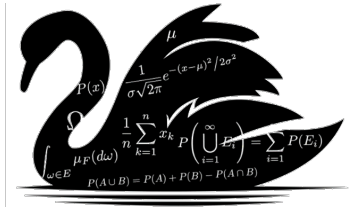
lecture 10: Interdisciplinarity

may work in complex interrelated domain (with rare control events)



unobserved scenarios

examples

Parameter estimation

Initial conditions

Simplified, Formal, explainable, actionable model/theory

Logical consequences

predictions

????

observations

Particular Instance

General Rule

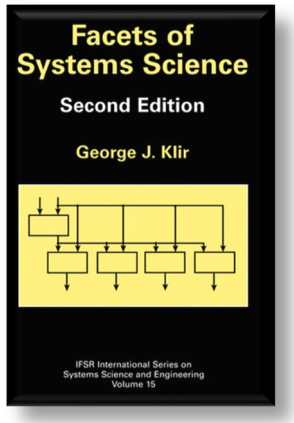
Symbols

Encoding

Measure

Measure

Measure



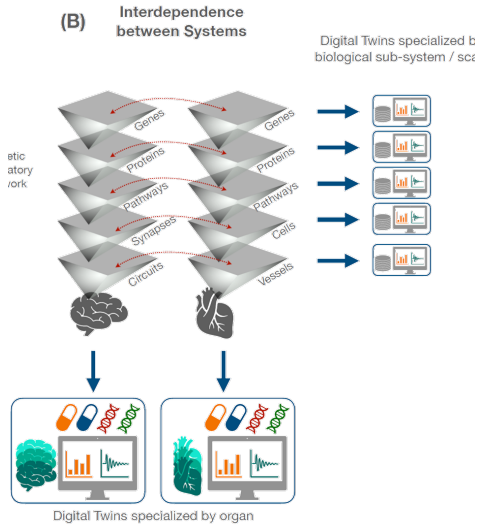
$World_0$

$World_1$

$World_2$

Howard Pattee

Robert Rosen



George Klir

Complex Physical Laws

Model and data simplification is key for feasibility and explainability.

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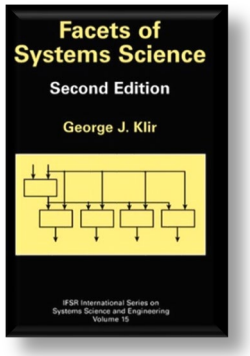
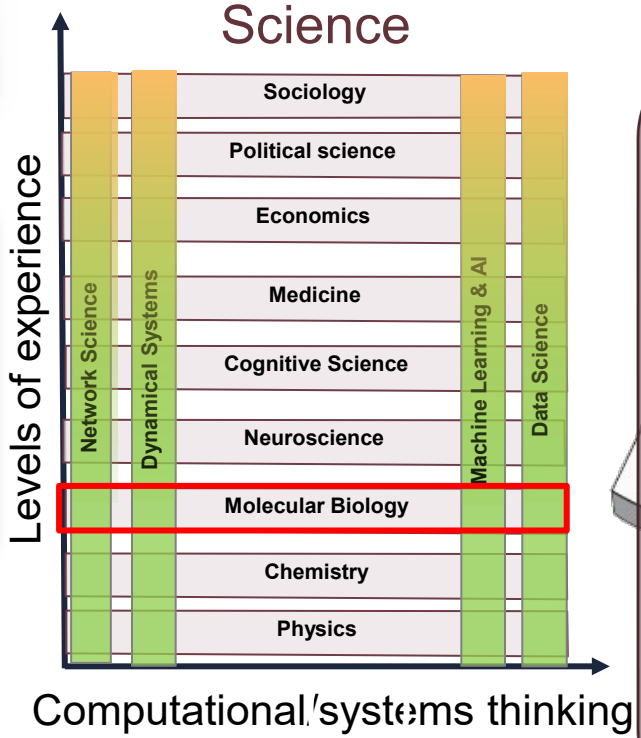
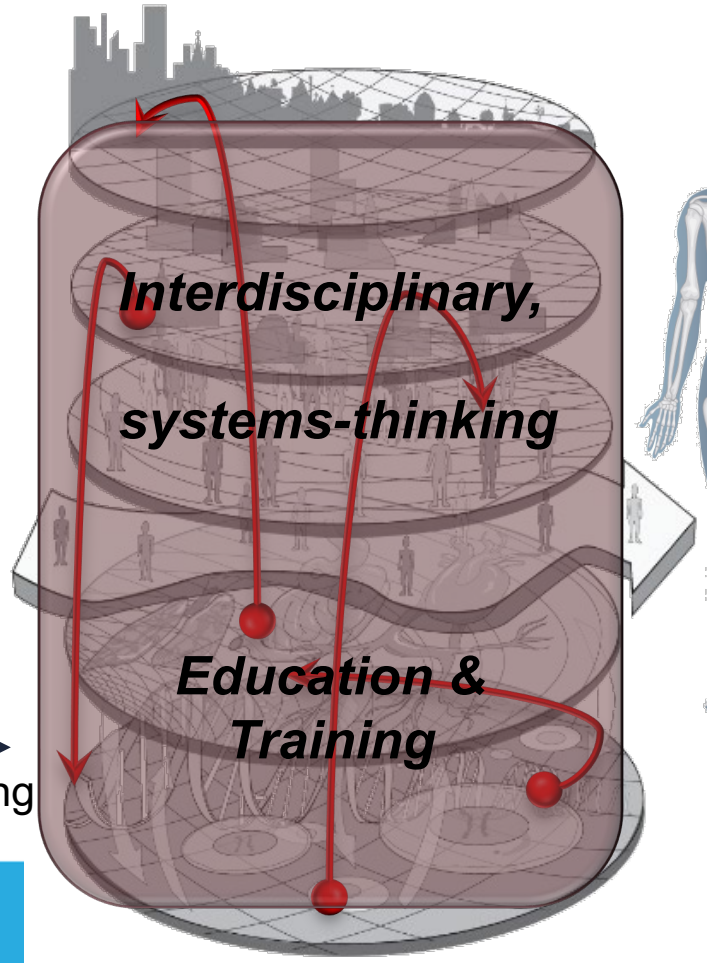
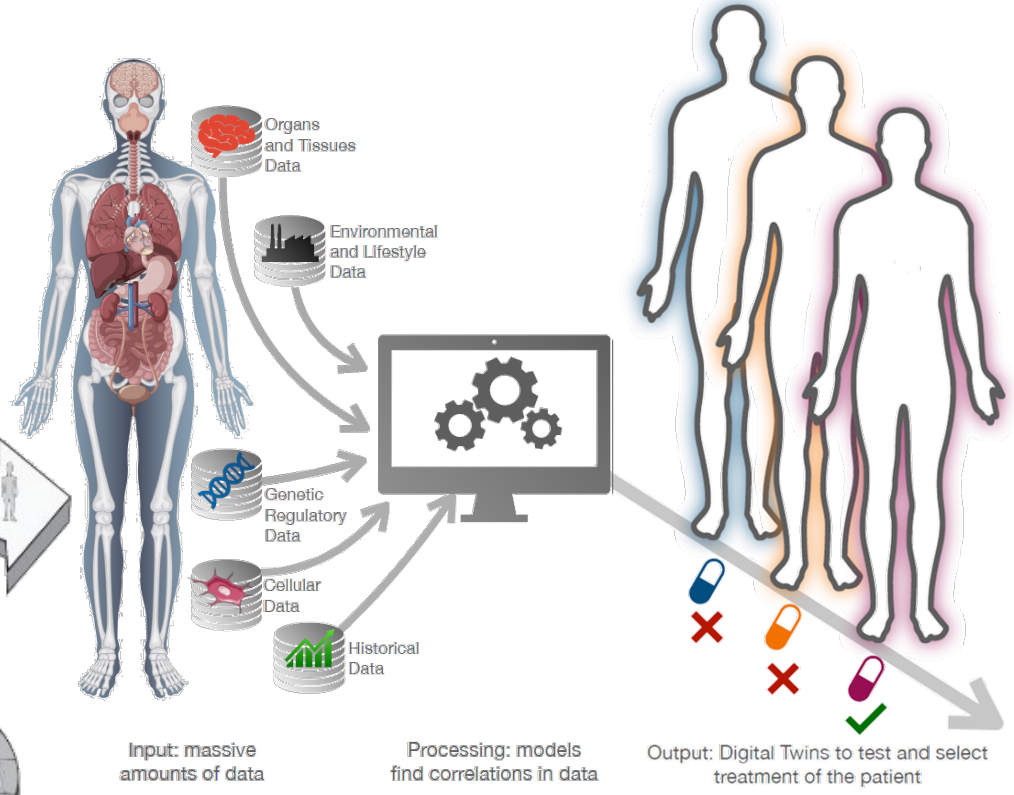
multiscale factors in social, technological and biomedical problems







Pescosolido, B.A. 2006. Journal of Health and Social Behavior 47: 189-208.



De Domenico, et al [2024]. *NPJ Digital Medicine*. In press. *arXiv*:2405.09649.

