Terminal Chess

by **Mini-Max Search**

& Parallelized **Alpha-Beta Pruning**

0310006
0310015
0310030
0312236

Content

- What is Minmax Search and Alpha-Beta Pruning
- Chess implementation
  - Bit board
  - Evaluation
  - Search
- Paralleling Mini-Max Search
- Result and Conclusion

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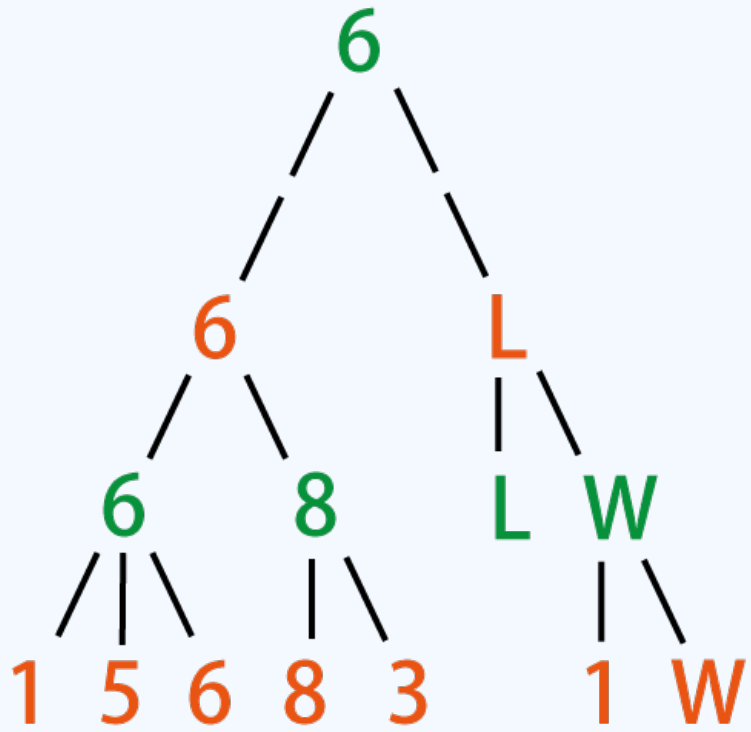
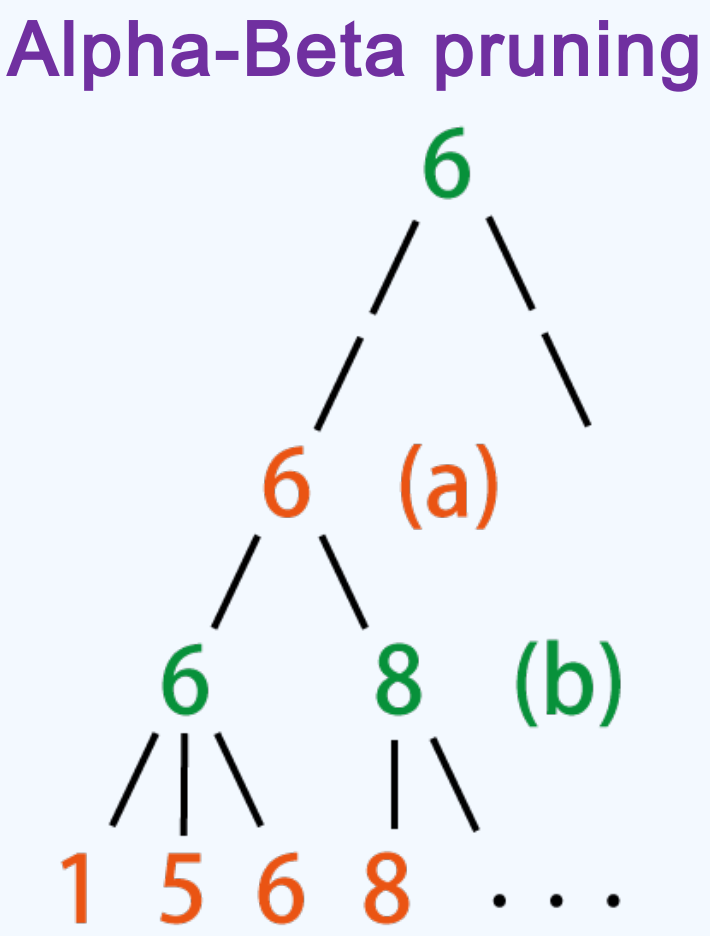
Mini-Max Search

```
(* the minimax value of n, searched to depth d *)

fun minimax(n: node, d: int): int =
if leaf(n) or depth=0
        return evaluate(n)
if n is a max node
        v := L
        for each child of n
                v' := minimax (child,d-1)
                if v' > v, v:= v'
        return v
if n is a min node
        v := W
        for each child of n
                v' := minimax (child,d-1)
                if v' < v, v:= v'
        return v
```



Alpha-Beta Pruning

```
(* the minimax value of n, searched to depth d.
 * If the value is less than min, returns min.
 * If greater than max, returns max. *)

fun minimax(n: node, d: int, min: int, max: int): int =
if leaf(n) or depth=0
        return evaluate(n)
if n is a max node
        v := min
        for each child of n
                v' := minimax (child,d-1,v,max)
                if v' > v, v:= v'
                if v > max return max
        return v
if n is a min node
        v := max
        for each child of n
                v' := minimax (child,d-1,min,v)
                if v' < v, v:= v'
                if v < min return min
        return v
```



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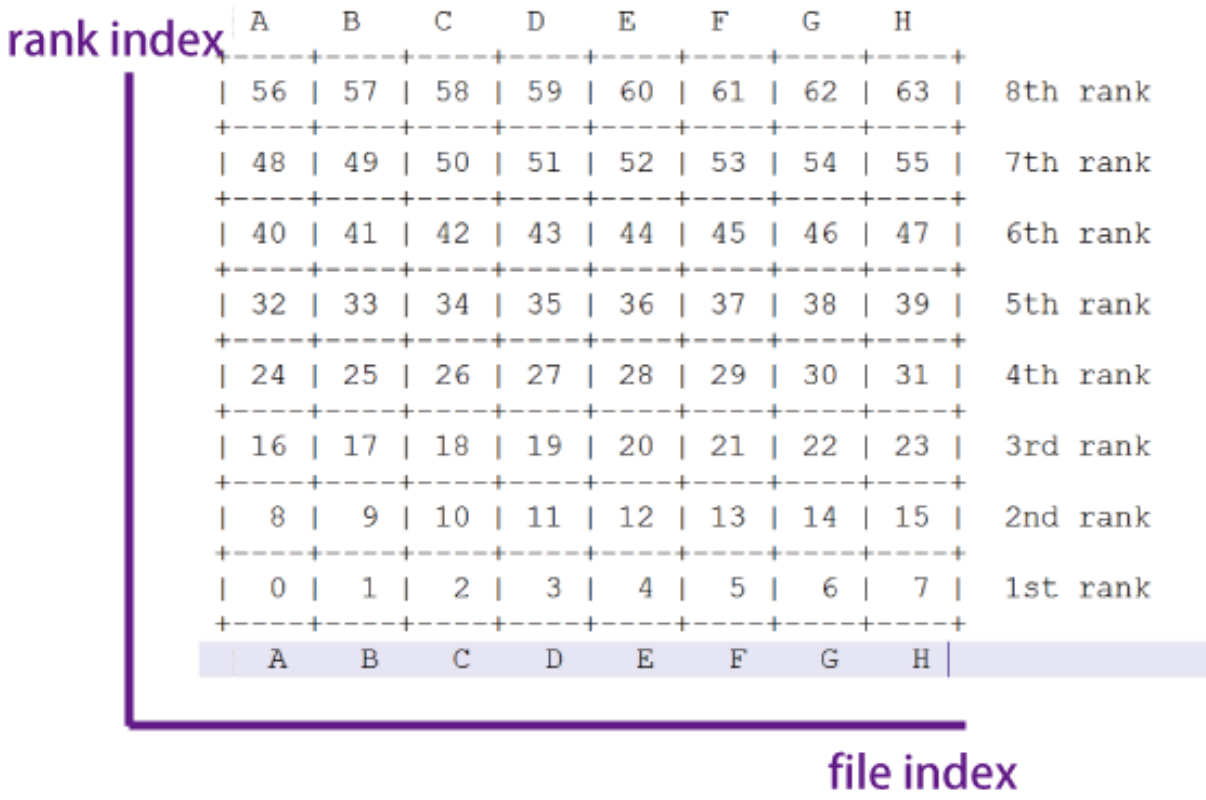
Bit Board

```
int boardMap[64] ;
map<int,Piece*> pieceMap;
```

