AI in Computer Chess

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CERCIA

History of Computer Chess

- “The Turk” – Baron Wolfgang von Kempelen – Early 19th Century
- First *real* algorithm – Turing (1947)
- 1948 – UNIVAC was supposedly “unbeatable”!
- 1952 – Turing postulated that computers would eventually become more powerful than humans
- 1958 – First victory for computer vs. human
- 1966 – Russian program beats US program
- 1968 – David Levy’s famous 10 year bet
- 1970 – First ever all-computer tournament

History (continued…)

- 1977 – ICCA founded
- 1977 – GM Michael Stean loses in blitz to a computer
- 1981 – Cray Blitz wins Mississippi state championship with perfect 5.0 score
- 1988 – DEEP THOUGHT shares top place in US Chess Championship
- 1992 – Fritz 2 defeats (W-C) Kasparov in speed chess
- Feb 1996 – Kasparov beats IBM Deep Blue (4 – 2)
- May 1997 – Deep Blue defeats Kasparov (3.5 – 2.5)
- Oct 2002 – Deep Fritz draws with (W-C) Kramnik 4-4 in “Brains in Bahrain” match
- Jan 2004 – ChessBrain plays 1st match against GM Nielsen

How Chess Programmes Work

Board representation

Tree search

Board Evaluation

Precalculated Data

http://www.chessbrain.net/

http://www.frayn.net/beowulf/theory.html

(1)
Board Representation

Algebraic Board Notation

	A	B	C	D	E	F	G	H
8								
7								
6								
5								
4								
3								
2								
1								

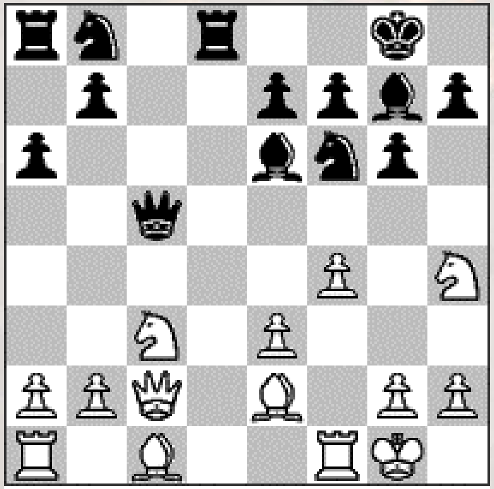
Information to be Stored

- Board position (location of all pieces)
- En-passant square, if any
- Castling permissions
- Draw by repetition / 50-move stats (often stored outside the board structure)
- Side to move

Board Storage

- 8*8 integer array with piece keys
- [-6 <= p <= 6] e.g. empty=0, wpawn=1, bpawn=-1
- Extended board representation
- 12*12 integer array with border to save branches when testing move legality
- Bitboard representation – Now used by all major commercial programmes:
- Represent board using a set of 64-bit numbers.

Bitboard Example



ChessBrain vs. cbexp
Move #14 White to move

White Pawns :

0000000000000000 00000000 00000000 0000010000001000 11000011 00000000

Black Pawns :

0000000001001101100000010000000000000000000000000000000000000000

Etc…

- For each board position : 12 Bitboards (12 * 64 bits) + Castling (4 bits) + side to move (1 bit) + E-P square (6 bits) = 779 bits (98 bytes)   [c.f. other methods]

- Can improve this e.g. no need to store BB for kings

Bitboards

- Complex, but fast (esp. on 64-bit arch.)
- Board is stored using 12 64-bit numbers

  (One per colour per piece-type)
- Move generation is now much quicker

  e.g. Pseudo-legal pawn moves :

  ```
  SimplePawnMove = (PawnWhite>>8) & ~(AllPieces)
  ```
- Sliding moves are more complicated, but still very fast

Bit Operations

- OR – Combine two boards
- AND – Use a mask on a board
- XOR – Flip bits on a board

OR	0	1
0	0	1
1	1	1

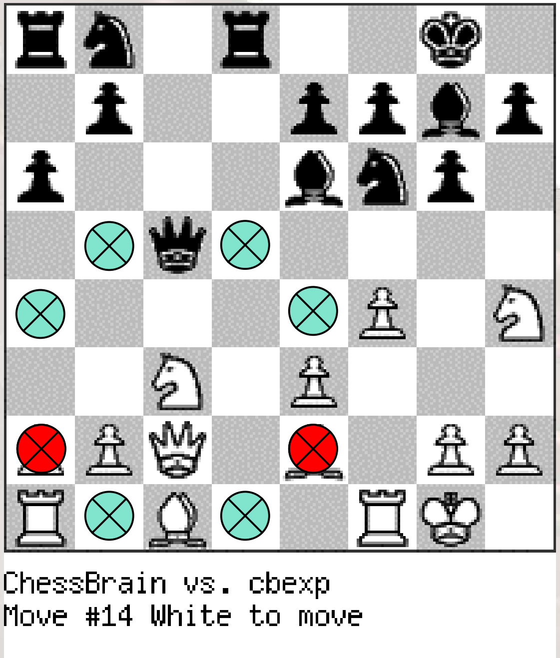
&	0	1
0	0	0
1	0	1

^	0	1
0	0	1
1	1	0

```
#define Remove(a,b)  ((a) = (a^(1<<b)))
#define RemoveFirst(a)   ((a) = ((a) & ((a)-1)))
```

```
int FirstPiece(BITBOARD B) {
  if (B&TwoFullRanks) return first_piece[B&TwoFullRanks];
  if (B&FPMask1) return first_piece[(B >> 16)&TwoFullRanks] + 16;
  if (B&FPMask2) return first_piece[(B >> 32)&TwoFullRanks] + 32;
  return first_piece[B >> 48] + 48;
}
```

```
/* Generate White Knight Moves */
Knights = B->WhiteKnights;
/* 'Knights' holds a board of all possible knights */
while (Knights) {
   /* Get the first available knight */
   from = FirstPiece(Knights);
   /* Mask out illegal moves */
   Dest = KnightMoves[from] & ~(B->WhitePieces);
   /* Add potential moves to global movelist */
   AddMovesToList(from,Dest);
   /* Remove this knight from the list */
   RemoveFirst(Knights);
}
```



