# 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

# Content

- <span style="color:red">What is Minmax Search and Alpha-Beta Pruning</span>

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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
```
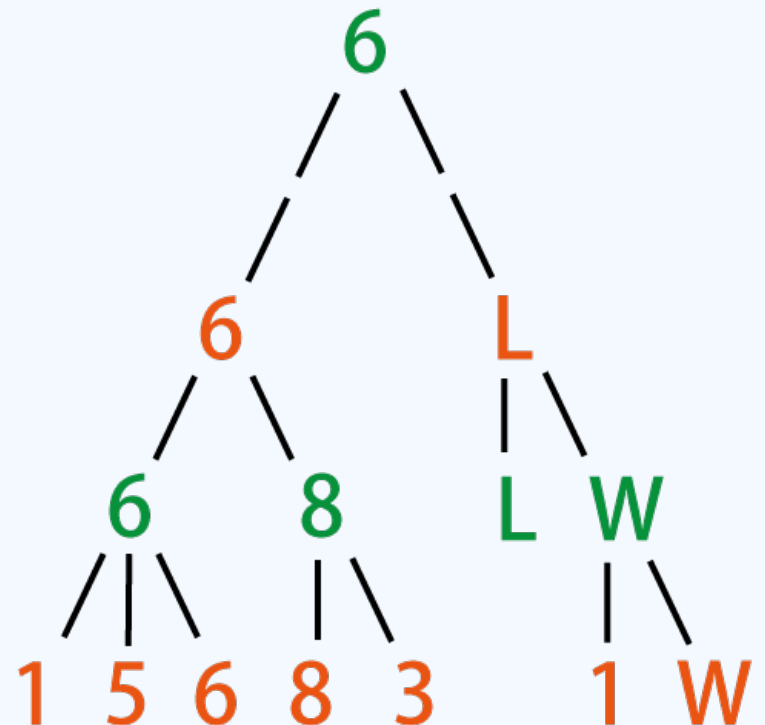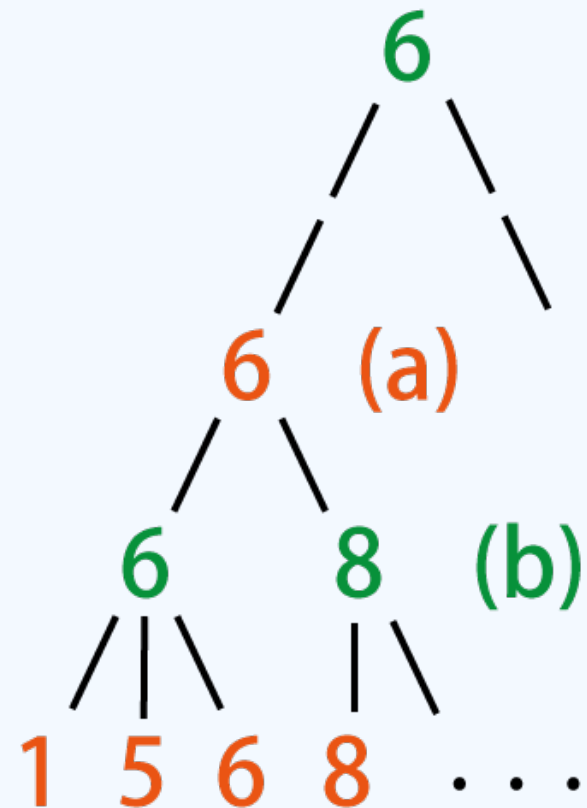
# Alpha-Beta Pruning

```
(* 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
```

**Alpha-Beta pruning**

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# Bit Board