- Complex Networks & Systems
- Computational and Systems Biology
- Computational Intelligence

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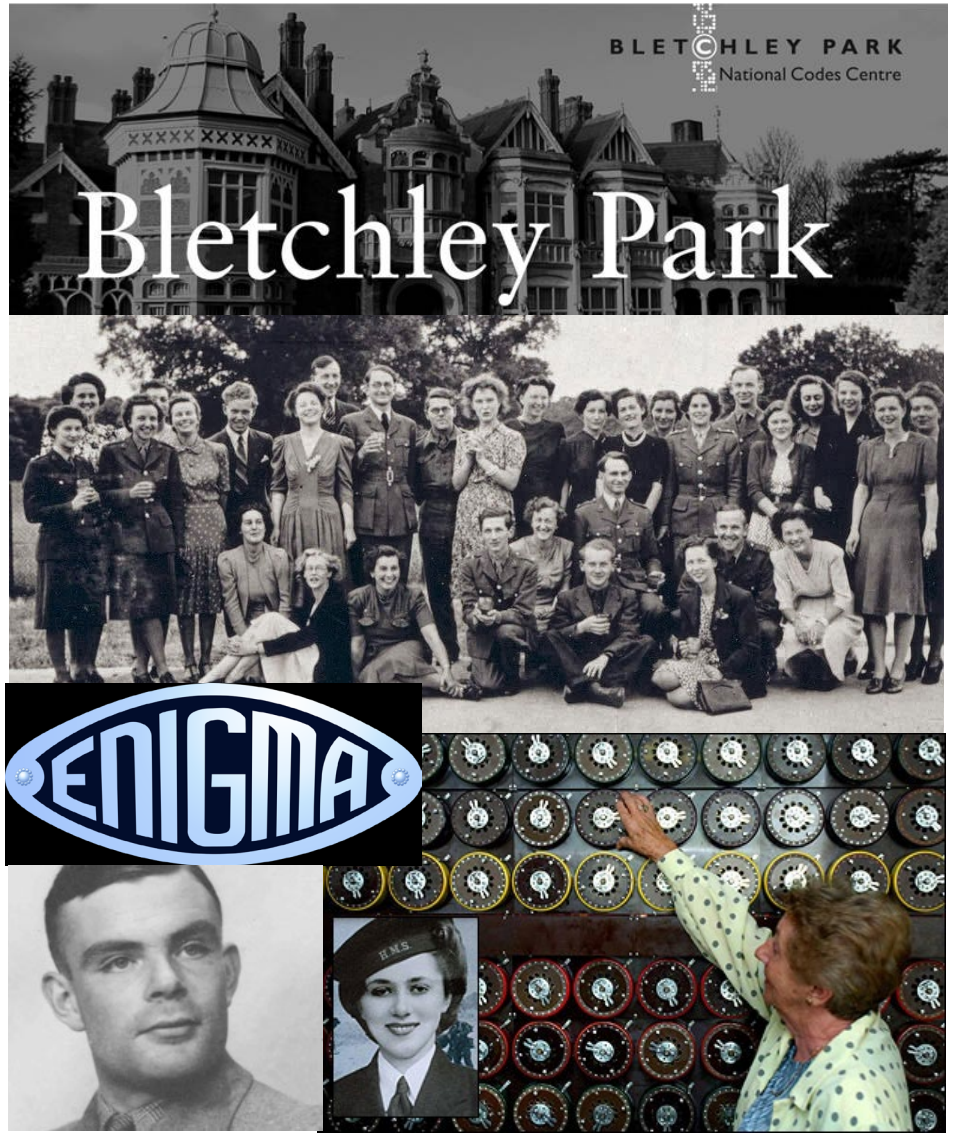
Necessity is the mother of invention



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necessary to tackle 21st century problems

Nature, **525**(7569):289–90.

Van Noorden, R. [2015]. "Interdisciplinary research by the numbers". *Nature*, **525**(7569):306–7.

Ledford, H. [2015]. *Nature,* **525**(7569):308–11.

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How to solve the world's biggest problems

Interdisciplinarity has become all the rage as scientists tackle climate change and other intractable issues. But there is still strong resistance to crossing borders.

Heidi Ledford

16 September 2015 | Corrected: 21 September 2015

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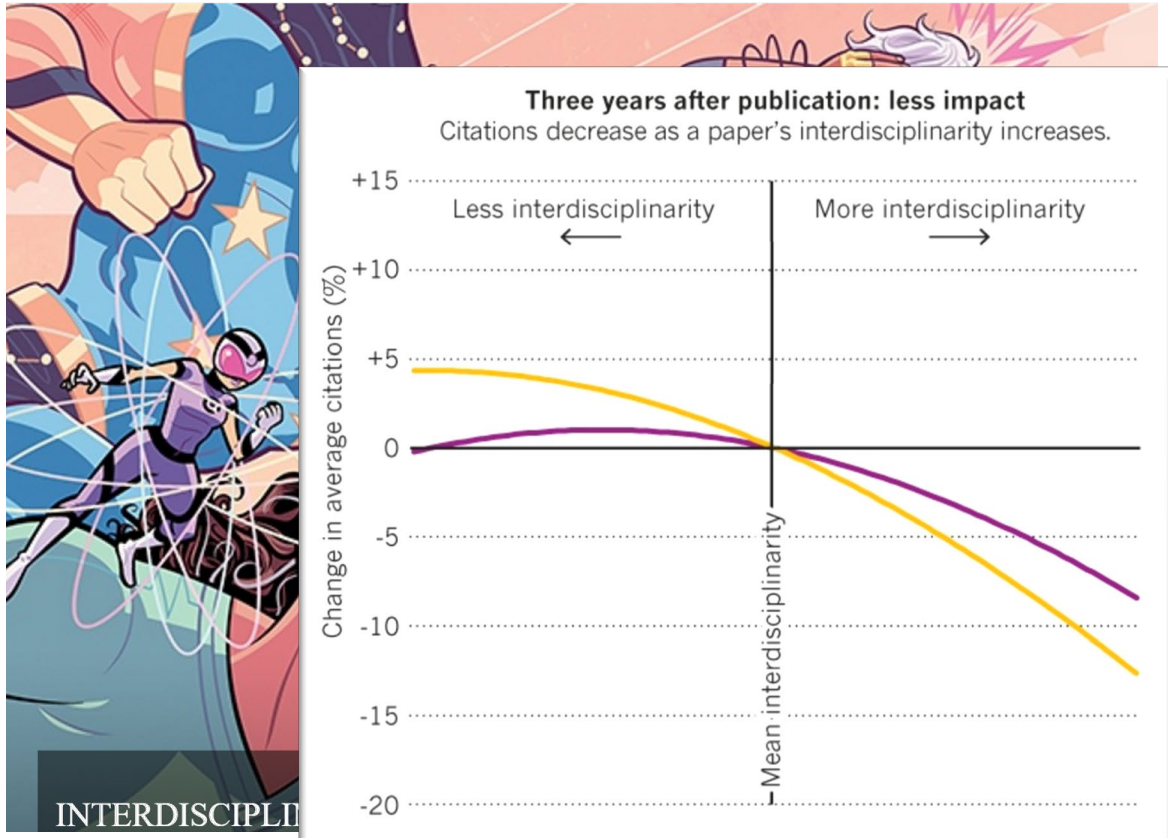
necessary to tackle 21st century problems



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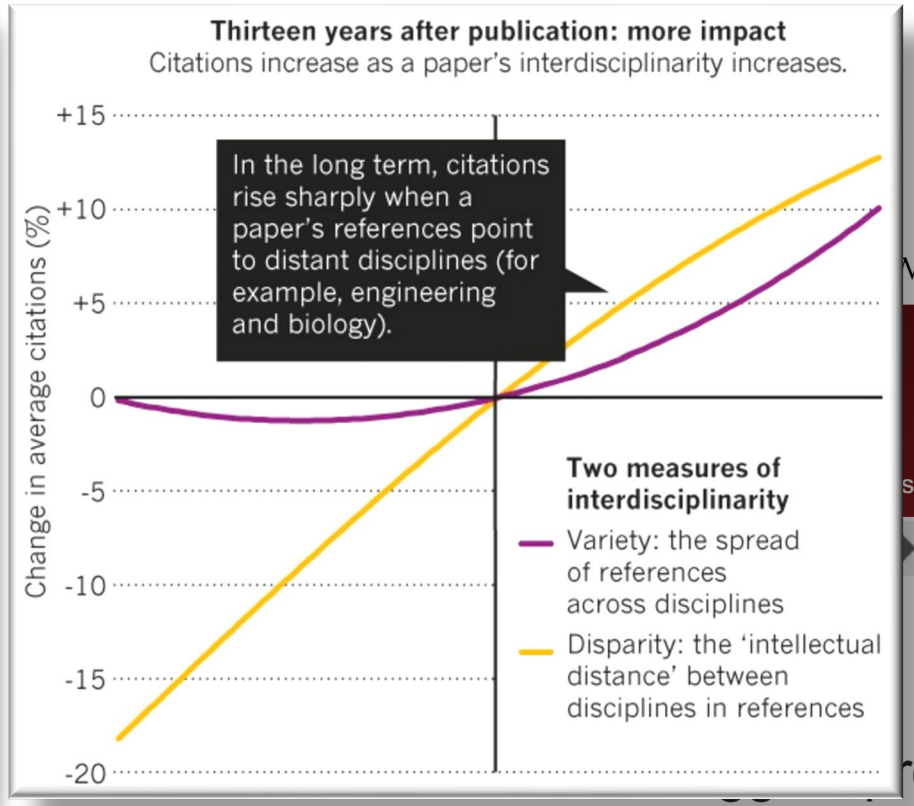

