

AVOIDING ROTATED BITBOARDS WITH DIRECT LOOKUP

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ABSTRACT

This paper describes an approach for obtaining direct access to the attacked squares of sliding pieces without resorting to rotated bitboards. The technique involves creating four hash tables using the built-in hash arrays from an interpreted, high-level language. The rank, file, and diagonal occupancy are first isolated by masking the desired portion of the board. The attacked squares are then directly retrieved from the hash tables. Maintaining incrementally updated rotated bitboards becomes unnecessary as does all the updating, mapping, and shifting required to access the attacked squares. Finally, rotated-bitboard move-generation speed is compared with that of the direct hash-table lookup method.

1. INTRODUCTION

Prior to their introduction by the Soviet chess program KAISSA in the late 1960s, bitboards were used in checkers playing programs as described in Samuel (1959). The elegance and performance advantages of bitboard-based programs attracted many chess programmers and bitboards were used by most early programs (Adelson-Velskii *et al.*, 1970; Slate and Atkin, 1978; Hyatt, Gower, and Nelson, 1990). However, to exploit the performance advantages of parallel, bitwise logical operations afforded by bitboards to its full details, most programs maintain, and incrementally update, rotated bitboards. These rotated bitboards allow for easy attack detection without having to loop over the squares of a particular rank, file, or diagonal as described in Heinz (1997) and Hyatt (1999). The file occupancy is computed by using an occupancy bitboard rotated 90 degrees and then using the rank attack hash tables to find the attacked squares. Once the attacked squares are known, they are mapped back to their original file squares for move generation. The diagonal attacks are handled similarly except that the rotation involved is 45 (or -45) degrees depending on which diagonal is being investigated. These rotated occupancy bitboards are incrementally updated after each move to avoid the performance penalty of dynamically recreating them from scratch at every move.

2. DIRECT LOOKUP

As researchers and practitioners explore Shannon (1950) type-B approaches to chess programming, code clarity and expressive power become important in implementing complex evaluation functions and move ordering algorithms. Many high-level programming languages (notably Python (van Rossum, 1993)) have useful predefined data structures (e.g., associative arrays) which are dynamically resizable hash tables that resolve collisions by probing techniques. The basic lookup function used in Python is based on Algorithm D: Open Addressing with Double Hashing from Section 6.4 in Knuth (1998). We define four dictionaries that are two dimensional hash tables which are the main focus of this paper: **rank_attacks**, **file_attacks**, **diag_attacks_ne**, and **diag_attacks_nw** representing the rank, file, and two diagonal directions (“ne” represents the northeast A1-H8 diagonals and “nw” represents the northwest A8-H1 diagonals). In order to use these hash tables directly, we need to also create rank, file, and diagonal mask bitboards for each of the squares too (e.g., *diag_mask_ne[c4] = a2|b3|c4|d5|e6|f7|g8*). These hash tables only need to be generated at the startup. The initial cost of calculating these tables can be avoided altogether if the table values are stored in a file and simply retrieved.

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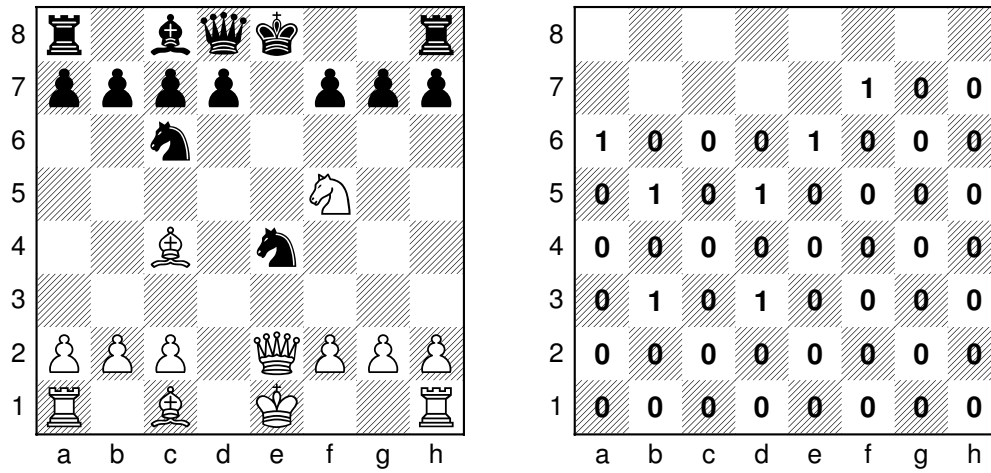


Figure 1: C4 White Bishop Attacks and Attacked Squares Bitboard.

