The Columbia River System: Water, Fish, People

Making Technically Sound, Legally Defensible Decisions on River Operations

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Driving Force

- US District Judge James Redden demands a "good" solution from NMFS and associated agencies.
- The system is very large, extremely complex, and highly variable.
- The existing tools have not worked adequately over the past 15 years.
- There is no consensus goal among all stakeholders.

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What This Presentation Includes

1. What we want to do.
2. Why previous efforts fell short.
3. How approximate reasoning models yield pragmatic solutions.
4. How to create a better Columbia River operations model that supports decisions.

Legal Goals

1. Resource agencies must produce an action plan acceptable to the court.
2. All constraints of the Endangered Species Act (ESA), National Environmental Policy Act (NEPA), and other environmental statutes must be met.
3. The process of plan development and its implementation must be legally defensible.

Political Goals

1. The solution must be accepted by all levels of government.
2. The solution must be acceptable across the political spectrum.
3. All economic sectors will find the solution acceptable, if not optimal or ideal.
4. The solution will survive changes in legislative and executive branches after elections.

Societal Goals

1. Must accommodate all river uses:
    1. Hydroelectric power generation.
    2. Irrigation of agricultural fields.
    3. Transportation of goods from the interior via barge tows.
    4. Recreational opportunities such as boating, fishing, windsurfing.
    5. Fish and wildlife habitats with emphasis on anadromous salmonids.
2. Acceptable to industry, business, preservationists.
3. Affordable implementation and maintenance.
4. Goals and objectives must be measurable and proof of progress toward them demonstrated.

Where Are We Going?

- What do we mean by "save the salmon?"
- How many individuals of each species are in a self-sustaining population?
- Do we want fish to catch commercially, for sport, and tribal treaty rights?
- Are æsthetics – the "heritage of the PNW" – the most important consideration?
- How do we know we're on the correct path? Where are we relative to our goal? How will we know when we get there?

Framing the Problem

- Columbia River basin drains almost 260,000 square miles.
- Many physiographic provinces.
- Five salmon species; two trout species.
- Diverse land uses from mountain wilderness to urban.
- Many political entities with control over different or overlapping areas.

Constraints

- Insufficient data and not uniformly distributed over the basin.
- Different levels of effort among agencies based on budgets and other priorities.
- No overall agenda because of varying statutory requirements.
- Must convince broad audience that solution works, and why it works.

Wrong Tools Used I

Example

Numeric Fish Passage/Survival Models

- Too many assumptions required.
- Data not available for all areas and all times.
- Relationships are rigid.
- Cannot realistically accommodate uncertainty.

Wrong Tools Used II

Example

Statistical Models

- Water quality data as predictor.
- Hatchery fish behavior versus stream-spawned fish behavior.
- Too spotty in coverage.
- Invalid for time series analyses.

Wrong Tools Used III

Example

Theoretical Concepts

- Many ecological theories are great concepts, but cannot be translated into real world applications.
- Lack of relevance to Columbia River system.
- Not technically sound or legally defensible.

Perspective

"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*.

Definitions I

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.

Definitions II

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.

Foundations

- Fuzzy set theory developed 40 years ago by Lotfi Zadeh to express the concept of partial truth characterized by fuzziness.
- 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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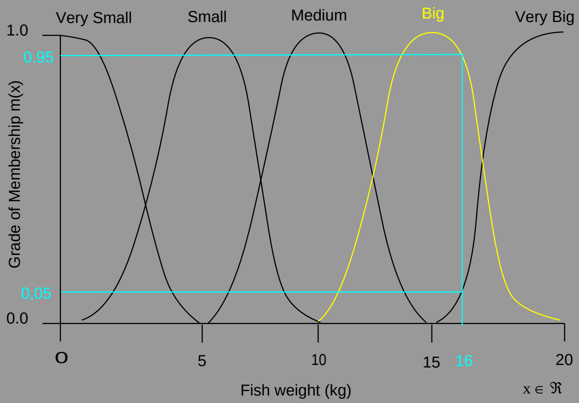
Foundations II

Example

The expression, *that fish is big*, can now be mathematically described by a fuzzy set, *Big*, in which the *fish* belongs to some degree. That is, how true is it that the *fish* 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 fish is big*, and of more complex concepts in daily language.

