Cloud-based Exploration of Complex Ecosystems for Science, Education and Entertainment

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Rich J. Williams
Ecosystems: Complex Ecological Networks

Little Rock Lake Food Web: 92 Species $S$ & 997 Links $L$
Connectance $(C) = \frac{L}{S^2}$

Node Color indicates Trophic Level of Taxa
Link Color indicates Type of Feeding Link

Martinez 1991 Ecological Monographs
Niche Model: $S$ & $C$ inputs

- Rule 1: Each of $S$ species gets uniformly random $n_i$
  - $0 < n_i < 1$

- Rule 2: Each $S$ gets assigned a Random feeding range $r_i$
  - $0 \leq r_i \leq 1$; beta function mean of $2C$ multiplied by $n_i$

- Rule 3: Range is placed: uniformly random center: $c_i$
  - $r_i/2 < c_i < n_i$

Williams and Martinez 2000 *Nature*
Paleofoodwebs

Compilation and Network Analyses of Cambrian Food Webs
Dunne, Williams, Martinez, Wood & Erwin et al. 2008
PLoS Biology
Niche Model

- Generates Realistic Network Architectures
  - Effects of $S$ and $C$ on network structure

- Provides a Benchmark

- Scaffolding for Network Dynamics
Bioenergetic Dynamics

Time evolution of species’ biomasses in a food web result from:

- Basal species grow via a carrying capacity, resource competition, or Tilman/Huisman models
- Other species grow according to feeding rates and assimilation efficiencies ($e_{ji}$)
- All species lose energy due to metabolism ($x_i$) and consumption
- Functional responses determine how consumption rates vary
- Rates of production and metabolism ($x_i$) scale with body size
- Metabolism specific maximum consumption rate ($y_{ij}$) scales with body type

Application: Species loss

Simple prediction of interaction strengths in complex food webs

Eric L. Berlow\textsuperscript{a,b,c,1}, Jennifer A. Dunne\textsuperscript{c,d}, Neo D. Martinez\textsuperscript{e}, Philip B. Stark\textsuperscript{a}, Richard J. Williams\textsuperscript{c,f}, and Ulrich Brose\textsuperscript{b,c,2}

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Edited by Simon A. Levin, Princeton University, Princeton, NJ, and approved November 10, 2008 (received for review July 15, 2008)

2009 *PNAS* 106:187-191

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![Graph showing predicted vs. observed biomass](image)

- **Predicted**
  - High R Biomass
  - Low R Biomass

- **Observed**
  - High R Biomass
  - Low R Biomass
Application: Dynamics of a Specific System

Lake Constance

Rich empirical data:
S = 24
Trophic network data
Weekly biomass & productivity data, 10-20 yrs
Metabolic data & body size

Run generic to specific versions of the ATN model and compare output to biomass time series data
(i.e., idealized system, generalized lake pelagic system, highly constrained system)

Germany, Austria, Switzerland

Lake Constance

- 24 Species, 104 Links, Conectance = 0.18
Mean Relative Biomass & Flows
Lake Constance Biomass: Model-Data Similarity = 0.82
Ecological Forecasting

- Parameterize Network Model for System of Interest
  - Network Structure
  - Body Size and Type

- Tune Parameters to Historical Record

- Update Model with Realtime Data

- Continue machine learning
Forecasting Example: Humans

- Coupled Human-Natural Networks
- Aleuts on the Sanak Archipeligo
Forecasting Example: Fisheries

\[ \dot{E} = \mu (pqB_i - c_0) E \]

- \( E \) is fishing effort for species \( I \)
- \( p \) is the price per unit catch
- \( q \) is the "catchability coefficient",
- \( B_i \) is the biomass density of exploited species \( i \),
- \( c_0 \) is the cost per unit effort,
- \( \mu \) is market openness

- \( E \) increases with profit
- \( E \) decreases with loss

Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne AAAI2012
Forecasting Example: Fisheries
Forecasting Example: Fisheries

Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne AAAI2012
Cyberinfrastructure: Network3D
Cyberinfrastructure for Ecological Networks

- Application as a Service
- Ease
  - Network3D written in C#
- Scalable
  - Azure Cloud
- Accessible
  - Web Services
  - Browser Client
  - Data
  - Game (WoB)
Network3D on Azure

- Additional opportunities for parallel computing within Azure

<table>
<thead>
<tr>
<th>Index No.</th>
<th>Food web</th>
<th>Node No.</th>
<th>Link No.</th>
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</tbody>
</table>
WoB: World of Balance
WoB: World of Balance

World of Balance YouTube Clip
Future: Cloud Enabled Exploration of Complex Ecological Networks

- Games and Research Simulations
  - Easy to conduct
  - Results Stored and Accessible
  - Computer Science
Future: Cloud Enabled Exploration of Complex Ecological Networks

- Integration with other Data
  - Empirical Observations (e.g., L. Constance, Fisheries)
  - Other simulations (e.g., Matlab)
  - Realtime observations (e.g., light and rain measures)
Solutions Obtained

- Behavior, Stability and Robustness of Ecological Networks
- Understanding and management of Human-Natural Networks
- Social Networks/Public Appreciation of Ecosystems
  - Ecological and Economic Interdependence
  - One’s own “place in the world”
Games and Research Simulations
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