COMMUNICATION ACROSS SCIENTIFIC DISCIPLINES

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FOUR ISSUES

(1) Two Scientific Perspectives

(2) Common Metaphors

(3) Shared Methods and Models

(4) Common Problems across Disciplines

- (a) Self-Organizing Processes
- (b) Complex Networks
- (c) Power Law Distributions
- (d) Processes of Binding and Dissolution
- (e) Multi-Level Analysis

Differences Between Science I and Science II

	Science I	*Science II*
Leading Fields of Science:	Classical Physics	Evolutionary Biology and the Sciences of Complexity
Theoretical Goal:	General, Universal Laws	Pattern Formation and Pattern Recognition
Theory Structures:	Axiomatic, Reductionist	Phenomena Nested in Multiple Levels of Reality Simultaneously
Forecasting Capacities or Ability to Make Predictions:	High	Low
Complexity:	Low	High
Ontology:	Dualism (*res extensa*/ *res cogitans*)	Monism, with a Highly Complex Architecture
Perspective on Change:	Emphasizes Static, Linear Phenomena in a State of Equilibrium	Emphasizes Dynamism, Openness of System, Operating Far from Equilibrium

Differences Between Science I and Science II

	Science I	*Science II*
Distribution of Phenomena:	Emphasis on Normal Distributions, Phenomena Which are Distributed Like a Bell-shaped Curve	Emphasis on Rare or Extreme Events; Sensitive to Phenomena with Power-law Distributions
Micro-Macro Distinctions:	Micro and Macro Level Processes are Viewed as Separate and Distinctive	Little Distinction: Macro Phenomena Emerge from the Collective Micro Level Behavior
Potential for Interdisciplinary Research:	Low	High
Leading Metaphors:	Clocks	Complex Networks, Living Cells, Clouds
Cognitive Distances between the Social Sciences and the Natural Sciences:	High	Medium
Inspirational Scientists:	René Descartes, Isaac Newton, Adam Smith	Charles Darwin, Ilya Prigogine

Common Metaphors

Shared Methods and Models

FIVE MAJOR, INTERRELATED AREAS OF SCHOLARSHIP IN WHICH SOCIAL SCIENTISTS AND NATURAL SCIENTISTS ARE WORKING ON COMMON TYPE PROBLEMS

1) Self organizing processes
2) The structure and dynamics of complex networks
3) Power-law distributions
4) The binding problem - also called the problems of integration and disintegration
5) Multi-level analysis

Self-Organizing Processes

Complex Networks

Complex Networks

THREE KEY CONCEPTS:

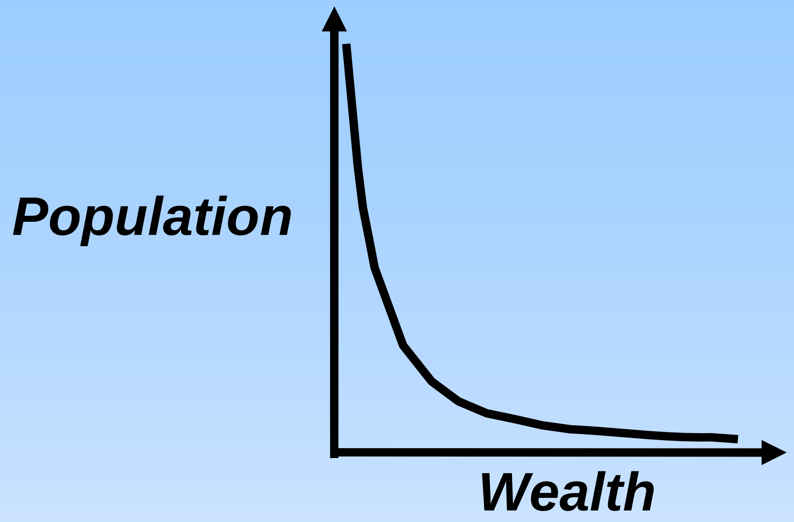
Growth

Preferential Attachment

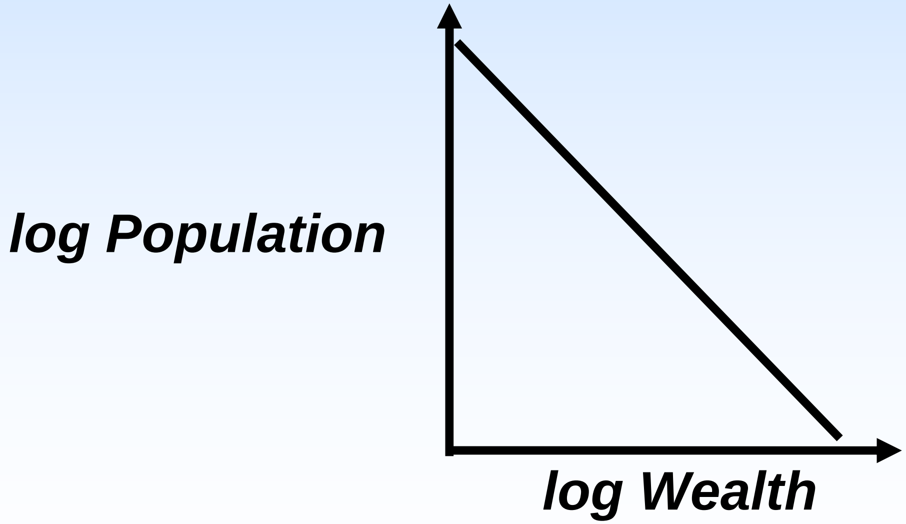
Rewiring

Power Law Distributions

Examples of Power-law Distributions

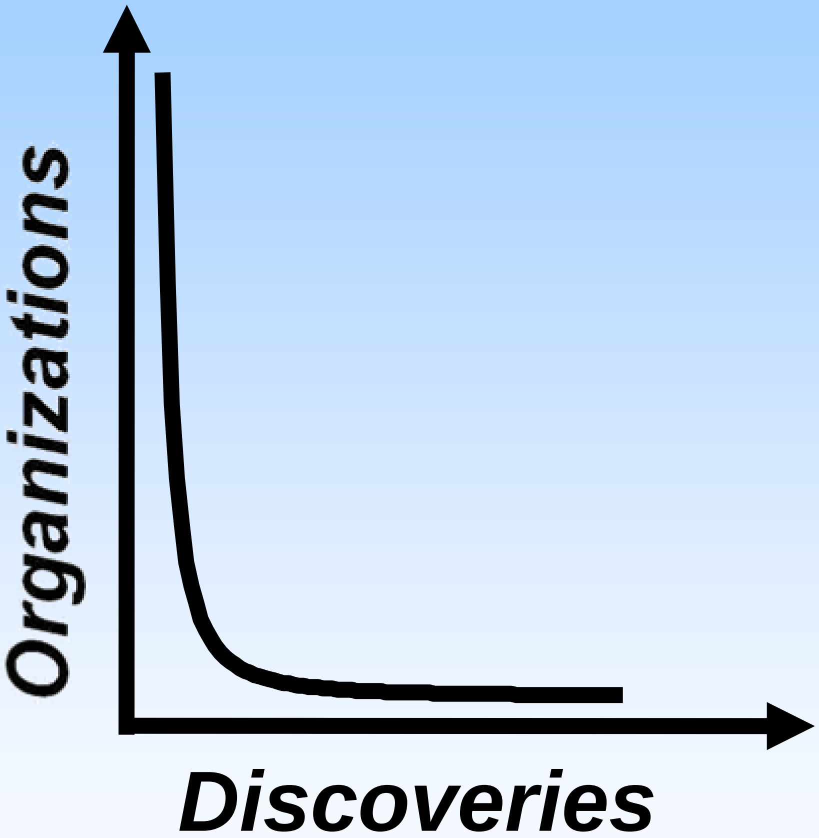


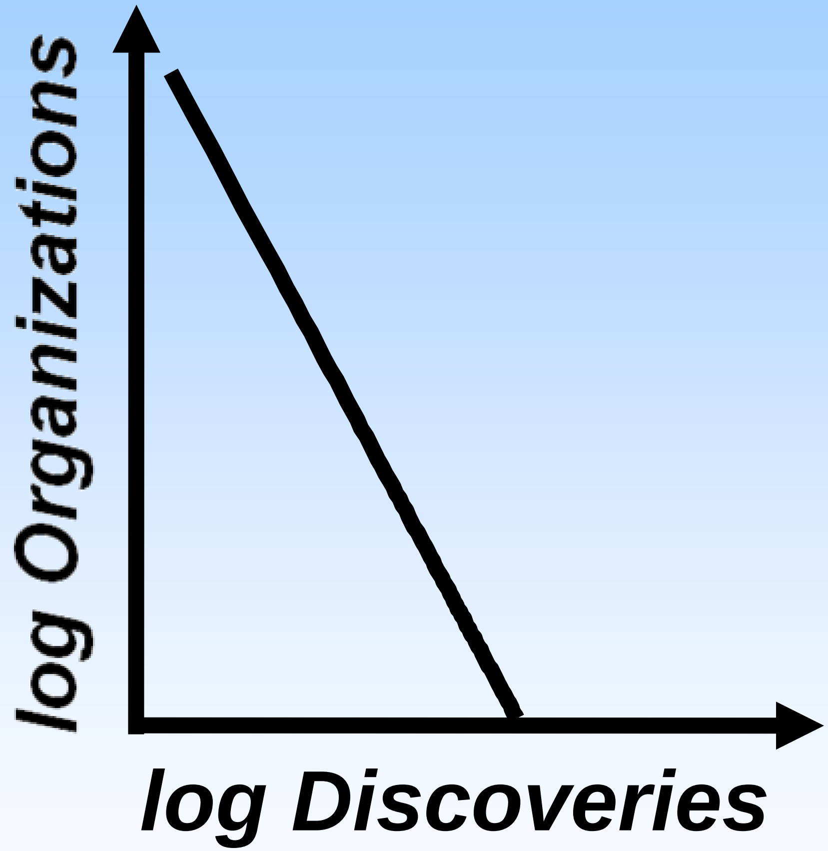
Power-law Distribution



Power-law Distribution on a log-log Plot

Power Law Distribution of Major Discoveries Across Research Organizations





n = 755

The exponent = -1.9962

Processes of Binding and Dissolution

Multi-Level Analysis

David Gear

and

Ellen Jane Hollingsworth

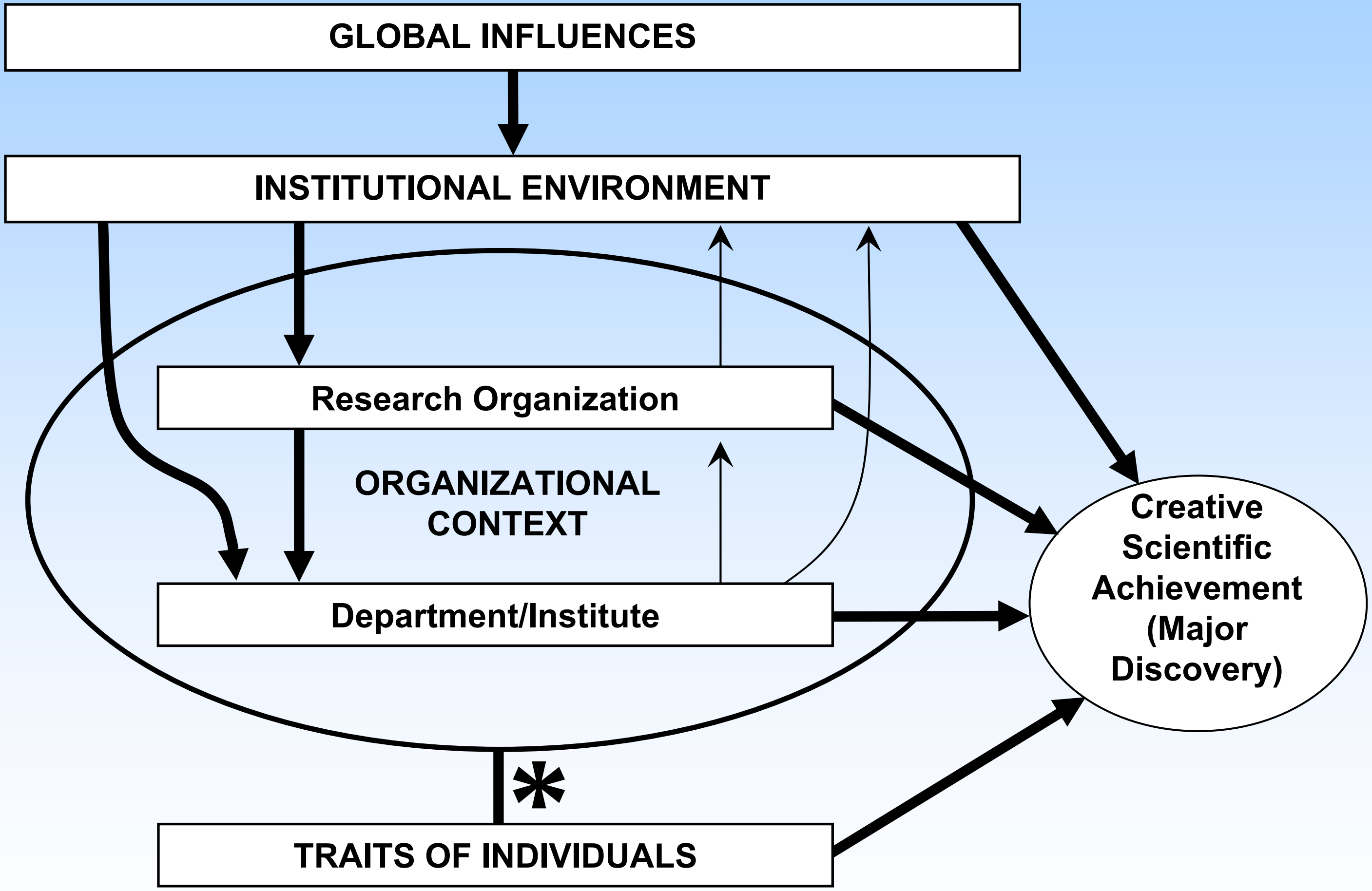
made enormous contributions

for this presentation

Examples of Multi-Level Analysis

Natural Sciences		Social Sciences	
Physical Science	***Biological Science***	***Spatial Analysis***	***Structural Analysis***
Cosmos	**Ecosystems**	**Global**	**Rules, Norms, Habits, Conventions, etc. (Institutions)**
Galaxies	**Organisms**	**Transnational Regions (e.g., European Union)**	**Institutional Arrangements (Markets, Hierarchies, States, etc.) and Institutional Sectors (Financial, Educational, Business, Research Systems, etc.)**
Stars	**Tissues**	**Nation State**	**Organizations, Firms**
Earth	**Cells**	**Subnational Region**	**Small Groups, Families**
Subsystems of Earth	**Molecules**	**Local Level**	**Individuals**
Molecules	**Atoms**		
Atoms			
Particles			

Factors at Multiple Levels Influencing Individual Creativity in Basic Biomedical Science



***Each organization attempts to recruit individuals who complement its culture and structure**

Definition of a Major Discovery

A major breakthrough or discovery in biomedical science is a finding or process, generally preceded by numerous "small advances," which leads to a new way of thinking about a problem. This new way of thinking is highly useful in addressing subsequent problems by numerous scientists in *DIVERSE* fields of science. Historically, a major breakthrough in biomedical science was a radical or new idea, the development of a new methodology, a new instrument or invention, or a new set of ideas. It has usually not been something which occurred all at once, but involved numerous experiments or a process of investigation taking place over a substantial period of time.

Indicators of Major Discoveries

1. Copley Medal
2. Nobel Prize for Physiology or Medicine
3. Nobel Prize for Chemistry
4. Ten nominations in three years for Nobel Prize for Physiology or Medicine
5. Ten nominations in three years for Nobel Prize for Chemistry
6. Prizeworthy in Physiology or Medicine
7. Prizeworthy in Chemistry
8. Lasker Prize in Basic Science
9. Louisa Gross Horwitz Prize
10. Crafoord Prize

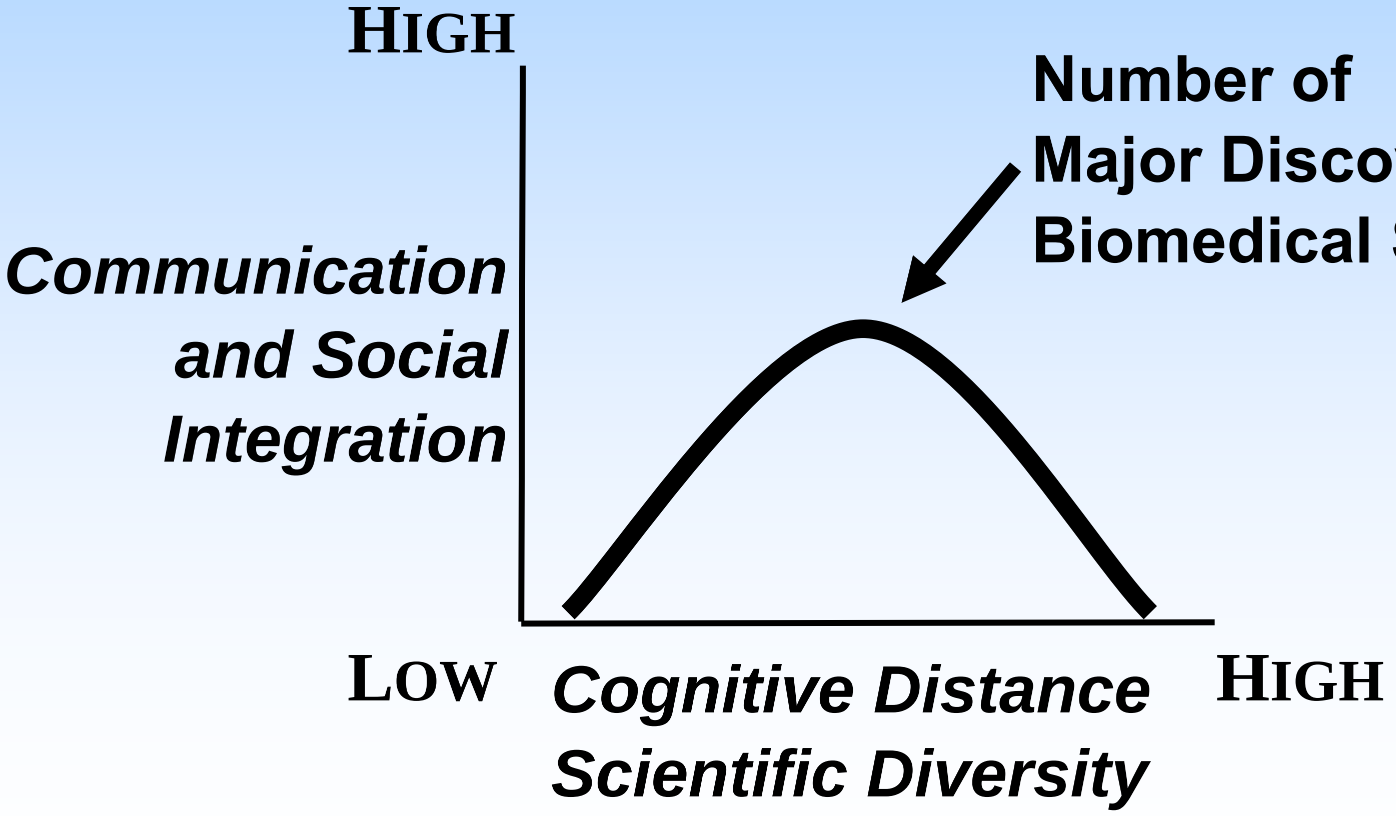
What qualities of an organization facilitate making major discoveries?

- ►Moderately high scientific diversity
- ►Capacity to recruit scientists who internalize scientific diversity
- ►Communication and social integration of scientists from different fields through *frequent* and *intense* interaction
- ►Leaders who integrate scientific diversity, have the capacity to understand the direction in which scientific research is moving, and provide rigorous criticism in a nurturing environment
- ►Flexibility and autonomy associated with loose coupling with the institutional environment

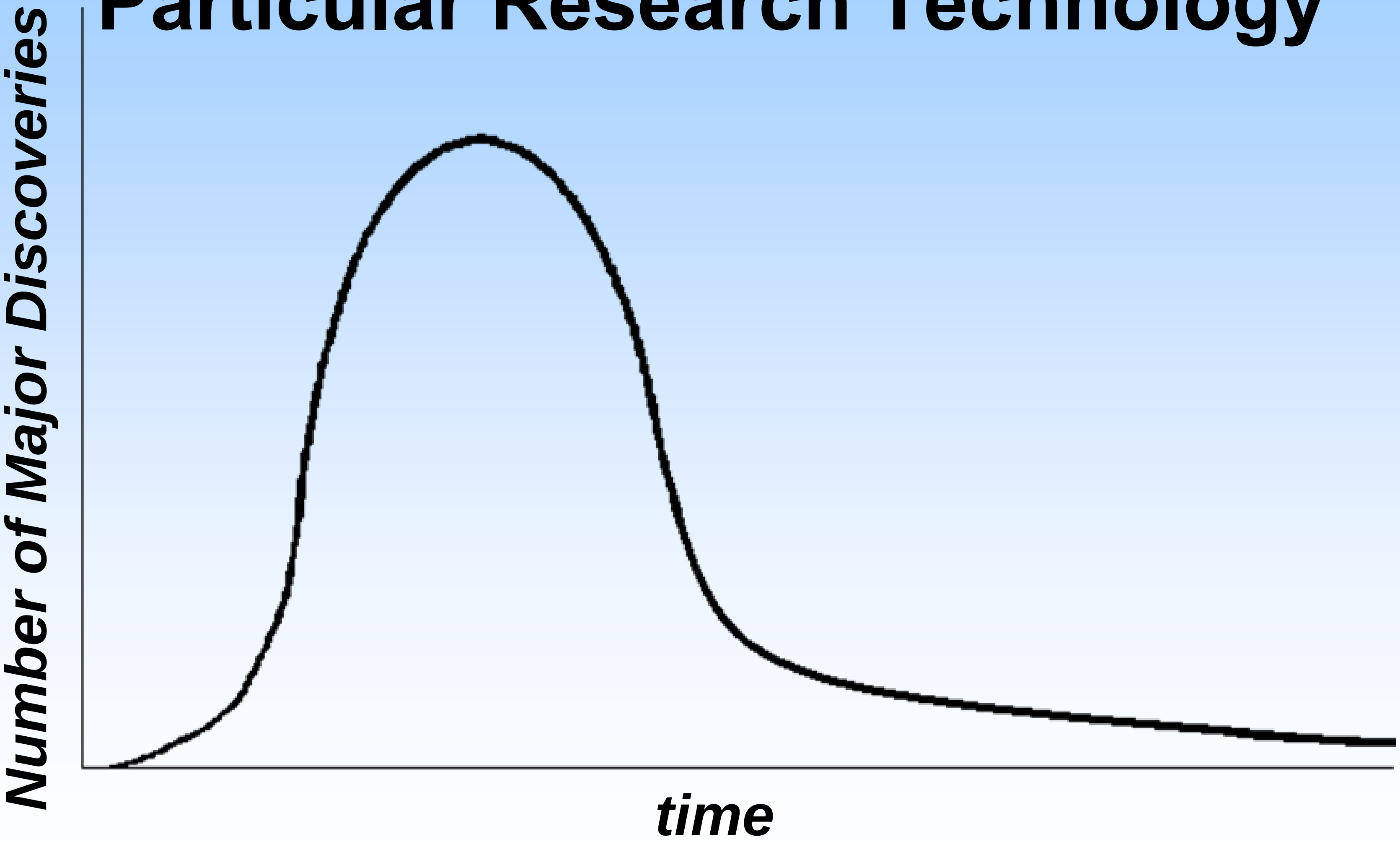
What qualities of an organization hamper the making of major discoveries?

