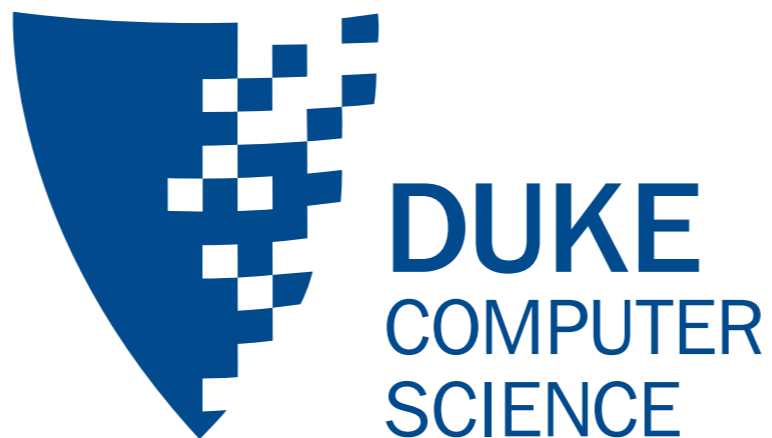


Adversarial Search

George Konidaris
gdk@cs.duke.edu



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Games



“Chess is the Drosophila of Artificial Intelligence”
Kronrod, c. 1966

TuroChamp, 1948

Why Study Games?

Of interest:

- Many human activities (especially intellectual ones) can be modeled as games.
- Prestige.

Convenient:

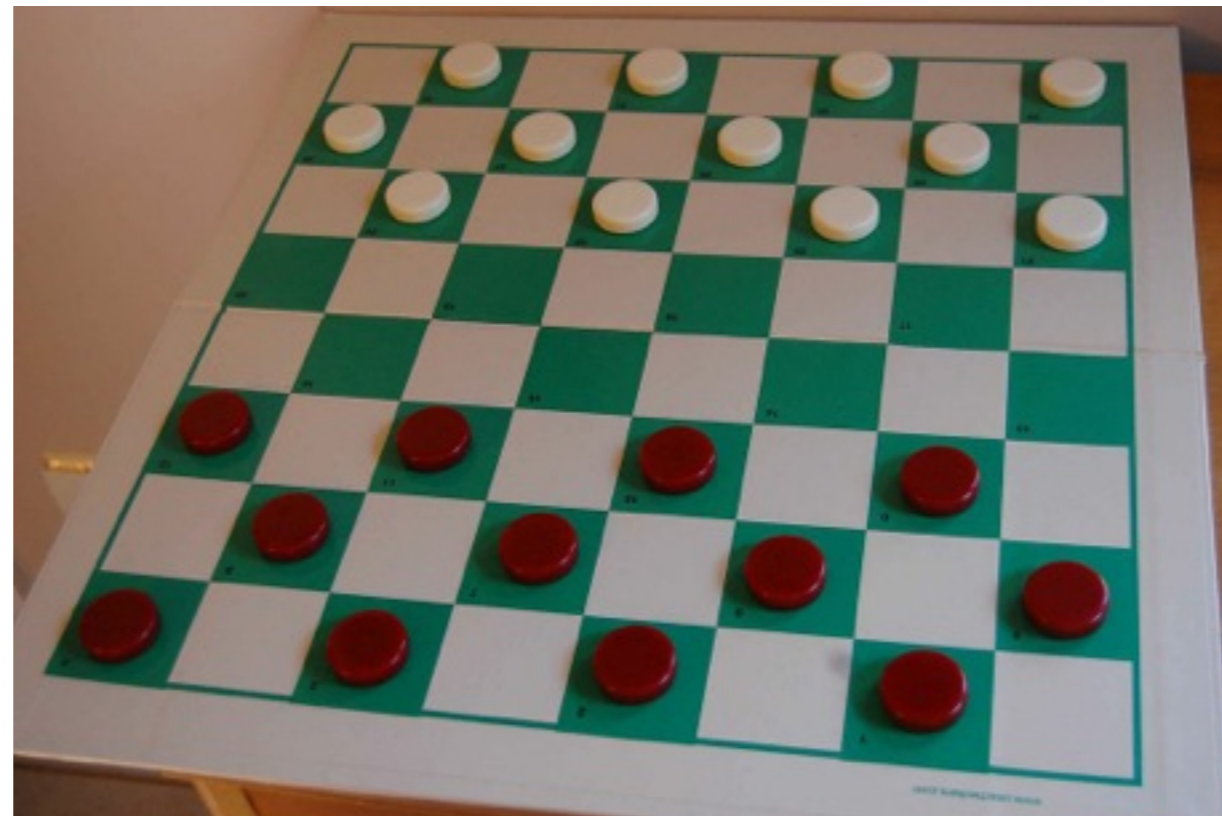
- Perfect information.
- Concise, precise rules.
- Well defined “score”.

