

# Vijay Balasubramanian

## Work Address:

David Rittenhouse Laboratories,  
University of Pennsylvania,  
Philadelphia, PA 19104.  
Tel: (215) 573-0982  
E-Mail: vijay@physics.upenn.edu

## Home Address:

96 E. Levering Mill Rd.,  
Bala Cynwyd, PA 19004.  
Tel: (610) 668-0285

- Education**
- Princeton University - Doctorate** Princeton, NJ  
PhD in Physics, defended May 1997. Area of specialization: high energy theory. Dissertation title: *Information, Entropy and Black Holes*. Thesis advisor: Curtis Callan
- Massachusetts Institute of Technology - Master's Degree** Cambridge, MA  
Master of Science in Computer Science, June 1992. Thesis: *Equivalence and Reduction of Hidden Markov Models*.
- Massachusetts Institute of Technology - Bachelor's Degrees** Cambridge, MA  
Bachelor of Science degrees in Physics and Computer Science, June 1991. GPA: 5.0 / 5.0, Phi Beta Kappa.
- Appointments**
- University of Pennsylvania** Philadelphia, PA  
Cathy and Marc Lasry Professor of Physics (October 2012 - present)  
Director, Computational Neuroscience Initiative (April 2014 - present)  
Merriam Term Professor of Physics (June 2011 - June 2012)  
Merriam Term Associate Professor of Physics (July 2005 - June 2011)  
Associate Professor of Neuroscience (secondary appointment) (2008 - present)  
Merriam Term Assistant Professor of Physics (July 2002 - June 2005)  
Assistant Professor of Physics and Astronomy (September 2000 - July 2002)  
Member of the Psychology Graduate Group (November 2011 - present)  
Member of the Neuroscience Graduate Group (January 2007 - present)  
Member of the David Mahoney Institute of Neurological Sciences (January 2007 - present)  
Member of the Bioengineering Graduate Group (September 2002 - present)
- Vrije Universiteit Brussels** Brussels, Belgium  
Visiting appointment as Buitengewoon Hoogleraar (Distinguished Full Professor) (2014-2020)
- International Center for Theoretical Physics** Trieste, Italy  
Research Staff Associate (2015-present)
- CUNY Graduate Center** New York, NY  
Presidential Professor (September 2013 - 2014); Presidential Visiting Professor (2014-2019)
- Rockefeller University** New York, NY  
Visiting Professor (September 2013 - September 2014)
- École Normale Supérieure** Paris, France  
Visiting Professor, supported by the Fondation Pierre-Gilles de Gennes (September 2012 - August 2013)
- Institute for Advanced Study** Princeton, NJ  
Helen and Martin Chooljian member (September 2007 - August 2008), theoretical physics group and Simons Center for Systems Biology.
- Harvard University** Cambridge, MA  
Junior Fellow of the Harvard Society of Fellows (June 1997 - August 2000).

**Principal Academic Awards and Grants**

- 2019** • Fellow of the American Physical Society
- 2019-2021:** • DOE QuantISED grant DE-SC0020360 *Distributed Quantum Information: Theory and Applications*
- 2019-2023:** • NIH grant R01EB026945 *Coincidence and continuity: uncovering the neural basis of auditory object perception*
- 2018-2019:** • President of the Penn chapter of the  $\phi\beta\kappa$  honor society.
- 2018-2021:** • NIH grant R01EB026945 *Mental, measurement, and model complexity in neuroscience*
- 2018-2021:** • Honda Research Institute grant: *Embodied, efficient, geometry-driven curiosity* (co-PI)
- 2017-2022:** • NIH 1T32DC016903-01: *Cross-disciplinary training in computational approaches to the neuroscience of audition and communication* (co-PI)
- 2017-2022:** • NSF Physics Frontiers Center PHY-1734030: *Center for the Physics of Biological Function* (co-PI)
- 2016-2019:** • Simons Foundation grant in Mathematical Modeling for Living Systems 400425 for *Adaptive Molecular Sensing in the Olfactory and Immune Systems*
- 2016-2017:** • National Science Foundation conference grant *Molecular coevolution: lessons from pathogen-immune system interactions*
- 2017-2018:** • FELS public policy grant: *Foundations of cooperative organization in living systems*
- 2015-2019:** • NIH grant R01EY07977 for *Central processing of visual information* (subaward through Cornell University, PI J. Victor)
- 2015-2012:** • Simons Foundation Collaboration in Mathematics and Physics 385592 – *It From Qubit*
- 2015-2016:** • NSF Ideas Lab: *Cracking the Olfactory Code*
- 2012-2016:** • US-Israel Binational Science Foundation grant 2011058 *What can a thousand neurons tell the brain?* (co-PIs R. Segev, P. Nelson)
- 2011-2016:** • NSF grant PHY-1058202 for *Neural population coding in the brain*
- 2011-2015:** • NIH grant R01 EY007977-21 for *Central processing of visual information* (subaward through Cornell University, PI J. Victor)
- 2011-2013:** • Fellowship of the Fondation Pierre-Gilles de Gennes, France
- 2011-2021:** • General member of the Aspen Center for Physics
- 2011** • Recipient of 2011 Ramond Family Gift from the Aspen Center for Physics
- 2011** • Penn Fellow
- 2009-2012:** • NSF grant EF-0928048 for *Adaptation, learning and decision making in biological networks*. (co-PI Philip Nelson)
- 2007-2010:** • US-Israel Binational Science Foundation grant 2006091 with the Weizmann Institute (co-PIs O. Aharony, M. Berkooz, E. Silverstein, S. Kachru)
- 2005-2006:** • Ira H. Abrams Memorial Award for Distinguished Teaching, School of Arts and Sciences, University of Pennsylvania
- 2005-2006:** • First Prize, Gravity Research Foundation essay competition
- 2005-2006:** • Fellow of the Institute of Physics (IOP), UK
- 2004-2009:** • NSF Grant IBN-0344678 for *What the retina might know about natural scenes*
- 2004-2008:** • NSF Grant OISE-0443607 for *US-Netherlands cooperative research: String theory and cosmological spacetimes*
- 2004-2005:** • Pew Foundation PRRUCS grant for course development of *Big Bang and Beyond*
- 2004-2005:** • Burroughs-Wellcome grant 1004943 for *Understanding The Brain* workshop at KITP
- 2003-2006:** • NSF grant PHY-0331728 *Time, Space and Information*
- 2002-2003:** • University of Pennsylvania Research Foundation Award
- 2001-2002:** • Fellow-at-Large of the Sante Fe Institute
- 1999-2000:** • Harvard Milton Fund Research Award
- 1997-2001:** • Junior Fellow of the Harvard Society of Fellows
- 1995-1996:** • Association of Princeton Graduate Alumni (APGA) summer research grant
- 1992-1993:** • Joseph Henry Prize (Physics Department, Princeton University)
- 1990-1991:** • Election to honour societies: Eta Kappa Nu (Electrical Engineering) and Sigma Xi (Science)
- 1989-1990:** • Election to honour societies: Phi Beta Kappa and Tau Beta Pi (Engineering)
- 1988-1989:** • MIT Burchard Scholarship
- Commendation from MIT Computer Science Department
- 1987-1988:** • Commendation from MIT Computer Science Department

## Patents

- Patent No. 5,606,643 issued on Feb. 27, 1997 for “Real Time Audio Recording System For Automatic Speaker Indexing”
- Patent No. 5,655,058 issued on Aug. 5, 1997 for “Segmentation of Audio Data for Indexing of Conversational Speech for Real-Time or Postprocessing Applications”

## TEACHING

- 2009-2020:** • (Penn) Phys 585: Theoretical and Computational Neuroscience. ( $\sim 45 - 69$  students)
- 2017-2020:** • (Penn) Phys 503: General Relativity and Gravitation ( $\sim 8 - 15$  students)
- 2009-2018:** • (Penn) INSC 573 CORE III Systems and Integrative Neuroscience – lectures on retina. ( $\sim 25$  students)
- 2012-2015:** • (Penn) INTG 002: Integrated Studies Program – The Order of Things ( $\sim 75$  students)
- 2014:** • (CUNY Graduate Center) Theoretical and Computational Neuroscience (6 students)
- 2003-2010:** • (Penn) Astro007: “The Big Bang and Beyond”, a freshman seminar (22 students, Spring 2003; 19 students, Spring 2004; 22 students, Fall 2004; 50 students, Spring 2005; 22 students, Fall 2005; 74 students, Spring 2007; 30 students, Spring 2009)
- 2007-2008:** • (Penn) Lectures in INSC 598: Advanced Systems Neuroscience ( $\sim 10$  students)
- 2003-2006:** • (Penn) Phys 611: “Statistical Mechanics”, graduate course (30 students, Fall 2003; 18 students, Fall 2005; 20 students, Fall 2006)
- 2000-2002:** • (Penn) Phys151: Electromagnetism for freshman engineers ( $\sim 60-70$  students each year)
- 2000-2002:** • (Penn) Phys601: Quantum Field Theory I ( $\sim 10$  students each year)
- 1995-1996:** • (Princeton) Lectures on problem solving in first-year Classical Mechanics and Electromagnetism
- 1993-1994:** • (Princeton) Problem solving sessions in first-year Classical Mechanics
- 1989-1990:** • (MIT) Teaching Assistant for Experimental Physics I and II
- 1988-1989:** • (MIT) Teaching Assistant for Structure and Interpretation of Computer Programs

## PROFESSIONAL SERVICE

- General Member of the Aspen Center for Physics (2011-2021)
- Co-organized the “Physics of the brain” session at the March Meeting 2020 conference of the American Physical Society
- Co-organized “The Quantum Future” symposium at Aspen Center for Physics and the Aspen Institute, March 2020
- Co-organized BIRS “Out-of-equilibrium processes in evolution and ecology” workshop, August 2019, Oaxaca, Mexico
- Grant reviewing for FWO (Netherlands), DOE (USA), NRF (South Africa) (2018-2020)
- International advisory board for the ICTP-ICTS Winter Schools on Quantitative Systems Biology, Trieste, Italy & Bangalore, India (2016-onwards)
- Co-organized “New developments in Quantum Field Theory” workshop, November 2018, CUNY Graduate Center
- Co-organized “Seeing beyond V1” workshop, November 2018, CUNY Graduate Center
- Editorial board for *Molecular Brain* (2017-present)
- External search committee member for Quantitative Living Systems search, International Center for Theoretical Physics, Trieste, Italy, 2017-2018
- Co-organized *It From Qubit* school, Bariloche, Argentina, January 2018
- Co-organized “New Developments in Quantum Field Theory” workshop, November 2017, CUNY Graduate Center
- Co-organized Princeton Center for Theoretical Physics Conference on “Molecular Co-evolution, Lessons from Pathogen Immune-System Interaction” (2016)
- Grant reviewing for EPSRC (UK) and FWO (Belgium) (2016)
- External search committee member for quantitative biology (2016): Initiative for the Theoretical Sciences (CUNY Graduate Center), Quantitative Living Systems (International Center for Theoretical Physics, Trieste, Italy)
- Co-organizer of ICTS workshop and Turing Lecture on Information Processing in Biological Systems (2015)
- Organizer of Penn workshop on New Frontiers in Entanglement (2015)
- Co-Organizer of the ICTP Winter Schools on Quantitative Systems Biology, Trieste, Italy (2012,2014,2016); Bangalore, India (2013,2015)
- Organization of the Initiative for the Theoretical Sciences at the CUNY Graduate Center (2013-2016)
- NSF Review Panelist (Physics of Living Systems, 2014; Robust Intelligence, 2016)
- Co-organizer of Aspen Winter Workshop on “New perspectives on thermalization: condensed matter, quantum information, QCD and string theory” (March 2014)
- Co-organizer of string theory workshop in Yerevan, Armenia, September 2013
- Advisor for International Center for Theoretical Physics, Trieste, Italy activities in Systems Biology
- Co-Organizer of 2012 KITP workshop on “Bits, branes and black holes”

- Director of the Undergraduate Computational Neuroscience Summer Program, held at Penn, summer 2012
- Organized session on “Computation in the retina and the visual system” at the FASEB 2012 meeting on retinal neurobiology
- Co-Organized 2011 Aspen Summer Workshop on “Computation and collective behavior in biological systems”
- Co-Organized International Center for Theoretical Physics (ICTP) 2011 Summer Workshop on “Cold materials, hot nuclei and black holes” ( Trieste, Italy)
- Co-organized 2006 Aspen summer workshop on “Recent advances in black hole physics in string theory”
- Organizing committee of 2006 Kavli Frontiers of Science symposium at the National Academy of Science
- Organizing committee of 2005 Beckman Frontiers of Science symposium at the National Academy of Science
- Co-Organized 2004 Iran String School and Workshop in Qeshm, Iran.
- Co-Organized a conference on *Simple Behaviour in Complex Neural Systems*, Penn, (April 2002) supported by the Santa Fe Institute and the School of Arts and Sciences at Penn.
- Co-Organized Kavli Institute of Theoretical Physics workshop “Understanding The Brain”, July 19 - Oct. 15 2004.
- Co-Organized 2003 IPM String School and Workshop in Anzali, Iran
- Co-Organized 2003 Aspen summer workshop on *Time and String Theory*
- Co-Organized string theory session at the 2003 APS/DPF joint April meeting.
- NSF Review Panelist for Physics of Living Systems (2012)
- Editorial Board member for *Classical and Quantum Gravity* 2004-2011
- Grant review panelist and Ad-Hoc Reviewer for the NSF, DOE, STFC (and formerly PPARC and EPSRC) (UK), Binational Research Foundation (Israel), National Research Foundation of South Africa, Dutch Research Council (NWO, Netherlands), Newton Institute (Cambridge, UK)
- Scientific advisory panel for Keck foundation (2006)
- Referee for *Physical Review D*, *Physical Review E*, *Physical Review Letters*, *Nuclear Physics B*, *Journal of High Energy Physics*, *Classical and Quantum Gravity*, *PNAS*, *Network: Computation in Neural Systems*, *Neural Computation*, *PLOS One*, *PLOS Computational Biology*, *PLoS Biology*, *J. Neuroscience*, *J. Comp. Neurology*, *J. Neurophysiology*, *Journal of Vision*, *Nature*, *eLife* and *Current Biology*

