Senior Project Proposal

Project Title: "Evaluating Methods for Detecting Critical Transitions in Agent-Based Models"

Description:

My senior project proposal is an extension of the work that I have undertaken at the Santa Fe Institute while fulfilling my internship requirements (Summer, 2013). There, I completed a research project entitled "Avoiding Collapse: Detecting Critical transitions in Simulated Ecological Data". This work focused on utilizing several methods for detecting abrupt, discontinuous shifts, referred to as critical transitions, in real-world dynamical systems (Scheffer et al., etc.) via computer modeling in an agent-based simulation environment (NetLogo). Though my hope was to have a more generalized understanding of coupled dynamical systems, the majority of my research was directed toward understanding fishery population dynamics and fisheries management techniques to see what possible relationships may exist. As my research experience only lasted ten weeks, the project was on the whole left incomplete, though this is not to say that the experience was in any way less than stellar: the project helped to confirm the trajectory of my academic interest. I gained invaluable experience in designing and constructing agent-based models and learned quite a bit about how to plan, execute, and reflect upon a directed course of scientific inquiry.

My proposed senior project would expand on my previous work by focusing in on a more generalized problem: across a wide variety of non-trivial agent-based modeling paradigms, what (if any) of the markers for critical transitions are discoverable on a consistent basis? My goal is both to answer this theoretical question and to provide a practical application: understanding the behavior of agents in dynamical systems has many applications in a wide variety of fields, such as engineering, resource conservation, and finance. My specific area of application will be in resource conservation, and as such I aim to utilize the computational efficiency of agent-based modeling to understand the general behavior of various conservation and control efforts in this regard. This project is inherently interdisciplinary, but will draw on my current understanding of mathematics, population ecology, economics, and computer science, and will demand that I expand my content knowledge in all four areas to include the basics of control theory, dynamical systems, theoretical ecology, dynamic programming, and more advanced methods of agent-based modeling. I believe that my previous background in mathematics and economics have thoroughly prepared me for this project.

Goals:

Educational:

- To become proficient in the construction and analysis of a variety of agent-based models and modeling environments
- To enhance my ability to apply various mathematical skills to questions of ecology, economics, and other fields.
- To undertake a project requiring deep research in several fields (mathematics, computer science, resource conservation, and ecology) in order to further my experiences with interdisciplinary research.

Project:

- To extract from my research a potentially publishable paper.
- To further the ability of computational models to aid in both theoretical understanding and policy recommendations.
- To successfully integrate several distinct disciplines into one research agenda.

New Learning

I will need to further my understanding of object-oriented programming languages (Python, R, NetLogo) in order to build my simulations and to run various statistical analyses on the results. I will also need to learn the basics of control theory (which will, in turn, require me to further my understanding of ordinary differential equations). Lastly, I will need to immerse myself in the technical literature regarding resource economics and resource conservation science.

Final Product

This project will produce two final products. One, I hope to produce a lengthy research paper that will act as a first draft for potential publication in an academic journal. Second, I hope to give a final presentation to the community on my research and results, both with the aim to educate interested parties on my research and to encourage interested community members to collaborate on future work.

Role of the Directors

This project will have both a primary and secondary director: Dr. Dave Feldman and Dr. Davis Taylor.

I have had a class with Dave Feldman every term since I have arrived at College of the Atlantic. This is not simply due to my interest in mathematics: Dave is an excellent instructor and has helped to instill a level of confidence in my own quantitative abilities that is necessary for such a

project. His primary role would be as a supervisor to the more technical aspects of my project: helping me to understanding potentially difficult mathematical readings, and offering guidance when faced with difficult quantitative problems. Additionally, his knowledge of computer programming languages would be invariable to the construction of my simulation environment.

I have had equally as many classes with Davis Taylor. It has been his courses which have been primarily driving my interest in resource economics: specifically through some of the issues which have arose tangentially in his course offerings on economic development and macroeconomics. His role would be to help assist me in some of the more theoretical aspects of the project: specifically, I imagine that Davis will be able to assist me in hypothesizing various socio-economic means of "control" which could be then modeled in my simulation environment. He is also well versed in some of the quantitative techniques necessary for me to properly analyze my results.

I plan to meet with either director on a bi-weekly basis through both the Winter and Spring terms (with the potential to have a few extra meetings as the end of the Spring term approaches). I would ask that both professors provide an evaluation of senior project, and in return I would provide both professors with evaluations of their participation in my project.

