Lecture 10 of 42

Introduction to Knowledge Representation and Logic

William H. Hsu
Department of Computing and Information Sciences, KSU

KSOL course page: http://snipurl.com/v9v3
Course web site: http://www.kddresearch.org/Courses/CIS730
Instructor home page: http://www.cis.ksu.edu/~bhsu

Reading for Next Class:

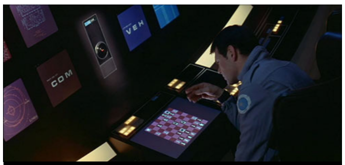
Section 7.5 – 7.7, p. 211 - 232, Russell & Norvig 2nd edition

Lecture Outline

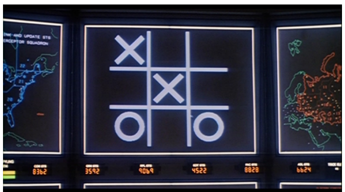
- Reading for Next Class: Sections 7.5 – 7.7 (p. 211 – 232), R&N 2e
  - Propositional calculus (*aka* propositional logic)
    - Syntax and semantics
    - Proof rules
    - Properties of sentences: entailment and provability
    - Properties of proof rules: soundness and completeness
  - Elements of logic: ontology and epistemology
- Last Class: Game Trees, Search Concluded
  - Minimax with alpha-beta (α - β) pruning
  - Expectiminimax: dealing with nondeterminism and imperfect information
  - "Averaging over clairvoyance" and when/why it fails
  - Quiescence and the horizon effect
- Today: Intro to KR and Logic, Sections 7.1 – 7.4 (p. 194 – 210), R&N 2e
  - Wumpus world and need for knowledge representation
  - Syntax and (possible worlds) semantics of logic
- Coming Week: Propositional and First-Order Logic (7.5 – 9.1)

Games: Review

- Games
- Perfect play
  - minimax decisions
  - α–β pruning
- Resource limits and approximate evaluation
- Games of chance
- Games of imperfect information



2001: A Space Odyssey © 1968 MGM.
http://tr.im/zdyp

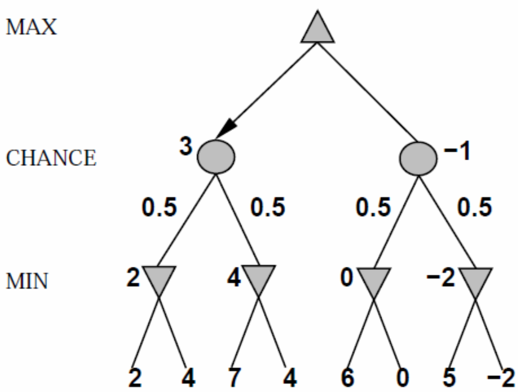


WarGames © 1983 MGM.
http://en.wikipedia.org/wiki/WarGames

Nondeterministic Games: Review

In nondeterministic games, chance introduced by dice, card-shuffling

Simplified example with coin-flipping:



Commonsense Example – Statement: Review

Day 1 Road A leads to a small heap of gold pieces
Road B leads to a fork:
take the left fork and you'll find a mound of jewels;
take the right fork and you'll be run over by a bus.

Day 2 Road A leads to a small heap of gold pieces
Road B leads to a fork:
take the left fork and you'll be run over by a bus;
take the right fork and you'll find a mound of jewels.

Day 3 Road A leads to a small heap of gold pieces
Road B leads to a fork:
guess correctly and you'll find a mound of jewels;
guess incorrectly and you'll be run over by a bus.