- ►High differentiation – sharp boundaries among subunits such as departments, divisions, or colleges
- ►Hierarchical authority – centralized decision-making about research programs, number of personnel, work conditions, and/or budgetary matters
- ►Bureaucratic coordination – high standardization of rules and procedures
- ►Hyperdiversity – diversity to the degree that there cannot be effective communication among actors in different fields of science

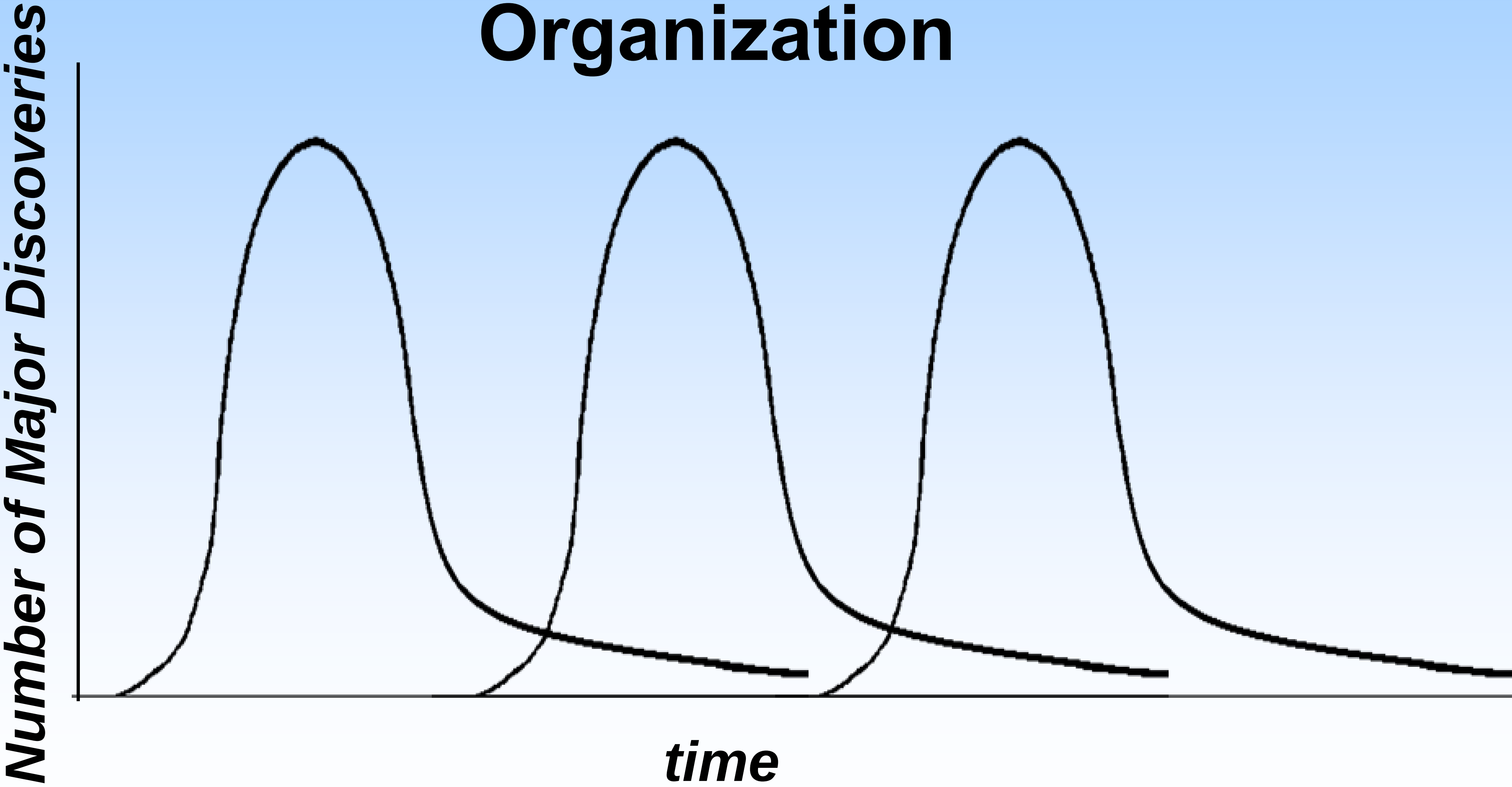
The Impact of Communication and Cognitive Distance on Making Major Discoveries in Biomedical Science



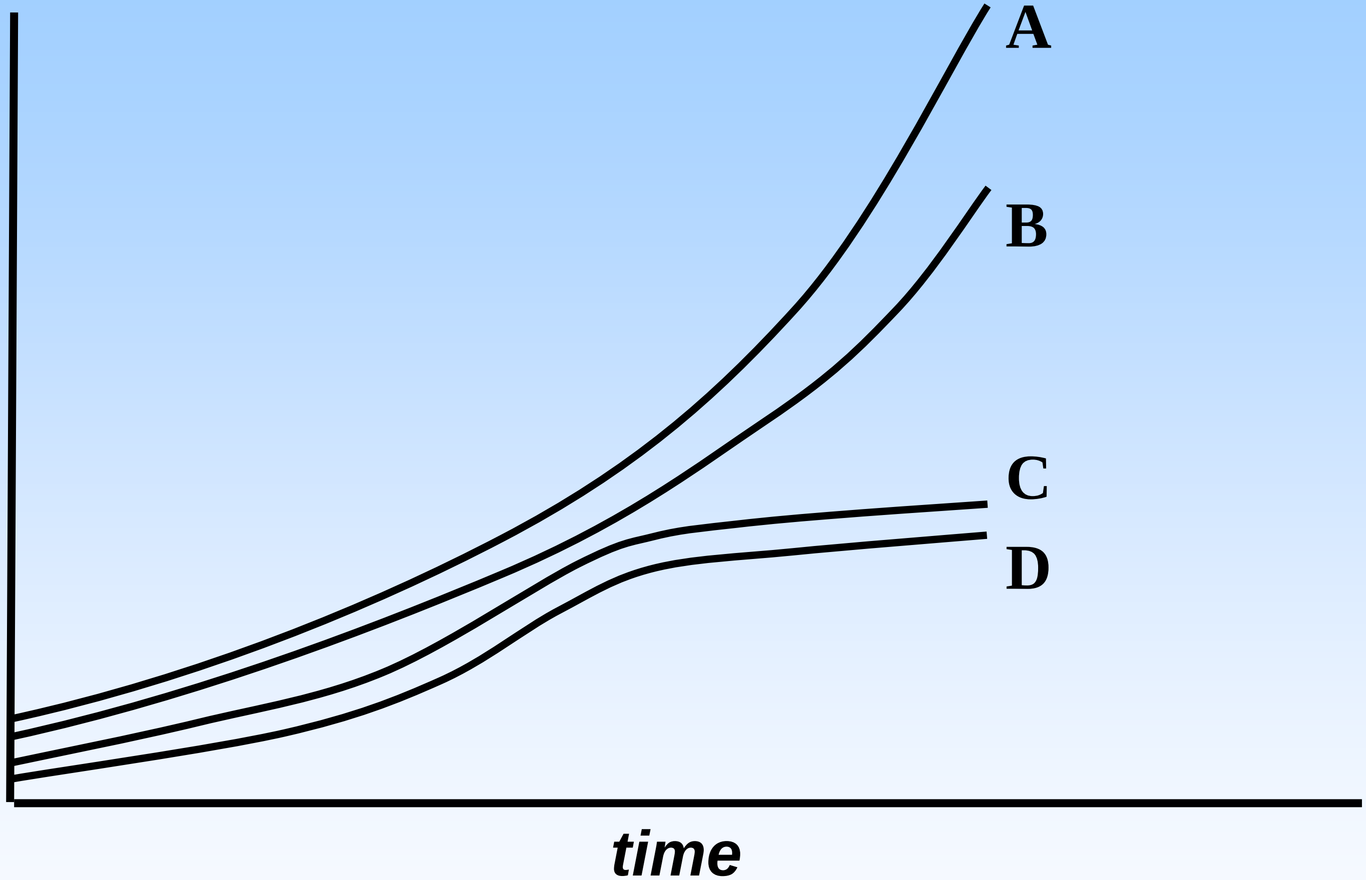
Emergence and Decline of Major Discoveries in a Problem Area Given a Particular Research Technology



Rise and Decline of Major Discoveries in Multiple Problem Areas in a Single Organization

