More on games (Ch. 5.4-5.6)

*Move*

Why'd you move your knight away?

Just think logicially. The goal is checkmate, so you should always move pieces toward the other player's king.

I guess occasionally you need to move backward, but it'd be trivial to make a list of those circumstances and—

Have you ever played chess? Not much, but wanna? Uh, ok.

*Move* *Move* *Move* *Move* *Move* *Move* *Move* Checkmate.

This game isn't very well-designed. For starters, knights are too weak...
Announcements

Writing 2 posted
Minimax

“Pruning” in real life:

Snip branch

“Pruning” in CSCI trees:

Snip branch

[Diagram showing a pruning process in a decision tree with nodes and arrows pointing to nodes to be pruned.]
Alpha-beta pruning

However, we can get the same answer with searching less by using efficient “pruning”

It is possible to prune a minimax search that will never “accidentally” prune the optimal solution

A popular technique for doing this is called alpha-beta pruning (see next slide)
Alpha-beta pruning

This can apply to max nodes as well, so we propagate the best values for max/min in tree

Alpha-beta pruning algorithm:
Do minimax as normal, except:
Going down tree: pass “best max/min” values
min node: if parent's “best max” greater than current node, go back to parent immediately
max node: if parent's “best min” less than current node, go back to parent immediately
Let's solve this with alpha-beta pruning
max( min(1,3), 2, min(0, ??) ) = 2, should pick action F

Order:
1\textsuperscript{st}. Red
2\textsuperscript{nd}. Blue
3\textsuperscript{rd}. Purp

Do not consider Alpha-beta pruning
Let best max be “↑” and best min be “↓”
Branches L to R:
Let best max be “↑” and best min be “↓”

Branches L to R:

Alpha-beta pruning
Let best max be \("\uparrow\)" and best min be \("\downarrow\)"
Branches L to R:

α-beta pruning

Branches L to R:
Alpha-beta pruning

Let best max be “↑” and best min be “↓”

Branches L to R:

```
  ↑=?
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```

