BIOGRAPHICAL SKETCH

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NAME: Moses, Melanie Elizabeth

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POSITION TITLE: Associate Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Stanford University	B.S.	03/93	Symbolic Systems (focus: agent based models)
University of New Mexico	Ph.D.	08/05	Biology
University of New Mexico	postdoctoral	08/06	Computer Science/Biology

A. Personal Statement

My research is situated at the intersection of biology and computer science, including agent-based modeling the immune system; mathematical models of animal growth, reproduction, and life history tradeoffs; and theory to explain how decentralized information exchange leads to efficient and robust search strategies in the adaptive immune system, ant colonies and other complex systems. My over 50 publications are highly interdisciplinary, and appear in high-impact journals including *Science*, *Nature*, *Proceedings of the National Academy of Sciences*, and *Journal of the Royal Society Interface*, as well as in more specialized computational venues focused on emergence and complexity. My diverse funding portfolio, including PI and co-PI funding, has totaled over $10 Million over the past 8 years.

My research in computational immunology includes computational and mathematical models of within-host viral spread of West Nile Virus and influenza, models of ovarian tumor vascularization, and most recently focuses on the effect of T cell motility on the timing and effectiveness of adaptive immune response. In a collaborative effort through the NIH-funded UNM Spatio-Temporal Modeling Center (STMC) we image T cells in lymph nodes to understand the basic mechanisms that drive how T cells move during the initiation and activation phases of adaptive immune response. Using two-photon microscopy, we have shown that T cell movements are not Brownian, but include rare but important periods of movement in a persistent direction and response to environmental cues. Our models demonstrate that such movement increases encounter rates with dendritic cells in the lymph node, balancing the extent and thoroughness of search better than idealized Brownian or Levy movement. We are working to understand how T cell response to chemokines and structural features of the lymph node influence motility and encounter rates; work in press extends this analysis to understand effector T cells in the lung.

I have extensive experience mentoring and teaching graduate and undergraduate students in interdisciplinary settings. I co-directed the NIH-funded UNM graduate training Program in Interdisciplinary Biological and Biomedical Sciences (PiBBs) from 2013 - 2015 and co-chaired the 2012 Gordon Research Conference on the Metabolic Basis of Ecology. My research lab includes 16 students and post docs with expertise in mathematics, computer science, immunology and behavioral ecology. I have graduated 2 Biology PhD students, 3 CS PhD students and mentored two students through simultaneous Ph.D. degrees in Biology and Masters degrees in CS. My approach to integrating computational, mathematical and experimental biological techniques has developed through long-standing collaborations at the Santa Fe Institute, a global leader in the study of complex systems and interdisciplinary science. I am the PI of the NASA Swarmathon (http://NasaSwarmathon.com) which has engaged 1100 undergraduates from 36 schools in a swarm robotics programming challenge, and I recently became the PI of the NM CSforAll program (http://cs4all.cs.unm.edu/) which has taught 60 high school teachers and 1000 high school students introductory computer programming and scientific modeling. My teaching and service reflect my interdisciplinary approach which inspires participation in science and engineering by a diverse group of students.

B. Positions and Honors

Positions and Employment

2007 to 2013, Assistant Professor, Department of Computer Science, University of New Mexico
2012 to present, External Faculty, Santa Fe Institute
2013 to April 2018, Associate Professor, Department of Computer Science, University of New Mexico
Joint Appointment, Department of Biology, University of New Mexico
April 2018 to Present, Professor, Department of Computer Science, University of New Mexico
Joint Appointment, Department of Biology, University of New Mexico

Other Experience

2010 to 2013 Advisory Council, UNM T32 Program in Biological and Biomedical Sciences (PiBBS)
2013 to 2015, Co-Director UNM T32 Program in Biological and Biomedical Sciences (PiBBS)

Honors

2004-2005 Ford Foundation Dissertation Fellow
2008 New Mexico Academy of Science Annual Distinguished Lecturer
2008 Microsoft New Faculty Fellowship Finalist
2010 University of New Mexico Faculty of Color Research Award
2011 University of New Mexico Outstanding New Teacher of the Year
2012 UNM School of Engineering Junior Research Excellence Award
2013 UNM School of Engineering Junior Teaching Excellence Award

C. Contributions to Science

My research develops theoretical understanding of search in complex systems, and specific applications that model T cell motility and cancer immunotherapy. My highly interdisciplinary research uses computational models to understand biological complexity, and biological approaches to design scalable and adaptable computer systems. My research focuses on understanding how cooperative behavior emerges in complex systems and how systems change systematically with size and scale. I model how T cells interact with environmental features and signals in the lymph nodes and lungs in order to find cognate antigen, and how animals interact with each other and features of their external environment in order to find food resources. The insights from lab studies of my collaborators, field studies and computer models have led to swarm robotics systems that embody the search principles we understand from biology to search for targets in the physical world. We study these three systems to understand how cooperative search emerges at different scales, in different environments, and with different levels of experimental control and analytical precision. Our simulations test how sensing, navigation and communication behaviors affect collective search success as individuals interact with each other and with complex environments. These contributions are described below, student advisees are designated with an *. A complete list of my 50 publications is available at https://scholar.google.com/citations?user=WFZ4azsAAAAJ&hl=en.

