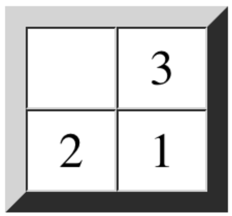
General Game Playing

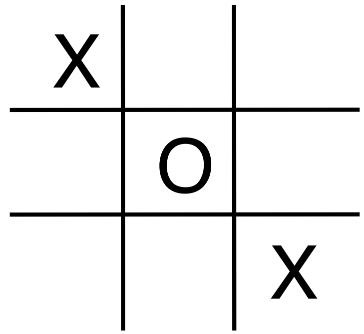
Incomplete Search

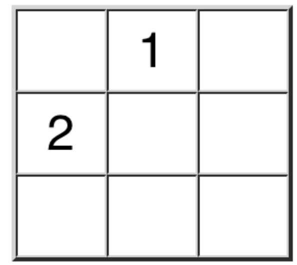
Michael Genesereth
Computer Science Department
Stanford University

Game Variety

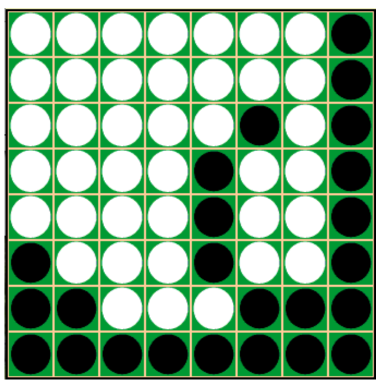
Small Games

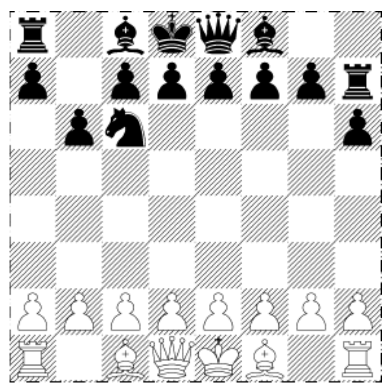


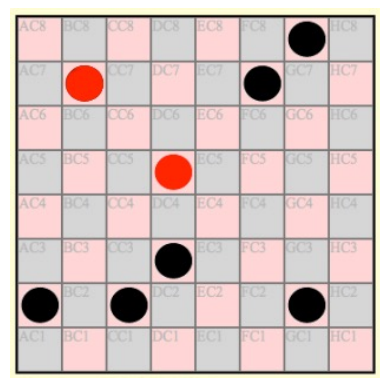




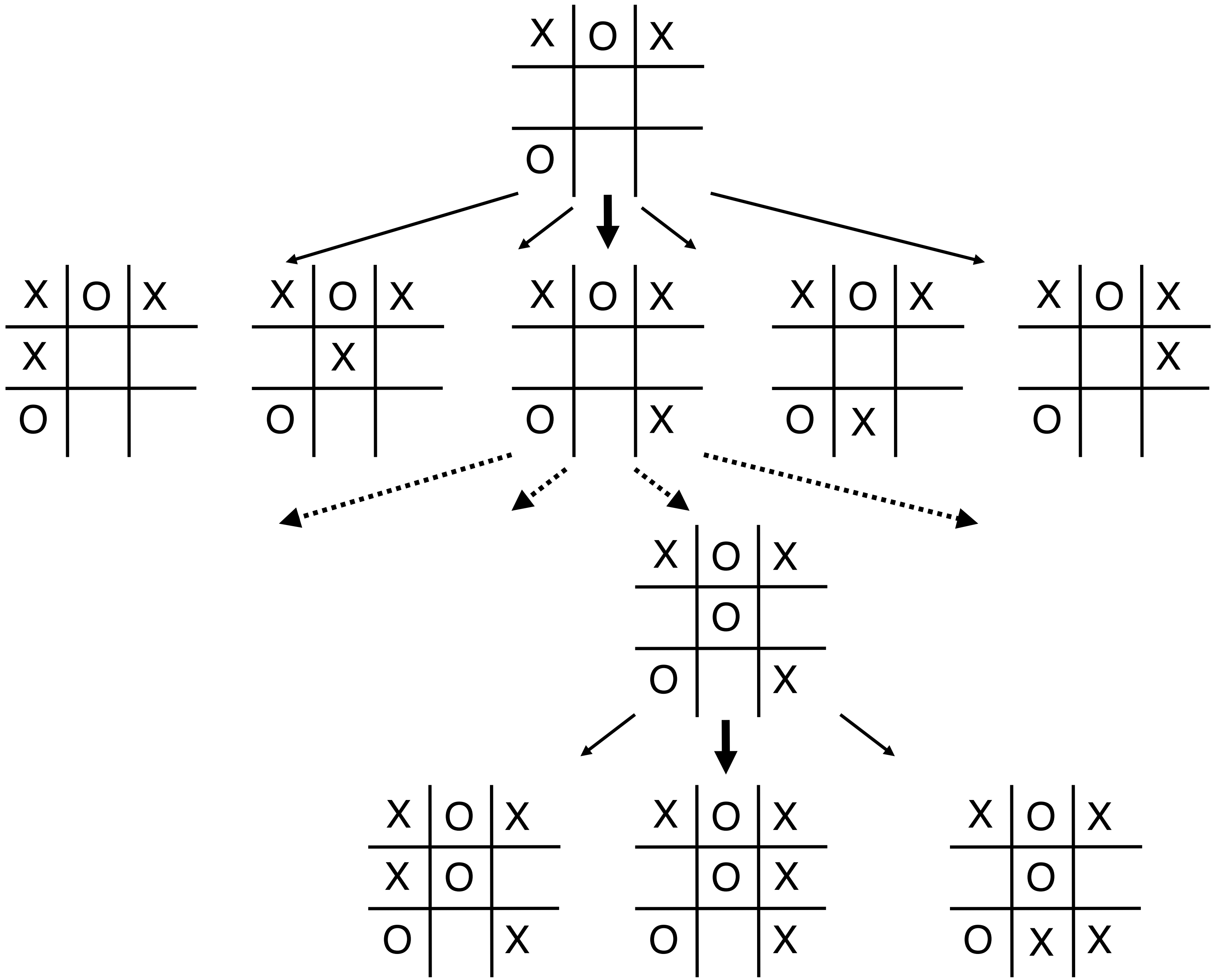
