CSC 480: Artificial Intelligence

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Logistics - Nov. 1, 2012

- **AI Nugget presentations scheduled**
  - Section 1:
    - Erik Sandberg: Traffic Ground Truth Estimation Using Multisensor Consensus Filter
  - Section 3:
    - Bryan Stoll: Virtual Composer (delayed from Oct. 25)
    - Spencer Lines: What IBM's Watson has been up to since it won in 2011 (delayed from Oct. 30)
    - Mathew Cabutage: Evolution of Robots by Darwinian Selection (delayed from Oct. 30)
    - Rudy Alfaro: League of Legends Bot AI
    - DJ Mitchell: Simulated Therapists and SIM Sensei
    - Alex Waas: Mining Patterns in Search Data
- **A2 Wumpus World**
  - Part 1: Knowledge Representation and Reasoning
    - Web form, no programming required
    - Due: Nov. 8
  - Part 2: Implementation
    - Due: Nov. 15
- **A3 Competitions cancelled**
  - weight of remaining assignments adjusted accordingly

Course Overview

- Introduction
- Intelligent Agents
- Search
  - problem solving through 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
- Propositional Logic
  - syntax
  - semantics
  - validity and inference
  - models
  - inference rules
  - complexity
- Wumpus Agents
- Important Concepts and Terms
- Chapter Summary

Dog vs. Wumpus

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

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 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

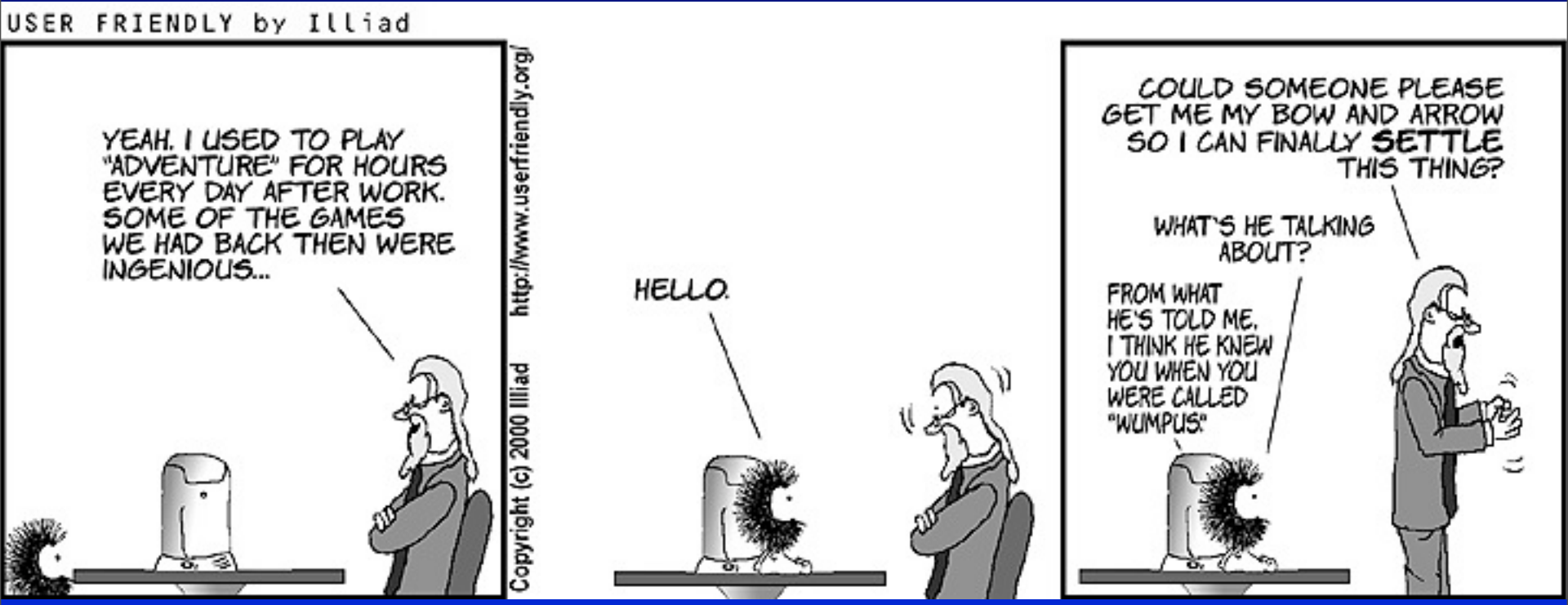
```
function KB-AGENT(percept) returns action
   static KB      // knowledge base
          t       // counter indicating time; initially 0

   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.

