CSC 480: Artificial Intelligence

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Course Overview

- **Introduction**
- **Intelligent Agents**
- **Search**
  - problem solving through search
  - uninformed search
  - informed search
- **Games**
  - games as search problems
- **Knowledge and Reasoning**
  - reasoning agents
  - propositional logic
  - predicate logic
  - knowledge-based systems
- **Learning**
  - learning from observation
  - neural networks
- **Conclusions**

Chapter Overview
Reasoning Agents

- **Motivation**
- **Objectives**
- **Agents and Knowledge**
- **Wumpus World**
  - environment
  - agents
- **Representation, Reasoning and Logic**
  - representation
  - inference
  - logics
- **Wumpus Agents**
- **Important Concepts and Terms**
- **Chapter Summary**

Wumpus World Challenge

- **agent must find its way from the starting point to the goal in the presence of enemies and hazards**
  - wumpus
    - creature that likes to eat agents
  - pits
    - bottomless holes
  - limited information about the world
    - no map
    - wumpus and pits are perceivable from adjacent squares
      - wumpus: smell
      - pits: breeze
  - limited actions by the agent
    - move, turn, shoot arrow

http://2.bp.blogspot.com/-rzPhKevirHI/T8SI7YGbekI/AAAAAAAADSg/5o0IyiIE78o/s1600/cat+photos+4.jpg

Dog vs. Wumpus
or
Cat vs. Wumpus?

https://s-media-cache-ec0.pinimg.com/736x/d5/86/14/d5861431bc214a2d0d8c50a8cd752e77.jpg

http://www.baxaart.com/artchives/magiccards/15_wumpus.jpg

Dog

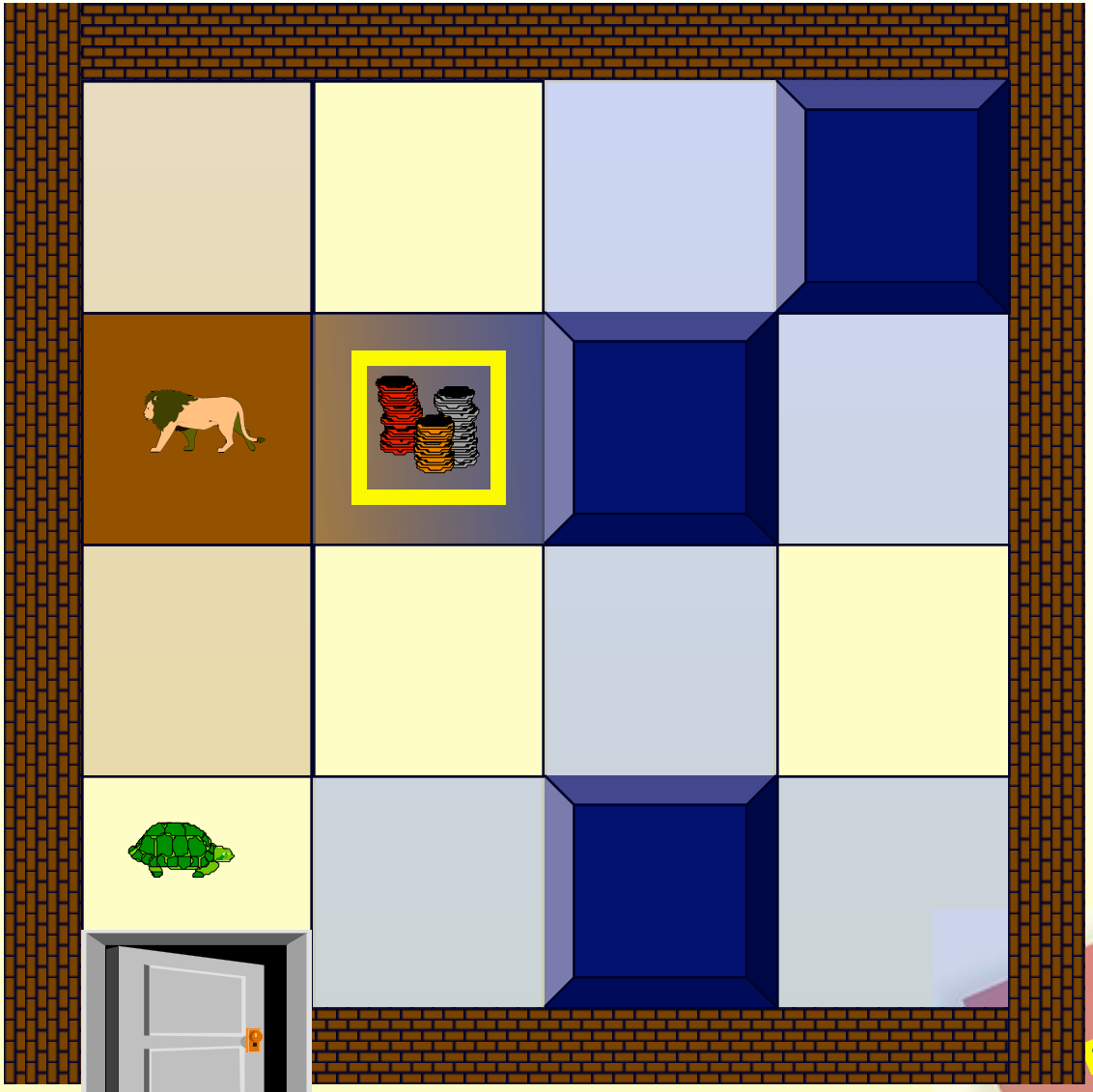
- **Is a dog smart enough**
  - avoid pits
  - avoid Wumpus
  - eliminate the Wumpus
  - find gold
  - pick up gold
  - return

https://s-media-cache-ec0.pinimg.com/736x/d5/86/14/d5861431bc214a2d0d8c50a8cd752e77.jpg

Cat vs. Wumpus

- **Is a cat smart enough to solve the Wumpus World challenge?**
  - avoid pits
  - avoid Wumpus
  - eliminate the Wumpus
  - find gold
  - pick up gold
  - return

Wumpus World Diagram



Motivation

- **many tasks are too complex to be solved by search alone**
  - "logical thinking" is often necessary
- **existing knowledge about the environment and the agent itself can be combined and transformed into new knowledge**
  - more applicable to the task
  - solution to a specific problem
  - possible ways to solve a problem
  - properties of the environment, task, agent
- **formal methods to perform reasoning are required**

Objectives

- understand the need to apply knowledge-based reasoning for some tasks
- know the elementary concepts of representation, inference and logics
- know the important aspects of propositional logic
  - syntax, semantics, models, inference rules, complexity
- understand the limitations of propositional logic
- apply simple reasoning techniques to specific tasks

