Fuzzy Systems in the Wild

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Outline

- Introduction
  - Fuzzy Sets
  - Type-1, Interval Type-2, General Type-2 Fuzzy Sets
  - Fuzzy Systems

- Fuzzy Logic Toolboxes
  - Overview
  - Juzzy – a Java based toolkit
  - Demo / Examples

- Applications
  - From Intervals to Words
  - FLSs in Environmental Conservation

- Questions
Fuzzy Set = ?
Crisp Sets

μ

1.00

Prime Numbers
Crisp Sets

\[ \mu \]

- Reals Less Than 20
Crisp Sets?

μ

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Young
Fuzzy Sets

Graph showing a function $\mu$ of age. The function decreases rapidly from 1 to 0 as age increases, illustrating the concept of a fuzzy set where the membership grade $\mu$ decreases with age.
Linguistic Variables

A fuzzy set provides a relationship between an element and its grade of membership in that set i.e. the *truth* of the notion that the element belongs to the corresponding set.
Some different Types of Fuzzy sets …

- Fuzzy Sets capture degree of truth…
- Type-1, Interval Type-2 and General Type-2 Fuzzy Sets
- Modelling Capability and Complexity increase dramatically.
zSlices based General Type-2 Fuzzy Sets

- Drastically reduced complexity & highly parallelizable.
- Lots of applications from robotic control to ambient intelligent agents and most recently, modelling of expert opinion...
From Fuzzy Sets to Fuzzy Systems
Fuzzy Systems and Fuzzy Control

- Fuzzy systems/control are built on the framework of ‘fuzzy logic’ and ‘fuzzy sets’

- Fuzzy Logic is an extension of classical logic:
  - ‘conventional’, formal logic
    - false (F) and true (T)
  - Boolean logic
    - zero (0) and one (1)
  - fuzzy logic
    - ‘completely false’, ‘partially true’, ‘true-ish’, etc. (any value between 0 and 1)

- Fuzzy Sets support partial membership

**Fuzzy Sets:**
Things can be part of one or more sets to a degree (e.g. \( \mu_A(x) = 0.8 \))

**Crisp Sets:**
Something is either part or not part of a specific set (e.g. \( \mu_A(x) = 0 \) OR \( \mu_A(x) = 1 \))
Fuzzy Systems – Some History

- Fuzzy Logic introduced by Lotfi Zadeh in 1965 through introduction of Fuzzy Sets.

- First applications in control appeared quickly:
  - 1975: Cement Kiln in Denmark
  - 1985: Sendai Railway in Japan (braking, acceleration)

- Traditionally, Fuzzy Logic based applications have been embraced in Asia – less so in the West.

- However, today there are a vast number of applications in control and beyond.

VW DSG gearbox   Panasonic FL rice cooker   Samsung FL washing machine   CNC milling   …and of course - robots
Fuzzy Inference for FLSs

- Fuzzy Inference is the process underlying (most) fuzzy logic systems (FLSs).
- The inference process relates the input of an FLS to its output based on logical rules.
Fuzzy Inference – a basic example:

Illustration of Mamdani style fuzzy inference in a two rule system:

1. IF x is A\(_1\) AND y is B\(_1\) THEN C\(_1\)
2. IF x is A\(_2\) AND y is B\(_2\) THEN C\(_2\)

Defuzzify solution.
Interval Type-2 Fuzzy Systems

- Very similar to type-1 FLSs
- Keep track of the upper and the lower membership function
- Defuzzification is a bit trickier (use type-reduction to reduce an IT2 set to its type-1 centroid and then defuzzify that centroid)
zSlices based General Type-2 Fuzzy Systems

zSlices based general type-2 FLC

Crisp Inputs

Interval Type-2 FLC associated with zlevel $z_1$

Fuzzifier

Input Interval Type-2 Fuzzy Sets

Rule Base

Inference

Output Interval Type-2 Fuzzy Sets

Interval Type-2 FLC associated with zlevel $z_2$

Fuzzifier

Input Interval Type-2 Fuzzy Sets

Rule Base

Inference

Output Interval Type-2 Fuzzy Sets

... (Repetitive structure)

Fuzzifier

Input Interval Type-2 Fuzzy Sets

Rule Base

Inference

Output Interval Type-2 Fuzzy Sets

Defuzzifier

Crisp Outputs
OK, enough with the theory already!

How to build and use FLSs in Java
There are a variety of toolkits available to develop Fuzzy Logic based applications, e.g.:

- And other sources, in particular source code snippets…
Juzzy – Java based Fuzzy Logic Toolkit

“An object-oriented toolkit for the development of

- type-1,
- interval type-2 and
- general type-2 fuzzy systems.”

Freely available, open source: http://juzzy.wagnerweb.net/
Why object-oriented design makes it easy...
Example – The tipping problem

- We would like to determine the amount of tip (as a percentage) one should give to the waiting staff based on two variables: the quality of the food and the level/quality of service provided by the member(s) of waiting staff.

- Inputs
  - Food: [0, 10]
  - Service: [0, 10]

- Output
  - Service(%): [0, 30]

- Three FLSs: type-1, interval type-2 and zSlices based general type-2
Type-1 FLS
Interval Type-2 FLS
zSlices based general type-2 FLS
Applications beyond “Control”?
2 Examples:

- From Intervals to words
- Modelling of conservation processes
Deriving Fuzzy Sets From Expert Opinion

Problem: Multiple experts, each providing interval based answers.
- Intra-expert uncertainty (different answers on different days)
- Intra-expert uncertainty (different answer by different experts)

Overall, how would you rate this eating place?

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<th>Expert A</th>
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1st | 2nd | 3rd
0   | 10  | 20  | 30  | 40  | 50  | 60  | 70  | 80  | 90  | 100
From Intervals to Fuzzy Sets

Diagram showing intervals on the left and a fuzzy set on the right.
From Intervals to Fuzzy Sets

If we repeat this process for multiple experts:
From Intervals to Fuzzy Sets

- Resulting General Type-2 Fuzzy Set Models capture intra- and inter-expert uncertainty.

- Computation & Inference with the resulting models
- Current work largely based on similarity

Modelling of Conservation Processes

- Data-Driven Environmental Policy Design
  - An EPSRC funded joint project between:

- Objective:
  - Operationalize and develop a partially existing environmental management framework.
  - Transparently capture and aggregate both qualitative information from stakeholders and quantitative information from sensors etc. to enable informed policy design and feed-back/
Natural Conservation Project

- Natural Diversity Recovery Catchment - Recovery Plans
  - Wetlands are a “high-value” ecosystem
  - Based on a Values-Plan
  - Natural resource management framework that is driven by human values (cf. Wallace 2012).

Thank you! 😊

- Questions?

- Coming up – transferring FLS design to the cloud!