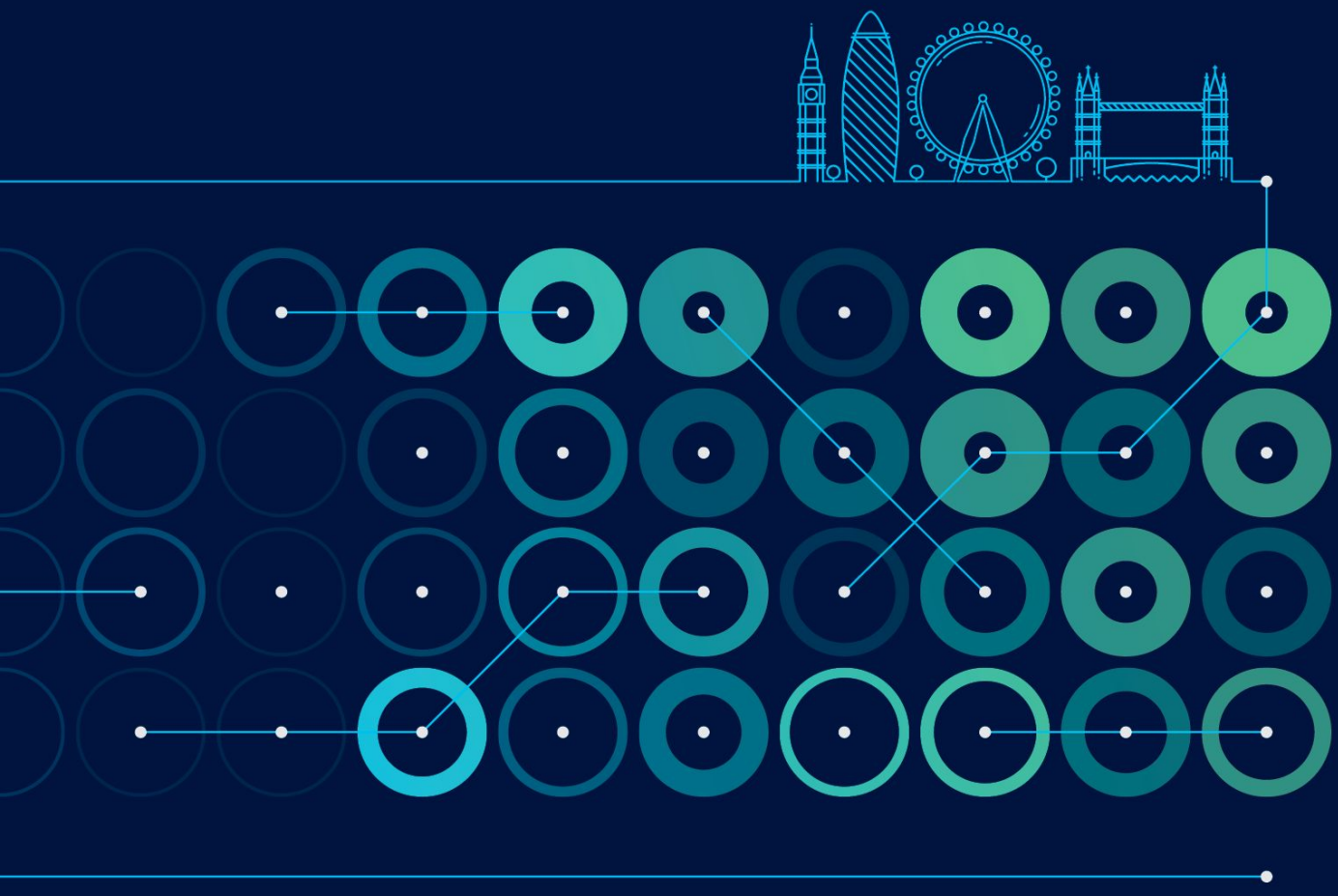
Google DeepMind

Challenge Match

8-15 March 2016



Game 5: “Renewal”

Commentary by Fan Hui

Go expert analysis by Gu Li and Zhou Ruiyang

Translated by Lucas Baker, Thomas Hubert, and Thore Graepel

Renewal

Lee Sedol's triumph in the fourth game attracted a surge of interest in the match throughout the world. Even the Western media, including CNN and the BBC, came to conduct reports and interviews. For Go, this level of attention was utterly unprecedented. More and more people started trying to learn and understand the game. To give just one example, Go Game Guru, the largest Go website in English, reported that its daily visitors had jumped tenfold.