0000000000000000000000000101000010001000000000000000000001010000

```
/* Generate Black Rook Moves */
Rooks = B->BlackRooks;
/* 'Rooks' holds a board of all possible rooks */
while (Rooks) {
    from = FirstPiece(Rooks);
    /* First generate horizontal moves */
    mask = (B->All >> (Rank(from)*8)) & FullRank;
    Dest = MovesRank[from][mask];
    /* Next generate vertical moves */
    mask = (B->R90 >> (File(from)*8)) & FullRank;
    Dest |= MovesFile[from][mask];
    /* Mask out illegal moves */
    Dest &= ~(B->BlackPieces);
    /* Add potential moves to global movelist */
    AddMovesToList(from,Dest);
    /* Remove this rook from the list */
    RemoveFirst(Rooks);
}
```

H = 11010010	V = 10000000
01111110	11111111
00101100	01111111

Making a Simple Knight Move

```
/* Sort out the new board state */
B->WhiteKnights ^= Mask[from] | Mask[to];
/* Test for Capture */
switch (CapturedPiece) {
   case (bpawn)  : B->BlackPawns ^= Mask[to]; break;
   case (brook)  : B->BlackRooks ^= Mask[to]; break;
   case (bknight): B->BlackKnights ^= Mask[to]; break;
   case (bbishop): B->BlackBishops ^= Mask[to]; break;
   case (bqueen) : B->BlackQueens ^= Mask[to]; break;
}
/* Check for alterations to castling permissions */
switch(from) {
  case (a1): B->castle &= 13; break;
  case (h1): B->castle &= 14; break;
  case (e1): B->castle &= 12; break;
}
switch(to) {
   case (a8): B->castle &= 7; break;
   case (h8): B->castle &= 11; break;
}
```

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Tree Search

Tree Search Fundamentals

- Computers work recursively, like humans
- Computers have no (little) intuition

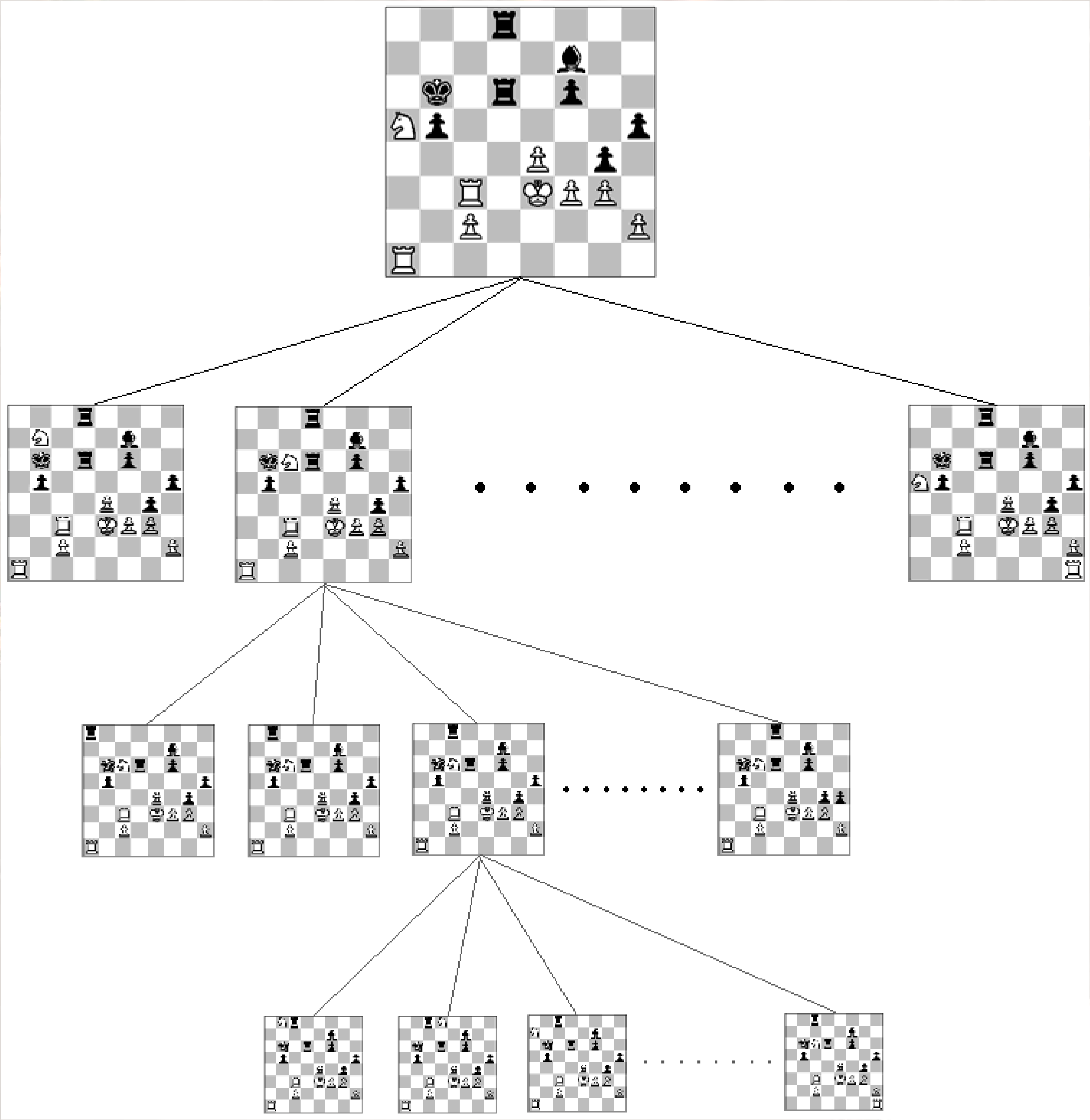
…so must work by (intelligent) brute force