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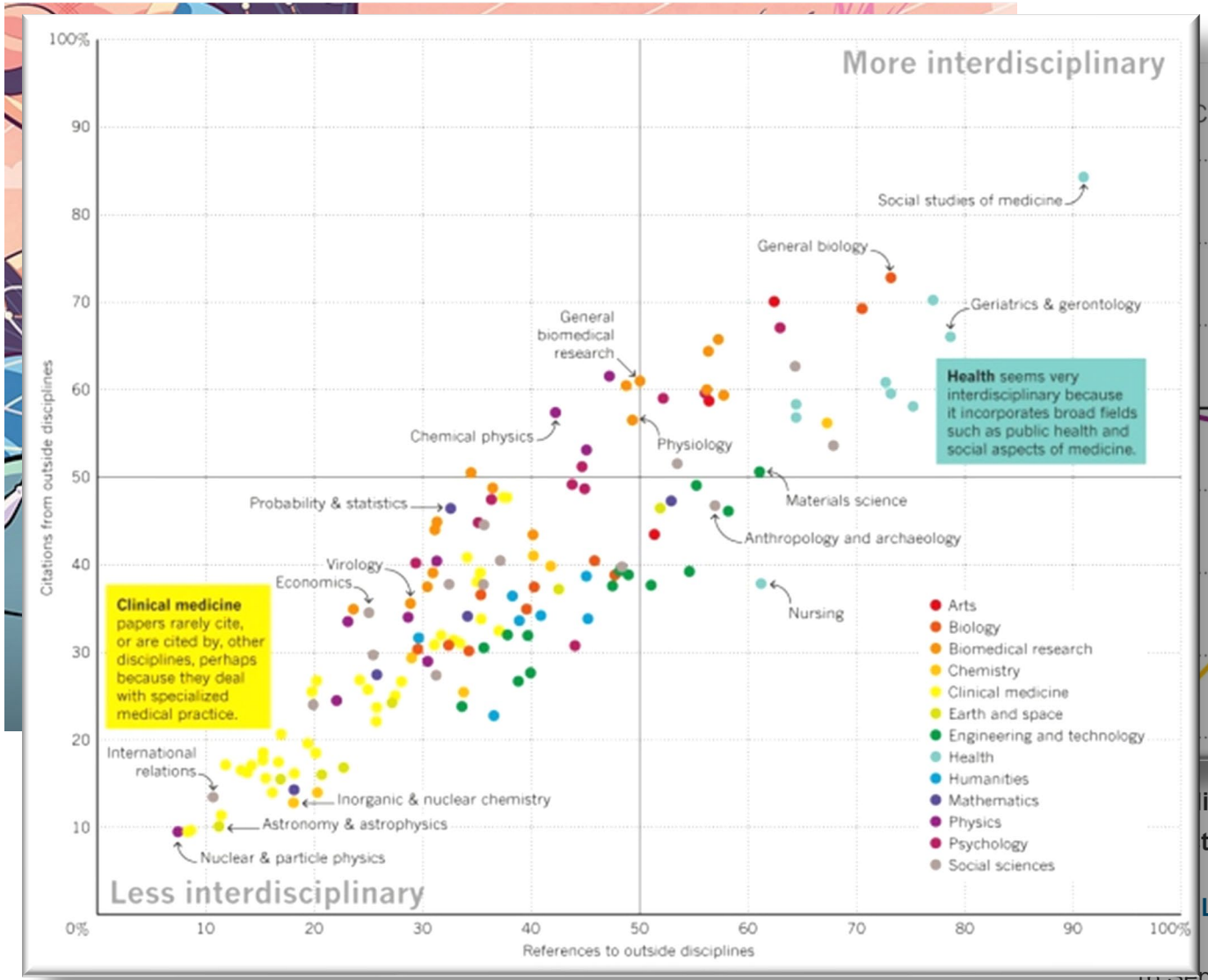

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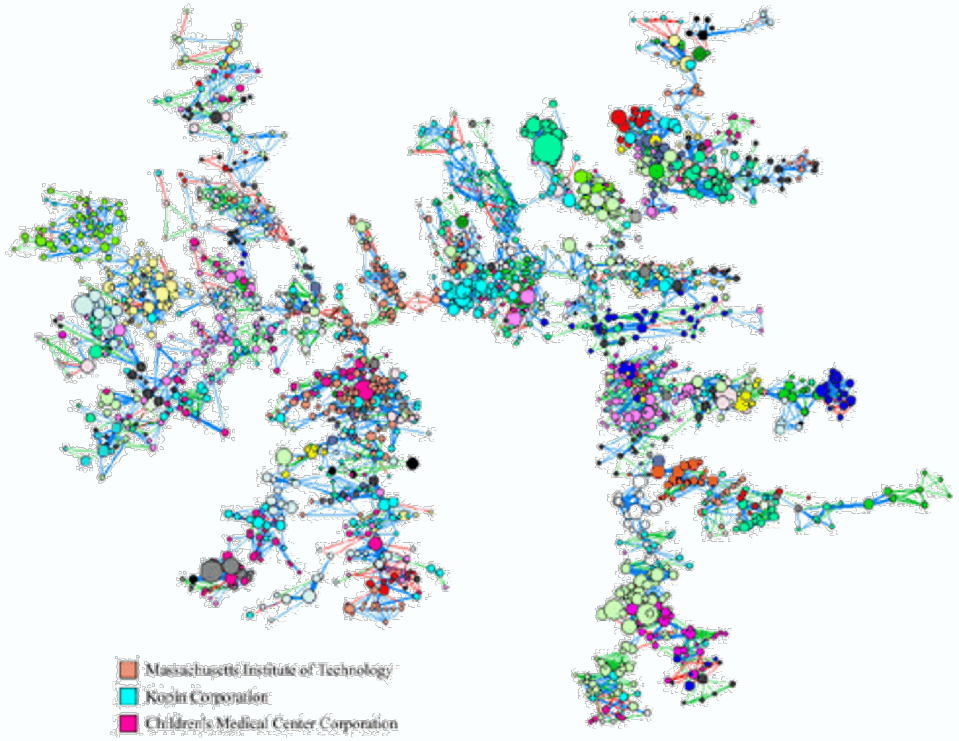
Biotech Invention Network



Fleming, Lee. "Perfecting Cross-Pollination." *Harvard Business Review* **82** (9) : 22-24.

Fleming, Lee, and Adam Juda. "A Network of Invention." *Harvard Business Review* **82** (4).

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siloed academic, research, and career incentives

S. Baker. “Interdisciplinary research ‘struggles to bridge academic silos’”. *Times Higher Education*. June 7, 2019.

- Frozen department structure
  - university departments built within disciplinary walls hinder collaboration and team building
  - difficult for a single-PI group to develop interdisciplinary competence
  - promotion of Faculty/PIs based on short-term rewards
  - incentives for teaching and training to move within walls (e.g. tuition revenue, faculty lines)
  - academic inbreeding

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CNS, interdisciplinarity and universities

siloed academic, research, and career incentives

S. Baker. “Interdisciplinary research ‘struggles to bridge academic silos’”. *Times Higher Education*. June 7, 2019.

- How to increase Collaboration & Team Science?
  - University departments built within disciplinary walls make it very difficult for a single-PI group to develop competence in computational/systems science as well as the methodology of the natural and social sciences.
    - How to enable teams capable of escaping the silos of disciplinary training and be collectively rewarded, rather than made to follow the single agenda of a lead investigator?
    - no single lab can address the complex challenges of the 21st century

Thorp, Holden, and Buck Goldstein. "How to create a problem-solving institution." *Chronicle of Higher Education* **57**.2 (2010): A43-A44.

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siloed peer-evaluation

Thorp, Holden, and Buck Goldstein. "How to create a problem-solving institution." *Chronicle of Higher Education* **57**.2 (2010): A43-A44.

