Game Playing

Chapter 4

Outline

- Overview
- Minimax search
- Adding alpha-beta cutoffs
- Additional refinements

Overview

Old beliefs

Games provided a structured task in which it was very easy to measure success or failure.

Games did not obviously require large amounts of knowledge, thought to be solvable by straightforward search.

Overview

Chess

The average branching factor is around 35.

In an average game, each player might make 50 moves.

One would have to examine 35^{100} positions.

Overview

- Improve the generate procedure so that only good moves are generated.
- Improve the test procedure so that the best moves will be recognized and explored first.

Overview

- Improve the generate procedure so that only good moves are generated.

  plausible-moves vs. legal-moves

- Improve the test procedure so that the best moves will be recognized and explored first.

  less moves to be evaluated

Overview

- It is not usually possible to search until a goal state is found.
- It has to evaluate individual board positions by estimating how likely they are to lead to a win.

  Static evaluation function

- Credit assignment problem (Minsky, 1963).

Overview

- Good plausible-move generator.
- Good static evaluation function.

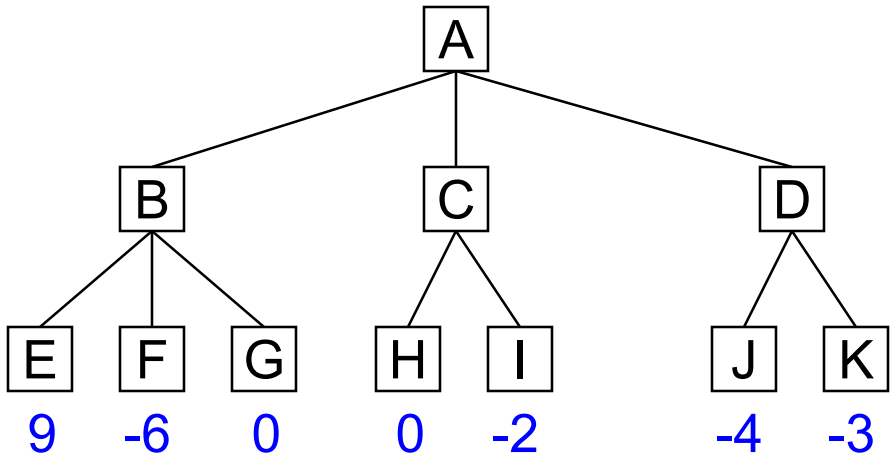
Overview

- What search strategy should we use then?
  - One-person game
  - Two-person game

Minimax Search

- Depth-first and depth-limited search.
- At the player choice, maximize the static evaluation of the next position.
- At the opponent choice, minimize the static evaluation of the next position.

Minimax Search

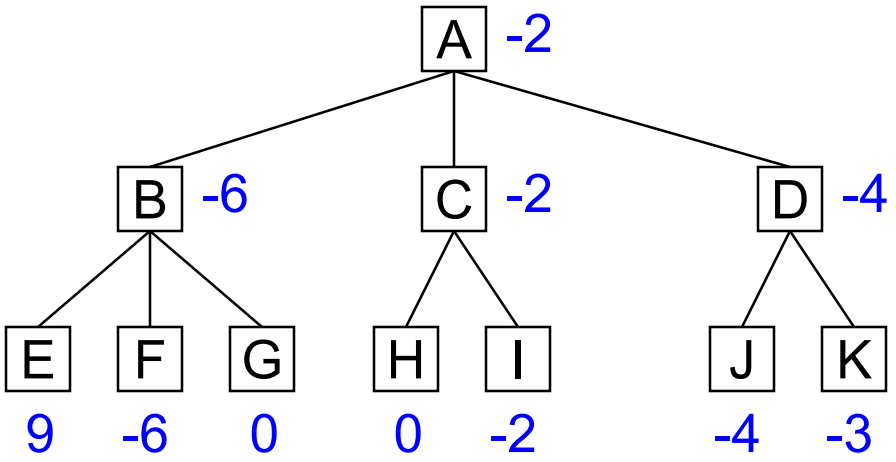


Maximizing ply
Player

Minimizing ply
Opponent

Two-ply search

Minimax Search



Maximizing ply
Player

Minimizing ply
Opponent

Two-ply search

Minimax Search

```
Player(Position, Depth):
for each S ∈ SUCCESSORS(Position) do
        RESULT = Opponent(S, Depth + 1)
        NEW-VALUE = VALUE(RESULT)
        if NEW-VALUE > MAX-SCORE, then
                MAX-SCORE = NEW-VALUE
                BEST-PATH = PATH(RESULT) + S
return
        VALUE = MAX-SCORE
        PATH = BEST-PATH
```

