

Final Report to Northwest Academic Computing Consortium on Grant
Web Loop Analysis: A Web-Based Computer Application to Model Complex
Ecosystems

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Web site: <http://www.ent.orst.edu/loop/default.aspx>

Summary of Completed Project:

In this project, we developed web-based resources for the purpose of teaching qualitative modeling in ecology. Because most education-oriented websites present non-interactive contents, we are creating a web application that allows students to analyze complex ecological systems and explore qualitative models with a web browser. Throughout the user-friendly web interface, students can construct qualitative models of an ecosystem and use the models to gain a better understanding of the direct and indirect ecological interactions. Students will also learn new tools and improve their skills at "qualitative reasoning" to understand the dynamics of complex systems, gain insights into their own understanding of the ecosystem they are studying, and use their models to predict possible experimental outcomes or patterns in the ecosystems they are studying. In this project, we have accomplished the following tasks:

1. to develop a Java applet (called PowerPlay) for drawing signed digraphs to represent community systems
2. to compute the inverse matrix and Hurwitz criteria for stability testing
3. to assess potential for Lyapunov stability by qualitative metrics corresponding to Hurwitz criteria
4. to test the response of the system to input through the adjoint and weighted-predictions matrices
5. to validate results with a run of 5000 random simulations
6. to access a help menu and directions
7. to build an online database of community systems coded from published ecological research papers.

Description of the Loop Analysis web site

Purpose of web site:

Modeling has become an important tool in the study and management of ecological systems. Sometimes it is not possible to manipulate an ecological system to test rival hypotheses in field tests. For example, costs and time constraints can limit large-scale experiments for testing community responses to an environmental disturbance. In contrast, models can help explore hypotheses quickly and rigorously, and can help to define research questions and identify data needs. While modeling is widely considered by ecologists to be an important component of ecological education, most ecology students have a misconception that ecological models (particularly those dealing with ecosystems and communities) are always extremely complex and filled with mathematical equations. On the contrary, a complex ecological system can be simply and formally described with a set of 'boxes and arrows'. The loop analysis for qualitative modeling represents a simplified approach.

Web Site Description:

The Loop Analysis web site includes the following components:

- PowerPlay Java Applet

PowerPlay was originally designed as a stand along desktop application written with Java. In this project, we converted the desktop version into a web accessible applet. We also added several new functions for the applet version, such as a dialogue window for the student writing down the note for the species interaction. Powerplay is very useful for drawing a large community system with many variables and reducing the transcription errors when the signed the digraph converts to a matrix.

- Loop Analysis

The Loop Analysis web page includes several matrix operations. This page provides several buttons and a text box for entering a community matrix using a text string format. If the user uses PowerPlay to create a digraph of community system, the text string of the community matrix is automatically generated.

- Assess potential for stability by qualitative metrics

Two criteria are used to test the system stability: (1) all coefficients of the characteristic equation are positive and (2) all the Routh-Hurwitz determinants are positive.

- Compute the adjoint matrix (and predict changes in abundance)

The adjoint of the community matrix computes the sensitivity of any variable to the change of system parameters. Mathematically, the elements of the adjoint matrix are nothing more than the cofactors of the transposed matrix. Thus, a change in the population abundance of a species is determined by the net effect of complementary feedback loops, i.e., the subsystems not in the direct path of these species. Because the adjoint is the sum of positive and negative loops, we don't know the numbers of positive and negative loops in the subsystem. An absolute feedback matrix can detail the total number of complementary feedback loops involved in each community response. Lastly, a weighted prediction matrix scales the response of adjoint and allows for the reliability of each predication.

- Test the response of the system to input through weighted-predictions matrices

Using the adjoint matrix, the user can click the column header of each species to mimic a positive impact to the species of column header and displays the response of all community species to the positive input.

- Validate results with a random simulations

The stability test is based on the signed digraph, in which the relationships between species are (+1, -1, 0). The qualitative stability offers no insight into the stable structure of quantitative domain of the system. For example, a signed digraph has an overall negative feedback with two negative loops (-2) and one positive loop (+1). However if we have the measure of interaction strengths between species, the values of two negative loops may be -0.2 and -0.3, and the value of positive loop may be 0.6. In this case the strength of overall feedback is 0.1 and then we will obtain a positive overall feedback. In order to know the probability that the system is also stable in a quantitatively specified matrix, 5000 quantitative matrices are constructed based on the unchanged sign structure of the system. Non-zero elements of each matrix are quantitatively specified with a pseudorandom number generator that assigns interaction strength but not a sign from a uniform distribution between 0.01-1.0. The stability of each quantitatively specified matrix is then examined in terms of two stability criterion.

- Food Web Bank

This web page contains 113 community systems coded from published ecological research papers. Students can use this database as examples for their ecological models. This database provides very valuable learning materials for ecology students practicing loop analysis and ecological modeling.

- Example

In this web page, we use real ecological research data to demonstrate a loop analysis of an aquatic system where an invasive species has been introduced. This example is provided by Michael Chi-Chun Liu, a Fisheries and Wildlife graduate student from Oregon State University. We demonstrate how to use the prediction matrix from loop analysis to suggest several management scenarios in which the reduction of the invasive species is predicted.

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Blackwood, J.S., M. Dresner and H.-K. Luh. 2006. Using Student Generated Qualitative Ecological Models. Teaching Issues and Experiments in Ecology. Teaching Issues and Experiments in Ecology, Vol. 4: Experiment #4 [online].
http://tiee.ecoed.net/vol/v4/experiments/ecological_models/abstract.html

Outreaches:

This application was used in the Soil Biodiversity Workshop held at Taiwan Forestry Research Institute in October. The PI (Hans Luh) was invited to demonstrate how to design and analyze a qualitative model for a soil ecosystem by using Web Loop Analysis. There were very valuable feedbacks from the workshop. The feedback information helped us to improve our design and our web application.

Contribution:

Web Loop Analysis has been incorporated into the procedure to reflect the synergy of a new inter-site ecology education program, Teaching Ecological Complexity, funded by National Science Foundation.