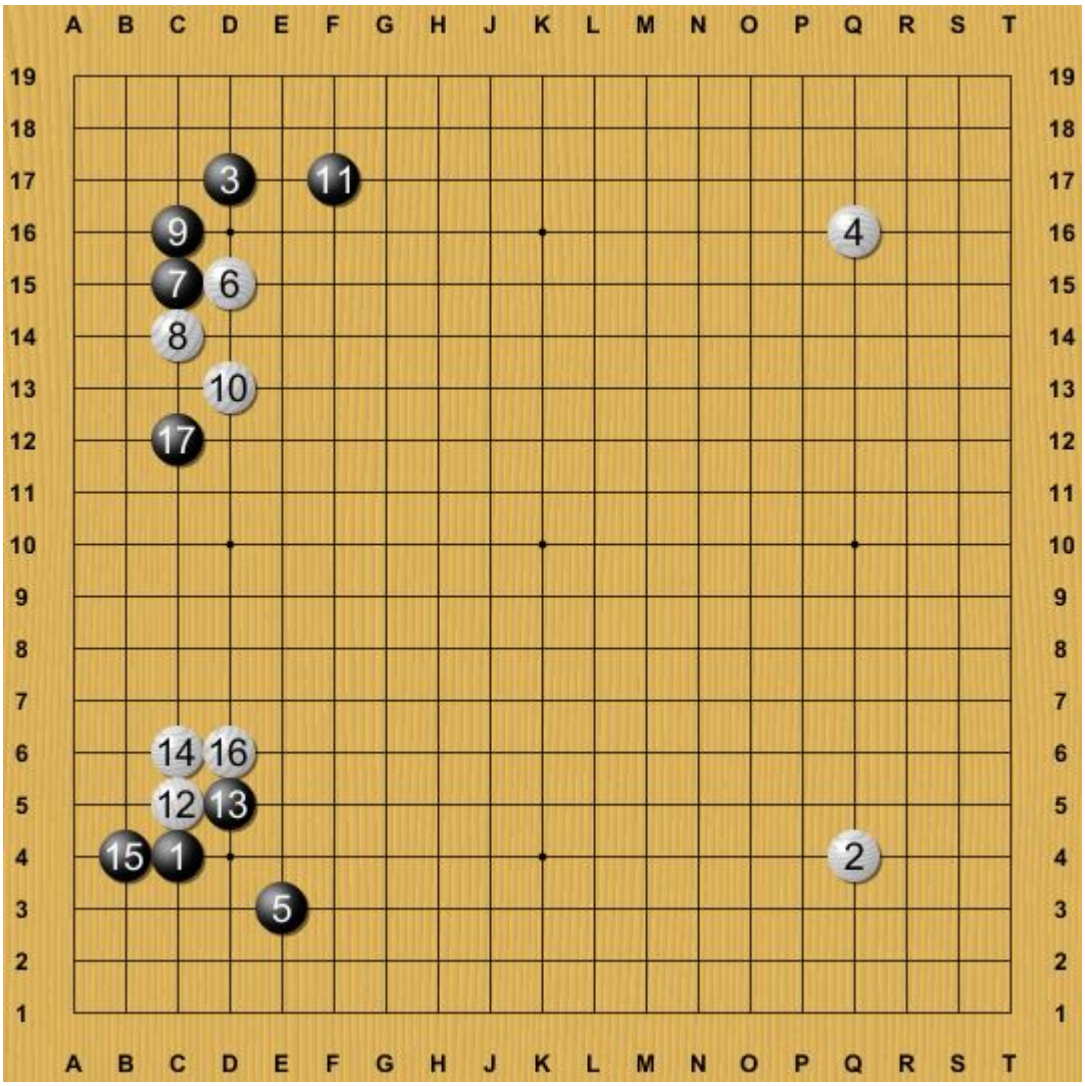
In Korea, the heart of the craze, the media could talk of little else. For the next two days, the top three items at every news station invariably had something to do with the match. After winning the fourth game, Lee Sedol had risen to the status of a national hero. His brave request during the press conference after the fourth game was particularly inspiring. Normally, the two players would have chosen colors in the fifth game by nigiri, but Lee asked to play Black. The reason was simple: although AlphaGo prefers White, Lee had won as White already, and wanted to prove he was equally capable of winning with Black. His courageous spirit deeply moved the team, so for the fifth game, there was no need to choose colors. Lee would take Black.

After the fourth game, people had finally seen that AlphaGo was not invincible. Though the outcome of the match had already been decided, the result of the fifth game now seemed more important than the winner of the contest. If Lee prevailed again, it would perhaps mean that he had found the key to defeating AlphaGo. If so, the match score would no longer reflect the real balance between the two players.

During the rest day, reporters from around the world poured into Seoul, and any news stations that had lessened their coverage regretted their lack of foresight. On the morning of the final game, the press room was packed beyond capacity.

Since the match was taking place in Korea, Go fans in Europe had no choice but to wake up long before dawn, to catch the start of the game at 5 or even 4 AM. It felt like the World Cup!

Moves 1-17



Lee entered the playing room looking relaxed and confident. He carried himself as if destined to win.

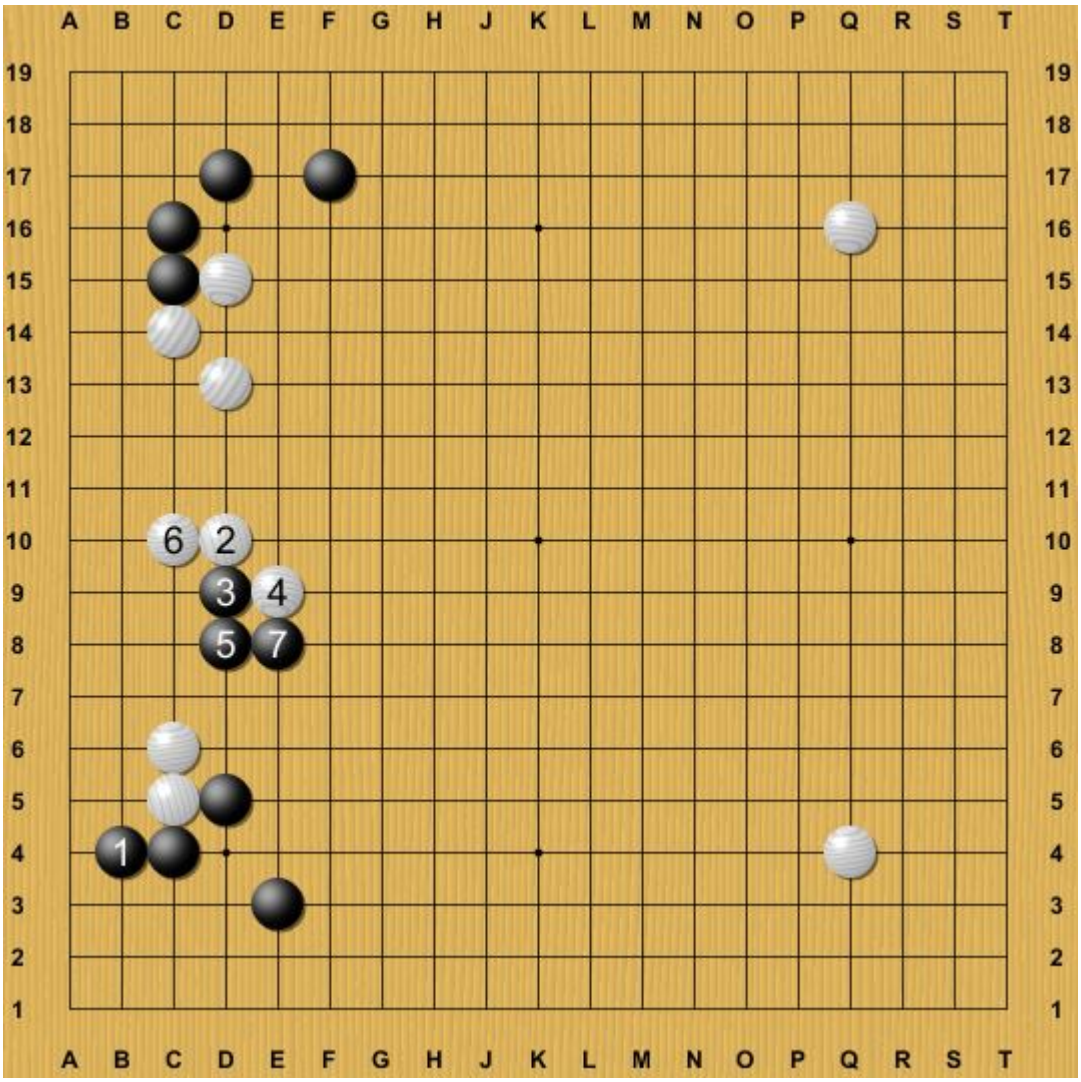
Drawing on the experience of game 4, Lee started with a territorial fuseki, taking double 3-4 points. He played the opening up to 16 unusually fast, as if he had prepared it in advance and anticipated AlphaGo's responses.