Minimax Search

```
Opponent(Position, Depth):
for each S ∈ SUCCESSORS(Position) do
        RESULT = Player(S, Depth + 1)
        NEW-VALUE = VALUE(RESULT)
        if NEW-VALUE < MIN-SCORE, then
                MIN-SCORE = NEW-VALUE
                BEST-PATH = PATH(RESULT) + S
return
        VALUE = MIN-SCORE
        PATH = BEST-PATH
```

Minimax Search

```
Any-Player(Position, Depth):

for each S ∈ SUCCESSORS(Position) do
        RESULT = Any-Player(S, Depth + 1)
        NEW-VALUE = – VALUE(RESULT)
        if NEW-VALUE > BEST-SCORE, then
                BEST-SCORE = NEW-VALUE
                BEST-PATH = PATH(RESULT) + S
return
        VALUE = BEST-SCORE
        PATH = BEST-PATH
```

Minimax Search

MINIMAX(Position, Depth, Player):

- MOVE-GEN(Position, Player).
- STATIC(Position, Player).
- DEEP-ENOUGH(Position, Depth)

Minimax Search

1. if DEEP-ENOUGH(Position, Depth), then return:

   VALUE = STATIC(Position, Player)
   PATH = nil

2. SUCCESSORS = MOVE-GEN(Position, Player)

3. if SUCCESSORS is empty, then do as in Step 1

Minimax Search

4. if SUCCESSORS is not empty:

   RESULT-SUCC = MINIMAX(SUCC, Depth+1, Opp(Player))

   NEW-VALUE = – VALUE(RESULT-SUCC)

   if NEW-VALUE > BEST-SCORE, then:

      BEST-SCORE = NEW-VALUE

      BEST-PATH = PATH(RESULT-SUCC) + SUCC

5. Return:

   VALUE = BEST-SCORE

   PATH = BEST-PATH

Adding Alpha-Beta Cutoffs

- Depth-first and depth-limited search.

  branch-and-bound

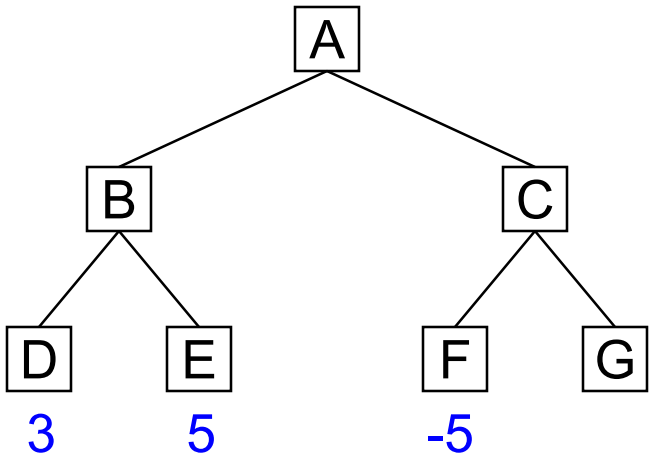
- At the player choice, maximize the static evaluation of the next position.

  > α threshold

- At the opponent choice, minimize the static evaluation of the next position.

