# Ishanu Chattopadhyay

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## APPOINTMENTS

2014-2015 Research Scientist, Computation Institute, University of Chicago, Chicago IL
2015-2016 Director of Quantitative Research, Guggenheim Partners, Liquid Strategies Division, NYC, NY
2016- Assistant Professor, Department of Medicine, University of Chicago, Chicago IL

## ACADEMIC TRAINING

| | |
|---|---|
| 1997-2001 | B.S., Mechanical Engineering, **Jadavpur University**, Kolkata, India |
| 2003-2005 | M.S., Mechanical Engineering, **The Pennsylvania State University**, State College, PA |
| 2004-2006 | M.A., Mathematics, **The Pennsylvania State University** |
| 2001-2006 | PhD. Mechanical Engineering, **The Pennsylvania State University**, State College, PA |
| 2006-2008 | Post Doctoral Fellow, Department of Mechical Engineering, **The Pennsylvania State University**, State College, PA |
| 2008-2011 | Research Associate, Department of Mechical Engineering, **The Pennsylvania State University**, State College, PA |
| 2011-2014 | Post Doctoral Fellow, Sibley School Of Mechanical & Aerospace Engineering, Department of Computer Science (Joint), **Cornell University**, Ithaca, NY |

## EXPERTISE & EXPERIENCE

- Extensive experience in machine learning, with emphasis on unsupersived learning, zero knowledge analysis, model-free and feature-free classification, non-parametric, non-linear modeling, classification, and prediction (See patents, publications, and contributions later).
- Experience with designing high capacity trading strategies targeting the futures market (not high frequency regime, average holding period ∼1 week)
- Experience in working with big data problems arising in healthcare analytics

## FUNDING

### Current

PROJECT: **Defense Advanced Research Projects Agency** , *Big Mechanisms*, (August 2014 to -) • ROLE: (Key Research Scientist)

### Pending

PROJECT: #DARPA-16-43 **Defense Advanced Research Projects Agency** , *ZeD: Zero-Knowledge Discovery Using Data Smashing*, (August 2016 to 2019, $3.2M) • ROLE: (**Principal Investigator**)

PROJECT: **ARmy Research Office, Mathematical Biology Program** , *Reverse-engineering The Connectome Via Zero-Knowledge Non-linear Non-parametric Discovery*, (August 2016 to 2019, $600K) • ROLE: (**Principal Investigator**)

**Past**

PROJECT: #W911NF-12-1-0499 **Army Research Office** (PM: Dr. V. Passour), *Mathematical Biology*, (August 2012 to 2015, $300K) • ROLE: (**Co-Principal Investigator**)

PROJECT: #HDTRA 1-09-1-0013 **Defense Threat Reduction Agency** , *Minimal Models For Abiotic Signaling Networks*, (August 2011 to 2014, $400K) • ROLE: (**Co-Principal Investigator**)

PROJECT: #W911NF-12-1-0499 **Army Research Office** (PM: Dr. V. Passour), *Mathematical Biology*, (August 2012 to 2015, $300K) • ROLE: (**Co-Principal Investigator**)

PROJECT: #ECCS 0941561 **National Science Foundation** , *Cyber-enabled Discovery & Innovation*, (September 2011 to 2012) • ROLE: (Key Researcher)

PROJECT: #N00014-09-1-06888 **Office of Naval Research** (PM: Dr. M. Steinberg), *Science of Autonomy*, (July 2009 to 2011) • ROLE: (Key Author, Key Researcher, Laboratory Director)

PROJECT: #N00014-08-1-380 **Office of Naval Research** (PM: Dr. M. Traweek), *Multi-objective Optimization for Control of Tactical Military Missions*, (February 2008 to 2011) • ROLE: (Key Author, Key Researcher, Laboratory Director)

PROJECT: MURI 2007 #W911NF-07-1-0376 **Army Research Office** MURI (PM: Dr. L. Dai), *Fusion Driven Urban Sensor Networks* (September 2007 to 2011) • ROLE: (Key Author, Key Researcher, Laboratory Director)

PROJECT: #W911NF-06-1-046 **Army Research Office** (PM: Dr. C. Arney), *Language-theoretic Control of Mobile Robots*, (September 2006 to September 2007, $450K) • ROLE: (**Co-Principal Investigator)**