User Friendly and Wumpus



Wumpus World

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

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

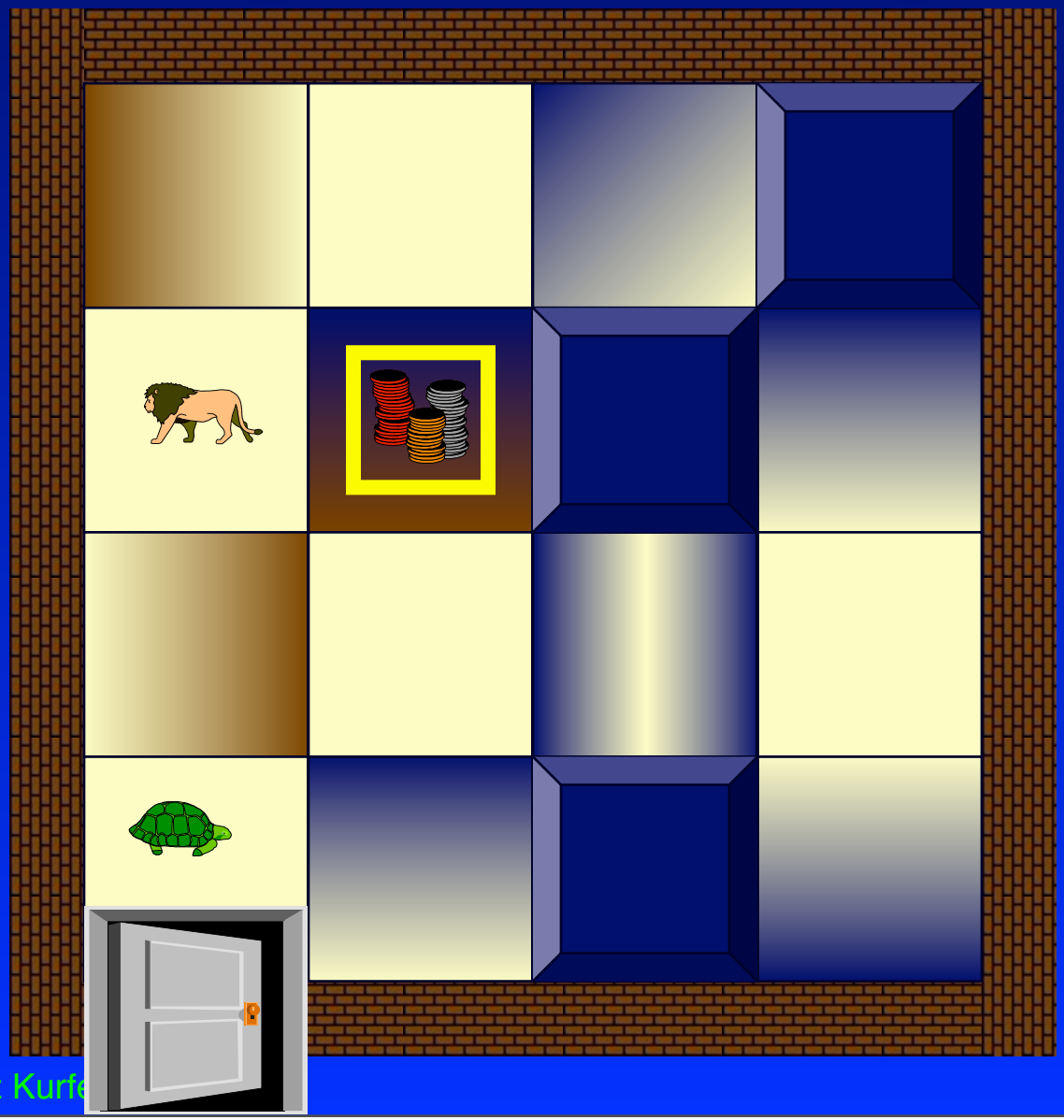
Wumpus

- 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 Diagram



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)

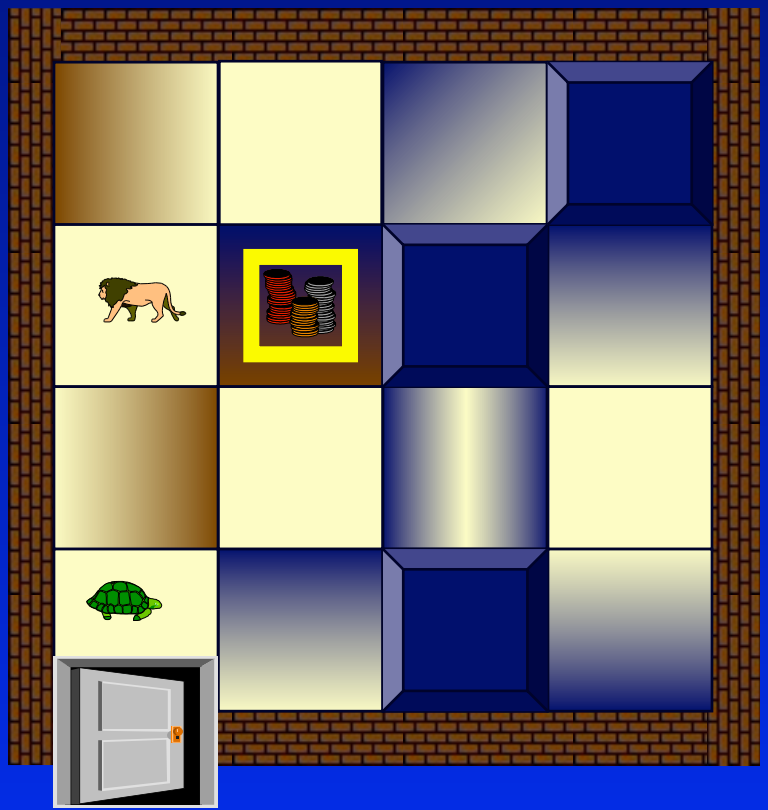
```
[Stench, Breeze, Glitter, Bump, Scream]
```

Life in the Wumpus World

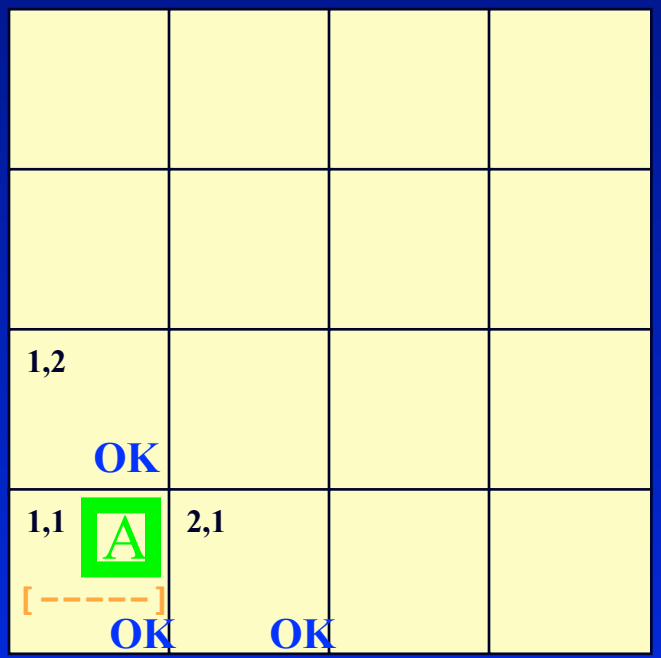
- before performing an action, it is advisable for the agent to “think” about it
  - perceive current state
  - avoid danger
    - wumpus, pits
  - seek rewards
    - gold
  - keep track of the environment