#### DEPARTMENTAL AND UNIVERSITY SERVICE

- Director of the Computational Neuroscience Initiative (2014-present)
- Co-director of the Computational Neuroscience of Audition and Communication training grant (2018-present)
- Co-advisor for the Computational Neuroscience minor in the Biological Basis of Behavior major (2014-present)
- MindCORE Advisory Board (2018-present)
- Phi Beta Kappa selection committee (2019-2020)
- Condensed Matter Search Committee and diversity liaison (2019-2020)
- President of the Phi Beta Kappa electoral board (2018-2019)
- Primakoff Lecture committee (2018-2019)
- Vice-president of the Phi Beta Kappa electoral board (2017-2018)
- Junior faculty mentorship committee (2017-2018)
- Faculty Advisory Board of MindCORE – Neuroscience Initiative of the School of Arts and Sciences, (2017- present)
- School of Arts and Sciences Planning group on Mapping the Mind (2015-2017)
- Review committee for the Penn Genomics and Computational Biology Program (2016-2017)
- High Energy Theory faculty search committee (2016-2017)
- Year of Cognition organizing committee (2015-2016)
- School of Arts and Sciences committee to formulate an Integrated Studies Program (2009 - 2012)
- Created the cross-school Computational Neuroscience Minor (2011) and currently a minor advisor
- Neuroscience Graduate Group admissions committee (2011-2012)
- University planning committee for “Year of Proof” (2011)
- Primakoff Lecture committee (2011-2012)
- Phi Beta Kappa selection committee (2009-2011)
- School of Arts and Sciences satellite committee to select Neuroscience PIK University Professors (2010)
- Committee to review the Positive Psychology Center (2009-2010)
- University Academic Planning and Budget Committee (2006-2007)
- Departmental mentoring committees (various years 2006-present)
- Department undergraduate committee (2005-2007)

- Departmental computing committee (2000 - 2009)
- High energy theory search committee (2005-2006)
- University Curriculum Committee (2003-2005)
- Astrophysics Search Committee (2003-2004)
- Physics Graduate Committee (2000-2003)
- Organizing the visitor program of the High Energy Theory group (2000 - 2011)
- Lectures to the Physics Club, the Science and Technology Wing, Preceptorials, Philomathean Society and other student groups (multiple years)
- Lectures in the Penn Summer Science Academy (multiple years)
- Lectures in the Penn Science Cafe (multiple years)

## UNDERGRADUATE STUDENTS SUPERVISED

### Thesis Students

- Rachel Brodsky (BSc, Physics 2018-2019): thesis research on dynamical chaos theory
- Sanjay Subramanian, Christopher Lo and Jeffrey Cheng (BSc, Computer Science, Bioengineering; 2018-2019): senior design project on self-organized representations of space
- Zachary Sheldon (BSc, Cognitive Science 2018-2019): thesis research on spatial cognition and the hippocampus
- Kalina Slavkova (BSc, Physics, 2017; graduate student at University of Texas, Austin)
- Joshua Merel (BSc, 2011, Fluharty Award for Biological Basis of Behavior thesis; grad school in Neuroscience, Columbia)
- Lauren Wozniak Pearce (BSc, 2007, undergraduate physics thesis, graduate school in Physics at UCLA)
- Erika Nelson (BSc, 2005, undergraduate physics thesis, graduate school in Physics at UCLA)

### Other research projects

- Greg Forkin (2019-2020): Population codes in the cortex, Thouron Award (grad school at Oxford University)
- Songhan Zhang (2019-2020): Population codes in the cortex (grad school at at University of Chicago)
- Alicia Zeng (2017-2019): Dynamical analysis of birdsong
- Ilayda Onur (2019): “Neuromorphic computing”
- Alicia Zeng (exchange student 2017-2019): “Complexity of birdsong and social behavior”
- Chetan Parthiban (Computer Science 2017-2019): “Machine learning of the visual and auditory codes”
- Jordan Lei (Computer Science 2017-2018): “Deep learning from the retina”
- Annie Su (Visual Studies 2017-2018): “Automatic extraction of the gist of visual scenes”
- Sneha Advani (Physics 2017-2018): “Dynamical modeling of the olfactory bulb”
- James Chapman (Math 2017-2018): “Optimal adaptive immune repertoires”
- Kuanhao Jiang (Math 2017-2018): “An algorithm for controlled generation of visual textures”
- Kalina Slavkova (Physics 2016-2017): “Perception of visual textures” (grad school at UT Austin)
- Xiping Yang (Physics 2016-2017): “Dynamics of adaptive immune systems” (PURM grant)
- Eli Pollock ( Physics 2015-2016): “Border cells error correct grid cells” (grad school at MIT)
- Niral Desai (Physics 2015-2016): “Border cells error correct grid cells” (grad school at UT Austin)
- Nicholas Rego (Biochemistry, 2015-2016): “Population dynamics of phage and bacteria with CRISPR immunity”
- Peter Lee (2011-2012): “Color contrast adaptation in the mammalian retina”
- Manusnan Suriyalaksh (2011-2012): “Adaptation of pairwise interactions in the retina”
- Pavel Konov (2011-2012): “Orientation maps in primary visual cortex”
- Josh Merel (2009-2011): “Shape sensitivity in inferotemporal cortex and natural scene statistics” (grad school at Columbia)
- Neil Mehindratta (2010): “Maximum likelihood estimation of neural receptive fields”
- Shihang Wei (2010): “Orientation maps and texture sensitivity” (Hong Kong University)
- Sushanth Bhaskarabhatla (2009): “Automated clustering methods for spike sorting”
- Kevin Schaeffer (2008): “Optimal orientation maps in V1” (grad school at Berkeley)
- Lauren Wozniak (2005): “A natural image database” (grad school at UCLA)
- Erika Nelson (2004): “Minimal complexity Bayesian inference” (grad school at UCLA)

## GRADUATE STUDENTS SUPERVISED

### Thesis Students

- Arjun Kar (PhD, Physics, PhD anticipated June 2020)
- Matt deCross (PhD, Physics; NSF Graduate Fellowship, current)
- David Kersen (MD/PhD, Bioengineering, current)
- Ron Ditullio (PhD, Neuroscience, current)
- Yue (Cathy) Li (PhD, Physics, current)
- Alexandra Keinath (PhD, Psychology; defended February 2018; McGill University on NSERC fellowship; Banting Fellow)
- Kamesh Krishnamurthy (PhD, Neuroscience; defended November 2017; postdoctoral fellow at Princeton)
- Louis Kang (MD/PhD Physics; degree in summer 2017; Miller Fellow at Berkeley; Group Leader at RIKEN Japan)
- John Briguglio (PhD, Physics/Neuroscience; defended November 2016; postdoctoral fellow at HHMI Janelia Research Center)
- Xuexin Wei (PhD, Psychology and Neuroscience; defended April 2015; Flexner Award for best neuroscience dissertation; postdoctoral fellow at Columbia; Assistant Professor, UT Austin)
- Jan Homann (PhD, Physics and Neuroscience, PhD 2015, postdoctoral fellow at Princeton)
- Kristina Simmons (PhD, Neuroscience, PhD 2014, MINS student poster award, Penn postdoctoral fellow in neurosurgery)
- Jason Prentice (PhD, Physics / Neuroscience, Swartz Cosyne Fellowship, Cosyne, 2009, Phd 2012; C.V. Starr Fellow at Princeton)
- Charles Ratliff (PhD, Physics and Neuroscience, Ph.D. 2007; postdoctoral fellowships at Northwestern (S. de Vries lab), USC (S. Alapakkam lab); Assistant Professor, Oklahoma School of Science and Technology)
- Klaus Larjo (PhD, High energy physics, Ph.D. 2008; postdocs at UBC, Brown; currently: Goldman Sachs)
- Bartolomiej Czech (PhD, High energy physics, Ph.D. 2009; postdocs at UBC, Amsterdam, Stanford; Professor at Tsinghua University, Beijing, China)
- Minxin Huang (PhD, High energy physics, Ph.D. 2004, postdocs at University of Wisconsin; CERN; IPMU, Tokyo; Professor of physics, University of Science and Technology, China).
- Thomas Levi (PhD, High energy physics, Ph.D. 2006, KITP Graduate Fellow; postdocs at NYU, UBC; software industry)

### Rotation Students and Other Research

- Songhan Zhang (Engineering 2018-2019): “Population coding in the auditory cortex”
- Ron Ditullio (Neuroscience 2017-2018): “Self-organized grid cell modules and boundary interactions”
- Xiaomao Ding (Neuroscience 2017-2018): “Balanced networks in the auditory cortex”
- Ilena Jones (Neuroscience 2016-2017): “Complexity and decision making”
- David White (Neuroscience 2015-2016): “Multi-electrode recording of olfactory responses”

## POSTDOCTORAL FELLOWS SUPERVISED

### High Energy Physics

- Tomonori Ugajin, PhD from Tokyo University, Simons It From Qubit postdoctoral fellow, currently Hakubi Assistant Professor, Kyoto University
- Onkar Parrikar, PhD from University of Illinois, Simons It From Qubit postdoctoral fellow, currently at Stanford
- Gabor Sárosi, PhD from University of Budapest, Simons It From Qubit postdoctoral fellow, currently at CERN
- Charles Rabideau, PhD from University of British Columbia, Simons It From Qubit postdoctoral fellow; NSERC Fellowship, currently at the Vrije Universiteit Brussel
- Monica Guica, PhD from Harvard, currently professor at CEA Saclay, Paris, France
- Joan Simon, PhD from Barcelona, currently Professor at University of Edinburgh, Edinburgh, UK
- Asad Naqvi, PhD from MIT, currently at Goldman-Sachs

## Biophysics and Neuroscience

- Nachi Stern, PhD from the University of Chicago
- Philipp Fleig, PhD from Max Planck Institute, Potsdam
- Hanrong Chen, PhD from Harvard, Simons Foundation Mathematical Modeling in Living Systems fellow at Penn
- Gaia Tavoni, PhD from ENS, Paris, Swartz Foundation Fellow at Penn
- Clélia de Mulatier, PhD from Paris-Saclay, Simons Foundation Mathematical Modeling in Living Systems fellow at Penn
- Eugenio Piasini, PhD University College London, Italy, Computational Neuroscience Initiative Fellow, Penn
- Eve Armstrong, PhD University of California at San Diego, Computational Neuroscience Initiative Fellow, Penn; currently Assistant Professor, New York Institute of Technology
- Vijay Singh, PhD from Emory, Computational Neuroscience Initiative Fellow, Penn; currently Assistant Professor, University of North Carolina A&T
- Serena Bradde, PhD from SISSA, Trieste, Italy, currently editor at the *Physical Review*
- Tiberiu Tesileanu, PhD from Princeton, currently on the research staff at the Simons Flatiron Institute
- Ann Hermundstad, PhD from UCSB, currently Group Leader, Janelia Research Campus, HHMI, Ashburn, VA
- Gasper Tkacik, PhD from Princeton, currently Associate Professor at Institute of Science and Technology, Austria
- Patrick Garrigan, PhD from UCLA, currently Professor at St. Joseph's University, Philadelphia, PA

## INDUSTRIAL EXPERIENCE

### Speech Recognition - Speech-Based Information Retrieval

Xerox PARC

*June 1993 to September 1993*

Built a speech-based information retrieval system with Dr. J. Kupiec and Dr. D. Kimber to find articles in an encyclopaedia relevant to spoken queries. Achieved good retrieval performance on short queries by using novel techniques for generating word hypotheses from a speaker-dependent phoneme recognition front end.

### Speech Recognition - Speaker Identification

Xerox PARC

*June 1992 to September 1992*

Built a real-time speaker identification system with Dr. L. Wilcox, Dr. P. Chou and Dr. D. Kimber. Applications included automatic segmentation by speaker of conference videotapes, as well as the real-time identification of speakers addressing a listening SPARCstation. Patent Nos. 5,606,643 (Feb. 27, 1997) and 5,655,058 (Aug. 5, 1997).

### Pattern Recognition - Characterization of Hidden Markov Models

Xerox PARC

*June 1991 to January 1992*

Discovered a complete classification of Hidden Markov Models (HMMs) in terms of equivalence classes representing the same stochastic processes. Developed a polynomial time algorithm to detect equivalence and to reduce HMMs to the least complex representative of an equivalence class. Presented for a Master's degree under the supervision of Dr. L. Niles of PARC and Prof. T. Poggio of MIT.

### Natural Language and Computer-Human Interaction

Xerox PARC

*June 1990 to September 1990*

With Dr. R. Rao, constructed part of the architecture for a natural language interface to SILICA, a reflective window system forming part of the Common Lisp Interface Manager.

### Dynamics and Complexity of Large Distributed Systems

Xerox PARC

*June 1989 to September 1989*

Modelled the dynamics of large distributed systems lacking global controls, and especially the effects of delays and uncertainties in information flow through computational economies, with Prof. B. Huberman of Stanford.

### Polymer Chemistry

Union Carbide Indonesia

*September 1986 to November 1986*

Worked in the emulsion polymer chemistry laboratory and wrote a paper entitled "A Study of the Effect of Changing Relative Monomer Concentration on the Emulsion Copolymerisation of Vinyl Acetate and 2-Ethyl-Hexyl-Acrylate".

