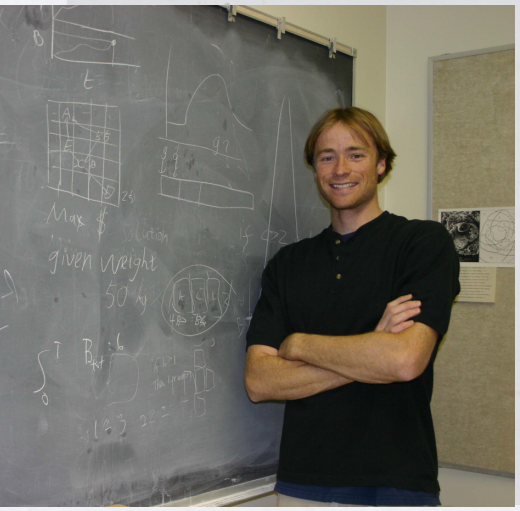
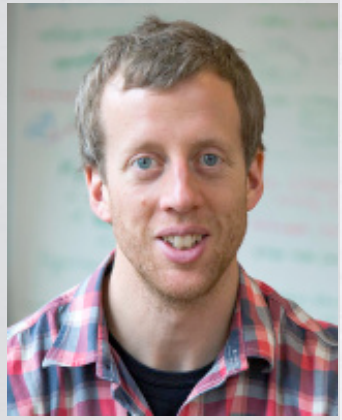
FINDING CULTURAL HOLES

How Structure and Culture Diverge in Networks of Scholarly Communication

Jacob G. Foster
Department of Sociology
UCLA

...with Daril Vilhena, Martin Rosvall, Jevin West, James Evans, and Carl Bergstrom...





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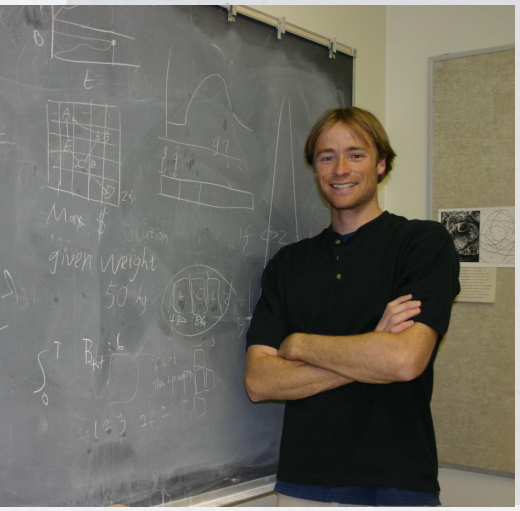
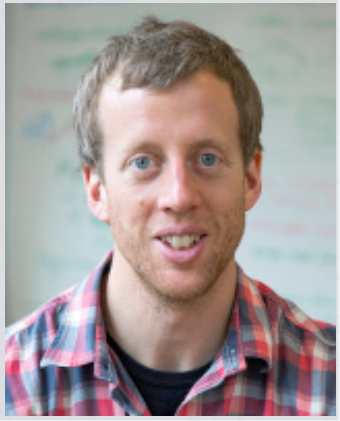


forthcoming:

sociological science



PRELUDE

Structure & Culture

STRUCTURE

★ ★ ★ ★

★ ★ ★ ★

"Patterning of social connections among individuals, among groups, and other aggregates…"

--Pachucki and Breiger, Annu. Rev. Sociol. 36, 2010

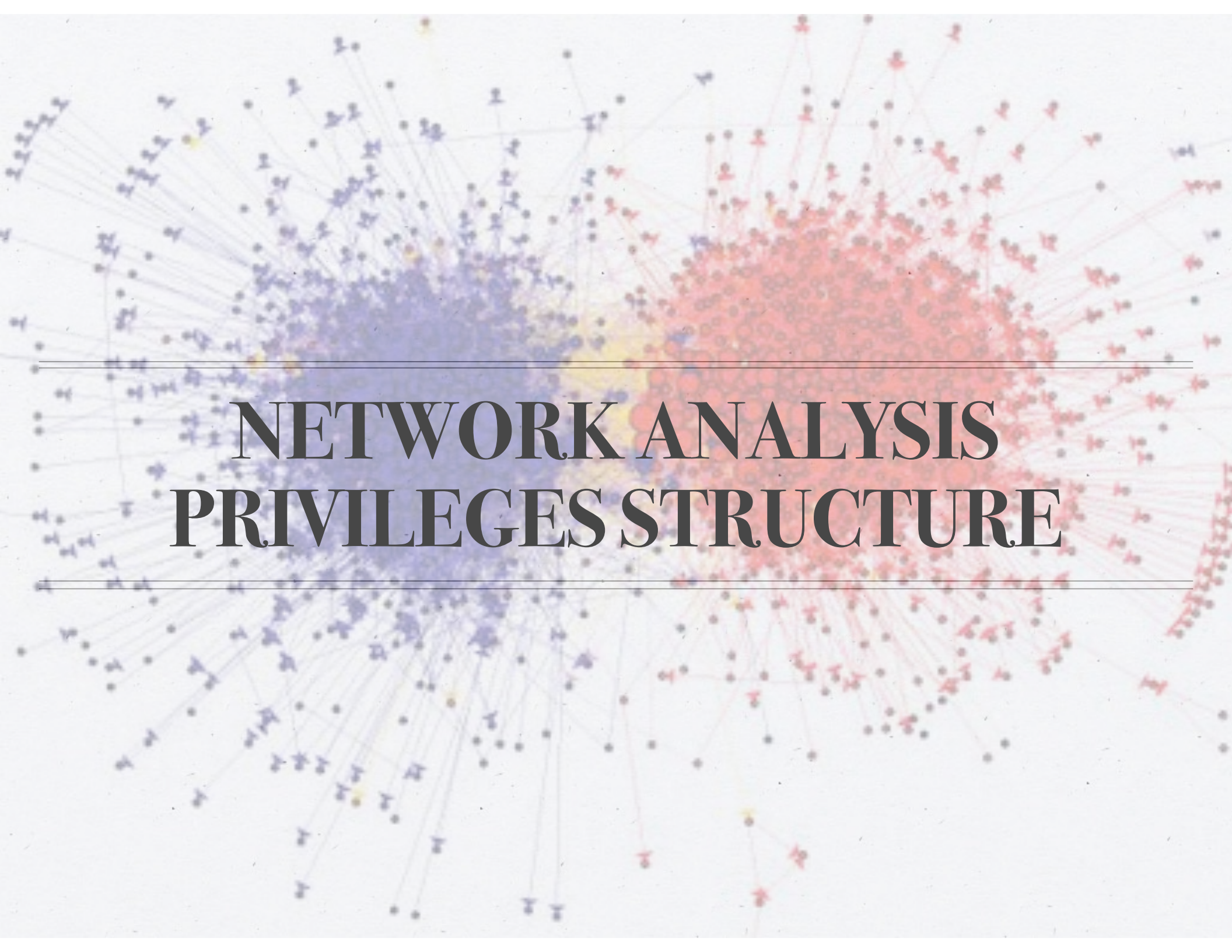
CULTURE

★ ★ ★ ★

★ ★ ★ ★

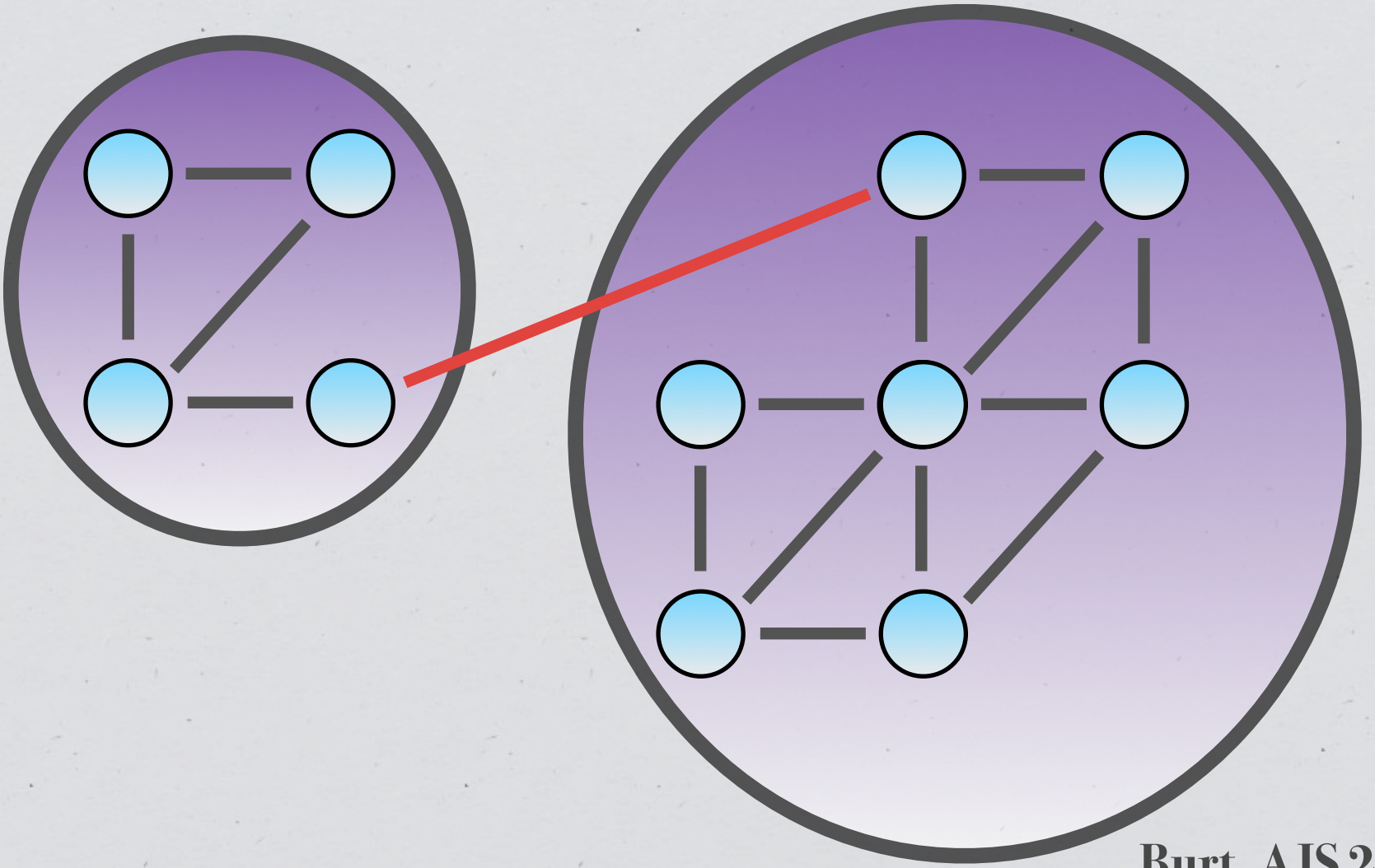
"…meanings, local practices, discourse, repertoires, and norms…"

--Pachucki and Breiger, Annu. Rev. Sociol. 36, 2010



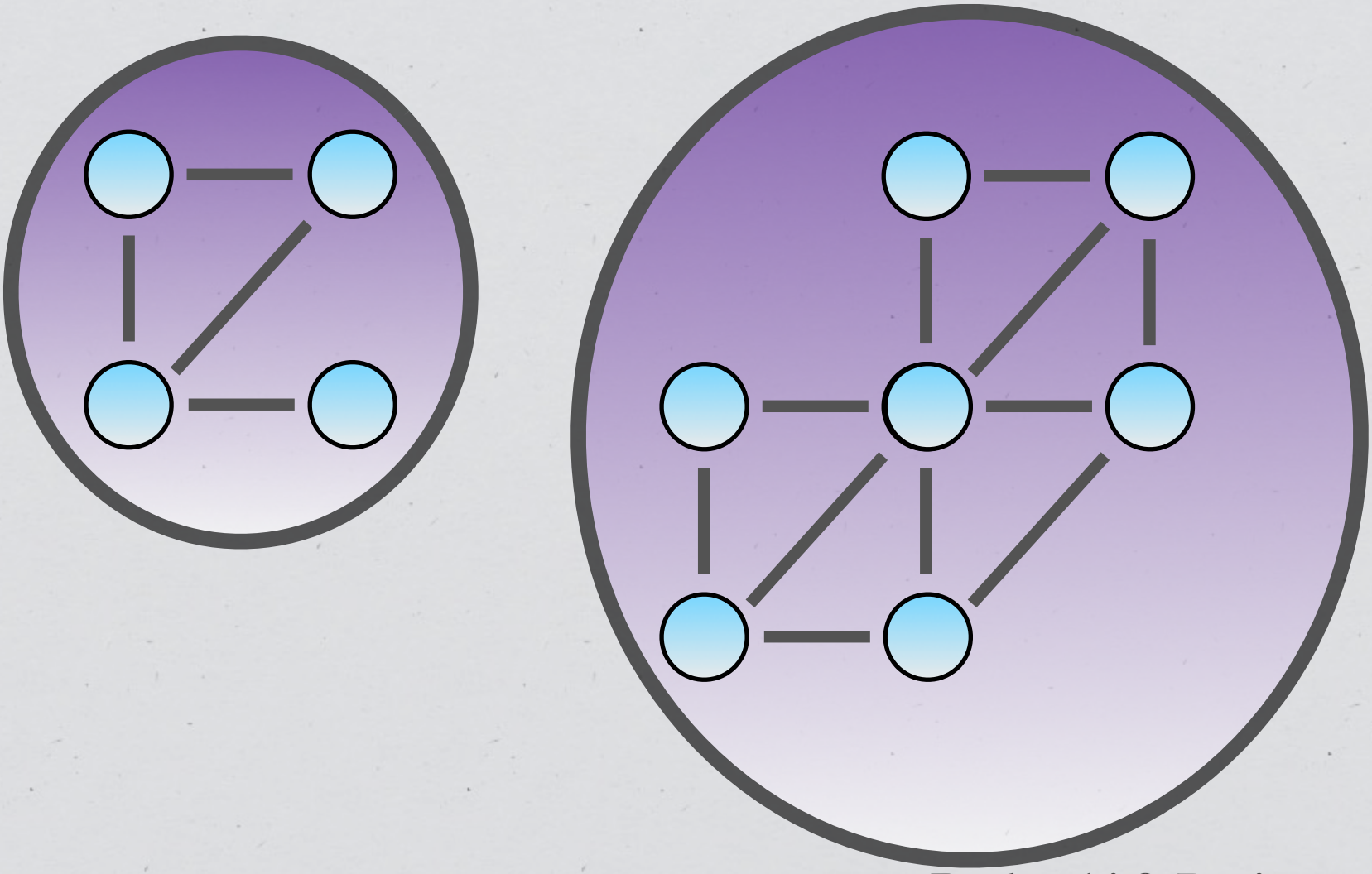
NETWORK ANALYSIS PRIVILEGES STRUCTURE

Structural Hole



Burt, AJS 2004

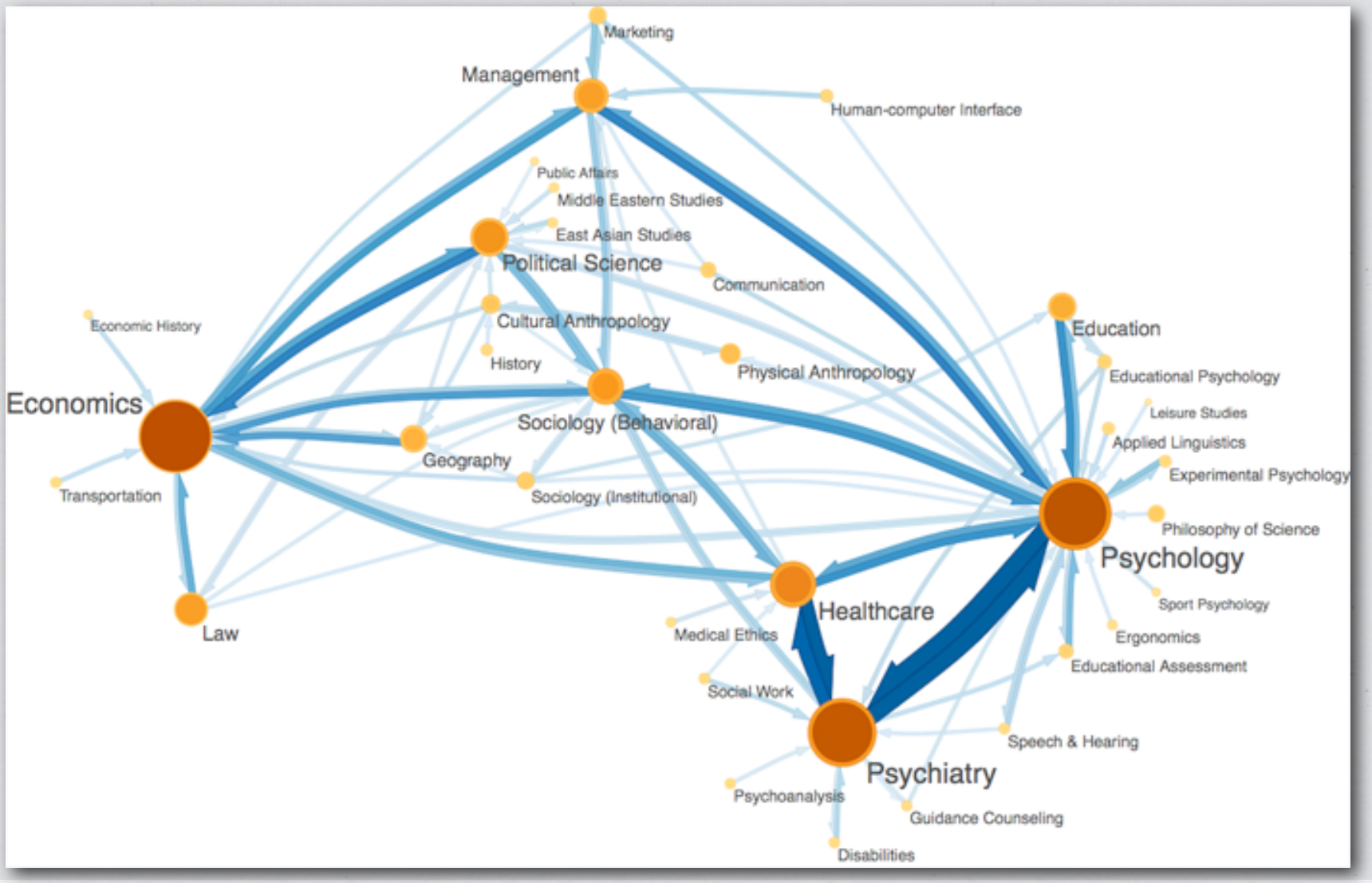
Cultural Hole

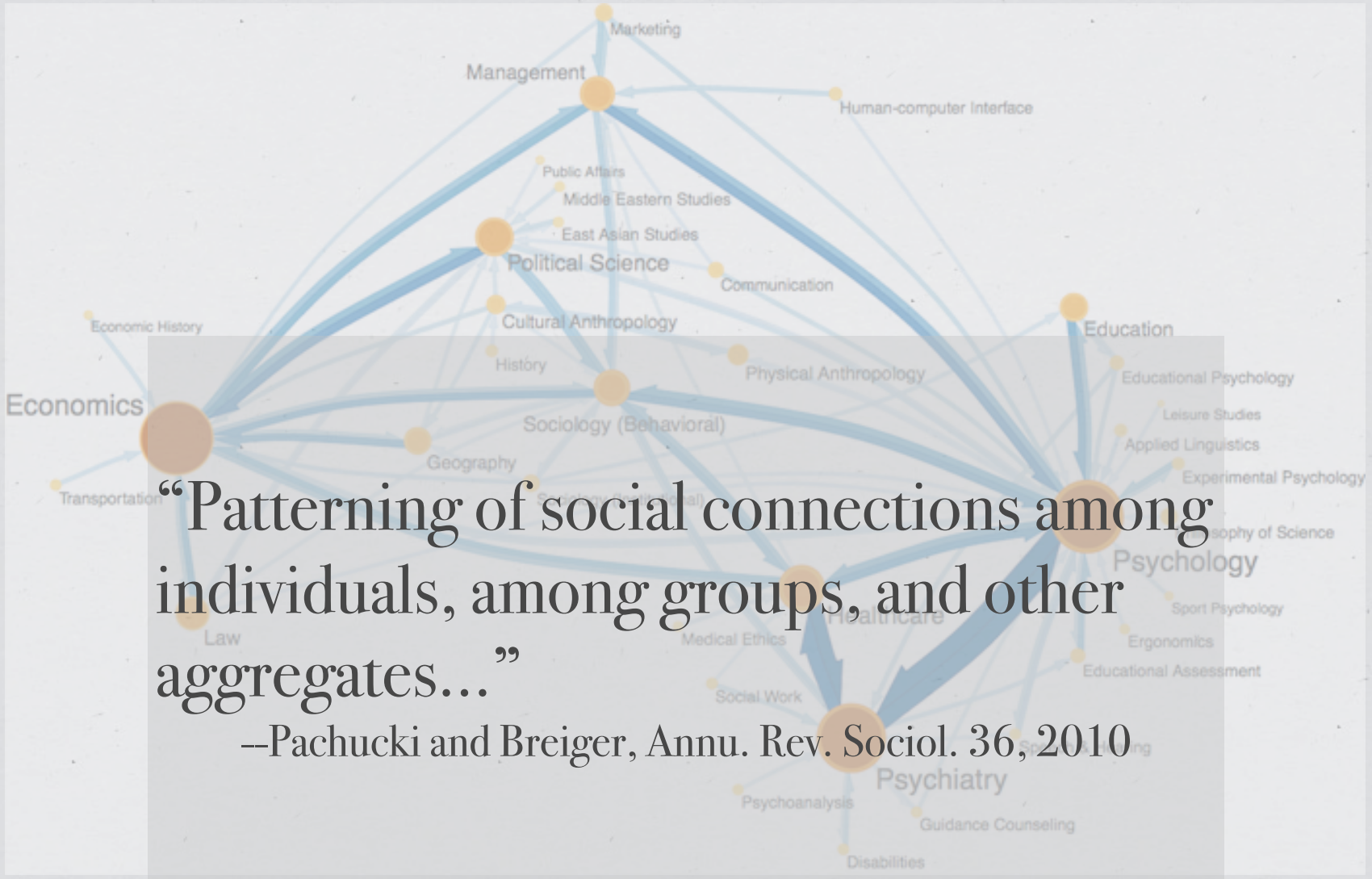


Pachucki & Breiger, 2010

Scientific Communication

Citations reveal





"Patterning of social connections among individuals, among groups, and other aggregates..."