    - internal map, properties of squares
    - escape route

Wumpus World Exploration 1

World State



Agent's View



Position: [1,1]

Percept:

```
[None, None, None, None, None]
```

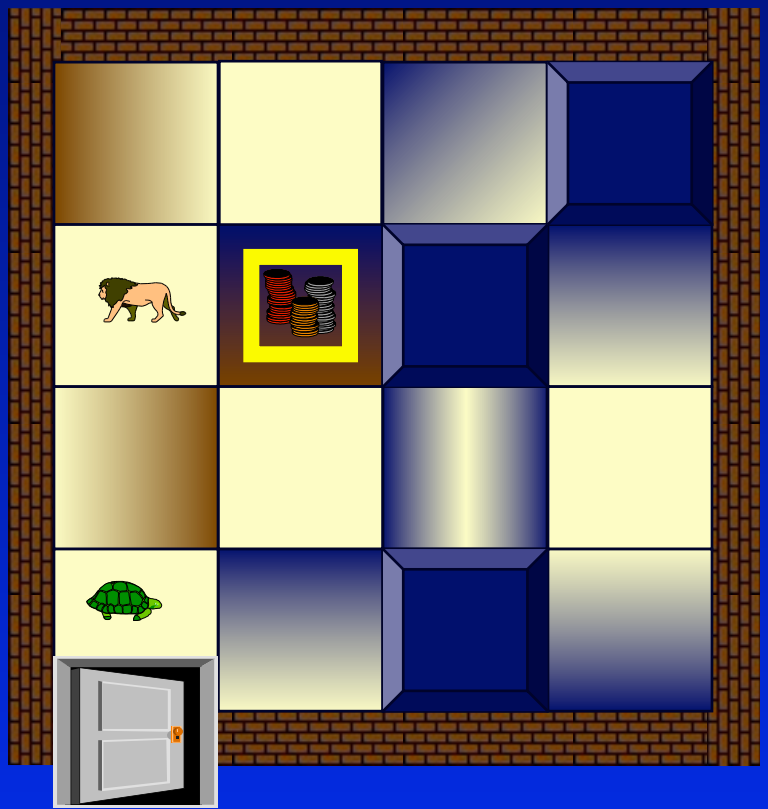
Action: Turn right, forward

Inferences:

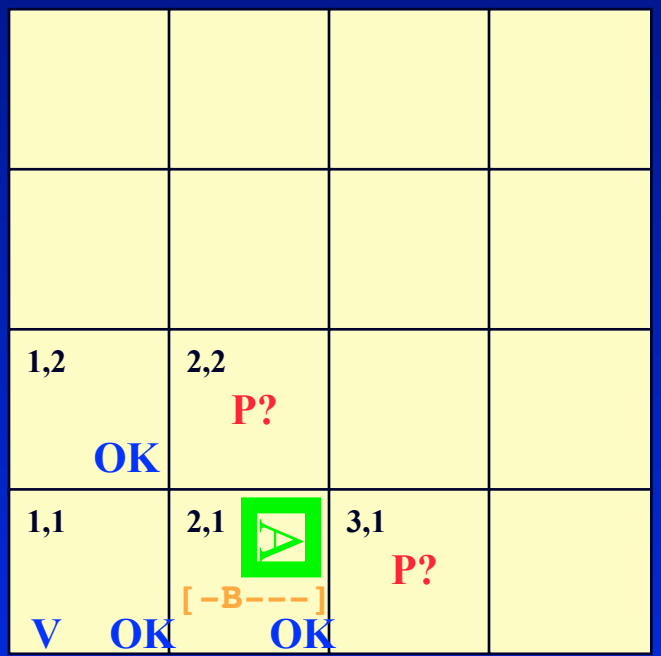
```
current position is safe
adjacent positions are safe
```

Wumpus World Exploration 2

World State



Agent's View



Position: [2,1]

Percept:

[None, Breeze, None, None, None]

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

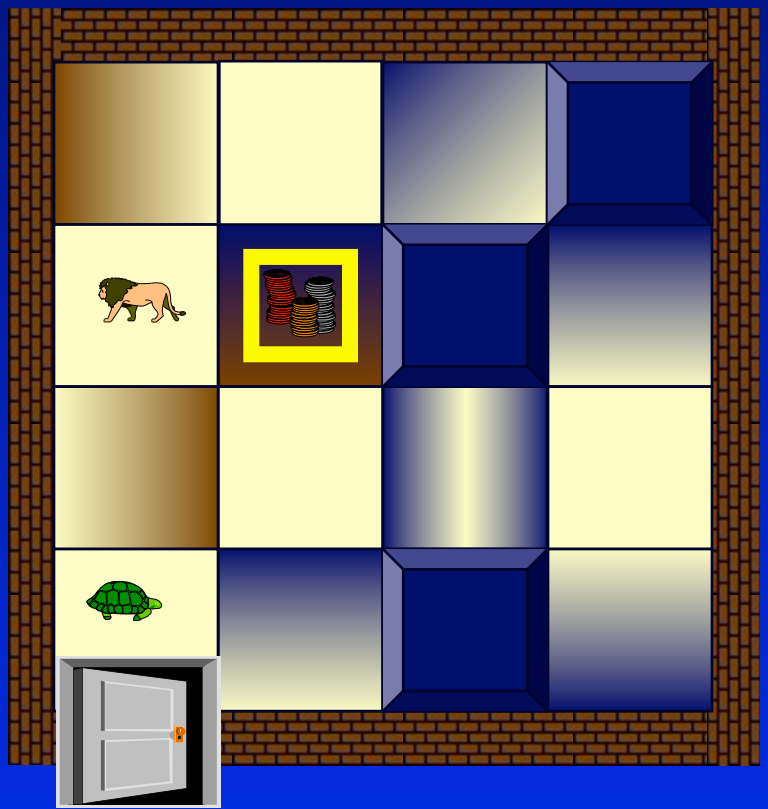
Inferences:

current position is safe

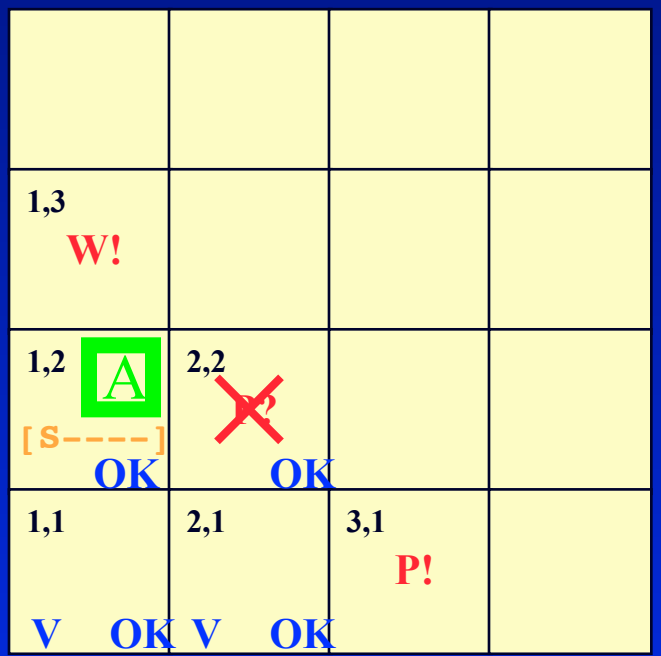