squareIndex = 8 * rankIndex + fileIndex

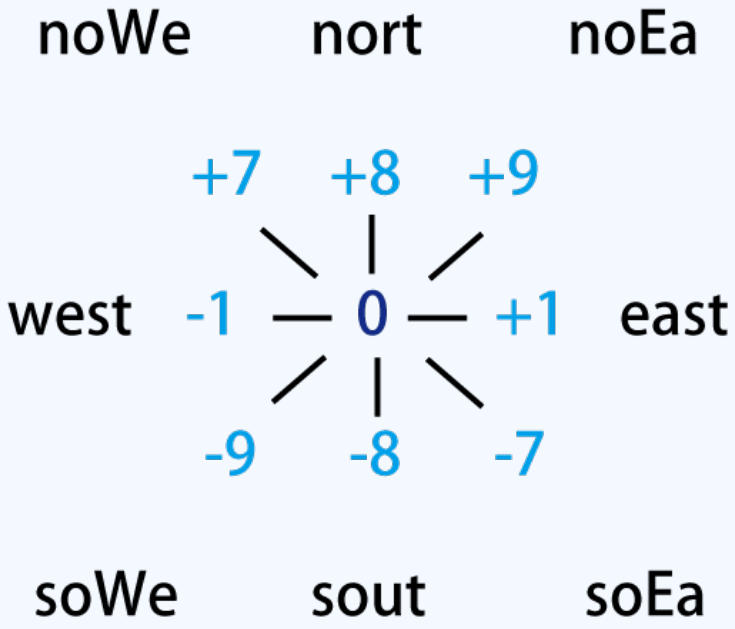
rankIndex = squareIndex div 8

fileIndex = squareIndex mod 8



Bit Board

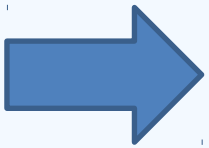
```
enum enumSquare {
 a1,  b1,  c1,  d1,  e1,  f1,  g1,  h1,    // 0 .. 7
 a2,  b2,  c2,  d2,  e2,  f2,  g2,  h2,    // 8 .. 15
 a3,  b3,  c3,  d3,  e3,  f3,  g3,  h3,    // 16 .. 23
 a4,  b4,  c4,  d4,  e4,  f4,  g4,  h4,    // 24 .. 31
 a5,  b5,  c5,  d5,  e5,  f5,  g5,  h5,    // 32 .. 39
 a6,  b6,  c6,  d6,  e6,  f6,  g6,  h6,    // 40 .. 47
 a7,  b7,  c7,  d7,  e7,  f7,  g7,  h7,    // 48 .. 55
 a8,  b8,  c8,  d8,  e8,  f8,  g8,  h8     // 56 .. 63
};
```



Evaluation

- Score is based on the position on the chessboard

```
int score_pawn[64]  =   {
        0,   0,   0,   0,   0,   0,   0,   0,
        50,  50,  50,  50,  50,  50,  50,  50,
        10,  10,  20,  30,  30,  20,  10,  10,
        5,   5,  10,  25,  25,  10,   5,   5,
        0,   0,   0,  20,  20,   0,   0,   0,
        5,  -5, -10,   0,   0, -10,  -5,   5,
        5,  10,  10, -20, -20,  10,  10,   5,
        0,   0,   0,   0,   0,   0,   0,   0
};
```



0	0	0	0	0	0	0	0
50	50	50	50	50	50	50	50
10	10	20	30	30	20	10	10
5	5	10	25	25	10	5	5
0	0	0	20	20	0	0	0
5	5	10	0	0	10	5	5
5	10	10	-20	-20	10	10	5
0	0	0	0	0	0	0	0

8

8

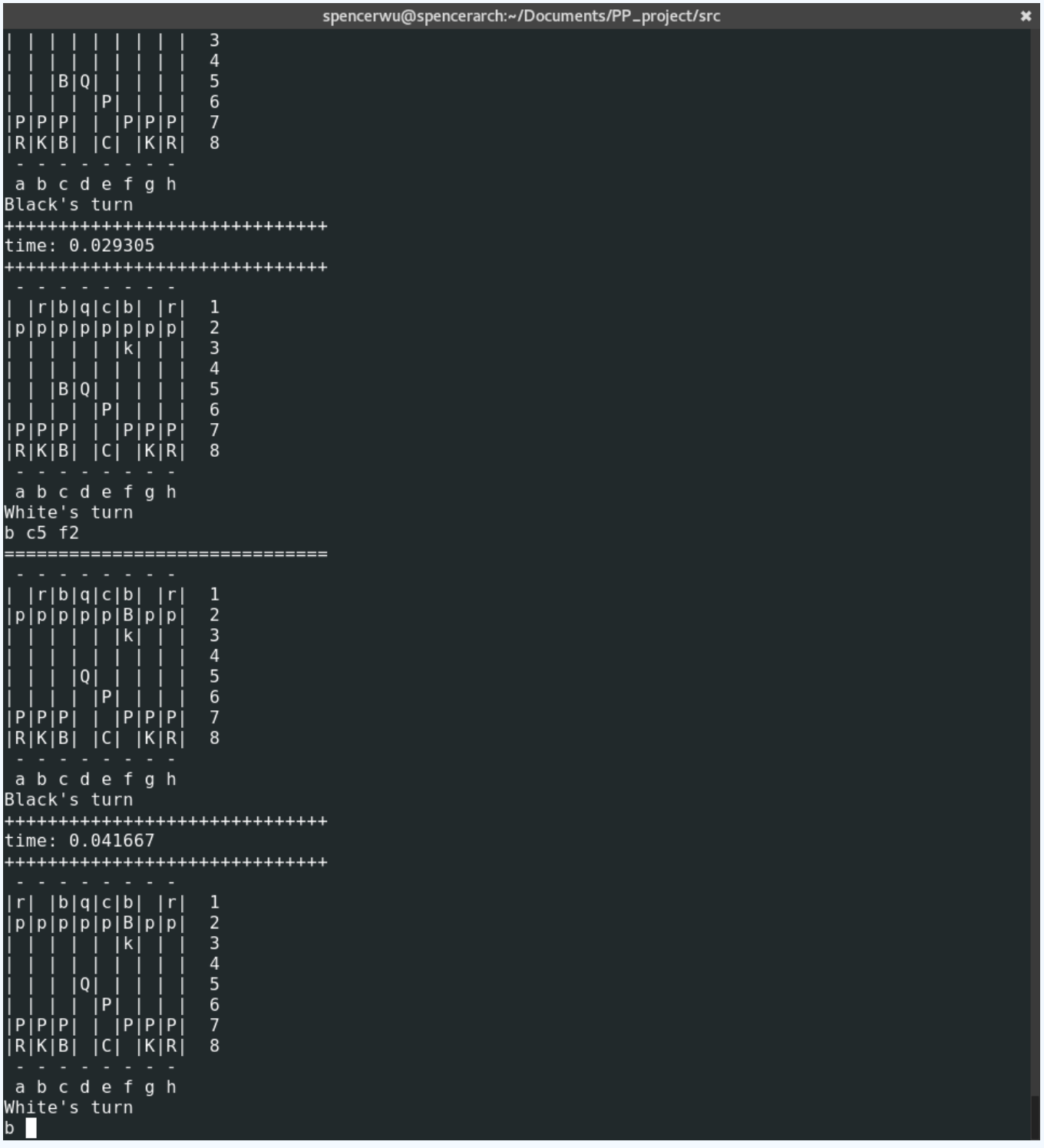
```
int ChessBoard::eval(int color){
    // color: white 0 negative, black 1 positive
    int eval=0;
    for(int i = 0 ; i < 64 ; i++){
        eval += myscore.score[boardMap[i]][i];
    }
    return eval;
}
```

Mini-Max Search

```
29 static ChessBoard* _MinMaxMove(ChessBoard* board, int dept_limit, int dept, enum FindAction action) {
30     vector<ChessBoard*> moves;
31     ChessBoard* best_move = NULL;
32     int best_real_move = 0;
33     ChessBoard* move = NULL;
34 
35     if (dept >= dept_limit) {//if depth limit is reached
36         return board;
37     }
38     moves = board->listAllMove(action);
39     for (int i = 0; i < moves.size(); i++) {
40         move = _MinMaxMove( moves[i], dept_limit, dept+1, child(action));
41         if (best_move == NULL || cmp_move(action, move, best_move)) {
42             best_move = move;
43             best_real_move = i;
44         }
45     }
46 
47     ChessBoard* res = new ChessBoard;
48     *res = *moves[best_real_move];
49     for (int i = 0; i < moves.size(); i++) {
50         delete moves[i];
51     }
52     return res;
```

Alpha-Beta Search

```
12 ChessBoard* ABMinMaxMove(ChessBoard* board, int dept_limit, int dept, enum FindAction action, int alpha, int beta)
13 {
14     if (dept >= dept_limit) {//if depth limit is reached
15         return board;
16     }
17
18     vector<ChessBoard*> moves = board->listAllMove(action);
19     ChessBoard* best_move = NULL;
20     int best_real_move = 0;
21     for (int i = 0; i < moves.size(); i++) {
22         ChessBoard* move = ABMinMaxMove( moves[i], dept_limit, dept+1, child(action), alpha, beta);
23         if (best_move == NULL || cmp_move(action, move, best_move)) {
24             best_move = move;
25             best_real_move = i;
26             if ( child(action) == FIND_MAX ) {
27                 beta = move->eval(BLACK); // upper bound
28             } else {
29                 alpha = move->eval(WHITE); // lower bound
30             }
31         }
32         if (alpha > beta){
33             break;
34         }
35     }
36     ChessBoard* res = new ChessBoard;
37     *res = *moves[best_real_move];
38     for (int i = 0; i < moves.size(); i++) {
39         delete moves[i];
40     }
41     return res;
42 }
43
44
```


spencerwu@spencerarch:~/Documents/PP_project/src
| | | | | | | | | 3
| | | | | | | | | 4
| | |B|Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
Black's turn
++++++++++++++++++++++++++++++
time: 0.029305
++++++++++++++++++++++++++++++
- - - - - - - -
| |r|b|q|c|b| |r| 1
|p|p|p|p|p|p|p|p| 2
| | | | | |k| | | 3
| | | | | | | | | 4
| | |B|Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
White's turn
b c5 f2
==============================
- - - - - - - -
| |r|b|q|c|b| |r| 1
|p|p|p|p|p|B|p|p| 2
| | | | | |k| | | 3
| | | | | | | | | 4
| | | |Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
Black's turn
++++++++++++++++++++++++++++++
time: 0.041667
++++++++++++++++++++++++++++++
- - - - - - - -
|r| |b|q|c|b| |r| 1
|p|p|p|p|p|B|p|p| 2
| | | | | |k| | | 3
| | | | | | | | | 4
| | | |Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
White's turn
b

