

Forest Sustainability

Measurement, Interpretation, and Assessment

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Applied Ecosystem Services, Inc.

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Forest Sustainability

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Fuzzy Sets, Fuzzy
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Summary

- Sustainability is an abstract concept that cannot be directly measured.
- There is large political and social pressure to measure and assess sustainability.
- Indicators are being developed that are believed to reflect various aspects of sustainability.
- Interpreting and combining indicators is a frustrating exercise.

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What This Presentation Includes

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- 1 Introduction to fuzzy sets and fuzzy logic.
- 2 Why fuzzy system models solve problems.
- 3 How an approximate reasoning model assesses forest sustainability.

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- Fuzzy set theory developed 40 years ago by Lotfi Zadeh to express the concept of partial truth characterized by uncertainty.
- Results are more accurate mathematical representations of truth perception than can be expressed by crisp sets.
- *Perception* refers to how the human brain observes and expresses reality.
- *Perception* also refers to natural and artificial languages.
- Applying fuzzy set theory to move from crisp (true/false) mathematics to fuzzy mathematics allows us to express natural language mathematically.

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Definition

Fuzzy set

A collection of similar items which allow partial memberships across a continuous range of membership values.

Examples:

Plants

There are two sets, *Peach* and *Plum*. However, the *Nectarine* is a member of both sets to some degree as it is a hybrid of both pure fruits.

Animals

There are two sets, *Horse* and *Donkey*. They can be mated to produce a *Mule*, which is a partial member of both sets.

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Definition

Fuzzy logic

The formal methods embodied in fuzzy set theory in which the conventional binary logic based on choices “yes” and “no” is replaced with a continuum of possibilities that effectively embody the alternatives “maybe” or “somewhat”.

Approximate reasoning

The application of fuzzy set theory and fuzzy logic in fuzzy systems that mimic the way humans make decisions based on expertise and common sense. Approximate reasoning models use IF-THEN rules to express the consequences of antecedent conditions.

Example

The expression, *that forest is big*, can now be mathematically described by a fuzzy set, *Big*, in which the *forest* belongs to some degree. That is, how true is it that the *forest is big*?

- A major element of the transition from crisp to fuzzy is **possibility theory**.
- These possibilities are distributed in a *membership function*.
- Membership function concept completes the mathematical formulation of *that forest is big*, and of more complex concepts in daily language.

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Fuzzy Multi-Expert and Multi-Criteria Decision Making



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- Major advantage of approximate reasoning systems is ability to assimilate and use knowledge from multiple experts.
- These experts can be conflicting, cooperating, or collaborative.
- Conflicting expert opinions can be incorporated into the results.
- Disagreements over the meaning of social, environmental, and economic numbers common among experts.
- Defining and assessing *sustainable* is the type of complex system resolved only with approximate reasoning techniques.

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Example

Prime Rate Movement Model 1

```
[Expert A]: IF PrimeRate[t-1] is greater than PrimeRate[t]
              THEN InvestmentPolicy is Aggressive;
```

```
[Expert B]: IF PrimeRate[t-1] is greater than PrimeRate[t]
              THEN InvestmentPolicy is Conservative
```

Example

Prime Rate Movement Model 2

```
[Expert A]: IF PrimeRate is MovingDOWN  
            THEN InvestmentPolicy is Aggressive;
```

```
[Expert B]: IF PrimeRate is MovingDOWN  
            THEN InvestmentPolicy is Conservative;
```

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Example

New Product Pricing Model

```
[R1] our Price must be High;  
[R2] our Price must be Low;  
[R3] our Price must be Around 2*MfgCost;  
[R4] if the CompetitionPrice is not Very_high  
then our Price must be Near CompetitionPrice;
```


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- **Important Point:** Experts can have relative weights assigned to them:
 - Adaptive Peer Ranking Parameter:
$$P_{truth} = (1 + R_{peer}) * P_{truth}$$
 - Peer Ranking by Membership Modification:
$$\mu_A[X] = \mu_A^{1-R_i}[X]$$

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- Use fewer rules than do conventional numeric or expert models.
- Use natural language of experts, decision makers, and the public.
- **Uncertainty** and imprecision are what are modeled.
- Tuning, sensitivity analyses, and testing done quickly and easily.
- Possibilities more representative of the real world than are probabilities.
- Components beyond human control (e.g., fire, wind throw) incorporated into the model.

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Corporations Using Fuzzy Logic Solutions

- Shearson-Lehman (portfolio safety and suitability)
- Boeing Corporation (manufacturing optimization)
- BP Corporation (petroleum refining and transportation)
- Dow Chemical (project risk analysis)
- IBM (managed health care fraud detection)
- American Express (credit capacity and stress prediction)

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Fuzzy Logic Business Applications

- Risk assessment/management (banks, credit card companies)
- Fraud detection (medical provider, consumer)
- Project management
- Scheduling
- Drug concentrations for maximum therapeutic value
- Investment portfolio safety and stability
- Data mining

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“Fuzzy logic theory is very broad and is perhaps the only theory that easily propagates into multiple disciplines such as sociology, biology, psychology, artificial intelligence, linguistics, engineering, medicine, law and so forth. **This is due to the capability of computing with words in a manner no other method can cope with.**”

– *Riza C. Berkan, Univ. of Tennessee*

These models work because they are based on so *what?* rather than on *what*.