“Solved” Games

A game is solved if an optimal strategy is known.

Strong solved: *all positions.*

Weakly solved: *some (start) positions.*



Typical Game Setting

Games are usually:

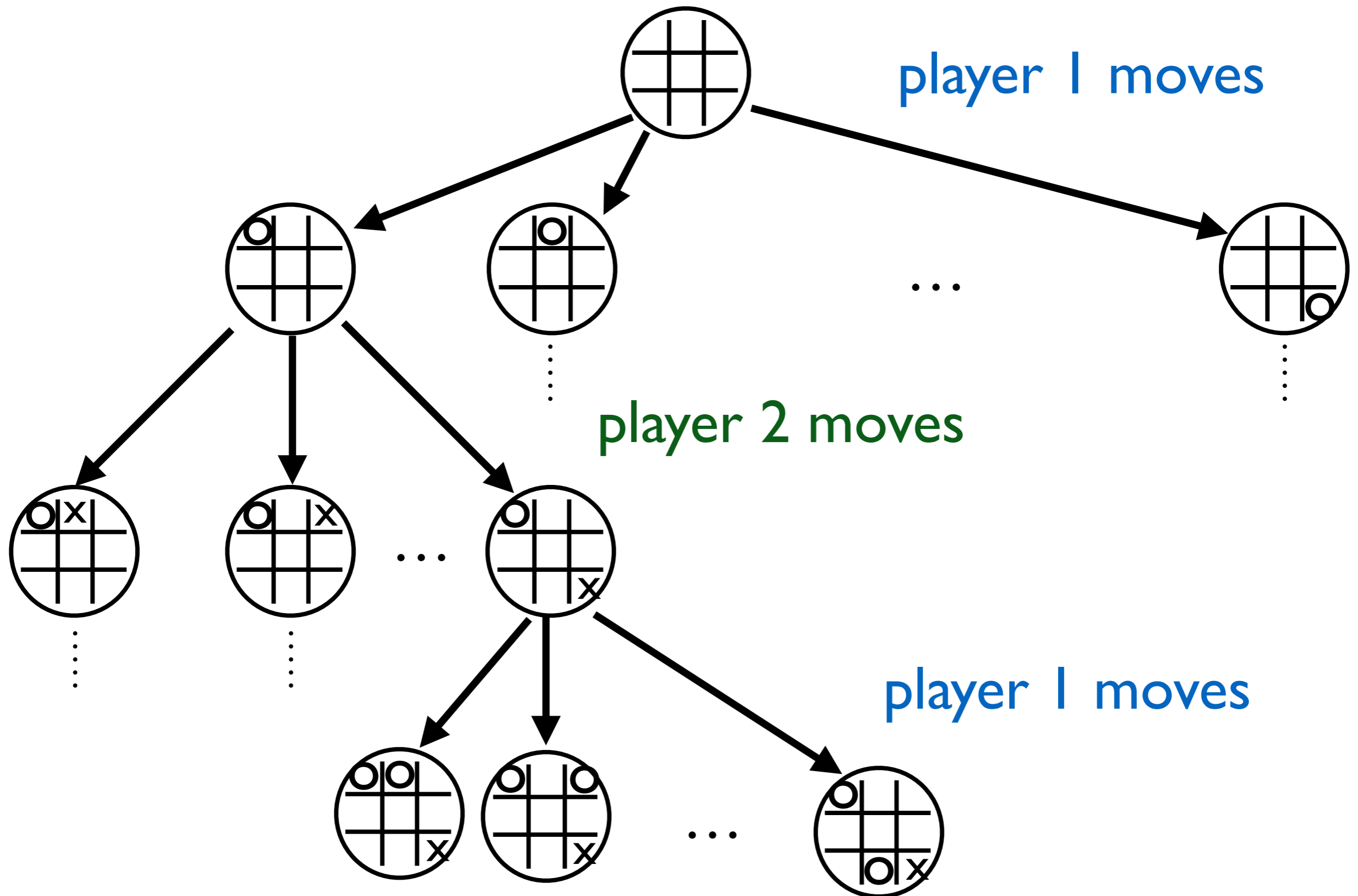
- 2 player
- Alternating
- Zero-sum
 - Gain for one loss for another.
- Perfect information