(**Q**) Which is the best move in any position?

(**A**) The one with the weakest ‘best reply’

Note : This is *not* (always) the move with the best chances

Search Recursion



Termination of the Search

We could continue this recursive search forever BUT it is going to get prohibitively slow.

Average branching factor = 35

Average game length = 50 moves

$$\text{Total Nodes} = 35^{50*2} \approx 10^{154}$$

(There have been $5 * 10^{17}$ seconds so far…)

So we must terminate the search prematurely

Quiescence Search

We can’t just “stop searching”

- The Horizon effect
- Perform a quiescence search until the board is ‘calm’!
- Search only ‘non-quiescent’ moves (to a maximum depth)

Definitions vary. I use:

- Captures
- Pawn promotions (or near-promotions)
- Checking moves

Iterative Deepening

- Start with a shallow search
- Using information from this search, look slightly deeper
- Keep increasing the depth until we run out of time, or find a definite outcome
- This is the most efficient way to search
- May look wasteful, but safeguards against extremely damaging mistakes!
- Allows us to use knowledge to improve searches

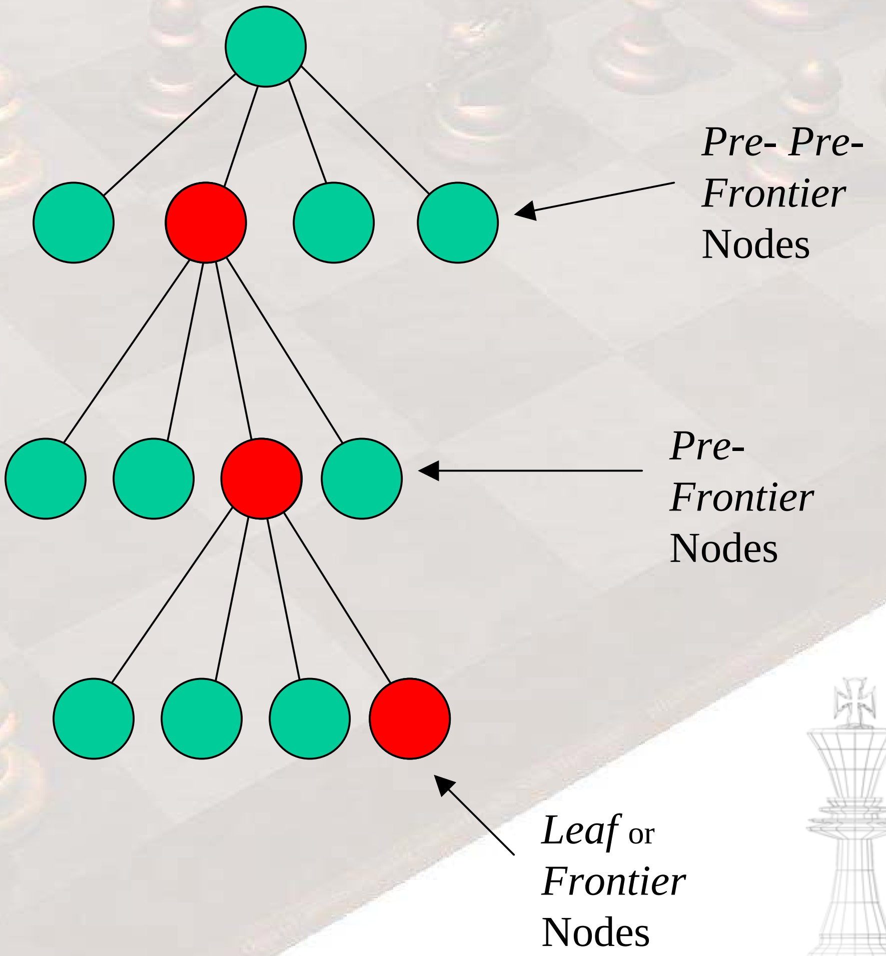
Tree Pruning

Depth	**Node Count**	**Search Time**
2 ply	900	0.005s
3 ply	27,000	0.14s
4 ply	810,000	4.05s
5 ply	24,300,000	2 mins
6 ply	729,000,000	1 hour
7 ply	21,870,000,000	30 hours
8 ply	656,100,000,000	38 days

Branching factor 30, evaluating 200,000 nodes/sec

Tree Pruning Methods

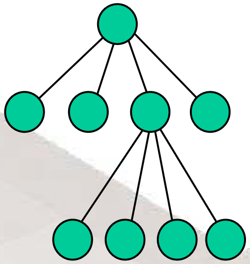
- Negamax Search
- Iterative Deepening
- Alpha-Beta Pruning
- Principal Variation Search
- Aspiration Windows
- Transposition Table
- Killer Moves
- History Heuristic
- Internal Iterative Deepening
- Null Move Heuristic
- Futility Pruning
- Razoring
- Search Extensions
- etc….