Agents and Knowledge

Knowledge-Based Agents

KB-Agent Program

Description Levels for Agents

Agents and Knowledge

- **knowledge helps agents to form representations of the world**
  - sometimes called “world model”
- **new knowledge is obtained by applying reasoning methods to existing knowledge**
  - results in new or refined representational aspects of the world
- **decisions about actions are based on the new knowledge**

Knowledge and Tasks

- **knowledge helps to describe tasks and goals for agents more explicitly**
  - specification in accordance with their world model
  - in search-based problems, the goal is to a large degree determined by the context of search
    - find a state with specific properties
- **agents obtain new knowledge about their task and the environment**
  - from the environment or designer
  - by reasoning
  - by observing changes
- **agents can adapt their behavior**

Knowledge-Based Agent

- **maintains a repository for representations of facts about the world**
  - often referred to as **knowledge base**
  - usually described through a knowledge representation language
  - one item in the knowledge base is usually called a **sentence**
    - also: formula, proposition, statement
    - frequently, but not necessarily a sentence in a natural language
  - operations to add and retrieve sentences
    - **TELL, ASK**
  - inference mechanism
    - new sentences may be added through reasoning about existing sentences

KB-Agent Program

```
function KB-AGENT(percept) returns action
   static KB      // knowledge base
     t    // counter indicating time; initially 0

   TELL(KB, MAKE-PERCEPT-SEQUENCE(percept, t))
   action := ASK (KB, MAKE-ACTION-QUERY(t))
   TELL(KB, MAKE-ACTION-SEQUENCE(action, t))
   t := t + 1
  return action
```

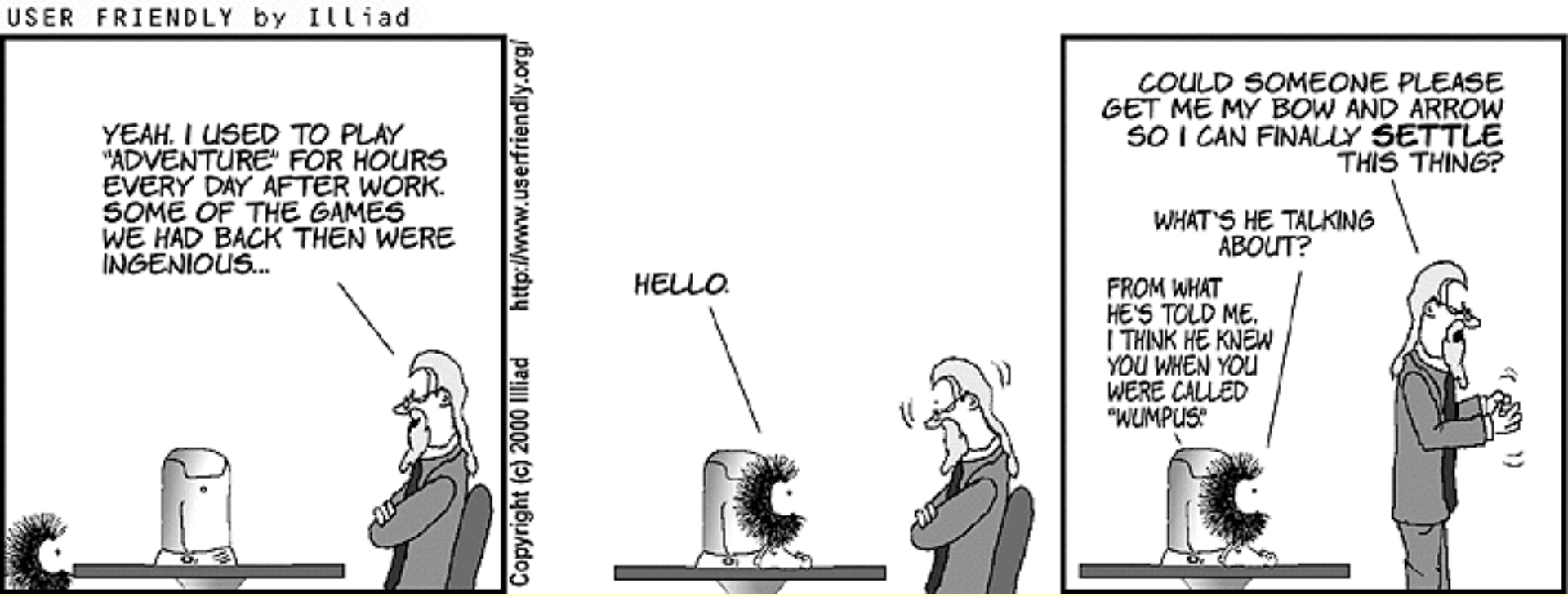
Description Levels for Agents

- **knowledge level or epistemological level**
  - describes what the agent knows at an abstract level
  - **TELL, ASK** are used for interaction
  - should be easy to understand for human interaction
- **logical level**
  - knowledge is encoded into sentences
  - visible representation of the knowledge base
  - often based on logic as a formal representation language
- **implementation level**
  - physical representation on the agent architecture
    - symbols, strings, table entries, etc.

Wumpus World

History
Relevance
Description
Example

User Friendly and Wumpus



[Illiad: User Friendly]

Wumpus World

- **early computer game**
  - invented by Gregory Yob, 1975
  - originally in a dodecahedron topology
  - simplified to a two-dimensional grid for didactic purposes
    - multiple variations in use
- **agents explores a cave**
  - rooms with properties
  - passageways connect rooms
- **test bed for intelligent agents**

https://en.wikipedia.org/wiki/Hunt_the_Wumpus

Wumpus Environment

- **grid of squares**
  - limited by walls
  - a square may contain agents and objects
  - a square has properties that the agent may perceive
  - configuration is chosen randomly
- **pit**
  - square that represents a bottomless hole
  - agent dies if it enters a pit
  - a pit causes a breeze in surrounding squares
- **gold**
  - causes glitter in the square it is on

Wumpus

- awful creature that eats agents
- emanates a stench on adjacent squares
- can be killed with an arrow
- gives out a scream when it is killed
  - can be heard all over the cave

Wumpus Agents

- **task**
  - find the gold, return it to the start square, leave the cave
- **capabilities**
  - move around
  - perceive properties of squares
  - shoot once at a wumpus with a single arrow
  - grab the gold
- **limitations**
  - the agent cannot perceive its own location

Wumpus World PEAS Description

Performance Measures

+1000	picking up the gold
1000	falling into a pit, get eaten by wumpus
- 1	each action (step)
- 10	shooting the arrow

Environment

grid of rooms
starting position, goal position (gold)
pits, breeze in adjacent rooms
wumpus position, stench in adjacent rooms

