CSE 473

Chapter 9 Wrap-Up and Midterm Review

Inference IV: Compilation to Prop. Logic

- Sentence S:

  $\forall_{city}\ a,b$ Connected(a,b)
- Universe

  Cities: seattle, tacoma, enumclaw
- Equivalent propositional formula?

  Cst $\wedge$ Cse $\wedge$ Cts $\wedge$ Cte $\wedge$ Ces $\wedge$ Cet

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Compilation to Prop. Logic (cont)

- Sentence S:

  $\exists_{city}\ c$ Biggest(c)
- Universe

  Cities: seattle, tacoma, enumclaw
- Equivalent propositional formula?

Bs $\vee$ Bt $\vee$ Be

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Compilation to Prop. Logic (cont again)

- Universe
  - Cities: seattle, tacoma, enumclaw
  - Firms: IBM, Microsoft, Boeing
- First-Order formula

  $\forall_{firm}\ f\ \ \exists_{city}\ c$ HeadQuarters(f, c)
- Equivalent propositional formula

[(HQis $\vee$ HQit $\vee$ HQie) $\wedge$
(HQms $\vee$ HQmt $\vee$ HQme) $\wedge$
(HQbs $\vee$ HQbt $\vee$ HQbe)]

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Hey!

- You said FO Inference is semi-decidable
- But you compiled it to SAT
  Which is NP Complete
- So now we can always do the inference?!?
  (might take exponential time but still decidable?)
- Something seems wrong here….????

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Compilation to Prop. Logic: The Problem

- Universe
  - People: homer, bart, marge
- First-Order formula
  $\forall_{people}\, p \quad Male(FatherOf(p))$
- Equivalent propositional formula

$$[\ (M_{father-homer} \wedge M_{father-bart} \wedge M_{father-marge} \wedge$$
$$(M_{father-father-homer} \wedge M_{father-father-bart} \wedge \cdots$$
$$(M_{father-father-father-homer} \wedge \cdots$$
$$\ldots]$$

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Restricted Forms of FO Logic

- Known, Finite Universes

  Compile to SAT
- Function-Free Definite Clauses (exactly one positive literal)

  Aka Datalog knowledge bases
- Definite clauses + Inference Process

  E.g., Logic programming using Prolog (uses depth-first backward chaining) – may not terminate in some cases

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Back To the Wumpus World

- Recall description:

  Squares as lists: [1,1] [3,4] etc.

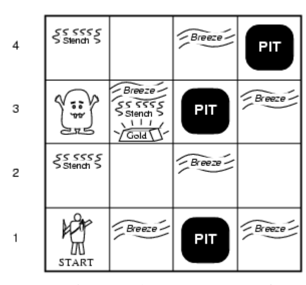
  Square adjacency as binary predicate.

  Pits, breezes, stenches as unary predicates:

  Pit(x)

  Wumpus, gold, homes as functions:

  Home(Wumpus)



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Back To the Wumpus World

- "Squares next to pits are breezy":

  $\forall x, y, a, b:$
  $\text{Pit}([x, y]) \land \text{Adjacent}([x, y], [a, b]) \Rightarrow \text{Breezy}([a, b])$

- "Breezes happen *only* and *always* next to pits":

  $\forall a,b\ \text{Breezy}([a, b])$
  $\exists\ x,y\ \text{Pit}([x, y]) \land \text{Adjacent}([x, y], [a, b])$

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What About Our Agent?

- How do we go from knowledge of the world to *action* in the world?

  $\Rightarrow$ Planning algorithms
  (after Midterm)

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Midterm Logistics

- When: Wednesday, class time
- Where: Here
- What to read: Lecture slides, your notes, homework problems, and Chapters 1-4 and 6-9 (skip 5)
- Format: Closed book, closed notes except for one 8½" x 11" sheet of notes (double-sided ok)
- Blank sheets will be provided

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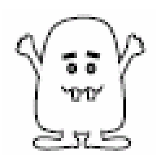

Watch this space for the Midterm Review Slides

Good luck on the midterm!

Happy Halloween!

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Review: Chapters 1 & 2
Agents and Environments

- Browse Chapter 1
- Chapter 2: Definition of an Agent

  Sensors, actuators, environment of agent, performance measure, rational agents

- Task Environment for an Agent = PEAS description

  E.g., automated taxi driver, medical expert

  Know how to write PEAS description for a given task environment

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Review: Chapter 2
Agents and Environments

- Properties of Environments

  Full *vs.* partial observability, deterministic *vs.* stochastic, episodic *vs.* sequential, static *vs.* dynamic, discrete *vs.* continuous, single *vs.* multiagent

- Agent Function *vs.* Agent Program

  State space graph for an agent

- Types of agent programs:

  Simple reflex agents, reflex agent with internal, goal-based agents, utility-based agents, learning agents

