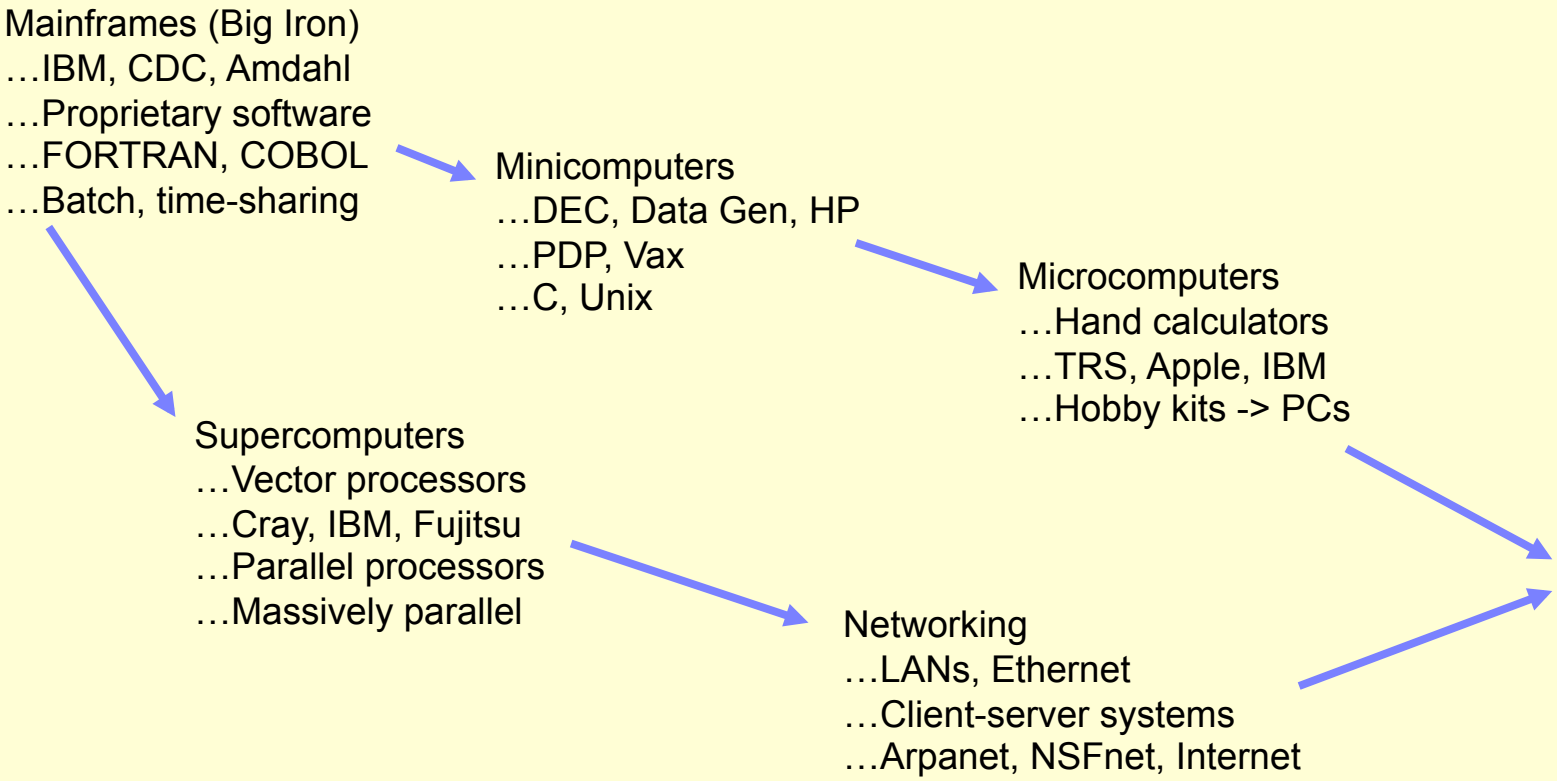
The Evolution of Information Technology

The Themes of Our Times

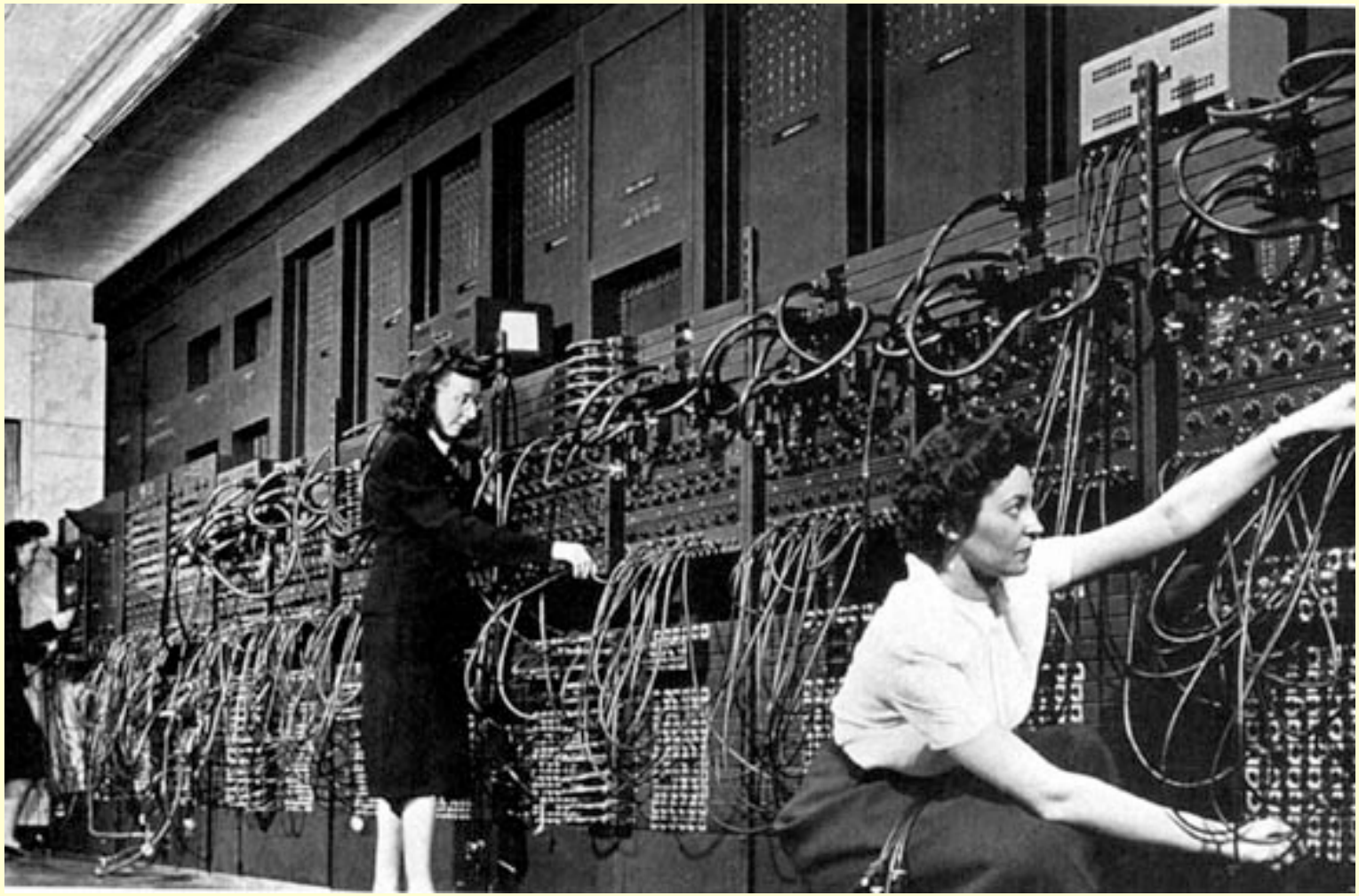
- An Age of Knowledge, in which educated people and their ideas have become the strategic commodities determining prosperity, security, and social well-being.
- The global nature of our society.
- Rapidly evolving information technology that reshapes, strengthens, and accelerates the activities of knowledge driven organizations.
- Networking, the degree to which cooperation and collaboration among individuals and institutions are replacing more formal social structures such as governments and states.