PROJECT: MURI 2001 #DAAD19-01-1-0646, **Army Research Office** (PM: Dr H. Chang), *Mathematics of Complex Systems Failure*, (August 2001 to August 2006) • ROLE: (Graduate Student)

## SELECTED CONTRIBUTIONS & BREAKTHROUGHS IN DIFFERENT FIELDS

○ **Systems Biology**

- Developed an **inverse Gillespie algorithm** `iGillespie`, which reverse-engineers intermittent measurements of population counts, species concentrations, or gene expression intensities to infer stochastic mechanisms in chemical, biological & ecological systems (PNAS paper)

○ **Machine Learning & Data Science**

- Developed algorithm `GenESeSS` for **unsupervised inference of deep causal structures** from quantized data streams, showing that any ergodic stationary quantized stochastic process may be PAC-efficiently learned (Roy. Soc. Phil. Trans. A paper)
- Developed a rigorous notion of **universal similarity** between data streams, which may be computed without knowing how and where the data is generated.
- Developed notion of "anti-streams", which capture rigorously the notion of "inverted statistical structure" with respect to a given data stream
- Developed the **theory of Data Smashing**, showing that universal similarity between two data streams may be estimated by computing the anti-stream of one, adding to the other, and checking if the result is flat white noise (Roy. Soc. Interface paper)

○ **Probabilistic Robotics**

- Proposed the formal-language-theoretic $\nu^\star$ **path planning algorithm** for mobile robots that was shown to outperform the state of the art in computational complexity and plan robustness.

○ **Swarms & Self-organization**

- Developed **broadcast-based control algorithm for swarms** of unbounded size using ergodic projections of Markov chains
- Developed algorithm GODDeS: a fundamentally new, highly efficient **probabilistic routing algorithms** for ad-hoc wireless environments using distributed optimal supervision of probabilistic automata (SIAM Jnl of Control & Opt. paper)

○ **Optimal Control & Autonomous Decision-making**

- Developed the theory of rigorous **measures of probabilistic formal languages**
- Used the language-measure-theoretic approach to finite state stochastic optimization problems to establish a **search-free highly efficient alternative to dynamic programming** in a broad class of problems
- Achieved fundamental theoretical breakthroughs in **optimal control of partially observable decision processes** via modeling decision processes as probabilistic regular languages
- Achieved fundamental theoretical breakthroughs in deriving polynomial time computable $\epsilon$**-optimal solutions to decentralized Markov decision processes**

## HONORS, PRIZES AND AWARDS

- Best Paper In Session *"Learning-Control"* American Control Conference 2010
  - I. Chattopadhyay, Y. Wen and A. Ray, *Pattern Classification In Symbolic Streams Via Semantic Annihilation of Information*, American Control Conference, 2010, Baltimore, MD, June 30-July 2

  (Official list of best session paper award recipients at ACC 2009 can be publicly viewed online at: http://www.a2c2.org/conferences/acc2010/SessionBest.html)
- Best Paper In Session *"Path-Planning"* American Control Conference 2009
  - I. Chattopadhyay and A. Ray, *Optimal Path-Planning under Finite Memory Obstacle Dynamics Based on Probabilistic Finite State Automata Models*, American Control Conference 2009
- Best Paper In Session *"Large Scale Systems"* American Control Conference 2009
  - I. Chattopadhyay and A. Ray, *Supervised Self-Organization of Large Homogeneous Swarms Using Ergodic Projections of Markov Chains*, American Control Conference 2009
- Best Paper In Session *"Agent Based Systems II"* American Control Conference 2009
  - W. Lu, I. Chattopadhyay, G. Mallapragada and A. Ray, *A Real Time Implementable All-Pair Dynamic Planning Algorithm for Robot Navigation Based on the Renormalized Measure of Probabilistic Regular Languages*, American Control Conference 2009

  (Official list of best session paper award recipients at ACC 2009 can be publicly viewed online at: http://a2c2.org/conferences/acc2009/BestPresentationAwards2_061209am.pdf)
- Paper Chosen as Sole Editorial Pick in IEEE Control Systems Society Discrete Event Systems Technical Committee (DESTC) Newsletter (August 2008) The newsletter can be viewed online at: http://www.cas.mcmaster.ca/destc/nl/nl_aug08.php#jrnl
  - I. Chattopadhyay and A. Ray, *Generalized projections in finite state automata & decidability of state determinacy*, Int. J. Control **81** (2008), no. 10, 1626–1644.

