Welcome to:

Logical approach to AI and knowledge based systems

Unit objectives

After completing this unit, you should be able to:

- Understand the importance of knowledge representation
- Understand the use of formal logic as a knowledge representation language
- Gain knowledge on the concept of Tautologies and Logical Implication
- Learn about the resolution in normal forms
- Gain an insight into the concept of derivations using resolutions and resolution algorithm
- Learn about the Semantic Nets
- Understand frame data structure

Introduction to knowledge representation systems

- To solve the complex problems encountered in Artificial Intelligence, large amount of knowledge and mechanisms for manipulating that knowledge are required.

- There are many ways of knowledge representation

- Properties of Knowledge Representation Systems
  - Representational adequacy
  - Inferential adequacy
  - Inferential efficiency
  - Acquisitional efficiency

Knowledge representation using logic

- Formal Logic is the primary vehicle for representing & reasoning about knowledge.

- Formal logic is
  - Precise and Definite
  - Declarative

- Logic consists of two parts, a language and a method of reasoning.

- Language has syntax and semantics

- Logical systems with different syntax and semantics
  - Propositional logic
  - First order predicate logic
  - Temporal logic
  - Modal
  - Higher order logic
  - Non-monotonic

Propositional logic

- A proposition is a sentence that has a truth value.
- Propositional logics are the atomic formulas.
- Propositional logic studies the relationship two statements defined by a set of propositional symbols
- Propositional logics are of two forms: atomic propositions and compound propositions.

Atomic proposition

- Compound proposition is defined by values of elementary propositions and the meaning of connectives.
- The knowledge base is the set of all sentences where each sentence in Propositional Logic

Semantics of propositional logic

- Semantics
  - Semantics specifies the value true or false for each proposition symbol.
  - An *interpretation* for a sentence or group of sentences is an assignment of vale true to every propositional symbol.
  - For example, consider the statement (A ∧ ¬ B). Interpretation 1 assigns true to A and false to B. Interpretation 2 assign false to A and false to B. Hence, there are four distinct interpretations.

- Semantics for the Logical connectives:

Negation ¬	
A	¬ A
T	F
F	T

Conjunction ∧		
A	B	A ∧ B
T	T	T
T	F	F
F	T	F
F	F	F

Implication →		
A	B	A → B
T	T	T
T	F	F
F	T	T
F	F	T

Disjunction ∨		
A	B	A ∨ B
T	T	T
T	F	T
F	T	T
F	F	F

Biconditional ↔		
A	B	A ↔ B
T	T	T
T	F	F
F	T	F
F	F	T

Properties of propositional logic statements

- Satisfiable
- Valid or Tautology
- Contradiction
- Contingent
- Equivalence

Tautologies and logical implication

- A formula that is always T, independent of the interpretation of the propositions, is a tautology.
- Logical Implication: A formula M logically implies N if M $\rightarrow$ N is a tautology.
- Theorem:
  - An argument is valid if and only if the conjunction logically implies the conclusion.
- Logical Arguments
  - Logical arguments is known as a valid argument formed by the series of statements

Resolution

- Uniform
- Fewer Rules
- Heuristic Guide
- Algorithmic

Conjunctive normal form

- A literal is a variable or a negated variable.
- A clause is either a single literal or the disjunction of two or more literals.
  - P, $P \vee \neg P$, and $P \vee \neg Q \vee R \vee S$ are clauses.
  - $\neg(R \vee S)$ and $P \rightarrow \neg Q$ are not clauses.
- A wff is in conjunctive normal form iff it is either a single clause or the conjunction of two or more clauses.
  - $(P \vee \neg Q \vee R \vee S) \wedge (\neg P \vee \neg R)$ is in cnf
  - $(P \wedge \neg Q \wedge R \wedge S) \vee (\neg P \wedge \neg R)$ is not in cnf

Resolution is valid

P	A	B	$(P \vee A)$	$\wedge$	$(\neg P$	$\vee B)$	$\Rightarrow$	$A \vee B$
T	T	T	T	T	F	T	T	T
T	T	F	T	F	F	F	T	T
T	F	T	T	T	F	T	T	T
T	F	F	T	F	F	F	T	F
F	T	T	T	T	T	T	T	T
F	T	F	T	T	T	T	T	T
F	F	T	F	F	T	T	T	T
F	F	F	F	F	T	T	T	F