The attachment at White 12 has been one of the most popular choices of late, but when White turned with 16, Lee stopped to think. Had this turn ever been played before? See diagram 1.

At move 16, Lee's clock showed 1 hour and 55 minutes, AlphaGo's 1 hour and 51 minutes.

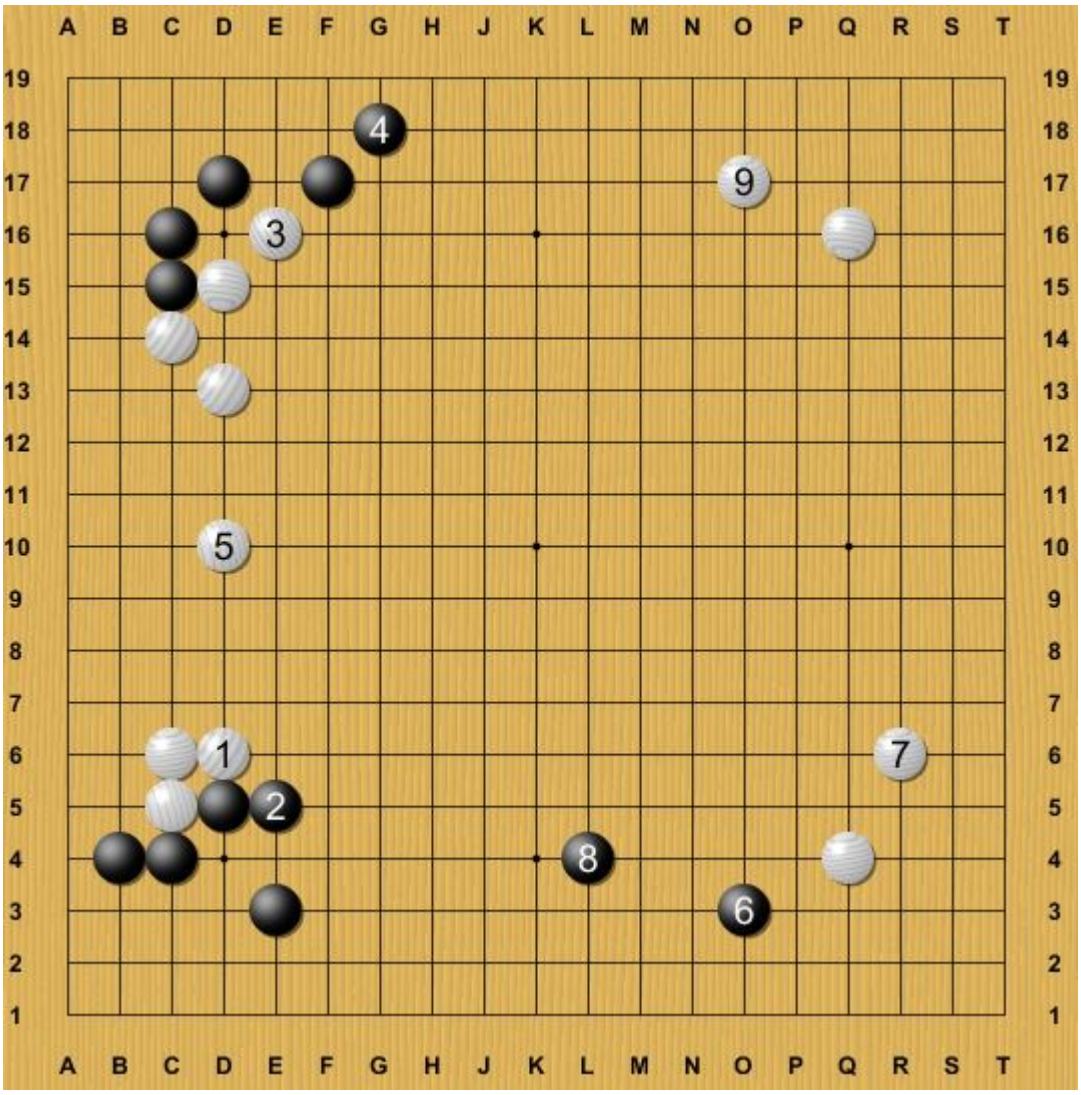
Lee had probably researched this shape already, and after a few minutes of thought, he decided to attack White's top group with 17. However, AlphaGo thought Black should simply extend. See diagram 2.

