What is *Mental Modeler*?

*Mental Modeler* is modeling software that helps individuals and communities capture their knowledge in a standardized format that can be used for scenario analysis. Based on Fuzzy-logic Cognitive Mapping (FCM) users can easily develop semi-quantitative models of environmental issues, social concerns or social-ecological systems in *Mental Modeler* by:

- Defining the important components of a system
- Defining the relationships between these components
- Running "what if" scenarios to determine how the system might react under a range of possible changes.
Design Goals:

- **Represent** and **standardize** stakeholder knowledge and values in resource decision-making
- Provide flexibility and ease in the modeling process
- Create datasets which can compare and combine stakeholder understanding and values
- Create datasets which can be integrated with expert knowledge, scientific datasets, and used to test co-developed hypotheses
- Increase understanding of the structure and function of social-ecological systems
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Two ways this is intended to be useful:

1. **Research context**: Understand how the structure and function of individual and group understanding varies reliably with different value orientations, attitudes and behaviors.

2. **Planning context**: Share, construct, and revise knowledge about a system to promote learning and adaptability among different experts or stakeholders.
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Outline

• Overview of Fuzzy-logic Cognitive Mapping
  – Fuzzy Numbers and Fuzzy Sets
  – Cognitive Mapping
  – Doing the calculations the old fashioned way:
    • Structural Metrics
    • Functional Metrics

• Introduction to Mental Modeler
  – Case study of Collaborative Modeling for Citizen Scientists

• New Analytical Capabilities coming soon!
  – Integrating MMP files into R

• Building a Model
  – How do stakeholders view the relationship between logging, economic development and wildlife habitat?
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What is a FCM?
A **Fuzzy cognitive map** is a cognitive map within which the relations between the elements (e.g. concepts, events, project resources) of a "mental landscape" can be used to compute the "strength of impact" of these elements.

Fuzzy cognitive maps are signed fuzzy digraphs.

Spreadsheets or tables are used to map FCMs into matrices for further computation.

Reliant on **fuzzy logic** AND cognitive mapping.
Fuzzy Set Theory

• Fuzzy Number
  • Number ‘x’
  • Near ‘x’
  • Almost ‘x’
Fuzzy Set Theory

A fuzzy set $A$ in $U$ may be represented as a set of ordered pairs. Each pair consists of a generic element $x$ and its grade of membership function; that is

(a) Crisp membership function
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(a) Crisp membership function

(b) Fuzzy membership function
Fuzzy Set Theory

- Fuzzy set operations = OR, AND, NOT
- Establishes a rule-based interference system:
Fuzzy Set Theory

- Fuzzy set operations = OR, AND, NOT
- Establishes a rule-based interference system:

If apples are green AND small THEN Not ready to eat
Fuzzy Set Theory

- Fuzzy set operations = OR, AND, NOT
- Establishes a rule-based interference system:

  If apples are red AND large THEN Ready to eat
Fuzzy Set Theory

- Fuzzy set operations = OR, AND, NOT
- Establishes a rule-based interference system:

Apply qualitative Rules → Make Decisions
Fuzzy Set Theory

• Fuzzy set operations = OR, AND, NOT
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![Diagram of Fuzzy Set Theory](image)
Fuzzy-logic Cognitive Mapping

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Robert Axelrod (1976) was the first to use the term in reference to the content and structure of individuals’ minds, thereby shifting its applied meaning from referring to a map that is cognitive, to a map of cognition (Doyle and Ford 1999).
Concept or Cognitive Mapping?

A concept map is a diagram showing the relationships among concepts. It is a graphical tool for organizing and representing knowledge. Concepts, usually represented as boxes or circles, are connected with labeled arrows in a downward-branching hierarchical structure. The relationship between concepts can be articulated in linking phrases such as "gives rise to", "results in", "is required by," or "contributes to"
Brining it all together:
Fuzzy-logic Cognitive Mapping (FCM)

Explicit representation of an internal mental model of relationships between concepts constructed over time...
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Explicit representation of an internal mental model of relationships between concepts constructed over time...