A Detour: The Evolution of Computers



Batch → Time-sharing → Personal → Collaborative

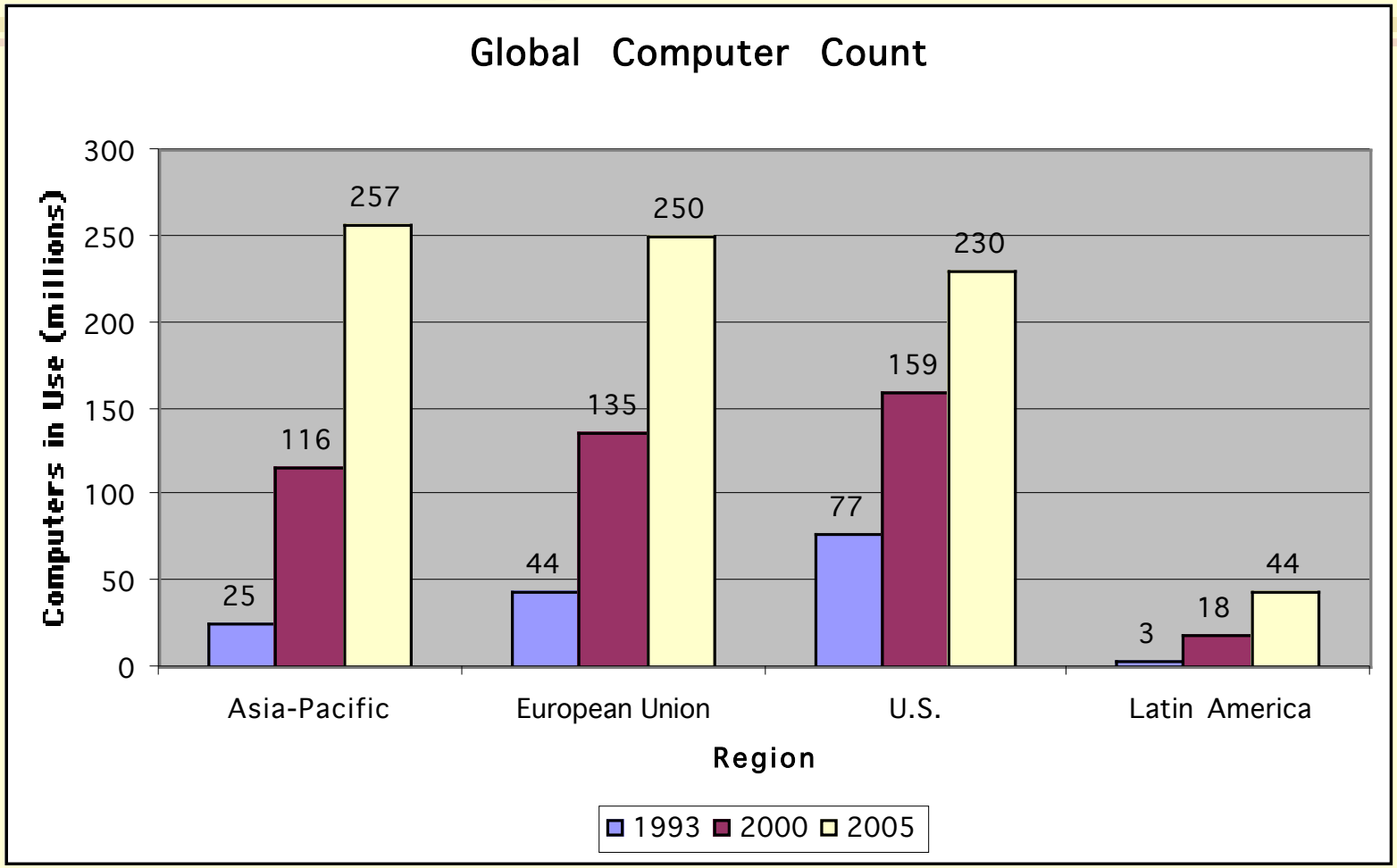
From Eniac



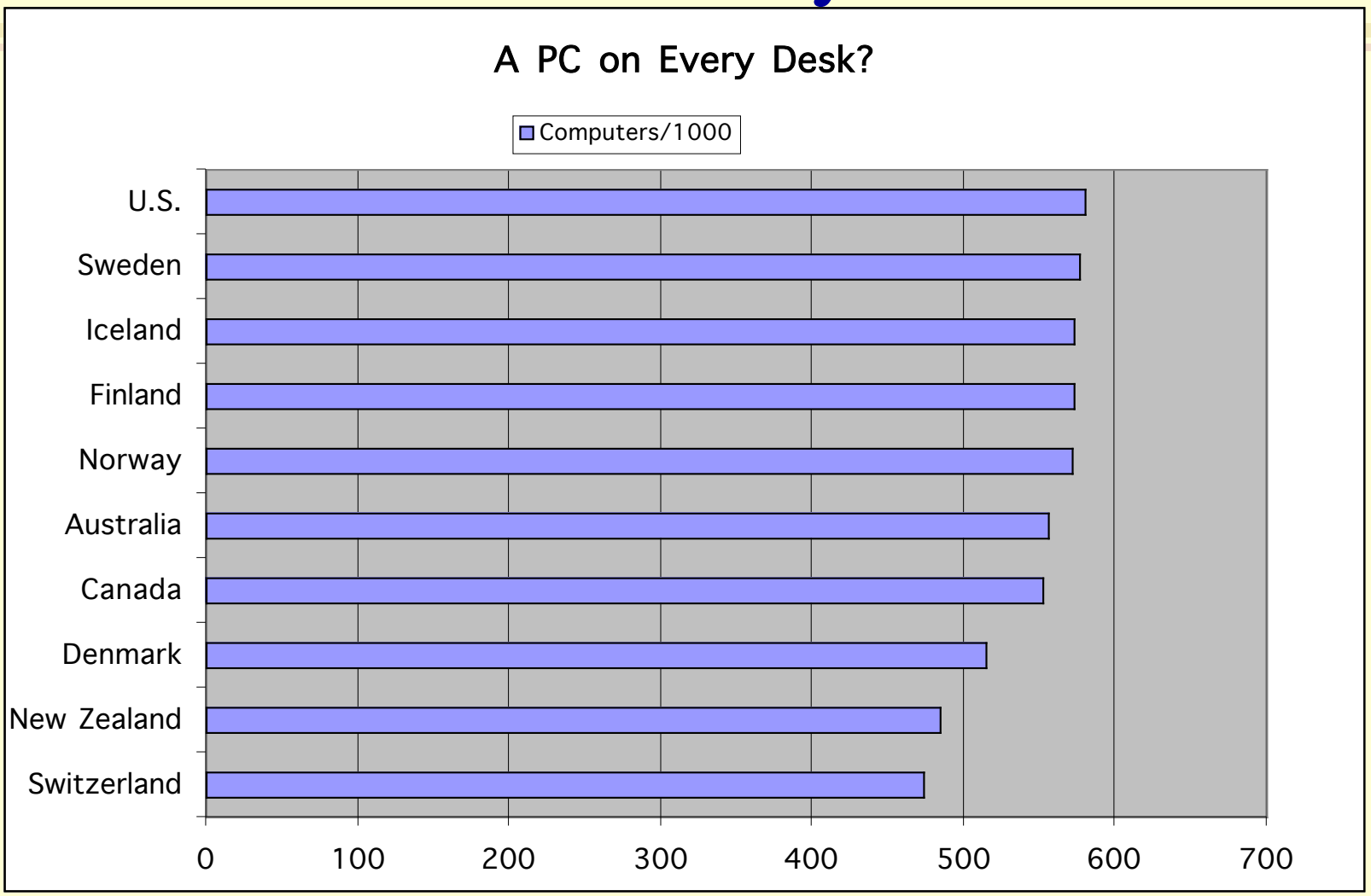
To ASCI White


MICHIGAN

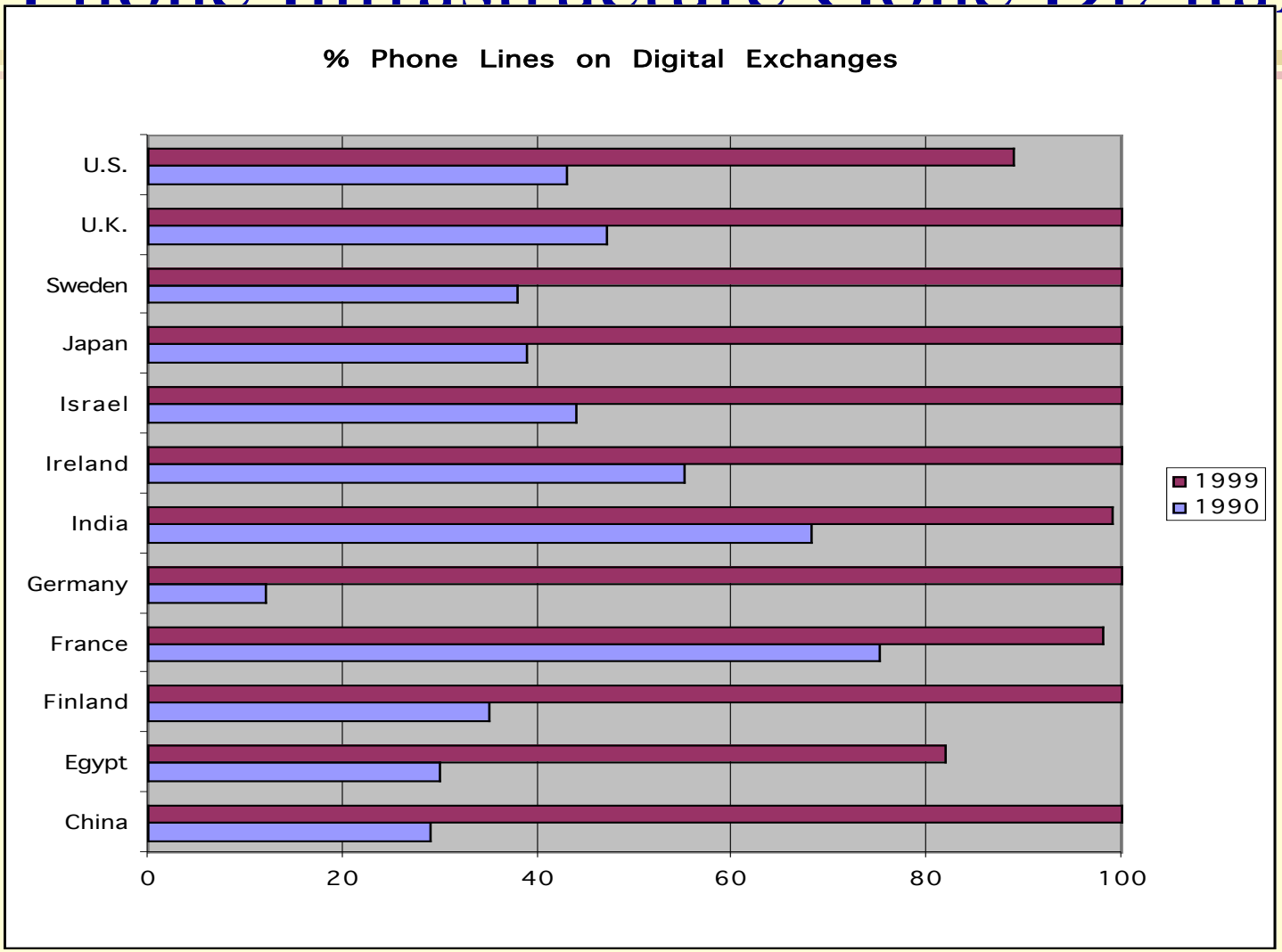
Global Computer Count (millions)



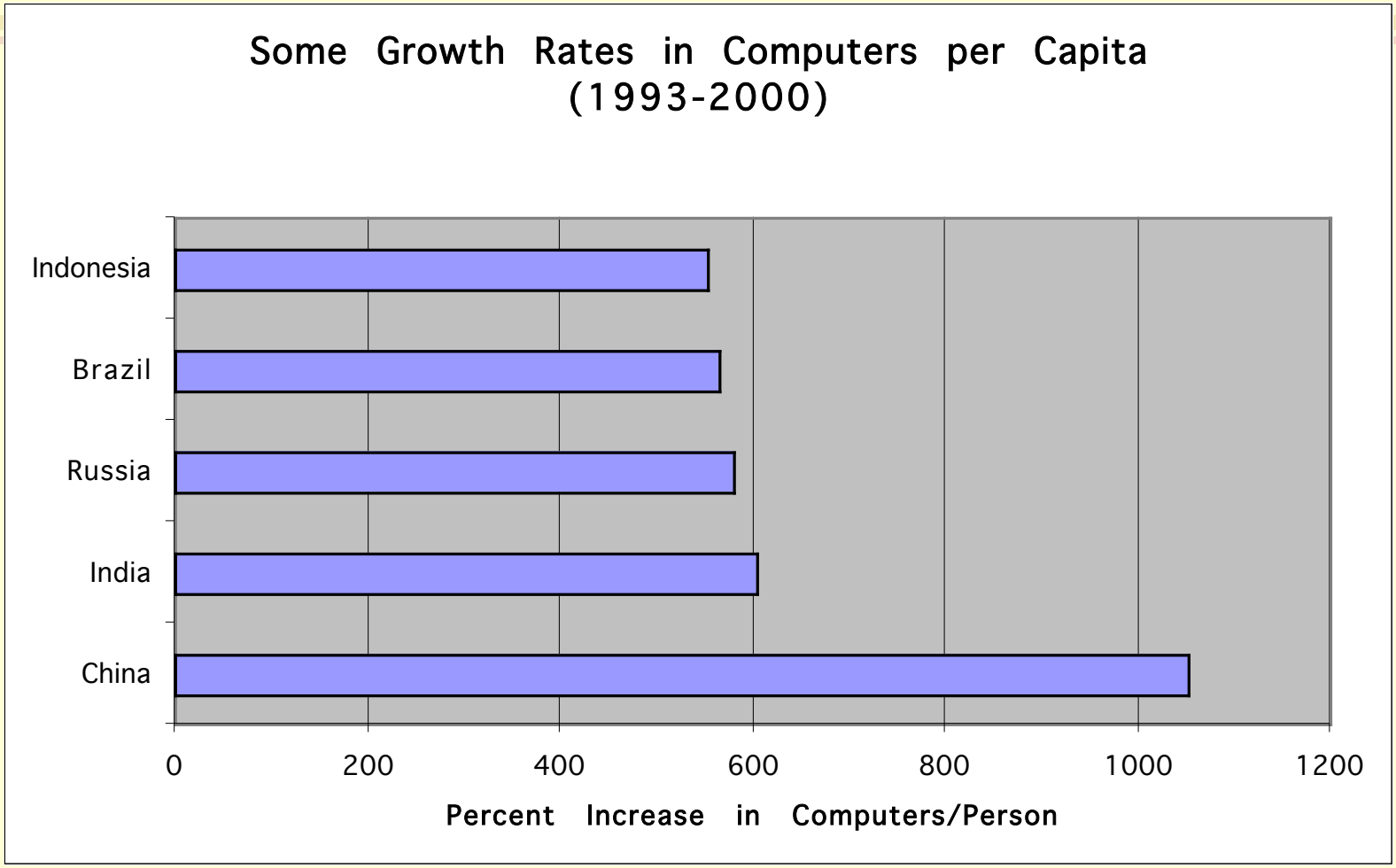
A PC on Every Desk?



Phone Infrastructure Gone Digital



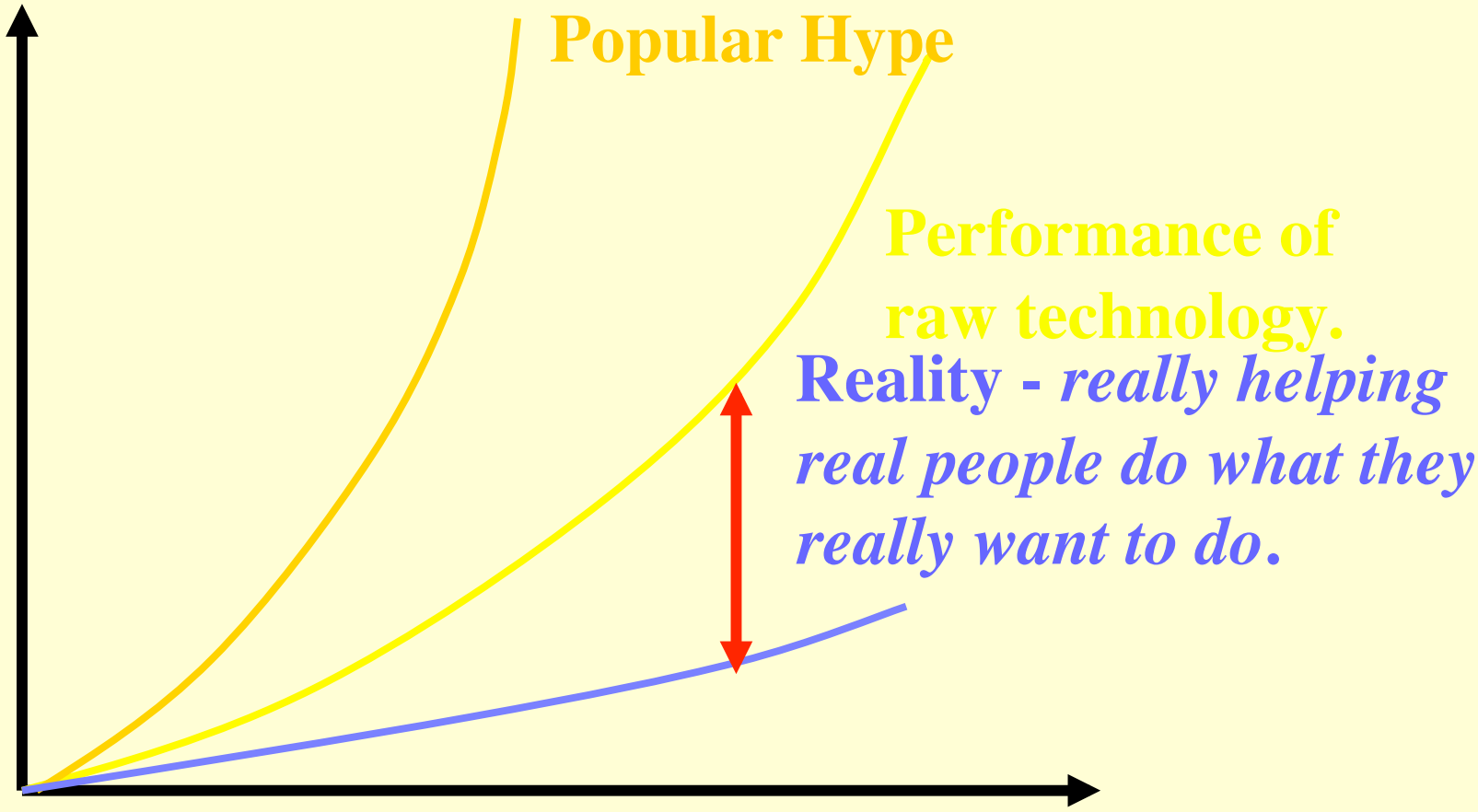
Growth Rates



Digital Convergence

- A bit is a bit.
- Digital representations of existing genres.
- New multi-media, interactive genres.
- *Not* books versus bytes.
- Trends towards institutional “digital convergence,” e.g. libraries, archives, museums.

