“ALEXANDRU-IOAN CUZA” UNIVERSITY OF IASI

**FACULTY OF COMPUTER SCIENCE**

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BACHELOR THESIS

**Artificial Intelligence techniques for Chess**

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July 2021

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**Avizat,**

**Îndrumător Lucrare**

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# Introduction

My bachelor thesis consists of an overview of Artificial Intelligence techniques used in Chess programming and the presentation of the results of a self-developed program, capable of showing optimal and intelligent behaviour in the environment of the chess game. Moreover, comparing its performance with the theoretical analysis of the latest trends in the field and state-of-the-art chess engines led to the conclusion drawn from the study. Therefore, the approach of the given subject contains both theoretical and practical aspects.

Besides coding theoretical aspects learned from various courses during the computer science study, the general objective of this thesis is getting an in-depth view about techniques and tendencies of the Artificial Intelligence domain by facing real challenges with academic writing and selecting suitable literature for a limited subject area.

AI for Chess is one of the oldest and most studied fields in this domain and computer’s performance has grown considerably with the transition from game tree search to Deep Reinforcement Learning. Nowadays, AI algorithms have reached a superhuman level, as the world champion was firstly defeated by a computer in 1997 and are frequently used not only for training for high-level tournaments, but also for cheat detection in online games.

“*Over the years, chess has proven to be a fertile ground for ideas and techniques that have spread to other areas of AI . These include database enumeration techniques, chunking, search techniques (minimax, alpha-beta, iterative deepening), and the utility of information. Considering the lack of funding for chess, it is significant that it has produced so many results. Chess has been fertile because it provides a complex reasoning problem from a simple domain with a builtin performance criteria. The simple domain permits research to progress with little initial overhead. Having a hostile opponent adds complexity to the reasoning. In many domains (natural language understanding comes to mind), progress can be hindered by lack of performance criteria - it can be hard to tell whether the latest thesis is an improvement on the current state of the art, Chess provides precise answers to performance questions.* (...)

*Research into artificial intelligence using chess as the application domain has produced several important contributions to AI :*

* *The effectiveness of brute-force search. Chess has clearly demonstrated that simple, brute-force approaches should not be quickly discarded.*
* *Iterative search. Some of the ideas developed for alpha-beta search, iterative deepening in particular, are applicable to other search domains and games such as go, shogi and tic-tac-toe.”* (1)

## Summary

The thesis is structured in four chapters which ilustrates all needed details in cronological order:

* **Chess game elements** provides information for linking the programming part to the Chess game environment. It focuses on implementation details and prepares the data for applying further algorithms
* **The Artificial Intelligence approach** explains how the AI technique is used in oreder to make the computer simmulate smart behaviour related to the game
* **Game behaviour and stats** shows the results obtained in real game situations with conclusive examples and performance measurements
* **State of the art** brings a theoretical analysis of most the latest and most performant engines and shows a performance comparison with early used techniques that prepares the conclusion

## Motivation

I choose this specific topic for my final thesis as I saw the great potential of improving both my practical programming skills and academic research and writing by approaching a merger of two passions of mine. I have been playing chess, go to training and participate in championships for a long period of time in my childhood, as well as I recently got interested in the AI field and how computers can show intelligent human-like behaviour in different situations. Moreover, getting insights into how a computer can become smarter than people in a specific field and developing a program that can respond and adapt to a chess game is a personal fulfilment. When I first started programming, I truly considered this too hard to understand, but working on this thesis gave me the necessary steps to make it possible and bring my contribution.

## Contributions

1. Implementing the game of Chess with the user interface, playable for two players, with board representantion and move validation
2. Finding and adapting an AI algorithm for the scenerio of playing against the computer and optimize it for a greater response time and strategy
3. Analizing the results and obtained performance
4. Getting overview on current, most powerfull chess engines and in-depth knowledge in how they work and what theoretical aspects and algorithms are required for best performance
5. Making observation on the evolution in this domain drawing conclusions by comparing the researched techniques

# The implementation of Chess game elements

In this section, there will be presented details about data structures and classes used to ensure the data and functions call flow. These combined toghether form the core of the program, the chess engine.