Resolution algorithm

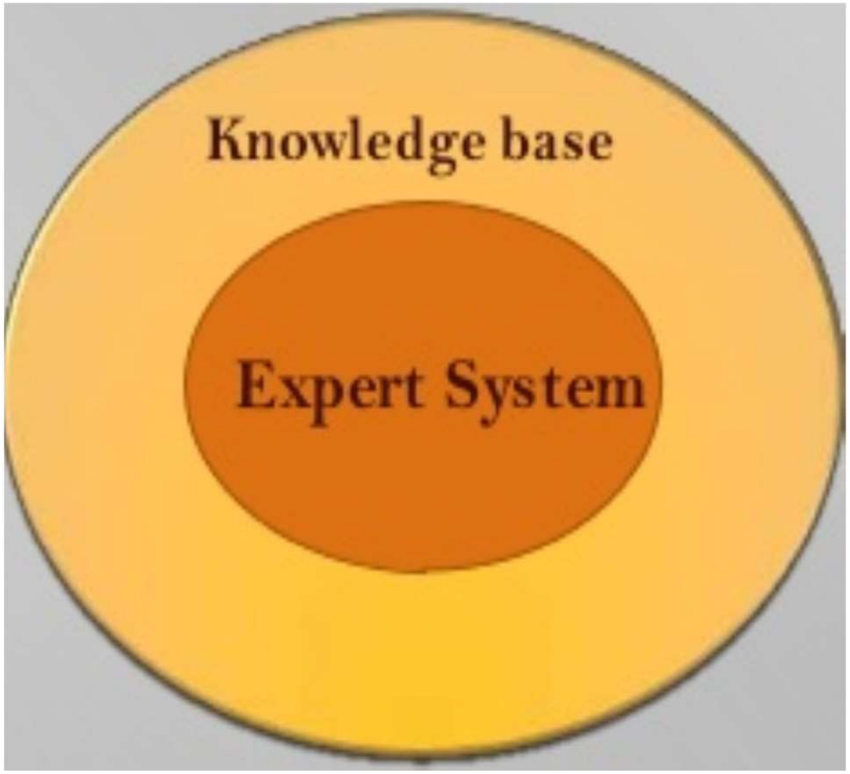
- Resolution works by using the principle of proof by contradiction.
- Negate the conclusion so as to find the conclusion.
- Apply the resolution rule to the resulting clauses.
- Each clause contains complementary literals.
- They are resolved and produce 2 new clause and they are be added to the set of facts if they are not already exist.
- This process continues until any one of the following occur:
  - No more new clauses that can be added
  - An application of the resolution rule derives the empty clause
- An empty clause shows that the negation of the conclusion is a complete contradiction, hence the negation of the conclusion is invalid or false or the assertion is completely valid or true.

Knowledgebase systems

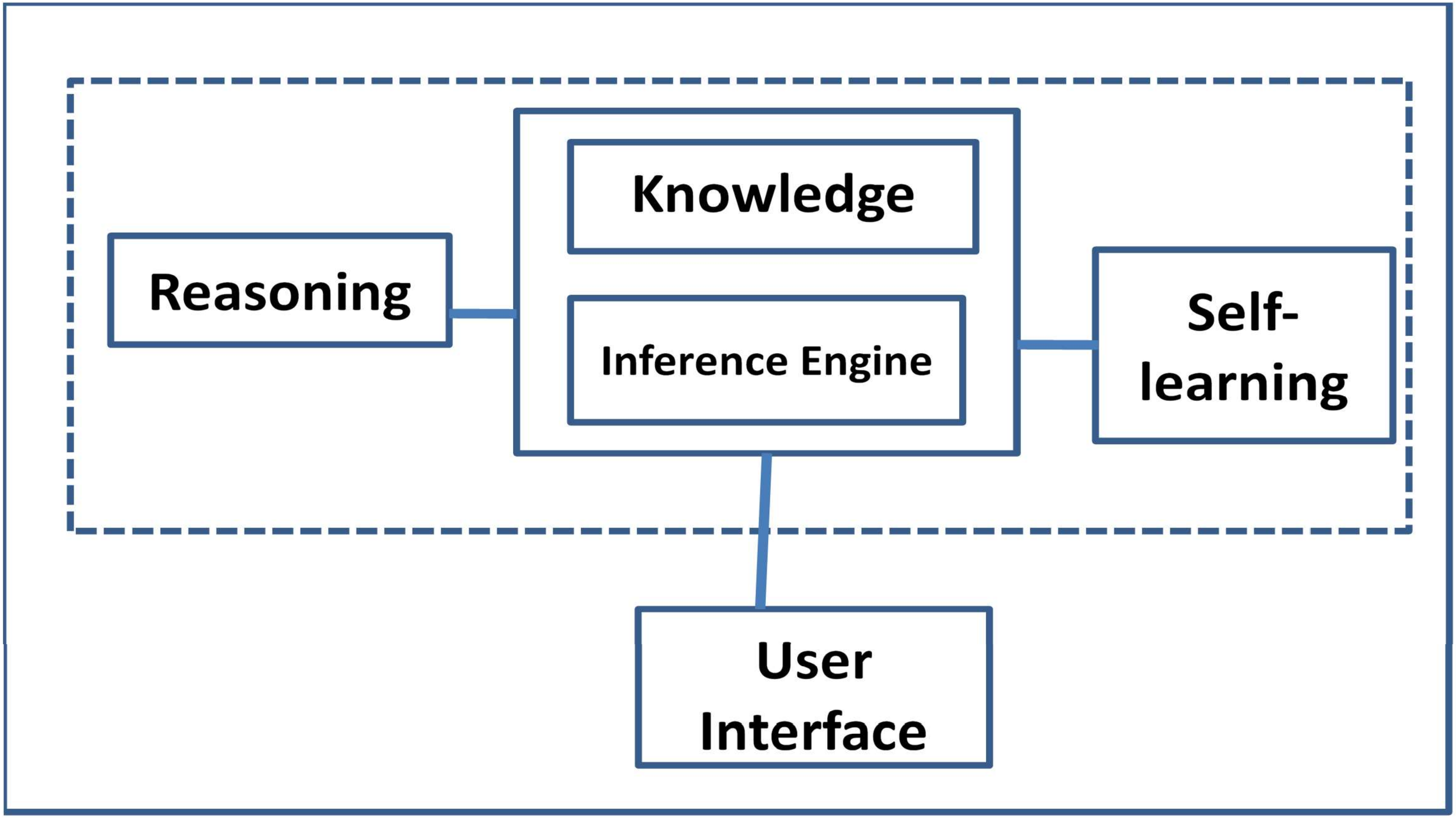
- A knowledgebase system is a program that uses AI to solve problems within a specialized domain that ordinarily requires human expertise.

- Typical tasks of expert systems include classification, diagnosis, monitoring, design, scheduling and planning for specialized tasks.