## TEACHING

- Served on the Doctoral Dissertation Committee for *Yicheng Wen* (Graduation: 2011)
  - Dissertation Topic: *Information Space Modeling & Design In Large Scale Sensor Networks* (M.E.)
- Served on the Doctoral Dissertation Committee for *Dr. Goutham Mallapragada* (Graduation: August 2009)
  - Dissertation Title: *A language-theoretic framework for decision & control of autonomous systems* (M.E.)
- Served on the Masters Committee for *Anthony Cascone* (Graduation: 2010)
  - Topic: *Formal Language-theoretic Control Algorithms for Large Scale Systems* (M.E.)
- Served on the Masters Committee for *Wei Lu* (Graduation: May 2009)
  - Topic: *Real Time All Pair Dynamic Path Planning Using* $\nu^\star$ (M.E.)
- Mentoring Undergraduate/Graduate Students Interested in Robotics
  - Young Bum (Senior Year Project, Mechanical Engineering, Cornell University)
  - Amit K. Patel (Masters Student, Mechanical Engineering, Penn State)
  - Jeremy G. Bridon (Senior, Computer Science & Engineering, Penn State)

## ACADEMIC SERVICE

- Chaired session entitled *"Disease Modeling and Control"*, June 30, 2010, at the American Control Conference, 2010.
- Co-chaired session in American Control Conference 2004 Boston Massachusetts June 29-July 3
- Co-chaired session in American Control Conference 2009 St. Louis Missouri June 10 - 12

## Dissertation Topics

- I. Chattopadhyay, "*Quantitative Control of Probabilistic Discrete Event Systems: A Formal Measure-theoretic Approach*", PhD Dissertation, Dept. of Mech. Engg. Pennsylvania State University, http:// etda.libraries.psu.edu / theses / approved / WorldWideIndex / ETD-1443 (August 2006).
- I. Chattopadhyay, "*Decidability Of Monadic Second Order Theory Of Two Successors*", Masters Paper for M.A. (Mathematics) submitted to the Department of Mathematics, The Pennsylvania State University (March 2006)

## Invited Speaking

- *Mining for Causality*, CSE Seminar Series, The Department of Computer Science and Engineering at the University of Notre Dame, https://cse.nd.edu/seminars/cse-seminar-series-ishanu-chattopadhyay-1
- *Deep Text-Mining for Cancer and Disease*, Inside The Discovery Cloud Speaker Series 2014-15, May 20 2015 https://ci.uchicago.edu/events/deep-text-mining-cancer-and-disease
- *Automating Science: Anti-streams, Universal Similarity and Statistical Causality*, Argonne National Laboratory, Chicago, May 4 2015. http://www.anl.gov/events/automating-science-anti-streams-universal-similarity-and-statistical-causality
- *Automating Scientific Discovery: Anti-streams, Universal Causality & Statistical Causality*, Santa Fe Institute, Santa Fe, April 2 2015. http://www.santafe.edu/gevent/detail/science/2057/
- *Causality Streamlines: Uncovering Disease Etiology From Zero-knowledge Machine Inference of Statistical Causality*, Center for Nonlinear Studies, Los Alamos National Laboratory, April 1 2015 http://cnls.lanl.gov/External/showtalksummary.php?selection=6256
- *Automating Scientific Discovery: From Machine Learning To Machine Science*, Natural History Seminar, Department of Ecology and Evolution, University of Chicago, October 28 2014
- *Data Smashing: Universal Similarity To Computational Causality In Complex Systems*, Center for Nonlinear Studies, Los Alamos National Laboratory, June 5 2014
- *Search For Causal Spatio-temporal Structure In Global Seismicity - Reverse-Engineering History To Predict The Future*, Center for Nonlinear Studies, Los Alamos National Laboratory, June 6 2014
- *Inverse Gillespie Methods for Stochastic Inference*, Department of Mathematics, Rutgers University, Oct 16, 2013
- *Data smashing: Finding causal similarity in natural data sets*, Workshop: Natural Algorithms and the Sciences, Center for Computational Intractability, Princeton University, May 21, 2013
- *Information Annihilation for Feature-free Classification*, AI Seminar, Department of Computer Science, Cornell University, Feb 8, 2013
- *Semantic Cross-compression: A Formal Linguistic Approach To Evolutionary Machine Sentience*, September 2010, Invited Lecture, Department of Mechanical & Aerospace Engineering, Creative Machines Laboratory, Cornell University
- *A Cyber-physical Paradigm For Situation Aware Decision Adaptation*, March 2010, Invited Lecture, University at Buffalo, State University Of New York
- *A Cyber-physical Paradigm For Robust Intelligence*, March 2010, Invited Lecture, University Of Alabama, Huntsville
- *Autonomous Navigation in Space*, Infotech @Aero-space, AIAA 5th Aviation, Technology, Integration and Operations Conference, Arlington, Virginia, September 26-29, 2005
- Invited Speaker at Association for Computing Machinery (ACM) Penn State Chapter, *Rise of The machines: Toasters to Autonomous Robotics*, 18 September, 2007