The first dimension represents the location of the attacking (sliding) piece and the second dimension represents the occupancy of the particular rank, file, or diagonal. The first dimension has 64 possible values and the second has 256 possible values (except for the diagonals with fewer than eight squares). While the sizes of these hash tables are small, the actual values are fairly large (up to $2^{64} - 1$). The reason for this is that these hash tables are called directly from the bitboard values retrieved from the chess board. In Figure 1, the squares attacked by the bishop at square c4 would ideally be found by simply calculating the occupancy of the two diagonals intersecting at the square c4 and then performing a logical OR of the attacked squares provided by direct lookup of the two diagonal hash tables and then removing squares occupied by friendly pieces. The techniques described in this paper provide the attacked squares that are both unoccupied and occupied. These same attack vectors are also used in evaluation functions that require attacks from a certain square as well as attacks on a certain square.

2.1 Rank Attacks

The rank attack hash array can best be understood by starting with the first rank. (Note: in the subsequent listings, the convenience variables for each square are created so that $h1=1$, $a1=128$, $h8=72057594037927936$, $a8=9223372036854775808$, etc.) The rank attack for the first rank is given by the following:

$$rank_attacks_{rank_1}(p_{rank_1}, o_{rank_1}) = \sum_{i=l}^{p_{rank_1}-1} B_i + \sum_{i=p_{rank_1}+1}^r B_i,$$

where p_{rank_1} is the position of the sliding piece (Rook or Queen) on the first rank, o_{rank_1} is the occupancy value for the first rank, l is the first occupied square to the left of the sliding piece, and r is the first occupied square to the right of the sliding piece. B_i is the value given by

$$B_i = \begin{cases} 2^i, & \text{if 1 exists at } i^{th} \text{ bit of } o_{rank_1}; \\ 0, & \text{otherwise.} \end{cases}$$

Then finally, to find the rank attacks at the i^{th} rank, we simply move this first rank value “up” in rank by multiplying by 256^{rank-1} since moving a piece up one rank on the chessboard is the same as left shifting a binary number by 8 or multiplying by 2^8 . Thus,

$$rank_attacks_{rank_i}(p_{rank_i}, o_{rank_i}) = rank_attacks_{rank_1}(p_{rank_1}, o_{rank_1}) \cdot 256^{i-1},$$

where the piece position index and occupancy index at rank i are also multiplied by the same value as the rank attack. Thus,

$$p_{rank_i} = p_{rank_1} \cdot 256^{i-1},$$

$$o_{rank_i} = o_{rank_1} \cdot 256^{i-1}.$$

An implementation of this is shown in Listing 1. Here, the function's outer loop (variable i in line 3) iterates the attacking piece over the squares of the first rank beginning with square h1. The `rank_attacks` hash table is initialized in line 2 and in lines 4 and 5. The second loop iterates over the possible 256 occupancy values for a rank (line 6). After some initialization, the function moves one square to the right of the attacking piece, adding the value to the hash table. If the square is occupied, there is a piece that will block further movement in this direction and so we break out of this right side summation. This process is repeated for the left side of the attacking square (lines 12-15). Finally, when the `rank_attack` hash table is complete for the particular attacking square, the function shifts the values for each respective rank for the remaining ranks (lines 16-21). Note that this hash table includes blocking squares that are occupied by both enemy and friendly pieces. The friendly piece occupancy will need to be removed before assembling the legal moves.