--Pachucki and Breiger, Annu. Rev. Sociol. 36, 2010

and conceal

"…meanings, local practices, discourse, repertoires, and norms…"

--Pachucki and Breiger, Annu. Rev. Sociol. 36, 2010

Every science requires a special language, because every science has its own ideas.

Etienne Bonnot de Condillac

Fitness landscape…

Comparing expected relative reproductive success across multiple genotypes…

Jargon facilitates…

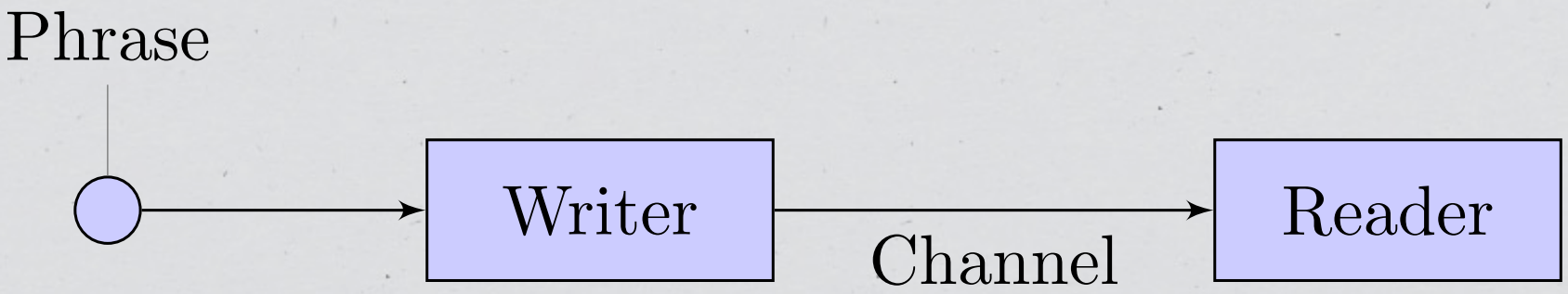
* “The N = 4 super Yang-Mills plasma is studied in the regime of weak coupling. Collective excitations and collisional processes are discussed and compared to those of QCD plasma. The two systems are concluded to be very similar to each other with the differences mostly reflecting different numbers of degrees of freedom.”

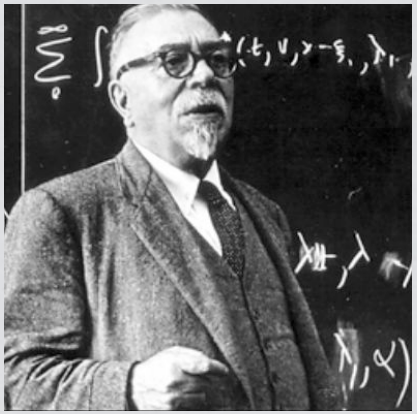
and impedes…

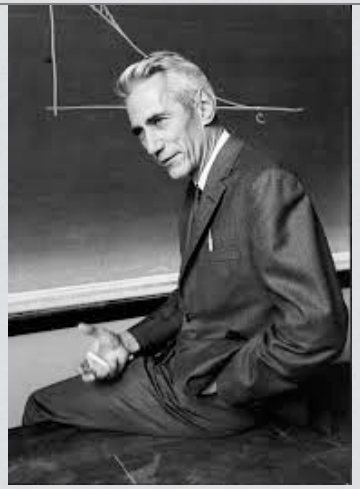
* communicating medical information to a patient
* publishing material for public outreach
* presenting technical information to a multidisciplinary audience

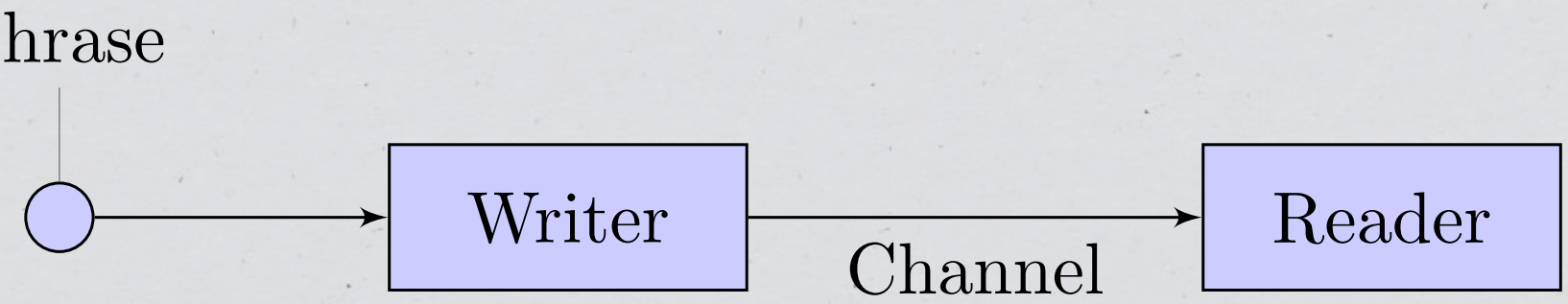
MODELING COMMUNICATION

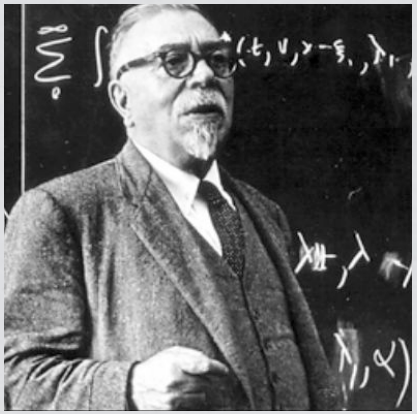
Communication

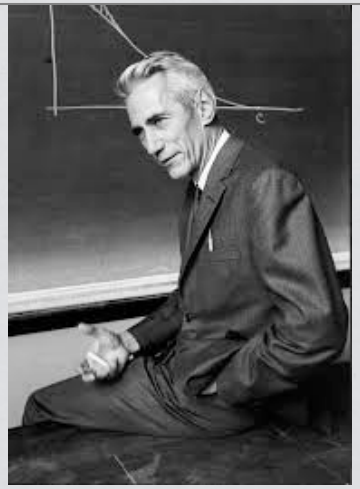


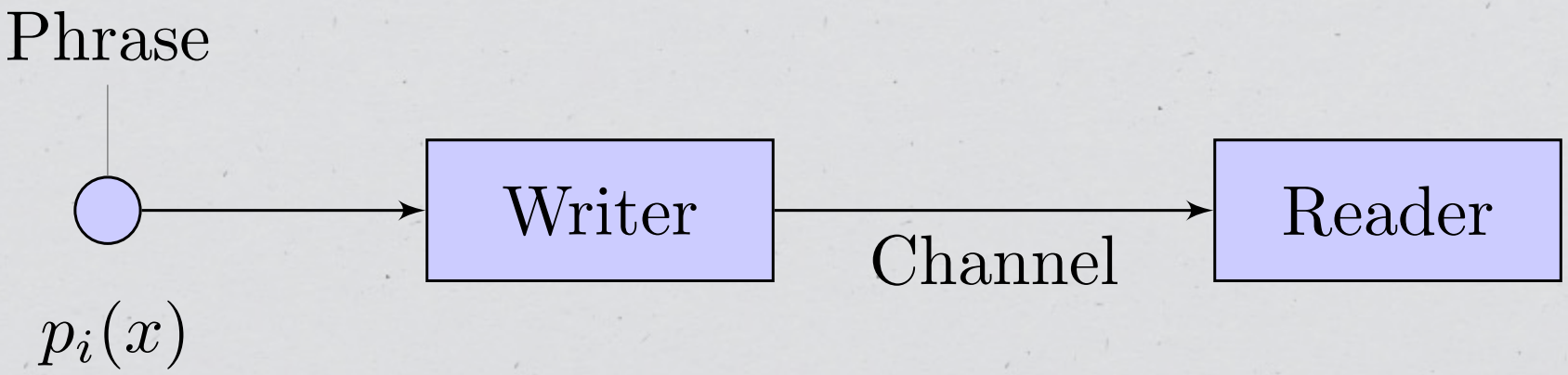


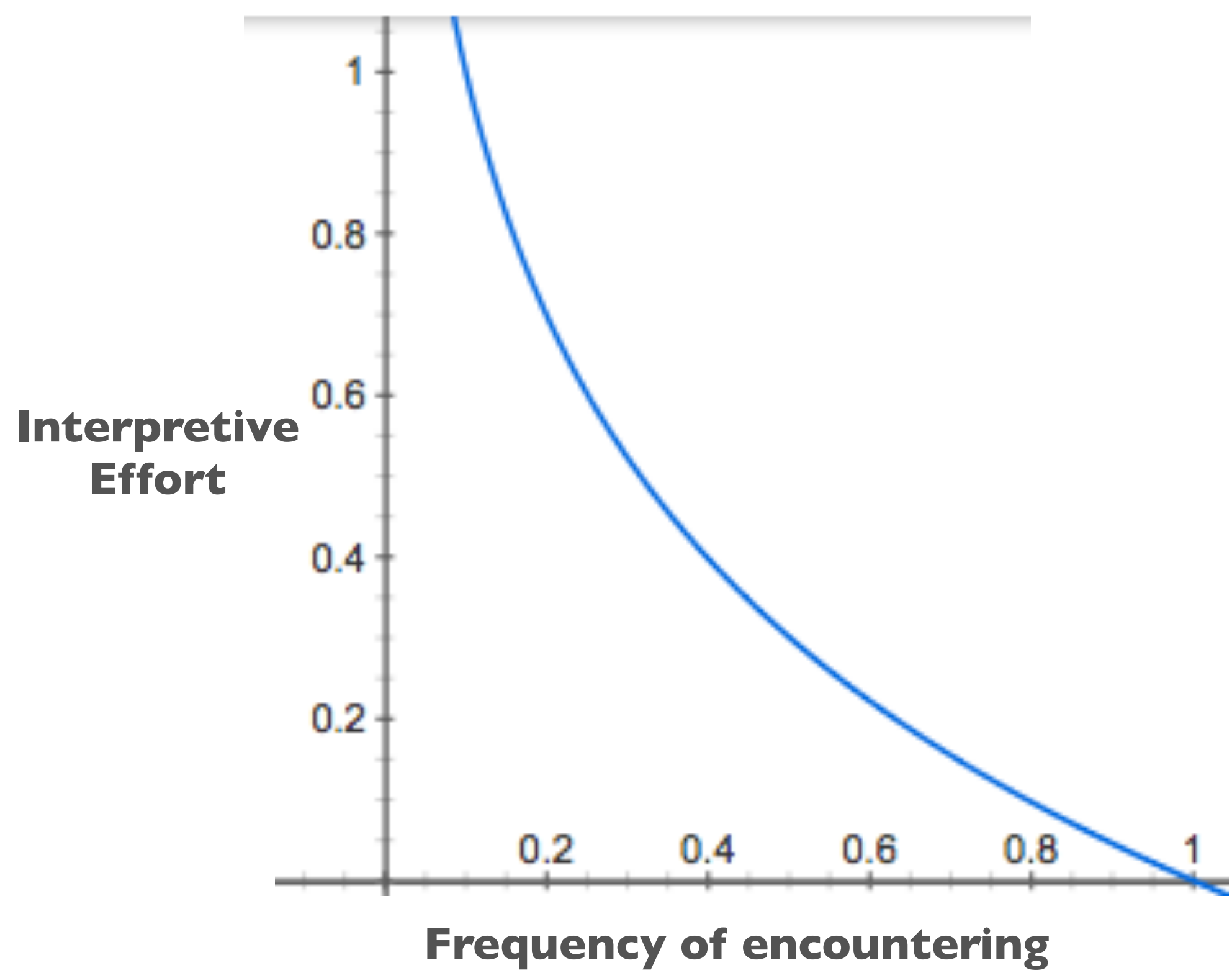


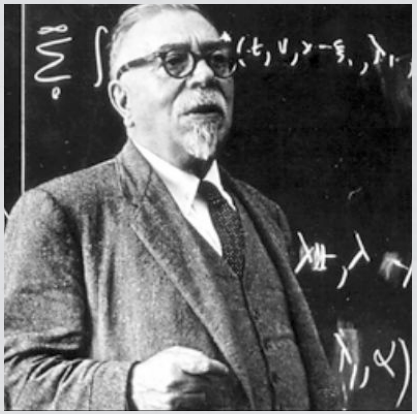

Phrase
Writer
Channel
Reader

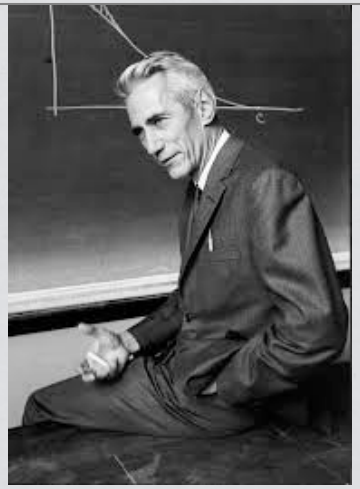


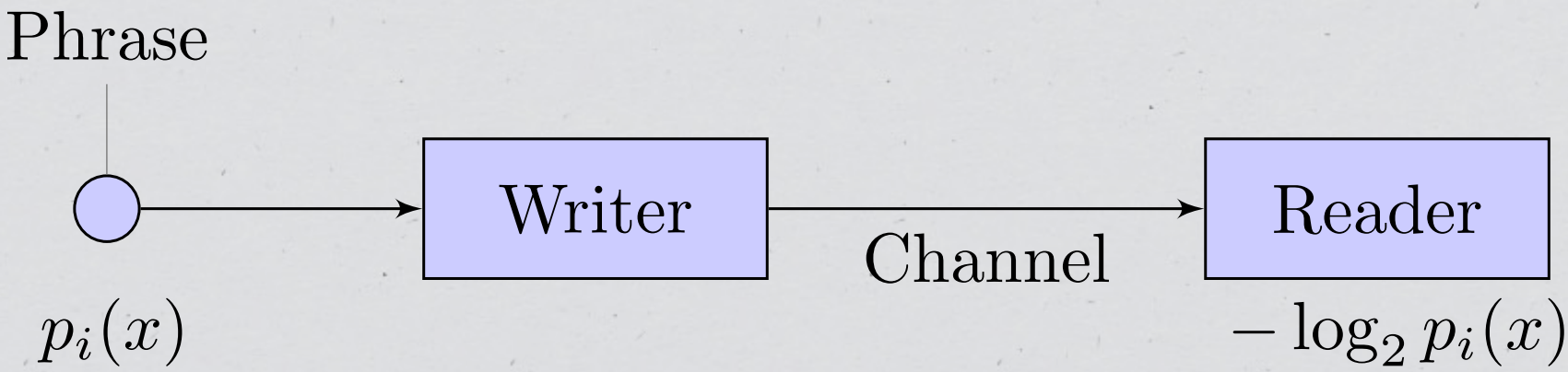


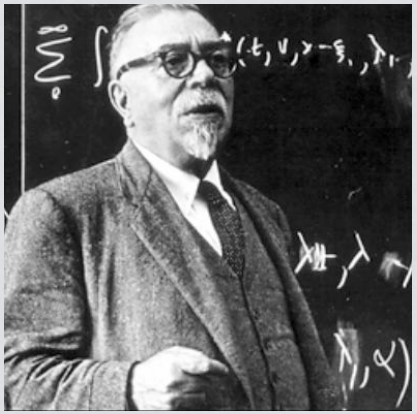

Phrase
Writer
Channel
Reader
$p_i(x)$

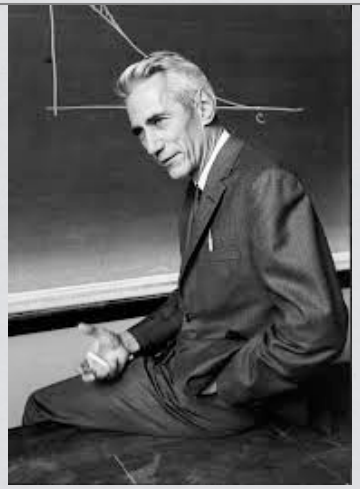

Interpretive Effort
1
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1
Frequency of encountering