```
int boardMap[64] ;
map<int,Piece*> pieceMap;
```
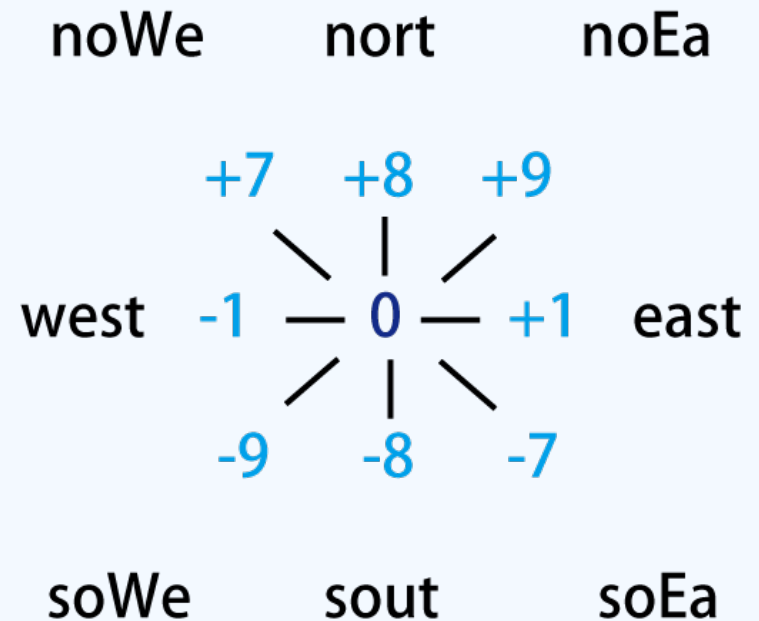
squareIndex = 8 * rankIndex + fileIndex

rankIndex    = squareIndex div 8

fileIndex      = squareIndex mod 8

```
            A     B     C     D     E     F     G     H
rank index +----+----+----+----+----+----+----+----+
           | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |  8th rank
           +----+----+----+----+----+----+----+----+
           | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 |  7th rank
           +----+----+----+----+----+----+----+----+
           | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |  6th rank
           +----+----+----+----+----+----+----+----+
           | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |  5th rank
           +----+----+----+----+----+----+----+----+
           | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |  4th rank
           +----+----+----+----+----+----+----+----+
           | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |  3rd rank
           +----+----+----+----+----+----+----+----+
           |  8 |  9 | 10 | 11 | 12 | 13 | 14 | 15 |  2nd rank
           +----+----+----+----+----+----+----+----+
           |  0 |  1 |  2 |  3 |  4 |  5 |  6 |  7 |  1st rank
           +----+----+----+----+----+----+----+----+
             A    B    C    D    E    F    G    H
                                                      file index
```

# 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
};
```

noWe        nort        noEa

$+7$    $+8$    $+9$

west    $-1$ — $0$ — $+1$    east

$-9$    $-8$    $-7$

soWe        sout        soEa

# 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
};
```

| 8 | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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
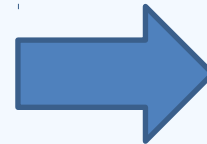
```
int ChessBoard::eval(int color){
    // color: white 0 negative, black 1 positive
    int eval=0;
    for(int i = 0 ; i < 64 ; i++){
        eval += myscore.score[boardMap[i]][i];
    }
    return eval;
}
```

# Mini-Max Search

```cpp
static ChessBoard* _MinMaxMove(ChessBoard* board, int dept_limit, int dept, enum FindAction action) {
    vector<ChessBoard*> moves;
    ChessBoard* best_move = NULL;
    int best_real_move = 0;
    ChessBoard* move = NULL;

    if (dept >= dept_limit) {//if depth limit is reached
        return board;
    }
    moves = board->listAllMove(action);
    for (int i = 0; i < moves.size(); i++) {
        move = _MinMaxMove( moves[i], dept_limit, dept+1, child(action));
        if (best_move == NULL || cmp_move(action, move, best_move)) {
            best_move = move;
            best_real_move = i;
        }
    }

    ChessBoard* res = new ChessBoard;
    *res = *moves[best_real_move];
    for (int i = 0; i < moves.size(); i++) {
        delete moves[i];
    }
    return res;
```

# Alpha-Beta  Search