Large Games



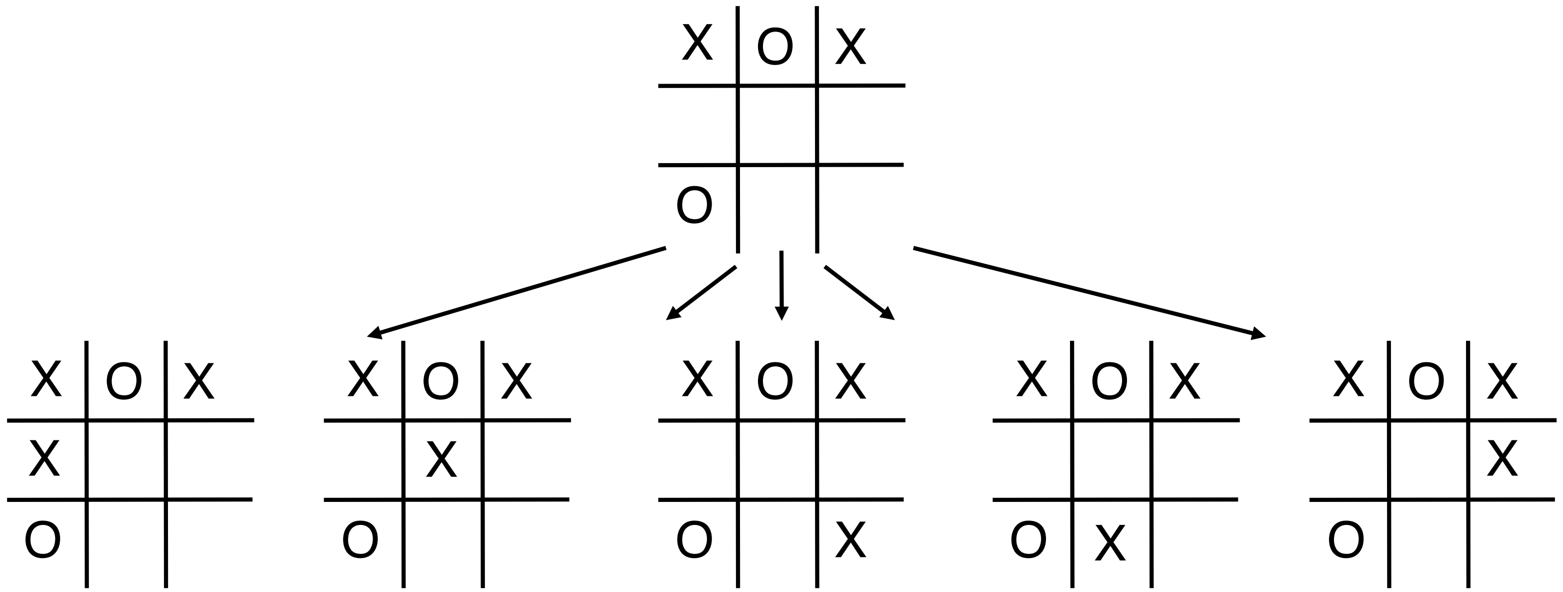




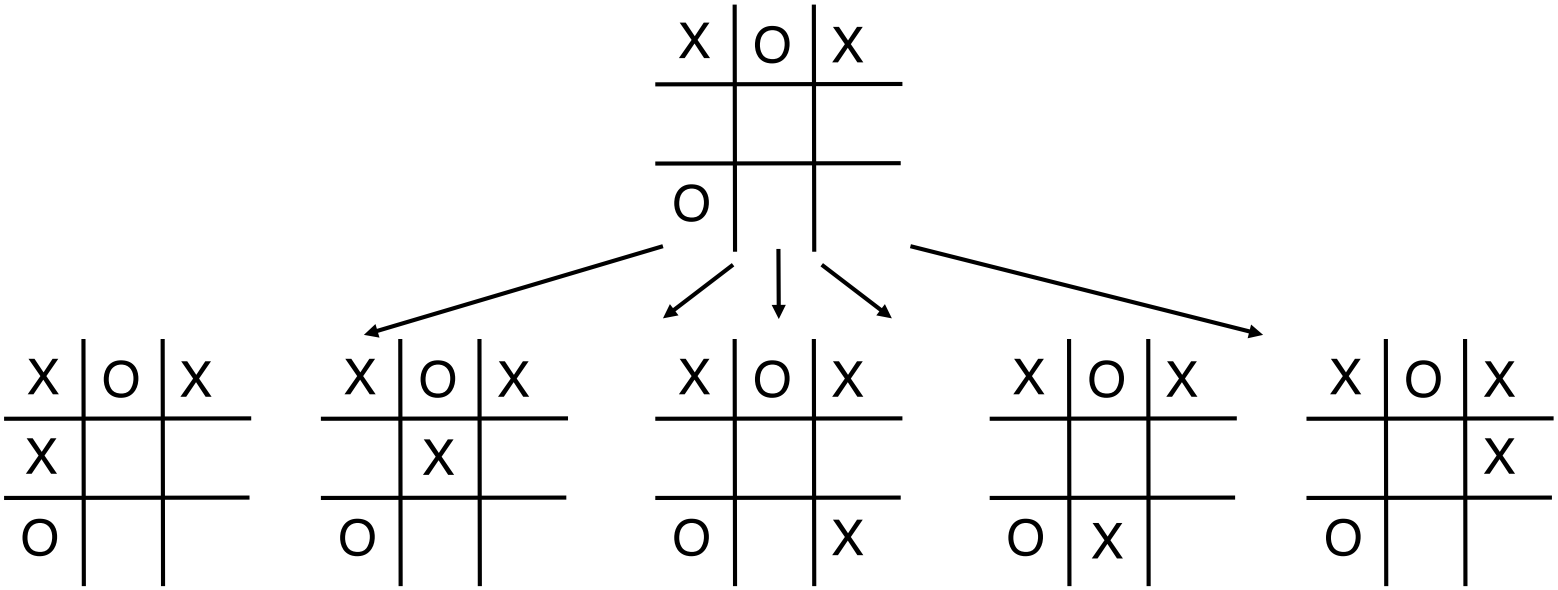
Complete Game Graph Search



Incomplete Search

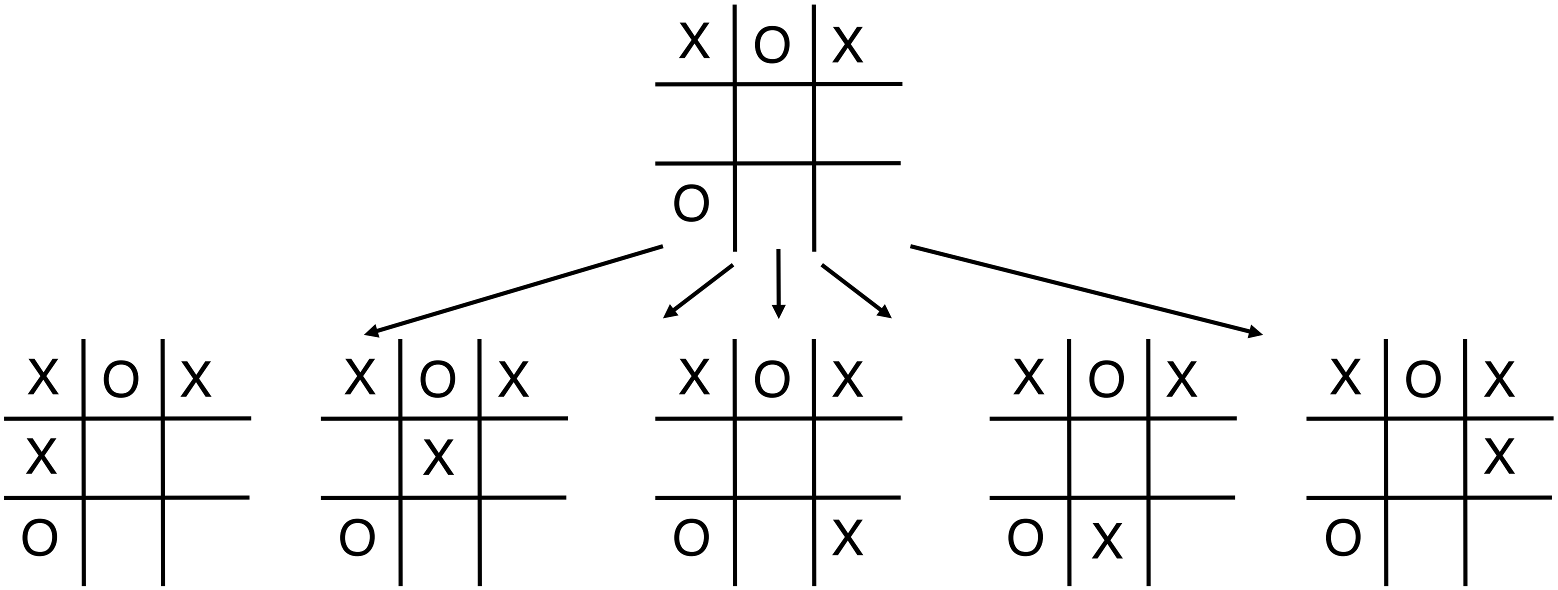


Evaluation of Non-Terminal States



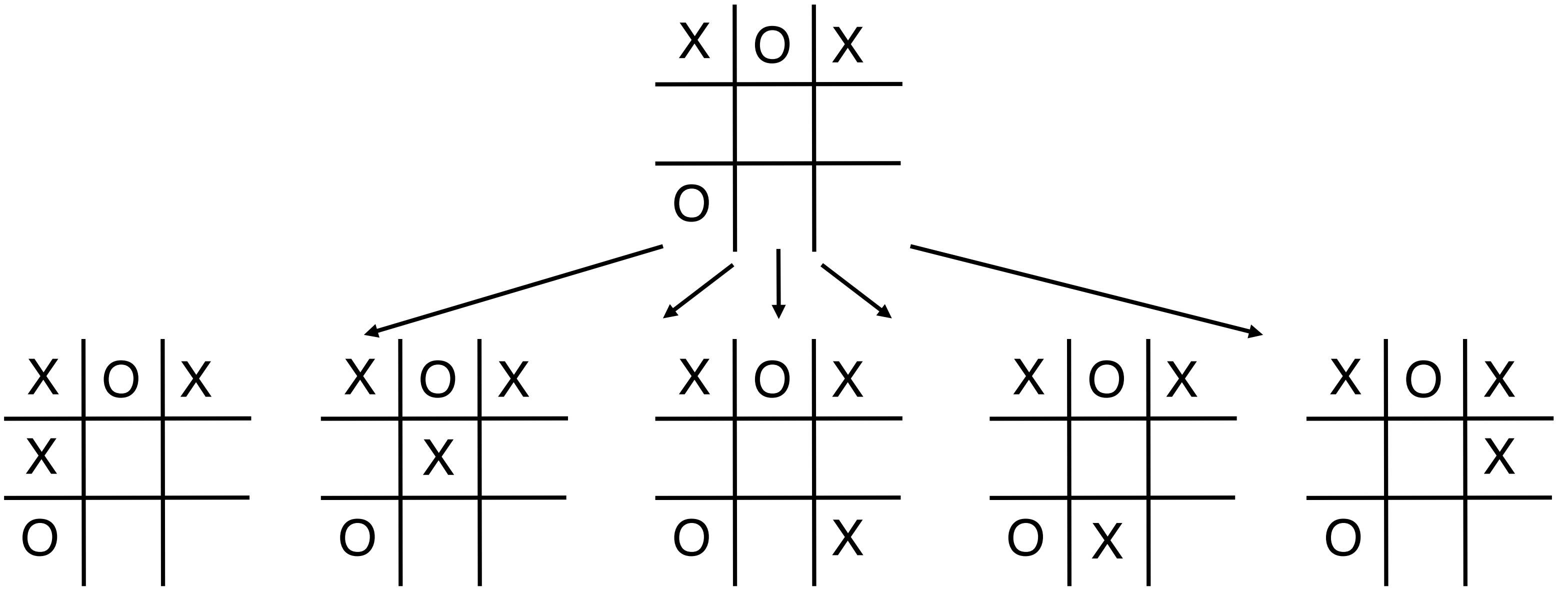
How do we evaluate non-terminal states?

Choice of Depth



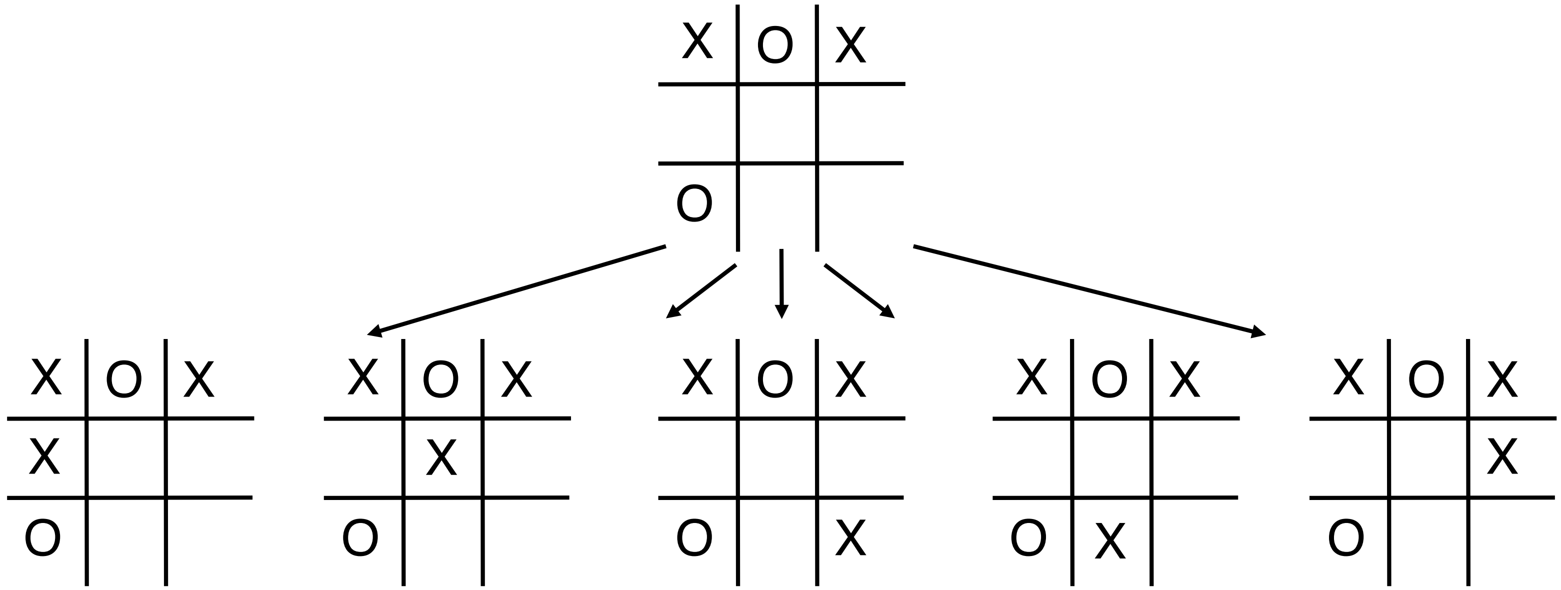
To what depth should we search?