## Patents

- □ 6259-01-US Stochastic Automata for Earthquake Prediction from Large Scale Surveys
- □ 6259-02-PC Systems and Methods for Abductive Learning of Quantized Stochastic Process
- □ 6024-03-PC System and Methods for Analysis of Data PCT/US13/62397
- □ 6998-01-US Causality Network Construction Algorithm (Application no. 62170063, EFS ID 2517508)

## SCHOLARSHIP

### Published Journal Papers

1) I. Chattopadhyay and H. Lipson, "Data Smashing: Uncovering Lurking Order In Data" *Jnl. of Royal Society: Interface*, 2014 11:101 http://dx.doi.org/10.1098/rsif.2014.0826

2) I. Chattopadhyay, *Scalable $\epsilon$-Optimal Decision-making and Stochastic Routing In Large Networks Via Distributed Supervision of Probabilistic Automata*, SIAM Journal of Control & Optimization, SIAM Journal on Control and Optimization 2014 52:4, 2512-2547)

3) I. Chattopadhyay, A. Kuchina, G. Suel and H. Lipson , *Inverse Gillespie for inferring stochastic reaction mechanisms from intermittent samples*, Proceedings of the National Academy of Sciences, USA, **110** (32), July 2013, pp 12990-5.

4) I. Chattopadhyay and H. Lipson, *Abductive Learning of Quantized Stochastic Processes Using Probabilistic Automata*, Philosophical Transactions A of the Royal Society, **371** (1984), Feb 2013, pp 20110543.

5) I. Chattopadhyay and A. Ray, *Measure-theoretic Optimal Control of Infinite Horizon Partially Observable Decision Processes Modeled as Generators of Probabilistic Regular Languages*, Int. J. Control, **83**, No. 3, March 2010, pp 457–483.

6) I. Chattopadhyay and A. Ray, *Supervised self-organization of homogeneous swarms using projections of Markov chains*, IEEE Transactions on Systems, Man, and Cybernetics, Part B (2009), **39**, No. 6, 2009, pp 1505–1515.

7) G. Mallapragada, I. Chattopadhyay, and A. Ray, *Autonomous robot navigation using optimal control of probabilistic regular languages*, Int. J. Control **82** (2009), no. 1, 13–26.
(First author was closely guided by me as a member of his Doctoral Dissertation Committee)

8) I. Chattopadhyay, G. Mallapragada, and A. Ray, *$\nu^\star$: A robot path planning algorithm based on renormalized measure of probabilistic regular languages*, Int. J. Control **82** (2009), no. 5, 849–867.

9) I. Chattopadhyay and A. Ray, *Generalized projections in finite state automata & decidability of state determinacy*, Int. J. Control **81** (2008), no. 10, 1626–1644.

10) I. Chattopadhyay and A. Ray, *Structural transformations of probabilistic finite state machines*, Int. J. Control **81** (2008), no. 5, 820–835.

11) G. Mallapragada, I. Chattopadhyay, and A. Ray, *Automated behavior recognition in mobile robots using symbolic dynamic filtering*, Proceedings of the I Mech E Part I: Journal of Systems & Control Engineering **222** (2008), no. 6, 409–424.
(First author was closely guided by me as a member of his Doctoral Dissertation Committee)

12) I. Chattopadhyay and A. Ray, *Language-measure-theoretic optimal control of probabilistic finite-state systems*, Int. J. Control **80** (2007), no. 8, 1271–1290.