Alpha-Beta Search

- Enormously reduces search tree size
- Alpha-beta pruning is just a complicated-sounding name for “**Don't check moves which cannot possibly have an effect on the outcome of your search**.”
- Reduces the branching factor from 30-40 to 6-7. Approximately doubles search depth.
- Absolutely vital to any strong engine

Alpha-Beta Continued…



Imagine we're searching all the possible moves in a position and the best move so far scores +15 centipawns.

We continue to the next move and start examining the opponent's replies:

-20,-22,-19,-16,-11,-18,-20,-30,-70,-75,-55,-2,-628,-M3

We abort as soon as we get to the '-11'

Doesn't matter what the rest of the moves score – the '-11' is already *good enough* even though the opponent can actually do better (-2)

Best moves should be as near the front as possible!

Alpha-Beta Pseudo-code

```
initially alpha = -INFINITY, beta=INFINITY

search(position,side,depth,alpha,beta) {

  best_score = -INFINITY

  for each move {
    do_move(position, move)

    if ( depth is 0 ) move_score = static_score(position, side)
    else move_score = - search(position, opponent side, depth-1, -beta, -alpha)

    undo_move(position,move)

    if ( move_score > best_score ) best_score = move_score
    if ( best_score > alpha ) alpha = best_score
    if ( alpha >= beta ) return alpha
  }
  return best_score
}
```

Transposition Table

- To save calculation, there is no point evaluating positions that we've seen before!
- Every result is stored on a priority basis (most expensive first, most important first)
- Replacement schemes vary
- When we find a 'hit' we see if we can make use of the new information
- Must be careful about depths and bounds
- Makes sense with Iterative Deepening
- Individual key for each board position (we hope – clashes do happen)
- Key is generated using XOR of 64 random numbers

Other Tree Pruning Algorithms

- History Heuristic
- Killer Moves Heuristic
- Razoring
- Extensions
- Window search
- Null move search

(3)
Board Evaluation

Static Board Evaluation

- A computer has no *a priori* chess knowledge
- Humans evaluate positions using numerous methods (‘intuition’)
- The goal of computer chess is to mimic the concept of intuition
- Brute force vs. Intelligence
- Diminishing returns in brute force?
- The intelligent way to proceed – add knowledge

A typical board evaluation

Current Position

White Points: 39
Black Points: 39
(Even Sides)

Lazy Eval

Game Stage = 0   [0=Opening, 5=Late Endgame]

Material Eval : 0
Positional Eval : 0

Total Lazy Eval : 0

Full Eval

Square a8 [r] : Blocked -3, HBlock 1, [-5]
Square b8 [n] : Opp.KTrop. -10, Bad Develop. -12, [-19]
Square c8 [b] : Bad Develop. -12, Mobility -12, [-24]
Square d8 [q] : KAtt 3, Trapped -10, Quarts 0 (-15), [-22]
Square e8 [k] : {bqbnppppp DEF=6, Sh 3 [43]}, [43]
Square f8 [b] : Bad Develop. -12, Mobility -12, [-24]
Square g8 [n] : Opp.KTrop. -9, Bad Develop. -12, [-19]
Square h8 [r] : Blocked -3, HBlock 1, [-5]
Square a7 [p] : DEF=1, DefSc 4, [4]
Square b7 [p] : DEF=1, DefSc 4, [4]
Square c7 [p] : DEF=1, DefSc 4, [4]
Square d7 [p] : DEF=4, DefSc 16, [16]
Square e7 [p] : DEF=4, DefSc 16, [16]
Square f7 [p] : DEF=1, DefSc 4, [4]
Square g7 [p] : DEF=1, DefSc 4, [4]
Square h7 [p] : DEF=1, DefSc 4, [4]

Square a6 [.] : -3
Square b6 [.] : -4
Square c6 [.] : -4
Square d6 [.] : -4
Square e6 [.] : -4
Square f6 [.] : -4
Square g6 [.] : -4
Square h6 [.] : -3
Square a5 [.] : 0
Square b5 [.] : 0
Square c5 [.] : 0
Square d5 [.] : 0
Square e5 [.] : 0
Square f5 [.] : 0
Square g5 [.] : 0
Square h5 [.] : 0
Square a4 [.] : 0
Square b4 [.] : 0
Square c4 [.] : 0
Square d4 [.] : 0
Square e4 [.] : 0
Square f4 [.] : 0
Square g4 [.] : 0
Square h4 [.] : 0
Square a3 [.] : 3
Square b3 [.] : 4
Square c3 [.] : 4
Square d3 [.] : 4
Square e3 [.] : 4
Square f3 [.] : 4
Square g3 [.] : 4
Square h3 [.] : 3