## Python and Classes

The whole structure of the game is implemented in Python 3.9 as its widely known features make it suitable for this kind of project. It is a high-level programming language without strict emphasis on syntax and background behaviour, therefore there are considerably fewer lines of code needed to perform a complex task than other major programming languages such as C/C++ and Java. It is way more efficient in Python to implement functions with multiple data types such as dictionaries strings list and arrays, considering the fact that the compiler does not need to know any kind of data type and automatically assigns them during the execution. In my case, this simplicity made the debugging process way easier and helped me to focus more on solving the problem and algorithms.

In terms of disadvantages, the slow speed in execution is the main problem of a program written in Python. The interpreter has to do extra work while executing the code because the interpreter has to dynamically interpret the instructions. That is the reason why many optimizations are required in order to reach a good level of performance and search depth, as a consequence of the constant trade-off between speed and intelligence, as we will below.

The whole program is structured using the Object-oriented approach based on classes with their specific attributes and methods. This has been done to better organize the functionality structure into small parts assembling the big puzzle, in order to make it easy to read, change and debug.

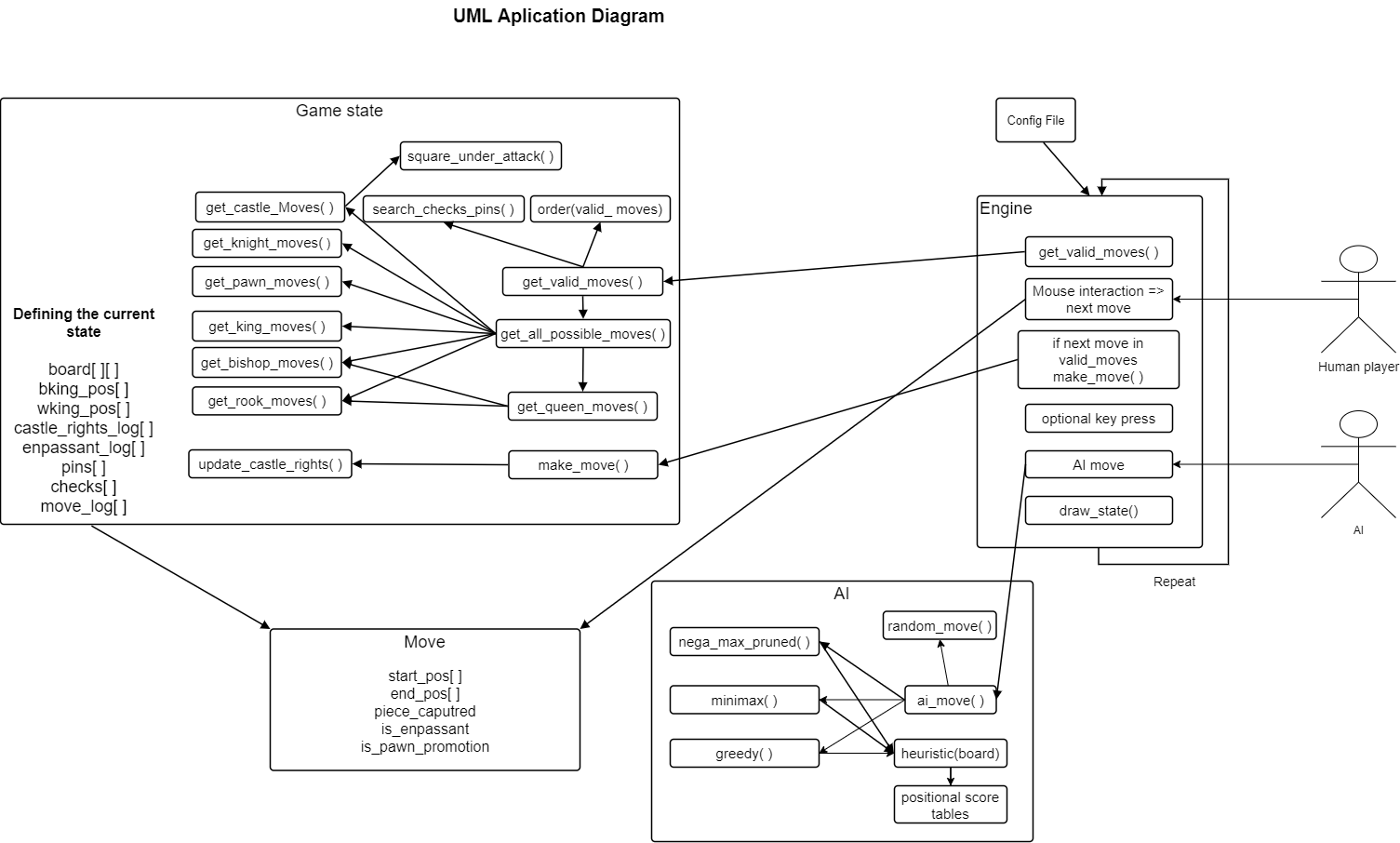
## Chess rules

|  |  |
| --- | --- |
| Fig. 1 – Initial Setup | Fig. 2 – Enpassant capturing |

The pieces are always placed as in the initial setup image and White always starts. Despite basic piece movement and their implementation from 2.6.1 (including castling), there are special rules like pawn promotion, enpassant, pins, checks, checkmate and stale mate:

* [Promotion] Pawns that are advanced to the 8th line for white and 1st line for black are transformed, by player’s choice in a figure (Queen, Knight, Rook or Bishop)
* [Enpassant] When a pawn advances two squares from its original square and ends the turn adjacent to a pawn of the opponent's on the same rank, it may be captured by that pawn of the opponent's, as if it had moved only one square forward. This capture is only legal on the opponent's next move immediately following the first pawn's advance. *Fig. 2* demonstrates an instance of this.
* [Checks and Pins] A king is in check when it is under attack by at least one enemy piece. A piece unable to move because it would place its own king in check (it is pinned against its own king) may still deliver check to the opposing player. It is illegal to make a move that places or leaves one's king in check. The possible ways to get out of check are moving the King, capturing the checking piece or blocking the check by placing a piece between the king and the opponent's threatening piece.
* [Checkmate] If a player's king is placed in check and there is no legal move that player can make to escape check, then the king is said to be checkmated, the game ends, and that player loses. Unlike other pieces, capturing the opponent's king is not allowed.
