[[1]](#footnote-1)

AI Algorithms in hexagonal chess

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***Abstract - This report is respresent the statistic of AI algorithms using to play hexagonal chess game.This problem contains a lot of challenges, such as no available product/open source public on the internet, no suitable chess egine, different set of rules,.. Base on the complexity of search algorithms, we would implement basic algorithms such as minimax, environment, client app .***

# INTRODUCTION and Task Settings

T

he most important of an AI algorithms is how to make decison smart. And one of key factors is evaluation function. In this paper, we will implement 3 evaluation functions to combine with 2 search algorithms to compare speed and peformance. To do statistic and scaling up, python 3 is appropriate choice.

Because of no ancestor of this kind of chess - hexagonal chess - environment of chess is a problem. We decide to build an environment of hexagonal chess on python 3.

**1. Game introduction.**

Hexagonal chess refers to a group of chess variants played on boards composed of hexagon cells. The best known is Gliński's variant, played on a symmetric 70-cell hexagonal board.

Since each hexagonal cell not on a board edge has six neighbor cells, there is increased mobility for pieces compared to a standard orthogonal chessboard. Three colours are typically used so that no two neighboring cells are the same colour, and a colour-restricted game piece such as the orthodox chess bishop usually comes in sets of three per player in order to maintain the game's balance.

Many different shapes and sizes of hexagon-based boards are used by variants. The nature of the game is also affected by the 30° orientation of the board's cells; the board can be horizontally (Wellisch's, de Vasa's, Brusky's) or vertically (Gliński's, Shafran's, McCooey's) oriented. (E.g., when the sides of hexagonal cells face the players, pawns typically have one straightforward move direction. If a variant's gameboard has cell vertices facing the players, pawns typically have two oblique-forward move directions.) The six-sidedness of the symmetric hexagon gameboard has also resulted in a number of three-player variants.

The first applications of chess on hexagonal boards probably occurred mid-19th century, but two early examples did not include checkmate as the winning objective. More chess-like games for hexagon-based boards started appearing regularly at the beginning of the 20th century. Hexagon-celled gameboards have grown in use for strategy games generally; for example, they are popularly used in modern wargaming.

In this report, we using minimalist version of glinski chess which has synmetric 70-cell hexagonal chess board. In terms of board pieces, we using 7 pawns, 2 knights, rooks, 3 bishop, 1 queen and 1 king for each team.

Initial chess board:

A picture containing object, honeycomb, standing, tiled

Description automatically generated

Different rules:

*No castling moves*

*No promotion for pawns*

Move of chess pieces:

PAWN: Knight

A picture containing honeycomb

Description automatically generated

A picture containing object, honeycomb, tiled, tile

Description automatically generated

*Reversed for black pawn*

KNIGHT:

A picture containing honeycomb

Description automatically generatedBISHOP: ROOK:

A picture containing object, honeycomb, standing

Description automatically generated

A picture containing honeycomb, tiled, tile, display

Description automatically generatedQUEEN: KING:

A close up of a logo

Description automatically generated

**2.Environment and Client UI/UX**

To start with environment, we created classes which refer to kinds of chess, such as Pawn, Bishop,Knight,... Each class contains valid position on chessboard, team, value, and it can generate moves itself. Moreover, an chessboard contains valid position of chess pieces. Through chess board, we can generate all posible legal moves of each team. In order to support look-ahead chessboard, we allow creating new chessboard by list of legal position of each chess pieces.

By using chessboard environment, users can generate next legal moves, create new chessboard by using list of pieces' position.

Godot Engine is appropriate tool for create client app, which allow user to play with our AI. We used basic chess sprites which are available on internet, including chess board sprite. Client has to follow basic logic of an chess game. Because of spliting, we must have an comunicating between client and our algorithms. Flask is an appropriate choice because it base on REST paradigm.

**3. Algorithms**

We decide to implement algorithms in python using our environment. The reasons are easy to debug, test, scale,.. rather than implement algorithms on client.

MINIMAX

Chess is a zero-sum game, so minimax algorithm is a good choice to make decision. This algorithm bases on max and min value of state board. Each chess board will have an value which is generated by heuristic evaluation function. If an value is greather than 0, the advantage belongs to White.If an value is lower than 0, the advantage belongs to Black team. If you are playing as Black team, you need to make a move generating advantage - the lower value the higher advantage.