adjacent positions may be pits because of a perceived breeze

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]

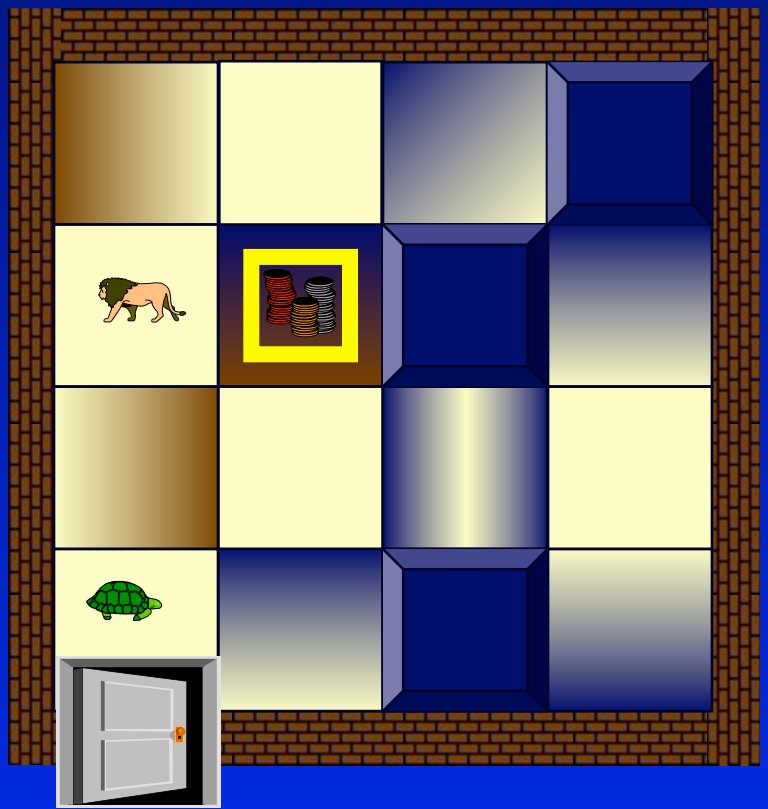
Percept:

[Stench, None, None, None, None]

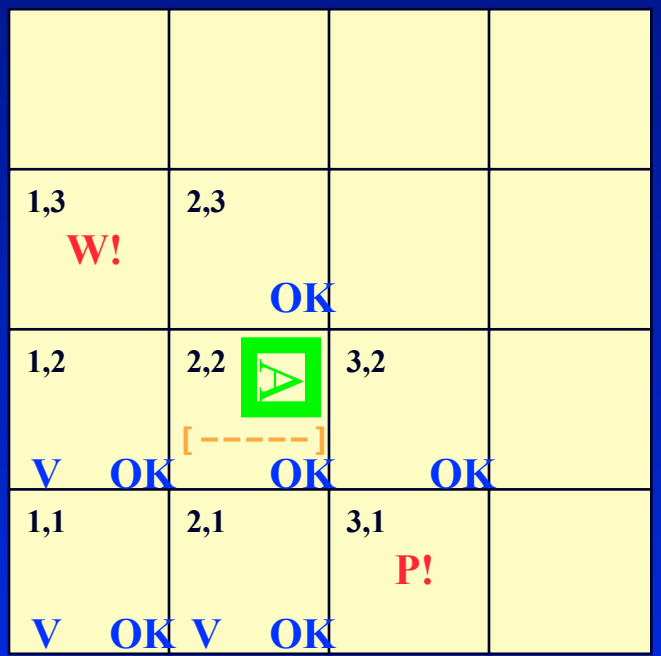
Action: Turn right, forward

Wumpus World Exploration 4

World State



Agent's View



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]

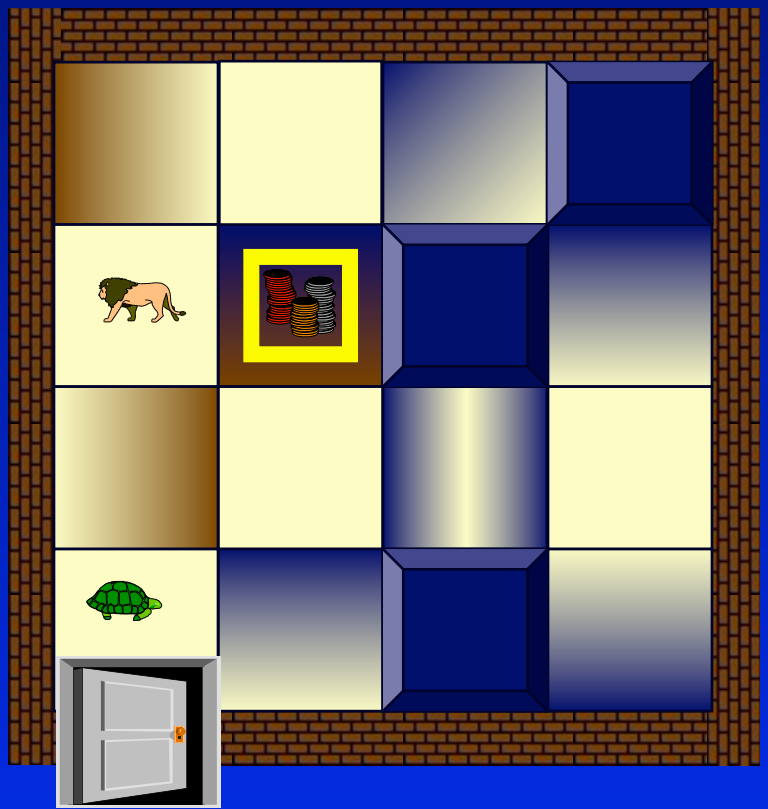
Percept:

[None, None, None, None, None]

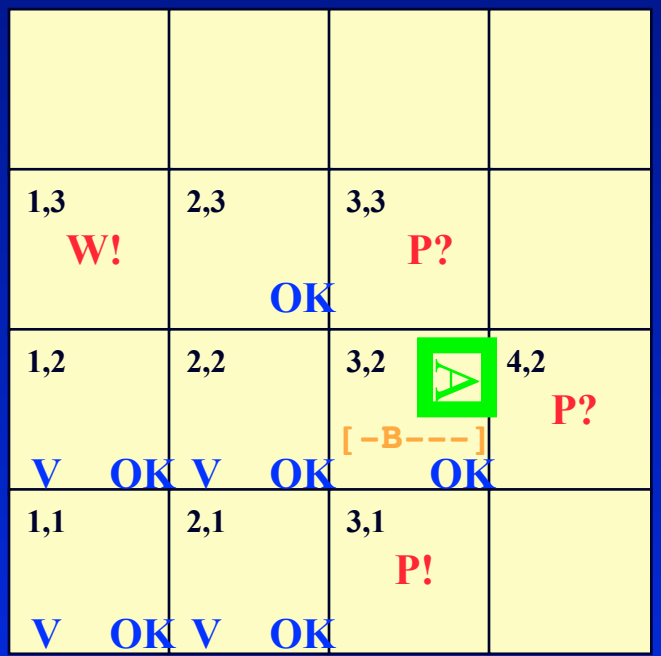
Action: Turn right, forward

Wumpus World Exploration 5

World State



Agent's View



Position: [3,2]

Percept:

[None, Breeze, None, None, None]