Variable Depth Search



Should we search different branches to different depths?

Persistence



Can we preserve results across moves?

Evaluation Functions

How do we evaluate non-terminal states?

Evaluation Functions

Chess examples:

Piece count

Board control

Comments

Not *necessarily* successful

Game-specific but this is *general* game playing

Heuristic #1 - Mobility / Focus

Mobility is a measure of the number of things a player can do. *Focus* is a measure of the narrowness of the search space. It is the opposite of mobility.

Basis - number of actions in a state or number of states reachable from that state. Horizon - current state or *n* moves away.

Sometimes it is good to focus to cut down on search space. Often better to restrict opponents' moves while keeping one's own options open.

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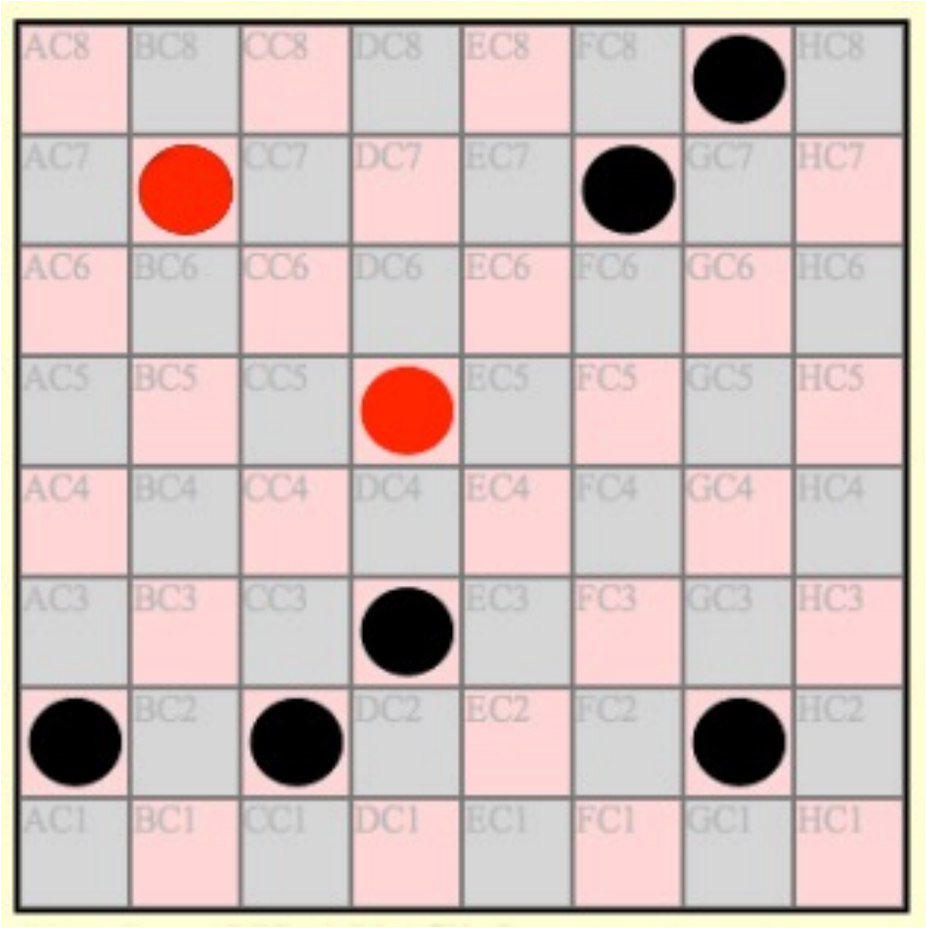
Sometimes it is good to focus to cut down on search space. Often better to restrict opponents' moves while keeping one's own options open.

Implementation

```
function mobility (state)
 {var actions = findlegals(state,library);
  var feasibles = findactions(library);
  return (actions.length/feasibles.length * 100)}

function focus (state)
 {var actions = findlegals(state,library);
  var feasibles = findactions(library);
  return (100 - actions.length/feasibles.length * 100)}
```

GGP-06 Final - Cylinder Checkers

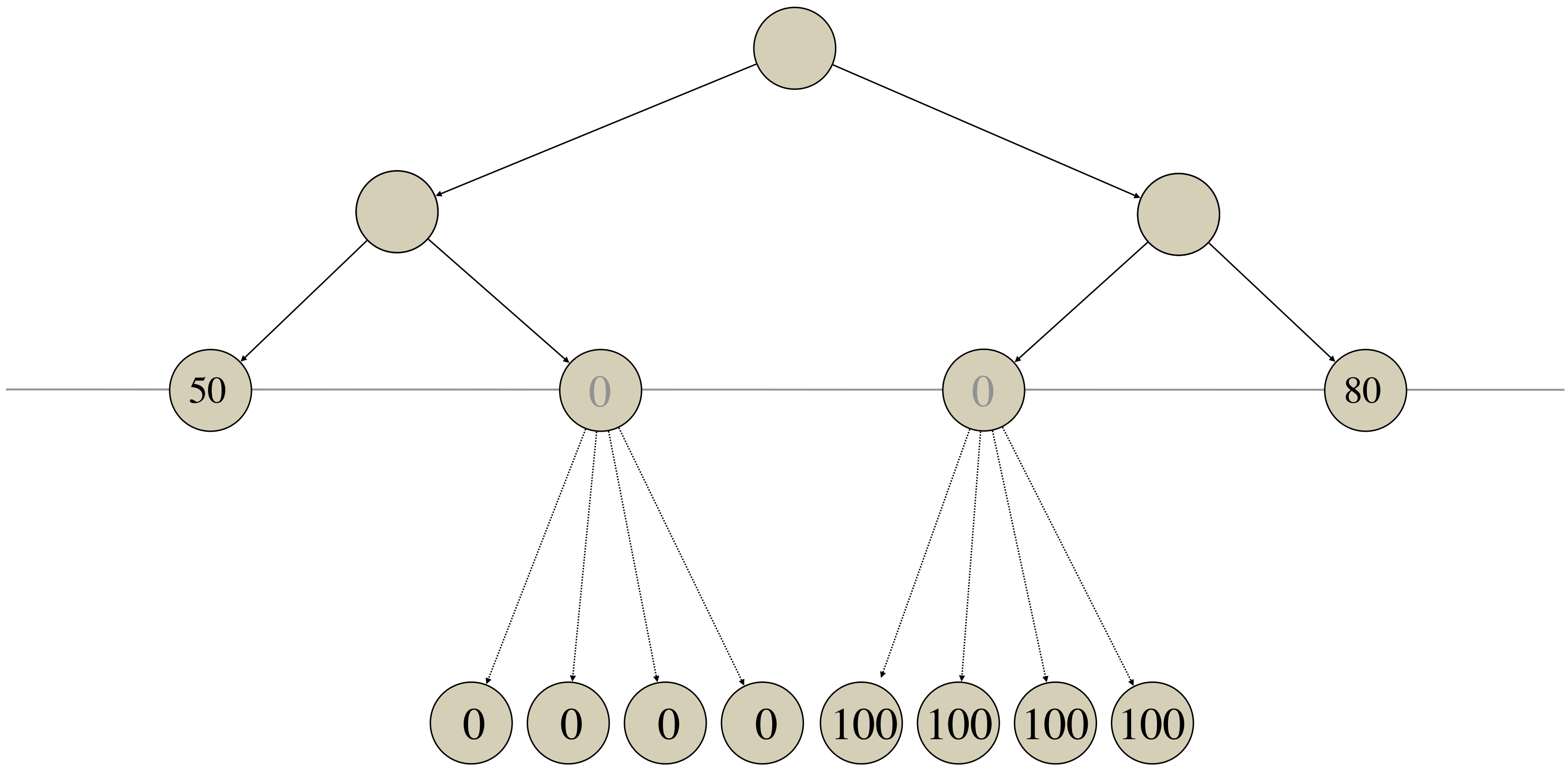


Heuristic #2 - Pessimism

Assume value of 0 for non-terminal states.

$$
\begin{array}{ll}
value(state) = goal(role, state) & \text{if } terminal(state) \\
value(state) = 0 & \text{otherwise}
\end{array}
$$

Example



Grey - estimates of rewards in non-terminal states - here 0.
Black - rewards in terminal states.