Actuators

movement (forward, turn right/left, exit)
grab object in the same square
shoot arrow (straight ahead)

```
[Forward, Right, Left, Grab, Shoot, Exit]
```

Sensors

stench (wumpus), breeze(pit), glitter (gold)
bump (wall), scream (wumpus dies)

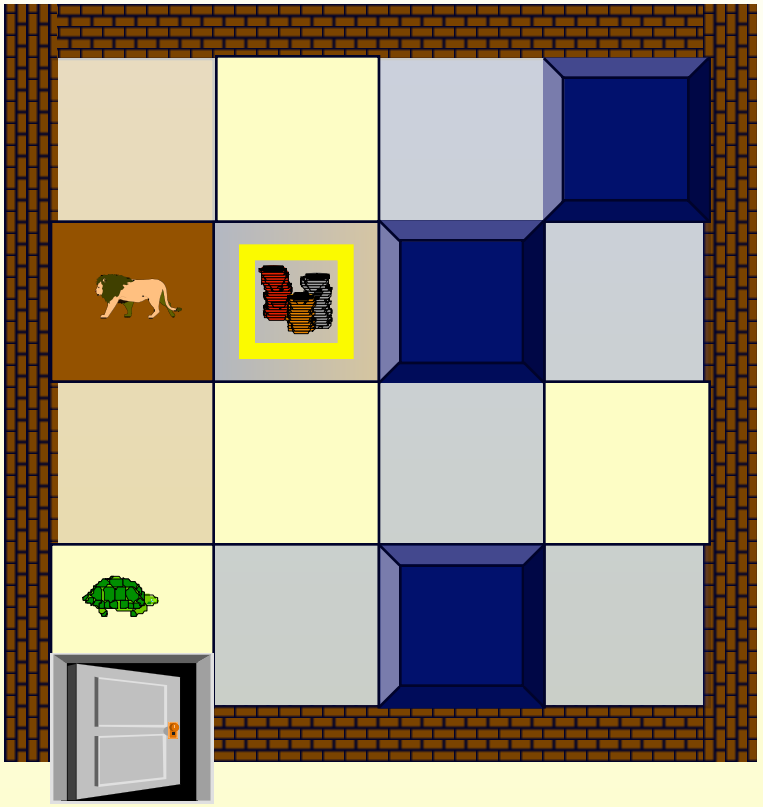
```
[Stench, Breeze, Glitter, Bump, Scream]
```

Life in the Wumpus World

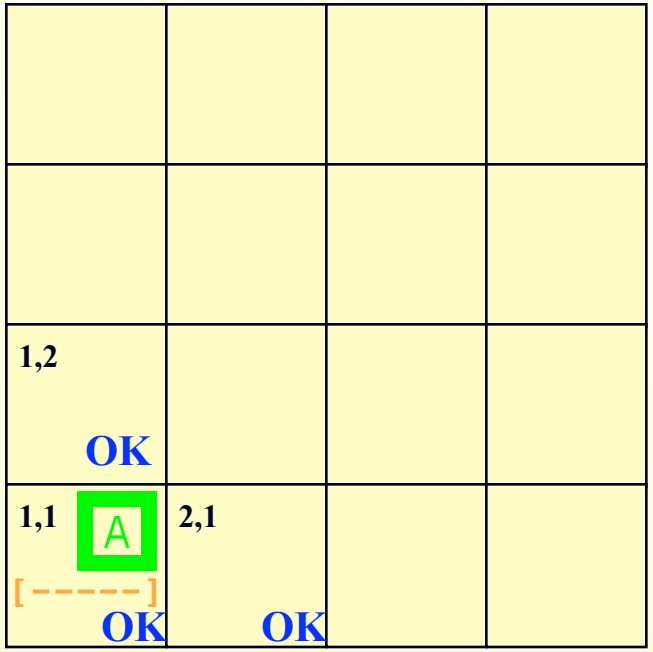
- **before performing an action, it is advisable for the agent to "think" about it**
  - perceive current state
  - avoid danger
    - wumpus, pits
  - seek rewards
    - gold
  - keep track of the environment
    - internal map, properties of squares
    - escape route

Wumpus World Exploration 1

World State



Agent's View



Position: [1,1]

Percept:

[None, None, None, None, None]

Action: Turn right, forward

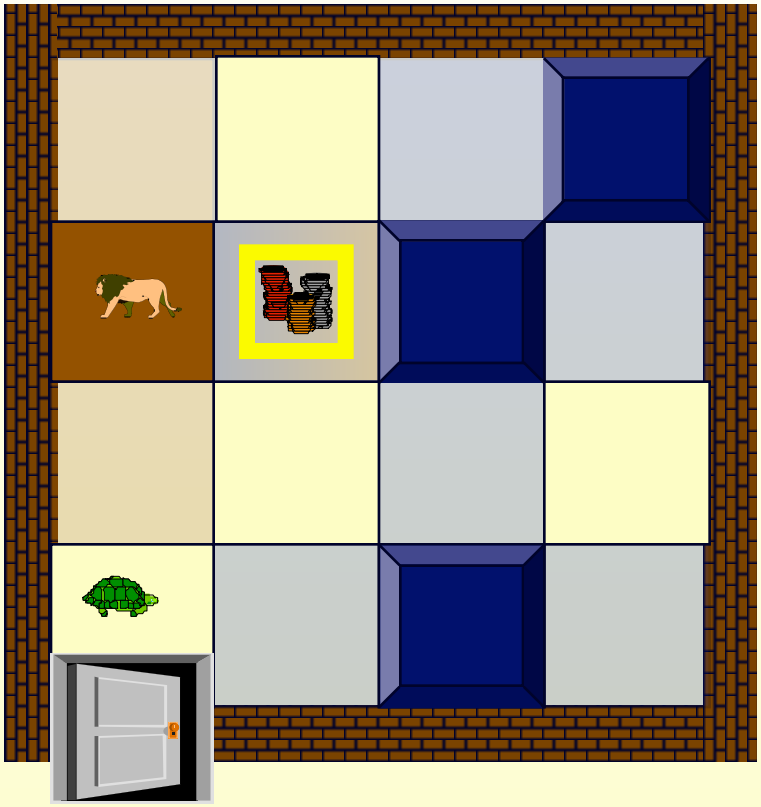
Inferences:

current position is safe

adjacent positions are safe

Wumpus World Exploration 2

World State



Agent's View

1,2 OK	2,2 P?		
1,1 V OK	2,1 A [-B---] OK	3,1 P?	

