Search in Games

CPS 170
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Why Study Games?

• Many human activities can be modeled as games
  – Negotiations
  – Bidding
  – TCP/IP
  – Military confrontations
  – Pursuit/Evasion

• Games are used to train the mind
  – Human game-playing, animal play-fighting
Why Are Games Good for AI?

- Games typically have concise rules
- Well-defined starting and end points
- Sensing and effecting are simplified
  - Not true for sports games
  - See robocup
- Games are fun!
- Downside: Getting taken seriously (not)
  - See robo search and rescue

Some History of Games in AI

- Computer games have been around almost as long as computers (perhaps longer)
  - Chess: Turing (and others) in the 1950s
  - Checkers: Samuel, 1950s learning program
- Usually start with naïve optimism
- Follow with naïve pessimism
- Simon: Predicted computer chess champ by 1967
- Many, e.g., Kasparov, predicted that a computer would never be champion
Games Today

• Computers perform at champion level
  – Backgammon, Checkers (solved), Chess, Othello
• Computers perform well
  – Bridge, poker
• Computers still do badly
  (but recent breakthroughs show promise)
  – Go, Hex

Simple Game Setup

• Most commonly, we study games that are:
  – 2 player
  – Alternating
  – Zero-sum
  – Perfect information
• Examples: Checkers, chess, backgammon
• Assumptions can be relaxed at some expense
• Economics studies case where #of agents is very large
  – Individual actions don’t change the dynamics
Zero Sum Games

- Assign values to different outcomes
- Win = 1, Loss = -1
- With zero sum games every gain comes at the other player’s expense
- Sum of both player’s scores must be 0
- Are any games truly zero sum?

Characterizing Games

- Two-player alternating move games are very much like search
  - Initial state
  - Successor function
  - Terminal test
  - Objective function (heuristic function)
- Unlike search
  - Terminal states are often a large set
  - Full search to terminal states usually impossible
Game Trees

```
Player 1

```

Player 1

Player 2

```
Player 1

```

Game Trees (abstracted)

Max nodes

A1

A2

A3

Min nodes

A11

A12

A21

A22

A31

A32

Terminal Nodes
Minimax

- Max player tries to maximize his return
- Min player tries to minimize max’s return
- This is optimal for both (assuming zero sum)

$$\minimax(n_{\text{max}}) = \max_{s \in \text{successors}(n)} \minimax(s)$$
$$\minimax(n_{\text{min}}) = \min_{s \in \text{successors}(n)} \minimax(s)$$

Minimax Values

[Diagram showing a game tree with nodes labeled from 3 to 15]
Minimax Properties

- Minimax can be run depth first
  - Time $O(b^n)$
  - Space $O(bm)$

- Assumes that opponent plays optimally

- Based on a worst-case analysis

- What if this is incorrect?

Minimax in the Real World

- Search trees are too big
- Alternating turns double depth of the search
  - 2 ply = 1 full turn
- Branching factors are too high
  - Chess: 35
  - Go: 361
- Full search from start to end never terminates in non-trivial games
Evaluation Functions

- Like heuristic functions
- Try to estimate value of a node without expanding all the way to termination
- Using evaluation functions
  - Do a depth-limited search
  - Treat evaluation function as if it were terminal
- What’s wrong with this?
- How do you pick the depth?
- How do you manage your time?
  - Iterative deepening, quiescence

Desiderata for Evaluation Functions

- Would like to put the same ordering on nodes (even if values aren’t totally right)
- Is this a reasonable thing to ask for?
- What if you have a perfect evaluation function?
- How are evaluation functions made in practice?
  - Buckets
  - Linear combinations
    - Chess pieces (material)
    - Board control (positional, strategic)
Search Control Issues

• Horizon effects
  – Something interesting is just beyond the horizon?
  – How do you know?

• When to generate more nodes?

• If you selectively extend your frontier, how do you decide where?

• If you have a fixed amount of total game time, how do you allocate this?

Pruning

• *The most important search control method is figuring out which nodes you don’t need to expand*

• Use the fact that we are doing a worst-case analysis to our advantage
  – Max player cuts off search when he knows min player can force a provably bad outcome
  – Min player cuts of search when he knows max can force a provably good (for max) outcome
How to prune

- We still do (bounded) DFS
- Expand at least one path to the “bottom”
  - If current node is **max** node, and **min** can force a *lower* value, then prune siblings
  - If current node is **min** node, and max can force a *higher* value, then prune siblings
Max node pruning

```
max_value(state, alpha, beta)
if cutoff(state) then return eval(state)
for each s in successors(state) do
    alpha = max(alpha, min_value(s, alpha, beta))
    if alpha >= beta the return beta
end
return alpha
```

```
min_value(state, alpha, beta)
if cutoff(state) then return eval(state)
for each s in successors(state) do
    beta = min(beta, max_value(s, alpha, beta))
    if beta <= alpha the return alpha
end
return beta
```

- **Max nodes**

Implementing alpha-beta

- **alpha**=value of best alternative available to max player
- **beta**=value of best alternative available to min player
Amazing facts about alpha-beta

- Empirically, alpha-beta has the effect of reducing the branching factor by square root for many problems
- Effectively doubles search horizon
- Alpha-beta makes the difference between novice and expert computer players

What About Probabilities?

Max nodes

Chance nodes

P=0.5
P=0.6
P=0.4
P=0.9
P=0.1

Min nodes
Expectiminimax

- $n$ random outcomes per chance node
- $O(b^m n^m)$ time

\[
\begin{align*}
\text{eminimax}(n_{\text{max}}) &= \max_{s \in \text{successors}(n)} \text{eminimax}(s) \\
\text{eminimax}(n_{\text{min}}) &= \min_{s \in \text{successors}(n)} \text{eminimax}(s) \\
\text{eminimax}(n_{\text{chance}}) &= \sum_{s \in \text{successors}(n)} \text{eminimax}(s) \rho(s)
\end{align*}
\]

Expectiminimax is nasty

- High branching factor

- Randomness makes evaluation fns difficult
  - Hard to predict many steps into future
  - Values tend to smear together
  - Preserving order is not sufficient

- Pruning is problematic
  - Need to prune based upon bound on an expectation
  - Need a priori bounds on the evaluation function
Multiplayer Games

• Things sort-of generalize, but can get complicated

• Maintain vector of possible values for each player at each node

• Might assume that each player acts greedily, but what’s wrong with this?

• Correct treatment requires the full machinery of game theory

Conclusions

• Game tree search is a special kind of search
• Rely heavily on heuristic evaluation functions
• Alpha-beta is a big win
• Most successful players use alpha-beta
• Final thought: Tradeoff between search effort and evaluation function effort
• When is it better to invest in your evaluation function?