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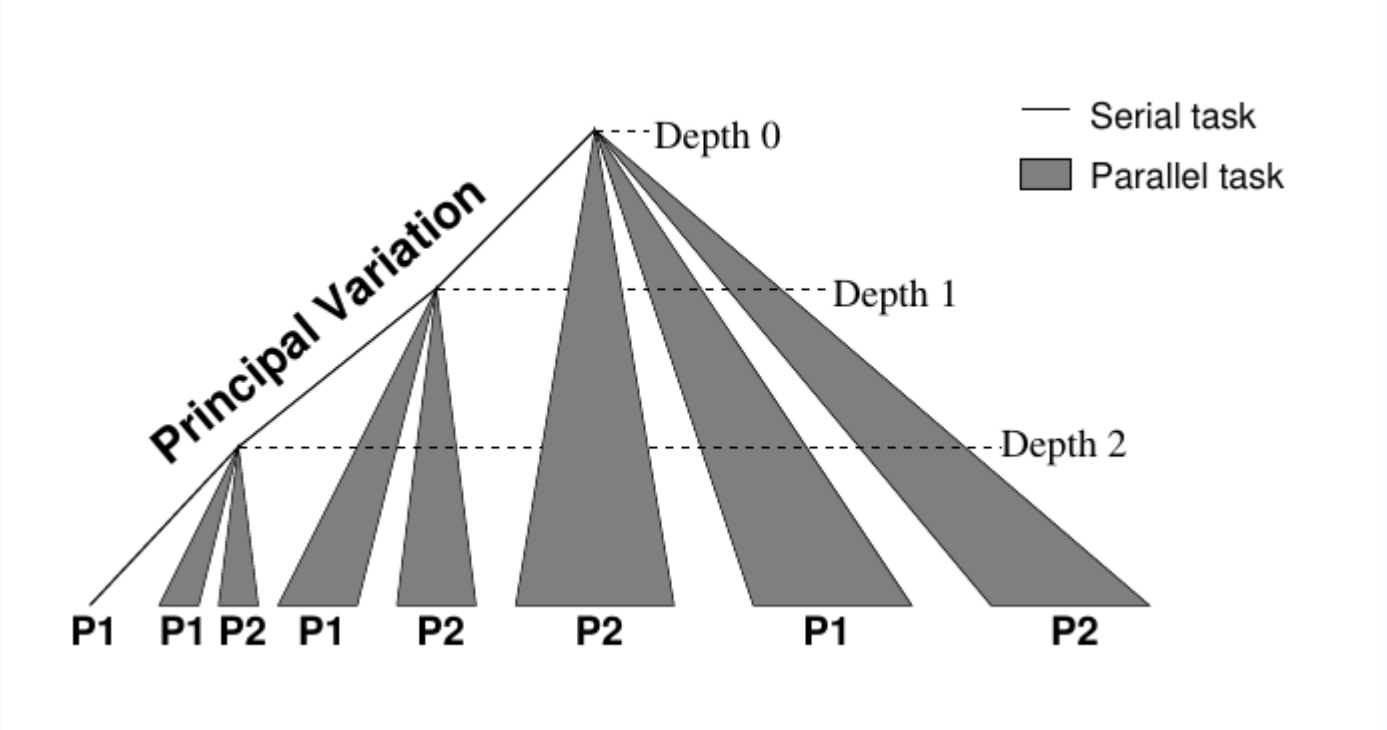
Parallelizing Alpha-beta

- PVSplit:
  - easier to implement, less scalability, poor load balan cing
- YBWC:
  - little bit better scalability
- Dynamic Tree Splitting (DTS)
  - good scalability, good load balancing
  - most of chess engines use this
  - hard to implement

PVSplit

- Principal Variation (http://iacoma.cs.uiuc.edu/~greskamp/pdfs/412.pdf)



Implementation

- pthread → glib thread pool
- use g_thread_mutex to protect saved best soluti on and alpha-beta values.

Why worse than normal A-B?

- too many threads
  - in the beginning, we try to invoke N threads at once t o avoid this.
- bad load balance
  - wait other threads to complete
- solution make this a little bit better: thread pool

Why worse than normal A-B?

- too many threads
  - in the beginning, we try to invoke N threads at once t o avoid this.
- bad load balance
  - wait other threads to complete
- solution make this a little bit better: thread pool

Bad Scalability

- idle cores
- possible solution: enhanced PVSplit (EPVS).
  - idle cores can help other cores to handle som e subtrees.
  - we haven't implemented this.
- in 16 cores, speedup is at most 6x with EPVS.
  - from the original research