Foundations III



General Business Examples I

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)

General Business Examples II

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

Fuzzy Multi-Expert and Multi-Criteria Decision Making

- 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 fish, water flow, and economic numbers common among experts.
- Operation of the Columbia River system and balance among fish, water, and people is type of complex system resolved only with approximate reasoning techniques.

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Conflicting Experts

- Frequently the situation in complex business models involving:
  - Stock market position.
  - Prime interest rate movement.
  - Pricing decisions.
  - Portfolio rate of change.
- Conventional expert systems use crisp decision thresholds.
- When decision strategies are literal strings, expert systems and numeric models fail.
- The recommended strategy is that of the last executed rule, with unpredictable results.

Fuzzy Expert Systems I

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 less than PrimeRate[t]
                 THEN InvestmentPolicy is Conservative
```

Fuzzy Expert Systems II

Example

Prime Rate Movement Model 2

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

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

Fuzzy Expert Systems III

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;
```

Distinguishing Among Experts

- 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: $\mu_A[x] = \mu_A^{1-R_i}[x]$

Multi-Objective

The Columbia River system must include and balance competing uses:

- Fish and wildlife support.
- Hydroelectric generation.
- Barge transport of agricultural goods.
- Recreation.
- Irrigation water supply.
- Potable water for municipalities and urban areas.
- International maritime commerce.

Multi-Criteria

Each objective must be evaluated by several criteria

- Land cover/land use.
- Economic value.
- Political considerations.
- Jobs, taxes, transportation.
- Quality of life concerns.
- ESA-mandated considerations:
  - Habitats.
  - Dam effects on juvenile and adult salmonids.
  - Harvest policies (fresh water and marine).
  - Hatchery operations and policies.

Complex Modeling

- 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., ocean conditions) incorporated into the model.

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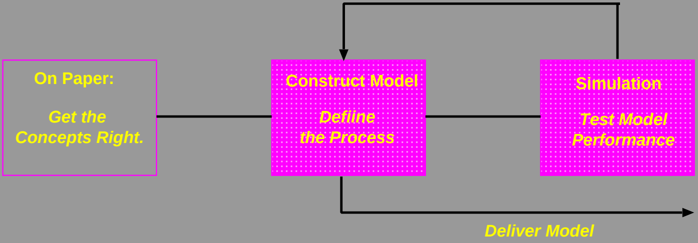
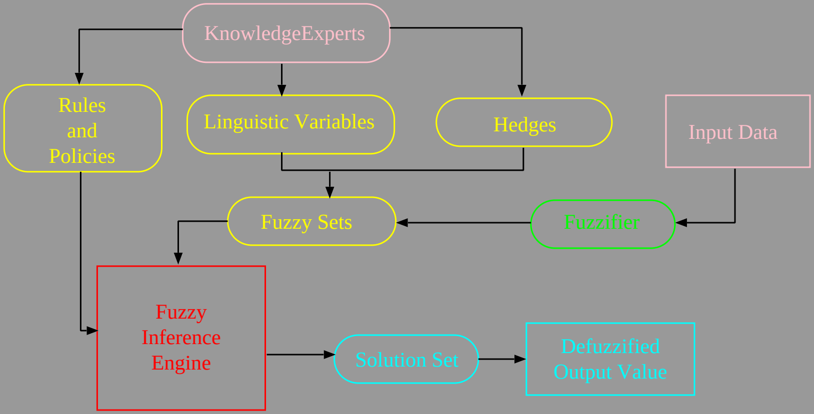
Generic Organization I



Generic Organization II



Features

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 (water quality, flow volumes, fish counts).
- Output options:
  1. Linguistic, with possibilty value.
  2. Crisp numeric value.