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1. Scaling principles for growth, development and immune response. In this work, I have developed mathematical theory explaining systematic changes in physiological rates, life history patterns and immune response across animal body size. My work provides a theoretical explanation for nearly all biological rates are slower in larger animals. It also demonstrates that immune response is an exception to this pattern, with nearly scale-invariant adaptive immune response times.

Tasnim, H., Fricke, G. M., Byrum, J. R., Sotiris, J. O., Cannon, J. L., & Moses, M. E., Quantitative Measurement of naïve T cell association With Dendritic cells, Frcs, and Blood Vessels in lymph nodes. Frontiers in immunology. 9, 2018. doi.org/10.3389/fimmu.2018.01571.

M. Moses, G. Bezerra, B. Edwards, J. Brown, and S. Forrest, "Energy and time determine scaling in biological and computer designs," *Phil. Trans. R. Soc. B*, vol. 371, no. 1701, p. 20150446, 2016.

Moses, M.E., C. Hou, W.H. Woodruff, G.B. West, J.C. Nekola, W. Zuo, and J.H. Brown (2008). "Revisiting a Model of Ontogenetic Growth: Estimating Model Parameters from Theory and Data." *The American Naturalist* 171(5):632-645.

Banavar, J.R., M.E. Moses, J.H. Brown, J. Damuth, A. Rinaldo, R.M. Sibly and A. Maritan (2010). "A general basis for quarter power scaling in animals." *Proceedings of the National Academy of Sciences* 107(36): 15816-158120.

*Banerjee, S., and M. E. Moses (2009). "A hybrid agent based and differential equation model of body size effects on pathogen replication and immune system response." In *Artificial Immune Systems*, pp. 14-18. Springer Berlin Heidelberg.

Hou, C, W. Zuo, M. E. Moses, J.H. Brown and G. B. West (2008). "Energy Uptake and Allocation During Ontogeny." *Science* 332(5902):736-739.

Cable, J.M., B.J. Enquist and M.E. Moses (2007). "The Allometry of Host-Pathogen Interactions." *PLoS ONE* 2(11): e1130.

2. Computational models demonstrate how movement and signaling among immune cells affects adaptive response times, pathogen detection and immunotherapy outcomes. In published and ongoing work, we use statistical and agent based models to quantify how T cells move as they are trafficked through the cardiovascular and lymphatic networks, within lymph nodes (LN) and in the lung. We show that empirical movement patterns of T cells in LN balance detection of unique dendritic cells and resampling of known dendritic cells (and antigen) better than any mathematically idealized model previously proposed. Our work suggests that T cell movement is finely tuned to the LN environment and adapts to environmental cues within the LN to search more thoroughly in specific regions. Ongoing collaborations with experimental collaborators is investigating the hypotheses generated by our computational models. We use a similar agent based and mathematical framework to model the movement of therapeutic antibodies in ovarian cancer treatment to demonstrate the effect of different tumor sizes and microenvironments on treatment efficacy.

P. Mrass*, S. Oruganti, G. M. Fricke*, J. Tafoya*, J. Byrum, L. Yang, S. Hamilton, M. Miller, M. Moses, and J. Cannon., "Rock regulates the intermittent mode of interstitial t cell migration in inflamed lungs," Nature Communications. in press, 2017.

S. Banerjee*, J. Guedj, R. M. Ribeiro, M. Moses, and A. S. Perelson, "Estimating biologically relevant parameters under uncertainty for experimental within-host murine west nile virus infection," Journal of The Royal Society Interface, vol. 13, no. 117, p. 20160130, 2016.

G. M. Fricke*, K. A. Letendre*, M. E. Moses, and J. L. Cannon, "Persistence and adaptation in immunity: T cells balance the extent and thoroughness of search," PLoS Comput Biol, vol. 12, no. 3, p. e1004818, 2016.

