Problem 2. Write up your Project Proposal with the following sections. The result should be 2-3 pages long.

2a. *Goal*: What is your primary project goal? What you would like to learn?

2b. *System*: Describe how the dynamical system is nonlinear and time-dependent.

What's the state space?

What's the dynamic?

Why is the system behavior interesting?

2c. *Dynamical properties*: What dynamical properties are you going to investigate?

2d. *Intrinsic computation properties*: What information processing properties are you going to investigate?

2e. *Methods*: What methods will you use? Why are they appropriate?

2f. *Hypothesis: What is your current guess as to what you will find?
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2g. *Steps*: List the appropriate steps for your investigation; for example, read literature, write simulator, do mathematical analysis, estimate properties from simulation, write up report, and so on.

2h. *Time*: Estimate how long each step will take. Can you complete the project within one month?

SOLUTION:

2a) For this project, I intend to investigate the role of biological soil crusts in spatial organization in drylands. Biological soil crusts are complex microbial communities commonly found in arid and semi-arid ecosystems. These crusts greatly influence ecological processes such as the hydrologic cycle, nutrient cycles, and weathering. The effect these crusts have on ecological processes depends on their composition, which is largely determined by the degree of aridity. Despite our understanding of the role of biological soil crusts, they are not well understood and empirical findings often are contradictory. These crusts, as well as vegetation and bare soil, are discrete components in arid and semi-arid landscapes. Understanding the organizing principles of these components will shed light onto their ecological relationships and perhaps even shed light on our understanding of catastrophic shifts in drylands. In order to do this, and stay within a reasonable scope, I intend to calculate information measures in two-dimensional space using synthetic data created from amended ecological models.

2b) Although nonlinear behavior in biological soil crusts has not been investigated as of yet, the system in which they are components is well understood to display nonlinearity. Many water stressed ecosystems are considered to be near to catastrophic shifts. Spatial patterns of vegetation are commonly used as warning signs before a catastrophic shift. The system is time dependent because the interactions change along ecologic time – as the ecosystem develops and the stresses of aridity are lifted, competitive interactions become more prevalent. Development after disturbance may provide an opportunity to observe transitions in these soil communities. The state space of this system includes: bare soil, biological soil crust, and vegetation. Although I will at first include three states in this system, I intend to analyze the system with more states. Biological soil crusts are composed of distinct components, largely cyanobacteria, moss, and lichens. These individual components interact and have distinct ecological roles. If time allows, I hope to expand my project to include these individual biological soil crust components. The dynamic of the system including biological soil crusts is not well understood, though vegetation dynamics are well understood. Dynamical models of the state variables will be amended from common population models. This system behavior is interesting because drylands are sensitive to increases in stress and understanding state change in drylands is paramount in light of ongoing climatic changes.

2c) The dynamical properties I intend to analyze include: stability behavior in parameter space by varying interaction terms between vegetation and biological soil crust, as well as changes in spatial patterns when extending the model to two-dimensional space.

2d) The information measures I intend to investigate are entropy density, excess entropy, and statistical complexity of synthetic simulations, as well as some classified remote sensing data, in two-dimensional space. By calculating information measures in classified remote sensing data, I can at least assess the inherent randomness of real-world systems in comparison to the modeled data.

2e) For my project, I will use numerical modelling methods in space and time to create synthetic data for analysis. Stability behavior of the system in time only will be assessed using approaches and code from last quarter. This method is appropriate for this project because many theoretical ecology studies utilize dynamical systems simulations to test hypotheses. This proves to be particularly useful in light of noisy empirical data. In order to assess changes in spatial patterns over time, I will calculate the semi-variogram of synthetic matrices in time – another common approach in spatial ecology. Assessing changes in spatial organization along an aridity gradient may prove useful for predicting catastrophic shifts. In order to calculate information metrics of synthetic data, I will use the methods presented in Feldman and Crutchfield, 2002 as well as the work of Dr. Michael Batty. Feldman and Crutchfield outlined a methodology for calculating entropy density and excess entropy in two-dimensional space.

2f) My hypotheses for this project are:

H1: Biological soil crusts, considering their ecological services provided to vegetation, will reduce inherent spatial randomness in dryland ecosystems compared to models solely considering vegetation in space (such as Rietkerk et al., 2008).

H2: Biological soil crusts and vegetation populations will likely exhibit stable spirals. Given sufficient time, a stable point is reached but initial oscillatory behavior is expected given variable interaction effects relative to cover. Biological soil crusts benefit vegetation, and vegetation are believed to also in turn benefit biological soil crusts, but when plant cover becomes too high it limits available light to crusts, thus decreasing their population and increasing stress on vegetation.

H3: Entropy density will converge in time given expected stable spatial patterns

H4: Classified remote sensing images will exhibit higher inherent randomness

H5: Biological soil crusts and vegetation will display spatial signals of “critical slowing down” and ecosystem state change

2g) The steps for this project include:

1 – Read literature

2 – Write mathematical models (in time as well as in space and time – going to stay simple)

3 – Collect remote sensing images and classify into states considered

4 – Assess stability behavior of population models

5 – Calculate information measures in simulated data and classified data

6 – Write report

2h) The expected time necessary to complete each step is outlined below:

1 – Read literature (7 days)

2 – Write mathematical models (2 days)

3 – Collect remote sensing images and classify into states considered (2 days)

4 – Assess stability behavior of population models (3 days)

5 – Calculate information measures in simulated data and classified data (7 days)

6 – Write report (7 days)

Adding 20% for safety, this project will take me around 33 days. This means I very well should be able to finish this project within the time limit of the course, but I may have to skip on including remote sensing data or spend

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