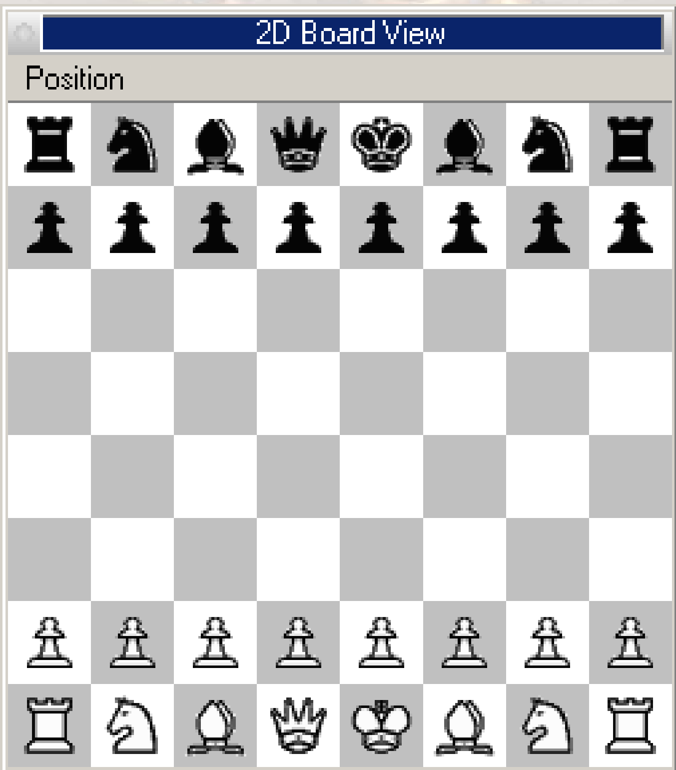
Square a2 [P] : DEF=1, DefSc 4, [4]
Square b2 [P] : DEF=1, DefSc 4, [4]
Square c2 [P] : DEF=1, DefSc 4, [4]
Square d2 [P] : DEF=4, DefSc 16, [16]
Square e2 [P] : DEF=4, DefSc 16, [16]
Square f2 [P] : DEF=1, DefSc 4, [4]
Square g2 [P] : DEF=1, DefSc 4, [4]
Square h2 [P] : DEF=1, DefSc 4, [4]
Square a1 [R] : Blocked -3, HBlock 1, [-5]
Square b1 [N] : Opp.KTrop. -10, Bad Develop. -12, [-19]
Square c1 [B] : Bad Develop. -12, Mobility -12, [-24]
Square d1 [Q] : KAtt 3, Trapped -10, Quarts 0 (-15), [-22]
Square e1 [K] : {PPPPPBQBN DEF=6, Sh 3 [43]}, [43]
Square f1 [B] : Bad Develop. -12, Mobility -12, [-24]
Square g1 [N] : Opp.KTrop. -9, Bad Develop. -12, [-19]
Square h1 [R] : Blocked -3, HBlock 1, [-5]
After Piece Tactics : 0
Control Balance = 0

Effective Castling : NONE
White Not Castled -8
Black Not Castled 8
White centre pawns : 6
Black centre pawns : 6
Positional Score : 0
White has a bishop pair [+15]
Black has a bishop pair [-15]
Final Score : 0   [Delta 0]

Static Analysis Score
Exactly Even Sides

Approx. 3,200 lines!

Evaluating Defences



0	-1	-1	-1	-1	-1	-1	0
-1	-1	-1	-4	-4	-1	-1	-1
-2	-2	-3	-2	-2	-3	-2	-2
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
2	2	3	2	2	3	2	2
1	1	1	4	4	1	1	1
0	1	1	1	1	1	1	0

(White +0.00)

Rnbqkbnr/pppppppp/8/8/8/8/PPPPPPPP/RNBQKBNR w KQkq -

Evaluating Defences 2

0	-2	-2	-2	-2	-2	-2	0
-2	-1	-1	-4	-4	-1	-1	-2
-1	-1	1	-2	-1	-2	-2	0
-2	1	-1	1	-2	1	1	0
2	-1	1	0	0	1	-1	0
1	3	1	3	2	3	2	0
2	1	2	3	5	1	0	1
0	2	2	2	2	3	1	0

(White +0.41)

r1bqkb1r/1p2pppp/p1np1n2/1B6/3NP3/2N5/PPP2PPP/R1BQK2R w KQkq -

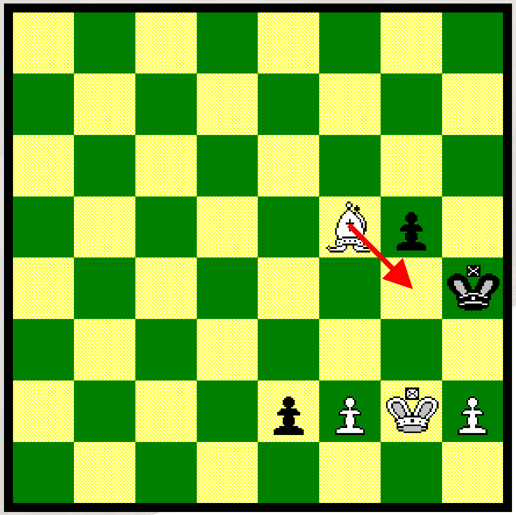
Notice Bb5!

What else is in the Eval?

- Individual positional bonuses for each piece
- Specific bonuses for piece tactics
- King safety
- Board control
- Passed pawns
- Endgame evaluation
- Special cases / positional knowledge

Knowledge vs. Strength

- Trade off eval complexity versus tactical search speed
- We are beginning to see diminishing returns
- Way forward – Moore’s Law & advanced analysis
- Expert testing
- ‘Never Tests’



V. Chekover, 1952

White to play and draw

(4)
Precalculated Data

Internal Precalculations

- Lots of algorithms require precalculated data
- E.g. sliding piece moves, knight moves, masks, corner avoidance
- King area, square control, positional weighting
- Penalties / bonuses based on game stage
- Hash table initialisation

Opening Books

- All professional programs use these
- The opening position is too complicated
- Often strategies prove good/bad after 20-30 moves
- Usually generated from GM game databases
- Saves computation time
- Can be tweaked by a GM-level player