```cpp
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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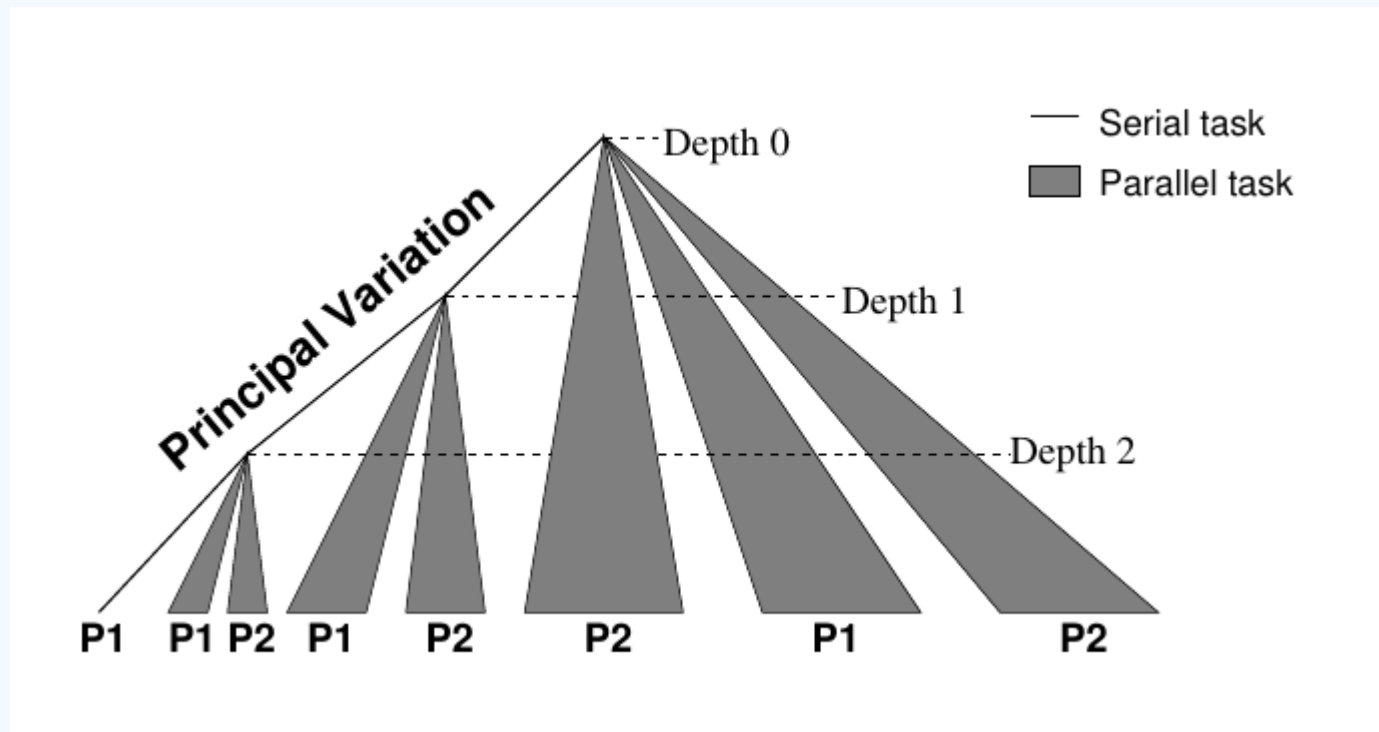
- Result and Conclusion

# Parallelizing Alpha-beta

- PVSplit:

  - easier to implement, less scalability, poor load balancing

- 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 to 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 to 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 some subtrees.
  - we haven't implemented this.
- in 16 cores, speedup is at most 6x with EPVS.
  - from the original research

