Replacement schemes and two-level tables

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NOTES

REPLACEMENT SCHEMES AND TWO-LEVEL TABLES

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ABSTRACT

This note completes the comparison of the performances of seven replacement schemes. The performances are presented as functions of the transposition-table size. Some 200 chess middle-game and endgame positions have been studied. It turns out that the number of nodes of a subtree is a better estimate for potential savings than the depth of a subtree. A two-level table, using the number of nodes in the subtree searched as the deciding criterion, performs best and is recommended. Previous results based on fewer experiments are confirmed.

1. BACKGROUND

This note is a sequel to our previous article (Breuker, Uiterwijk and Van den Herik, 1994) in which we compared the performance of seven replacement schemes on 18 middle-game positions. We then concluded that the *number of nodes* of a subtree is a better estimate of the work performed (and therefore potentially to be saved) than the *depth* of that subtree. Moreover, we arrived at the tentative conclusion that the traditional one-level implementation (one position per entry) was not the best implementation. A two-level scheme, first proposed by Ebeling (1986), seemed to work better. However, the observations were only based on 18 consecutive middle-game positions taken from one champion's game. Therefore, the result we arrived at was only a preliminary result.

2. EXPERIMENTAL

This note reports on experiments extended in two ways, again using the program ALIBABA[2]. The experiments are performed

- on 94 middle-game positions (including the 18 already tested), taken from six games between top-level Grandmasters;
- on 112 endgame positions[3], taken from five historic games between well-known chess (Grand)masters.

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[2] A full description of the program will be given in the forthcoming Ph.D. thesis of one of us (D.M.B.), who can also be contacted for a free copy of the full C source code, which is available for public distribution.

[3] The endgame positions consist of positions both with and without blocked Pawns.

The test positions are listed in the Appendix. In the experiments time stamping[1] is used (Breuker *et al.*, 1994). It only requires one additional bit per table position and requires little additional computation. The seven replacement schemes used (DEEP, NEW, OLD, BIG1, BIGALL, TWODEEP and TWOBIG1) are based on the following five concepts.

1. DEEP preserves the position with the *deepest* subtree.

2. NEW *always* replaces any position in the table.

3. OLD *never* replaces an existing position in the table.

4. BIG1 and BIGALL preserve the position with the *biggest* subtree (in terms of the number of nodes).

5. TWODEEP and TWOBIG1 are *two-level* tables[2], i.e., each entry has two table positions. TWODEEP combines NEW with DEEP and TWOBIG1 combines NEW with BIG1. This means that the newest position is *always* stored, and the less important position of the remaining two positions (in terms of the depth of the search, or in terms of the number of nodes of the search) is overwritten.

The replacement schemes have been tested on eight different table sizes, viz. from 8K to 1024K positions[3], each time doubling the number of positions in the table. The middle-game positions have been searched to a depth of 7 ply, while the endgame positions have been searched to a depth of 10 ply. The number of nodes investigated during a search is used as a measure, including *all* nodes, i.e., summing up interior nodes and leaf nodes. For more details of the experiments we refer to Breuker *et al.* (1994).

3. RESULTS

We provide our results in graphical format. For each table size the number of *positions* has been kept constant. This implies that the three BIG schemes (BIG1, BIGALL and TWOBIG1) use slightly more memory than the other schemes since a BIG-scheme entry needs an additional field (to store the information about the size of the subtree searched). It is claimed that these minor differences do not affect the interpretation of the results. Further, we note that the two-level schemes (TWODEEP and TWOBIG1) have half the number of entries compared to the other five schemes.

In Figure 1, the results of the experiments on the middle-game positions are depicted. The graph shows the number of nodes investigated (in millions) as a function of the transposition-table size. The number of nodes is the sum of the nodes investigated for the 94 test positions (see Appendix). We note that the graphical representations of the schemes BIG1 and BIGALL are so near that it is difficult to distinguish them.

