LOGIC CONCEPTS & LOGIC PROGRAMMING
INFERENCE AND RESOLUTION FOR PROBLEM SOLVING

Fundamentals of Artificial Intelligence

Session 17

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Agenda

- Introduction
- Wumpus World
- Logic Concepts & Logic Programming
- Inference and Resolution for Problem Solving

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Agent's Knowledge Representation

Atomic	States are indivisible; No internal structure	Search on atomic states; Heuristic and Blind searches
Propositional (aka Factored)	States are made of state variables that take values (Propositional or multi-values or Continuous)	Search + Inference in (prop logic) and probabilistic (Bayes Nets) representations
Relational	States Describe the objects in the world and their inter-relations	Search + Inference in predicate logic (or relational prob. Models)
First-order	States Describe the objects in the world and their inter-relations along with Functions over the objects	Search + Inference in first order logic

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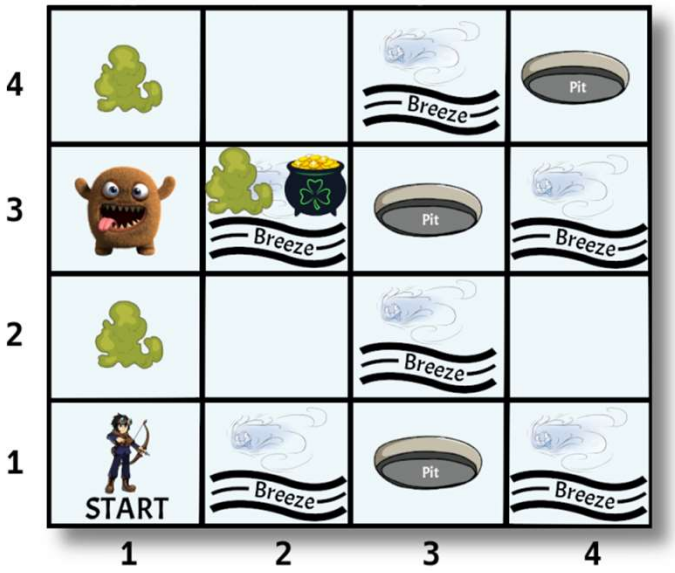
Wumpus World



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PEAS Description of Wumpus World

- Performance measure:
  - +1000 reward points if the agent comes out of the cave with the gold.
  - -1000 points penalty for being eaten by the Wumpus or falling into the pit.
  - -1 for each action, and -10 for using an arrow.
  - The game ends if either agent dies or came out of the cave.

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PEAS Description of Wumpus World

- Environment:
  - A 4*4 grid of rooms.
  - The agent initially in room square [1, 1], facing toward the right.
  - Location of Wumpus and gold are chosen randomly except the first square [1,1].
  - Each square of the cave can be a pit with probability 0.2 except the first square.

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PEAS Description of Wumpus World

- Actuators:
  - Left turn
  - Right turn
  - Move forward
  - Grab
  - Release
  - Shoot

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PEAS Description of Wumpus World

- Sensors:
  - The agent will perceive the stench if he is in the room adjacent to the Wumpus (Not diagonally).
  - The agent will perceive breeze if he is in the room adjacent to the Pit (Not diagonally).
  - The agent will perceive the glitter in the room where the gold is present.
  - The agent will perceive the bump if he walks into a wall.
  - When the Wumpus is shot, it emits a horrible scream which can be perceived anywhere in the cave.
- These percepts can be represented as five element list, in which we will have different indicators for each sensor.
- Example if agent perceives stench, breeze, but no glitter, no bump, and no scream then it can be represented as:
  [Stench, Breeze, None, None, None].

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Wumpus World Properties

- Partially observable: The Wumpus world is partially observable because the agent can only perceive the nearby environment such as an adjacent room
- Deterministic: It is deterministic, as the result and outcome of the world are already known.
- Sequential: The order is important, so it is sequential.
- Static: It is static as Wumpus and Pits are not moving.
- Discrete: The environment is discrete.
- One agent: The environment is a single agent as we have one agent only and Wumpus is not considered as an agent.

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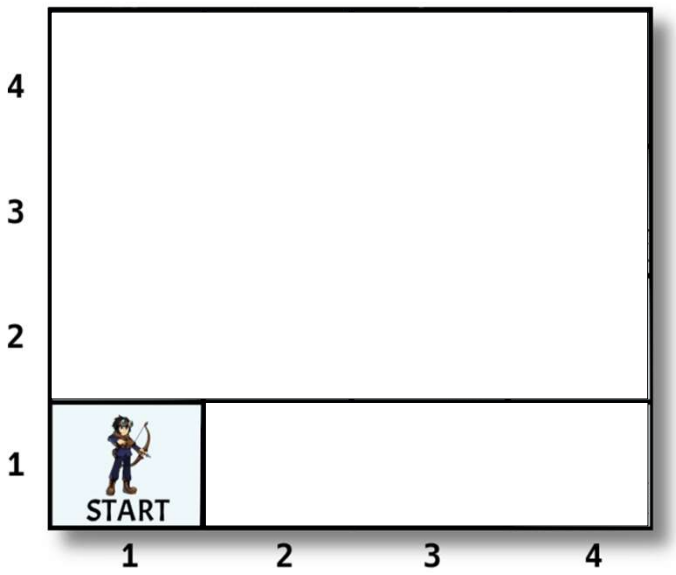
Wumpus World



Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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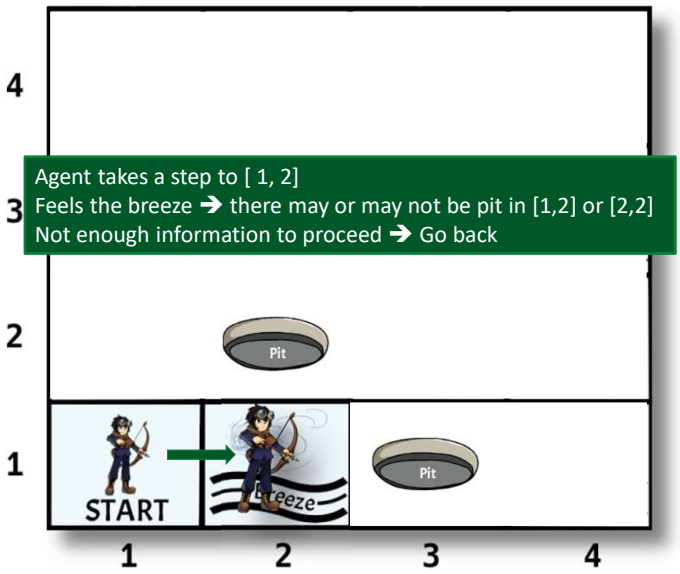
Wumpus World



Agent takes a step to [1, 2]
Feels the breeze ➔ there may or may not be pit in [1,2] or [2,2]
Not enough information to proceed ➔ Go back

Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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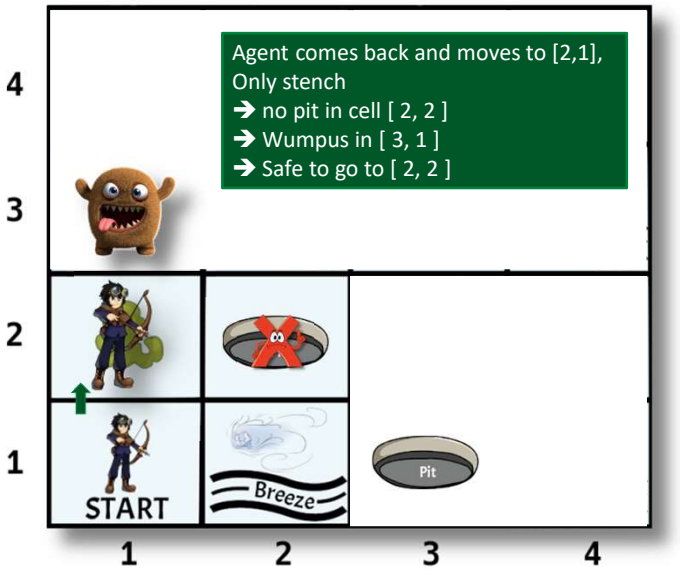
Wumpus World



Agent comes back and moves to [2,1],
Only stench
➔ no pit in cell [2, 2]
➔ Wumpus in [3, 1]
➔ Safe to go to [2, 2]

Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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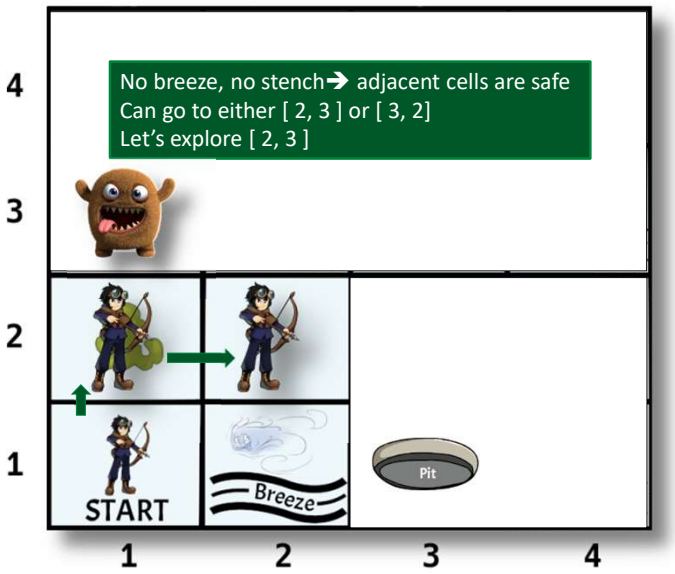
Wumpus World



Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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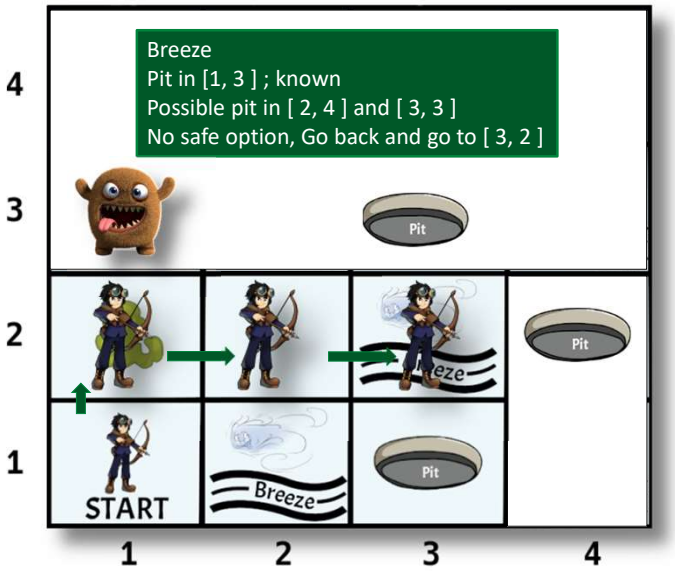
Wumpus World



Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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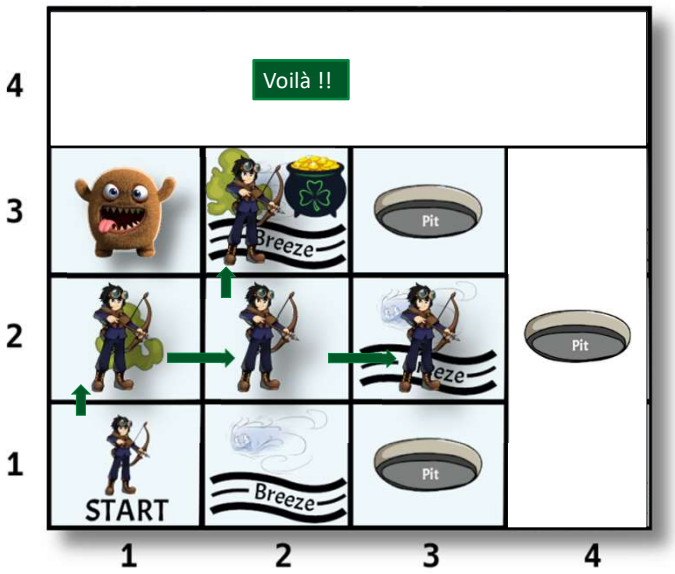
Wumpus World



Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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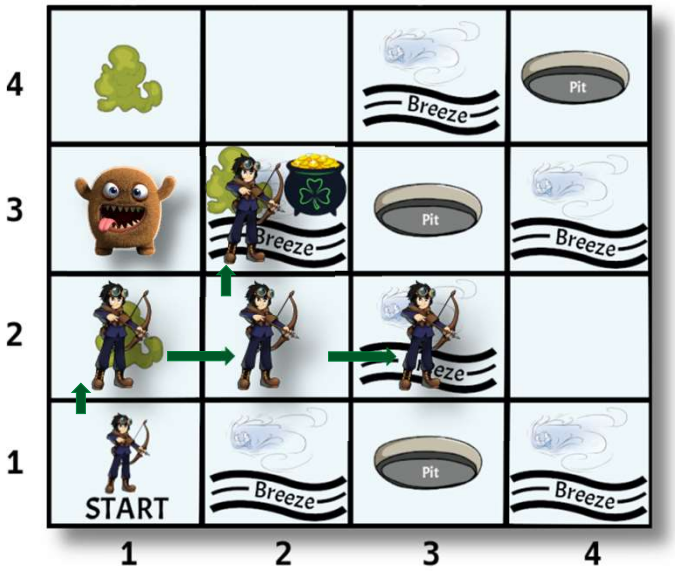
Wumpus World



Stench: Wumpus alert

Breeze: Pit alert

Glitter : Gold !!

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Logic

- Knowledge bases consist of sentences
- Sentences are expressed according to the syntax of the representation language
- Notion of syntax is clear enough in math:
  - "x + y = 4" makes sense whereas "x4y+ =" is invalid
- Logic also must define semantics or meaning of the sentence
  - For example semantics of math defines x + y = 4 is true in a world where x = 2 and y = 2
  - But false in a world where x = 1 and y = 1
- In standard logic every sentence is true or false in each possible world
  - There is no "in between"
- A possible world: having x men and y women sitting at a table playing bridge
  - Mathematically: x + y = 4

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How do we represent!

- Mohan owns the book.

person — predicate — subject

- Once you break it down in some logic easy to tell the computer
  - `Owns (book, Mohan)`
- That's how they created IBM Watson knowledge base for playing games…

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Logic

- What is Logic?
- It's very broad topic… no universally accepted definition
- For purpose of today's discussion, Logic is way we program computers
  - Logics are formal languages within well-defined rules for manipulation of representation
  - Welcome back to your school days… 
- Three logicians sitting in a bar…
  - Bar tender ask "will all of you have beer?"
  - First logician says " I don't know"
  - Second logician says " I don't know"
  - Third logician says "yes!"
  - How?????

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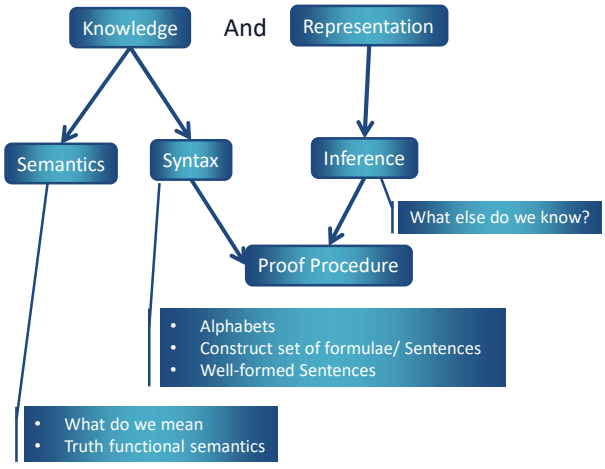
Logic

- Logic is concerned with the properties of and relations between Syntax, Semantics and Inference
- Syntax (formulae, sentences, etc.)
- Semantics (truth, validity, semantic consequences , etc.)
  - How sentences are interpreted and stating under what conditions it is true
  - It is true under all interpretations then it is "valid"
  - If sentence A is always true if B is true, then A is semantic consequence of sentence B
    - A = "Sun is visible in the East."; B = "It is morning."
- Inferences (proofs, theorems, soundness, completeness, etc.)



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Example

- Statement A: “It is an apple”
- Statement B: “It is a banana”
- Consider following logic

A or B, but not A

$$\frac{A \vee B, \quad \neg A}{B}$$ Premises / Conclusion

- This reasoning does not depend on contents of A and B
- It does not even depends on the truth of the premises
- We can deduce from the structure of the statements
- This concrete inference rule is also known as *modus tollendo ponens*

Model that proves by denying
Google: “Putting the measure abolishing”

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What is a Logic?

- A language with concrete rules
  - No ambiguity in representation (may be other errors!)
  - Allows unambiguous communication and processing
  - Very unlike natural languages e.g. English
- Many ways to translate between languages
  - A statement can be represented in different logics
  - Perhaps differently in same logic
- Expressiveness of a logic
  - How much can we say in this language?
- Not to be confused with logical reasoning
  - Logics are languages, reasoning is a process (may use logic)