Systems Properties and Problem Types

Definition

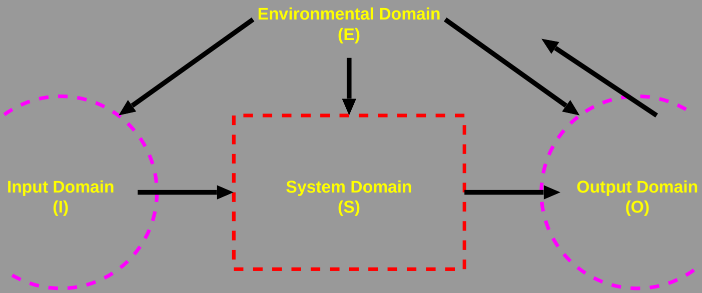
A system is defined as a process, event, or mechanism. It can be characterized analytically, algorithmically, symbolically, or linguistically within defined boundaries. A system can be physical, numerical, or conceptual.

Information Domains

Each system is defined relative to four basic information domains:

1. Input
2. System
3. Environment
4. Output

Information Domains II



Information Domains: Columbia River

For Columbia River dam operations a possible set of domains is:

Input	Fish
Environment	Passage Route
System	Dam
Output	Survival

Forward Problems Type

- Construct **Output** domain based on **Input**, **System**, and **Environment** domains.
- Typical forward problem is one of estimation, prediction, or forecast.
- Can incorporate costs (e.g., monetary, political, social).

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Estimation, Prediction, Forecast

- Terms used interchangeably.
- All guess a future outcome; time is implicit.
- Time can be clock time or sequence.
- Expressed by $O_{t+1} = S\{I_t, E_t\}$.
- Solution can be numbers or risk.

Inverse Problems

- Construct **Input** domain based on **Output**, **System**, and **Environment** domains.
- Control problems have two input domains: not controllable, and controllable.
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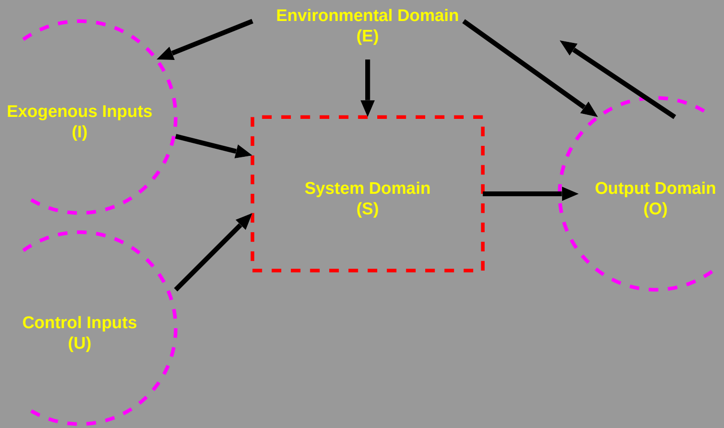
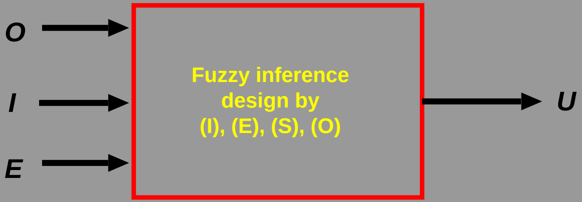


Control Problem Definition II



Model Organization: Policies

Definition

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

In a Columbia River model, each dam can be a separate policy, so can political constraints, economic constraints, and societal values.

How To Proceed

1. Define the goal of the model; what is the decision factor?
2. Identify the main participants.
3. Identify potential experts for input (agencies, consultants).
4. Decide what supporting documentation is desired.
5. Achieve conceptual agreement on what is to be provided and the value added to the organizations.

Benefits of Approximate Reasoning Models

- The approaches used so far are litigated and rejected.
- 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.

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