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```
| | | | | | | | |   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
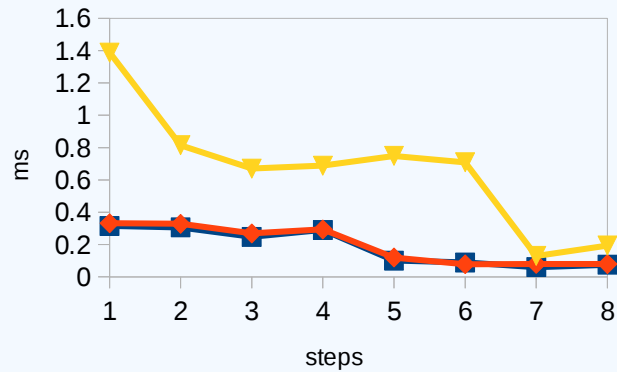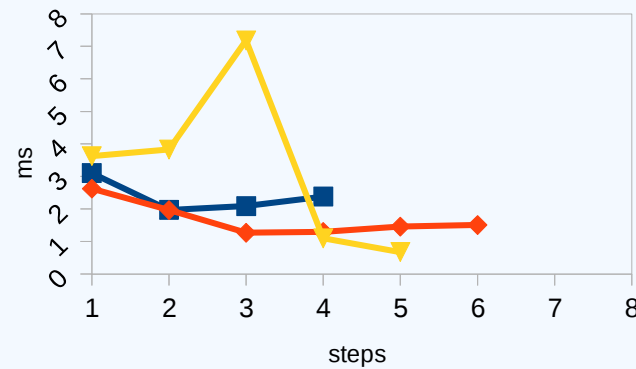
```
  1 [                                0.0%]   5 [                                0.0%]
  2 [|                               0.7%]   6 [                                0.0%]
  3 [                                0.0%]   7 [||||||||||||||||||||||||||||||100.0%]
  4 [                                0.0%]   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  0.1  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  0:00.04 /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/nautilus --gapplicati
  587 spencerwu  20   0 1844M  190M 91780 S  0.0  1.2  0:00.03 /usr/bin/gnome-shell
F1Help  F2Setup  F3Search F4Filter F5Tree  F6SortBy F7Nice -F8Nice +F9Kill  F10Quit
```
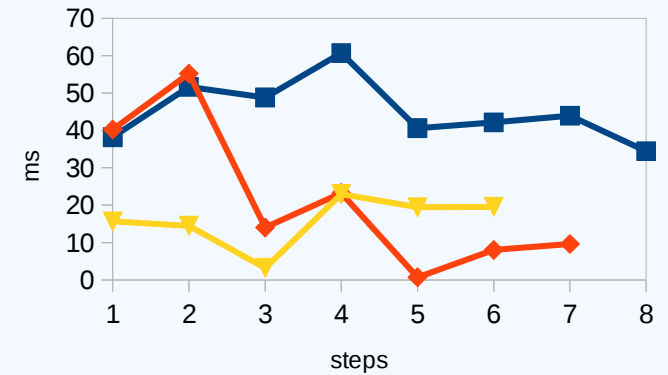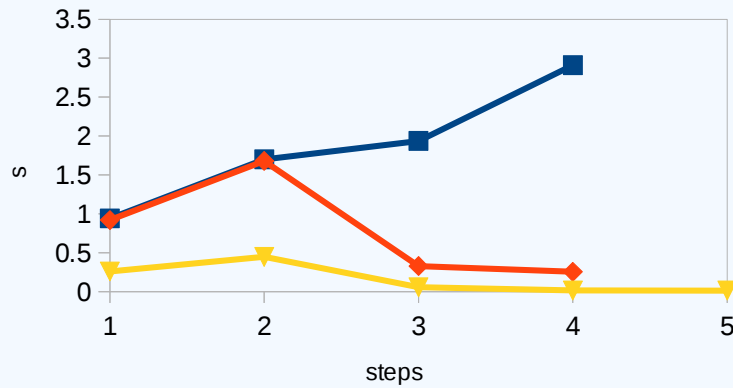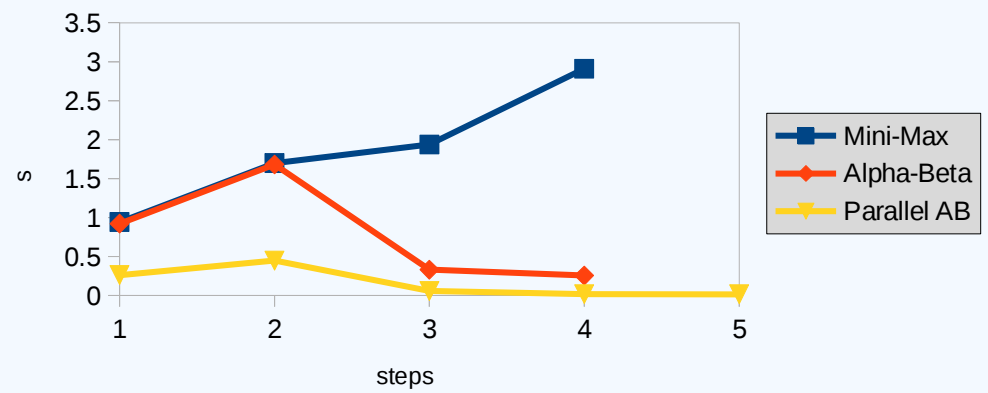
```
  1 [||||||||||||||||||        55.3%]   5 [|||||||||||||||||        44.6%]
  2 [||||||||||||||||||        54.0%]   6 [|||||||||||||||||        43.1%]
  3 [||||||||||||||||||        54.5%]   7 [|||||||||||||||||        43.1%]
  4 [||||||||||||||||||        53.1%]   8 [|||||||||||||||||        43.1%]
  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 R 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 -rootles
F1Help  F2Setup  F3Search F4Filter F5Tree  F6SortBy F7Nice -F8Nice +F9Kill  F10Quit
```

```
  1  [||||||||||||||||||||||||||100.0%]     5  [|||||||||||||||||||||||||||||99.3%]
  2  [||||||||||||||||||||||||||100.0%]     6  [||||||||||||||||||||||||||||100.0%]
  3  [||||||||||||||||||||||||||100.0%]     7  [|||||||||||||||||||||||||||||99.3%]