Heuristic #3 - Intermediate Values

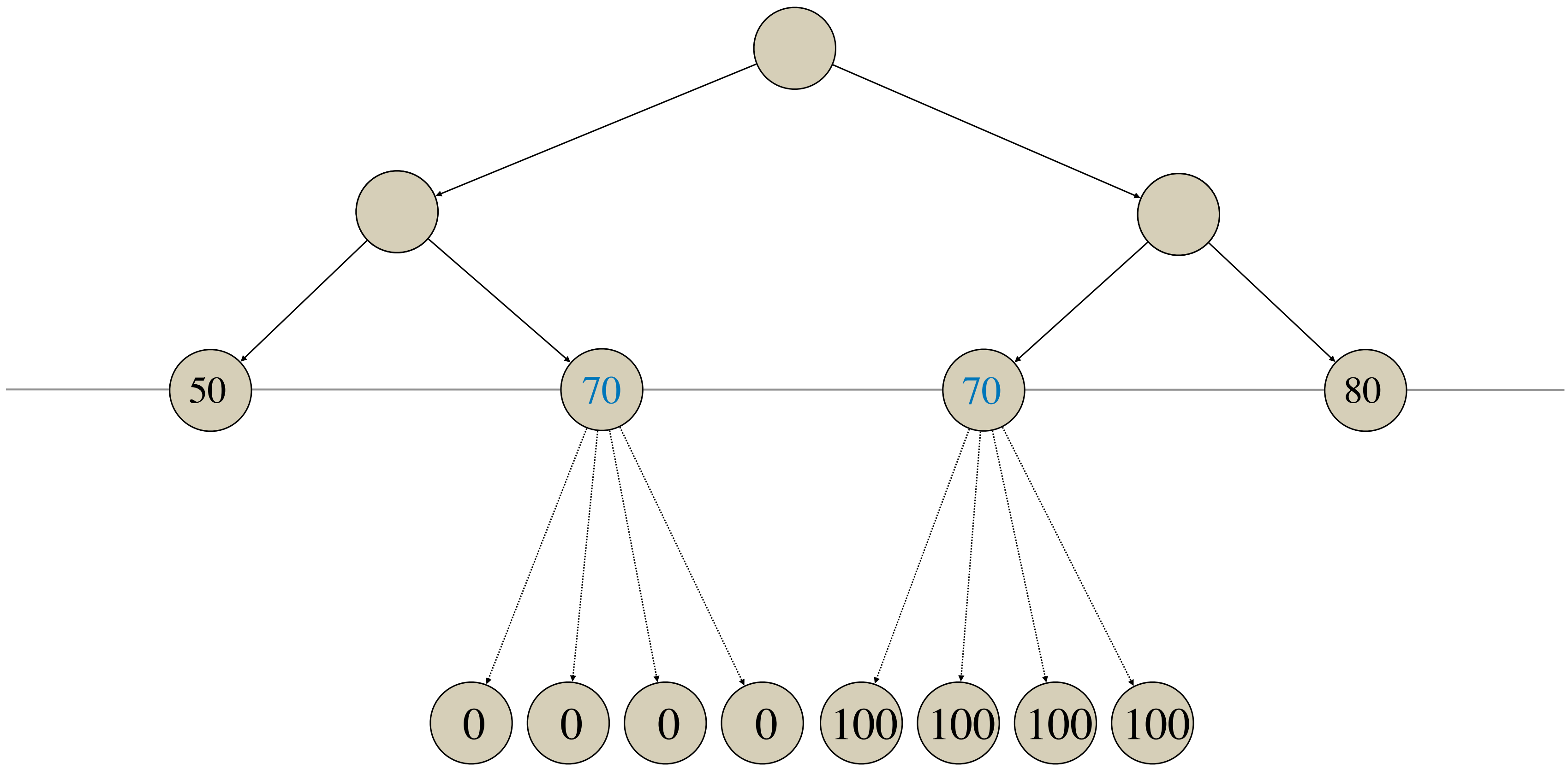
Assume reward for non-terminal states.

$$value(state) = goal(role, state)$$

Good on monotonic games (where utility accumulates as the game progresses), e.g. alquerque.

Not so good on nonmonotonic games. Susceptible to "false summits".

Example



Blue - rewards in non-terminal states.

Black - rewards in terminal states.

Weighted Linear Combinations

Definition

$$f(s) = w_1 \times f_1(s) + \ldots + w_n \times f_n(s)$$

Examples:

- Final State Value when known
- Mobility / Focus
- Intermediate State Values
- Other

Some players estimate weights by experimentation during the start clock. *More on this in a few weeks*.

Weighted Linear Combinations

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Examples:

Mobility / Focus

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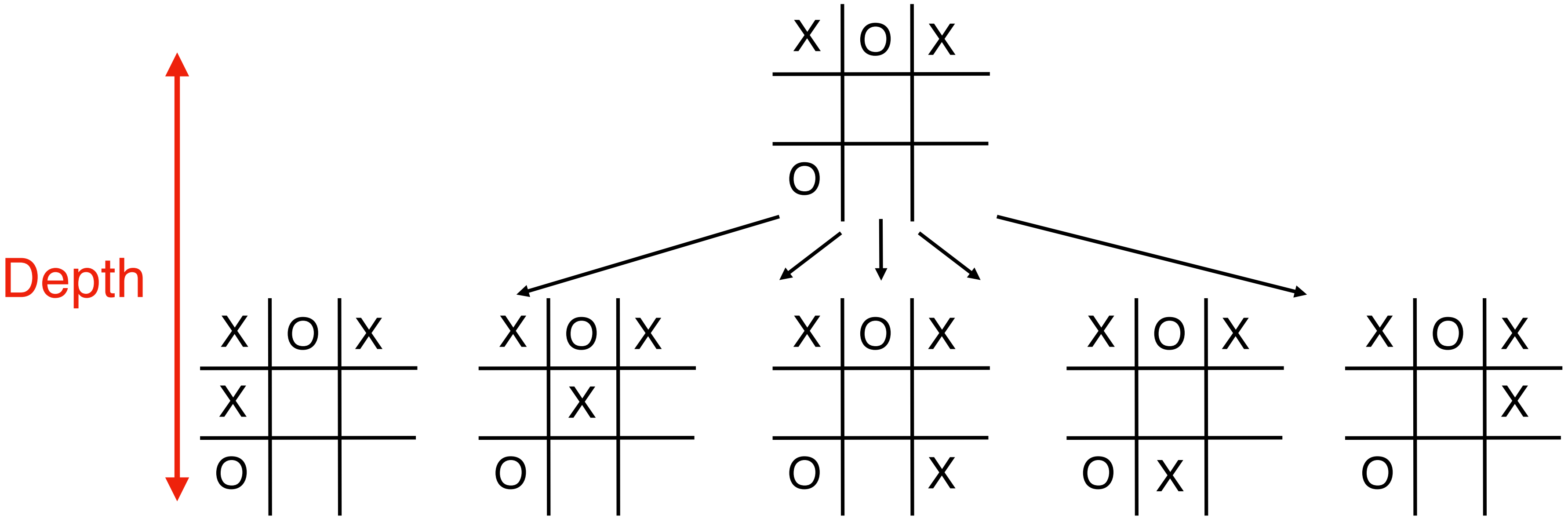
Depth-Limited Search

To what depth should we search?

Depth-Limited Search



Depth-Limited Minimax

Minimax:

```
function minimax (state)
 {if (findterminalp(state,library))
     {return findreward(role,state,library)*1};
  var active = findcontrol(state,library);
  if (active===role) {return maximize(state)};
  return minimize(state)}
```

Depth-Limited Minimax

```
function minimaxdepth (state,depth)
 {if (findterminalp(state,library))
     {return findreward(role,state,library)*1};
  if (depth<=0) {return evalfun(state,library)};
  var active = findcontrol(state,library);
  if (active===role) {return maxscore(state,depth-1)};
  return minscore(state,depth-1)}
```

maxscore and minscore

```
function maxscore (state,depth)
 {var actions = findlegals(state,library);
  if (actions.length===0) {return 0};
  var score = 0;
  for (var i=0; i<actions.length; i++)
      {var newstate = simulate(actions[i],state,library);
       var newscore = minimaxdepth(newstate,depth);
       if (newscore===100) {return 100};
       if (newscore>score) {score = newscore}};
  return score}

function minscore (state,depth)
 {var actions = findlegals(state,library);
  if (actions.length===0) {return 0};
  var score = 100;
  for (var i=0; i<actions.length; i++)
      {var newstate = simulate(actions[i],state,library);
       var newscore = minimaxdepth(role,newstate,depth);
       if (newscore===0) {return 0};
       if (newscore<score) {score = newscore}};
  return score}
```

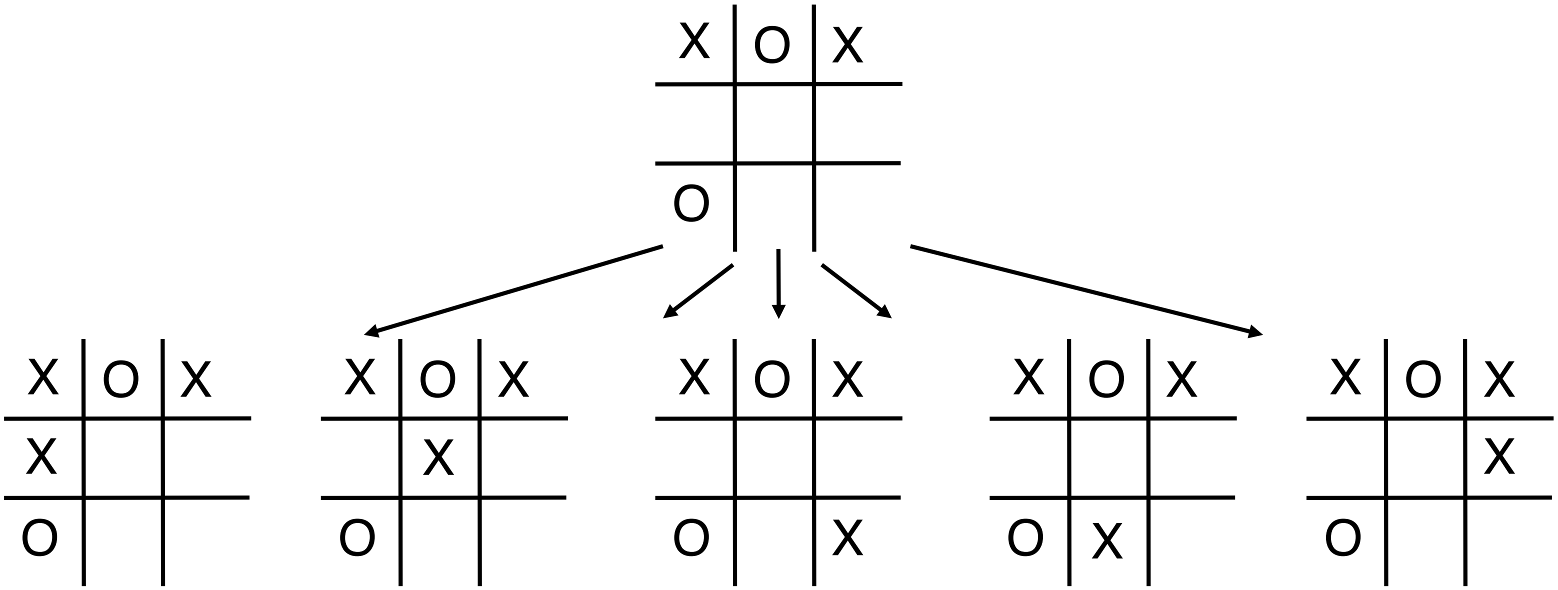
Remarks

Legal and random players are degenerate depth-limited search with depth 0.

