Nano-bio-cogno-socio-techno convergence for enhancing human performance:

Perspectives on the great unsolved problems of learning

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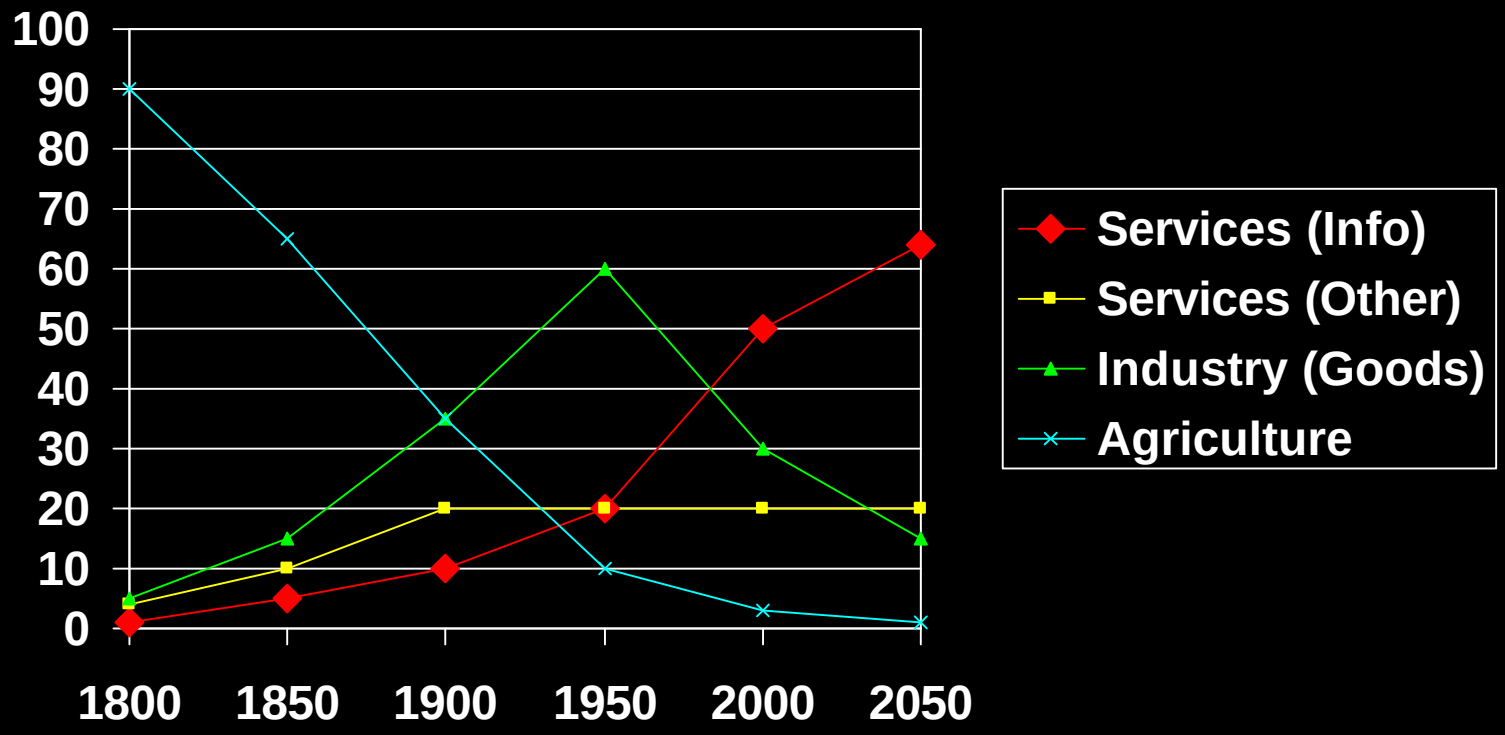
Six R's of Learning

- Remind & Remediate – **I knew it**
  1. Remind: Give me a hint
  2. Remediate: Give me practice
- Receive & Reconstruct – **You know it**
  3. Receive: Give me it fast (training)
  4. Reconstruct: Give me it deep (education)
- Research & Reflect – **No one knows it**
  5. Research: What's the right answer?
  6. Reflect: What's the right question?

Problems

- **Optimization and adaptation to environment**
  - **Rate of change acceleration**
  - **Deciding to stop or change other aspects of the system**
- **Knowledge transfer between agents**
  - **Individual to individual**
  - **Organization to organization**
  - **Artifact to individual**
- **Knowledge transfer across space**
- **Knowledge transfer across time**
  - **Accumulation of knowledge**
- **Knowledge transfer at lowest energy cost**

U.S. Employment Percentages by Sector



Estimations based on Porat, M. (1977) Info Economy: Definitions and Measurement, Augmented with recent data and projections from http://www.bls.gov/

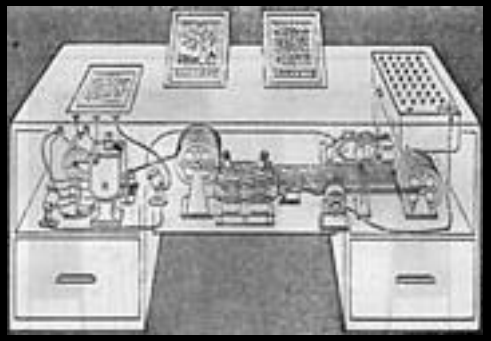
Today's Talk

- **The Pioneers**
  - **Enhancing human performance with information technology**
- **The Science**
  - **Nano-bio-cogno-socio-techno convergence**
- **Business Implications**
  - **The business of people**
  - **The evolution of businesses and organizations**
- **Concluding remarks**

The Pioneers

Thanks to the pioneers whose early visions of enhancing human performance with new information technologies have helped to inspire many of us…