Reality Gaps

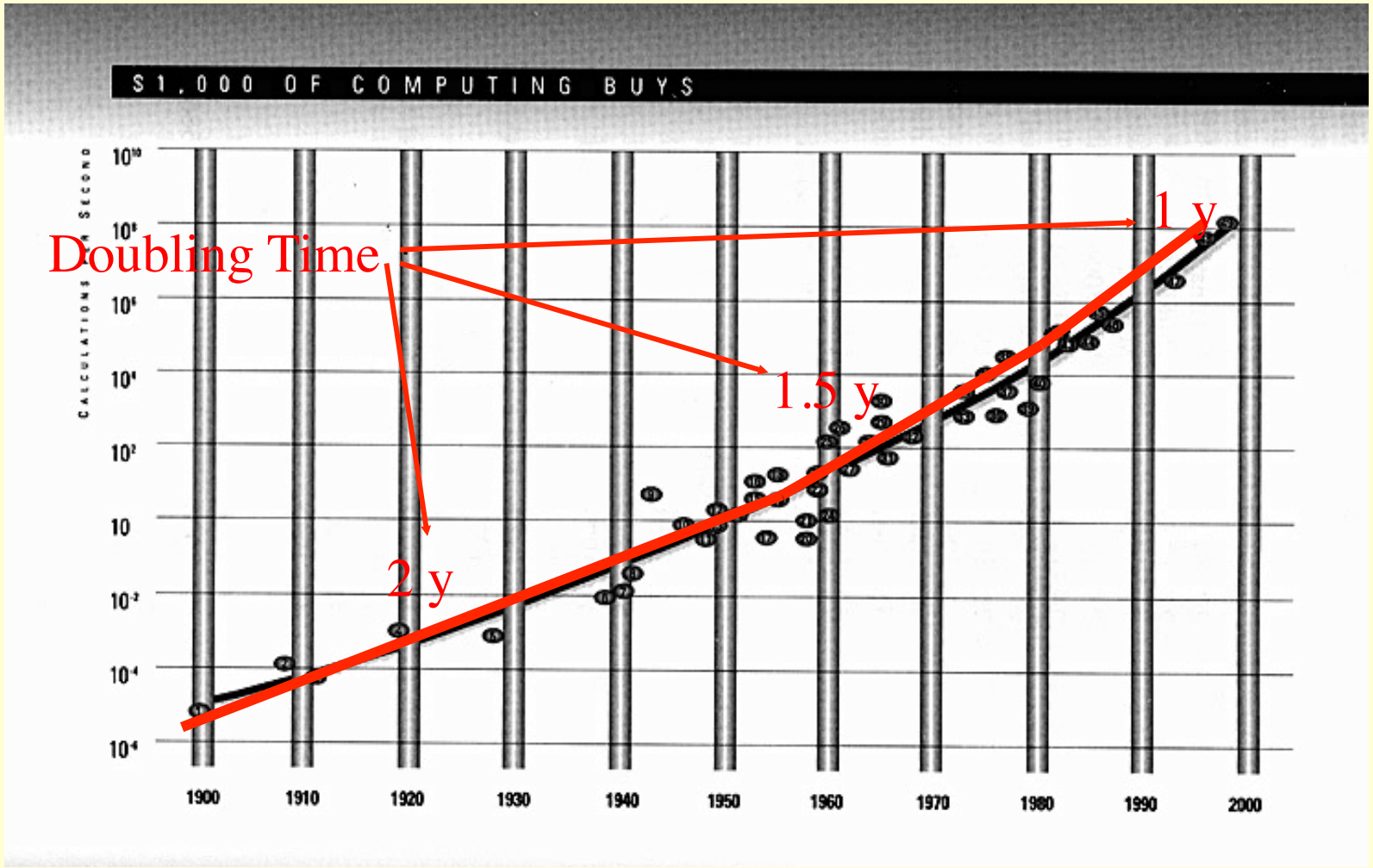


Shift in Information Environments*

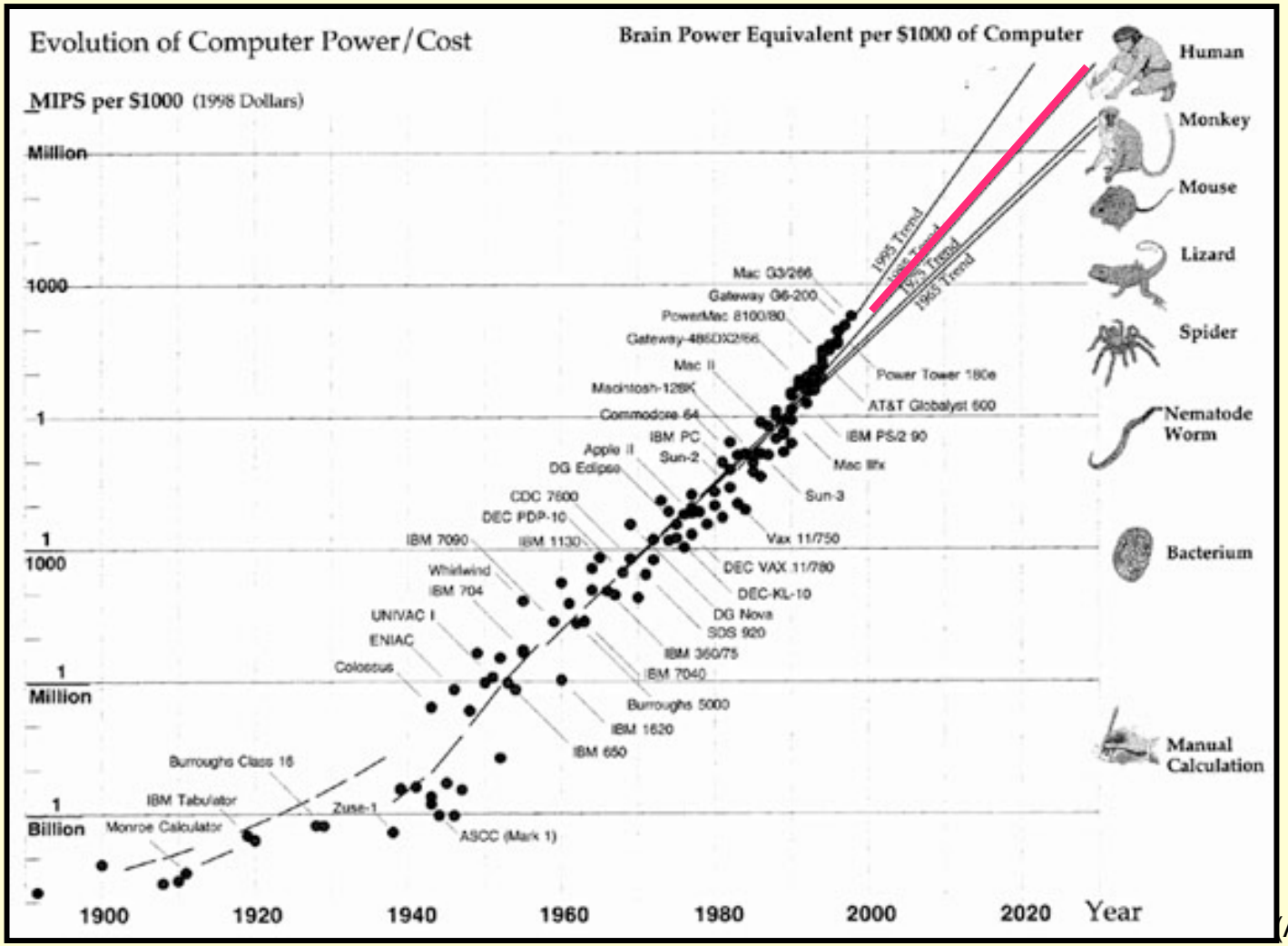
OLD	NEW
stable	dynamic, ephemeral, versions
atomic	inter-linked
mostly print	multimedia
big, crisp chunks	multi-size, fractal, ill-defined
flat	internal structure
minimal context/meta info	significant context/meta info
scholar-authored	everyone a player
credentialled	credentialling
ponderous publishing stream	lightweight publication
centralized	distributed & ubiquitous
physical&logical co-control	physical & logical separation; virtual collections
universal access (public)	rich layers of access control
free	not necessarily free
one-way communication	two-way communication
loosely coupled interaction (slow)	tight, fast interaction
one-way search(consumers)	symmetric search (push & pull)
Electronic: query-based access	navig+query+social access

* From work by Prof. George Furnas

The Evolution of Computing



The Evolution of Computer Power



(After Moravec)

Some Extrapolation of the PC

	2000	2010	2020
Speed	10^9	10^{12}	10^{15}
RAM	10^8	10^{11}	10^{14}
Disk	10^9	10^{12}	10^{15}
LAN	10^8	10^{12}	10^{15}
Wireless	10^6	10^9	10^{12}

Some Examples

- **Speed**
  - MHz to GHz (Merced) to THz to Peta Hz
- **Memory**
  - MB (RAM) to GB (CD,DVD) to TB (holographic)
- **Bandwidth**
  - Kb/s (modem) to Mb/s (Ethernet) to Gb/s
  - Internet (Project Abilene): 10 Gb/s
- **Networks**
  - Copper to fiber to wireless to photonics
  - “Fiber to the forehead…”

Computer-Mediated Human Interaction

- **1-D (words)**
  - Text, e-mail, chatrooms, telephony
- **2-D (images)**
  - Graphics, video, WWW, multimedia
- **3-D (environments)**
  - Virtual reality, distributed virtual environments
  - Immersive simulations, avatars
  - Virtual communities and organizations
- **And beyond… (experiences, “sim-stim”)**
  - Telepresence
  - Neural implants

Evolution of the Net

- Already beyond human comprehension
- Incorporates ideas and mediates interactions among millions of people
- 100 million today; more than 1 billion in 2001
- Internet II, Project Abilene

Another Way to Look at It …

A “communications” technology that is increasing in power by a factor of 1,000 every decade will soon allow any degree of fidelity that one wishes. All of the senses will be capable of being reproduced at a distance … sight, sound, touch, taste, smell … through intelligence interfaces.

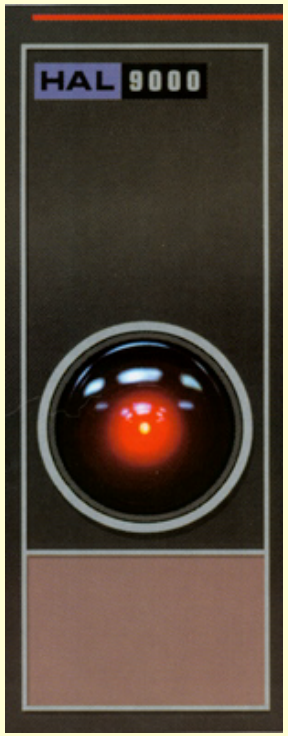
At some point, we will see a merging of

…natural and artificial intelligence

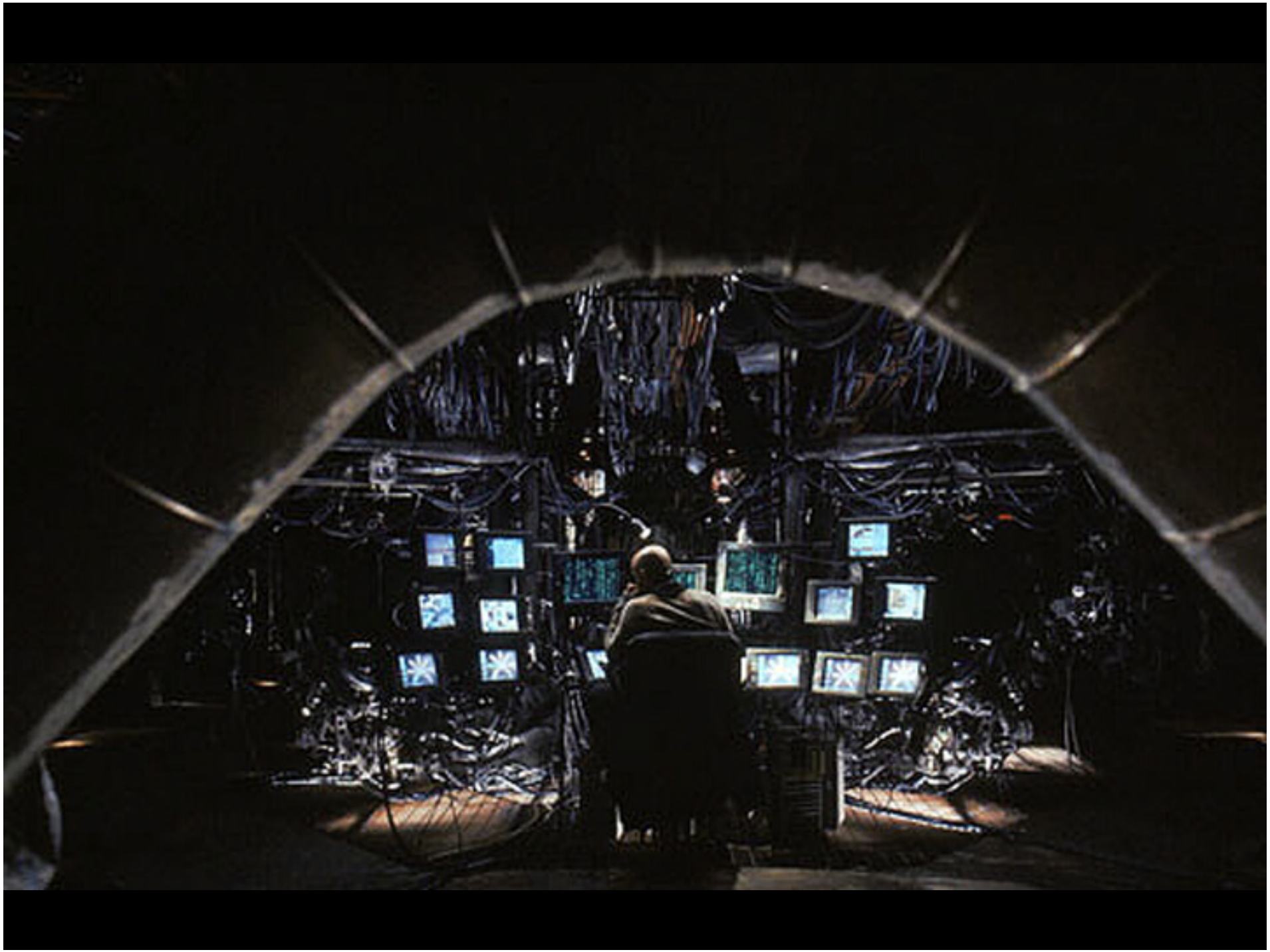
…reality and virtual reality

…carbon and silicon …

Some Other Possibilities



- **Ubiquitous computing?**
  - Computers disappear (just as electricity)
  - Calm technology, bodynets
- **Agents and avatars?**
  - Fusing together physical space and cyberspace
  - Plugging the nervous system into the Net
- **Emergent behavior?**
  - … Self organization
  - … Learning capacity
  - … Consciousness (HAL 9000)



A Case Study: the University

Missions: teaching, research, service?

