Curiouser and Curiouser!: Evolution of Inquisitive Behavior

Pennock, Holekamp, Hintze

Curiosity is one of the most important character traits in science (Pennock & Miller, 2016) and it is a behavioral predisposition with broad potential significance for understanding the evolution of intelligence. Darwin recognized this disposition in himself, speaking of it as "an instinct for truth, or knowledge or discovery" (Darwin 1848), and in *The Descent of Man* he began to lay out ideas about such matters, including places where he explicitly mentioned curiosity as part of his discussion on the evolution of instincts. Biologists have shown varying levels of curiosity in a wide range of animals (Glickman & Sroges 1966) and have offered some general hypotheses regarding environments within which curiosity would provide a selective advantage. For instance, speaking of the boldness and curiosity of Galapagos finches, West-Eberhard says that these traits "would be highly positively selected if learning is especially important in these birds." (West-Eberhard 2003 p. 347). Specifically, West-Eberhard speculates that "active curiosity" could affect the likelihood of learned flexibility—"To learn by trial and error in a particular context requires that an individual dare to perform the appropriate trials." (West-Eberhard 2003 p. 342). We propose to test such hypotheses in the wild using spotted hyenas and in the lab using digital evolution.

We conceptualize curiosity as a behavioral disposition to explore novelties in one's environment, where novelty is defined as a perceived anomaly in one's mental model of the world. One may think of such anomalies as causing puzzlement. Emotionally, this may be experienced as a combination of confusion and interest, but what matters for our purposes is that it motivates a behavioral response, leading an organism to investigate the anomaly. Such behavior may be expressed as boldness because anomalies may represent danger as well as opportunity, but the general trait of inquisitiveness may be useful either way, for it can help organisms discover potentially useful information to help avoid a new danger or exploit a new resource. We hypothesis that evolution will favor such a disposition in environments where such anomalies arise because of variability that occurs in ways (e.g. spatially and/or temporally) such that appropriate behavioral responses cannot be hard-wired directly by evolution but must be acquired within one's lifetime. Curiosity provides the motivation for intralife learning. We will investigate how different degrees of regularity in the environment affect the evolution of inquisitive behavior.

We will investigate this in both natural and digital systems, starting with a behavioral experiment in spotted hyenas. To investigate curiosity in hyenas we will introduce novel objects into their environment and observe how they respond. Holekamp performed some informal trials along these lines some 20 years ago, and this study will let us do so more systematically. Will the objects be ignored or investigated? How will hyenas approach and interact with novel objects, which may or may not be a resource? Does inquisitive behavior vary among individuals? Does it matter how recently they have eaten or how easy food is to acquire locally? It will not be possible to observe possible fitness effects in the short period of this study, but we hope to gather preliminary data that will serve as the basis for a grant proposal for a longer term study. What we will be able to do is compare any

inquisitive behavior to previous data collected about hyena boldness (Yoshida, Van Meter, Holekamp 2016). Those data involved response to known dangers vs possible resources (e.g., risks to life when challenging lions over food), but here we will see responses to unknown (e.g., unfamiliar objects introduced into their environment).

We will be able to investigate fitness effects over generational time using digital evolution experiments. Imagine that there are three types of depletable foods: red, blue, and green. Consuming them will give feedback on their nutritious value. How predictable these values are given the color of the food, as well as how homogeneously or heterogeneously, and how predictably they will be replenished are all factors to be varied. Less complex, and thus more regular environments, should favor organisms that are less curious. However, as environments increase in complexity, the ability to reliably succeed with specialized behavior is reduced, and conditions should favor the evolution of inquisitive behavior, where the ability to exploit novel resources while avoiding threats will yield better rewards.

After populations of agents have been evolved under the various experimental conditions, their behavior will be quantified and correlated to the conditions. The diversity can be quantified from the frequencies of expression of behavioral traits via standard information theoretic measures, such as the Shannon diversity index. Methods like Novelty and Diversity Search already established ways to quantify how novel or diverse strategies are, so we can use established metrics to begin to quantify curiosity. We hypothesize that more complex environments that require more curious agents to evolve should allow for faster evolution if, in addition, Novelty and Curiosity search are used to augment the genetic algorithm.

