Introduction to Soft Computing and Intelligent Systems

Outline

- **Logic of Inferencing**
- **Soft Computing**
  - Fuzzy Logic
  - Neural Networks
  - Genetic Algorithms
  - Probabilistic Reasoning
- **Approximation and Intelligence**

Knowledge-Based Systems

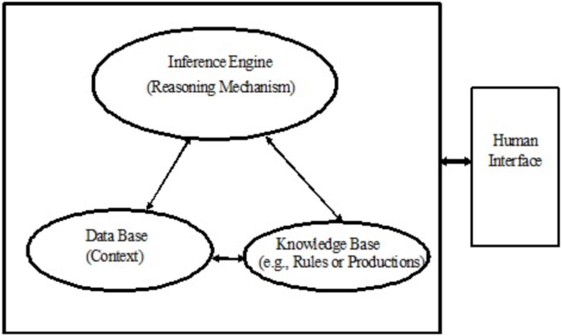
Definition

A knowledge-based system is able to make perceptions (e.g., sensory perception) and new inferences or decisions using its reasoning mechanism (inference engine).

This is done by interpreting the meaning and implications of the new information within the capabilities of the existing knowledge base. These inferences may form the outputs of the knowledge-based systems.

Decision Making

The associated decision-making task is an intelligent processing activity, which in turn may lead to enhancement, refinement, and updating of the knowledge base itself.



The Structure of a Knowledge-Based System

Example

Consider a knowledge base for selecting a control technique, as given by the following set of rules:

- If the plant is linear and uncoupled then use Control Category A.
- If the plant is linear and coupled then use Control Category B.
- If the plant is nonlinear use Control Category C.
- If Category A and a plant model is known then use Subgroup 1.
- If Category B and a plant model is known then use Subgroup 2.
- If Subgroup 1 and high model uncertainty then use H-infinity control.

Example (Cont.)

Consider a knowledge base for selecting a control technique, as given by the following set of rules:

- Now suppose that the database received the following context : Linear, uncoupled; model available, model uncertainty high.
- In this case, the first two items in the context will fire Rule 1. The results will form a new item in the context. This new item, along with the third item in the old context, will fire Rule 4.
- The result, along with the last item of the old context, will fire Rule 6, which will lead to the selection of H control.

Knowledge Representation

An appropriate representation of knowledge, including intuition and heuristic knowledge, is central to the development of machine intelligence and of knowledge-based systems.

Definition

In a knowledge-based system, two types of knowledge are needed; knowledge of the problem (problem representation or modelling) and knowledge regarding methods for solving the problem. Ways of representing and processing knowledge include: Logic, Semantic Networks, Frames, Production Systems, and Fuzzy Logic.

Logic of Inferencing

Definition

Logic is a useful technique of representing and processing knowledge, and is applicable in knowledge-based systems. In logic, knowledge is represented by statements called propositions, which may be joined together using connectives.

The knowledge may be processed through reasoning, by the application of various laws of logic including an appropriate rule of inference. There are two type of logics: crisp (binary) and fuzzy (multivalued).

Crisp Logic

Definition

Conventional (crisp) logic deals with statements called ”propositions”. In binary (or, two-valued) logic, a proposition can assume one of only two truth values: true(T), false (F). An example of a proposition would be ”John is over 50 years old”.

Crisp Logic (Cont.d)

Now consider the following propositions:

1. Charcoal is white
2. Snow is cold
3. Temperature is above 60C

Here proposition 1 has the truth value F, and proposition 2 has the truth value T. But, for proposition 3 the truth value depends on the actual value of the temperature. Specifically, if the temperature is above 60C the truth value is T and otherwise it is F.

Knowledge Representation

Definition

In logic, knowledge is represented by propositions. A simple proposition does not usually make a knowledge base. Many propositions connected/modified by logical connectives such as AND, OR, NOT, EQUALS, and IMPLIES may be needed.

A and B are crisp sets/propositions.

Set Theory Concept	Set Theory Notation	Binary Logic Concept	Binary Logic Notation	Boolean Algebra Notation
Universal Set	X	(Always) True	(Always) T	1
Null Set	ϕ	(Always) False	(Always) F	0
Complement	A'	Negation (*NOT*)	$\overline{A}$ or $\sim A$	$\overline{A}$
Union	$A \cup B$	Disjunction (*OR*)	$A \vee B$	$A + B$
Intersection	$A \cap B$	Conjunction (*AND*)	$A \wedge B$	$A \cdot B$
Subset	$A \subseteq B$	Implication (If-Then)	$A \rightarrow B$	$A \leq B$

Reasoning and Inferencing

Knowledge may be processed through reasoning. This is done by the application of various laws of logic including an appropriate rule of inference, subjected to a given set of data (measurements, observations, external commands, previous decisions, etc.) to arrive at new inferences or decisions.