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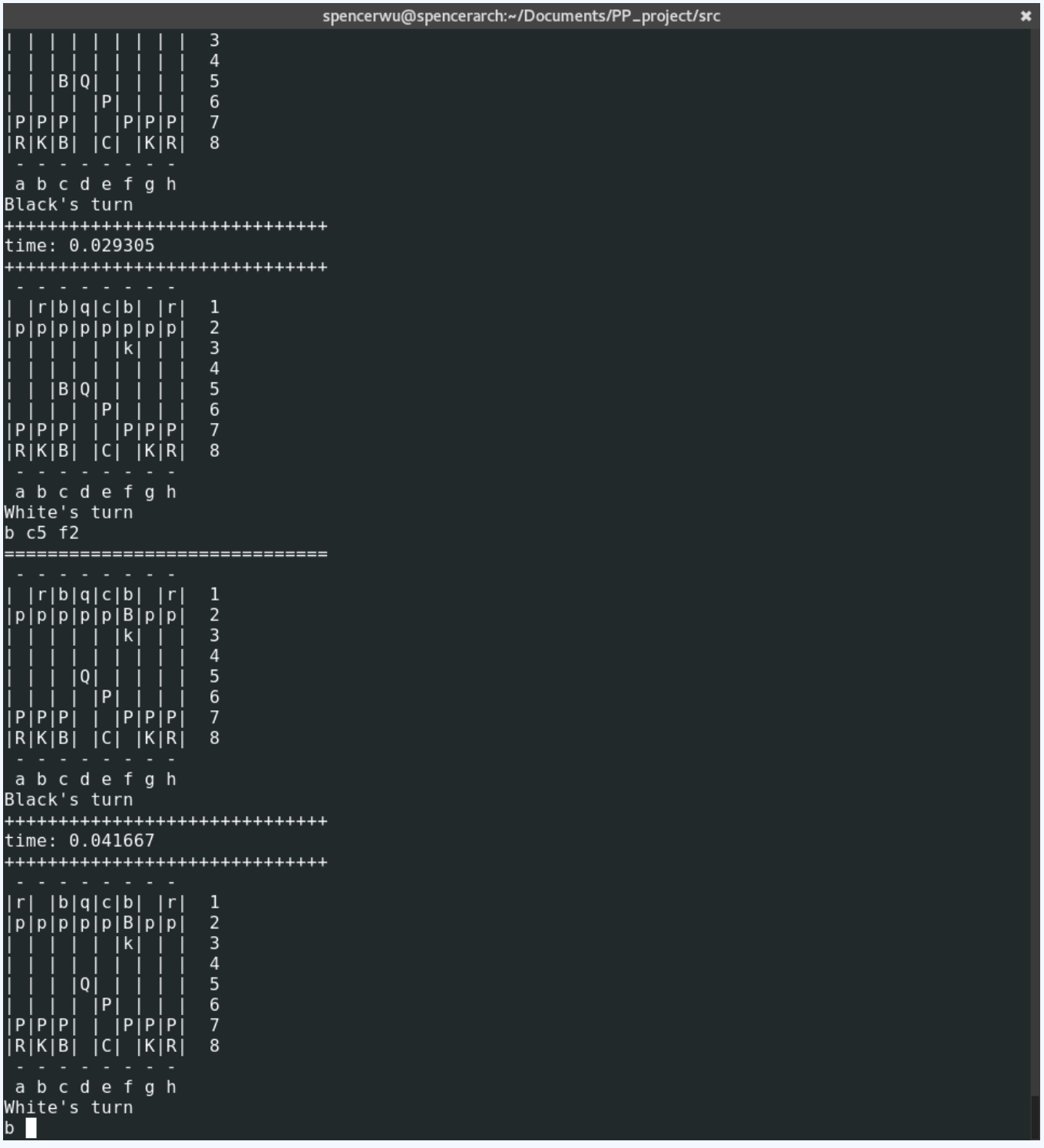
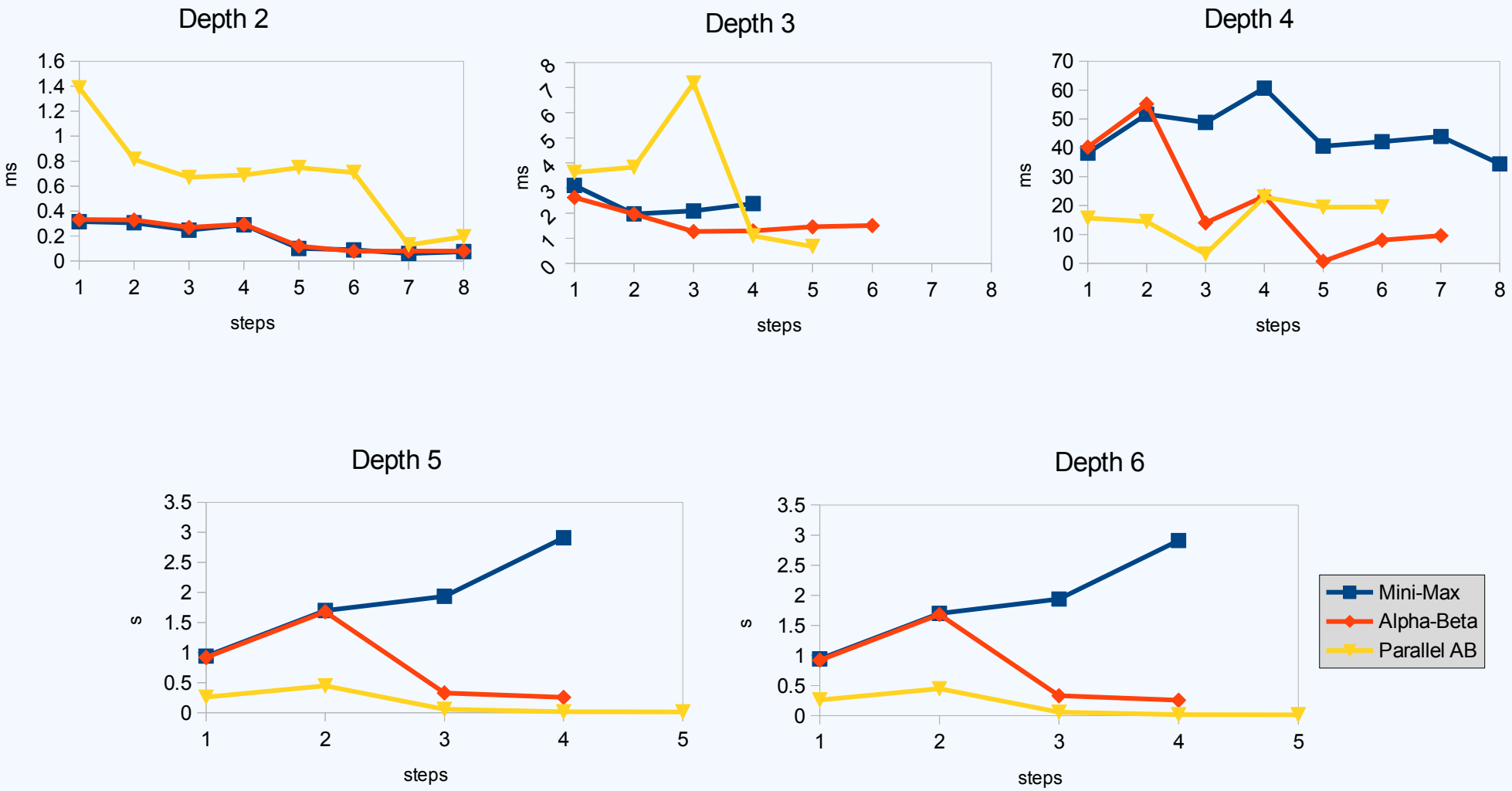
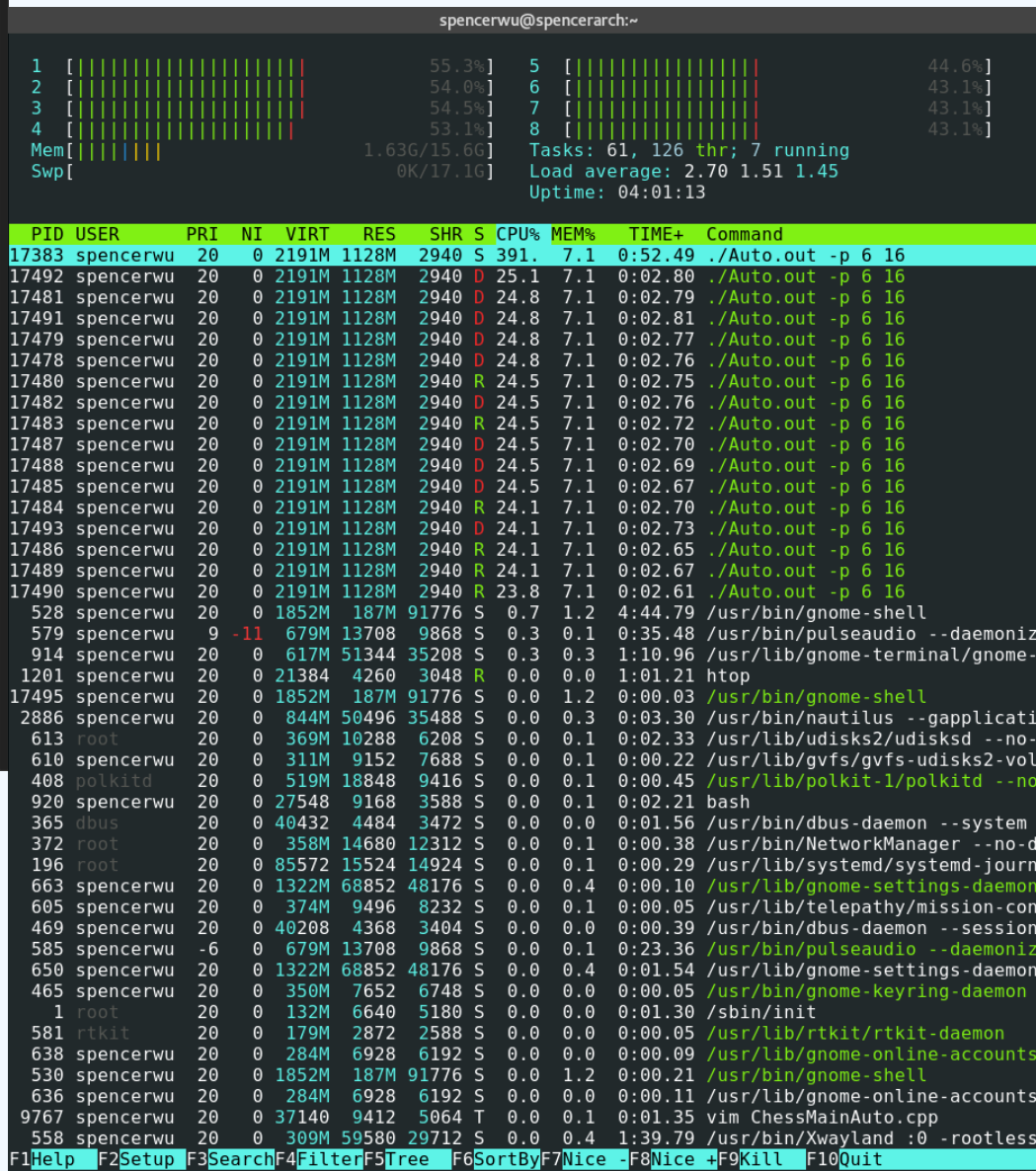
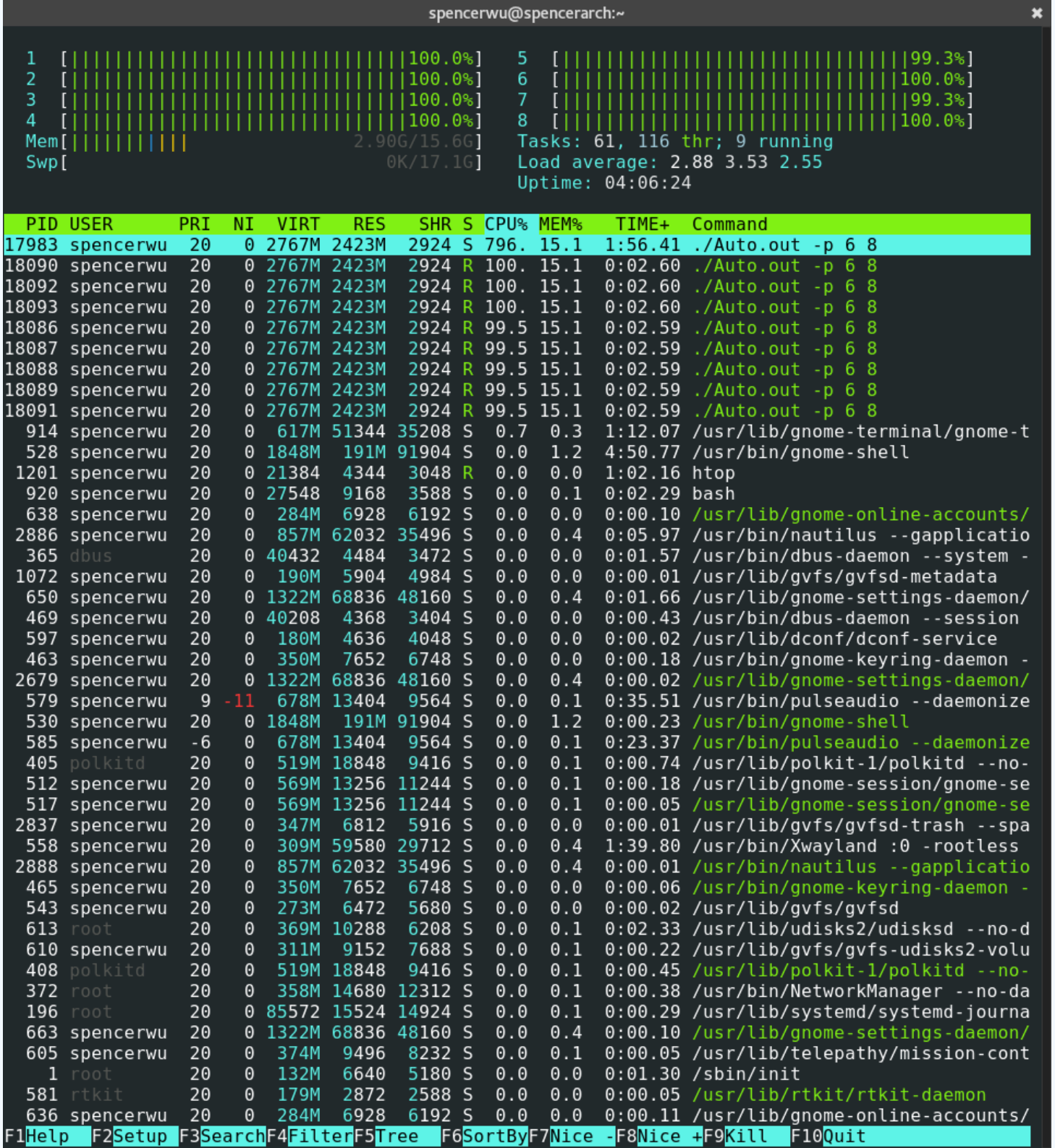