13) I. Chattopadhyay and A. Ray, *Generalized language measure for finite state logical systems*, Int. J. Control **80** (2007), no. 5, 789–799.

14) I. Chattopadhyay and A. Ray, *Renormalized measure of regular languages*, Int. J. Control **79** (2006), no. 9, 1107–1117.

15) I. Chattopadhyay and A. Ray, *A language measure for partially observed discrete event systems*, Int. J. Control **79** (2006), no. 9, 1074–1086.

16) I. Chattopadhyay and A. Ray, *A complex measure for linear grammars*, Demonstratio Mathematica **38** (2005), no. 3, 761–775.

### Book Chapter

- I. Chattopadhyay, X. Wang and A. Ray, *Advanced topics in Supervisory Control Theory, Chapter 4: Quantitative Measure for Discrete Event Supervisory Control: Theory and Applications*, Springer 2005, ISBN 0387021086

**Refereed Conference Publications**

1) I. Chattopadhyay and H. Lipson, *Distilling Evidence of Long-Range Direction-Specific Causal Cross-Talk in Molecular Evolution of Retro-Viral Genomes*, Discovery Informatics Workshop at the Twenty-Eighth AAAI Conference on Artificial Intelligence, Quebec City, Quebec, July 2014
2) I. Chattopadhyay and H. Lipson, *Computing Entropy Rate Of Symbol Sources & A Distribution-free Limit Theorem*, 48th Annual Conference of Information Science and Systems (CISS 2014), Princeton University, March 2014
3) I. Chattopadhyay, A. Kuchina, G. Suel and H. Lipson, *Inverse Gillespie: Inference of Stochastic Mechanisms*, International Conference of Computational Cell Biology, Virgina Bioinformatics Institute, Blacksburg, Virginia, August 2013
4) I. Chattopadhyay and H. Lipson, *De novo Inference of Stochastic Mechanisms*, q-bio 2013, Santa Fe, NM, August 2013
5) I. Chattopadhyay , *Scalable $\epsilon$-optimal Control Of Engineered Swarms Using Probabilistic Automata*, American Control Conference 2012, Montreal, Canada, June 27-June 29, 2012
6) I. Chattopadhyay, and A. Ray, *Scalable $\epsilon$-optimal Control Of Engineered Swarms Using Probabilistic Automata*, American Control Conference 2012, Montreal, Canada, June 27-June 29, 2012
7) A. Srivastav, Y. Wen, E. Hendrick, I. Chattopadhyay, A. Ray and S. Phoha , *Information Fusion for Object & Situation Assessment in Sensor Networks*, American Control Conference 2011, San Francisco, CA, June 29-July 01, 2011
8) Y. Wen, I. Chattopadhyay, A. Ray and S. Phoha , *Hilbert Space Formulation of Symbolic Systems for Model Identification and Order Reduction*, American Control Conference 2011, San Francisco, CA, June 29-July 01, 2011
9) Y. Wen, I. Chattopadhyay, A. Ray and S. Phoha , *Vector Space Formulation of Probabilistic Finite State Automata*, American Control Conference 2011, San Francisco, CA, June 29-July 01, 2011
10) I. Chattopadhyay, Y. Wen and A. Ray, *Unsupervised Inductive Learning In Symbolic Sequences via Recursive Identification of Self-Similar Semantics*, American Control Conference 2011, San Francisco, CA, June 29-July 01, 2011
11) I. Chattopadhyay and A. Ray, *GODDeS: Globally $\epsilon$-Optimal Routing Via Distributed Decision-theoretic Self-organization*, American Control Conference 2011, San Francisco, CA, June 29-July 01, 2011
12) I. Chattopadhyay, Y. Wen, S. Phoha and A. Ray, *Mathematical foundations of sensor network design based on linguistic informatics*, American Control Conference, 2010, Baltimore, MD, June 30-July 2
13) I. Chattopadhyay and S. Mohinta, *A Decision-theoretic Model Of Selection Modulated Intra-host Antigenic Variation For Multi-strain Pathogens*, American Control Conference, 2010, Baltimore, MD, June 30-July 2
14) I. Chattopadhyay, Y. Wen and A. Ray, *Pattern Classification In Symbolic Streams Via Semantic Annihilation of Information*, American Control Conference, 2010, Baltimore, MD, June 30-July 2
15) K. Mukherjee, A. Ray, T. Wettergreen, I. Chattopadhyay and S. Phoha, *Signal Threshold Estimation in a Sensor Field for Undersea Target Tracking*, American Control Conference 2009, St. Louis Missouri June 10 - 12.
16) W. Lu, I. Chattopadhyay, G. Mallapragada and A. Ray, *A Real Time Implementable All-Pair Dynamic Planning Algorithm for Robot Navigation Based on the Renormalized Measure of Probabilistic Regular Languages*, American Control Conference 2009, St. Louis Missouri June 10 - 12.
(First author was closely guided by me as a member of his Masters Committee)
17) I. Chattopadhyay and A. Ray, *Supervised Self-Organization of Large Homogeneous Swarms Using Ergodic Projections of Markov Chains*, American Control Conference 2009, St. Louis Missouri June 10 - 12.
18) I. Chattopadhyay and A. Ray, *Generalization of $\nu^*$-Path Planning for Accommodation of Amortized Dynamic Uncertainties in Plan Execution*, American Control Conference 2009, St. Louis Missouri June 10 - 12.
19) I. Chattopadhyay and A. Ray, *Optimal Path-Planning under Finite Memory Obstacle Dynamics Based on Probabilistic Finite State Automata Models*, American Control Conference 2008, Seattle Washington June 11 - 13.
20) I. Chattopadhyay, G. Mallapragada and A. Ray, *A Measure-theoretic Path Planning Algorithm for Mobile Robots*, American Control Conference 2008, Seattle Washington June 11 - 13.
21) I. Chattopadhyay and A. Ray, *Language-measure-theoretic Optimal Control of Probabilistic Finite State Systems*, 46th IEEE Conference on Decision & control, New Orleans LA, December 12-14, 2007.
22) I. Chattopadhyay and A. Ray, *Generalized Unobservability Maps in DES*, American Control Conference 2007, New York NY July 11 - 13.
23) G. Mallapragada, I. Chattopadhyay and A. Ray, *Autonomous Navigation in Mobile Robotic Platforms using Formal Language Measures*, 45th IEEE Conference on Decision & control, San Diego CA, December 13-15, 2006.
24) I. Chattopadhyay and A. Ray, *Generalized Formal Measure Families in Finite State Logical Systems*, 8th International Workshop on Discrete Event Systems (WODES) 2006, Ann Arbor, Michigan, July 9-10
25) I. Chattopadhyay and A. Ray, *Renormalized Measure of Regular Languages*, 8th International Workshop on Discrete Event Systems (WODES) 2006, Ann Arbor, Michigan, July 9-10