Knowledge Representation (Cont.)

In intelligent control, for example, a knowledge base is processed through reasoning, subjected to a given set of data (measurements, observations, external commands, previous decisions, etc.) to arrive at new control decisions.

Knowledge Representation (Cont.)

The typical end objective of knowledge processing is to make inferences. This may involve the following steps:

- Simplify the knowledge base by applying various laws of logic.
- Substitute into the knowledge base any new information (including data and previous inferences).
- Apply an appropriate rule of inference.

These steps may be followed in any order and repeated any number of times, depending on the problem.

Laws of Logic

- The laws of logic govern the truth-value equivalence of various types of logical expressions consisting of the connectives AND, OR, NOT, etc.
- They are valuable in simplifying a logical knowledge base. Consider three propositions A, B, and C whose truth values are not known.
- Also, suppose that X is a proposition that is always true (T) and is a proposition that is always false (F), then:.

Set Theory, Logic, and Boolean Algebra

Law	Truth Value Equivalence
Commutativity	$A \cap B = B \cap A$ $A \cup B = B \cup A$
Associativity	$(A \cap B) \cap C = A \cap (B \cap C)$ $(A \cup B) \cup C = A \cup (B \cup C)$
Distributivity	$A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$ $A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$
Absorption	$A \cup (A \cap B) = A$ $A \cap (A \cup B) = A$
Idempotency (Idem = same; potent = power) (Similar to unity or identity operation)	$A \cup A = A$ $A \cap A = A$
Exclusion: Law of excluded middle Law of contradiction	$A \cup \overline{A} = X \equiv T$ $A \cap \overline{A} = \phi \equiv F$
DeMorgan's Laws	$\overline{A \cap B} = \overline{A} \cup \overline{B}$ $\overline{A \cup B} = \overline{A} \cap \overline{B}$
Boundary Conditions	$A \cup X = X \equiv T$ $A \cap X = A$ $A \cup \phi = A$ $A \cap \phi = \phi \equiv F$

Example

Consider the following two propositions:
(1) A = ”Plant 1 is stable” and (2) B = ”Plant 2 is stable”.

Now consider the combined proposition:
$\overline{A \cap B}$ = ”It is not true that both plants 1 and 2 are stable”
and the combined proposition:
$\overline{A} \cup \overline{B}$ = ”Either Plant 1 is not stable or Plant 2 is not stable.”

These combined propositions have same truth value (and the same linguistic meaning). This verifies DeMorgan law.

Rules of Inference

The inference process used in a rule-based system is deductive inference. Recall that this means that the rules of logic are used to deduce new knowledge from existing knowledge and rules.

There are various different approaches to managing deductive inference. The most significant distinction is between

- Forward Chaining
- Backward Chaining

This can be further detailed.

Rules of Inference

Whether forward or backward chaining is used to make inferences, Four types of rules of inference are given below:

- Conjunction Rule of Inference (CRI)
- Modus Ponens Rule of Inference (MPRI)
- Modus Tollens Rule of Inference (MTRI)
- Hypothetical Syllogism Rule of Inference (HSRI)

Some Rules Of Inference In Conventional Logic

Rule of Inference	Operation
Conjunction	$(A, B) \Rightarrow A \wedge B$
Modus Ponens	$(A \wedge (A \rightarrow B)) \Rightarrow B$
Modus Tollens	$(\overline{B} \wedge (A \rightarrow B)) \Rightarrow \overline{A}$
Hypothetical Syllogism	$((A \rightarrow B) \wedge (B \rightarrow C)) \Rightarrow (A \rightarrow C)$

Conjunction

Conjunction

The CRI states that, if a proposition A is true and a second proposition B is true, then the combined proposition ”A AND B” is also true. This seemingly simple and obvious fact has applications in rule-based reasoning.

Example

Consider a simple knowledge base of response characteristics consisting of just two propositions:

- ”The speed of response is high”, and
- ”The overshoot is excessive”

Each statement is a proposition, which may or may not be true.