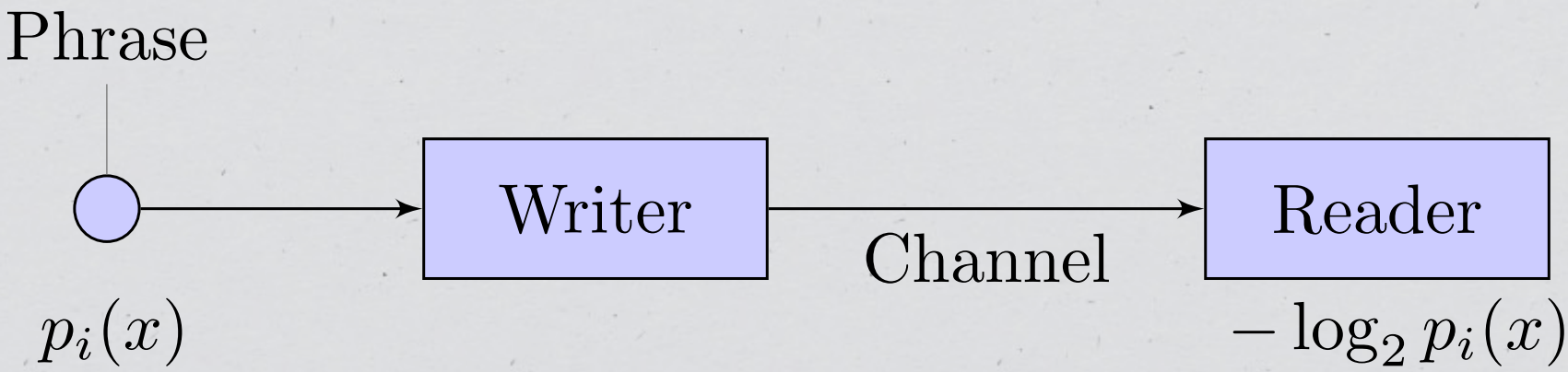





Phrase
Writer
Channel
Reader
$p_i(x)$
$-\log_2 p_i(x)$

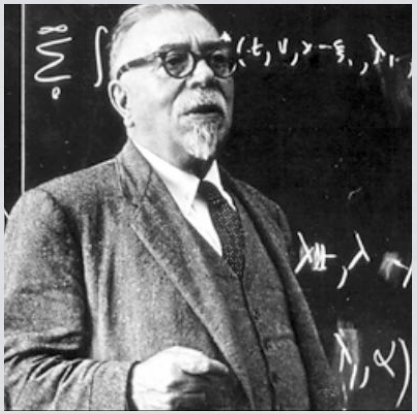


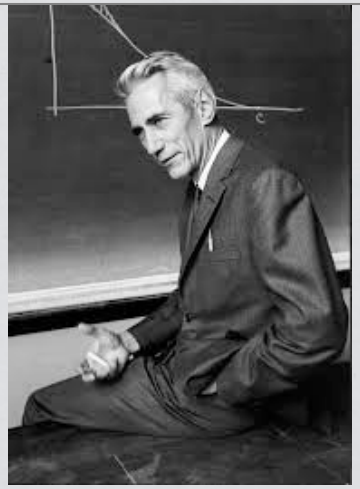


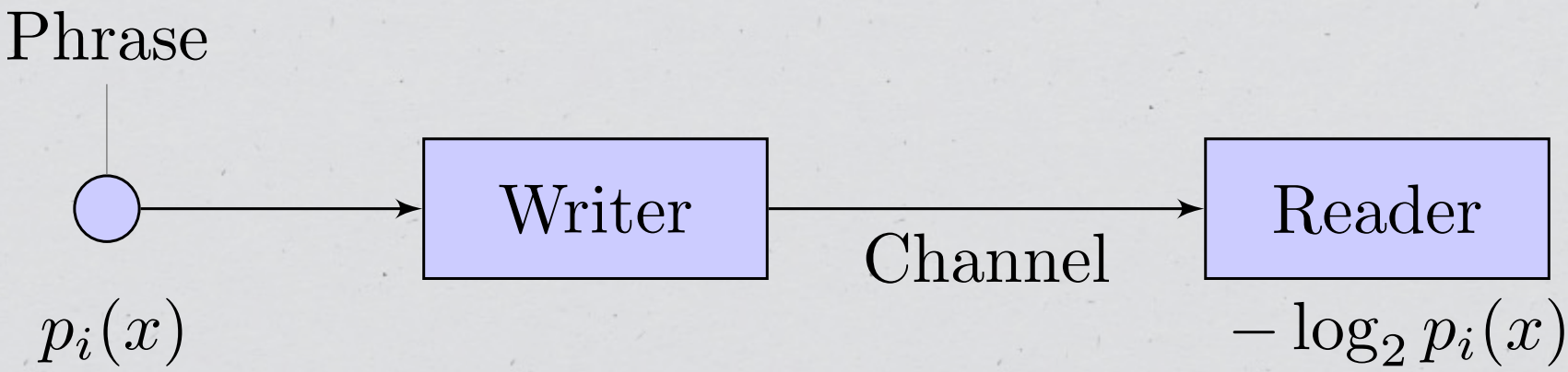


Entropy

$$H(X_i) = -\sum_{x \in \mathcal{X}} p_i(x) \log_2 p_i(x)$$







(equivalently, expected message length)

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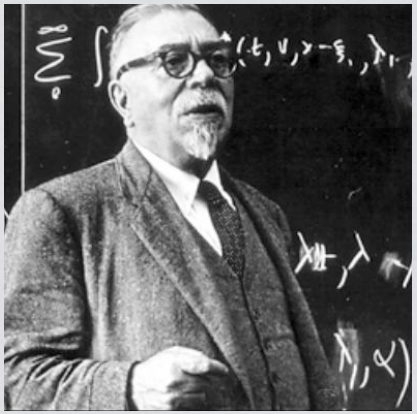

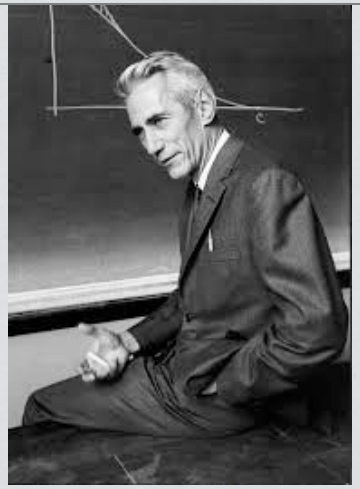

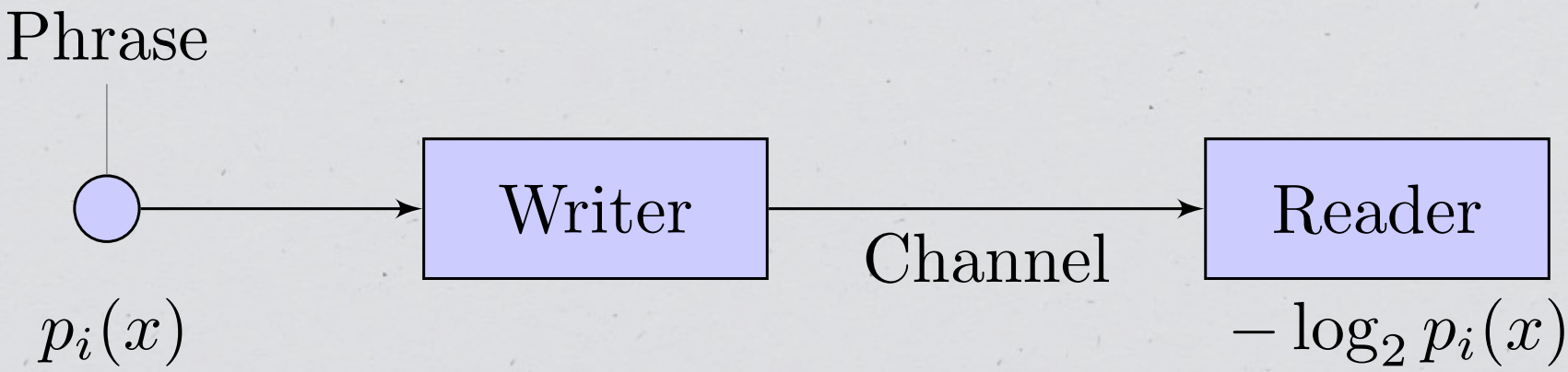

(equivalently, expected interpretive effort)

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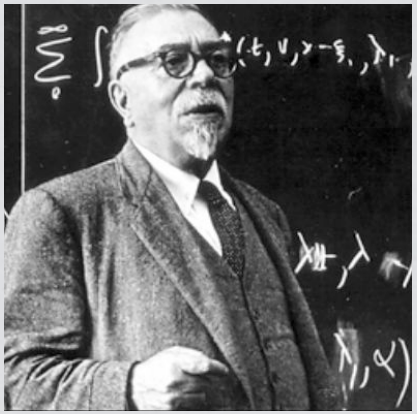

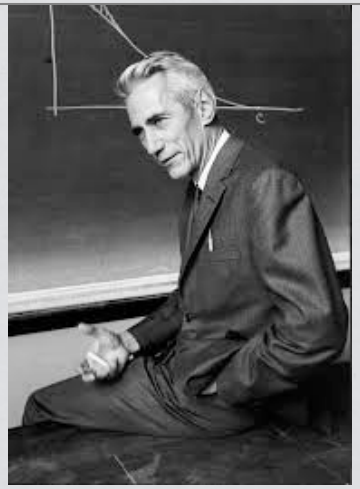

High
Entropy

Phrase

Writer

Channel

Reader

$p_i(x)$

$-\log_2 p_i(x)$

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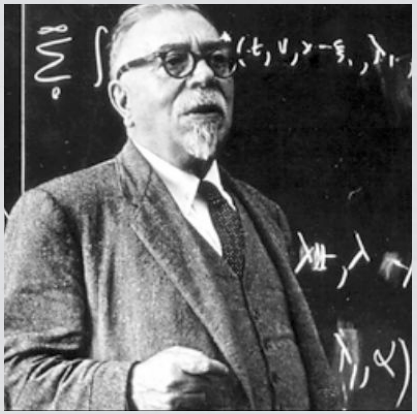
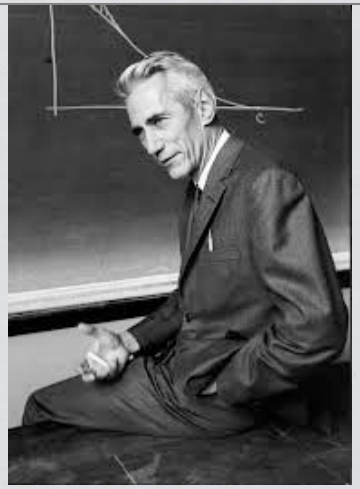
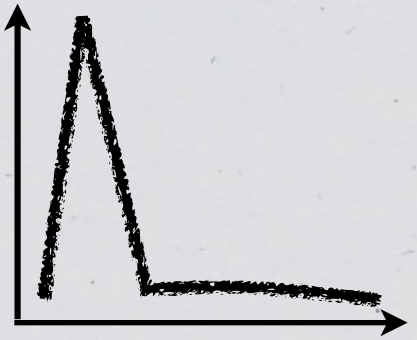




Low
Entropy



Phrase

Writer

Channel

Reader

$p_i(x)$

$-\log_2 p_i(x)$

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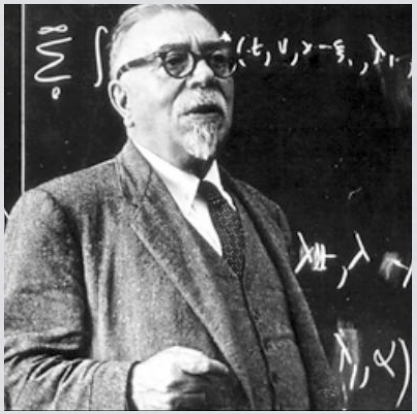
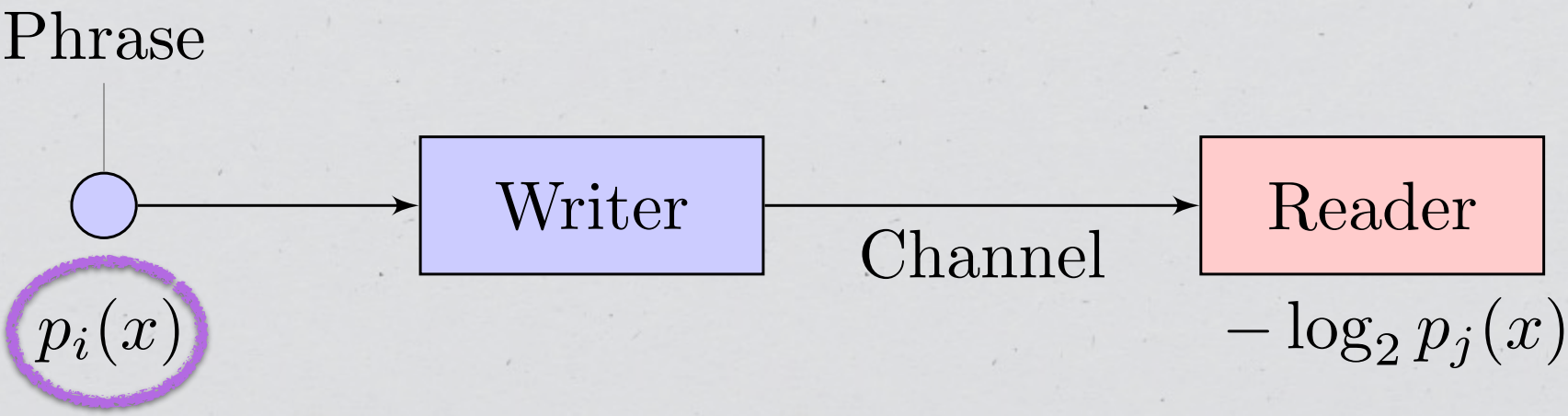
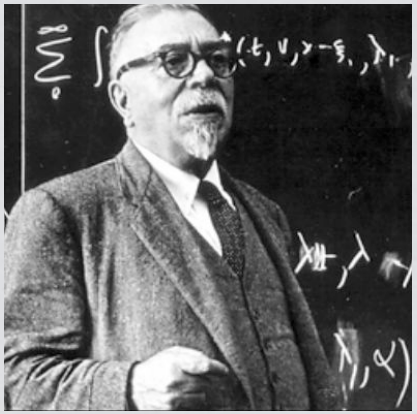
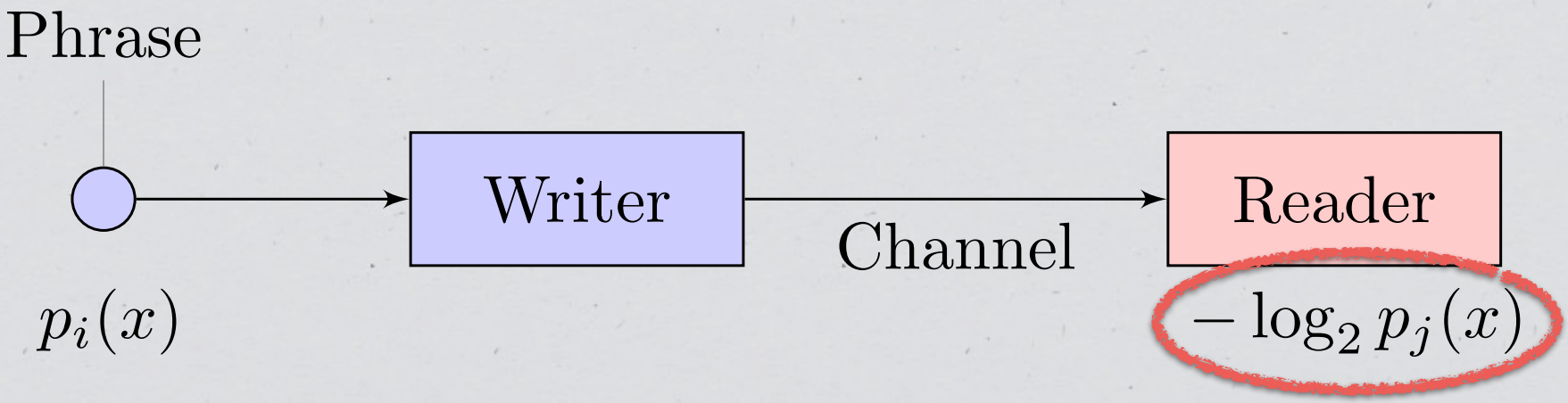



Phrase
Writer
Channel
Reader
$p_i(x)$
$-\log_2 p_j(x)$




Phrase
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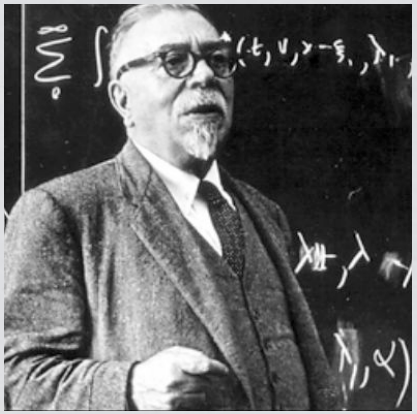
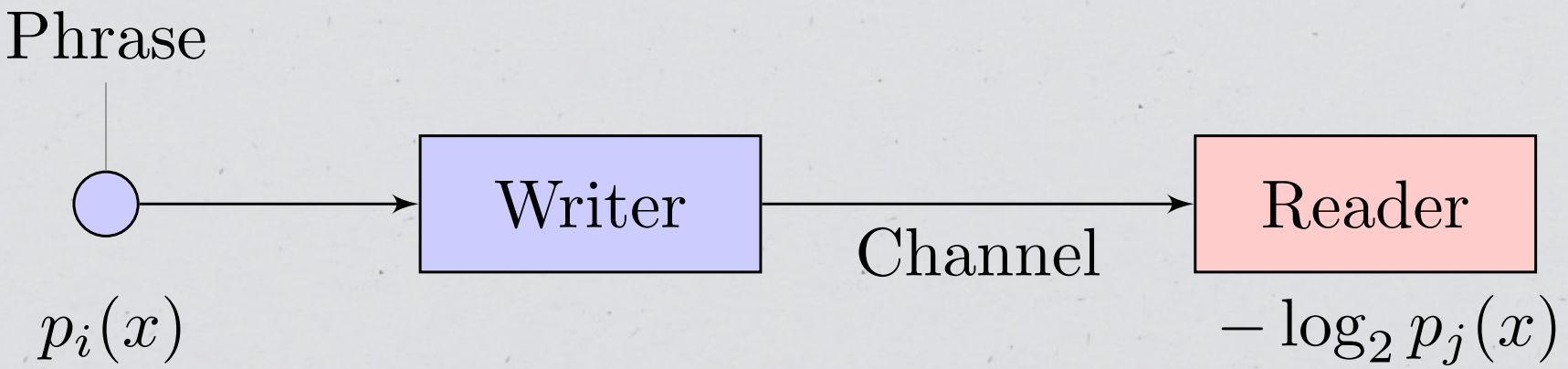
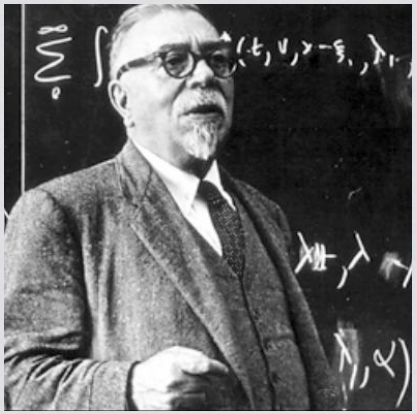
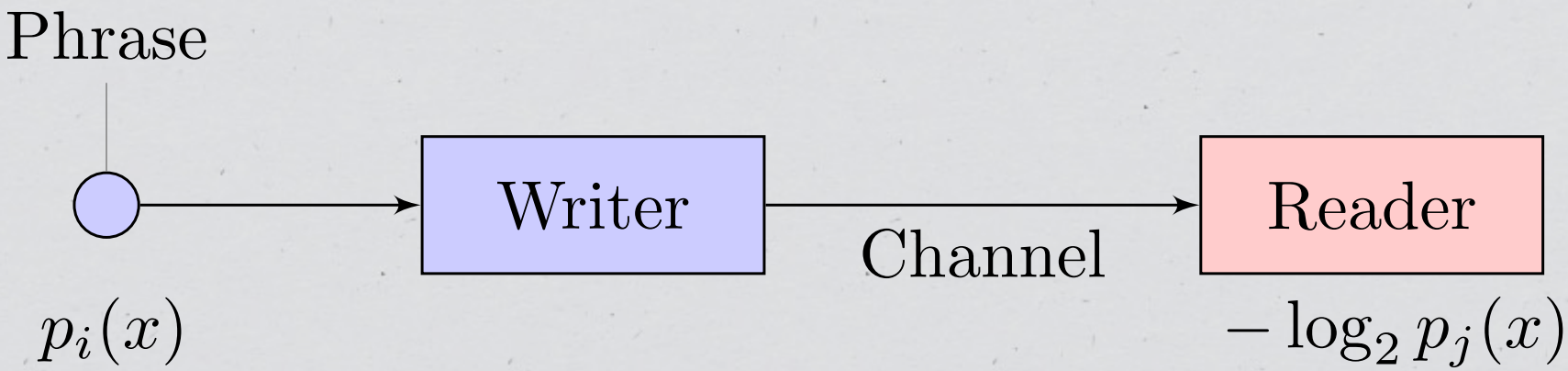




Cross Entropy

$$Q(p_i||p_j) = -\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)$$





(equivalently, expected interpretive effort)