The model is completely transparent. That is, it is easy to see how it works and to understand it.

- Input options:
 - 1 Expert knowledge (IF-THEN rules, variables, fuzzy sets, hedges).
 - 2 Existing databases (harvest rates, listed species populations).
- Output options:
 - 1 Linguistic, with possibility value.
 - 2 Crisp numeric value.
- You and the technical work group are the experts who determine how the model is structured and works. No outside experts limiting your options by the way they created the model.

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Definition

A *policy* is a block of similar events or conditions that is treated the same as a sub-model.

In a forest sustainability model, each major and minor category can be a separate policy.

Each policy is evaluated by itself, then aggregated into the whole result.

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1 Diverse Plant and Animal Populations:

- 1 Populations
- 2 Forest Structure
- 3 Ecosystem Diversity

2 Legal, Institutional, Economic Framework

- 1 Monitoring
- 2 Legal
- 3 Economic
- 4 Recreational

Some indicators can be measured, others cannot. But, they can all be described with words.

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Summary

- Within each policy, indicator variables are interpreted by IF-THEN rules.
- These rules are expressed by subject matter experts, not by us.
- We do not set the relationships in the model, *you* and your experts do.
- IF-THEN rules can be unconditional or conditional, simple or complex.

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Rules:

- [R1] our Price must be High;
- [R2] our Price must be Low;
- [R3] our Price must be around $2 * \text{MfgCosts}$;
- [R4] if the CompetitionPrice is not Very_high
then our Price must be near the CompetitionPrice;

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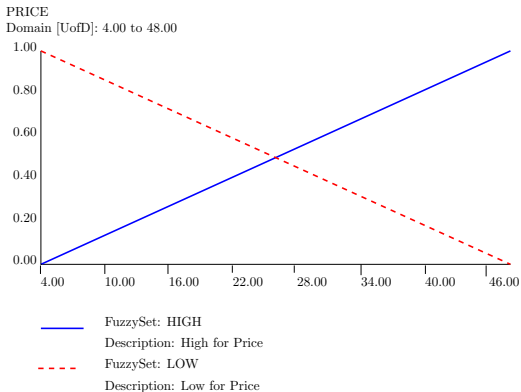
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Around $2 * \text{MfgCost}$ Price

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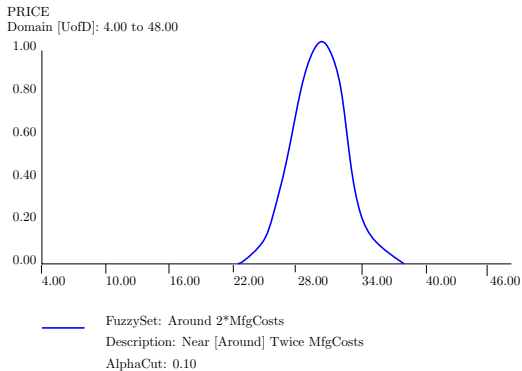
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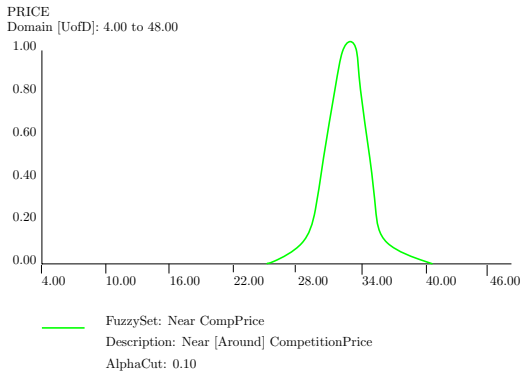
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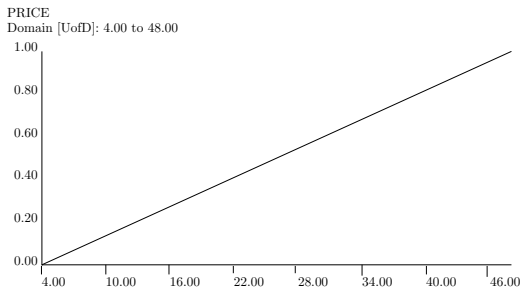
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— FuzzySet: PRICE
Description: The estimated product price
Rule1: our price must be HIGH