The four main observations given by Breuker *et al.* (1994) still hold:

- As table size increases, the number of nodes searched tends to constancy. This is caused by the larger percentage of tree nodes that can be retained in the transposition table: the probability of harmful collisions (i.e., collisions that cost many nodes) then greatly decreases. At a certain point the transposition table is big enough to hold the entire search tree.

- As table size increases, the spread between the replacement schemes shrinks.

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[1] We note that game 1 and game 6 both end in a draw since one player forces repetition of positions. As a consequence of using time stamping the last positions of both games are investigated efficiently.

[2] We note that the concept of a two-level table is different from applying a second hash function (e.g., as in CRAY BLITZ) to find another entry in a one-level table in case of a collision.

[3] K positions is equal to 1024 positions.

- The two-level schemes outperform those with one level only.

- Our data confirm Ebeling's (1986) statement, based on 10 positions, that TWODEEP "reduces search times by 5 to 10% for middle game positions" when compared with DEEP.

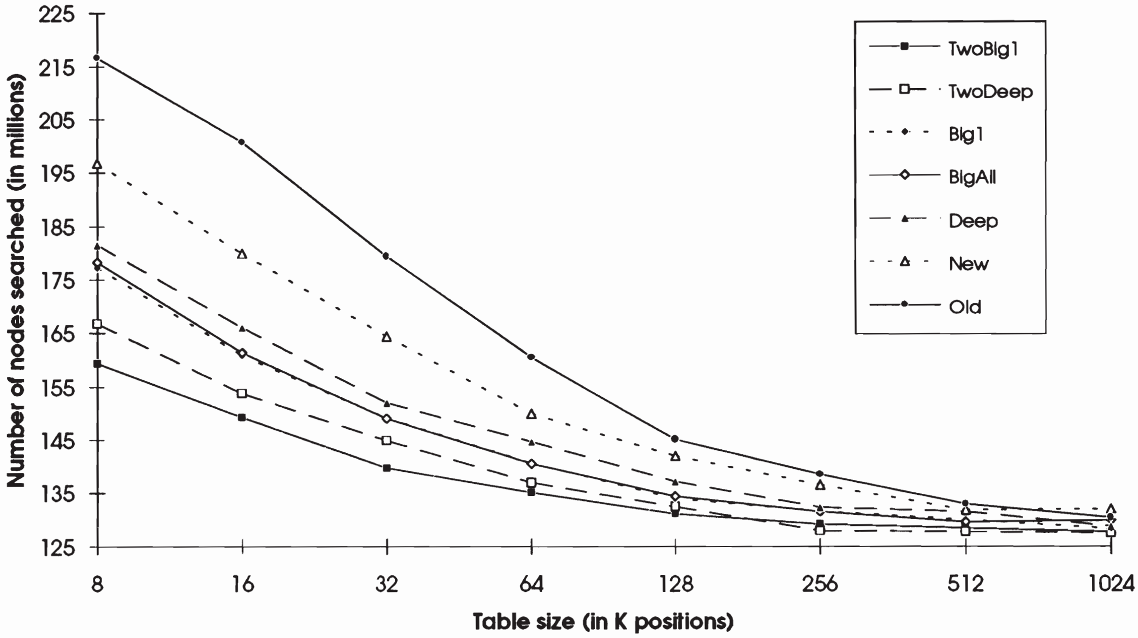

Figure 1: Effect of table size in the middle game; 7-ply searches.

If we use a 1% reduction in node counts as criterion for the usefulness of doubling the transposition-table size, then we obtain for 3, 4 to 5, 6 and 7-ply searches in the middle game the following suggested table sizes: ≤8K, 16K, 32K and 256K positions, respectively.

The results of the experiments on the endgame positions are depicted in Figure 2. The graph again shows the number of nodes investigated (in millions) as a function of the transposition-table size. The number of nodes is the sum of the nodes investigated for the 112 test positions, given in the Appendix.