* [Stalemate] The game is automatically a draw if the player to move is not in check and has no legal move. This situation is called a stalemate.

## Overview Diagram



## The Engine

The Engine Class is the main core of the program which synchronize the human interaction and User Interface with the Chess Game State representation and the AI logic.

First of all, player type is taken from the configuration file for both White and Black, it can either be ‘human’ or ‘ai’. Then, the depth of the search tree and the AI technique used is set on the next two lines. The algorithm can use pruned and unpruned exhaustive search functions and the depth directly impacts the speed and performance, because it represents the number of forward moves computed for both players, in order to make the best decision (move) on each current step.

Another functionality of the Engine is to create the User Interface. It simply loads all the prepared images from the folder for the board and each type of piece. After each move made by the human player or the computer, the state is updated and displayed accordingly. By doing so, the execution is significantly lowered, because large files as photos are loaded in an array only once in the beginning.

It further listens to mouse events made on the board window and transforms them into moves with two coordinates for the start and the end. There are also keyboard options, by pressing the ‘Z’ key the user can undo the last move and, by pressing ‘R’, the board is reset to the initial setup. (*Fig.1*)

The Engine calls the specific function in the Game State Class which provides all valid moves from the current board and if the move received from the player is in that set, the “make\_move” function is called and the state of the game changes accordingly. Otherwise, if the move is not valid, the engine listens to another move from the player.

Finally, the Engine ensures that the player type (human or ai) is assigned to its pieces and creates the synchronization between White moves and Black moves. The game loop is simulated with White always starting and repeated until a final game state is reached, either Stalemate or Checkmate.

## Move Class

The Move class represents a key functionality of the project and is used for representing a chess action in a raw form, without any further verification or validation. It is only formed from start and end postion of the move and it’s type, whether it is a standard, capturing, a castle, promotion or enpassant move.

It is created by the Game State and returned in the list of valid moves. It is further analyzed by the AI logic or compared with the actions given by the player.

## Game state

In the program, there is a class especially created for storing the information of the current game state and all necesary methods for further use in the engine and AI move finder. It ensures that all chess rules are optimally verified and the restrictions regarding piece movement, castling, checks, enpassant capturing, pawn promotions and game ending situations are not violated by both the player and the AI.