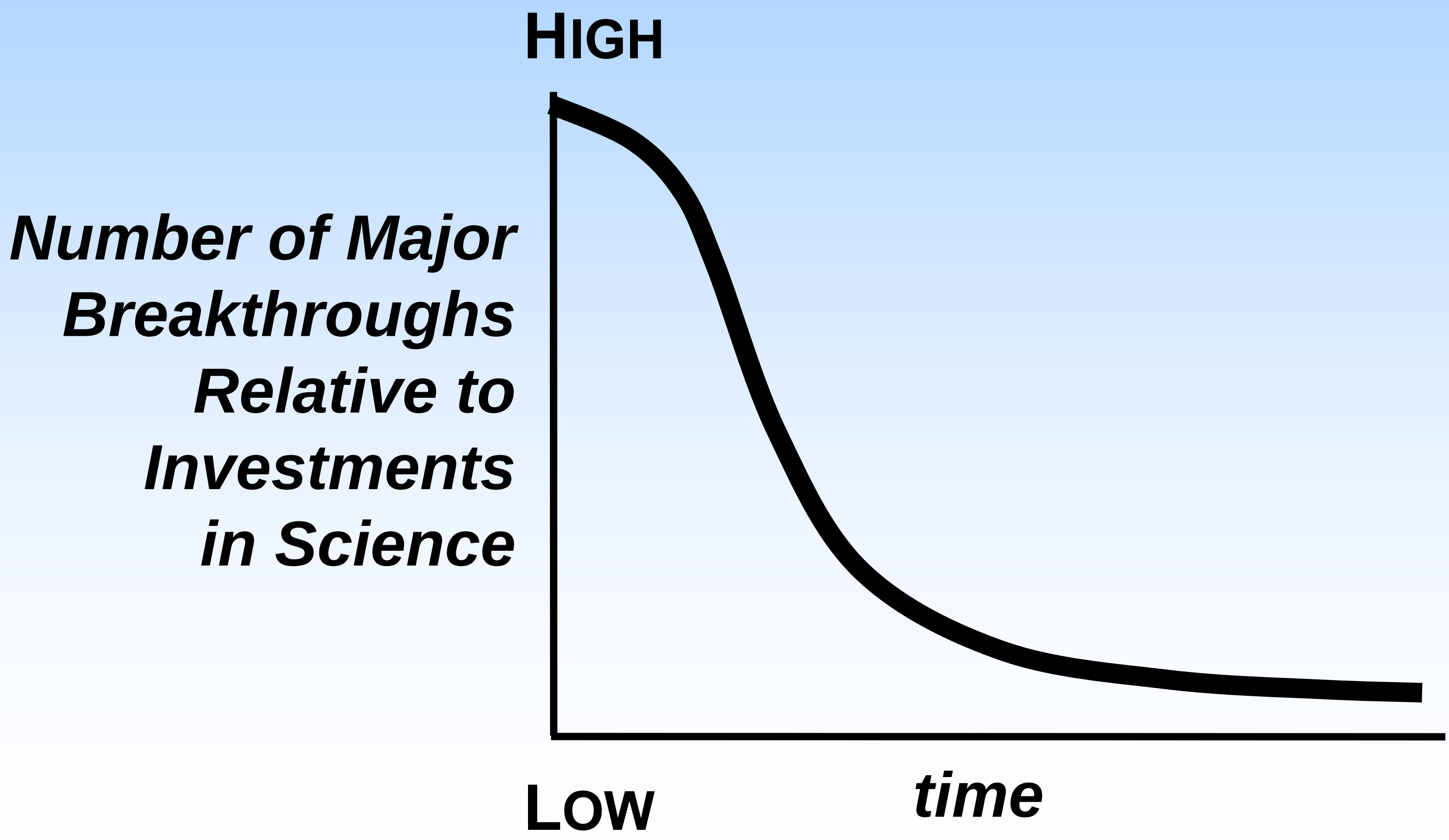


Historical Growth of Investments in Science

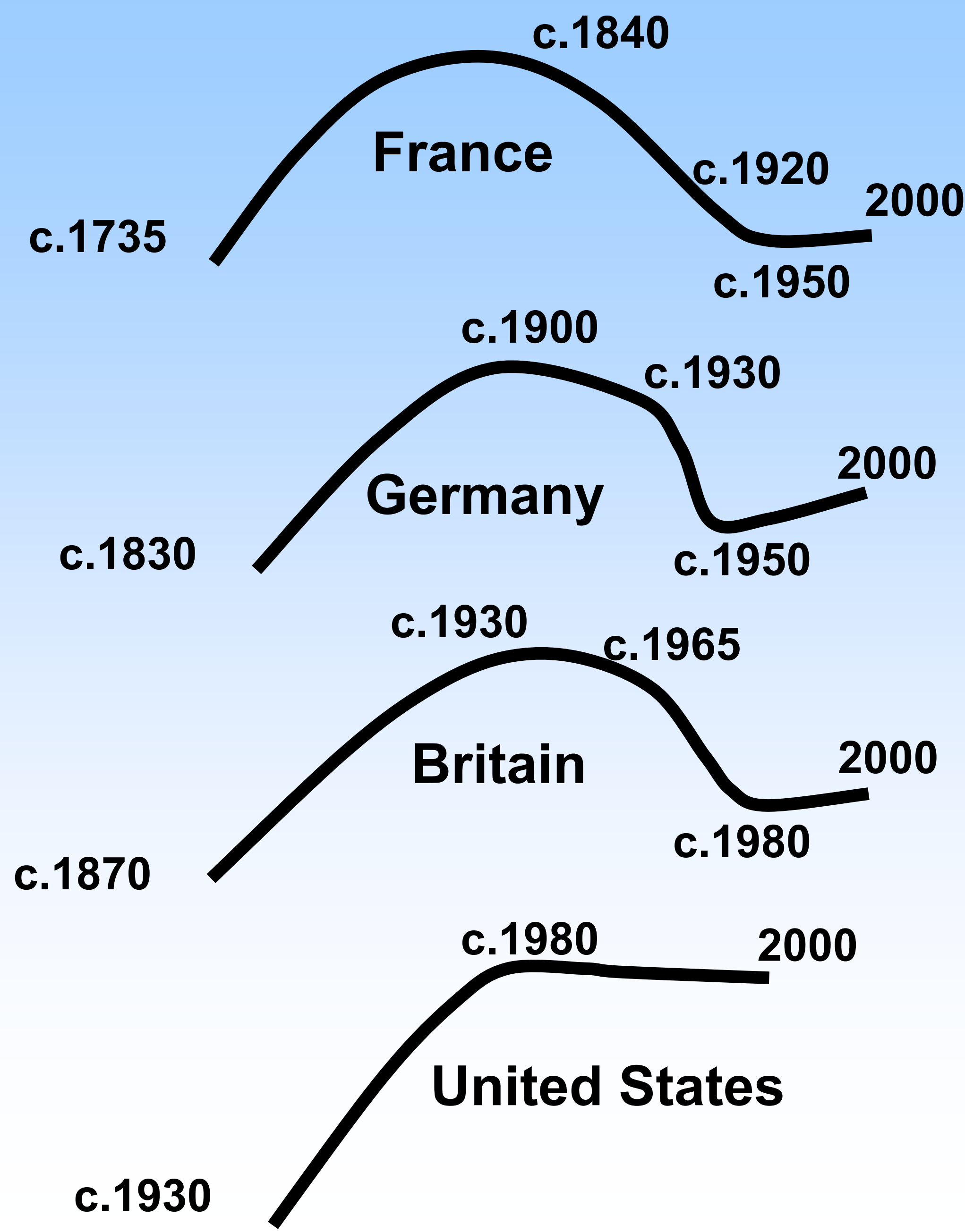


A Number of Scientific Papers
B Numbers of Scientific Journals
C Percent of Workforce in Research and Development
D Percent of Gross National Product for Research and Development

Diminishing Returns to Scientific Effort to Make Major Breakthroughs



The Rise and Decline of Hegemonic Systems of Science



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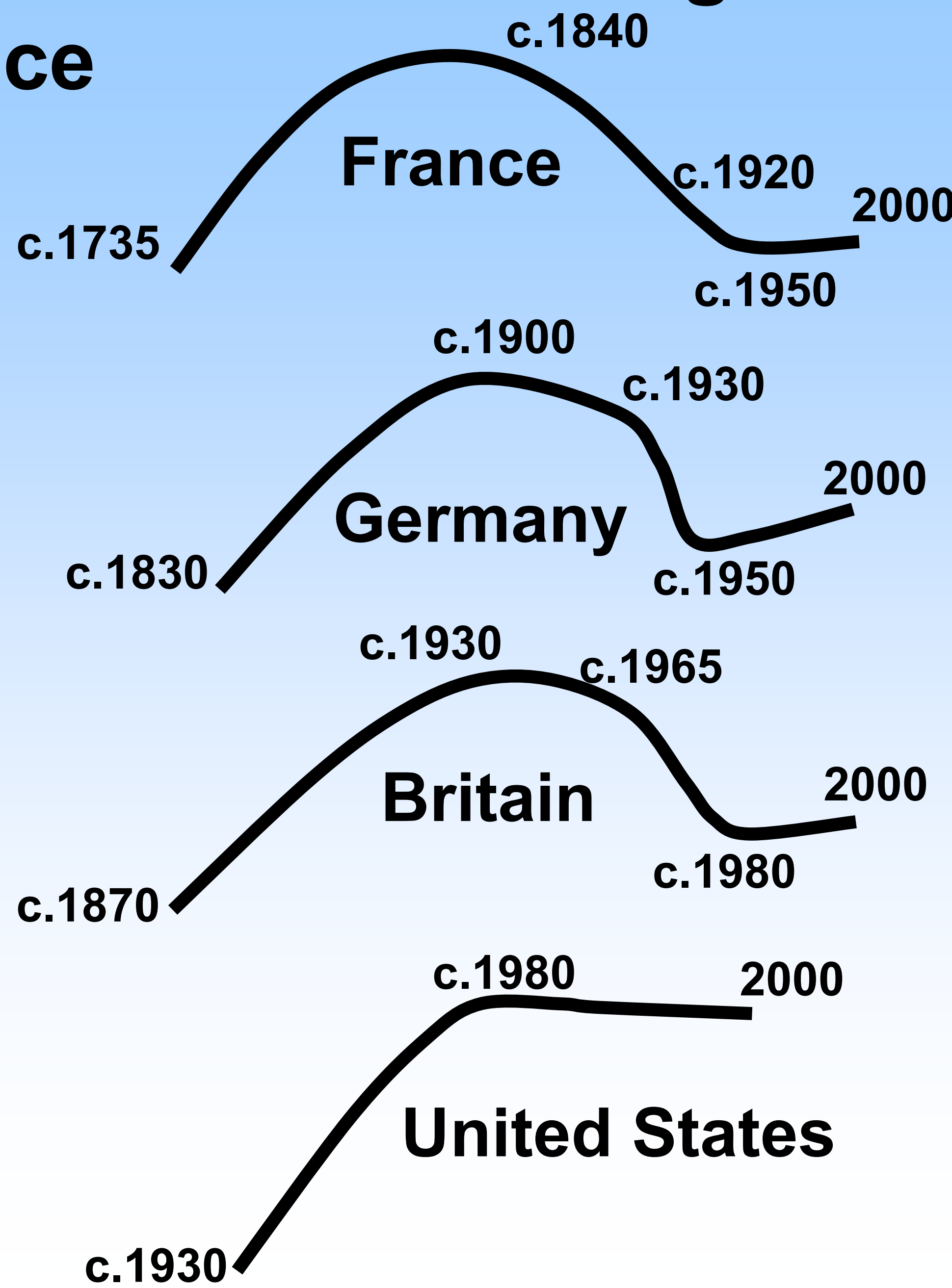


Ellen Jane Hollingsworth made enormous contributions for this presentation

Characteristics of Type A Laboratories

- **Cognitive: High scientific diversity**
- **Social: Well connected to invisible colleges (for example, networks) in diverse fields**
- **Material Resources: Access to new instrumentation and funding for high-risk research**
- **Personality of lab head: High cognitive complexity, high confidence and motivation**
- **Leadership: Excellent grasp of ways that different scientific fields might be integrated and ability to move research in that direction**

Characteristics of Type B Laboratories

- Cognitive: Moderately low scientific diversity
- Social: Well connected to invisible colleges (for example, networks) in a single discipline
- Material Resources: Limited funding for high-risk research
- Personality of lab head: Lack of high cognitive complexity, limited inclination to conduct high-risk research
- Leadership: Not greatly concerned with integrating different scientific fields

Weak Institutional Environments

1. Weak Control over Personnel
2. Weak Control over Scientific Disciplines
3. Weak Control over Funding for Scientific Research
4. Many Different Types of Training Systems
5. Strong Normative Environment for High Risk Research

Strong Institutional Environments

1. Strong Control over Personnel
2. Strong Control over Which Scientific Disciplines Will Exist in an Organization
3. Strong Control over Funding for Scientific Research
4. Strong Prescription of Level of Training Necessary for a Scientific Appointment
5. Strong Control over Scientific Entrepreneurship