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- Funding
  - national agencies tend to organize opportunities *within disciplinary walls* and prefer to fund the *agendas of lead principal investigators* from a discipline.
    - need to foster diverse teams tackling truly vexing interdisciplinary problems

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Funding biases (Australian Research Council)

nature International weekly journal of science

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日本語要約

Interdisciplinary research has consistently lower funding success

Lindell Bromham, Russell Dinnage & Xia Hua

Affiliations | **Contributions** | **Corresponding author**

Nature **534**, 684–687 (30 June 2016) | doi:10.1038/nature18315

Received 10 December 2015 | Accepted 11 May 2016 | Published online 29 June 2016

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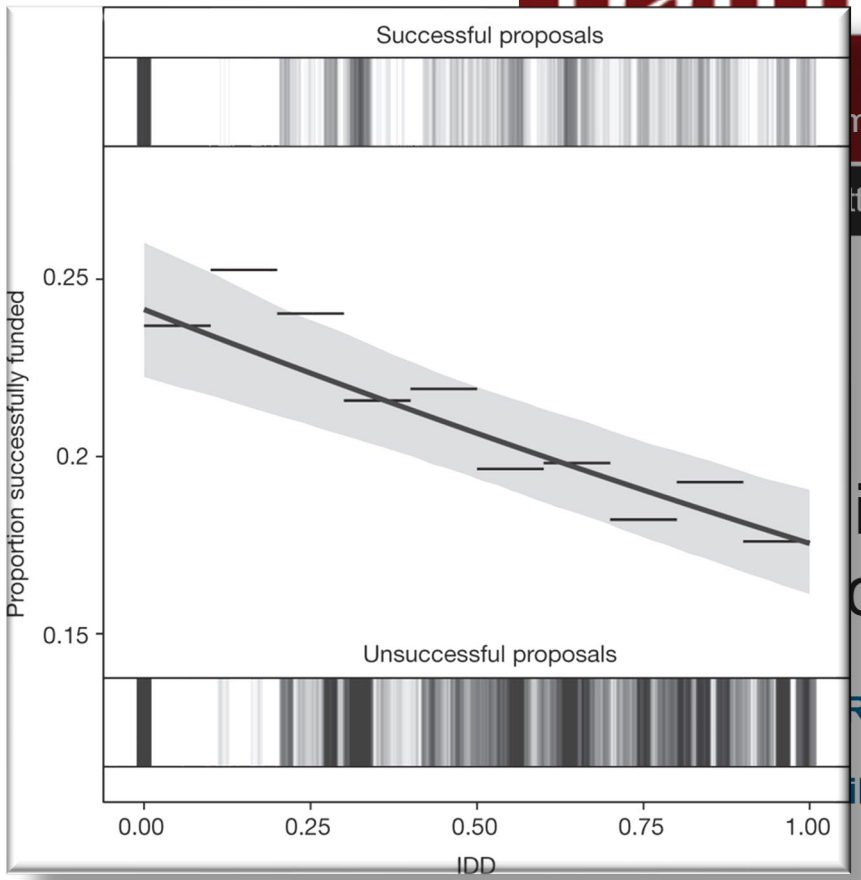

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Nature **534**, 684–687 (30 June 2016) | doi:10.1

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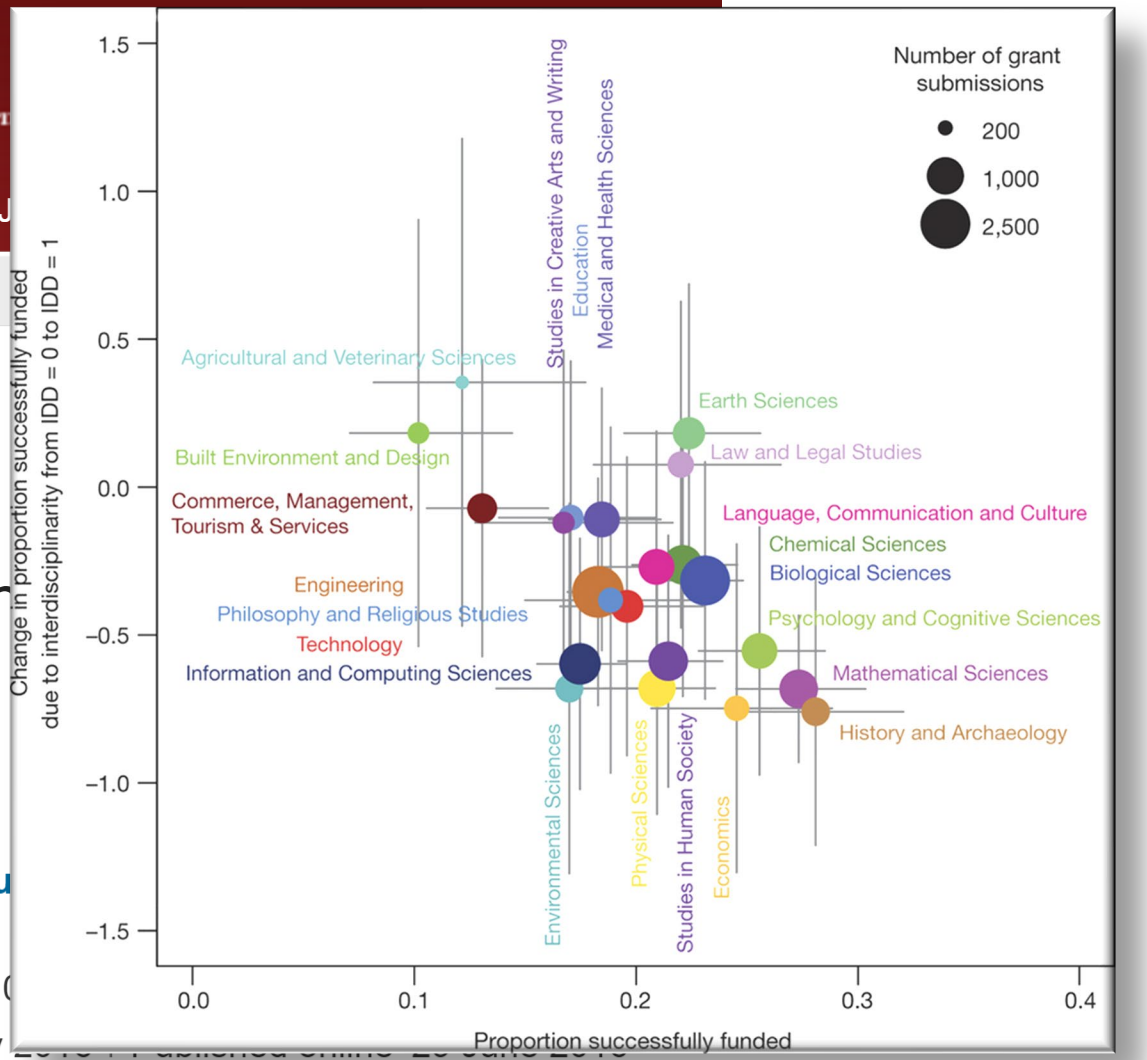

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In Portugal

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8 de fevereiro a 11 de março de 2022

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Earth Sciences and Engineering
Mechanical Engineering and Engineering Systems
Environmental Biotechnology and Engineering

Evaluation Panel
Bioengineering and Biotechnology
Nanotechnology
Animal and Veterinary Sciences and Agro-Food Biotechnology

Evaluation Panel
Experimental Biology and Biochemistry
Biological Sciences
Clinical Medicine, Immunology and Infection

FCT Fundação para a Ciência e a Tecnologia

Evaluation Panel
Mathematics
Computer and Information Sciences and Informatics
Physics

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National Institutes of Health, USA

U.S. Department of Health & Human Services

NIH National Institutes of Health
Office of Strategic Coordination - The C

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Interdisciplinary Research

Interdisciplinary Research program has transitioned fro

- Systems Science and Health in the Behavioral and Sciences (R01)
- LIMITED Research Program
- Advances in Biologica
- Smart and Connected
- Division of Molecular a Initiated Research Proj
- Development of Innova for Cancer Research ar
- Computational Mathematics
- Collaborative Activity Awards
- Resource Implementations for Data Intensive Research in the Social Behavioral and Economic Sciences (RIDIR) — 27 Feb 2017 Full Proposal

U.S. Department of Health and Human Services | National Institutes of Health

NIH Data Science at NIH

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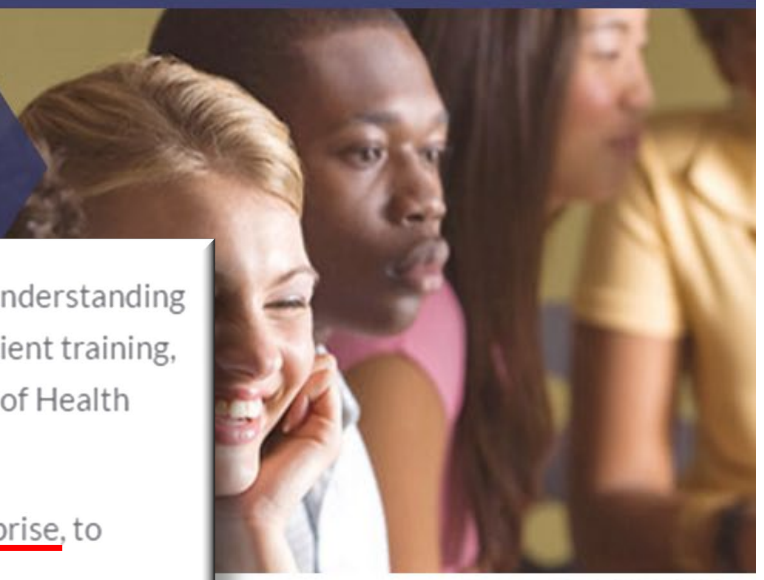
BD2K funds biomedical data science research programs.