Position: [2,1]

Percept:

[None, Breeze, None, None, None]

Action: Turn right, turn right, forward, turn right, forward

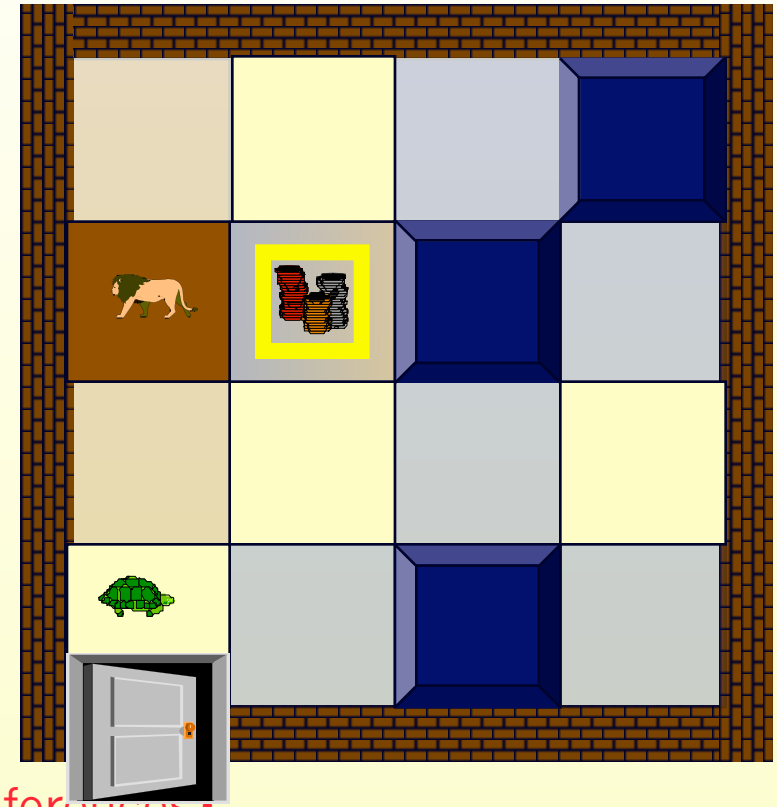
Inferences:

current position is safe

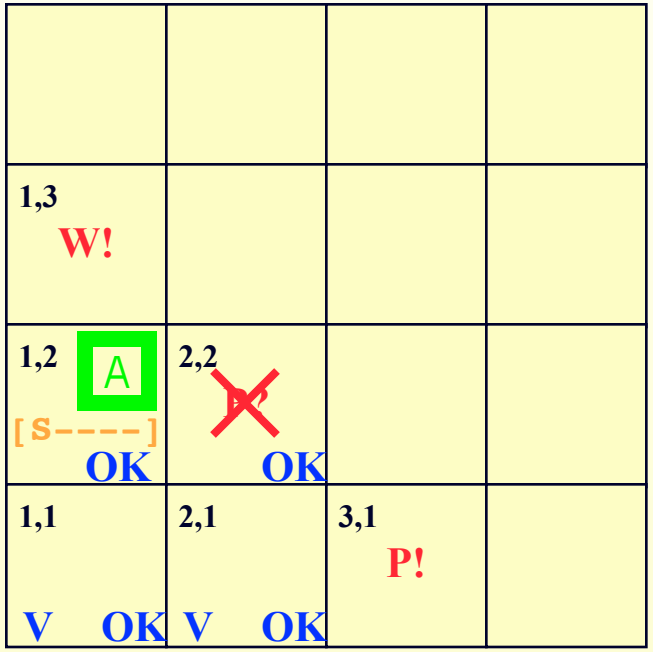
adjacent positions may be pits because of a perceived breeze

Wumpus World Exploration 3

World State



Agent's View



Inferences:
current position is safe
[2,2] not a pit, no breeze;
hence [3,1] must be a pit
[1,3] wumpus because of stench

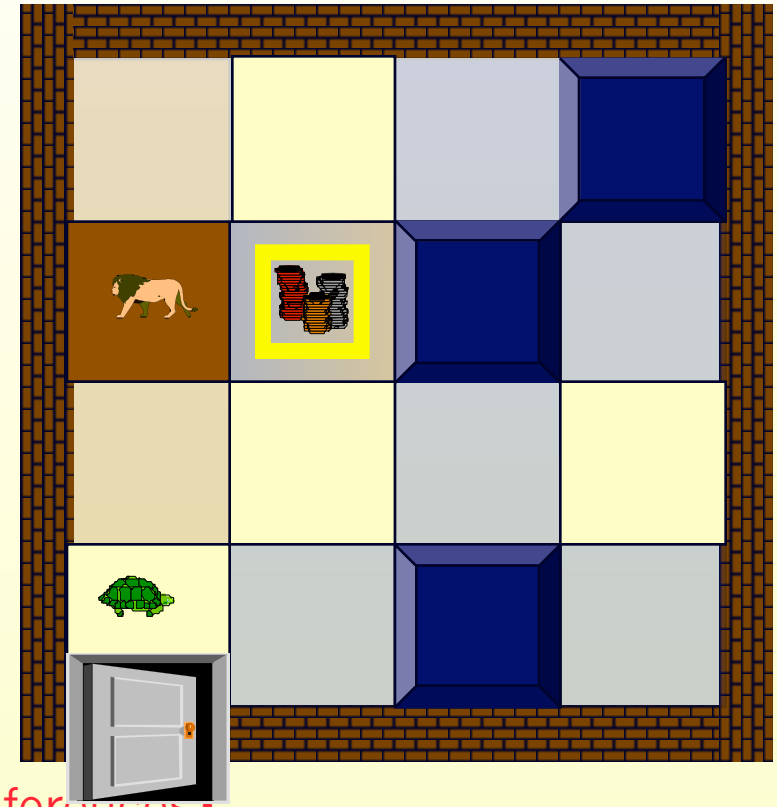
Position: [1,2]

Percept:
[Stench, None, None, None, None]

Action: Turn right, forward

Wumpus World Exploration 4

World State



Agent's View

1,3 W!	2,3 OK		
1,2 V OK	2,2 A [-----] OK	3,2 OK	
1,1 V OK	2,1 V OK	3,1 P!	