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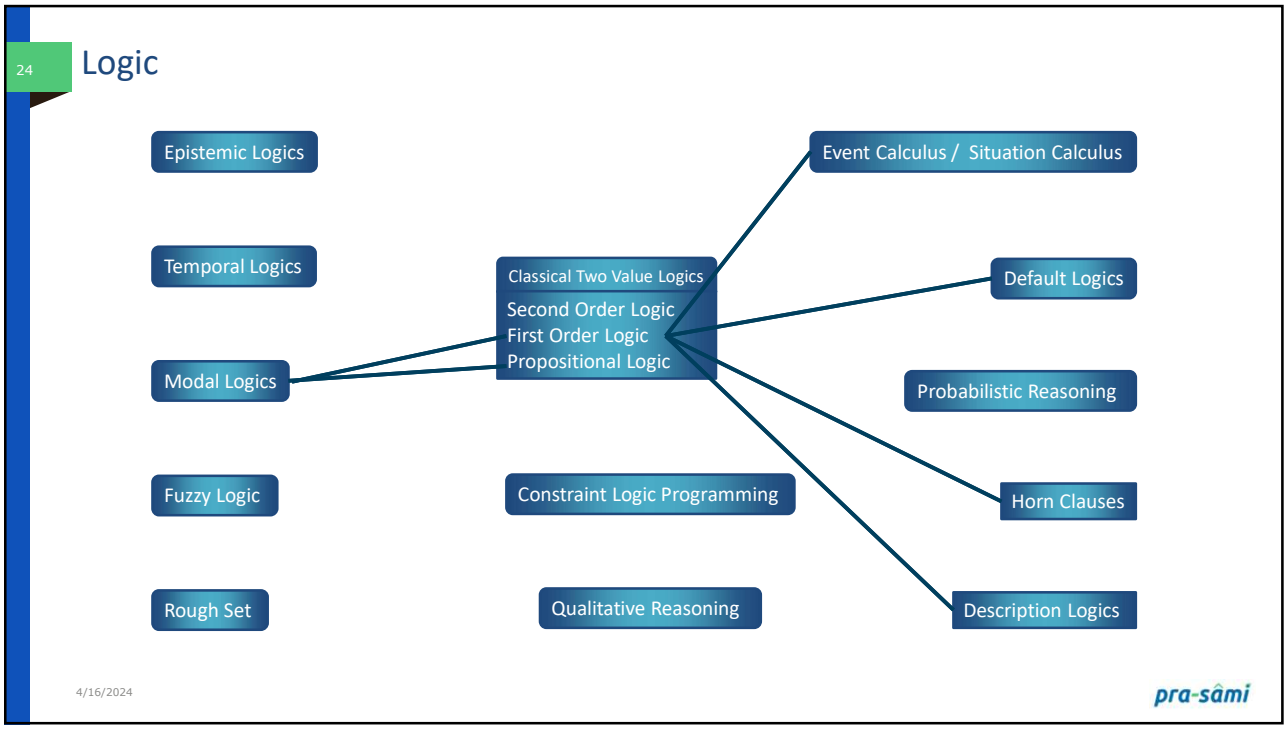
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Logic
Epistemic Logics
Temporal Logics
Modal Logics
Fuzzy Logic
Rough Set
Classical Two Value Logics
Second Order Logic
First Order Logic
Propositional Logic
Constraint Logic Programming
Qualitative Reasoning
Event Calculus / Situation Calculus
Default Logics
Probabilistic Reasoning
Horn Clauses
Description Logics
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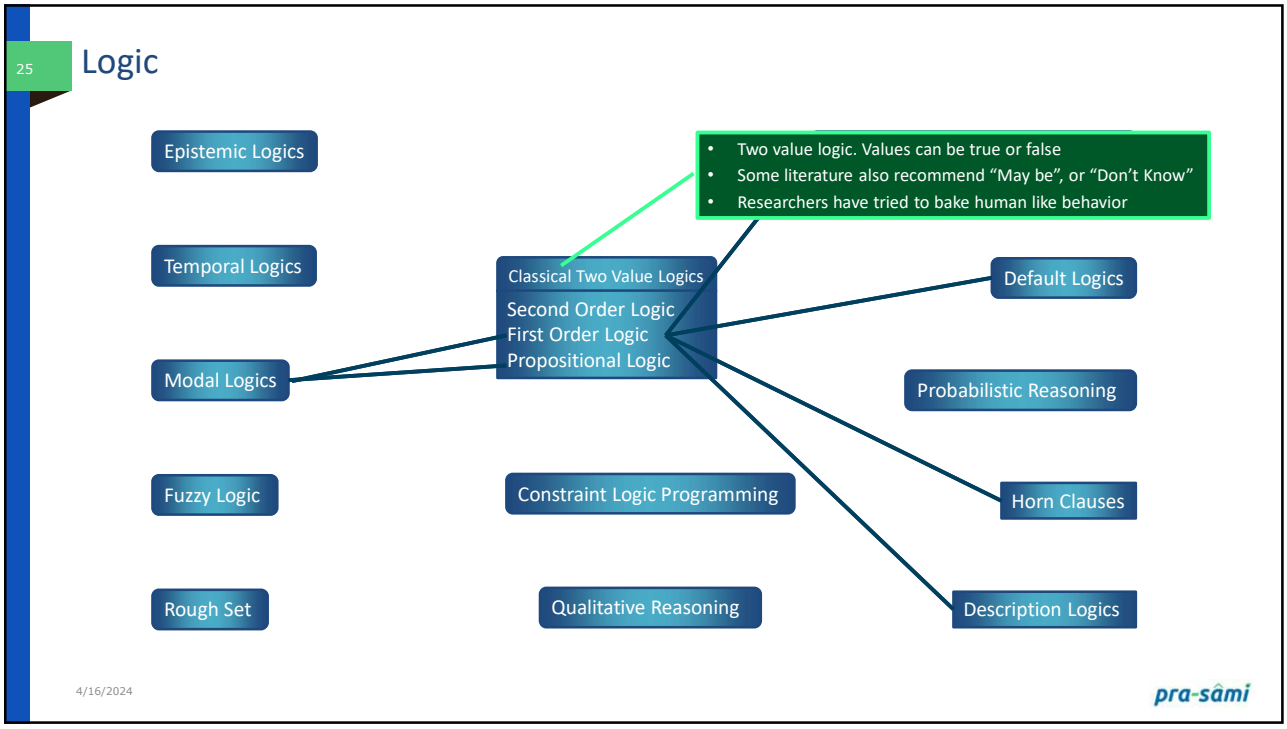
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Logic
Epistemic Logics
Temporal Logics
Modal Logics
Fuzzy Logic
Rough Set
Classical Two Value Logics
Second Order Logic
First Order Logic
Propositional Logic
Constraint Logic Programming
Qualitative Reasoning
Two value logic. Values can be true or false
Some literature also recommend “May be”, or “Don’t Know”
Researchers have tried to bake human like behavior
Default Logics
Probabilistic Reasoning
Horn Clauses
Description Logics
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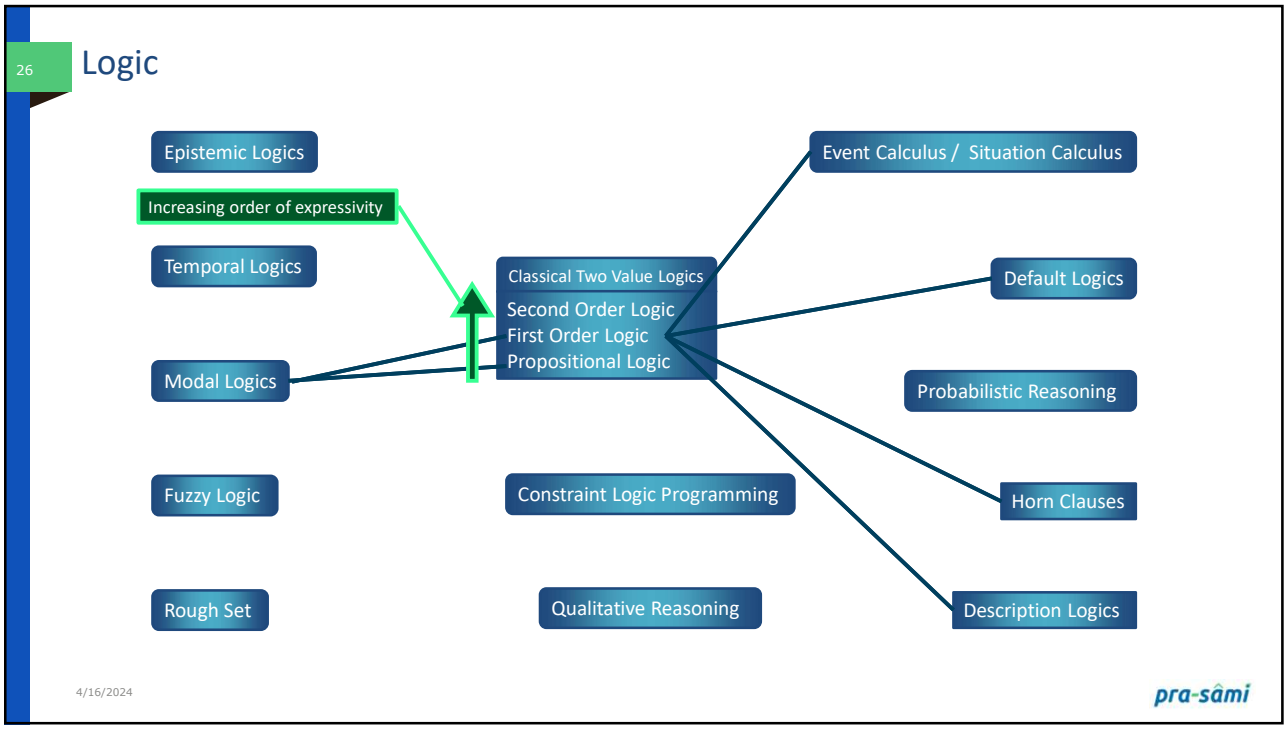
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Logic
Epistemic Logics
Increasing order of expressivity
Temporal Logics
Modal Logics
Fuzzy Logic
Rough Set
Classical Two Value Logics
Second Order Logic
First Order Logic
Propositional Logic
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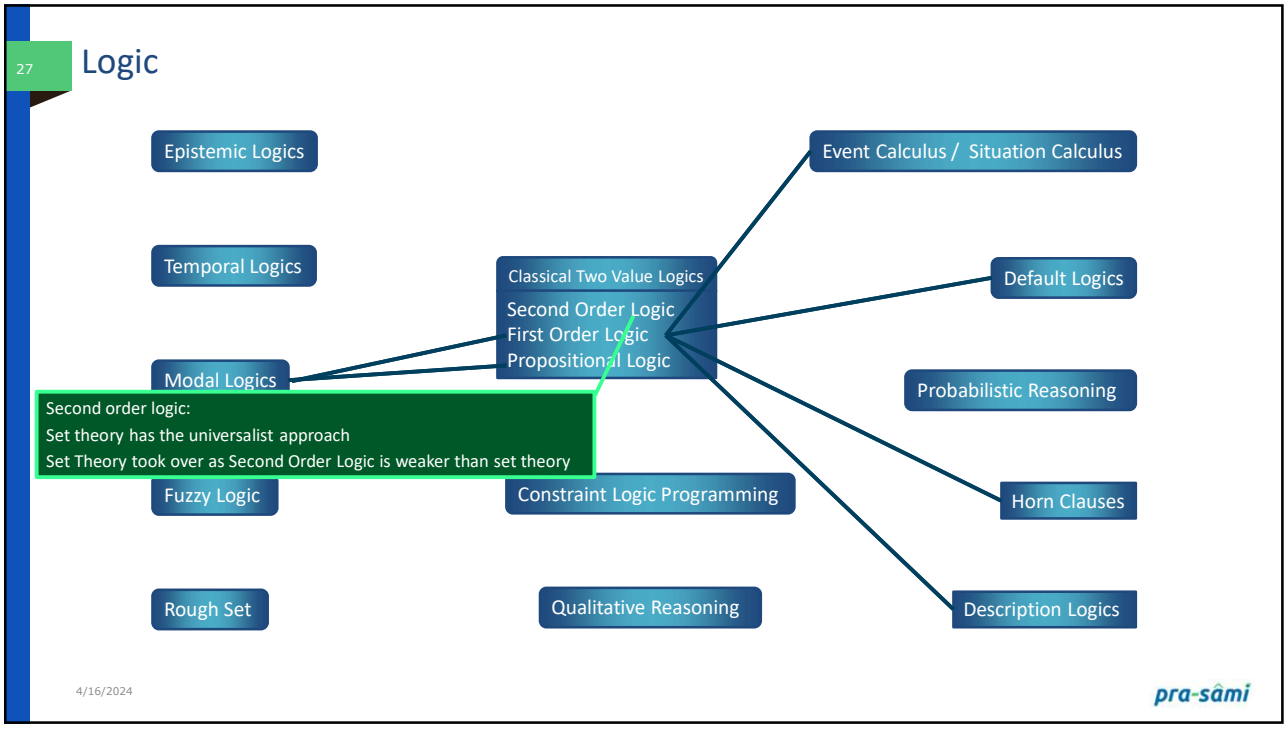
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Logic
Epistemic Logics
Temporal Logics
Modal Logics
Second order logic:
Set theory has the universalist approach
Set Theory took over as Second Order Logic is weaker than set theory
Fuzzy Logic
Rough Set
Classical Two Value Logics
Second Order Logic
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Constraint Logic Programming
Qualitative Reasoning
Event Calculus / Situation Calculus
Default Logics
Probabilistic Reasoning
Horn Clauses
Description Logics
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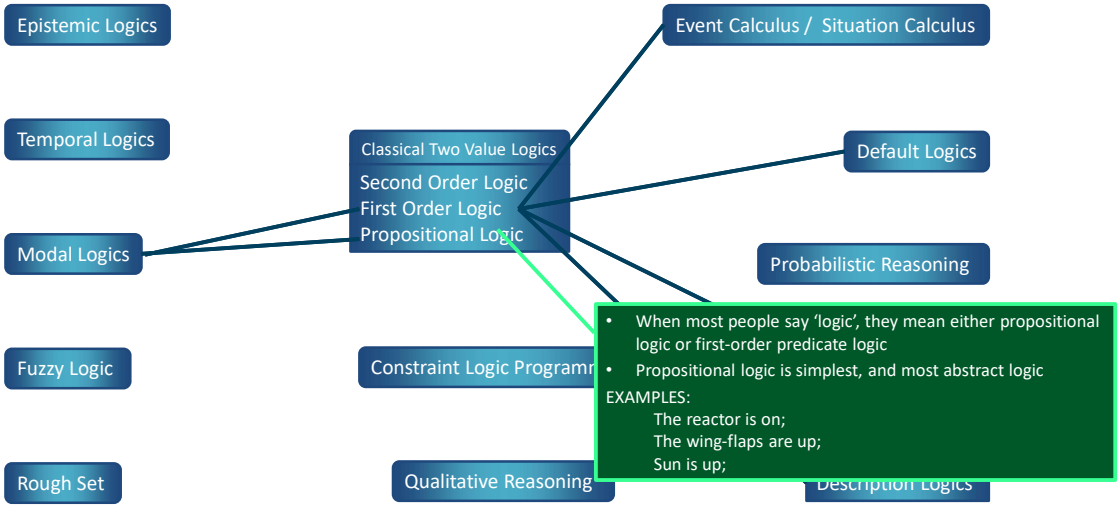
Logic