26) I. Chattopadhyay, Subhadeep Chakraborty and A. Ray, *Autonomous Navigation in Space*, Infotech @Aero-space, AIAA 5th Aviation, Technology, Integration and Operations Conference, Arlington, Virginia, September 26-29, 2005

27) X. Wang, I. Chattopadhyay and A. Ray, *Probabilistic Fault Diagnosis in Discrete Event Systems*, Proceedings of the 43rd IEEE Conference on Decision & Control, December 14-17, 2004, Atlantis, Paradise Island, Bahamas, pp 45 - 50

28) I. Chattopadhyay and A. Ray, *A language measure for partially observable discrete event systems*, Proceedings of the 43rd IEEE Conference on Decision & Control, December 14-17, 2004, Atlantis, Paradise Island, Bahamas, pp 4794-4799

29) I. Chattopadhyay, X. Wang and A. Ray, *A complex measure for non-regular languages for Discrete-event Supervisory Control*, Proceedings of the American Control Conference, Boston, Massachusetts, June 30-July 2, 2004, pp 5120-5125

30) D. Friedlander, I. Chattopadhyay, A. Ray. S. Phoha. N. Jacobson, *Anomaly prediction in mechanical systems using symbolic dynamics*, Proceedings of the American Control Conference, Denver, Colorado, June 4-6, 2003, pp 4275 - 4280