## SELECTED WORKSHOPS AND EXTENDED VISITS

- 2020:**
  - “Frontiers of holographic duality”, Steklov Mathematical Institute (Moscow, Russia, May 2020)
  - “The Quantum Future” symposium, Aspen Center for Physics and Aspen Institute (Aspen, CO, March 2020)
  - “20 Years of Grid Cells” workshop at COSYNE 2020 (Breckenridge, CO, March 2020)
- 2019:**
  - It From Qubit Annual Meeting, Simons Foundation, (New York, NY, December 2019)
  - Honda Research Institute Curious Minded Machines workshop (San Jose, CA, October 2019)
  - “Entangle This” workshop (Madrid, Spain, September 2019)
  - Aspen Center for Physics summer program (Aspen, CO, August 2019)
  - Extended visit to the Kavli Institute for the Physics and Mathematics of the Universe (Tokyo, Japan; July 2019)
  - YITP Quantum Information in String Theory conference (Kyoto, Japan, June 2019)
  - 121st Statistical Physics Conference, Rutgers (New Brunswick, NJ, May 2019)
  - Workshop on invariance and geometry in sensation, action, cognition (Harvard, Cambridge, MA, April 2019)
  - New Directions in Physics Conference (Edinburgh, UK, January 2019)
  - Colloquium of the Belgian National Committee on Pure and Applied Physics on “Quantum Information: the second quantum revolution” (Royal Academy, Brussels, Belgium, March 2019)
- 2018:**
  - Extended visit to International Center for Theoretical Physics (ICTP) and SISSA (Trieste, Italy, Jan. 2018)
  - American Physical Society March Meeting (Los Angeles, March 2018)
  - Simons Foundation Theory in Biology workshop (NYC, April 2018)
  - Extended visit (1 month) to Vrije Universiteit Brussel (Brussels, Belgium, May 2018)
  - Solvay workshop on “Cosmological frontiers in fundamental physics” (Brussels, Belgium, May 2018)
  - DIEP symposium on emergence (Leiden, Netherlands, May 2018)
  - Galileo Galilei Institute workshop on “Entanglement in Quantum Systems” (Florence, Italy, June 2018)
  - Biological Distributed Algorithms 2018 (Egham, UK, July 2018)
  - Aspen Center for Physics Summer Workshops (August 2018)
  - Brookhaven National Laboratory workshop on “Entanglement in high energy collisions” (September 2018)
- 2017:**
  - Computational and Systems Neuroscience 2017, Salt Lake City, Utah (Feb. 2017)
  - Columbia workshop on Brains, Machines and Computation, New York, NY (March 2017)
  - Simons Foundation workshop on Theory in Biology, New York, NY (April 2017)
  - Vrije Universiteit Brussel, Brussels, Belgium (May 2017)
  - Cargese summer school on Theoretical Biophysics (July 2017)
  - International Center for Theoretical Physics (ICTP) conference on olfaction Trieste, Italy (July 2017)
  - Extended visit to Quantitative Living Systems group at ICTP, Trieste, Italy (July 2017)
  - Aspen Center for Physics Summer Workshops (August 2017)
  - Princeton Center for Theoretical Science workshop on “20 Years of AdS/CFT” (Nov. 2017)
  - Simons It From Qubit Workshop (Dec. 2017)
- 2016:**
  - Lectures at ICTP-SAIFR School on Physics Applications in Biology, Sao Paolo, Brazil (Jan. 2016)
  - Bellairs Institute Conference on Complexity Theory (Barbados) (Feb. 2016)
  - Panel at New York Academy of Science conference on the Future of Physics, New York, NY (April 2016)
  - PCTS workshop Molecular Co-evolution, Lessons from Pathogen Immune-System Interaction, Princeton, NJ (April 2016)
  - Simons workshop on quantum entanglement, Yukawa Institute for Theoretical Physics, Kyoto, Japan (June 2016)
  - Extended visits to International Center for Theoretical Physics, Trieste, Italy (April 2016, Dec. 2016)
  - Extended visits to Vrije Universiteit Brussels, Brussels, Belgium (April 2016, Dec. 2016)
  - Solvay workshop on Non-equilibrium Dynamics, Brussels, Belgium (July 2016)
  - Statistical Physics 2016, Lyons, France (July 2016)
  - Perimeter Institute Summer School and Workshop on quantum entanglement, Waterloo, Canada (July 2016)
  - Aspen Center for Physics Summer Workshop on Bacteria, Aspen, CO (Aug. 2016)
  - Princeton Center for Theoretical Sciences workshop on “Journey to the Center of the Bulk” (Oct. 2016)
  - Princeton Center for Theoretical Sciences workshop on “Hyperuniform States of Matter in Physics, Mathematics and Biology” (Dec. 2016)



- 2015:**
- 40th Anniversary conference of the Ecole Normale Supérieure, Paris (Jan. 2015)
  - Extended visits to Vrije Universiteit Brussels, Brussels, Belgium (March, May 2015)
  - Panels at the World Science Festival on "Time is of the essence" and "Until the End of Time" (May 2015)
  - Theory at Sea meeting, Oostende, Belgium (April 2015)
  - Gauge/Gravity Duality 2015, Galileo Galilei Institute for Theoretical Physics, Florence, Italy (April 2015)
  - Deconstructing The Sense of Smell, KITP, Santa Barbara (June-July 2015)
  - Cracking The Olfactory Code, NSF-run workshop at the HHMI Janelia Research Campus (June-July 2015)
  - Entanglement in Strongly Correlated Matter, KITP, Santa Barbara (June-July 2015)
  - Aspen Center for Physics (Aug. 2015)
  - Simons It From Qubit Workshop (Dec. 2015)
  - ICTS workshop and Turing Lecture on Information Processing in Biological Systems (Dec. 2015)
- 2014:**
- COSYNE (Computational and Systems Neuroscience) 2014 workshop (Feb. 2014)
  - Aspen winter workshop on "New approaches to thermalization" (March 2014)
  - NSF workshop on "Quantitative theories of learning memory and prediction" (May 2014)
  - Neural Networks in the Arctic workshop, Spitsbergen, Norway (June 2014)
  - Aspen summer workshop on "Emergent Spacetime in String Theory" (July 2014)
  - Santa Fe Institute (Aug. 2014)
  - Winter School on Quantitative Systems Neuroscience, ICTP, Trieste, Italy (Dec. 2014)
  - Bernstein Conference in Computational Neuroscience (Sep. 2014)
- 2013:**
- Visit to theoretical physics group of École Normale Supérieure, Paris
  - Visit to Kavli Institute for Systems Neuroscience, Trondheim, Norway
  - Claude Itzykson conference, Saclay, France
  - Rank Prize Symposium workshop on the Computational Basis of Early Vision, Grasmere, UK
  - Cargese workshop on Quantitative Population Genomics, Cargese, France
  - Workshop on Natural Environments, Tasks and Intelligence (Austin, TX)
- 2012:**
- FASEB workshop on Retinal Neurobiology (Steamboat Springs, CO)
  - Workshop on Natural Environments, Tasks and Intelligence (Austin, TX)
  - ICTP Winter School on Quantitative Systems Biology (Trieste, Italy)
  - Newton Institute (Cambridge, UK) meeting on Branes and Black Holes
  - KITP workshop on "Bits, Branes and Black Holes"
  - Aspen Center for Physics – workshop on string theory
  - Santa Fe Institute – invited summer visitor
  - SFI workshop on "The Principles of Complexity: Life, Scale and Civilization", Santa Fe, NM
  - Virginia/Maryland String and Particle Theory Meeting
  - Lorentz Center workshop on Holographic Thermalization (Leiden, Netherlands)
- 2011:**
- Visitor of the theoretical physics group, Weizmann Institute, Israel
  - COSYNE (Computational and Systems Neuroscience) 2011 workshop
  - 2011 INFN summer school on *Black Objects in Supergravity*, Frascati, Italy
  - Institut de Hautes Etudes Scolaires, Paris – "Three generations of string theory" workshop
  - Aspen Center for Physics – workshop on "Computation and collective behavior in biological systems"
  - Santa Fe Institute – invited summer visitor
  - Workshop on black holes at McGill University, Canada
  - ICTP, Trieste, Italy – workshop on "Hot Nuclei, Cold Atoms, and Black Holes"
  - European retina meeting
  - Visitor of the theoretical physics group, Vrije Universiteit Brussels, Brussels, Belgium
- 2010:**
- KITP workshop on Emerging Techniques in Neuroscience
  - Visitor of the Vrije Universiteit Brussel, Brussels, Belgium
  - FASEB 2010 (Retinal neurobiology and visual perception)
  - NSF Workshop on "Interdisciplinary challenges beyond the scaling limits of Moore's Law", Washington D.C.
  - UBC theoretical physics group visitor
  - Santa Fe Institute – invited summer visitor
  - Aspen Center for Physics – independent summer working group
  - Amsterdam summer workshop in string theory

- 2009:**
- COSYNE (Computational and systems neuroscience) 2009 workshop
  - AFORS Workshop on “Mathematical methods in machine learning”, Washington D.C.
  - Aspen summer workshop on “Unity of string theory”
  - Aspen summer workshop on “Bacteria meet physics”, Aspen, CO
  - Yukawa Institute for Theoretical Physics Workshop on “Branes, Strings and Black Holes”, Kyoto, Japan
  - Extended visit to theoretical physics group, Weizmann Institute, Israel
  - Extended visit to theoretical physics group, University of Amsterdam, Netherlands
  - Workshop on “Holography and universality of black holes”, McGill, Canada
- 2008:**
- Visiting fellow of the IAS, Jerusalem and participant in “From Perception to Action” workshop, Jerusalem, Israel
  - Workshop on “Information theoretic methods in science and engineering”, Tampere, Finland.
  - Extended visit to theoretical physics group, Vrije Universiteit Brussel (VUB), Belgium
  - PI/APC Cosmological Frontiers in Fundamental Physics, Paris, France
  - “Gravitational scattering, black holes, and the information paradox”, Institut Henri Poincaré, Paris, France.
  - Eurostrings, Amsterdam, Netherlands.
  - Monsoon Workshop in String Theory, TIFR, Mumbai, India
  - New England String Meeting, Providence, RI
  - Princeton Center for Theoretical Physics workshop on Cosmic Singularities, Princeton, NJ
- 2007:**
- Sowers Theoretical Physics Workshop, Virginia Tech, Blacksburg, VA
  - Extended visit to theoretical physics group, University of Amsterdam, Netherlands
  - Extended visit to theoretical physics group, University of British Columbia, Vancouver, Canada
  - Pre-strings workshop on Gravitational Aspects of String Theory, Granada, Spain
- 2006:**
- COSYNE (Computational and Systems Neuroscience) 2006 Workshop, Salt Lake City, UT
  - Gordon conference on “Natural scene statistics and sensory systems”, Saxton Springs, VT
  - Amsterdam summer workshop in string theory
  - Weizmann Institute for Science, Rehovot, Israel
  - Arnold Sommerfeld Center Workshop on “Black holes and topological strings”, Munich, Germany
  - Indian Strings Meeting – Toshali Sands, Puri, India.
- 2005:**
- NORDITA String Cosmology conference, Uppsala, Sweden.
  - Fields Institute Workshop on black holes, University of British Columbia, Canada
  - US National Academy of Science, Beckman Frontiers in Science symposium, Los Angeles, CA
  - Lecturer, PIMS/Perimeter Institute Summer School in string theory, Waterloo, Canada.
  - Plenary speaker, Strings 2005, Toronto, Canada.
  - Japan Gravity Research Group (JGRG) meeting, Tokyo, Japan.
  - Annual UK Theory meeting, Durham, UK.
- 2004:**
- US National Academy of Science, Beckman Frontiers in Science symposium, Los Angeles, CA
  - Conformal Field Theory Reunion, Lake Arrowhead, CA
  - OCTS workshop on “Quantum Theory of Black Holes”, Columbus, OH
  - KITP workshop on “Understanding the Brain”, Santa Barbara, CA
- 2003:**
- Mitchell Institute for Fundamental Physics, Texas A&M, Inaugural string theory workshop and conference.
  - Pacific Institute of Mathematical Sciences summer school, Vancouver, Canada.
  - Aspen Center for Physics, summer workshop in string theory, Aspen, Colorado.
  - String theory school of the RTN network, Copenhagen, Denmark.
  - National Academy of Science, Frontiers of Science symposium, Shanghai, China.
- 2002:**
- Aspen Center for Physics, Summer Workshop, Fundamentals of String theory.
  - 35<sup>th</sup> International Ahrenschoop Symposium on the Theory of Elementary Particles, Berlin, Germany.
  - Perimeter Institute, Waterloo, Canada, Visitor.
  - “Branes and Cosmology” conference, Leiden University, Netherlands.
- 2001:**
- ITP, Santa Barbara, M-theory workshop.
  - Weizmann Institute for Science, Rehovot, Israel, Visitor
  - Helsinki Institutue for Physics, Helsinki, Finland, Visitor
  - Amsterdam Summer Workshop in String Theory, University of Amsterdam.
  - APCTP/KIAS Winter School in String Theory, Seoul, Korea.
  - Neural Information Processing Systems Worskhop, Whistler, Canada

- 2000:** • Enrico Fermi Laboratory, University of Chicago, Visitor.
  - Universidad Autonoma Metropolitana de Iztapalapa (UAMI), Lectures on string theory in Mexico City.
  - Duke Center for Geometry and Physics, Visitor, Durham, NC
  - Physiological Laboratories (Fly Vision Lab.) Cambridge University, Visitor.
  - Computational Neuroscience workshop (CNS-2000), Bruges, Belgium.
- 1999:** • ITP, Santa Barbara (Nov. 1998 - March 1999), Visitor.
  - Amsterdam Summer Workshop on String Theory and Black Holes, University of Amsterdam.
  - ICTP Summer Conference on Black Holes, Trieste, Italy.
  - Symposium on Model Complexity at the 32nd Annual Workshop on Mathematical Psychology (Santa Cruz, CA).
  - Ecole Normale Supérieure, Summer Institute on String Theory (Paris, France).
  - Aspen Center for Physics, Summer Workshop on String Theory.
  - ITP (Santa Barbara) workshop on Supersymmetric Gauge Theories
  - Stanford Theory Group, Visitor.
- 1998:** • ITP (Santa Barbara) workshop on Dualities in String Theory (Santa Barbara, CA).
  - Spinoza Meeting on the Quantum Black Hole (Utrecht, Netherlands).
  - Amsterdam Summer Workshop on String Theory and Black Holes, University of Amsterdam.
  - Aspen Center for Physics, Summer Workshop on String Theory.
  - Rutgers Theory Group, Visitor (Nov. 1998).
  - Seoul National University – Lecture Series (Seoul, Korea).
- 1997:** • NATO Advanced Study Institute on “Strings, Branes and Dualities” (Cargèse, France).
- 1996:** • Theoretical Advanced Study Institute (TASI): “Duality” (Boulder, CO).
  - AMS-IMS-SIAM Joint Summer Research Conference in the Mathematical Sciences on “Adaptive Selection of Models and Statistical Procedures” (Holyoke, MA).
- 1995:** • ICTP Spring School on String Theory and Quantum Gravity (Trieste, Italy).
  - 15<sup>th</sup> International Workshop on Maximum Entropy and Bayesian Methods (Santa Fe, NM).
- 1994:** • Theoretical Advanced Study Institute (TASI): “Beyond the Standard Model” (Boulder, CO).

