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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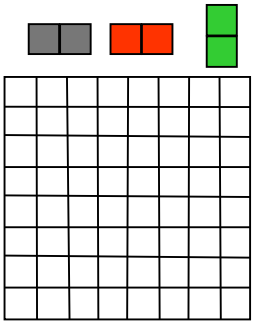
When search may not solve the problem…

- 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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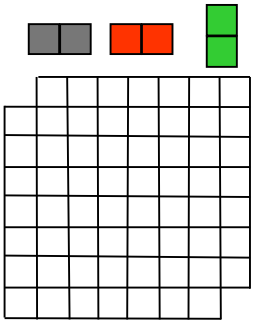
When search may not solve the problem…

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



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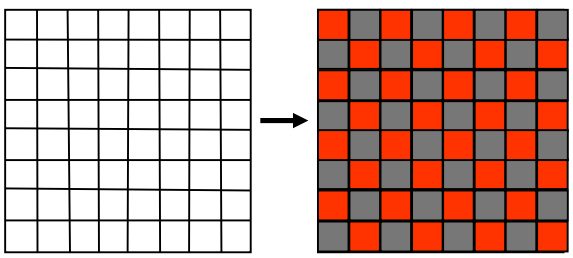
A right representation can help answer the question



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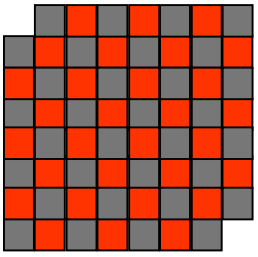
A right representation can help answer the question

- 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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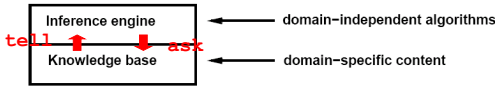
Knowledge Base

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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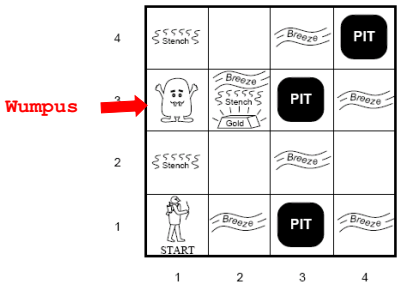
A Typical Wumpus World



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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?
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- 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

[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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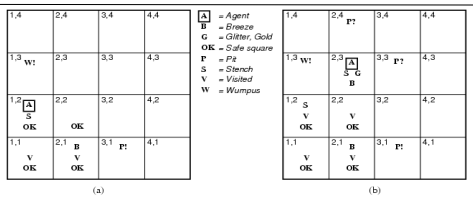
Exploring the Wumpus World



[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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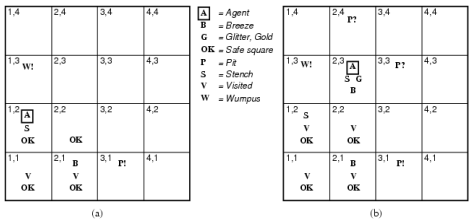
Exploring the Wumpus World



[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 ≥ y is a sentence, x2+y is not a sentence
  - X+2 ≥ y is true in a world where x=7 and y =1
  - X+2 ≥ 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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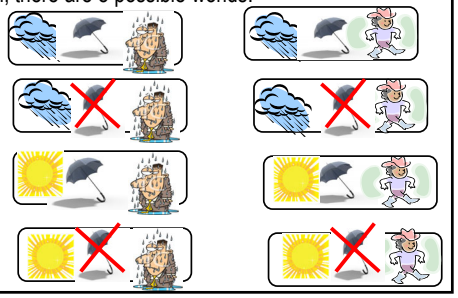
Entailment: Example

- 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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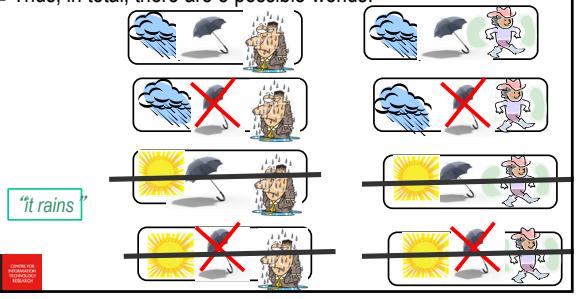