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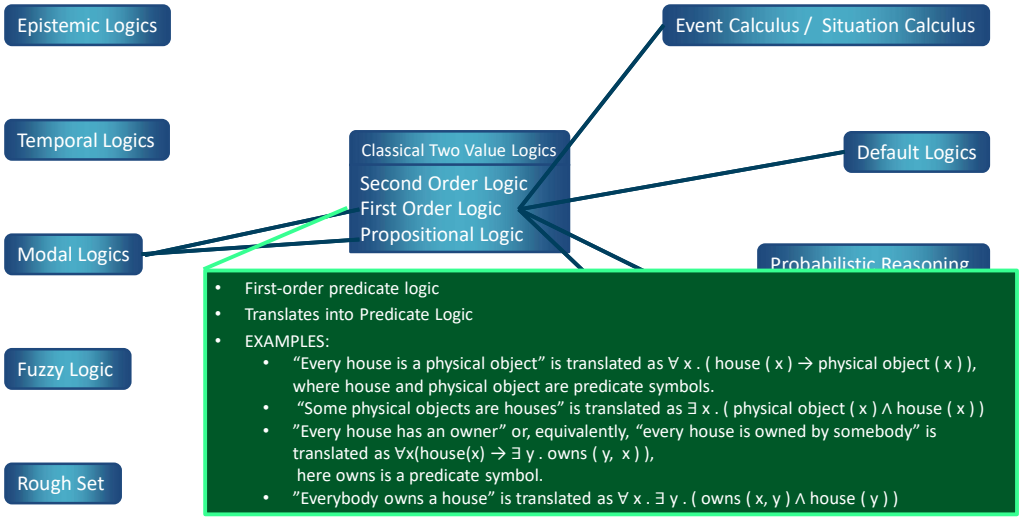
Logic



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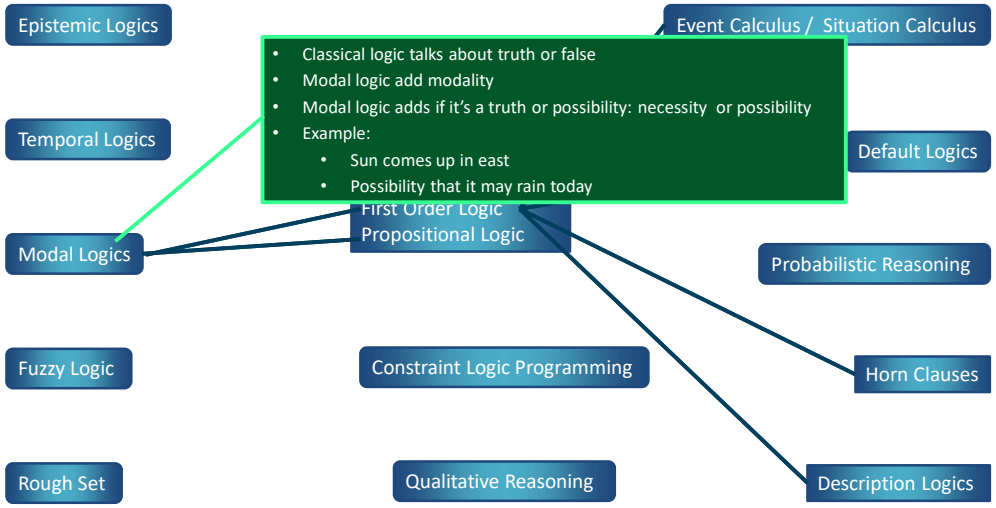
30 Logic



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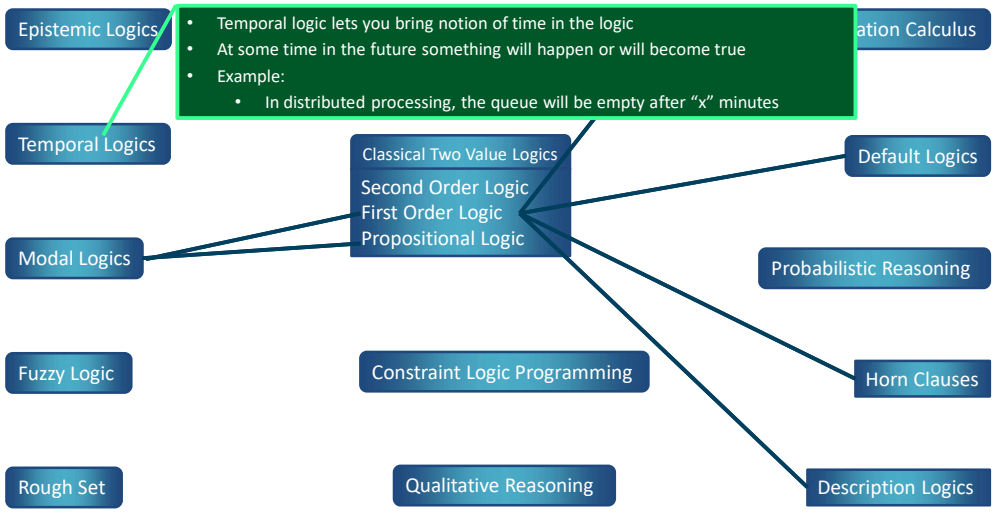
31 Logic