- **Vannevar Bush (1945) "As We May Think"**
- **J.C.R. Licklider (1960) "Man-Machine Symbiosis"**
- **Douglas Engelbart (1962) "Augmenting Human Intellect"**



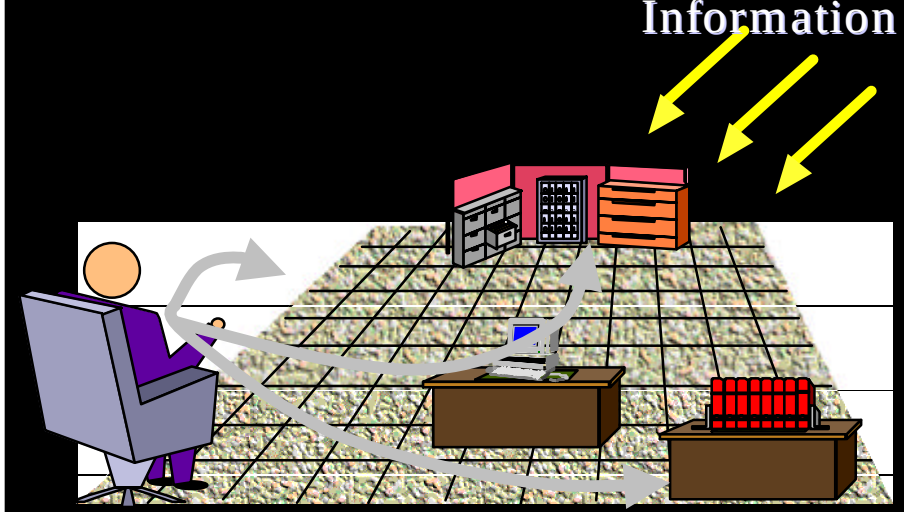
Original Source:
Atlanta Monthly 1945

The pioneers all clearly saw people adapting to a new environment…
moving from a natural environment to a human-made information-rich environment.

The New Environment and Human Activity: Where does our time go? From the search for food to the search for information

Humans as Informavore (Miller, 1983)

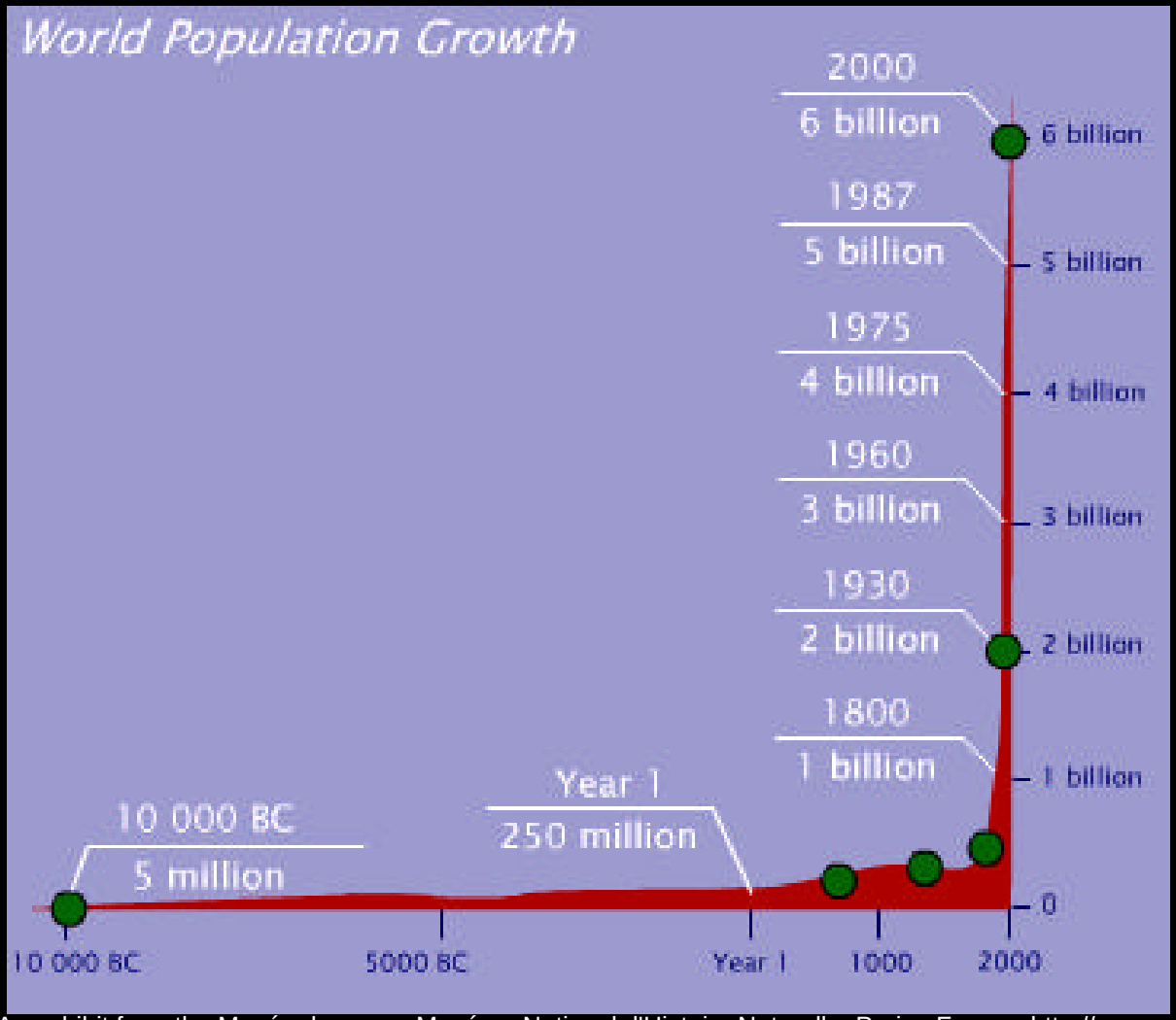
Source: Pirolli (2002)



$$\text{Max}\left[\frac{\text{Energy}}{\text{Time}}\right] \qquad \text{Max}\left[\frac{\text{Useful info}}{\text{Time}}\right]$$

Our environment is changing increasingly rapidly due to a positive feedback loop between population and information

Effects of Agriculture, Colonial Expansion & Economics, Scientific Method, Industrialization & Politics, Education, Healthcare & Information Technologies, etc.