Alternative: Creating, preserving, integrating, transferring, and applying knowledge.

The University: A "knowledge server", providing knowledge services in whatever form is needed by society.

Note: The fundamental knowledge roles of the university have not changed over time, but their realizations certainly have.

Research

- Simulating reality
- Collaboratories: the virtual laboratory
- Changing nature of research
  - Disciplinary to interdisciplinary
  - Individual to team
  - “Small think” to “big think”
- Analysis to creativity
  - Tools: materials, lifeforms, intelligences
  - Law, business, medicine to art, architecture, engineering

Libraries

- Books to bytes (atoms to bits)
- Acquiring knowledge to navigating knowledge
- What is a book?
  - A portal to the knowledge of the world.
  - Minsky: “Can you imagine a time when books didn’t talk to one another?”

The Plug and Play Generation

- Raised in a media-rich environment
  - Sesame Street, Nintendo, MTV,
  - Home computers, WWW, MOOs, virtual reality
- Learn through participation and experimentation
- Learn through collaboration and interaction
- Nonlinear thinking, parallel processing

Some Interesting Statistics

- Today's entering UM student
  - 90% enter with 3 or more years of computer experience
  - 60% own a computer (90% will own a computer when they graduate
  - Spend 15 to 20 hours a week using computer
- The Global Teenager
  - In year 2000 there will be 2 billion teenagers
  - Cellular phones and PDAs are replacing Sony Walkmans
  - They will identify more with their age group than with their ethnicity or nationality, creating a new world culture …

Teaching to Learning

- Student to learner
  - Classroom to environment for interactive, collaborative learning
  - Faculty to designer, coach, Mr. Chips
- Classroom
  - Handicraft to commodity
  - Learning communities
  - Virtual, distributed environments
- Open learning
  - Teacher-centered to learner-centered
  - Student to learner to consumer
  - (Unleashing the power of the marketplace!)

IT-Mediated Distance Learning

The Sloan Foundation has invested over $30 million in the development of Asynchronous Learning Networks. Their conclusions from over 100,000 sponsored course units in thousands of courses:

I) **This stuff works.** You can reproduce the classroom over the Internet with no apparent loss of educational quality (as measured by test scores, etc.).

2) **It is not expensive** to convert a course into ALN format (about $10,000 per course), if the aim is interactive rather than automated teaching.

The key: Don't automate the classroom, but break it free from the constraints of space and time!

A Concern

Although there is a great deal of activity in IT-mediated distance learning (over 1,000 “virtual universities”), as one goes up the learning curve, from community colleges to regional universities to research activities, there is less and less participation.

While there are experiments by research universities such as Unext.com, these are largely hands off, with little participation by the research university faculty. As a result, most research universities are not really learning how to implement this technology like others in the post-secondary education enterprise.

The Digital Divide

Concern: The "digital divide" between those who have access to information and those who do not.

Another View: The real divide is not access to technology but rather between those who have access to educational opportunity and those who do not because of economic means, family responsibilities, or job constraints.

As access to IT appliances becomes more ubiquitous (e.g., PDAs) and IT breaks learning free from constraints of space and time, technology may actually narrow the stratification in our society by opening up access to education.

Implications for Research Universities

Activities: teaching, research, outreach

Organization and structure: disciplinary structure, faculty roles, financing, leadership

Enterprise: markets, competitors, role in evolving national research enterprise, globalization

Some Examples

- The digital generation will demand interactive, collaborative, nonlinear learning experiences.
- Faculty members will be challenged to become designers of learning experiences, motivators of active learning.
- We are experiencing a transition to open learning environments in which strong market forces will challenge the traditional university monopolies.

Information Technology and the Future of the Research University

Premise: Rapidly evolving information technology poses great challenges and opportunities to higher education in general and the research university in particular. Yet many of the key issues do not yet seem to be on the radar scope of either university leaders or federal research agencies.

NAS/NAE/IOM Steering Committee

- Jim Duderstadt (chair)
- Dan Atkins, Michigan
- John Seely Brown, Xerox PARC
- Gerry Butters, Lucent
- Marye Anne Fox, NCSU
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- Paul Horn, IBM
- Shirley Jackson, RPI
- Frank Rhodes, Cornell
- Marshall Smith, Stanford
- Lee Sproull, NYU
- Doug Van Houweling, Internet2
- Bob Weisbuch, Woodrow Wilson
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Technology **Education** **Staff**

Process

Technology Scenarios: What technologies are likely (possible) in the future (perhaps a 10 year planning horizon).

Implications for Research Universities: What are the implications of this evolving technology for the activities, organization, and enterprise of the research university?

Policies, Programs, Investments: What is the role, if any, for the federal government in protecting the valuable contributions of the research university in the face of these challenges

Some Early Conclusions About the Evolution of Information Technology

1) There is no evidence of slowdown in the pace of IT evolution, by any measure or characteristic. In fact we appear to be on a superexponential technology learning curve that is likely to continue for at least the next several decades.

2) Photonic technology is evolving at twice the rate of information technology, with miniaturization moving even faster, implying that the rate of growth of network appliances will be incredible.

3) For planning purposes, we can assume that within the decade we will have infinite bandwidth and infinite processing power (at least compared to current capabilities).

3) There are likely to be major technology surprises, comparable in significance to the PC in 1980 and the Internet browser in 1994, but at more frequent intervals.

Some early conclusions (continued)

4) Getting people to think about the implications of accelerating technology learning curves as well as technology cost-performance curves is very important. The event horizons are much closer that most realize.

5) Yet most universities still look at IT as a cost, not as an investment with staggering cost benefits. If you are not going to invest in IT, you may as well get out of the game. Investment in robust information technology represents the table stakes for survival in the age of knowledge!

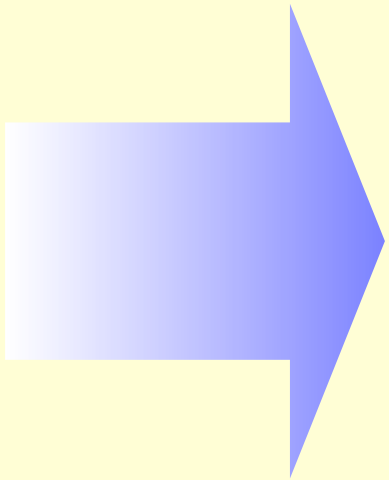
6) We need to distinguish between two time frames for the university:

A decade or less: Comprehensible change

Two decades and beyond: All bets are off …

A Social Transformation

The 20th Century		The 21st Century
Transportation		Communications
Cars, planes, trains		Computers, networks
Energy, materials		Knowledge, bits
Prosperity, security		Prosperity, security
Social structures		Social structures



Another Perspective …

The impact of information technology will be even more radical than the harnessing of steam and electricity in the 19th century. Rather it will be more akin to the discovery of fire by early ancestors, since it will prepare the way for a revolutionary leap into a new age that will profoundly transform human culture.

–Jacques Attali, *Millennium*

The Knowledge Industry

Hardware	Boxes, PCs, PDAs	IBM, HP, Sun, Lucent, Nokia, Erickson
Networks	Backbones, LANs, Wireless	AT&T, MCI, Telcoms
Software	OS, Middleware, Applications	Microsoft, IBM, Sun
Solutions	Systems, Integrators	Anderson, Peoplesoft, EDS, IBM
Content	Data, Knowledge, Entertainment, Learning?	Time-Warner, Disney, “dot.coms”, **AAU?**

Some Further Speculation

The Age of Spiritual Machines:

When Computers Exceed Human Intelligence

–Ray Kurzweil

2009

- A $1,000 PC delivers Terahertz speeds
- PCs with high resolution visual displays come in a range of sizes, from those small enough to be embedded in clothing and jewelry up to the size of a thin book.
- Cables are disappearing. Communication between components uses wireless technology, as does access to the Web.
- The majority of text is crated using continuous speech recognition. Also ubiquitous are language user interfaces.
- Most routine business transactions (purchases, travel, etc.) take place between a human and a virtual personality. Often the virtual personality includes an animated visual presence that looks like a human face.

2009 (continued)

- Although traditional classroom organization is still common, intelligent courseware has emerged as a common means of learning.
- Translating telephones (speech-to-speech language translation) are commonly used.
- Accelerating returns from the advance of computer technology have resulted in a continued economic expansion.
- The neo-Luddite movement is growing.

2019

- A $1,000 PC is now approximately equal to the computational ability of the human brain.
- Computers are now largely invisible and are embedded everywhere–in walls, tables, chairs, desks, clothing, jewelry, and bodies.
- 3-D virtual reality displays, embedded in glasses and contact lenses, as well as auditory “lenses”, are used routinely as primary interfaces for communication with other persons, computers, the Web, and virtual reality.
- Most interaction with computing is through gestures and two-way natural-language spoken communication.

2019 (continued)

- Nanoengineered machines are beginning to be applied to manufacturing and process control.
- High-resolution, 3-D visual and auditory virtual reality and realistic all-encompassing tactile environments enable people to do virtually anything with anybody, regardless of physical proximity.
- Paper books or documents are rarely used and most learning is conducted through intelligent, simulated software-based teachers.
- The vast majority of transactions include a simulated person.
- Automated driving systems are now installed in most roads.

2019 (continued)

- People are beginning to have relationships with automated personalities and use them as companions, teachers, caretakers, and lovers.
- There are widespread reports of computers passing the Turing Test, although these tests do not meet the criteria established by knowledgeable observers.

2029

- A $1,000 unit of computation now has the computation capacity of roughly 1,000 human brains.
- Permanent removable implants for the eyes and ears are now used to provide input and output between the human user and the worldwide computing network.
- Direct neural pathways have been perfected for high-bandwidth connection to the human brain. A range of neural implants is becoming available to enhance visual and auditory perception and interpretation, memory, and reasoning.
- Automated agents are now learning on their own, and significant knowledge is being crated by machines with little or no human intervention.

2029 (continued)

- Computers have read all available human- and machine-generated literature and multimedia material.
- There is widespread use of all-encompassing visual, auditory, and tactile communication using direct neural connections, allowing virtual reality to take place (“sim-stim”)
- The majority of communication does not involve a human; rather it is between a human and a machine.
- There is almost no human employment in production, agriculture, or transportation. Basic life needs are available for the vast majority of the human race.

2029 (continued)

- There is a growing discussion about the legal rights of computers and what constitutes being “human”. Although computers routinely pass apparently valid forms of the Turing Test, controversy persists about whether or not machine intelligence equals human intelligence in all of its diversity.
- Machines claim to be conscious. These claims are largely accepted.

2049

- The common use of nanoproduced food, which has the correct nutritional composition and the same taset and texture of organically produced food, means that the availability of food is no longer affected by limited resources, bad weather, or spoilage.
- Nanobot swarm projections are used to create visual-auditory-tactile projections of people and objects in real reality.
- Picoengineering begins to become practical.

By 2099

- There is a strong trend toward a merger of human thinking with the world of machine intelligence that the human species initially created.
- There is no longer any clear distinction between humans and computers.
- Most conscious entities do not have a permanent physical presence.
- Machine-based intelligences derived from extended models of human intelligence claim to be human, although their brains are not based on carbon-based cellular process, but rather electronic and photonic equivalents. Most of these intelligences are not tied to a specific computational process unit. The number of software-based humans vastly exceeds those still using native neuron-cell-based computation.

By 2099 (continued)

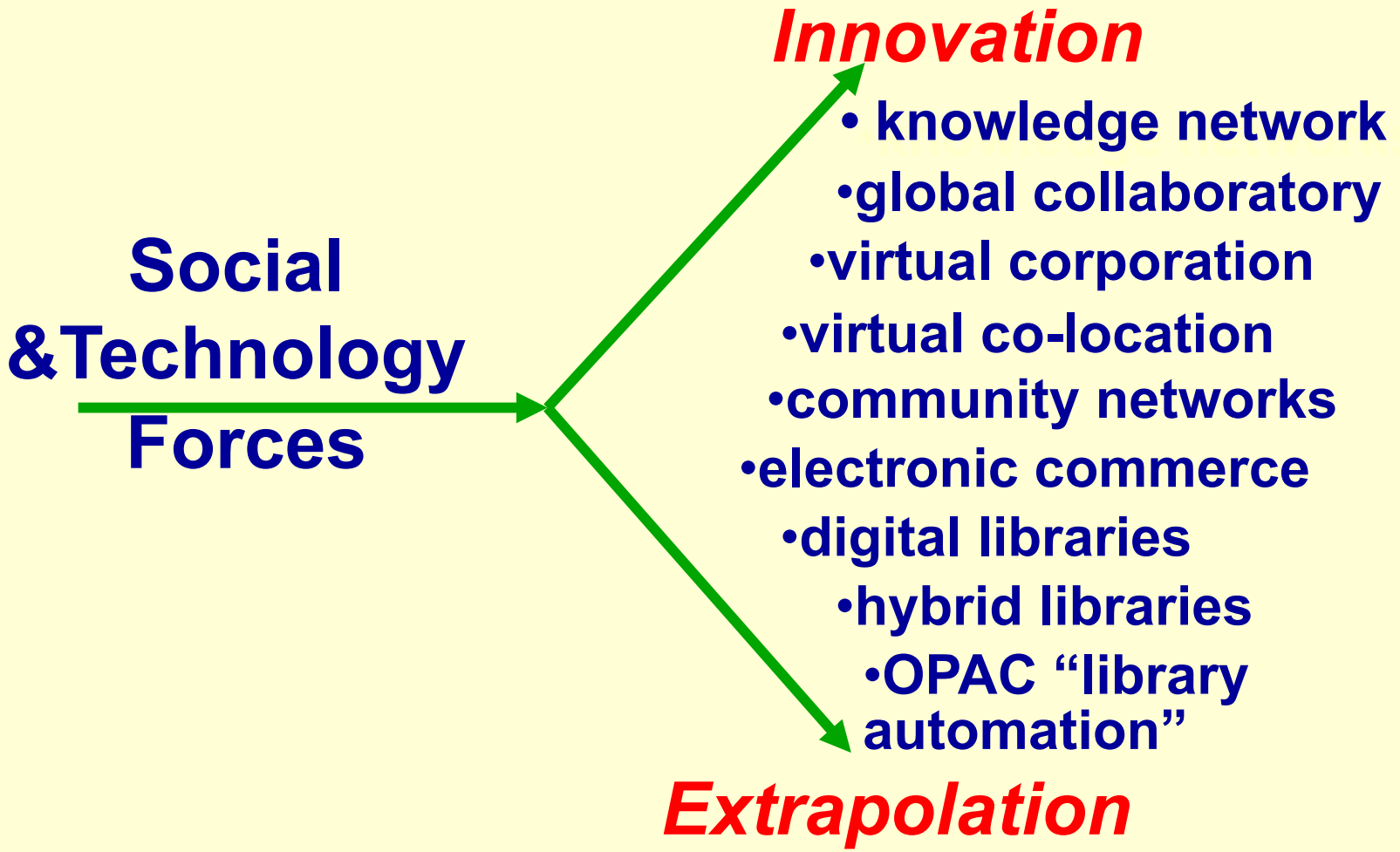
- Even among those human intelligences still using carbon-based neutrons, there is ubiquitous use of neural-implant technology, which provides enormous augmentation of human perceptual and cognitive abilities. Humans who do not utilize such implants are unable to meaningfully participate in dialogues with those who do.
- Because most information is published using standard assimilated knowledge protocols, information can be instantly understood. The goal of education, and of intelligent beings, is discovering new knowledge to learn.
- Life expectancy is no longer a viable term in relation to intelligence beings.