From this graph it follows that the above conclusions for the middle-game experiment also hold for the endgame, with one exception. In the middle-game positions it is clear that the size of a search tree is a better concept than the depth of a search tree: the schemes BIG1 and BIGALL use fewer nodes than the scheme DEEP, and the scheme TWOBIG1 uses fewer nodes than the scheme TWODEEP (for small table sizes). In the endgame positions, this difference between the two concepts has disappeared. The explanation reads as follows. If a subtree contains many forcing moves or is well-ordered, many cutoffs occur. Since in the middle game the mobility of each player is larger than in the endgame (Hartmann, 1989), pruning of well-ordered subtrees will on average cause larger savings in middle-game positions than in endgame positions. Therefore, the size of search trees of equal depth will vary more in middle-game positions than in endgame positions. The schemes DEEP and TWODEEP do not have any preference for a subtree (since both have the same depth), but the schemes BIG1, BIGALL and TWOBIG1 have a preference for the largest subtree. Thus, in the middle game the size (as compared to the depth) of the search tree investigated is a better characteristic for measuring the work performed than it is in the endgame.

If we again use a 1% reduction in node counts as criterion for the usefulness of doubling the transposition-table size, then we obtain for 3 to 5, 6, 7, 8, and 9 to 10-ply searches in the endgame the following suggested table sizes: ≤8K, 32K, 64K, 512K, and ≥1024K positions, respectively.

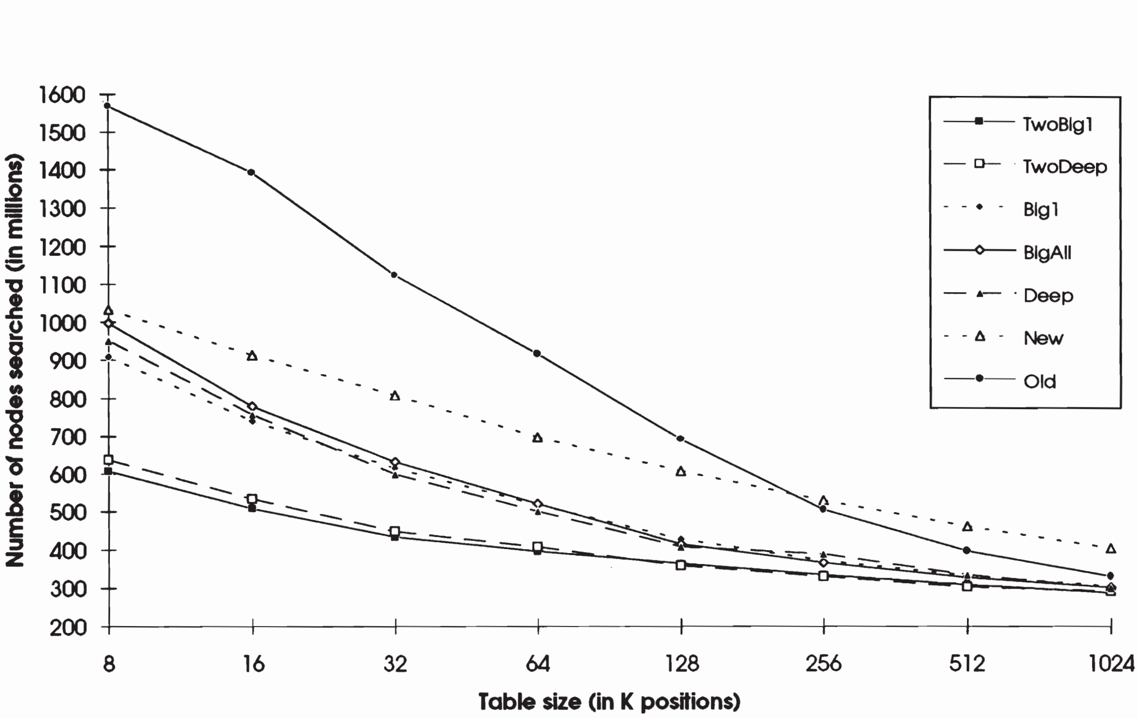

Figure 2: Effect of table size in the endgame; 10-ply searches.

4. CONCLUSIONS

Based on preliminary experiments we have stated that "On logical grounds, one is tempted to conclude that the *number of nodes* of a subtree is a better estimate of the work performed (and therefore potentially to be saved) than the *depth* of that subtree" (Breuker *et al.*, 1994). Our recent experiments support this tentative conclusion for middle-game positions: the schemes BIG1 and BIGALL perform better than the scheme DEEP, and the scheme TWOBIG1 performs better than the scheme TWODEEP. In endgame positions this difference has disappeared: the lower mobility diminishes the differences between the two measures. Hence, for one-level tables we conclude that for the middle-game and endgame positions together DEEP, the most widely-used scheme, is not the best scheme.

Based on the 7-ply results in the middle games investigated and the 10-ply results in the endgames investigated we also confirm our previous presumption that a two-level scheme is better than any one-level scheme. In summary, based on these conclusions we recommend using the scheme TWOBIG1.

Comparing the middle-game and endgame experiments the results also verify the established knowledge that transposition tables are more useful in the endgame than in the middle game.

Taking a 1% reduction in node counts as criterion we conclude that for the current search depths (10 ply) doubling the transposition-table size in the endgame still pays off above 1024K positions.

5. ACKNOWLEDGEMENTS

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7. APPENDIX: THE TEST POSITIONS

In the transposition-table experiments on middle-game positions we used the 94 positions as indicated below.

The 6 White-to-move positions from move 15 to move 20 of
Kasparov-Ivanchuk, Amsterdam (round 1) 1994
1. e4 e5 2. Nf3 Nc6 3. d4 exd4 4. Nxd4 Nf6 5. Nxc6 bxc6 6. e5 Qe7 7. Qe2 Nd5 8. c4 Ba6 9. b3 g6 10. Ba3 Qg5 11. g3 Nc3 12. Nxc3 Bxa3 13. Ne4 Qe7 14. Nf6+ Kf8 15. Bg2 Bb4+ 16. Kf1 Rd8 17. Qb2 Ba3 18. Qc3 Bb4 19. Qb2 Ba3 20. Qc3 Bb4 $^1/_2$-$^1/_2$

The 18 White-to-move positions from move 15 to move 32 of
Kasparov-Short, Amsterdam (round 2) 1994
1. e4 e6 2. d4 d5 3. Nc3 Nf6 4. e5 Nfd7 5. f4 c5 6. Nf3 Nc6 7. Be3 cxd4 8. Nxd4 Bc5 9. Qd2 0-0 10. 0-0-0 a6 11. h4 Nxd4 12. Bxd4 b5 13. Rh3 b4 14. Na4 Bxd4 15. Qxd4 f6 16. Qxb4 fxe5 17. Qd6 Qf6 18. f5 Qh6+ 19. Kb1 Rxf5 20. Rf3 Rxf3 21. gxf3 Qf6 22. Bh3 Kf7 23. c4 dxc4 24. Nc3 Qe7 25. Qc6 Rb8 26. Ne4 Nb6 27. Ng5+ Kg8 28. Qe4 g6 29. Qxe5 Rb7 30. Rd6 c3 31. Bxe6+ Bxe6 32. Rxe6 1-0

The 20 Black-to-move positions from move 15 to move 34 of
Timman-Kasparov, Amsterdam (round 3) 1994
1. d4 Nf6 2. Nf3 g6 3. Bg5 Bg7 4. c3 b6 5. Bxf6 Bxf6 6. e4 Bb7 7. Bd3 c5 8. d5 e6 9. Bc4 0-0 10. 0-0 Na6 11. Qd3 Nc7 12. d6 Ne8 13. Nbd2 Bg7 14. h4 a6 15. a4 Qb8 16. e5 f6 17. h5 fxe5 18. hxg6 h6 19. Rfe1 Qxd6 20. Qxd6 Nxd6 21. Nxe5 Bxe5 22. Rxe5 Rf4 23. Bd3 Raf8 24. f3 a5 25. Kf2 Kg7 26. Rh5 Ne8 27. Kg3 Nf6 28. Re5 Nd5 29. Be4 R4f6 30. Nc4 Nf4 31. Bxb7 Rxg6+ 32. Kh2 Rxg2+ 33. Kh1 d5 34. Nxb6 Rb8 35. Rxe6 Rxb7 36. Rd6 Rg5 37. Rd1 d4 38. Nc4 Kh7 39. Re1 Rh5+ 40. Kg1 Rg7+ 0-1

The 24 Black-to-move positions from move 15 to move 38 of
Ivanchuk-Kasparov, Amsterdam (round 4) 1994
1. e4 c5 2. Nf3 d6 3. d4 cxd4 4. Nxd4 Nf6 5. Nc3 a6 6. f4 Qc7 7. Qf3 g6 8. Be3 Bg7 9. h3 e5 10. fxe5 dxe5 11. Bh6 Bxh6 12. Qxf6 0-0 13. Nd5 Qa5 14. b4 Qd8 15. Ne7+ Qxe7 16. Qxe7 exd4 17. Bc4 Nc6 18. Qc5 Be3 19. Rf1 Nd8 20. Rf3 Be6 21. Rxe3 dxe3 22. Bxe6 Nxe6 23. Qxe3 a5 24. b5 Rac8 25. 0-0-0 Rc5 26. Rd5 b6 27. Qg3 Rc7 28. Qd6 Rfc8 29. Rd2 Rb7 30. g4 Nc5 31. Qf6 h6 32. e5 Re8 33. h4 Kh7 34. h5 g5 35. Rd6 Re6 36. Qd8 Kg7 37. a3 a4 38. Kb2 Rbe7 39. Rxb6 1-0

The 15 White-to-move positions from move 15 to move 29 of
Kasparov-Timman, Amsterdam (round 5) 1994
1. e4 e5 2. Nf3 Nf6 3. Nxe5 d6 4. Nf3 Nxe4 5. d4 d5 6. Bd3 Nc6 7. 0-0 Be7 8. Re1 Bg4 9. c4 Nf6 10. Nc3 dxc4 11. Bxc4 0-0 12. d5 Na5 13. Bd3 c6 14. h3 Bh5 15. Re5 Bg6 16. Bg5 Bd6 17. Re2 Bb4 18. Bxf6 gxf6 19. Rc1 Rc8 20. Ne4 f5 21. Ng3 Qxd5 22. a3 Bd6 23. Nxf5 Rcd8 24. Re5 Bxe5 25. Ne7+ Kg7 26. Nxd5 Bxb2 27. Nf4 Bxd3 28. Nxd3 Bxc1 29. Qxc1 Rxd3 30. Qg5+ 1-0

The 11 Black-to-move positions from move 15 to move 25 of
Short-Kasparov, Amsterdam (round 6) 1994
1. e4 c5 2. Nc3 e6 3. Nf3 a6 4. d4 cxd4 5. Nxd4 d6 6. g4 b5 7. a3 h6 8. Bg2 Bb7 9. 0-0 Nd7 10. f4 Rc8 11. Be3 g5 12. Qe2 gxf4 13. Rxf4 e5 14. Rf5 exd4 15. Bxd4 Ne5 16. Nd5 Bg7 17. Raf1 Rh7 18. Kh1 Bh8 19. c3 Ne7 20. Bxe5 dxe5 21. Qf3 Nxf5 22. Qxf5 Rg7 23. Nf6+ Kf8 24. Nd7+ Kg8 25. Nf6+ Kf8 $^1/_2$-$^1/_2$

In the transposition-table experiments on endgame positions we used the 112 positions as indicated below.

The 28 White-to-move positions from move 31 onwards of
Gossip-Mason, New York (round 20) 1889
1. e4 e6 2. d4 d5 3. Nc3 Nf6 4. e5 Nfd7 5. f4 c5 6. dxc5 Nc6 7. Nf3 Bxc5 8. Ne2 Qb6 9. c3 Bf2+ 10. Kd2 Qe3+ 11. Kc2 Qe4+ 12. Qd3 Nc5 13. Qxe4 Nxe4 14. Ned4 Bd7 15. Nxc6 bxc6 16. Bd3 Nc5 17. Be2 Nb7 18. Rf1 Bb6 19. Bd2 c5 20. Ba6 Rb8 21. Rae1 Nd8 22. Bd3 a5 23. Kc1 a4 24. a3 Nb7 25. f5 c4 26. fxe6 Bxe6 27. Bc2 Nc5 28. Nd4 0-0 29. Nxe6 fxe6 30. Rxf8+ Rxf8 31. Be3 Nb3+ 32. Bxb3 Bxe3 33. Rxe3 cxb3 34. Re2 Rf4 35. Kd2 Kf7 36. Re3 Rf2+ 37. Re2 Rxe2+ 38. Kxe2 Kg6 39. Ke3 Kf5 40. Kd4 h5 41. g3 g5 42. h3 h4 43. g4+ Kf4 44. Kc5 Kxe5 45. Kb4 d4 46. Kxa4 d3 47. Kxb3 Ke4 48. a4 Ke3 49. a5 d2 50. Kb4 d1Q 51. b3 Qa1 52. c4 Kd4 53. Kb5 Qc3 54. Kc6 Qxb3 55. a6 Qxc4+ 56. Kb7 Qb5+ 57. Ka7 Kc5 58. Ka8 Kc6 0-1

The 21 White-to-move positions from move 34 onwards of
Rabinovich-Romanovsky, Leningrad Championship 1934
1. c4 Nf6 2. Nc3 c6 3. d4 d5 4. Nf3 Ne4 5. e3 e6 6. Bd3 f5 7. Qc2 Nd7 8. b3 Bb4 9. Bb2 Qa5 10. Rc1 0-0 11. 0-0 Bd6 12. Ne2 Qd8 13. Ne5 Qh4 14. f3 Nec5 15. g3 Qh6 16. Nf4 Nxd3 17. Nexd3 g5 18. Ng2 Nf6 19. Rce1 g4 20. fxg4 Nxg4 21. Ngf4 Nf6 22. Re2 Rf7 23. b4 Ne4 24. Nc5 Rb8 25. a3 b6 26. Nxe4 fxe4 27. Ref2 Bd7 28. c5 Bxf4 29. Rxf4 Rxf4 30. Rxf4 b5 31. Qf2 Be8 32. Rf6 Bg6 33. Qf4 Qxf4 34. Rxf4 h5 35. h3 Kg7 36. Bc3 Bf5 37. g4 hxg4 38. hxg4 Bg6 39. Kg2 Kh6 40. Rf6 Re8 41. Be1 Kg7 42. Rf1 Ra8 43. Kh3 a6 44. Bg3 Rh8 45. Bh4 Rf8 46. Rxf8 Kxf8 47. Bg3 e5 48. Bxe5 Kf7 49. Kh4 Ke6 50. Kg5 Be8 51. Kh6 Bf7 52. Kg7 Be8 53. g5 Kf5 54. Kf8 1-0

The 17 White-to-move positions from move 26 onwards of
Capablanca-Alekhine, Buenos Aires World Championship (round 5) 1927
1. d4 d5 2. c4 e6 3. Nc3 Nf6 4. Bg5 Nbd7 5. e3 c6 6. a3 Be7 7. Nf3 0-0 8. Bd3 dxc4 9. Bxc4 Nd5 10. Bxe7 Qxe7 11. Rc1 Nxc3 12. Rxc3 e5 13. dxe5 Nxe5 14. Nxe5 Qxe5 15. 0-0 Be6 16. Bxe6 Qxe6 17. Rd3 Qf6 18. Qb3 Qe7 19. Rfd1 Rad8 20. h3 Rxd3 21. Rxd3 g6 22. Qd1 Qe5 23. Qd2 a5 24. Rd7 b5 25. Qc3 Qxc3 26. bxc3 Rc8 27. Kf1 Kg7 28. Ra7 a4 29. c4 Kf6 30. Ra5 Ke6 31. Ke2 bxc4 32. Rc5 Kd6 33. Rxc4 Ra8 34. Rd4+ Ke6 35. Kd3 c5 36. Rh4 h5 37. g4 hxg4 38. Rxg4 Kd6 39. Rf4 f5 40. Rh4 Kd5 41. Kc2 Ra6 42. Kc3 ½-½

The 17 White-to-move positions from move 38 onwards of
Fischer-Reshevsky, New York Championship (round 5) 1962
1. e4 c5 2. Nf3 d6 3. d4 cxd4 4. Nxd4 Nf6 5. Nc3 a6 6. h3 g6 7. g4 Bg7 8. g5 Nh5 9. Be2 e5 10. Nb3 Nf4 11. Nd5 Nxd5 12. Qxd5 Nc6 13. Bg4 Bxg4 14. hxg4 Qc8 15. Qd1 Nd4 16. c3 Nxb3 17. axb3 Qe6 18. Ra5 f6 19. Qd5 Qxd5 20. Rxd5 Kd7 21. gxf6 Bxf6 22. g5 Be7 23. Ke2 Raf8 24. Be3 Rc8 25. b4 b5 26. Rdd1 Ke6 27. Ra1 Rc6 28. Rh3 Bf8 29. Rh1 Rc7 30. Rh4 d5 31. Ra1 Rc6 32. exd5+ Kxd5 33. Rd1+ Ke6 34. Rd8 Kf5 35. Ra8 Re6 36. Rh3 Bg7 37. Rxh8 Bxh8 38. Rxh7 Re8 39. Rf7+ Kg4 40. f3+ Kg3 41. Kd3 e4+ 42. fxe4 Rd8+ 43. Bd4 Kg4 44. Rf1 Be5 45. Ke3 Bc7 46. Rg1+ Kh5 47. Kf3 Rd7 48. e5 Rf7+ 49. Ke4 Rf5 50. e6 Bd8 51. Bf6 Bxf6 52. gxf6 Rxf6 53. Ke5 Rf2 54. Re1 1-0

The 29 White-to-move positions from move 38 onwards of
Lisitsin-Capablanca, Moscow (round 5) 1935
1. Nf3 d5 2. c4 c6 3. e3 Nf6 4. Nc3 Bg4 5. cxd5 Nxd5 6. Be2 e6 7. d4 Nd7 8. 0-0 Qc7 9. Bd2 Bd6 10. Ne4 N7f6 11. Nxd6+ Qxd6 12. Ne5 Bxe2 13. Qxe2 0-0 14. Rc1 Nb6 15. Nd3 Re8 16. Rfe1 Nbd7 17. h3 Qd5 18. b3 Qb5 19. Bc3 Nd5 20. Qd2 Nxc3 21. Qxc3 Rad8 22. a4 Qb6 23. b4 Nf6 24. Qc4 Ne4 25. a5 Qc7 26. a6 Rc8 27. axb7 Qxb7 28. Ra1 Rc7 29. Rec1 Rb8 30. Qc2 Qc8 31. Ra5 Rb6 32. Qa4 Qb8 33. f3 Nf6 34. Rc5 Nd5 35. Rxc6 Rcxc6 36. Rxc6 Rxc6 37. Qxc6 Nxe3 38. Nc5 Nd5 39. b5 Nb6 40. Nd7 Qd8 41. Nxb6 axb6 42. Qc4 h5 43. Kf1 g6 44. Kg1 Kg7 45. Kf1 Qd6 46. Kg1 Qf4 47. Qc3 Kh7 48. Kf1 Qf5 49. Qc4 Kg7 50. Kf2 Qg5 51. Qe2 Kf6 52. Qb2 Qd5 53. Ke3 e5 54. f4 exf4+ 55. Kxf4 Ke6 56. h4 f6 57. Ke3 Qc4 58. g3 g5 59. hxg5 fxg5 60. Qh2 Qb3+ 61. Ke4 g4 62. Qe2 Qxg3 63. Qc4+ Ke7 64. Qc8 Qf3+ 65. Ke5 Qf6+ 66. Kd5 Qd6+ 0-1