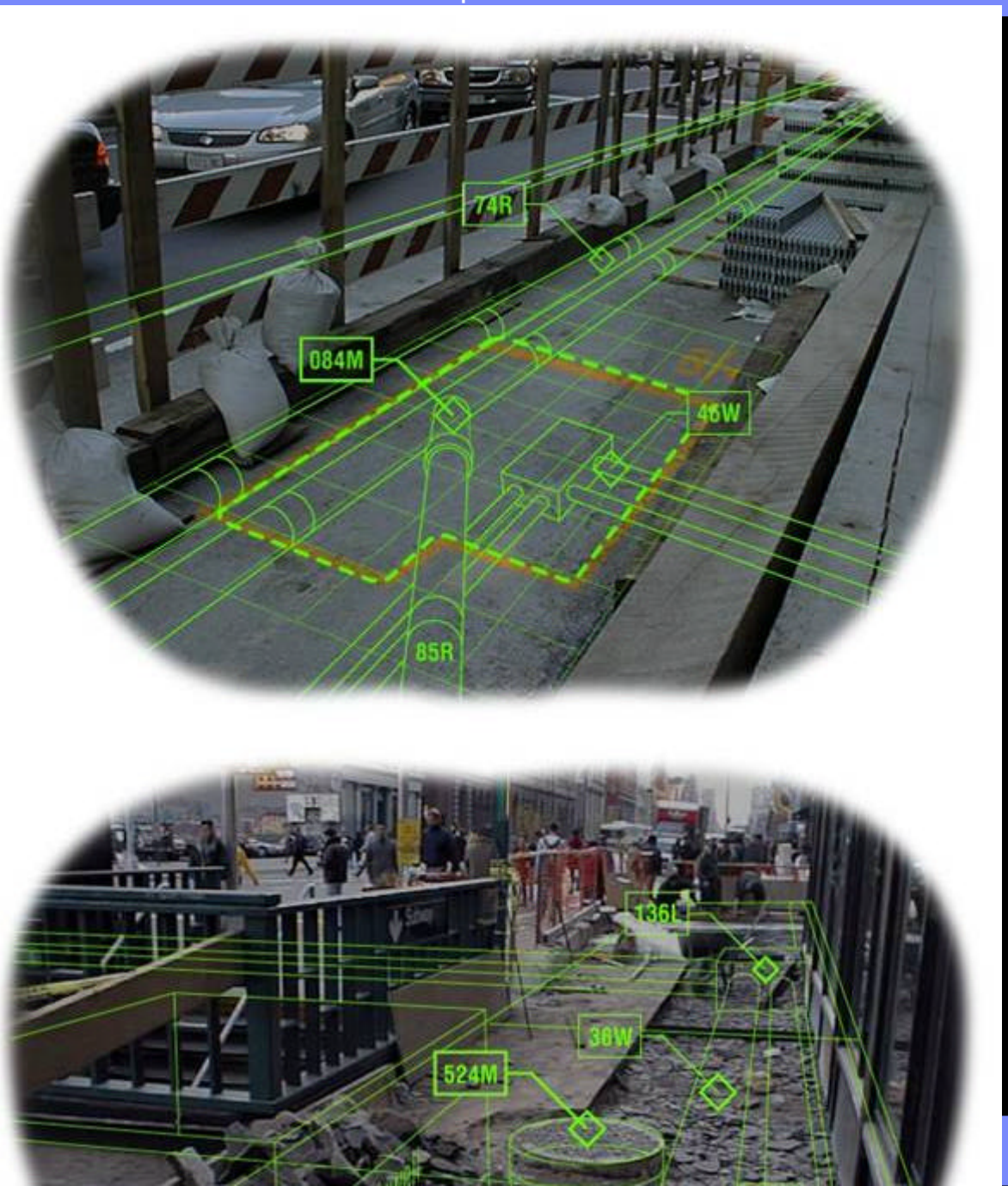
Positive feedback loop for the new environment
More people leads to more information
leads to more people…

6 Billion Human Beings: An exhibit from the Musée de l'Homme Muséum National d'Histoire Naturelle, Paris –France http://www.popexpo.net/english.html

WorldBoard: Learning Contexts

Stage 1: Reach out and touch rocks, trees, natural atoms
Stage 2: Reach out and touch table, computer human placed atoms
Stage 3: Reach out and perceive information in places (WorldBoard)

Art by Ian Bruce



Sutherland (’65)

IBM (’00)

The Science

The Science of Nano-bio-cogno-socio-techno Convergence

- **The Question:** Can we **understand and control to suit our purposes the different information** encoding, processing, and replication processes across multiple systems?
  - Natural Systems – Natural environment that people exist in
    - Information in Physical Systems (Matter & Energy Flows, Atoms Matter)
    - Information in Living Systems (Chemistry of Life, Molecules/Ecosys. Matter)
    - Information in Cognitive Systems (Brains, Neurons Matter)
      - Knowledge of the natural world and human made world
  - Human Made Systems – Human Made environment that people exist in
    - Information in Social Systems (Organizations, People Matter)
    - Information in Technology Systems (Tools, Machines Matter)