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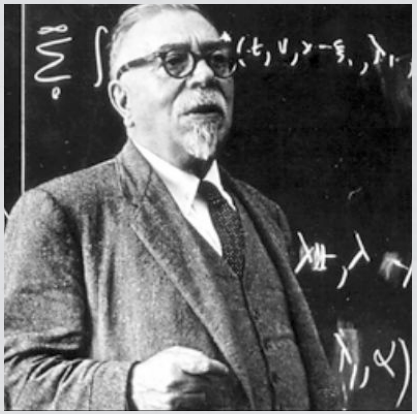
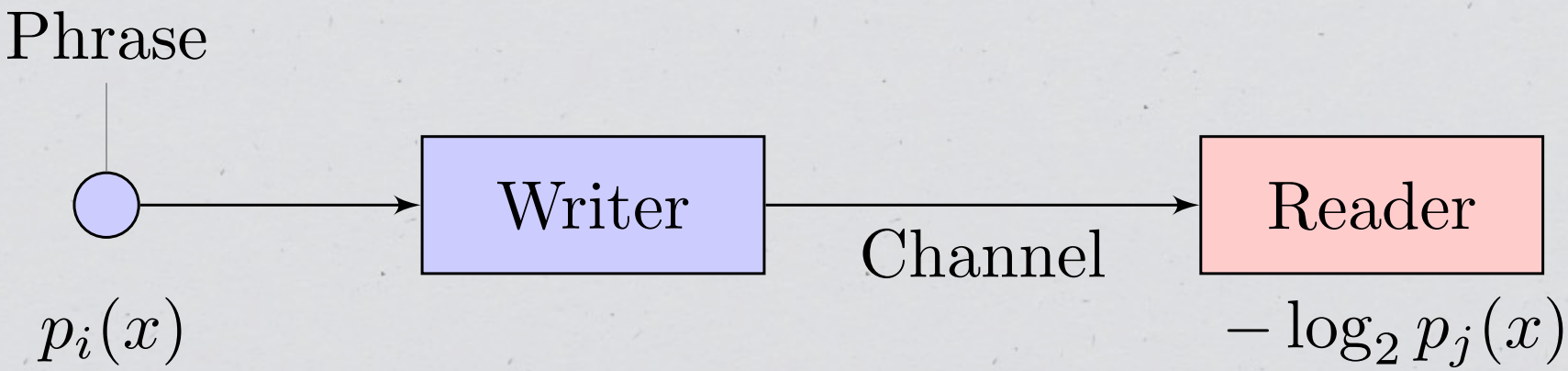
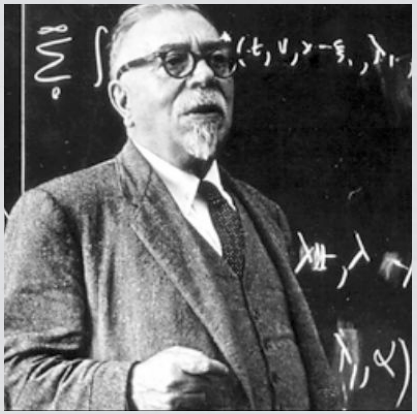


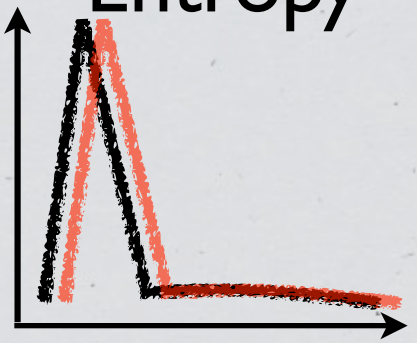


"Efficiency" of communication

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$



Low
Cross
Entropy



Phrase

Writer

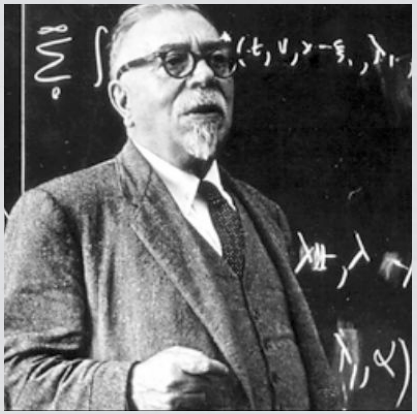
Channel

Reader

$p_i(x)$

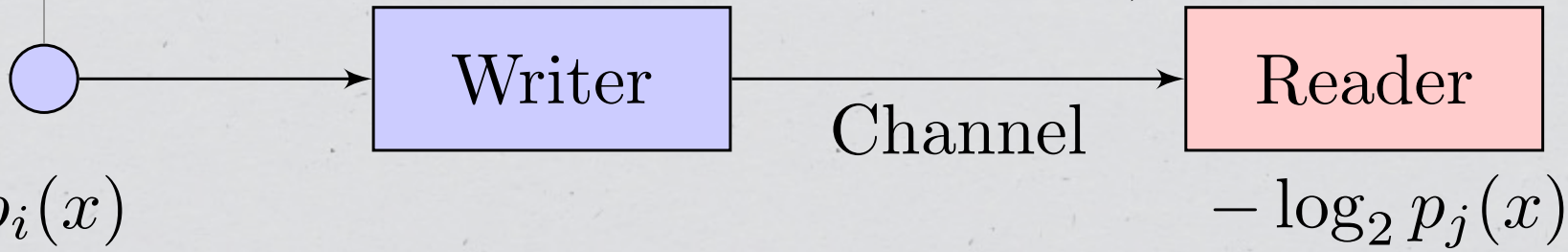
$-\log_2 p_j(x)$

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$



Efficient

Phrase



$p_i(x)$

$-\log_2 p_j(x)$

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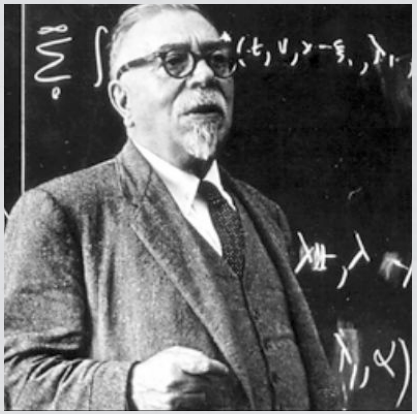


Small
Cultural
Hole

Phrase

Writer

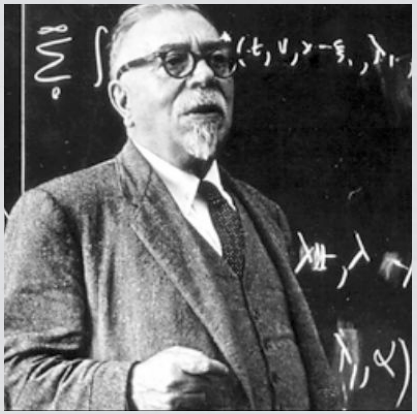
Channel

Reader

$p_i(x)$

$-\log_2 p_j(x)$

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$



High Cross Entropy

Phrase

Writer

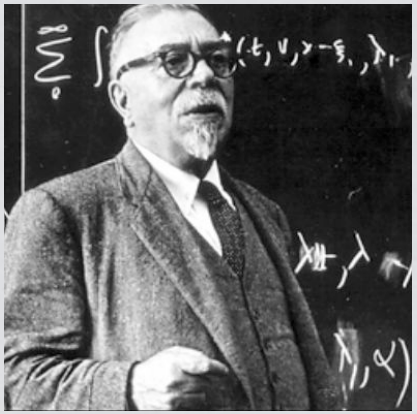
Channel

Reader

$p_i(x)$

$-\log_2 p_j(x)$

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$



Inefficient

Phrase

Writer

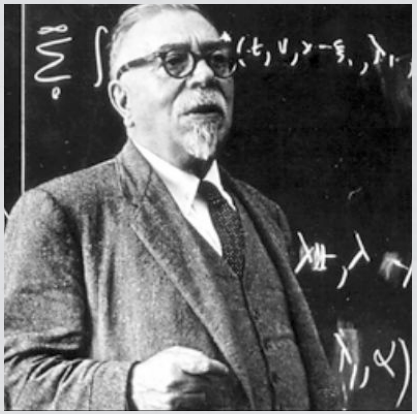
Channel

Reader

$p_i(x)$

$-\log_2 p_j(x)$

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$



Large
Cultural
Hole

Phrase

Writer

Channel

Reader

$p_i(x)$

$-\log_2 p_j(x)$

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$

“Cultural Hole”

Relative Efficiency

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$

Cultural Hole

$$C_{ij} = 1 - E_{ij}$$

Average Cultural Hole

$$C_i = \sum_j C_{ij}/N$$

It's practical!

Possible Bubbles of Spacetime Curvature in the South Pacific

Benjamin K. Tippett*
Department of Mathematics and Statistics
University of New Brunswick
Fredericton, NB, E3B 5A3
Canada

In 1928, the late Francis Wayland Thurston published a scandalous manuscript in purport of warning the world of a global conspiracy of occultists. Among the documents he gathered to support his thesis was the personal account of a sailor by the name of Gustaf Johansen, describing an encounter with an extraordinary island. Johansen's descriptions of his adventures upon the island are fantastic, and are often considered the most enigmatic (and therefore the highlight) of Thurston's collection of documents.

We contend that all of the credible phenomena which Johansen described may be explained as being the observable consequences of a localized bubble of spacetime curvature. Many of his most incomprehensible statements (involving the geometry of the architecture, and variability of the location of the horizon) can therefore be said to have a unified underlying cause.

We propose a simplified example of such a geometry, and show using numerical computation that Johansen's descriptions were, for the most part, not simply the ravings of a lunatic. Rather, they are the nontechnical observations of an intelligent man who did not understand how to describe what he was seeing. Conversely, it seems to us improbable that Johansen should have unwittingly given such a precise description of the consequences of spacetime curvature, if the details of this story were merely the dregs of some half remembered fever dream.

We calculate the type of matter which would be required to generate such exotic spacetime curvature. Unfortunately, we determine that the required matter is quite unphysical, and possess a nature which is entirely alien to all of the experiences of human science. Indeed, any civilization with mastery over such matter would be able to construct warp drives, cloaking devices, and other exotic geometries required to conveniently travel through the cosmos.

STRUCTURE

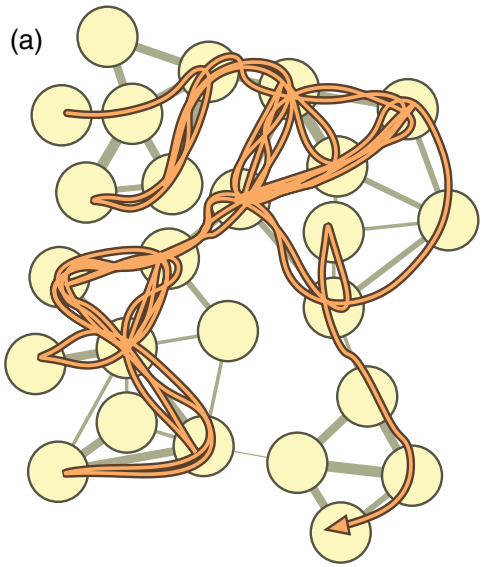
Using citations

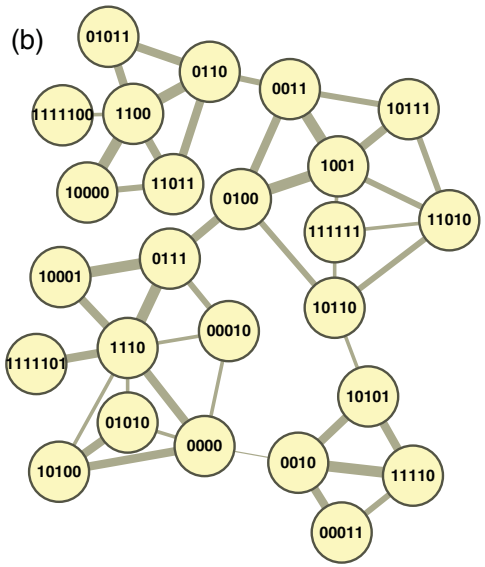
CULTURE

Using text

Data

* 1.5 million interconnected papers
* 1990-2010
* Select 60 largest fields (1000+ papers)
* Determine phrase (=trigram) distribution from sample of 500 papers





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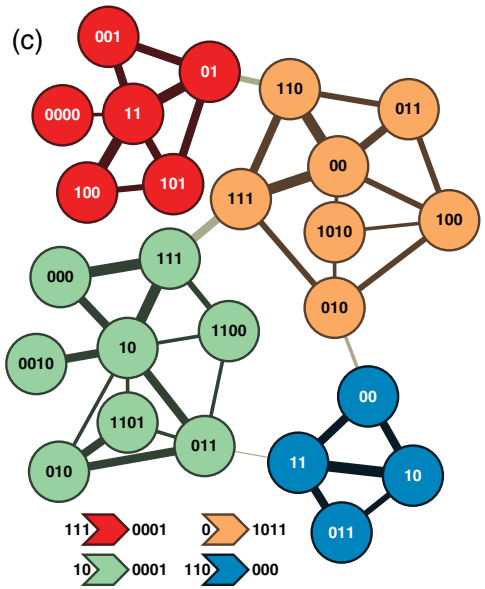

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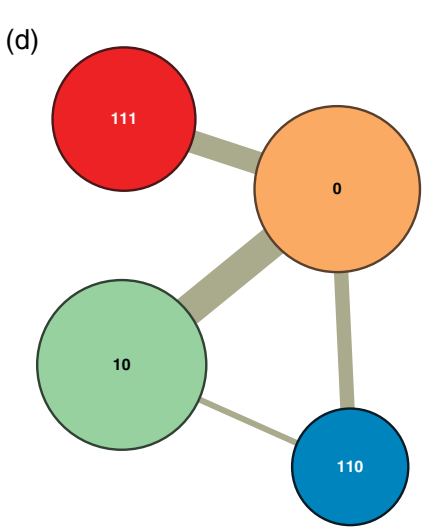

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00 011 00 111 00 111 110 111 110 1011 111 01 101 01 0001 0
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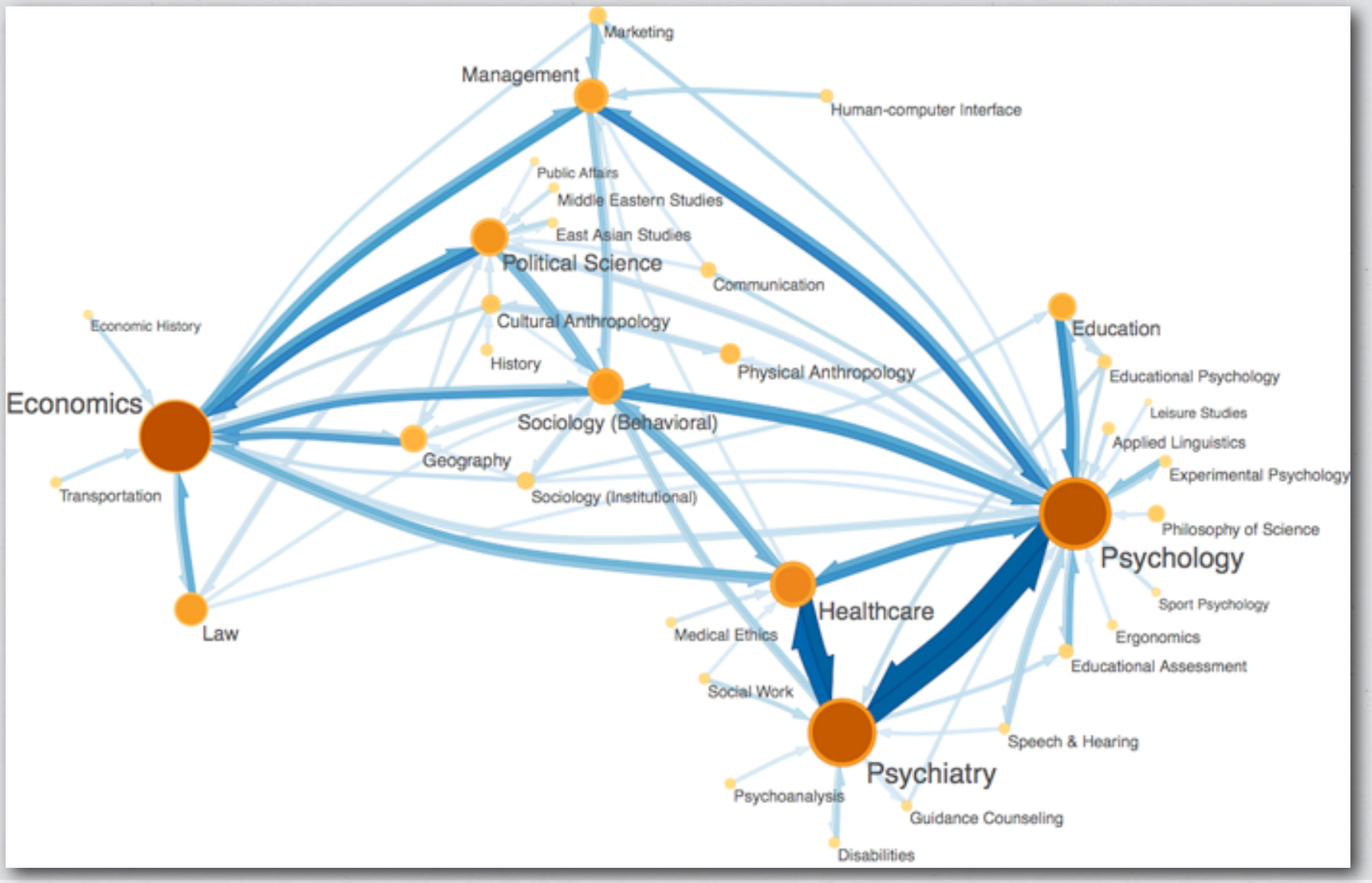
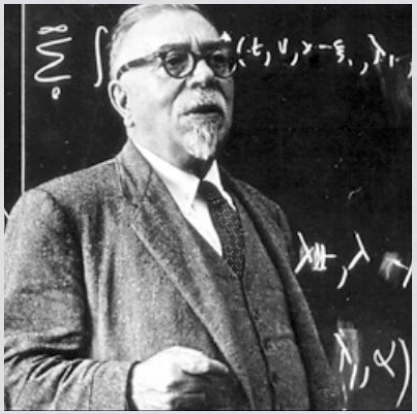
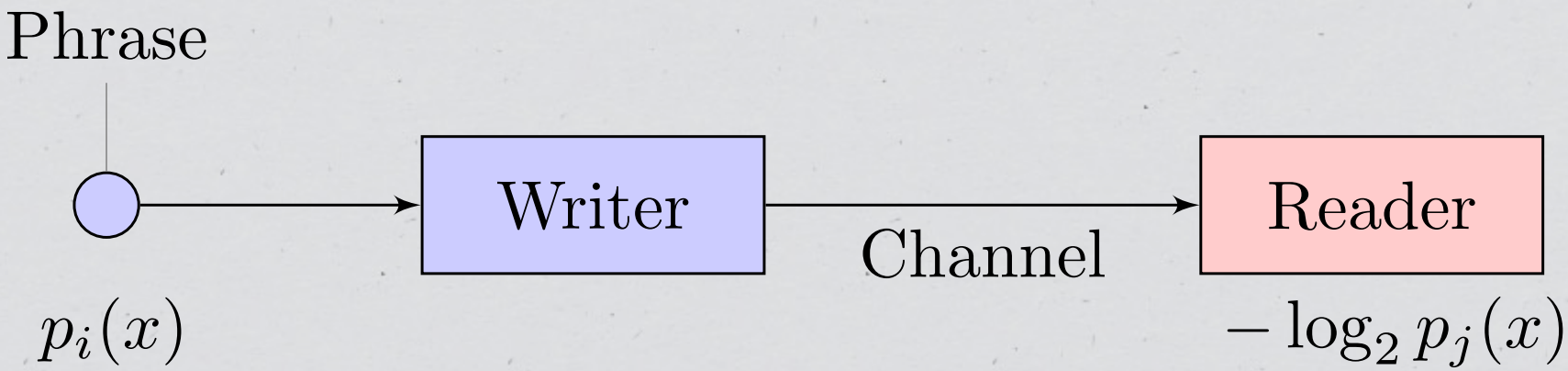
M. Rosvall, D. Axelsson, and C.T. Bergstrom

Eur. Phys. J. Special Topics 178, 13–23 (2009)


Marketing
Management
Human-computer Interface
Public Affairs
Middle Eastern Studies
East Asian Studies
Political Science
Communication
Economic History
Cultural Anthropology
History
Physical Anthropology
Education
Educational Psychology
Economics
Sociology (Behavioral)
Leisure Studies
Applied Linguistics
Geography
Experimental Psychology
Transportation
Sociology (Institutional)
Philosophy of Science
Psychology
Healthcare
Sport Psychology
Law
Medical Ethics
Ergonomics
Educational Assessment
Social Work
Speech & Hearing
Psychiatry
Psychoanalysis
Guidance Counseling
Disabilities





$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$

“Cultural Hole”

Relative Efficiency

$$E_{ij} = \frac{H(X_i)}{Q(p_i||p_j)} = \frac{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_i(x)}{-\sum_{x\in\mathcal{X}} p_i(x)\log_2 p_j(x)}$$

Cultural Hole

$$C_{ij} = 1 - E_{ij}$$

Average Cultural Hole

$$C_i = \sum_j C_{ij}/N$$

A
Average Jargon
0.46
0.44
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strategic management
mathematics education
growth economics
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international relations
social movements
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cytoskeleton
membrane cell biology
extracellular matrix
Scientific field