Due to the digital nature of the experiment, we have perfect knowledge of agent locations, behavior, and even internal states. We will use the EvoSphere platform, which permits experiments that should distinguish the selective value of different strategies under varying treatments of environmental regularity. EvoSphere has the special advantage of allowing us to run our digital experiments in the same environment with different digital models (e.g. artificial neural networks, Avida, Markov brains), letting us see the generality of evolutionary effects independent of possible artifacts caused by the particular system.

There have been only a few attempts to study curiosity using digital models, notably Oudeyer and Kaplan's applied work at Sony Labs on what they called Intelligent Adaptive Curiosity (Oudeyer 2004), and recently on curiosity-driven learning, (Gotlieb 2013), which suggest it will be a promising approach, especially with our digital evolution systems. Pennock has done previous work on the evolution of phenotypic plasticity (Clune et al 2007), memory (Grabowski et al 2010), and navigation for resources (Grabowski et al 2013) that provide a strong practical foundation for this new line of research. We have identified opportunities for subsequent external funding to pursue following this seed project.

References

Kristin M Campbell et al. "Do differences in skull morphology and bite performance explain dietary specialization in sea otters?", *Journal of Mammalogy* (2017). DOI: 10.1093/jmammal/gyx091

Clune, Jeff; Charles Ofria, Robert T. Pennock. "Investigating the Emergence of Phenotypic Plasticity in Evolving Digital Organisms" In Almeida e Costa, F., Rocha, L.M., Costa, E., Harvey, I. and Coutinho, A., *Advances in Artificial Life*. Berlin: Springer. (2007, pp. 74-83).

Darwin, Charles. *The Descent of Man*.

Darwin, Charles. *The Origin of Species*.

Glickman, Stephen E. and Sroges, Richard W. "Curiosity in Zoo Animals." (1966) *Behaviour* Vol 26, Issue 1, pp. 151–187.

Gottlieb, Jacqueline; Pierre-Yves Oudeyer, Manuel Lopes, Adrien Baranes. (2013) "Information-seeking, curiosity, and attention: computational and neural mechanisms." *Trends in Cognitive Science*.

Grabowski, Laura M.; David M. Bryson, Fred C. Dyer, Charles Ofria, Robert T. Pennock. "Early Evolution of Memory Usage in Digital Organisms." *Proceedings of the International Conference on Artificial Life (ALife XII)* (August 2010)

Grabowski, Laura M.; David M. Bryson, Fred C. Dyer, Robert T. Pennock and Charles Ofria. "A Case Study in the De Novo Evolution of a Complex Odometric Behavior in Digital Organisms." *PLoS ONE* (2013; 8(4):e60466)

Oudeyer, Pierre-Yves and Kaplan, Frederic. (2004) "Intelligent Adaptive Curiosity: a source of Self-Development". In Berthouze, L., Kozima, H., Prince, C. G., Sandini, G., Stojanov, G., Metta, G., and Balkenius, C. (Eds.) *Proceedings of the Fourth International Workshop on Epigenetic Robotics*. Lund University Cognitive Studies

Oudeyer, P-Y. and Smith. L. (2016). "How Evolution may work through Curiosity-driven Developmental Process." *Topics in Cognitive Science* 8(2):492-502.

Pennock, Robert and Miller, Jon D. (2016) "The Virtues of the Scientist: Results of a National Study" American Association for the Advancement of Science symposium. Washington DC

Stanton, Christopher and Clune, Jeff. (2016) "Curiosity Search: Producing Generalists by Encouraging Individuals to Continuously Explore and Acquire Skills throughout Their Lifetime." *PLOS One*. 11(9) e0162235.

West-Eberhard, Mary Jane. (2003) *Developmental Plasticity and Evolution*. Oxford: Oxford University Press.