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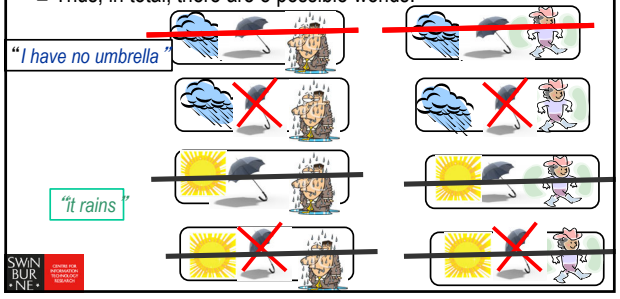

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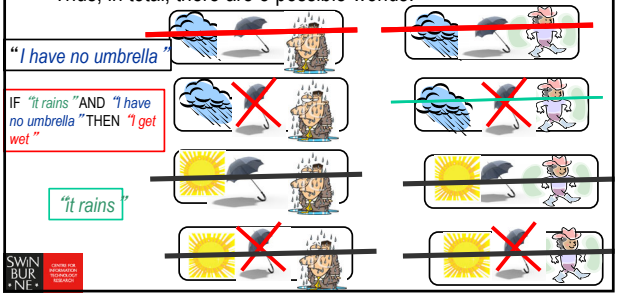

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Models

- 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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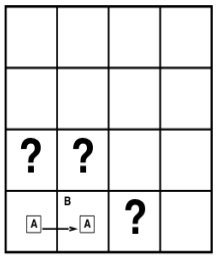
Wumpus world model

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

Consider possible models for ?s assuming only pits

3 Boolean choices ⇒ 8 possible models



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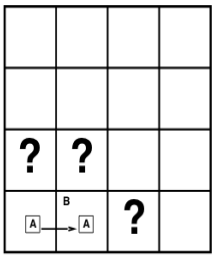

- P12={T/F} (there is/isn't a pit in cell [1,2])
- P22={T/F} (there is/isn't a pit in cell [2,2])
- P31={T/F} (there is/isn't a pit in cell [3,1])

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Wumpus world model

Situati moving],

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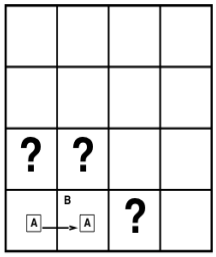
3 B

	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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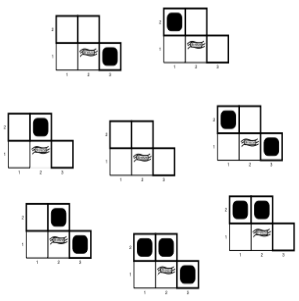

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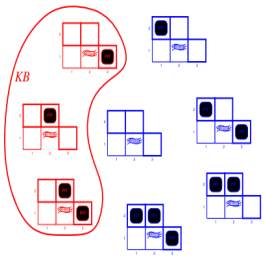

KB = wumpus-world rules + observations

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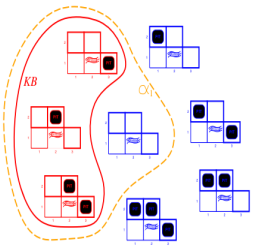
Wumpus world model



KB = wumpus-world rules + observations

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

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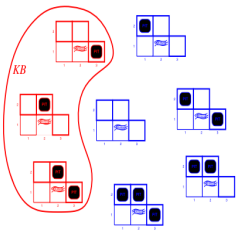
Wumpus world model



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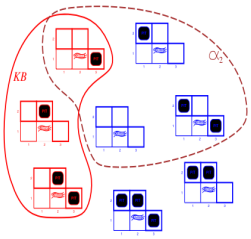

KB = wumpus-world rules + observations

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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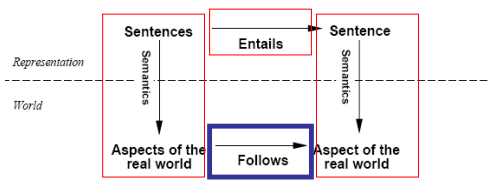
Schematic perspective



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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