spencerwu@spencerarch:~/Documents/PP_project/src
| | | | | | | | | 3
| | | | | | | | | 4
| | |B|Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
Black's turn
++++++++++++++++++++++++++++++
time: 0.029305
++++++++++++++++++++++++++++++
- - - - - - - -
| |r|b|q|c|b| |r| 1
|p|p|p|p|p|p|p|p| 2
| | | | | |k| | | 3
| | | | | | | | | 4
| | |B|Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
White's turn
b c5 f2
==============================
- - - - - - - -
| |r|b|q|c|b| |r| 1
|p|p|p|p|p|B|p|p| 2
| | | | | |k| | | 3
| | | | | | | | | 4
| | | |Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
Black's turn
++++++++++++++++++++++++++++++
time: 0.041667
++++++++++++++++++++++++++++++
- - - - - - - -
|r| |b|q|c|b| |r| 1
|p|p|p|p|p|B|p|p| 2
| | | | | |k| | | 3
| | | | | | | | | 4
| | | |Q| | | | | 5
| | | | |P| | | | 6
|P|P|P| | |P|P|P| 7
|R|K|B| |C| |K|R| 8
- - - - - - - -
a b c d e f g h
White's turn
b

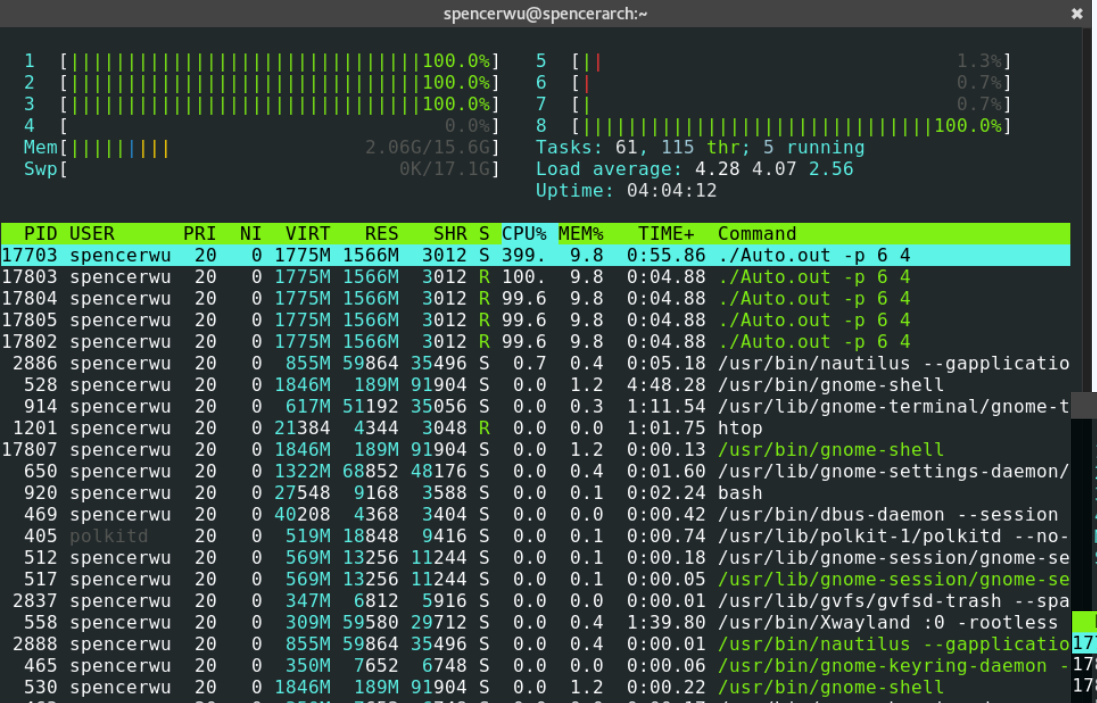
Result

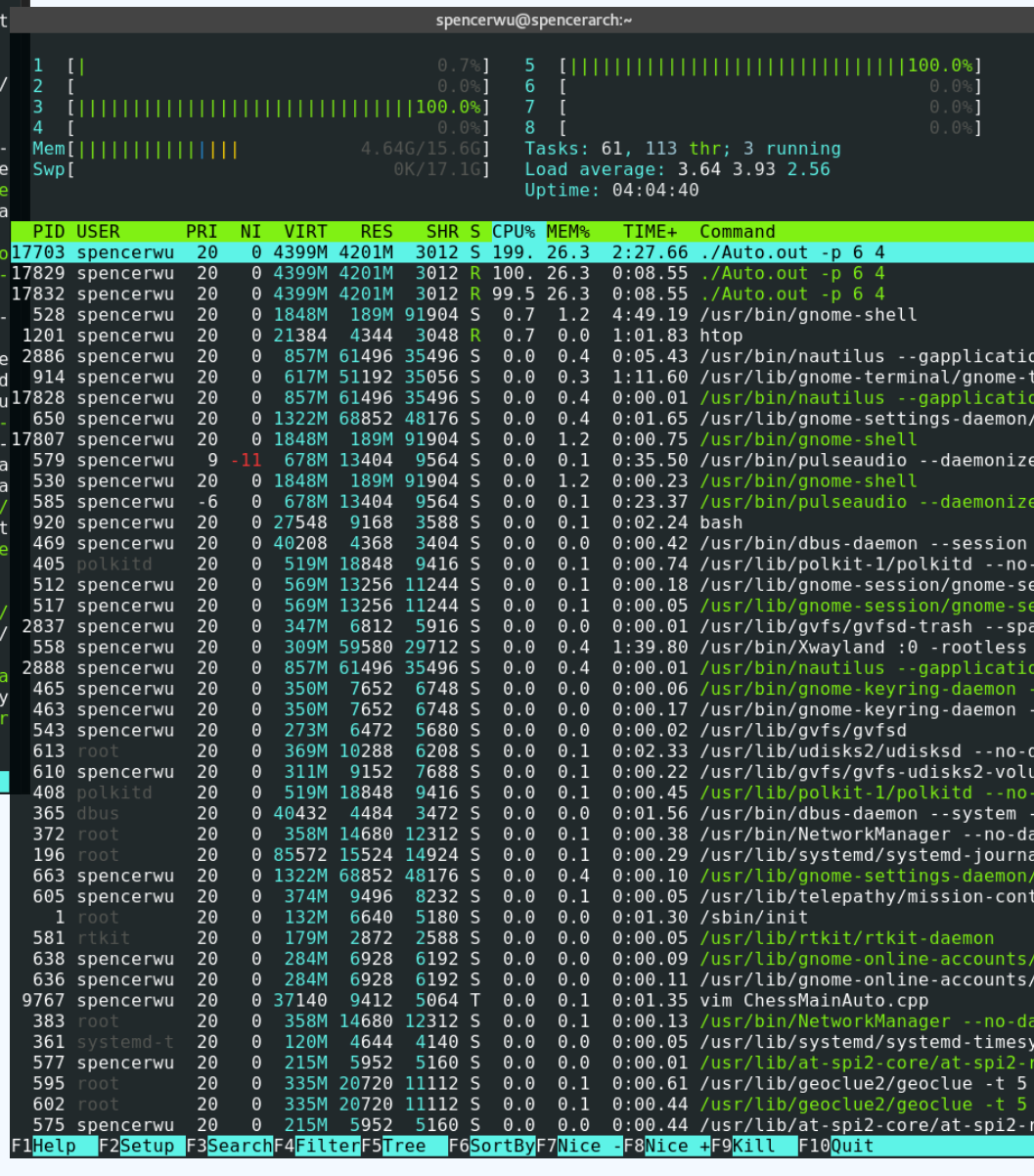

Depth 2
ms
steps
Depth 3
ms
steps
Depth 4
ms
steps
Depth 5
s
steps
Depth 6
s
steps
Mini-Max
Alpha-Beta
Parallel AB