Diagram 1



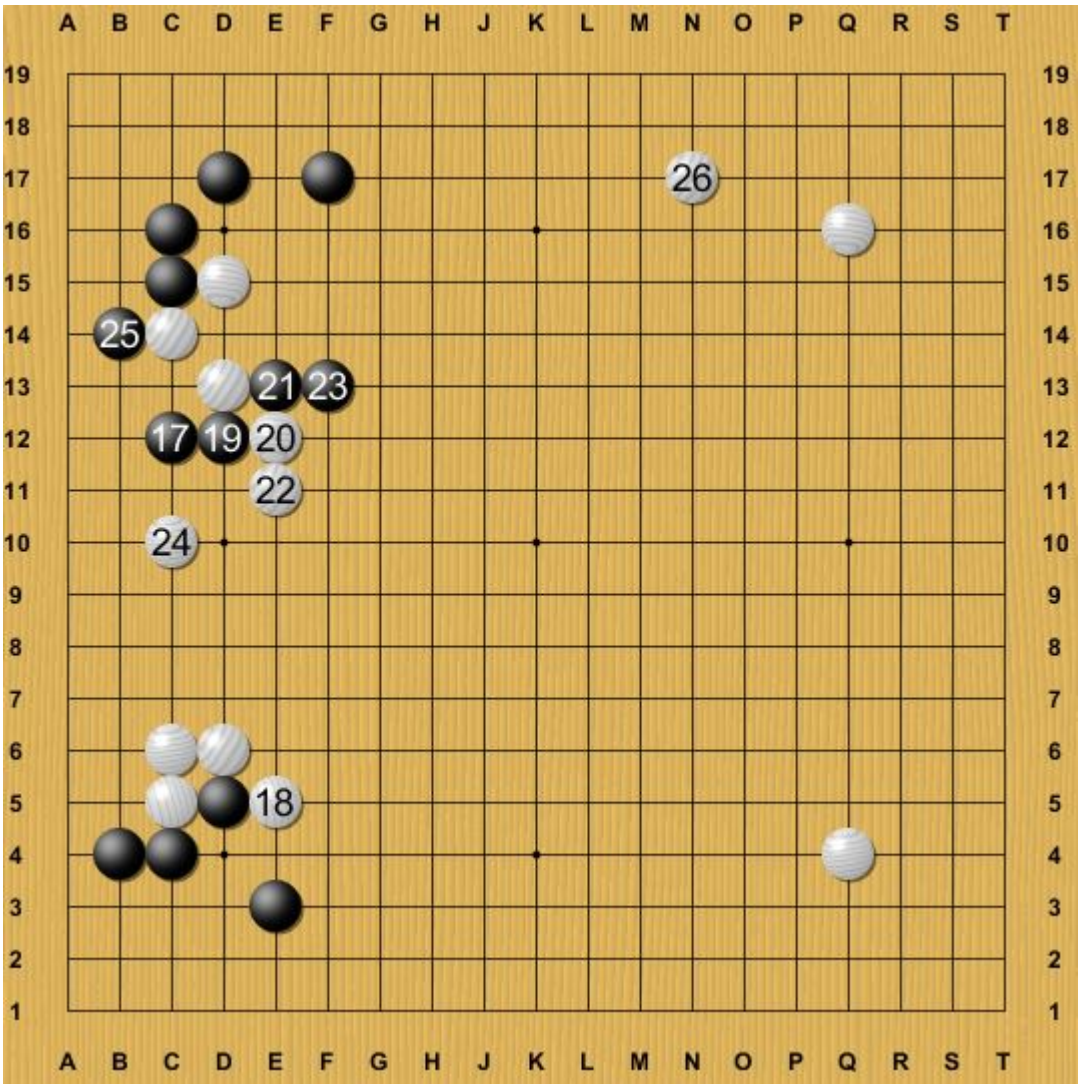
Against Black 1, White usually extends with 2, after which Black can attack White with the attachment at 3. The moves through 7 settle the local area.

Diagram 2



AlphaGo believes Black should play the normal extension at 2. White's forcing move at 3 is typical AlphaGo style, and it suggests that Black answer with the second-line kosumi at 4. Through 9, the opening is equal.

Moves 17-26



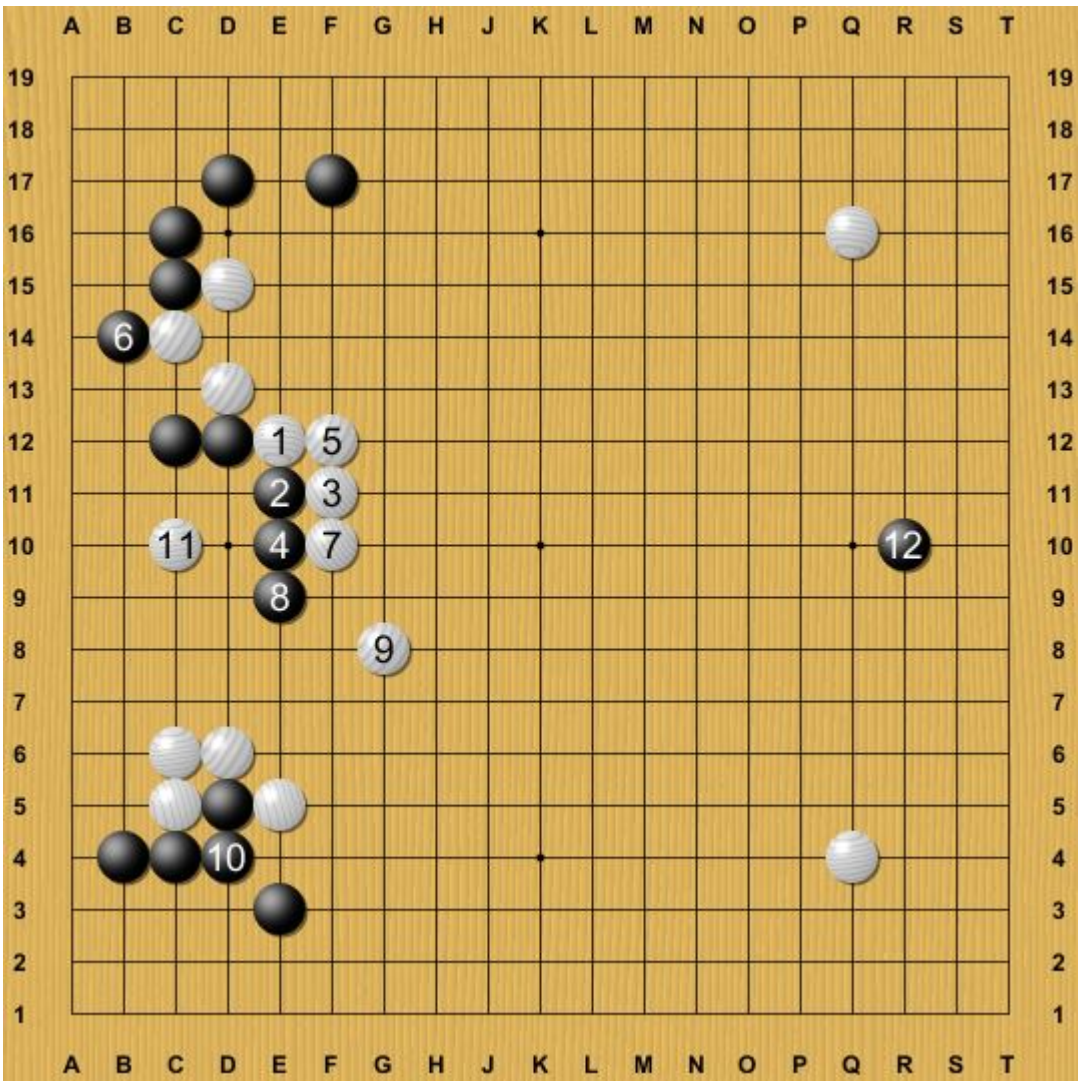
When White ataried at 18, Lee mumbled a few words and pushed out at 19. White's hane at 20 was mandatory. Looking carefully across the board, Lee sighed and cut through at 21. Afterwards, many professionals asked what happens if Black hanes at 22 instead. In fact, AlphaGo would have preferred the hane. See Diagram 3.