Many Milleniums Hence …

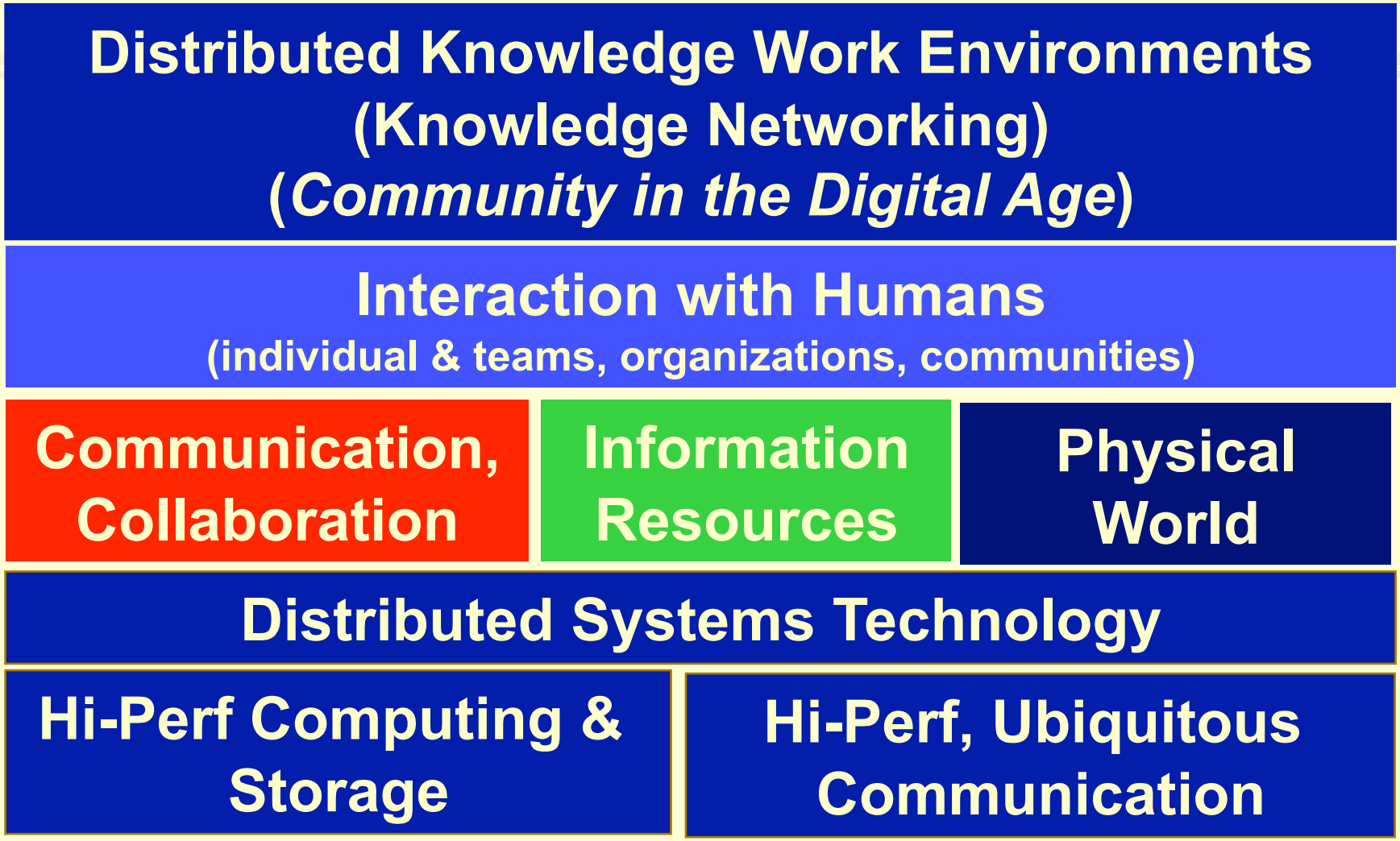
Intelligent beings consider the fate of the Universe …

Rapid social, technological and workplace transformations taking place

Stretch & Explore the "Vision Space"

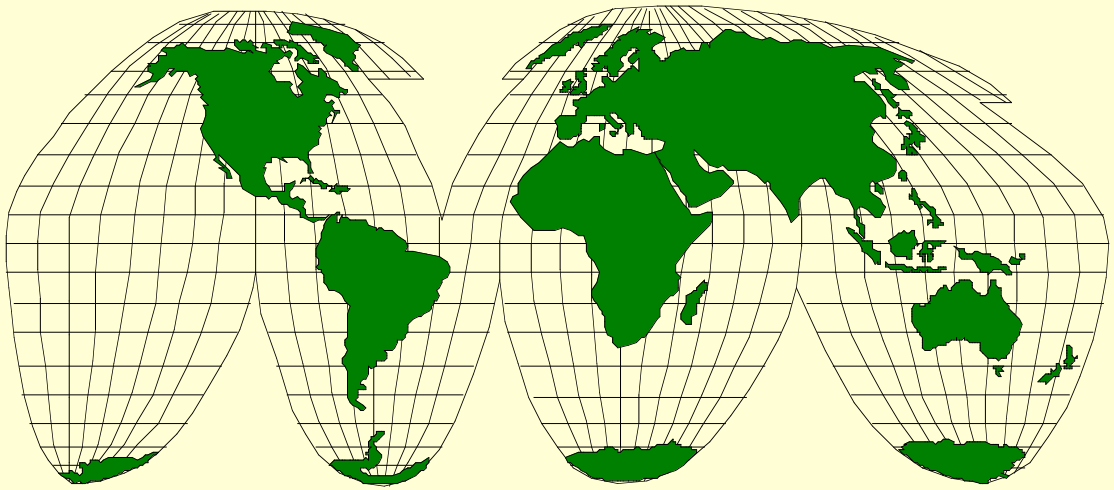


Framework for Knowledge Networks

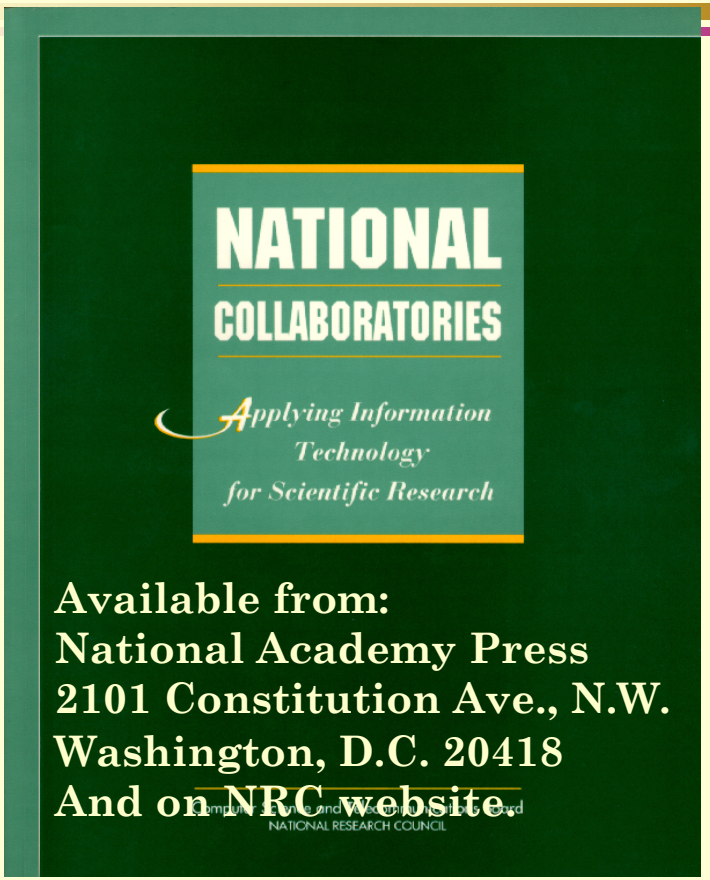


Technology-Supported Organizations Can Be Simultaneously

- Big and Small
- Centralized and Decentralized
- Local and Global



1993 National Research Council Study



Available from:
National Academy Press
2101 Constitution Ave., N.W.
Washington, D.C. 20418
And on NRC website.

COMMITTEE ON A NATIONAL COLLABORATORY: DEVELOPING THE USER-DEVELOPER PARTNERSHIP

V. CERF, CNRI, *Chair*
A. G. W. CAMERON, Harvard, *Vice-Chair*
J. LEDERBERG, Rockefeller Univ.
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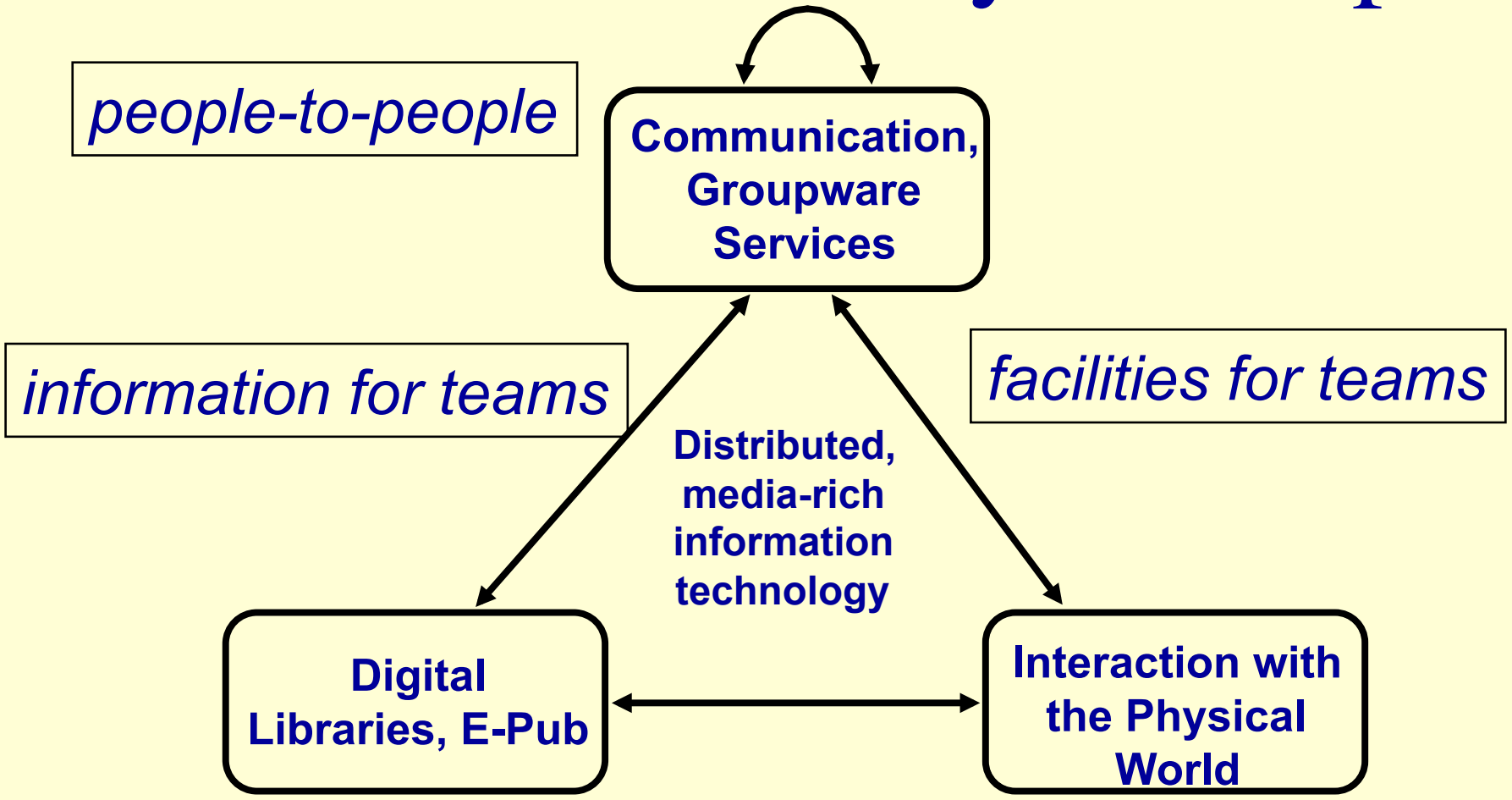
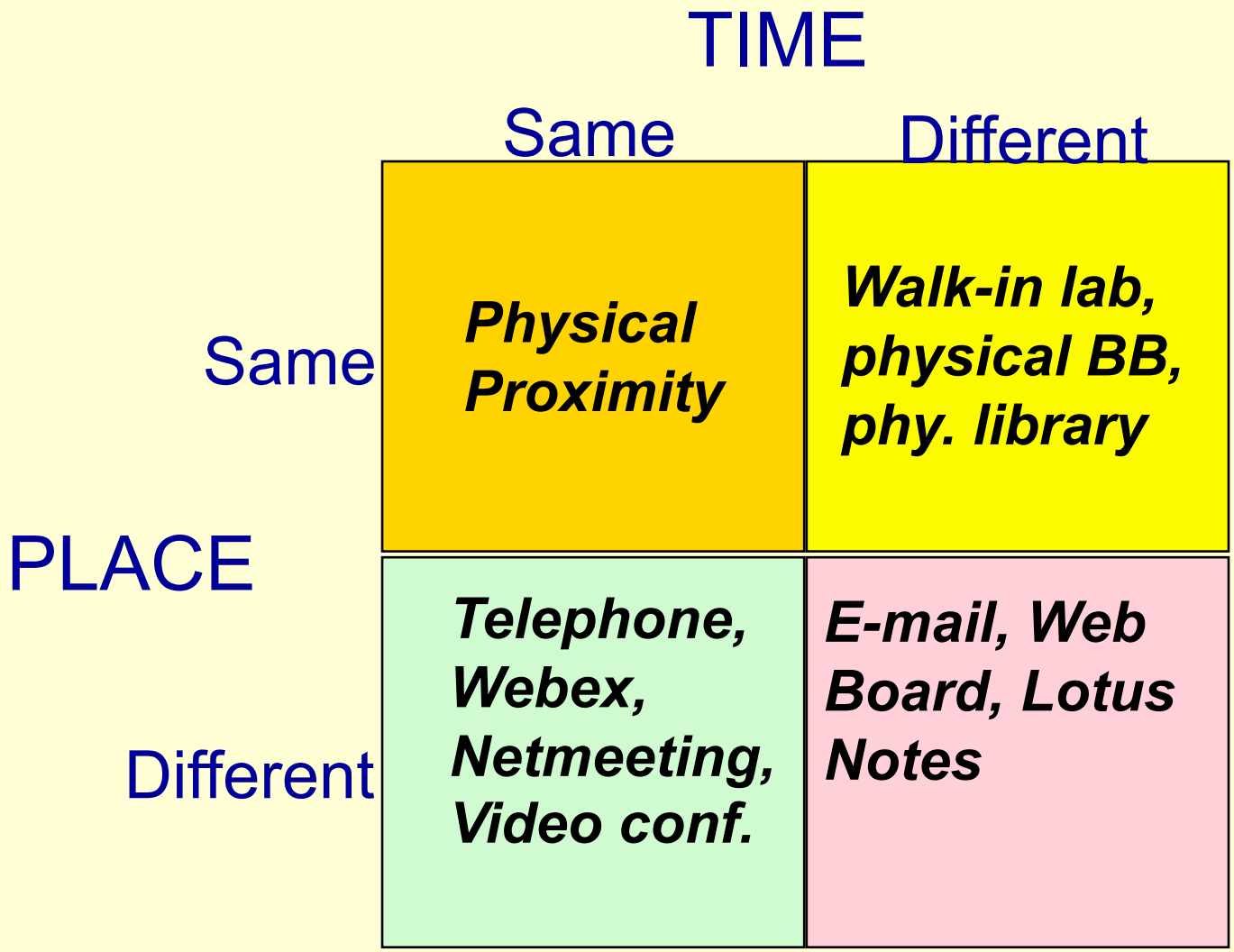
The Collaboratory Concept