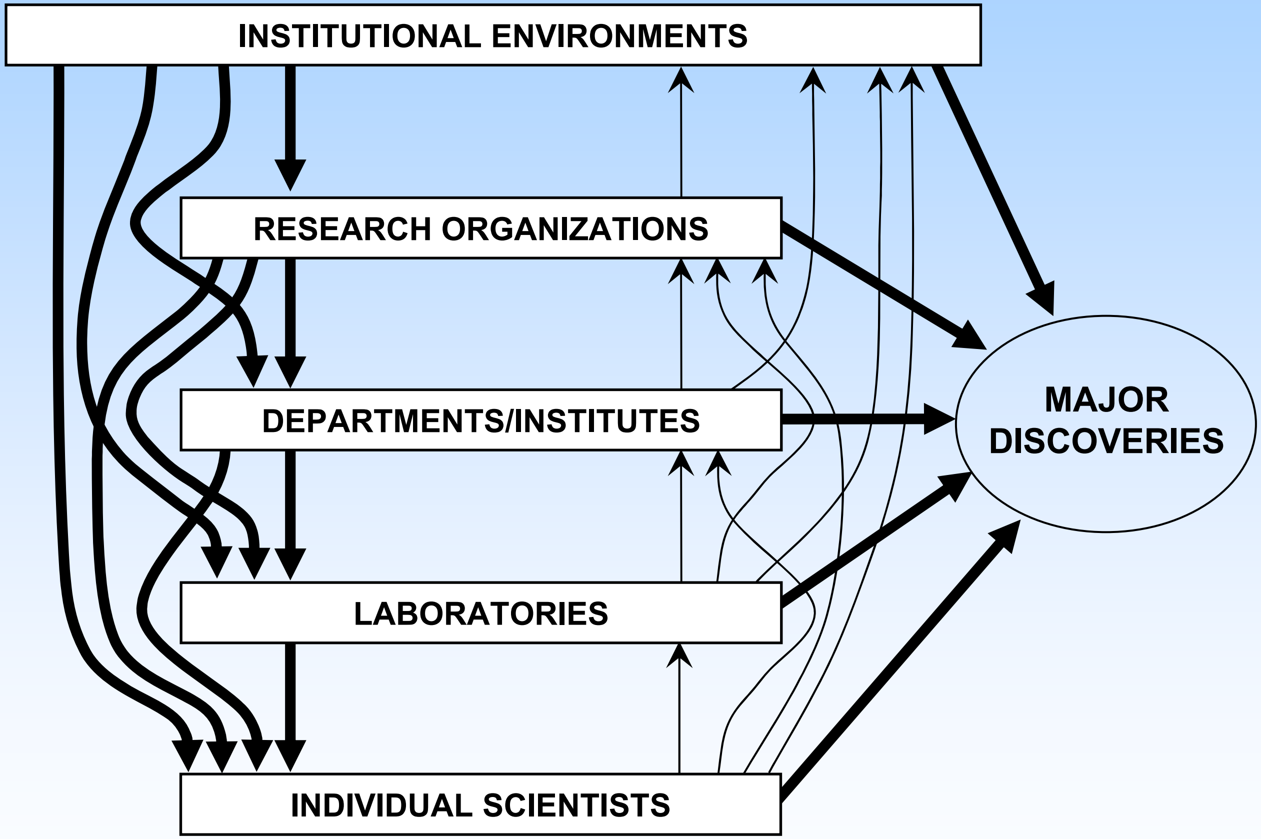
What is defined as creativity varies across fields, across societies and time within specific societies. Creativity at the level of individuals is influenced by personality traits and is facilitated or hindered by the social environment. This paper focuses on a single but broad area of science: the basic biomedical sciences. The analysis focuses on creativity in this area in Britain, France, Germany, and the United States from the late nineteenth century to the present. The paper focuses on personal, institutional, and organizational factors which facilitated individuals making major discoveries.

The paper addresses three basic questions:

1. **What were some of the traits at the level of individuals which influenced their creativity and the making of major discoveries?**
2. **How did institutional and organizational factors facilitate or hinder creativity and the making of major discoveries?**
3. **How did the global economic environment of these four countries facilitate or hamper creativity and the making of major discoveries?**

It was the internalization of multiple cultures and/or strong commitment to non-scientific avocations which led individuals to have high cognitive complexity, scientific diversity, and creativity.

Factors at Multiple Levels Influencing Major Discoveries



Multi-Level Analysis and Complex Networks

I. Lowest Level

1. Attempting to understand the network of networks responsible for the behavior of the cell
2. Many diseases are independent of one another
3. Many diseases are linked in a network consisting of multiple genes, transcription factors, RNAs, enzymes, and metabolites; thus, the need to understand the functionally relevant genetic, regulatory, metabolic, and protein-protein interactions in a cellular network

II. Disease networks

Examples: diabetes mellitus, obesity, asthma, insulin resistance

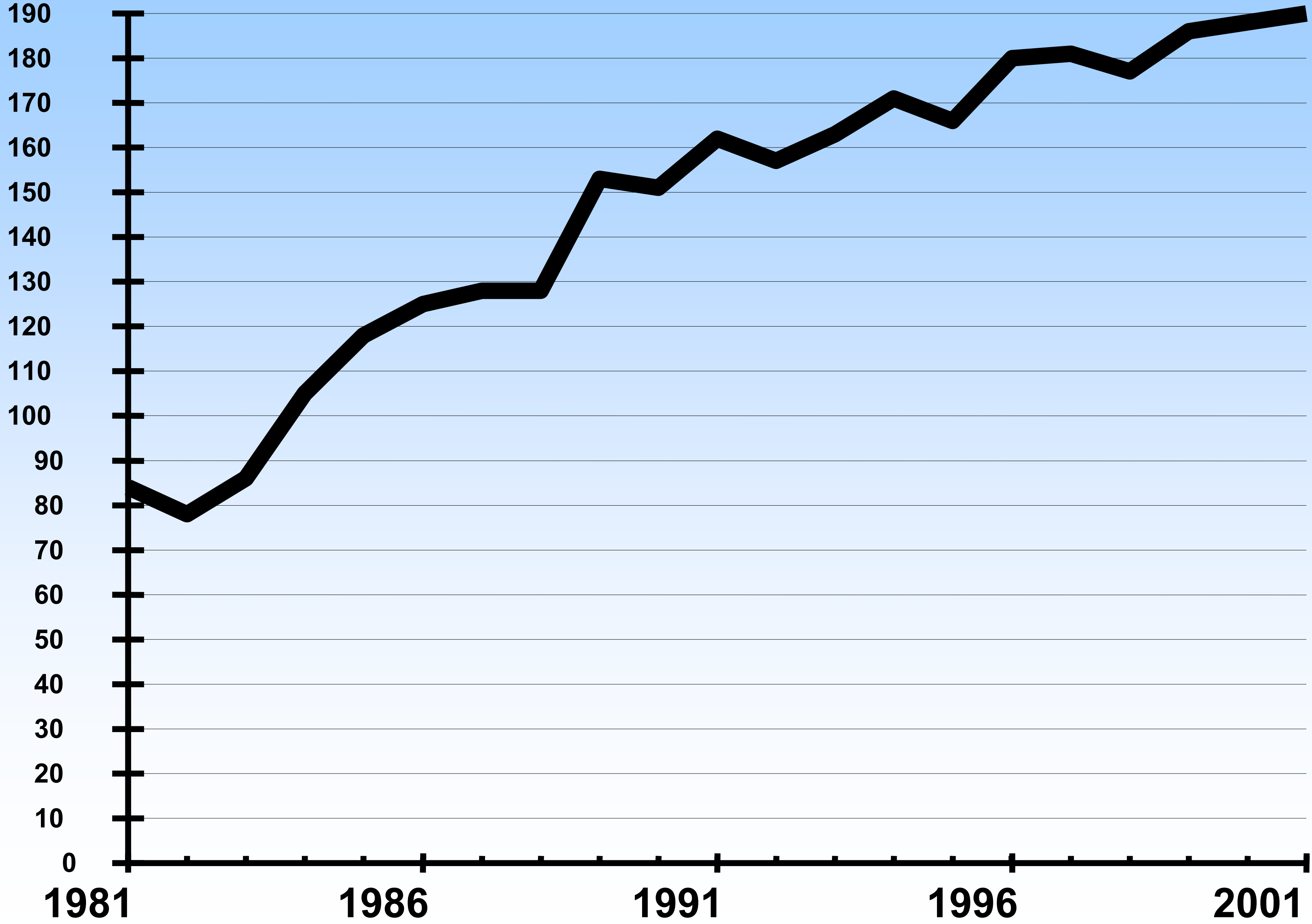
III. Social networks

1. Social links
2. Family ties
3. Physical proximity

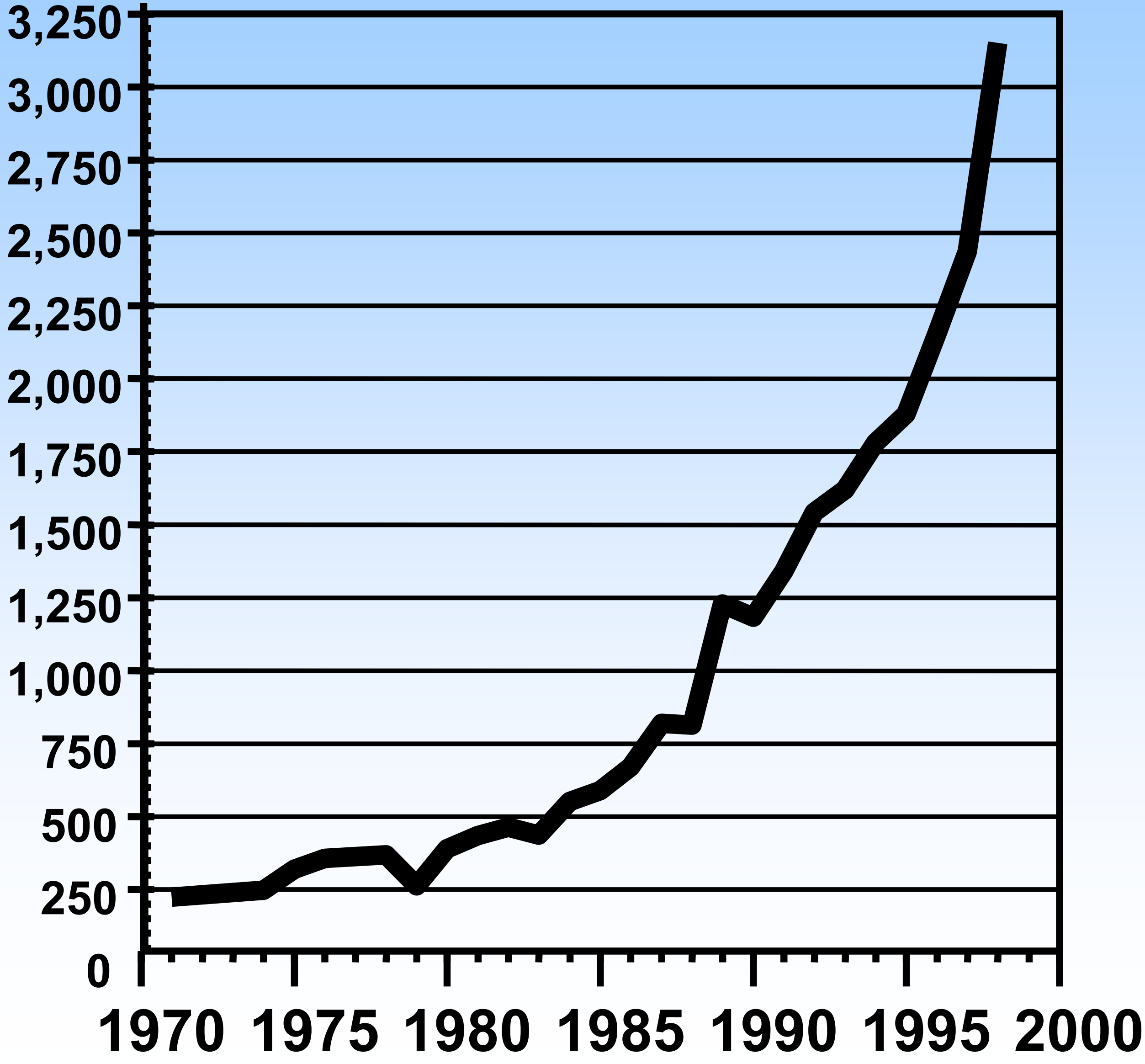
IV. Advancing new technologies

1. IBM and NSF's efforts to develop a new supercomputer with benchmark of one petaflop: one thousand trillion mathematical computations per second
2. The Japanese contend they will have one with a capability of ten petaflops by 2011 - Consult: Albert-Lázlo Barabási, *New England Journal of Medicine* July 26, 2007, and *Nature Reviews Genetics* February 2004

