as many Bachelors degrees in 1997 as did the US (325,000 vs. 1.2M)
  - But China granted **2.5 times as many** Bachelors degrees in engineering (149,000 vs. 63,000)
- In 2003, China and India each produced about 200,000 Bachelors degrees in engineering

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- Proportion of Bachelors degrees that are in engineering:
  - US: 4%
  - United Kingdom: 12%
  - China: 40%

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- What's the fastest-growing undergraduate major in America today?

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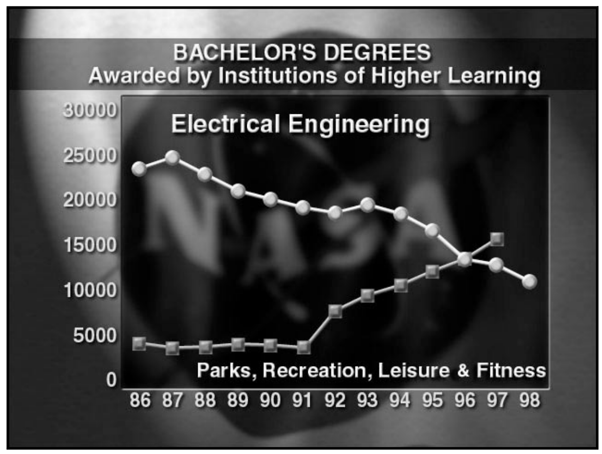

- At the doctoral level (also 1997):
  - 40,000 J.D.'s
  - **857** Ph.D. computer scientists
    - **And roughly half of the Ph.D.s in engineering and computer science were awarded to non-residents**

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