Endgame Tablebases

- Allow perfect play for the very end of the game
- 2-piece is a trivial draw
- 3-piece is fairly simple (381k)
- 4-piece is significantly larger (40Mb compressed)
- 5-piece is huge (8.2Gb compressed)
- 6-piece (Computational time & size prohibitive – 1.2Tb?)
- Most games are over well before this stage (but allows computer to use obscure tactics)
- Longest forced CM (3-, 4-, 5-piece) = 56, 85, 254 moves. Unknown for 6-piece.
- More examples – e.g. longest forced mate from underpromotion = 199 plies (5-piece)

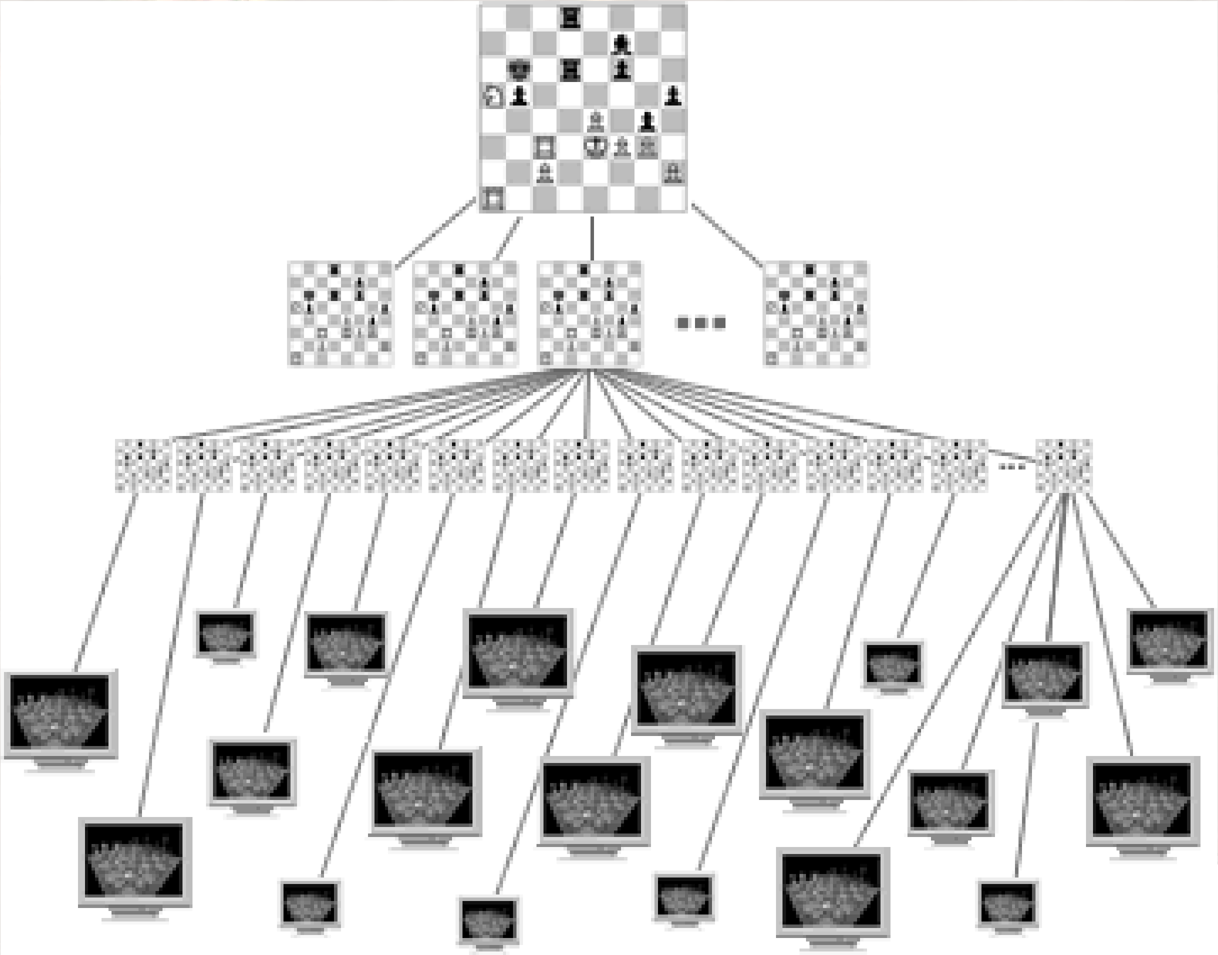
(5)
The ChessBrain Project

Project Overview

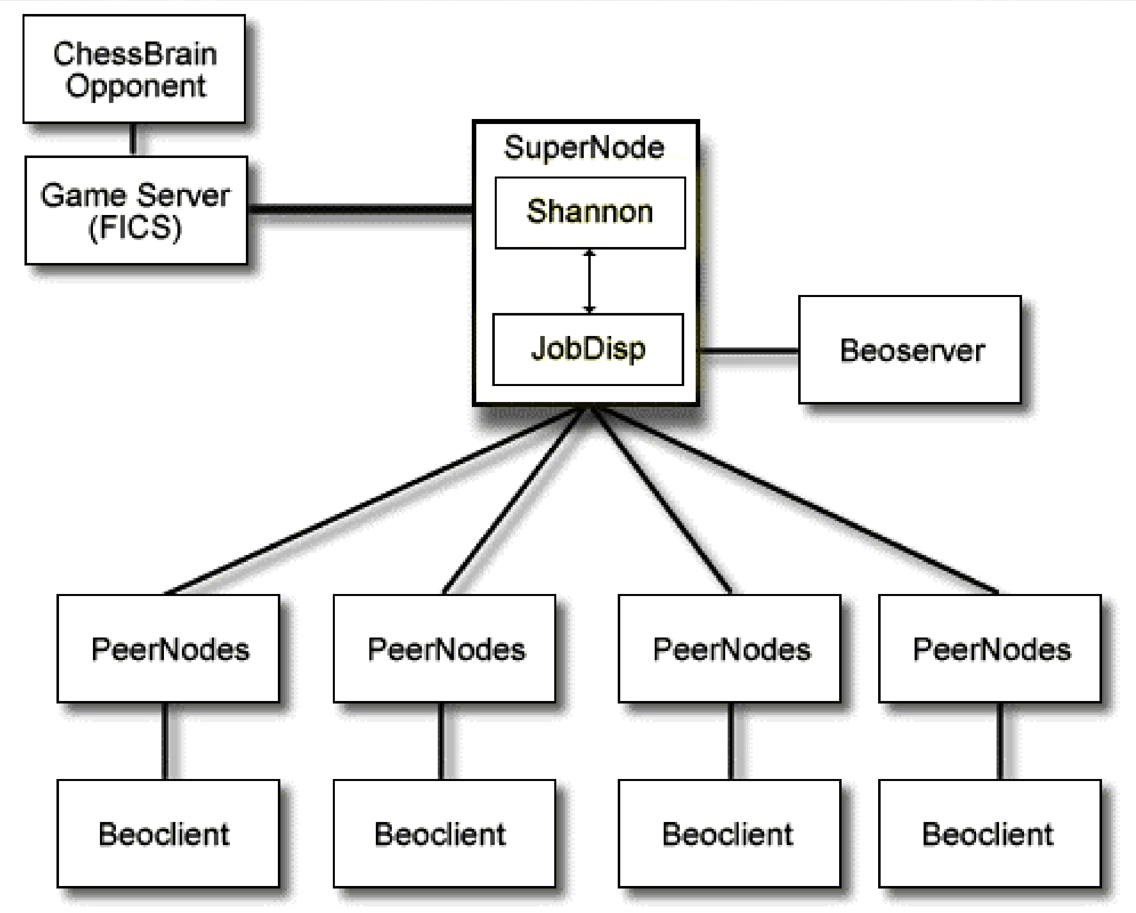
- ChessBrain was founded in January 2002 by Carlos Justiniano
- CMF joined in summer 2002
- ChessBrain played its first ever match just after Christmas 2002
- ChessBrain is the world’s leading distributed chess project

http://www.chessbrain.net/

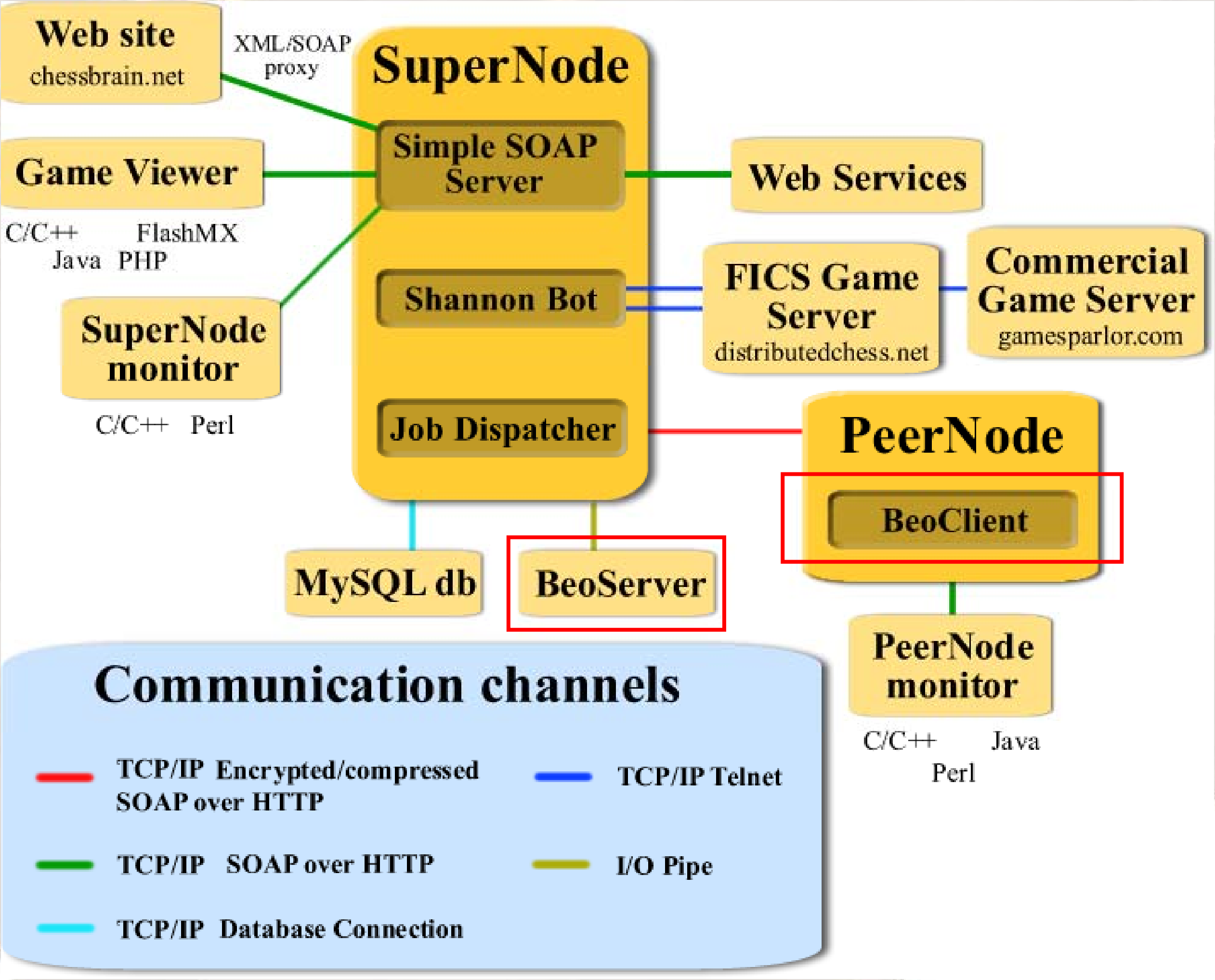
How does it work?