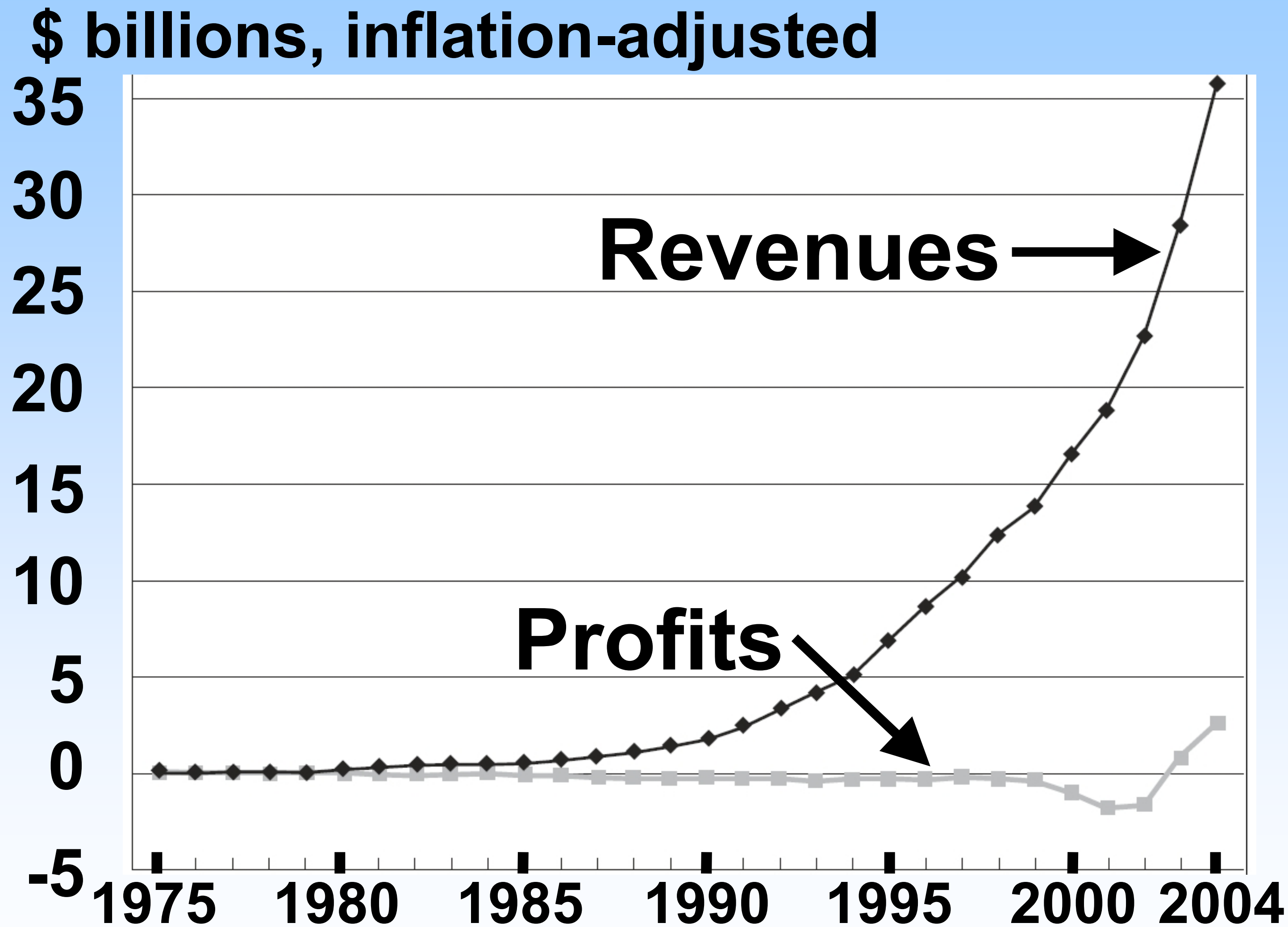
Number of Academic Institutions Granted Patents 1981 – 2001



U.S. Patents Granted to U.S. Academic Institutions 1971 – 1998



Revenues and Profits in the Biotechnology Sector 1975 – 2004

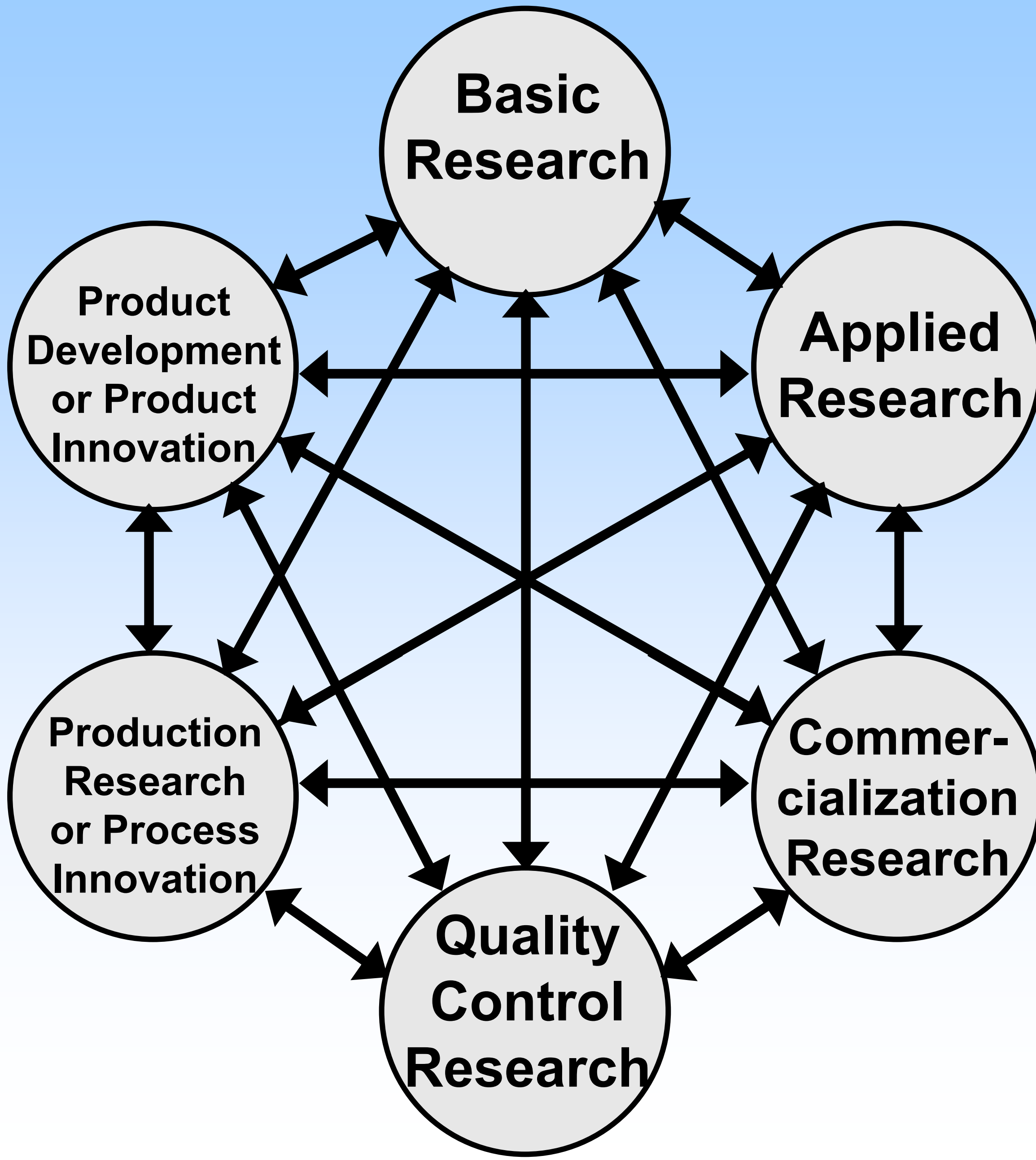


Data from: Gary P. Pisano. 2006. *Science Business: The Promise, the Reality, and the Future of Biotech*. (Harvard Business School Press) p. 5.

Gifts to 20 U.S. Universities, 2007

	MILLIONS		MILLIONS
1. Stanford	$ 832	11. MIT	$ 329
2. Harvard	614	12. Chicago	328
3. USC	470	13. Wisconsin	325
4. Johns Hopkins	430	14. Washington	300
5. Columbia	424	15. Michigan	293
6. Cornell	407	16. Minnesota	289
7. Pennsylvania	392	17. New York	288
8. Yale	391	18. Virginia	283
9. Duke	372	19. Indiana	279
10. UCLA	365	20. UCSF	252

Functional Arenas in the Idea Innovation Network



Link on Basic Research: Research on preservation of marine life and diverse biofuels

Link on Applied Research: Developing strategies for more effective use of ethanol, shale oil; for generating and transporting solar energy

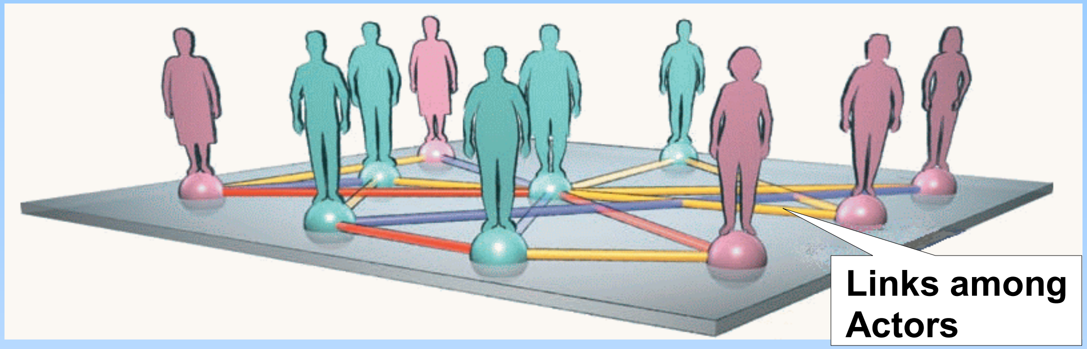
Link on Product Development Research: Product development of solar panels, ethanol, shale oil, lighter materials for use in transportation

