CSSI
RETREAT 2021

# BRIEF PROGRAM OVERVIEW

August 24-26, 2021

Tuesday, August 24

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|---|---|
| Check in: | 4:00pm |
| Dinner: | 6:00pm – 7:30pm |
| Introduction: | 7:45pm – 8:00pm |
| Talks: | 8:00pm – 9:00pm |

Wednesday, August 25

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|---|---|
| Breakfast: | 8:00am – 9:00am |
| Talks: | 9:00am – 10:20am |
| Coffee Break: | 10:20am – 10:40am |
| Talks: | 10:40am – 12:00pm |
| Lunch: | 12:30pm – 2:00pm |
| Free time: | 2:00pm – 6:00pm |
| Dinner: | 6:00pm – 7:30pm |
| Talks: | 7:30pm – 8:30pm |
| Mingle: | 8:30pm |

Thursday, August 26

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|---|---|
| Breakfast: | 8:00am – 9:00am |
| Check out: | 10:00am |

# DETAILED PROGRAM OVERVIEW

August 24-26, 2021

## Tuesday, August 24th

### EVENING SESSION: 8:00PM – 9:00PM

**Algorithms and Shepherds in AI-Driven Scientific Discovery**

*Lav Varshney*

Artificial Intelligence (AI) is becoming a prominent cognitive support tool in scientific discovery. Here we discuss four vignettes of our own work in AI-driven discovery: (1) discovering active phytochemicals in herbs and spices for different health conditions from a network science representation of traditional knowledge; (2) discovering new formulations of sustainable building materials that are stronger and require half the carbon emissions as existing formulations using variational autoencoders; (3) discovering laws of music theory in the same human-interpretable form as textbooks using a novel group-theoretic and information-theoretic technique called information lattice learning; and (4) showing that rates of technological innovation are explained in part by the structure of online friendship networks in universities. We close by discussing the role of human shepherds in AI-driven science, and how AI may impact human autonomy.

**Intellectual Property Revisited**

*Filippo Mezzanotti*

TBD

**The Political Mobilization of Scientists in the United States**

*Zander Furnas*

Science has become increasingly politicized in the United States in recent decades. Climate Change --- an issue on which there was once relative agreement on the nature of the problem, but disagreement over the appropriate policy responses --- has become so polarized that one major political party largely refuses to acknowledge the overwhelming scientific consensus of anthropogenic climate change. Shortly following the election of Donald Trump, over 100,000 marched in the streets of Washington D.C., critical of the Trump Administration's agenda and calling for "evidence-based policy." As he made his case to the American people during his nominating speech given at a largely virtual Democratic National Convention held amidst a global pandemic, Joseph Biden's announced that "decency, science, democracy. They are all on the ballot." (emphasis added). These individual examples represent a profound change in the role of science in American politics in the 21st century; they mark the widespread mobilization of scientists as a political constituency --- a coherent set of policy demanders largely aligned with the democratic party network. This mobilization has important implications for polarization, evidenced-based policy making, the rejection of expertise, and the rise of misinformation. In this project we document the decades-long growth of political activity among scientists using comprehensive publication records of over 20 million scientists, campaign contributions from 28 million individuals between 1980 and 2018. Over this period, we find a consistent shift in scientists' contribution behavior indicating that the population of scientists active in American politics has increased, grown more liberal, and gives a higher percentage of their contributions to Democratic candidates. This shift is not only compositional, but is driven by within-scientist changes in campaign contribution behavior as well. Moreover, we find that scientists that give campaign contributions are disproportionately influential in both science, and public policy, and that policy-makers selectively cite science produced by co-partisan scientists.

**Winners, Losers, and Future Achievements**

*Suman Maity*

One of the most fundamental principles of human performance is that past success predicts future success. Partly owing to its robustness, this principle and its corollary—selecting candidates based on their history of winning—has become one of the most commonly used heuristics in identifying talent across a wide range of domains, from arts and sciences to sports and business. Here we systematically examine the future performance of past winners and non-winners across three different settings using three different empirical strategies. First, we track young athletes participating in world-class track and field competitions and compare the future performance of bronze medalists and fourth-place finishers. Second, we examine a novel natural experiment in tennis, where players are artificially shifted into the positions of just above and below a cutoff for entering the main competition, allowing us to compare the future performance of the "narrow winners" and "near misses". In our third study, we examine participants in the International Mathematical Olympiad (IMO), focusing on participants just above and below the bronze medal cutoff, and compare their later scientific output. Across all three studies, we find one systematic result: while on average past performance indeed robustly correlates with future performance, performance systematically reverses at the margin, meaning that those who narrowly lost end up outperforming those who narrowly won in the long run. We further conceptualize these empirical findings through a theoretical framework we developed to help us identify conditions under which such performance reversal may occur. Together, these results begin to challenge the simple notion of selecting on past winners, showing that "losers" can exhibit anomalous performance improvement that propels them to greater success, which may have potentially broad implications in identifying and nurturing talents.