- **Implications:** As we get closer to a more complete answer, we can expect to realize many interesting, new capabilities that happen between the different systems:
  - artificial cochlea and retina (technology to cognitive)
  - terra-form Mars (physical to living)

The science: nano-bio-cogno-socio-techno convergence:

It's all about information – encoding, processing, replicating – in different systems (ultimately all grounded in matter patterns)

	System	Encoding	Processing	Replicating
Nano	Matter (Nature)	Atoms & Molecules	Universe to Atoms	Galactic, Solar, Planet Systems
Bio	Life (Nature)	DNA	Cells to Ecosystems	Evolution
Cogno	Thought (Nature/Human)	Brains	Neural Nets	Evolution - Culture
Socio	Culture (Human)	People	Organizations	Evolution - Culture
Techno	Technology (Human)	Artifacts & Bits	Computers	Design-Factories

Co-Evolution

Rapidly increasing rates of advancement in each system area is creating cross pollination

Examples: FOXP2, Complex Adaptive Systems (CAS) – Variability, Interaction, Selection

The Scale of Things – Nanometers and More

Sponsor: Science & Business Perspective

IBM

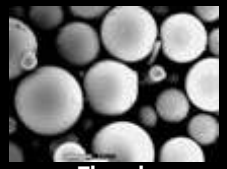
Source: NSF website

Things Natural

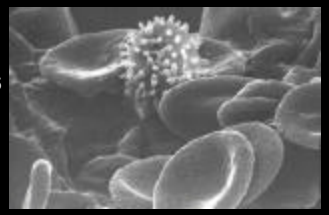
Dust mite
200 µm

Ant
~ 5 mm

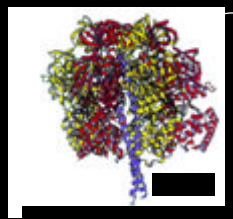
Human hair
~ 10-50 µm wide



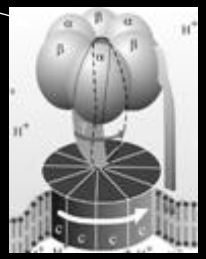
Fly ash
~ 10-20 µm



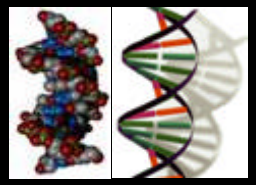
Red blood cells with white cell
~ 2-5 µm



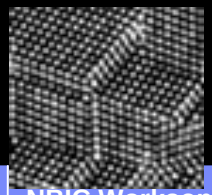
~10 nm diameter



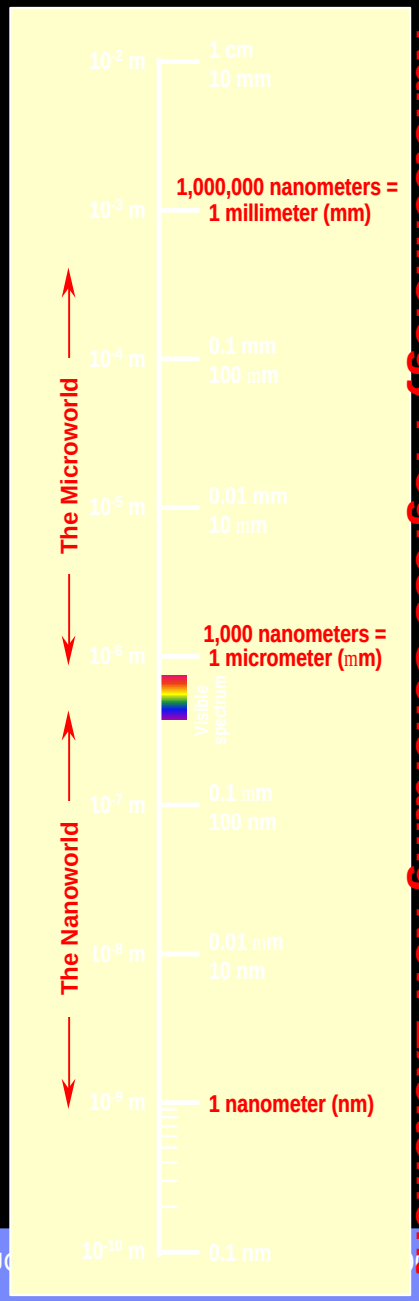
ATP synthase



DNA
~2 1/2 nm diameter

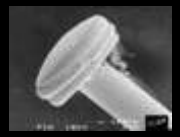


Atoms of silicon
spacing ~tenths of nm



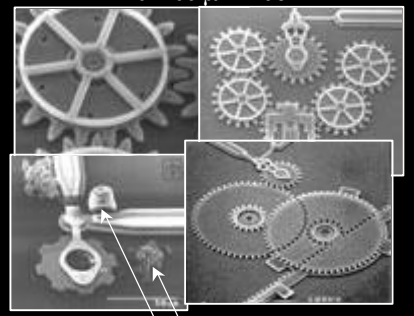
Nanotechnology Progress Generating New Excitement

