Deep Blue Chess Computer

Bradley Conn
Outline

- History
- Match Controversy
- System Overview
- The chess chip
- Alpha Beta Pruning
- Quiescence Search
- Parallelization
- Other strategy
- Timers
- References
History

Chiptest

- Carnegie Mellon 1985
- 3 graduate students
- Special VLSI move generator chip
- 50,000 moves per second

Chiptest-M

- 1987
- 500,000 moves per second
- Removed chiptest bugs
History

Deep thought

- 1988
- IBM took over the project and hired the people behind it
- First computer to beat a grandmaster
- 700,000 moves per second


- Stepping stone to Deep Blue
- 24 processor system
- Complete software rewrite to handle parallelism
History

Deep Blue (1996)

- 1.6 to 2 million positions per second per chip
- 50 to 100 million positions per second for system
- Played Garry Kasparov and lost the series with 2 wins, 4 losses

Deep Blue (1997)

- Enhanced chess chip with 2 to 2.5 million positions per chip
- 200 million positions per second
- Beat Garry Kasparov with 3.5 wins, 2.5 losses (.5 is awarded for draws)
History

- The 1997 defeating of Garry Kasparov was considered a turning point in Artificial intelligence
- Many articles are still being written today about the computer
  - As recently as this month
  - [http://mashable.com/2016/02/10/kasparov-deep-blue/#mNpePE_fkkqd](http://mashable.com/2016/02/10/kasparov-deep-blue/#mNpePE_fkkqd) Feb 2016
Match controversy

- Kasparov set a trap in which Deep Blue would gain material but lose position
- Deep blue didn’t take the bait and instead went for a long positional play
- Kasparov was shaken by this and never won a game against Deep Blue after
- Kasparov accused the IBM team of cheating
  - Claimed a move was too human like and that there was no way a computer could choose a move like that
- He asked to see the logs and IBM refused to show them
- He requested a rematch but IBM soon after dismantled the computer and ended all work on the chess computer
- Many believe Kasparov was still the better player but let emotions get the best of him
System overview (Deep Blue 1997)

- Massively Parallel
- 30 nodes
  - 30 P2SC processor (one per node)
    - 28 @ 120Mhz, 2 @ 135 Mhz
  - 480 single chip chess search engines (16 per node)
    - 2 to 2.5 million chess positions per second each
    - Communicate with host through microchannel bus
  - 1 GB RAM per node
  - 4 GB disk per node
  - High Speed Switch for Communication
- AIX 4.2 Operating system
System overview (Deep Blue 1997)

- Works on chess game “tree searches”
- Three layers
  - Master
    - One node is the master
    - Searches top level of tree and then distributes “leaf” positions to workers
  - Workers
    - Remaining nodes are workers
    - Compute a few levels of addition search and then distribute to chess chips
  - Chess chips
    - Finish searching through tree structure
- Can evaluate 100 to 200 million positions/second depending on board status
  - Averaged 126 million positions per second against Kasparov
- Could average 12.2 moves ahead in a 3 minute search
The Chess Chip

- 1.5 Million Transistors
- 0.6 micron CMOS technology
- 24 MHz
- 2-2.5 million positions per second
  - 1 position was roughly 40,000 instructions on a general purpose processor
  - Equivalent to 100 billion instructions per second on normal processor
- 3 Main parts
  - Move Generator
  - Evaluation Function
  - Search Control
The Chess Chip

The move generator, an 8 × 8 array of combinational logic, appears in the die photo as the block at the upper right. All the sub-blocks to the right of the move generator belong to the evaluation function. The lower sub-blocks provide fast evaluation. The upper sub-blocks, the systolic evaluation array, the pipelined evaluation RAMs, and the pipelined postevaluation logic compute slow evaluation.
Move generator

● 8 × 8 array of combinatorial logic
  ○ effectively a silicon chessboard
● Controlled by finite state machine
● Computes all moves at one time and selects one to work on further
● Order of selected moves
  ○ Low valued piece captures high valued piece
  ○ High valued piece captures low valued piece
  ○ No capture
● Keeps list of already searched moves
Evaluation Function

- Evaluates different “features” of a chess position such as
  - square control
  - pins
  - skewers
  - king safety
  - pawn structure
  - development
  - passed pawns
  - pawn majority
  - rook on the 7th
  - trapped pieces
  - and so on
Evaluation

- Each feature is given a programmable weighting
- 2 types, fast and slow
- Fast
  - Single clock cycle evaluation
  - Gives approximate score of position
  - Calculates fastest and most valuable features
- Slow
  - 3 clock cycle latency
  - 1 cycle per each column
  - 11 cycles total
Search Control

- Uses state machines
- Implements alpha beta search
- Has a move stack to keep track of previous searches
- Includes repetition detector
  - implemented as a 32-entry circular buffer of the last 32 moves
Figure C. A chess chip's basic search algorithm: search tree (left), flow chart (right).
Alpha Beta Pruning

- A form of pruning for efficiency of searching
  - Can go deeper without wasting calculations
- Alpha pruning - least bad thing can happen to you
- Beta pruning - least bad thing can happen to opponent
- Alpha example - Evaluate all my moves and all responses
  - Move #1 for me - worst outcome is opponent moves and we are even
  - Move #2 for me - find an outcome where opponent can capture a piece
    - No need to continue to evaluate move #2 as the outcome would be worse
- Beta
  - Include another move
  - Ignore cases where there is a better move for opponent
Quiescence search

