Chapter 1: Introduction to Soft Computing

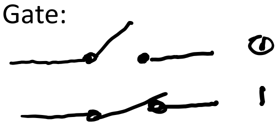
What is Soft Computing?

Soft computing is an emerging approach to computing, which parallels the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision.
(Dr. Lotfi A. Zadeh)

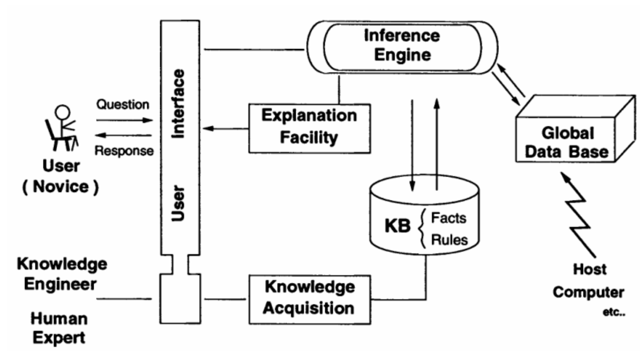
Conventional Artificial Intelligence (AI) and Soft Computing (SC)

- Symbolic tools
- Crisp calculation < 1 : true, 0 : False

Gate:



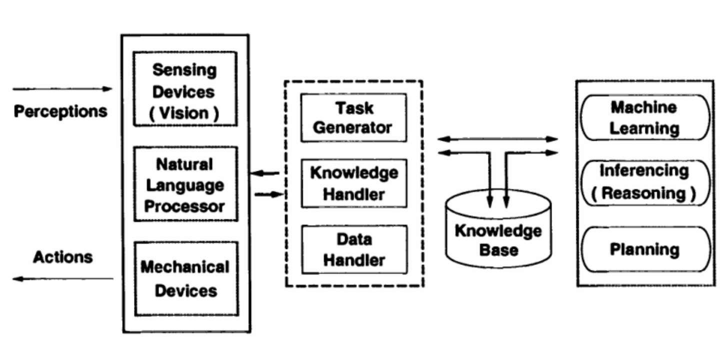
AI Intelligent System (expert system)



Advantages:
- Easy to set up
- Still commonly used today

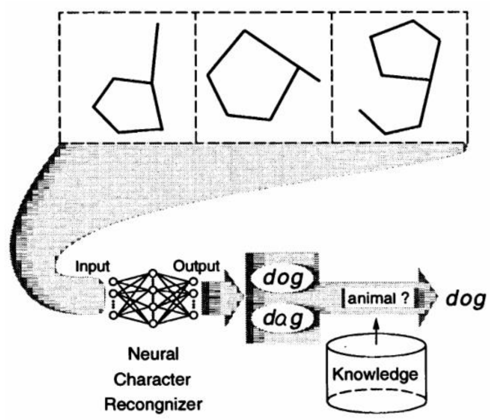
Disadvantages:
- Difficult to improve, how do you implement new knowledge to the system?
- How do you represent knowledge to the users?

SC Intelligent System



It is intelligent because it can sense the environment (temperature, acceleration, etc.)

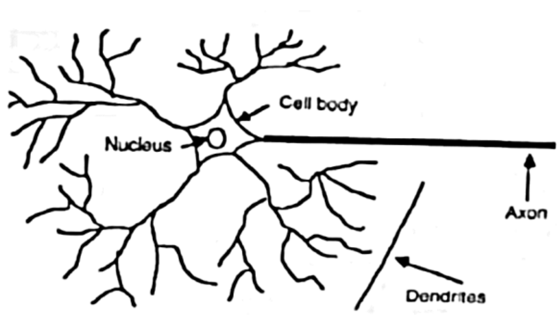
Example of a SC Intelligent System:



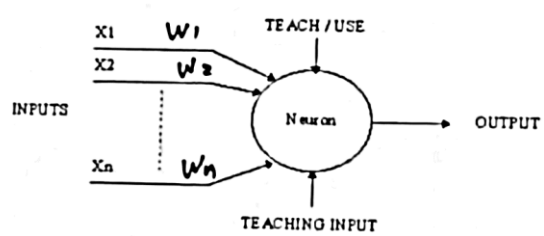
Two systems co-operate with each other to determine the written character.