Onestep and Twostep are degenerate depth-limited search with depths 1 and 2.

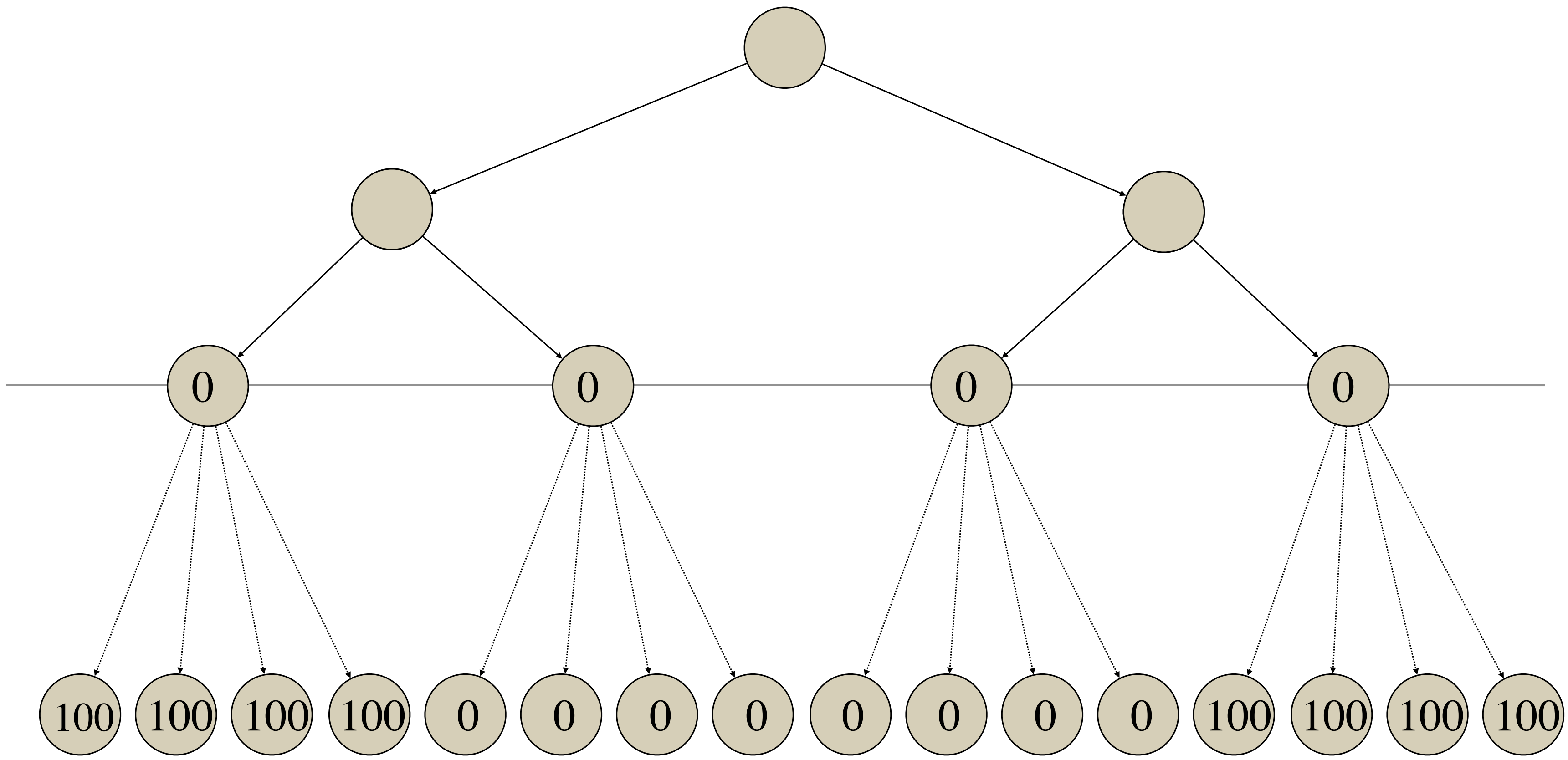
In general, we would like to allow greater depths.

Problem

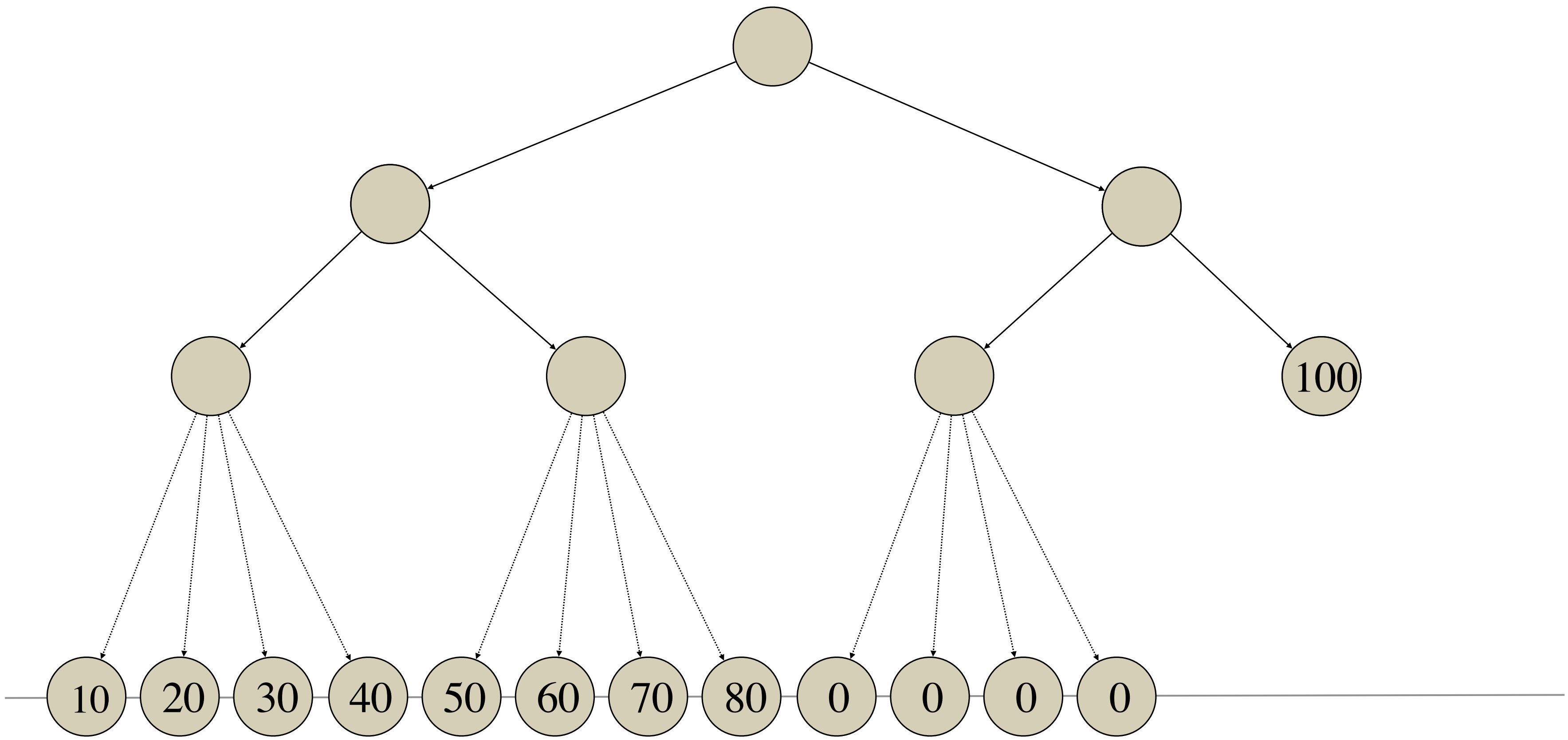


To what depth should we search?

Problem - Insufficient Depth



Problem - Excessive Depth



Iterative Deepening

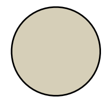
To what depth should we search?

Iterative Deepening

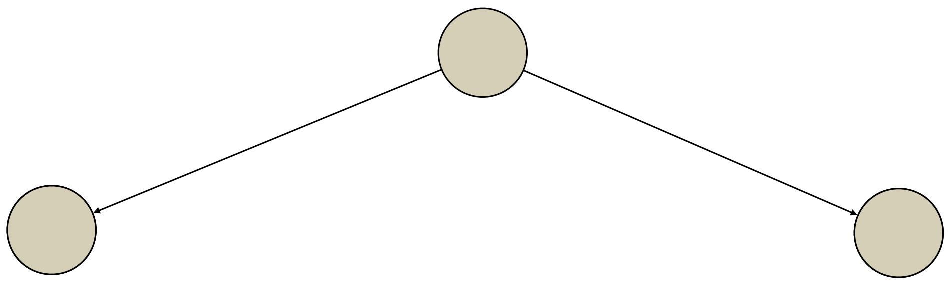
Use depth-limited search to explore entire tree to level 1
Use depth-limited search to explore entire tree to level 2
Use depth-limited search to explore entire tree to level 3
And so forth

Continue till time runs out
Choose action that gives maximal value

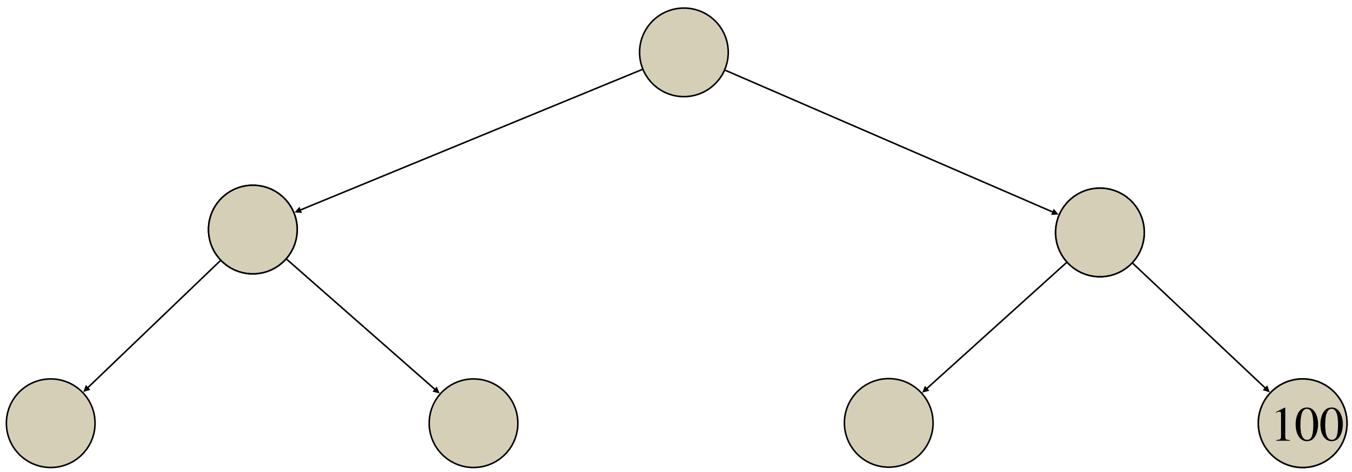
Level 1



Level 2



Level 3



Naive Implementation

```
function playminimaxid ()
 {var best = findlegalx(state,library);
  for (var depth=1; depth<10; depth++)
      {var action = minimaxdepth(state,depth);
       best = action};
  return best}
```

At what depth do we stop?