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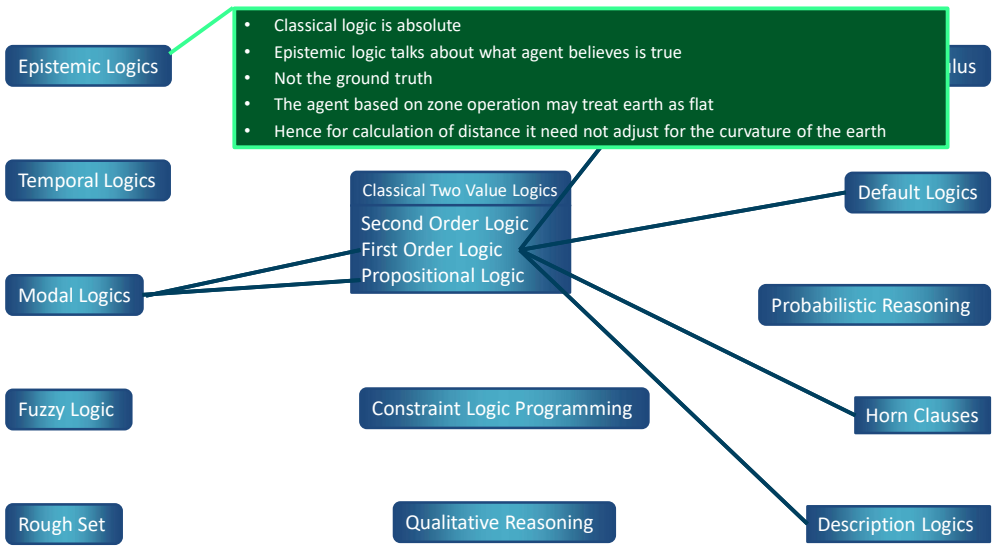
Logic



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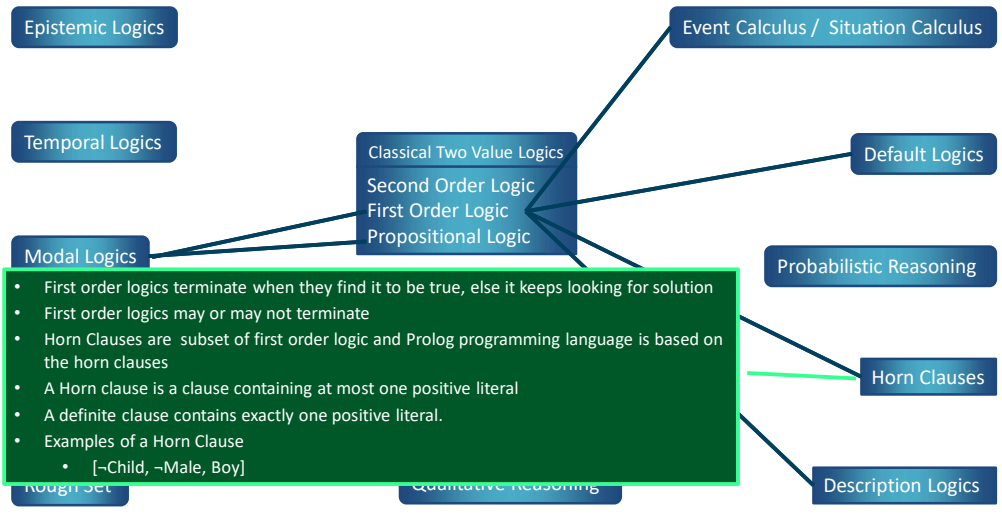
Logic



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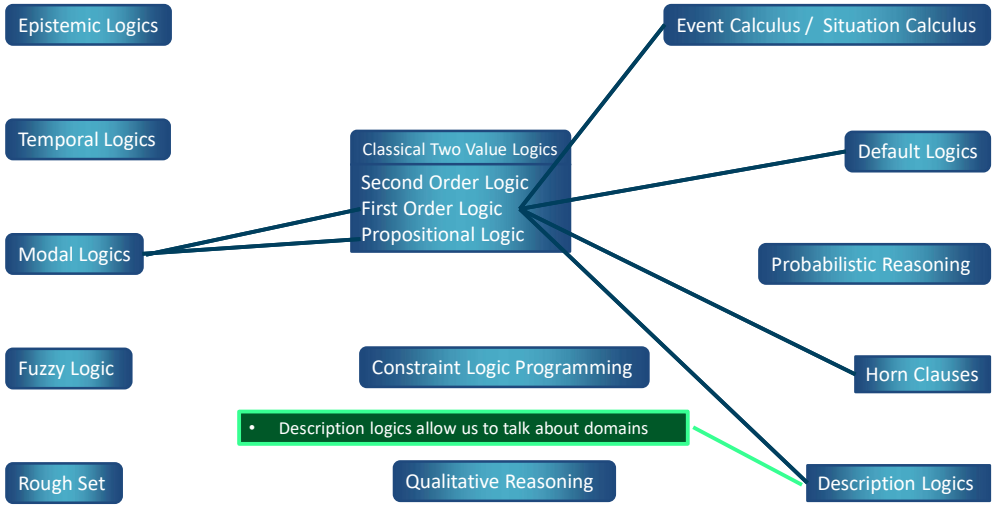
Logic



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Description Logics

- Description logics provide a formal language for constructing and combining category definitions and efficient algorithms for deciding subset and superset relationships between categories
- The syntax of first-order logic is designed to make it easy to say things about objects.
- Description logics are notations that are designed to make it easier to describe definitions and properties of categories
- The principal inference tasks for description logics are:
  - Subsumption: checking if one category is a subset of another by comparing their definitions
  - Classification: checking whether an object belongs to a category
  - Consistency: whether the membership criteria are logically satisfiable
    - Some systems also include consistency of a category definition
- For example, to say that bachelors are unmarried adult males:
  - Bachelor = And(Unmarried, Adult, Male)
- The equivalent in first-order logic would be
  - Bachelor (x) ⇔ Unmarried(x) ∧ Adult(x) ∧ Male(x)

Description logic has an algebra of operations on predicates

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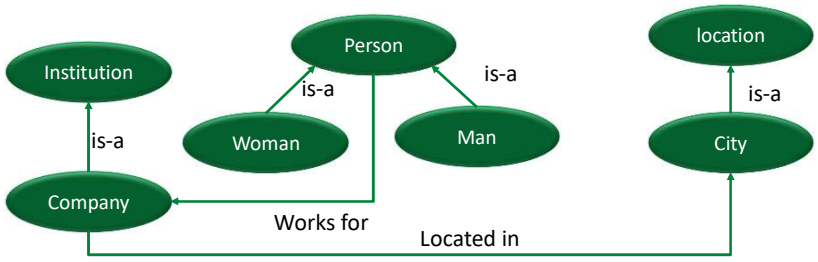
Description Logic - basics

- Designed for knowledge representations



- Allowing to encode general knowledge (as above) as well as world models (with individuals, Such as Pramod)

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Description Logics

- A set of men with at least three sons who are all professors in physics or math departments, and at most two daughters who are unemployed and married to doctors

And(Man, AtLeast(3, Son), AtMost(2, Daughter),
All(Son, And(Professor ,Fills(Department, Physics, Math))),
All(Daughter , And(Unemployed, Married, All(Spouse, Doctor)))

Man(x) $\wedge \exists\, s_1, s_2, s_3$ Son (s_1, x) $\wedge$ Son (s_2, x) $\wedge$ Son(s_3 , x)
$\wedge\, s_1 \neq s_2 \wedge s_1 \neq s_3 \wedge s_2 \neq s_3$

At least Three sons exist

$\wedge \exists\, d_1, d_2$ Daughter(d_1,x) $\wedge$ Daughter(d_2,x)
$\wedge d_1 \neq d_2$

$\wedge \neg \exists\, d_1, d_2, d_3$ Daughter(d_1,x) $\wedge$ Daughter(d_2,x) $\wedge$ Daughter(d_3,x)
$\wedge d_1 \neq d_2 \wedge d_1 \neq d_3 \wedge d_2 \neq d_3$

At most Two daughter

$\wedge \forall$ s Son (s, x) $\Rightarrow$ Professor(s)$\wedge$ (Department(s) = Physics $\vee$ Department(s) = Math)

$\wedge \forall$ d Daughter (d, x) $\Rightarrow$Unemployed(d) $\wedge$ Married(d) $\wedge$ Doctor(Spouse(d))