spencerwu@spencerarch:~
1 [0.0%] 5 [0.0%]
2 [| 0.7%] 6 [0.0%]
3 [0.0%] 7 [|||||||||||||||||||||||||||||100.0%]
4 [0.0%] 8 [|||||||||||||||||||||||||||||100.0%]
Mem[|||||||||| 2.58G/15.6G] Tasks: 61, 111 thr; 3 running
Swp[0K/17.1G] Load average: 0.97 2.10 1.62
Uptime: 03:56:12
PID USER PRI NI VIRT RES SHR S CPU% MEM% TIME+ Command
17104 spencerwu 20 0 2207M 2108M 2912 S 199. 13.2 1:10.46 ./Auto.out -p 6 2
17209 spencerwu 20 0 2207M 2108M 2912 R 99.1 13.2 0:04.14 ./Auto.out -p 6 2
17208 spencerwu 20 0 2207M 2108M 2912 R 99.1 13.2 0:04.14 ./Auto.out -p 6 2
528 spencerwu 20 0 1844M 190M 91780 S 0.7 1.2 4:42.00 /usr/bin/gnome-shell
914 spencerwu 20 0 617M 51192 35056 S 0.0 0.3 1:10.21 /usr/lib/gnome-terminal/gnome-t
1 root 20 0 132M 6640 5180 S 0.0 0.0 0:01.30 /sbin/init
1201 spencerwu 20 0 21408 4260 3048 R 0.0 0.0 1:00.16 htop
2886 spencerwu 20 0 844M 50400 35472 S 0.0 0.3 0:02.40 /usr/bin/nautilus --gapplicatio
920 spencerwu 20 0 27548 9168 3588 S 0.0 0.1 0:02.10 bash
581 rtkit 20 0 179M 2872 2588 S 0.0 0.0 0:00.05 /usr/lib/rtkit/rtkit-daemon
650 spencerwu 20 0 1322M 68768 48092 S 0.0 0.4 0:01.53 /usr/lib/gnome-settings-daemon/
638 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.09 /usr/lib/gnome-online-accounts/
530 spencerwu 20 0 1844M 190M 91780 S 0.0 1.2 0:00.21 /usr/bin/gnome-shell
579 spencerwu 9 -11 678M 13400 9560 S 0.0 0.1 0:35.43 /usr/bin/pulseaudio --daemonize
585 spencerwu -6 0 678M 13400 9560 S 0.0 0.1 0:23.35 /usr/bin/pulseaudio --daemonize
636 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.11 /usr/lib/gnome-online-accounts/
9767 spencerwu 20 0 37140 9412 5064 T 0.0 0.1 0:01.35 vim ChessMainAuto.cpp
558 spencerwu 20 0 309M 59584 29716 S 0.0 0.4 1:39.79 /usr/bin/Xwayland :0 -rootless
469 spencerwu 20 0 40208 4368 3404 S 0.0 0.0 0:00.37 /usr/bin/dbus-daemon --session
463 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.16 /usr/bin/gnome-keyring-daemon -
365 dbus 20 0 40432 4484 3472 S 0.0 0.0 0:01.55 /usr/bin/dbus-daemon --system -
383 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.13 /usr/bin/NetworkManager --no-da
613 root 20 0 369M 10284 6208 S 0.0 0.1 0:02.25 /usr/lib/udisks2/udisksd --no-d
361 systemd-t 20 0 120M 4644 4140 S 0.0 0.0 0:00.05 /usr/lib/systemd/systemd-timesy
577 spencerwu 20 0 215M 5952 5160 S 0.0 0.0 0:00.01 /usr/lib/at-spi2-core/at-spi2-r
595 root 20 0 335M 20720 11112 S 0.0 0.1 0:00.61 /usr/lib/geoclue2/geoclue -t 5
602 root 20 0 335M 20720 11112 S 0.0 0.1 0:00.44 /usr/lib/geoclue2/geoclue -t 5
405 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.73 /usr/lib/polkit-1/polkitd --no-
575 spencerwu 20 0 215M 5952 5160 S 0.0 0.0 0:00.44 /usr/lib/at-spi2-core/at-spi2-r
542 spencerwu 20 0 1844M 190M 91780 S 0.0 1.2 0:00.02 /usr/bin/gnome-shell
408 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.44 /usr/lib/polkit-1/polkitd --no-
2862 spencerwu 20 0 363M 7104 6284 S 0.0 0.0 0:00.18 /usr/lib/gvfs/gvfsd-dnssd --spa
2679 spencerwu 20 0 1322M 68768 48092 S 0.0 0.4 0:00.01 /usr/lib/gnome-settings-daemon/
512 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.17 /usr/lib/gnome-session/gnome-se
700 spencerwu 20 0 293M 55940 30032 S 0.0 0.3 0:06.90 fcitx
705 spencerwu 20 0 39752 3564 3144 S 0.0 0.0 0:01.52 /usr/bin/dbus-daemon --fork --p
372 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.37 /usr/bin/NetworkManager --no-da
610 spencerwu 20 0 311M 9152 7688 S 0.0 0.1 0:00.21 /usr/lib/gvfs/gvfs-udisks2-volu
580 rtkit 21 1 179M 2872 2588 S 0.0 0.0 0:00.09 /usr/lib/rtkit/rtkit-daemon
573 spencerwu 20 0 39624 3408 3064 S 0.0 0.0 0:00.10 /usr/bin/dbus-daemon --config-f
9393 spencerwu 20 0 37140 9296 4948 T 0.0 0.1 0:01.00 vim ChessMainAuto.cpp
578 spencerwu 20 0 1844M 190M 91780 S 0.0 1.2 0:00.04 /usr/bin/gnome-shell
587 spencerwu 20 0 1844M 190M 91780 S 0.0 1.2 0:00.03 /usr/bin/gnome-shell
F1Help F2Setup F3SearchF4FilterF5Tree F6SortByF7Nice -F8Nice +F9Kill F10Quit


spencerwu@spencerarch:~
1 [55.3%] 5 [44.6%]
2 [54.0%] 6 [43.1%]
3 [54.5%] 7 [43.1%]
4 [53.1%] 8 [43.1%]
Mem[|||||| 1.63G/15.6G] Tasks: 61, 126 thr; 7 running
Swp[0K/17.1G] Load average: 2.70 1.51 1.45
Uptime: 04:01:13
PID USER PRI NI VIRT RES SHR S CPU% MEM% TIME+ Command
17383 spencerwu 20 0 2191M 1128M 2940 S 391. 7.1 0:52.49 ./Auto.out -p 6 16
17492 spencerwu 20 0 2191M 1128M 2940 D 25.1 7.1 0:02.80 ./Auto.out -p 6 16
17481 spencerwu 20 0 2191M 1128M 2940 D 24.8 7.1 0:02.79 ./Auto.out -p 6 16
17491 spencerwu 20 0 2191M 1128M 2940 D 24.8 7.1 0:02.81 ./Auto.out -p 6 16
17479 spencerwu 20 0 2191M 1128M 2940 D 24.8 7.1 0:02.77 ./Auto.out -p 6 16
17478 spencerwu 20 0 2191M 1128M 2940 D 24.8 7.1 0:02.76 ./Auto.out -p 6 16
17480 spencerwu 20 0 2191M 1128M 2940 R 24.5 7.1 0:02.75 ./Auto.out -p 6 16
17482 spencerwu 20 0 2191M 1128M 2940 D 24.5 7.1 0:02.76 ./Auto.out -p 6 16
17483 spencerwu 20 0 2191M 1128M 2940 R 24.5 7.1 0:02.72 ./Auto.out -p 6 16
17487 spencerwu 20 0 2191M 1128M 2940 D 24.5 7.1 0:02.70 ./Auto.out -p 6 16
17488 spencerwu 20 0 2191M 1128M 2940 D 24.5 7.1 0:02.69 ./Auto.out -p 6 16
17485 spencerwu 20 0 2191M 1128M 2940 D 24.5 7.1 0:02.67 ./Auto.out -p 6 16
17484 spencerwu 20 0 2191M 1128M 2940 R 24.1 7.1 0:02.70 ./Auto.out -p 6 16
17493 spencerwu 20 0 2191M 1128M 2940 D 24.1 7.1 0:02.73 ./Auto.out -p 6 16
17486 spencerwu 20 0 2191M 1128M 2940 R 24.1 7.1 0:02.65 ./Auto.out -p 6 16
17489 spencerwu 20 0 2191M 1128M 2940 R 24.1 7.1 0:02.67 ./Auto.out -p 6 16
17490 spencerwu 20 0 2191M 1128M 2940 R 23.8 7.1 0:02.61 ./Auto.out -p 6 16
528 spencerwu 20 0 1852M 187M 91776 S 0.7 1.2 4:44.79 /usr/bin/gnome-shell
579 spencerwu 9 -11 679M 13708 9868 S 0.3 0.1 0:35.48 /usr/bin/pulseaudio --daemoniz
914 spencerwu 20 0 617M 51344 35208 S 0.3 0.3 1:10.96 /usr/lib/gnome-terminal/gnome-
1201 spencerwu 20 0 21384 4260 3048 R 0.0 0.0 1:01.21 htop
17495 spencerwu 20 0 1852M 187M 91776 S 0.0 1.2 0:00.03 /usr/bin/gnome-shell
2886 spencerwu 20 0 844M 50496 35488 S 0.0 0.3 0:03.30 /usr/bin/nautilus --gapplicati
613 root 20 0 369M 10288 6208 S 0.0 0.1 0:02.33 /usr/lib/udisks2/udisksd --no-
610 spencerwu 20 0 311M 9152 7688 S 0.0 0.1 0:00.22 /usr/lib/gvfs/gvfs-udisks2-vol
408 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.45 /usr/lib/polkit-1/polkitd --no
920 spencerwu 20 0 27548 9168 3588 S 0.0 0.1 0:02.21 bash
365 dbus 20 0 40432 4484 3472 S 0.0 0.0 0:01.56 /usr/bin/dbus-daemon --system
372 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.38 /usr/bin/NetworkManager --no-d
196 root 20 0 85572 15524 14924 S 0.0 0.1 0:00.29 /usr/lib/systemd/systemd-journ
663 spencerwu 20 0 1322M 68852 48176 S 0.0 0.4 0:00.10 /usr/lib/gnome-settings-daemon
605 spencerwu 20 0 374M 9496 8232 S 0.0 0.1 0:00.05 /usr/lib/telepathy/mission-con
469 spencerwu 20 0 40208 4368 3404 S 0.0 0.0 0:00.39 /usr/bin/dbus-daemon --session
585 spencerwu -6 0 679M 13708 9868 S 0.0 0.1 0:23.36 /usr/bin/pulseaudio --daemoniz
650 spencerwu 20 0 1322M 68852 48176 S 0.0 0.4 0:01.54 /usr/lib/gnome-settings-daemon
465 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.05 /usr/bin/gnome-keyring-daemon
1 root 20 0 132M 6640 5180 S 0.0 0.0 0:01.30 /sbin/init
581 rtkit 20 0 179M 2872 2588 S 0.0 0.0 0:00.05 /usr/lib/rtkit/rtkit-daemon
638 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.09 /usr/lib/gnome-online-accounts
530 spencerwu 20 0 1852M 187M 91776 S 0.0 1.2 0:00.21 /usr/bin/gnome-shell
636 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.11 /usr/lib/gnome-online-accounts
9767 spencerwu 20 0 37140 9412 5064 T 0.0 0.1 0:01.35 vim ChessMainAuto.cpp
558 spencerwu 20 0 309M 59580 29712 S 0.0 0.4 1:39.79 /usr/bin/Xwayland :0 -rootless
F1Help F2Setup F3SearchF4FilterF5Tree F6SortByF7Nice -F8Nice +F9Kill F10Quit