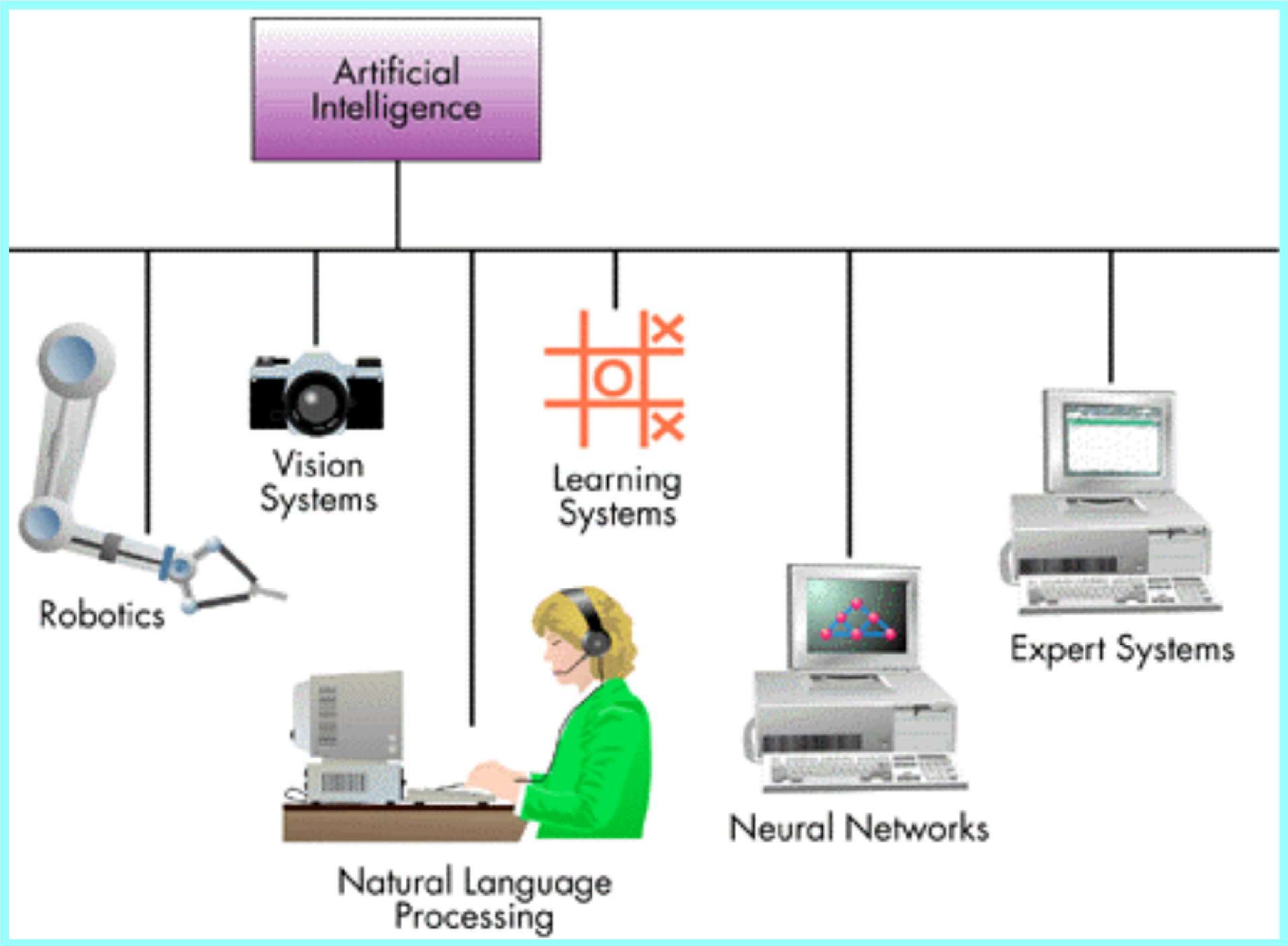
- Knowledgebase is a more general than expert system