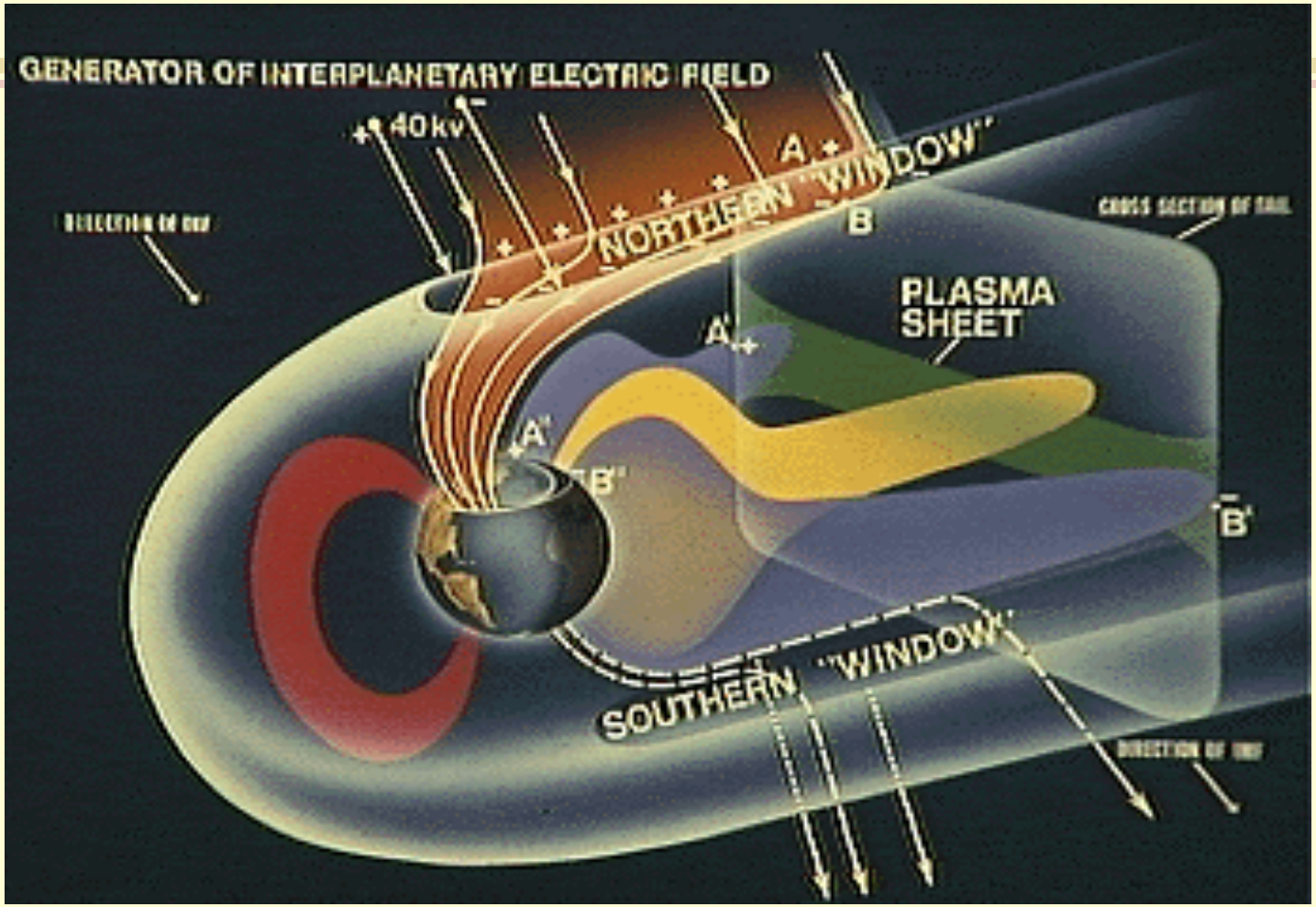


Work in all 4 variations of same and different, time and place.

Modes of Collaborative Work & *Examples*



Collaboratory Example: UARC



Sondrestrom Facility, Greenland

Current UARC Facilities

UARC Interface

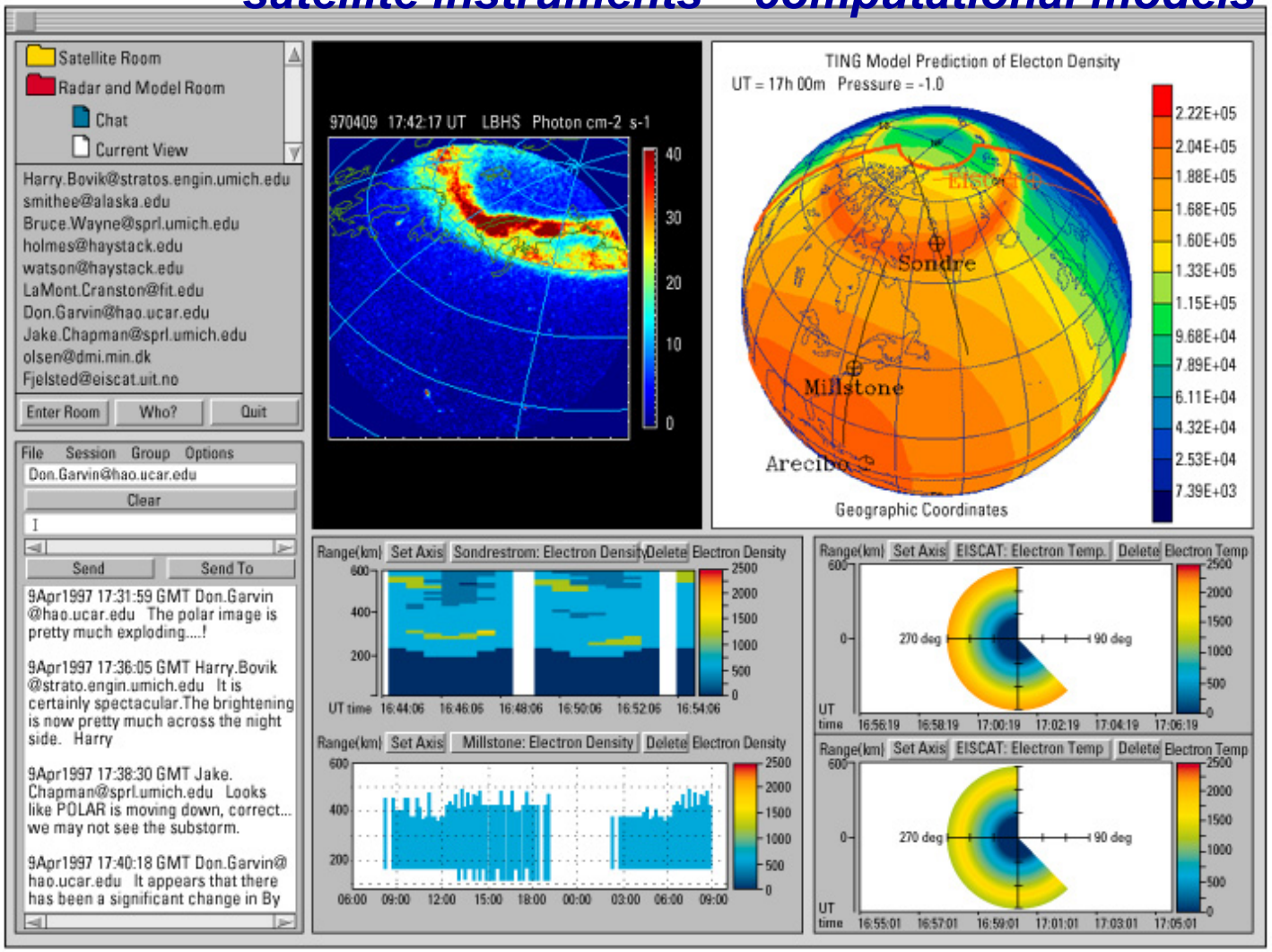
satellite instruments ***computational models***