spencerwu@spencerarch:~
1 [||||||||||||||||||||||||||||100.0%]
2 [||||||||||||||||||||||||||||100.0%]
3 [||||||||||||||||||||||||||||100.0%]
4 [||||||||||||||||||||||||||||100.0%]
5 [||||||||||||||||||||||||||||99.3%]
6 [||||||||||||||||||||||||||||100.0%]
7 [||||||||||||||||||||||||||||99.3%]
8 [||||||||||||||||||||||||||||100.0%]
Mem[|||||||||| 2.90G/15.6G]
Swp[0K/17.1G]
Tasks: 61, 116 thr; 9 running
Load average: 2.88 3.53 2.55
Uptime: 04:06:24
PID USER PRI NI VIRT RES SHR S CPU% MEM% TIME+ Command
17983 spencerwu 20 0 2767M 2423M 2924 S 796. 15.1 1:56.41 ./Auto.out -p 6 8
18090 spencerwu 20 0 2767M 2423M 2924 R 100. 15.1 0:02.60 ./Auto.out -p 6 8
18092 spencerwu 20 0 2767M 2423M 2924 R 100. 15.1 0:02.60 ./Auto.out -p 6 8
18093 spencerwu 20 0 2767M 2423M 2924 R 100. 15.1 0:02.60 ./Auto.out -p 6 8
18086 spencerwu 20 0 2767M 2423M 2924 R 99.5 15.1 0:02.59 ./Auto.out -p 6 8
18087 spencerwu 20 0 2767M 2423M 2924 R 99.5 15.1 0:02.59 ./Auto.out -p 6 8
18088 spencerwu 20 0 2767M 2423M 2924 R 99.5 15.1 0:02.59 ./Auto.out -p 6 8
18089 spencerwu 20 0 2767M 2423M 2924 R 99.5 15.1 0:02.59 ./Auto.out -p 6 8
18091 spencerwu 20 0 2767M 2423M 2924 R 99.5 15.1 0:02.59 ./Auto.out -p 6 8
914 spencerwu 20 0 617M 51344 35208 S 0.7 0.3 1:12.07 /usr/lib/gnome-terminal/gnome-t
528 spencerwu 20 0 1848M 191M 91904 S 0.0 1.2 4:50.77 /usr/bin/gnome-shell
1201 spencerwu 20 0 21384 4344 3048 R 0.0 0.0 1:02.16 htop
920 spencerwu 20 0 27548 9168 3588 S 0.0 0.1 0:02.29 bash
638 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.10 /usr/lib/gnome-online-accounts/
2886 spencerwu 20 0 857M 62032 35496 S 0.0 0.4 0:05.97 /usr/bin/nautilus --gapplicatio
365 dbus 20 0 40432 4484 3472 S 0.0 0.0 0:01.57 /usr/bin/dbus-daemon --system -
1072 spencerwu 20 0 190M 5904 4984 S 0.0 0.0 0:00.01 /usr/lib/gvfs/gvfsd-metadata
650 spencerwu 20 0 1322M 68836 48160 S 0.0 0.4 0:01.66 /usr/lib/gnome-settings-daemon/
469 spencerwu 20 0 40208 4368 3404 S 0.0 0.0 0:00.43 /usr/bin/dbus-daemon --session
597 spencerwu 20 0 180M 4636 4048 S 0.0 0.0 0:00.02 /usr/lib/dconf/dconf-service
463 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.18 /usr/bin/gnome-keyring-daemon -
2679 spencerwu 20 0 1322M 68836 48160 S 0.0 0.4 0:00.02 /usr/lib/gnome-settings-daemon/
579 spencerwu 9 -11 678M 13404 9564 S 0.0 0.1 0:35.51 /usr/bin/pulseaudio --daemonize
530 spencerwu 20 0 1848M 191M 91904 S 0.0 1.2 0:00.23 /usr/bin/gnome-shell
585 spencerwu -6 0 678M 13404 9564 S 0.0 0.1 0:23.37 /usr/bin/pulseaudio --daemonize
405 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.74 /usr/lib/polkit-1/polkitd --no-
512 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.18 /usr/lib/gnome-session/gnome-se
517 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.05 /usr/lib/gnome-session/gnome-se
2837 spencerwu 20 0 347M 6812 5916 S 0.0 0.0 0:00.01 /usr/lib/gvfs/gvfsd-trash --spa
558 spencerwu 20 0 309M 59580 29712 S 0.0 0.4 1:39.80 /usr/bin/Xwayland :0 -rootless
2888 spencerwu 20 0 857M 62032 35496 S 0.0 0.4 0:00.01 /usr/bin/nautilus --gapplicatio
465 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.06 /usr/bin/gnome-keyring-daemon -
543 spencerwu 20 0 273M 6472 5680 S 0.0 0.0 0:00.02 /usr/lib/gvfs/gvfsd
613 root 20 0 369M 10288 6208 S 0.0 0.1 0:02.33 /usr/lib/udisks2/udisksd --no-d
610 spencerwu 20 0 311M 9152 7688 S 0.0 0.1 0:00.22 /usr/lib/gvfs/gvfs-udisks2-volu
408 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.45 /usr/lib/polkit-1/polkitd --no-
372 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.38 /usr/bin/NetworkManager --no-da
196 root 20 0 85572 15524 14924 S 0.0 0.1 0:00.29 /usr/lib/systemd/systemd-journa
663 spencerwu 20 0 1322M 68836 48160 S 0.0 0.4 0:00.10 /usr/lib/gnome-settings-daemon/
605 spencerwu 20 0 374M 9496 8232 S 0.0 0.1 0:00.05 /usr/lib/telepathy/mission-cont
1 root 20 0 132M 6640 5180 S 0.0 0.0 0:01.30 /sbin/init
581 rtkit 20 0 179M 2872 2588 S 0.0 0.0 0:00.05 /usr/lib/rtkit/rtkit-daemon
636 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.11 /usr/lib/gnome-online-accounts/
F1Help F2Setup F3SearchF4FilterF5Tree F6SortByF7Nice -F8Nice +F9Kill F10Quit


spencerwu@spencerarch:~
1 [||||||||||||||||||||||||||||100.0%]
2 [||||||||||||||||||||||||||||100.0%]
3 [||||||||||||||||||||||||||||100.0%]
4 [0.0%]
Mem[||||||||| 2.06G/15.6G]
Swp[0K/17.1G]
5 [|| 1.3%]
6 [| 0.7%]
7 [| 0.7%]
8 [||||||||||||||||||||||||||||100.0%]
Tasks: 61, 115 thr; 5 running
Load average: 4.28 4.07 2.56
Uptime: 04:04:12
PID USER PRI NI VIRT RES SHR S CPU% MEM% TIME+ Command
17703 spencerwu 20 0 1775M 1566M 3012 S 399. 9.8 0:55.86 ./Auto.out -p 6 4
17803 spencerwu 20 0 1775M 1566M 3012 R 100. 9.8 0:04.88 ./Auto.out -p 6 4
17804 spencerwu 20 0 1775M 1566M 3012 R 99.6 9.8 0:04.88 ./Auto.out -p 6 4
17805 spencerwu 20 0 1775M 1566M 3012 R 99.6 9.8 0:04.88 ./Auto.out -p 6 4
17802 spencerwu 20 0 1775M 1566M 3012 R 99.6 9.8 0:04.88 ./Auto.out -p 6 4
2886 spencerwu 20 0 855M 59864 35496 S 0.7 0.4 0:05.18 /usr/bin/nautilus --gapplicatio
528 spencerwu 20 0 1846M 189M 91904 S 0.0 1.2 4:48.28 /usr/bin/gnome-shell
914 spencerwu 20 0 617M 51192 35056 S 0.0 0.3 1:11.54 /usr/lib/gnome-terminal/gnome-t
1201 spencerwu 20 0 21384 4344 3048 R 0.0 0.0 1:01.75 htop
17807 spencerwu 20 0 1846M 189M 91904 S 0.0 1.2 0:00.13 /usr/bin/gnome-shell
650 spencerwu 20 0 1322M 68852 48176 S 0.0 0.4 0:01.60 /usr/lib/gnome-settings-daemon/
920 spencerwu 20 0 27548 9168 3588 S 0.0 0.1 0:02.24 bash
469 spencerwu 20 0 40208 4368 3404 S 0.0 0.0 0:00.42 /usr/bin/dbus-daemon --session
405 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.74 /usr/lib/polkit-1/polkitd --no-
512 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.18 /usr/lib/gnome-session/gnome-se
517 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.05 /usr/lib/gnome-session/gnome-se
2837 spencerwu 20 0 347M 6812 5916 S 0.0 0.0 0:00.01 /usr/lib/gvfs/gvfsd-trash --spa
558 spencerwu 20 0 309M 59580 29712 S 0.0 0.4 1:39.80 /usr/bin/Xwayland :0 -rootless
2888 spencerwu 20 0 855M 59864 35496 S 0.0 0.4 0:00.01 /usr/bin/nautilus --gapplicatio
465 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.06 /usr/bin/gnome-keyring-daemon -
530 spencerwu 20 0 1846M 189M 91904 S 0.0 1.2 0:00.22 /usr/bin/gnome-shell
463 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.17 /usr/bin/gnome-keyring-daemon -
543 spencerwu 20 0 273M 6472 5680 S 0.0 0.0 0:00.02 /usr/lib/gvfs/gvfsd
579 spencerwu 9 -11 679M 13708 9868 S 0.0 0.1 0:35.48 /usr/bin/pulseaudio --daemonize
613 root 20 0 369M 10288 6208 S 0.0 0.1 0:02.33 /usr/lib/udisks2/udisksd --no-d
610 spencerwu 20 0 311M 9152 7688 S 0.0 0.1 0:00.22 /usr/lib/gvfs/gvfs-udisks2-volu
408 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.45 /usr/lib/polkit-1/polkitd --no-
365 dbus 20 0 40432 4484 3472 S 0.0 0.0 0:01.56 /usr/bin/dbus-daemon --system -
372 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.38 /usr/bin/NetworkManager --no-da
196 root 20 0 85572 15524 14924 S 0.0 0.1 0:00.29 /usr/lib/systemd/systemd-journa
663 spencerwu 20 0 1322M 68852 48176 S 0.0 0.4 0:00.10 /usr/lib/gnome-settings-daemon/
605 spencerwu 20 0 374M 9496 8232 S 0.0 0.1 0:00.05 /usr/lib/telepathy/mission-cont
585 spencerwu -6 0 679M 13708 9868 S 0.0 0.1 0:23.36 /usr/bin/pulseaudio --daemonize
1 root 20 0 132M 6640 5180 S 0.0 0.0 0:01.30 /sbin/init
581 rtkit 20 0 179M 2872 2588 S 0.0 0.0 0:00.05 /usr/lib/rtkit/rtkit-daemon
638 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.09 /usr/lib/gnome-online-accounts/
636 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.11 /usr/lib/gnome-online-accounts/
9767 spencerwu 20 0 37140 9412 5064 T 0.0 0.1 0:01.35 vim ChessMainAuto.cpp
383 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.13 /usr/bin/NetworkManager --no-da
361 systemd-t 20 0 120M 4644 4140 S 0.0 0.0 0:00.05 /usr/lib/systemd/systemd-timesy
577 spencerwu 20 0 215M 5952 5160 S 0.0 0.0 0:00.01 /usr/lib/at-spi2-core/at-spi2-r
595 root 20 0 335M 20720 11112 S 0.0 0.1 0:00.61 /usr/lib/geoclue2/geoclue -t 5
602 root 20 0 335M 20720 11112 S 0.0 0.1 0:00.44 /usr/lib/geoclue2/geoclue -t 5
F1Help F2Setup F3SearchF4FilterF5Tree F6SortByF7Nice -F8Nice +F9Kill F10Quit