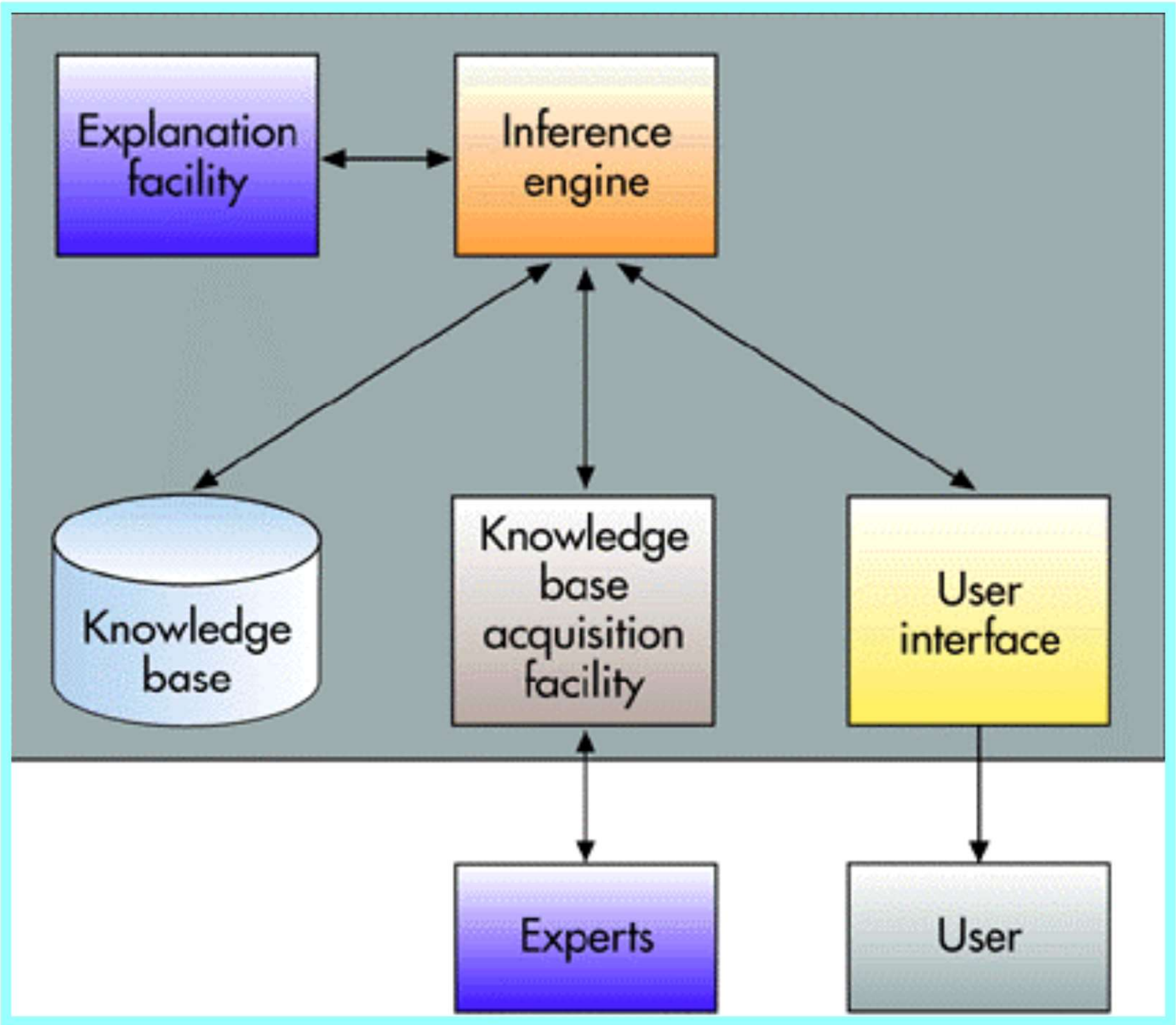
Structure of a knowledge based system



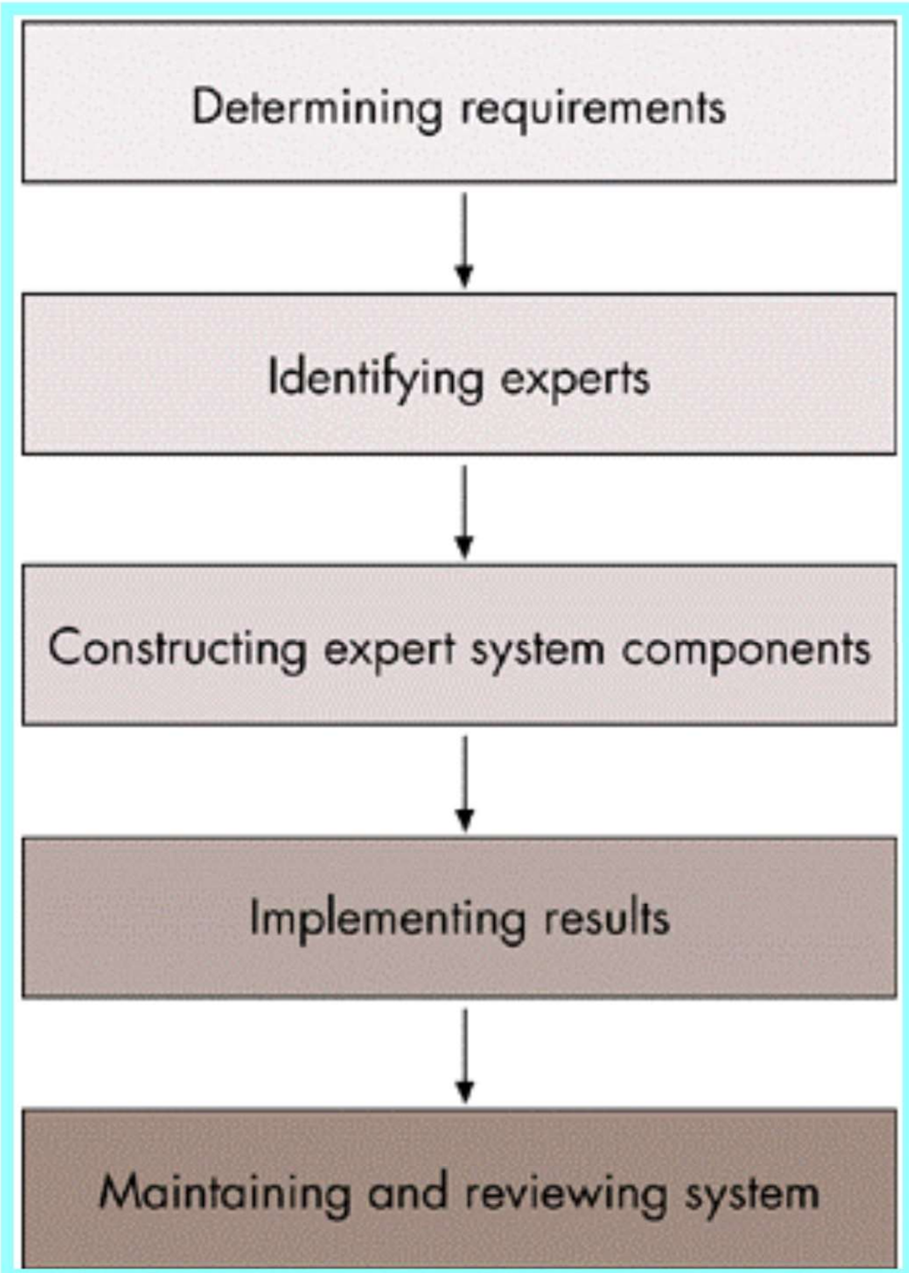
Recap of artificial intelligence

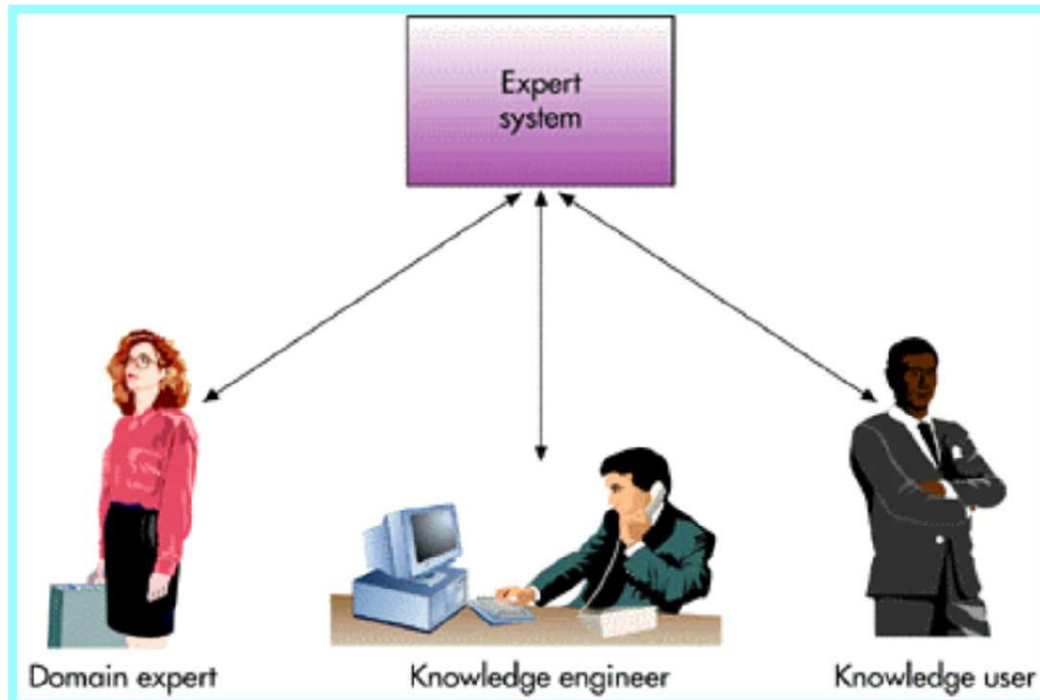


Components of expert systems



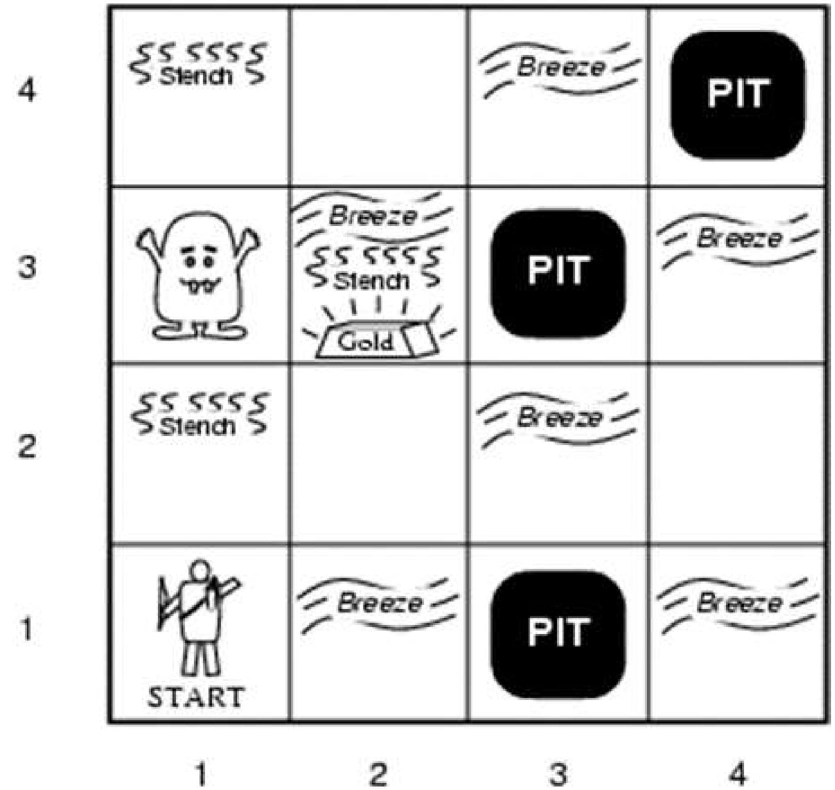
Expert systems development





Wumpus world

- Performance measure
  - gold +1000,
  - death -1000 (falling into a pit or being eaten by the wumpus)
  - -1 per step, -10 for using the arrow
- Environment
  - Squares adjacent to wumpus are smelly
  - Squares adjacent to pit are breezy
  - Glitter iff gold is in the same square
  - Shooting kills wumpus if you are facing it
  - Shooting uses up the only arrow
  - Grabbing picks up gold if in same square
  - Releasing drops the gold in same square
- Sensors: Stench, Breeze, Glitter, Bump, Scream
- Actuators: Left turn, Right turn, Forward, Grab, Release, Shoot



Logic

- Knowledge bases consist of sentences in a formal language
- Syntax: Sentences are well formed
- Semantics
- The “meaning” of the sentence.
    - ***The truth of each sentence with respect to each possible world (model)***