Yoshida, K. C. S.; VanMeter, P.E. Holekamp, K. E. "Variation among free-living spotted hyenas in three personality traits " *Behaviour* 153 (2016) 1665–1722.

BIOGRAPHICAL SKETCH: **ROBERT T. PENNOCK**

(i) Professional Preparation

Earlham College	Biology/Philosophy	B.A. w/ Honors, 1980
University of Pittsburgh	History & Philosophy of Science	Ph.D., 1991

(ii) Academic and Professional Appointments

2005-present	Professor. Lyman Briggs College, Dept. of Philosophy, and Dept. of Computer Science and Engineering, Michigan State University
2000-2005	Associate Professor (tenured 2002). Lyman Briggs School of Science and Dept. of Philosophy, Michigan State University
1999-2000	Assistant Professor, Dept. of Philosophy, The College of New Jersey
1991-1999	Assistant Professor, Dept. of Philosophy, University of Texas, Austin

(iii) Products

Five most related to proposed project

R. T. Pennock. Lead developer of Avida-ED 1.0 and 2.0 digital evolution education software platform, and associated model exercises, user manual, and instructor support materials.

Grabowski, Laura M.; David M. Bryson, Fred C. Dyer, **R. T. Pennock** and Charles Ofria. "A Case Study in the De Novo Evolution of a Complex Odometric Behavior in Digital Organisms." *PLoS ONE* (2013; 8(4):e60466)

Grabowski, Laura M.; David M. Bryson, Fred C. Dyer, Charles Ofria, **R. T. Pennock**. "Early Evolution of Memory Usage in Digital Organisms." *Proceedings of the International Conference on Artificial Life (ALife XII)* (August 2010)

R. T. PENNOCK. (2007) "Models, Simulations, Instantiations and Evidence: The Case of Digital Evolution" *Journal of Experimental and Theoretical Artificial Intelligence* Vol. 19, No. 1 pp. 29-42.

Clune, Jeff; Charles Ofria, **R. T. Pennock**. "Investigating the Emergence of Phenotypic Plasticity in Evolving Digital Organisms" In Almeida e Costa, F., Rocha, L.M., Costa, E., Harvey, I. and Coutinho, A., Advances in Artificial Life. Berlin: Springer. (2007, pp. 74-83).

Five other significant products

Jeff Clune, **R. T. PENNOCK**, Charles Ofria and Richard Lenski. "Ontogeny tends to recapitulate phylogeny in digital organisms" *The American Naturalist*, Vol. 180, No. 3 (July 2012)

L. Grabowski, W. Elsberry, C. Ofria and **R. T. PENNOCK**. (2008) "On the Evolution of Motility and Intelligent Tactic Response" *Genetic and Evolutionary Computation Conference (GECCO '08) Proceedings.* New York: Assn for Computing Machinery (pp. 209-216)

Lenski, R. E., C. Ofria, **R. T. PENNOCK**, and C. Adami. (2003) The evolutionary origin of complex features. *Nature* **423**:139-144.

R. T. PENNOCK. "Can Darwinian Mechanisms Make Novel Discoveries?: Learning from discoveries made by evolving neural networks." (2000) *Foundations of Science* Vol. 5 no. 2, pp. 225-238.

R. T. PENNOCK. *Tower of Babel: The Evidence against The New Creationism*. (1999) Cambridge, MA: The MIT Press - Bradford Books.