Implementation

```
function playminimaxid ()
 {var deadline = Date.now()+(playclock-1)*1000;
  var best = findlegalx(state,library);
  for (var depth=1; depth<10; depth++)
      {var action = playminimaxidinner(state,depth,deadline);
       if (action===false) {return best};
       best = action};
  return best}
```

Implementation

```
function playminimaxidinner (state,depth,deadline)
 {var actions = shuffle(findlegals(state,library));
  var best = actions[0];
  var score = 0;
  for (var i=0; i<actions.length; i++)
      {var newstate = simulate(actions[i],state,library);
       var newscore = minimaxid(newstate,depth,deadline);
       if (newscore===false) {return false};
       if (newscore===100) {return actions[i]};
       if (newscore>score) {best = actions[i]; score=newscore}};
  return best}
```

Implementation

```
function minimaxid (state,depth,deadline)
 {if (findterminalp(state,library))
     {return findreward(role,state,library)*1};
  if (depth<=0) {return evalfun(state,library)*1};
  if (Date.now()>deadline) {return false};
  if (findcontrol(state,library)===role)
     {return maxscoreid(state,depth,deadline)};
  return minscoreid(state,depth,deadline)}
```

maxscore and minscore

```
function maxscore (state,depth,deadline)
 {var actions = findlegals(state,library);
  if (actions.length===0) {return 0};
  var score = 0;
  for (var i=0; i<actions.length; i++)
      {var newstate = simulate(actions[i],state,library);
       var newscore = minimaxid(newstate,depth,deadline);
       if (newscore===false) {return false};
       if (newscore===100) {return 100};
       if (newscore>score) {score = newscore}};
  return score}

function minscore (state,depth,deadline)
 {var actions = findlegals(state,library);
  if (actions.length===0) {return 0};
  var score = 100;
  for (var i=0; i<actions.length; i++)
      {var newstate = simulate(actions[i],state,library);
       var newscore = minimaxid(newstate,depth,deadline);
       if (newscore===false) {return false};
       if (newscore===0) {return 0};
       if (newscore<score) {score = newscore}};
  return score}
```

Advantages and Disadvantages

Advantages

requires storage linear in depth

still finds shortest path to an optimal solution

Disadvantages (?)

Repeated work

but

Cost only a constant factor more than depth-first search

Why? *Tree is growing exponentially, so fringe of tree and size of tree above fringe are approximately same*

More Information

https://en.wikipedia.org/wiki/Iterative_deepening_depth-first_search

Monte Carlo Search

Basic Idea

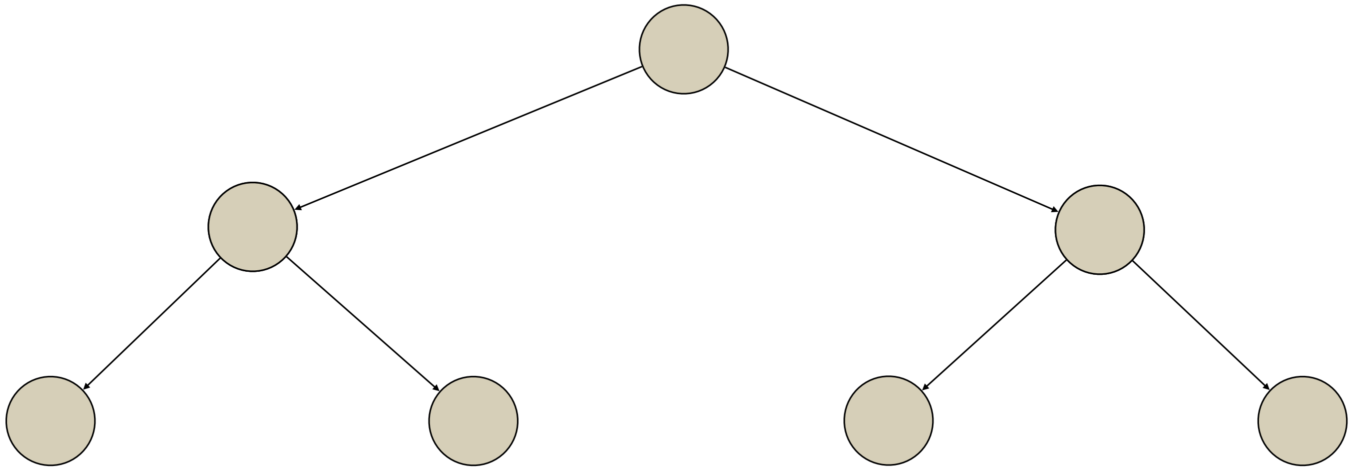
Sample a few branches of the game tree and use results to estimate values.

(1) Optionally explore game graph to some level.

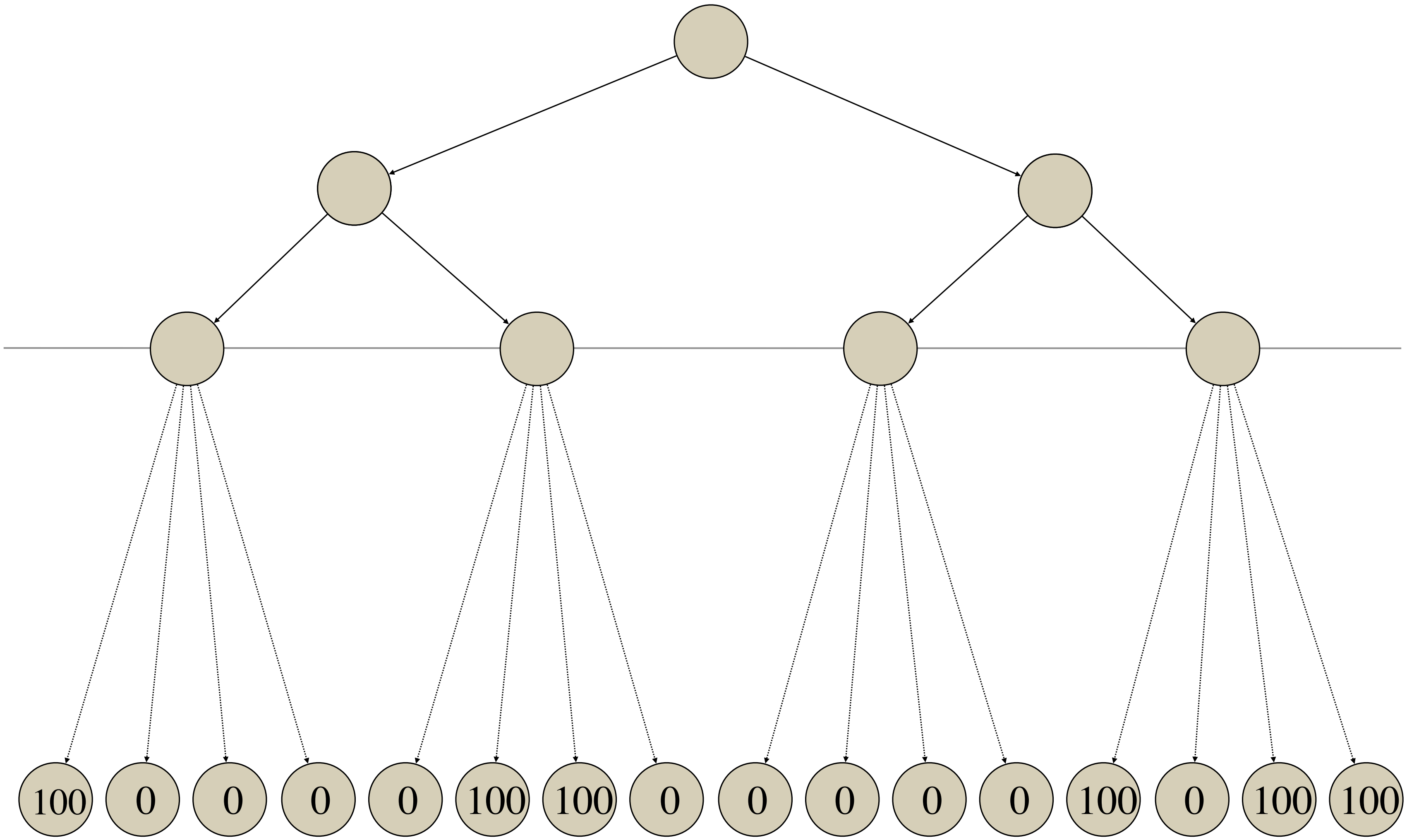
(2) Beyond this, explore to end of game from fringe nodes, making random choices for moves of all players.

(3) Assign expected utilities to fringe states by summing utilities and dividing by number of trials.