### INVITED TALKS AND COLLOQUIA

1. 8/94: Xerox PARC, Machine Perception Seminar, Palo Alto, CA, USA.
2. 2/95: Seminar, NEC Research Laboratories, Princeton, NJ, USA.
3. 6/95: Seminar at the 15th International Conference on Maximum Entropy and Bayesian Methods, Santa Fe, NM, USA.
4. 8/95: Xerox PARC Machine Perception Seminar, Palo Alto, CA, USA.
5. 12/95: Seminar at Statistical Mechanics Conference, Rutgers University, Piscataway, NJ, USA.
6. 3/96: Seminar at Institute for Advanced Study, Princeton, NJ, USA.
7. 4/96: Condensed Matter Seminar, Princeton, NJ, USA.
8. 6/96: Seminar at TASI, Boulder, CO, USA.
9. 10/96: Seminar at University of Illinois at Urbana, Champaign, IL, USA.
10. 11/96: Seminar at the Penn State Gravity Conference, USA.
11. 11/96: Seminar at Brown University, Providence, RI, USA.
12. 1/97: Seminar at the University of North Carolina, Chapel Hill, USA.
13. 1/97: Colloquium at the University of North Carolina, Chapel Hill, USA.
14. 5/97: Seminar at the Cargese Summer School on Strings Branes and Dualities, Cargese, Corsica, France.
15. 6/97: Poster at the Strings 97 Conference, Amsterdam, Netherlands.
16. 10/97: Seminar at University of Massachusetts, Amherst, MA, USA.
17. 10/97: Seminar at Harvard University, Cambridge, MA, USA.
18. 11/97: Seminar at the Center for Astrophysics, Harvard, Cambridge, MA, USA.

19. 3/98: Seminar at Caltech, Pasadena, USA.
20. 3/98: Seminar at the PASCOS conference, Cambridge, MA, USA.
21. 3/98: Seminar at MIT, Cambridge, MA, USA.
22. 6/98: Seminar at the Amsterdam Summer Workshop on String Theory, Amsterdam, Netherlands.
23. 6/98: Seminar at the Potsdam Max Planck Institut fur Gravitationphysik, Potsdam, Germany.
24. 8/98: Xerox PARC Machine Perception Seminar, Palo Alto, CA, USA.
25. 8/98: Seminar at Xerox PARC, Palo Alto, CA, USA.
26. 8/98: Seminar at the Aspen Center for Physics, Aspen, CO, USA.
27. 10/98: Seminar at Princeton University, Princeton, NJ, USA.
28. 10/98: Seminar at Rutgers University, Piscataway, NJ, USA.
29. 10/98: Seminar at Brown University, Providence, RI, USA.
30. 11/98: Seminar at the NEC Research Institute, Princeton, NJ, USA.
31. 12/98: Three seminars at Seoul National University, Seoul, Korea.
32. 12/98: Seminar at KIAS, Seoul, Korea.
33. 1/99: Seminar at Durham University, Durham, UK.
34. 1/99: Seminar at Cambridge University, Cambridge, UK.
35. 2/99: Seminar at SLAC, Stanford, CA, USA.
36. 5/99: Seminar at U.C. Santa Barbara, Santa Barbara, CA, USA.
37. 3/99: Seminar at Caltech, Pasadena, CA, USA.
38. 4/99: Seminar at U.T. Austin, Austin, TX, USA.
39. 4/99: Seminar at Harvard University, Cambridge, MA, USA.
40. 4/99: Seminar at Argonne National Labs, Argonne, IL, USA.
41. 4/99: Seminar at University of Chicago, Chicago, IL, USA.
42. 5/99: Seminar at University of Pennsylvania, Philadelphia, PA, USA.
43. 5/99: Seminar at Harvard University, Cambridge, MA, USA.
44. 7/99: Seminar at the Amsterdam Summer Workshop on String Theory, Amsterdam, Netherlands.
45. 7/99: Seminar at the Trieste Conference on Black Holes, Trieste, Italy.
46. 7/99: Seminar at the Model Selection Symposium of the Meeting on Mathematical Psychology, Santa Cruz, CA, USA.
47. 8/99: Seminar at the Ecole Normale Supérieure Summer Workshop on String Theory, Paris, France.
48. 9/99: Seminar at Cornell University, Ithaca, NY, USA.
49. 10/99: Seminar at Brandeis University Center for Neuroscience, Waltham, MA, USA.
50. 9/99: Seminar at Stanford University, Stanford, CA, USA.
51. 9/99: Seminar at the Salk Institute for Neurobiology, San Diego, CA, USA.
52. 12/99: Seminar at the Caltech-USC Center for Theoretical Physics, Los Angeles, CA, USA.
53. 12/99: Director's Blackboard Seminar at the Institute for for Theoretical Physics, Santa Barbara, CA, USA.
54. 12/99: Seminar at the University of Pennsylvania, Philadelphia, PA, USA.
55. 2/00: Seminar at the University of Chicago, , IL, USA.
56. 2/00: Seminar at SUNY Stony Brook, Stony Brook, NY, USA.
57. 2/00: Two seminars at UCLA, Los Angeles, CA, USA.
58. 2/00: Seminar at McGill University, Montreal, Canada.
59. 3/00: Lecture series at Universidad Autonoma Metropolitana de Iztapalapa, Mexico City, Mexico.
60. 3/00: Colloquium at Universidad Autonoma Metropolitana de Iztapalapa, Mexico City, Mexico.

61. 4/00: Seminar at Duke University, Durham, NC, USA.
62. 7/00: Poster at the Computational Neuroscience 2000 conference, Bruges, Belgium.
63. 10/00: Seminar at Syracuse University, Syracuse, NY, USA.
64. 10/00: Colloquium at the Laboratory for Information and Decision Systems, MIT, Cambridge, MA, USA.
65. 11/00: Math Department Seminar, Université Quebec à Montreal (UQAM), Montreal, Canada.
66. 11/00: Seminar at Ohio State University, Columbus, OH, USA.
67. 12/00: Seminar at University of Maryland, College Park, MD, USA.
68. 1/01: Seminar at Yale University, New Haven, CT, USA.
69. 2/01: Seminar at Princeton University, Princeton, NJ, USA.
70. 2/01: Seminar at Columbia University, New York, NY, USA.
71. 2/01: Seminar at Rutgers University, Piscataway, NJ, USA.
72. 2/01: Vision Colloquium, University of Pennsylvania, Philadelphia, PA, USA,
73. 2/01: Seminar at U.T. Austin, Austin, TX, USA.
74. 3/01: Seminar at U.C. Berkeley, Berkeley, CA, USA.
75. 3/01: Seminar at Caltech-USC Center for Theoretical Physics, Los Angeles, CA, USA.
76. 3/01: Seminar at the Neurosciences Institute, La Jolla, CA, USA.
77. 4/01: Seminar at the Institute for Advanced Study, Princeton, NJ, USA.
78. 4/01: Review Seminar at the APS April Meeting, Washington D.C., USA.
79. 5/01: Joint Tel Aviv, Jerusalem, Weizmann Institute seminar, Neve Shalom, Israel.
80. 6/01: Seminar at the Helsinki Institute for Physics, Helsinki, Finland.
81. 7/01: Seminar at the Amsterdam Summer Workshop in string theory, Amsterdam, Netherlands.
82. 11/01: Seminar at Yale University, New Haven, CT.
83. 12/01: Series of lectures at APCTP/KIAS Winter School. Seoul, Korea.
84. 12/01: Talk at the Neural Information Processing Systems workshop, Whistler, Canada.
85. 1/02: IRCS Colloquium, University of Pennsylvania, Philadelphia, PA.
86. 2/02: Colloquium at U. Wisconsin at Madison, Madison, MI.
87. 3/02: Seminar at Virginia Tech, Blacksburg, Virginia, VA.
88. 4/02: Complex System Colloquium at U. Michigan, Ann Arbor, Michigan, MI.
89. 4/02: Seminar at Cornell University, Ithaca, NY.
90. 4/02: Undergraduate Physics Club lecture, University of Pennsylvania, Philadelphia, PA.
91. 8/02: Seminar at the Aspen Center for Physics, Aspen, CO.
92. 8/02: Plenary talk at 35<sup>th</sup> International Ahrenshoop Symposium on the Theory of Elementary Particles, Berlin, Germany.
93. 9/02: Seminar at University of Kentucky, Lexington, KY.
94. 10/02: Two seminars at the Perimeter Institute, Waterloo, Ontario, Canada.
95. 11/02: Plenary lecture at the “Branes and Cosmology Workshop”, Lorentz Center, Leiden, Netherlands.
96. 1/03: Seminar at Harvard University, Cambridge, MA.
97. 2/03: Colloquium at University of New Hampshire, Durham, NH.
98. 3/03: Seminar at Mitchell Institute, Texas A&M, College Station, TX.
99. 3/03: Seminar at “Holography and AdS/CFT” conference, Galveston, TX.
100. 4/03: Seminar at Princeton University, Princeton, NJ.
101. 5/03: Seminar at Los Alamos National Labs., Los Alamos, NM.
102. 5/03: Seminar at Queen Mary and Westfield College, London, UK.

103. 5/03: Seminar at the Newton Institute, Cambridge, UK.
104. 5/03: Seminar at the Newton Institute, Cambridge, UK.
105. 6/03: Plenary talk at SUSY03 conference, Tucson, AZ.
106. 7/03: Lecture series at PIMS string summer school, Vancouver, BC, Canada.
107. 8/03: Lecture series at 2003 School of the RTN Network, Copenhagen, Denmark.
108. 1/04: Seminar at University of Toronto, Toronto, Canada.
109. 8/04: Seminar at KITP “Understanding the Brain” workshop, Santa Barbara, CA.
110. 8/04: Seminar at the DPF2004 workshop, Riverside, CA.
111. 9/04: Lecture at OCTS workshop on “Quantum Theory of Black Holes”, Columbus, OH.
112. 11/04: Lecture at National Academy of Science, Beckman Frontiers of Science symposium, Los Angeles, CA.
113. 11/04: Seminar at the Enrico Fermi Institute, Chicago, IL.
114. 1/05: Seminar at Los Alamos National Labs, Los Alamos, NM.
115. 2/05: Colloquium at University of Pennsylvania, Department of Physics, Philadelphia, PA.
116. 3/05: Public lecture at the Penn Science Cafe on “Einstein and the Answers to Life, the Universe and Everything”, Philadelphia, PA.
117. 4/05: Appearance on Radio Times, Philadelphia PBS radio show.
118. 4/05: Lecture in the NORDITA String Cosmology conference, Uppsala, Sweden.
119. 6/05: Seminar at Newton Institute, Cambridge, UK.
120. 6/05: Seminar at Zoology Lab, Cambridge, UK
121. 7/05: Lecture series at Summer School on Strings, Gravity and Cosmology, Perimeter Institute, Waterloo, Canada.
122. 7/05: Lecture at Strings 2005 conference, Toronto, Canada.
123. 10/05: Colloquium at Brandeis University, Waltham, MA.
124. 11/05: University of Pennsylvania homecoming lecture.
125. 12/05: Plenary lecture at Japan Gravity Research Group 15, Tokyo, Japan.
126. 12/05: Plenary lecture at Annual UK Theory Meeting, Durham, UK.
127. 2/06: Seminar at City College of New York, New York, NY.
128. 3/06: Seminar at Computational and Systems Neuroscience Workshop 2006, Salt Lake City, UT.
129. 3/06: Seminar at University of Kentucky, Lexington, KY.
130. 4/06: Lecture at Arnold Sommerfeld Center for Theoretical Physics, Munich, Germany.
131. 6/06: Joint Tel Aviv, Jerusalem, Weizmann seminar, Neve Shalom, Israel.
132. 6/06: Seminar in Computational Neuroscience group, Jerusalem, Israel.
133. 6/06: Public lecture at the Penn Science Cafe on “Let There Be Light: A Physicist Looks at the Phenomena of Vision”, Philadelphia, PA.
134. 7/06: Seminar at Amsterdam summer workshop in string theory, Amsterdam, Netherlands.
135. 8/06: Lecture series at the Summer School on Strings, Gravity and Cosmology, PIMS, Univ. of British Columbia, Canada.
136. 8/06: Plenary lecture at 2006 Gordon Conference on “Natural scene statistics and sensory systems”, Big Sky, MO.
137. 9/06: Seminar at Michigan Center for Theoretical Physics, Ann Arbor, Michigan.
138. 9/06: Lecture to Penn undergraduate Physics club.
139. 9/06: Lecture to Penn Philomathean Society.
140. 10/06: Colloquium at UC Davis, Davis, California.
141. 10/06: Seminar at Center for Theoretical Physics, MIT, Boston, Massachusetts.
142. 10/06: Seminar at Columbia Center for Theoretical Neuroscience, New York, New York.

