Lecture Series on

Intelligent Control

Lecture 17

Fuzzy Logic Systems

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Overview

Fuzzy logic was first introduced by Zaheh [1965, 1973], as a means for handling and processing vague, linguistic information.

He reasoned that "conventional qualitative techniques of system analysis are intrinsically unsuited for dealing with humanistic systems,"

and formulated this in his *principle of incompatibility*:

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Overview

As a complexity of system increases, our ability to make precise and yet significant statements about its behavior diminishes,

until a threshold is reached beyond which *precision* and *significance* (or relevance) become almost mutually exclusive characteristics.

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Overview

Fuzzy logic has been developed to provide *soft* information processing algorithms, which can reason about and utilize *imprecise* data.

It allows variables to be *partial* members of a particular set and uses generalizations of the conventional Boolean logical operators to manipulate this information.

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Overview

By allowing partial membership of a set, it is possible to represent the *smooth* transition from one rule to another as the input is varied smoothly, which is a very desirable property in modeling and control applications.

In contrast, conventional expert systems reason using hard, *crisp* rules and are unable to represent a smooth input, output transformation.

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Overview

The basic fuzzy theory and reasoning algorithms were developed in the late sixties, and the first control applications were investigated by Mamdani [1974] and his co-workers [Procyk and Mamdani, 1979].

During the eighties, many fuzzy logic control applications were developed, mostly in Japan; products ranging from subway and helicopter controllers to auto-focus camera mechanisms and washing machine controllers [Sugeno, 1985, Self, 1990], and it has also found a large product base in the automotive industry.

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Overview

Despite the many successful applications, there has been a notable lack of *rigorous analysis* associated with the development of the fuzzy systems.

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Fuzzy Representations

Fuzzy information is generally represented by a set of *fuzzy rules*, which provide relationships between vague quantities. These relationships are typically linguistic production rules of the form:

IF (the speed is higher than the set point) **AND** (the speed is decreasing)
THEN (keep the fuel constant).

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Fuzzy Representations

Each of the *linguistic statements*, such as *the speed is higher than the set point*, is represented using fuzzy sets. A fuzzy set allows partial membership, so that it can represent the fact that the speed is higher than the set point with a degree of belief (membership) 0.7.

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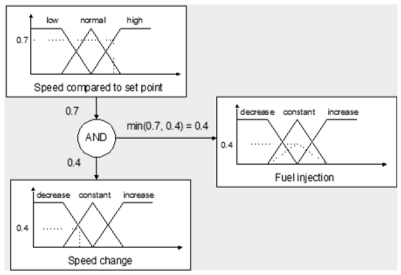
Fuzzy Representations



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Fuzzy Representations

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A set of such rules forms a fuzzy *algorithm* or a rule base, which is used to store imprecise knowledge, for instance the above rule could form part of a larger fuzzy rule base which attempts to control the fuel injection in the cruise control.

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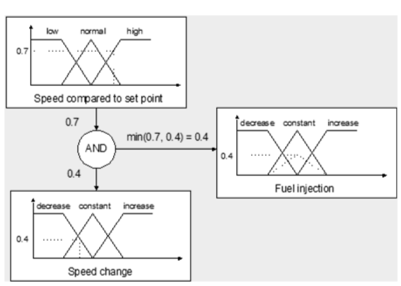
Fuzzy Representations



An implementation of a fuzzy rule. The dashed fuzzy output set represents the contribution of this rule to the system output.

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Fuzzy Representations

These *fuzzy knowledge bases* contain *imprecise* but significant information in the form of fuzzy rules.

However, this imprecision is completely resolved once the fuzzy input and output sets and the knowledge manipulation routines have been defined.

Two *precise inputs* are applied to the fuzzy system: the relative speed and the change of speed of a car.

The degree of membership of each of the linguistic fuzzy sets is calculated (*fuzzification*),

and this knowledge is combined to represent the degree of belief of the *antecedent* in the above production rule.

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Fuzzy Representations

The output of this fuzzy rule is the respective fuzzy output set which is scaled by a parameter, which signifies the confidence in this rule being true, and the overall fuzzy output set is formed from the contribution of each fuzzy rule.

A real-valued output is then obtained by *defuzzifying* this output set.

In practice, many fuzzy rules are used to generate the fuzzy output set and this *distributed representation* gives the fuzzy logic controller its ability to generalize locally (*interpolate*) between rules.

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Fuzzy Control

The most of fuzzy logic applications are in the modeling and control field [Schwartz, 1990].

The earlier applications were on ill-defined plants for which a complete mathematical analysis was not possible [Tong, 1977],

such as water and chemical reactor temperature regulation, pressure and mixture control, all of which are highly nonlinear, noisy and subject to time delays.

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Fuzzy Control

In fact, the fuzzy controllers performed better than well-tuned PI and PID controllers.

Later in the eighties, applications are found in controlling cement kilns, diesel engines, traffic junctions, pump operations, and many commercial products [Sugeno, 1985a, 1985b].

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Fuzzy Control

Later, fuzzy rule sets have been used to control helicopters, where various control tasks were identified (hover, forward, up, etc.)

and *small*, *separate* fuzzy controllers were designed for each subproblem.

This *hierarchical* structuring of the fuzzy rule bases allows the techniques to be applied to high-dimensional control problems.

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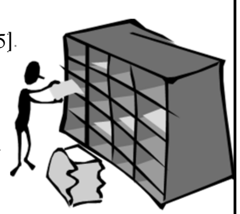
Fuzzy Control

Many of the advanced applications are focusing on *self-organizing* or adaptive fuzzy systems [Park, Moon and Lee, 1995].

The ability to *construct* a rule base automatically is a very desirable property for learning systems.

Much of this work has been motivated by the *neural network* research,

and new algorithms combine the representational advantage of fuzzy systems with the learning power of neural networks [Kosko, 1992a, Wang and Wendel, 1992].



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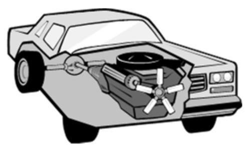
Fuzzy Control

Adaptive fuzzy logic control is used in automotive products, where *neural networks* have been used for on-line training of fuzzy logic controllers for car engine speed control [Feldkamp and Puskorius, 1993];

in this, the neural network acts as a *local optimizer* to initiate the fuzzy rule base.



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