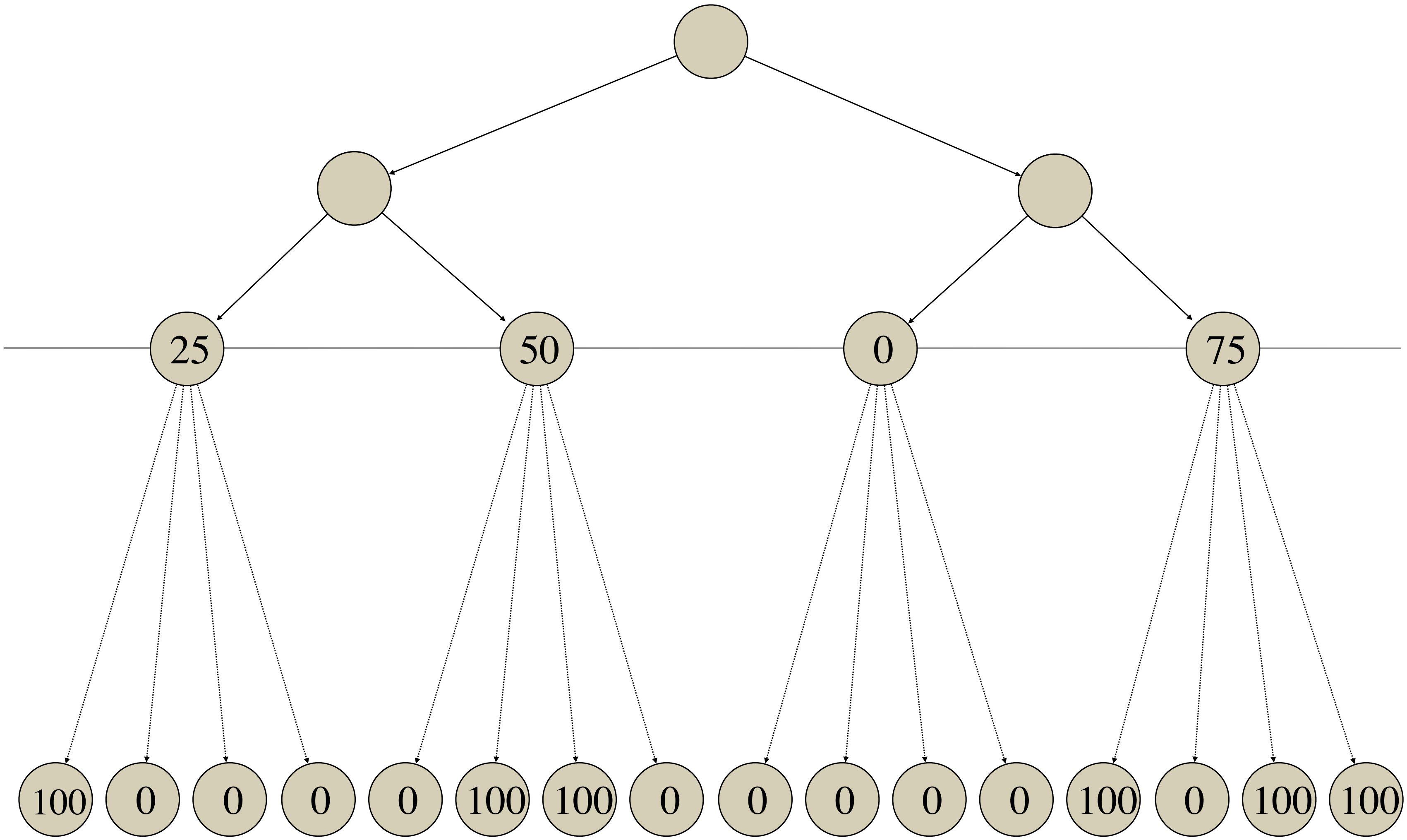
Example



Example



Example



mcs

```
function mcs (state,level)
 {if (findterminalp(state,library))
     {return findreward(role,state,library)*1};
  if (level>levels) {return montecarlo(state)};
  var active = findcontrol(state,library);
  if (active===role) {return maxscore(state,level+1)};
  return minscore(state,level+1)}
```

maxscore and minscore

```
function maxscore (state,level)
  {var actions = findlegals(state,library);
   if (actions.length===0) {return 0};
   var score = 0;
   for (var i=0; i<actions.length; i++)
       {var newstate = simulate(actions[i],state,library);
        var newscore = mcs(newstate,level);
        if (newscore===100) {return 100};
        if (newscore>score) {score = newscore}};
  return score}

function minscore (state,level)
 {var actions = findlegals(state,library);
  if (actions.length===0) {return 0};
  var score = 100;
  for (var i=0; i<actions.length; i++)
      {var newstate = simulate(actions[i],state,library);
       var newscore = mcs(role,newstate,level);
       if (newscore===0) {return 0};
       if (newscore<score) {score = newscore}};
  return score}
```

Implementation

```
function montecarlo (state)
 {var total = 0;
  for (var i=0; i<count; i++)
      {total = total + depthcharge(state)};
  return total/count}

function depthcharge (state)
 {if (findterminalp(state,ruleset))
     {return findreward(role,state,ruleset)}*1;
  var actions = findlegals(state,library);
  if (actions.length===0) {return 0};
  var best = randomindex(actions.length);
  var newstate = simulate(actions[best],state,library);
  return depthcharge(newstate)}
```

Problems and Features

Problems

- Optimistic - opponent might not respect probabilities
- Does not utilize game structure in any useful way

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Problems

- Optimistic - opponent might not respect probabilities
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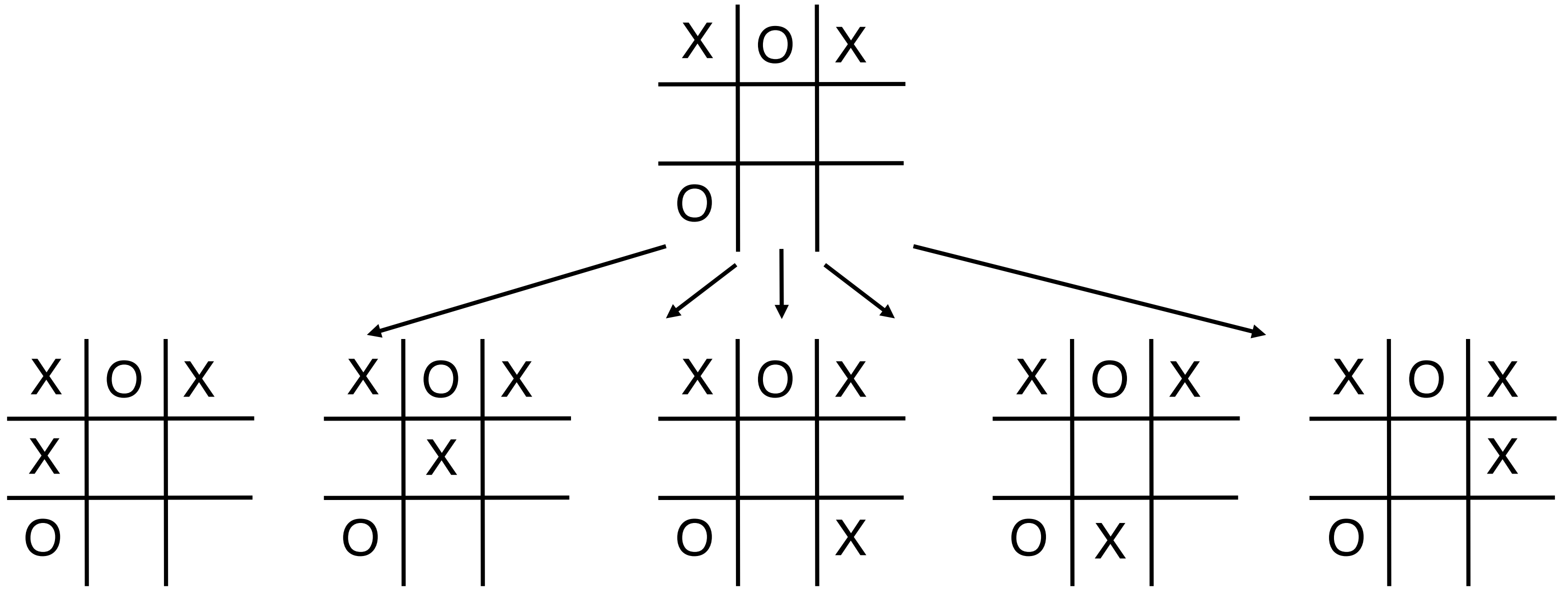
Benefits

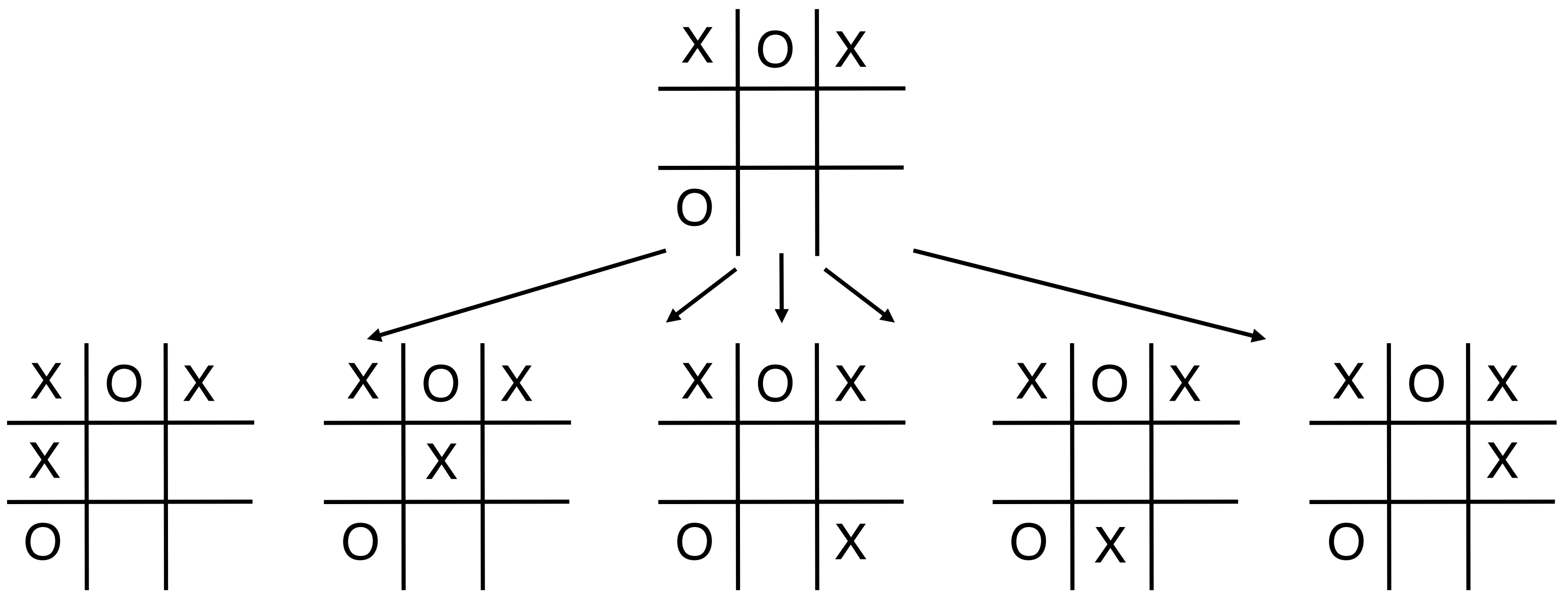
- Fast because no branching in depth charges
- Small space because nothing stored in probes
- Provides guidance when other heuristics fail