Listing 1: Rank Attack Lookup Table.

```

1 def get_rank_attacks ():
2     rank_attacks = {}
3     for i in range(8):
4         for r in range(8):
5             rank_attacks[1 << (i + (r * 8))] = {}
6         for j in range(256):
7             rank_attacks[1 << i][j] = 0
8             for right in range(i-1, -1, -1):
9                 rank_attacks[1 << i][j] |= 1 << right # save it
10                if ((1 << right) & j != 0): # non empty space
11                    break
12            for left in range(i+1, 8):
13                rank_attacks[1 << i][j] |= 1 << left # save it
14                if ((1 << left) & j != 0): # non empty space
15                    break
16            for rank in range(1, 8):
17                x = 1 << (i+(rank*8))
18                y = j << (rank*8)
19                value = rank_attacks[1 << i][j]
20                newvalue = value << (rank*8)
21                rank_attacks[x][y] = newvalue
22
23     return(rank_attacks)

```

2.2 File Attacks

The file attacks hash table uses the values obtained in the rank attack table on the first rank and performs a 90 degree rotation. In the approach shown here, the 8th file `file_attacks_files` hash table is obtained by converting the rank 1 `rank_attacks_rank1` table to base 256. The bitboard position of the sliding piece as well as the occupancy are also converted in a similar fashion. Thus,

$$file_attacks_files(p_{files}, o_{files}) = \sum_{i=1}^8 B_i \cdot 256^i,$$

where B_i is the i^{th} bit of the rank 1 `rank_attacks` table (with h1 being the LSB and a1 being the MSB) and

$$p_{files} = p_{rank_1} \cdot 256^{(9-\bar{f})},$$

$$o_{files} = \sum_{i=1}^8 O_{file_i} \cdot 256^i,$$

Listing 2: File Attack Lookup Table.

```

1 def get_file_attacks ():
2     # this routine assumes that the rank_attacks have already
3     # been calculated.
4     file_attacks = {}
5     for i in range(64):
6         r = rank[1 << i] - 1
7         mirror_i = rank_to_file((1 << i) >> (8*r)) << r
8         file_attacks[mirror_i] = {}
9         for j in range(256):
10            mirror_j = rank_to_file(j) << r
11            value = rank_attacks[1 << i][j << (8*r)]
12            lower_value = value >> (8*r)
13            file_value = rank_to_file(lower_value)
14            final_value = file_value << r
15            file_attacks[mirror_i][mirror_j] = final_value
16 return(file_attacks)

```

where \tilde{f} is the actual file number of the position square p_{files} on the first rank and O_{file_i} is the i^{th} bit of the occupancy on the first rank.

The implementation of this is shown in Listing 2 and uses the rank_attacks hash table found earlier (line 11). This function has an outer loop that ranges over the 64 squares, for the attacking piece, and for each of these, an inner loop that loops over all the occupancy values. In line 7, we find the symmetric square value if reflected across the A8-H1 diagonal (e.g., g1 is reflected across the line of symmetry onto square h2, f1 to h3, etc.). In this way, the position values are flipped or “rotated” 90 degrees and the occupancy values are also rotated in line 10. The function rank_to_file() performs this rotation by converting the number to base two and then to base 256. In line 11, the attacked squares that were calculated in Listing 1 are also rotated.

2.3 Diagonal Attacks

The attacked squares along the diagonals are a little more complex to calculate using the base conversion technique used on the file_attacks. A more direct approach like the one used to find the rank_attacks, involving shifting and adding, is used. The diagonal hash tables can be found by summing over the squares up to and including the blocking square. The A1-H8 diagonal can be found

$$diag_attacks_ne(p, o) = \sum_{i=l}^{p-1} B_i + \sum_{i=p+1}^r B_i$$

where p is the position of the sliding piece (Bishop or Queen), o is the occupancy value for the diagonal, l is the first occupied square along the diagonal to the left of the sliding piece, and r is the first occupied square along the diagonal to the right of the sliding piece. B_i is the value of the number if the i^{th} bit is set

$$B_i = \begin{cases} 2^i, & \text{if 1 exists at } i^{th} \text{ bit of } o; \\ 0, & \text{otherwise.} \end{cases}$$

The other diagonal hash table (for the A8-H1 direction) is not shown but has a similar structure.

An implementation of this is shown in Listing 3. Each diagonal is looped over (line 5) for the outer loop and the attacking piece is moved along the diagonal for the inner loop (line 7). For each position of the attacking piece, all of the possible occupancies are generated (line 10) and the two inner loops, one for the right side (lines 12-15) and one for the left side (lines 16-19), are used to accumulate open squares until blocking bits are encountered. The function completes by converting the occupancy value to a bitboard number along the diagonal. Not shown is a hash table called **bin2index** used to convert bitboard values to square index values (e.g., a1→7). The function is called with a list of lists of the values of the diagonals. For the A1-H8 direction (also referred to as the “northeast” or ne direction), the diagonal values are shown in lines 28-42 and for the A8-H1 diagonals, the diagonal values passed into the function are shown in lines 46-60.