Inferences:
current position is safe
[2,2] not a pit, no breeze;
hence [3,1] must be a pit
[1,3] wumpus because of stench

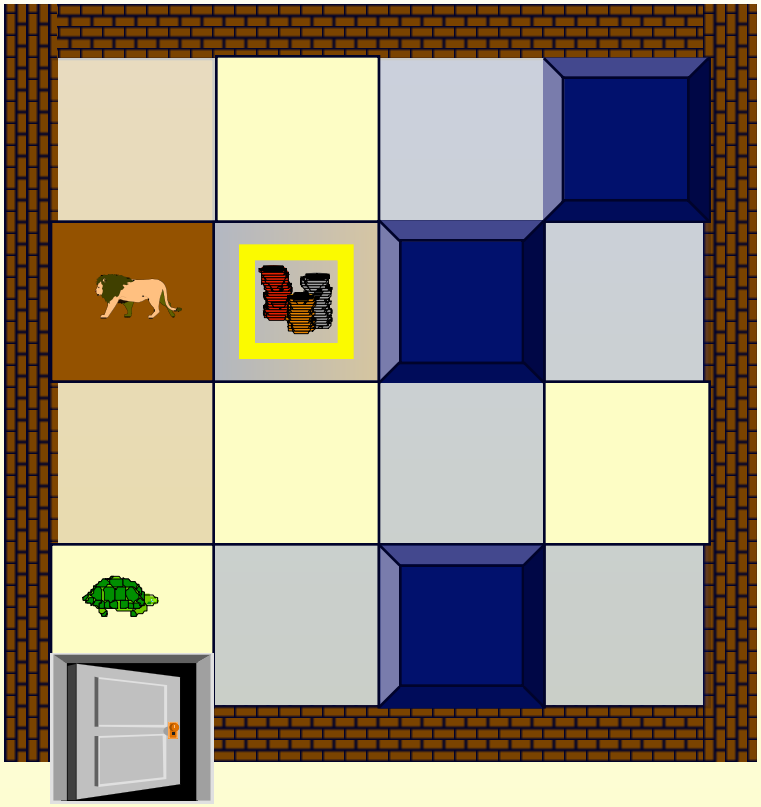
Position: [2,2]

Percept:
[None, None, None, None, None]

Action: Turn right, forward

Wumpus World Exploration 5

World State



Agent's View

1,3 W!	2,3 OK	3,3 P?	
1,2 V OK	2,2 V OK	3,2 A [-B---] OK	4,2 P?
1,1 V OK	2,1 V OK	3,1 P!	

Position: [3,2]

Percept:

[None, Breeze, None, None, None]

Action: Turn left, turn left, forward, turn right, forward

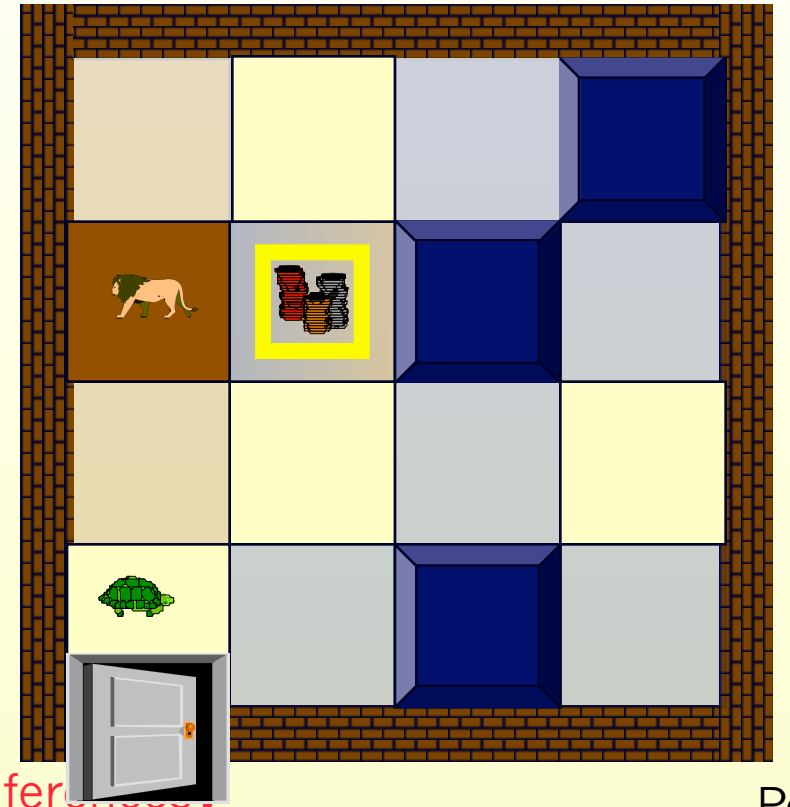
Inferences:

current position is safe

[3,3], [4,2] may be pits because of breeze;

Wumpus World Exploration 6

World State



Agent's View

	2,4 P?		
1,3 W!	2,3 A [SBG--] OK	3,3 P?	
1,2 V OK	2,2 V OK	3,2 V OK	4,2 P?
1,1 V OK	2,1 V OK	3,1 P!	

Inferences:
current position is safe
[2,4], [3,3] may be pits because of breeze;
[1,3] wumpus

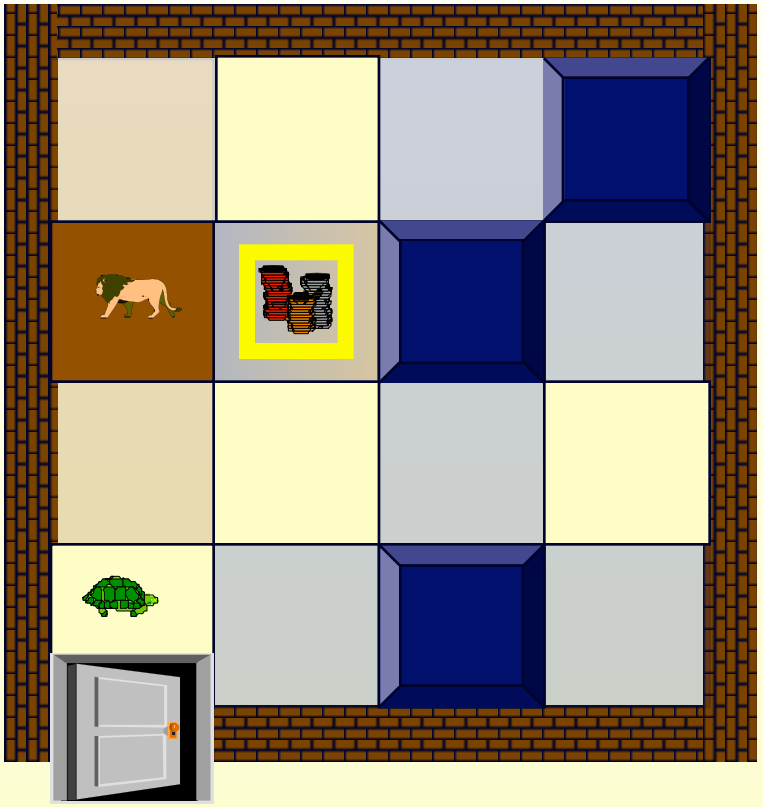
Position: [3,2]

Percept:
[Stench, Breeze, Glitter, None, None]