White discards the three stones with 22. Through 25, the impression is that Black has claimed considerable territory, but has he really? AlphaGo thought Black 23 was not the biggest move. See diagram 4.

Among professionals, there is a consensus that the most difficult aspect of Go is judgment. This means not only evaluating the overall shape of the game but, most importantly, judging the pros and cons of local variations. The hardest aspect is finding a reference point to which each variation can be compared. Of course, the higher a player's level, the deeper their understanding of local shape. Professional players leverage this understanding through tewari analysis, either pairing off moves or permuting their order to create a clearer reference point. During a dinner I attended with Nie Weiping, he raised the subject of this opening. The analysis in diagram 5, he stated, illustrates that AlphaGo's judgment was correct, and the result favors White.

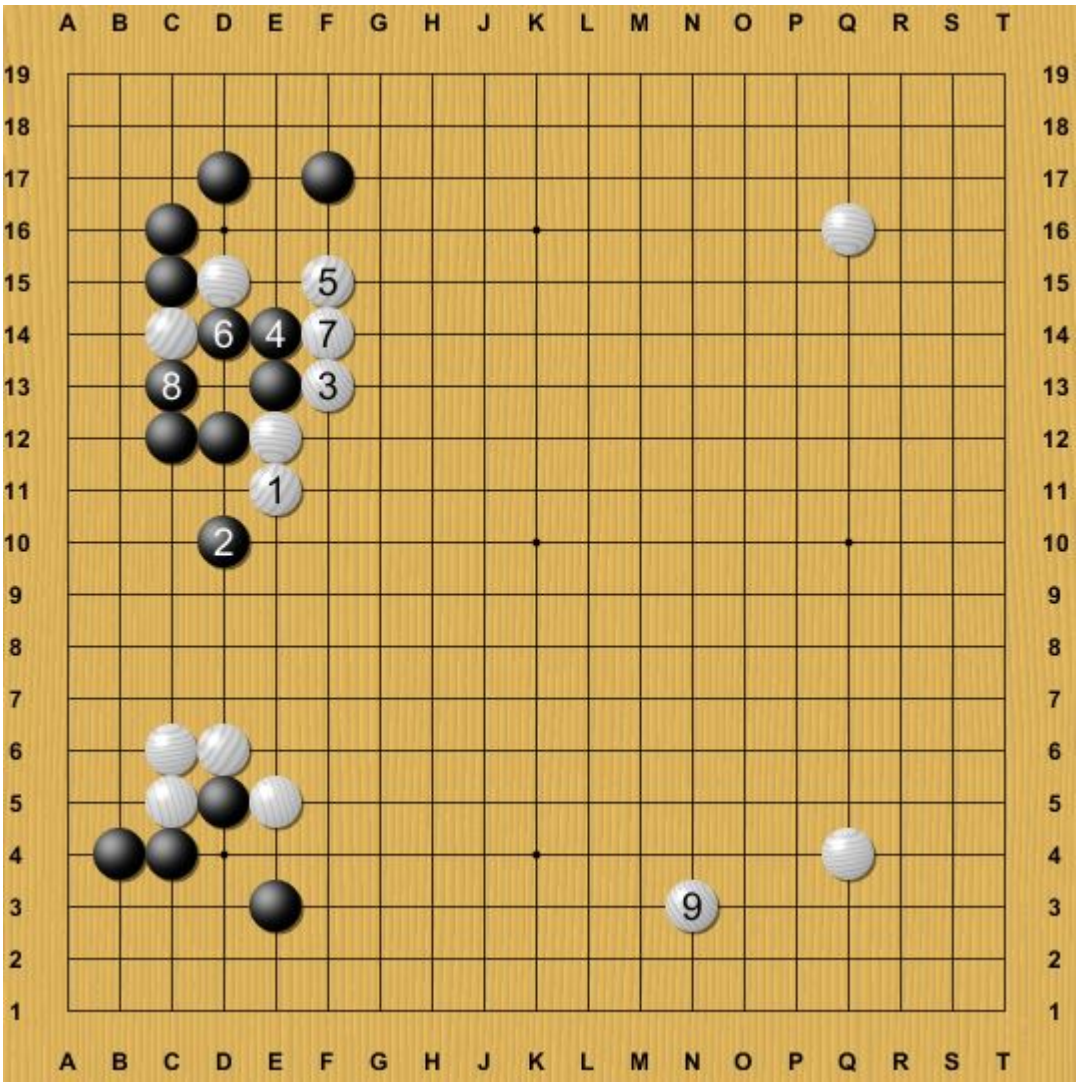
White 26 protected the corner while diminishing Black's potential on the top. At this point, AlphaGo’s win rate was 56%.

Diagram 3



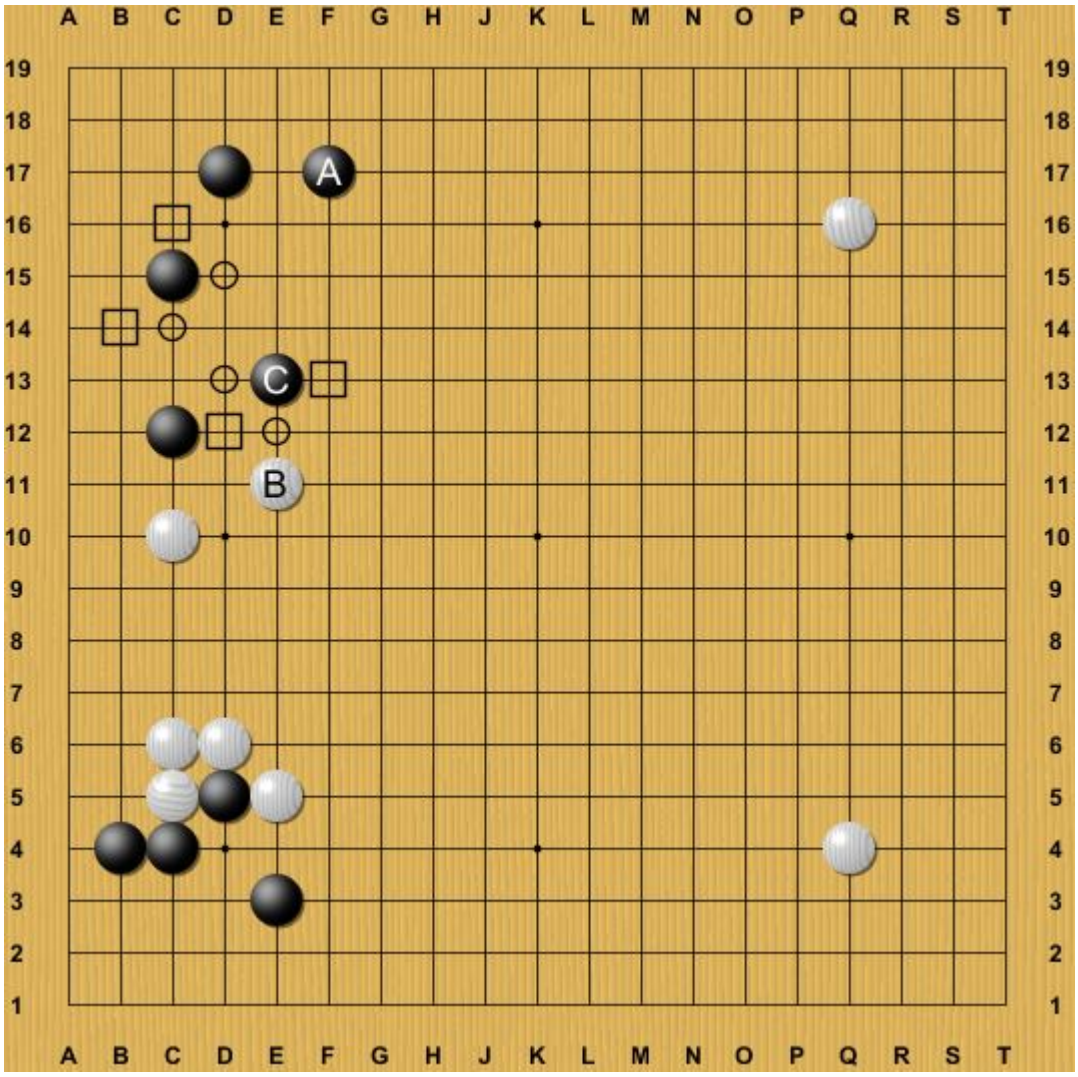
Like many professionals, AlphaGo thinks Black should counter-hane at 2 after White 1. Through 12, AlphaGo judges this variation acceptable for both sides.