(iv) Synergistic Activities

- **Professional service** including American Association for the Advancement of Science (AAAS) Committee on Public Understanding of Science and Technology (2007 - 2010); Society for the Study of Evolution Education Committee (Since 2000, Chair 2005-2010); *Invitational Summit on Undergraduate Biology: The Role of Disciplinary Societies.* Howard Hughes Medical Institute, 2008; *AAAS/AIBS Biology Education Summit*; Planning Committee, *Life Discovery - Doing Science* conference. 2013 – present.
- **Public service** includes Founder & Board member, Michigan Citizens for Science (MCFS) (2001 – present), President (2005 – 2008); Authoring Committee for National Academies of Science committee for *Science, Evolution and Creationism: A View from the National Academy of Sciences* (2005-07); Expert Witness. *Kitzmiller et al v. Dover Area School Board* (2005) trail, which ruled that teaching Intelligent Design in public schools is unconstitutional.
- **Outreach** includes Organizer, *Evolution, Here and Now* exhibit for SSE booth at the USA Science & Engineering Festival, held Oct 22-23, 2010, April 22-23, 2012, and April 24-26, 2014, Washington DC; Digital evolution demonstration exhibit for Darwin Discovery Days, 2000-present, MSU; museum exhibits development on evolution; dozens of public talks.
- **Recognitions** include Sigma Xi National Distinguished Lecturer (2000); National Center for Science Education *Friend of Darwin Award* (2003); Fellow of American Association for the Advancement of Science (2006); National Associate of the National Academies of Science (2008); American Institute of Biological Sciences (AIBS) Outstanding Service Award (2009); PKP Excellence Award in Interdisciplinary Scholarship for Avida-ED Project (2012).

KAY E. HOLEKAMP

Contact

Department of Integrative Biology, 288 Farm Lane, Room 203, Michigan State University, East Lansing, MI,48824-1115. Tel: 517-432-3691; holekamp@msu.edu
Web: http://www.holekamplab.org/
http://msuhyenas.blogspot.com/
https://web.facebook.com/MaraHyenas?_rdr

Professional preparation

Smith College, Northampton, MA, Psychology & Biology, A.B. 1973
University of California, Berkeley, CA, Psychobiology, Ph.D. 1983
University of California, Santa Cruz, CA, N.R.S.A. Postdoc, Endocrinology, 1983-1986

Appointments

2009-present: University Distinguished Professor**,** Michigan State University
2009-present: Director, interdisciplinary program in Ecology, Evolutionary Biology & Behavior, Michigan State University
1999-present: Professor, Department of Integrative Biology, Michigan State University
1992-1999: Assistant and Associate Professor, Department of Zoology, Michigan State University
1987-1991: Research Associate, Department of Ornithology and Mammalogy, California Academy of Sciences, San Francisco, CA.

Most relevant publications (total=148)

1. Lehmann, K.D.S., Montgomery, T.M., MacLachlan, S.M., Parker, J.M., Spagnuolo, O.S., VandeWetering, K., Bills, P.S. & **Holekamp, K.E.** (2016) Lions, hyenas and mobs (oh my!). Current Zoology. 63(3), 313–322.

2. Benson-Amram, S., Dantzer, B., Stricker, G., Swanson, E.M. & **Holekamp, K. E.** (2016) Brain size predicts problem-solving ability in mammalian carnivores. PNAS 113: 2532-2537.

3. **Holekamp, K.E**., Dantzer, B., Stricker, G., Yoshida, K.C.S. & Benson-Amram, S. (2015) Brains, brawn and sociality: a hyaena's tale. Animal Behaviour. 103: 237-248.

4. Benson-Amram, S. & **Holekamp, K. E.** (2012). Innovative problem solving by wild spotted hyenas. Proceedings of the Royal Society, London B. 279: 4087-4095.

5. Gersick, A.S., Cheney, D.L., Schneider, J. M., Seyfarth, R. M. & **Holekamp, K. E**. (2015) Long-distance communication facilitates cooperation among spotted hyaenas (*Crocuta crocuta*). Animal Behaviour. 103: 107-116.

Other significant publications

1. **Holekamp, K.E**. & Miikkulaninen, R. (2017) The evolution of general intelligence in *all* animals and machines. Behavioral and Brain Sciences. 40: 32-33.

2. Ilany, A., Booms, A. S. & **Holekamp, K. E**. (2015) Structural constraints on long-term social network dynamics in a wild mammal. Ecology Letters. 18: 687–695.

3. Yoshida, K.C.S., Van Meter, P.E. & **Holekamp, K.E**. (2016) Variation among free-living spotted hyenas in three personality traits. Behaviour. DOI:10.1163/1568539X-00003367.