...that applies a set of associative rules thought to be similar to the ways in which individuals are able to make context appropriate decisions.
How to construct a FCM?
Brining it all together:
Fuzzy-logic Cognitive Mapping (FCM)

- A **Fuzzy cognitive map** is a special kind of cognitive/concept map within which the **components** and **relationships** between the components are defined in specific ways.
  - **Components** in a fuzzy-logic cognitive map need to be defined as things that can go increase or decrease (like precipitation, animal populations, satisfaction, hunger, or traffic)
  - **Relationships** in an fuzzy-logic cognitive map have 2 main characteristics: (a) the direction of a relationship (which way the arrow is pointing) and (b) the degree of influence one component can have on another (positively or negatively) parameterized between a fuzzy set from 0 and 1.
Example
Example

Components

The amount of wetland, the amount of law enforcement and income can all go up or down.
Components
The amount of wetland, the amount of law enforcement and income can all go up or down.

Relationships
These direction of the arrows, positive or negative sign and numbers (between +1.0 and -1.0) all indicate the degree of influence one component can have on another.
Thinking about relationships

As the amount of wetlands increases, the number of fish increases a lot (indicated by the +1)

As lake pollution increases, the amount of wetlands decreases slightly (-0.2)

As law enforcement increases, lake pollution decreases a medium amount (+0.5)
Thinking about relationships

Remember, the direction of the arrow indicates the direction of increase or decrease. The number value included on the arrow could be anything between +1 (as one component goes up the other component increases a lot) to -1 (as one component goes up the other component decreases a lot)
Thinking about relationships

Remember, the direction of the arrow indicates the direction of increase or decrease. The number value included on the arrow could be anything between +1 (as one component goes up the other component increases a lot) to -1 (as one component goes up the other component decreases a lot).

These number values on the lines could even be qualitatively defined and then later translated into quantitative values:

- increases a lot = +1
- increases = +0.5
- increases a little = +0.25
- decreases a little = -0.25
- decreases = -0.5
- decreases a lot = -1
Rule of Thumb for Relationships

When determining the relationships between components in an FCM always ask yourself 2 questions:

1. When this component increases, does the other component increase or decrease?
2. Is it a high increase/decrease, medium increase/decrease or low increase/decrease?
How can you analyze an FCM?
What are they good for?

• Calculating Structural Network Metrics
  --Measuring and representing knowledge (and variation)
  --Determining driving variables and sensitive variables and common belief structures
What are they good for?

• Calculating Structural Network Metrics
  --Measuring and representing knowledge (and variation)
  --Determining driving variables and sensitive variables and common belief structures

• Calculating Scenario (Functional) Analysis
  -- Understanding how stakeholders anticipate the impacts of environmental change
  -- Decreasing uncertainty associated with environmental change
Knowledge Structure

Cognitive Maps collected can then be translated into a matrix format for analyses.
### Mental Model Structural Measurement

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<tr>
<th>Mental Model Structural Measurement</th>
<th>Description of Measure and Cognitive Inference</th>
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<tbody>
<tr>
<td>N (Concepts)</td>
<td>Number of variables included in model; higher number of concepts indicates more components in the mental model (Özesmi and Özesmi 2004)</td>
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<tr>
<td>N (Connections)</td>
<td>Number of connections included between variables; higher number of connections indicates higher degree of interaction between components in a mental model (Özesmi and Özesmi 2004)</td>
</tr>
<tr>
<td>N (Transmitter)</td>
<td>Components which only have “forcing” functions; indicates number of components that effect other system components but are not affected by others (Eden et al. 1992)</td>
</tr>
<tr>
<td>N (Receiver)</td>
<td>Components which have only receiving functions; indicates the number of components that are affected by other system components but have no effect (Eden et al. 1992)</td>
</tr>
<tr>
<td>N (Ordinary)</td>
<td>Components with both transmitting and receiving functions; indicates the number of concepts that influence and are influenced by other concepts (Eden et al. 1992)</td>
</tr>
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### Table