dynamic work rooms

team chat

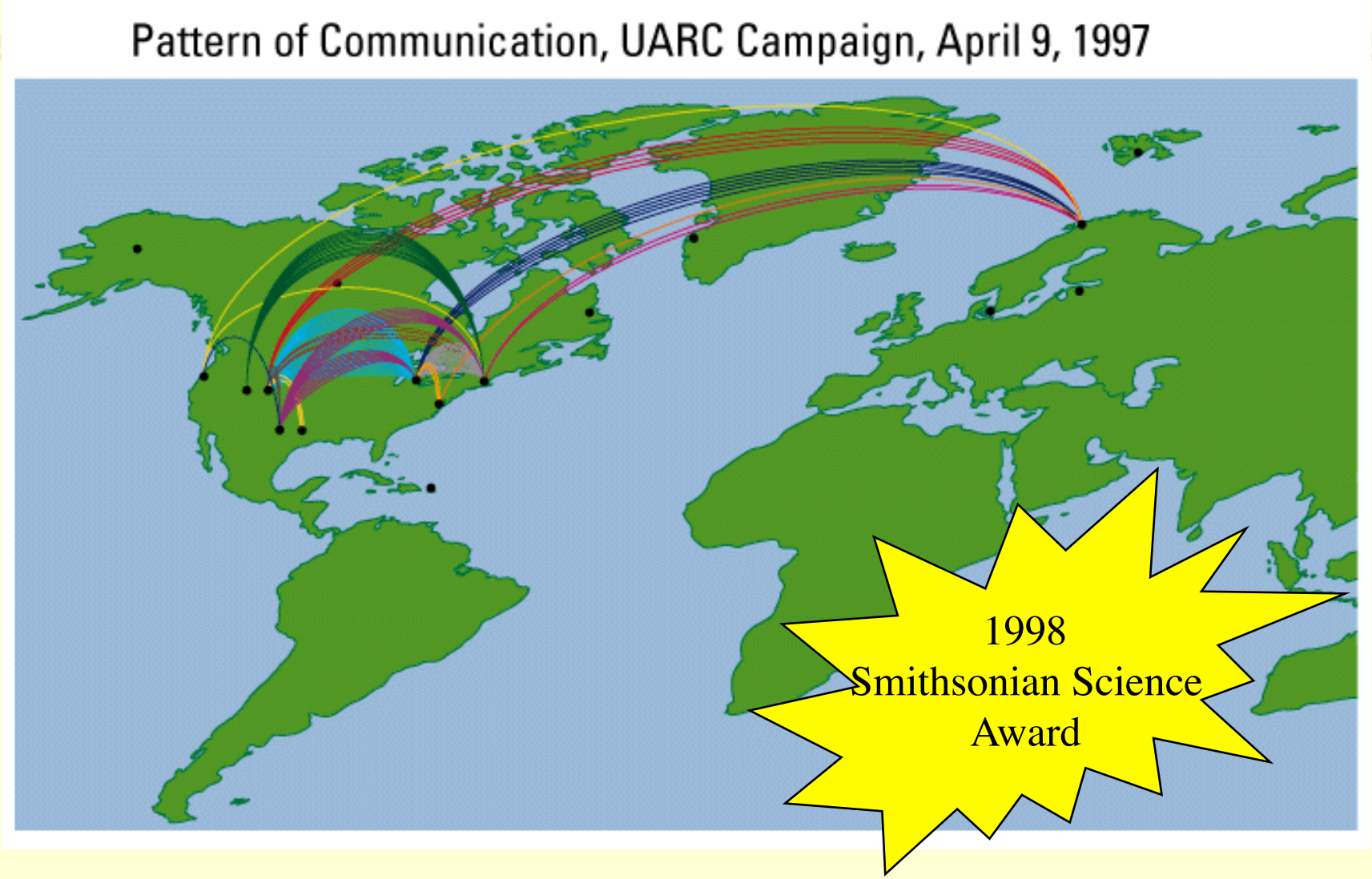
annotation

Session replay



Real-time ground instruments ***Archival data*** ***Journals***

UARC Patterns of Communication

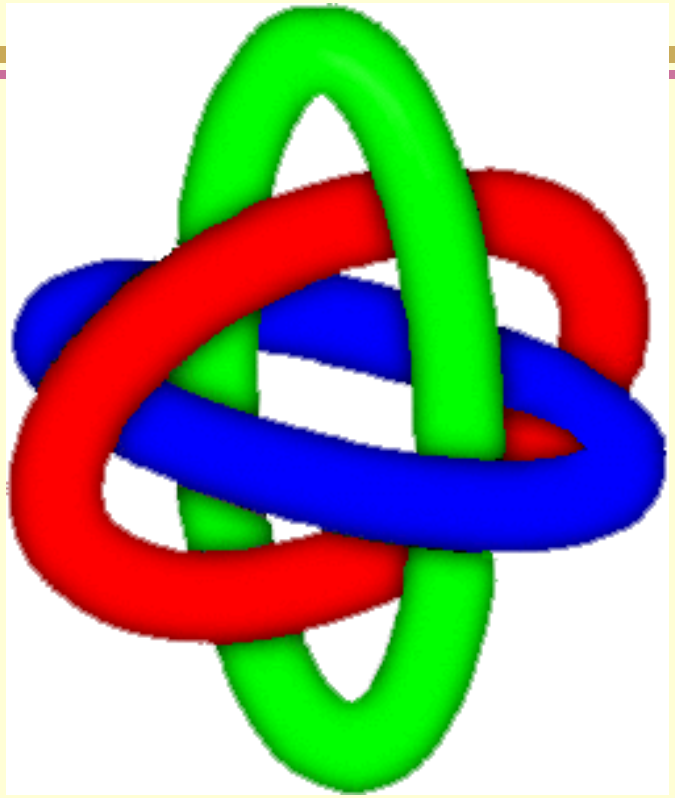


Approaches to Creating Change

“Closing the Reality Gap”

Borromean Ring

Behavioral & Organizational Sciences



Computer, Information, Library Sciences

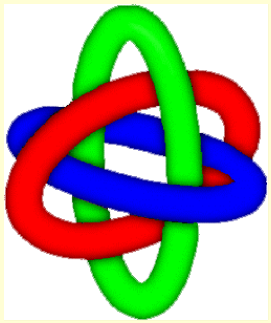
Individuals and Organizations in Society

*Three symmetric, interlocking rings, no two of which are interlinked. Removing one destroys the synergy.

Iterative, Human-Centered Design

Conceptualize:
Interview, Observe & Define objects in current practice; establish baseline.

Build:
Rapid prototyping in OO framework.



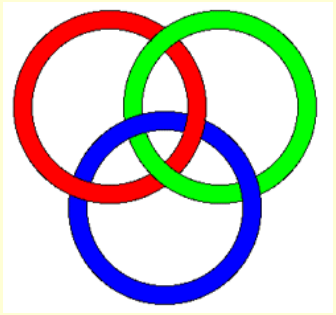
living specification

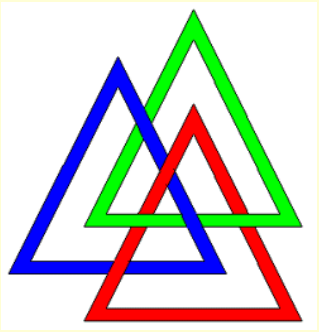
Trials:
Deploy, use, evaluate.

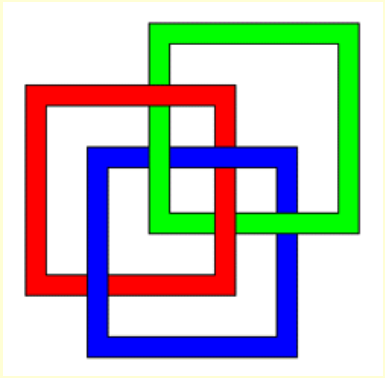
Modify,
extend design, evolution

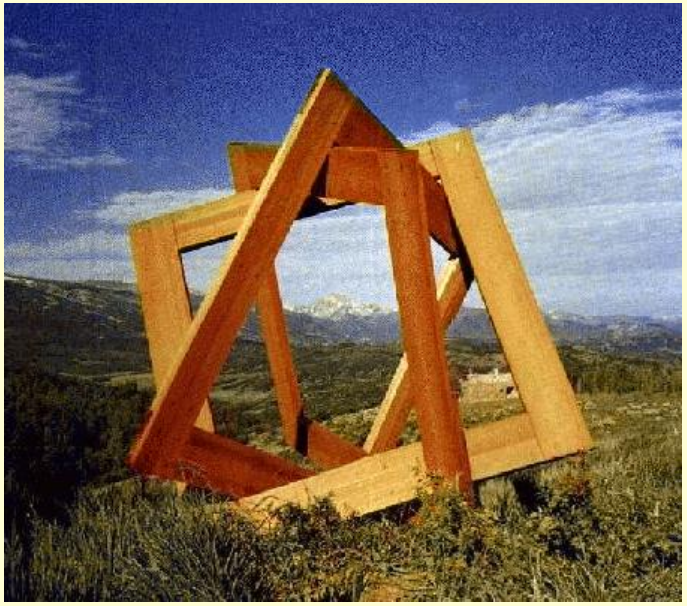
* as individuals and members of teams

Borromean Rings

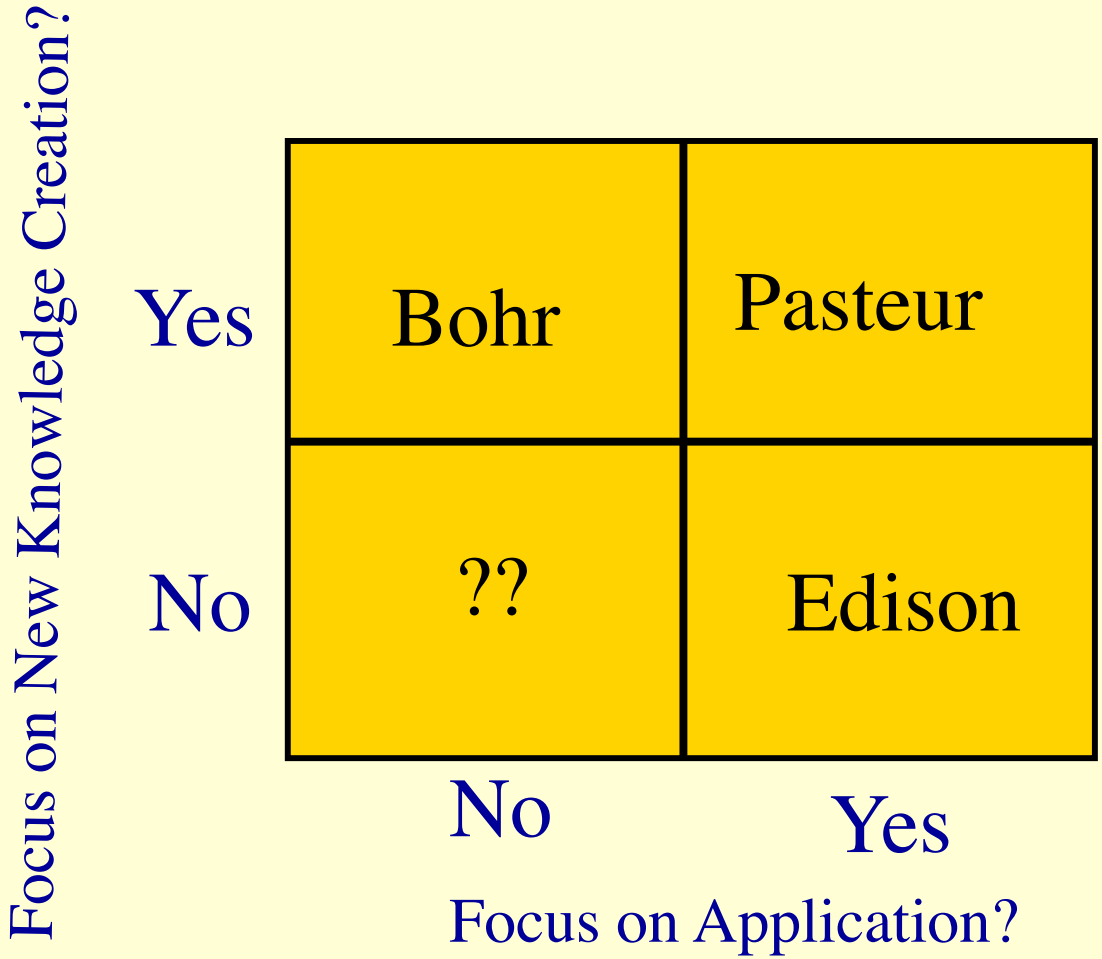








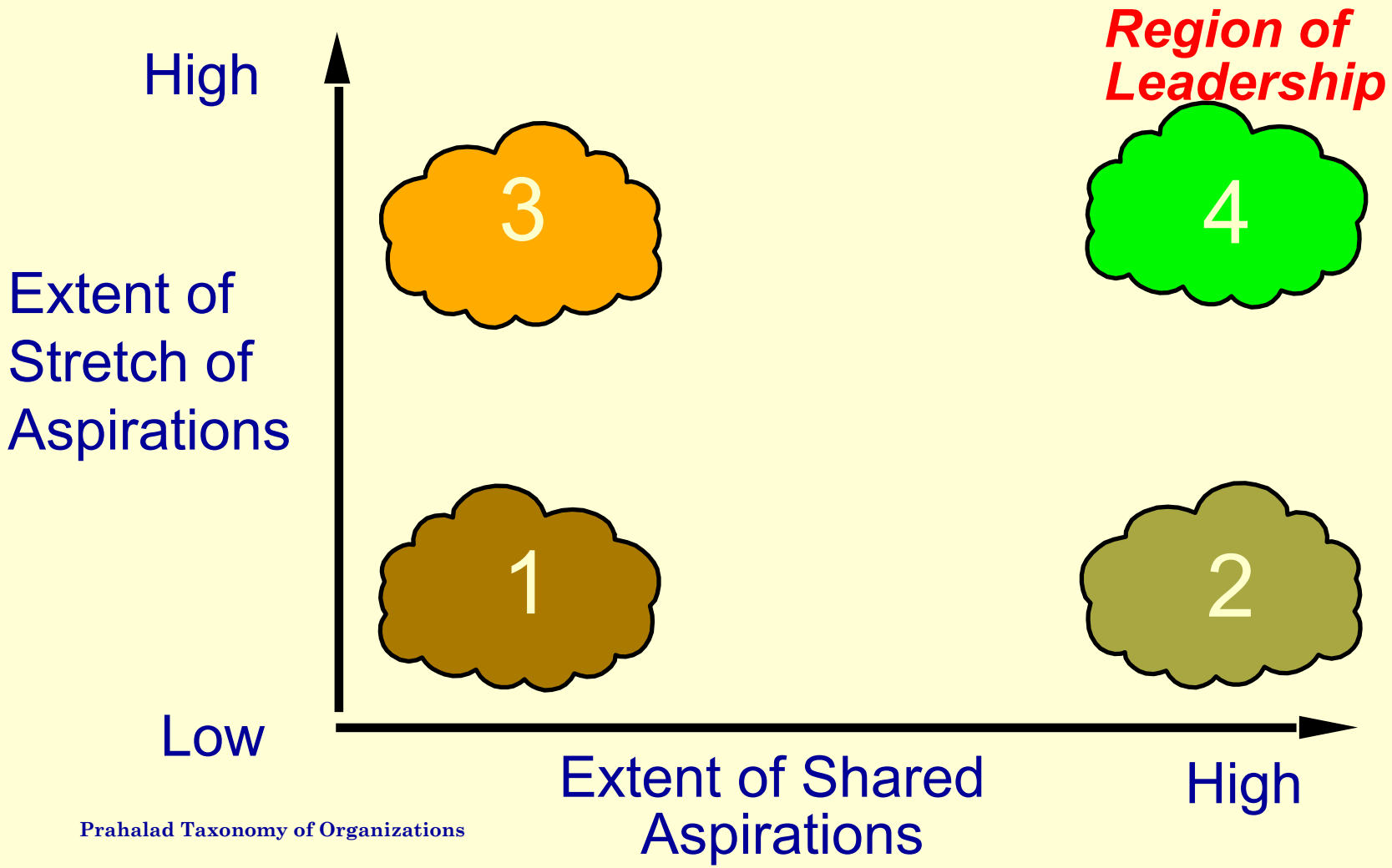
Pasteur's Quadrant Research
(from Michael Stokes)