Example (Cont.)

Now suppose that we have some new data (say from a speed sensor and a position sensor), which indicate a high speed of response and also an excessive overshoot. With these data, each one of the two propositions becomes a premise (which is known to be true). Then by applying the CRI we can infer the following result:

The speed of response is high and the overshoot is excessive.

Modus Ponens

Modus Ponens

The MPRI states that if proposition A is true and also the implication AB holds then it can be concluded that proposition B is also true. This rule of inference is much more widely applicable than the CRI in rule-based reasoning.

Example (MPRI)

Suppose that a knowledge base has the rule:
If the trajectory error exceeds 1.0 mm, the robot performance is unacceptable

Also, suppose that during operation of the robot, a position sensor indicates that the trajectory error is 1.1 mm. Then by using this information and applying the MPRI the following inference can be made:
Robot performance is unacceptable

Note that this inference may serve as data (new information) for another rule such as:
If the robot performance is unacceptable, tune the controller, which may be processed by another application of MPRI.

Modus Tollens

Definition

The MTRI states that if proposition B is not true and also the implication $A \rightarrow B$ holds, then it can be concluded that proposition A is also not true.

Hypothetical Syllogism

Hypothetical Syllogism: The term syllogism means ”deductive reasoning” or ”calculation with words”. The HSRI states that if the implication $A \rightarrow B$ holds and also the implication $B \rightarrow C$ holds, then it can be concluded that the implication $A \rightarrow C$ also holds.

Definition

Propositional calculus is the branch of logic where propositions (i.e., statements that are either true or false) are used in logic ”calculations”. Note that the term ”calculus” in the present terminology denotes ”the approach of calculation” and has nothing to do with differential or integral calculus.

Reasoning

Reasoning or (knowledge processing) in predicate calculus is quite similar to, albeit more general than, propositional calculus, and may be accomplished through the application of a rule of inference.

Example

Consider the knowledge base consisting of the rule:

($\forall$ x)[Servomotor(x) Speedsensor(x)]

The rule states that all servomotors have speed sensors and may be represented by a model number x. Now suppose that a particular positioning system has a servomotor whose model number is H0176. This is now an available data item and is expressed as ”Servomotor (H0176)”. Then by applying (MPRI) to the rule base, we obtain the inference ”Speed-sensor (H0176)”. Specifically, this infers that there exists a speed sensor in that particular motor unit.

Soft Computing

Definition

Soft computing is an important branch of study in the area of intelligent and knowledge-based systems. It has effectively complemented conventional AI in the area of machine intelligence (computational intelligence).

Human reasoning is predominantly approximated, qualitative, and ”soft”. Humans can effectively handle incomplete, imprecise, and fuzzy information in making intelligent decisions.

Soft Computing

- Fuzzy logic, probability theory, neural networks, and genetic algorithms are cooperatively used in soft computing for knowledge representation and for mimicking the reasoning and decision-making processes of a human.
- Quite effective are the mixed or hybrid techniques, which synergistically exploit the advantages of two or more of these areas.
- Decision making with soft computing involves approximate reasoning.

Fuzzy Logic

- Fuzzy logic is useful in representing human knowledge in a specific domain of application and in reasoning with that knowledge to make useful inferences or actions.
- The conventional binary (bivalent) logic is crisp and allows for only two states. This logic cannot handle fuzzy descriptors, examples of which are ”fast” which is a fuzzy quantifier and weak which is a fuzzy predicate.

Fuzzy Logic

- Fuzzy logic (FL) allows for a realistic extension of binary, crisp logic to qualitative, subjective, and approximate situations, which often exist in problems of intelligent machines.
- In (FL), the knowledge base is represented by if-then rules of fuzzy descriptors. An example of a fuzzy rule would be, ”If the speed is slow and the target is far, then moderately increase the power”, which contains the fuzzy descriptors slow, far, and moderate.

Neural Networks

Definition

Artificial neural networks (NN) are massively connected networks of computational neurons, and represent parallel-distributed processing structures. The inspiration for NN has come from the biological architecture of neurons in human brain.

A key characteristic of neural networks is their ability to approximate arbitrary nonlinear functions. Since machine intelligence involves a special class of highly nonlinear decision-making, neural networks would be effective there.