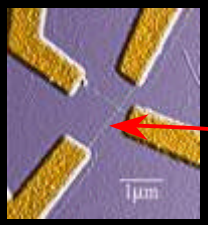
Things Manmade



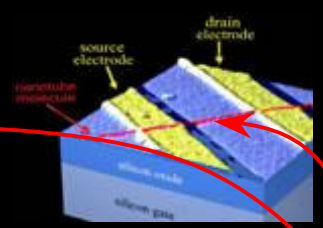
Head of a pin
1-2 mm

MicroElectroMechanical Devices
10 -100 µm wide

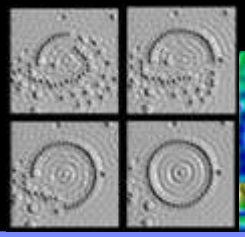


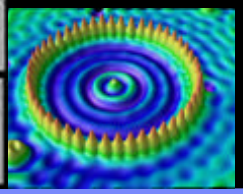


Nanotube electrode



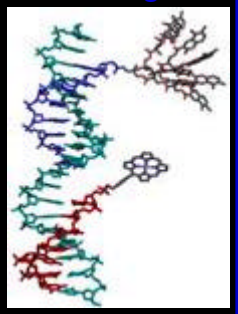
Nanotube transistor

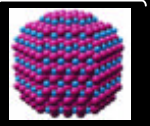




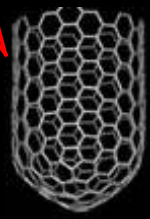
Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip
Corral diameter 14 nm

21st Century Challenge





Combine nanoscale building blocks to make functional devices, e.g., a photosynthetic reaction center with integral semiconductor storage



Carbon nanotube
~2 nm diameter

Brief History of Accelerating Change

Billion Years Ago	
12	Big Bang (EMST)
11.5	Milky Way (Atoms)
8	Sun (Energy)
4.5	Earth (Molecules)
3.5	Bacteria (Cell)
2.5	Sponge (Body)
0.7	Clams (Nerves)
0.5	Trilobites (Brains)
0.2	Bees (Swarms)
0.065	Mass Extinctions
0.002	Humans Tools & Clans Co-evolution

Generations Ago	
100,000	Speech
750	Agriculture
500	Writing
400	Libraries
40	Universities
24	Printing
16	Accurate Clocks
5	Telephone
4	Radio
3	Television
2	Computer
1	Internet/e-Mail
0	GPS, CD, WDM

Improving Human Performance: Outside-Inside Framework

Relative Position	Improvement Areas
External (outside the body; environmental)	Materials - Cost, Affordances, Dynamics
	Agents – Organizations, Bots, Animals
	Places – Real, Virtual, Mixed
	Mediators - Tools
External (outside the body; personal)	Mediators – Wearables, Mobile Tools
Internal (inside the body; temporary)	Ingestibles – Medicines, Foods
Internal (inside the body; permanent)	Organs – Implants, Sensor & Effectors
	Skills – Learning, New Uses of Old
	Genes – New Species, Devel. Process

Outside-Inside Framework can be used to analyze the past, and speculate about futures.

Outside-Inside Framework Applied: Past & Future

- **- 100,000 Generations: Speech**
  - New Species (Kind of Agent)
  - New Use of Old Sense (sounds -> symbols: language)
- **- 500 : Writing**
  - New Mediator: Store symbols for later use (and New Skills = Scribes)
- **- 400 : Libraries, 40 Universities, 24 Printing**
  - New Mediator, Places: Communicate/Distribute (and Agents = Organizations)
- **- 16 : Accurate Clocks for Navigation & More**
  - New Mediator: Measure (and Agents = Organization)
- **- 5 : Telephone, 4 - Radio, 3 - TV, 2 - Computers, 1 - Internet**
  - New Mediator: Communicate/Distribute (and Agents = Organizations/Businesses)
  - New Use Old Sense: Stories (e.g., Why Honeymooners = Flintstones)
- **-0.5 :GPS/Sensors for Navigation & More**
  - New Mediator: Measure (and Agents = Organizations/Businesses)
- **+0.5 : On-Demand e-Business (?business on demand?)**
  - New Agent (Businesses become more automated, adaptive, resilient, responsive)
- **+1 : NBIC (?nano-bio-info-cogno convergence?)**
  - New Material (Nanotechnology – first impact on materials, electronics, and life sciences)
  - New Sense (Bionics - neural & biochemical interfaces cure deafness, blindness, organ failure)
  - New Mediator (Information WorldBoard - planetary augmented reality system)
  - New Agents (Cognitive robots or Bots - natural language interface to all human knowledge)
- **+5 : Utility Fog (?materials on demand?)**
  - New Material (Utility Fog – billions of particles assemble on-demand to create macro-scale objects)

Business Implications: The Business of People

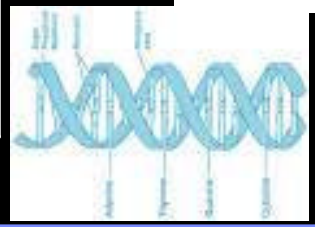
People science or human sciences increasingly driving technology and hence business

The Business of People – Healthy, Wealthy, and Wise

U.S. Census website defines quality of life metrics (health, material goods, info access)

	Science	Technology	Business
Group	Social Science, Economics, Org. Behavior		Financial Services, Legal, Insurance, Government
Individual	Cognitive Science		Education, Communication
Brain	Neurophysiology		Healthcare, Public
Cell	Proteomics		Healthcare, Industrial
Gene	Genomics		Healthcare, Distribution

Science produces Data, drives Info Tech
Tech underlies new Products & Services
New Products & Services drive Business