A simple knowledgebase

$B_{1,1}$	$B_{2,1}$	$P_{1,1}$	$P_{1,2}$	$P_{2,1}$	$P_{2,2}$	$P_{3,1}$	KB	α_1
$false$	$false$	$false$	$false$	$false$	$false$	$false$	$false$	$true$
$false$	$false$	$false$	$false$	$false$	$false$	$true$	$false$	$true$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$false$	$true$	$false$	$false$	$false$	$false$	$false$	$false$	$true$
$false$	$true$	$false$	$false$	$false$	$false$	$true$	$\underline{true}$	$\underline{true}$
$false$	$true$	$false$	$false$	$false$	$true$	$false$	$\underline{true}$	$\underline{true}$
$false$	$true$	$false$	$false$	$false$	$true$	$true$	$\underline{true}$	$\underline{true}$
$false$	$true$	$false$	$false$	$true$	$false$	$false$	$false$	$true$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$true$	$true$	$true$	$true$	$true$	$true$	$true$	$false$	$false$

Exploring the Wumpus world

1,4	2,4	3,4	4,4
1,3	2,3	3,3	4,3
1,2 OK	2,2	3,2	4,2
1,1 A OK	2,1 OK	3,1	4,1

1,4	2,4	3,4	4,4
1,3	2,3	3,3	4,3
1,2 OK	2,2 P?	3,2	4,2
1,1 V OK	2,1 A B OK	3,1 P?	4,1

1,4	2,4	3,4	4,4
1,3 W!	2,3	3,3	4,3
1,2 A S OK	2,2 OK	3,2	4,2
1,1 V OK	2,1 V B OK	3,1 P?	4,1

1,4	2,4	3,4	4,4
1,3 W!	2,3 OK	3,3	4,3
1,2 V S OK	2,2 A OK	3,2 OK	4,2
1,1 V OK	2,1 V B OK	3,1 P!	4,1

Semantic net

- A semantic net is a labeled directed graph, where each node represents an object (a proposition), and each link represents a relationship between two objects.
- Semantic nets represent propositional information.

- Relations between propositions are of primary interest because they provide the basic structure for organizing knowledge.

- Some important relations are:
  - "IS-A" (is an instance of). Refers to a member of a **class,** where a class is a group of objects with one or more common attributes (properties). For example, "Tom IS-A bird".
  - "A-KIND-OF". Relates one class to another, for example "Birds are A-KIND-OF animals".
  - "HAS-A". Relates attributes to objects, for example "Mary HAS-A cat".
  - "CAUSE". Expresses a causal relationship, for example "Fire CAUSES smoke".

Inference in semantic networks

- Find relationships between pairs of words
  - Search graphs outward from each word in a breath-first fashion
  - Search for a common concept or intersection node
  - The path between the two given words passing by this intersection node is the relationship being looked for