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<tr>
<td>1. Amount of wetland</td>
<td>0</td>
<td>1</td>
<td>-0.1</td>
<td>0.8</td>
<td>0</td>
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<tr>
<td>2. Fish Population</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>3. Pollution</td>
<td>-0.2</td>
<td>-1</td>
<td>0</td>
<td>-0.2</td>
<td>0</td>
</tr>
<tr>
<td>4. Livelihood</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. Laws</td>
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<td>Centrality</td>
<td>Absolute value of either (a) overall influence in the model (all + and – relationships indicated, for entire model) or (b) influence of individual concepts as indicated by positive (+) or negative (−) values placed on connections between components; indicates (a) the total influence (positive and negative) to be in the system or (b) the conceptual weight/importance of individual concepts (Kosko 1986a). The higher the value, the greater is the importance of all concepts or the individual weight of a concept in the overall model.</td>
</tr>
<tr>
<td>C/N</td>
<td>Number of connections divided by number of variables (concepts). The lower the C/N score, the higher the degree of connectedness in a system (Özesmi and Özesmi 2004).</td>
</tr>
<tr>
<td>Complexity</td>
<td>Ratio of receiver variables to transmitter variables. Indicates the degree of resolution and is a measure of the degree to which outcomes of driving forces are considered. Higher complexity indicates more complex systems thinking (Eden et al.1992; Özesmi and Özesmi 2004).</td>
</tr>
<tr>
<td>Density</td>
<td>Number of connections compared to number of all possible connections. The higher the density, the more potential management polices exist (Özesmi and Özesmi 2004; Hage and Harary 1983).</td>
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<td>Hierarchy Index</td>
<td>Index developed to indicate hierarchical to democratic view of the system. On a scale of 0-1, indicates the degree of top-down (score 1) or democratic perception (score 0) of the mental model (McDonald 1983).</td>
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\[
D = \frac{C}{N(N-1)} \quad h = \frac{12}{(N-1)N(N+1)} \sum_{i} \left( \frac{\text{od}(v_i) - \left( \frac{\sum \text{od}(v_i)}{N} \right)}{N} \right)^2
\]
### Comparison of Structures

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Values in Mean (SD)

Comparison of Structures

Number of components and type of components

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Complexity is a measure of the amt of Receiver to Driver components and indicates the degree of resolution in the model.
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Density is a measure of potential change within the system.
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<td>8(3.47)</td>
<td>8.8(3.90)</td>
<td>10.33(3.72)</td>
<td>10.67(4.50)</td>
<td>20</td>
</tr>
<tr>
<td>Number of Connections</td>
<td>26.22(7.70)</td>
<td>22.5(13.80)</td>
<td>25(13.80)</td>
<td>27.33(7.60)</td>
<td>40.67(19.00)</td>
<td>117</td>
</tr>
<tr>
<td>C/N</td>
<td>1.65(0.30)</td>
<td>1.66(1.24)</td>
<td>1.42(0.23)</td>
<td>1.41(0.30)</td>
<td>2.56(1.02)</td>
<td>4.34</td>
</tr>
<tr>
<td>Complexity (R:D)</td>
<td>0.34(0.40)</td>
<td>0.38(0.49)</td>
<td>0.27(0.22)</td>
<td>0.50(0.58)</td>
<td>0.17(0.29)</td>
<td>0.17</td>
</tr>
<tr>
<td>Density</td>
<td>0.11(0.02)</td>
<td>0.14(0.01)</td>
<td>0.11(0.04)</td>
<td>0.09(0.02)</td>
<td>0.12(0.08)</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Values in Mean (SD)

Scientists see the more components in the system, more complexity in the system, but less amount of room for change.
Knowledge Function

\[ x [1,1,1,1,1,\ldots] \]

Scenario State

- Steady State

Relative Change

Components in the FCM can be increased or decreased to understand how the system would react under a range of policy, social, or environmental changes (Kosko 1986)
Comparison of Function

Scenario: Increase Summer Flounder Population

Increase in recreational and commercial fishing, coastal community, fishing pressure and reproduction/spawn
Comparison of Function

Scenario: Increase Summer Flounder Population

Increase in **recreational** and commercial fishing, coastal community, fishing pressure and reproduction/spawn

Increase in recreational and commercial fishing, and **coastal community**
Comparison of Function

Scenario: Increase Summer Flounder Population

- Increase in recreational and commercial fishing, coastal community, fishing pressure and reproduction/spawn
- Increase in recreational and commercial fishing, and coastal community
- Increase in recreational fishing, coastal community, reproduction/spawn, and fishing pressure
Comparison of Function

Scenario: Increase Summer Flounder Population

Increase in **recreational** and commercial fishing, coastal community, fishing pressure and reproduction/spawn

Increase in recreational and commercial fishing, and **coastal community**

Increase in **recreational** fishing, coastal community, reproduction/spawn, and fishing pressure

Increase in reproduction/spawn, fishing pressure, and predators, and Decrease in **prey**
Comparison of Function

Scenario: Increase Summer Flounder Population

Increase in recreational and commercial fishing, coastal community, fishing pressure and reproduction/spawn
Increase in recreational and commercial fishing, and coastal community
Increase in recreational fishing, coastal community, reproduction/spawn, and fishing pressure
Increase in reproduction/spawn, fishing pressure, and predators, and Decrease in prey
Increase in summer flounder population and Decrease in fishing pressure
Outline