143. 12/06: Seminar at Indian Strings Meeting, Puri, India.
144. 3/07: Seminar in the Berkeley theoretical physics group, UC Berkeley, CA.
145. 3/07: Seminar at Simons Center for Systems Biology, Institute for Advanced Study, NJ.
146. 4/07: Colloquium at Amsterdam Center for Theoretical Physics, Amsterdam, Netherlands.
147. 5/07: Seminar at Sowers Theoretical Physics Workshop, Virginia Tech., Blacksburg, VA.
148. 5/07: Public lecture at Virginia Tech., Blacksburg, VA.
149. 6/07: Seminar at Pre-strings Workshop on Gravitational Aspects of String Theory, Granada, Spain.
150. 7/07: Seminar at University of British Columbia, Vancouver, Canada.
151. 11/07: Colloquium at Louisiana State University, Baton Rouge, LA.
152. 11/07: Seminar at McGill University, Montreal, Canada.
153. 2/08: Seminar at Rockefeller University, New York NY.
154. 2/08: Seminar at “From Perception to Action” Workshop, Jerusalem, Israel
155. 3/08: Colloquium at NYU, New York, NY.
156. 3/08: Seminar at Gatsby Neuroscience Institute, London, U.K.
157. 3/08: Seminar at Cambridge University, DAMTP, Cambridge, U.K.
158. 4/08: Seminar at Institute for Advanced Study, Princeton, NJ.
159. 4/08: Seminar at Cornell University Weil Medical School, New York.
160. 5/08: Seminar at “Workshop on Cosmological Frontiers in Fundamental Physics”, Paris, France.
161. 5/08: Seminar at “Workshop on Gravitational Scattering, Black Holes and The Information Paradox”, Paris, France.
162. 5/08: Keynote lecture at Science and Technology Wing banquet, Penn, Philadelphia, PA.
163. 6/08: Seminar at Eurostrings 2008, Amsterdam, Netherlands.
164. 7/08: Seminar at Monsoon Workshop in String theory, TIFR, Mumbai, India.
165. 9/08: Seminar at Center for Neural Science, NYU, New York, NY.
166. 9/08: Seminar in Biophysics group, Rutgers, Piscataway, NJ.
167. 10/08: Seminar at New England String Meeting, Providence, RI.
168. 12/08: Seminar at Princeton Center for Theoretical Science workshop on Cosmic Singularities, Princeton, NJ
169. 1/09: Seminar at AFORS workshop on Mathematical Methods in Machine Learning, Washington D.C.
170. 2/09: Seminar at SUNY College of Optometry, New York, NY.
171. 2/09: Panel discussion at launch event of the Penn Center for Particle Cosmology.
172. 4/09: Triangle Nuclear Theory Colloquium, Duke University, Durham, NC.
173. 4/09: Seminar at University of Chicago theory group, Chicago, IL.
174. 5/09: Institute for Gravitation and the Cosmos colloquium, Penn State, State College, PA.
175. 5/09: Theoretical neuroscience seminar at Janelia Farms HHMI campus, Ashburn, VA.
176. 5/09: Joint theory seminar, Neve Shalom, Israel.
177. 6/09: Computational Neuroscience summer program lecture, University of Pennsylvania, Philadelphia, PA.
178. 10/09: Seminar at Yukawa Institute for Theoretical Physics, Kyoto, Japan.
179. 1/10: Seminar at Salk Institute, San Diego, CA.
180. 1/10: Biophysics seminar at UCSD, San Diego, CA.
181. 2/10: Neuroscience graduate student recruitment seminar, Penn, Philadelphia, PA.
182. 11/09: Seminar at workshop on black holes in string theory, McGill, Canada.
183. 3/10: Biophysics seminar at Princeton University, Princeton, NJ.
184. 5/10: High energy physics seminar at Harvard University, Boston, NJ.

185. 6/10: High energy physics seminar at UBC, Vancouver.
186. 6/10: Integrating theoretical neuroscience and systems biology seminar at Princeton, NJ.
187. 7/10: Seminar to Computational Neuroscience Summer Program, Penn, Philadelphia, PA.
188. 8/10: NSF Workshop on Interdisciplinary Challenges beyond the Scaling Limits of Moore's Law, Washington DC.
189. 9/10: Physics Colloquium at Emory University, Atlanta GA.
190. 9/10: Vision Seminar at University of Pennsylvania, Philadelphia, PA.
191. 11/10: Seminar at KITP conference on "Emerging methods in neuroscience", Santa Barbara, CA.
192. 12/10: Seminar at Vrije Universiteit Brussels and Solvay Institute, Brussels, Belgium.
193. 1/11: Joint Tel Aviv-Jerusalem-Weizmann High Energy Physics seminar at Neve Shalom, Israel.
194. 1/11: Neurobiology seminar at Weizmann Institute, Israel.
195. 3/11: High energy physics seminar at University of Florence, Italy.
196. 4/11: Seminar in "New Horizons in the Foundations of Physics" conference, Washington, DC.
197. 4/11: Seminar at Penn Computational Neuroscience Retreat
198. 5/11: Four lectures at 2011 INFN summer school on *Black Objects in Supergravity*, Frascati, Italy
199. 5/11: Seminar at "Three generations of string theory" conference, IHES, Bures-sur-Yvette, France
200. 6/11: Seminar to Computational Neuroscience Summer Program, Penn, Philadelphia, PA.
201. 7/11: Public lecture at Kids Science BBQ, Aspen Center for Physics, Aspen, CO.
202. 7/11: Lecture to high school students at the Penn Summer Science Academy.
203. 8/11: Theoretical Neuroscience seminar at Santa Fe Institute.
204. 8/11: Theoretical Neuroscience seminar at International Center for Theoretical Physics, Trieste, Italy.
205. 9/11: Seminar at McGill workshop on black holes, Montreal, Canada.
206. 9/11: Physics colloquium at University of Maryland ("How smart can we get?"), College Park, MD.
207. 9/11: Plenary talk at the 2011 European Retina Meeting, Amsterdam, Netherlands.
208. 10/11: Physics colloquium at Yale ("How smart can we get?"), New Haven, CT.
209. 10/11: Swartz seminar in computational neuroscience at Yale, New Haven, CT.
210. 11/11: Physics colloquium at Ohio State University ("How smart can we get?"), Columbus, OH.
211. 12/11: Informal seminar in Systems Biology group at IAS, Princeton, NJ.
212. 12/11: Theoretical physics seminar at Solvay Institute, Brussels, Belgium.
213. 1/12: Biological Chemistry Colloquium at University of Pennsylvania, Philadelphia, PA.
214. 3/12: Seminar on "Momentum space entanglement and renormalization", Newton Institute, Cambridge, UK
215. 4/12: Seminar on "Sensory and cognitive maps in the brain" at Cornell Weil Medical School
216. 4/12: Seminar "Sensory and cognitive maps in the brain" at CUNY Graduate Center
217. 4/12: "Momentum space entanglement and renormalization" at University of Virginia, Charlottesville, VA.
218. 7/12: "Momentum space entanglement and renormalization", Aspen Center for Physics, Aspen, CO.
219. 7/12: Aspen Center for Physics Kids talk (public lecture) on "The maps inside your head", Aspen, CO.
220. 8/12: "The mystical art of spike sorting" at the FASEB meeting on Retinal Neurobiology, Steamboat Springs, CO.
221. 8/12: "The variational universe: from strings to neurons" at the SFI workshop on "The Principles of Complexity: Life, Scale and Civilization", Santa FE, NM.
222. 9/12: Joint Paris Theory Seminar "Momentum space entanglement and renormalization", Paris, France.
223. 10/12: IVY+STEM conference "The maps inside your head", Philadelphia, PA.
224. 10/12: "Holographic Thermalization" at the Lorentz Center, Leiden, Netherlands.
225. 10/12: "The maps inside your head", colloquium at the Institute of Science and Technology (IST), Vienna, Austria
226. 12/12: Lectures on systems neuroscience at the ICTP Winter School on Quantitative Systems Biology, Trieste, Italy.



227. 1/13: Séminaire Generale (colloquium) of the École Normale Supérieure on "The Maps Inside Your Head", Paris, France.
228. 1/13: Seminar at the Pasteur Institute on "Grid cells in the brain and the transcendental number  $e$ ", Paris, France.
229. 1/13: Solvay Colloquium on "The maps inside your head", Solvay Institute, Brussels, Belgium.
230. 4/2013: Seminar "Grid cells in your brain and the transcendental number  $e$ ", at Kavli Institute for Systems Neuroscience, Trondheim, Norway.
231. 4/2013: Seminar on "Working together: Coordination and collective effects in the representation of information by neural populations", of the Laboratoire de Physique Statistique, ENS.
232. 4/2013: Seminar "Grid cells in your brain and the transcendental number  $e$ ", at the Gatsby Institute for Computational Neuroscience, London, UK.
233. 4/2013: "Coordination and collective computation in the retina", at Rank Prize Symposium on the Computational Basis of Early Vision, Grasmere, UK
234. 6/2013: "The entropy of holes in spacetime", at 18th Itzykson Conference, Saclay, France.
235. 6/2013: Plenary lecture on "Information, Quantum Mechanics and Spacetime", French Physical Society General Congress 2013, Marseilles, France.
236. 9/2013: Seminar "Grid cells in your brain and the transcendental number  $e$ ", at Columbia University, New York, NY.
237. 9/2013: Seminar "Grid cells in your brain and the transcendental number  $e$ ", at the CUNY Graduate Center, New York, NY.
238. 10/2013: Seminar "The maps inside your head: How the brain represents sensory and cognitive spaces" at Rockefeller University, NY.
239. 10/2013: Seminar "The sense of place: grid cells in your brain and the transcendental number  $e$ ", Cold Spring Harbor Laboratory, Long Island, NY.
240. 4/2014: Colloquium "The maps inside your head" at Universidad Autonoma Madrid, Madrid, Spain.
241. 8/2014: Public lecture "The maps inside your head" at the Aspen Center for Physics, Aspen, CO
242. 9/2014: Seminar "Coordination and collective computation in the retina" at the Bernstein Symposium, Göttingen, Germany
243. 9/2014: Colloquium "The maps inside your head", Brown University, Providence, RI
244. 9/2014: Seminar "The maps inside your head", Center for Brain Sciences, Harvard University, Boston, MA
245. 11/2014: NIH neuroscience colloquium: "The maps inside your head", Bethesda, Maryland
246. 11/2014: Computational Neuroscience Seminar "The maps inside your head", Boston University, Boston, MA
247. 12/2014: Lecture at the ICTP Winter School on Quantitative Systems Neuroscience, Trieste, Italy.
248. 3/2015: Seminar "Entwinement and the emergence of spacetime", Leuven University, Leuven, Belgium.
249. 4/2015: Seminar "Entwinement and the emergence of spacetime", Galileo Galilei Institute, Florence, Italy
250. 4/2015: Seminar "Entwinement and the emergence of spacetime", MIT, Cambridge, MA
251. 5/2015: Seminar "Entwinement and the emergence of spacetime", Uppsala University, Uppsala, Sweden
252. 5/2015: Seminar "Entwinement and the emergence of spacetime", University of Leuven, Leuven, Belgium
253. 5/2014: Plenary lecture "Entanglement and spacetime", Theory at Sea conference, Oostende, Belgium
254. 6/2015: Seminar "Disorder as an organizing plan of the olfactory system, KITP workshop on olfaction
255. 6/2015: Seminar "Entwinement and the emergence of spacetime, KITP workshop on Entanglement in Strongly-Correlated Quantum Matter
256. 9/2015: Seminar "Molecular sensing in the immune and olfactory systems, CUNY ITS symposium
257. 10/2015: Colloquium "The maps inside your head", University of Toronto, Toronto, Canada
258. 10/2015: "New forms of entanglement", It From Qubit workshop, Stanford, CA.
259. 11/2015: Colloquium "The maps inside your head", Carnegie Mellon University (ECE Department), Pittsburgh, PA
260. 11/2015: Colloquium "The maps inside your head", Carnegie Mellon University (Physics Department), Pittsburgh, PA
261. 11/2014: Seminar "Entanglement and spacetime", Carnegie Mellon University, Pittsburgh, PA.