Diagram 4



After the game, some professionals looked into the jump at Black 2. AlphaGo recommends sacrificing a stone with 3 and squeezing with 5. Having taken sente, White protects the lower right corner with the large knight's move at 9.

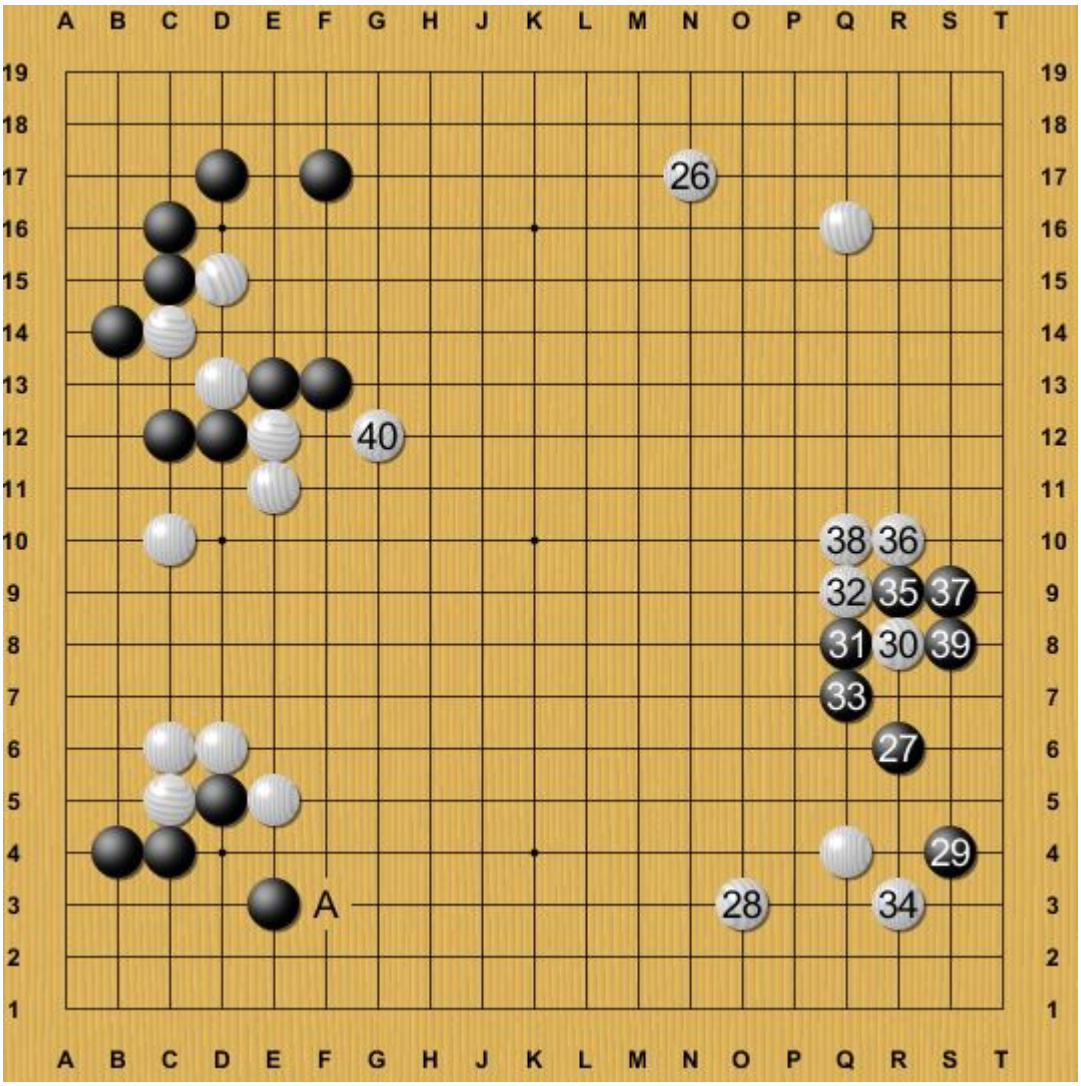
Diagram 5



Nie Weiping evaluates the position as follows. Imagine we remove four white stones, marked by the circles, and four corresponding black stones, marked by the squares. The overall balance remains about the same, but it immediately becomes clear that Black's shape is no good, as the extension at A is too narrow and the exchange of B for C makes Black overconcentrated.

Of course, Black benefits from the exchange of the circled stones for the squared ones, so the position is not exactly equivalent. Regardless, Black has lost more from inefficiency than he has gained from the exchanges, so the real game still favors White.