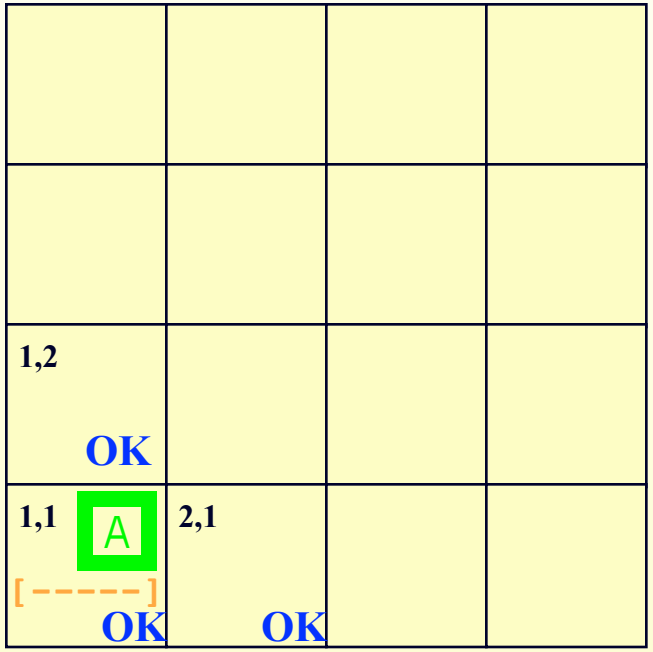
Action: Grab gold, left, left, forward, right, forward, left, forward, climb out

Wumpus Example

World State



Agent's View



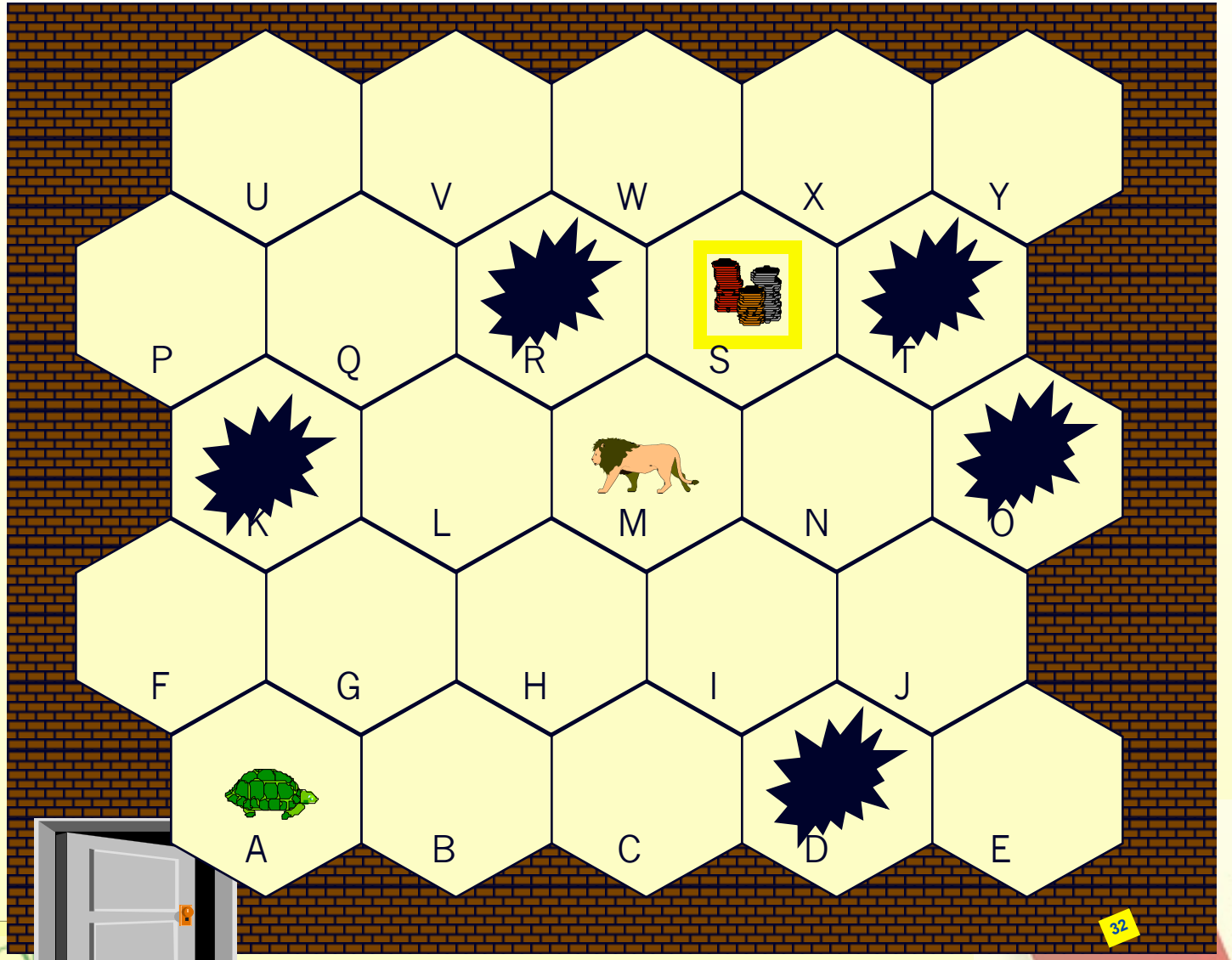
Position: [1,1]

Percept: [None, None, None, None, None]