Algorithms description:

The minimax function returns a heuristic value for leaf nodes - also know as chess board (terminal nodes and nodes at the maximum search depth). Non leaf nodes inherit their value from a descendant leaf node. The heuristic value is a score measuring the favorability of the node - chess board - for the maximizing player. Hence nodes resulting in a favorable outcome, for the maximizing player have higher scores than nodes more favorable for the minimizing player. For non terminal leaf nodes at the maximum search depth, an evaluation function estimates a heuristic value for the chess board. The quality of this estimate and the search depth determine the quality and accuracy of the final minimax result. So evaluationg function is one of important part of this algorithms. The better evaluation function, the higher, the more accuracy decision was made.

Example:

A picture containing table, drawing

Description automatically generated

Pseudo code:

A picture containing bird

Description automatically generated

*maximizing* player : WHITE

*minimizing* player : BLACK

**Initial invoke for BLACK - AI player:**

*minimax(board,3,false)*

NEGAMAX

Algorithms desciption:

Negamax algorithm is a variant of minimax which based on the fact that:

to simplify the implementation of the minimax algorithm. More precisely, the value of a position to maximizing player (WHITE) in a game is the negation of the value to minimizing player. Thus, the player on move looks for a move that maximizes the negation of the value resulting from the move: this successor position must by definition have been valued by the opponent. The reasoning of the previous sentence works regardless of whether WHITE or BLACK is on move. This means that a single procedure can be used to value both positions. This is a coding simplification over minimax, which requires that maximizing selects the move with the maximum-valued successor while B selects the move with the minimum-valued successor.

Pseudo code:

A picture containing bird

Description automatically generated

**Initial invoke for BLACK - AI player:**

*negamax(board,3,-1)*

MINIMAX WITH ALPHA-BETA PRUNING

Algorithms desciption:

Alpha–beta pruning is a search algorithm that seeks to decrease the number of nodes that are evaluated by the minimax algorithm in its search tree. It stops evaluating a move when at least one possibility has been found that proves the move to be worse than a previously examined move. Such moves need not be evaluated further. When applied to a standard minimax tree, it returns the same move as minimax would, but prunes away branches that cannot possibly influence the final decision.

The algorithm maintains two values, alpha and beta, which represent the minimum score that the maximizing player is assured of and the maximum score that the minimizing player is assured of respectively. Initially, alpha is negative infinity and beta is positive infinity, i.e. both players start with their worst possible score. Whenever the maximum score that the minimizing player (beta aka BLACK) is assured of becomes less than the minimum score that the maximizing player (alpha aka WHITE) is assured of (beta <= alpha), the maximizing player need not consider further descendants of this node, as they will never be reached in the actual play.

Example:

A picture containing drawing

Description automatically generated

by using alpha-beta pruning, we can reduce alot of computations.

Pseudo code:

A picture containing bird

Description automatically generated

**Initial invoke for BLACK - AI player:**

*minimaxAlphaBeta(board,3,10000000000,1000000000, BLACK)*

NEGAMAX WITH ALPHA-BETA PRUNING

Negamax is an more simplified version of minimax. We can using alpha-beta pruning for negamax algorithm.

Pseudo code:

A screenshot of a cell phone

Description automatically generated

**Initial invoke for BLACK - AI player:**

*negamaxAlphaBeta(board,3,-10000000000,1000000000,-1)*

4. Evaluation Function

The important part of minimax, negamax algorithms is evaluation function - which is also a heart of AI. As long as AI player can appropriate evaluation state, it still can make good decisions. But how to evaluate an evaluation function is good ennough? We use 2 different evaluation function.

**Material Evaluation Function**

Consider each piece of pieces on board have different value as following table:

|  |  |  |
| --- | --- | --- |
|  | WHITE | BLACK |
| PAWN | 10 | -10 |
| KNIGHT | 30 | -30 |
| BISHOP | 60 | -60 |
| ROOK | 100 | -100 |
| QUEEN | 250 | -250 |
| KING | 900 | -900 |

We compute sum of all pieces' value on the board:

Evaluation =

x: piece's value of WHITE

y: piece's value of BLACK

It's is naive material position because of comparision of number of piece for each team whatever it's position. It's not good as when a piece stands at appropriate position, it may has more impact on adversary. For example, a knight have more impact when its at center position of board, not angle. So we imporve material position evaluation function by adding coefficient of position of each board.