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

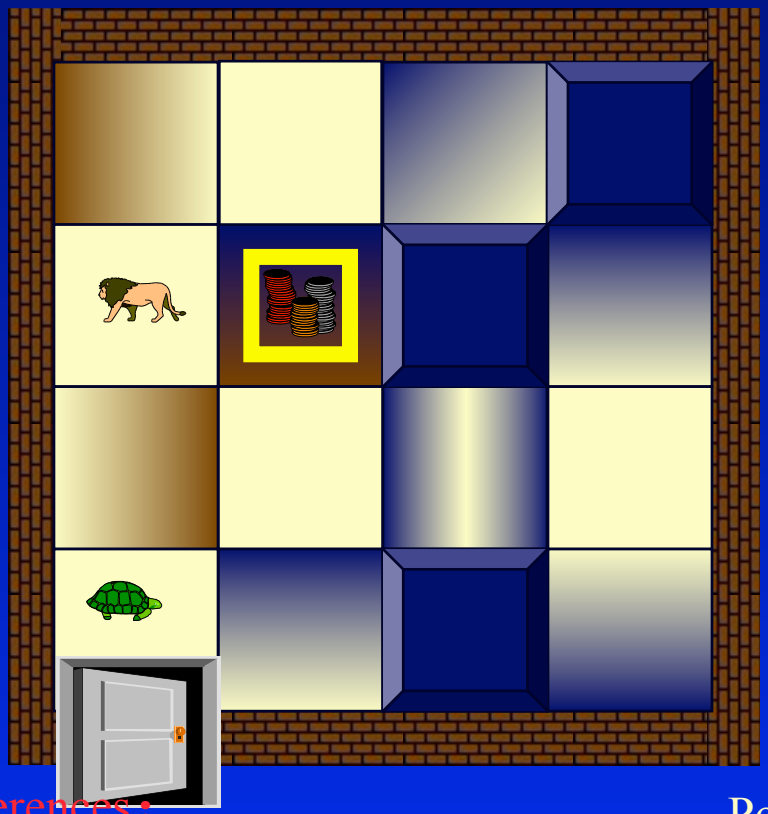
Inferences:

current position is safe

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

Wumpus World Exploration 6

World State



Agent's View

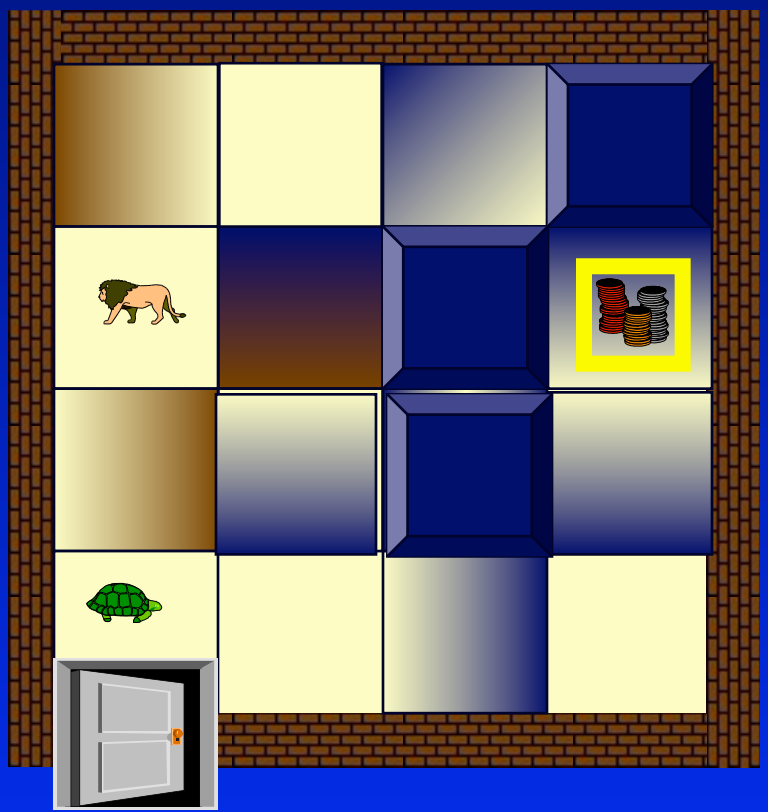
	2,4 P?		
1,3 W!	2,3 A [SBG--] OK	3,3 P?	
1,2 V OK	2,2 V OK	3,2 V OK	4,2 P?
1,1 V OK	2,1 V OK	3,1 P!	

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

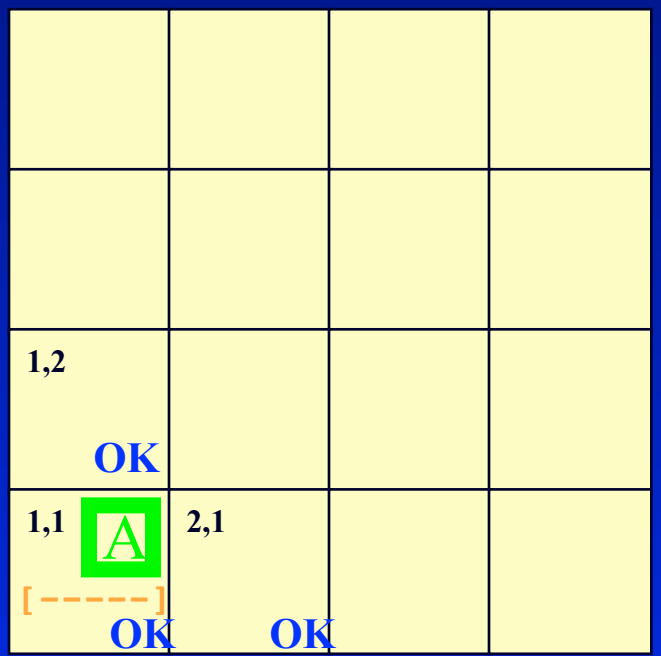
Position: [3,2]
Percept:
[Stench, Breeze, Glitter, None, None]
Action: Grab gold, left, left, forward, right, forward, left, forward, climb out

Wumpus Example

World State