Criteria for Evaluation

Criteria will be based primarily on completion of both a written report and a verbal presentation to the community. There is an explicit understanding that the project may provide either positive (detection *is* possible, control either is or is not) or negative (detection *isn't* possible) results, and that the discovery of either is valid and not means for academic assessment. There is also room for several "check-in" assessments if deemed necessary by the two directors: i.e., preliminary finding reports, methodology and technique explanations to prove competence, literature reviews, etc.

Timetable

1 Senior Project Credit during WI-14

2 Senior Project Credits during SP-14

Weeks 1-4 WI-14:

Extensive background reading on agent-based modeling, complexity theory, computer programming, and work in differential equations via readings and MIT OCW Scholars website, build theoretical computer model to discuss with advisors before programming begins

Weeks 5-10 WI-14: Begin construction of computer simulation environment, continue mathematical work in control theory and dynamical systems, write-up a "project so far" summary to be due in by the end of Week 10.

Weeks 1-6 SP-14: Finalize and run simulations and analyze results, begin project write-up.

Weeks 7-8 SP-14: Finish and turn-in final research paper.

Weeks 9-10 SP-14: Give community talk regarding findings

Selected Bibliography and List of Resources

Programming Texts:

Bolker, Benjamin M. Ecological Models and Data in R. Princeton, NJ: Princeton UP, 2008. Print.

Braun, John, and Duncan James Murdoch. *A First Course in Statistical Programming with R*. Cambridge: Cambridge UP, 2007. Print.

Dalgaard, Peter. Introductory Statistics with R. New York: Springer, 2002. Print.

Damaceanu, Romulus-Catalin. Agent Based Computational Social Sciences Using NetLogo: Theory and Applications. Saarbrücken: LAP Lambert Academic Publ., 2011. Print.

Guttag, John V. *Introduction to Computation and Programming Using Python*. New York: MIT, 2013. Print.

Lovász, László, J. Pelikán, and K. Vsztergombi. *Discrete Mathematics: Elementary and beyond*. New York: Springer, 2003. Print.

Matloff, Norman S. *The Art of R Programming: Tour of Statistical Software Design*. San Francisco: No Starch, 2011. Print.

Miller, John H., and Scott E. Page. Complex Adaptive Systems: An Introduction to Computational Models of Social Life. Princeton, NJ: Princeton UP, 2007. Print.

Moore, Cristopher, and Stephan Mertens. *The Nature of Computation*. Oxford [England: Oxford UP, 2011. Print.

Railsback, Steven F., and Volker Grimm. Agent-based and Individual-based Modeling: A Practical Introduction. Princeton: Princeton UP, 2012. Print.

Scheinerman, Edward R. *Mathematics: A Discrete Introduction*. Belmont, CA: Thomson Brooks/Cole, 2005. Print.

Zelle, John M. *Python Programming: An Introduction to Computer Science*. Sherwood, Or.: Franklin, Beedle & Associates, 2010. Print.

Unsorted Articles:

Acheson, James. "The Lobster Fiefs : Economic and Ecological Effects of Territoriality in the Maine Lobster Industry." *Human Ecology* 3.3 (1975): 183-207. Print.

Adams, W. M. "Managing Tragedies: Understanding Conflict over Common Pool Resources." *Science* 302.5652 (2003): 1915-916. Print.

Allesina, Stefano, and Mercedes Pascual. "Food Web Models: A Plea for Groups." *Ecology Letters* 12.7 (2009): 652-62. Print.

Beddington, J. R., D. J. Agnew, and C. W. Clark. "Current Problems in the Management of Marine Fisheries." *Science* 316.5832 (2007): 1713-716. Print.

Bell, G. "The Evolution of Trophic Structure." *Heredity* 99.5 (2007): 494-505. Print.

Boettiger, Carl, Noam Ross, and Alan Hastings. "Early Warning Signals: The Charted and Uncharted Territories." *Theoretical Ecology* 6 (2013): 255-64. Print.

Caddy, J. F., and J. C. Seijo. "This Is More Difficult than We Thought! The Responsibility of Scientists, Managers and Stakeholders to Mitigate the Unsustainability of Marine Fisheries." *Philosophical Transactions of the Royal Society B: Biological Sciences* 360.1453 (2005): 59-75. Print.

Dakos, Vasilis, S. R. Carpenter, W. A. Brock, A. M. Ellison, and V. Futtal. "Methods for Detecting Early Warnings of Critical Transitions in Time Series Illustrated Using Simulated Ecological Data." *PLoS ONE* 7.7 (2012): 1-20. Print.

Food and Agriculture Organization of the United Nations. *The State of the World Fisheries and Aquaculture*. Rome: FAO, 2012. Print.