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Review: Chapter 3
Search

- State-Space Search Problem
  - Start state, goal state, successor function
- Tree representation of search space
  - Node, parent, children, depth, path cost $g(n)$
- General tree search algorithm
- Evaluation criteria for search algorithms
  - Completeness, time and space complexity, optimality
  - Measured in terms of b, d, and m

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Review: Chapter 3
Uninformed Search Strategies

- Know how the following work:
  - Breadth first search
  - Uniform cost search
  - Depth first search
  - Depth limited search
  - Iterative deepening search
- Implementation using FIFO/LIFO
- Completeness (or not), time/space complexity, optimality (or not) of each
- Bidirectional search
- Repeated states and Graph Search algorithm

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Review: Chapter 4
Informed Search

- Best-First Search algorithm
  - Evaluation function f(n)
  - Implementation with priority queue
- Greedy best-first search
  - f(n) = heuristic function h(n) = estimate of cost from n to goal
  - E.g, $h_{SLD}(n)$ = straight-line distance to goal from n
  - Completeness, time/space complexity, optimality

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Review: Chapter 4
A* Search

- A* search =
  - best-first search with f(n) = g(n) + h(n)
- Know the definition of *admissible* heuristic function h(n)
- Relationship between admissibility and optimality of A*
- Completeness, time/space complexity, optimality of A*
- Comparing heuristics: Dominance
- Iterative-deepening A*

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Review: Chapter 4
Heuristics & Local Search

- Relaxed versions of problems and deriving heuristics from them
- Combining multiple heuristic functions
- Pattern Databases
- Disjoint pattern databases
- Local search:
  - Hill climbing, global vs. local maxima
    - Stochastic hill climbing
    - Random Restart hill climbing
  - Simulated Annealing
  - Local Beam Search
  - Genetic Algorithms

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Review: Chapter 6
Adversarial Search

- Games as search problems
- MAX player, MIN player
- Game Tree, n-Ply tree
- Minimax search for finding best move
  - Computing minimax values for nodes in a game tree
  - Completeness, time/space complexity, optimality
- Minimax for multiplayer games

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Review: Chapter 6
Adversarial Search

- Alpha Beta Pruning
  - Know how to prune trees using alpha-beta
  - Time complexity
- Fixed Depth (cutoff) search
  - Evaluation functions
- Iterative deepening game tree search
  - Quiescent nodes
- Transposition tables (what? why?)
- Game trees with chance nodes
  - Expectiminimax algorithm

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Review: Chapter 7
Logical Agents

- What is a Knowledge Base (KB)?
  - ASK, TELL
- Wumpus world as an example domain
- Syntax vs. Semantics for a language
- Definition of Entailment
  - $KB \models \alpha$ *if and only if* α is true in all worlds where KB is true.
- Models and relationship to entailment
- Soundness vs. Completeness of inference algorithms

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Review: Chapter 7 Logical Agents

- Propositional Logic
  - Syntax and Semantics, Truth tables
  - Evaluating whether a statement is true/false
- Inference by Truth Table Enumeration
- Logical equivalence of sentences
  - Commutativity, associativity, etc.
- Definition of validity and relation to entailment
- Definition of satisfiability, unsatisfiability and relation to entailment

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Review: Chapter 7 Logical Agents

- Inference Techniques
  - Model checking vs. using inference rules
- Resolution
  - Know the definition of literals, clauses, CNF
  - Converting a sentence to CNF
  - General Resolution inference rule
- Using Resolution for proving statements
  - To show $KB \models \alpha$, show $KB \wedge \neg\alpha$ is unsatisfiable by deriving the empty clause via resolution

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Review: Chapter 7
Logical Agents

- Forward and Backward chaining
  - Know definition of Horn clauses
  - AND-OR graph representation
  - Modus ponens inference rule
  - Know how forward & backward chaining work
- DPLL algorithm
  - How is it different from TT enumeration?
- WalkSAT: Know how it works
  - Evaluation function, 3-CNF
  - m/n ratio and relation to hardness of SAT

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Review: Chapter 8
First-Order Logic (FOL)

- First-Order Logic syntax and semantics
  - Constants, variables, functions, terms, relations (or predicates), atomic sentences
  - Logical connectives: and, or, not, $\Rightarrow$, $\Leftrightarrow$
  - Quantifiers: $\forall$ and $\exists$
- Know how to express facts in FOL
  - Interaction between quantifiers and connectives
  - Nesting of quantifiers
- Interpretations, validity, satisfiability, and entailment

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Review: Chapter 9
Inference in FOL

- FOL Inference Techniques
  - Universal instantiation
  - Existential instantiation
    - Skolemization: Skolem constants, Skolem functions
  - Unification
    - Know how to compute most general unifier (MGU)
  - Generalized Modus Ponens (GMP) and Lifting
  - Forward chaining using GMP
  - Backward chaining using GMP
  - Resolution in FOL
    - Standardizing apart variables, converting to CNF
  - Compilation to Propositional Logic and using SAT solvers

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