**Material Evaluation with Coefficient of Position**

White pawn's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 3 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 |
| 4 | 0.75 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0.75 |
| 5 | -1 | 0.75 | 0.5 | 0 | 0 | 0 | 0.5 | 0.75 | -1 |
| 6 | -2 | -1 | 0.75 | 0.5 | 0 | 0.5 | 0.75 | -1 | -2 |
| 7 | x | -2 | -1 | 0.75 | 0.5 | 0.75 | -1 | -2 | x |
| 8 | x | x | -2 | -1 | 0.75 | -1 | -2 | x | x |
| 9 | x | x | x | -2 | -1 | -2 | x | x | x |
| 10 | x | x | x | x | -2 | x | x | x | x |

Black pawn's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 |
| 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 3 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| 4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | x | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x |
| 8 | x | x | 0 | 0 | 0 | 0 | 0 | x | x |
| 9 | x | x | x | 0 | 0 | 0 | x | x | x |
| 10 | x | x | x | x | 0 | x | x | x | x |

Knight's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | -5 | -4 | -3 | -2 | -1 | -2 | -3 | -4 | -5 |
| 2 | -4 | -3 | 0 | 0 | 0.5 | 0 | 0 | -3 | -4 |
| 3 | -3 | -2 | 1 | 1 | 1.5 | 1 | 1 | -2 | -3 |
| 4 | -3 | -1 | 1.5 | 1.5 | 2 | 1.5 | 1.5 | -1 | -3 |
| 5 | -4 | -2 | 1.5 | 2 | 2 | 2 | 1.5 | -2 | -4 |
| 6 | -5 | -3 | 1 | 1.5 | 2 | 1.5 | 1 | -3 | -5 |
| 7 | x | -4 | 0 | 1 | 2 | 1 | 0 | -4 | x |
| 8 | x | x | -3 | 0 | 1.5 | 0 | -3 | x | x |
| 9 | x | x | x | -2 | 0.5 | -2 | x | x | x |
| 10 | x | x | x | x | -1 | x | x | x | x |

Bishop's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | -2 | -1 | -0.5 | -1 | 0 | -1 | -0.5 | -1 | -2 |
| 2 | -1 | 0.5 | 0 | -0.5 | 0 | -0.5 | 0 | 0.5 | -1 |
| 3 | -0.5 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | -0.5 |
| 4 | -0.5 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | -0.5 |
| 5 | -1 | 1 | 2 | 2 | 0 | 2 | 2 | 1 | -1 |
| 6 | -2 | 0.5 | 1 | 2 | 0 | 2 | 1 | 0.5 | -2 |
| 7 | x | -1 | 0 | 1 | 0 | 1 | 0 | -1 | x |
| 8 | x | x | -0.5 | -0.5 | 0 | -0.5 | -0.5 | x | x |
| 9 | x | x | x | -1 | 0 | -1 | x | x | x |
| 10 | x | x | x | x | 0 | x | x | x | x |

Rook's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | -1 | 0.5 | 0.5 | 0.5 | -1 | 0.5 | 0.5 | 0.5 | -1 |
| 2 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1.5 | 1.5 | 2 | 1.5 | 1.5 | 1 | 1 |
| 4 | 1 | 1 | 1.5 | 2 | 2 | 2 | 1.5 | 1 | 1 |
| 5 | 1 | 1 | 1.5 | 2 | 2 | 2 | 1.5 | 1 | 1 |
| 6 | -1 | 1 | 1.5 | 2 | 2 | 2 | 1.5 | 1 | -1 |
| 7 | x | 0.5 | 1 | 1.5 | 2 | 1.5 | 1 | 0.5 | x |
| 8 | x | x | 0.5 | 1 | 2 | 1 | 0.5 | x | x |
| 9 | x | x | x | 0.5 | 1.5 | 0.5 | x | x | x |
| 10 | x | x | x | x | -1 | x | x | x | x |