  < β threshold

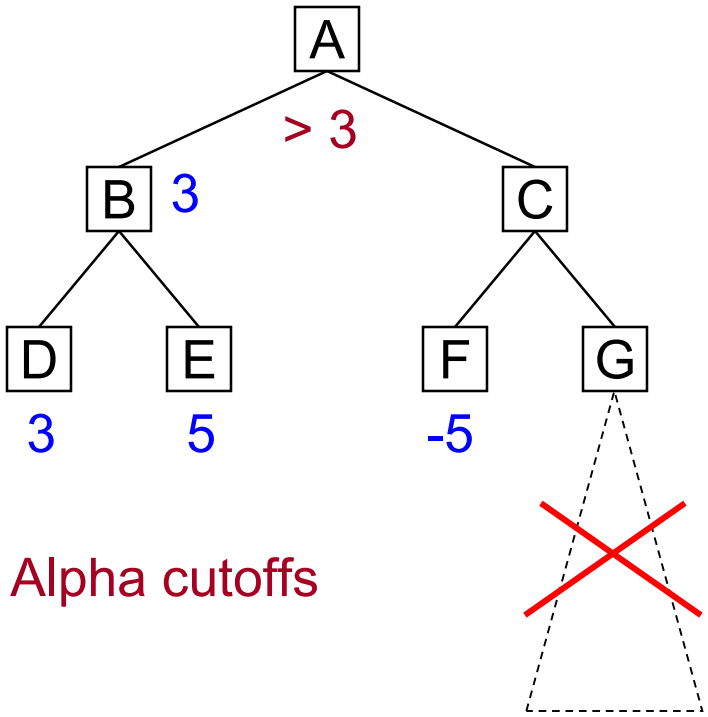
Adding Alpha-Beta Cutoffs



Maximizing ply
Player

Minimizing ply
Opponent

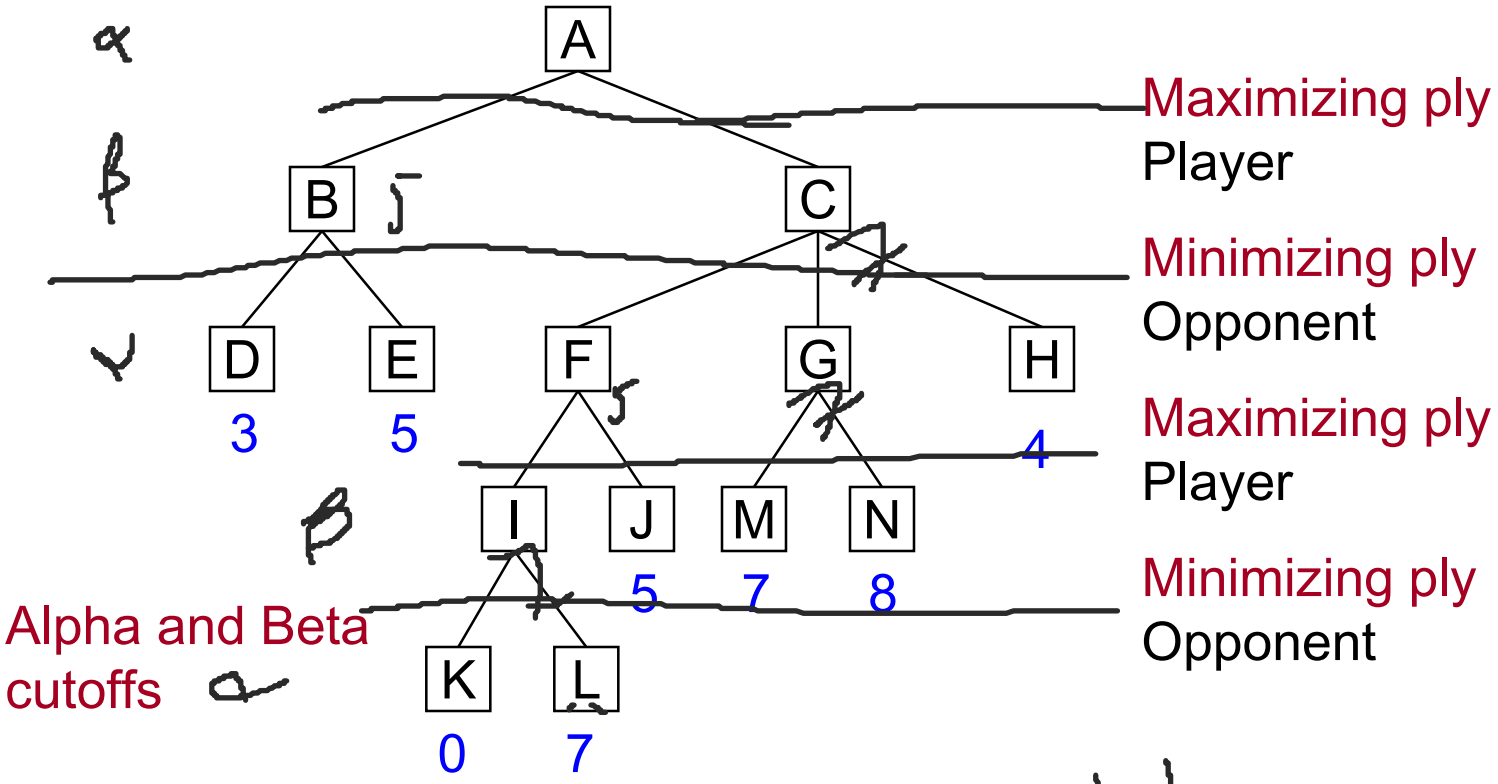
Adding Alpha-Beta Cutoffs



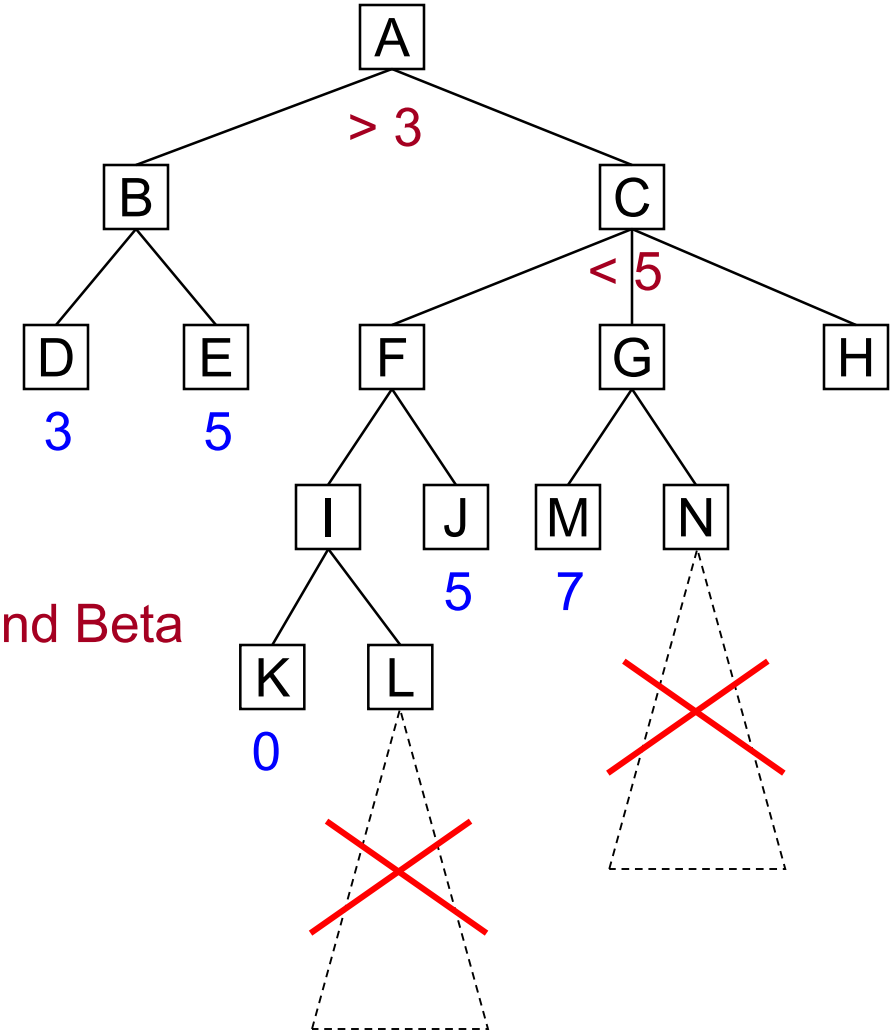
Maximizing ply
Player

Minimizing ply
Opponent

Adding Alpha-Beta Cutoffs



Adding Alpha-Beta Cutoffs



Alpha and Beta cutoffs

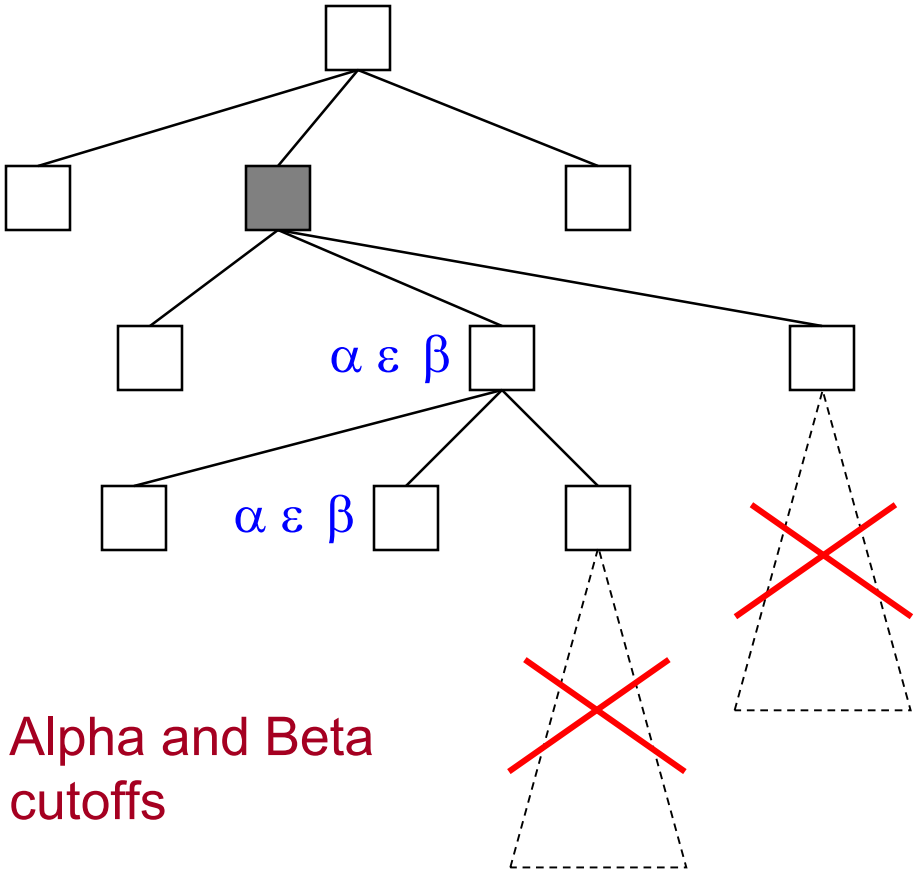
Maximizing ply
Player

Minimizing ply
Opponent

Maximizing ply
Player

Minimizing ply
Opponent

Adding Alpha-Beta Cutoffs



Opponent

β

Player

α

Opponent

Player

Alpha and Beta cutoffs

```
Player(Position, Depth, α, β):
for each S ∈ SUCCESSORS(Position) do
        RESULT = Opponent(S, Depth + 1, α, β)
        NEW-VALUE = VALUE(RESULT)
        if NEW-VALUE > α, then
                α = NEW-VALUE
                BEST-PATH = PATH(RESULT) + S
        if α ≥ β then return