Moves 26-40



Black 27 approached the corner, and White defended with 28. After Lee played the knight's move at 29, he removed his watch, and I noticed his hands were shaking tremendously. Was it stress, or excitement? I could not tell.

At move 29, Lee Sedol had 1 hour and 38 minutes, AlphaGo 1 hour and 42 minutes.

White pincered at 30, and this is one of AlphaGo's favorite joseki. Later, Chang Hao mentioned that Go Seigen felt that this joseki, which encloses Black in the corner, clearly favors White. The great master was one of the few professionals who placed great emphasis on the centre. Regrettably, he passed away in 2014 at the age of one hundred. It would be fascinating to learn his views on AlphaGo if he were alive to see it today.

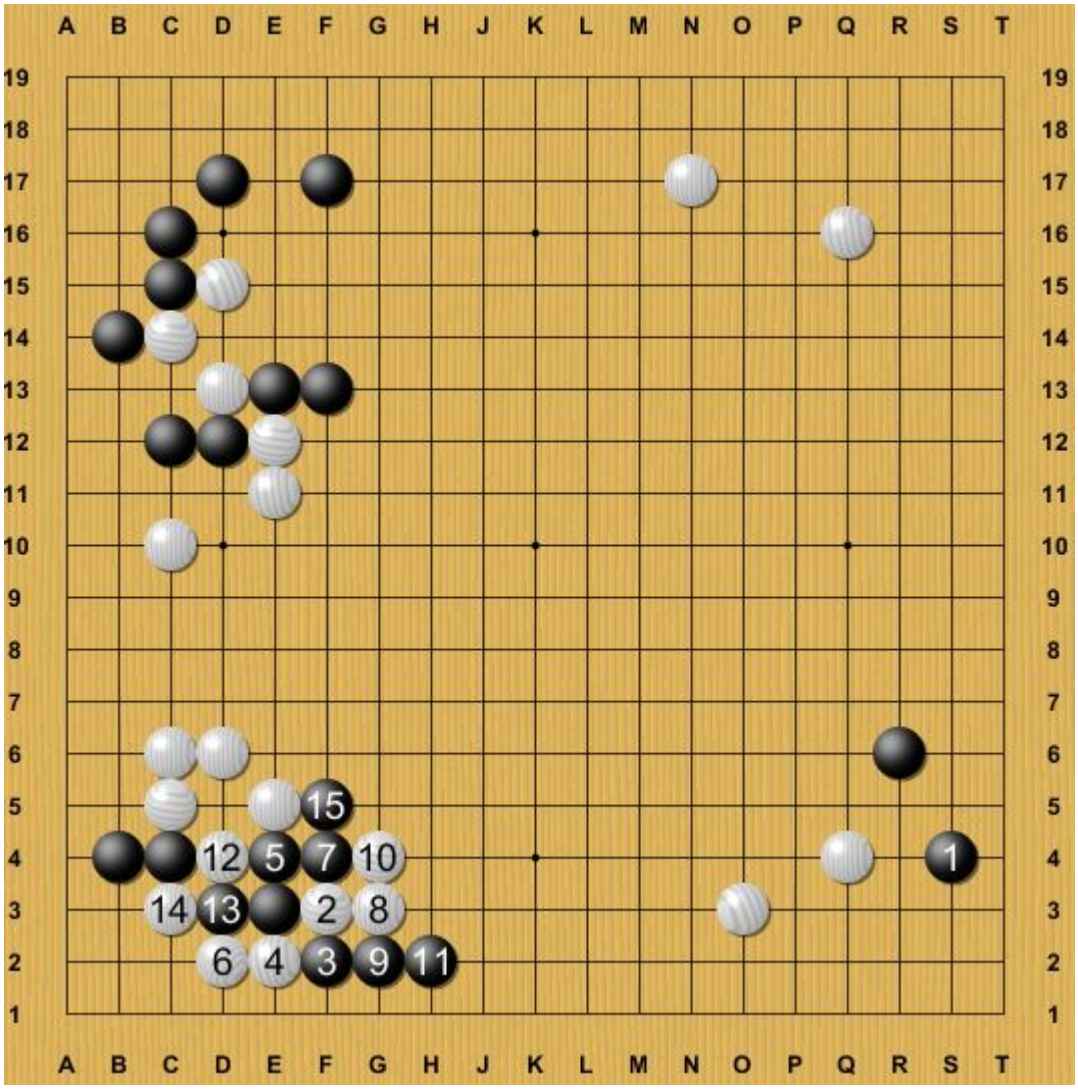
After the match, during a Go program with Meng Tailing, I raised the question of the proper timing for White's attachment at A. According to him, professional research has shown that although A is tempting, the result may turn out badly if one plays it too early. See diagrams 6 and 7.

The attachment at Black 31 emerged from Lee's desire to avoid being sealed in, especially considering AlphaGo's outstanding strength in the centre. Nonetheless, AlphaGo thought Black should have taken the corner. See diagram 8.

Through 39, the right side was settled for the time being, but the result was difficult to evaluate. Lee sighed again as he looked at the board, perhaps dissatisfied with the direction the game had taken.