*Winner, Kimberly Kanigel, Steinkamp, Mara P, Lee, Rebecca J, Swat, Maciej, Muller, Carolyn Y, Moses, Melanie E, Jiang, Yi & Wilson, Bridget S (2015). Spatial modeling of drug delivery routes for treatment of disseminated ovarian cancer. Cancer Research 1620. doi:10.1158/0008-5472.CAN-15-1620.

*Letendre, K, F. Donnadieu, E., Moses, M.E. and Cannon, J.L. (2015). "Bringing Statistics Up To Speed With Data in Analysis of Lymphocyte Motility" PLoS ONE 10 (25): e0126333.

*Fricke, G. Matthew, *Kenneth A. Letendre, Melanie E. Moses, and Judy L. Cannon (2016) "Persistence and adaptation in immunity: T cells balance the extent and thoroughness of search" PLoS Computational Biology: 12.3 (2016): e1004818.

*Fricke, M., *S.R. Black, *J. P. Hecker, *J. L. Cannon & M. E. Moses (2015). "Distinguishing Adaptive Search from Random Search in Robots and Immune Systems." Proceedings of the 2015 on Genetic and Evolutionary Computation Conference: 105 – 112.

Steinkamp MP, *Winner KK, Davies S, Muller C, Zhang Y, Hoffman RM, Shirinifard A, Moses ME, Jiang Y, and Wilson BS. (2013).Ovarian tumor attachment, invasion, and vascularization reflect unique microenvironments in the peritoneum: insights from xenograft and mathematical models. Frontiers in oncology 3.

*Banerjee, *S., Levin, D., Moses, M., Koster, F., & Forrest, S. (2011). "The value of inflammatory signals in adaptive immune responses." In Artificial Immune Systems (pp. 1-14). Springer Berlin Heidelberg. 2011.

4. Models demonstrate how efficient search emerges in ant colonies and other complex systems. Effective immune response requires coordinated interactions between billions of immune cells with no central point of control. Similarly and the behavior of ant colonies emerges from distributed communication between millions of ants. Our research examines how ant colonies and immune systems form distributed information exchange networks to search, adapt and respond to their environments. Our computer models and field studies of ant foraging reveal how emergent behavior arises from interactions among how ants move and communicate in different environments. Models developed to understand distributed search in ant colonies are the foundation for models of both T cell and robotic movement.

*Letendre, K., & Moses, M. E. (2013). Synergy in ant foraging strategies: memory and communication alone and in combination. In *Proceedings of the fifteenth annual conference on Genetic and evolutionary computation conf.* (pp. 41-48).

Flanagan, T., K. Letendre, W. Burnside*, G. Fricke* and M. E. Moses (2012). "Quantifying the effect of colony size and food distribution on harvester ant foraging." *PLoS ONE* 7(7), e39427.

*Flanagan TP, Pinter-Wollman NM, Moses ME, Gordon DM. (2013). Fast and flexible: Argentine ants recruit from nearby trails. *PloS one* 8(8):e70888.

5. Biologically Inspired Robotics. The mathematical and computational models of immune cells and foraging ants above suggest how effective search strategies can emerge in complex distributed systems. To test the efficacy of the search strategies, we go beyond simulation to test how search is influenced by environments in physically embodied robots. The iAnts that we designed and built implement elements of search strategies that we understand from the movement, signaling and environmental interactions of T cells and ants. The physical robots have revealed that in addition to being efficient search strategies, T cell and ant inspired movement and communication are also error-tolerant, flexible, and scalable. This work forms the foundation for the NASA-sponsored national Swarmathon competition which encourages students to build upon these algorithms for space exploration.

G. M. Fricke*, J. P. Hecker*, J. L. Cannon, and M. E. Moses, "Immune-inspired search strategies for robot swarms," Robotica, vol. 34, no. 08, pp. 1791–1810, 2016.

*Hecker, J. P., and M E. Moses (2015)."Beyond pheromones: evolving error-tolerant, flexible, and scalable ant-inspired robot swarms." *Swarm Intelligence*: 1-28.

*Fricke, M, J. L. Cannon and M.E. Moses (2016). "Immunological Search Strategies Applied to a Robot Swarm." *Robotica* (accepted pending revisions).

Hecker, J. P., K. Letendre, K. Stolleis*, D. Washington* and M. E. Moses (2012).. "Formica ex Machina: Ant Swarm Foraging From Physical to Virtual and Back Again." Proceedings of the Eighth International Conference on Swarm Intelligence, Brussels in *Lecture Notes in Computer Science*: 7461.

*Hecker J, *Stolleis K, *Swenson B, *Letendre K, Moses M. (2013). Evolving Error Tolerance in Biologically-Inspired iAnt Robots. *Advances in Artificial Life:* Volume 12, 1025–1032.