The ability to harvest the wealth of information contained in biomedical Big Data will advance our understanding of human health and disease; however, lack of appropriate tools, poor data accessibility, and insufficient training, are major impediments to rapid translational impact. To meet this challenge, the National Institutes of Health (NIH) launched the Big Data to Knowledge (BD2K) initiative in 2012.

BD2K is a trans-NIH initiative established to enable biomedical research as a digital research enterprise, to facilitate discovery and support new knowledge, and to maximize community engagement.

Big Data to Knowledge (BD2K)

BD2K Recent News

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Interdisciplinary Research

- Introduction
- Definition
- Sources of Support
- Contact Options

Home › Research Areas

Introduction to Interdisciplina

NSF has long recognized the value of interdisciplinary rese
and accelerating scientific discovery. Important research id
a single discipline or program. NSF also understands that t

- **Unsolicited Interdisciplinary Proposals.** NSF also invites interdisciplinary proposals that are not targeted by a Program Solicitation. Such a proposal may be suitable for submission to and review by a single unsolicited core program, may be more appropriate for co-review by more than one program, or may extend beyond the scope of any current program (in which case it must be appropriate for NSF support; see the Grant Proposal Guide, NSF Programs and Funding Opportunities, https://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg_1.jsp#IB). Core programs, even if managed within a single NSF division and with scope within a discipline, often handle interdisciplinary proposals by co-reviewing, and possibly co-funding, with other appropriate programs. Thus, an interdisciplinary idea could be appropriate for submission to a core program, whether implicitly or explicitly stated in the corresponding Program Description. Because we recognize that there might not be an obvious natural "home" for every interdisciplinary proposal, a primary purpose of this site is to assist investigators in submitting an interdisciplinary proposal when there is not an appropriate existing NSF program.

- **Education and Training.** NSF promotes interdisciplinary research through programs that support development of the next generation of researchers. The support from these programs is in addition to the support for undergraduates, graduate students, and postdoctoral researchers to conduct research on NSF-funded grants. Examples of these programs include: Integrative Graduate Education and Research Traineeship Program; Research Experiences for Undergraduates; and Interdisciplinary Training for Undergraduates in Biological and Mathematical Sciences.

How Does NSF Support Interdisciplinary Research?

NSF supports interdisciplinary research through a number of solicited and unsolicited mechanisms (see also the Grant Proposal Guide, Categories of Funding Opportunities, https://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg_1.jsp#IC):

- **Solicited Interdisciplinary Programs.** Numerous NSF programs are designed explicitly to be interdisciplinary, often involving several NSF directorates. Program Solicitations are developed for these programs and posted on the NSF website.Recent examples include: Cyber-enabled Discovery and Innovation; Water Sustainability and Climate; Collaboration in Mathematical Geosciences; Dynamics of Coupled Natural Human Systems; Macrosystems Biology; Emerging Frontiers in Research and innovation 2010; and Regional Climate Prediction using Earth System Models.

tional Importance. NSF develops activity portfolios focusing on areas of
est, often in collaboration with other federal agencies. Because the
at we face as a society are often complex and require an integrative,
approach, these areas are often interdisciplinary. Examples include
ineering, and Education for Sustainability; Networking and Information
Research and Development; and the National Nanotechnology Initiative.

petitions. Many of the Centers funded by NSF bring together
ary research teams. Some examples include Materials Research and Engineering; Science of Learning
Science and Technology Centers.

proteins.

This K-12 outreach program learns about sediment-coring in the Canadian Arctic.

Credit: *Doug Levere, SUNY*

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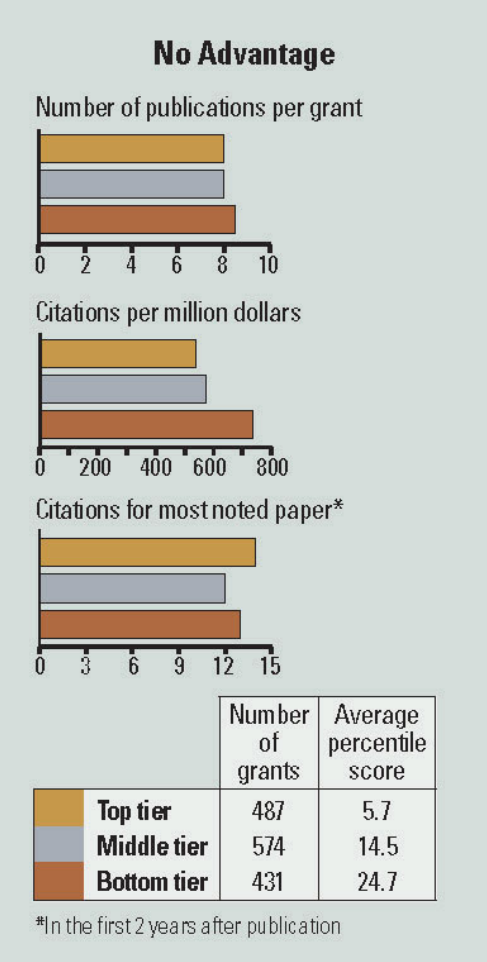
human “elite” choice problematic

NIH proposals

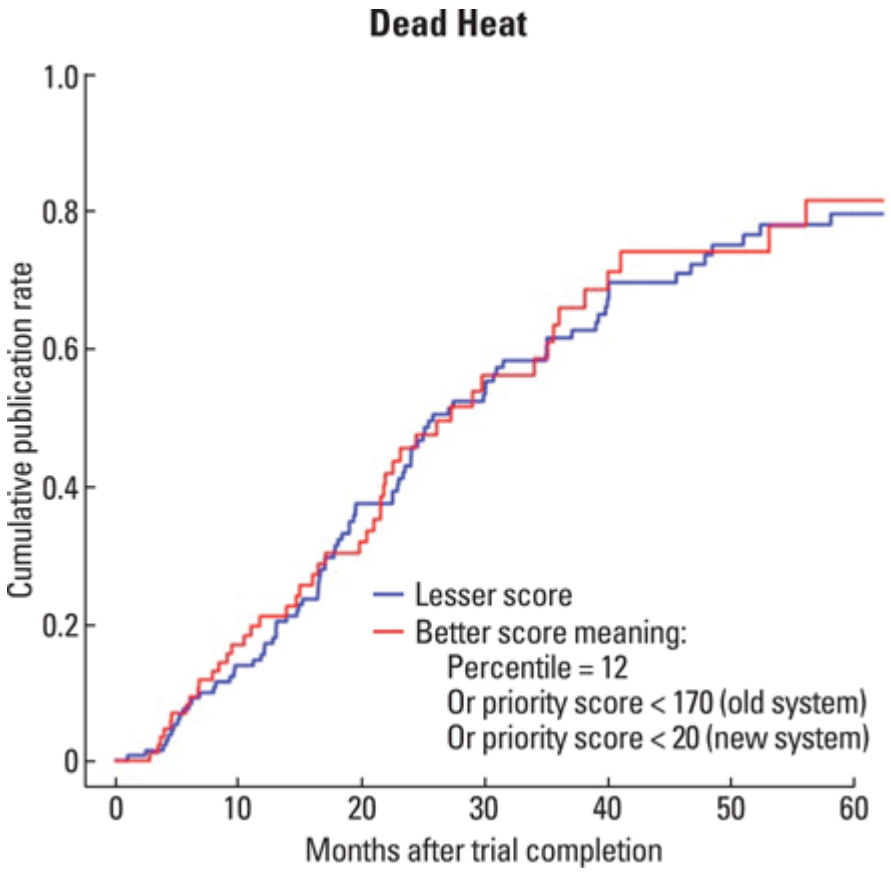


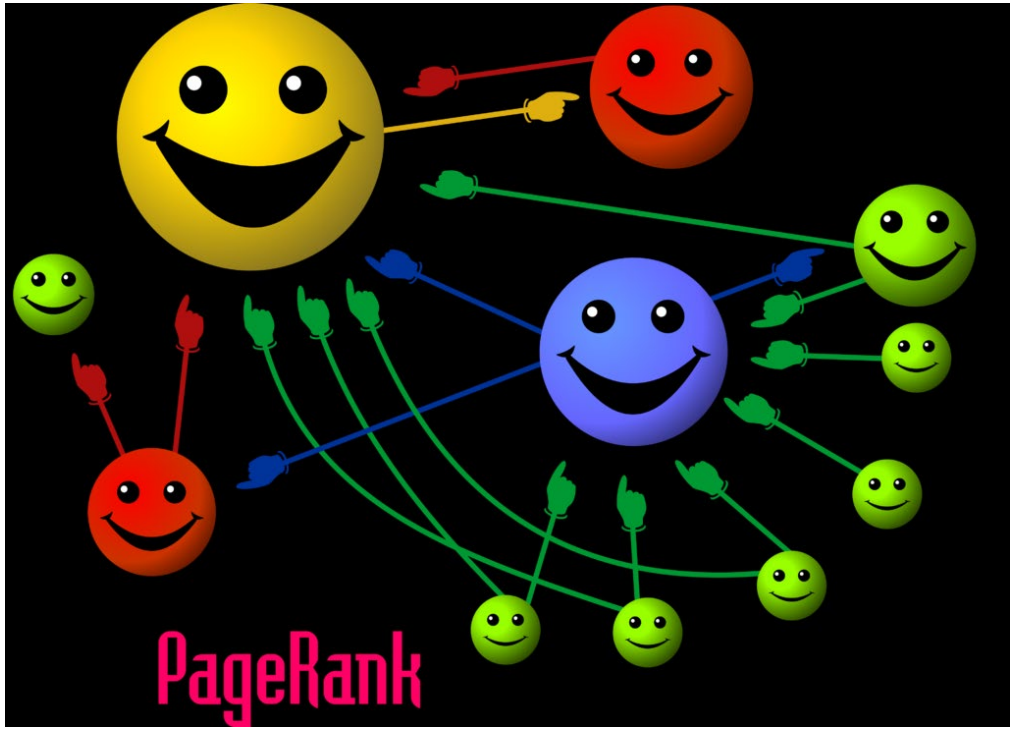
	Number of grants	Average percentile score
Top tier	487	5.7
Middle tier	574	14.5
Bottom tier	431	24.7

*In the first 2 years after publication

Mervis, J. [2014]. *Science*. **343** (6171), 596-598

L.M. Rocha [2014]. *Expresso* 8 Fevereiro, pp. 35.