4. Theis, K. R., Greene, K. M., Benson-Amram, S. R., & **Holekamp, K. E**. (2007). Sources of variation in the long-distance vocalizations of spotted hyenas. Behaviour.144: 557-584.

5. Theis, K.R., Venkataraman, A., Dycus, J. A., Koonter, K.D.S., Schmitt-Matzen, E.N., Wagner. A.P., **Holekamp, K.E**., & Schmidt, T.M (2013) Symbiotic bacteria appear to mediate hyena social odors. PNAS 110: 19832–19837.

Synergistic activities:

1) Teaching: Each year I teach a graduate class (IBIO801) on research ethics, grantsmanship, pedagogical techniques & other professional development issues at MSU (2005-present).

2) Service as a reviewer: I frequently serve as a reviewer for NSF and various other funding agencies, as well as for many different professional journals.

3) Advisory service: I am a member of the Scientific Advisory Committee for the MSU Museum, 2004-present, and faculty advisor for the *Kila Nafasi* Student Group (a charitable organization based at MSU dedicated to raising funds to educate Masai women; *Kila Nafasi* is Swahili for "Every Opportunity"), 2008-present. I also advise Honors College undergraduates majoring in Integrative Biology, MSU,1997-present.

4) Educational Outreach: Extensive facilitation of work by film, radio & print media on hyenas and other large African carnivores. We typically host at least one film crew and one science writer per year at our field camp, and help them get good information about hyenas, recordings of hyena vocalizations, footage of hyena behavior, etc. My students and I also give weekly lectures to lay audiences about hyenas in general and our research in particular.

5) Conservation work: I am a member of the Kenya Wildlife Service Committee on Carnivore Conservation (2001-present). I am also a member (1989-present) and former Chair (2003-2016) of the IUCN Hyaena Specialist Group, attempting to enhance conservation of hyaenids and responsible for maintenance of an educational IUCN website about hyaenids at http://www.hyaenaspecialistgroup.org/.

Arend Hintze

Professional Preparation

Westfälische Wilhlems-Universität Münster (Germany)	Biology	Undergraduate Diploma, 1996
Technische Universität Braunschweig (Germany)	Biology	Graduate Diploma, 2001
Technische Universität Braunschweig (Germany)	Biology	Dr. rer. nat., 2006

Appointments

Sep. 2015 - present	Assistant Professor Tenure Track, Michigan State University
Aug. 2010 - Aug. 2015	Postdoctoral Research Associate, Michigan State University,
Aug. 2010 - Jul.2011	Research Assistant Professor on Leave, Keck Graduate Institute,
Aug. 2006 - Aug.2010	Postdoctoral Research Associate, Keck Graduate Institute,
June 2001- July 2006	Research Assistant, TU Braunschweig,

Products related to this proposal

Hintze, A., Schossau, J., & Bohm, Clifford (2018). The evolutionary buffet method. Proceedings of the Genetic Programming Theory and Practice conference, in print

Schossau, J., Adami, C., & Hintze, A. (2015). Information-theoretic neuro-correlates boost evolution of cognitive systems. *Entropy*, *18*(1), 6.

Chapman, S., Knoester, D.B., Hintze, A., & Adami, C. (2013) Evolution of an artificial visual cortex for image recognition. In ECAL (pp 1067-1074).

Albantakis, L., Hintze, A., Koch, C., Adami, C., & Tononi, G. (2014). Evolution of integrated causal structures in animats exposed to environments of increasing complexity. *PLoS computational biology*, *10*(12), e1003966.

Marstaller, L., Hintze, A., & Adami, C. (2013). The evolution of representation in simple cognitive networks. *Neural computation*, *25*(8), 2079-2107.

Other Research Products

Kvam, P., Cesario, J., Schossau, J., Eisthen, H., & Hintze, A. (2015). Computational evolution of decision-making strategies. Proceedings of the 37th Annual Meeting of the Cognitive Science Society, 1225-1230.