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Scientific field

$$C_{ij} < C_{ji}$$

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plant pathogens
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environmental toxicology
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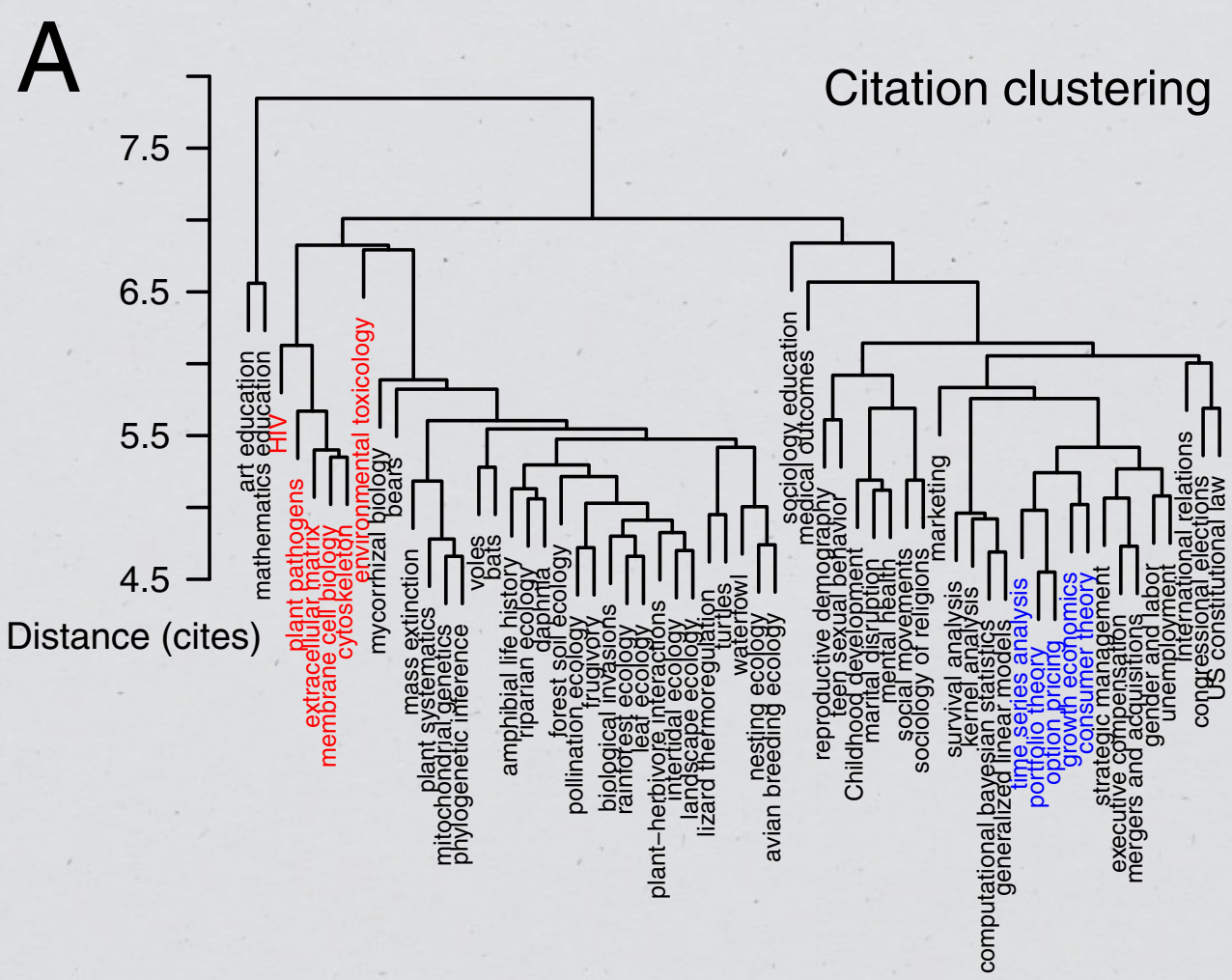
gender and labor
consumer theory
social movements
marital disruption
unemployment
mathematics education
marketing
portfolio theory
mergers and acquisitions
strategic management
international relations
US constitutional law
Scientific field

UPGMA:

$$\frac{1}{|\mathcal{A}| \cdot |\mathcal{B}|} \sum_{x \in \mathcal{A}} \sum_{y \in \mathcal{B}} d(x, y)$$



UPGMA = Unweighted Pair Group Method with Arithmetic Mean

UPGMA:

$$\frac{1}{|\mathcal{A}| \cdot |\mathcal{B}|} \sum_{x \in \mathcal{A}} \sum_{y \in \mathcal{B}} d(x, y)$$

UPGMA = Unweighted Pair Group Method with Arithmetic Mean

COMBINING STRUCTURE & CULTURE

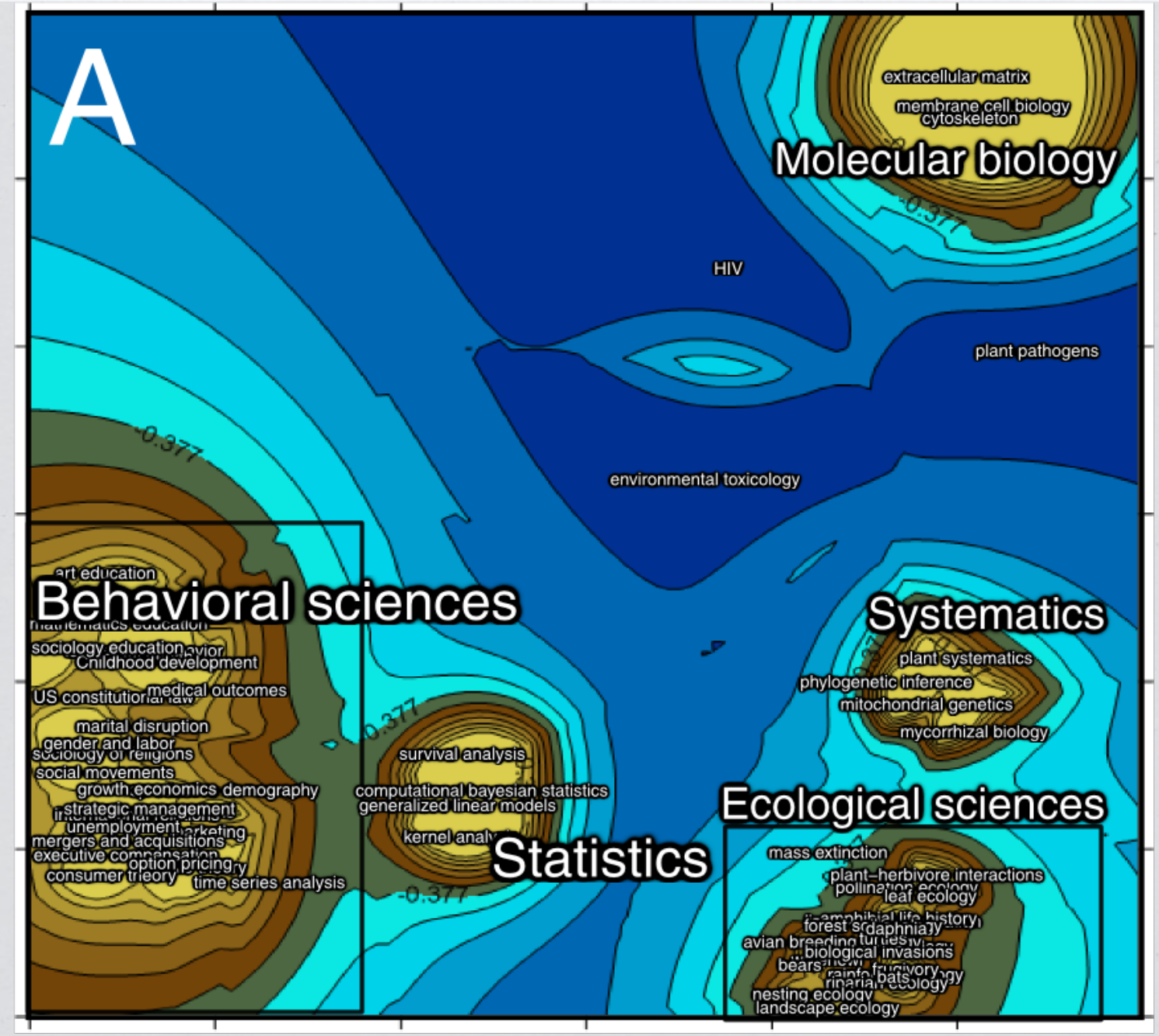
$$D(i,j) = \langle d_{ij} \rangle$$

(structural distance: measured using citation paths)

COMBINING STRUCTURE & CULTURE

$$w^i_{P_{xy}} = (\sqrt{(x - F^i_x)^2 + (y - F^i_y)^2})^{-\alpha}$$

$$P_{xy} = \sum_{i \neq max(\overrightarrow{w_{P_{xy}}})} \sum_{j \neq max(\overrightarrow{w_{P_{xy}}}), j \neq i} w^i_{P_{xy}} w^j_{P_{xy}} \tilde{J}_{ij}.$$


A
Molecular biology
extracellular matrix
membrane cell biology
cytoskeleton
HIV
plant pathogens
environmental toxicology
Behavioral sciences
art education
sociology education
Childhood development
US constitutional law
medical outcomes
marital disruption
gender and labor
sociology of religions
social movements
growth economics
demography
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consumer theory
time series analysis
Statistics
survival analysis
computational bayesian statistics
generalized linear models
kernel analysis
Systematics
plant systematics
phylogenetic inference
mitochondrial genetics
mycorrhizal biology
Ecological sciences
mass extinction
plant–herbivore interactions
pollination ecology
leaf ecology
amphibian life history
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biological invasions
bears
riparian ecology
nesting ecology
landscape ecology
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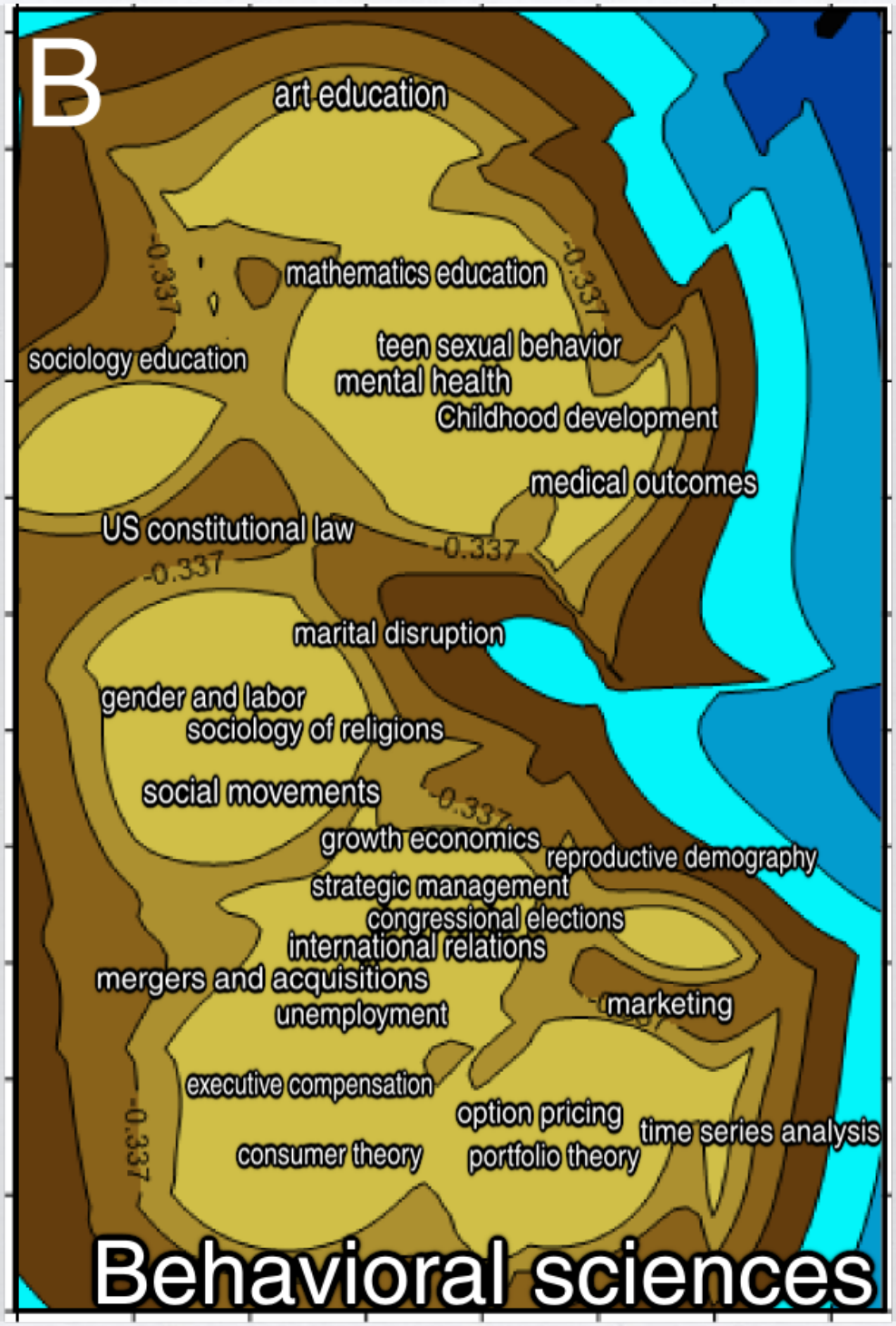
-0.41
-0.32


B
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mathematics education
sociology education
teen sexual behavior
mental health
Childhood development
medical outcomes
US constitutional law
marital disruption
gender and labor
sociology of religions
social movements
growth economics
reproductive demography
strategic management
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unemployment
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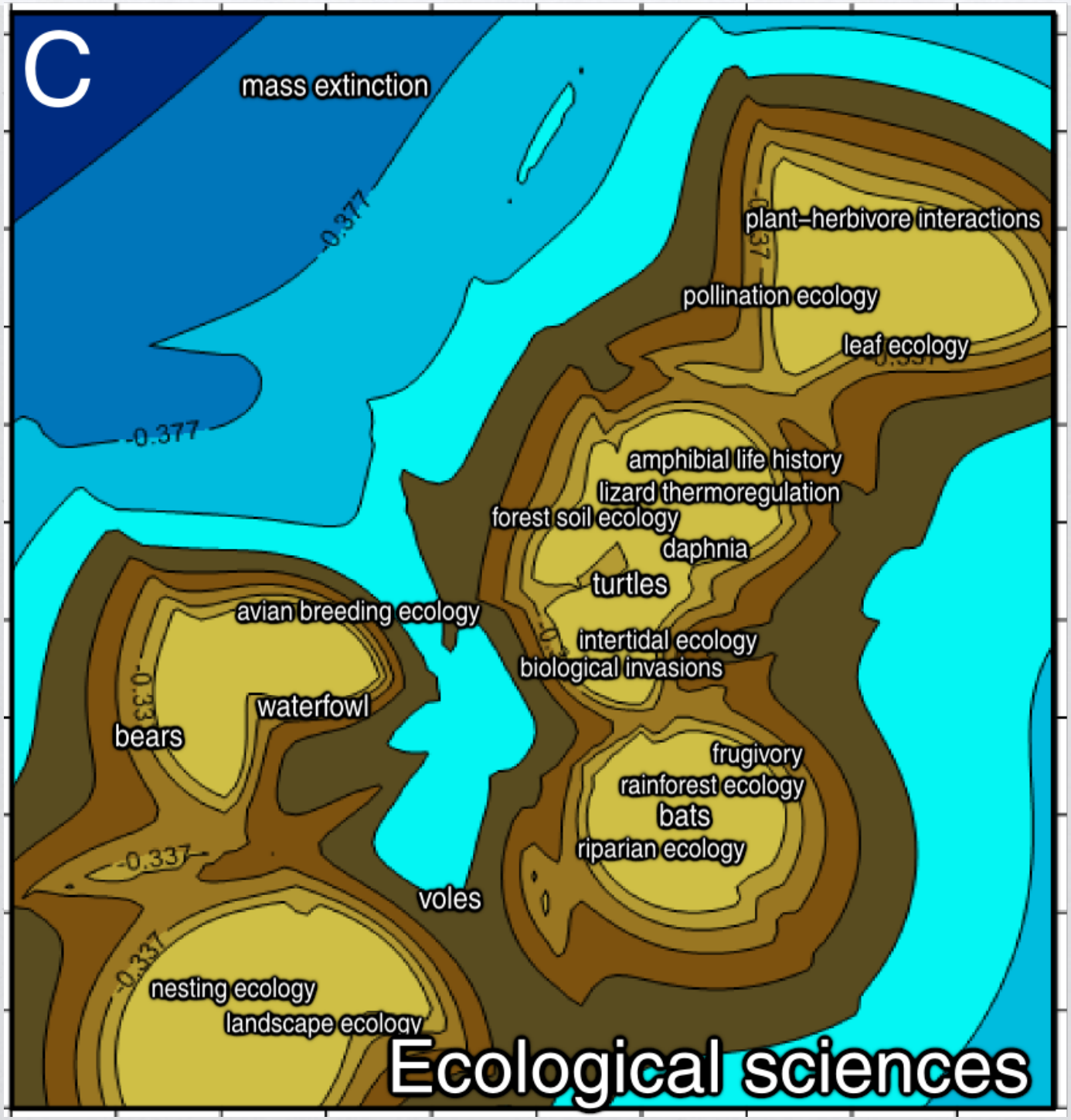
Behavioral sciences


C
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plant–herbivore interactions
pollination ecology
leaf ecology
amphibial life history
lizard thermoregulation
forest soil ecology
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turtles
avian breeding ecology
intertidal ecology
biological invasions
waterfowl
bears
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voles
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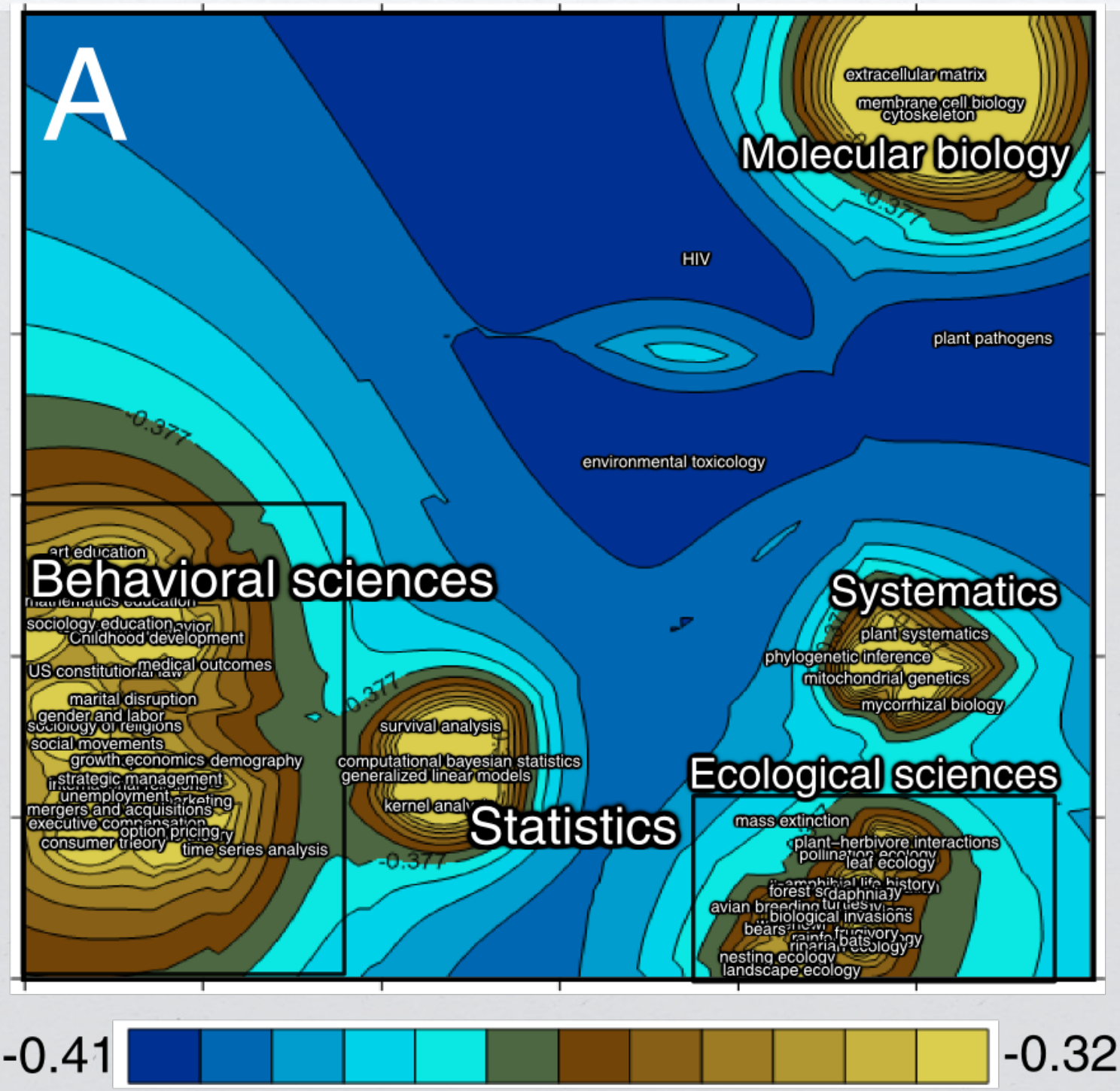
nesting ecology
landscape ecology
Ecological sciences