The properties of game\_state class, initiated with the built-in \_init\_ function are:

* board[ ][ ] – two dimensional array with 8 columns and 8 rows, simmulating a chess table, which stores “--“ for an empty square or the piece shortened name such as “wp” for a white pawn or “bk” for a black rook for example. In the beginning, the Chess initial setup is represented.
* white and black king position – two tuples with the coordinates of each king such as (7,6). It is used for decideing whch moves are legal by computing checks and pins, castle rights and king moves.
* castle\_rights\_log[ ] – it is updated after the move of the rook or king which changes the castle rights of a player. Contains boolean values for king and queen side for both white and black
* enpassant\_log[ ] – stores and updates after each move of a pawn by checking the condition stated in chess rules above
* checks[ ] and pins[ ] – contains the checks and the pins on a given position. A pin is considered a piece that is not alowed to be moved from the direction of the attacker, as it leaves the king in check. The array contains the direction of the pin and the position of the pinned piece or the direction of the check and the attacking piece: (piece\_row, piece\_column, d[0], d[1]). Both arrays are used for move validation.
* move\_log[ ] – was previosly used for searching valid moves by simulating the capture of the king. In the last version it is used for undoing the last move by pressing the ‘R’ key

## The implemenation of rules and constraints

The chess rules and piece movement restrictions are verified in the Game State Class, as the valid moves from a given position can be obtained easily in the Engine or AI by calling the get\_valid\_moves method that expands and make calls to the other functions. It basically brings Chess logic to the program not allowing neither human nor the ai to make mistakes or violating the rules.

Firstly, get\_valid\_moves takes all possible moves when considering chess piece movement and capturing rules, without considering checks and pins that eliminates some possible moves. It iterates through all squares on the board, and call the specific function of every piece when found, as it follows.

### Piece movement

* get\_pawn\_moves() – A pawn moves straight forward one square if that square is vacant. If it has not yet moved, a pawn also has the option of moving two squares straight forward, provided both squares are vacant. Pawns cannot move backwards. A pawn, unlike other pieces, captures differently from how it moves. A pawn can capture[[1]](#footnote-1) on either of the two squares diagonally in front of the pawn (but cannot move to those squares if they are vacant). The pawn is also involved in the two special moves en passant and promotion. (2.2) The function returns all these moves.
* get\_knight\_moves() – The Knight can move and capture in an “L” pattern (two squares horizontally then one square vertically, or moving one square horizontally then two squares vertically) and can not be blocked, as it “jumps”.
* get\_bishop\_moves() – The Bishop can move on all the 4 diagonals and can capture only the first enemy piece met in any of those directions
* get\_king\_moves() – The king can move and capture exactly one square horizontally, vertically, or diagonally. A special move with the king known as castling is allowed only once per player, per game. In that case, get\_castle\_moves() is called. You are not allowed to place your king near the other king.
* get\_castle\_moves() – Castling consists of moving the king two squares towards a rook, then placing the rook on the other side of the king, adjacent to it. Castling is only permissible if all of the following conditions hold:
* The king and rook involved in castling must not have previously moved, so it can only be queenside or kingside
* There must be no pieces between the king and the rook;
* The king may not currently be in check, nor may the king pass through or end up in a square that is under attack by an enemy piece (though the rook is permitted to be under attack and to pass over an attacked square);
* get\_rook\_moves() – The Rook can move vertically and horizontally and can capture only the first enemy piece met in any of those directions
* get\_queen\_moves() – The Queen can move vertically, horizontally and diagonally and can capture only the first enemy piece met in any of those directions.

### Check constraint and pins

There are two methods possible to use for validating the moves generated as above. The first one is probably more intuitive and logic, but also considerably more expensive in terms of memory used and especially execution time, which turned to be one of the most important aspect of the algorithm.

In the first method:

* all possible moves are generated
* each move is made (simulated in the background and then reversed)
* generate all possible moves of the opponent
* for each one of them, if it “captures” the king, it means that the player left or moved the king in check last time and made an invalid move

The second method and the one actualy used in the program:

* On the current board, start iterating in all nine directions from the position of the king
* if the position of an ally piece is reached

- if it is the first one it becomes a possible pin

- if is the second one, the search in that direction stops

* if the position of an enemy piece is reached
* we check using the rules for every type of piece if it attacks
* if it does not attack the king the loop ends for that direction
* if it attacks the king the possible pin is added to the array of pins or if we do not have a possible pin, the king is in check

Comparing these two methods, in terms of complexity, the first one simulates two moves ahead on every move made in reality, only for deciding if it was legal or not. That means 900 positions in average, for 30 possible moves on the current board. In contrast, the second method only iterates through 28 squares in the worst case, when the king is located in the centre.