Olson, R. S., Hintze, A., Dyer, F. C., Knoester, D. B., & Adami, C. (2013). Predator confusion is sufficient to evolve swarming behaviour. *Journal of The Royal Society Interface*, *10*(85), 20130305.

Edlund, J. A., Chaumont, N., Hintze, A., Koch, C., Tononi, G., & Adami, C. (2011). Integrated information increases with fitness in the evolution of animats. *PLoS computational biology*, *7*(10), e1002236.

Adami, C., & Hintze, A. (2013). Evolutionary instability of zero-determinant strategies demonstrates that winning is not everything. *Nature communications*, *4*, 2193.

Hintze, A., & Adami, C. (2008). Evolution of complex modular biological networks. *PLoS computational biology*, *4*(2), e23.

Synergistic Activities

Diversity Board (2017, ongoing development) – a web portal to share and explore teaching methods for diversification and the support of diversity, Heather Goldsby, Leigh Sheneman, and Arend Hintze.

aBeeDa (2012) – evolution of Swarming computational tool kit, C++ and processing, Randal S. Olson, Arend Hintze

MABE (2016 – ongoing), Modular Agent Based Evolution Framework, toolkit to support computational evolution research, Clifford Bohm, Arend Hintze

Curriculum Vitae: Jory Schossau

a) Professional Preparation

Undergraduate: Linfield College	Linfield, OR	Computer Science	2003-2007
Industry: Aeshen, LLC	Portland, OR	Developer & Instr Designer	2008-2009
Graduate: Keck Graduate Institute	Claremont, CA	Computational Biology	2009-2011
Graduate: Michigan State University	East Lansing, MI	CSE,EEBB,BEACON	2011-2017

b) Appointments

Teaching Assistant: In Vitro Diagnostics graduate course, Keck Graduate Institute	2010
Teaching Assistant: CSE 801 Computational Modeling for Biologists, BEACON	2014
Teaching Assistant: CSE 231 Programming with Python, MSU CSE Dept.	2017
Instructor: CSE 801 Graduate, Design & Theory of Algorithms, MSU CSE Dept.	2019

c) Publications

A. Hintze, **J. Schossau**, C. Bohm, (2019). *The evolutionary Buffet method*. In Genetic Programming Theory and Practice XVI (pp. 17-36).

H. J. Goldsby, R. L. Young, **J. Schossau**, H. A. Hofmann, A. Hintze (2018, July). *Serendipitous scaffolding to improve a genetic algorithm's speed and quality*. In Proceedings of the Genetic and Evolutionary Computation Conference (pp. 959-966).

J. Schossau, A. Hintze. (2018). *Neuronal Variation as a Cognitive Evolutionary Adaptation*. In Artificial Life Conference Proceedings (pp. 57-58).

J. Schossau, L. Albantakis, and A. Hintze, (2017). *The Role of Conditional Independence in the Evolution of Intelligent Systems*, GECCO 2017 in Berlin Germany, July 15-19.

J. S. MacCready, **J. Schossau,** K. W. Osteryoung, D. C. Ducat, (2016). *Robust Min-System Oscillation in the Presence of Internal Photosynthetic Membranes in Cyanobacteria*. Molecular Microbiology, ISSN 1365-2958, doi:10.1111/mmi.13571.

C. Adami, **J. Schossau**, A. Hintze (2016). *Evolutionary Game Theory using Agent-Based Methods*. Physics of Life Reviews, 19:1-26. ISSN 1571-0645, doi:10.1016/j.plrev.2016.08.015

C. Adami, **J. Schossau**, A. Hintze (2016). *The reasonable effectiveness of agent-based simulations in evolutionary game theory: Reply to comments on "Evolutionary game theory using agent-based methods"*, Physics of Life Reviews, 19:38-42. doi:10.1016/j.plrev.2016.11.005