Neural Networks

- A neural network consists of a set of nodes, usually organized into layers, and connected through weight elements called synapses. The analogy to the operations in a biological neuron is interesting.
- Specifically, in a biological neuron, the dendrites receive information from other neurons. The soma (cell body) collects and combines this information, which is transmitted to other neurons using a channel (tubular structure) called axon.

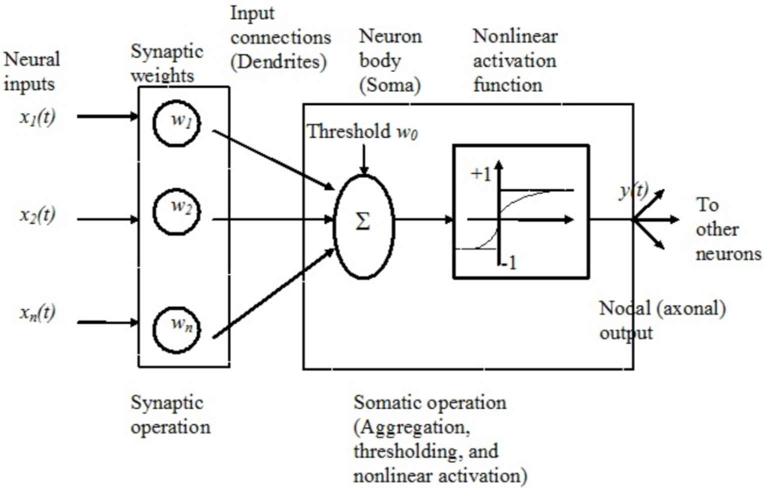
Neural Networks

This biological analogy, apart from the abilities to learn by example, approximation of highly nonlinear functions, massive computing power, and memory, may be a root reason for inherent "intelligence" in a neural network. If the weighted sum of the inputs to a node (neuron) exceeds a threshold value w0, then the neuron is fired and an output y(t) is generated according to:

$$y(t) = f[\Sigma_{i=1}^{n} w_i x_i - w_0]$$

where x_i are neuron inputs, w_i are the synaptic weights, and f [] is the activation function.

Neural Networks



Genetic Algorithms

Definition

Genetic algorithms (GA) are derivative-free optimization techniques, which can evolve through procedures analogous to biological evolution.

Genetic algorithms belong to the area of evolutionary computing. They represent an optimization approach where a search is made to "evolve" a solution algorithm, which will retain the "most fit" components in a procedure that is analogous to biological evolution through natural selection, crossover, and mutation.

Genetic Algorithms

Evolutionary computing can play an important role in the development of an optimal and self-improving intelligent machine.
Evolutionary computing has the following characteristics:

1. It is based on multiple searching points or solution candidates (population based search)
2. It uses evolutionary operations such as crossover and mutation
3. It is based on probabilistic operations

Probabilistic Reasoning

- Probabilistic reasoning may be viewed in an analogous manner to fuzzy-logic reasoning, considering uncertainty in place of fuzziness as the concept of approximation that is applicable.
- Probability distribution/density functions are employed in place of membership functions

Uncertainty vs Fuzziness

- it is important to compare the concepts of uncertainty and fuzziness. Uncertainty is statistical inexactness due to random future events.
- Fuzziness arises when the decision of whether a particular object belongs to a given set is a matter of perception, which can be subjective. Probabilistic and statistical techniques may be employed in conjunction with fuzzy logic in a complementary manner.
- The two concepts are compared in next Table.

Uncertainty vs Fuzziness

	Fuzziness	Uncertainty
Advantages	• Incomplete information can be handled • Particularly useful in representing and processing human-oriented knowledge • Approximate reasoning is possible, with qualitative and linguistic knowledge • It is a technique of soft computing	• Useful in situations having random influences with known probability distributions • Governs many practical situations • Mathematical procedures are well established • System parameters can be determined using crisp experiments
Disadvantages	• May introduce a degree of inaccuracy • Needs prior knowledge and experience of the problem in generating the knowledge base • Can be slow	• Not related to fuzzy sets • May fail under incomplete information • Results are directly affected by the type and accuracy of the probability distributions

Summary

Techniques of soft computing are powerful by themselves in achieving the goals of machine intelligence. They have a particular appeal in view of the biological analogies that exist within humans.

Fuzzy techniques attempt to approximate human knowledge and the associated reasoning process; neural networks are a simplified representation of the neuron structure of a brain; genetic algorithms follow procedures that are crudely similar to the process of evolution in biological species; and probabilistic techniques can analyze random future action of a human.