262. 12/2015: Seminar on “Molecular sensing in the olfactory and immune systems”, Int. Cent. for Theor. Sciences, Bangalore, India
263. 1/2016: Series of five lectures at ICTP-SAIFR School on “Diversity and Self-Organization of Neural Circuits”, Sao Paolo, Brazil
264. 4/2016: Panel at the New York Academy of Science on “Are there limits to human knowledge?”, New York, NY
265. 6/2016 Seminar “Novel forms of entanglement and spacetime”, Yukawa Institute for Theoretical Physics, Kyoto, Japan
266. 7/2016: Seminar “Adaptive molecular sensing in the olfactory and immune systems”, Solvay Institute conference on Non-equilibrium Dynamics, Brussels, Belgium
267. 7/2016: Discussion “Tensor Networks” at It From Qubit summer school, Perimeter Institute, Waterloo, Canada
268. 8/2016: Kids lecture on “What is time?”, Aspen Center for Physics, Aspen, Co
269. 9/2016: Series of five lectures, 14th Göttingen Summer School on Computational Neuroscience on Mathematical Approaches to Neural Circuit Dynamics, Göttingen, Germany
270. 9/2016: Seminar at Monell Chemical Sciences Center on “Adaptive molecular sensing”, Philadelphia, PA
271. 9/2016: Seminar “Entwinement in discretely gauged theories”, Princeton University, Princeton, NJ
272. 9/2016: Public lecture, “Decoding your mental GPS: transcendental numbers in the brain”, Penn Science Cafe, Philadelphia, PA
273. 10/2016: Lecture on “Interpreting the function of neural circuits in the brain”, Penn Institute for Computational Science 2016 Symposium on Emerging Paradigms in Scientific Discovery, Philadelphia, PA
274. 10/2016: Panel discussion on “Bulk reconstruction”, Princeton Center for Theoretical Sciences workshop on “Journey to the Center of the Bulk”, Princeton, NJ
275. 11/2016: Colloquium “The maps inside your head”, University of Pennsylvania Physics department, Philadelphia, PA
276. 11/2016: Seminar “New forms of quantum entanglement”, International Center for Theoretical Physics, Trieste, Italy
277. 12/2016: Seminar “Jam packed: optimal molecular sensing in the immune and olfactory systems”, at the Princeton Center for Theoretical Sciences Workshop on “Hyperuniform States of Matter in Physics, Mathematics and Biology”, Princeton, NJ
278. 2/2017: Seminar on “The visual perception of textures and natural statistics of light” in the Computational and Systems Neuroscience 2017 workshops, Snowbird, UT.
279. 3/2017: Seminar on “Cracking the olfactory code” in the Columbia University workshop on Brain Circuits, Memory and Computation, New York, NY
280. 3/2017: Seminar “A theory of the olfactory system”, New York University, New York, NY
281. 4/2017: Seminar on “Adaptive molecular sensing in the olfactory system”, 2017 Theory in Biology meeting, Simons Foundation, New York, NY
282. 4/2017: TedX talk on “The Sense of Place”, Philadelphia, PA
283. 4/2017: Colloquium at University of California, San Diego “The maps inside your head”, La Jolla, CA
284. 4/2017: Seminar at University of California, San Diego “Novel forms of entanglement”, La Jolla, CA
285. 6/2017: Public lecture at the Franklin Institute on “The end of spacetime”, Philadelphia, PA
286. 6/2017: Mapping the mind summer school, University of Pennsylvania, “Theoretical and computational neuroscience”, Philadelphia, PA
287. 6/2017: Seminar at Korea Institute for Advanced Studies, “Novel forms of entanglement”, Seoul, Korea
288. 6/2017: Seminar at Seoul National University, “Novel forms of entanglement”, Seoul, Korea
289. 7/2017: Seminar at Seoul National University, “The maps inside your head”, Seoul, Korea
290. 7/2017: Lecture in Theoretical Biophysics school, “Disorder and the neural representation of odors”, Cargese, Corsica
291. 7/2017: ICTP Quantitative Living Systems seminar, “Optimal inference of hazard rates in decision making processes”, Trieste, Italy
292. 7/2017: SISSA neuroscience seminar, “Optimal inference of hazard rates in decision making processes”, Trieste, Italy
293. 9/2017: UNC/Chapel Hill Colloquium “The maps inside your head”, Chapel Hill, NC

294. 9/2017: Biophysics seminar, at University of Illinois, “The maps inside your head”, Urbana-Champaign, IL
295. 10/2017: MIT Lab. for Information and Decision Systems colloquium. “The maps inside your head”, Cambridge, MA
296. 10/2017: Biophysics seminar, Princeton University, “Spatial localization in the brain via dynamical self-organization of grid cells, Princeton, NJ
297. 11/2017: Princeton Center for Theoretical Sciences workshop *20 Years of AdS/CFT*: “Emergent Time”, Princeton, NJ
298. 1/2018: CERN General Colloquium, “The maps inside your head”, Geneva, Switzerland
299. 3/2018: WBUR Boston “On Point” with Meghna Chakraborty, March 2018: Program on the life of Stephen Hawking
300. 3/2018: Seminar at UT Austin, “Dynamical self-organization and reorganisation of grid cells”, Austin, TX.
301. 5/2018: Solvay workshop, “Potential signatures of entanglement of the visible world with a hidden sector, Brussels, Belgium.
302. 5/2018: Colloquium at Institute of Physics Amsterdam, “The Maps Inside Your Head”, Amsterdam, Netherlands.
303. 5/2018: Colloquium at DIEP symposium on emergence, “From brains to black holes: information and emergent phenomena”, Leiden, Netherlands.
304. 6/2018: Colloquium at Scuola Normale Pisa, “The maps inside your head”, Pisa, Italy.
305. 7/2018: Seminar at Galileo Galilei Institute, “Random couplings from entanglement with dark matter”, Florence, Italy.
306. 7/2018: Seminar at Biological Distributed Algorithms 2018, “The brain distributes computation to function efficiently, Egham, UK.
307. 7/2018: Seminar at Google DeepMind, “Dynamical self-organization and reorganization in the grid system”, London, UK.
308. 8/2018: Public lecture at the Kids BBQ at the Aspen Center for Physics on “The Physics of Smell”
309. 9/2018: Seminar “Momentum-space entanglement and the renormalization group”, at Brookhaven National Laboratory conference, Stony Brook, NY
310. 9/2018: Seminar “The maps inside your head” at the Simons Center for Physics and Geometry, Stony Brook, NY
311. 1/2019: Colloquium “Information and emergence from black holes to the brain”, Edinburgh, UK
312. 3/2019: Colloquium “Quantum information and high energy physics”, Royal Academy, Brussels, Belgium
313. 4/2019: Colloquium “Becoming what you smell: adaptive sensing in the olfactory system”, Applied Math, Northwestern, Evanston, IL
314. 4/2019: Seminar “Becoming what you smell: adaptive sensing in the olfactory system”, Applied Math, Harvard, Cambridge, MA
315. 5/2019: Seminar “Becoming what you smell”, 121st Statistical Physics Conference, Rutgers, New Brunswick, NJ
316. 5/2019: Colloquium “Becoming what you smell”, Peking University, Beijing, China
317. 5/2019: Seminar “Entanglement with hidden sectors and statistically random couplings”, USTC, Hefei, China
318. 5/2019: Colloquium “Distributed quantum entanglement”, USTC, Hefei, China
319. 5/2019: Seminar “Entanglement and the discovery of new physics”, Tsinghua University, Beijing, China
320. 5/2019: Discussion with Science Leadership Academy Middle School students on black holes, Teacher: Eunice Ko, Philadelphia.
321. 5/2019: Seminar “Dynamical self-organization of the grid system in the brain”, Center for the Physics of Biological Function lecture, Princeton, NJ
322. 6/2019: Seminar on “Quantum complexity of time evolution”, Yukawa Institute, conference on Quantum Information in String Theory, Kyoto, Japan
323. 7/2019: Seminar on “Stochastic couplings and entanglement with hidden sectors”, Tokyo University, Tokyo, Japan
324. 8/2019: Seminar on “Quantum complexity of time evolution”, Max Planck Institute, Potsdam, Germany
325. 9/2019: Seminar on “Quantum complexity of time evolution”, *Entangle This* workshop, Institute of Theoretical Physics, Madrid, Spain.
326. 10/2019: Seminar “Learning, adaptation and curiosity in complex, changing environments”, Honda Research Institute, San Jose, CA

- 327. 10/2019: Colloquium “Becoming what you smell: adaptive sensing in the olfactory system”, University of Washington, Seattle, WA
- 328. 10/2019: Seminar on “Becoming what you smell: adaptive sensing in the olfactory system”, University of Oregon, Eugene, OR
- 329. 12/2019 Seminar “Quantum complexity of time evolution”, Simons Foundation It From Qubit Annual Meeting, New York
- 330. 3/2020: Seminar on “Dynamical self-organization of the grid system in the brain”, Workshop on *Twenty years of grid cells* at COSYNE 2020, Breckenridge, CO
- 331. 5/2020: Seminar on “Geometric secret sharing in a model of Hawking radiation”, Conference on *Frontiers of holographic duality*, Steklov Mathematical Institute, Moscow, Russia
- 332. 5/2020 Seminar on “Geometric secret sharing in a model of Hawking radiation”, It From Qubit online seminar

### PUBLICATIONS IN PHYSICS

All publications refereed unless indicated by \*\*

- 1. V. Balasubramanian and H. Verlinde. *Back-Reaction and Complementarity in 1+1 Dilaton Gravity*. hep-th/9512148 and Nucl. Phys. B464:213-247, 1996.
- 2. V. Balasubramanian and F. Larsen. *On D-Branes and Black Holes in Four Dimensions*. hep-th/9604189 and Nucl. Phys. B478:199-209, 1996.
- 3. V. Balasubramanian and I. Klebanov. *Some Aspects of Massive World-Brane Dynamics*. hep-th/9605174 and Mod. Phys. Lett. A11:2271-2284, 1996.
- 4. V. Balasubramanian and F. Larsen. *Extremal Branes as Elementary Particles*. hep-th/9610077 and Nucl. Phys. B495:206-218, 1997.
- 5. V. Balasubramanian and R. Leigh. *D-Branes, Moduli and Supersymmetry*. hep-th/9611165 and Phys. Rev. D55:6415-6422, 1997.
- 6. V. Balasubramanian and F. Larsen. *Relativistic Brane Scattering*. hep-th/9703039, and Nucl. Phys. B506:61-83, 1997.
- 7. V. Balasubramanian, F. Larsen and R. Leigh. *Branes at Angles and Black Holes*. hep-th/9704143 and Phys. Rev. D57:3509-3528, 1998.
- 8. V. Balasubramanian, R. Gopakumar and F. Larsen. *Gauge Theory, Geometry and the Large N Limit*. hep-th/9712077 and Nucl. Phys. B526:415-431, 1998.
- 9. \*\* V. Balasubramanian. *How to Count the States of Extremal Black Holes in N=8 Supergravity*. Proceedings of the 1997 Cargese school on “Strings, Branes and Dualities”, pp. 399-408, NATO ASI Series, Kluwer, Boston, 1997 [hep-th/9712215].
- 10. V. Balasubramanian and F. Larsen. *Near Horizon Geometry and Black Holes in Four Dimensions*. hep-th/9802198 and Nucl. Phys. B528:229-237, 1998.
- 11. V. Balasubramanian, P. Kraus and A. Lawrence. *Bulk vs. Boundary Dynamics in Anti-de Sitter Spacetime*. hep-th/9805171 and Phys. Rev. D59:046003 (16 pages), 1999.
- 12. V. Balasubramanian, P. Kraus, A. Lawrence and S. Trivedi. *Holographic Probes of Anti-de Sitter Spacetimes*. hep-th/9808017 and Phys. Rev. D59:104021 (14 pages), 1999.
- 13. V. Balasubramanian, D. Kastor, J. Traschen and K.Z. Win. *The Spin of the M2-Brane and Spin-Spin Interactions*. hep-th/9811037 and Phys. Rev. D59:084007 (9 pages), 1999.
- 14. V. Balasubramanian, S.B. Giddings and A. Lawrence. *What Do CFTs Tell Us About Anti-de Sitter Spacetimes?* hep-th/9902052 and JHEP03(1999)001 (32 pages), 1999.
- 15. V. Balasubramanian and P. Kraus. *A Stress Tensor for Anti-de Sitter Gravity*. hep-th/9902121 and Commun. Math. Phys. 208:413-428, 1999.
- 16. V. Balasubramanian and P. Kraus. *Spacetime and the Holographic Renormalization Group*. hep-th/9903190 and Phys. Rev. Lett. 83:3605-3608, 1999.

17. V. Balasubramanian and S.F. Ross. *Holographic Particle Detection*. hep-th/9906226 and Phys. Rev. D61:044007 (12 pages), 2000.
18. V. Balasubramanian, E. Gimon and D. Minic. *Consistency conditions for holographic duality*. hep-th/0003147 and JHEP:05(2000)014 (15 pages), 2000.
19. V. Balasubramanian, E. Gimon, D. Minic and J. Rahmfeld. *Four dimensional conformal supergravity from AdS space*. hep-th/0007211 and Phys. Rev. D63:104009 (10 pages), 2001.
20. V. Balasubramanian, J. de Boer, E. Keski-Vakkuri and S.F. Ross. *Supersymmetric conical defects: Towards a string theoretic description of black hole formation*. Phys. Rev. D **64**:064011 (19 pages), 2001 [arXiv:hep-th/0011217].
21. V. Balasubramanian, P. Hořava and D. Minic. *Deconstructing de Sitter*. JHEP 0105:043 (17 pages), 2001 [hep-th/0103171].
22. V. Balasubramanian, M. Berkooz, A. Naqvi and M. J. Strassler. *Giant gravitons in conformal field theory*. JHEP **0204**:034 (35 pages), 2002 [arXiv:hep-th/0107119].
23. V. Balasubramanian, J. de Boer and D. Minic. *Mass, entropy and holography in asymptotically de Sitter spaces*. Phys. Rev. D **65**:123508 (15 pages), 2002 [arXiv:hep-th/0110108].
24. V. Balasubramanian and A. Naqvi. *Giant gravitons and a correspondence principle*. Phys. Lett. B **528**:111-120 (2002) [arXiv:hep-th/0111163].
25. V. Balasubramanian, S. F. Hassan, E. Keski-Vakkuri and A. Naqvi, “A space-time orbifold: A toy model for a cosmological singularity,” Phys. Rev. D **67**:026003 (11 pages), 2003 [arXiv:hep-th/0202187].
26. V. Balasubramanian, M. Huang, T. S. Levi and A. Naqvi. *Open strings from  $N = 4$  super Yang-Mills*. JHEP **0208**:037 (19 pages), 2002 [arXiv:hep-th/0204196].
27. V. Balasubramanian and S.F. Ross. *The dual of nothing*. Phys. Rev. D **66**:086002 (9 pages), 2002 [arXiv:hep-th/0205290].
28. V. Balasubramanian, J. de Boer and D. Minic, “Exploring de Sitter space and holography,” Annals of Physics **303**(1), 59-116, (2003). [arXiv:hep-th/0207245].
29. V. Balasubramanian, J. de Boer and D. Minic. *Holography, time and quantum mechanics*. 9 pages, arXiv:gr-qc/0211003, Proceedings of the Third International Sakharov Conference on Physics, Moscow, Russia, June 2002.
30. V. Balasubramanian, J. de Boer, B. Feng, Y. H. He, M. x. Huang, V. Jejjala and A. Naqvi. *Multi-trace superpotentials vs. Matrix models*. Commun. Math. Phys. **242**, 361–392 (2003) [arXiv:hep-th/0212082].
31. V. Balasubramanian, B. Feng, M. x. Huang and A. Naqvi, “Phases of  $N = 1$  supersymmetric gauge theories with flavors,” arXiv:hep-th/0303065, Annals of Physics **310**:375-427, 2004.
32. V. Balasubramanian, T. S. Levi and A. Naqvi, “A comment on multiple vacua, particle production and the time dependent AdS/CFT correspondence,” Phys.Rev.D **69**:124003 (7 pages), 2004 [arXiv:hep-th/0303157].
33. V. Balasubramanian, A. Naqvi, J. Simon, “A multi-boundary AdS orbifold and DLCQ holography: A universal holographic description of extremal black hole horizons”, JHEP **048**:023 (49 pages), 2004 [arXiv:hep-th/0311237].
34. V. Balasubramanian, E. Keski-Vakkuri, P. Kraus and A. Naqvi, “String scattering from decaying branes,” Commun. Math. Phys. **257**, 363-394 (2005) [arXiv:hep-th/0404039].
35. V. Balasubramanian, “Accelerating universes and string theory,” Class. Quant. Grav. **21**, S1337-1358 (2004) [arXiv:hep-th/0404075].
36. V. Balasubramanian and T. S. Levi, “Beyond the veil: Inner horizon instability and holography,” Phys. Rev. D **70**, 106005 (18 pages), 2004 [arXiv:hep-th/0405048].
37. V. Balasubramanian and P. Berglund, “Stringy corrections to Kähler potentials, SUSY breaking, and the cosmological constant problem,” JHEP **0411**, 085 (21 pages), 2004 [arXiv:hep-th/0408054].
38. V. Balasubramanian, D. Berenstein, B. Feng and M. x. Huang, “D-branes in Yang-Mills theory and emergent gauge symmetry,” JHEP **0503**, 006 (2005) (55 pages) [arXiv:hep-th/0411205].
39. V. Balasubramanian, P. Berglund, J. P. Conlon and F. Quevedo, “Systematics of moduli stabilisation in Calabi-Yau flux compactifications,” JHEP **0503**, 007 (2005) (23 pages) [arXiv:hep-th/0502058].
40. V. Balasubramanian, K. Larjo and J. Simon, “Much ado about nothing,” Class. Quant. Grav. **22**, 4149–4170 (2005) [arXiv:hep-th/0502111].