Gordon, H. Scott. "The Economic Theory of a Common-Property Resource: The Fishery." *Journal of Political Economy* 62.2 (1954): 124. Print.

Hardin, Garrett. "The Tragedy of the Commons." *Science* 162.3859 (1968): 1243-248. Print.

Helmke, Gretchen, and Steven Levitsky. "Informal Institutions and Comparative Politics: A Research Agenda." *Perspectives on Politics* 2.4 (2004): 725-40. Print.

Hotelling, Harold. "The Economics of Exhaustible Resources." *Journal of Political Economy* 39.2 (1931): 137. Print.

Hutchings, Jeffrey A., and Ransom A. Myers. "What Can Be Learned from the Collapse of a Renewable Resource? Atlantic Cod, *Gadus Morhua*, of Newfoundland and Labrador." *Canadian Journal of Fisheries and Aquatic Sciences* 51.9 (1994): 2126-146. Print.

Jackson, J. B. C. "Historical Overfishing and the Recent Collapse of Coastal Ecosystems." *Science* 293.5530 (2001): 629-37. Print.

Longhurst, Alan. "Cod: Perhaps If We All Stood Back a Bit?" *Fisheries Research* 38 (1998): 101-08. Print.

North, Douglass C. *Institutions, Institutional Change, and Economic Performance*. Cambridge: Cambridge UP, 1990. Print.

North, Douglass. "Institutions." *The Journal of Economic Perspectives* 5.1 (1991): 97-112. Print.

Ostrom, Elinor. "Beyond Markets and States: Polycentric Governance of Complex Economic Systems." *The American Economic Review* 100 (2010): 1-33. Print.

Ostrom, Elinor. *The Drama of the Commons*. Washington, DC: National Academy, 2002. Print.

Ostrom, Elinor, Roy Gardner, and James Walker. *Rules, Games, and Common-pool Resources*. Ann Arbor: University of Michigan, 1994. Print.

Pauly, Daniel, et al. "Fishing Down Marine Food Webs." *Science* 279 (1998): 860-63. Print.

Pauly, Daniel, Ray Hilborn, and Trevor A. Branch. "Does Catch Reflect Abundance?" *Nature* 494 (2013): 303-06. Print.

Pikitch, E. K., Et Al. "Ecosystem-based Fishery Management." *Science* 305 (2004): 346-47. Print.

Poggie, John J., Jr., Richard B. Pollnac, and Carl Gersuny. "Risk as Basis for Taboos among Fishermen in Southern New England." *Journal for the Scientific Study of Religion* 15.3 (1976): 257-62. Print.

Scheffer, Marten, Et Al. "Anticipating Critical Transitions." *Science* 338.6105 (2012): 344-48. Print.

Scheffer, Marten, et al. "Early-warning Signals for Critical Transitions." *Nature* 461.7260 (2009): 53-59. Print.

Schlager, Edella, and Elinor Ostrom. "Property-rights Regimes and Natural Resources: A Conceptual Analysis." *Land Economics* 68.3 (1992): 249-62. Print.

Smith, M. D., C. A. Roheim, L. B. Crowder, B. S. Halpern, M. Turnipseed, J. L. Anderson, F. Asche, L. Bourillon, A. G. Guttormsen, A. Khan, L. A. Liguori, A. McNevin, M. I. O'Connor, D. Squires, P. Tyedmers, C. Brownstein, K. Carden, D. H. Klinger, R. Sagarin, and K. A. Selkoe. "Sustainability and Global Seafood." *Science* 327.5967 (2010): 784-86. Print.

Smith, Vernon. "Economics of Production from Natural Resources." *The American Economic Review* 1st ser. 58.3 (1968): 409-31. Print.

Walters, Carl, and Jean-Jacques Maguire. "Lessons for Stock Assessment from the Northern Cod Collapse." *Reviews in Fish Biology and Fisheries* 6.2 (1996): 125-137. Print.

Wikan, A., and A. Eide. "An Analysis of a Nonlinear Stage-structured Cannibalism Model with Application to the Northeast Arctic Cod Stock." *Bulletin of Mathematical Biology* 66.6 (2004): 1685-704. Print.

Wilson, J., L. Yan, and C. Wilson. "The Precursors of Governance in the Maine Lobster Fishery." *Proceedings of the National Academy of Sciences* 104.39 (2007): 15212-5217. Print.

Yami, Mastewal, Christian Vogl, and Michael Hauser. "Comparing the Effectiveness of Informal and Formal Institutions in Sustainable Common Pool Resources Management in Sub-Saharan Africa." *Conservation and Society* 7.3 (2009): 153-64. Print.