B. Patra, Y. Kon, G. Yadav, A.W. Sevold, J. P. Frumkin, R. R. Vallabhajosyula, A. Hintze, B. Østman, **J. Schossau**, A. Bhan, B. Marzolf, J. K. Tamashiro, A. Kaur, N. S. Baliga, E. J. Grayhack, C. Adami, D. J. Galas, A. Raval, E. M. Phizicky, A. Ray (2016). *A genome wide dosage suppressor network reveals genetic robustness*. Nucleic Acids Research. doi:10.1093/nar/gkw1148

J. Schossau, C. Adami, and A. Hintze (2015). *Information-theoretic neuro-correlates boost evolution of cognitive systems*. Entropy, 18, (1):6. ISSN 1099-4300, doi:10.3390/e18010006

P. Kvam, J. Cesario, **J. Schossau**, H. Eisthen, and A. Hintze (2015). *Computational evolution of decision-making strategies*. In Proceedings of the 37th Annual Conference of the Cognitive Science Society, 37:225-1230, Pasadena, CA, USA.

C. Adami, **J. Schossau**, A. Hintze (2012). *Evolution and stability of altruist strategies in microbial games*. Physical Review E. 85 011914

J. Schossau, G. Wilson (2014). Which Sustainable Software Practices Do Scientists Find Most Useful?. arXiv:1407.6220 in proceedings of Working towards Sustainable Software for Science: Practice and Experiences 2, arXiv:1507.01715, Journal of Open Research Software (in press).

(continued on next page)

d) Synergistic Activities

- **Education:** Schossau is a certified Software Carpentry volunteer instructor and has taught computational skills to junior and senior biologists at universities including MSU and University of Washington. His software carpentry work has included formal assessments with demonstrated learning gains, now published in a peer-reviewed conference proceeding, helping pave the way for what is now known as Data Carpentry.
- **Education:** Schossau helped redesign and teach CSE 801, Computational Science for Evolutionary Biologists resulting in a large improvement of skill-based student proficiency and stark improvement of course reviews. Graduate students and postdocs left this class already applying their new skills and knowledge to their own research and new ideas.
- **Professional Development:** Schossau has served for two years as the lead organizer (+1 as committee mentor) of BEACON's Graduate Student and Postdoctoral association and has organized three Graduate Student/Postdoc Retreats for the annual BEACON Congress. Those in attendance came from 5 universities across the United States. Topics include "Biases within academia", "Accessibility inside and outside the lab", "alternatives to the pure academic career path", "The science behind Science Communication", "How to tailor science communication", "Time management, and other tips", and "Opportunities for BEACON affiliates." Using his teaching experience Schossau found giving attendees a hands-on breakout discussion time after each talk followed by discussion with the speaker drastically increased the participation and takeaway value for everyone.
- **Professional Development**: Schossau has given special interest seminars and workshops here at MSU on emerging technologies which are much better alternatives in many cases to currently used languages or simulation frameworks. These workshops help scientists stay abreast modern tools and methods, make better decisions when beginning projects, and lowering the barrier to entry for using these tools.
- **Mentoring:** Schossau has mentored one Ph.D. student in Integrative Biology, and three undergraduate research assistants in computer science and computational biology, including students from underrepresented backgrounds.
- **Cross-Institutional / Outreach:** Schossau has taught special interest seminars for a new computer science course at his undergraduate college: Linfield College. This introduced students and professors to newer technologies and methods for nonlinear simulation and visualization which helped bootstrap their new class focusing on that technology.

e) Awards and Fellowships

Travel: GECCO & ALife 2018. From MSU, BEACON, EEBB ($1800)
Travel: Evolution 2016. From MSU & Conference Org. ($1200)
Dissertation Completion Fellowship: Fall 2016. From MSU & BEACON. ($9,800)
Proposal: BEACON 2016. Gene-level selection, phage, and the evolution of antibiotic resistance. ($8,591)
Best Poster: CI Days 2016. From iCER. ($200)
Travel: Dynamic Brain Workshop 2014. From MSU. ($500)
Travel: Second Workshop Towards Sustainable Software for Science Practices and Experiences 2014. From MSU & Conference. $(1000)
Travel: Workshop on Evolutionary Game Theory in Arolla, CH 2013. From MSU. $(1200)