41. \*\* V. Balasubramanian, V. Jejjala and J. Simon, “The library of Babel,” *Int. J. Mod. Phys. D* **14**, 2181 (2005) [arXiv:hep-th/0505123], Essay receiving honorable mention in the 2005 Gravity Research Foundation essay competition.
42. V. Balasubramanian, J. de Boer, V. Jejjala and J. Simon, “The library of Babel: On the origin of gravitational thermodynamics,” *JHEP* **0512**, 006 (2005) (72 pages) [arXiv:hep-th/0508023].
43. V. Balasubramanian, P. Kraus and M. Shigemori, “Massless black holes and black rings as effective geometries of the D1-D5 system,” *Class. Quant. Grav.* **22**, 4803–4838 (2005) [arXiv:hep-th/0508110].
44. V. Balasubramanian, B. Czech, K. Larjo and J. Simon, “Integrability vs. information loss: A simple example,” *JHEP* **0611**, 001 (2006) [arXiv:hep-th/0602263].
45. V. Balasubramanian, D. Marolf and M. Rozali, “Information recovery from black holes,” *Gen. Rel. Grav.* **38**, 1529 (2006) [*Int. J. Mod. Phys. D* **15**, 2285 (2006)] [arXiv:hep-th/0604045], essay winning First Prize in the Gravity Research Foundation essay competition.
46. J. Simon, R. Jimenez, L. Verde, P. Berglund and V. Balasubramanian, “Using cosmology to constrain the topology of hidden dimensions,” arXiv:astro-ph/0605371.
47. V. Balasubramanian, E. G. Gimon and T. S. Levi, “Four Dimensional Black Hole Microstates: From D-branes to Spacetime Foam,” *JHEP* **0801**, 056 (2008) [hep-th/0606118].
48. V. Balasubramanian, N. Jokela, E. Keski-Vakkuri and J. Majumder, “A thermodynamic interpretation of time for rolling tachyons,” *Phys. Rev. D* **75**, 063515 (2007) [arXiv:hep-th/0612090].
49. V. Balasubramanian, B. Czech, V. E. Hubeny, K. Larjo, M. Rangamani and J. Simon, “Typicality versus thermality: An analytic distinction,” *Gen. Rel. Grav.* **40**, 1863 (2008) [arXiv:hep-th/0701122].
50. V. Balasubramanian, B. Czech, K. Larjo, D. Marolf and J. Simon, “Quantum geometry and gravitational entropy,” *JHEP* **0712**, 067 (2007) [arXiv:0705.4431 [hep-th]].
51. V. Balasubramanian, J. de Boer, V. Jejjala and J. Simon, “Entropy of near-extremal black holes in AdS<sub>5</sub>,” *JHEP* **0805**, 067 (2008) [arXiv:0707.3601 [hep-th]].
52. V. Balasubramanian, P. Berglund, R. Jimenez, J. Simon and L. Verde, “Topology from Cosmology,” *JHEP* **0806**, 025 (2008) [arXiv:0712.1815 [hep-th]].
53. V. Balasubramanian, K. Larjo and R. Sheth, “Experimental design and model selection: The example of exoplanet detection,” arXiv:0802.0498 [astro-ph], Festschrift for Jorma Rissanen, TCSP Series 38 – Tampere University of Technology.
54. V. Balasubramanian, J. de Boer and A. Naqvi, “Statistical Predictions From Anarchic Field Theory Landscapes,” *Phys. Lett. B* **682**, 476 (2010) [arXiv:0805.4196 [hep-th]].
55. V. Balasubramanian, B. Czech, A. D. Shapere and B. Wecht, “Quiver Topology and RG Dynamics,” *JHEP* **0904**, 079 (2009) [arXiv:0811.4427 [hep-th]].
56. V. Balasubramanian, J. de Boer, S. El-Showk and I. Messamah, “Black Holes as Effective Geometries,” *Class. Quant. Grav.* **25**, 214004 (2008) [arXiv:0811.0263 [hep-th]].
57. V. Balasubramanian, J. de Boer, M. M. Sheikh-Jabbari, J. Simon, “What is a chiral 2d CFT? And what does it have to do with extremal black holes?,” *JHEP* **1002**, 017 (2010). [arXiv:0906.3272 [hep-th]].
58. \*\* V. Balasubramanian, “Are black holes really two dimensional?,” *a Viewpoint in Physics* **2**, 102 (2009).
59. V. Balasubramanian, P. Berglund and I. Garcia-Etxebarria, “Toric Lego: A method for modular model building,” *JHEP* **1001**, 076 (2010) [arXiv:0910.3616 [hep-th]].
60. V. Balasubramanian, J. Parsons, S. F. Ross, “States of a chiral 2d CFT,” *Class. Quant. Grav.* **28**, 045004 (2011). [arXiv:1011.1803 [hep-th]].
61. V. Balasubramanian, B. Czech, K. Larjo, T. S. Levi, “Vacuum decay in multidimensional field landscapes: thin, thick and intersecting walls,” *Phys. Rev.* **D84**, 025019 (2011). [arXiv:1012.2065 [hep-th]].
62. V. Balasubramanian, I. Garcia-Etxebarria, F. Larsen and J. Simon, “Helical Luttinger Liquids and Three Dimensional Black Holes,” *Phys. Rev. D* **84**, 126012 (2011) [arXiv:1012.4363 [hep-th]].
63. V. Balasubramanian, A. Bernamonti, J. de Boer, N. Copland, B. Craps, E. Keski-Vakkuri, B. Muller, A. Schafer *et al.*, “Thermalization of Strongly Coupled Field Theories,” *Phys. Rev. Lett.* **106**, 191601 (2011). [arXiv:1012.4753 [hep-th]].
64. V. Balasubramanian, B. Czech, “Quantitative approaches to information recovery from black holes,” *Class. Quant. Grav.* **28**, 163001 (2011). [arXiv:1102.3566 [hep-th]].

65. V. Balasubramanian, A. Bernamonti, J. de Boer, N. Copland, B. Craps, E. Keski-Vakkuri, B. Muller, A. Schafer *et al.*, “Holographic Thermalization,” *Phys. Rev.* **D84**, 026010 (2011). [arXiv:1103.2683 [hep-th]].
66. V. Balasubramanian, “What we don’t know about time,” to appear in *Foundations of Physics* 43(1):101-114, [arXiv:1107.2897 [hep-th]] (2011).
67. V. Balasubramanian, A. Bernamonti, N. Copland, B. Craps and F. Galli, “Thermalization of mutual and tripartite information in strongly coupled two dimensional conformal field theories,” *Phys. Rev. D* **84**, 105017 (2011) [arXiv:1110.0488 [hep-th]].
68. V. Balasubramanian, M. B. McDermott and M. Van Raamsdonk, “Momentum-space entanglement and renormalization in quantum field theory,” *Phys. Rev. D* **86**, 045014 (2012) [arXiv:1108.3568 [hep-th]].
69. V. Balasubramanian, A. Bernamonti, N. Copland, B. Craps and F. Galli, “Thermalization of mutual and tripartite information in strongly coupled two dimensional conformal field theories,” *Phys. Rev. D* **84**, 105017 (2011) [arXiv:1110.0488 [hep-th]].
70. V. Balasubramanian, P. Berglund, V. Braun and I. Garcia-Etxebarria, “Global embeddings for branes at toric singularities,” *JHEP* **1210**, 132 (2012) [arXiv:1201.5379 [hep-th]].
71. V. Balasubramanian, M. Guica and A. Lawrence, “Holographic Interpretations of the Renormalization Group,” *JHEP* **1301**, 115 (2013) [arXiv:1211.1729 [hep-th]].
72. V. Balasubramanian, A. Bernamonti, B. Craps, V. Keranen, E. Keski-Vakkuri, B. Müller, L. Thorlacius and J. Vanhoof, “Thermalization of the spectral function in strongly coupled two dimensional conformal field theories,” *JHEP* **1304**, 069 (2013) [arXiv:1212.6066 [hep-th]].
73. V. Balasubramanian, M. Berkooz, S. F. Ross and J. Simon, “A strongly coupled zig-zag transition,” *JHEP* **1309**, 066 (2013) [arXiv:1305.3574 [hep-th]].
74. V. Balasubramanian, B. Czech, B. D. Chowdhury and J. de Boer, “The entropy of a hole in spacetime,” *JHEP* **1310**, 220 (2013) [arXiv:1305.0856 [hep-th]].
75. V. Balasubramanian, A. Bernamonti, J. de Boer, B. Craps, L. Franti, F. Galli, E. Keski-Vakkuri and B. Muller *et al.*, “Inhomogeneous Thermalization in Strongly Coupled Field Theories,” *Phys. Rev. Lett.* **111**, 231602 (2013) [arXiv:1307.1487 [hep-th]].
76. V. Balasubramanian, A. Bernamonti, J. de Boer, B. Craps, L. Franti, F. Galli, E. Keski-Vakkuri and B. Muller *et al.*, “Inhomogeneous holographic thermalization,” *JHEP* **1310**, 082 (2013) [arXiv:1307.7086].
77. V. Balasubramanian, B. D. Chowdhury, B. Czech, J. de Boer and M. P. Heller, “Bulk curves from boundary data in holography,” *Phys. Rev. D* **89**, no. 8, 086004 (2014) [arXiv:1310.4204 [hep-th]].
78. V. Balasubramanian, M. Berkooz, S. F. Ross and J. Simon, “Black Holes, Entanglement and Random Matrices,” *Class. Quant. Grav.* **31**, 185009 (2014) [arXiv:1404.6198 [hep-th]].
79. V. Balasubramanian, P. Hayden, A. Maloney, D. Marolf and S. F. Ross, “Multiboundary Wormholes and Holographic Entanglement,” *Class. Quant. Grav.* **31**, 185015 (2014) [arXiv:1406.2663 [hep-th]].
80. V. Balasubramanian, B. D. Chowdhury, B. Czech and J. de Boer, “Entwinement and the emergence of spacetime,” *JHEP* **1501**, 048 (2015) [arXiv:1406.5859 [hep-th]].
81. V. Balasubramanian, J. J. Heckman and A. Maloney, V. Balasubramanian, J. J. Heckman and A. Maloney, “Relative Entropy and Proximity of Quantum Field Theories,” *JHEP* **1505**, 104 (2015) doi:10.1007/JHEP05(2015)104 [arXiv:1410.6809 [hep-th]].
82. C. Agon, V. Balasubramanian, S. Kasko and A. Lawrence, “Coarse Grained Quantum Dynamics,” *Phys. Rev. D* **98**, no. 2, 025019 (2018) doi:10.1103/PhysRevD.98.025019 [arXiv:1412.3148 [hep-th]].
83. V. Balasubramanian, A. Bernamonti, B. Craps, T. De Jonckheere and F. Galli, “Entwinement in discretely gauged theories,” *JHEP* **1612**, 094 (2016) doi:10.1007/JHEP12(2016)094 [arXiv:1609.03991 [hep-th]].
84. V. Balasubramanian, J. R. Fliss, R. G. Leigh and O. Parrikar, “Multi-Boundary Entanglement in Chern-Simons Theory and Link Invariants,” *JHEP* **1704**, 061 (2017) doi:10.1007/JHEP04(2017)061 [arXiv:1611.05460 [hep-th]].
85. V. Balasubramanian, B. Craps, B. Czech and G. Sárosi, “Echoes of chaos from string theory black holes,” *JHEP* **1703**, 154 (2017) [arXiv:1612.04334 [hep-th]].
86. V. Balasubramanian, A. Lawrence, A. Rolph and S. Ross, “Entanglement shadows in LLM geometries,” *JHEP* **1711**, 159 (2017) doi:10.1007/JHEP11(2017)159 [arXiv:1704.03448 [hep-th]].