Listing 3: Generalized Attack Lookup Table.

```

1 def get_attacks (square_list=None):
2     attack_table = {}
3     attack_table[0] = {}
4     attack_table[0][0] = 0
5     for i in range(len(square_list)):
6         list_size = len(square_list[i])
7         for current_position in range(list_size):
8             current_bb = square_list[i][current_position]
9             attack_table[current_bb] = {}
10            for occupation in range(1 << list_size):
11                moves = 0
12                for newsquare in range(current_position+1, list_size):
13                    moves |= square_list[i][newsquare]
14                    if ((1 << newsquare) & occupation):
15                        break
16                for newsquare in range(current_position-1, -1, -1):
17                    moves |= square_list[i][newsquare]
18                    if ((1 << newsquare) & occupation):
19                        break
20                temp_bb = 0
21                while (occupation):
22                    lowest = lsb(occupation)
23                    temp_bb |= square_list[i][bin2index[lowest]]
24                    occupation = clear_lsb(occupation)
25            return(attack_table)
26
27 def get_diag_attacks_ne ():
28     diag_values = [[h1],
29                    [h2,g1],
30                    [h3,g2,f1],
31                    [h4,g3,f2,e1],
32                    [h5,g4,f3,e2,d1],
33                    [h6,g5,f4,e3,d2,c1],
34                    [h7,g6,f5,e4,d3,c2,b1],
35                    [h8,g7,f6,e5,d4,c3,b2,a1],
36                    [g8,f7,e6,d5,c4,b3,a2],
37                    [f8,e7,d6,c5,b4,a3],
38                    [e8,d7,c6,b5,a4],
39                    [d8,c7,b6,a5],
40                    [c8,b7,a6],
41                    [b8,a7],
42                    [a8]]
43     return(get_diag_attacks(diag_values))
44
45 def get_diags_attacks_nw ():
46     diag_values = [[a1],
47                    [b1,a2],
48                    [c1,b2,a3],
49                    [d1,c2,b3,a4],
50                    [e1,d2,c3,b4,a5],
51                    [f1,e2,d3,c4,b5,a6],
52                    [g1,f2,e3,d4,c5,b6,a7],
53                    [h1,g2,f3,e4,d5,c6,b7,a8],
54                    [h2,g3,f4,e5,d6,c7,b8],
55                    [h3,g4,f5,e6,d7,c8],
56                    [h4,g5,f6,e7,d8],
57                    [h5,g6,f7,e8],
58                    [h6,g7,f8],
59                    [h7,g8],
60                    [h8]]
61     return(get_diag_attacks(diag_values))

```

Listing 4: Generalized Rank and File Attack Lookup Table.

```

1 def get_rank_attacks ():
2     # these are the rank square values
3     rank_values = [[a1,b1,c1,d1,e1,f1,g1,h1],
4                     [a2,b2,c2,d2,e2,f2,g2,h2],
5                     [a3,b3,c3,d3,e3,f3,g3,h3],
6                     [a4,b4,c4,d4,e4,f4,g4,h4],
7                     [a5,b5,c5,d5,e5,f5,g5,h5],
8                     [a6,b6,c6,d6,e6,f6,g6,h6],
9                     [a7,b7,c7,d7,e7,f7,g7,h7],
10                    [a8,b8,c8,d8,e8,f8,g8,h8]]
11     return (get_attacks (rank_values))
12
13 def get_file_attacks ():
14     # these are the file square values
15     file_values = [[a1,a2,a3,a4,a5,a6,a7,a8],
16                    [b1,b2,b3,b4,b5,b6,b7,b8],
17                    [c1,c2,c3,c4,c5,c6,c7,c8],
18                    [d1,d2,d3,d4,d5,d6,d7,d8],
19                    [e1,e2,e3,e4,e5,e6,e7,e8],
20                    [f1,f2,f3,f4,f5,f6,f7,f8],
21                    [g1,g2,g3,g4,g5,g6,g7,g8],
22                    [h1,h2,h3,h4,h5,h6,h7,h8]]
23     return (get_attacks (file_values))

```

This algorithm is general enough to allow for the rank and file attack tables to be generated at once. So, the tables are reformulated and will conveniently work with this approach. The listings are shown in Listing 4.