A
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membrane cell biology
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Molecular biology
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HIV
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environmental toxicology
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Behavioral sciences
sociology education
Childhood development
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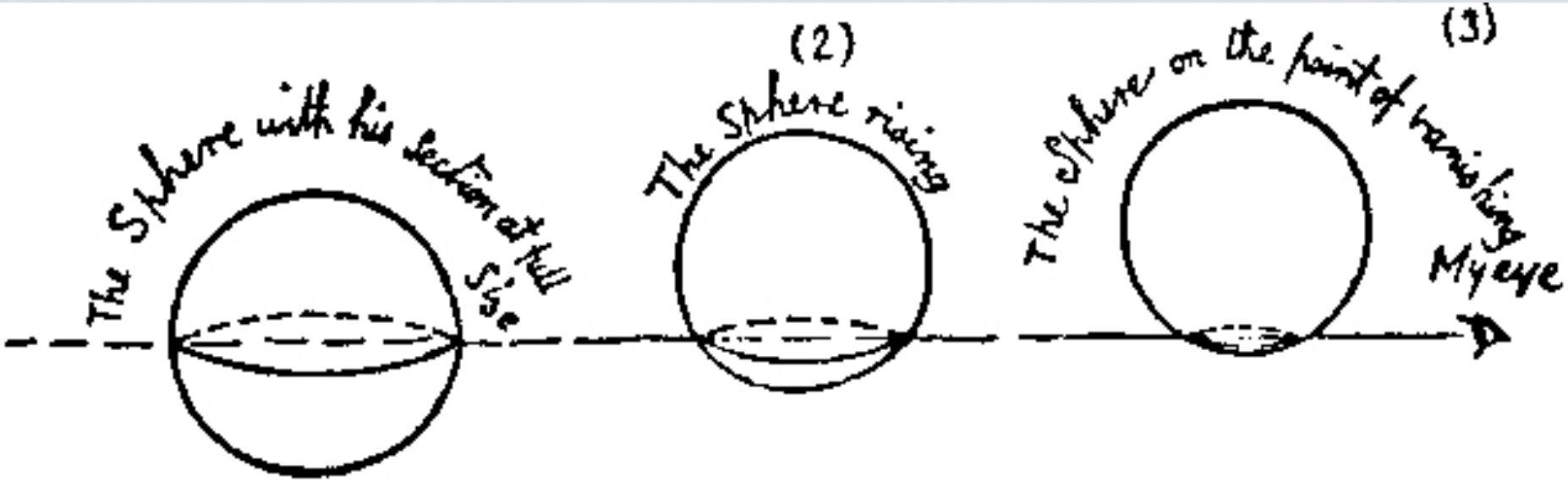
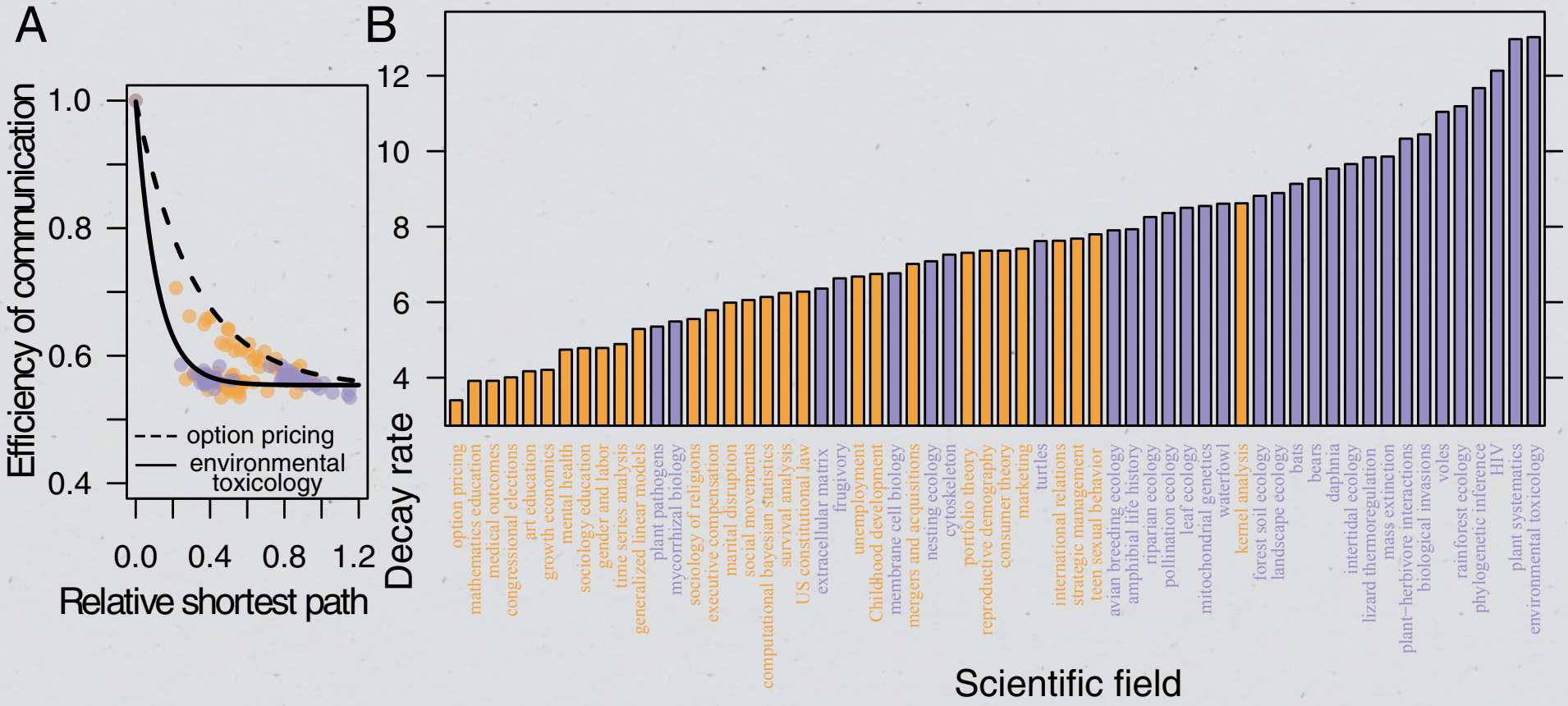
pollination ecology
leaf ecology
forest s
daphnia
avian breeding
biological invasions
bears
bats
riparian ecology
nesting ecology
landscape ecology
-0.41
-0.32

A CONCERN: ARTIFACTUAL?

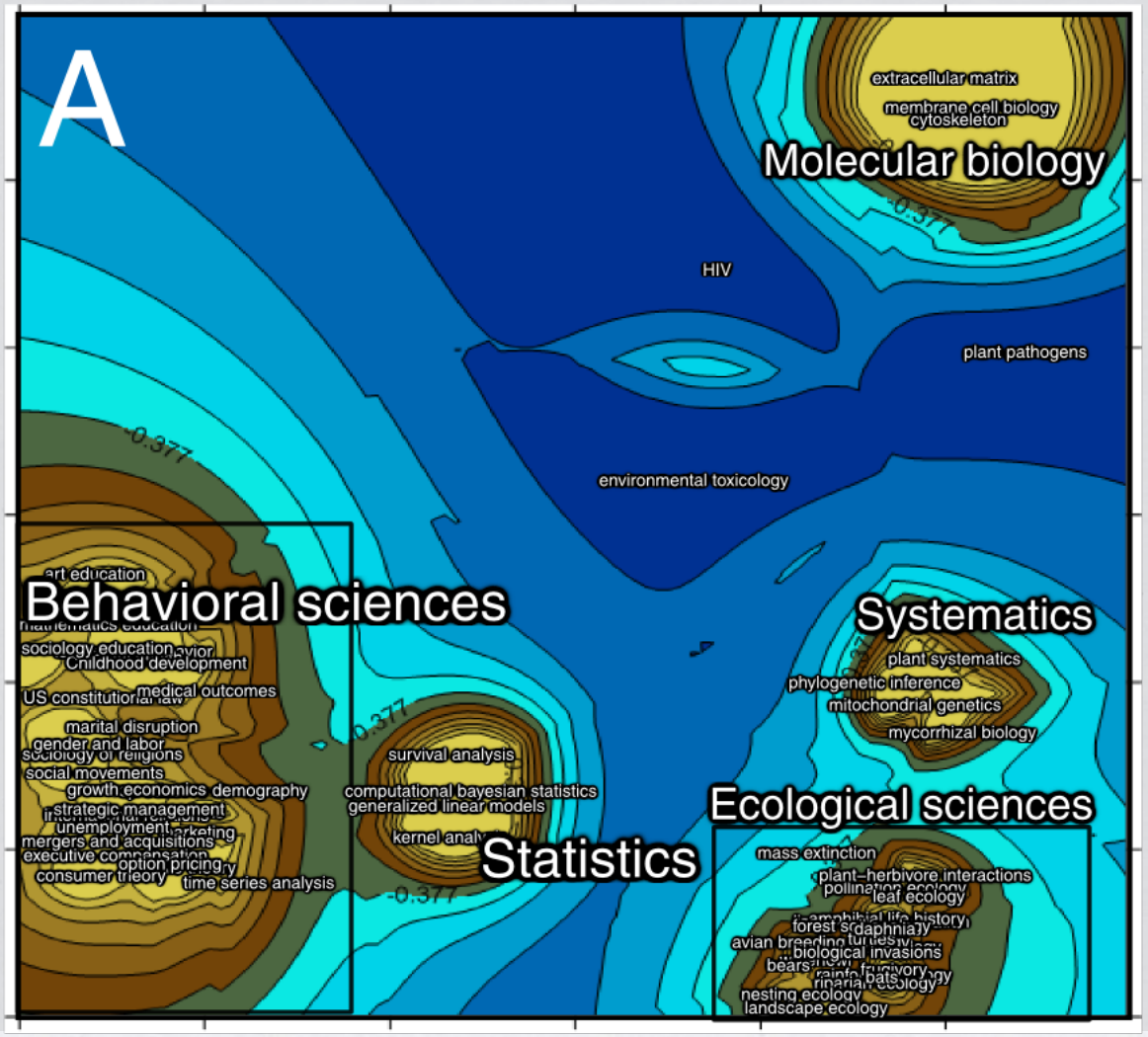

The Sphere with his section at full Size
(2)
The Sphere rising
(3)
The Sphere on the point of vanishing
My eye

$$\tilde{D}(i,j) = 1 - \frac{\langle d_{ij} \rangle}{\langle d_{ii} \rangle}$$



$$E_{ij} = 1 - \beta(1 - e^{-\alpha \tilde{D}(i,j)})$$

Case 1: Molecular Biology



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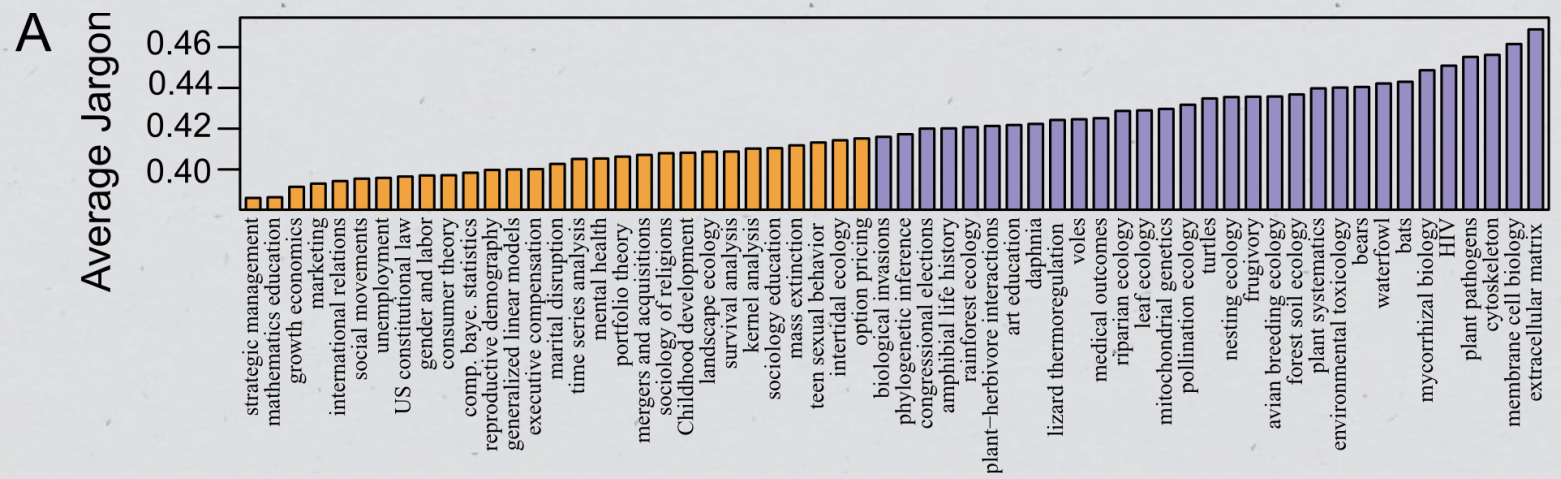
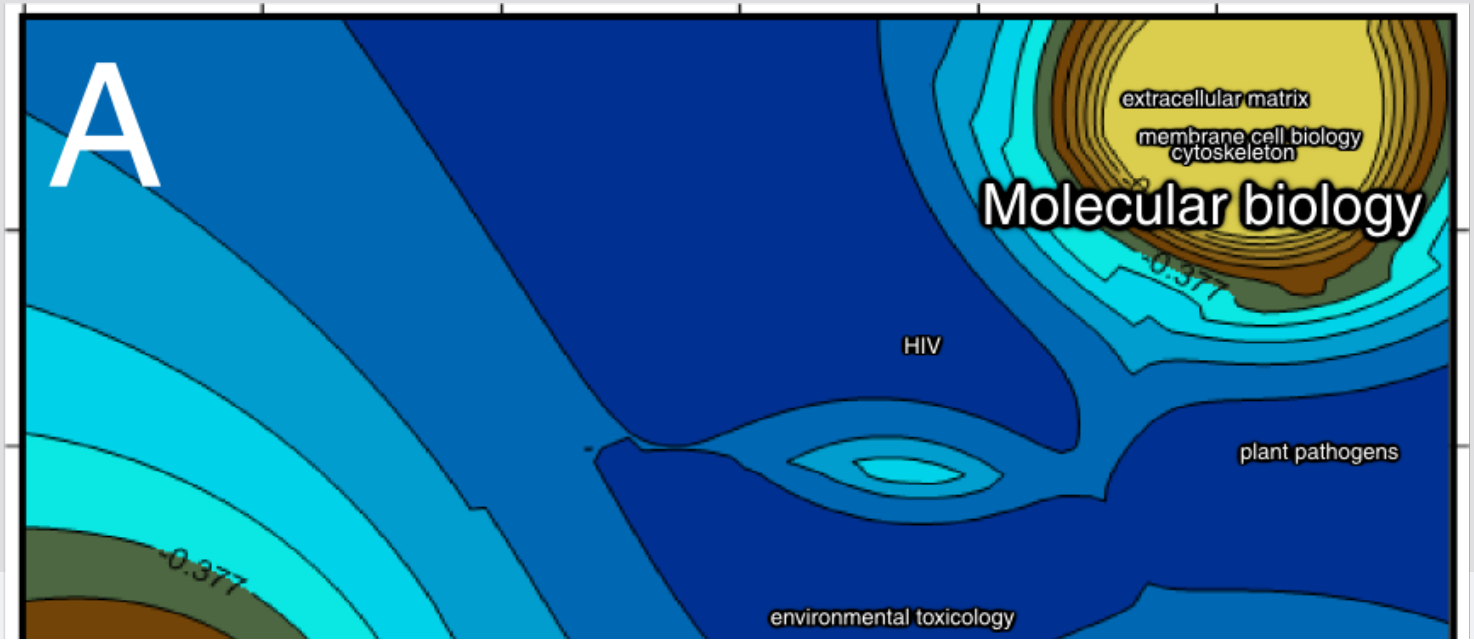
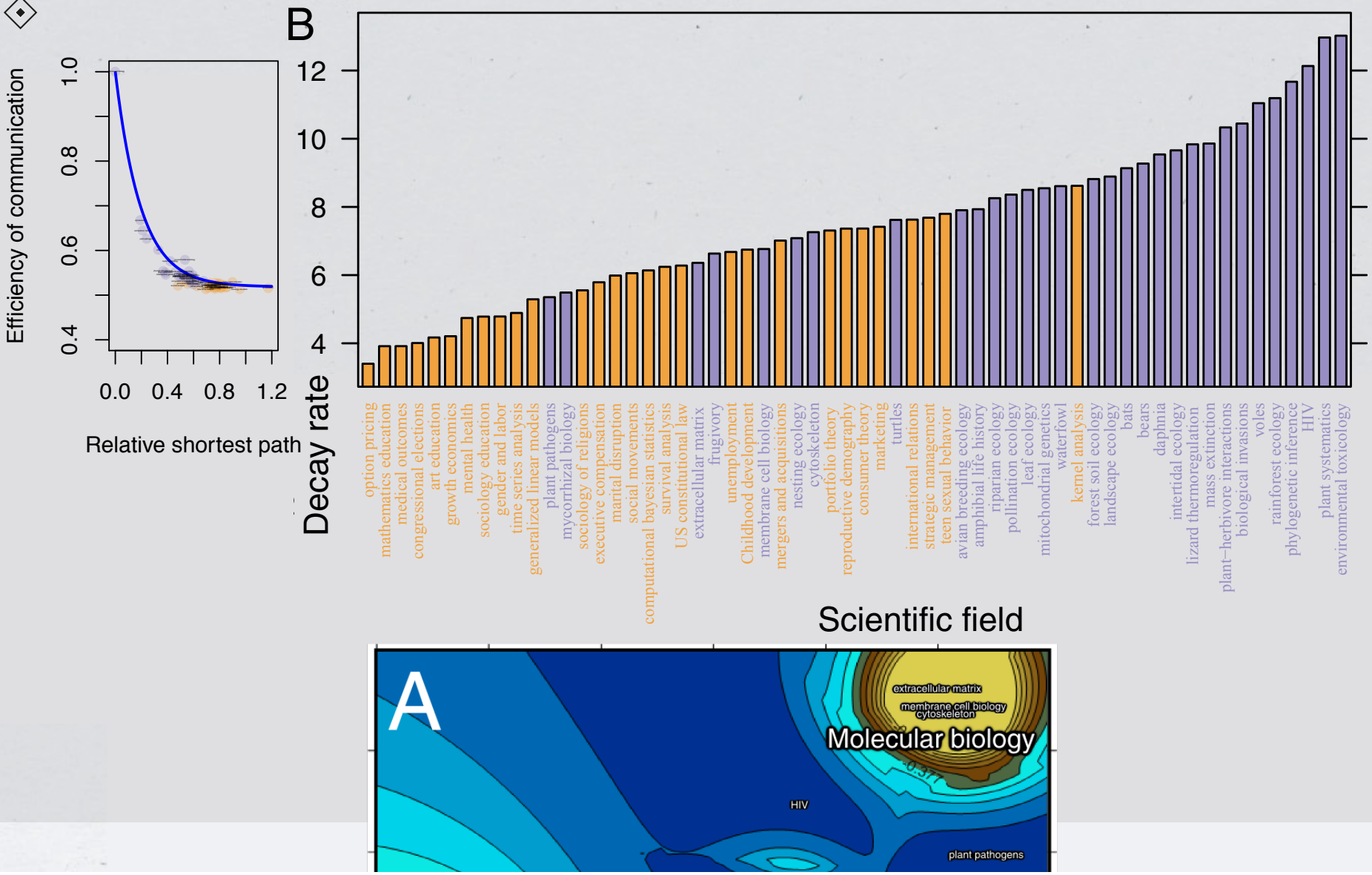
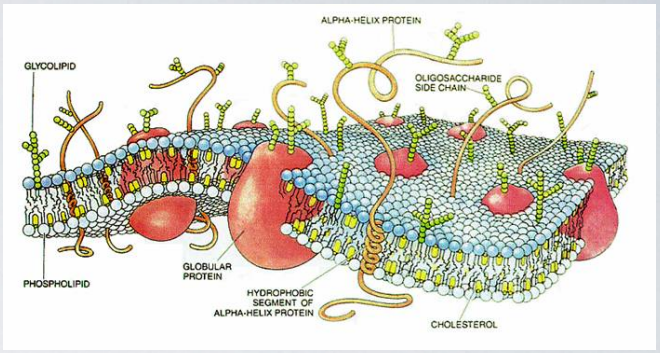
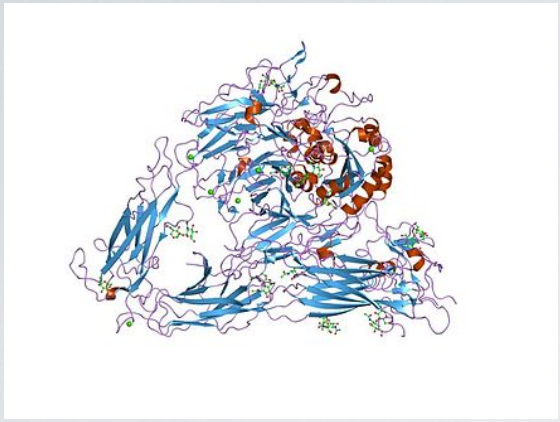