spencerwu@spencerarch:~
1 [| 0.7%]
2 [0.0%]
3 [||||||||||||||||||||||||||||100.0%]
4 [0.0%]
Mem[||||||||||||| 4.64G/15.6G]
Swp[0K/17.1G]
5 [||||||||||||||||||||||||||||100.0%]
6 [0.0%]
7 [0.0%]
8 [0.0%]
Tasks: 61, 113 thr; 3 running
Load average: 3.64 3.93 2.56
Uptime: 04:04:40
PID USER PRI NI VIRT RES SHR S CPU% MEM% TIME+ Command
17703 spencerwu 20 0 4399M 4201M 3012 S 199. 26.3 2:27.66 ./Auto.out -p 6 4
17829 spencerwu 20 0 4399M 4201M 3012 R 100. 26.3 0:08.55 ./Auto.out -p 6 4
17832 spencerwu 20 0 4399M 4201M 3012 R 99.5 26.3 0:08.55 ./Auto.out -p 6 4
528 spencerwu 20 0 1848M 189M 91904 S 0.7 1.2 4:49.19 /usr/bin/gnome-shell
1201 spencerwu 20 0 21384 4344 3048 R 0.7 0.0 1:01.83 htop
2886 spencerwu 20 0 857M 61496 35496 S 0.0 0.4 0:05.43 /usr/bin/nautilus --gapplicatio
914 spencerwu 20 0 617M 51192 35056 S 0.0 0.3 1:11.60 /usr/lib/gnome-terminal/gnome-t
17828 spencerwu 20 0 857M 61496 35496 S 0.0 0.4 0:00.01 /usr/bin/nautilus --gapplicatio
650 spencerwu 20 0 1322M 68852 48176 S 0.0 0.4 0:01.65 /usr/lib/gnome-settings-daemon/
17807 spencerwu 20 0 1848M 189M 91904 S 0.0 1.2 0:00.75 /usr/bin/gnome-shell
579 spencerwu 9 -11 678M 13404 9564 S 0.0 0.1 0:35.50 /usr/bin/pulseaudio --daemonize
530 spencerwu 20 0 1848M 189M 91904 S 0.0 1.2 0:00.23 /usr/bin/gnome-shell
585 spencerwu -6 0 678M 13404 9564 S 0.0 0.1 0:23.37 /usr/bin/pulseaudio --daemonize
920 spencerwu 20 0 27548 9168 3588 S 0.0 0.1 0:02.24 bash
469 spencerwu 20 0 40208 4368 3404 S 0.0 0.0 0:00.42 /usr/bin/dbus-daemon --session
405 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.74 /usr/lib/polkit-1/polkitd --no-
512 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.18 /usr/lib/gnome-session/gnome-se
517 spencerwu 20 0 569M 13256 11244 S 0.0 0.1 0:00.05 /usr/lib/gnome-session/gnome-se
2837 spencerwu 20 0 347M 6812 5916 S 0.0 0.0 0:00.01 /usr/lib/gvfs/gvfsd-trash --spa
558 spencerwu 20 0 309M 59580 29712 S 0.0 0.4 1:39.80 /usr/bin/Xwayland :0 -rootless
2888 spencerwu 20 0 857M 61496 35496 S 0.0 0.4 0:00.01 /usr/bin/nautilus --gapplicatio
465 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.06 /usr/bin/gnome-keyring-daemon -
463 spencerwu 20 0 350M 7652 6748 S 0.0 0.0 0:00.17 /usr/bin/gnome-keyring-daemon -
543 spencerwu 20 0 273M 6472 5680 S 0.0 0.0 0:00.02 /usr/lib/gvfs/gvfsd
613 root 20 0 369M 10288 6208 S 0.0 0.1 0:02.33 /usr/lib/udisks2/udisksd --no-d
610 spencerwu 20 0 311M 9152 7688 S 0.0 0.1 0:00.22 /usr/lib/gvfs/gvfs-udisks2-volu
408 polkitd 20 0 519M 18848 9416 S 0.0 0.1 0:00.45 /usr/lib/polkit-1/polkitd --no-
365 dbus 20 0 40432 4484 3472 S 0.0 0.0 0:01.56 /usr/bin/dbus-daemon --system -
372 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.38 /usr/bin/NetworkManager --no-da
196 root 20 0 85572 15524 14924 S 0.0 0.1 0:00.29 /usr/lib/systemd/systemd-journa
663 spencerwu 20 0 1322M 68852 48176 S 0.0 0.4 0:00.10 /usr/lib/gnome-settings-daemon/
605 spencerwu 20 0 374M 9496 8232 S 0.0 0.1 0:00.05 /usr/lib/telepathy/mission-cont
1 root 20 0 132M 6640 5180 S 0.0 0.0 0:01.30 /sbin/init
581 rtkit 20 0 179M 2872 2588 S 0.0 0.0 0:00.05 /usr/lib/rtkit/rtkit-daemon
638 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.09 /usr/lib/gnome-online-accounts/
636 spencerwu 20 0 284M 6928 6192 S 0.0 0.0 0:00.11 /usr/lib/gnome-online-accounts/
9767 spencerwu 20 0 37140 9412 5064 T 0.0 0.1 0:01.35 vim ChessMainAuto.cpp
383 root 20 0 358M 14680 12312 S 0.0 0.1 0:00.13 /usr/bin/NetworkManager --no-da
361 systemd-t 20 0 120M 4644 4140 S 0.0 0.0 0:00.05 /usr/lib/systemd/systemd-timesy
577 spencerwu 20 0 215M 5952 5160 S 0.0 0.0 0:00.01 /usr/lib/at-spi2-core/at-spi2-
595 root 20 0 335M 20720 11112 S 0.0 0.1 0:00.61 /usr/lib/geoclue2/geoclue -t 5
602 root 20 0 335M 20720 11112 S 0.0 0.1 0:00.44 /usr/lib/geoclue2/geoclue -t 5
575 spencerwu 20 0 215M 5952 5160 S 0.0 0.0 0:00.44 /usr/lib/at-spi2-core/at-spi2-
F1Help F2Setup F3SearchF4FilterF5Tree F6SortByF7Nice -F8Nice +F9Kill F10Quit

Scalability

	2	4	8	16
Depth 5	0.764	0.572	0.357	1.103
Depth 6	21.784	12.240	10.207	18.643

Conclusion

1. In our Chess Evaluation, we may have a different result by paralleling alpha-beta Search.

2. If the search cut off too early, we may not have speed up when paralleling

Future Works

- Implementing the Dynamic Tree Splitting.
- Using GPU algorithm.
- Better evaluation.

Reference

- Chess Programming Wiki
  - https://chessprogramming.wikispaces.com/
- Parallel Alpha-Beta Search on Shared Memory Multiprocessors
  - http://www.top-5000.nl/ps/Parallel%20Alpha-Beta%20Search%20on%20Shared%20Memory%20Multiprocessors.pdf

Reference

- Parallelizing a Simple Chess Program
  - http://iacoma.cs.uiuc.edu/~greskamp/pdfs/412.pdf
- Parallel Game Tree Search
  - http://www.iis.sinica.edu.tw/~tshsu/tcg/2013/slides/slide11.pdf

Q & A