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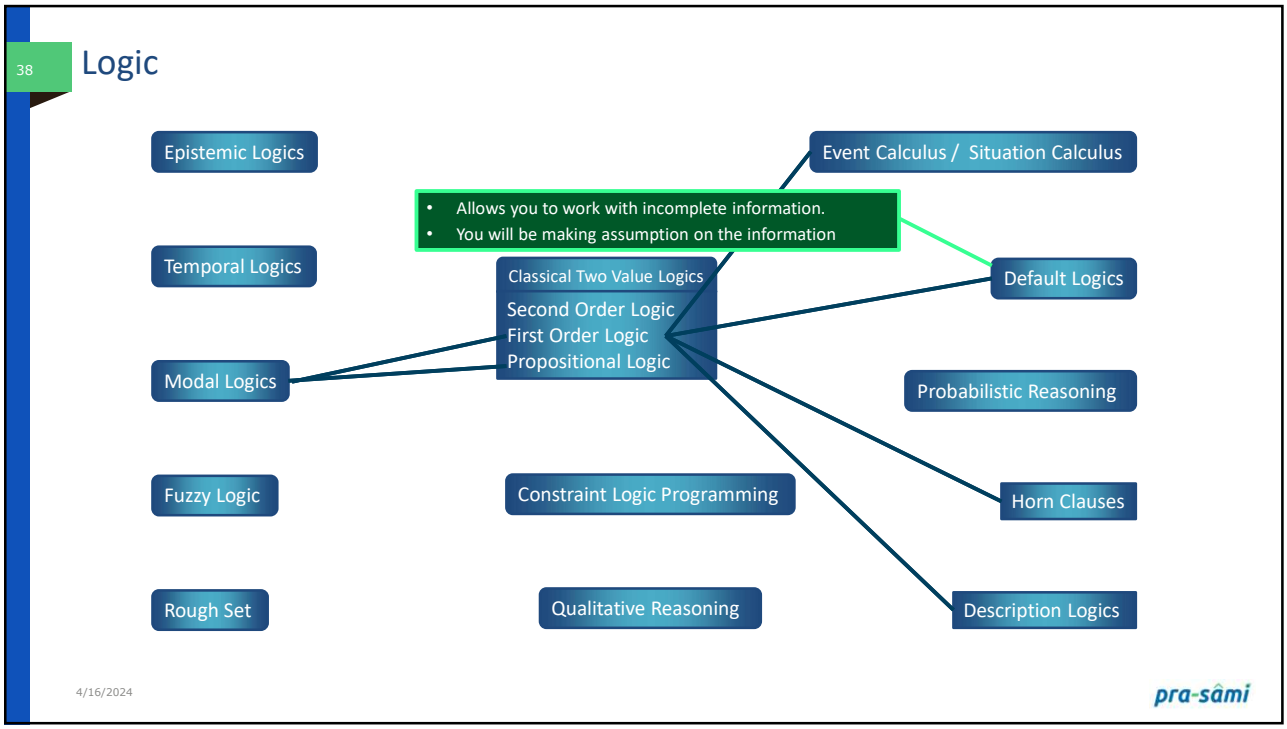
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Logic
Epistemic Logics
Temporal Logics
Modal Logics
Fuzzy Logic
Rough Set
Event Calculus / Situation Calculus
• Allows you to work with incomplete information.
• You will be making assumption on the information
Classical Two Value Logics
Second Order Logic
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Constraint Logic Programming
Qualitative Reasoning
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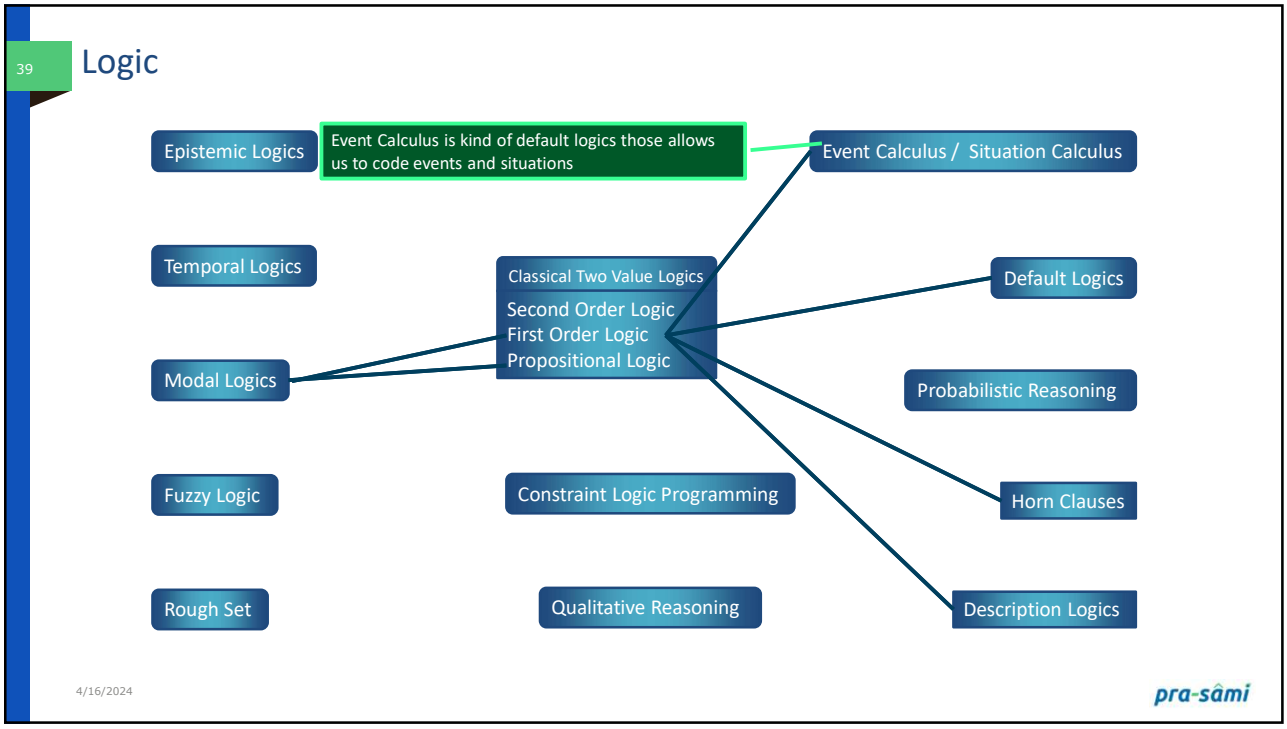
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Logic
Epistemic Logics
Event Calculus is kind of default logics those allows us to code events and situations
Temporal Logics
Modal Logics
Fuzzy Logic
Rough Set
Event Calculus / Situation Calculus
Classical Two Value Logics
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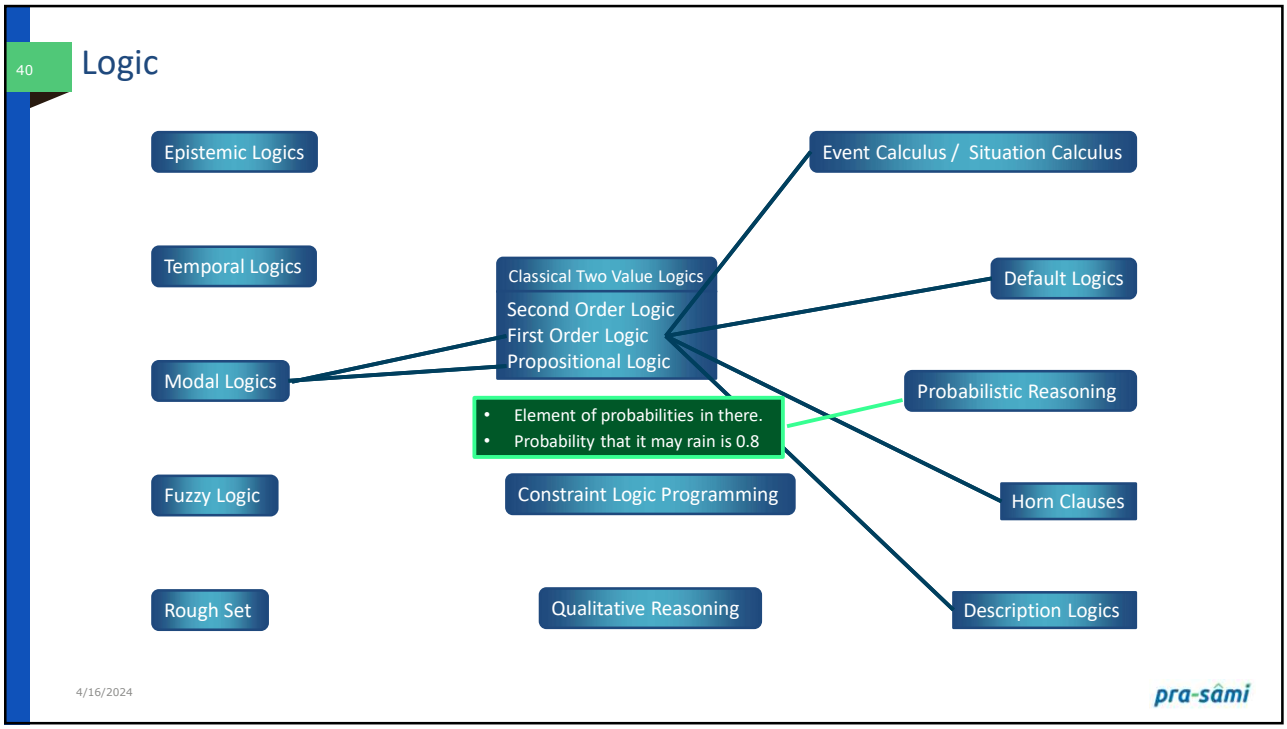
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Constraint Logic Programming
Qualitative Reasoning
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Default Logics
Probabilistic Reasoning
Horn Clauses
Description Logics
• Element of probabilities in there.
• Probability that it may rain is 0.8
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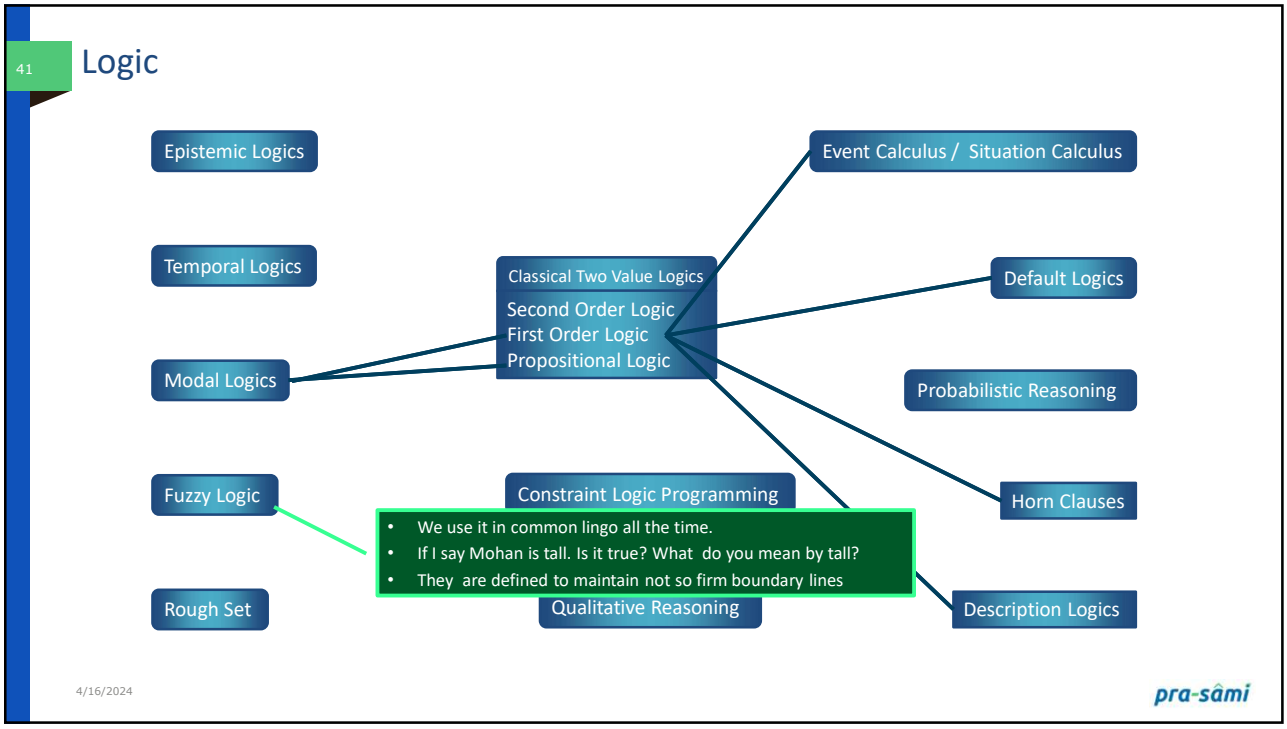
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Horn Clauses
Description Logics
• We use it in common lingo all the time.
• If I say Mohan is tall. Is it true? What do you mean by tall?
• They are defined to maintain not so firm boundary lines
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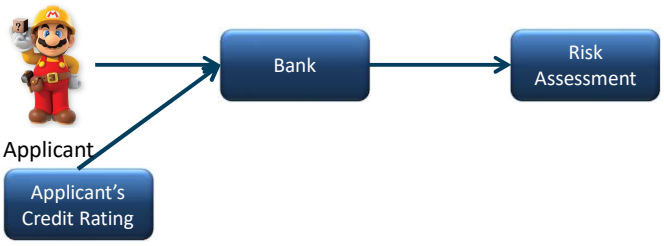
Fuzzy Logic in Decision Making Process

- Simplified Risk assessment



- Inference
  - Banker looks at credit rating and makes an assessment of risk
  - Good Credit Rating → Low Risk
  - Neutral Credit Rating → Medium Risk
  - Bad Credit Rating → High Risk
- Need some encoding of knowledge to make the assessment
- Experience is coded in vague terms!

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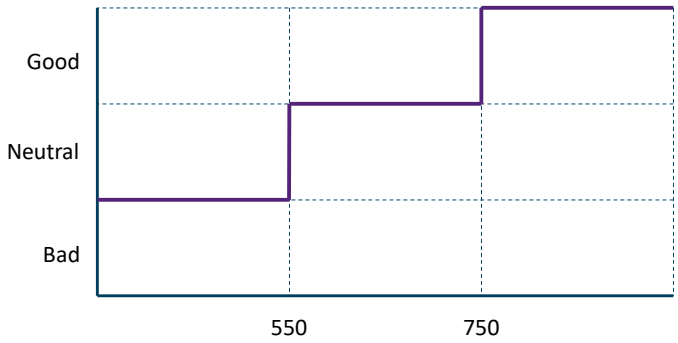
Encoding

- What is good Credit Rating?
  - More than 750; what about 749?
  - Pretty hard to justify
- Move away from rigid boundaries – Binary logic is not sufficient



Welcome Fuzzy Logic!

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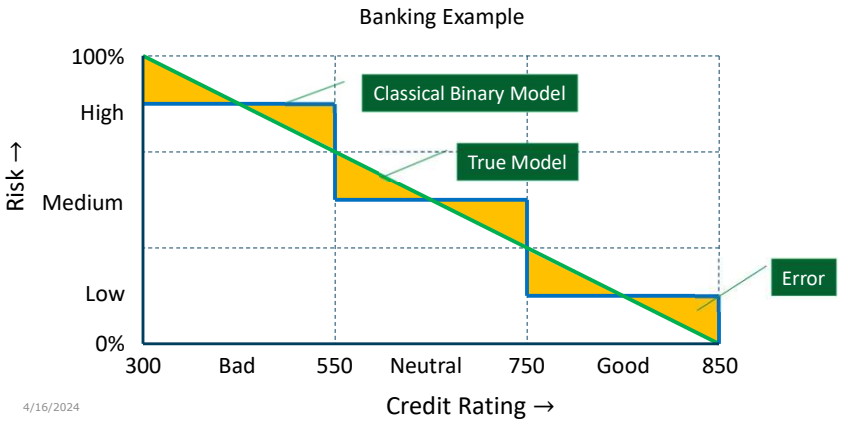
Fuzzification



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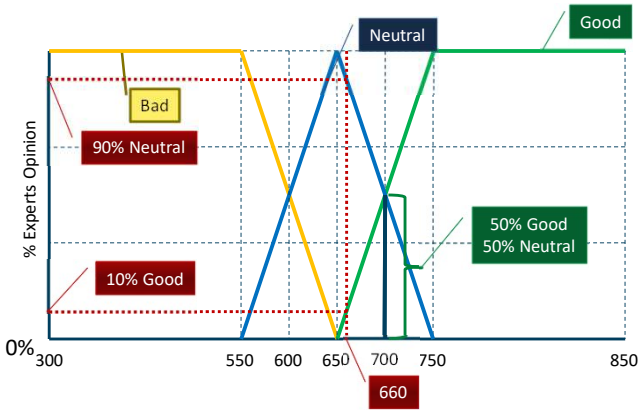
Expert Opinion

- Fussifier: 660 = [0.0, 0.9, 0.1]
  - Bad:0.0; Neutral:0.9; good: 0.1
- Fuzzy Logic Rules
  - [0.0, 0.9, 0.1] → [0.0, 0.9, 0.1] for Lawyers
  - [0.0, 0.9, 0.1] → [0.0, 0.8, 0.2] for Entrepreneurs
  - [0.0, 0.9, 0.1] → [0.0, 0.9, 0.1] for Salaried



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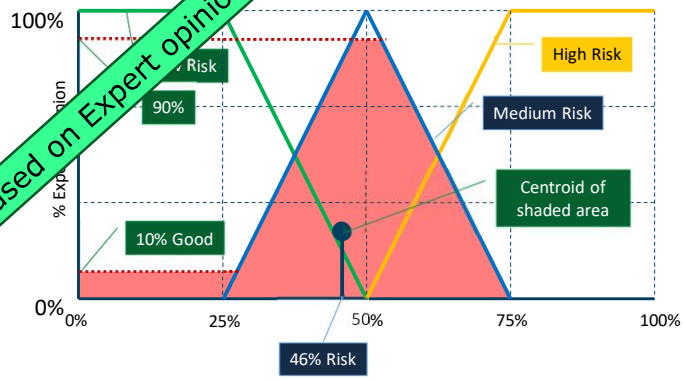
Expert Opinion

- Rules:
  - Good credit → low risk
  - Neutral Credit → medium risk
  - Bad Credit → high risk
- Inference:
  - Based on expert opinion
- Crisp Output
  - Centroid of shaded area @46% Risk

It's all based on Expert opinions!



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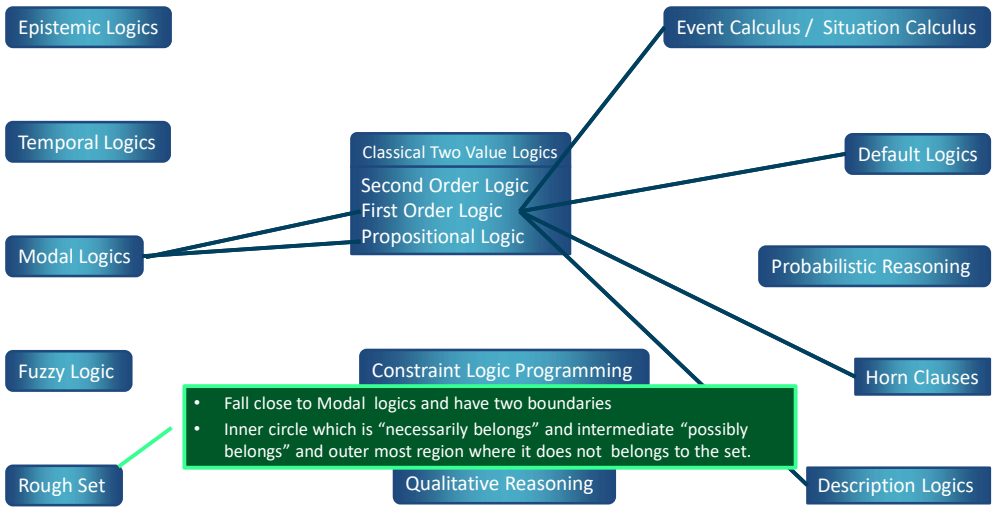
Logic



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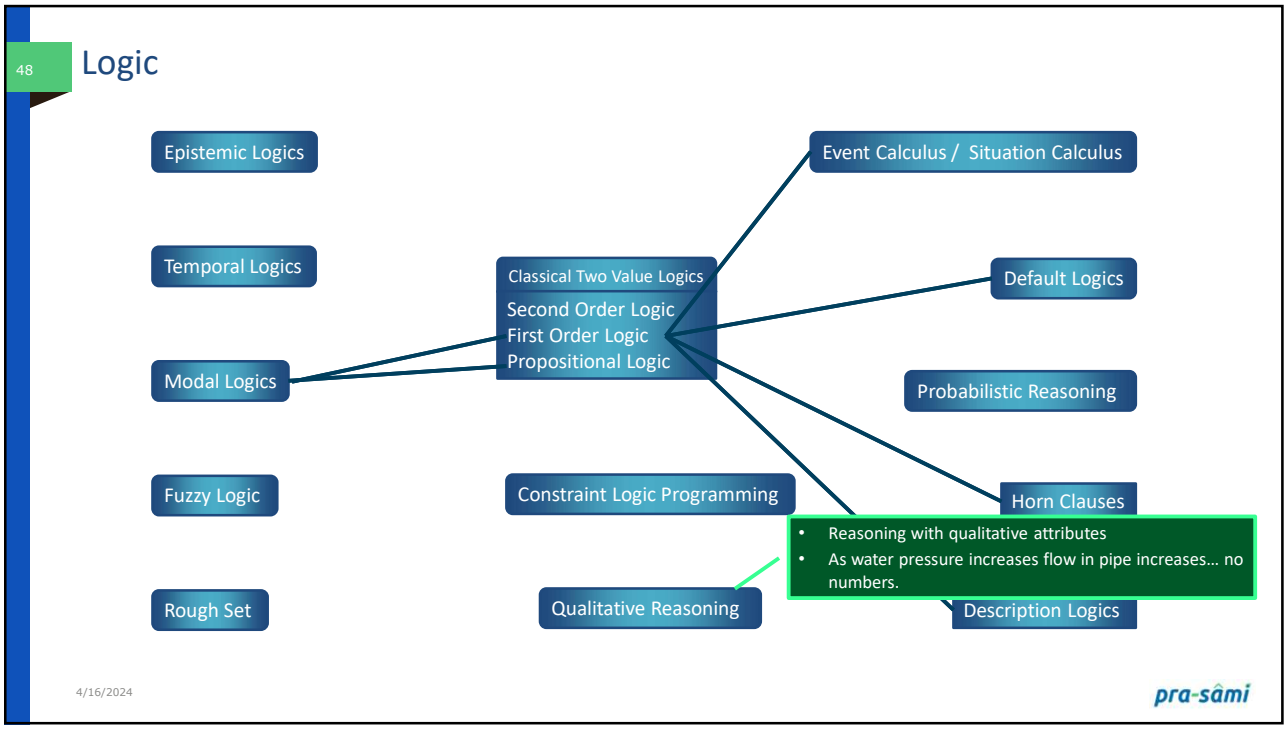
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Logic
Epistemic Logics
Temporal Logics
Modal Logics
Fuzzy Logic
Rough Set
Classical Two Value Logics
Second Order Logic
First Order Logic
Propositional Logic
Constraint Logic Programming
Qualitative Reasoning
Event Calculus / Situation Calculus
Default Logics
Probabilistic Reasoning
Horn Clauses
Description Logics
• Reasoning with qualitative attributes
• As water pressure increases flow in pipe increases… no numbers.
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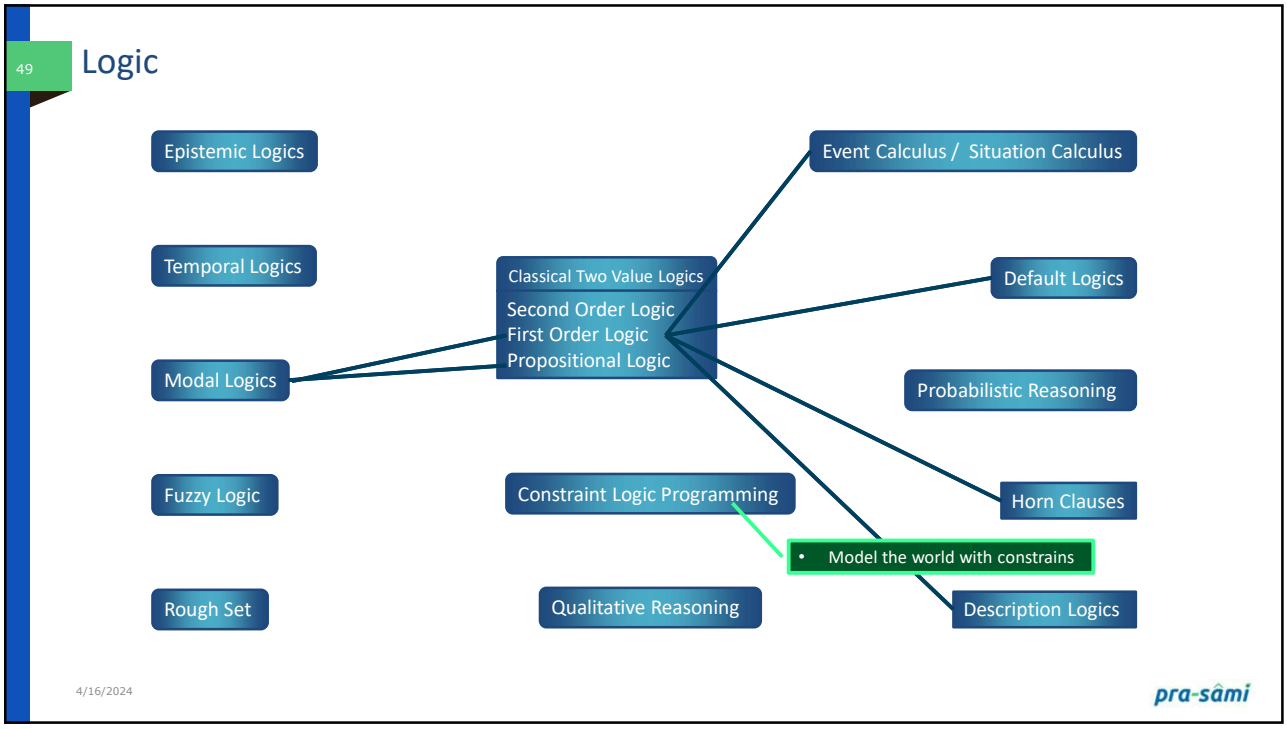
49
Logic
Epistemic Logics
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Fuzzy Logic
Rough Set
Classical Two Value Logics
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First Order Logic
Propositional Logic
Constraint Logic Programming
Qualitative Reasoning
Event Calculus / Situation Calculus
Default Logics
Probabilistic Reasoning
Horn Clauses
Description Logics
• Model the world with constrains
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Next session

- Logic continues…

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EXTRA MATERIAL

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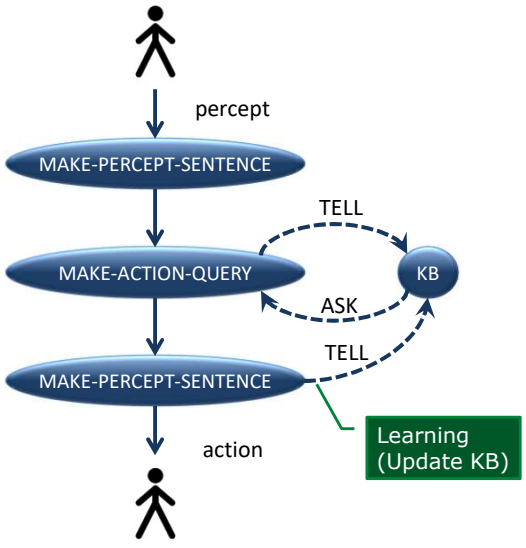
Operations Performed by Knowledge Bases Agent

- Knowledge Bases Agent exhibits intelligent behavior by doing something
- TELL: This operation tells the knowledge base what it perceives from the environment
- ASK: This operation asks the knowledge base what action it should perform
- Perform: It performs the selected action
- TELLs: KB what action has been performed



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Source of Agent's Intelligence

- Knowledge base:
  - A central component of a knowledge-based agent,
    - it is also known as KB
  - It is a collection of sentences
    - 'sentence' is a technical term and it is not identical to sentence in English
  - Sentences are expressed in a language which is called a knowledge representation language
  - It stores fact about the world
  - Knowledge-base is required for updating knowledge for an agent to learn with experiences and take action as per the knowledge

- Inference system:
  - Inference means deriving new sentences from old
  - Inference system allows us to add a new sentence to the knowledge base
  - A sentence is a proposition about the world
  - Inference system applies logical rules to the KB to deduce new information
  - Inference system generates new facts so that an agent can update the Knowledgebase

- An inference system works mainly in two rules which are given as:
  - Forward chaining
  - Backward chaining