```
  ↑=?
  ↓=1
  ↓=1
L
```
Let best max be “↑” and best min be “↓”
Branches L to R:

α-beta pruning
Let best max be “↑” and best min be “↓”

Branches L to R:

Let best max be “↑” and best min be “↓”

Branches L to R:
Let best max be “↑” and best min be “↓”

Branches L to R:

Alpha-beta pruning
Let best max be “↑” and best min be “↓”

Branches L to R:
Let best max be “↑” and best min be “↓”

Branches L to R:

Stop exploring
Let best max be “↑” and best min be “↓”

Branches L to R:

α-beta pruning

↑ = 2
↓ = ?

θ = 1
↓ = 1

√ = ?

□ 1
□ 3
□ 0
□ 4

Done!
αβ pruning

Solve this problem with alpha-beta pruning:
In general, alpha-beta pruning allows you to search to a depth $2d$ for the minimax search cost of depth $d$

So if minimax needs to find: $b^m$
Then, alpha-beta searches: $b^{m/2}$

This is exponentially better, but the worst case is the same as minimax
Alpha-beta pruning

Ideally you would want to put your best (largest for max, smallest for min) actions first.

This way you can prune more of the tree as a min node stops more often for larger “best”

Obviously you do not know the best move, (otherwise why are you searching?) but some effort into guessing goes a long way (i.e. exponentially less states)
In alpha-beta pruning, the heuristic for guess which move is best can be complex, as you can greatly effect pruning.

While for A* search, the heuristic had to be very fast to be useful (otherwise computing the heuristic would take longer than the original search).
Alpha-beta pruning

This rule of checking your parent's best/worst with the current value in the child only really works for two player games...

What about 3 player games?
3-player games

For more than two player games, you need to provide values at every state for all the players.

When it is the player's turn, they get to pick the action that maximizes their own value the most.

(We will assume each agent is greedy and only wants to increase its own score... more on this next time)
3-player games

(The node number shows who is max-ing)

What should player 1 do?
What can you prune?
3-player games

How would you do alpha-beta pruning in a 3-player game?
3-player games

How would you do alpha-beta pruning in a 3-player game?

TL;DR: Not easily

(also you cannot prune at all if there is no range on the values even in a zero sum game)

This is because one player could take a very low score for the benefit of the other two
Mid-state evaluation

So far we assumed that you have to reach a terminal state then propagate backwards (with possibly pruning)

More complex games (Go or Chess) it is hard to reach the terminal states as they are so far down the tree (and large branching factor)

Instead, we will estimate the value minimax would give without going all the way down
Mid-state evaluation

By using mid-state evaluations (not terminal) the “best” action can be found quickly

These mid-state evaluations need to be:
1. Based on current state only
2. Fast (and not just a recursive search)
3. Accurate (represents correct win/loss rate)

The quality of your final solution is highly correlated to the quality of your evaluation
Mid-state evaluation

For searches, the heuristic only helps you find the goal faster (but A* will find the best solution as long as the heuristic is admissible)

There is no concept of “admissible” mid-state evaluations... and there is almost no guarantee that you will find the best/optimal solution

For this reason we only apply mid-state evals to problems that we cannot solve optimally
A common mid-state evaluation adds features of the state together

(we did this already for a heuristic...)

\[
\text{eval} = 20
\]

We summed the distances to the correct spots for all numbers
We then minimax (and prune) these mid-state evaluations as if they were the correct values.

You can also weight features (i.e. getting the top row is more important in 8-puzzle).

A simple method in chess is to assign points for each piece: pawn=1, knight=4, queen=9...
then sum over all pieces you have in play.
Mid-state evaluation

What assumptions do you make if you use a weighted sum?
Mid-state evaluation

What assumptions do you make if you use a weighted sum?

A: The factors are independent (non-linear accumulation is common if the relationships have a large effect)

For example, a rook & queen have a synergy bonus for being together is non-linear, so queen=9, rook=5... but queen&rook = 16
Mid-state evaluation

There is also an issue with how deep should we look before making an evaluation?
There is also an issue with how deep should we look before making an evaluation?

A fixed depth? Problems if child's evaluation is overestimate and parent underestimate (or visa versa)

Ideally you would want to stop on states where the mid-state evaluation is most accurate
Mid-state evaluations also favor actions that “put off” bad results (i.e. they like stalling).

In go this would make the computer use up ko threats rather than give up a dead group.

By evaluating only at a limited depth, you reward the computer for pushing bad news beyond the depth (but does not stop the bad news from eventually happening).