                VALUE = α
                PATH = BEST-PATH
return
        VALUE = α
        PATH = BEST-PATH
```

Opponent(Position, Depth, α, β):

for each S $\in$ SUCCESSORS(Position) do

RESULT = Player(S, Depth + 1, α, β)

NEW-VALUE = VALUE(RESULT)

if NEW-VALUE $<$ β, then

β = NEW-VALUE

BEST-PATH = PATH(RESULT) + S

if $\beta \leq \alpha$ then return

VALUE = β

PATH = BEST-PATH

return

VALUE = β

PATH = BEST-PATH

```
Any-Player(Position, Depth, α, β):
for each S ∈ SUCCESSORS(Position) do
        RESULT = Any-Player(S, Depth + 1, –β, –α)
        NEW-VALUE = – VALUE(RESULT)
        if NEW-VALUE > α, then
                α = NEW-VALUE
                BEST-PATH = PATH(RESULT) + S
        if α ≥ β then return
                VALUE = α
                PATH = BEST-PATH
return
        VALUE = α
        PATH = BEST-PATH
```

Adding Alpha-Beta Cutoffs

MINIMAX-A-B(Position, Depth, Player, UseTd, PassTd):

- UseTd: checked for cutoffs.
- PassTd: current best value

Adding Alpha-Beta Cutoffs

1. if DEEP-ENOUGH(Position, Depth), then return:

   VALUE = STATIC(Position, Player)
   PATH = nil

2. SUCCESSORS = MOVE-GEN(Position, Player)

3. if SUCCESSORS is empty, then do as in Step 1

Adding Alpha-Beta Cutoffs

4. if SUCCESSORS is not empty:

   RESULT-SUCC = MINIMAX-A-B(SUCC, Depth + 1,
   Opp(Player), – PassTd, – UseTd)

   NEW-VALUE = – VALUE(RESULT-SUCC)

   if NEW-VALUE > PassTd, then:

   PassTd = NEW-VALUE

   BEST-PATH = PATH(RESULT-SUCC) + SUCC

   if PassTd ≥ UseTd, then return:

   VALUE = PassTd

   PATH = BEST-PATH

5. Return:

   VALUE = PassTd

   PATH = BEST-PATH

Additional Refinements

- Futility cutoffs
- Waiting for quiescence
- Secondary search
- Using book moves
- Not assuming opponent's optimal move

Homework

Exercises 1-7, 9 (Chapter 12)