Fuzzy Systems

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Lecture Outline

- Fuzzy systems
- Developing fuzzy systems
- Advantages of fuzzy systems
- Disadvantages of fuzzy systems

Fuzzy Systems

- Three major components
  - Fuzzy membership functions
  - Fuzzy rules
  - Fuzzy inference engine

Fuzzy Systems

- Membership Functions
  - numerous types available
    - Gaussian, Triangular, Singleton, Trapezoidal
  - each type has different parameters
    - e.g. centre, spread
  - parameters effect the output of the function

Fuzzy Systems

- Fuzzy Rules
  - map fuzzy facts to fuzzy conclusions
  - different antecedent operators
- AND, OR, NOT
  - consequents
- Zadeh-Mamdani
- Takagi-Sugeno

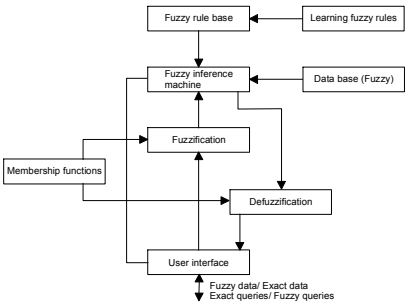
Fuzzy Systems

- Fuzzy inference engine
  - final result depends on
    - inference
    - composition
    - defuzzification

Fuzzy Systems

- Used in fuzzy expert systems
- Like other expert systems, but knowledge base is a fuzzy logic system

Fuzzy Systems



Developing a Fuzzy System

- Steps
  - identify the problem
  - define the input and output variables
  - define the membership functions
  - define the fuzzy rules
  - select the inference / composition methods
  - select the defuzzification method
  - validate the system

Developing a Fuzzy System

- Identify the problem
  - most essential step of solving any problem
  - if you don't know what the problem is, how can you solve it?
  - is the problem clearly defined?
  - what are the goals of the system?

Developing a Fuzzy System

- Identify the problem
  - is the problem suited to a fuzzy system?
  - will one fuzzy system do, or are several needed?
- modular approach
- easier to optimise

Developing a Fuzzy System

- Define the input and output variables
  - are all available input variables needed?
  - are all available output variables needed?
  - data analysis
  - ranges of the variables
- universe of discourse
  - variation of the variables
- implications for MF design

Developing a Fuzzy System

- Define the membership functions
  - what type to use?
    - Gaussian smoothly tends towards zero
    - Triangular has a more constant slope
    - Singelton useful for binary values
    - Rectangular good for clear, non-overlapping groups
    - Trapezoidal combines triangular and rectangular

Developing a Fuzzy System

- Define the membership functions
  - what parameters?
  - spread of each MF
  - distribution of the MF
  - labels attached to each MF
    - meaningful

Developing a Fuzzy System

- Define the fuzzy rules
  - main problem in developing fuzzy systems
  - how to get them?
    - expert
    - extract from data
      - clustering
    - extract from learning algorithm
      - ANN
      - EA

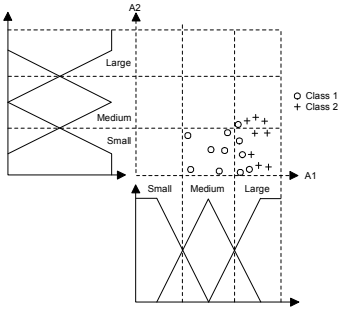
Developing a Fuzzy System

- Rules from experts
  - does the developer understand the problem?
    - Can the developer define the rules themselves?
    - Can the developer understand the expert well enough to transcribe accurate rules?
  - does the expert understand fuzzy logic?
    - Can the expert define the rules directly?
    - Can the expert verify the rules created by the developer?