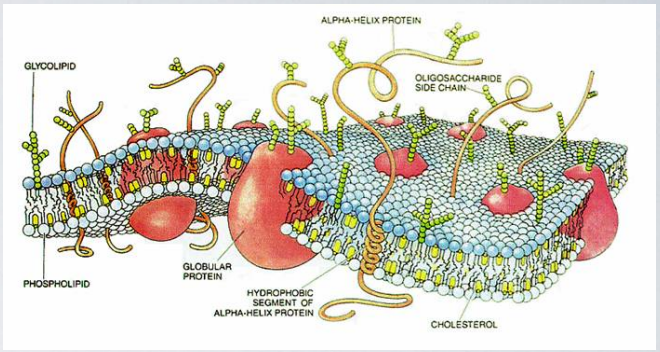


Case 1: Molecular Biology

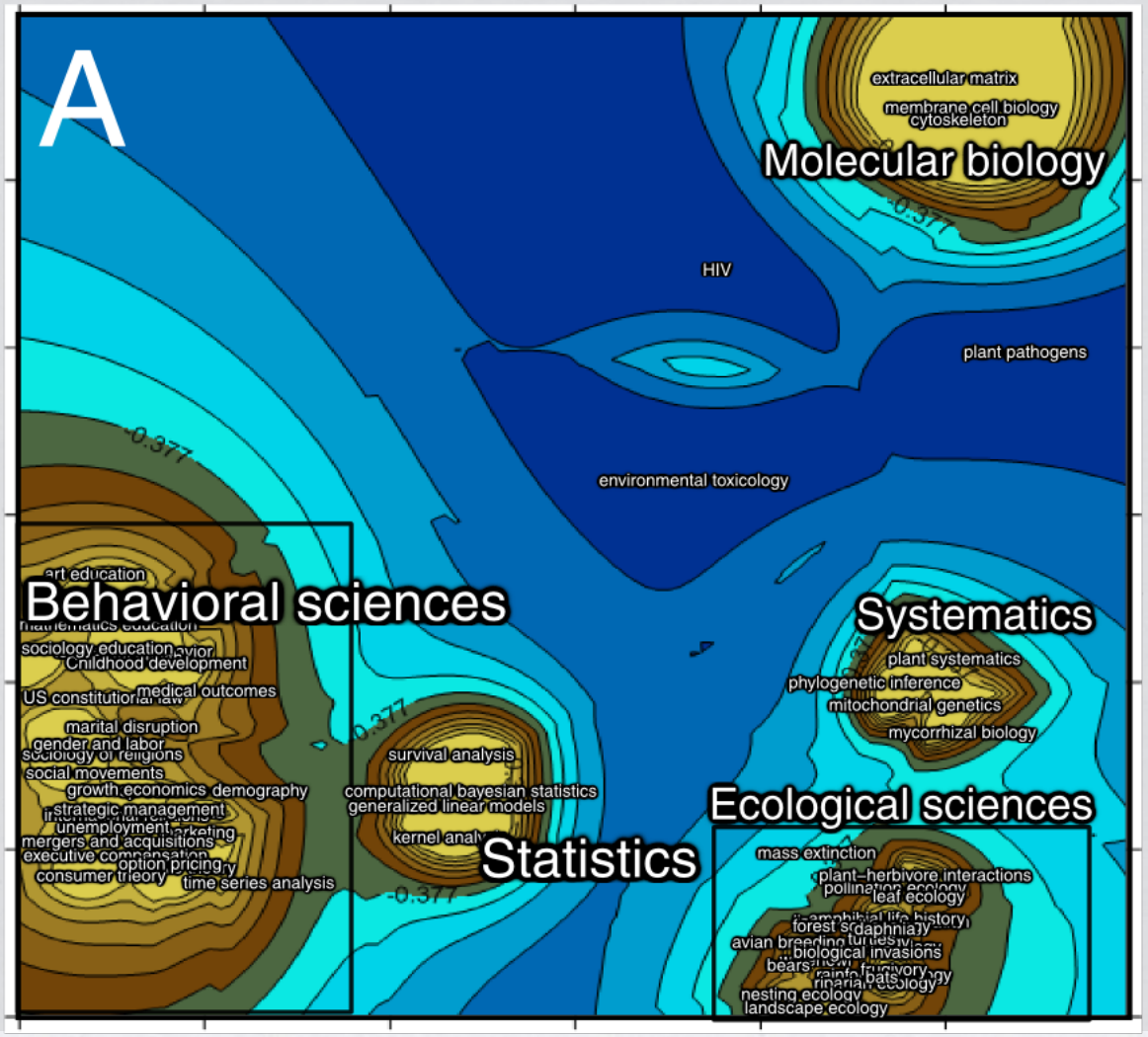


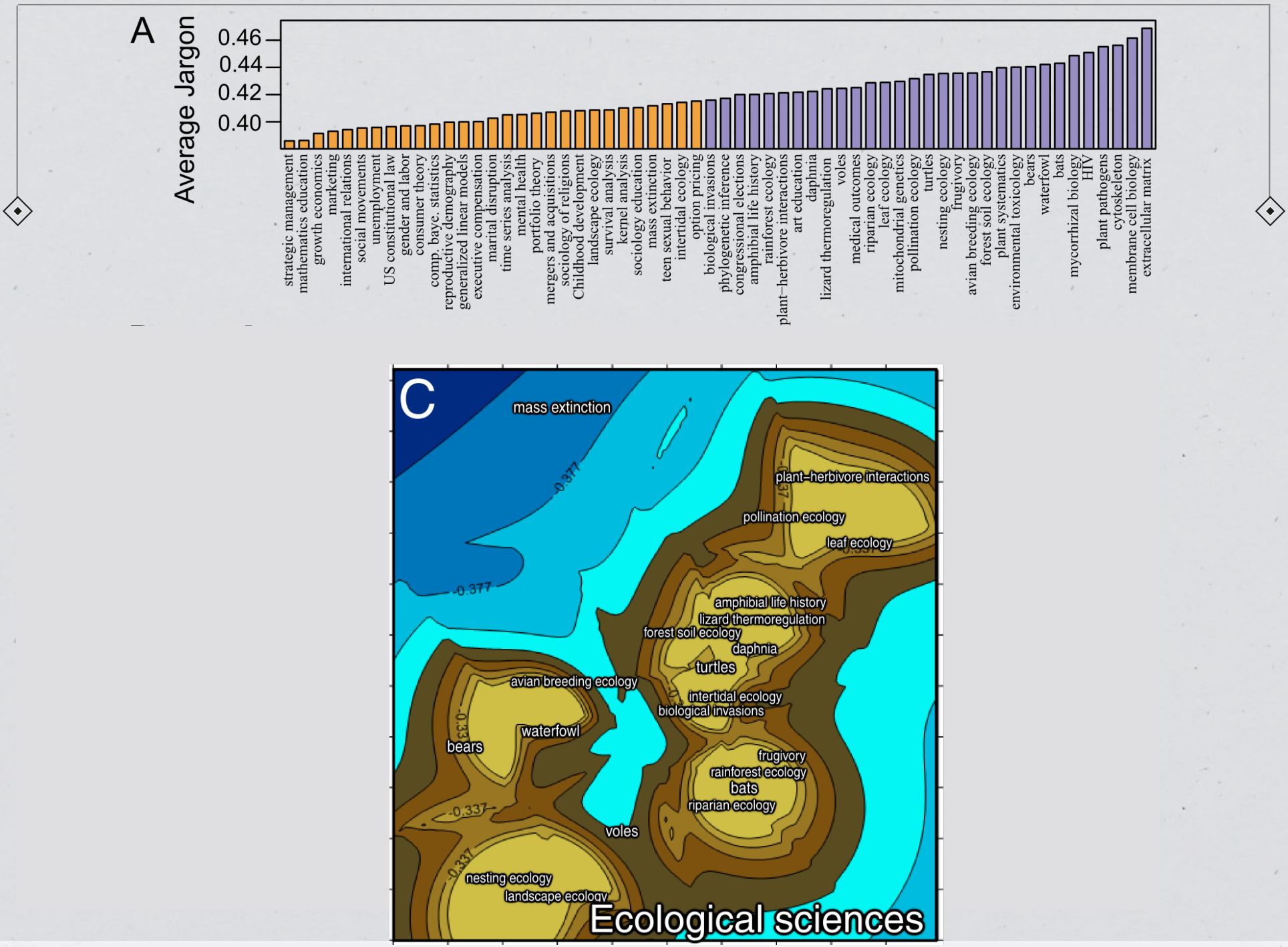

ALPHA-HELIX PROTEIN
GLYCOLIPID
OLIGOSACCHARIDE SIDE CHAIN
GLOBULAR PROTEIN
PHOSPHOLIPID
HYDROPHOBIC SEGMENT OF ALPHA-HELIX PROTEIN
CHOLESTEROL



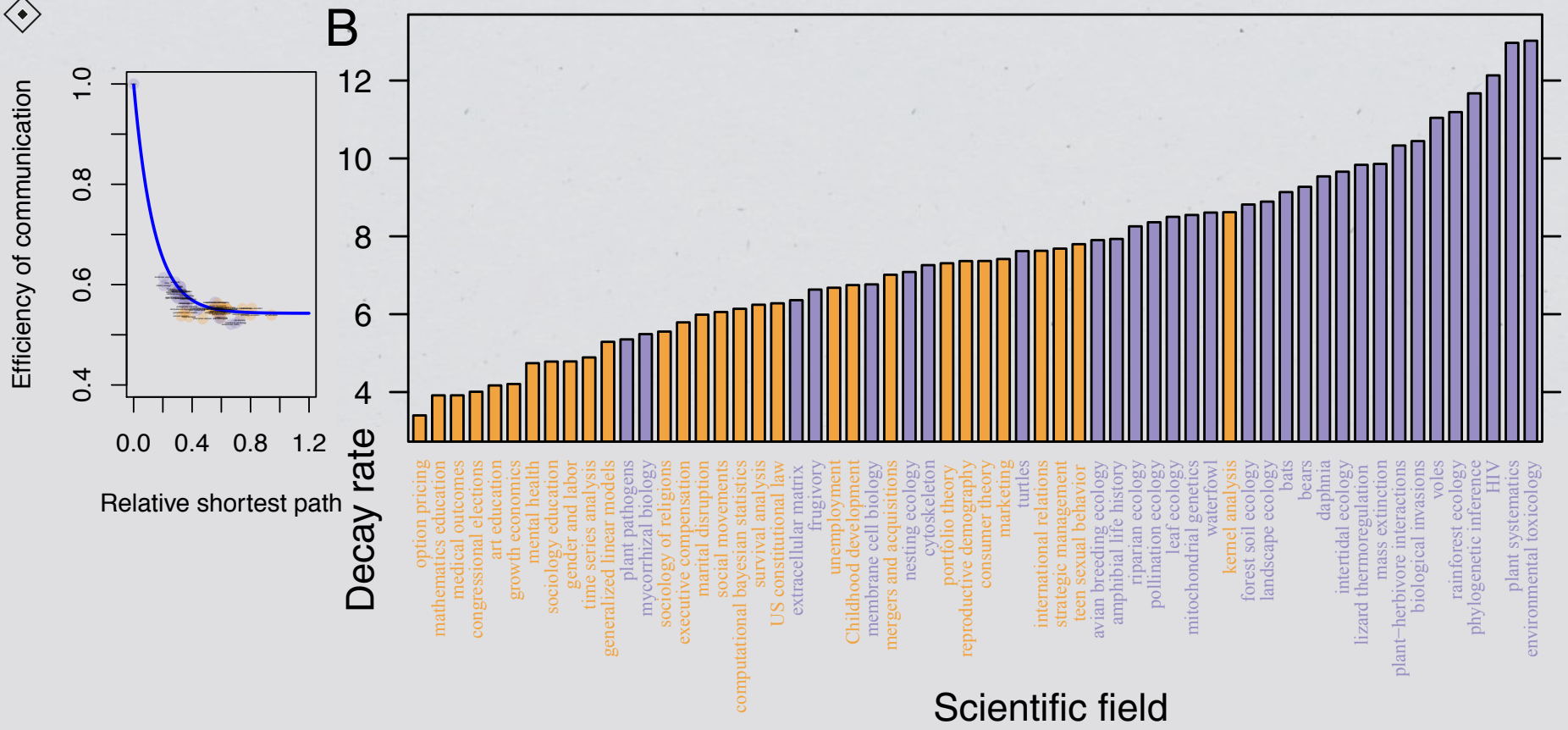

ALPHA-HELIX PROTEIN
GLYCOLIPID
OLIGOSACCHARIDE SIDE CHAIN
GLOBULAR PROTEIN
PHOSPHOLIPID
HYDROPHOBIC SEGMENT OF ALPHA-HELIX PROTEIN
CHOLESTEROL

Case 2: Ecological Sciences

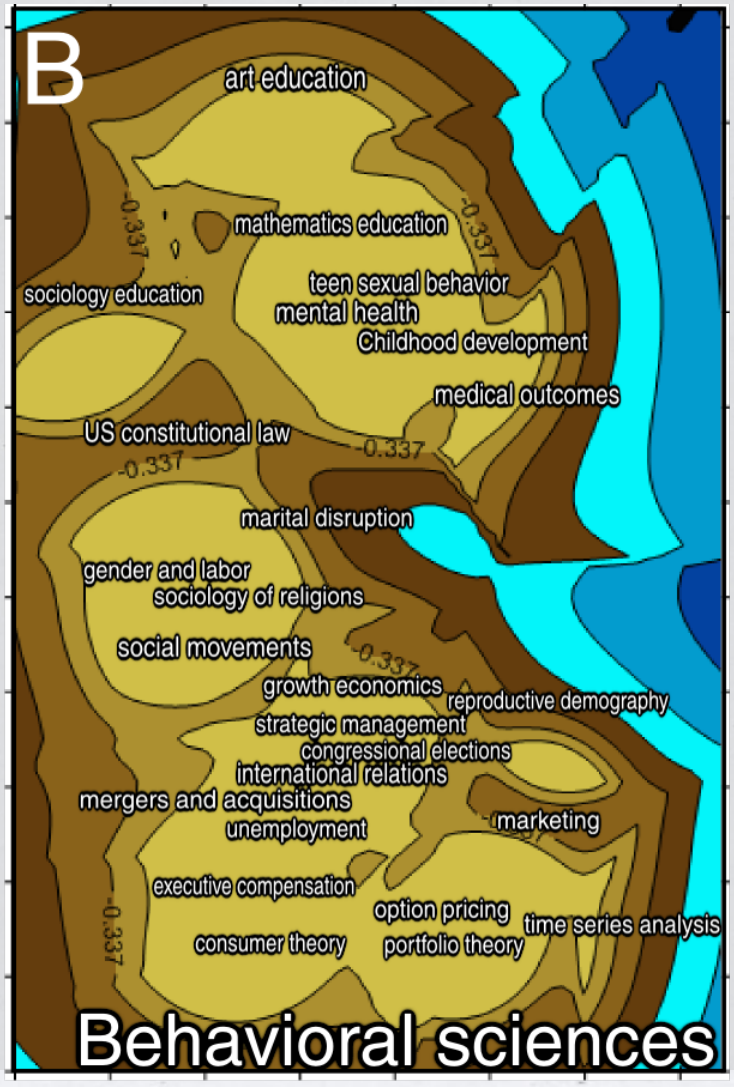



A
Average Jargon
0.46
0.44
0.42
0.40
strategic management
mathematics education
growth economics
marketing
international relations
social movements
unemployment
US constitutional law
gender and labor
consumer theory
comp. baye. statistics
reproductive demography
generalized linear models
executive compensation
marital disruption
time series analysis
mental health
portfolio theory
mergers and acquisitions
sociology of religions
Childhood development
landscape ecology
survival analysis
kernel analysis
sociology education
mass extinction
teen sexual behavior
intertidal ecology
option pricing
biological invasions
phylogenetic inference
congressional elections
amphibial life history
rainforest ecology
plant–herbivore interactions
art education
daphnia
lizard thermoregulation
voles
medical outcomes
riparian ecology
leaf ecology
mitochondrial genetics
pollination ecology
turtles
nesting ecology
frugivory
avian breeding ecology
forest soil ecology
plant systematics
environmental toxicology
bears
waterfowl
bats
mycorrhizal biology
HIV
plant pathogens
cytoskeleton
membrane cell biology
extracellular matrix
C
mass extinction
-0.377
-0.377
plant–herbivore interactions
pollination ecology
leaf ecology
amphibial life history
lizard thermoregulation
forest soil ecology
daphnia
turtles
avian breeding ecology
intertidal ecology
biological invasions
-0.33
waterfowl
bears
frugivory
rainforest ecology
bats
riparian ecology
-0.337
voles
-0.337
nesting ecology
landscape ecology
Ecological sciences