## Wednesday, August 25th

### MORNING SESSION #1: 9:00AM – 10:20AM

**Reshaping the research enterprise**

*B. Ian Hutchins*

Biomedical research has entered a phase of "hypercompetition"; current organization and policies are straining under this pressure. Scientists seeking to remain competitive depend on publishing in artificially scarce space in prestigious journals. I transitioned from neuroscience into computational science policy in order to build analytical tools that can be used to inform policy responses to these challenges. At the same time, I designed my methods such that they can also be used by scientists to communicate the impact of their work regardless of publication venue, in order to help alleviate undue career stresses for researchers. I will discuss the network science behind my measure of scientific influence, and the machine learning system I developed to predict early stages of bench-to-bedside translation, a crucial applied goal of biomedical research. These quantitative measures provide researchers with two additional ways to showcase their work's influence, and are increasingly driving policy-making discussions as the research enterprise responds to modern pressures.

**Accelerating science with human versus alien artificial intelligences**

*Jamshid Sourati*

Data-driven artificial intelligence models fed with published scientific findings have been used to create powerful prediction engines for scientific and technological advance, such as the discovery of novel materials with desired properties and the targeted invention of new therapies and vaccines. These AI approaches typically ignore the distribution of human prediction engines—scientists and inventors—who continuously alter the landscape of discovery and invention. As a result, AI hypotheses are designed to substitute for human experts, failing to complement them for punctuated collective advance. We show that incorporating the distribution of human expertise into self-supervised models by training on inferences cognitively available to experts dramatically improves AI prediction of future human discoveries and inventions. Moreover, by tuning our model to avoid the crowd, it generates scientifically promising "alien" hypotheses unlikely to be imagined or pursued without intervention, which we demonstrate hold promise to not only accelerate but also punctuate scientific advance.

**A novel approach to symmetry-aware machine learning**

*Nima Dehmamy*

The reductionist view of the world has been very successful in disciplines such as physics. Reductionism requires us to simplify and minimize the number of variables needed to describe the behavior of a system. In physics, such simplifications lead to the idea of symmetry: that the laws of physics stay the same if the system is moved, rotated, or transformed in other ways. In machine learning, this reductionism can lead to a significant reduction of parameters to be learned. As a result, symmetry-aware neural networks have become an active area of research in recent years. Yet, existing methods can only encode known symmetries into neural networks and are difficult to implement. We take a step toward simplifying the process of encoding symmetries by introducing a novel and easy-to-implement neural network architecture, which we call L-conv. We prove that L-conv can approximate many other symmetry encoding architectures. Additionally, the simplicity of L-conv allows us to learn symmetries from data. Lastly, we find that L-conv is closely related to models used in physics. This connection could allow for using mature physics tools in ML and to use ML to make more general and flexible physics models.

**Learning, Fast and Slow: The Returns to Experience and Team Size for High-Impact Innovation in the United States between 1836 and 1975**

*Christopher Esposito*

We study changes in the returns that U.S. patent inventors received from experience and collaboration between 1836 and 1975. Our study combines two novel datasets which allow us to trace the careers of inventors, record instances of collaboration, and measure the impact of patents on subsequent invention across a long period of U.S. history. We show that the returns to experience, measured by the change in the likelihood that inventors create high-impact invention as their careers progress, have been negative since the 1920s, while the returns to collaboration, measured as the change in the likelihood of inventing a high-impact invention when collaborating with larger teams, became positive and significant in the 1920s. We develop a model to interpret these findings. The model proposes that teams "learn" quickly by pooling together the knowledge of their co-inventors while inventors learn slowly by accumulating experience. When the knowledge frontier is rapidly expanding, inventors are not able to learn quickly enough to keep up with the new ideas that are being introduced, creating a negative association between experience and impact. To test the model, we examine whether the returns to experience and collaboration vary across knowledge fields that are advancing at different rates, finding that (a) the average level of experience inventors is lower in fast-advancing knowledge fields, (b) the returns to experience are more negative in fast-advancing fields, (c) the average size of inventor teams is larger in fast-advancing fields, and (d) the returns to team size are greater in fast-advancing fields.