### Game endings

The checkmate si decided by counting the possible moves and verifying if the King is in check. If there are no possible moves and the King is attacked by an enemy piece, then the game ends and the attacker wins. Otherwise, if there are no possible moves returned by get\_valid\_moves(), but the king is not attacked, that is a Stalemate and the game ends with a draw.

In both cases, no other moves are allowed to be made and a message is displayed in the console.

|  |  |
| --- | --- |
| Fig. 3 – Stalemate | Fig. 4 - Checkmate |

## Move making

|  |  |
| --- | --- |
| Fig. 5 – UI Board before the move | Fig. 6 – Board state before the move |
| Fig. 7 - UI Board before the move | Fig. 8 - Board state after the move |

As it can be seen in the example, the make\_move() method from the Game State Class makes the former position of the moved pieced empty (“--” value) and updates the value on landing spot, from captured pieced “wb” to “bq”.

## Possible imporvements

The logic and implemention of the program can considerably impact the speed of the chess engine and further the performance of the AI. Both ideas presented bring a low-level approach for the representation and code.

### Bitboard

*“Bitwise methods for programming games centre around the concept of the bitboard. This is a data structure designed for efficiently encoding game boards as sets of bits, first used for computer chess in the 1950s (Frey, 1977). Rather than allocating an integer for each board cell to store the value of any piece there, each cell is assigned a bit indicating the presence or absence of a piece (or pattern) there, requiring only a fraction of the memory. For example, the cells of an 8×8 chess board conveniently pack into a single 64-bit long integer.*

*Bitboards allow common game-related operations to be performed using fast bitwise manipulations. Pepicelli (2005) lists three main advantages of using bitboards.*

* *Memory Usage: Bitboards encode the board state more efficiently than integer-per-cell encodings.*
* *Efficient Operation: Read and write operations can be performed efficiently using bitwise operations.*
* *Bitwise-Parallel Operation: Bitwise operations can be applied to all board cells simultaneously.*

*Efficient memory usage can be beneficial if it allows more operations to be performed from the (much faster) registers or cache. However, the potential for bitwise-parallel operation can also yield significant performance improvements. This means that game-specific calculations such as movement or win tests need only be applied once over the entire board in a bitwise-parallel manner, rather than individually for each cell or piece. Such operations are typically stateless as they operate equally over all cells with no prior knowledge about the board state, but can sometimes be optimised with the inclusion of state information.”* (2)

### Numpy

To begin with, standard Python is an interpreted language with high-level syntax, that it is, in general, slower than C-like programming languages, which are compiled and much faster.

Numpy is a library designed for Python that brings functionality for arrays and algebraic

operations. It performs its complex computation using a well-optimized C code, therefore the core of Numpy makes it possible to incorporate the flexibility of Python with the speed of compiled code.

Using Numpy arrays for the game representation and engine will significantly improve the speed of the program on execution or will facilitate the exploration of a deeper search tree in the same amount of time.

# The Artificial Intelligence approach

Chess is one of the most complex and strategic games and the Artificial Intelligence Agent needs to forward plan as many states as possible and efficient to reach a favourable game-ending state, such as a checkmate from a favourable material position or stalemate from a position with far more material than the opponent. The game is completely deterministic because there is no randomness involved in winning the game and the search space is very large, as there are approximately 10120 possible games of chess[[2]](#footnote-2), and is not be computational in a reasonable time.

The purpose of the program is to show human-like intelligence and analyze the chess environment and apply its strategy to shrink search space in its favour. The method used for achieving this goal is finding the best move based on chess generally known pre-sets, by dynamically iterating through the game tree search as it follows.

## Defining the problem

The program basicaly gives a solution to a problem which can be organized with the standard AI structure:

* describe a state : 2.6
* identify special states and the problem space : 2.7.3
* describe the transition and validate them : 2.7.1 and 2.7.2
* specify a search strategy : 3.2

## Game tree search

|  |  |
| --- | --- |
| Fig. 9 – Game tree | The Initial Setup represents the root node and the possible position are added consequently as a new node after a possible move of a player. Each player turn is located on a new level, on a higher depth as the game advances. Therefore, the branching factor[[3]](#footnote-3) of the tree is represented by the number of possible moves of a player at a certain moment, with a value between 25 and 40 in most cases. The maximum depth is given by the length of the chess game. |

This representation is natural and optimal designed for searching in such a big space as it successfully simulates the rules and logic of the chess game. The game tree can further integrate move comparison and optimizations that can enlarge the amount of relevant position analyzed.