Opportunities

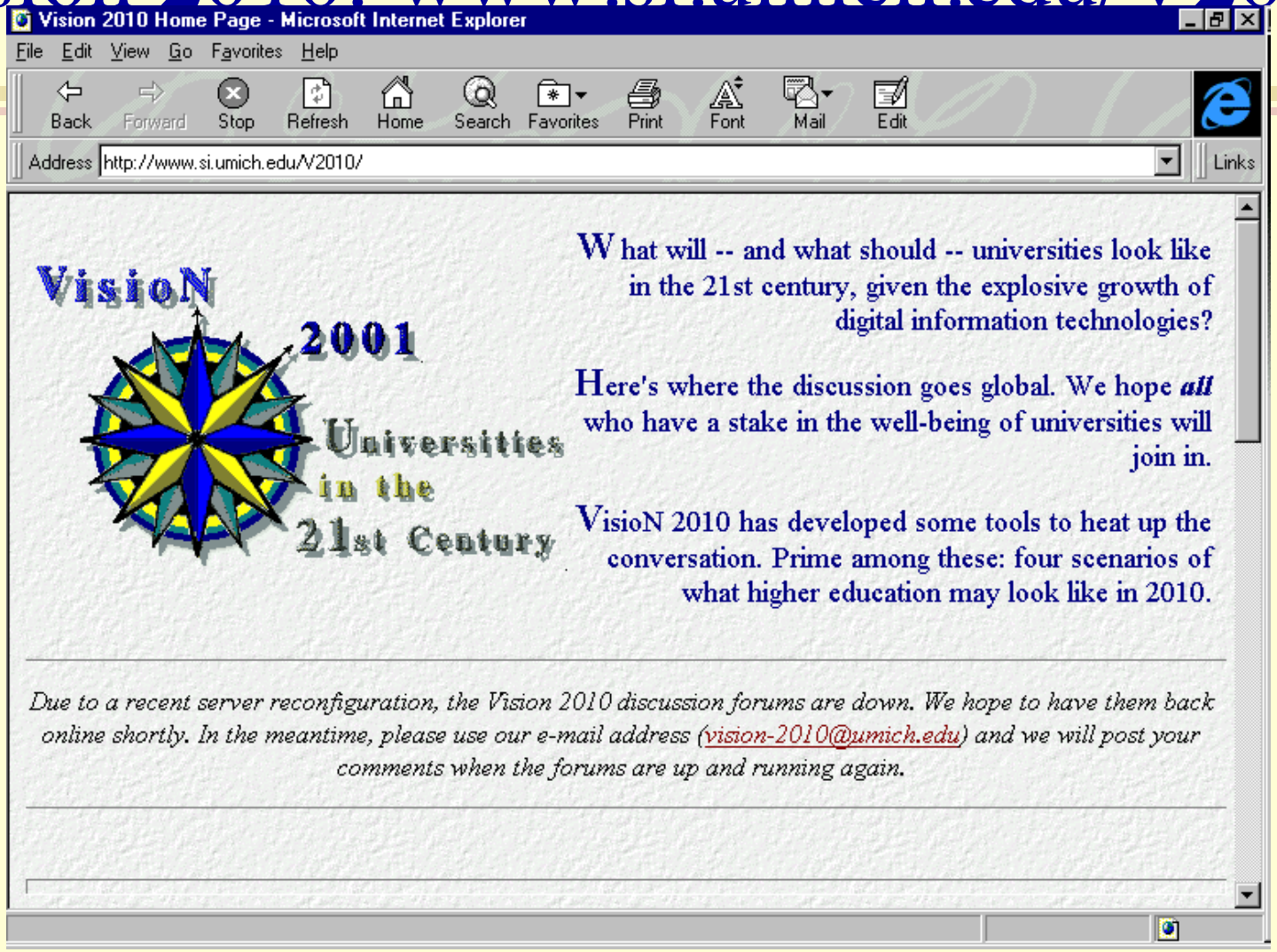
- Enhance, reinterpret, and use the generic skills of librarians -- e.g. “information architecture.”
- Providing relevant education.
- Creation and maintenance of digital collections and repositories.
- Joint ventures/collaborations
  - With other units of the university in Pasteur Quadrant type research. (NSF ITR, IAMS, etc.)
  - Digital library federations
  - Library, Archives, Museum Federations
  - E-publishing ventures (profit and non-profit).

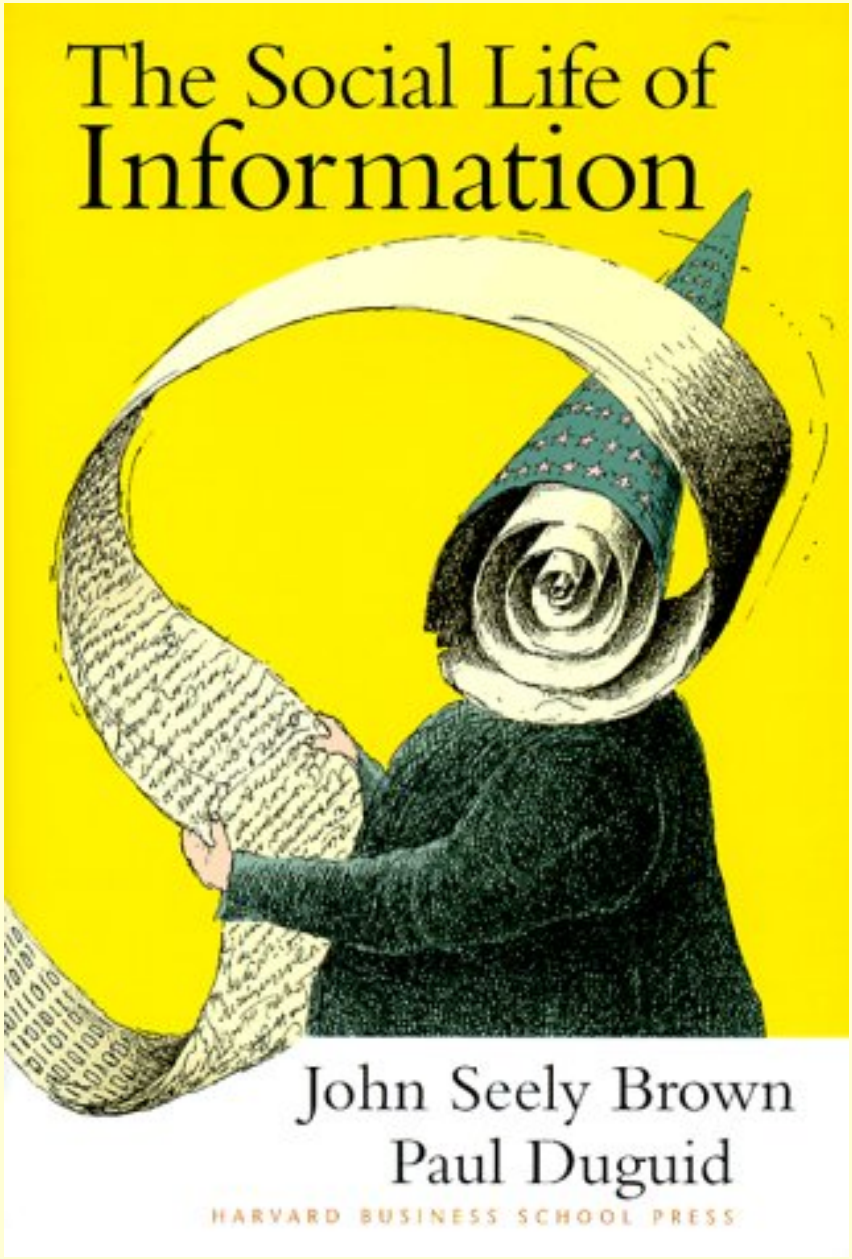
Prahalad Model of Organizational Change



Prahalad Taxonomy of Organizations

Vision 2010: www.si.umich.edu/V2010

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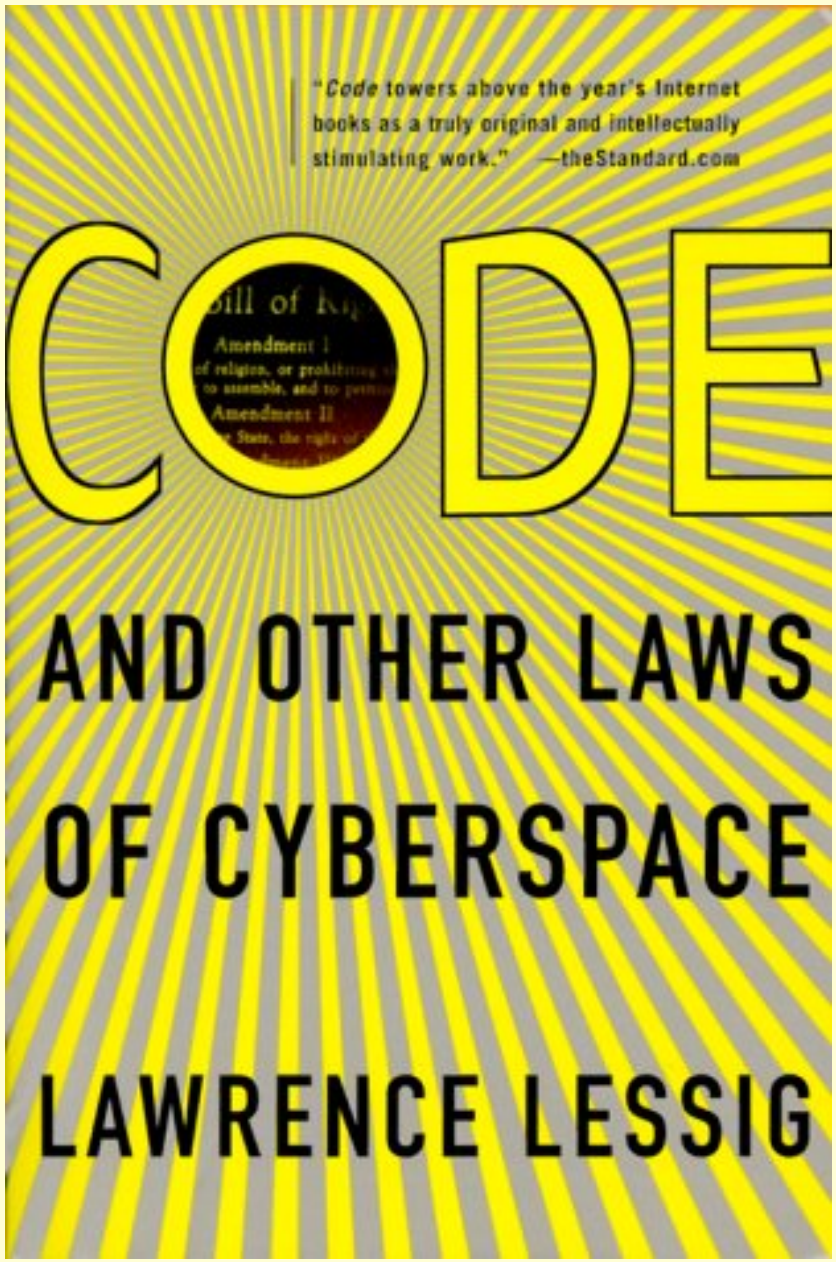
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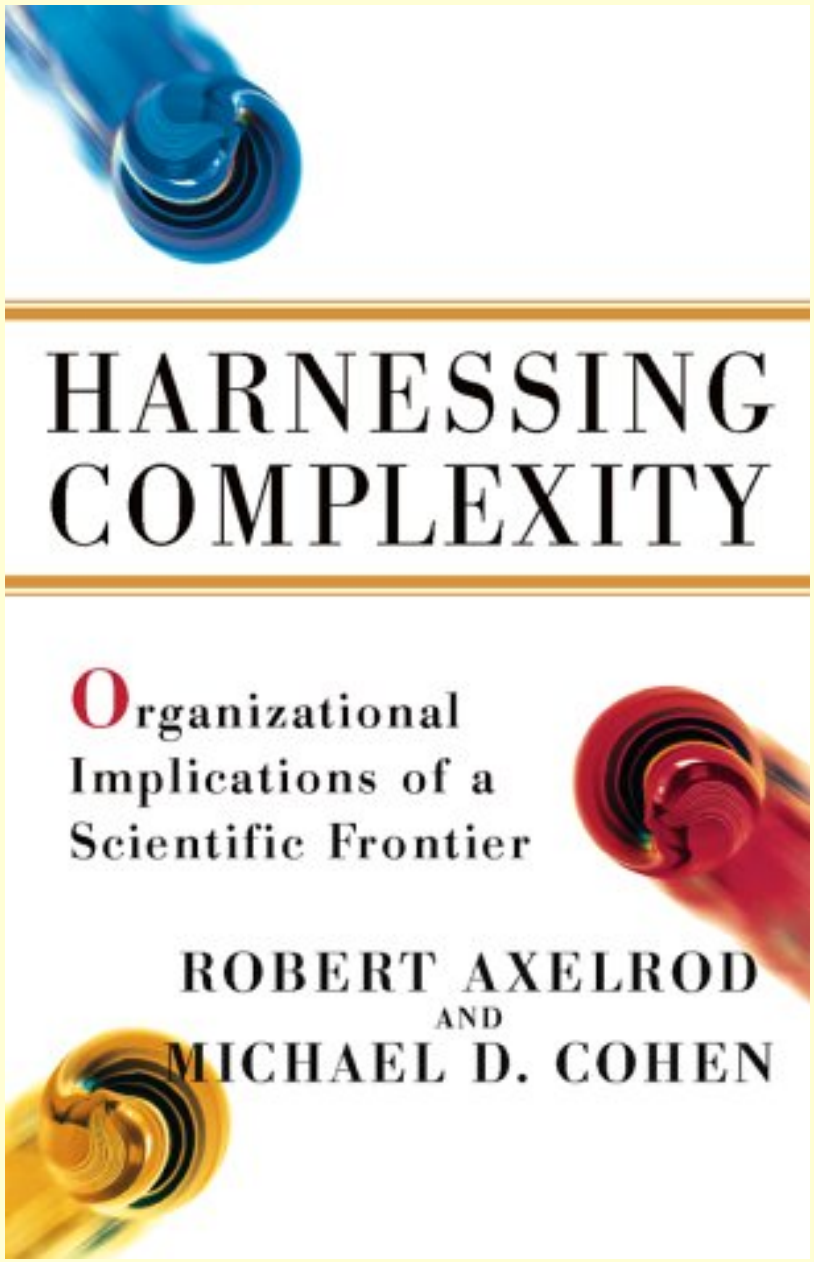
HARNESSING
COMPLEXITY
Organizational
Implications of a
Scientific Frontier
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