Very much like search:

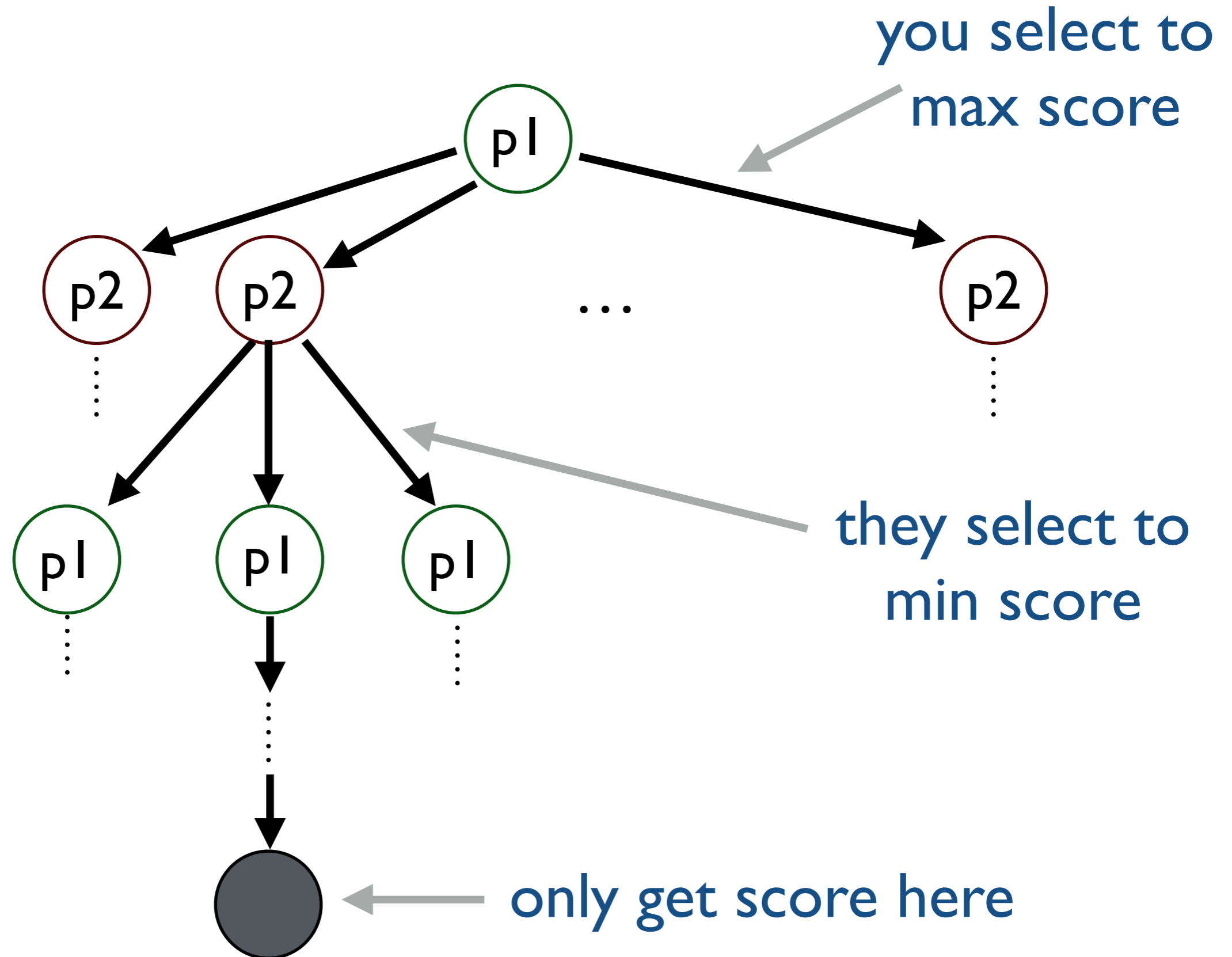
- Start state
- Successor function
- Terminal states (many)
- Objective function