• Overview of Fuzzy-logic Cognitive Mapping
  – Fuzzy Numbers and Fuzzy Sets
  – Cognitive Mapping
  – Doing the calculations the old fashioned way:
    • Structural Metrics
    • Functional Metrics

• Introduction to Mental Modeler
  – Case study of Collaborative Modeling for Citizen Scientists

• New Analytical Capabilities coming soon!
  – Integrating MMP files into R

• Building a Model
  – How do stakeholders view the relationship between logging, economic development and wildlife habitat?
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  - *How do stakeholders view the relationship between logging, economic development and wildlife habitat?*
Case Study: Collaborative land management in Virginia
www.collaborativescience.org

Welcome to Collaborative Science!
This project is intended to help engage individuals in using technology to conduct locally based, but regionally connected, natural resource stewardship projects. We will use a series of web-based modeling and social media tools to engage Virginia Master Naturalists in conducting authentic science. This includes making field observations, engaging in collaborative discussions, graphically representing data, and modeling ecological systems. The goal of these efforts is to allow volunteers to engage in open-space conservation.

Announcing Collaborative Science Grants
We are pleased to announce the availability of funds to support citizen science projects within the Virginia Master Naturalists. This money, provided through grants to chapter members or through reimbursements of materials of up to $1,000, is available thanks to a grant from the National Science Foundation. Please download the Collaborative Science Grant Application for more information.

Stream Protection

A local chapter of Virginia Master Naturalists volunteers interested in local land issues and developing an evidence-based management plan.

Private land owners lease their land to farmers.

Farmers who want to increase grazing capacity and economic benefits from cattle production.

State agencies and land owners are concerned about water quality.
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State agencies and land owners are concerned about water quality.

Research/Management Question: How can management decisions balance environmental and economic needs?
Supporting the model with Evidence

Data Collection (Monthly):
- Bacterial Coliform and E. Coli Presence/Absence Cows
- Sedimentation
- Prior Stream Buffering
Supporting the model with Evidence

Data Collection (Monthly):
Bacterial Coliform and *E. Coli*
Presence/Absence Cows
Sedimentation
Prior Stream Buffering

Water Entering Property
Water on Site
Supporting the model with Evidence

Data Collection (Monthly):
- Bacterial Coliform and E. Coli
- Presence/Absence Cows
- Sedimentation
- Prior Stream Buffering
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Introducing: FCM Scenario*

R-Package with Shiny User Interface
(still under development)

*working title
Objectives

- Provide **addition** to Mental Modeler (... and other FCM software)
- Enable complex FCM simulation and analysis - no programming background required
- Flexible: Open source code in R to facilitate further development
- Web-based: no need to install software
- Free
If <Variable 1> and <Variable 2> then Operation 1
Modeled after workflow

• Build FCM model / Knowledge Capture with Mental Modeler
• Refine FCM Model
• Define scenarios for simulation
• Run simulations
• Analyze and visualize results

Upload from Mental Modeler or .csv file
Define squashing function (binary, sigmoid, hyperbolic tangent, ...) for all concepts of each concept individually. In the near future: define your own squashing function.
Define squashing function (binary, sigmoid, hyperbolic tangent, ...) for all concepts of each concept individually.

In the near future: define your own squashing function

“Clamp” Concepts
Build interesting scenarios and run them together

Can be automated: Program finds all scenarios (Condition: concept states are 0 or 1 and weights are -1, 0, 1)
Show and compare results for each scenario

Analysis per concept
Network Plot
Display Iteration:

Green (+ve), Blue (0), Red (-ve)

Display change of concepts iteration by iteration
Future plans and how you can help

• Test and further refine, go life (We need daring beta testers!)
• Document R package for further development (Collaborators welcome!)
• Please send e-mail if you want to stay informed: ajetter@pdx.edu
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Modeling Logging in the Pacific Northwest
Henly-Shepard, S., Gray, S., and Cox, L. Facilitating community adaptation through participatory modeling and social learning (in press) *Environmental Science and Policy*

Funding: USDA
NSF (Belmont Forum)
Agriculture, Food Security & Climate Change: Sustainable Management of Agro-ecological Resources for Tribal Societies
Academic: 76%
Government: 13%
NGO: 11%
Area of Study
Thanks for coming!

stevenallangray@gmail.com
ajetter@pdx.edu