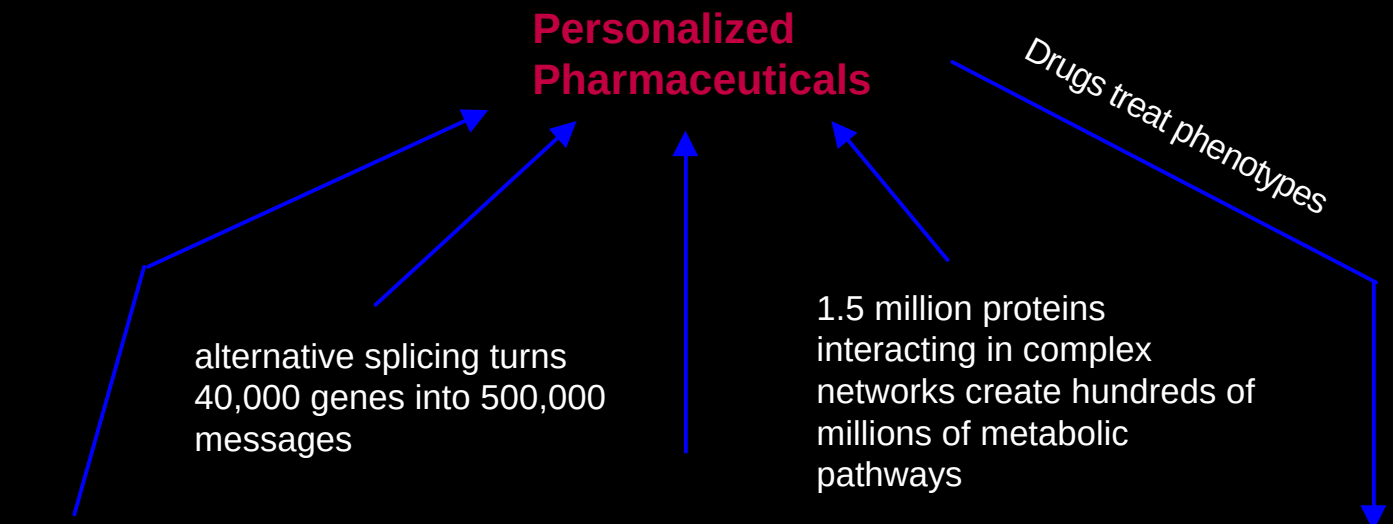
Business Implications: Three examples

- Healthy: Our Bodies & Our Environment
  - Someday Personalized Pharmaceuticals (nano for sensors, delivery, design)
- Wealthy: Our Material Goods (Sustainable, Cheaper, Stronger)
  - Someday On Demand Materials (nano for manufacturing materials)
- Wise: Our Thinking and Perception (Access to Information)
  - Someday Learning Conversations (nano for compute performance, interface)

Healthy

IBM Life Sciences Solutions

Rational drug development requires managing enormous complexity. Pharmaceutical companies are beginning to differentiate themselves on the power of their information technology platforms. IT Platform intellectual property is likely to be more valuable than content (gene sequences, metabolic pathways, protein structures, etc.)



40,000 genes (approx.100 million bases) represent less than 3% of the genome (approx. 3 billion bases). The function of the remaining 97% remains elusive

post translational modification turns 500,000 messages into 1.5 million proteins

hundreds of millions of pathways influenced by the environment and stochastic processes create 6 billion different individuals

Historically, 220 targets have generated $3trillion of value. Industrialized genome sequencing has created a target rich, lead poor environment that will slowly reverse over the next several years as in-silico biology drives the discovery of new lead compounds.

DNA to Phenotype = 300 terabytes per person x 6 billion persons = 1800 billion terabytes of data

Wealthy

Material Goods

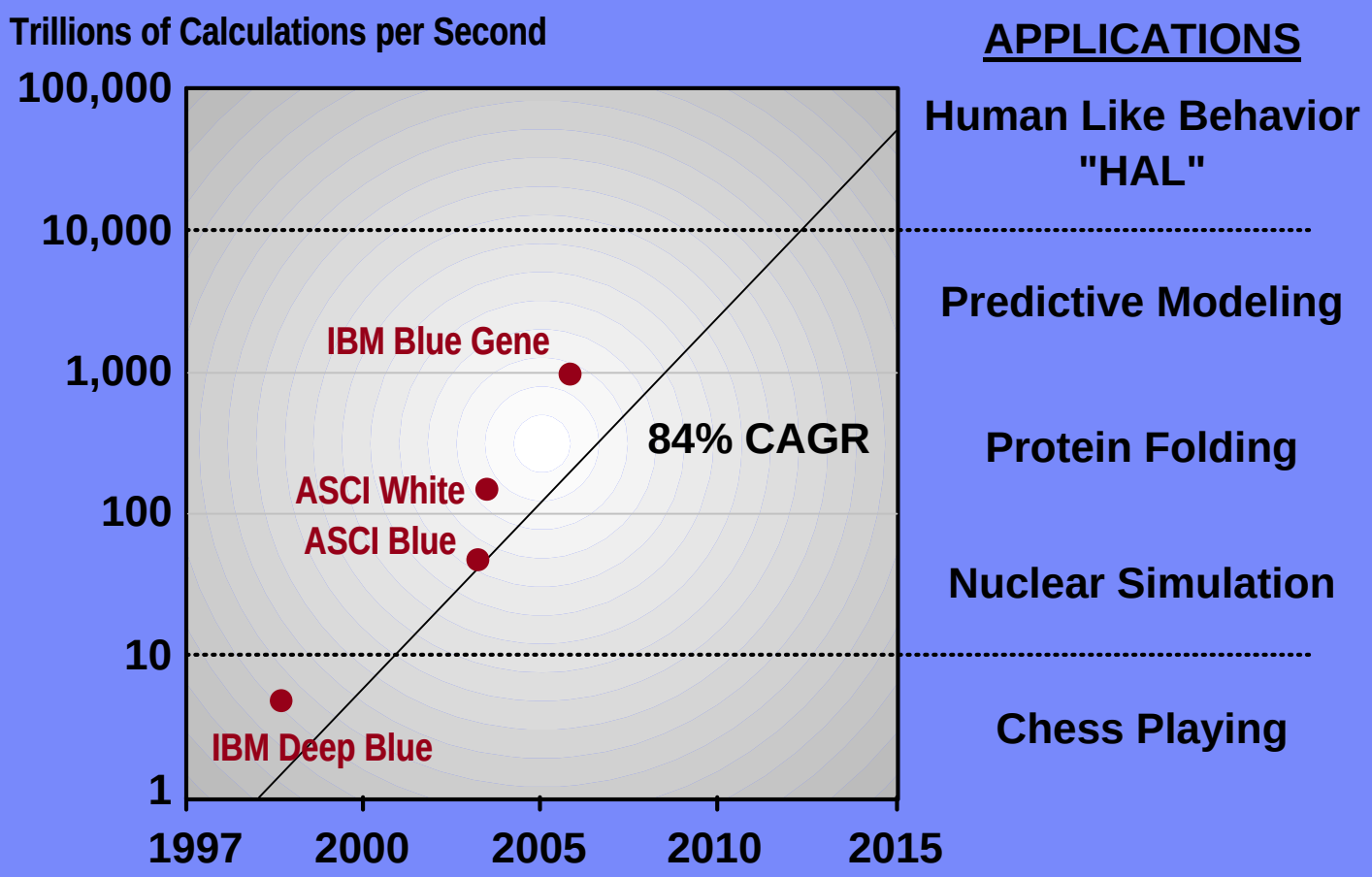
- Environmentally friendly, sustainable production
- Cheaper, Stronger, Lighter, Durable, Active, etc.
- Smart, polymorphic, chromatically active materials
- Clothing and Textiles – stain resistant
- Computing technologies – roll-to-roll manufacturing
- Cars and Vehicles
- Roads
- Houses and Buildings
- Furniture and Appliances
- Foods