In order to determine the best decision, the depth-first search is used in the tree, because the outcomes from a branch are obtained only in leaf nodes and must be further compared to the other possibilities.

The advantage of this method is that it knows exactly what move is the most optimal, with the given criteria and methods to evaluate each possible branch of the game, because the search is exhaustive.

The disadvantage is that the costs are high and grow exponentially as the depth of the search is increased, thus making it limited. Therefore, further variants of the game could not be explored and the evaluation of the leaf nodes is considered valid and representative for the whole branch until the end of the game. In most cases, the short term outcome computed over the actual path to win can be losing or deceptive in chess.

### Minimax

|  |  |
| --- | --- |
| Fig. 10 - Minimax | We consider the fact that each leaf node has an arbitrary value which represents how favourable the position for both players is, in the sense that it is lower if the reached state is in the advantage of the first player and higher otherwise. (3.3) |

The Minimax is an exhaustive search algorithm mainly used in artificial intelligence decision making in adeversarial turn-based games like chess, that uses backtracking and depth first search. It simulates the succession of the moves that each chess player has to take in order to maximise his chances to win. The agents are placed alternative on the levels in the game tree, starting with who is on turn in the root node and ending if a game final state or maximum declared depth is reached. Each possible move adds a new node as a reachable chess position in an analyzed branch, on the next level in the tree.

The evaluation takes place only on leaf nodes and then back propagate, up to the initial call (root) as it follows. The two players have directly opposing strategies, because one of them always chooses and takes the maximum available value from child nodes, while the other one minimizes the score.

### Negamax

## Heuristic evaluation function

<https://www.chessprogramming.org/Simplified_Evaluation_Function>

|  |  |  |  |
| --- | --- | --- | --- |
| Fig. 11 - Knight Positional Score | Fig. 12 - Rook Positional Score | Fig. 13 - Pawn Positional Score | Fig. 14 - King Positional Score |

## Optimization

Memory time complexity

facing problems with testing time and the accuracy of moves => need of optimization speed

### Alpha – Beta pruning

|  |  |
| --- | --- |
| Fig. 15 - Alpha Beta Pruning | ab description  exploration |

### Zoobrist hashing

Just analyze new poss, if on a branch already calculated just take vlaue

### Move ordering

<https://www.chessprogramming.org/MVV-LVA>

https://youtu.be/U4ogK0MIzqk?list=PLohmICelvXr8DBe-nWcCheDTRFlbPNBFz&t=933

https://www.youtube.com/watch?v=-ivz8yJ4l4E&list=PLohmICelvXr8DBe-nWcCheDTRFlbPNBFz&index=15&t=231s

### quisence search

event horizon (csua)

### beam search ?!

## General structure of the program

greedy, negamax, initial call etc ?

# Game behaviour examples & stats

## Positional development

screen shots

## Force mate

## Trapping a more valuable piece

## End game situations

# State of the art

why each algorithm. why ecuations ?

## Monte Carlo Tree Search for chess

## AlphaZero

# Conclusions

Why do we achieved great results

Further possible improvements

New AI techniques DL + RL> Minmax + wtv

(bibliografie)

Mainly articles and publications

Not wiki/stack..

interactiune om

# Bibliography

1. *The Role of Chess in Artificial Intelligence Research.* **Robert Levinson, David E. Wilkins, T. Anthony Marsland, Jonathan Schaeffer, Feng-hsiung Hsu.** 1991. International joint conference on Artificial intelligence.

2. *Bitboard methods for games.* **Cameron Browne ( QUT, Brisbane, Australia ).** s.l. : ICGA Journal, 2014.

# Appendix with code

refs (Chess rules wikip, chessprogramming wiki)

1. You can capture only enemy pieces except for the King [↑](#footnote-ref-1)
2. Shannon number (lower bound approximation) – 35 moves for each player on a move, resulting in 103 for a both sides, the factor being multplied by 40 – the average length of a game [↑](#footnote-ref-2)
3. Branching factor - the indicative average number of children for each node. In this case, it is a uniform average as it can vary from move to move [↑](#footnote-ref-3)