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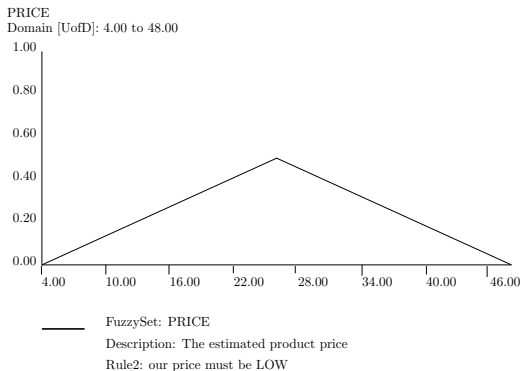
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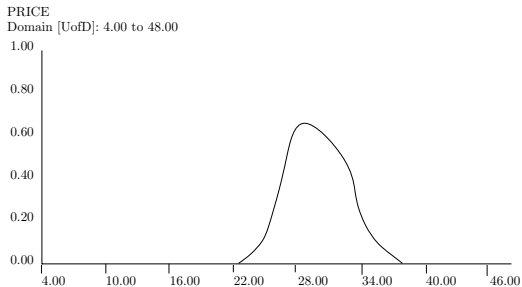
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— FuzzySet: PRICE
Description: The estimated product price
Rule3: our price must be AROUND $2 * MFGCOSTS$

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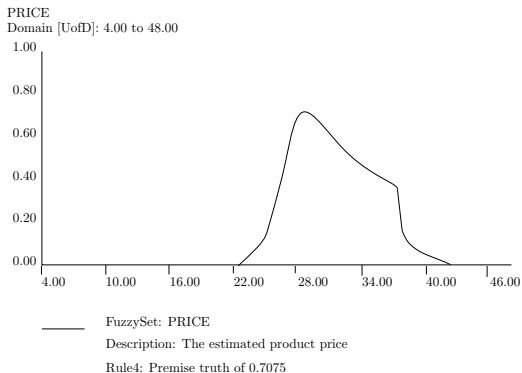
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'CENTROID' defuzzification. Value: 29.438, [0.5417]

Model Solution:

Price	=	29.44
CIX	=	0.54
SurfaceHght	=	0.71

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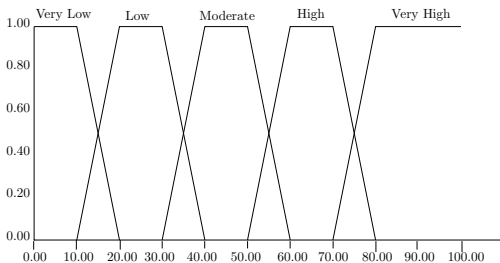
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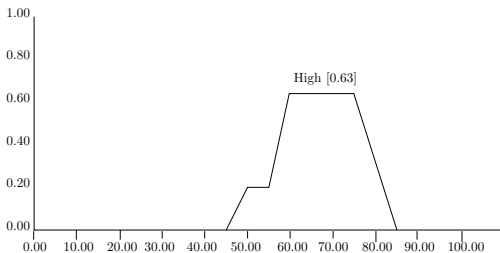
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- The result is an estimate of *Sustainability* measured on an arbitrary scale, e.g., 0-100.
- The variable, *Sustainability*, can be a single fuzzy set or partitioned into several sets such as *Very_low*, *Low*, *Moderate*, *High*, and *Very_high*.
- If a single fuzzy set, the result is defuzzified to a crisp number (and confidence index) that can be compared spatially and temporally.
- If multiple term sets, the result can be defuzzified or expressed linguistically.

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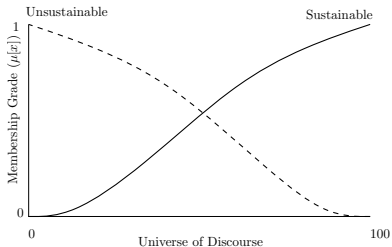
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S-curve Membership Function

Thresholds approached asymptotically.
Change is gradual and varies across the Universe of Discourse.

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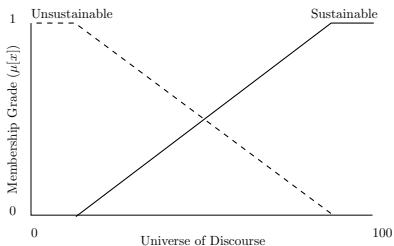
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Shouldered Membership Function

Distinct thresholds when $\mu[x] = 0.0, 1.0$.

Sudden transition and constant rate of change between shoulder thresholds.

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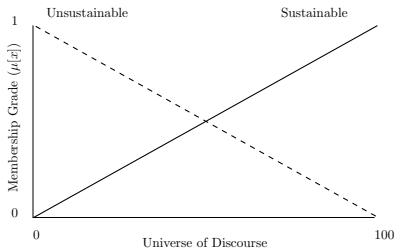
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Straight Membership Function

No threshold.
Constant rate of change in
membership grade across
the Universe of Discourse.

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- The approaches used so far are subjective and unsatisfactory.
- Approximate reasoning models work with words and numbers; focus is on *so what?*, not *what*.
- Subjective values are quantified and modeled with mathematical rigor.
- Risk assessments of highly complex systems are the strength of fuzzy system models.
- Multiple, conflicting expert opinions all included in the output values.

Benefits of Approximate Reasoning Models

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