but alternating control.

Game Trees



Key Differences vs. Search



Minimax Algorithm

Max player: select action to maximize return.

Min player: select action to minimize return.

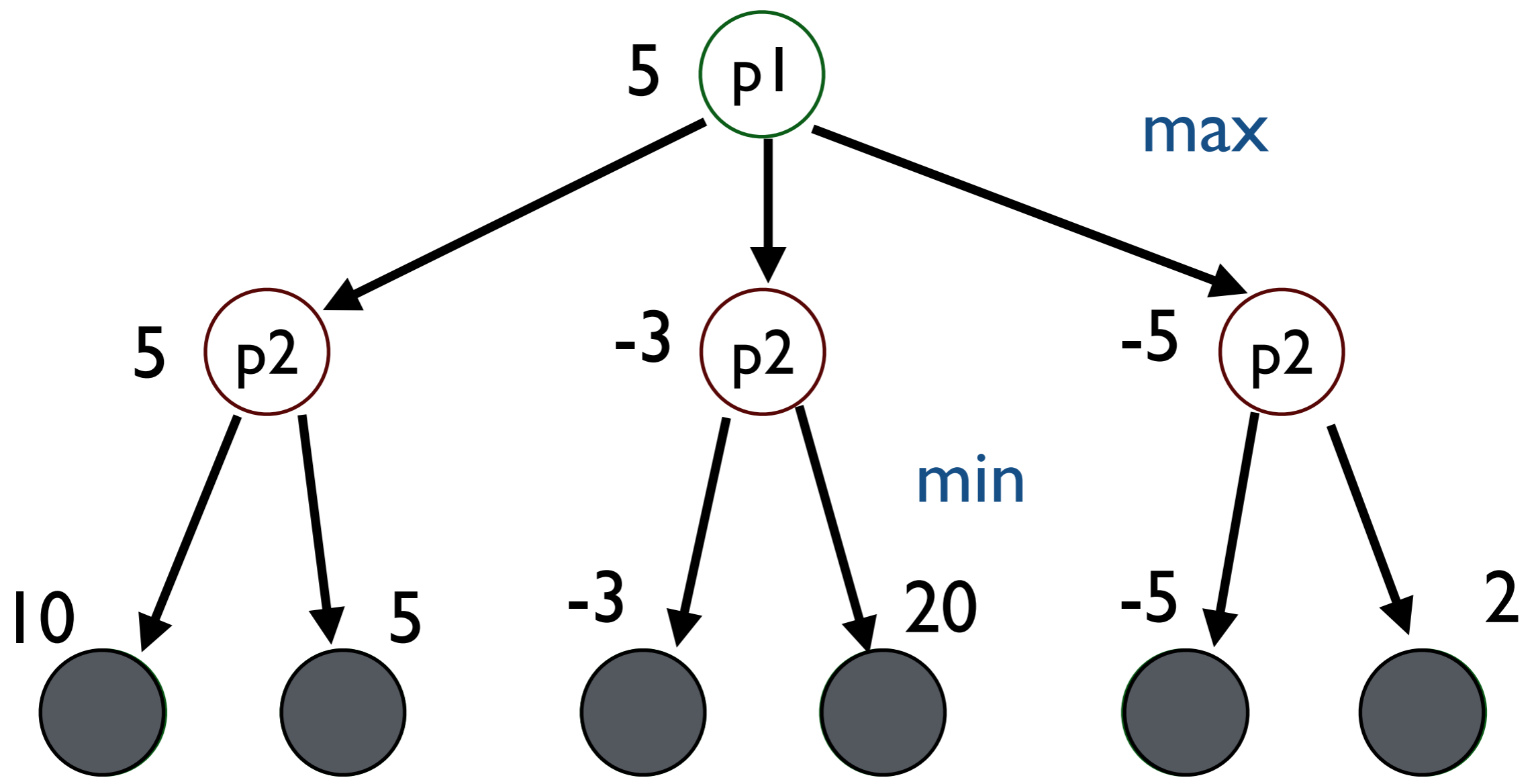
This is optimal for both players (if zero sum).