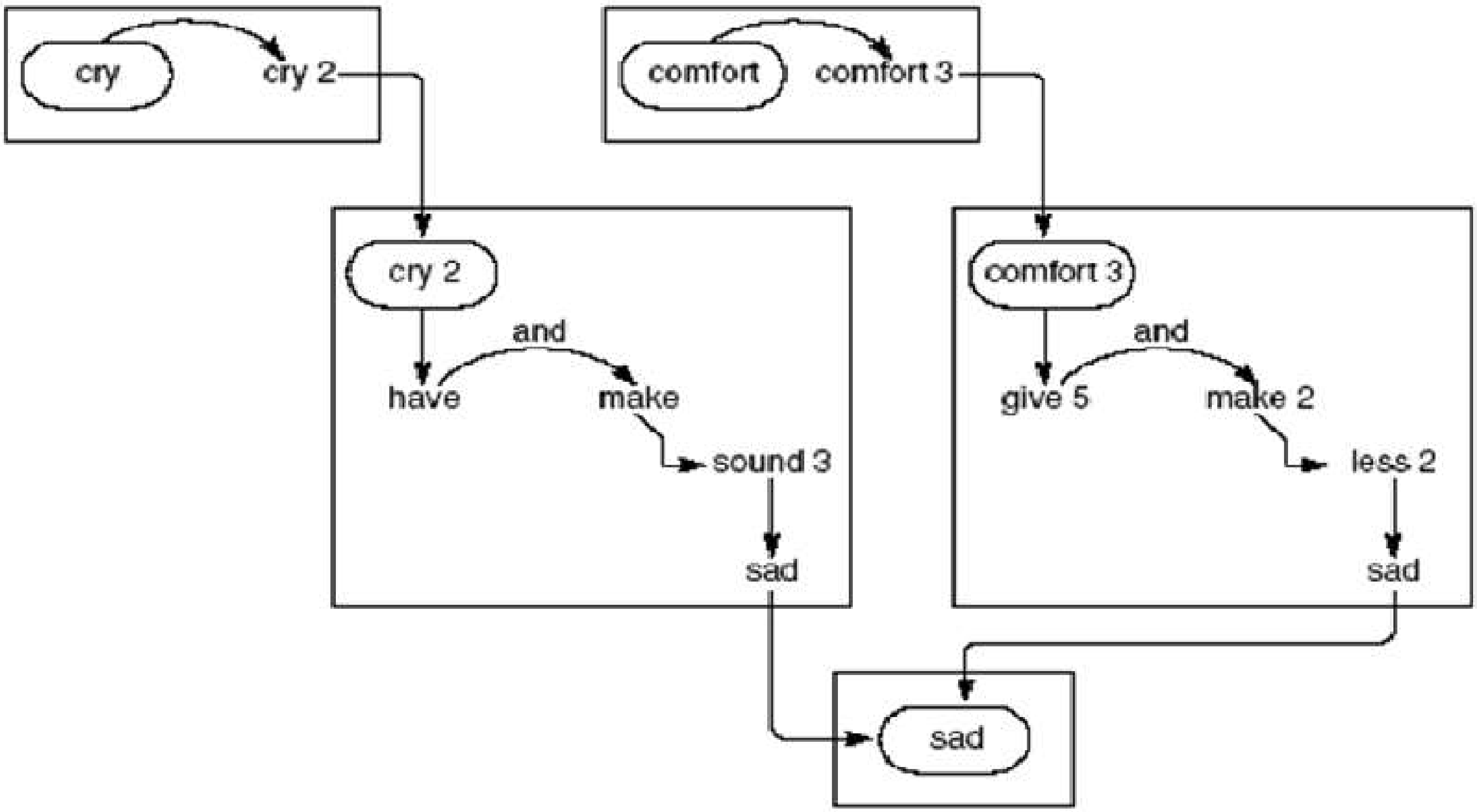
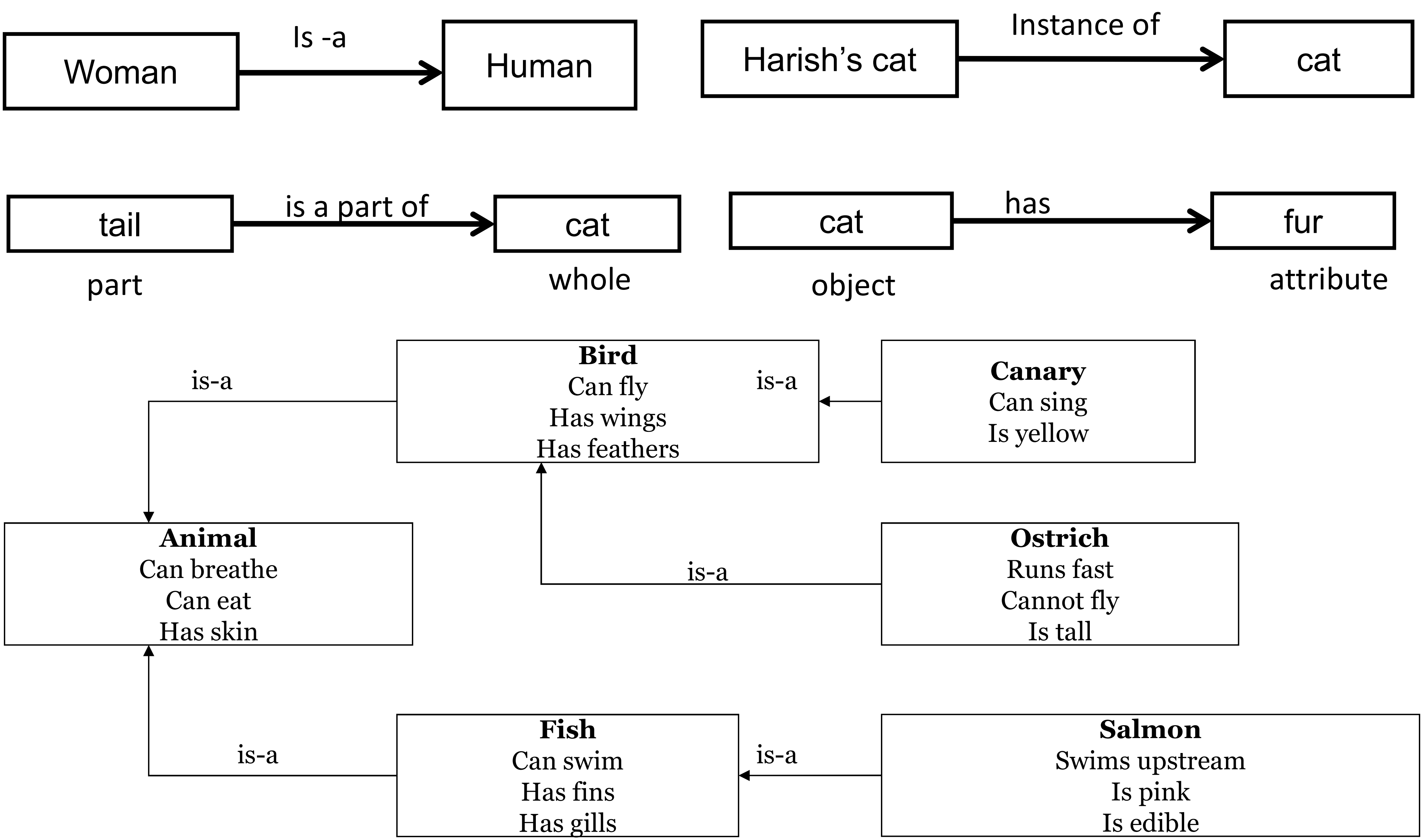


Fig. Find the relationship (intersection path) between “cry” and “comfort”

Semantic networks: Types and components

- Six types of semantic networks are:
  - Definitional network
  - Assertional network
  - Implicational network
  - Executable network
  - Learning network
  - Hybrid network
- Semantic network components
  - Lexical component
  - Structural components
  - Semantic component
  - Procedural part