### Quantifying punctuated record-breaking dynamics in science and technology

*Yian Yin*

As the fundamental engine of human society and economic growth, science and technology not only advance in breadth, opening up more novel areas for exploration, they also progress in depth, developing increasingly sophisticated solutions to accomplish specific tasks. Yet our quantitative understanding of the record-breaking dynamics in science and technology remains limited. Here we collect large-scale datasets of record-breaking innovations across various domains to shed light on our mechanistic understanding of technology breakthroughs. We find a universal punctuated dynamics of innovation record-breaking where short periods of clustered breakthroughs and long periods of stasis appear alternatively, highlighting a short-term predictability but long-term uncertainty in technology breakthroughs. We further develop a simple mathematical framework that not only allows us to probe quantitatively the punctuated pattern, but also offers a new quantitative basis to study its relationship with other contingency factors.

## MORNING SESSION #2: 10:40AM – 12:00PM

### Innovation and Change in Urban Environments

*Luis Bettencourt*

While humans have been evolving and innovating since early times, it was with the advent of urban environments that these processes accelerated and eventually gained a global and sustained scope. I will present some evidence, theory and questions about the fundamental nature of these processes, how we measured them, and how we may foster environments to test these ideas.

### TBD

*Hyejin Youn*

TBD

### Abandonment of Innovation and Emergence of Fragility in Robust Ecosystems

*Binglu Wang*

Despite extensive studies on diffusion of innovations, our knowledge about the reverse process—abandonment of innovations—remains limited. Here, we analyze two large-scale datasets, each capturing detailed socio-temporal patterns that trace the entire lifecycle of innovations. By analyzing 2.5 M scholars studying in 2651 scientific fields and 3.5 M individuals using 994 mobile handsets, we find that, in contrast to the Poissonian dynamics commonly assumed in the abandoning process of the lifecycle, the abandoning probability increases with the number of past abandonments, reveling that a bandwagon effect characterizes the abandonment of innovations. We examine the social networks underneath the two systems through co-authorships and mobile communication records, finding that a preferential abandonment mechanism at a network level is responsible for generating the observed effect. Most importantly, we show analytically that the presence of preferential abandonment induces a structural collapse in heterogeneous system, where networked systems that were thought to be robust undergo a novel phase transition. We test the theoretical predictions systematically in our datasets, obtaining broadly consistent empirical support. Together these results demonstrate that the collapse of real systems follows reproducible but fundamentally different dynamics than what traditional theoretical frameworks predicted. Our findings suggest that preferential abandonment and the structural collapse it induces may be a generic property that prevails in the declining phase of the innovation lifecycle.

**Estimating the Impact of Artificial Intelligence across Scientific Disciplines**

*Jian Gao*

The ongoing artificial intelligence (AI) revolution has the potential to change almost every line of work. Despite the enormous efforts devoted to understanding the impact of AI in labor, we know relatively little about how AI might impact science. By integrating a variety of data sources including millions of publications, university course syllabi, research funding, and their inter-linkages, here we attempt to estimate the benefits of AI in science. Our analyses reveal several findings: (1) while research disciplines overall increasingly use more AI and have larger potential AI benefits during the past two deceases, there is an abrupt increase in the direct use of AI since 2015, especially new AI capabilities. (2) A field's potential AI benefits can predict its future direct use of AI, and new AI capabilities are increasingly applicable for direct use. (3) Despite discipline-level heterogeneity, every discipline has some subfields that can benefit from AI, suggesting that AI benefits are pervasive across disciplines. (4) The education of AI in courses is overall misaligned with AI benefits in science, while there is a well alignment between AI funding investment and AI scientific benefits. (5) There are disparities of AI benefits across gender and race, where women and under-represented minorities are disproportionately present in disciplines of smaller AI benefits. Our work may help deepen our understanding of AI's important policy implications for the future of science.