3. EXPERIMENTAL RESULTS

OS and CPU	Rotated Bitboards Time (s)	Direct Lookup Time (s)
OS X 10.4.9 2.33 GHz Intel Core 2 Duo	7.29	6.42
Linux 2.6.9 3.4 GHz Intel Quad Xeon	8.82	7.67
OS X 10.4.9 1.67 GHz PowerPC G4	16.31	14.13
SunOS 5.8 1.5 GHz dual UltraSPARC-IIIi	23.95	19.06
FreeBSD 6.2 500 MHz Pentium 3	58.17	44.85

Table 1: Move Generation Results for Rotated Bitboards and Direct Lookup.

A performance comparison of simple move generation was made between a rotated bitboard implementation and a direct lookup implementation. The test results are shown in Table 1. The times shown reflect a comparison of the move generation routines. A well known and well studied set of test cases exists in the Encyclopedia of Chess Middle Games (ECM). Positions were selected from the ECM (Krogius, 1980) and for each of the 879 test positions, a list of the main board position as well as three rotated boards were precalculated and saved in a list used by both methods. The moves were then generated for each of these 879 positions using the same list of bitboards generated earlier. The move generation functions for direct lookup and those for the rotated bitboards differed only in how they handled the sliding piece attacks. This process was repeated 10 times for each of the two types of approaches. In generating moves for rotated bitboards, we required additional shifting and masking operations before the lookup of the attacks could take place. Furthermore, the overhead of maintaining and updating the rotated bitboards is not accounted for since these test positions represent games in mid play where the rotated bitboards were precalculated.

The results shown indicate that directly looking up the attacking moves for sliding pieces in hash tables improves the move generation speeds from 10% to 15% depending on the computer architecture. Further efficiencies can be expected in a full implementation where the overhead of maintaining rotated bitboards is eliminated. The implementation and test code is made available in an Open-Source, interactive, chess programming module called SHATRANJ (Tannous, 2006).

4. CONCLUSIONS AND FUTURE WORK

We have described an approach for obtaining direct access to the attacked squares of sliding pieces without resorting to rotated bitboards. Detailed algorithms and working code illustrate how the four hash tables were derived. The attacked squares are directly retrieved from the hash tables once the occupancy for the particular rank, file or diagonal was retrieved by the appropriate masks. Using these four hash tables, maintaining incrementally updated rotated bitboards becomes unnecessary as does the required shifting and masking required to obtain the consecutive occupancy bits for a rank, file or diagonal. In addition to simplifying the implementation, we can expect a performance improvement in move generation of at least 10%. Taking the implementation a bit further, the hash tables described in this paper are also useful for implementing evaluation functions which include piece mobility and attack threats. When the additional impact of complex evaluation functions is taken into account, the speed improvements should be greater than the results presented here.

Since most chess implementations do not use a high level interpreted language such as Python, it is difficult to estimate the effect of cache loading and execution speed. The results presented here only reflect the savings seen by move generation and not those of a fully implemented chess engine. Further research is needed to quantify the effect of these changes on cache utilization in a complete chess engine.

Alternatives to rotated bitboards have gained some popularity recently. Minimal perfect hash functions as described in Czech, Havas, and Majewski (1992) have been used to create hash tables where the index is calculated based on the mover square and occupancy bitboard. A recent refinement of this method described in Leiserson, Prokop, and Randall (1998), called the magic move generation, further reduces the memory requirements of the hash table. In this approach, a “magic multiplier” for a particular square is multiplied by an occupancy bitboard and then shifted by another “magic” number. This provides a hash index where the attacked squares can be retrieved from a hash table. Performance comparisons of the built-in hash tables provided by interpreted languages and techniques involving manually creating minimal perfect hash functions as well as hash functions using de Bruijn sequences (also known as magic move generation techniques) could be explored in future work too. Representation of chess knowledge with the data structures provided by high-level languages seems to have received very little attention since the primary focus of the majority of work has been improving execution speed, an area that places interpreted languages at a distinct disadvantage.

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