Internal Structure 1



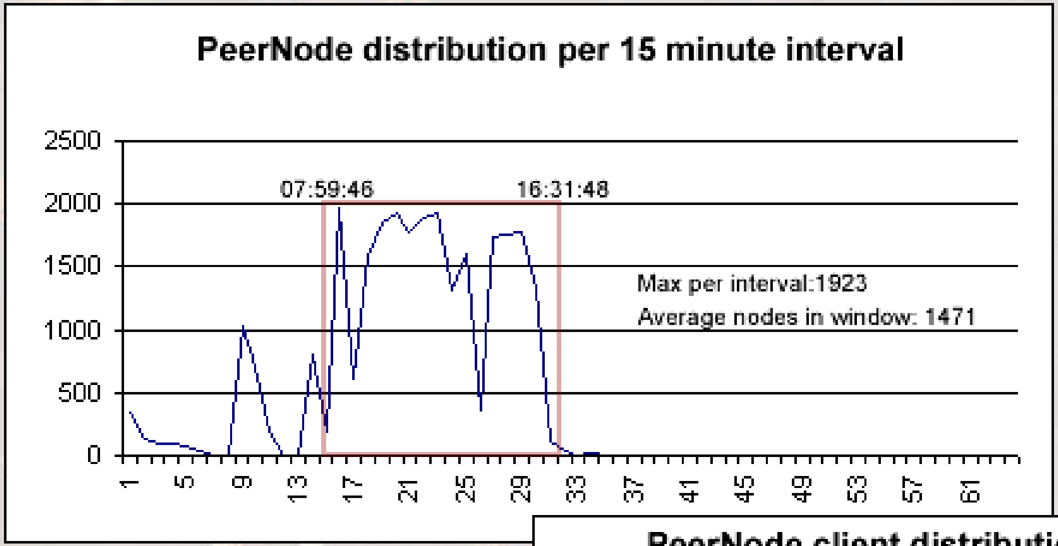
Internal Structure 2

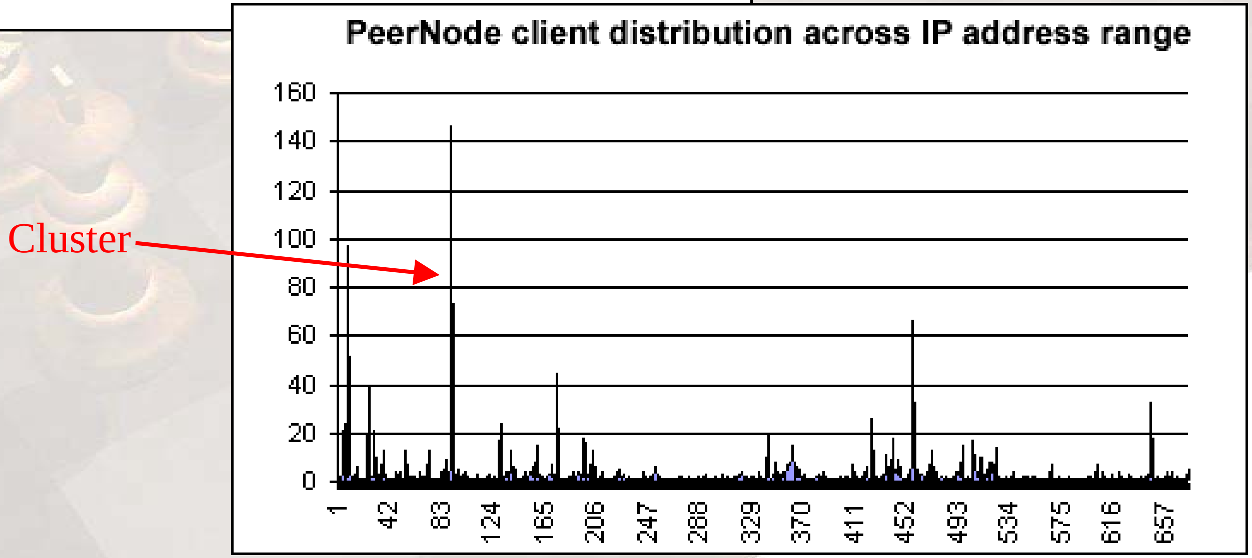


World Record Attempt

- Friday 30th January, 2004 in Copenhagen, Denmark
- Opponent was Peter Heine Nielsen (#1 in Denmark, 2620 ELO)
- The game lasted 34 moves
- 2,070 individual contributors from 56 countries
- The result was an agreed draw
- Official Guinness World Record

Some game statistics





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The End?

The Future

- Chess will almost certainly NEVER be solved
- EGTBs are already getting too large – it is unlikely that anyone will use more than 6-man TBs
- Computers are now as good as the world champion.
- Processing power is linked to playing strength (*2 speed = ~+75 ELO points)
- GM players only analyse 2 or 3 positions per second!
- Diminishing returns – the future is in creating more “human” evaluation functions
- They will be in a league of their own within 5 years
- Chess as a test for complex computational frameworks?

Questions