Mid-state evaluation

It is not easy to get around these limitations:
1. Push off bad news
2. How deep to evaluate?

A better mid-state evaluation can help compensate, but they are hard to find

They are normally found by mimicking what expert human players do, and there is no systematic good way to find one
Forward pruning

You can also use mid-state evaluations for alpha-beta type pruning

However as these evaluations are estimates, you might prune the optimal answer if the heuristic is not perfect (which it won't be)

In practice, this prospective pruning is useful as it allows you to prioritize spending more time exploring hopeful parts of the search tree
Forward pruning

You can also save time searching by using “expert knowledge” about the problem.

For example, in both Go and Chess the start of the game has been very heavily analyzed over the years.

There is no reason to redo this search every time at the start of the game, instead we can just look up the “best” response.
Random games

If we are playing a “game of chance”, we can add chance nodes to the search tree.

Instead of either player picking max/min, it takes the expected value of its children.

This expected value is then passed up to the parent node which can choose to min/max this chance (or not).
Random games

Here is a simple slot machine example:

\[
V(\text{chance}) = -1 \cdot \frac{999}{1,000} + 100 \cdot \frac{1}{1,000} = -0.899
\]
Random games

You might need to modify your mid-state evaluation if you add chance nodes.

Minimax just cares about the largest/smallest, but expected value is an implicit average:

R is better

L is better
Random games

Some partially observable games (i.e. card games) can be searched with chance nodes.

As there is a high degree of chance, often it is better to just assume full observability (i.e. you know the order of cards in the deck).

Then find which actions perform best over all possible chance outcomes (i.e. all possible deck orderings).
Random games

For example in blackjack, you can see what cards have been played and a few of the current cards in play.

You then compute all possible decks that could lead to the cards in play (and used cards).

Then find the value of all actions (hit or stand) averaged over all decks (assumed equal chance of possible decks happening).
Random games

If there are too many possibilities for all the chance outcomes to “average them all”, you can sample.

This means you can search the chance-tree and just randomly select outcomes (based on probabilities) for each chance node.

If you have a large number of samples, this should converge to the average.
This idea of sampling a limited part of the tree to estimate values is common and powerful.

In fact, in monte-carlo tree search there are no mid-state evaluations, just samples of terminal states.

This means you do not need to create a good mid-state evaluation function, but instead you assume sampling is effective (might not be so)
MCTS

MCTS has four steps:
1. Find the action which looks best (selection)
2. Add this new action sequence to a tree
3. Play randomly until over
4. Update how good this choice was
MCTS

How to find which actions are “good”?

The “Upper Confidence Bound applied to Trees” UCT is commonly used:

$$\max \left( \frac{\text{win}(n)}{\text{times}(n)} + \sqrt{\frac{2 \ln \text{TotalTimes}}{\text{times}(n)}} \right)$$

This ensures a trade off between checking branches you haven't explored much and exploring hopeful branches

( https://www.youtube.com/watch?v=Fbs4InGLS8M )
MCTS
MCTS

\[
\frac{\text{win}(n)}{\text{times}(n)} + \sqrt{\frac{2 \ln \text{TotalTimes}}{\text{times}(n)}}
\]

\[
= \frac{0}{0} + \sqrt{\frac{2\ln 0}{0}}
\]

\[
= \infty
\]
MCTS

\[ \frac{\text{win}(n)}{\text{times}(n)} + \sqrt{\frac{2 \ln \text{TotalTimes}}{\text{times}(n)}} \]

\[ = \frac{0}{0} + \sqrt{\frac{2 \ln 0}{0}} \]

\[ = \infty \]
MCTS

UCB value

Pick max (I'll pick left-most)
MCTS

(random playout)

lose
MCTS

update (all the way to root)
(random playout)

lose
update UCB values (all nodes)
select max UCB & rollout

MCTS
MCTS

update statistics

win
update UCB vals

MCTS

1/2

1.1 0/1 2.1 1/1 ∞ 0/0
select max UCB & rollout

MCTS
MCTS

update statistics

1/3

1.1  0/1  2.1  1/1  ∞  0/1

lose
MCTS

update UCB vals

1/3

1.4 0/1 2.5 1/1 1.4 0/1
MCTS

select max UCB

1.4 0/1 2.5 1/1 1.4 0/1

∞ 0/0 ∞ 0/0
MCTS

rollout

```
1/3

1.4 0/1 2.5 1/1 1.4 0/1

∞ 0/0 ∞ 0/0 ∞ 0/0

win
```
update statistics

MCTS

1.4 0/1 2.5 2/2 1.4 0/1

∞ 1/1 ∞ 0/0

win
MCTS

update UCB vals

2/4

1.7 0/1 2.1 2/2 1.7 0/1

2.2 1/1 ∞ 0/0
DIFFICULTY OF VARIOUS GAMES FOR COMPUTERS

EASY

SOLVED COMPUTERS CAN PLAY PERFECTLY

- Tic-tac-toe
- Nim
- Ghost (1989)
- Connect Four (1995)
- Gomoku
- Checkers (2007)
- Scrabble
- Counterstrike
- Beer Pong (Viacom)

COMPUTERS CAN BEAT TOP HUMANS

- Chess
- Jeopardy!
- Starcraft
- Poker
- Go
- Arimaa

COMPUTERS STILL LOSE TO TOP HUMANS
(BUT FOCUS ON R&D COULD CHANGE THIS)

- Mao
- Snakes and Ladders

HARD

COMPUTERS MAY NEVER OUTPLAY HUMANS

- Seven Minutes in Heaven
- Calvinball