## EVENING SESSION: 7:30PM – 8:30PM

**Gender Inequities in the Online Dissemination of Scholars' Work**

*Agnes Horvat*

Unbiased science dissemination has the potential to alleviate some of the known gender disparities in academia by exposing female scholars' work to other scientists and the public. And yet, we lack comprehensive understanding of the relationship between gender and science dissemination online. Our large-scale analyses, encompassing half a million scholars, revealed that female scholars' work is mentioned less frequently than male scholars' work in all research areas. When exploring the characteristics associated with online success, we found that the impact of prior work, social capital, and gendered tie formation in co-authorship networks are linked with online success for men, but not for women--even in the areas with the highest female representation. These results suggest that while men's scientific impact and collaboration networks are associated with higher visibility online, there are no universally identifiable facets associated with success for women. Our comprehensive empirical evidence indicates that the gender gap in online science dissemination is coupled with a lack of understanding the characteristics that are linked with
female scholars' success, which might hinder efforts to close the gender gap in visibility.

**Scientific Prizes and the Extraordinary Growth of Scientific Topics**

*Ching Jin*

Fast growing scientific topics have famously been key harbingers of the new frontiers of science, yet, large-scale analyses of their genesis and impact are rare. We investigated one possible factor connected with a topic's extraordinary growth: scientific prizes. Our longitudinal analysis of nearly all recognized prizes worldwide and over 11,000 scientific topics from 19 disciplines indicates that topics associated with a scientific prize experience extraordinary growth in productivity, impact, and new entrants. Relative to matched non-prizewinning topics, prizewinning topics produce 40% more papers and 33% more citations, retain 55% more scientists, and gain 37% and 47% more new entrants and star scientists, respectively, in the first five-to-ten years after the prize. Funding do not account for a prizewinning topic's growth. Rather, growth is positively related to the degree to which the prize is discipline-specific, conferred for recent research, or has prize money. These findings reveal new dynamics behind scientific innovation and investment.

**Connecting biomedical laboratory science to studies of science and scholarship**

*Thomas Stoeger*

Biomedical research currently concentrates on a small set of genes that have already been heavily investigated more than 30 years ago. This concentration cannot be explained by current experimental possibilities or the physiological importance of individual genes. Yet, this concentration leaves more than half of the human genes ignored by small-scale laboratory science, which constitutes most of current-day biomedical research. Shockingly, this also extends to frequently investigated topics of direct societal relevance such as COVID-19 or Alzheimer's disease. Hoping that this situation can be remedied by a more complete understanding of science, and by laboratory science becoming directly informed by studies of science and scholarship, I will dare to establish a "laboratory of the overlooked". While I believe that such an endeavor is quite likely to fail, I will try to establish such a laboratory in a way that seems most promising to succeed and to create further opportunities for my trainees and serve as a potential proof-of-feasibility to other laboratories. Consequently, my laboratory will be investigating overlooked aspects of already heavily investigated biological phenomena such as human aging. However, the number of pressing research questions outnumbers by at least two orders of magnitude the number of questions that the most productive laboratories have historically been able to resolve over the course of their existence. Consequently, I will in parallel strive to connect studies of science and scholarship more directly toward biomedical laboratory sciences, and to make the mutual exposure mutually rewarding. As parts of this effort, I will in the next few years continue to integrate over 100 different bibliometric and biomedical knowledge-sources to allow others and my laboratory to probe how science progresses as an activity that depends not only on human scientists and prior knowledge, but also depends on chemical and physical properties of molecules, and the interactions of these molecules.

**Structure of Research Team and Scientific Output**

*Fengli Xu*

Science and technology today are characterized by the increasing specialization of scholars and the division of labor in all areas, as renaissance persons diminish in prevalence. This shift into collective knowledge production raises the question of whether and how team member coordination affects the process of search and evaluation, the two processes through which science advances. Here we analyze the contribution statements in four prestigious journals and identify two team roles: 1) "brains" as those who contribute to conceptual work, including designing research and writing papers, and 2) "muscles" as those who are responsible for empirical work, such as implementing experiments, analyzing data, drawing figures, etc. We define "flat teams" as those in which conceptual work is shared evenly by multiple "brains" and "tall team" those dominated by only one or two "brains." As designing research and writing papers involve identifying and citing prior work, we assumed and validated that "brains" actively contribute to the references and authors contribute to the references equally in "flat teams." This allows us to extend team structure analysis to 2 millions articles over the past two decades without contribution statements. We demonstrate that "flat teams" effectively fuse "brain" and "muscle", capable of searching more broadly but producing fewer papers than "tall teams" in which these two roles are segregated and in which the linkage between search and testing is socially weakened or broken.