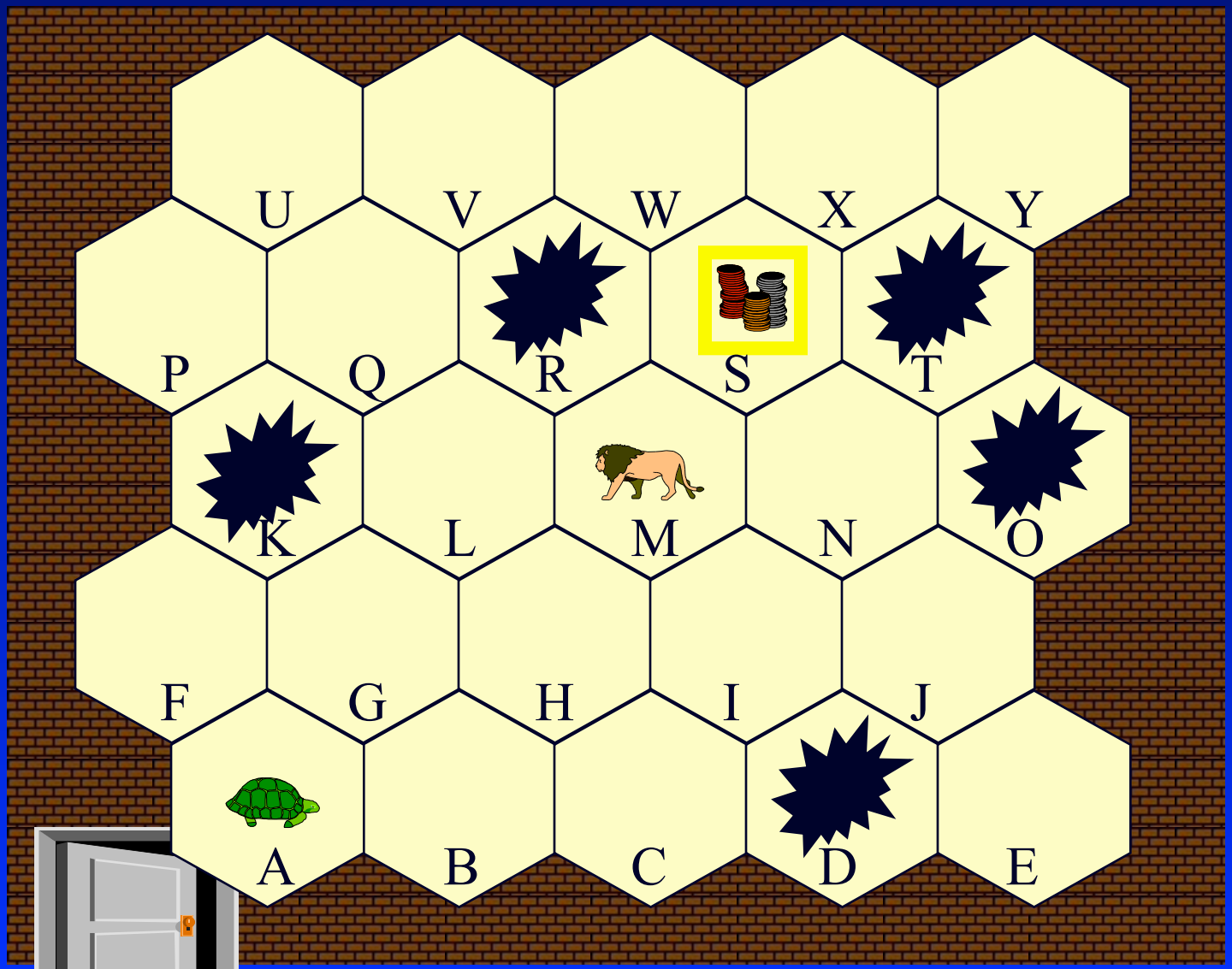
Agent's View



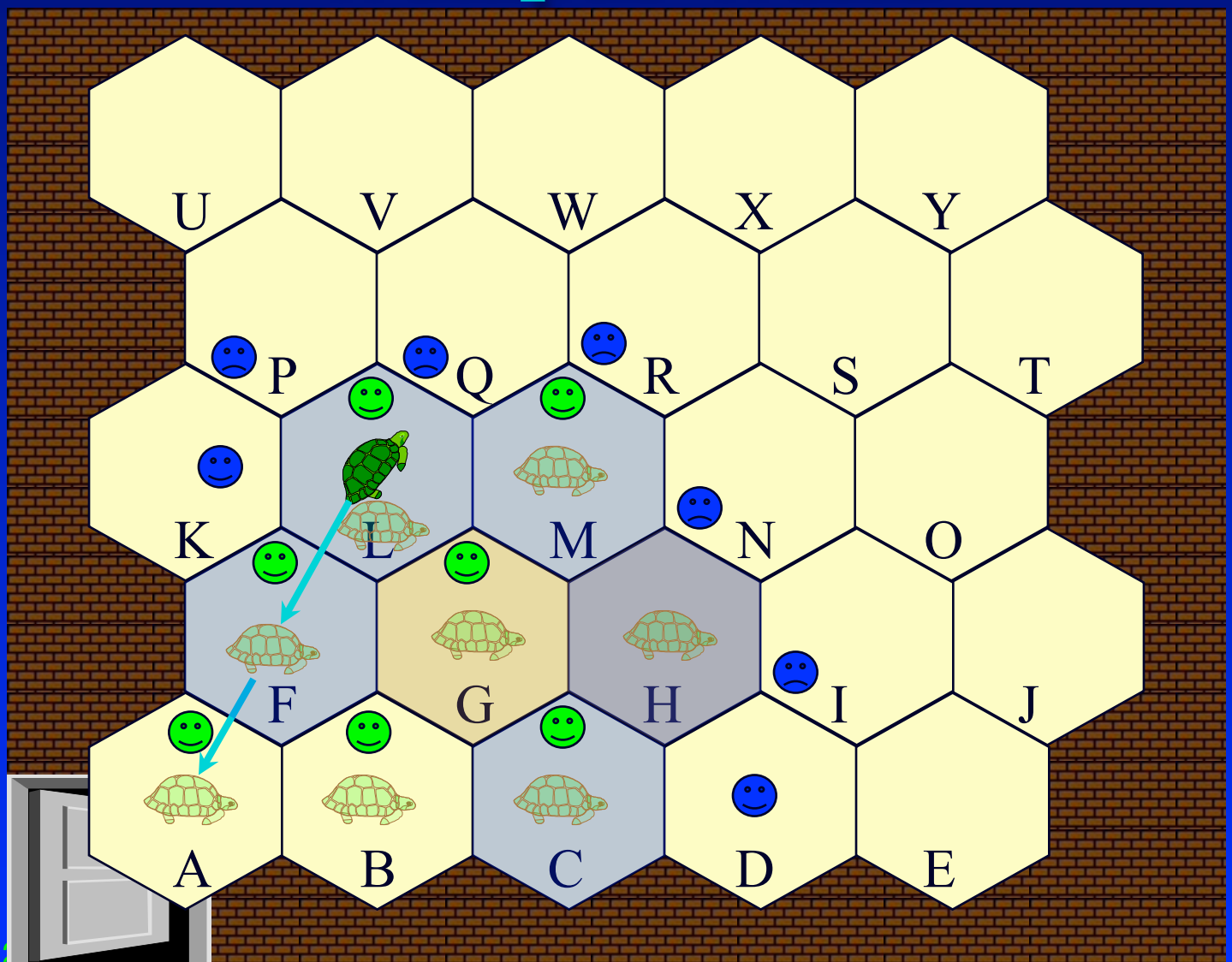
Position: [1,1]
Percept:
[None, None, None, None, None]
Action: Turn right, forward

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
    - e.g grid-based world vs. graph-based world

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 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

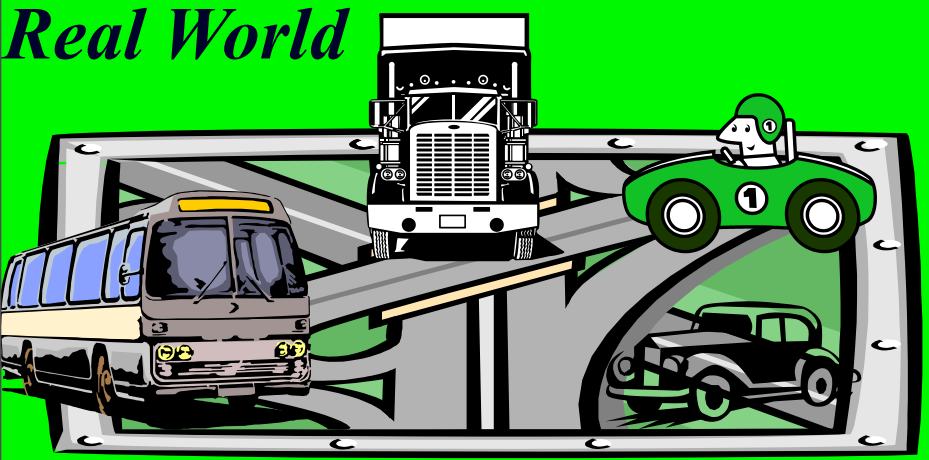
Consistency Model - World

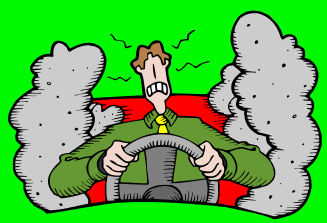
- *grounding* is the connection between the real world and the model/reasoning process
  - ideally, all true statements in the model are true in the real world, and vice versa