Bollen J et al [2014] *EMBO Rep*. 10.1002/embr.201338068

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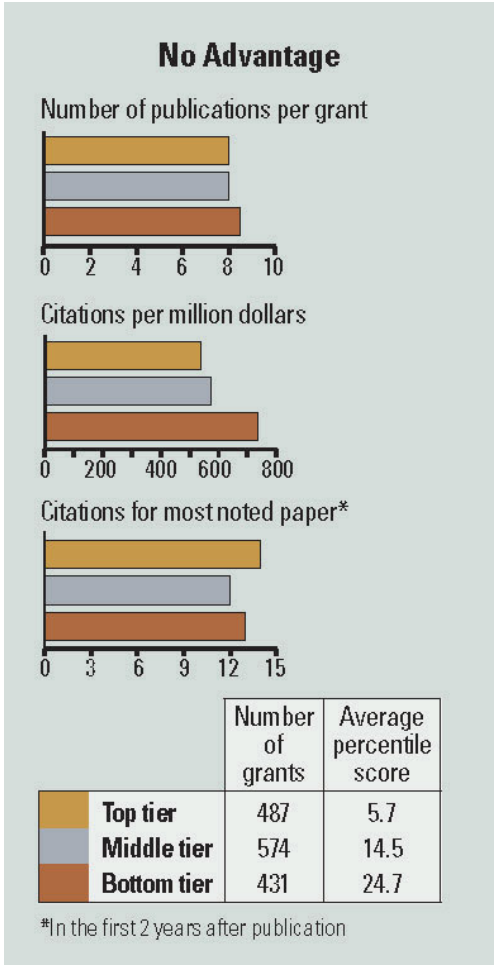

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Ciência 2.0: do elitismo à decisão coletiva

Luís Mateus Rocha

A nova estratégia da Fundação para a Ciência e Tecnologia foi resumida por Leonor Parreira, secretária de Estado da Ciência, ao reforço da "seletividade e exigência da qualidade". A ênfase na qualidade da ciência por parte dos dirigentes do Ministério, pelos quais tenho o maior respeito, vai no *zeitgeist* internacional nesta matéria. Mas existem problemas sérios com esta ideia. À partida temos a ironia do conceito de qualidade não ser científico. Daí que na prática, através da avaliação por pares, se tente prever o impacto futuro de investigação proposta ou feita no presente um substituto mensurável.

Convém notar que impacto académico e económico não estão necessariamente alinhados. Darwin teve o maior impacto académico possível, mas Turing e Von Neumann causaram a era da informação de muito maior impacto económico. Pior, está demonstrado que a avaliação por pares falha a prever o impacto académico futuro. Por exemplo, as pontuações de avaliadores da National Science Foundation nos Estados Unidos não são correlacionadas com sucesso (detalhes em *http://bit.ly/1d8ix08*). É irónico que cientistas e organismos que financiam a ciência se baseiem não na evidência desta falha profunda, mas na fé que a avaliação por pares consegue identificar "qualidade".

Além da falta de eficácia, este processo é caro e elitista. Grande parte do orçamento de ciência vai para a avaliação e gestão de projetos. O elitismo deriva dos cientistas, como pessoas, preferirem quem concorda com eles, vem da mesma família académica, ou tem o melhor pedigree (MIT, Harvard, etc.) Por exemplo, apesar do impacto de Turing e Von Neumann, o Conselho nacional de ciência e tecnologia, no século XXI, não inclui um doutorado em Informática. No contexto de afunilamento de fundos, o que se perde com a ênfase na "qualidade" é a diversidade de soluções para problemas científicos, tecnológicos e sociais.

A única correlação significativa no investimento em ciência é a quantidade: mais dinheiro aumenta a produtividade. É também da diversidade de investigação que nasce a criatividade e daí o impacto económico. Não foi da elite académica que saíram Bill Gates e Steve Jobs. Mas, o financiamento da ciência em quantidade e diversidade não precisa de ser cego. Pode ser reforçado e gerido de forma automática e económica. Colegas na Indiana University propuseram uma solução de *crowd-sourcing* para o problema. Utiliza o algoritmo que deu origem ao Google, em que a recomendação de páginas é uma decisão coletiva medida do padrão de *links* na *web*. Os resultados não dependem de elites de anotadores como fazia o Yahoo! original. No caso do financiamento da ciência, em vez de *links*, os cientistas recebem um montante fixo. Uma parte é para eles, a outra é por eles distribuída por outros cientistas. No Google, *links* para uma página são votos de relevância; aqui os fundos distribuídos coletivamente são votos de reconhecimento. As vantagens são óbvias: mais dinheiro e tempo para a ciência, sem burocracias para alocar e gerir projetos, e um sistema comprovadamente bom a identificar o que é relevante. Porque não esta alternativa, em vez de seguir o que é (mal) feito por outros?

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Science

Sander Dekker Secretary of Education during the debate on the annual report of the Ministry of Education, Culture and Science. © Reuters

Researchers will grant each other subsidies themselves

State Secretary Dekker embraces radical plan Christian Union

Secretary Sander Dekker talks to science funding body NWO an experiment in which scientists can grant each other direct research funding. He said Thursday in parliament. Dekker took a motion from the Christian Union is pushing for such an experiment.

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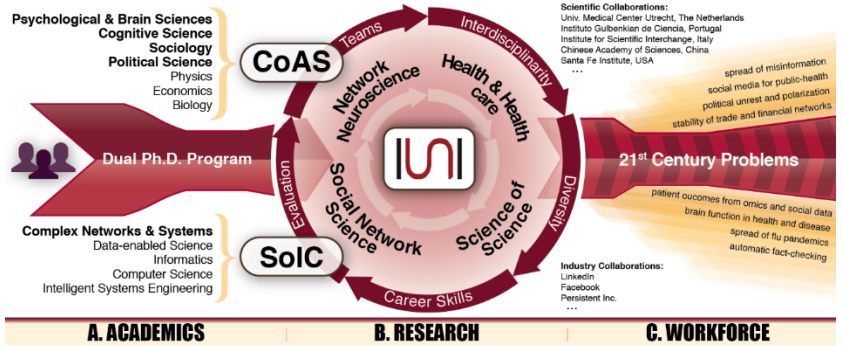
CNS, interdisciplinarity and training

Challenges and opportunities



CNS NRT

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    - no single lab can address the complex challenges of the 21st century
- Funding
  - national agencies tend to organize opportunities *within disciplinary walls* and prefer to fund the *agendas of lead principal investigators* from a discipline.
    - need to foster diverse teams tackling truly vexing interdisciplinary problems
- Training
  - graduate training in one of the two dimensions
    - experimental and observational methods *in a specific area* **or** *in general methodologies*.
    - shortening of academic training periods make it more difficult
  - need to integrate the general-purpose, computational expertise of CNS with the deep, domain-specific research methodologies of the natural, behavioral, and social sciences.

Thorp, Holden, and Buck Goldstein. "How to create a problem-solving institution." *Chronicle of Higher Education* **57**.2 (2010): A43-A44.