Commonsense Example – Analysis: Review

* Intuition that the value of an action is the average of its values in all actual states is WRONG

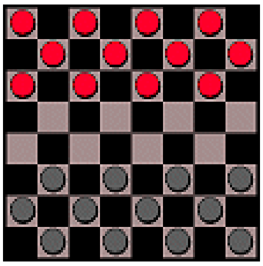
With partial observability, value of an action depends on the information state or belief state the agent is in

Can generate and search a tree of information states

Leads to rational behaviors such as
- ◊ Acting to obtain information
- ◊ Signalling to one's partner
- ◊ Acting randomly to minimize information disclosure

Segue: From Games to Knowledge Representation & Learning

- **Learning = Improving with Experience at Some Task**
  - Improve over task *T,*
  - with respect to performance measure *P*,
  - based on experience *E*.
- **Example: Learning to Play Checkers**
  - *T*: play games of checkers
  - *P*: percent of games won in tournament
  - *E*: opportunity to play against self
- **Refining the Problem Specification: Issues**
  - What experience?
  - What *exactly* should be learned?
  - How shall it be *represented*?
  - What specific algorithm to learn it?
- **Defining the Problem Milieu**
  - Performance element: How shall the results of learning be applied?
  - How shall performance element be evaluated? Learning system?



Learning to Play Checkers: Experience and Target Function

- **Type of Training Experience**
  - Direct or indirect?
  - Teacher or not?
  - Knowledge about the game (e.g., openings/endgames)?
- **Problem: Is Training Experience *Representative* (of Performance Goal)?**
- **Software Design**
  - Assumptions of the learning system: *legal* move generator exists
  - Software requirements: generator, evaluator(s), parametric target function
- **Choosing a Target Function**
  - *ChooseMove: Board → Move* (action selection function, or *policy*)
  - *V: Board* $\rightarrow \mathbb{R}$ (board evaluation function)
  - Ideal target *V*; approximated target $\hat{V}$
  - Goal of learning process: operational description (approximation) of *V*

Learning to Play Checkers: Representation of Evaluation Function

- **Possible Definition**
  - If *b* is a final board state that is won, then *V(b)* = 100
  - If *b* is a final board state that is lost, then *V(b)* = -100
  - If *b* is a final board state that is drawn, then *V(b)* = 0
  - If *b* is not a final board state in the game, then *V(b)* = *V(b')* where *b'* is best final board state according to Minimax (optimal play to end of game)
  - *Correct values, but not operational*
- **Choosing Representation for Target Function**
  - Collection of rules?
  - Neural network?
  - Polynomial function (e.g., linear, quadratic combination) of board features?
  - Other?
- **Representation for Learned Function**
  - $\hat{V}(b) = w_0 + w_1 bp(b) + w_2 rp(b) + w_3 bk(b) + w_4 rk(b) + w_5 bt(b) + w_6 rt(b)$
  - bp/rp = number of black/red pieces; bk/rk = number of black/red kings; bt/rt = number of black/red pieces *threatened* (can be taken next turn)

Learning to Play Checkers: Training Procedure, Gradient Function

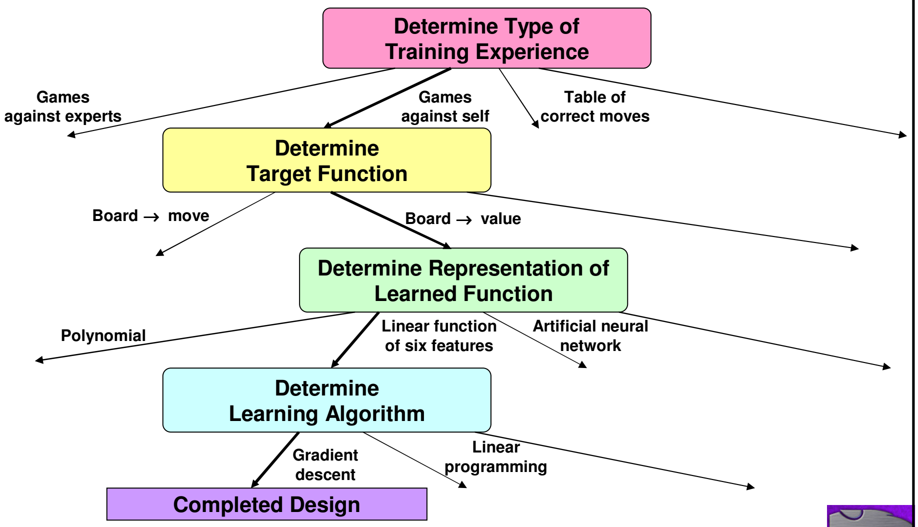
- **Obtaining Training Examples**
  - $V(b)$ the target function
  - $\hat{V}(b)$ the learned function
  - $V_{train}(b)$ the training value
- **One Rule For Estimating Training Values:**
  - $V_{train}(b) \leftarrow \hat{V}(Successor(b))$
- **Choose Weight Tuning Rule**
  - Least Mean Square (LMS) weight update rule:
    REPEAT
    - ⇨ Select a training example *b* at random
    - ⇨ Compute the *error(b)* for this training example
    - ⇨ For each board feature f_i, update weight w_i as follows:

$$error(b) = V_{train}(b) - \hat{V}(b)$$

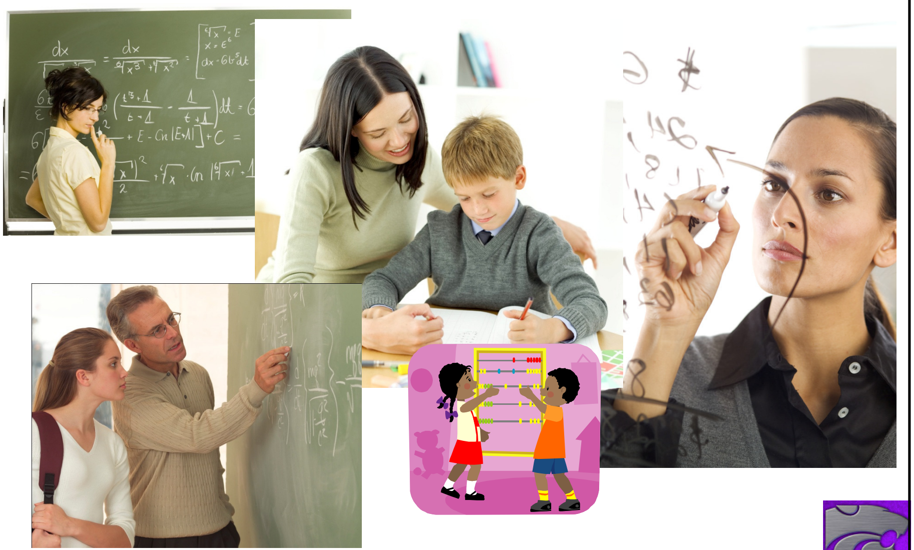
where *c* is small, constant factor to adjust learning rate

$$w_i \leftarrow w_i + c \cdot f_i \cdot error(b)$$

Learning to Play Checkers: Design Choices



Section III: Knowledge and Reasoning



Chapter 7: Overview

- ◇ Knowledge-based agents
- ◇ Wumpus world
- ◇ Logic in general—models and entailment
- ◇ Propositional (Boolean) logic
- ◇ Equivalence, validity, satisfiability
- ◇ Inference rules and theorem proving
  - forward chaining
  - backward chaining
  - resolution

Knowledge bases

- Knowledge base = set of **sentences** in a **formal** language
- **Declarative** approach to building an agent (or other system):
  `Tell` it what it needs to know
- Then it can `Ask` itself what to do - answers should follow from KB
- Agents can be viewed at the **knowledge level**
  i.e., **what they know**, regardless of how implemented
- Or at the **implementation level**
  i.e., data structures in KB and algorithms that manipulate them

Simple Knowledge-Based Agent

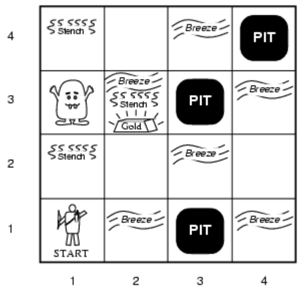
function KB-AGENT(*percept*) **returns** an *action*
  static: *KB*, a knowledge base
    t, a counter, initially 0, indicating time

  TELL(*KB*, MAKE-PERCEPT-SENTENCE(*percept*, *t*))
  action ← ASK(*KB*, MAKE-ACTION-QUERY(*t*))
  TELL(*KB*, MAKE-ACTION-SENTENCE(*action*, *t*))
  $t \leftarrow t + 1$
  return *action*

The agent must be able to:
  Represent states, actions, etc.
  Incorporate new percepts
  Update internal representations of the world
  Deduce hidden properties of the world
  Deduce appropriate actions

Wumpus World [1]: 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**



- **Actuators: Left turn, Right turn, Forward, Grab, Release, Shoot**
- **Sensors: Stench, Breeze, Glitter, Bump, Scream**

WUMPUS WORLD *XTREME*!