Wise

Access to Information

Semantic Web and Natural Language Capabilities

Learning Conversations



Source: ACSI Roadmap www.llnl.gov/asci, IBM Brain ops/sec: Kurzweil 1999, The Age of Spiritual Machines

Business Implications: Evolution of Organizations

On Demand Enterprise – the Evolution of e-Business

- **Sense & respond organizations**
  - E-Utilities, Web Services, Real Time, Adaptive, Policy-Driven, Product Lifecycle Management (PLM), Value-Driven to Profit Zone
- **Business Processes as the evolving DNA of business**
  - People (costs rising)
    - Labor Value Creation: Empowerment via tools and new organizations, Learning
  - Technology (cost dropping)
  - Outsourced Services (cost dropping)
    - Labor Commoditization: Automation, Off-shore, Deskilling
  - External Regulations and Government Policy
- **Organizations as the fastest evolving "agents" on the planet**
  - Monetizing science is done increasingly rapidly as new products/services
  - New products/services accelerating science, new data, new technologies
  - People costs and ability to change are increasingly the limiting factor

Other examples of organizational evolution

- Governments
  - Settlements to Towns to City-States to Empires to Nations
  - Authority by Wisdom, Military Might, Divine Designation, Birth Right, Election
- Cooperatives
  - Robert Owens (1844), Charles Fourier, Granger Movement, Collective Farms, Communes
- Franchises
  - Chain stores, malls, retail brands
- On-line services
  - ISP (AOL), Portals (Yahoo), Retails (Amazon), Auctions (eBay)
- New Products and Services created by new kinds of businesses

Concluding Remarks

- The pioneers taught us that people are adapting to an increasingly information-rich environment
- The science of nano-bio-cogno-socio-techno convergence is about understanding information encoding, processing, and replication across multiple systems
- The sciences concerned with people (human sciences) from DNA, cell, brain, individual, and groups are on the rise, generating enormous amounts of data, and impacting the future of business
- Business (organizations) are the fastest evolving things on the planet, and while technology cost drop, people costs rise

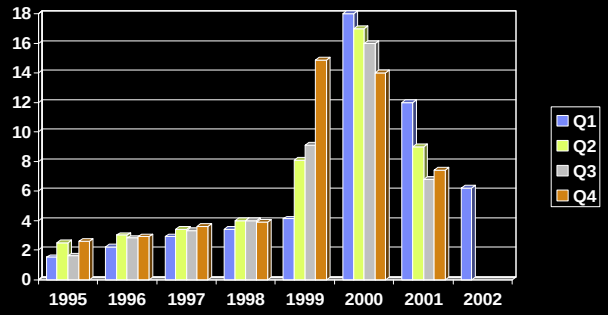
Thank-you for listening.

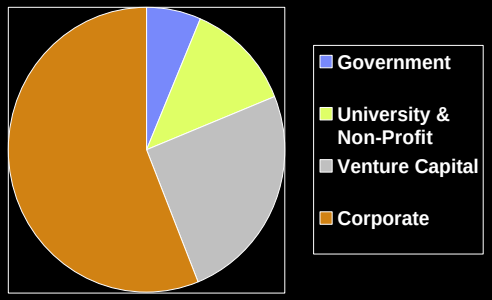
Suggestions, comments, and ideas are very welcome.
E-mail spohrer@almaden.ibm.com or
Jim Spohrer/Almaden/IBM.