Neural Networks

Consider a neuron:



This can be used to adapt the following model:



- Mimic the human brain to make decisions
- The functional speed of nerve cells is significantly slower than an electronic gate
- However, the brain can process A/V information significantly faster than a computer
    - especially under uncertainty and noise

Advantages:
- Good adaptive capability
- Can use machine learning algorithms to improve its function

Disadvantages:
- Difficult to recognize *how* decisions are made in the model
- Reasoning is complex, not immediately comprehensible

Fuzzy Logic

- Mimic linguistic reasoning to make a decision
    - Specifically, IF-THEN rules are utilized

IF – THEN rules

- Based on inputs, make a decision
    - IF (food quality = good, service = fast) THEN (tip = 20%)
    - IF (food quality = okay, service = slow) THEN (tip = 10%)

Advantages:

- Easy to follow logical process
- Intuitive

Disadvantages:

- Poor learning capability
- Difficult to optimize if application changes, or the environment varies

Table: Soft computing constituents (the first three items) and conventional artificial intelligence

Methodology	**Strength**
Neural network	Learning and adaptation
Fuzzy set theory	Knowledge representation via fizzy if-then rules
Genetic algorithm and simulated annealing	Systematic random search
Conventional AI	Symbolic manipulation

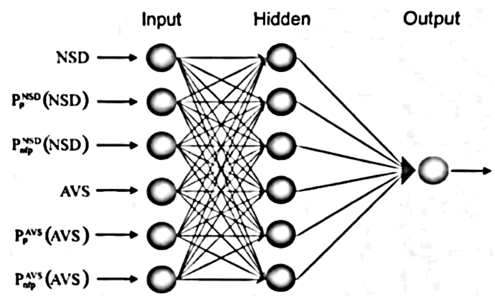
Neuro-fuzzy modeling

- Combining a fuzzy logic system with a neural network leads to a neuro-fuzzy system.

Why neuro-fuzzy?

	Fuzzy Logic	**Neural Networks**
Knowledge Representation	Linguistic description of knowledge	Knowledge distributed within computational unit
Intuitiveness	Explicit and easy to interpret (intuitive)	Implicit and difficult to interpret ("black box")
Verification	Easy	Not as easy
Adaptation	Manual	Automatic
Learning	None	Excellent tools for imparting learning

Consider:



Historical development of related techniques:

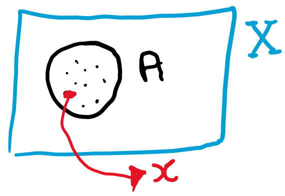
	Conventional AI	Neural networks	Fuzzy systems	Other methodologies
1940s	1947 Cybernetics	1943 McCulloch-Pitts neuron model		
1950s	1956 Artificial Intelligence	1957 Perceptron		
1960s	1960 Lisp language	1960s Adaline Madaline	1965 Fuzzy sets	
1970s	mid- 1970s Knowledge Engineering (expert systems)	1974 Birth of Back-propagation algorithm 1975 Cognitron Neocognitron	1974 Fuzzy controller	1970s Genetic algorithm
1980s		1980 Self-organizing map 1982 Hopfield Net 1983 Boltzmann machine 1986 Backpropagation algorithm boom	1985 Fuzzy modeling (TSK model)	mid- 1980s Artificial life Immune modeling
1990s			1990s Neuro-fuzzy modeling 1991 ANFIS 1994 CANFIS	1990 Genetic programming

Chapter 2: Fuzzy Sets

2.1 Review of Conventional AI (Crisp Logic or Crisp Sets)

Logic ~ representation of processing of knowledge

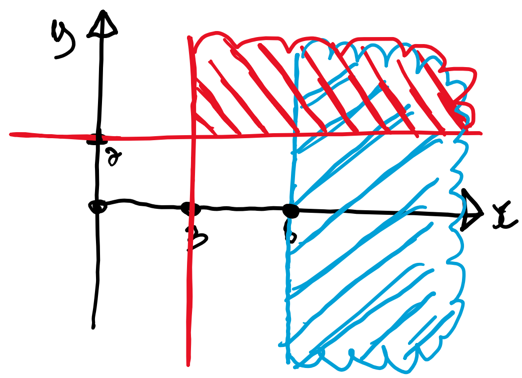
A ~ a set
X ~ universe of discourse



ϕ ~ null set
x ~ element in set A
$x \in A$

Consider:

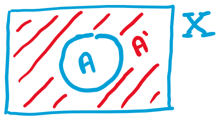
$A = \{ x \mid x \geq 6 \}$
$B = \{ x, y \mid x \geq x \geq 3, y \geq 2 \}$



1) Operations of Sets

1. <u>Complement</u>

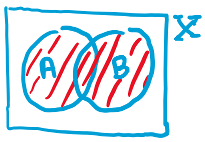
Given set A, the complement is everything outside of $A \rightarrow A'$



2. <u>Union</u>

Given sets A and $B \rightarrow A \cup B$

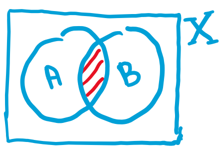
union



3. <u>Intersection</u>

Given sets A and $B \rightarrow A \cap B$

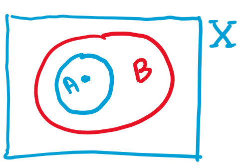
intersection



4. <u>Subset</u>

subset

Set A is a subset of B, if the elements of A are contained within $B \rightarrow A \subset B$ (or $A \subseteq B$)



2) Conventional Logic

Knowledge statement is represented by proposition.