Assumes perfect play, worst case.

Can run as depth first:

- Time $O(b^d)$
- Space $O(bd)$

Minimax



In Practice

Depth is too deep.

- 10s to 100s of moves.

Breadth is too broad.

- Chess: 35, Go: 361.

Full search never terminates for non-trivial games.

Solution: substitute evaluation function.

- Like a heuristic - estimate value.
- Perhaps run to fixed depth then estimate.

Search Control

- Horizon Effects
 - What if something interesting at horizon + 1?
 - How do you know?
- When to generate more nodes?
- How to selectively expand the frontier?
- How to allocate fixed move time?

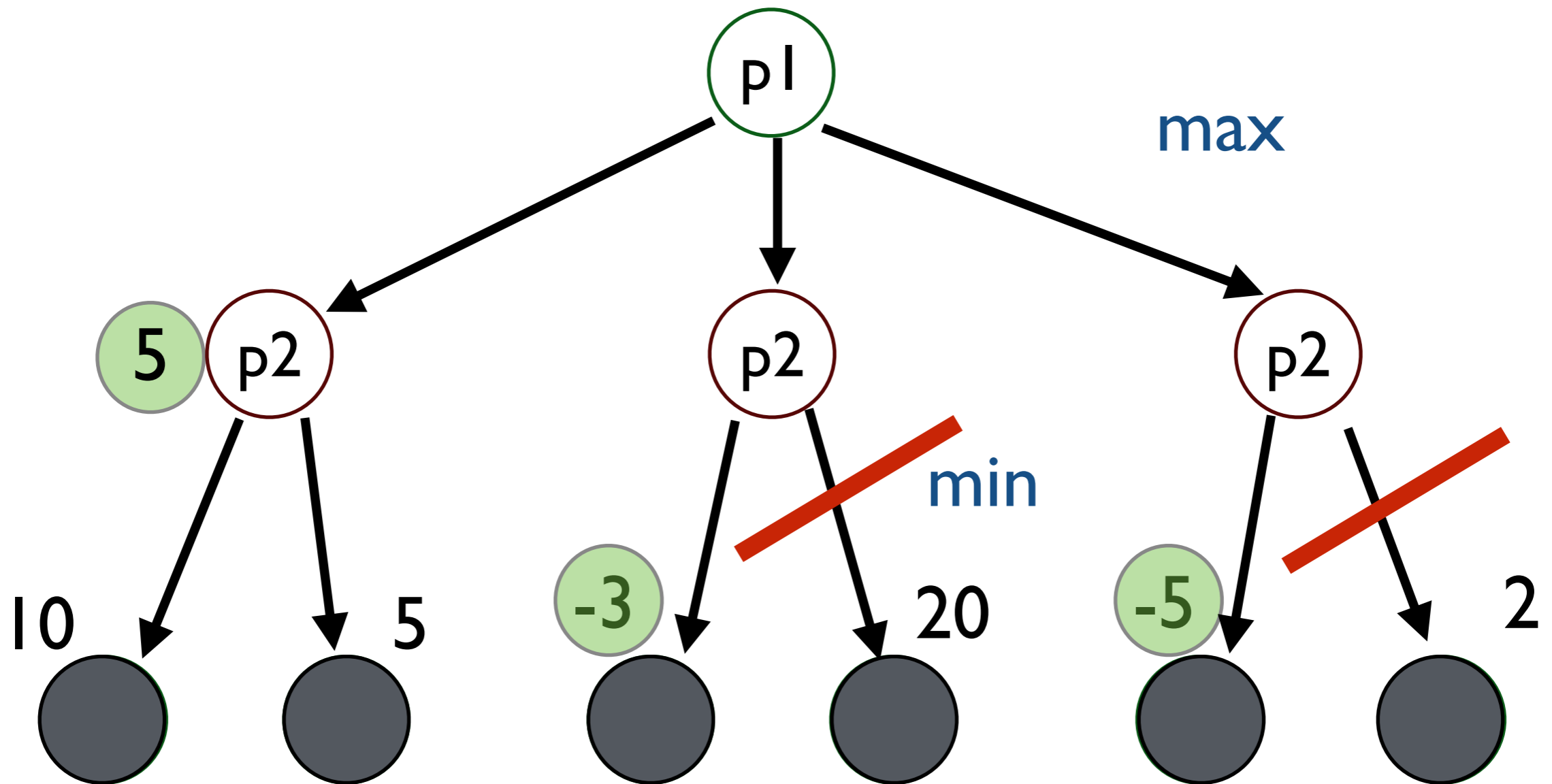
Pruning

Single most useful search control method:

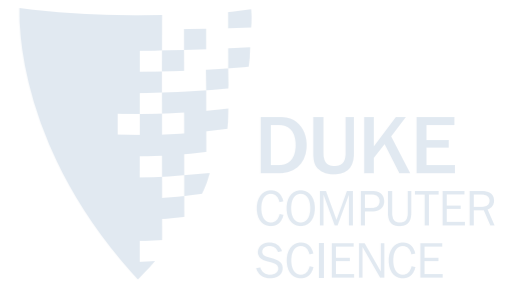
- Throw away whole branches.
- Use the min-max behavior.