D. Research Support

Ongoing Research Support

NASA *MUREP* M.E. Moses (PI)

06/2015 – 05/2018

A NASA challenge to develop cooperative robots and revolutionize space exploration. This Cooperative Agreement will launch a national swarm robotics competition for Minority Serving Institutions, with the goal of

1000 students from 50 MSIs competing in a combination of virtual and physical robot competitions. The challenges will be designed to advance technologies for robotic swarms to gather resources on the surface of remote planets to support subsequent human settlements.

Google Education Award M. E. Moses (PI)
04/2015 -04/2019
Sponsorship for the University of New Mexico Swarmathon project for outreach, education and research.

JSMF Complex Systems Scholar Award M.E. Moses (PI)
08/2014 – 04/2020
Emergent cooperative search in natural and engineered systems. Through empirical studies, engineering, simulation and mathematical analysis, we will deepen understanding of how cooperative search emerges in natural systems and how it can be designed into human-built systems. The research particularly focuses on analysis of search efficiency and robustness in ant colonies, biologically-inspired robotic swarms, and the T cell response in adaptive immunity.

NSF CNS-1240992 M. E. Moses (PI)
09/2016-10/2017
Supplement for "New Mexico Computer Science for All (NM-CSforAll)". This project teaches introductory computer science through scientific modeling to high school teachers who have taught over 1000 students.

NSF DUE 1068182 T. Aziz (PI)
08/2011 – 07/2017
STEPs in the Right Direction: Transforming Engineering/Computer Science Education at the University of New Mexico. This project provides summer internships and mentoring to 70 Computer Science and Engineering undergraduates at UNM each year.
Role: Co-PI

Sandia National Labs University Alliance LDRD Award M. E. Moses (PI)
07/2017-10/2018
Applying biological immune system concepts to improve electronic surveillance. This project uses immune-inspired search strategies and decentralized architectures to develop a scalable national disease alert system that rapidly detects epidemic outbreaks.

Microsoft Research M. E. Moses (PI)
08/2008-7/2018
New Faculty Fellowship Award
Distributed Computation in Ant Pheromone Networks. This project develops a framework for predicting efficiency and scalability of network topologies in which distributed components exchange information.

Completed Research Support

NIH R01 AI097202-01A1 J. Cannon (PI) 05/2012 – 04/2017
The role of PKCtheta in T cell and T-ALL migration
The goal of this application is to elucidate the mechanisms involved in controlling T cell migration and migration of T-ALL leukemia cells.
Role: Consultant

DARPA P-1070-113237 S. Forrest (PI) 10/2010 – 09/2015
Scalable RADAR for Co-evolutionary Adversarial Environments
This project mimics processes in immune response to develop scalable, automated and adaptive computer security systems. The project includes building models of adaptive immune response to better understand

mechanisms that increase search efficiency and using evolutionary computation to automatically repair computer bugs.
Role: Co-PI

NIH T32EB009414 J. H. Brown (PI) 08/2009-03/2015
Program in Interdisciplinary Biological and Biomedical Science (PiBBs). PiBBs unites faculty and trains graduate students from 6 main departments, 2 colleges and 3 institutions (University of New Mexico, Santa Fe Institute and Los Alamos National Laboratory) with research interests in biological theory, modeling and bioinformatics into a comprehensive program leading to a Ph.D. minor in Integrative Biology.
Role: Senior Personnel, Program Co-director 2013-present

NSF EF 1038682 M.E. Moses (PI) 09/2010-08/2014
NSF Collaborative Proposal: Search, Signals and Information Exchange in Distributed Biological Systems
This research develops agent based models and mathematical theory to understand how immune systems an ant colonies use distributed information processing to effectively search dynamic environments.
Role: PI

NIH P20RR018754 E.S Loker (PI) Subproject Period 08/2009–05/2011
Institutional Development Award (IDeA) Program of the National Center for Research Resources
Predicting Pathogenesis, Immune Response and Epidemic Spread of Multi-host Pathogens, a subproject of the UNM COBRE Center for Evolutionary and Theoretical Immunology
Role: Project Leader

NIH P20RR018754 E.S Loker (PI) Subproject Period 7/2007–06/2009
Modeling viral dynamics and immune response in vertebrates: A subproject of the COBRE Center for Evolutionary and Theoretical Immunology.
Role: Project Leader

Sandia National Labs LDRD 09-1292 M.E. Moses (PI) 08/2008–07/2011
An agent based approach to understanding cooperative foraging in ant colonies. Support for a graduate student to develop an agent based model to demonstrate how memory and communication contribute to collective search efficiency in foraging ants.
Role: PI