Queen's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | -2 | -1 | -0.5 | -1 | -2 | -1 | -0.5 | -1 | -2 |
| 2 | -1 | 0 | 1 | 0 | -1 | 0 | 1 | 0 | -1 |
| 3 | 1 | 0 | 1.5 | 0.5 | 0 | 0.5 | 1.5 | 0 | 1 |
| 4 | 1 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 1 |
| 5 | -1 | 0 | 1.5 | 0.5 | 1 | 0.5 | 1.5 | 0 | -1 |
| 6 | -2 | 0 | 1.5 | 0.5 | 1 | 0.5 | 1.5 | 0 | -2 |
| 7 | x | -1 | 1 | 0.5 | 1 | 0.5 | 1 | -1 | x |
| 8 | x | x | 0.5 | 0 | 0.5 | 0 | 0.5 | x | x |
| 9 | x | x | x | -1 | -1 | -1 | x | x | x |
| 10 | x | x | x | x | -2 | x | x | x | x |

King's coefficient position table:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I |
| 1 | -2 | -1 | 0.5 | -1 | -2 | -1 | 0.5 | -1 | -2 |
| 2 | -1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 0.5 | -1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 |
| 5 | -1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | -1 |
| 6 | -2 | 0.5 | 1 | 2 | 2 | 2 | 1 | 0.5 | -2 |
| 7 | x | -1 | 1 | 1 | 2 | 1 | 1 | -1 | x |
| 8 | x | x | 0.5 | 1 | 1 | 1 | 0.5 | x | x |
| 9 | x | x | x | -1 | 1 | -1 | x | x | x |
| 10 | x | x | x | x | -2 | x | x | x | x |

x: position is not valid so it doesn't have coefficient

We compute sum of all pieces' value on the board:

Evaluation =

x: piece's value of WHITE

y: piece's value of BLACK

: position coefficient of x - WHITE

: position coefficient of y - BLACK

# Statistic

When No next state is 42 using naive material evaluation function:

|  |  |  |
| --- | --- | --- |
|  | depth = 2 | depth=3 |
| Minimax | 0.7836 | 33.8448 |
| Minimax with alpha-beta pruning | 0.1699 | 1.9678 |
| Negamax | 0.7503 | 33.1839 |
| Negamax with alpha-beta pruning | 0.6329 | 13.2482 |

When No next state is 42 using coefficient position material evaluation function :

|  |  |  |
| --- | --- | --- |
|  | depth = 2 | depth=3 |
| Minimax | 0.7779 | 33.9653 |
| Minimax with alpha-beta pruning | 0.1703 | 1.9557 |
| Negamax | 0.7479 | 33.0685 |
| Negamax with alpha-beta pruning | 0.6203 | 12.6925 |

When No next state is 76 using material evaluation function :

|  |  |  |
| --- | --- | --- |
|  | depth = 2 | depth=3 |
| Minimax | 2.2416 | 174.7319 |
| Minimax with alpha-beta pruning | 1.2120 | 33.7114 |
| Negamax | 2.1064 | 162.2979 |
| Negamax with alpha-beta pruning | 1.8852 | 54.7841 |

When No next state is 76 using coefficient position material evaluation function:

|  |  |  |
| --- | --- | --- |
|  | depth = 2 | depth=3 |
| Minimax | 2.2353 | 174.3262 |
| Minimax with alpha-beta pruning | 1.1929 | 34.9731 |
| Negamax | 2.2674 | 177.1767 |
| Negamax with alpha-beta pruning | 2.0694 | 61.5858 |

Assumption that each state have average 50 next state (50 legal moves of AI player):

|  |  |  |
| --- | --- | --- |
|  | depth = 2 | depth=3 |
| Minimax | ~1.5s ± 0.75s | ~100 ± 70s |
| Minimax with alpha-beta pruning | ~0.75s ± 0.5s | ~30s ± 25s |
| Negamax | ~2s ± 0.5s | ~100 ± 70s |
| Negamax with alpha-beta pruning | ~1.75s ± 0.25s | ~30s ± 25s |

# Conclusion

Glinski's chess is an variant of chess game, which has different rules, board. This report is an overview of implement algorithms as AI player and statistic. Through statistic, we can evaluation that negamax with alpha-beta pruning has highest performance and easy to implement. In addition , using alpha-beta reduce a lot of computations. To improve AI policy, we need more computational resource or implement another algorithms.

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