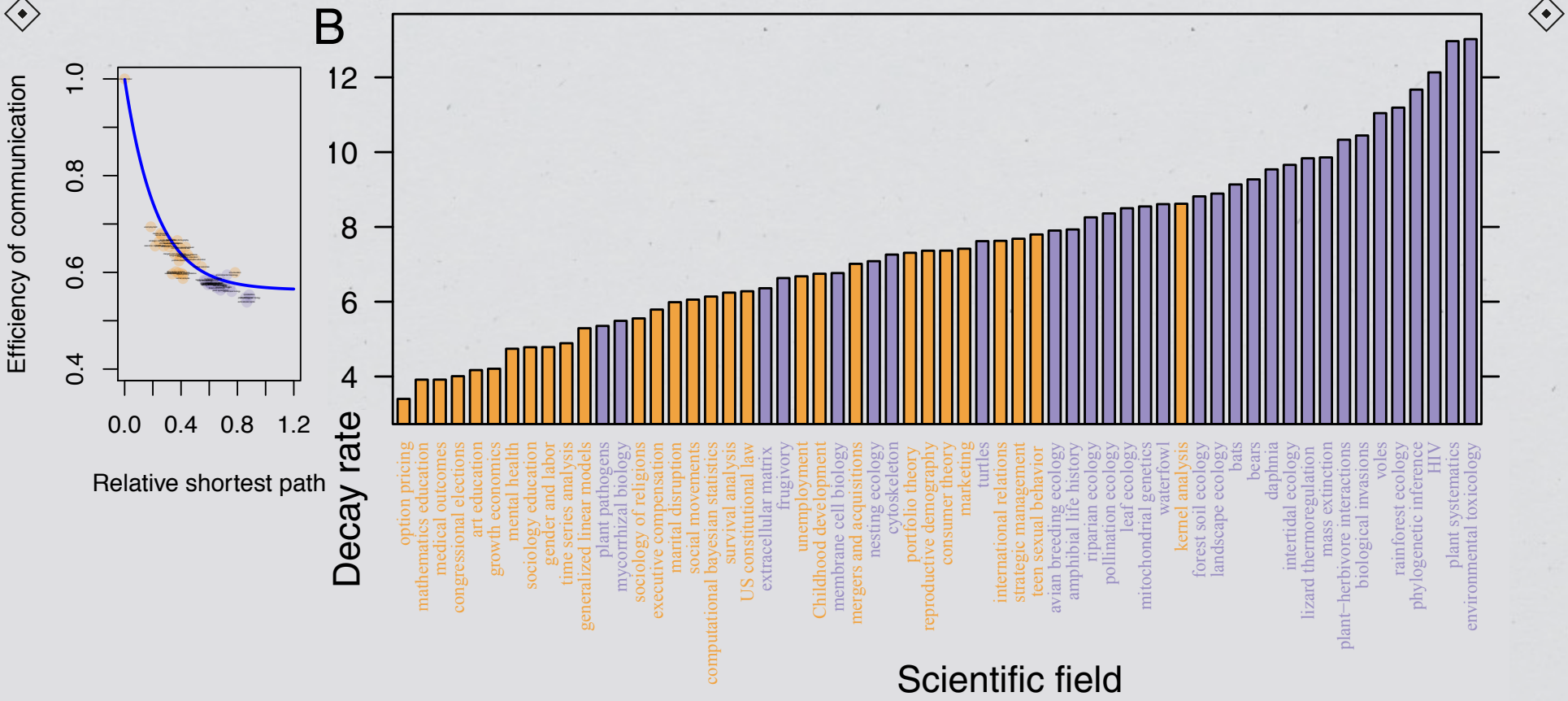
Case 2: Ecological Sciences

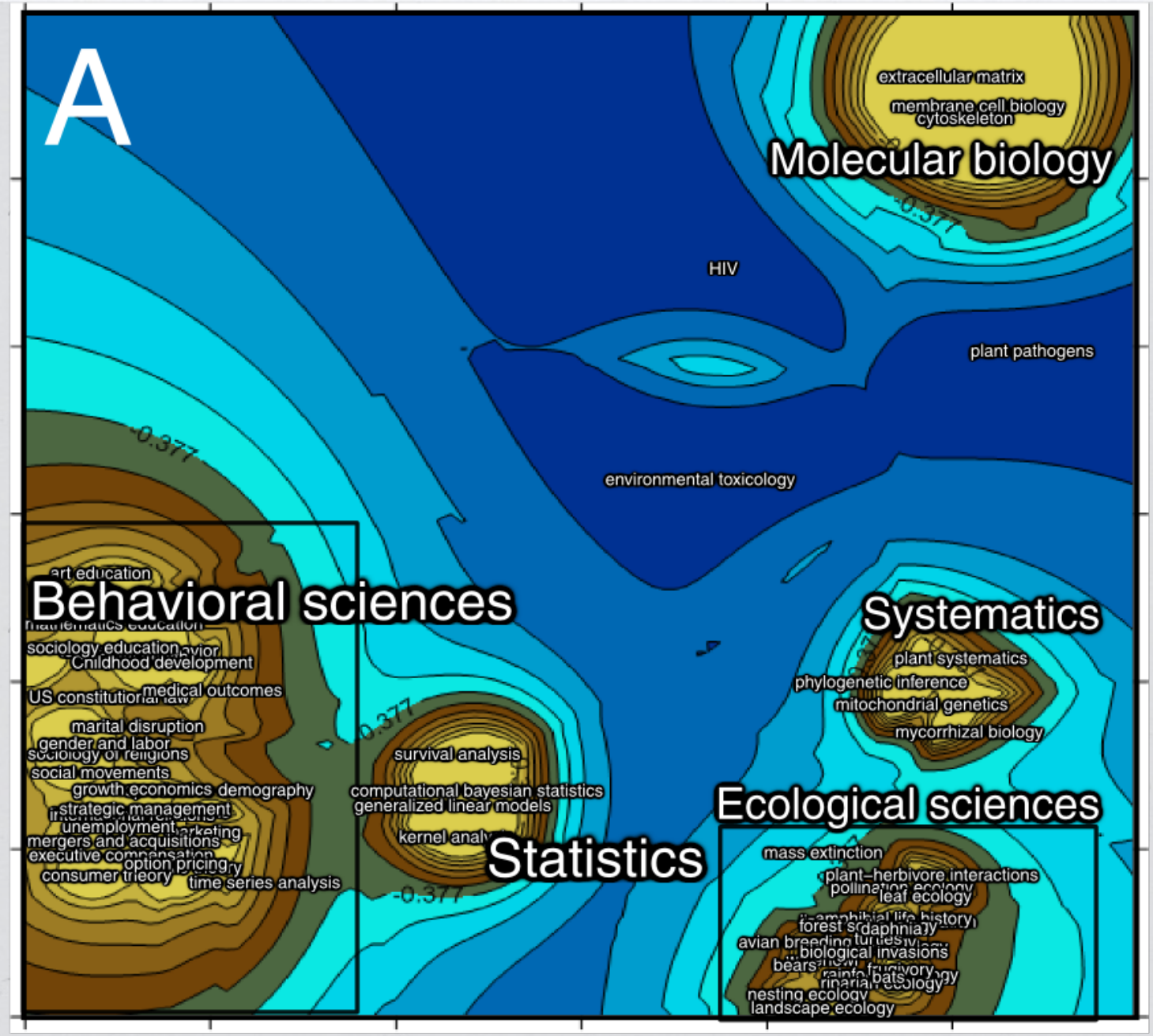


Case 3: Social Sciences



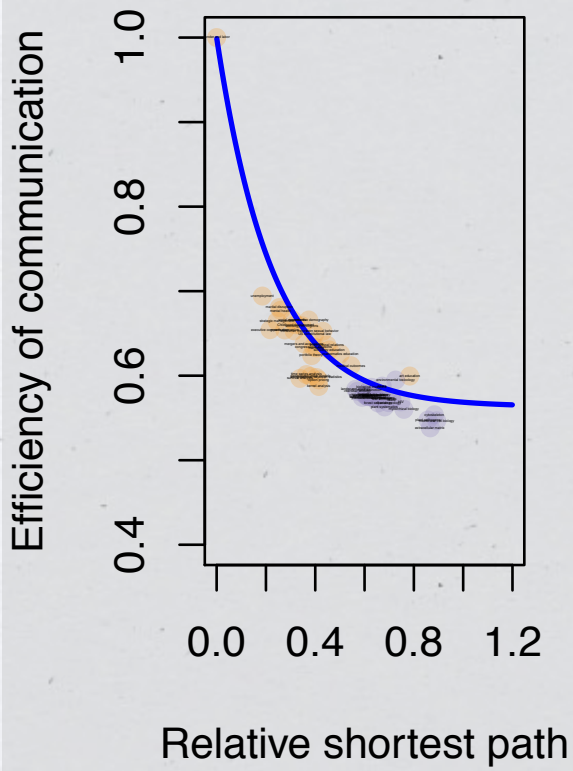
Case 3: Social Sciences

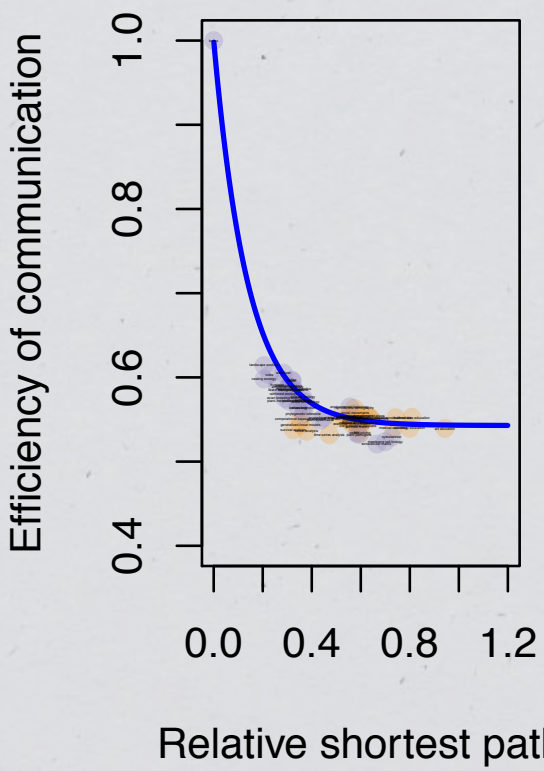


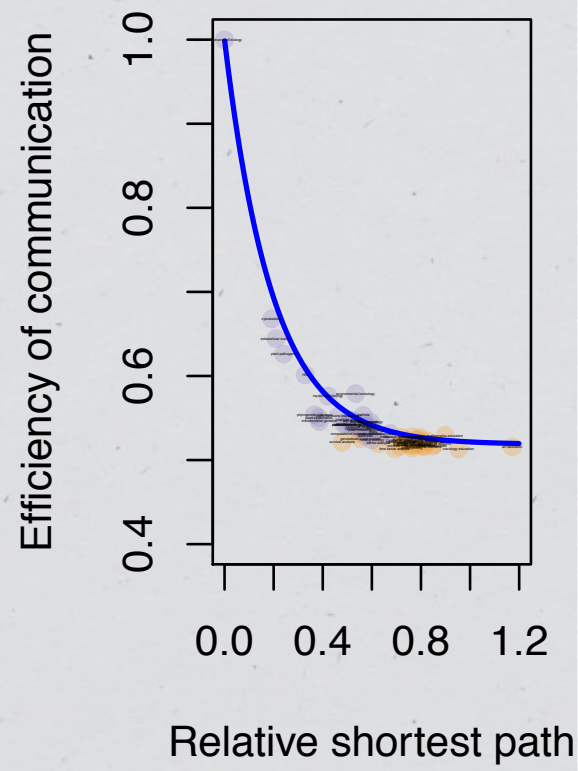

A
extracellular matrix
membrane cell biology
cytoskeleton
Molecular biology
-0.377
HIV
plant pathogens
environmental toxicology
-0.377
art education
Behavioral sciences
sociology education
Childhood development
US constitutional law
medical outcomes
marital disruption
gender and labor
sociology of religions
social movements
growth economics
demography
strategic management
unemployment
mergers and acquisitions
executive compensation
option pricing
consumer theory
time series analysis
0.377
survival analysis
computational bayesian statistics
generalized linear models
kernel analysis
Statistics
-0.377
Systematics
plant systematics
phylogenetic inference
mitochondrial genetics
mycorrhizal biology
Ecological sciences
mass extinction
plant–herbivore interactions
pollination ecology
leaf ecology
amphibian life history
forest succession
daphnia
avian breeding
biological invasions
bears
frugivory
bats
riparian ecology
nesting ecology
landscape ecology
-0.41
-0.32

What do cultural holes tell us?

* Four “domains”, three tied together by scale: social sciences; ecological sciences; molecular biology; statistics
* Social sciences have lower jargon barriers and smooth intra-domain communication (integrated)
* Ecological sciences have higher jargon barriers and inefficient communication with neighbors (balkanized by particularities)
* Molecular sciences have higher jargon barriers but communicate efficiently with neighbors (shared reductive substrate)


Efficiency of communication
0.4
0.6
0.8
1.0
0.0
0.4
0.8
1.2
Relative shortest path

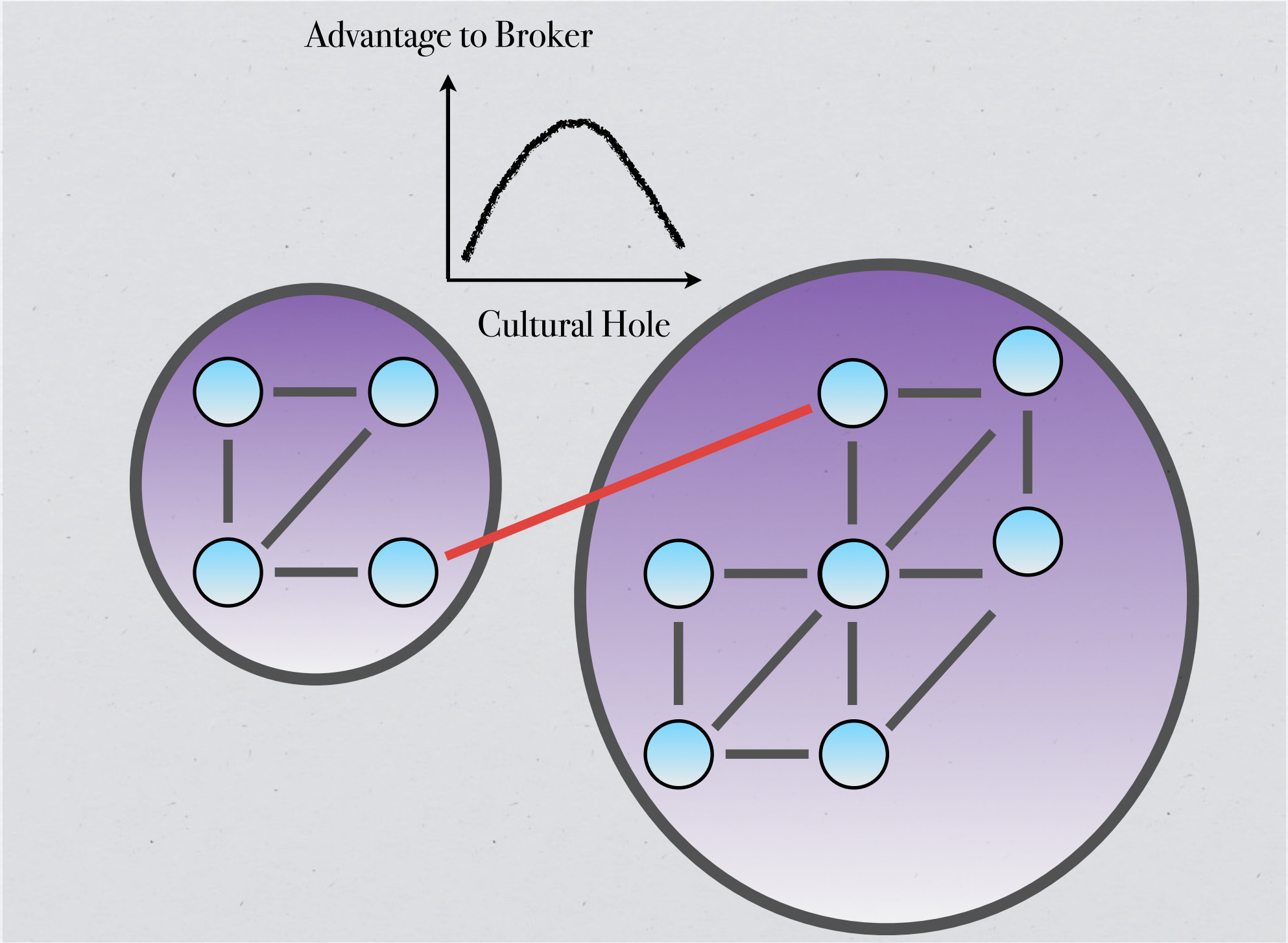

Efficiency of communication
0.4
0.6
0.8
1.0
0.0
0.4
0.8
1.2
Relative shortest path

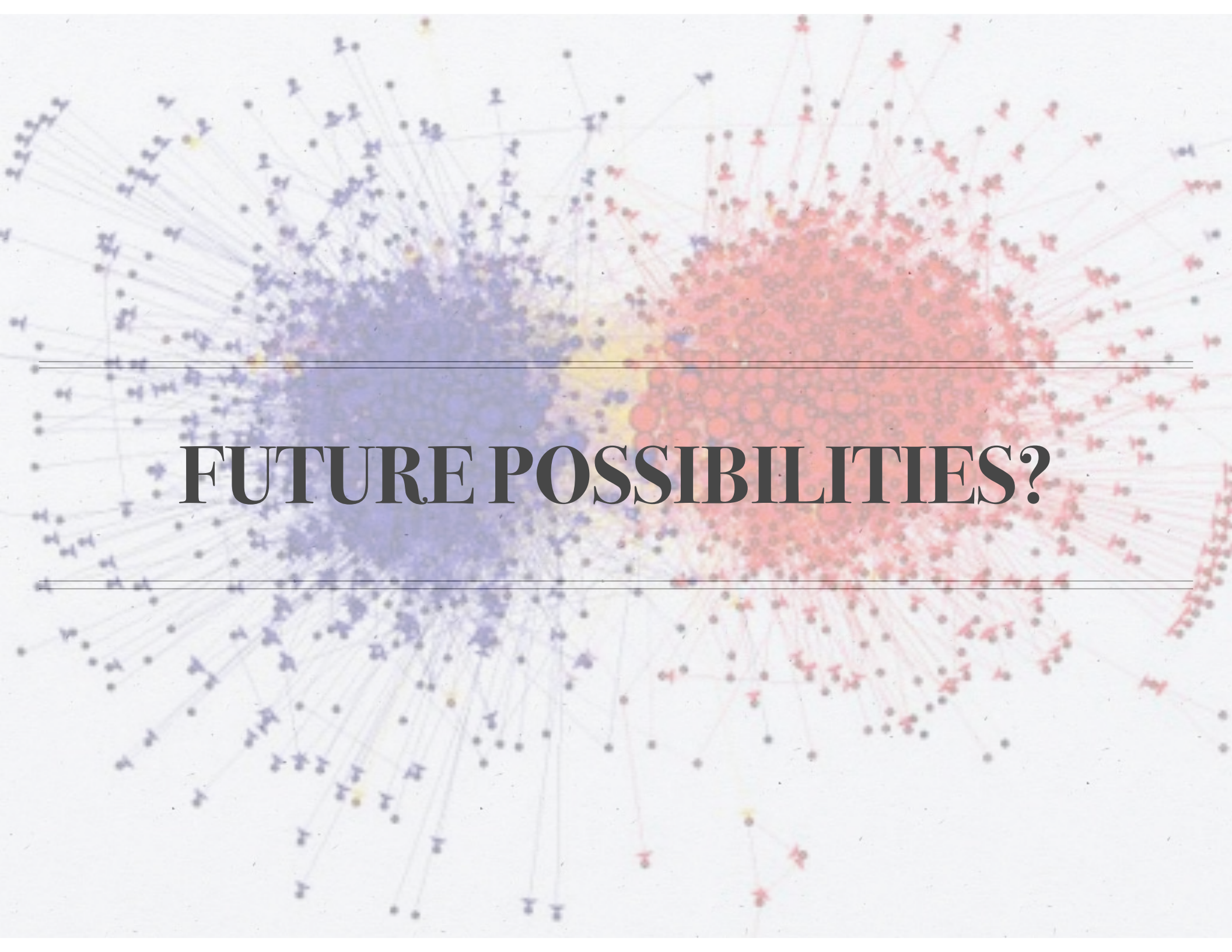

Efficiency of communication
0.4
0.6
0.8
1.0
0.0
0.4
0.8
1.2
Relative shortest path

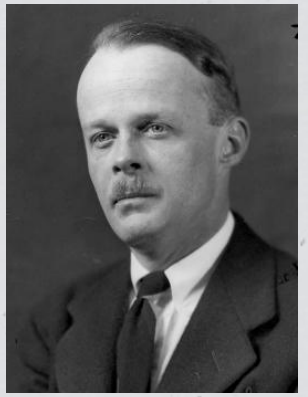
Ways Forward

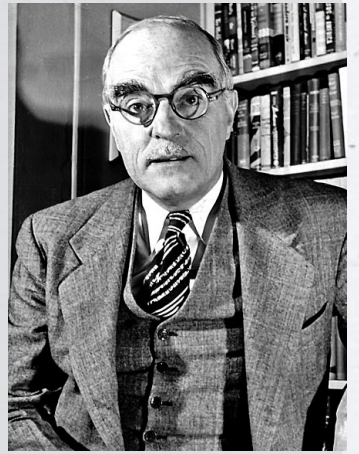
- Better models of scientific language (topic models?)
- More diverse "symbol set" (e.g., white space, equations, etc.)
- Temporality & temporal dynamics of jargon/cultural holes

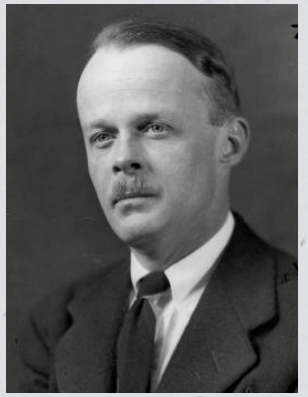
Structure and *culture* are complementary, cross-cutting, & co-constituting

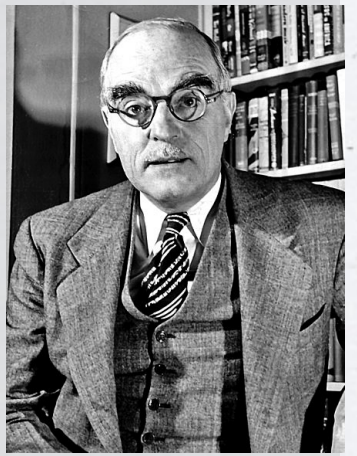

Advantage to Broker
Cultural Hole


FUTURE POSSIBILITIES?









ALIEN OBJECTS