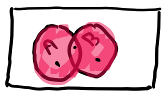
Truth table: True (T) / False (F)

1. Negation (NOT)

$$\sim A$$

A	$\bar{A}$
T	F
F	T

2. Disjunction (OR)

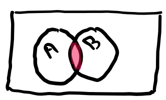


A no X (logic representation)

$$A \vee B$$

A	B	$A \vee B$
T	T	T
T	F	T
F	T	T
F	F	F

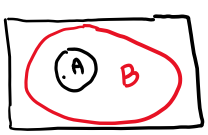
3. Conjunction (AND)



$$A \wedge B$$

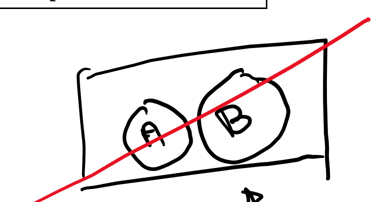
A	B	$A \wedge B$
T	T	T
T	F	F
F	T	F
F	F	F

4. Implication (IF-THEN)

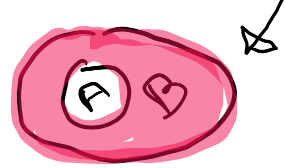


IF A THEN B

$$A \rightarrow B$$



A	B	$A \rightarrow B$
T	T	T
T	F	F *contradicts logic*
F	T	T *does not contradict logic could be T, could be F*
F	F	T *(same reason as above)*



Boolean Algebra: 0 or 1

Table 1.2: Isomorphism between set theory, logic, and Boolean algebra

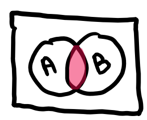
Set theory concept	Set theory notation	Binary logic concept	Binary logic notation	Boolean algebra notation
Universal set	X	(Always) true	*(Always) T*	1
Null set	$\emptyset$	(Always) false	*(Always) F*	0
Complement	A'	Negation (*NOT*)	$\bar{A}$ or $\sim A$	$\bar{A}$
Union	$A \cup B$	Disjunction (*OR*)	$A \vee B$	$A + B$
Intersection	$A \cap B$	Conjunction (*AND*)	$A \wedge B$	$A \cdot B$
Subset	$A \subseteq B$	Implication (if-then)	$A \rightarrow B$	$A \leq B$

3) Logic Processing

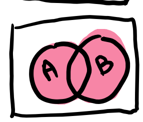
Knowledge is usually represented by a proposition.
Consider 3 propositions; A, B, and C.
$X(always\ T)$ and $\phi(always\ F)$

1. <u>Commutativity</u>

$$A \wedge \mathrm{B} = \mathrm{B} \wedge \mathrm{A}$$

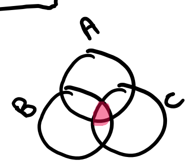


$$A \vee \mathrm{B} = \mathrm{B} \vee \mathrm{A}$$

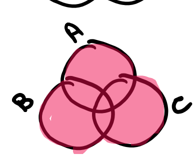


2. <u>Associativity</u>

$$(A \wedge \mathrm{B}) \wedge \mathrm{C} = A \wedge (\mathrm{B} \wedge \mathrm{C})$$



$$(A \vee \mathrm{B}) \vee \mathrm{C} = A \vee (\mathrm{B} \vee \mathrm{C})$$



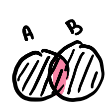
3. <u>Distributivity</u>

$$A \wedge (\mathrm{B} \vee \mathrm{C}) = (\mathrm{A} \wedge \mathrm{B}) \vee (\mathrm{B} \wedge \mathrm{C})$$

$$A \vee (\mathrm{B} \wedge \mathrm{C}) = (\mathrm{A} \vee \mathrm{B}) \wedge (\mathrm{B} \vee \mathrm{C})$$

4. <u>Absorption</u>

$$A \vee (\mathrm{A} \wedge \mathrm{B}) = \mathrm{A}$$



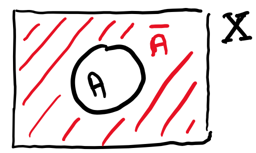
$$A \wedge (\mathrm{A} \vee \mathrm{B}) = \mathrm{A}$$

