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Programmer Corner



Articles on computer chess at programmer level, very technical stuff, don't bother to read if you failed the [introduction](#) course.

On this page I will try to explain most of the workings of REBEL (and some of its successor Pro Deo). It's my hope that it might serve as an inspiration for starting chess programmers.

I would like to present the following issues found in REBEL.

Move Ordering (1)

Contrary to most chess programs, when going one ply deeper in the chess tree REBEL generates all moves for the given (and new) ply. During move generation REBEL quickly evaluates each move generated by using the piece-square technique, this evaluation is only used for move ordering later, it is certainly not for evaluating the position.

The advantage of this *time consuming* process is that it pays off later when move ordering becomes an issue, this provided you have created 12 reasonable organized piece-square tables for the move generator. REBEL's data structure for move generation looks as follows:

```
static char move_from [5000];
static char move_to   [5000];
static char move_value [5000];
```

So when adding a new generated move to "move_from" and "move_to" REBEL also will fill "move_value" via the corresponding piece-square table using the formula:

```
move_value = table[move_to] - table[move_from];
```

An example for the White Knight

+-----+-----+-----+-----+							
8	00	10	20	20	10	10	00
+-----+-----+-----+-----+							
7	10	24	26	26	24	24	10
+-----+-----+-----+-----+							
6	10	28	40	50	50	28	10
+-----+-----+-----+-----+							
5	10	23	36	40	40	23	10
+-----+-----+-----+-----+							
4	10	22	28	30	30	22	10
+-----+-----+-----+-----+							
3	00	26	26	30	30	26	00
+-----+-----+-----+-----+							
2	05	20	20	23	20	20	05
+-----+-----+-----+-----+							
1	00	05	15	15	15	15	00
+-----+-----+-----+-----+							
a b c d e f g h							

Ng1-f3 usually is a good move, so is Nc3-d5, both get a high value. Nf3-h4 and Nf3-e1 are usually not so good moves and both get a low value. The system works like a charm for move ordering, all generated moves get a value and every time the search needs a next move simply the next highest

Ng1-f3 will give 26 - 00 = +26

Nc3-d5 will give 40 - 26 = +14

Nf3-h4 will give 10 - 26 = -16

Nf3-e1 will give 15 - 26 = -11

Topics

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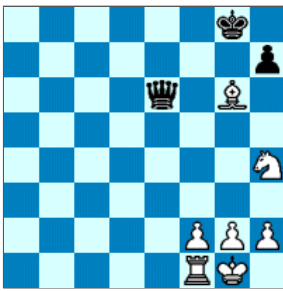
one from the list is taken.

Last time I removed the code REBEL ran about a factor of 2 slower. It's of course very important the 12 piece-square tables are in harmony with each other.

Move Ordering in REBEL (2)

Now that REBEL has generated all moves (with values) it moves to the second step, it will update the values of moves which are more important than others, thus further sort the moves to improve move ordering. Its final ordering looks as follows:

- The move from the Hash Table, it will get the highest value +127 to ensure the move is searched first.
- The Mate-Killer-Move, when present it will get the value +126. A Mate-Killer-Move is a normal Killer-Move coming from the 2 slots REBEL uses for killer moves, more below. However when a Killer-Move has produced a mate-value in the tree it is promoted to Mate-Killer-Move and thus searched as second move. It works very well in positions where mate threats are an issue.
- The Winning Capture moves. Moves that are winning material are searched third. REBEL maintains a sorted list of the so called hanging pieces with a maximum of 3 squares, the 3 squares are sorted on the expected material gain. Each move in the move list that captures on a hanging-square is rewarded with 124, 123 or 122 depending on the status of the expected material gain. If you don't have such stuff in your program yet make sure you do, it is good for a tremendous speed-up of your program. The technique most programs use for this is called: SEE (Static Exchange Evaluator).



HINT: when it is possible that 2 or more moves can capture a "hanging-piece" make sure you search the move first that captures the piece with the lower piece-type, have a look at the diagram.

Black can capture the hanging-piece on square G6 with 2 pieces, the pawn and the queen, it's obviously better to search the lower piece-type capture (pawn) first then the higher piece-type capture (queen) when the issue is move ordering. By head I remember it speed-ups by some 5% doing so.

- Queen promotions with capture come next, value 121, given in the move generator. Most of them become automatically part of the Winning Material moves, see above.
- Normal Queen promotions (no capture) are next, value 120, given in the move generator. During Phase II REBEL makes sure they end up in the 125-122 area.
- Next are the so called Good Captures, these are the following captures: QxQ (119), RxR (118), NxB (117), BxB (116), BxN (115) and pxp (114). This is all done in the Move Generator part.
- Next are the so called Killer Moves maintained in 2 slots during Search. Killer Moves are the best moves found on a given depth in the Search. The idea behind Killer Moves is that if a given move brings the score above ALPHA it is usually a good thing to try the same move again when the Search reaches that ply again.

REBEL uses 2 slots, Killer-One and Killer-Two, both are depth based, Killer Moves get the following values:

```
Killer-One [current ply]      110
Killer-One [current ply-2]    108
```

- [Strong Squares](#)
- [Center Control](#)
- [Pinned Pieces](#)
- [Miscellaneous](#)
 - [More on Bishops](#)
 - [More on Rooks](#)
 - [Attack Bonus](#)
 - [Pawn Ending](#)
 - [Endgame](#)

```
Killer-Two [current ply]      106
Killer-Two [current ply-2]    104
```

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HINT: most important while maintaining your killer moves during Search, never ever allow the following moves in your Killer Slots:

- . Moves that win material (see hanging pieces), they are polluting your valuable killer slots.
- . Good captures (see above), they are polluting your valuable killer slots.
- . Promotions, same reason.

REMARK: the above is true for REBEL, it might be different in programs who use a different move ordering scheme, nevertheless it can't hurt trying.

LAST: needless to say, but.... make sure you don't have any double moves in your 2 killer slots.

- Next in move ordering is the Historic Mate Killer, note it gets the value 109 so right after the first Killer Move, see above. You can safely skip this, it gives only a small speed-up of 3-4%. To make it work you will need to create 2 x 32-bit two-dimensional tables, one for white and one for black, for example:

```
static int Historic_Mate_Killer_White [12][64]; // [piece-type][square]
static int Historic_Mate_Killer_Black [12][64];
```

During Search (not in Q-Search) whenever you find a mate-score you increment the table with the remaining depth (horizon depth - current depth) and maintain the highest number as best historic-mate-killer move. Note the table(s) are piece-type-square based, so not square-square based. The advantage of this formula is that you get more hits then when using the square-square approach.

- We are still not finished, next in move ordering are the two castling moves: 0-0 (103) and 0-0-0 (102), all done in the Move Generator.
- Next are all the minor promotions, they get the value 101 in the Move Generator.

In principle that's it, REBEL's move ordering. However 2 fine correction principles are added, for all moves below the value of 70 a correction of 30 points might be added or subtracted, the principle works as follows:

1) Subtract 30 points if the move gives away material, for instance if the queen moves to a square that is covered by the opponents pawn, bishop etc. The data for that is directly available because of REBEL's concept, if you don't have this data available in your program it will be most probably too costly to try this move ordering feature.

2) Add 30 points if a piece that is hanging moves, it is usually good.

Let me try to put all of this in a nutshell before going to part-3, whenever REBEL goes one ply deeper in the chess tree it does the following:

- Generate_all_Moves();
- Update_all_Moves();
- Get_highest_Move();
- Do_something_till_all_moves_are_done();

Move Ordering in REBEL (3)

Another move-ordering mechanism handles the so called large unsorted trees. An unsorted tree occurs when "Update_all_Moves" (see above) does not report:

- A move from the Hash Table, or
- A Winning Capture move, see above.

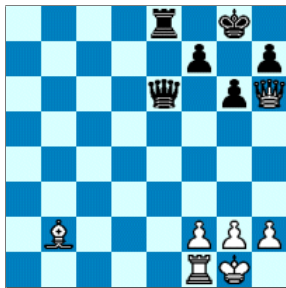
REBEL then will lower the remaining depth to search with a factor of 2 and search the subtree first with this depth before searching the unsorted tree at full depth. The larger the unsorted tree the more powerful the algorithm performs. The speed-up in general is about 13-14% but at longer time controls will certainly increase.

There is room for improvement here, there could be more powerful formula's such as going through the unsorted tree in steps of 2 plies (or one) till the actual depth is reached, one should try.

All in all it makes REBEL's move ordering to look like this:

- Generate_all_Moves();
- Update_all_Moves();
- Reduce_depth_in_case_of_an_unsorted_tree();
- Get_highest_Move();
- Do_something_till_all_moves_are_done();

Move Ordering in REBEL (4)



There is another move ordering trick worth to mention. REBEL has special code to recognize mate-threats in its evaluation part (EVAL), have a look at the diagram. It's obvious with white to move white can give a checkmate with Qg7# on the next ply.

When REBEL recognizes such a pattern in EVAL it doesn't even bother to search further, EVAL just returns the mate value avoiding to go deeper into the tree, it gives a nice speed-up depending on the number patterns the program knows.

But there is more to gain, when it is black to move it still can defend itself against the Qg7 mate threat, as in this case black can defend itself perfectly with 1..f6 (or even 1..Qe5 and Qf6) but all other moves lead to checkmate with Qg7#. The trick is to search the Qg7 move right after the Hash Table move in move ordering, a high chance it will lead to mate.

This ends the description of REBEL's move-ordering mechanism, if there is more to mention (I am sure I have forgotten a few things) this page will be updated, let's move now to the next chapter, Search Techniques.

Search Techniques in REBEL (alpha-beta)

PREAMBLE, to understand this issue it is assumed you have a working chess program with a working search algorithm. This topic is not meant to be an introduction to Search, for that I refer to other excellent web-pages on the Internet, to name a few:

- The home page of [Bruce Moreland](#), excellent for starters.
- The work of [Aske Plaat](#), more advanced techniques.

REBEL uses the standard Aspiration Alpha-Beta Search technique with 0.50 as basic value, no null-window tricks or whatsoever, just the bald algorithm. There is very little to say about this issue, there are only two small modifications worth to mention, both give a nice speed-up.

- Whenever REBEL gets a fail-low or fail-high at the root position (we are back at ply one), REBEL doesn't immediately opens the entire alpha or beta window, instead of that it tries a new window of 2.00 and only then when REBEL is faced again with a fail it opens the complete (corresponding) window. The 2.00 window will do for most of the positions when a fail occurs, that's the thought behind.
- REBEL keeps track of the best score of the previous ply, using that value we can do a little trick. Normally Aspiration-Search when it finds a new main-variation (best move) the BETA-WINDOW is either closed (null-window) or left untouched (standard). REBEL instead does the following,

It measures the difference in score from the previous iteration and when there is not too much decline in score BETA is narrowed, not null-windowed. Using the initial position as an example,

At the end of iteration 5 the best move is 1.e4 score 0.20, we save the 0.20 score, we go to iteration 6, ALPHA is set to -0.30, BETA is set to +0.70 and we search 1.e4 again this time with a depth of 6, we get a new main-variation and new score for 1.e4 say 0.15

Since there is only a small decline in score (0.20 to 0.15) or in case the score has gone up it is assumed safe to narrow BETA, REBEL's new window will look as follows: ALPHA=0.15 and BETA=0.25 (ALPHA + 0.10). The advantage is that possible new best moves do not automatically will fail-high, the second advantage is that BETA is narrowed with 0.45 which is quite a lot.

In the case the decline in score is bigger (say 0.20 and up) it is still unlikely a new best move will be higher than 0.20 so REBEL will narrow BETA anyway, only less, with 0.25, so BETA becomes 0.45 (previous score + 0.25).

Search Techniques in REBEL (Lazy Eval)

Definition, LAZY EVAL (abbreviated to LE) is a surrogate routine for EVAL that with a few instructions tries to estimate the value of EVAL.

Its goal, why do a time consuming EVAL (of hundreds, maybe thousands of instructions) if you can guess the score of EVAL with only a few instructions, thus speed-up the program.

Where to use LE, only at horizon depth and Quiescent-Search (QS) plies.

Is LE safe? No, in fact it is a most dangerous piece of software, don't ever use it in its original form, use either REBEL's modification or find solutions for the drawback of LE yourself, I will try to point out the danger of LE later, let's first explain how LE works in practice.

When you are at the horizon depth or in QS, try LE first before you call EVAL, it might save you from doing an expensive EVAL. Actually in REBEL LE is called BEFORE "Make_Move" trying to win even more processor time, the pseudo code:

```
if (own_king_is_in_check)           -> don't try LE, too dangerous.
if (move_does_check_the_opponent_king) -> don't try LE, too dangerous.
if (special_case_position)          -> don't try LE, description below.
Lazy_Eval();                        -> calculate (guess) score, more below.
if (ALPHA < SCORE)                  -> don't reward LE, do normal EVAL.
else: reward the LE SCORE as the real score from EVAL and skip EVAL.
```

The routine "Lazy_Eval" calculates the all the material on the board plus its piece-square values in I_SCORE, actually REBEL has I_SCORE always at hand since it is incremental maintained in "Make_Move" and "Undo_Move" and always is up-to-date.

HINT, if you don't have such a variable in your program yet it's advised to make it, as I_SCORE is handy to use in many other places in your program, for instance in EVAL as it saves you a lot of processor time, but this aside.

The next step is to update I_SCORE with the move, exactly like you do in "Make_Move". Then you add-up a MARGIN to I_SCORE of say 0.50 and return I_SCORE as SCORE and then make the compare to ALPHA. MARGIN is an estimated value of all the positional aspects of EVAL and it is assumed that EVAL stays in that boundary, +0.50 in our example.

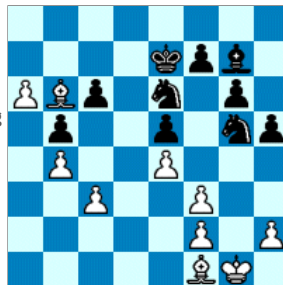
The idea of LE, if I_SCORE + MARGIN can't make it to ALPHA why bother to do an expensive EVAL, the move isn't any good, just use the score from LE and skip EVAL. The system works like a charm, however we are now ready to point out its main drawback, that is the value of MARGIN.



Consider the left diagram, if you have any good "king safety" in your program its value will be certainly over 1.00 or more rewarding the black attack on the white king thus, EVAL will result in a score where the material balance - the positional aspects exceed the value of 0.50, the value of MARGIN.

Houston we have a problem, LE returns a wrong value, nevertheless LE is rewarded, as practice has learned me the results are disastrous when king safety (with scores above 0.50) is dominant in the search, actually when MARGIN is exceeded too many times it will ruin all your chess knowledge and the program will start playing bad moves.

Second example, see diagram at the right, same story. If you have any reasonable passed-pawn evaluation it will consider the white pawn at A6 as extremely dangerous and accordingly evaluate that giving it a big score. Again the LE algorithm is going to fail tremendously, resulting in bad moves.



Solutions are many, simply increase the value of MARGIN to 2.00 or even 5.00, but doing that you will lose much of the power of LE as you force the program to do more full EVAL's. Here is the compromise I found for the problem, it works very well for REBEL, but you must have the score of the depth-1 EVAL at your disposal.

The default value of MARGIN in REBEL is 0.50, however the difference of I_SCORE - SCORE of the depth-1 evaluation is added to MARGIN. I_SCORE - SCORE of one ply back in the tree in most cases will correctly represent what's going on on the board, its value is highly reliable and thus MARGIN is updated with this value.

This is just another example how useful it can be to do EVAL on every ply in the main search, in this case it solves the main drawback of LE while keeping MARGIN very low.

```
if (special_case_position)          -> don't try LE, description below.
```

This still needs to be explained, these are a few exception cases where the I_SCORE - SCORE of the depth-1 evaluation trick doesn't work or those cases I don't want to rely on LE because I find the situations too dangerous, here is the list:

- REBEL doesn't use LE when on the evaluation of depth-1 the quadrant-rule is used, the quadrant-rule is practiced in "pawn-endings", in case the king can't stop an opponent pawn from promoting the pawn is evaluated close to the value of a queen. If this happens, no LE is allowed one ply

deeper.

- Other typical special end-game stuff, such as KPK endings where REBEL also knows when the pawn will make it to promotion.
- In case of the presence of a [Mate Threat](#) Killer.

SOME MORE THOUGHTS ON LAZY EVAL

- It's highly questionable if LE is of any use if you have a cheap evaluation with only few chess knowledge, I wouldn't know for sure because REBEL never had a cheap and fast evaluation. The power of LE lies in a big fat evaluation routine, for the latest REBEL the speed-up factor of LE is 3.2.
- It's a strange mechanism, the bigger the evaluation routine, the more the speed-up factor of LE will increase. In this way it is not so bad to have an expensive evaluation routine, adding new chess knowledge is relative cheap because of LE.
- The drawbacks of LE are only few, at least if you practice it in the way REBEL does, this includes that you must have the evaluation of depth-1, if you don't have it and have a big fat evaluation routine yourself, consider it as useful to do full evaluations starting at horizon-1 depth and onwards, it might give your program a real push, I sincerely hope so.
- Last, if you have one of the latest REBEL versions you can experiment with LE, in the Personalities is a parameter called [ChessKnowledge = 100]. When you increase this value to 200 it will set the default MARGIN of 0.50 to 1.00, when you use [ChessKnowledge = 400] MARGIN is set to 2.00, when you use [ChessKnowledge = 500] MARGIN is set to infinite, meaning LE is not used at all. Using [ChessKnowledge = 500] you can check how well LE works in REBEL and that the side-effects are about to neglect.

Search Techniques in REBEL (Futility Pruning)

Futility Pruning is the original idea of Ernst Heinz practiced in his chess playing program DARK THOUGHT, it's well documented [on his own pages](#).

The idea has been adapted in REBEL and improved using the LAZY EVAL technique as a base, see [description](#) above.

Futility Pruning is done at horizon-1 depths and horizon-2 depths, it basically comes down to LAZY EVAL only that MARGIN is increased. So when SCORE + MARGIN can't make it to ALPHA the subtree is pruned, its pseudo code:

```
if (current_depth == horizon_depth-1) then
{
  if (own_king_is_in_check)           -> don't try FUTILITY, too dangerous.
  if (move_does_check_the_opponent_king) -> don't try FUTILITY, too dangerous.
  if (move_is_a_capture)              -> don't try FUTILITY, too dangerous.
  if (special_case_position)          -> don't try FUTILITY, see Lazy Eval.
  Futility_One();                     -> calculate (guess) score, more below.
  if (ALPHA < SCORE + MARGIN)          -> don't reward FUTILITY, just proceed.
  else: prune tree (don't go deeper) using SCORE as the real score.
}
```

The routine "Futility_One" does exactly the same as the routine "Lazy_Eval" (see above). MARGIN however instead of 0.50 is set to a higher value, basically 3.00 (3 pawn units) but is increased to 5.00 in the end-game. Another difference in comparison with LAZY EVAL is that SCORE isn't updated with MARGIN.

About exactly the same is done at horizon-2 depths, only its MARGIN is further increased to avoid errors, its pseudo code:

```

if (current_depth == horizon_depth-2) then
{
  if (own_king_is_in_check)          -> don't try FUTILITY, too dangerous.
  if (move_does_check_the_opponent_king) -> don't try FUTILITY, too dangerous.
  if (move_is_a_capture)             -> don't try FUTILITY, too dangerous.
  if (special_case_position)         -> don't try FUTILITY, see Lazy Eval.
  Futility_Two();                    -> calculate (guess) score, more below.
  if (ALPHA < SCORE + MARGIN)         -> don't reward FUTILITY, just proceed.
  else: prune tree (don't go deeper) using SCORE as the real score.
}

```

The routine "Futility_Two" does exactly the same as the routine "Futility_One" (see above). MARGIN is set to 5.00 (5 pawn units) as standard value.

Futility Pruning was good for a speed-up of 22% in REBEL with only very few side effects, hardly any.

Search Techniques in REBEL (Horizon)

At HORIZON-DEPTH after evaluation of the position it is decided to go to Quiescent-Search (QS) or not. There are a couple of tricks that will avoid REBEL doing unnecessary expensive Q-searches, but let's examine the base code first before going into detail.

```

if (Lazy_Eval_is_true)          -> return score, no eval, no QS
Evaluate_Position();
if (current_depth == maximum_depth) -> return score, no QS
if (Trick_one_is_true)          -> return score, no QS, more below
if (move_does_check_the_opponent_king) -> Do QS
if (ALPHA >= SCORE)              -> return score, no QS
if (Trick_two_is_true)          -> return score, no QS, more below
Quiescent_Search();             // QS coding

```

Trick_One gives about a 10% speed-up, its thought behind: The goal of QS mainly is to see if a piece is hanging (en-prise), based on that thought it is likely the score will not go down further than the value of the hanging piece itself.

So it must be able to calculate a margin for calling QS or else just return the score and thus not call QS at all. The formula in pseudo code:

```

MARGIN = 3.00                      // 3 pawns safe-guard value
MARGIN + highest hanging piece value // Queen=900, Rook=500 etc.
MARGIN + 9.00 when own_king_was_in_check_before_make_move
MARGIN + 6.00 when the opponent can promote the next ply
if (SCORE-MARGIN > BETA)           -> return TRUE
else return FALSE

```

Trick_Two gave about a 5-8% speed-up, I don't quite remember exactly, its thought behind: if the score is already 9.00 above BETA don't bother to do QS, it won't matter, the score is way too good, its pseudo code:


```

if (own_king_was_in_check_before_make_move) -> return FALSE (too risky)
if (opponent_can_promote_the_next_ply)      -> return FALSE (too risky)
if (SCORE-900 > BETA)                        -> return TRUE
else return FALSE

```

IMPORTANT : Naturally the 2 tricks can be practiced in QS itself too!

Search Techniques in REBEL (reductions)

REDUCTIONS are the opposite of extensions. Extensions extend the search with one ply, reductions do the opposite, reduce the search with one ply. Reductions are very powerful, they speed-up the search tremendously. However the reductions-business is a wasps' nest, when you reduce too much or use wrong formula's your engine goes down in strength rapidly, so be extremely careful using reductions.

I would like to introduce some of the reduction techniques I use in REBEL which I consider safe, at least in the REBEL concept, realize they might work counter productive in your engine.

REDUCTION-1 : In the main-search (not Q-search) after REBEL has called "Make_Move();" it investigates if the move is candidate for a reduction. REBEL uses the following formula:

```

if (remaining_depth > 2
    && own_king_was_not_in_check_before_make_move
    && move_is_no_capture
    && move_does_not_check_the_opponent_king) then    // such as Bf1-b5+
{ if (ALPHA > SCORE + MARGIN) reduce depth with 1 }

```

SCORE = The score of the position (material value +
piece-square value's)

MARGIN = TABLE [remaining_depth];

```

static int TABLE    0,    0,    0, 500, 500, 700, 700, 900,
                    900,1500,1500,1500,1500,1500,1500,1500,
                    1500,1500 ..... };

```

Furthermore REBEL makes sure this type of reduction is only used once. The basic thought behind the idea is to reduce the search with one ply if the side to move is already behind a rook or worse depending on remaining depth. The effect is that for positions near the root REBEL will use a MARGIN of 15.00 (pretty safe) and deeper in the tree a MARGIN of 5.00 (more risk).

The reduction in practice is pretty safe, sometimes a tactical shot is seen one ply too late but it outweighs the advantage of the nice speed-up of 15% I got.

REMARK: for clearness sake, *remaining_depth* = *horizon_depth* - *current_depth*, thus the number of plies to go to the horizon.

OTHER REDUCTIONS : REBEL does several other reductions, to understand them you will need to know a little bit more about the quite different approach of REBEL's Search Algorithm in comparison to other chess programs, I therefore highly question the relevance of this topic as I assume that it can't be used in other programs without drastic changes, nevertheless here goes...

When we (for example) are at iteration 8, all the positions in the tree till the horizon are evaluated by REBEL's normal EVAL routine where the complete chess knowledge is. This is a costly operation, but (for REBEL) it pays off because it allows all kind of static evaluation tricks.

Mind you, if you have the complete evaluation at your disposal (the score, hanging pieces for both sides, king safety for both sides etc. etc.) and also have most of this information available for [current_depth-1] and [current_depth-2] all the way to the root position, stored on the stack, there are many static tricks you can do.

Actually the system has been (and still is) the sole base for REBEL's [Selective Search](#) approach, it allows reductions, prune complete subtrees, more accurate extensions, avoids needless null-move searches. More later, for now let's stick to the topic reductions.

REDUCTION-2a : When we are in the main-search (not Q-search) and have evaluated a position it is checked for being candidate for a reduction, to clarify where we are in the tree some free-style pseudo code:

```
Make_Move();           // update board position
Evaluate_Position();    // do a complete evaluation
Reduce_Depth();         // reduce one ply (Y/N)
```

Continue.....

"Reduce_Depth" first checks for a list of exceptions, it checks for situations a move never ever is considered being candidate for a reduction, the list:

```
the_move_is_already_reduced
own_king_was_in_check_before_make_move
move_does_check_the_opponent_king      // such as Bf1-b5+
move_wins_material                     // winning_capture
move_increases_pressure_on_opponents_king // see remark below
```

The coding for move_increases_pressure_on_opponents_king is tricky tricky, you must have some kind of code that recognizes mate-threats, that measures if a move makes progress attacking the opponents king in a dangerous way, you can't afford to reduce moves like that. For REBEL it's not so time consuming, most of the data is directly available from the evaluation, issue King_Safety.

"Reduce_Depth" does check for several cases, reduction-2a goes as follows, when the score (from EVAL!) is already below ALPHA the move (or position) is candidate to be not so good, but then it shows up that the position has a direct threat, for instance it attacks the opponents queen (value 900) which would bring the score above ALPHA, then maybe the move is not so bad after all.

It is then checked if we divide the threat by 4 (making it 2.25 in this case) would again bring the score above ALPHA, if not the move is candidate for a reduction, the assumption is made the move will never make to ALPHA, the depth is reduced by one.

For reduction-2a there is another safe-guard (exception) rule which I practise on more occasions in REBEL. The idea is to check the hash table and gain some extra information on the position. The scores in the Hash Table are of course not so reliable because of the ALPHA/BETA algorithm but it may give a clue after all and just for an extra safe-guard check it can't hurt. The pseudo code:

```
(1) if (current_move_is_the_move_from_the_hash_table) - do not reduce
    if (current_position_is_not_in_the_hash_table)    - reduce
(2) if (ALPHA < hash_table_score)                     - do not reduce
(3) if (hash_table_score - evaluation_score > 0.50)   - do not reduce
    else                                              - reduce
```

The idea behind the code is another check for the credibility of the move, if it turns out to be the best move from the Hash Table it might be risky after all to reduce here, see (1), secondly since the position is known in the Hash Table and its score strangely enough is higher than ALPHA, better not reduce, see (2), thirdly the hash table score is half a pawn higher than the evaluation score, so

While it is true that the hash table score in (2) and (3) is probably maltreated by the behaviour of the ALPHA/BETA algorithm it is not so bad to pay attention in this case, thus the move is not reduced.

REDUCTION-2b :

```
middle game      : maximum is 8
early end game  : maximum is 6
end game        : maximum is 4
late end game    : maximum is 3           // rook endings, B/N endings
pawn ending      : maximum is 2
```

```
static char table_for_mid_game [] = { 0,1,1,1,2,2,3,3,3,4,4,5,5,6,6,7,8,8,8,8,8,8,8,8,8,8... };  
x = table_for_mid_game [iteration_depth];
```

```
if (remaining_depth<=x && remaining_depth>1) then
{ if (ALPHA > SCORE + THREAT &&
    ALPHA < SCORE + THREAT + MARGIN) -> reduce depth with one ply. }
```

```
SCORE : score of EVAL
THREAT : Queen=900, Rook=500, Bishop=300, Knight=300, Pawn=100
MARGIN : TABLE [remaining_depth];
```

```
static int TABLE[] = { 00,00,10,15,20,25,25,25,25,25,25,25,25,25,25,25,
                        25,25,25,25,25,25,25 ..... };
```

```
if (remaining_depth<=x && remaining_depth>2) then
{ if (ALPHA > SCORE + THREAT &&
    ALPHA < SCORE + THREAT + MARGIN) -> reduce depth with 2 plies. }
```

```
SCORE : score of EVAL
THREAT : Queen=900, Rook=500, Bishop=300, Knight=300, Pawn=100
MARGIN : TABLE [remaining_depth];
```

```
static int TABLE[] = { 00,00,20,30,40,50,50,50,50,50,50,50,50,50,50,
                        50,50,50,50,50,50,50 ..... };
```

REDUCTION-2d :



The idea looks great at first glance but is full of stings and some special safe-guard coding is needed before rewarding the

[illegible]

```
static char table_for_reductions [] = { 0,1,1,1,1,2,2,2,2,3,3,3,3,4,4,4,4,5,5,5,5... };
maximum_number_of_reductions = table_for_reductions [iteration_depth];
```

This reduction is given an own [page](#).

This ends the description of REBEL's reduction mechanisms, let's move now to the next chapter, Extensions.

Extension Techniques in REBEL (checks)

INTRODUCTION : Extensions are very powerful, yet if you use too many extensions it will blow up the Search and produce a very bad branch-factor.

In the early days of computer chess when you only had a slow 5 Mhz processor at your disposal and you only could hit 5-7 plies at tournament time control, extensions were dominant, you needed them, and a lot of them too, to produce reasonable moves at such low depths.

Nowadays, having fast PC's, the need to use a lot of extensions has declined considerable, it is in my opinion better to focus on a low branch factor then to have a lot of extensions.

Mind you, if you are able to produce a chess program with an effective branch-factor of 2.0 then every doubling in processor speed will give you an extra iteration, in most cases good for an increase of +30-50 elo points in the computer-computer competition.

However, you still can't do without extensions, the check-extension is obliged to have, without the check-extension the elo of REBEL would drop 100-150 elo points, I am pretty sure of that. The re-capture extension as practiced in REBEL is good for +30-40 elo points, the remaining ones REBEL has are debatable, I use them but their elo strength is hardly measurable.

The check extension in REBEL is rewarded in MakeMove(); when it is recognized that the side to move moves out of check, the depth is extended with 1 ply, the common procedure in most chess programs.

An exception is made for the first check, it is not extended, also the fourth check is extended with 2 plies being in sync again with common procedure to extend every out_of_check situation with one ply. The idea behind: when there is only one check in the tree, it is probably not so important, thus skip it. However when you have 4 checks in the Search, the chance is big that checks play an important role, better get in sync, thus extend 2 plies.

Skipping the "first check" is very time sensitive, it speed-up REBEL with 25%, however its elo gain is very small in comparison with the common procedure to extend every out_of_check situation, for REBEL the gain is about +5 elo, you must find out yourself if the idea works in your own engine.

Through the years many experiments have been tried to improve the formula, about every year I have tried 3-5 new formula's, it was all in vain, there is a proverb that says, "Genius is the ability to reduce the complicated to the simple", this seems to be very true for extending checking moves, just extend with one play in every out_of_check situation.

Extension Techniques in REBEL (recaptures)

The sense of recaptures is an old discussion among chess programmers, are they useful or not? For REBEL it certainly pays off, I have used them since the early days and still use the recapture extension. Without the recapture extension REBEL will run a factor of 2.2 to 2.5 faster, so it is quite an investment, still it is good for an elo of +30-40, let me try to present how it works.

REBEL has no limitation on recapture extensions. However there is a (flexible) WINDOW the recapture should fit in, which at the root is set to +5.00 / -5.00 and narrowed each ply the Search goes deeper, this to a minimum value of +2.00 / -2.00, the names of the 2 variables: HIGH and LOW, its pseudo code:

```
static int LOW,HIGH;
```

```

I_SCORE = Sum_Material_plus_Piece-Square_Values // see elsewhere
HIGH = I_SCORE + 5.00 // pre-fill HIGH and LOW
LOW = I_SCORE - 5.00 // before the search.

HIGH = HIGH - TABLE [current_depth] // narrow HIGH and LOW when
LOW = LOW + TABLE [current_depth] // going one ply deeper.

HIGH = HIGH + TABLE [current_depth] // restore HIGH and LOW when
LOW = LOW - TABLE [current_depth] // climbing back one ply.

static int TABLE 00,00,50,50,50,50,25,25, // narrow HIGH and LOW till
                25,25,00,00... }; // 2.00 at ply=9 and onwards.

```

The idea is of course to extend only those recaptures which are close to the material balance of the root position. REBEL deliberately uses 2 new variables (HIGH and LOW) since it is not wise to rely on ALPHA or BETA here, this because of possible fail-high and fail-low cases at the root that might occur and suddenly all kind of unwanted recaptures are extended because of the low value(s) of ALPHA and/or BETA.

The recapture extension is rewarded in "Make_Move", its pseudo code:

```

if (move_already_extended) -> do not extend
if (previous_ply_was_no_capture) -> do not extend
if (move_does_not_capture_on_the_same_square) -> do not extend
if (move_is_not_a_winning_capture) -> do not extend, see elsewhere
if (I_SCORE < LOW) -> do not extend
if (I_SCORE > HIGH + piece value depth-1) -> do not extend
else: extend tree with one ply.

```

piece value depth-1 is the value of the captured piece of the previous ply (current_depth-1) to widen HIGH. Also here through the years many experiments have been tried to improve the recapture extension, this seems to work best.

Extension Techniques in REBEL (pawn)

White Pawns that reach the 7th rank and Black Pawns that reach the 2th rank are extended with one ply.

Extension Techniques in REBEL (endgame)

In the endgame 2 extensions are recognized and rewarded:

- When (during Search) a transition occurs to the simple ending the search is extended with one ply. A simple ending is defined as a rook and/or bishop/knight ending, it is useful to extend then.
- The Search is extended with 3 plies when the search transits to a pawn-ending. An extra window check of 3 pawns is done on I_SCORE before the extension is rewarded, its pseudo code:


```

if (no_capture) -> do not extend
if (no_pawn_ending) -> do not extend
if (I_SCORE > +3.00) -> do not extend
if (I_SCORE < -3.00) -> do not extend
else: extend tree with 3 plies.

```

The extension is very powerful, it will often avoid REBEL entering a lost ending and vice versa.

Extension Techniques in REBEL (king safety)



An extension is done when a move seriously increases its chances to attack the opponent king, you will need to have some sophisticated code to recognize such occasions, consider the diagram.

The moves 1.e5 and 1.g6 are extended with one ply since it seriously increases the attack on the black king, the other moves are not extended as they do not increase the pressure on the black king, also checks (such as 1.Qh6+) are excluded as an

exception condition.

The extension in practise isn't very powerful, say +5-10 elo, its costs is pretty cheap, a 5% slowdown of REBEL's search.

Extension Techniques in REBEL (PVS extensions)

A powerful extension is what I have called the Principal Variation Search (PVS) extension, at the time it was implemented good for an 20-30 elo gain. However anno 2007 we are living in the days of [History Reductions](#) and/or [LMR](#) and it's arguable if the extension still works as nowadays trend is to reduce the tree and not have too many extensions. Nevertheless it can't hurt to try so here is the description.

The logic is to extend when the search is full of PVS moves (best moves from the hash table). However this is costly business and so a number of restrictions are needed to avoid the search to explode. After a lot of research I found the following simple formula working quite well:

```
int count=0;
int margin=0x100;
if (node[depth]=PVS && node[depth-1]=PVS && alpha > pvs_score+margin)
{
    count++;
    if (count=4) { extend(); count=0; }
}
```

Description: for each continues PVS move (2 x best move from the hash table) the hash table score is checked with alpha and if within a reasonable margin (1 pawn) it is marked in a variable (counter). If such a situation is discovered 4 times the tree is extended and counter set to zero again, ready to receive the next 4 continues PVS moves.

If you have [Pro Deo 1.5](#) you can experiment with the PVS extension using the following parameters:

```
[Pruning = MISC_37]          * turn off PVS extension
[M37_VAL = 2.00]             * set margin to 2.00 (default is 1.00)
[M37_COUNT = 3]              * set counter to 3 (more PVS extensions)
```

Some final remarks on Extensions

- When a move is extended make sure the same move is not extended another time, it's good in general not to extend moves twice.

- It's good to have some kind of formula that will control the `maximum_number_of_extensions`, REBEL does this based on its iteration.
- REBEL uses the concept of fractional extensions which gives you as a programmer more freedom to define extensions more precise. The fractional extension technique as used in REBEL divides a ply into 4 parts. To extend the tree with a full ply the value "4" is added to a counter which is used later to calculate the real depth.

Having such a system you can do all sort of tricks, reward extensions on their importance by toying with values between 1-4, or even 6 (1.5 ply) and so on.

This ends the description of REBEL's used extensions, let's move now to the next chapter, Selective Search, one of the most complicated parts to understand, especially when you are a null-mover and are not familiar with static evaluation pruning.

Selective Search Techniques in REBEL (introduction)

REBEL since its early existence in 1980 has been a selective program, in those days you had 2 choices, either have a pure brute force program or enter the dangerous path of selective search by static evaluation, the latter was only done by a few, among them Richard Lang (Chess Genius) and myself which became the base of their success later.

In those days Null-Move (as we know it today) did not exist. I first heard of Null-Move in 1986 during the World Championship in Cologne, Germany. Don Beal was participating with his chess program that used a Null-Move technique in his Quiescent Search, the seed of a major breakthrough in computer chess was sowed.

During the tournament Frans Morsch (FRITZ) kept on talking about Null-Move to me, "Ed, there must be something real good in Null-Move, I am going to research this". I didn't pay attention and shrugged, Null-Move, no way.

But then in 1991/92 Frans Morsch implemented Null-Move in his Fritz in a new way and Null-Move became a big success as it was a very powerful and easy way of doing selective search, no more tricky static evaluation tricks, but the relative safe search based R=2 approach, easy, clean and powerful.

Then Frans leaked his Null-Move approach to Chrilly Donninger the author of NIMZO who wrote an article in the ICCA journal and Null-Move became public. Nowadays I can't mention a chess program that doesn't use Null-Move, the chess programmer community owes Frans Morsch a big thanks.

REBEL however kept loyal to its own system, that is, doing Selective Search by Static Evaluation and below you will find its main description. Later I added Null-Move to REBEL's Selective Search but it is used in a total different way namely: to find the errors (exceptions) in the static evaluation concept, more later.

Selective Search Techniques in REBEL (concept)

The first thing you will need to keep in mind is that REBEL's way of doing Selective Search demands doing a complete evaluation of each position in the Main-Search till `horizon_depth-1`.

You simply need to have decent information about the position before you can decide to prune a complete subtree, but let's start... take a deep breath first...

REBEL's search is split into 2 parts:

- The Null-Move Part (the first "x" plies of the iteration depth)
- The Static Evaluation Part (the remaining plies of the iteration depth)

For instance: we are at iteration 11, REBEL in the first 5 plies will practice (if needed) Null-Move, for the remaining 6 plies REBEL will fully rely on his own Static Evaluation Concept, no Null-Move is used.

The value of "x" is flexible, it depends on the stage of the game and is also iteration based, we will call "x" S_DEPTH (Static Depth) from now on, its formula plus tables:

define stage of the game before calling Search:

```
middle game      : STAGE = 0
end game         : STAGE = 1
late end game    : STAGE = 2    // rook endings, B/N and pawn endings
```

S_DEPTH is defined after each iteration, table driven, its formula:

```
S_DEPTH = TABLE [STAGE] [iteration_depth];
```

```
char TABLE [0][] = { 0, 1, 1, 1, 1, 2, 2, 3, 3, 3, 4, 4, 5, 5, // middle game
                      6, 6, 7, 8, 9,10,11,12,13,..... }
```

```
TABLE [1][] = { 0, 1, 1, 1, 1, 2, 2, 3, 3, 4, 5, 6, 7, 8, // endgame
                9,10,11,12,13,14,15,16,17,..... }
```

```
TABLE [2][] = { 0, 1, 1, 1, 1, 2, 2, 3, 4, 5, 6, 7, 8, 9, // late endgame
                10,11,12,13,14,15,16,17,18,..... };
```

Example: iteration = 11

```
S_DEPTH = middle game  -> 5 -> 5 plies Null-Move -> 6 plies Static Pruning.
S_DEPTH = end game     -> 7 -> 7 plies Null-Move -> 4 plies Static Pruning.
S_DEPTH = late end game -> 8 -> 8 plies Null-Move -> 3 plies Static Pruning.
```

REMARK: in reality S_DEPTH is more sophisticated, there are various between-forms, but that you can figure out yourself, this is only the main thought behind S_DEPTH.

Furthermore during Search S_DEPTH is incremental updated to be in sync with REBEL's extensions otherwise the Static Evaluation Part would become too long. In principle it comes down that every time REBEL does an extension it will increment S_DEPTH too.

REBEL's search in free style pseudo code looks as follows:

```
if (remaining_depth>1 && current_depth<=S_DEPTH) then do Null-Move Part
{ Make_Move(); // update board position
  Evaluate_Position(); // do a complete evaluation
  if Selective_Search_PART_ONE_is_true(); -> go one ply deeper (no Null-Move)
  else: do Null-Move Search } -> R=2 or R=3 (more later)

if (remaining_depth>1 && current_depth>S_DEPTH) then do Static Evaluation Part
{ Make_Move(); // update board position
  Evaluate_Position(); // do a complete evaluation
  if Selective_Search_PART_TWO_is_true(); -> go one ply deeper
  else: prune (cut-off subtree) }
```

Having explained the concept of S_DEPTH we now can move to the 2 parts of coding, the Null-Move Part and the Static Evaluation Part, let's do the Null-Move Part first.

Selective Search Techniques in REBEL (null-move)

We are in the very first plies of the tree defined by S_DEPTH, [see above](#), the goal of this part is to decide if it is necessary to do an expensive Null-Move-Search or not, this based on Static Evaluation.

To measure the performance of this routine REBEL keeps track of the percentage of Null-Move re-searches. Its percentage usually fluctuates between 5-7% which is excellent, it means that 93-95% of the total of Null-Move searches return OKAY meaning that no research at full depth is needed.

Mind you, if you have SCORE + THREAT (coming from the evaluation) already at your disposal, then why do an expensive Null-Move-Search by default? There is no need, REBEL tries the below first, its pseudo code:

```
if (ALPHA < SCORE + THREAT) return TRUE;    // search node with full depth.
```

The condition works very well to limit expensive Null-Move searches because when SCORE+THREAT is already greater than ALPHA, then in most of the cases (>95%) Null-Move will return FALSE (thus research) and so you will have to search the tree at full depth anyway.

This is the exact goal of the routine, find the likely situations where Null-Move will produce FALSE and save yourself a lot of unnecessary Null-Move searches, thus save processor time. We are going to the next conditions...

Other cases where Null-Move is avoided:

```
if (own_king_was_in_check_before_make_move) return TRUE;    // search node with full depth
if (move_does_check_the_opponent_king) return TRUE;        // search node with full depth
else: return FALSE;                                         // do Null-Move
```

REMARKS:

- Despite of the above advantages to avoid needless Null-Move Searches there is a disadvantage worth to mention, that is that move-ordering is slightly better in case you don't practice an Avoid_Null_Move routine, it can be different for each program.
 - It's very easy to make REBEL a full Null-Move program, all it needs to do is to make S_DEPTH equal to iteration_depth, actually REBEL has an Interface driven parameter for that: [Selective Search = 0] in the Personality Editor.
 - When REBEL uses Null-Move it uses R=3 for the middle-game and R=2 for the end-game.
-

Selective Search Techniques in REBEL (static)

We are in the last plies of the tree defined by S_DEPTH, [see above](#), the goal of this part is to decide if a subtree is worth to search to the full depth or prune it completely, this by Static Evaluation.

We are of course on very thin ice here, mind you if we are at iteration 11 where S_DEPTH=5 then REBEL from ply=6 and onwards will allow the complete pruning of a subtree (5 plies in this case!), very powerful of course if all works well, but extremely dangerous when the error-margin becomes too high.

Nevertheless REBEL since its early existence works that way and the system in practice works very well. Actually the below described pruning system gave REBEL quite a lead till 1995/96 before Null-Move made its entrance and became dominant the years after.

How it is done, some easy pseudo code to start with:

```
if (own_king_was_in_check_before_make_move) return TRUE; // search node with full depth
if (move_does_check_the_opponent_king) return TRUE;      // search node with full depth
if (move_is_winning_capture) return TRUE;                // search node with full depth
if (ALPHA < SCORE + THREAT + MARGIN) return TRUE;        // search node with full depth
```

```
SCORE   : score of EVAL
THREAT  : Queen=900, Rook=500, Bishop=300, Knight=300, Pawn=100
MARGIN  : TABLE [remaining_depth];

static int TABLE[] = { 00,00,10,15,20,25,25,25,25,25,25,25,
                        25,25,25,25,25,25,25 ..... };
```

After these check have all failed, the subtree in principle is now candidate for (complete) pruning, however there are 2 exception cases where REBEL will not prune, these are:

- In case the move (from Make_Move) is a white pawn that moves to the 7th or 6th rank.
- In case the move (from Make_Move) is a black pawn that moves to the 2th or 3th rank.
- When the move (from Make_Move) seriously increases the pressure on the opponents king, more below.

You must have some kind of code that recognizes mate-threats, that measures if a move makes progress attacking the opponents king in a dangerous way, you can't afford to prune moves like that. The issue is already described [elsewhere](#).

If these conditions aren't met also the whole subtree is pruned!

The complete pseudo code:

```
if (own_king_was_in_check_before_make_move) return TRUE; // search node with full depth
if (move_does_check_the_opponent_king) return TRUE;      // search node with full depth
if (move_is_winning_capture) return TRUE;                // search node with full depth
if (ALPHA < SCORE + THREAT + MARGIN) return TRUE;        // search node with full depth
if (white_pawn_moves_to_rank6_or_7) return TRUE;         // search node with full depth
if (black_pawn_moves_to_rank3_or_2) return TRUE;         // search node with full depth
if (move_threatens_opponent_king) return TRUE;          // search node with full depth
else: return FALSE;                                     // prune complete subtree
```

In reality the code is more sophisticated handling some more (minor) issues, but the above listed is REBEL's framework for static pruning subtrees and will do good in practice.

This ends the description of REBEL's Selective Search, let's move now to the next chapter, Quiescent Search.

Quiescent Search in REBEL

Quiescent Search (abbreviated to QS) in REBEL has 2 goals, in a nutshell:

- Check if the evaluation of the horizon depth (SCORE) is safe from tactical surprises such as captures, promotions, checks. SCORE tends to go down, a correction takes place.
- Check for possible (long) series of checking-moves, there could be some material gain, or even a mate. SCORE tends to go up.

For REBEL the focus of QS is entirely on getting the right score for the evaluation of the horizon position, no further special tricks.

Unlike other chess programs REBEL (since the early 80's) in QS does not investigate all captures, there is absolutely no need for that, it's pretty safe to search only the winning captures, equal captures (QxQ, RxR etc) and Queen Promotions. Minor promotions are also excluded from QS, it's a waste of valuable processor time.

Excluded from the above are of course the situations when the king is in check, all moves are generated and searched.

For a given ply in QS REBEL will first generate and search the winning captures, secondly when those moves do not cause a BETA cut-off then search the equal captures and third and last do the checking moves (this limited to a predefined depth, more later), the rest of the moves is skipped.

Queen Promotions are part of the winning-capture concept. Naturally when the position has a best move from the Hash Table that move is searched first.

It's pseudo code, note that apart from 3-stage order mechanism QS is much of the same as the Main Search.

```

Get_a_Move_Until_No_More_Moves      -> following the move ordering
                                     as described above
if (Lazy_Eval_is_true)               -> done, return score, see elsewhere
Evaluate_Position();
if (Trick_one_is_true)               -> done, return score, see elsewhere
if (move_does_check_the_opponent_king) -> go one ply deeper in QS
if (ALPHA >= SCORE)                  -> done, return score
if (Trick_two_is_true)               -> done, return score, see elsewhere
else: go one ply deeper in QS

```

Long Checks : REBEL in QS will search all moves that check the opponent king, this till a given depth, called MAX_CHECKS_DEPTH. This variable is defined during each iteration as:

```
MAX_CHECKS_DEPTH = iteration_depth + 2
```

It means that QS by default is allowed to search all checking moves during the first 2 plies of QS. Furthermore MAX_CHECKS_DEPTH is increased during the Main Search and QS when the following is true:

```

if (king_is_in_check) then
{ if (only_one_legal_move) MAX_CHECKS_DEPTH = MAX_CHECK_DEPTH + 2
  if (only_two_legal_moves) MAX_CHECKS_DEPTH = MAX_CHECK_DEPTH + 1
}

```



This mechanism will guarantee REBEL to find deep tactical shots such as deep mates, deep repetitions, deep material combinations when the position is dominant to checks, have a look at the diagram.

In this position REBEL is able to announce a Mate in 30 Moves at iteration 1 having searched only 2351 positions, all because of the above described update mechanism of MAX_CHECK_DEPTH.

I use this system since 1987/88, it was introduced in the Mephisto MMV, even on an ancient 6502 processor running at only 5 Mhz the system worked well. Only in the latest version of REBEL I have changed the formula a bit, that is:

```
MAX_CHECKS_DEPTH = current_depth + 2 // at the very start of QS
```

```

if (king_is_in_check && in_QS) then
{
  if (only_one_legal_move) MAX_CHECKS_DEPTH = MAX_CHECK_DEPTH + 2
  if (only_two_legal_moves) MAX_CHECKS_DEPTH = MAX_CHECK_DEPTH + 1
}

```

It practical means that during the Main-Search MAX_CHECKS_DEPTH is no longer increased, the change gave a +14% speed-up.

REMARK: to use the REBEL concept of long-checks you will need to have some kind of code that is able to count the number of legal moves when the king_is_in_check.

This ends the description of REBEL's Quiescent Search, let's move now to the last chapter Evaluation.

Evaluation in REBEL (introduction)

REBEL has a large and very expensive evaluation function with hundreds evaluation characteristics, it is impossible to present them all, therefore only the most dominant evaluation stuff will be presented, also a bit about its data structure and programming techniques, let's start with the latter.

Piece-Type, REBEL has a most simple data structure for the 12 piece types as used on its internal chess board:

```

+---+---+---+---+---+---+---+---+---+---+---+---+ 00 = empty square
| 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 01 = white pawn
+---+---+---+---+---+---+---+---+---+---+---+---| 02 = white knight
| .. | Wp | WN | WB | WR | WQ | WK | Bp | BN | BB | BR | BQ | BK | .. = .....
+---+---+---+---+---+---+---+---+---+---+---+---+ 12 = black king

```

The reason for this simple approach is two-sided:

- Easy access to tables for indexing, keep tables small and surveyable.
- Make use of the processor so called "indirect addressing" possibilities, for instance in the the case of the use of the popular C statement SWITCH - CASE and/or use "indirect addressing" for calling routines, a few examples to explain:

Example-1: Any good C compiler will produce perfect code if you use SWITCH - CASE using an unbroken and continuous string of characters, consider the following code while (for instance) generating moves or scanning the internal chess board:

```

switch (piece_type) { case 0 : goto empty;           // empty square, get next square
                     case 1 : goto white_pawn;       // evaluate white pawn
                     case 2 : goto white_knight;     // evaluate white knight
                     case 3 : goto white_bishop;
                     case 4 : goto white_rook;
                     case 5 : goto white_queen;
                     case 6 : goto white_king;
                     case 7 : goto black_pawn;       // evaluate black pawn
                     case 8 : goto black_knight;
                     case 9 : goto black_bishop;
                     case 10 : goto black_rook;
                     case 11 : goto black_queen;
                     case 12 : goto black_king; }

```

Any good C compiler will translate the above C code into one assembler instruction, something like:

```
jmp     TABLE [EAX]
```

Example-2: You can even do the same in just one C instruction for calling routines instead of using the goto instruction, here is how:

```
(TABLE[piece_type-1])();           // call routine as defined in TABLE

void (*TABLE[])() = { w_pawn,w_knight,w_bishop,w_rook,w_queen,w_king,
                      b_pawn,b_knight,b_bishop,b_rook,b_queen,b_king };

void w_pawn()    { code here }
void w_knight() { code here }
....
void b_king()    { code here }
```

Indexing: REBEL in EVAL wherever it makes sense will use square tables above fixed values. For instance, when evaluating an isolated pawn it can be given a fixed value as penalty, such as 0.10, however a square table is more precise, more flexible to tune too.

+-----+-----+-----+-----+-----+-----+-----+-----+ square table																		
8		00		00		00		00		00		00		00		Penalties for white isolated		
+-----+-----+-----+-----+-----+-----+-----+-----+										awns based on their position								
7		10		12		16		20		20		16		12		10		on the board.
+-----+-----+-----+-----+-----+-----+-----+-----+																		
6		10		12		16		20		20		16		12		10		Background: usually in the
+-----+-----+-----+-----+-----+-----+-----+-----+										middle game an isolated pawn								
5		10		12		16		20		20		16		12		10		on A2 is not so bad as an
+-----+-----+-----+-----+-----+-----+-----+-----+										isolated pawn in the center.								
4		06		08		10		16		16		10		08		06		
+-----+-----+-----+-----+-----+-----+-----+-----+										Advice: use such square tables								
3		04		06		08		10		10		08		06		04		wherever you can in EVAL.
+-----+-----+-----+-----+-----+-----+-----+-----+																		
2		02		04		04		10		10		04		04		02		Remark: this example is only
+-----+-----+-----+-----+-----+-----+-----+-----+										valid for REBEL's middle game,								
1		00		00		00		00		00		00		00		00		use different values for the
+-----+-----+-----+-----+-----+-----+-----+-----+										end game.								
		a		b		c		d		e		f		g		h		

Evaluation in REBEL (hanging pieces)



REBEL in EVAL (for the side to move) will detect the so called hanging pieces with a maximum of 3 squares, the 3 squares are sorted on the expected material loss.

The same applies for the opponent side, it's only called different, threatened pieces, consider the left diagram.

Hanging Pieces are used elsewhere in other parts of the program (move ordering, Q-Search etc.), the same applies for Threatened Pieces, it is mainly used as THREAT value, see Selective Search, Reductions etc.

With "black-to-move-next" REBEL's list will look as follows:

```
Hanging Pieces:   Qh7 (value 9.00), Bc1 (value 3.00), pawn d4 (1.00)
Threatened Pieces: Qg5 (value 9.00), Rh8 (value 5.00)
```

When "white-to-move-next" the list is swapped:

```
Hanging Pieces:   Qg5 (value 9.00), Rh8 (value 5.00)
Threatened Pieces: Qh7 (value 9.00), Bc1 (value 3.00), pawn d4 (1.00)
```

How it is done.

REBEL uses 2 board tables, one for white (WB), one for black (BB) which are zeroed at the beginning of EVAL. While scanning the board REBEL will update WB and BB, let's take the white knight on G1 from the diagram as an example: On G1 the knight can move to the squares: E2, F3 and H3, those squares are updated as follows:

```
WB[F3]=++WB[F3] | 16;    // square+1 , set bit 4
WB[H3]=++WB[H3] | 16;    // square+1 , set bit 4
WB[E2]=++WB[E2] | 16;    // square+1 , set bit 4
```

This process is done for all the white pieces, each square that is controlled by a white piece is incremented with 1 and a corresponding bit is set (using the OR operator), its data structure:

```
+-----+-----+-----+-----+-----+-----+
| BIT0 | BIT1 | BIT2 | BIT3 | BIT4 | BIT5 | BIT6 | BIT7 |
+-----+-----+-----+-----+-----+-----+
|      Number of      | PAWN | KNIGHT | ROOK | QUEEN | KING |
|      ATTACKERS      |      | BISHOP |      |      |      |
+-----+-----+-----+-----+-----+-----+
```

After all white pieces are done square F3 from WB looks as follows:

```
+-----+-----+-----+-----+-----+-----+ B0-B2 : 2 attackers
| BIT0 | BIT1 | BIT2 | BIT3 | BIT4 | BIT5 | BIT6 | BIT7 |
+-----+-----+-----+-----+-----+-----+ B3   : white pawn
|      Number of      | PAWN | KNIGHT | ROOK | QUEEN | KING |
|      ATTACKERS      |      | BISHOP |      |      |      | B4   : white knight/bishop
+-----+-----+-----+-----+-----+-----+
|  0   |  1   |  0   |  1   |  1   |  0   |  0   |  0   |
+-----+-----+-----+-----+-----+-----+
```

The same is done for all the black pieces updating the table for black (BB). It's very powerful to have such data, for each square on the board (empty or occupied) REBEL has the attackers and defenders, many interesting evaluation tricks can be tried for instance by using the value (bit-setting) of a square as an index to a 256 byte evaluation table, just think a bit of all the possibilities.

The data is used for evaluating mobility, king safety, pawn structure, passed pawns, center control, outposts and more. Also it is used to generate the hanging pieces of the position which is the current topic. Having the data of WB and BB REBEL has enough information to decide if a piece is hanging, its pseudo code:

```
get_next_piece_on_the_board          // scan the board
status = TABLE [piece_type] [WB[square]] [BB[square]]; // get status via the bits
if (status == 0) continue;           // piece safe -> next square
else: piece hangs, status contains its value          // Q=9 R=5 B=3 N=3 P=1

char TABLE [12] [256] [256];        // about 860 Kb
```

During program startup the 3-dimensional TABLE is filled from hard disk with the predefined values of all combinations of possible bit settings for white and black by piece_type. The formula to create the contents of TABLE will be given later, but maybe it's more fun to figure it out yourself.

HINT: WB and BB are zeroed at the beginning of EVAL, this is a costly operation in C, here is a trick to speed it up using redefinition:

```
unsigned char WB[64],BB[64];
long *PWB = (long *) WB;           // redefine char (8-bit) to long (32-bit)
long *PBB = (long *) BB;
```

```
PWB[0]=PWB[1]=PWB[2] ..... =PWB[15]=0; // 16 x 32-bit stores, clear WB
PBB[0]=PBB[1]=PBB[2] ..... =PBB[15]=0; // 16 x 32-bit stores, clear BB
```

This is about 8-10 times faster then the usual:

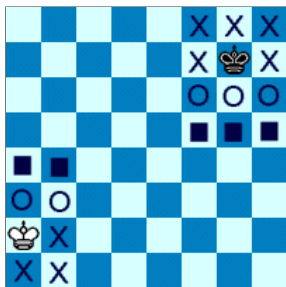
```
for (x=0; x<=63; x++) { WB[x]=0; BB[x]=0; }
```

Make sure that your compiler's alignment at least is set to 32 bit so that the generated memory addresses of WB and BB are divisible by 4. In most compilers the default setting is 32 or 64 bit which is okay.

King Safety in REBEL

REBEL has a large piece of code to evaluate the pressure on its own king and on the opponent king, both routines are each others mirror, REBEL doesn't practice the so called asymmetric approach.

It would go to far to list all REBEL's stuff regarding king-safety, presented below is its main frame. Excluded are issues like the "pawn shield", "pawn rams", "castling", handling "opposite kings".



Consider the diagram, the squares around the king will be evaluated using the data that is gathered in WB and BB, see [elsewhere](#).

The squares around the king marked with X are measured different than those marked with O, same story for the squares marked with ■, each type of squares has its own dynamics.

But before going into detail it is important to understand the following principle:

REBEL uses progressive evaluation for king safety, more REBEL will use progressive evaluation wherever it makes sense in EVAL, it's a quite different technique then normal evaluation, to clarify the terms:

- Normal Evaluation : evaluate square F8 regarding king safety, add the value to the collective evaluation variable (SCORE), evaluate the next square F7, F6, F5, G8 until all squares are evaluated.

Disadvantage : it won't evaluate the coherence between the pieces that attack the king, here progressive evaluation comes in.

- Progressive Evaluation : the final evaluation is delayed till all squares are measured, instead of that a counter is initialized (COUNTER=0) and updated while evaluating all the squares, then this counter is used as an index to the final evaluation table for king safety (TABLE) and TABLE [COUNTER] will added to SCORE.

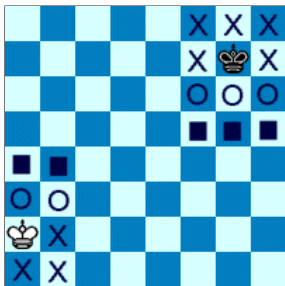
Advantage : depending on the quality of the contents of TABLE and COUNTER it is possible to measure the coherence between the pieces that attack the king, that when for instance there is only a Queen that attacks the king it isn't rewarded too high, but when a rook and a bishop participate in the attack the bonus jumps over a pawn, or more.


```
int TABLE [] = { 0, 2, 3, 6, 12, 18, 25, 37, 50, 75,
                  100, 125, 150, 175, 200, 225, 250, 275, 300, 325,
                  350, 375, 400, 425, 450, 475, 500, 525, 550, 575
                  600, 600, 600, 600, 600 ..... };
```

Consider the diagram on the right, the (well known) position occurs after the moves: 1.e4 Nf6 2.Bc4 Nxe4? 3.Bxf7+! Kxf7 4.Qh5+ Ke6? 5.Qg4+ Kd5?? Black wants to defend Nd5 by all means and will lose, black should have played 4...Kg8.

8	02	00	00	00	00	00	00	02
7	02	01	01	01	01	01	01	02
6	04	03	03	03	03	03	03	04
5	04	04	04	04	04	04	04	04
4	04	04	04	04	04	04	04	04
3	04	04	04	04	04	04	04	04
2	04	04	04	04	04	04	04	04
1	04	04	04	04	04	04	04	04
	a	b	c	d	e	f	g	h

Also, squares like H7, H8 are set a bit higher because there are less surrounding squares on the black king, this will avoid moves like Kg8-h8 when there is absolutely no need for that.



What is measured on those squares ONLY is the attack pattern using the bits (3-7) of WB[F5], WB[G5] and WB[H5] via the OR operator, it will represent the pressure it has on those squares.


```
char flag=0;
flag = flag | WB[F5];           // update attack pattern
flag = flag | WB[G5];           // update attack pattern
```

```
flag = flag | WB[H5]; // update attack pattern
```

The third step, measure the  squares (F7, F8, G8, H8, H7), update COUNTER and the attack pattern (flag), its formula and pseudo code:

```
if (WB[F7] != 0x00)
{
    COUNTER++; // white has pressure on F7
    flag = flag | WB[F7]; // update attack pattern
    if (BB[F7] == 0x81) COUNTER++; // square F7 not protected by
    // any of the black pieces
}

Do the same for the squares F8,G8,H8 and H7.
```

The fourth step, measure the  squares (F6, G6 and H6) update COUNTER and the attack pattern (flag), its code is only a bit different than step-3, it checks for the presence of an own piece too defending its king, the formula and pseudo code:

```
if (WB[F6] != 0x00)
{
    COUNTER++; // white has pressure on F6
    flag = flag | WB[F6]; // update attack pattern
    if (BOARD[F6] != own_piece) COUNTER++;
    if (BB[F6] == 0x81) COUNTER++; // square F6 not protected by
    // any of the black pieces
}

Do the same for the squares G6 and H6.
```

We are now ready for the last step, calculate the value for the attack pattern, add it to COUNTER, then calculate the final value for the black king regarding king safety, the pseudo code:

```
COUNTER = COUNTER + TABLE [flag << 3]; // reward the attack pattern with
// 1, 2 or 3 depending on the bits
// that were set.

SCORE = SCORE + EVAL [COUNTER]; // final evaluation.

char TABLE [] = {
//      . P N N R R R R Q Q Q Q Q Q K K K K K K K K K K K K K
//          P   P N N   P N N R R R R   P N N R R R R Q Q Q Q Q Q
//              P       P   N N N       P   P N N   P N N R R R R
//          0,0,0,0,0,1,1,0,1,2,2,2,3,3,3,0,0,0,0,1,1,2,2,2,3,3,3,3,3,3 };

int EVAL [] = {   0,   2,   3,   6, 12, 18, 25, 37, 50, 75,
                  100,125,150,175,200,225,250,275,300,325,
                  350,375,400,425,450,475,500,525,550,575
                  600,600,600,600,600 ..... };
```

REMARKS :

- King Safety in REBEL is not done when the opponent has no Queen, REBEL on such occasions fully relies on its Search, in practice it doesn't have any negative side effects. Actually I noticed that doing King Safety in the end-game seriously hurts REBEL's end-game knowledge. The issue is debatable of course.
- So when white has a Queen and black has no Queen, king safety for the black king is done, for the white king it is not, and vice versa.
- Furthermore when there is only a lone Queen left (no light pieces anymore) to attack the opponent king, king safety is skipped too. Debatable of course too, in practice it works best of REBEL.
- Last, when there are too few light pieces left to attack the opponent king (Rooks, Bishops, Knights) COUNTER isn't pre-set to the king position on the board, as explained [above](#), instead

COUNTER is zeroed, in principle it means the king is free to walk across the board without getting a huge penalty for that. Its pseudo code:

```
COUNTER = TABLE [black_king];           // see above
if (white_has_not_at_least_2_light_pieces)
    COUNTER=0;
```

- Again, it would go to far to list all REBEL's stuff regarding king-safety, this would make this already too long page even more longer. Excluded are issues like the "pawn shield", "pawn rams", "castling", handling "opposite kings".

*That's it folks, REBEL's main algorithm for King Safety, hope you haven't a headache by now!
Let's move to the next chapter, MOBILITY.*

Mobility in REBEL

Basically this is done while scanning the board, see section [bits](#). Each square is weighted and progressively evaluated for every piece type. At the beginning of EVAL a counter-variable COUNTER is set to zero and updated for Knights, Bishops and Rooks according to the following rules:

- White Knights : For each of the 8 directions a Knight can move it is checked what it controls, if it controls an enemy piece or it controls an empty square and that square is not controlled by a black pawn a piece-square bonus of 0, 2 or 4 is added to COUNTER depending on the importance of the square, see below table. If the square contains an own piece COUNTER is not updated, no bonus since the Knight can't move to that square.

+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
8		00		00		00		00		00		00		00		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
7		00		02		02		02		02		02		02		02		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
6		00		02		04		04		04		04		02		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
5		00		02		04		04		04		04		02		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
4		00		02		04		04		04		04		02		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
3		00		02		04		04		04		04		02		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
2		00		02		02		02		02		02		02		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
1		00		00		00		00		00		00		00		00		00	
+-----+-----+-----+-----+-----+-----+-----+-----+-----+																			
		a		b		c		d		e		f		g		h			

- White Bishops : For each square a bishop controls COUNTER is incremented, including XRAYs patterns. The latter means that (for example) a white bishop on G2 faced with a white knight on F3 will continue the direction scan and keeps on incrementing COUNTER till it encounters an own pawn or an enemy piece. This is done this way to avoid moves like Ne1, Ng5, Nh4 to open the diagonal G2-A8 without any need. With the XRAY code the white bishop on G2 receives the mobility bonus anyway no matter if there is a white knight on F3 or not.

There is more on Bishop mobility, this will be subject in the section [Minimum Mobility](#).

- White Rooks : For each square a rook controls COUNTER is incremented with 2 scanning the 2 vertical directions and with 1 scanning the horizontal directions because the strength of rook in

[illegible]

weakpwn 1

[illegible][illegible]

weakpawn 2

[illegible]

Remarks:

- A pawn formation like D4/E4 approximately gets a 50% higher bonus then a D4/C3 formation see the differences between table formation_1 and table formation_2.
- Weak pawns on open files approximately are penalized triple because of their vulnerability, often they are an easy target for the opponent. See tables weakpawn_1 (default) and weakpawn_2 (open file penalty).
- All values are binary ($256 = 1$ pawn).

- **Double Pawns** : Double Pawns get a standard penalty of 20, no piece-square table here.

- **Double Isolated Pawns** : In case a double pawn is isolated (no friendly pawns on rank+1 and rank-1) an extra penalty is given of 20 and in case the double pawn is on an open file an extra 10, so 30 in total. Since the pawn is double the real evaluation is 40 or 60. In case of an isolated triple pawn the total evaluation of such a lousy pawn structure easily exceeds the value of a pawn because of the 2 previous (see above) penalties it already has been given.

- Pawn Pressure : Pawns not covered by an own pawn are subject to a pressure penalty by the opponent. Formula: $\text{pressure} = (\text{number of attackers to the power of a factor})$. Pseudo code:

```
if (WB[pawn] & 8) break;
```

```
// pawn is covered by own pawn, no penalty
```

```
if (BB[pawn] & 8) break;
```

```
// pawn can capture opponent pawn, no penalty
```

```

    if (smallest defender < smallest attacker) break; // skip situations like wpd4 covered by Be3
                                                    // and just attacked by Rd8, this makes no sense.

    factor=TABLE[pawn]; // get square importance
    attackers=BB[pawn]&7; // get number of attackers
    penalty=factor << attackers;
    if (endgame) penalty=penalty*2; // double in end game
    score=score-penalty;

TABLE (square importance)
+---+---+---+---+---+---+---+---+
8 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
7 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 |
+---+---+---+---+---+---+---+---+
6 | 02 | 02 | 02 | 02 | 02 | 02 | 02 | 02 |
+---+---+---+---+---+---+---+---+
5 | 00 | 00 | 00 | 02 | 02 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
4 | 00 | 00 | 00 | 02 | 02 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
3 | 00 | 01 | 02 | 02 | 02 | 02 | 01 | 00 |
+---+---+---+---+---+---+---+---+
2 | 00 | 01 | 02 | 02 | 02 | 02 | 01 | 00 |
+---+---+---+---+---+---+---+---+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
    a   b   c   d   e   f   g   h

```

Remarks

- The effect is that pressure is build on weak pawns especially in the end game.
- Smallest Defender and smallest attacker are simply extracted from WB cq BB via an 256 byte conversion table that returns the lowest piece (0,1,3,5,9,99) (none, pawn, knight/bishop, rook, queen, king) that covers the square via the bits that are set. So:


```

SD=conversion[WB[pawn]]; // get smallest defender
SA=conversion[BB[pawn]]; // get smallest attacker

```

Passed Pawn evaluation in REBEL

Issues regarding passed pawns:

- Default evaluation : A piece-square bonus is given for each passed pawn, in the end game the bonus is double. In a pawn ending a different table is used, passed pawns on the A and H file are far more dangerous than a passed pawn on the C,D,E,F files. The pseudo code for white passed pawns, all values are binary:

```

score=score+TABLE[phase][pawn]; // phase is initialized at the start of EVAL
                                // 0=middle-game, 1=end-game, 2=pawn-ending

```

TABLE[0] (middle-game)	TABLE[1] (end-game)
<pre> +---+---+---+---+---+---+---+---+ 8 00 00 00 00 00 00 00 00 +---+---+---+---+---+---+---+---+ 7 52 52 52 52 52 52 52 52 +---+---+---+---+---+---+---+---+ </pre>	<pre> +---+---+---+---+---+---+---+---+ 8 00 00 00 00 00 00 00 00 +---+---+---+---+---+---+---+---+ 7 99 99 99 99 99 99 99 99 +---+---+---+---+---+---+---+---+ </pre>

```

6 | 39 | 39 | 39 | 39 | 39 | 39 | 39 | 39 |
+---+---+---+---+---+---+---+---+
5 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
+---+---+---+---+---+---+---+---+
4 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
+---+---+---+---+---+---+---+---+
3 | 07 | 07 | 07 | 07 | 07 | 07 | 07 | 07 |
+---+---+---+---+---+---+---+---+
2 | 07 | 07 | 07 | 07 | 07 | 07 | 07 | 07 |
+---+---+---+---+---+---+---+---+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
  a   b   c   d   e   f   g   h

```

TABLE[2] (pawn-ending)

```

+---+---+---+---+---+---+---+---+
8 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
7 |124 |110 | 99 | 99 | 99 | 99 |110 |124 |
+---+---+---+---+---+---+---+---+
6 | 96 | 80 | 78 | 78 | 78 | 78 | 80 | 96 |
+---+---+---+---+---+---+---+---+
5 | 70 | 60 | 54 | 54 | 54 | 54 | 60 | 70 |
+---+---+---+---+---+---+---+---+
4 | 42 | 34 | 28 | 28 | 28 | 28 | 34 | 42 |
+---+---+---+---+---+---+---+---+
3 | 42 | 20 | 14 | 14 | 14 | 14 | 20 | 00 |
+---+---+---+---+---+---+---+---+
2 | 26 | 20 | 14 | 14 | 14 | 14 | 20 | 00 |
+---+---+---+---+---+---+---+---+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
  a   b   c   d   e   f   g   h

```

```

6 | 78 | 78 | 78 | 78 | 78 | 78 | 78 | 78 |
+---+---+---+---+---+---+---+---+
5 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
+---+---+---+---+---+---+---+---+
4 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
+---+---+---+---+---+---+---+---+
3 | 14 | 14 | 14 | 14 | 14 | 14 | 12 | 14 |
+---+---+---+---+---+---+---+---+
2 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
+---+---+---+---+---+---+---+---+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
  a   b   c   d   e   f   g   h

```

- Connected Passed Pawns : When a passed pawn is supported by another friendly pawn the default bonus is doubled, recognized structures are: wpd5-wpe5/wpc5 but also cases like wpd5-wpe4/c4 are rewarded. So:

```
if (WB[rank+1]& 8 || WB[rank]& 8) score=score+TABLE[phase][pawn];
```

- Potential evaluation : The next step is to measure the potential of the passed pawn, is it a dangerous passed pawn or not. This is done by checking the 3 squares before the pawn and measure its chances to move safely to the next square(s). Example pseudo code for a white passed pawn on D5.

```

if (BOARD[rank+1] != EMPTY) break;           // square before white passed pawn (D6) occupied, no bonus.
if (BB[rank+1] && WB[rank+1]==0) break;       // white has no support on D6, black has, no bonus.

if (BOARD[rank+2]==0) goto 3;                 // end of board reached, triple bonus.

if (BOARD[rank+2] != EMPTY) goto 1;           // square D7 occupied, 1 time bonus.
if (BB[rank+2] && WB[rank+2]==0) goto 1;       // white has no support on D7, black has, 1 time bonus.

if (BOARD[rank+3]==0) goto 3;                 // end of board reached, triple bonus.

if (BOARD[rank+3] != EMPTY) goto 2;           // square D8 occupied, double bonus.
if (BB[rank+3] && WB[rank+3]==0) goto 2;       // white has no support on D8, black has, double bonus.

3: score=score+TABLE[phase][pawn];             // triple bonus
2: score=score+TABLE[phase][pawn];             // double bonus

```

```
1: score=score+TABLE[phase][pawn]; // 1 time bonus
```

I was never fully satisfied with this piece code but it seems to work properly together with the search, it's in there since 1986 since various other approaches never gave a better result.

- **Blocked Passed Pawns** : Passed pawns that are blocked receive a smaller bonus or no bonus at all.

```
if (BOARD[rank+1]==EMPTY) break; // square before pawn empty
if (BOARD[rank+1]==own piece) // 1 time bonus if blocked piece
    score=score+TABLE[phase][pawn]; // is an own piece
if (WB[rank] & 6) // pawn is covered by at least 2 own
    score=score+TABLE[phase][pawn]; // pieces -> 1 time bonus.
if (WB[rank+1]) // square before pawn is under control
    score=score+TABLE[phase][pawn]; // by own piece -> 1 time bonus
```

The same comment as above applies also here, I was never fully satisfied with this piece code but it seems to work properly together with the search, it's in there since 1986 since various other approaches never gave a better result.

- **Own King Support** : In the endgame a passed pawn that has the support of its own king receives an extra bonus via a piece-square table. Supported structures are:

wpd5 - wkc4/wkc5/wkc6/wkd4/wkd6/wke4/wke5/wke6.

```
if (endgame==NO) break; // no endgame, no bonus
if (WB[rank] & 0x80 || WB[rank+1] & 0x80) // if square surrounded the white pawn is under
    score=score+TABLE[pawn]; // control by white king -> bonus
```

TABLE (passed pawn king connection table)

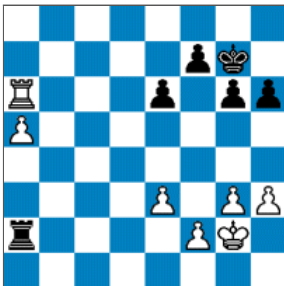
```
+-----+-----+-----+-----+-----+
8 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
+-----+-----+-----+-----+-----+
7 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
+-----+-----+-----+-----+-----+
6 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
+-----+-----+-----+-----+-----+
5 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
+-----+-----+-----+-----+-----+
4 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
+-----+-----+-----+-----+-----+
3 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
+-----+-----+-----+-----+-----+
2 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
+-----+-----+-----+-----+-----+
1 | 08 | 08 | 08 | 08 | 08 | 08 | 08 | 08 |
+-----+-----+-----+-----+-----+
    a     b     c     d     e     f     g     h
```

- **Enemy King Tropism** : In the late endgame it is important to move your king to enemies passed pawns. The below algorithm calculates the distance from the white passed pawn to the black king and this value (distance) serves as a multiply factor to a piece-square table and the result is added to score. The effect is: the further away the black king, the higher the bonus for the white passed pawn.

Definition late endgame: pawn-endings, light piece endings, rook endings, rook+light piece endings.

```
int x,y;
if (late_endgame==NO) break; // no late endgame -> no bonus
x=abs(RANK[pawn]-RANK[black_king]); // get horizontal distance pawn vs black king (0-7)
```


- **Immobility penalty** : Passed pawns that are blocked by an own rook are heavily penalized, consider the diagram.

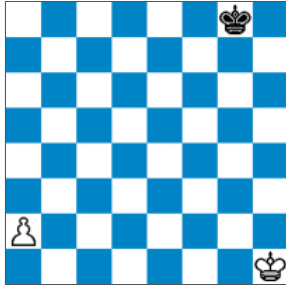


Effects: The height of the penalty is tuned in such a way that the engine in principle will never enter a position like this, not even to win a pawn on A6. A second effect (playing the black pieces) is that the engine immediately will put its rook on A2 to imprison the white rook. And last, the code ensures that in the hypothetical case the engine enters such a position anyway it sooner or later will find out its way even if it needs to give up the worthless passed pawn in order to get the rook back into play again.

-

8/15/2012

- **Quadrant Rule :** The Quadrant Rule is valid in the pawn ending only. If the black king is out of the quadrant of a white passed pawn the pawn is evaluated as promoted and so a bonus of 8 pawns is given, consider the diagram.



However the Quadrant Rule is full of stings and nasty obstacles, to name a few:

- All these exceptions must be coded very precisely to avoid your engine to play funny moves. It might keep you busy for a couple of days programming and testing but it's really worthwhile the trouble, the Quadrant Rule is a very powerful algorithm in pawn endings.

Bad Bishops



While scanning the board a white bishop that is faced with an
own pawn (only the 2 forward directions apply here!) the square
in front of the white pawn serves as a penalty multiply factor. If

```

int x,y;
if (BOARD[square] != WP) break;           // test next square
x=bad_bishop_1[BOARD[square+(rank+1)]]; // get factor piece type before white pawn (8)
y=bad_bishop_2[BOARD[square]];           // get square importance (2)
score=score-(x << y);                    // penalty (8 << 2) = 32

char bad_bishop_1[] = { 0,2,8,2,2,2,2,2,8,4,4,2,2,2 };
+---+---+---+---+---+---+---+---+---+---+---+---+

```

```

| .. | Wp | WN | WB | WR | WQ | WK | Bp | BN | BB | BR | BQ | BK |
+---+---+---+---+---+---+---+---+---+---+---+---+---+
| 02 | 08 | 02 | 02 | 02 | 02 | 02 | 08 | 04 | 04 | 02 | 02 | 02 |
+---+---+---+---+---+---+---+---+---+---+---+---+

char bad_bishop_2[]
+---+---+---+---+---+---+---+---+---+
8 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+---+
7 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+---+
6 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+---+
5 | 00 | 00 | 00 | 01 | 01 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+---+
4 | 00 | 00 | 01 | 02 | 02 | 01 | 00 | 00 |
+---+---+---+---+---+---+---+---+---+
3 | 00 | 01 | 02 | 02 | 02 | 02 | 01 | 00 |
+---+---+---+---+---+---+---+---+---+
2 | 00 | 00 | 02 | 02 | 02 | 02 | 02 | 00 |
+---+---+---+---+---+---+---+---+---+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+---+
    a    b    c    d    e    f    g    h

```

Bishop Pair

A bonus for the bishop pair is given depending on the board material, the less material on the board the more valuable the bishop pair. The board material is represented in 2 variables (white and black) following the formula: 3=knight/bishop, 5=rook and 9=queen, pawns are not counted. So white and black from the start position contain both 31 (9+10+6+6). This value serves as an index to the evaluation of the bishop pair.

```

if (white_bishop_pair) score=score + bishop_pair[black];
if (black_bishop_pair) score=score - bishop_pair[white];

int bishop_pair[] =
{ 128,128,128,128,128,128,128,128,      // very late endgame (00-07)
  96, 96, 96, 96,                        // late endgame      (08-11)
  64, 64,                                // regular endgame   (12-13)
  32, 32, 32, 32,                        // early endgame     (14-18)
  16, 16, 16, 16,                        // midgame           (19-23)
   8,  8,  8,  8,  8,  8,  8,           // midgame restant
   8,  8,  8,  8,  8,  8,  8,
   8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,
   8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,
   8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8,  8 };

```

Another good and simple approach is to evaluate the bishop pair depending on the number of pawns of the opponent, the less opponent pawns the more power the bishop pair will exercise.

Example pseudo code:

```

if (white_bishop_pair) score=score + bishop_pair[black_pawns];
if (black_bishop_pair) score=score - bishop_pair[white_pawns];

int bishop_pair[] = { 128,128,128,128,96,64,32,16,8 };

```

An extra bonus of 64 binary points (0.25) is given for a bishop pair when the opponent has no light pieces (knights and bishops), usually this increases the power of the bishop pair even more.

Minimum Mobility

Apart from the [regular mobility](#) knights and bishops are penalized if their minimum mobility is bad.

- **Knights** : For each of the 8 directions a Knight can move it is checked if it relatively safely can move to that square and if a Knight has no (or hardly any) safe place to go it is penalized.

```
int count=0;
char minimum_knight_mobilty [] = { 64,25,12,00,00,00,00,0,0,0,0,0,0,0,0,0,0,0 };

for each of the 8 directions do:
{ if (BOARD[knight] = own piece) continue;      // knight can't move to that square
  if (BOARD[knight] = out of board) continue;    // knight can't move to that square
  if (BOARD[knight] = empty &&                    // empty square is controlled by black
      BB[knight] & 8) continue;                  // pawn, knight can't safely move
  count++;                                        // knight relatively safely can move
} score=score-minimum_knight_mobilty[count];
```

- **Bishops** : The same is done for bishops only a different penalty table is used.

```
int count=0;
char minimum_bishop_mobilty [] = { 60,60,50,40,30,20,10,0,0,0,0,0,0,0,0,0,0,0 };

score=score-minimum_bishop_mobilty[count];
```

Strong Squares

When there 5 or more enemy pawns on the board a bonus is given if a white knight has an outpost position, meaning the knight can't be driven away by an enemy pawn. It's example pseudo code for a white knight on E5:

```
if (black_pawns <= 4) break;
if (BB[knight+rank1] & 8) break;      // black pawn on either D6 or F6 -> no bonus
if (BB[knight+rank2] & 8) break;      // black pawn on either D7 or F7 -> no bonus
score=score+TABLE[knight];

+---+---+---+---+---+---+---+---+
8 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
7 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
6 | 00 | 20 | 32 | 40 | 40 | 32 | 20 | 00 |
+---+---+---+---+---+---+---+---+
5 | 00 | 16 | 24 | 30 | 30 | 24 | 16 | 00 |
+---+---+---+---+---+---+---+---+
4 | 00 | 10 | 16 | 20 | 20 | 16 | 10 | 00 |
+---+---+---+---+---+---+---+---+
3 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
2 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+---+---+---+---+---+---+---+---+
  a   b   c   d   e   f   g   h
```

Center Control

Each square in the center (B3 till G6) is evaluated and a bonus is given for the colour that has the most influence on the square. The routine is called only when there are at least 4 white pawns and 4 black pawns in play. It's pseudo code for white and black:

```
int x=0; int square;
char range[] = { B3,B4,B5,B6,C3,C4,C5,C6,D3,D4,D5,D6,E3,E4,E5,E6,F3,F4,F5,F6,G3,G4,G5,G6,0 };

if (white_pawns <=4 || black_paws <= 4) return;
while (square=range[x])
{ if ((WB[square]&248)==0 && (BB[square]&248)==0) goto boss; // no control by white nor black
  if (WB[square]&248 && (BB[square]&248)==0) goto white;      // white has control, black does not
  if (BB[square]&248 && (WB[square]&248)==0) goto black;      // black has control, white does not
  if (WB[smallest attacker] < BB[smallest attacker] goto white;
  if (WB[smallest attacker] > BB[smallest attacker] goto black;
boss: if (square=empty) continue;
      if (square=black piece) goto black;
white: score=score+white_table[square]; continue;
black: score=score-black_table[square];
      }

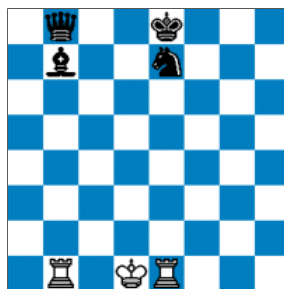
white_table
+-----+
8 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
7 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
6 | 00 | 08 | 12 | 16 | 16 | 12 | 08 | 00 |
+-----+
5 | 00 | 08 | 12 | 16 | 16 | 12 | 08 | 00 |
+-----+
4 | 00 | 00 | 08 | 12 | 12 | 08 | 00 | 00 |
+-----+
3 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
2 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
  a   b   c   d   e   f   g   h

black_table
+-----+
8 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
7 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
6 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
5 | 00 | 00 | 08 | 12 | 12 | 08 | 00 | 00 |
+-----+
4 | 00 | 08 | 12 | 16 | 16 | 12 | 08 | 00 |
+-----+
3 | 00 | 08 | 12 | 16 | 16 | 12 | 08 | 00 |
+-----+
2 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
1 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
+-----+
  a   b   c   d   e   f   g   h
```

PINS

A bonus is given for pins and subtraction attacks depending on their importance, consider the 2 diagrams.

During the board scan bishops, rooks and queens look through (xray) own and enemy pieces in order to measure the true mobility as already described [here](#).

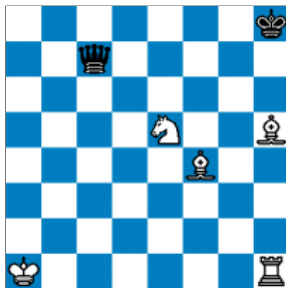


The bishop on G5 in diagram-1 xrays the black knight on F6 and will discover the black queen on D8

eventually resulting in a pin-bonus, the same applies for the 2 rook pins in diagram-2.

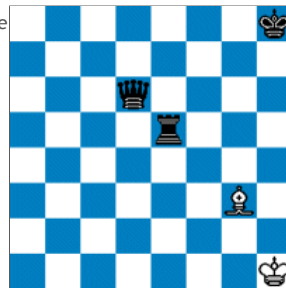
The value of the pin-bonus depends on the pattern, the 2 rook pins in diagram-2 are far more dangerous than the bishop pin in diagram-1. So based on the piece that pins and what is pinned a bonus is given.

	..	Wp	WN	WB	WR	WQ	WK	Bp	BN	BB	BR	BQ	BK	
	00	00	00	00	00	00	00	00	00	00	20	15	20	white_bishop_pin
	00	00	00	00	00	00	00	00	00	00	00	40	40	white_rook_pin



Consider diagram-3, the 2 white bishops both contain a subtraction attack and are evaluated as having a pin.

So, the the WBF4-E5-C7 xray receives a binary 20 bonus, the WRH1-H5-H8 xray a binary 40 bonus.



A special xray-case is diagram-4, if a bishop or rook xrays 2 higher valued pieces a full pawn bonus is given.

More on Bishops



A common problem every aspirant chess programmer will have to deal with in his chess engine is the trapped bishop on A7/H7 (A2/H2 for black) and yet the solution is amazing simple.

After 1...b6 the white bishop is trapped and in 90% of the cases will be lost. Whenever the pattern WBA7 and BPB6 applies give such a trapped bishop a penalty of 1.25 and it will avoid the capture of the poisoned pawn on A7.

No special extra code needed, search is good for the rest!

More on Rooks

Three more issues on rooks that matter:

- Rook connections : In the middle-game rook connections are rewarded, rooks need to cooperate. For each white rook that has a connection the following pseudo code applies:

```
if (white_rook_connection) score=score+TABLE[rook];
```

	8	7	6	5	4	3	2	1	
8	30	30	30	30	30	30	30	30	
7	50	50	50	50	50	50	50	50	
6	08	08	12	20	20	12	08	08	

```

+-----+-----+-----+-----+-----+-----+
5 | 00 | 00 | 04 | 06 | 06 | 04 | 00 | 00 |
+-----+-----+-----+-----+-----+-----+
4 | 00 | 00 | 04 | 06 | 06 | 04 | 00 | 00 |
+-----+-----+-----+-----+-----+-----+
3 | 00 | 00 | 04 | 06 | 06 | 04 | 00 | 00 |
+-----+-----+-----+-----+-----+-----+
2 | 00 | 00 | 04 | 06 | 06 | 04 | 00 | 00 |
+-----+-----+-----+-----+-----+-----+
1 | 00 | 00 | 04 | 06 | 06 | 04 | 00 | 00 |
+-----+-----+-----+-----+-----+-----+
      a      b      c      d      e      f      g      h

```

Effects:

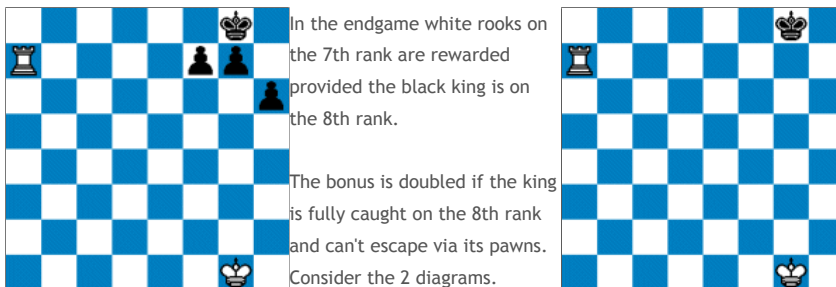
- Surprisingly the 2 x small bonus will keep the 2 white rooks on rank-1 preferable on the squares D1 and E1.
 - 2 connected white rooks on the 7th rank receive a bonus of 100 binary points (0.40).
 - The code already stimulates rook doubling, a rook D1/D6 connection gives a 26 (20+6) bonus, which automatically moves us to the next subject.
- Doubled Rooks : Doubled Rooks (horizontal only) receive an one time extra bonus when they are on a full open file. The height of the bonus depends on the file and (more important) how many black pawns there are in play. Mind you, a doubled rook on an open file with 7 black pawns on the board usually is far more worth then when black has only 4-5 pawns which usually ensures counter play on another open file. The pseudo code:

```

int file_value[] = { -12,-10,-4,0,0,-4,-10,-12 }; // initial value for the file of the rook
int pawn_tab[]   = { 0,0,0,0,0,8,16,32,32,0,0 }; // bonus table
bonus=file_value[file of the rook];              // -12 for A-file rooks, 0 for E-file rooks, etc.
bonus=bonus+pawn_tab[number_of_black_pawns];     // add bonus depending on number of black pawns
if (bonus>0) score=score+bonus;                  // avoid penalizing a doubled rook

```

- Rook on 7th Rank :



In diagram-1 the bonus is binary 50 since the black king still can escape from its bad position, in diagram-2 the bonus is binary 100 (0.40), the pseudo code for the black king on G8 :

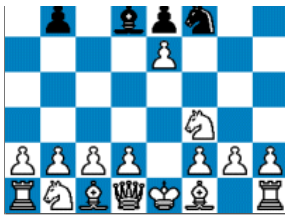
```

int bonus=50;
if (endgame && white_rook_on_7th_rank && black_king_on_8th_rank)
{
    score=score+bonus;
    if (WB[F7]&32 && WB[G7]&32 && WB[H7]&32) // test the 3 squares in front of the king, if all of them
        score=score+bonus;                  // are under control of the white rook double the bonus.
}

```

Double Attack Bonus





In the diagram white threatens 2 pieces, the black knight on F6 and the black bishop on D6. Usually black can only save one piece at the time the next ply, exceptions left aside.

In case like these the double attack is rewarded with a bonus depending on the less expected gain, in this case 2 pawns, represented as 2 in the variable "second_threatened_piece".

```
int double_attack_bonus[] = { 0, 64, 128, 192, 256, 256, 256, 256, 256, 256 };
score = score + double_attack_bonus[second_threatened_piece];
```

So in this particular case white gets a bonus of binary 128 (0.50)

Pawn Ending

Rule no. 1 in pawn endings: the side with a pawn up will win the game. The below code (or something similar) is a must have in every chess program:

```
int pawn[] = { 0x00, 0x00, 0x100, 0x200, 0x300, 0x400, 0x500, 0x600, 0x700 };
if (pawn_ending)
{
    score = score + pawn[number_of_white_pawns];
    score = score - pawn[number_of_black_pawns];
}
```

Effect: the difference in pawns is the bonus in pawns.

Remark: the rule does not function in case of isolated double pawns, special code is needed to count isolated double pawns as 1 pawn before using the above formula.

End Game

We have arrived at the last chapter of this page, applicable the end game.

REBEL doesn't use table bases, instead it uses a 2 dimensional table that catches the most important endings.

During the scanning of the board 2 variables (1 for white and 1 for black) are maintained that are used as an index to a 2 dimensional array of 16 x 16 (so 256 bytes) that can recognize 16 different ending types. Let's call these 2 variables "white" and "black", its layout:

```
+-----+-----+-----+-----+-----+-----+-----+-----+
| BIT0 | BIT1 | BIT2 | BIT3 | BIT4 | BIT5 | BIT6 | BIT7 |
+-----+-----+-----+-----+-----+-----+-----+-----+
| number of | number of | number of | Rook | Queen |
| white pawns | white knights | bishops | bit | bit |
+-----+-----+-----+-----+-----+-----+-----+-----+
```

Rules:

- When there are more than 3 pawns white is set to 0xff (all bits on), it means: endgame type not supported.
- When there are more than 2 knights white is set to 0xff -> endgame type not supported.
- When there are more than 2 bishops white is set to 0xff -> endgame type not supported.
- When there are 2 or more rooks white is set to 0xff -> endgame type not supported.
- When there are 2 or more queens white is set to 0xff -> endgame type not supported.


```
int x; // pointer to the 2 dimensional array
if (index_white[white]==17) break; // endgame type not supported
if (index_black[black]==17) break; // endgame type not supported
x=index_white[white]+index_black[black] // create pointer
```

[illegible][illegible]

```
score=score+adjust[x]; // adjust score, if applicable

switch (jump[x])
{ case 'N' : break; // do nothing
  case 'R' : score=0; break; // cold draw but the search needs to continue
  case '!' : score=0; break; // cold draw, stop further searching
  case 'L' : white_bad_bishop_ending(); break; // KBPK (with A or H pawn)
  case 'l' : black_bad_bishop_ending(); break; // KKBP (with A or H pawn)
  case 'P' : white_pawn_ending(); break; // KPK (with A or H pawn)
```

```

case 'p' : black_pawn_ending(); break;          // KKP (with A or H pawn)
case 'K' : white_mate_with_BN(); break;         // KBK (how to mate black)
case 'k' : black_mate_with_BN(); break;         // KKB (how to mate white)
case 'D' : white_queen_vs_black_pawn(); break;  // KQKP (how to win the black pawn)
case 'd' : black_queen_vs_white_pawn(); break;  // KPKQ (how to win the white pawn)
case 'T' : white_rook_ending(); break;          // KRPKR (how to play)
case 't' : black_rook_ending(); break;          // KRRP (how to play)
case 'Q' : white_queen_vs_black_rook(); break;  // KQKR (how to mate black)
case 'q' : black_queen_vs_white_rook(); break;  // KRRQ (how to mate white)
case 'X' : score=0.25; score=score+TABLE[white_king]-TABLE[black_king]; break; // keep kings
case 'Y' : score=0.50; score=score+TABLE[white_king]-TABLE[black_king]; break; // near the
case 'x' : score=-0.25; score=score+TABLE[white_king]-TABLE[black_king]; break; // center
case 'y' : score=-0.50; score=score+TABLE[white_king]-TABLE[black_king]; break;
}

char jump (jump table)
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|black|one |two |three|one |two |one |knght|two |black|rook |knght|bishp|bishp|black|black|
|king |black|black|black|black|black|black| + |black|rook | + | + |+rank|+norm|rook |queen|
|      |pawn |pawns|pawns|knght|knght|bishp|bishp|bishp|      |knght|pawn |pawn |pawn |+pawn|      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| ! | p | N | N | ! | R | ! | k | N | N | N | N | l | N | N | N |white king |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| P | N | N | N | N | N | N | N | N | N | N | N | l | N | N | d |1 white pawn |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | N | N | N | N | N | N | N | N | l | N | N | N |2 white pawns |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N |3 white pawns |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| ! | N | N | N | R | R | R | x | y | x | N | N | N | N | N | N |white knight |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| R | N | N | N | R | R | R | N | R | R | y | y | y | y | y | N |2x white knight|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| ! | N | N | N | R | R | R | x | x | x | N | x | y | y | N | N |white bishop |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| K | N | N | N | X | N | X | N | N | X | y | x | x | x | x | N |knight + bishop|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | Y | N | X | N | N | Y | x | X | X | X | X | N |2x white bishop|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | X | R | X | x | y | R | x | x | y | y | t | q |white rook |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | N | Y | N | Y | X | X | N | N | N | N | x | x |rook + N (or B)|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | N | Y | X | X | x | X | N | N | N | N | N | N |knight + pawn |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| L | L | L | N | N | Y | Y | X | x | Y | N | N | N | N | N | N |bad_bishop+pawn|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | N | Y | Y | X | x | Y | N | N | N | N | N | N |bishop+pawn |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | N | N | N | N | Y | N | X | x | T | X | N | N | N | N | N |white rook+pawn|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| N | D | N | N | N | N | N | N | N | Q | X | N | N | N | N | N |white queen |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

char adjust (adjustment table)
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|black|one |two |three|one |two |one |knght|two |black|rook |knght|bishp|bishp|black|black|

```

king	black	black	black	black	black	black		+	black	rook		+		+	+rank	+norm	rook	queen	
	pawn	pawns	pawns	knight	knight	bishop	bishop	bishop		knight	pawn	pawn	pawn	+pawn					
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	0	0	0	0	0	0	0	0	-1.00	-1.00	0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	white king	
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	0	0	0	2.00	4.00	2.00	0	0	0	0	0	0	0	0	0	0	0	0	1 white pawn
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	0	0	0	2.00	4.00	2.00	0	0	0.50	0	0	0	0	0	0	0	0	0	2 white pawns
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	0	0	0	1.50	3.00	1.00	1.00	1.00	0.50	0	0.50	0.50	0.50	0.50	0.50	0	0	0	3 white pawns
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	-2.00	-2.00	-2.00	0	0	0	0	0	0	0	0	0	0	0	-0.50	0	0	0	white knight
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	-4.00	-4.00	-3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	2x white knight
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	-2.00	-2.00	-2.00	0	0	0	0	0	0	0	0	0	0	0	-0.50	0	0	0	white bishop
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	0	0	-1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	knight + bishop
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	0	-1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.50	2x white bishop
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	-0.50	-0.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	white rook
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	rook + N (or B)
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	0	-0.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	knight + pawn
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	0	-0.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	bad_bishop+pawn
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	0	-0.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	bishop+pawn
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	0	-0.50	0.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	white rook+pawn
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+
1.00	0	0	0	0	0	-1.00	0	-1.00	-1.50	0	0	0	0	0	0	0	0	0	white queen
+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+	+-----+

So, with a few instructions and 2 tables we have managed to deal with many of the standard endgame types, either giving them an exact score + king placement or adjust the score to an appropriate value.

Furthermore we now can deal with the endgame types that need special code such as how to mate a lonely black king with Knight and Bishop, how to deal with KBPK endings where the white pawn is an A or H file pawn, etc.

I feel it's outside the realm of this project to give the pseudo code for all the above mentioned routines, let me give just two.

How to mate with Bishop and Knight

The black king needs to be driven in the corner of the colour of the bishop else a checkmate is not possible. For that purpose we use 2 piece square tables to evaluate the position of the black king. The second (and last!) thing we do is to add a king tropism bonus to the score in order the white king will follow the black king wherever it goes. And that's all there is. REBEL (via self-play) already mates the black king at depth 5 within 26 moves.

```
int x,y;
x=abs(file[white_king] - file[black_king]); // get file distance between the white king and black king
x=abs(rank[white_king] - rank[black_king]); // get rank distance between the white king and black king
```

```

if (x < y) x=y; // furthest distance is real distance
x = x << 3; // distance * 8
score = 0x780 - x; // score = 0x780 - distance
if (bishop on black square) score=score-TABLE1[black_king]; // drive black king into right corner
else score=score-TABLE2[black_king]; // drive black king into right corner

```

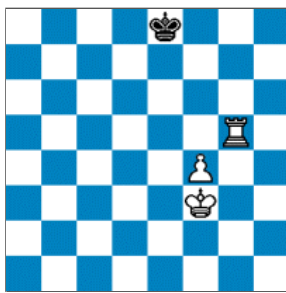
TABLE1

8		150		150		140		120		100		70		40		00	
7		150		160		190		210		130		100		70		40	
6		140		190		210		230		160		130		100		70	
5		120		210		230		250		200		170		130		100	
4		100		130		170		200		250		230		210		120	
3		70		100		130		160		230		210		190		140	
2		40		70		100		130		210		190		160		150	
1		00		40		70		100		120		140		150		150	
		a		b		c		d		e		f		g		h	

TABLE2

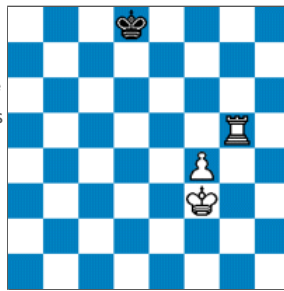
8		00		40		70		100		120		140		150		150	
7		40		70		100		130		210		190		160		150	
6		70		100		130		160		230		210		190		140	
5		100		130		170		200		250		230		210		120	
4		120		210		230		250		200		170		130		100	
3		140		190		210		230		160		130		100		70	
2		150		160		190		210		130		100		70		40	
1		150		150		140		120		100		70		40		00	
		a		b		c		d		e		f		g		h	

How to play the KRPKR ending



The only rule that applies in this ending: if the black king is in front of the white pawn the game is a draw and as such this ending type is evaluated.

Diagram-1 is a typical case of a draw, white can't make progress. Diagram-2 however



white plays 1.Re5! (avoiding the black king to enter the life saving square E8 or E7) and now the black king is isolated from the white pawn, white wins.

```

int x;
if (rank[pawn] >= rank[black_king]) break; // black king not in front of white pawn, no draw yet
x=abs(file[black_king]-file(white_pawn)); // get file difference
if (x >= 2) break; // black king not in front of white pawn, no draw yet
if (x == 0) score=0.10; // draw score 0.10 if black king on same file as white pawn
else score=0.20; // else draw score 0.20
score=score+TABLE[white_king]-TABLE[black_king]; // keep kings near the center to avoid silly moves

```

This ends the project to describe REBEL in pseudo code. I estimate that what's written on this page is responsible for 95% of REBEL's play, to describe the remaining lesser dominant stuff (many small adjustments and exception code, hardly responsible for REBEL's main play) fall outside the realm of this project and would require a separate page of a similar size.

It's my wish that every chess programmer at least will find 1 idea on this page valuable enough to give it try.

Ed Schröder
Deventer, June 2007