Developing a Fuzzy System

- Rules from data
  - use a clustering method
  - clusters of a class indicate regions to define with rules
    - a rule defines a region

Rules from Clusters



Developing a Fuzzy System

- Rules from learning systems
  - Artificial neural networks (ANN)
    - train an artificial neural network
    - analyse the connection weights
  - devise fuzzy rules from those weights
  - Evolutionary Algorithms (EA)
    - use performance of system to drive evolution

Developing a Fuzzy System

- Completeness of the rules
  - do the rules cover the entire input space?
  - what happens if they don't?
    - is "no response" acceptable?
  - contradictions in the rules?
  - combine or split OR'd rules?

Developing a Fuzzy System

- Select the inference / composition methods
  - different methods give very different results
  - how to choose them?

Developing a Fuzzy System

- Select the defuzzification method
  - many to choose from
  - each gives different crisp results
  - issues
    - speed
    - accuracy

Developing a Fuzzy System

- Validate the system
  - involves
    - gathering test data
    - evaluating performance of system
    - adjusting as necessary
  - testing system *in situ*
    - does the system give results the experts are happy with?
    - does it fail gracefully?

Developing a Fuzzy System

- Making adjustments
  - improve performance
  - correct errors
- Adding / deleting rules
  - modularity of rules helps here
- Altering inference / composition / defuzzification methods

Developing a Fuzzy System

- Modifying MF
  - alter
    - types
    - parameters
- Adding / removing variables
  - modularity of rules helps again here

Developing a Fuzzy System

- Adjustment gotchas
  - a change in the MF may require a change in the rules
  - a change in the rules may require a change in the MF
  - a change in the inference process will effect everything else
- optimisation is difficult

Advantages of Fuzzy Systems

- Universal function approximators
  - given enough rules, a fuzzy system can approximate any function to any degree of precision
  - number of rules required smaller than crisp rule based function approximator

Advantages of Fuzzy Systems

- Comprehensibility
  - well crafted fuzzy rules are easy to understand
    - requires meaningful labels for MF
  - makes a fuzzy expert system a "white box"
    - See workings of the system

Advantages of Fuzzy Systems

- Modularity
  - rules can be added and removed as needed
  - eases development
    - start with a small number of rules
  - add as necessary to improve performance
  - remove redundant rules to improve execution speed
  - optimise individual rules

Advantages of Fuzzy Systems

- Explainability
  - execution trace
  - which rules fired
  - explains how system reached conclusion

Advantages of Fuzzy Systems

- Uncertainty
  - rules can fire even if all antecedents don't match
  - can deal with inexact concepts
    - smaller, faster etc.
  - each rule corresponds to a wider range of input values

Advantages of Fuzzy Systems

- Parallel execution of rules
  - output calculated once at end of cycle
  - rules are evaluated in parallel
  - order does not matter
  - no need for execution selection methods
- Compare to crisp rules
  - order of rule execution can alter output of system

Disadvantages of Fuzzy Systems

- Computational cost
  - more computations involved
    - fuzzification
    - fuzzy operators
    - composition of output fuzzy set
    - defuzzification
  - complex MF can aggravate this problem
    - simple triangular vs.. *S* or *Pi* functions

Disadvantages of Fuzzy Systems

- Defining the rules
  - where do the rules come from?
  - major problem with rule-based systems
  - need to get enough rules to be accurate
  - rules need to be expressive
    - comprehensibility
  - rules need to be accurate

Disadvantages of Fuzzy Systems

- Optimisation
  - a change in the MF can require a change in the rules
  - a change in the rules can require a change in the MF
  - each parameter / choice effects the others
  - multi-parameter optimisation problem

Summary

- Identifying the problem is the most important step of developing a fuzzy system
- Data analysis can help in determining the variables to include in the system
- Care must be taken in defining the membership functions
  - data analysis can again help with this

Summary

- Biggest problem with fuzzy systems in defining the rules
- Rules can come from several sources
- Fuzzy rules more expressive than crisp rules
  - need fewer of them
- Modular nature of the rules make development easier

Summary

- Fuzzy rule based systems overcome most of the problems with crisp rule based systems
- It can be difficult to optimise fuzzy systems
  - MF <-> Rules <->Inference methods