5. Idempotency

$$A \vee A = A$$

$$A \wedge A = A$$

6. Exclusion



$$A \vee \overline{A} = X = (always\ T)$$

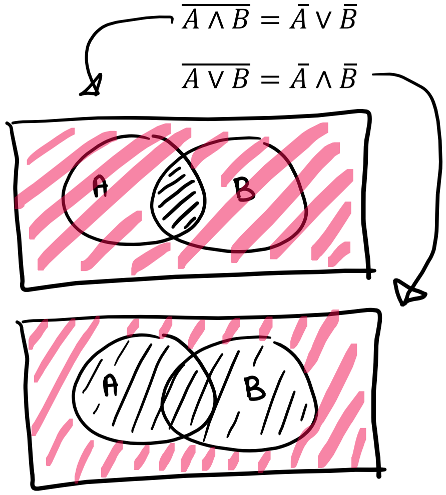
7. Contradiction

$$A \wedge \overline{A} = \phi = (always\ F)$$

8. De Morgan's Law

$$\overline{A \wedge B} = \bar{A} \vee \bar{B}$$

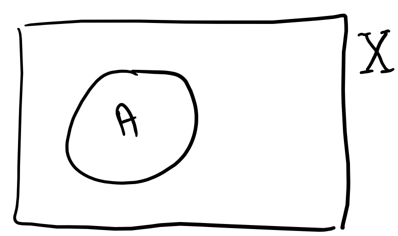
$$\overline{A \vee B} = \bar{A} \wedge \bar{B}$$



9. Boundary Conditions

$$A \vee X = X = T$$
$$A \wedge X = A$$

$$A \vee \phi = A$$
$$A \wedge \phi = \phi = F$$



Consider:
$A =$ "food is good"
$B =$ "service is good"

It is not true that both "food is good" and "service is good"
Either "food is not good" or "service is not good"

4) Rules of Inference

1. <u>Conjunction rule of inference (CRI)</u>

$$(A, B) \rightarrow A \wedge B$$

IF proposition A is TRUE and the second proposition B is TRUE
THEN the combined proposition A ∧ B is also TRUE

2. <u>Modus Ponens</u>

$$A \ \wedge \ (A \ \rightarrow \ B) => \ B$$

IF A → B, then B
IF A is T, then B is T

Consider:
$A =$ "food is good"
$B =$ "tips are generous"

Thus, IF "food is good" THEN "tips are generous"

3. <u>Modus Tollens</u>

$$\bar{B} \wedge (A \rightarrow B) => \bar{A}$$

IF proposition B is not T, and A → B holds
THEN A is NOT TRUE

4. <u>Hypothetical Syllogism</u>

$$[(A \rightarrow B) \wedge (\mathrm{B} \rightarrow \mathrm{C})] => (A \rightarrow C)$$

Consider:
$A =$ "machine performs well"
$B =$ "vibration level is low"
$C =$ "manufacturing accuracy is high"

If both terms hold, then
IF "machine performs well" THEN "manufacturing accuracy is high"

2.2 Concepts of Fuzzy Sets

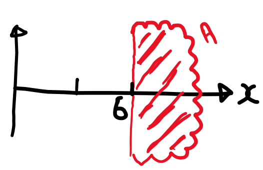
Conventional crisp logic utilizes 0 /1 (or true/false)

- Good for math operations
- Good for computers, chip designs

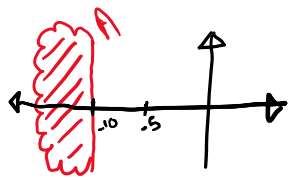
However, real applications have many abstract and imprecise concepts (think "grey" areas)

Crisp logic $\begin{cases} T = 1 \\ F = 0 \end{cases}$

Set:
$A = \{x | x \geq 6\}$

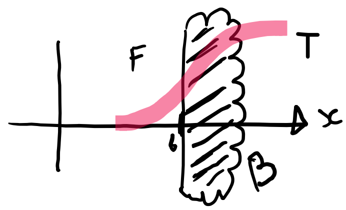


Temperature "cold"



Temp:
$A = \text{"}cold\text{"}$
$A = \{t \leq -10\ °C\}$

But what about:
$temp = -10.1\ °C$
$temp = -9.99\ °C$
$A \rightarrow T$
$A \rightarrow F$



$B =$ a person is tall
$B = \{x | x \geq 6\ ft\}$

$x = 6.01\ ft$
$B \rightarrow T$
$x = 5.99\ ft$
Fuzzy Logic

Ideal filter: