SWINBURNE UNIVERSITY OF TECHNOLOGY

COS30019: Introduction to Artificial Intelligence

Logical Agents &

Knowledge Representation

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"Thinking Rationally"

- Computational models of human "thought" processes
- Computational models of human behavior
- Computational systems that "think" rationally
- Computational systems that behave rationally

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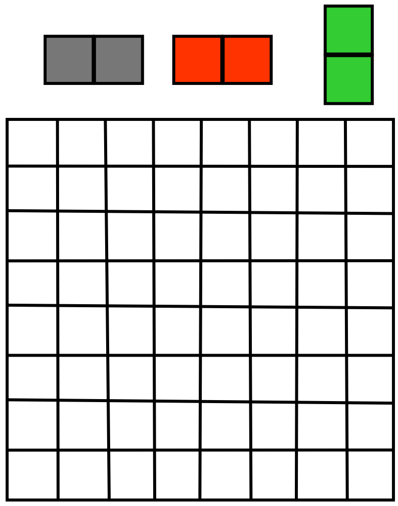
When search may not solve the problem…

- Given a grid 8x8
- Each domino can cover exactly 2 squares (on the grid)
- With 32 dominos, can the entire grid be covered by the dominos?



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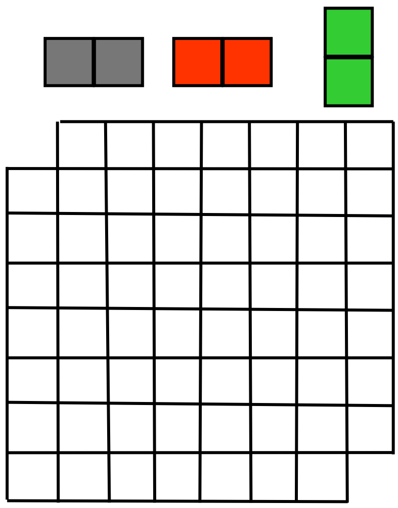
When search may not solve the problem…

- Now remove the two opposite corners of the grid
- Can we cover this new and deformed grid with 31 dominos?



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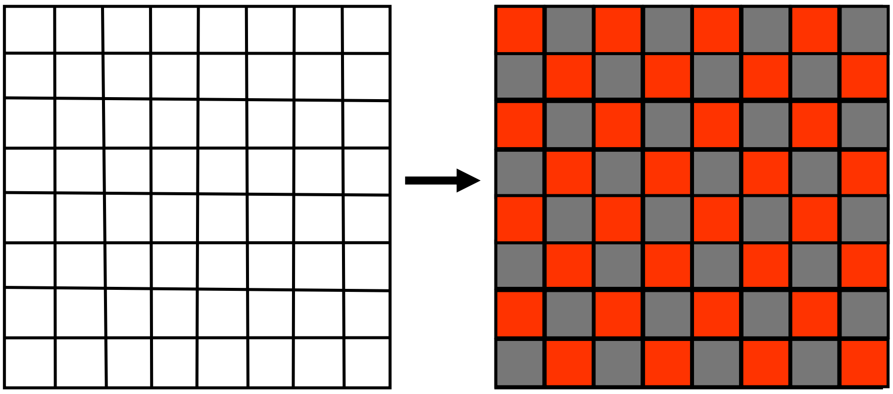
A right representation can help answer the question



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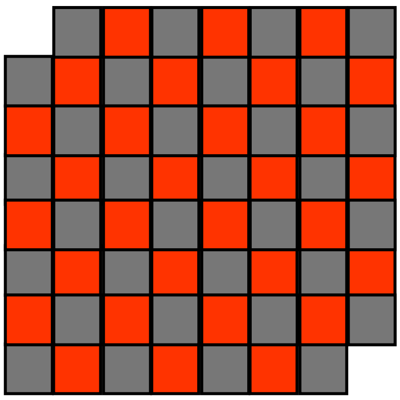
A right representation can help answer the question

- Removing the two opposite corners is equivalent to removing the two red squares
- Each domino can only cover at most one black square
- There are 32 black squares (and only 30 red squares)!

⇨ The problem is unsolvable.



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Logical Agents

- Reflex agents find their way from Arad to Bucharest by dumb luck
- Chess program calculates legal moves of its king, but doesn't know that no piece can be on 2 different squares at the same time
- Logic (Knowledge-Based) agents combine general knowledge with current percepts to infer hidden aspects of current state prior to selecting actions
  - Crucial in partially observable environments

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Outline

- Knowledge-based agents
- Wumpus world
- Logic in general
- Propositional and first-order logic
  - Inference, validity, equivalence and satifiability
  - Reasoning patterns
    - Resolution
    - Forward/backward chaining

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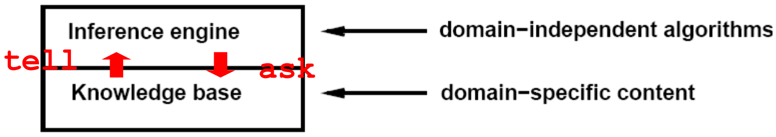
Knowledge Base

Knowledge Base : set of sentences represented in a knowledge representation language and represents assertions about the world.



Inference rule: when one ASKs questions of the KB, the answer should *follow* from what has been TELLed to the KB previously.

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Generic KB-Based Agent

```
function KB-AGENT(percept) returns an action
   static: KB, a knowledge base
           t, a counter, initially 0, indicating time
   TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
   action ← ASK(KB, MAKE-ACTION-QUERY(t))
   TELL(KB, MAKE-ACTION-SENTENCE(action, t))
   t ← t + 1
   return action
```

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Abilities of KB agent

- Agent must be able to:
  - Represent states and actions,
  - Incorporate new percepts
  - Update internal representation of the world
  - Deduce hidden properties of the world
  - Deduce appropriate actions

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Description level

- The KB agent is similar to agents with internal state
- Agents can be described at different levels
  - Knowledge level
    - What they know, regardless of the actual implementation. (Declarative description)
  - Implementation level
    - Data structures in KB and algorithms that manipulate them e.g propositional logic and resolution.

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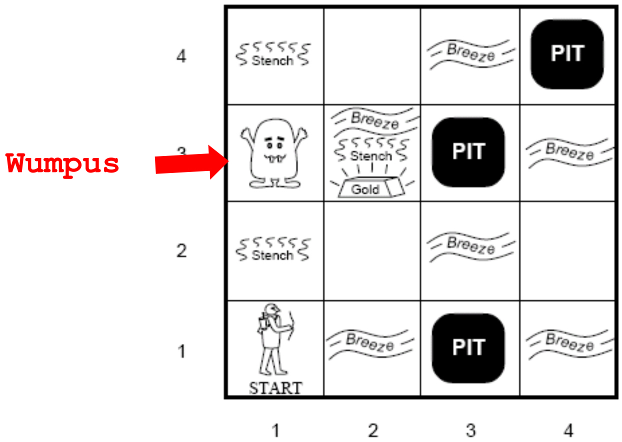
A Typical Wumpus World



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Wumpus World PEAS Description

Performance measure
- gold +1000, death -1000
- -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 Breeze, Glitter, Smell

Actuators Left turn, Right turn, Forward, Grab, Release, Shoot

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Wumpus World Characterization

- Observable?
- Deterministic?
- Episodic?
- Static?
- Discrete?
- Single-agent?

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Wumpus World Characterization

- Observable? No, only local perception
- Deterministic?
- Episodic?
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- Single-agent?

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Wumpus World Characterization

- Observable? No, only local perception
- Deterministic? Yes, outcome exactly specified
- Episodic?
- Static?
- Discrete?
- Single-agent?

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Wumpus World Characterization

- Observable? No, only local perception
- Deterministic? Yes, outcome exactly specified
- Episodic? No, sequential at the level of actions
- Static?
- Discrete?
- Single-agent?

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Wumpus World Characterization

- Observable? No, only local perception
- Deterministic? Yes, outcome exactly specified
- Episodic? No, sequential at the level of actions
- Static? Yes, Wumpus and pits do not move
- Discrete?
- Single-agent?

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Wumpus World Characterization

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Wumpus World Characterization

- Observable? No, only local perception
- Deterministic? Yes, outcome exactly specified
- Episodic? No, sequential at the level of actions
- Static? Yes, Wumpus and pits do not move
- Discrete? Yes
- Single-agent? Yes, Wumpus is essentially a natural feature.

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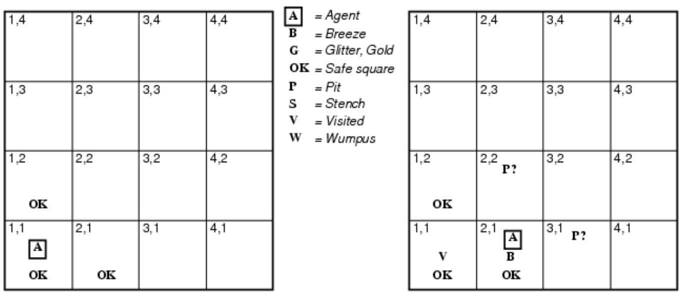
Exploring the Wumpus World



(a) (b)

[1,1] The KB initially contains the rules of the environment. The first percept is [*none, none,none,none,none*], move to safe cell e.g. 2,1

[2,1] breeze which indicates that there is a pit in [2,2] or [3,1], return to [1,1] to try next safe cell

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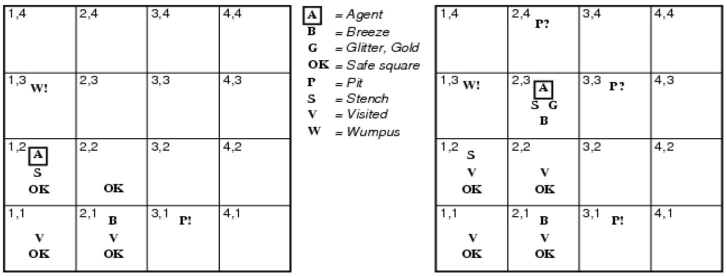
Exploring the Wumpus World



(a) (b)

[1,2] Stench in cell which means that wumpus is in [1,3] or [2,2]

YET … not in [1,1]

YET … not in [2,2] or stench would have been detected in [2,1]

THUS … wumpus is in [1,3]

THUS [2,2] is safe because of lack of breeze in [1,2]

THUS pit in [1,3]

➔ **move to next safe cell [2,2]**

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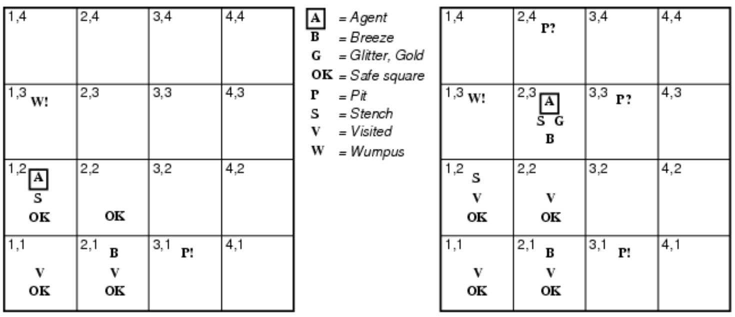
Exploring the Wumpus World



(a) (b)

[2,2] move to [2,3]

[2,3] detect glitter , smell, breeze

THUS pick up gold

THUS pit in [3,3] or [2,4]

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What is a logic?

- A formal language
  - Syntax – what expressions are legal (well-formed)
  - Semantics – what legal expressions mean
    - in logic the truth of each sentence with respect to each possible world.
- E.g the language of arithmetic
  - $X+2 \geq y$ is a sentence, x2+y is not a sentence
  - $X+2 \geq y$ is true in a world where x=7 and y =1
  - $X+2 \geq y$ is false in a world where x=0 and y =6

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Entailment

- One thing follows from another

  $KB \models \alpha$

- KB entails sentence α *if and only if* α is true in worlds where KB is true.
- Example: x+y=4 entails x+y > 3
- Entailment is a relationship between sentences that is based on semantics.

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Entailment: Example

- Let *KB* = {

  IF *"it rains"* AND *"I have no umbrella"* THEN *"I get wet"*,

  "it rains",

  "I have no umbrella"}

what can we say about α= *"I get wet"*?

Does α follows from *KB*???

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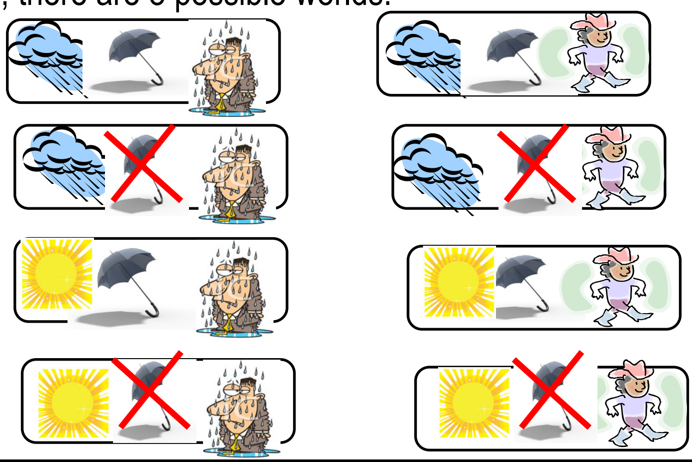
Entailment: Example

- Each of the statements: *"it rains"*, "*I have an umbrella*" and *"I get wet"* can be either **true** or **false**.
- Thus, in total, there are 8 possible worlds:



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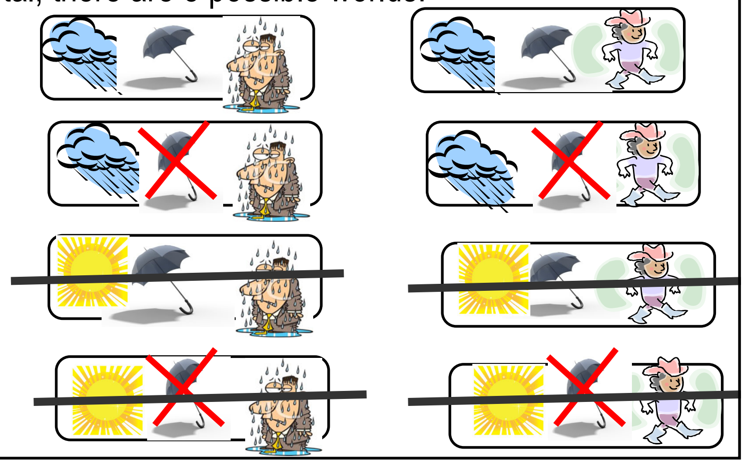

"it rains"

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Entailment: Example

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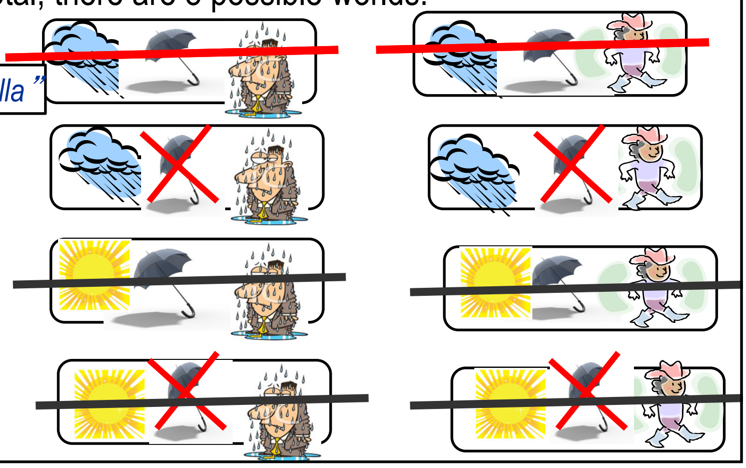

"I have no umbrella"

"it rains"

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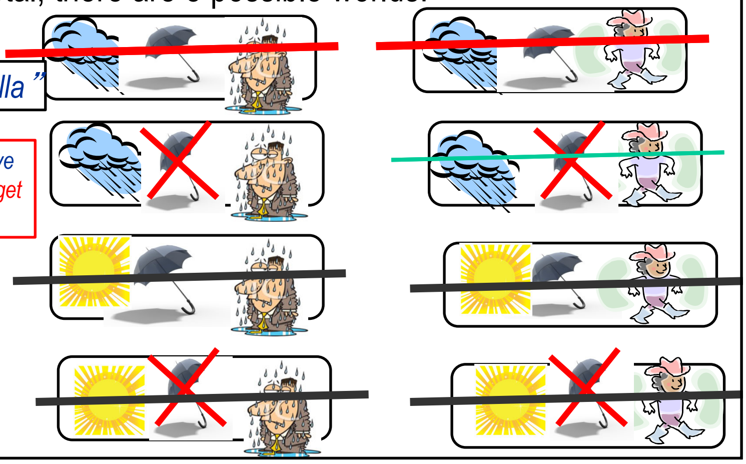
Entailment: Example

- Each of the statements: *"it rains"*, *"I have an umbrella"* and *"I get wet"* can be either **true** or **false**.
- Thus, in total, there are 8 possible worlds:

"I have no umbrella"

IF *"it rains"* AND *"I have no umbrella"* THEN *"I get wet"*

"it rains"



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Models

- Logicians typically think in terms of models, which are formally structured worlds with respect to which truth can be evaluated.
- *m* is a model of a sentence α if α is true in *m*
- $M(\alpha)$ is the set of all models of α

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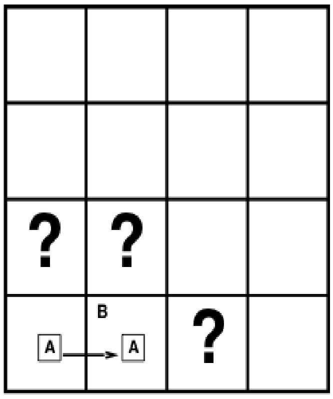
Wumpus world model

Situation after detecting nothing in [1,1], moving right, breeze in [2,1]

Consider possible models for ?s assuming only pits



3 Boolean choices $\Rightarrow$ 8 possible models

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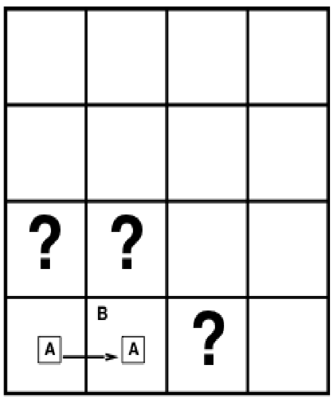

3 B

- P12={T/F} (there is/isn't a pit in cell [1,2])
- P22={T/F} (there is/isn't a pit in cell [2,2])
- P31={T/F} (there is/isn't a pit in cell [3,1])

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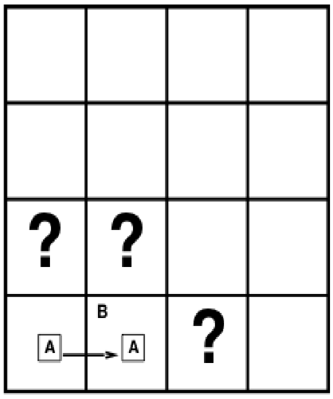
Wumpus world model

	P12	P22	P31
Model 1	F	F	F
Model 2	F	F	T
Model 3	F	T	F
Model 4	F	T	T
Model 5	T	F	F
Model 6	T	F	T
Model 7	T	T	F
Model 8	T	T	T



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Wumpus world model

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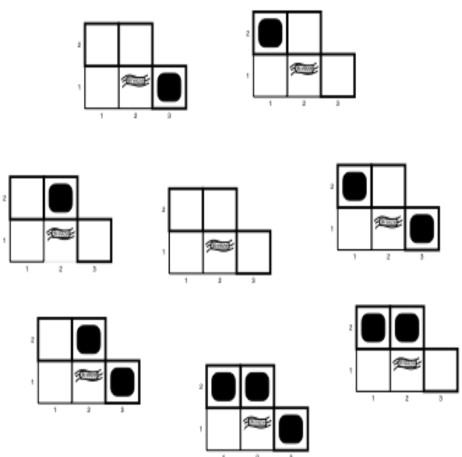
Model 8	T	T	T



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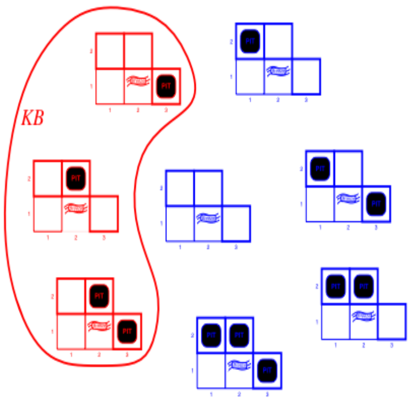
Wumpus world model



KB = wumpus-world rules + observations

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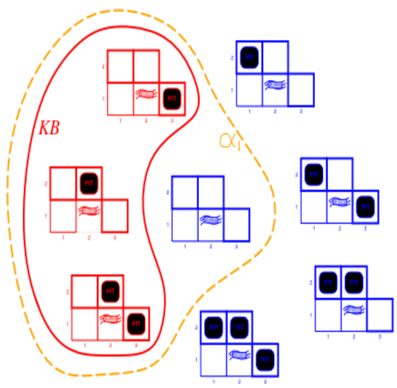
Wumpus world model



KB = wumpus-world rules + observations

α_1 = "[1,2] is safe", $KB \models \alpha_1$, proved by model checking

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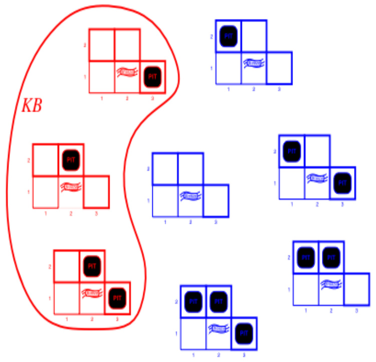
Wumpus world model



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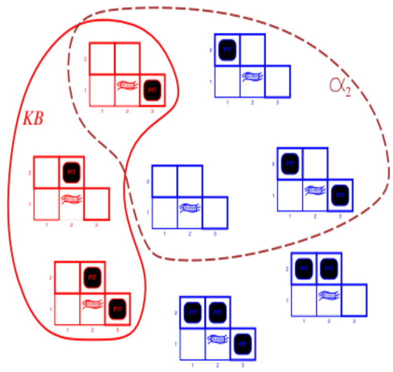
Wumpus world model



KB = wumpus-world rules + observations

α_2 = "[2,2] is safe", $KB \not\models \alpha_2$

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Logical inference

- The notion of entailment can be used for logic inference.
  - Model checking (see wumpus example): enumerate all possible models and check whether α is true.
- If an algorithm only derives entailed sentences it is called *sound* or *truth preserving*.
  - Otherwise it just makes things up.

    i is sound if whenever $KB \vdash_i \alpha$ it is also true that $KB \models \alpha$
- Completeness : the algorithm can derive any sentence that is entailed.

  i is complete if whenever $KB \models \alpha$ it is also true that $KB \vdash_i \alpha$

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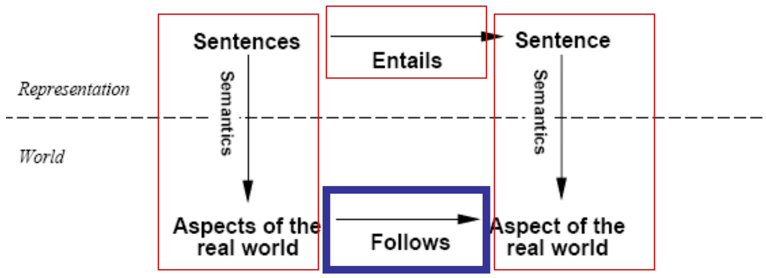
Schematic perspective



If KB is true in the real world, then any sentence α derived from KB by a sound inference procedure is also true in the real world.

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