- Cutoff search at *min* nodes where *max* can force a better outcome.
- Cutoff search at *max* nodes when *min* can force a worse outcome.

Resulting algorithm: *alpha-beta pruning*.

Alpha-Beta



Alpha-Beta



Empirically, has the effect of reducing the branching factor by a *square root* for many problems.

Effectively doubles the search horizon.

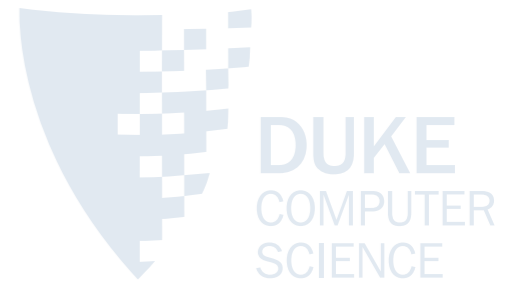
Alpha-beta makes the difference between novice and expert computer game players. *Most successful players use alpha-beta.*

Deep Blue (1997)



480 Special Purpose Chips
200 million positions/sec
Search depth 6-8 moves (up to 20)

Games Today



World champion level:

- Backgammon
- Chess
- Checkers (solved)
- Othello
- Some poker types:

“Heads-up Limit Hold’em Poker is Solved”, Bowling et al., *Science*, January 2015.