Types of relationships in semantic network

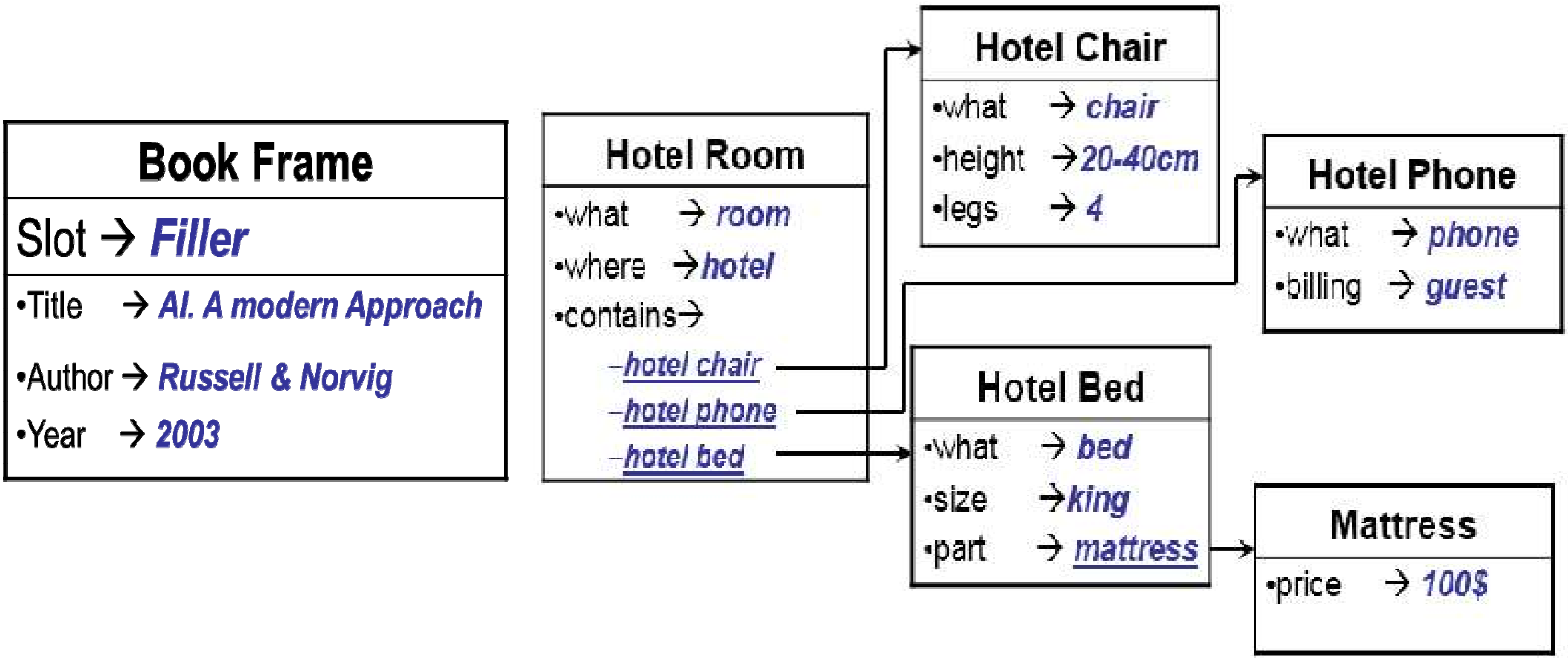


Frames

- Devised by Marvin Minsky, 1974.
- Incorporates certain valuable human thinking characteristics:
  - Expectations, assumptions, stereotypes. Exceptions. Fuzzy boundaries between classes.
- The essence of this form of knowledge representation is typicality, with exceptions, rather than definition.
- The idea of frame hierarchies is very similar to the idea of class hierarchies found in object-orientated programming.
- A frame system is a hierarchy of frames
- Each frame has:
  - a name.
  - slots: these are the properties of the entity that has the name, and they have values. A particular value may be:
    - a default value
    - an inherited value from a higher frame
    - a procedure, called a daemon, to find a value
    - a specific value, which might represent an exception.

Frames: Some examples

- The three components of a frame include:
  - frame name; attributes (slots); values (fillers: list of values, range, string, etc.)



Non-monotonic logic

- Monotonic: if KB1|=α , then KB2|=α for any KB1⊆KB2.
- Meaning new facts can only add to early conclusions not contradict them.
- Non-monotonic: New facts can change our conclusions.
- If we know tweety is a bird –we conclude it flies.
- If we find out that tweety is an ostrich we conclude it don't flies.
- A logic is non-monotonic if some conclusions can be invalidated by adding more knowledge.
- The logic of definite clauses with negation as failure is non-monotonic.
- Non-monotonic reasoning is useful for representing defaults.
- A default is a rule that can be used unless it overridden by an exception.
  - For example, to say that b is normally true if c is true, a knowledge base designer can write a rule of the form
  - $b \leftarrow c \wedge \sim aba$.
- Non – monotonic systems require more storage space as well as more processing time than monotonic systems.

Circumscription

- Circumscription is a powerful non-monotonic formalism created by John McCarthy(1977,1980), generalized (in1984)
- Independently explored by many researchers
- It is the most fascinating and the most controversial of all the formal approaches to non monotonic reasoning
- Extension: A predicate denoted by an expression U will be called extension of U.
- For example if U=Bird (unary constant predicate) and D=All individuals. Then the extension of U is a subset of D (intuitively D=All birds).
- Circumscription allows us to formalize non-monotonic reasoning directly in the language of classic logic.
- It is always the task of the user to specify which predicates to be minimized. Circumscription provides a general method for it.
- Circumscription is based on syntactic manipulations.

Default logic

- Default Logic is a Non-Monotonic Logic proposed by Raymond Reiter to formalize reasoning with default assumptions.
- Standard logic can only express that something is true or that something is false.
- This is a problem because reasoning often involves facts that are true in the majority of cases but not always.
- It mainly aims at formalizing default inference rules without stating all the exceptions.
  - Example : “Birds typically fly” vs “All birds fly”
  - Exceptions – Penguins, Ostriches
- Syntax of Default Logic
- A default theory is a pair <D,W>
  - W is a set of logical formulae, called the background theory, that formalize the facts that are known for sure.