87. V. Balasubramanian, A. Bernamonti, B. Craps, T. De Jonckheere and F. Galli, “Heavy-Heavy-Light-Light correlators in Liouville theory,” JHEP **1708**, 045 (2017) [arXiv:1705.08004 [hep-th]].
88. V. Balasubramanian and O. Parrikar, “Remarks on Entanglement Entropy in String Theory,” Phys. Rev. D **97**, no. 6, 066025 (2018) doi:10.1103/PhysRevD.97.066025 [arXiv:1801.03517 [hep-th]].
89. V. Balasubramanian, M. DeCross, J. Fliss, A. Kar, R. G. Leigh and O. Parrikar, “Entanglement Entropy and the Colored Jones Polynomial,” JHEP **0518**, 38 (2018) [arXiv:1801.01131 [hep-th]].
90. V. Balasubramanian, B. Craps, T. De Jonckheere and G. Sárosi, “Entanglement versus entwinement in symmetric product orbifolds,” JHEP **1901**, 190 (2019) doi:10.1007/JHEP01(2019)190 [arXiv:1806.02871 [hep-th]].
91. V. Balasubramanian, D. Berenstein, A. Lewkowycz, A. Miller, O. Parrikar and C. Rabideau, “Emergent classical space-time from microstates of an incipient black hole,” JHEP **1901**, 197 (2019) doi:10.1007/JHEP01(2019)197 [arXiv:1810.13440 [hep-th]].
92. V. Balasubramanian, M. DeCross, A. Kar and O. Parrikar, “Binding Complexity and Multiparty Entanglement,” JHEP **1902**, 069 (2019) doi:10.1007/JHEP02(2019)069 [arXiv:1811.04085 [hep-th]].
93. V. Balasubramanian, N. Jokela, A. Pönni and A. V. Ramallo, “Information flows in strongly coupled ABJM theory,” JHEP **1901**, 232 (2019) doi:10.1007/JHEP01(2019)232 [arXiv:1811.09500 [hep-th]].
94. V. Balasubramanian and C. Rabideau, “The dual of non-extremal area: differential entropy in higher dimensions,” arXiv:1812.06985 [hep-th].
95. V. Balasubramanian, M. Decross, A. Kar and O. Parrikar, “Quantum Complexity of Time Evolution with Chaotic Hamiltonians,” JHEP **2001**, 134 (2020) doi:10.1007/JHEP01(2020)134 [arXiv:1905.05765 [hep-th]].
96. V. Balasubramanian, B. Craps, M. De Clerck and K. Nguyen, “Superluminal chaos after a quantum quench,” JHEP **1912**, 132 (2019) doi:10.1007/JHEP12(2019)132 [arXiv:1908.08955 [hep-th]].
97. V. Balasubramanian, A. Kar and G. Sárosi, “Holographic Probes of Inner Horizons,” arXiv:1911.12413 [hep-th].
98. V. Balasubramanian, A. Kar, O. Parrikar, G. Sárosi and T. Ugajin, “Geometric secret sharing in a model of Hawking radiation,” arXiv:2003.05448 [hep-th].

## PUBLICATIONS IN NEUROSCIENCE, BIOPHYSICS AND INFORMATION SCIENCE

All publications refereed unless indicated by \*\*

1. \*\* V. Balasubramanian. *Equivalence and Reduction of Hidden Markov Models*. MIT Artificial Intelligence Laboratory Technical Report No.1370, (87 pages) Jan. 1993.
2. V. Balasubramanian, F. Chen, D. Kimber and L. Wilcox. *Segmentation of Speech Using Speaker Identification*. In the proceedings of the 1994 International Conference on Acoustics, Speech and Signal Processing (ICASSP-94), pp. 161-164.
3. V. Balasubramanian, D. Kimber and J. Kupiec. *Speech-Based Information Retrieval Through Semantic Co-Occurrence Filtering*. In the proceedings of the 1994 ARPA Human Language Technology Workshop.
4. V. Balasubramanian. *Occam’s Razor for Parametric Families and Priors on The Space of Probability Distributions*. In the proceedings of The Fifteenth International Workshop on Maximum Entropy and Bayesian Methods, Aug. 1995.
5. \*\* V. Balasubramanian. *A Geometric Formulation of Occam’s Razor for Inference of Parametric Distributions*. Princeton preprint PUPT-1588 and <http://xyz.lanl.gov/adap-org/9601001>, Jan. 1996.
6. V. Balasubramanian. *Statistical Inference, Occam’s Razor and Statistical Mechanics on The Space of Probability Distributions*. Neural Computation 9(2):349-368, Feb. 1997 [cond-mat/9601030].
7. I. J. Myung, M. A. Pitt, S. Zhang and V. Balasubramanian. *The use of MDL to select among computational models of cognition*. In Advances in Neural Information Processing Systems 13:38-44, T.K. Leen, T.G. Dietterich and V. Tresp (eds.), MIT Press.
8. I.J. Myung, V. Balasubramanian and M.A. Pitt. *Counting Probability Distributions: Differential Geometry and Model Selection*. Proceedings of the National Academy of Science, Vol. 97, No. 21, pp. 11170–11175, 2000.
9. V. Balasubramanian, “MDL, Bayesian inference and the geometry of the space of probability distributions”, chapter in *Advances in Minimum Description Length: Theory and Applications*, P.D. Grünwald, I.J. Myung, and M.A. Pitt eds., pp. 81-99, MIT Press, Cambridge, MA, 2005.



10. V. Balasubramanian, M.J. Berry and D. Kimber. *Metabolically Efficient Information Processing*. Neural Computation, Vol. 13, No.4, pp. 799-816, April 2001.
11. V. Balasubramanian and M.J. Berry II. *Evidence for Metabolically Efficient Codes in the Retina*. Network 13(4):531-553, 2002 [arXiv:cond-mat/0105128].
12. K. Koch, J. McLean, M. Berry, P. Sterling, V. Balasubramanian, M.A. Freed, "Efficiency of Information Transmission by Retinal Ganglion Cells", Current Biology 14:1523-1530, 2004.
13. K. Koch, J. McLean, R. Segev, M.A. Freed, M.J. Berry, V. Balasubramanian, P. Sterling, "How *much* the eye tells the brain", Current Biology 16:1428-1434, 2006.
14. B. Borghuis, C. Ratliff, R.H. Smith, P. Sterling, and V. Balasubramanian, "Optimal design of a neuronal array", J. Neuroscience 28:3178-3189, 2008.
15. J. Perge, J. Miller, V. Balasubramanian, P. Sterling, "How the optic nerve allocates space, energy capacity and information", J. Neuroscience 29(24):7917-1928, 2009.
16. V. Balasubramanian and P. Sterling, "Receptive Fields and Functional Architecture in the Retina", J. Physiology 587(12):2753-2767 (2009).
17. P. Garrigan, C.P. Ratliff, J.M. Klein, P. Sterling, D.H. Brainard and V. Balasubramanian, "Design of trichromatic cone array", PLoS Comput Biol 6(2): e1000677, doi:10.1371/journal.pcbi.1000677, (2010).
18. G. Tkacik, J. Prentice, V. Balasubramanian, E. Schneidman, "Optimal population coding by noisy spiking neurons", PNAS 107(32):14419-14424, 2010. [*Equal contribution indicated between Balasubramanian and Schneidman*]
19. G. Tkacik, J. Prentice, J. Victor and V. Balasubramanian, "Local statistics in natural scenes predict the saliency of synthetic textures", PNAS 107(42):18149-18154, (2010)
20. C. Ratliff, Y.-H. Kao, P. Sterling, V. Balasubramanian, "Retinal ganglion cell arrays are structured to process the excess of dark information in natural scenes", PNAS 107(40):17368-17373, (2010).
21. J.S. Prentice, J. Homann, K. Simmons, G. Tkacik, V. Balasubramanian, P. Nelson, "Fast, scalable, Bayesian spike identification for multi-electrode arrays", PLoS ONE 6(7): e19884, (2011).
22. G. Tkacik, P. Garrigan, C. Ratliff, G. Milcinski, J.M. Klein, P. Sterling, D. Brainard, and V. Balasubramanian, "Natural images from the birthplace of the human eye," PLoS ONE 6(6): e20409 (2011).
23. J. Perge, J.E. Niven, E. Mugnaini, V. Balasubramanian, and P. Sterling, "Why do axons differ in caliber?", J. Neuroscience 32(2):626-638 (2012).
24. S. Trenholm, D.J. Schwab, V. Balasubramanian, G.B. Awatramani, "Lag-normalization in an electrically coupled neural network", Nature Neuroscience 16:154-156, 2013.
25. K.D. Simmons, J.S. Prentice, G. Tkacik, J. Homann, H.K. Yee, S.E. Palmer, P.C. Nelson, V. Balasubramanian. "Transformation of stimulus correlations by the retina", PLoS Computational Biology 9(12):e1003344, 2013.
26. A.M. Hermundstad, J.J. Briguglio, M.M. Conte, J.D. Victor\*, V. Balasubramanian\*, G. Tkacik\*, "Variance predicts salience central sensory processing". E-life:10.7554/eLife.03722, 2014. Equal contribution between Victor, Balasubramanian and Tkacik.
27. A. Mayer, V. Balasubramanian, T. Mora, A.M. Walczak, "How a well-adapted immune system is organized". PNAS 112(19): 5950-5955, 2015 and arXiv:1407.6888.
28. V. Balasubramanian. "Heterogeneity and Efficiency in the Brain." Proceedings of the IEEE 103(8):1346-1358, 2015
29. X. Wei, J.S. Prentice, V. Balasubramanian. "A principle of economy predicts the functional architecture of grid cells". eLife, 10.7554/eLife.08362, 2015 and arXiv:1304.0031.
30. A. Sanzeni, V. Balasubramanian\*, G. Tiana, and M. Vergassola. "Complete coverage of space favors modularity of the grid system in the brain." Physical Review E 94, no. 6 (2016): 062409. \* = corresponding author.
31. S. Bradde, M. Vucelja, T. Tesileanu, and V. Balasubramanian. "Dynamics of adaptive immunity against phage in bacterial populations." arXiv preprint arXiv:1510.06082 (2015), PLoS Comp. Bio. 13(4), e1005486, 2017.
32. T. Tesileanu, B. Ölveczky and V. Balasubramanian. "Rules and mechanisms for efficient two-stage learning in neural circuits", eLife 6:e20944, 2017.
33. J. Briguglio, J.J. Aizenberg, V. Balasubramanian, M.N. Geffen. "Cortical neural activity predicts sensory acuity under optogenetic stimulation", bioRxiv 119453; doi: <https://doi.org/10.1101/119453>, 2017, Journal of Neuroscience, 28(8):2094-2105, 2017

34. C. Glaze, A.L.S. Fillipowicz, J. Kable, V. Balasubramanian, and J.I. Gold. “A bias-variance tradeoff governs individual differences in online learning in an unpredictable environment”. *Nature Human Behavior*, 2:213-224, 2018.
35. A.T. Keinath, R.A. Epstein, and V. Balasubramanian. “Environmental deformations dynamically shift the grid cell spatial metric.” *eLife* 7 (2018): e38169.
36. T. Tesileanu, S. Cocco, R. Monasson, and V. Balasubramanian. “Adaptation of olfactory receptor abundances for efficient coding”. *bioRxiv* 255547; doi: <https://doi.org/10.1101/255547>. *Elife* 8 (2019): e39279.
37. V. Singh, N.R. Murphy, J. Mainland, and V. Balasubramanian. “Competitive binding predicts nonlinear responses of olfactory receptors to complex mixtures”. *bioRxiv* 311514; doi: <https://doi.org/10.1101/311514>. *PNAS* 116(19):9598-9603, 2019.
38. A. Mayer, V. Balasubramanian, T. Mora and A. Walczak. “How a well-adapting immune system remembers”. *bioRxiv* 347856; doi: <https://doi.org/10.1101/347856>. *PNAS* 116(18):8815-8823, 2019.
39. G. Tavoni, V. Balasubramanian, J.I. Gold. “What is optimal in optimal inference?” *Current Opinion in Behavioral Sciences*, 29, 117-126, 2019
40. L. Kang and V. Balasubramanian. “A geometric attractor mechanism for self-organization of entorhinal grid modules.” *eLife* 8, 2019.
41. S. Bradde, A. Nourmohammad, A., S. Goyal, and V. Balasubramanian. “The size of the immune repertoire of bacteria”. *Proceedings of the National Academy of Sciences*, 117(10), pp.5144-5151, 2020. Commentary on our paper in *PNAS* by Michael Deem, <https://doi.org/10.1073/pnas.2002746117>.
42. Bucher, B., de Mulatier, C., Singh, S., Daniilidis, K., Balasubramanian, V., “Curiosity increases equality in competitive resource allocation.” *Proceedings of the Bridging AI and Cognitive (BAICS) workshop in the International Conference on Learning Representations (ICLR)*, To appear.

#### **Publications in review**

43. E. Piasini, L. Soltuzu, R. Caramellino, V. Balasubramanian, D. Zoccolan. ”Intrinsic dynamics enhance temporal stability of stimulus representation along a visual cortical hierarchy”, *bioRxiv* 822130; doi: <https://doi.org/10.1101/822130>. Submitted.
44. G. Tavoni, T. Doi, C. Pizzica, V. Balasubramanian\*, J.I. Gold\*. “The complexity dividend: when sophisticated inference matters”. *bioRxiv* 563346; doi: <https://doi.org/10.1101/563346>. \* = Equal contribution. Submitted.
45. V. Singh, M. Tchernookov, V. Balasubramanian. “What the odor is not: Estimation by elimination”. *bioRxiv* 568626; doi: <https://doi.org/10.1101/568626>. Submitted.
46. R. Ditullio, E. Pollock, N. Desai, X. Wei, and V. Balasubramanian. “Dynamic self-organized error-correction of grid cells by border cells”. *bioRxiv* 385229; doi: <https://doi.org/10.1101/385229>
47. T. Tesileanu, M.M. Conte, J.J. Briguglio, A.M. Hermundstad, J.D. Victor, and V. Balasubramanian. “Sensitivity to grayscale textures is adapted to natural scene statistics”. *bioRxiv* 2019.12.11.872994