

# Research Review: Deep Blue

For the research portion of the assignment, I chose to review the Deep Blue paper by Campbell et. al., IBM Research, 2002<sup>1</sup>. The reason I chose this paper was that this system was the first to beat a reigning human champion in tournament chess play, and thus is of significant historical interest.

Deep Blue, a computer system designed by IBM for the sole purpose of playing chess, played Gary Kasparov on 2 occasions - once in 1996 in which Kasparov prevailed, and one in 1997 in which Deep Blue prevailed. IBM never accepted a rematch against Kasparov, and retired the system after the win. The 1996 version is referred to as Deep Blue 1, while the 1997 version is referred to as Deep Blue 2. Deep Blue 1 was a parallel processing system consisting of 216 processors and was capable of searching 50 - 100 million nodes per second. Deep Blue 2 represented a significant upgrade from Deep Blue 1, consisting of 480 processors and capable of searching 100-200 million nodes per second. Deep Blue showed that it was possible to outperform human capabilities with a complex game like chess.

One of the innovations in Deep Blue consisted of the architecture. Deep Blue consists of specialized hardware specifically for computing chess positions and searching the game tree, called the "chess chip". The chess chip has three distinct functions:

- **Move generation:** implicitly computes all possible moves from the given position and selects the best move via an arbitration network;
- **Evaluation Function:** consists of a fast evaluation function and a slow evaluation function. The fast evaluation computes a score in a single clock cycle, and is appropriate for most tactical assessments, while the slow evaluation scans the board column by column computing values for more strategic positions such as X-Ray, pawn position, king safety, etc;
- **Search Control:** null window alpha-beta search is implemented on the chips. This is similar to the alpha-beta search that we learned in class, but alpha and beta are set to be equal

The full evaluation function used by Deep Blue is extremely detailed. It was developed in consultation with some of the world's best chess grandmasters, and encapsulates many (all?) of the known tactics in chess. It is capable of recognizing 8000 different patterns and assigns a score to each pattern. The features and weights were almost entirely hand-tuned to give Deep Blue the characteristics required to beat Gary Kasparov's aggressive chess playing style.

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<sup>1</sup> <https://pdfs.semanticscholar.org/ad2c/1effcd7c3b7106e507396bdaa5fe00fa597.pdf>

The opening book for Deep Blue was developed by hand by 4 chess grandmasters. The book consisted of 4000 opening moves, and were designed to enhance positions and tactics that Deep Blue played well. The paper doesn't mention this explicitly but I assume that they mean tactics that are explicitly computed in the evaluation function, like x-ray, bishop position, wasted pawns etc. The paper lists 37 different tactics in Appendix A, each of which have register assignments on the chess chip.

Deep Blue also had an extended book, which consists of 700,000 game database. Each position in each game of the database had been summarized and ranked, and was used to supply Deep Blue with prior information or boosting of scores during its alpha-beta search. For example, if a move in the database had been shown to be successful in a previous game, this position would be boosted during the alpha-beta search if Deep Blue encountered the same position during a game. In this way Deep Blue could take advantage of the previous knowledge of 700,000 previously played games by grandmasters of chess.

I remember hearing about the accomplishment of Deep Blue beating Gary Kasparov in a chess match. It was amazing at the time to think that computers had crossed a threshold previously thought to have been the clear domain of human intelligence. The accomplishment, as impressive as it was at the time, really is a hardware victory - Deep Blue searches faster and deeper than human players and thus can beat them. Another limitation is that Deep Blue was trained with a lot of human assistance, including hand tuning of features by chess grandmasters, a hand tuned opening book, and the advantage of 700,000 existing games from which to draw knowledge. How important was the human element in Deep Blue's success? This is not discussed in the paper.

More recently, Google's Alpha Go Zero program<sup>2</sup> showed complete domination over the best human players in the world. The remarkable thing about this system is that the only information that it received about the game was the rules of Go. The system learned to play Go by playing thousands upon thousands of games against itself using reinforcement learning coupled with monte-carlo search trees and convolutional neural networks for move selection. There was no hand-tuning of evaluation features, or creation of opening books, or leveraging a large database of previously played games - the system learned to play Go by itself, from a starting position of "Tabula Rosa" or blank slate.

The strength of the player that developed from the alpha Go Zero program is startling. Deep Blue won the game against Kasparov by a score of 3.5 to 2.5, meaning that Kasparov was competitive during the match. The Alpha Go Zero program has an Elo rating<sup>3</sup> of 5185. To put this into perspective, the Elo rating of the best player in the world is 3658. If these two players played a match, one would expect the Alpha Go Zero player to win 99.98% of the time, and the

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<sup>2</sup> <https://deepmind.com/blog/alphago-zero-learning-scratch/>

<sup>3</sup> [https://en.wikipedia.org/wiki/Elo\\_rating\\_system](https://en.wikipedia.org/wiki/Elo_rating_system)

human player to win only 0.02% of the time. Out of 10,000 matches, the Alpha Go player would win 9998 of them, and the best human player would win only 2 matches.

The fact that a player of this strength emerged from a program with no knowledge of Go other than the rules of the game is a remarkable achievement, one that dwarfs the accomplishment of the Deep Blue system in my opinion.