Link on Quality Control Research: Higher quality and safer nuclear facilities, higher quality refining facilities

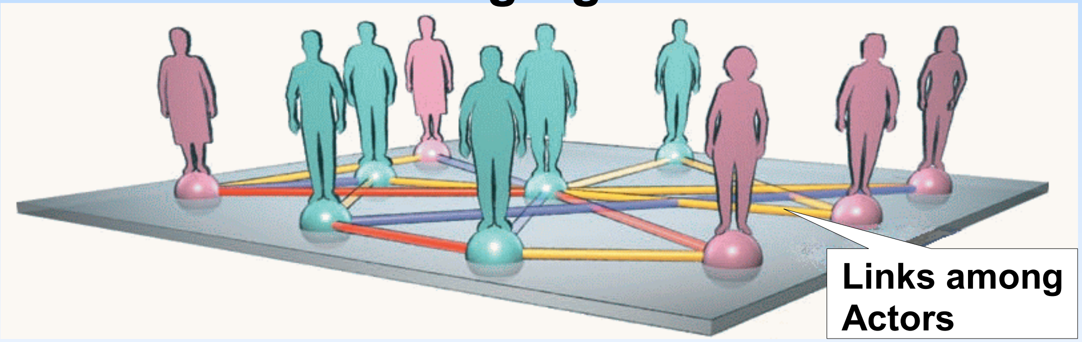
Link on Production Research: Research on more efficient systems of transportation, better systems for the transportation of energy

Links on Marketing and Mass-Education Research: Research on how to develop public awareness of the need for more effective energy usage, carbon controls, the protection of the environment

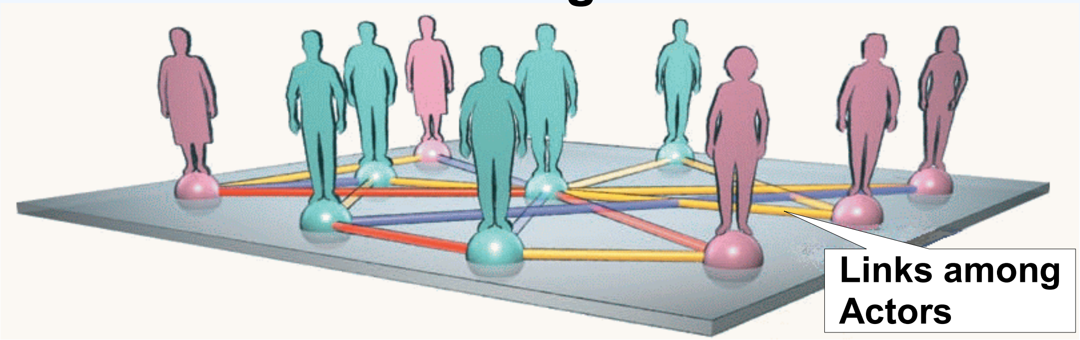
Scientific Networks



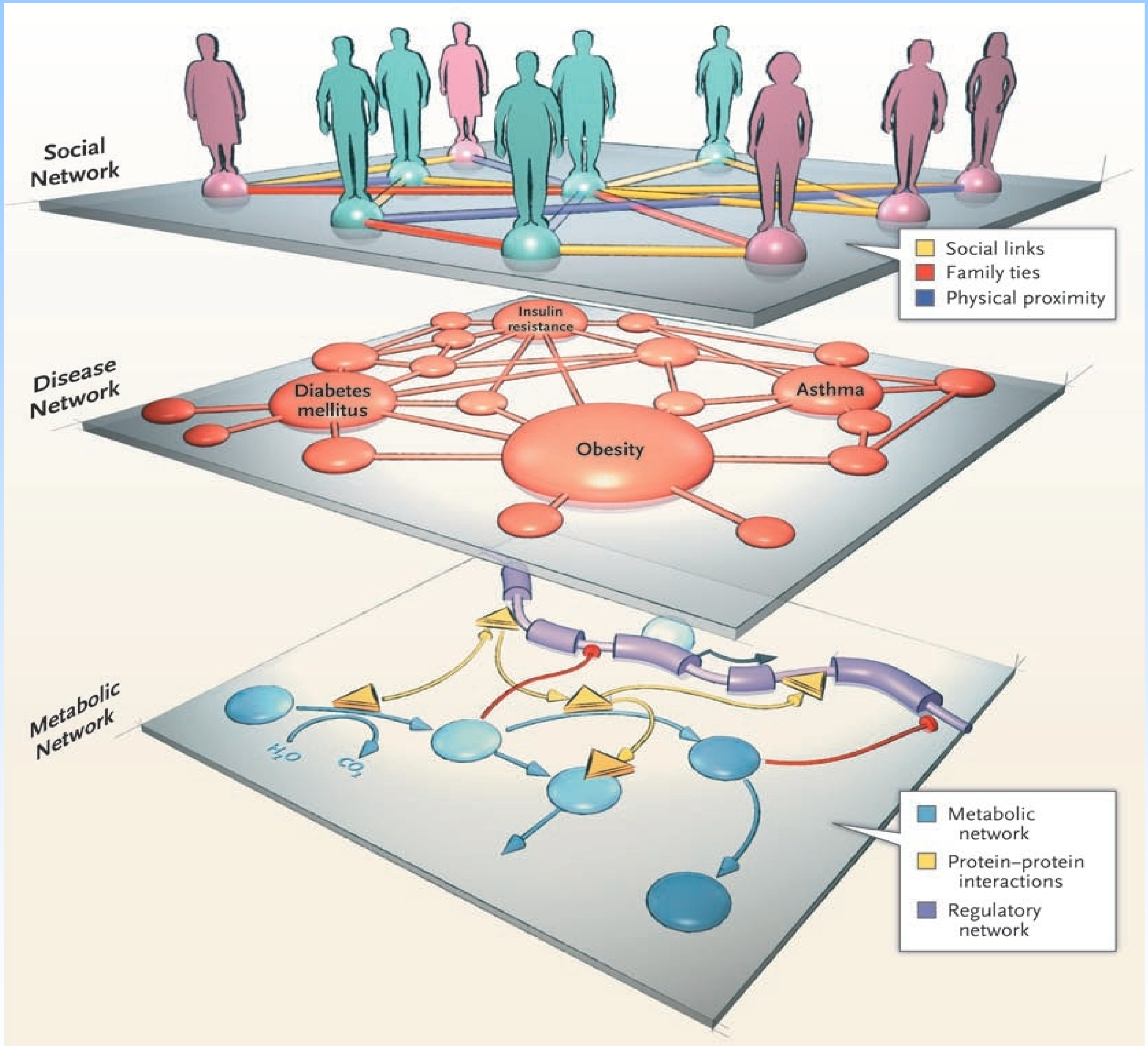
Global Network of Scientists, Journals, Funding Agencies



Network of Scientists in a Specific Research Organization

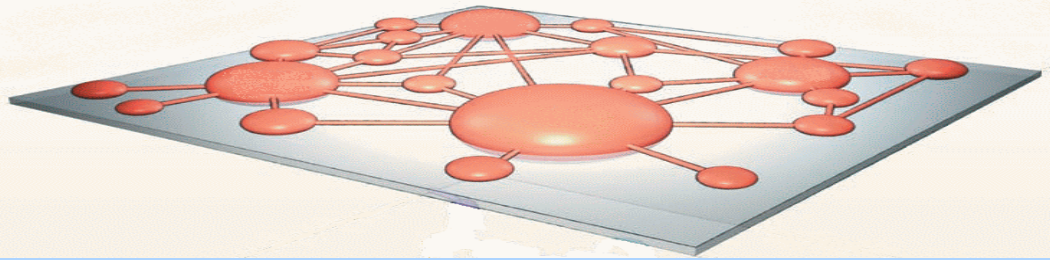


Network of Scientists within a Laboratory

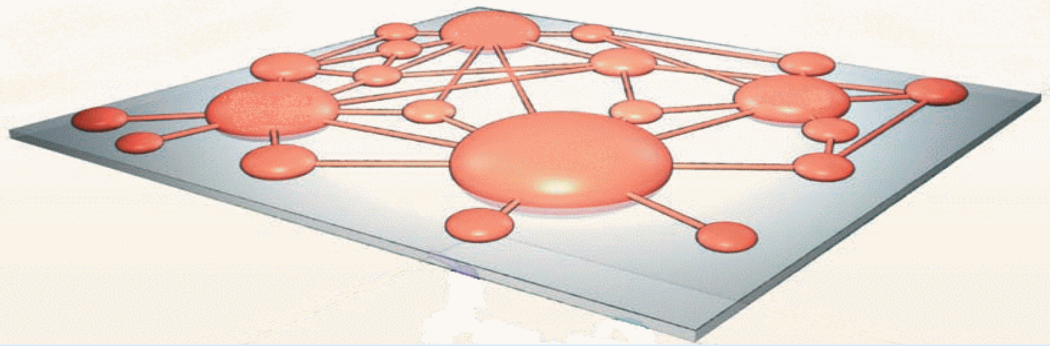


Source: Albert-László Barabási, "Network Medicine: From Obesity to the 'Diseasome'" *The New England Journal of Medicine* 357: 406 (July 26, 2007)

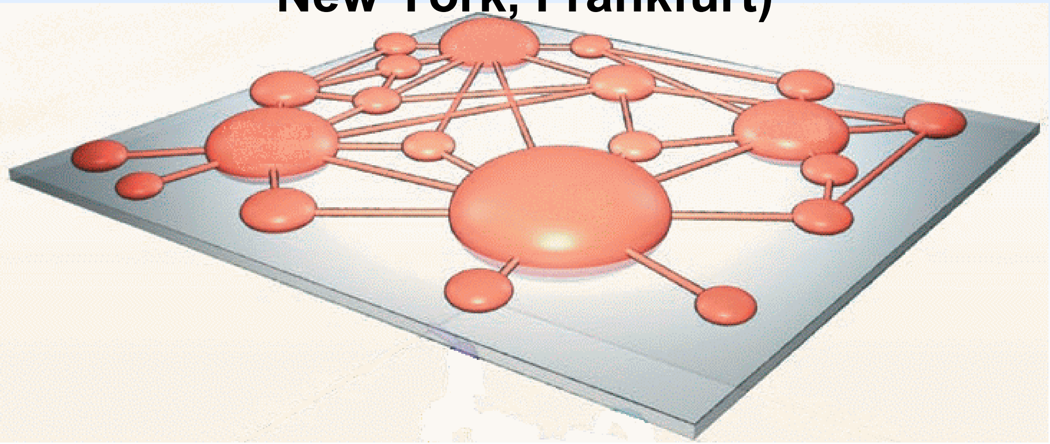
Banking Networks



Network of Global Banks



Network of National Banks (London, New York, Frankfurt)



Network of Local Banks (Dallas, St. Louis)