Techniques of Computational Intelligence

Technique	Characteristic	A Popular Analogy
Fuzzy Logic	Uses fuzzy rules and approximate reasoning	Human knowledge
Neural Networks	Network of massively connected nodes	Neuron structure in brain
Genetic Algorithms	Derivative-free optimisation	Biological evolution
Probability	Incorporates uncertainty in predicting future events	Random action of a human
Conventional AI	Symbolic processing of information	Symbolic languages

Approximation

Definition

Approximation is a ”soft” concept and is related to intelligence. The capability of approximation for the purpose of comparison, pattern recognition, reasoning and decision-making is a manifestation of intelligence (e.g., dealing with incomplete and subjective information, unfamiliar situations, comparison, and judgment).

Approximation (Contd.)

Concepts

There are many concepts of approximation, examples of which include imprecision, uncertainty, fuzziness, and belief. These concepts are not identical even though the associated methods of information representation and processing may display analytical similarities.

Concepts of Approximation and their Characteristics

Concept	Property	Example
Ambiguity	The condition has a several different possibilities, and it is not determined which one is valid.	The machine response "may or may not" satisfy the specification.
Vagueness	The condition is not precisely (clearly) defined.	The machine response "may have" met the specification.
Generality	The condition may apply to many (finite or infinite) situations depending on the specific context.	The machine response is "*x*" times the specification.
Imprecision	Condition can assume a state within a clearly defined (crisp) tolerance interval.	The machine response is "within ±5%" of the specification.
Uncertainty	There is a degree of probability associated with occurrence of the condition.	There is a "90% probability" that the machine response meets the specification.
Fuzziness	The membership of the condition is not crisply defined (set boundary of the condition is not crisp).	The machine response is "close to" the specification.
Belief (Subjective Probability)	The level of belief on the condition (membership of a crisp or fuzzy set) is through knowledge and evidence.	It is believed at a level of 90% that the machine response meets the specification.
Plausibility	The plausibility of nonmembership fully complements the belief of membership (dual condition of belief). $Bl(x \in A) + Pl(x \notin A) = 1$	It is plausible at a level of 95% that the machine response meets the specification.

Concepts of Approximation and their Characteristics

Concept	Qualitative Definition	Combination Axiom	Complement Relation
Uncertainty	Probabilistic/statistical inexactness of occurrence of an event (Crisp set)	$Pr(A \cup B) = Pr(A) + Pr(B) - Pr(A \cap B)$	$Pr(A) + Pr(A') = 1$
Fuzziness	Inexactness in human perception about a situation (Set boundary is non-crisp)	$Fz(A \cup B) = Fz(A) + Fz(B) - Fz(A \cap B)$	$Fz(A) + Fz(A') = 1$
Belief	Inexactness in human belief or confidence about a condition (Crisp or fuzzy set)	$Bl(A \cup B) \geq Bl(A) + Bl(B) - Bl(A \cap B)$	$Bl(A) + Bl(A') \leq 1$
Plausibility	A more liberal form of belief. Level is higher than belief, with the same amount of evidence (Crisp or fuzzy set)	$Pl(A \cup B) \leq Pl(A) + Pl(B) - Pl(A \cap B)$	$Pl(A) + Pl(A') \geq 1$

Technology Needs

Significant advances have been made, in machine implementation of characteristics of intelligence such as sensory perception, pattern recognition, knowledge acquisition and learning, inference from incomplete information, inference from qualitative or approximate information, ability to handle unfamiliar situations, adaptability to deal with new yet related situations, and inductive reasoning.

Technology Needs (Cont.)

Much research and development would be needed in these areas, pertaining to techniques, hardware, and software before a machine could reliably and consistently possess the level of intelligence of say, a dog.

Example

Consider a handwriting recognition system, which is a practical example of an intelligent system. The underlying problem cannot be solved through simple template matching, which does not require intelligence. Handwriting of the same person can vary temporally, due to various practical shortcomings such as missing characters, errors, non-repeatability, physiological variations, sensory limitations, and noise.

Example (Cont.)

It should be clear from this observation that a handwriting recognition system has to deal with incomplete information and unfamiliar objects (characters), and should possess capabilities of learning, pattern recognition, and approximate reasoning, which will assist in carrying out intelligent functions of the system. Techniques of soft computing are able to challenge such needs of intelligent machines.