S. Baker. “Interdisciplinary research ‘struggles to bridge academic silos’”. *Times Higher Education*. June 7, 2019.

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awards

Awards support preparation of future STEM workforce for interdisciplinary

- **Sustainable Food, Energy, and Water Systems (SFEWS)**: Rakesh Agrawal, Purdue University, and Aavudai Anandhi Swamy, Florida Agricultural and Mechanical University.
- **Training in Theory and Application of Cross-Scale Resilience in Agriculturally Dominated Social Ecological Systems**: Craig Allen, University of Nebraska-Lincoln.
- **A Training Incubator for Addressing Urban Environmental Change From Ridge to Reef (R2R)**: Steven Allison, University of California, Irvine.
- **Indigenous Food, Energy, and Water Security and Sovereignty**: Karletta Chief, University of Arizona.
- **Improving Strategies for Hunger Relief and Food Security Using Computational Data Science**: Lauren Davis, North Carolina Agricultural & Technical State University.
- **Training the Next Generation of Researchers in Engineering and Deciphering of Miniature Brain Machinery**: Martha Gillette, University of Illinois at Urbana-Champaign.
- **Graduate Training Program in Sensory Science: Optimizing the Information Available for Mind and Brain**: Victoria Interrante, University of Minnesota-Twin Cities.
- **Transformative Research in Urban Sustainability Training (T-RUST)**: Donna Kashian, Wayne State University.
- **Science of Learning, From Neurobiology to Real-World Application**: A Problem-Based Approach: James Magnuson, University of Connecticut.
- **Computational Data Science to Advance Research at the Energy-Environment Nexus**: Elisabeth Moyer, University of Chicago.
- **Quantitative & Evolutionary STEM Training (QUEST): An Integrative Training Program for Versatile STEM Professionals to Solve Environmental and Global Health Problems**: Melissa Pespeni, University of Vermont & State Agricultural College.
- **Integrated Urban Solutions for Food, Energy, and Water Management**: Laurent Pilon, University of California, Los Angeles.
- **Interdisciplinary Training in Complex Networks and Systems**: Luis Rocha, Indiana University.
- **Sustainable Oceans: From Policy to Science to Decisions**: James Sanchirico, University of California, Davis.
- **Boston UniverCity - Partnering Graduate Students and Cities to Tackle Urban Environmental Challenges**: Pamela Templer, Boston University.
- **Systems Training for Research on Geography-Based Coastal Food Energy Water Systems (STRONG-CFEWS)**: Maya Trotz, University of South Florida, and Sennai Habtes, University of the Virgin Islands.
- **Disaster Resilience and Risk Management (DRRM) - Creating Quantitative Decision Making Frameworks for Multi-Dimensional and Multi-Scale Analysis of Hazard Impact**: Robert Weiss, Virginia Polytechnic Institute and State University.

ocha@binghamton.edu
asci.binghamton.edu/academics/ssie501m

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integrated graduate training in both dimensions of science

dual Ph.D. degree: students are trained in Informatics/CNS and domain-specific program

interdisciplinary Ph.D. program committees, co-chaired by research mentors from both

embedded in interdisciplinary teams at the *Indiana University Network Science Institute*

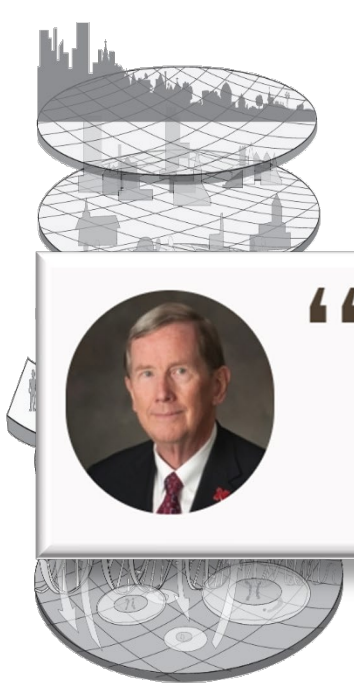
160+ faculty members who participate in CNS research

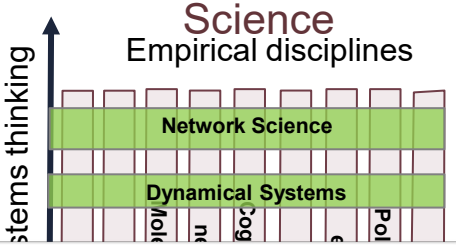
integrates academic education with interdisciplinary hands-on research

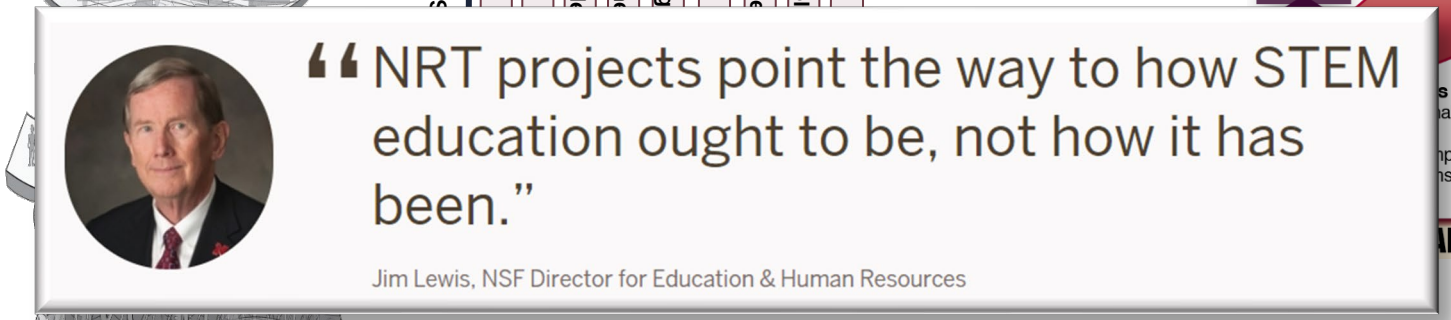
research rotations, extended colloquium, summer internships

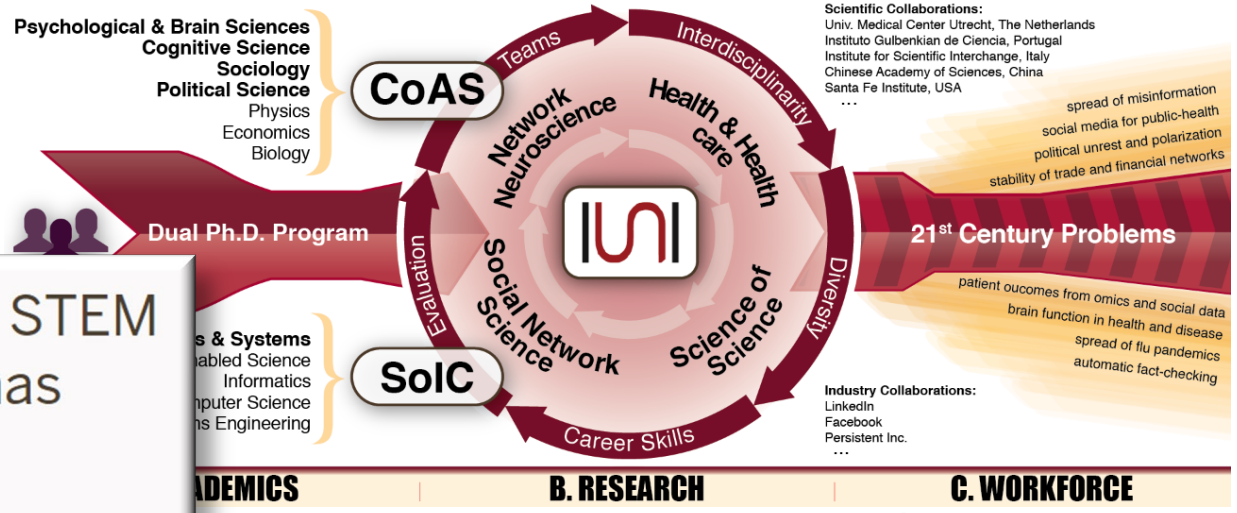
professional development in academic and industry environments