- Also called capture search
- A side has the choice of capturing a piece or accepting a position
  - If capturing a piece the opponent has a chance to decide between the two as well
- Can go on for many moves
  - until one side runs out of captures or until one side decides to take the position as is
- Includes other types of forcing moves
  - Example - checking moves
Quiescence search

- Average of going 4 moves deeper
- A program with quiescence search usually spends at least half of its computation time there
Parallelism

- Nodes communicate through message passing interface (MPI)
- Processors communicate with chess chip through Micro Channel bus
- Static processor hierarchy
  - 1 master node controls 29 worker nodes
    - Each worker node controls 16 chess chips
- Early iterations carried out on master
  - Not much parallelism and master has 16 chess chips so it can handle it
- As it gets deeper work gets distributed to nodes
  - Example - 12 move deep search (exhaustive)
    - 4 moves on master (x1000 new positions)
      - 4 moves on node processor (software) (x1000 new positions)
        - 4 moves on chess chips - could go deeper for specific cases as well
  - Software accounts for ⅔ depth but less than 1% of positions
Parallelism

- Uses tree structures for search whose complexity can vary widely based on positions
- As such load balancing is difficult
  - Handled by aborting long tasks, sending to master for further splitting
- Workers could not directly communicate with each other (for simplicity)
- Master was the bottleneck
  - Ensured nodes had tasks on deck for when they finished
Parallelism

- At the system level, the chess chip appears as a 32-bit device with a 17-bit address space
  - Writing to some of the addresses initiates a search from the current position on the chip
  - Parameters are sent over the micro channel bus as well
    - Full width fixed depth is one of the important parameters which accounts for much of the processing time
- This frees up the host processor
  - Can perform overhead tasks
    - Initiate a search on another chip
    - Cancel a job that is taking too long
    - Poll for completion of search
  - Perform its own software search
- Built into the chess chip was the ability for FPGA expansion but was never implemented due to time constraints
Evaluation

- Scores moves by assigning a value to each move
  - Chess chip recognizes roughly 8000 different “features” used to score a move
- Features range from very simple to very complex
  - Simple example - a particular piece on a particular square
- A feature can be either static or dynamic
- Dynamic values are initialized at the beginning of a search but during the search they are scaled based on the board position
  - Example - king safety is sensitive to the amount of material on the board
Evaluation

- 54 registers for parameters
- 8096 tables for parameters
- 8150 total parameters that could be set for the evaluation function
- Most of the features and weights tuned by hand
- The Deep Blue scores are composed of two 16-bit signed integers
  - Positive for good scores negative for bad scores
  - The regular search score is in one integer
  - The tie breaker score is in the other
    - If the computer should propose a draw
Other strategy

- Depending on the situation three different “books” were used
  - Opening book
  - Extended book
  - Endgame book
- The opening book in Deep Blue was created by hand, primarily by Grandmaster Joel Benjamin
- The opening book consisted of about 4000 positions,
- Openings were chosen to emphasize positions that Deep Blue played well.
- Prior to a game, a particular repertoire was chosen for Deep Blue.
  - There were a number of possible repertoires to choose from
  - The choice would be made on the basis of
    ▪ the match situation
    ▪ the previous experience playing with the same color.
The extended book

- Large Grandmaster game database
  - Used to influence Deep Blue’s moves
- Summarize the information available at each position of a 700,000 game database
- Use the summary information to push Deep Blue in the consensus direction of chess theory
- Bonuses or penalties were assigned to moves in a given position that had been played in the Grandmaster game database
Extended book factors

- **The number of times a move has been played**
  - A move frequently played by Grandmasters is likely to be good
- **Relative number of times a move has been played**
  - If move A has been played many more times than move B, then A is likely to be better
- **Strength of the players that play the moves**
  - A move played by Kasparov is more likely to be good than a move played by a low-ranked master
- **Recentness of the move**
  - A recently played move is likely to be good, an effect that can in some cases dominate other factors
- **Results of the move**
  - Successful moves are likely to be good
Extended book factors

- Commentary on the move.
  - Chess games are frequently annotated with the strong move or weak move indicators
- Game moves versus commentary moves.
  - Annotators of chess games suggest alternative moves
  - Game moves are considered more reliable than commentary moves
Endgame book

- Includes all chess positions with five or fewer pieces on the board
- Includes selected positions with six pieces
- The 30 processors in the system each contained the 4-piece and some important 5-piece databases on their local disk
- The rest were accessible through a 20GB raid storage
- Endgames were stored in the databases with one bit per position
- Not very useful against Kasparov
  - only used in 1 of the 6 matches
Time control

- Two time targets set before calculations
  - Normal target time
    - Time remaining/moves remaining
      - 40 moves in 2 hours against Kasparov
  - Panic target time
    - ⅓ time remaining
- Some buffer room was built into the calculations
Time control

- Under normal situations when the normal target time expires the best move is played
- Goes to panic time when the current best move is below a certain threshold
- Stops when
  - New move is found within the threshold
  - The iteration is completed
  - The panic time target is reached
- Went into panic time only once against Kasparov
References

- https://pdfs.semanticscholar.org/ad2c/1effcd7c3b7106e507396bd1a5fe00fa597.pdf
- https://upload.wikimedia.org/wikipedia/commons/thumb/9/91/AB_pruning.svg/400px-AB_pruning.svg.png
- https://chessprogramming.wikispaces.com/Alpha-Beta
- https://chessprogramming.wikispaces.com/Deep+Blue
- https://chessprogramming.wikispaces.com/Quiescence+Search
- BOOK: Deep Blue: An Artificial Intelligence Milestone