Issues

Incomplete Search

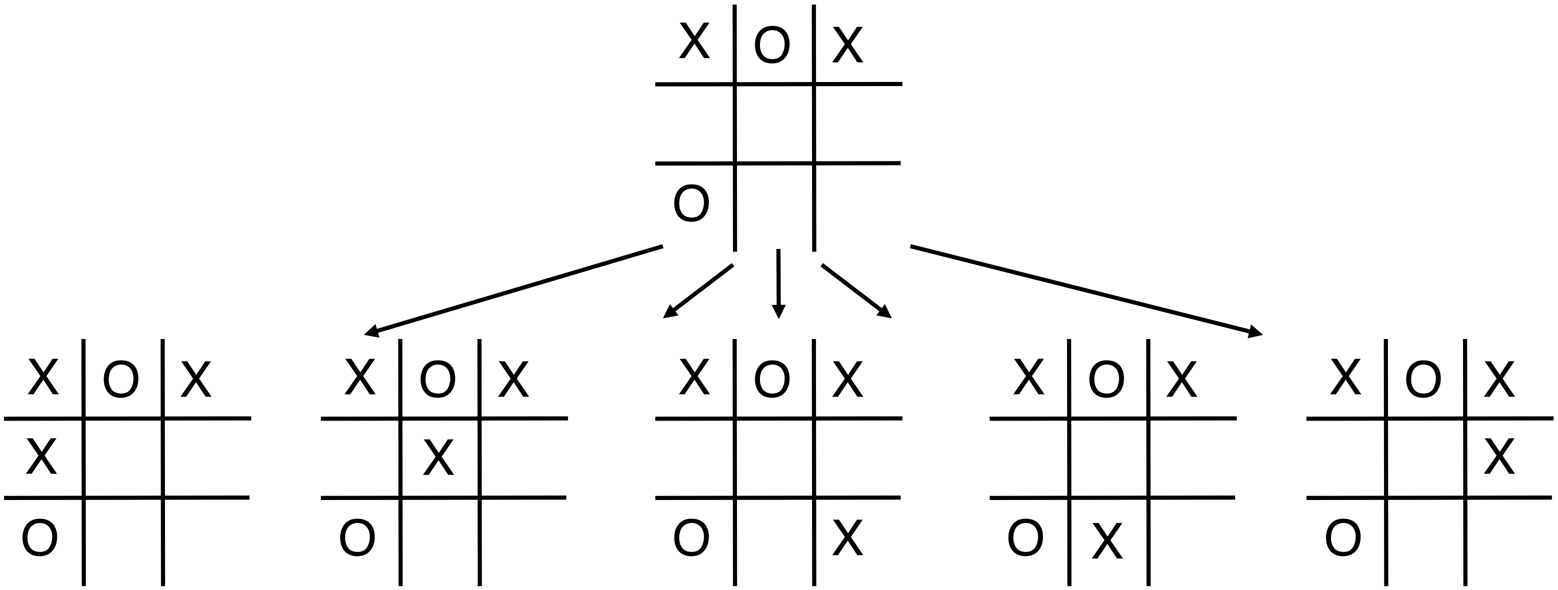


Evaluation of Non-Terminal States



How do we evaluate non-terminal states?

Choice of Depth



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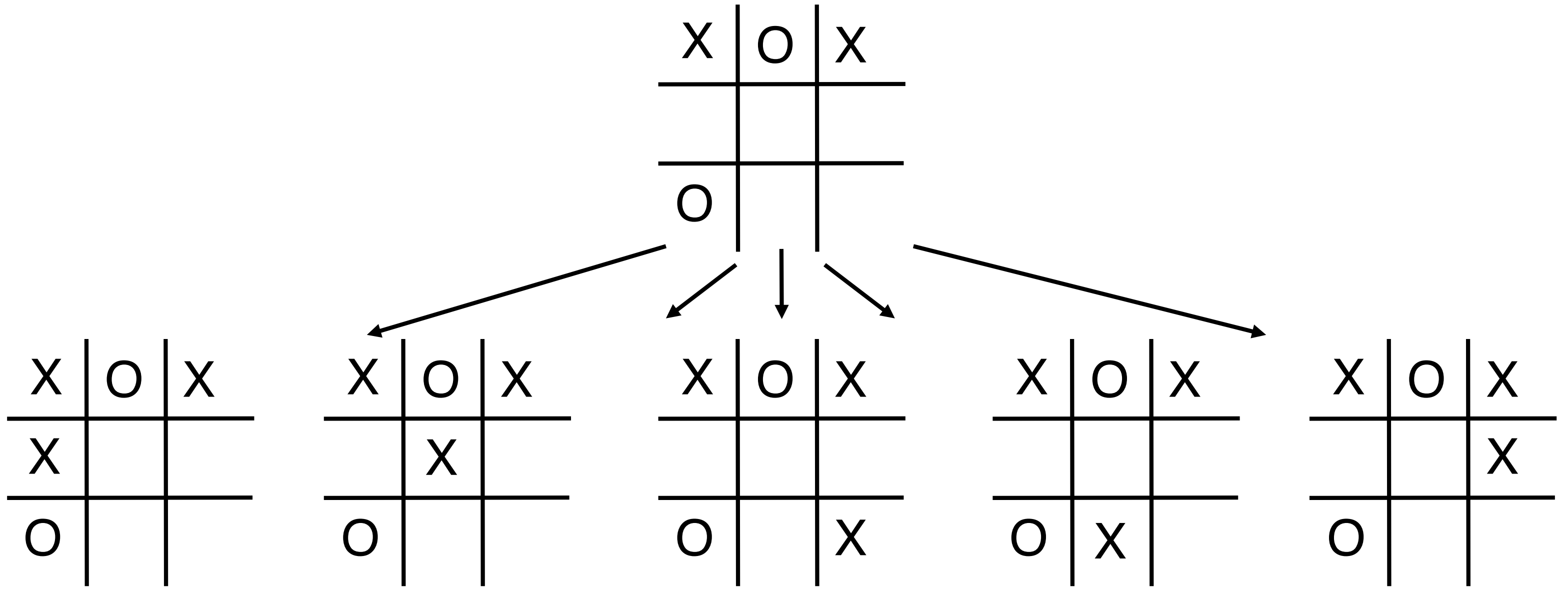
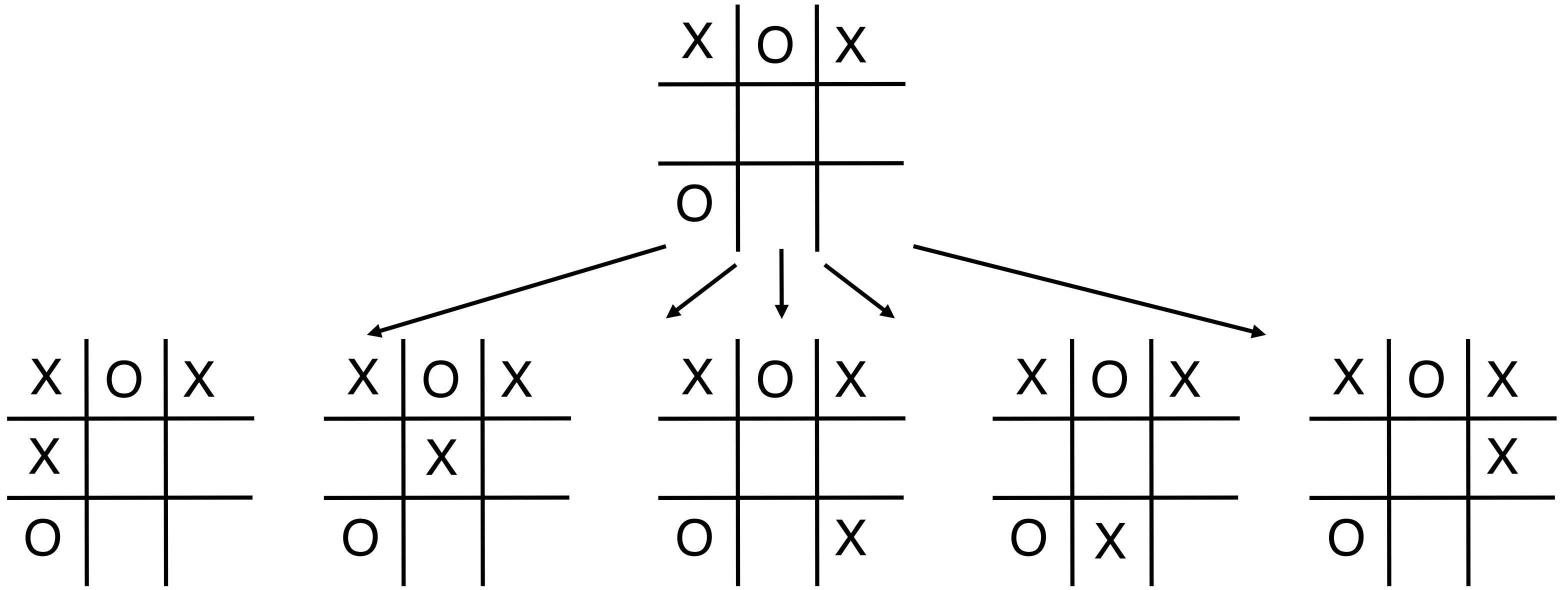
Variable Depth Search



Can we search different branches to different depths?

Persistence



Can we preserve tree across moves or phases of ID?


GENERAL
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PLAYING


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