

# Research Review

## of Deep Blue paper

### Paper's goals

Goal of the paper is to describe techniques used in Deep Blue computer and encourage further exploration of this space.

### Paper's techniques

Deep Blue is a complex system separated on hardware and software parts. Because of hardware search developers was force to make many tradeoffs. Software part is very flexible and may be changed as needed. The hardware part is difficult to modify and software part has to rely on existing implemented features of specialised chip to implement required functionality. Also there is additional difficulty in the choosing of best strategy to determine is software or hardware search should be used.

Evaluation function in Deep Blue is implemented in hardware. It contains of 8000 feature. Because of hardware implementation of evaluation function developer should not think about tradeoffs of evaluation, but has limited amount of features that could not be modified.

The evaluation function composed of «fast evaluation» and «slow evaluation». This allow to skip slow calculations when approximation is good enough. The fast evaluation, which computes a score for a chess position in a single clock cycle, contains all the easily computed major evaluation terms with high values. The most significant part of the fast evaluation is the «piece placement» value, i.e., the sum of the basic piece values with square-based location adjustments. Positional features that can be computed quickly, such as “pawn can run”, are also part of the fast evaluation. The slow evaluation scans the chess board one column at a time, computing values for chess concepts such as square control, pins, X-rays, king safety, pawn structure, passed pawns, ray control, outposts, pawn majority, rook on the 7th, blockade, restraint, color complex, trapped pieces, development, and so on. The features recognized in both the slow and fast evaluation functions have programmable weights, allowing their relative importance to be easily adjusted.

The search control portion of the chip uses a number of state machines to implement null-window alpha-beta search, which includes a quiescence search. The advantage of null-window search is that it eliminates the need for a value stack, simplifying the hardware design. The disadvantage is that in some cases it is necessary to do multiple searches, for example when an exact score is needed. Another limitation on the hardware search is the lack of a transposition table, which is known to improve search efficiency significantly in many cases. The effect of this limitation is lessened by the fact that the upper levels of the Deep Blue search are in software and have access to a transposition table.

Deep Blue contains software search function named «dual credit with delayed extensions». It was designed on such principles as: extend forcing/forced pairs of moves, forced moves are expectation dependent, fractional extensions, delayed extensions, dual credit, preserve the search envelope.

Search algorithm is highly parallelised and relies on complex hardware architecture.

Also Deep Blue contains opening, extended and endgame books of positions. All these allow to use experience of previous generations of Grandmasters.

Deep Blue contains of complex time management controls with two levels of time targets. First is considerable time buffer and other is «sudden-death» phase.

## **Paper's results**

There are no real results in paper. This is in fact something like postmortem about competition between Garry Kasparov and Deep Blue. Deep Blue was able to won with help of all described in paper techniques.