dual PhD training in general-purpose systems and empirical science









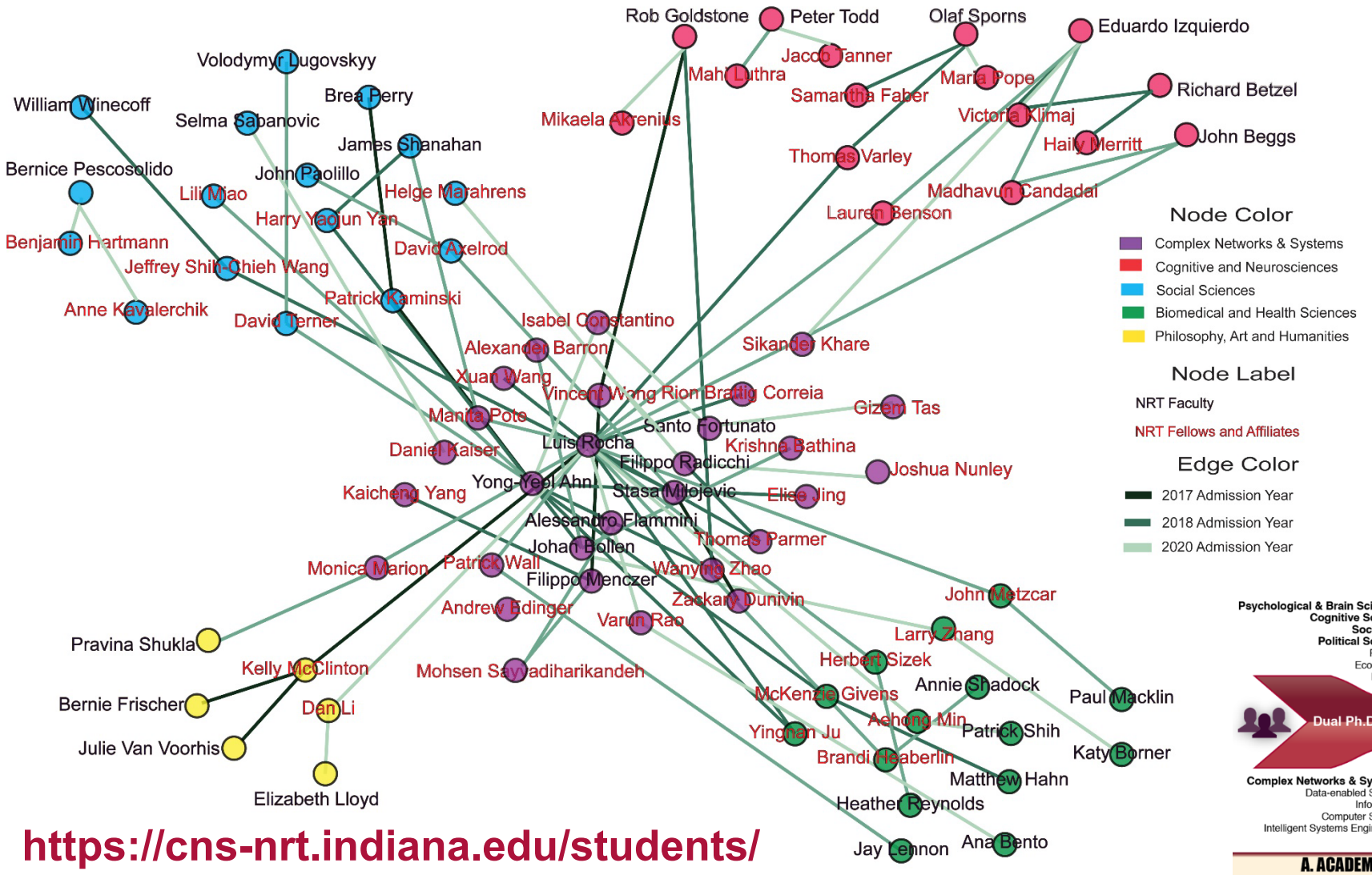
34 (22+12) PhD fellows, 40 summer affiliates and more than 300 participants across the participating PhD programs

CNS NRT

Pescosolido, B.A. 2006. Journal of Health and Social Behavior 47: 189-208.

BINGHAMTON UNIVERSITY STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/ssie501m

Interdisciplinary Complex Networks & Systems (@Informatics)



https://cns-nrt.indiana.edu/students/

CNS NRT

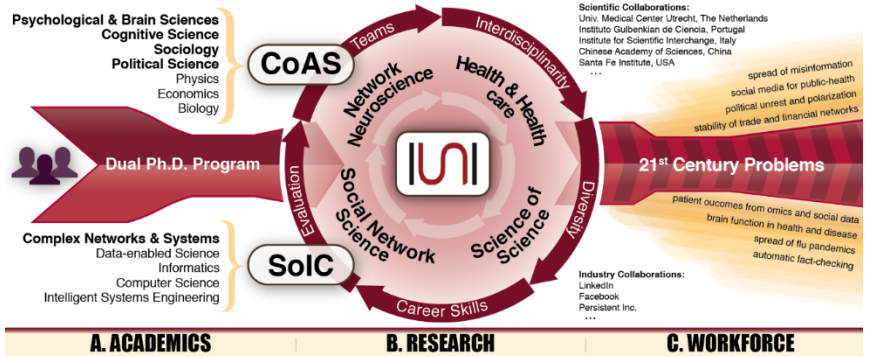


Figure 1: Network of trainees, affiliates and faculty. Dual-major PhD students (red node labels) establish bridges between disciplines via dual faculty (black node labels) mentorship. The academic areas shown contain various departments. Yellow : Art History, Philosophy of Science, Folklore. Green: Evolution, Ecology, and Behavior, Public Health, Health Informatics, Intelligent Systems Engineering, Geography. Blue: Sociology, Political Science, Media Studies, Computing, Culture, and Society. Red: Cognitive Science, Psychology and Brain Sciences, Neuroscience, Physics.

STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/ssie501m

Training to see the world differently

- The complexity worldview
  - Interdisciplinary and collaborative
    - Integration of empirical sciences with general-purpose modeling
    - Thrives in problem-driven environments
      - Los Alamos, Santa Fe, new computing centers
  - Data-driven, computational and mathematical modeling
    - Massive combinatorial searches
    - Networks, feedback, statistics, machine learning, dynamical systems
  - study of organization
    - whole is more than sum of parts
  - Nonlinear thinking
    - **Counterintuitive system-level properties**

Small changes in micro-level rules can change macro-level behavior dramatically

- Intuition can be a poor guide to predicting the behavior of a complex system.
- Simulation is a powerful tool for harnessing the dynamics of complex systems, but simplification is necessary dur to computational complexity.
- Induction can fail in the face of true complexity.
- Actionable models + parameter induction good strategy in the face of multi-level complexity.
- Interdisciplinarity and team culture essential in 2-dimensional science.

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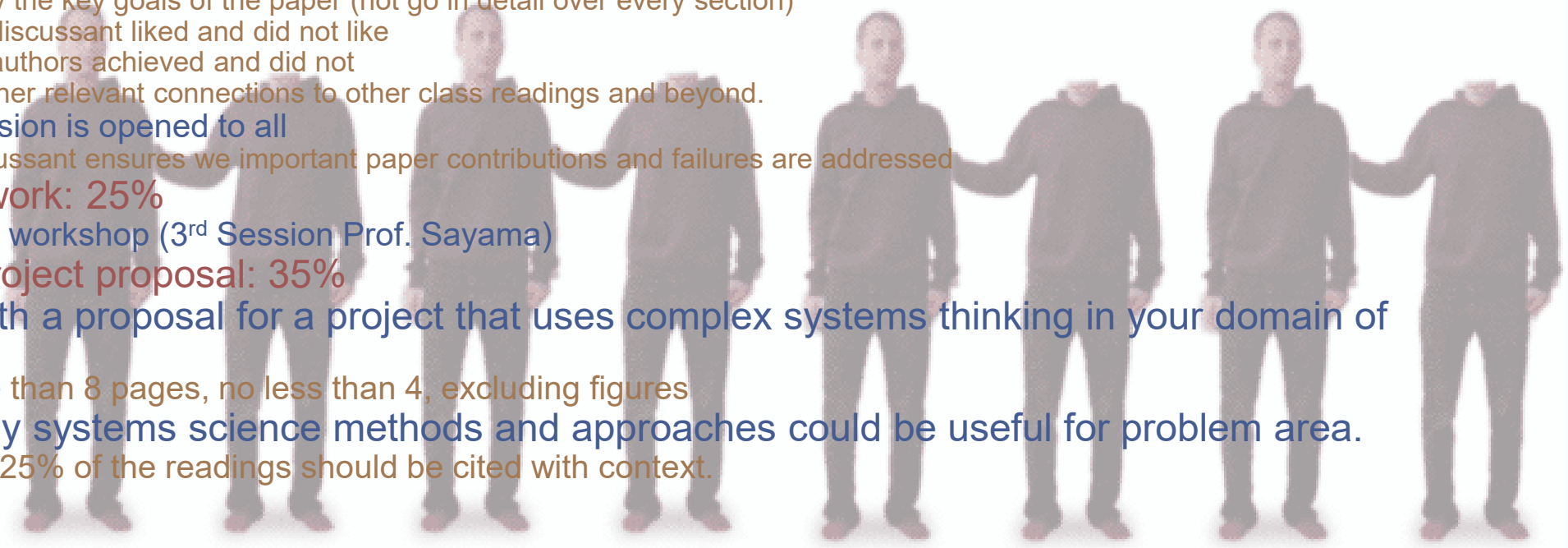
rocha@binghamton.edu
casci.binghamton.edu/academics/ssie501m

evaluation

- Participation and Discussion: 15%.
  - class discussion, everybody reads and discusses every paper
  - engagement in class
- Lead Discussions: 25%
  - Students are assigned to papers as lead discussants
    - all students are supposed to read and participate in discussion of every paper.
  - Lead discussant prepares short summary of assigned paper (10 minutes)
    - no formal presentations or PowerPoint unless figures are indispensable.
  - Summary should:
    - 1) Identify the key goals of the paper (not go in detail over every section)
    - 2) What discussant liked and did not like
    - 3) What authors achieved and did not
    - 4) Any other relevant connections to other class readings and beyond.
  - Class discussion is opened to all
    - lead discussant ensures we important paper contributions and failures are addressed
- Python Homework: 25%
  - From Python workshop (3rd Session Prof. Sayama)
- Term Paper/Project proposal: 35%
  - A paper with a proposal for a project that uses complex systems thinking in your domain of expertise.
    - no more than 8 pages, no less than 4, excluding figures
  - Explain why systems science methods and approaches could be useful for problem area.
    - At least 25% of the readings should be cited with context.



THANK YOU!

OBRIGADO!

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rocha@binghamton.edu
casci.binghamton.edu/academics/ssie501m