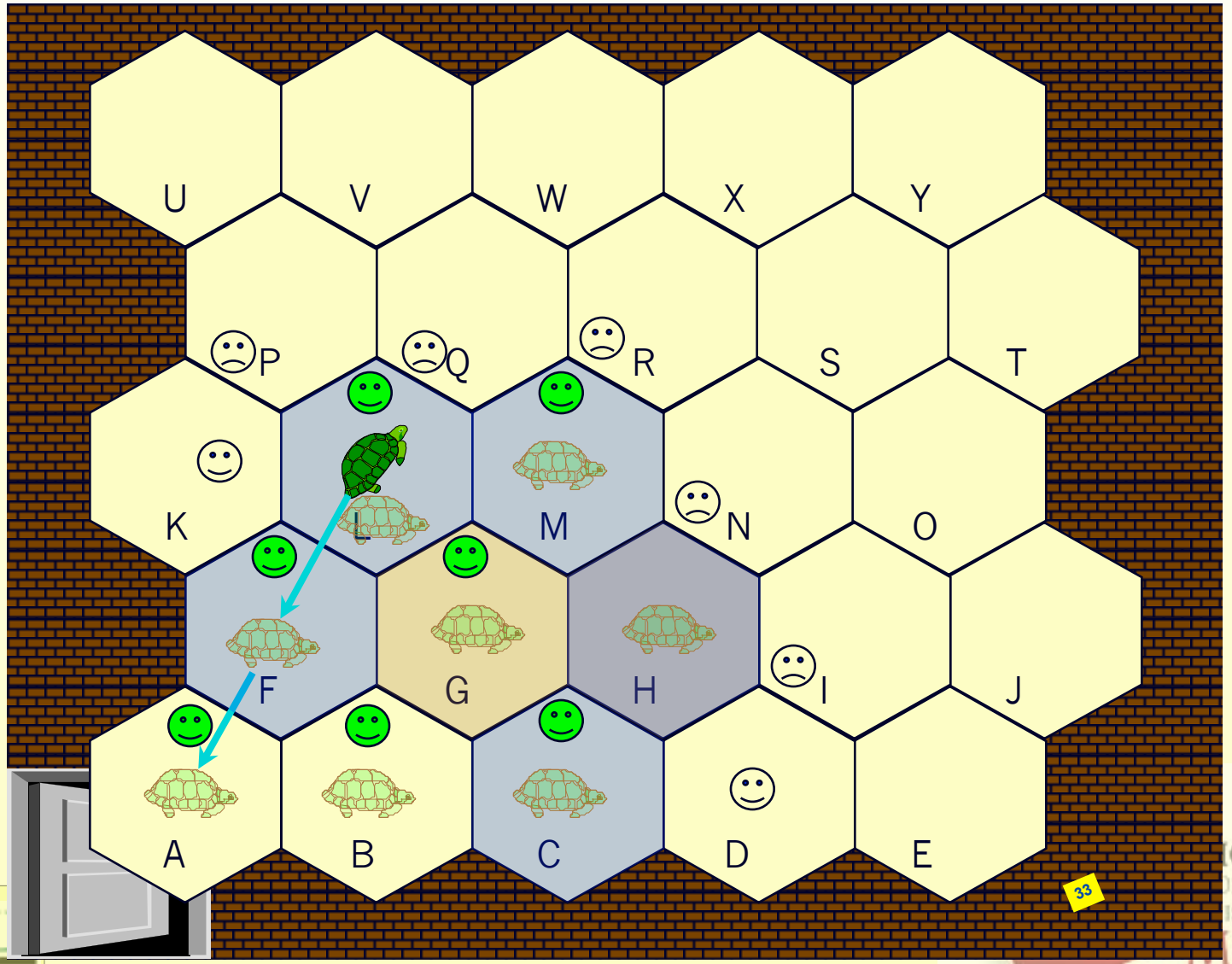
Action: Turn right, forward

Inferences: current position is safe
adjacent positions are safe

Hexagonal Wumpus World



Reasoning in the Hexagonal Wumpus World



Wumpus World Observations

- **many of the reasoning steps seem trivial to humans, but are not so trivial for computers**
  - knowledge gained in different places at different times must be combined
  - absence of percepts is used to draw conclusions
    - sometimes the "closed-world assumption" is used: everything that is not explicitly stated is assumed to be false
    - not always realistic
- **reasoning methods should be generalized**
  - ad hoc representation and methods may be sufficient for one situation, but may have to be augmented for others
    - grid-based world vs. graph-based world,
    - stationary vs. moving wumpus
    - presence of other agents
    - ...

Why Logic in the Wumpus World

- **survival in the wumpus world requires advanced skills**
  - explore the environment
  - remember information about the environment
  - connect different pieces of information
  - make decisions
  - evaluate risks
- **most animals are not "smart" enough to do well in the wumpus world**
- **computers can perform the above activities**
  - but some are difficult (the last three above)
  - an algorithmic solution may be possible, but not very flexible
  - logic provides a framework for knowledge representation and reasoning

Logic for Models

Logic and the world
Models and the real world
Knowledge representation (KR)
KR languages

Logic and the World

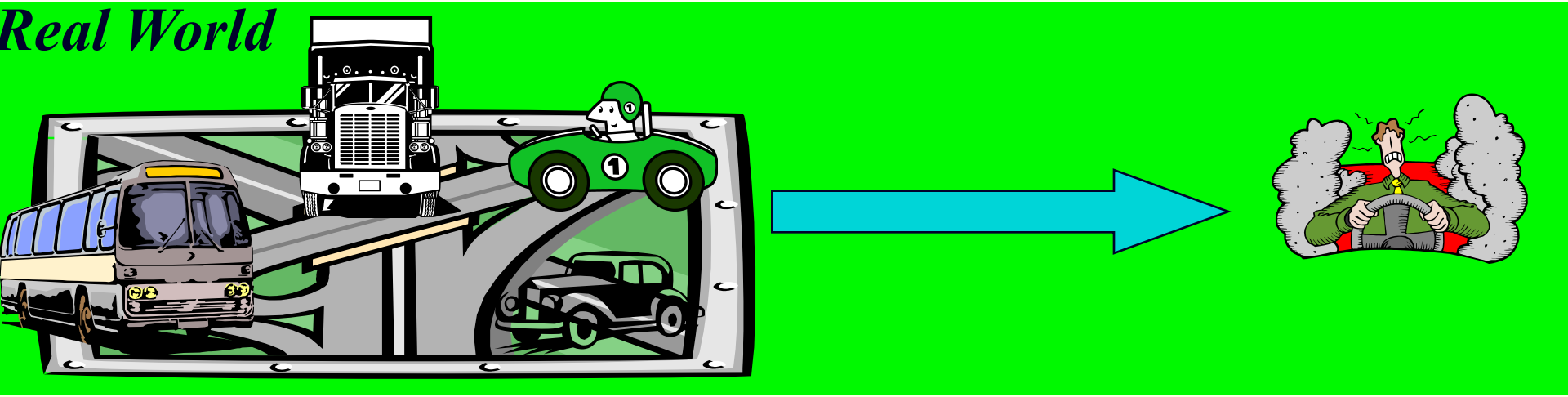
- **create a model**
  - an abstract representation of the real-world problem
  - must capture essential aspects we're interested in
- **reasoning**
  - manipulate the model according to well-established reasoning methods (inference methods)
  - update the model whenever we perceive changes in the real world
- **decisions**
  - make decisions based on the conclusions we derived
- **actions**
  - perform the actions suggested in the decision made
  - observe the outcome, and update the model