EXTRA SLIDES

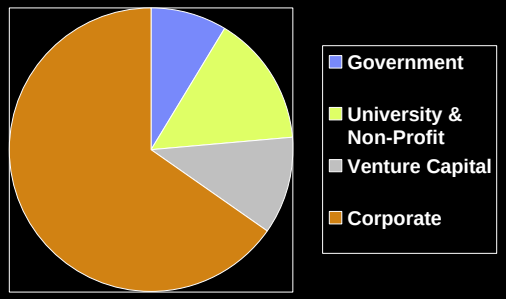
Innovation Ecosystems

- U.S. Government R&D
- U.S. University, Non-Profit R&D
- U.S. Corporate R&D
- U.S. Venture Capital ---------->





•2000, U.S. R&D + VC est. $320B



•2002, U.S. R&D + VC est. $290B

•Estimates from Venture Source & NSF, all numbers approximate

Repositories of Knowledge

- Explicit Knowledge

  Structured Repositories: Databases (e.g., DB2)

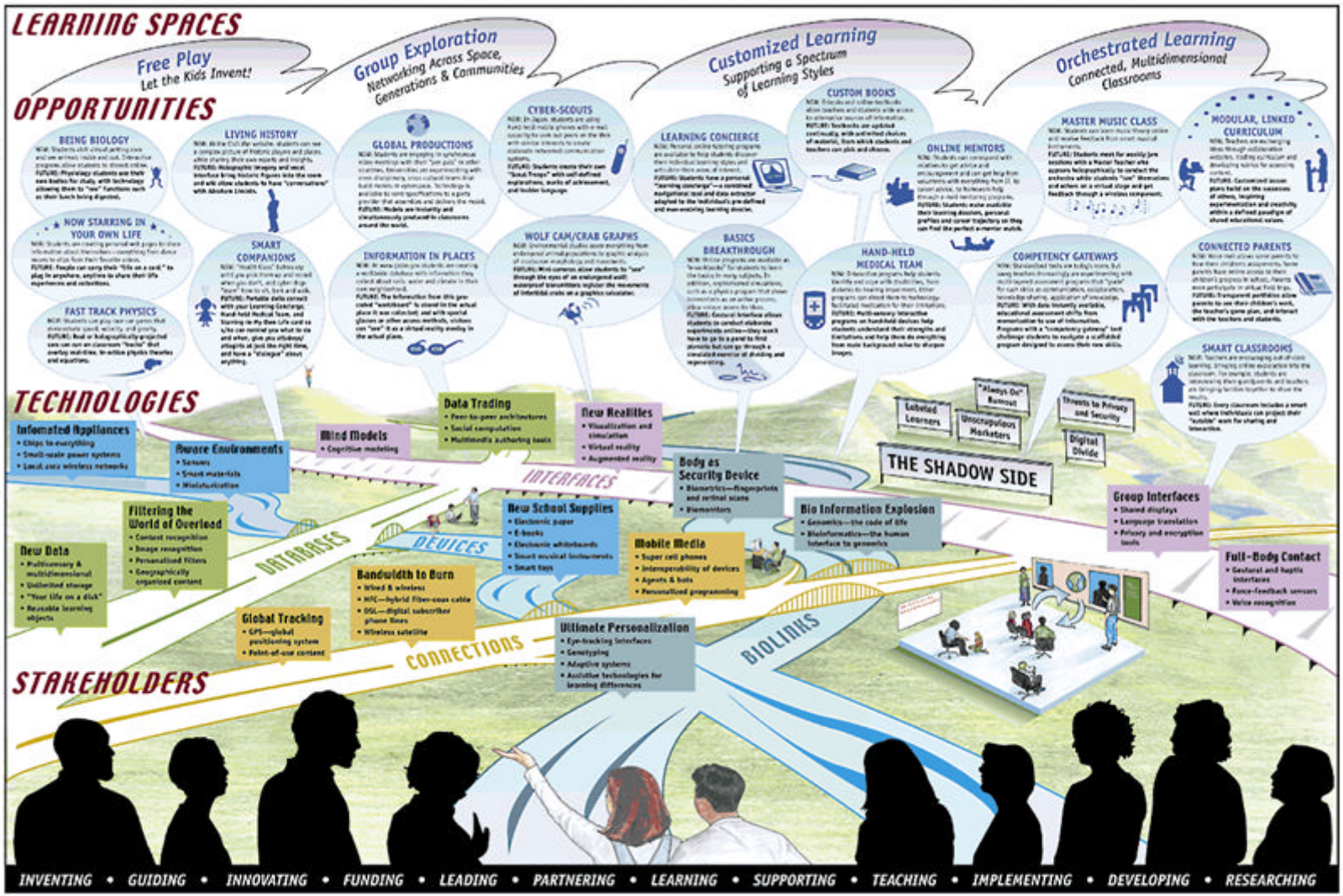
  Unstructured Repositories: Text (e.g., eClassifier, Project WF)

- Tacit Knowledge

  People as Repositories of Knowledge: Tacit knowledge resides in the heads of people. An important category of tacit knowledge is relationship knowledge, knowledge about other people and ways of accessing their services. (e.g., IGS)

  A study by the Delphi Group found that the largest segment of corporate knowledge resides in employees' brains (42%), followed by paper documents (26%) and electronic documents (20%). Quantifying the value of knowledge (e.g., relationship knowledge versus mere facts) is even more difficult to assess.

Sources: http://www.powerhomebiz.com/vol21/knowledge.htm, Delphi Group



Meta Trends: Exponential Growth

- **Moore's Law - Miniaturization - Continues**
  - Processing, Storage, ...
  - Price/Performance 2X over 12-18 months
- **Metcalf's Law - Interconnection - Continues**
  - Value of a network increases as the square of the number connections
- **Gilder's Law - Quantization - Continues**
  - Bandwidth increases 3X every 36 months
- **Negroponte's "Law" - Digitization - Emerges**
  - Superiority of "bits over atoms"
  - Profound impact felt in "Knowledge Economy" where ideas are ultimate raw material

Key Megatrends Driving Venture Investment

Key Mega*shifts*

Switching is shifting **from circuits to packets**.
- Data, then voice; Backbone, then access

Transmission is shifting **from electronic to photonic.**
- First long haul, then metro, then local access

Functions are moving **from the enterprise to the Net**.
- IP universal protocol/ platform of choice is the Net

Offerings are moving **from products to services**.
- "Utilitization" of processing, applications, storage, ... knowledge

Bioscience is moving **from *in vitro to in silico.***
- First Genomics, then Proteomics, ... nanotechnologies