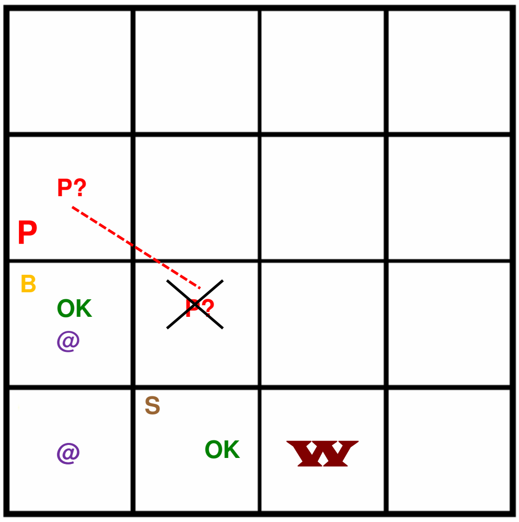
Adapted from slides © 2004 S. Russell & P. Norvig. Reused with permission.

WUMPUS WORLD [2]: CHARACTERIZATION

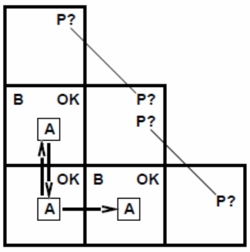
- Fully Observable?
  No – only local perception
- Deterministic?
  Yes – outcomes exactly specified
- Episodic?
  No – sequential at the level of actions
- Static?
  Yes – Wumpus and Pits do not move
- Discrete?
  Yes
- Single-agent?
  Yes – Wumpus is essentially a natural feature

Based on slide © 2004 S. Russell & P. Norvig. Reused with permission.

Exploring Wumpus World

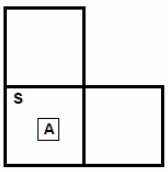


Other Safe Actions



Breeze in (1,2) and (2,1)
$\Rightarrow$ no safe actions

Assuming pits uniformly distributed,
(2,2) has pit w/ prob 0.86, vs. 0.31



Smell in (1,1)
$\Rightarrow$ cannot move

Can use a strategy of coercion:
- shoot straight ahead
- wumpus was there $\Rightarrow$ dead $\Rightarrow$ safe
- wumpus wasn't there $\Rightarrow$ safe

Logic in General

Logics are formal languages for representing information
such that conclusions can be drawn

Syntax defines the sentences in the language

Semantics define the "meaning" of sentences;
i.e., define truth of a sentence in a 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 iff the number $x + 2$ is no less than the number y

$x + 2 \geq y$ is true in a world where $x = 7,\ y = 1$
$x + 2 \geq y$ is false in a world where $x = 0,\ y = 6$

Entailment

Entailment means that one thing follows from another:

$KB \models \alpha$

Knowledge base KB entails sentence α
if and only if
α is true in all worlds where KB is true

E.g., the KB containing "the Giants won" and "the Reds won"
entails "Either the Giants won or the Reds won"

E.g., $x + y = 4$ entails $4 = x + y$

Entailment is a relationship between sentences (i.e., syntax)
that is based on semantics

Note: brains process syntax (of some sort)

Models (Possible Worlds Semantics)

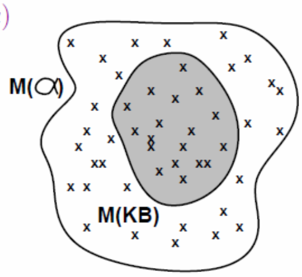
Logicians typically think in terms of models, which are formally structured worlds with respect to which truth can be evaluated