  - ideally, all aspects of the real world are reflected in the models
- appropriate representation
  - captures essential aspects
- 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?

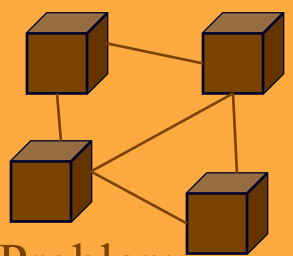
Real World





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

Model



Problem

Solutions

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

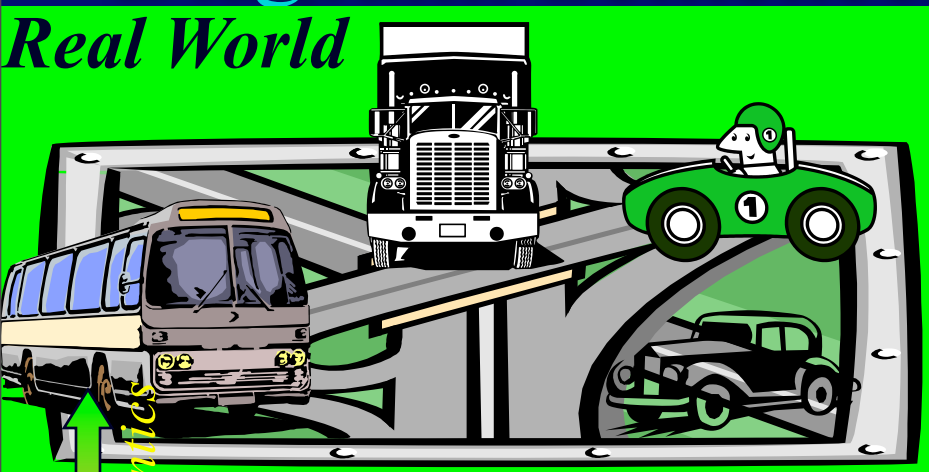
- describes the meaning of a sentence
  - correspondence between sentences and facts in the world
  - must be defined by the author of the sentence in the form of an interpretation
  - frequent problem: “parasitic” interpretation
    - meaning is implied, e.g. by the strings that represent words
- compositionality
  - 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

Sentences Sentence

Diagram: Sentences and the Real World



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

Evaluation

- Criteria

Important Concepts and Terms

- `and`
- atomic sentence
- automated reasoning
- completeness
- conjunction
- constant
- disjunction
- domain
- fact
- `false`
- implication
- inference mechanism
- inference rule
- interpretation
- knowledge representation
- logic
- model
- `or`
- proposition
- propositional logic
- propositional symbol
- semantics
- sentence
- 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