THE EMERGENCE OF A NEW SCIENTIFIC EPISTEMOLOGY: PERSPECTIVES FROM SOCIO-ECONOMICS

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EVALUATING THE PERFORMANCE OF BIOMEDICAL RESEARCH ORGANIZATIONS

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GLOBAL LEADERSHIP AND TECHNOLOGY EXCHANGE MEETING

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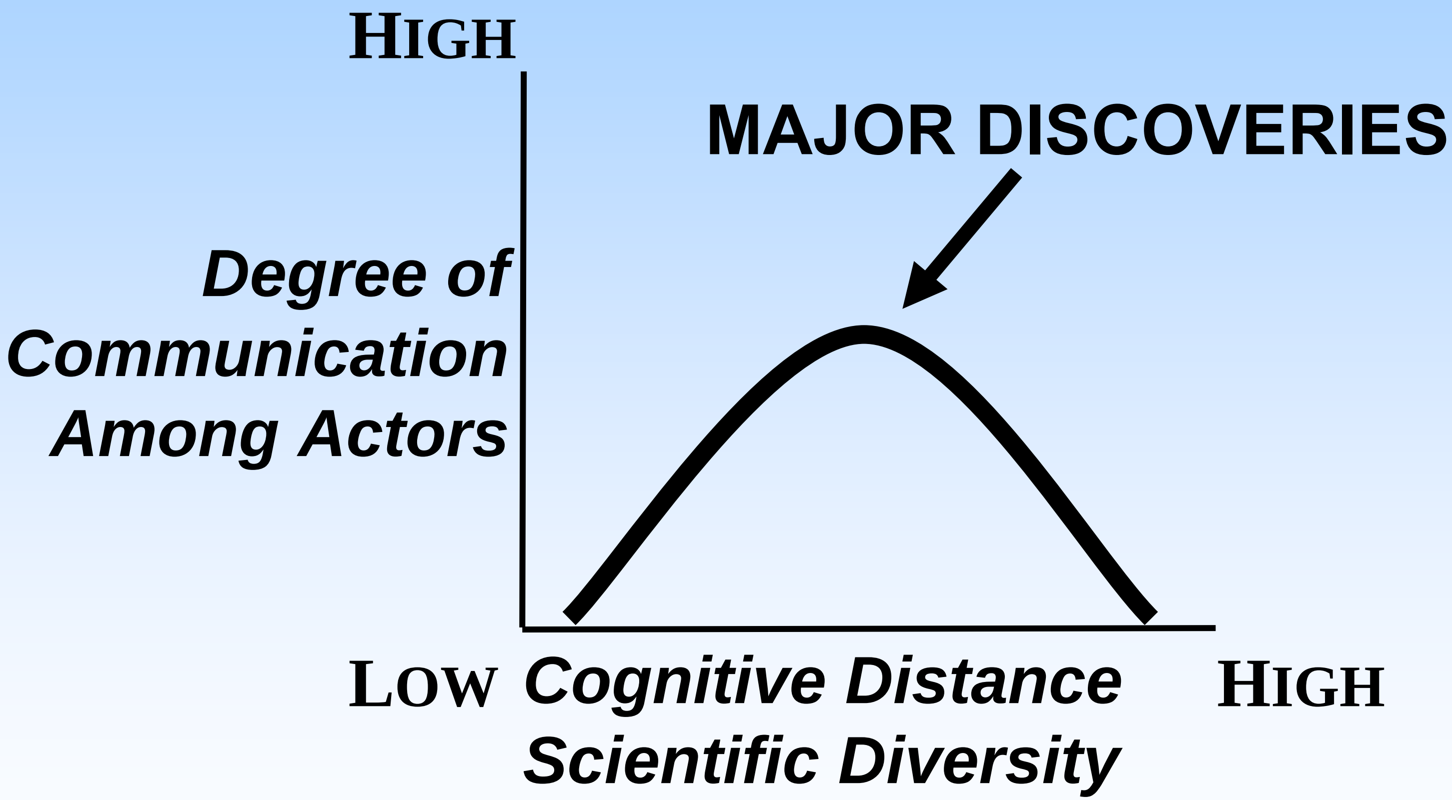
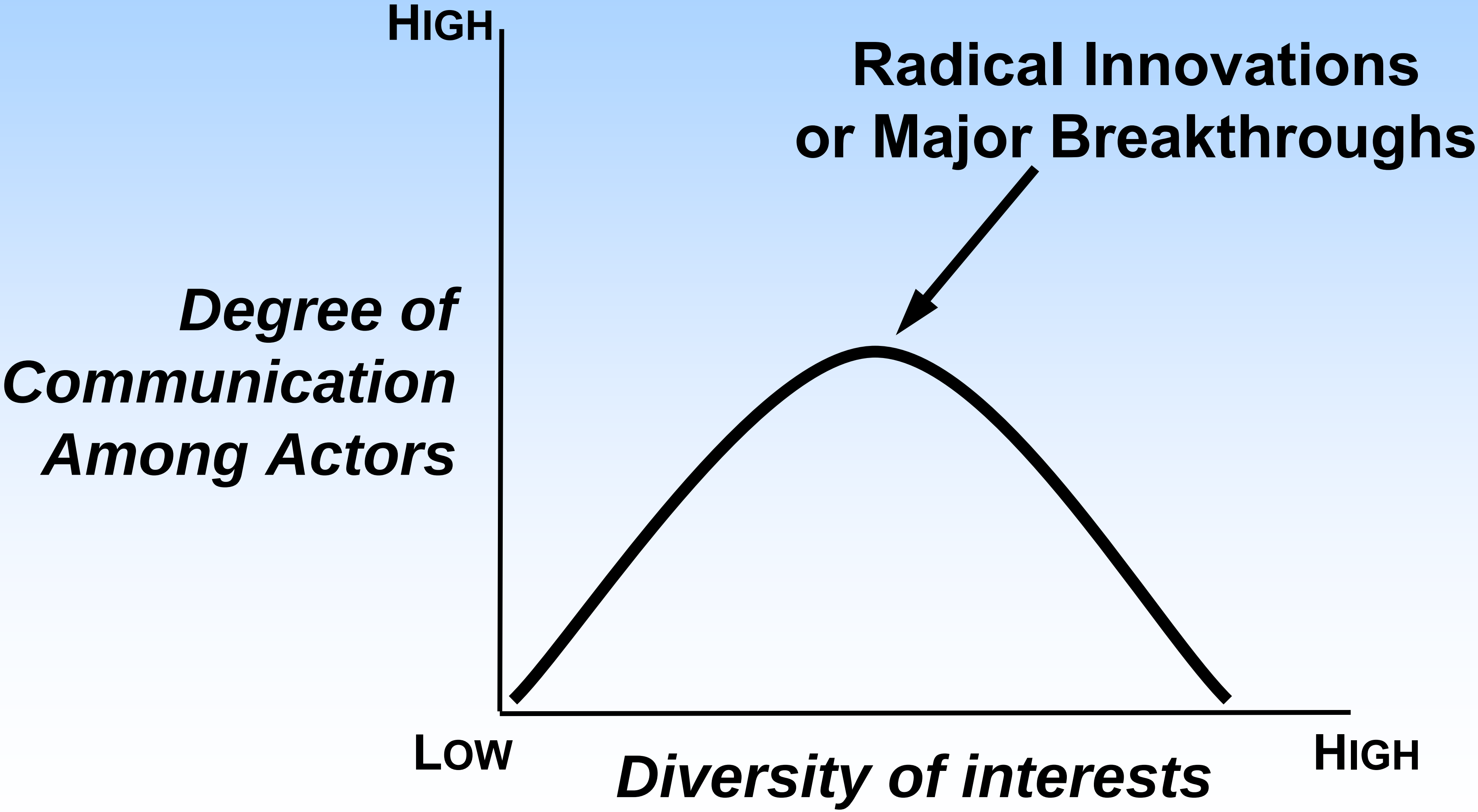
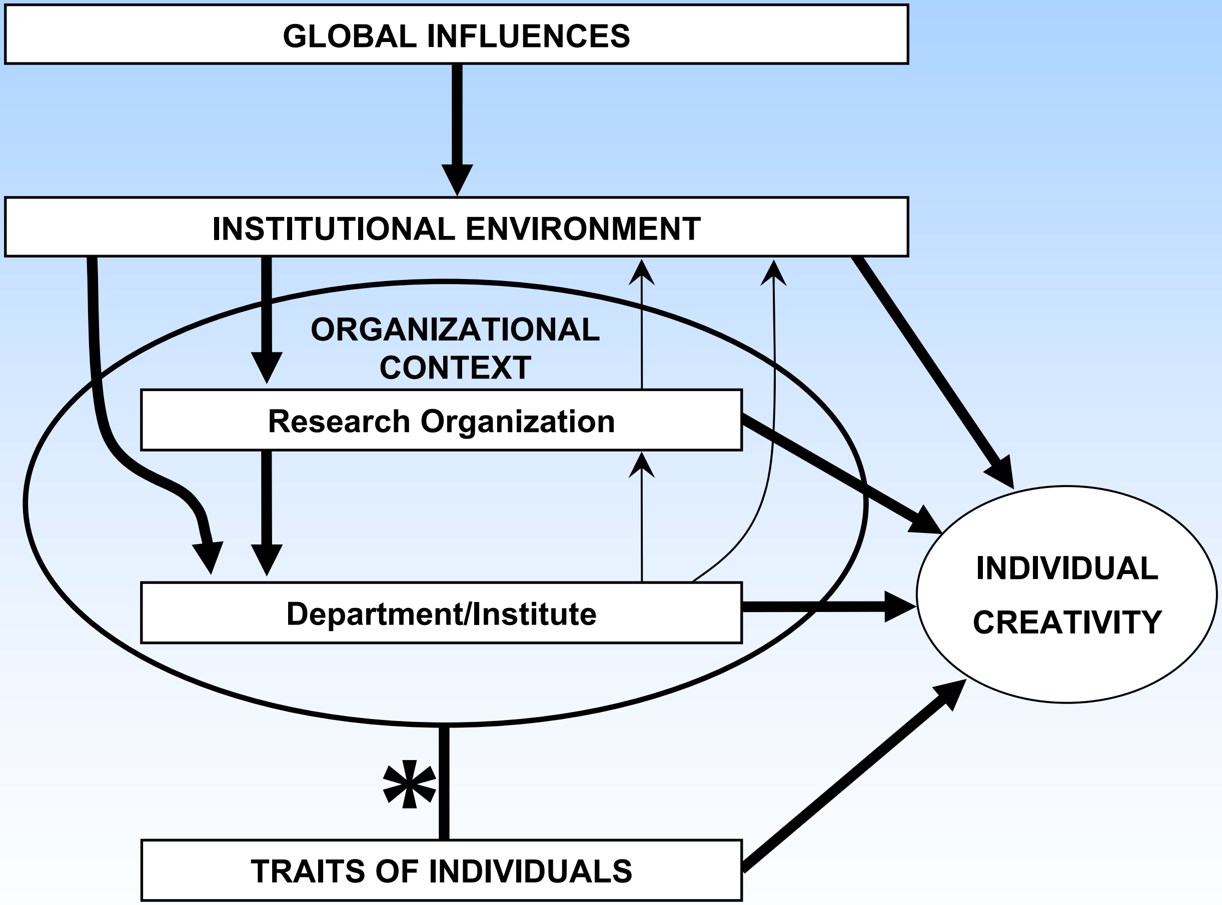
The Impact of Communication and Cognitive Distance on Major Discoveries



The Impact of the Degree of Communication and Diversity of Interests on Major Breakthroughs



Factors at Multiple Levels Influencing Individual Creativity in Basic Biomedical Science



***Each organization attempts to recruit individuals who complement its culture and structure**

Institutional Environments, Organizations, and Innovativeness