We say m is a model of a sentence α if α is true in m

$M(\alpha)$ is the set of all models of α

Then $KB \models \alpha$ if and only if $M(KB) \subseteq M(\alpha)$

E.g. KB = Giants won and Reds won
α = Giants won

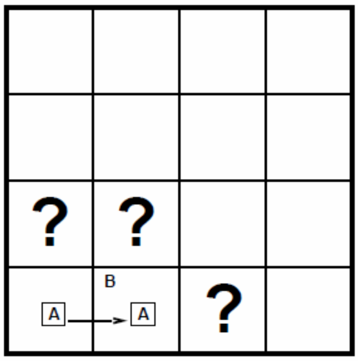


Entailment in Wumpus World

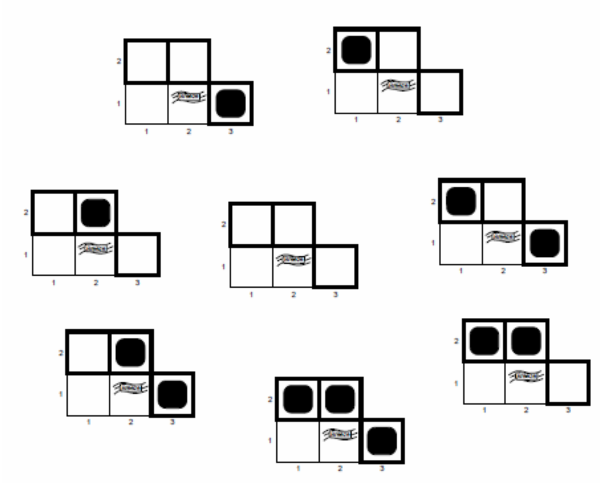
Situation after detecting nothing in [1,1], moving right, breeze in [2,1]

Consider possible models for ?s assuming only pits

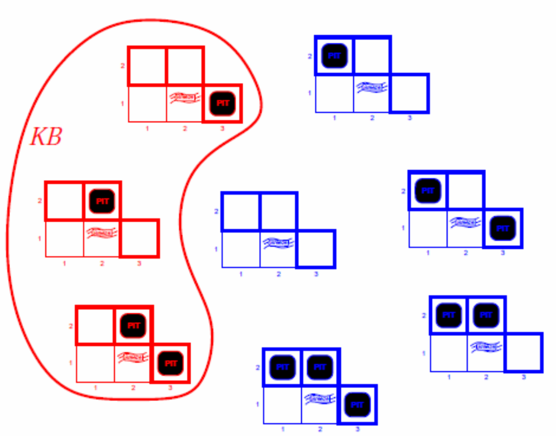
3 Boolean choices $\Rightarrow$ 8 possible models



Wumpus Models [1]



Wumpus Models [2]



KB = wumpus-world rules + observations

Terminology

- Game Trees
  - Expectiminimax: Minimax with alpha-beta (α - β) pruning and chance nodes
  - "Averaging over clairvoyance": expectation applied to hidden info
  - Quiescence: state of "calmness" in play
- PEAS (Performance, Environment, Actuators, Sensors) Specifications
- Wumpus World: Toy Domain
- Intro to Knowledge Representation (KR) and Logic
  - Logic
    - ⇨ Formal language for representing information
    - ⇨ Supports reasoning and learning
  - Sentences: units of logic
- Models: Interpretation (Denotation, Meaning) of Sentences
  - Possible worlds semantics: assigns sets of models to all sentences
  - Entailment: all models of left-hand side (LHS) are models of right (RHS)
- Next: Propositional Logic

Summary Points

- Last Class: Game Trees, Search Concluded
  - Minimax with alpha-beta (α - β) pruning
  - Expectiminimax: dealing with nondeterminism and imperfect information
  - "Averaging over clairvoyance" and when/why it fails
  - Quiescence and the horizon effect
- Today: Intro to Knowledge Representation (KR) and Logic
  - Logic as formal language
  - Representation: foundation of reasoning and learning
  - Logical entailment
- Wumpus World: PEAS Specification and Logical Description
- Reasoning Examples
- Possible Worlds Semantics: Models and Meaning
- Next Week: Propositional and First-Order Logic
  - Propositional logic
  - Resolution theorem proving in propositional logic
  - First-order predicate calculus (FOPC) *aka* first order logic (FOL)