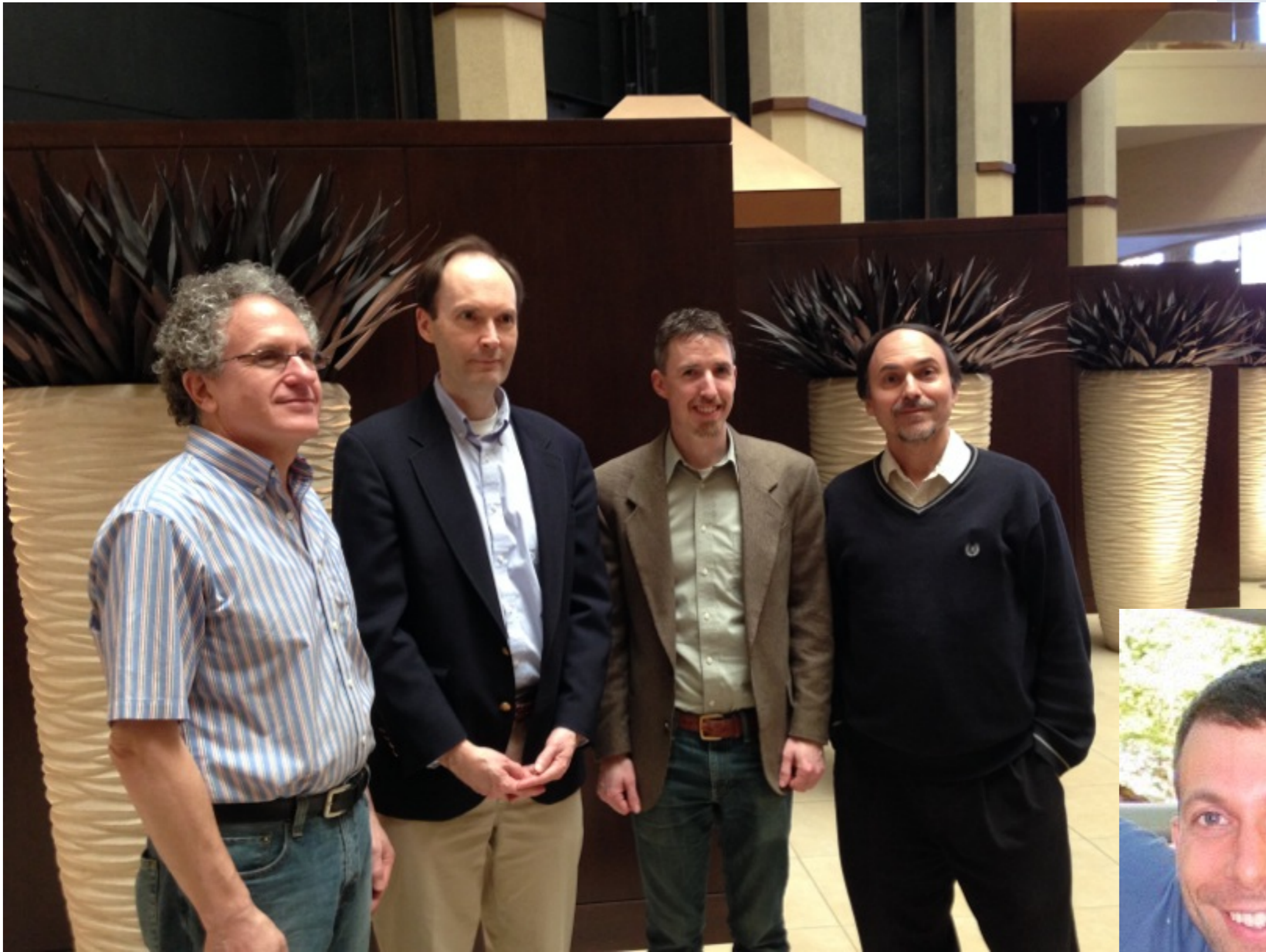
Perform well:

- Bridge
- Other poker types

~~Far off: Go~~



DUKE
COMPUTER
SCIENCE



Go



Very Recently



Fan Hui
European Go
Champion

0 - 5



AlphaGo

AlphaGo
(Google Deepmind)