Consistency Model - World

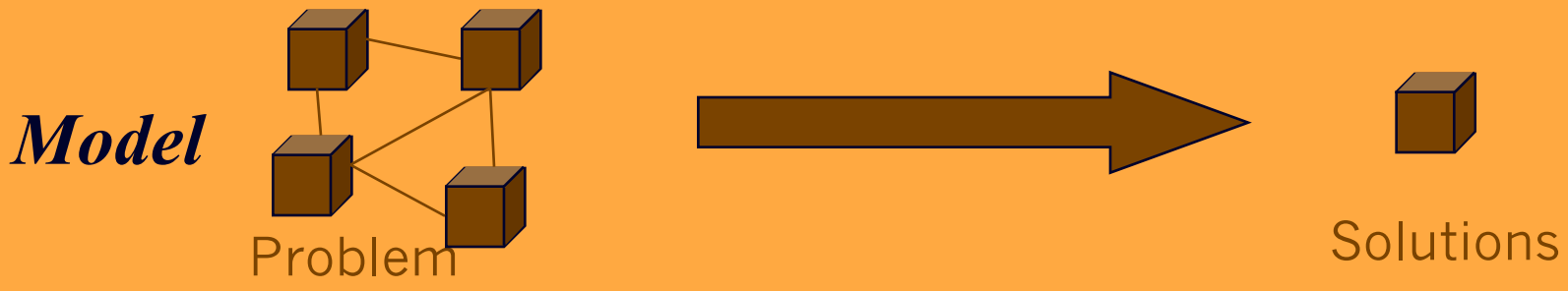
- **grounding is the connection between the real world and the model/ reasoning process**
  - ideally, all true statements in the model are true in the real world, and vice versa
  - ideally, all aspects of the real world are reflected in the models
- **appropriate representation**
  - captures essential aspects
- **sound reasoning method**
  - generates only correct results (truth-preserving)
- **complete reasoning method**
  - is guaranteed to find all possible solutions

Diagram: Models and the Real World

Problem: What is the best transportation method to get from SLO to Fresno?



Experimental Approach: Try out all the options, and then decide.



Analytical Approach: Assemble essential information about the different methods, determine an evaluation method, evaluate them, and decide.

Representation, Reasoning and Logic

- **Representation**
  - storage of knowledge and information in a form suitable for treatment by computers
- **Inference**
  - reasoning steps
  - drawing of conclusions on the basis of existing knowledge and percepts
- **Logics**
  - formal inference methods
  - must have *syntax* and *semantics*

Knowledge Representation Languages

- **syntax**
  - sentences of the language that are built according to the syntactic rules
  - some sentences may be nonsensical, but syntactically correct
- **semantics**
  - refers to the facts about the world for a specific sentence
  - interprets the sentence in the context of the world
  - provides meaning for sentences
- **languages with precisely defined syntax and semantics can be called logics**

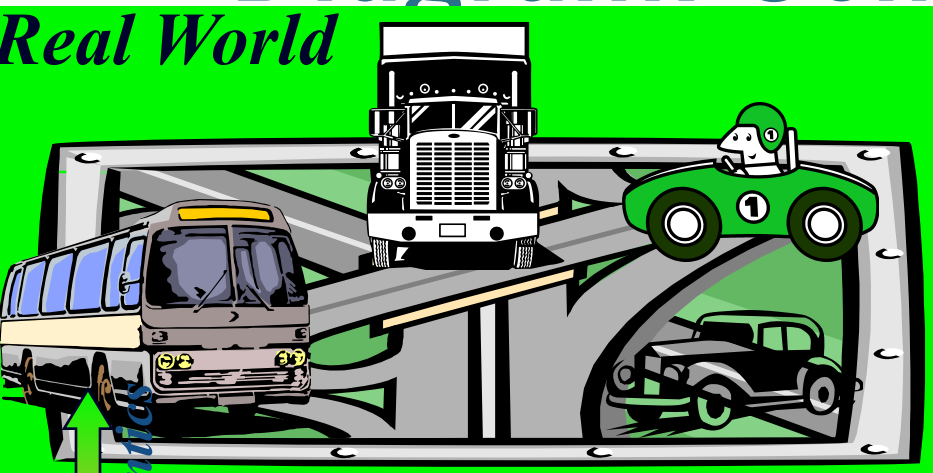
Semantics

- **describes the meaning of a sentence**
  - correspondence between sentences and facts in the world
  - must be defined by the author of the sentence in the form of an interpretation
  - frequent problem: “parasitic” interpretation
    - meaning is implied, e.g. by the strings that represent words
- **compositionality**
  - the meaning of a sentence can be constructed from the meanings of its parts
- **truth of a sentence**
  - the state of the real world corresponds to the meaning of a sentence

Sentences and the Real World

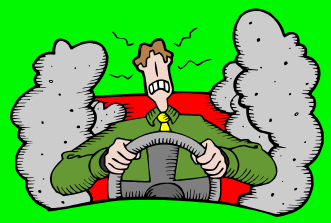
- **syntax**
  - describes the principles for constructing and combining sentences
    - e.g. BNF grammar for admissible sentences (“syntactically correct”)
    - inference rules to derive new sentences from existing ones through manipulations of the symbols representing the sentences
- **semantics**
  - establishes the relationship between a sentence and the aspects of the real world it describes
  - can be checked directly by comparing sentences with the corresponding objects in the real world
    - not always feasible or practical
  - complex sentences can be checked by examining their individual parts

Diagram: Sentences and the



Real World

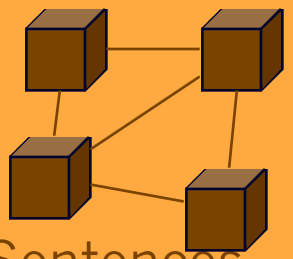
Follows



Semantics

Semantics

Model



Entails

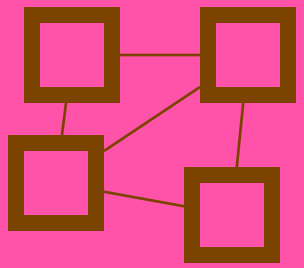
Sentences

Sentence

Syntax

Syntax

Symbols



Derives

Symbol Strings

Symbol String

Candidate Languages

- **programming languages**
  - good for algorithms, data structures
  - limited expressiveness
    - problematic for many knowledge-based aspects
    - “There is a wumpus in some square”
- **natural language**
  - very high expressiveness
  - very difficult to capture formally
    - imprecise syntax
    - ambiguous, context-dependent
- **mathematical logic**
  - good expressiveness
  - reasonably suitable for computers

Important Concepts and Terms

- `and`
- automated reasoning
- completeness
- conjunction
- disjunction
- domain
- fact
- `false`
- implication
- inference mechanism
- inference rule
- interpretation
- knowledge representation
- logic
- model
- `or`
- propositional logic
- semantics
- soundness
- syntax
- `true`
- variable

Chapter Summary

- **some problems require more sophisticated techniques than searching for a solution**
- **reasoning utilizes existing knowledge to generate new knowledge**
  - requires appropriate representation and reasoning methods
- **logic provides a flexible and powerful framework for representation and reasoning**
  - used for the formulation of abstract models that reflect essential aspects of the problem and environment
  - propositional logic is relatively simple, but also limited