  4  [||||||||||||||||||||||||||100.0%]     8  [||||||||||||||||||||||||||||100.0%]
  Mem[|||||||||||                2.90G/15.6G]     Tasks: 61, 116 thr; 9 running
  Swp[                              0K/17.1G]     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/lib/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 F3Search F4Filter F5Tree  F6SortBy F7Nice -F8Nice +F9Kill  F10Quit
```

```
1  [||||||||||||||||||||||||100.0%]    5  [||                                1.3%]
2  [||||||||||||||||||||||||100.0%]    6  [|                                 0.7%]
3  [||||||||||||||||||||||||100.0%]    7  [|                                 0.7%]
4  [                          0.0%]    8  [||||||||||||||||||||||||||||||100.0%]
Mem[|||||||||               2.06G/15.6G]  Tasks: 61, 115 thr; 5 running
Swp[                          0K/17.1G]   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  F3Search F4Filter F5Tree  F6SortBy F7Nice -F8Nice +F9Kill  F10Quit
```

```
1  [|                                0.7%]    5  [|||||||||||||||||||||||||||100.0%]
2  [                                 0.0%]    6  [                                 0.0%]
3  [||||||||||||||||||||||||||100.0%]         7  [                                 0.0%]
4  [                                 0.0%]    8  [                                 0.0%]
Mem[||||||||||||             4.64G/15.6G]     Tasks: 61, 113 thr; 3 running
Swp[                          0K/17.1G]       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-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
  575 spencerwu  20   0  215M  5952  5160 S  0.0  0.0  0:00.44 /usr/lib/at-spi2-core/at-spi2-r
F1Help  F2Setup  F3Search F4Filter F5Tree  F6SortBy F7Nice -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

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# Q & A