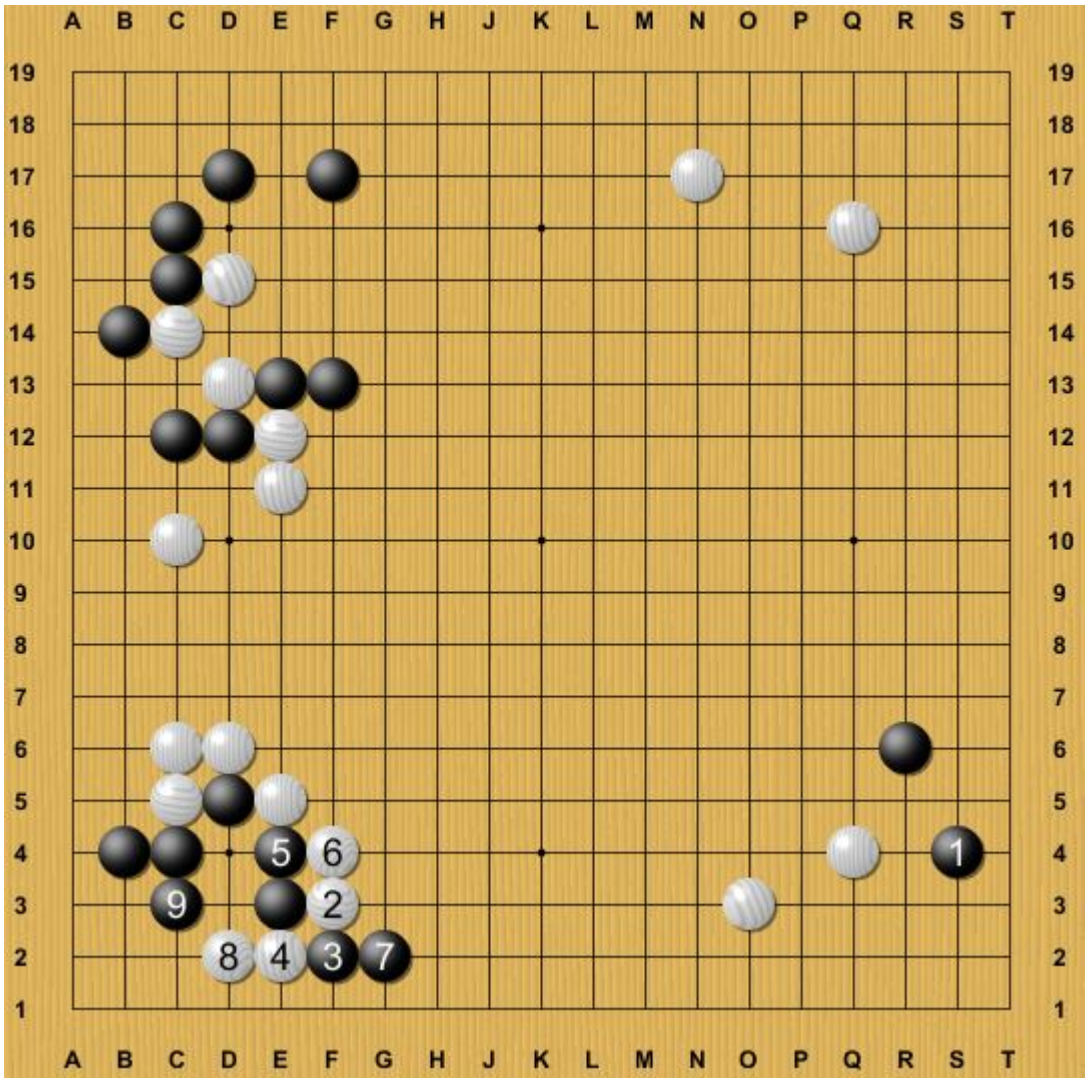
His expression only grew more serious when he saw White 40. This jump was an outstanding move, shining light across the whole board! Once again, AlphaGo's move had surpassed our imagination, but having seen it, we all agreed it was the right one. What makes this move so beautiful? See diagram 9 for a fuller illustration.

Diagram 6



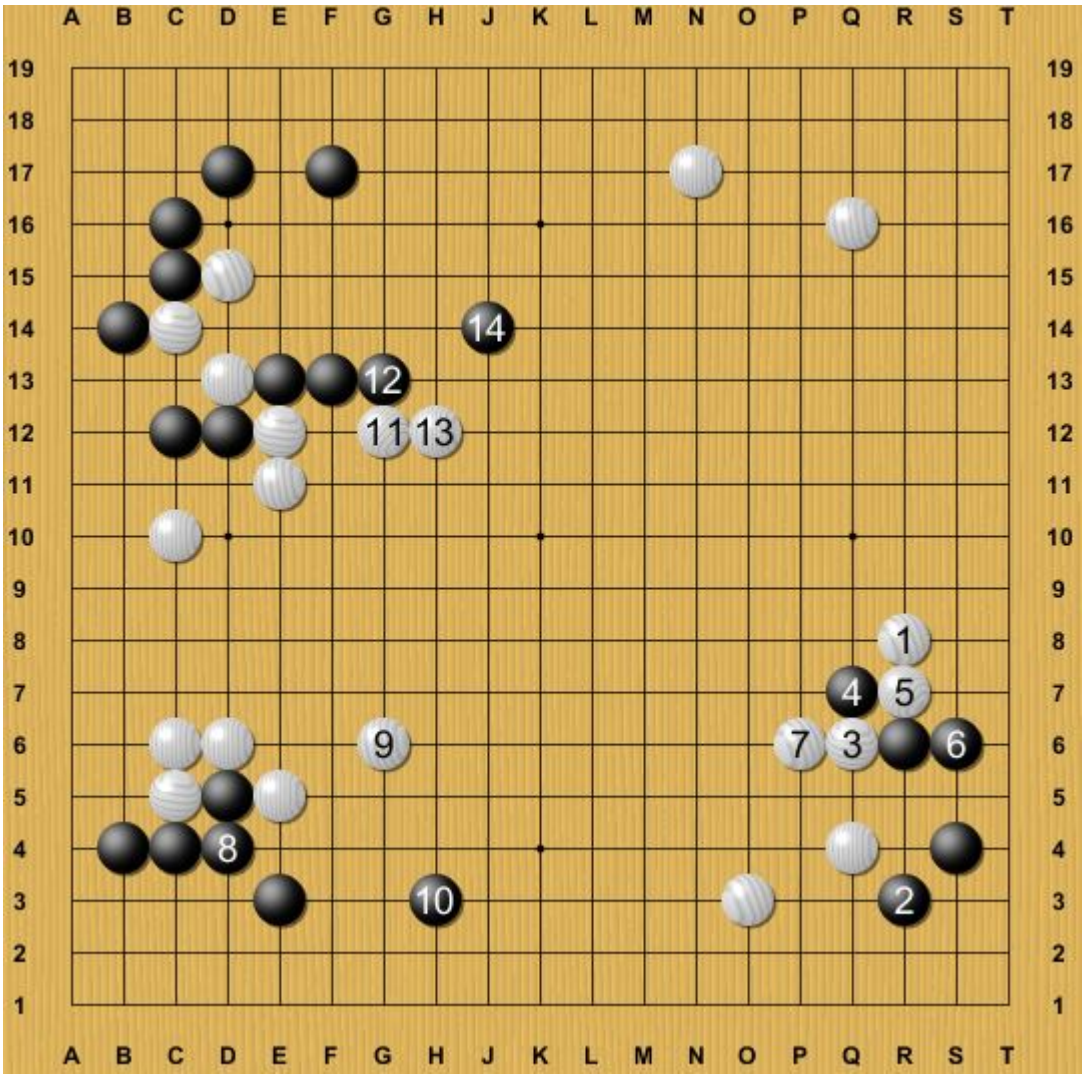
According to Meng Tailing, if White attaches immediately at 2, Black has a severe counterattack with 5 through 15. Although this variation leads to ko, it is a very heavy one for White, especially due to the lack of suitable threats. This strategy is untenable for White.

Diagram 7



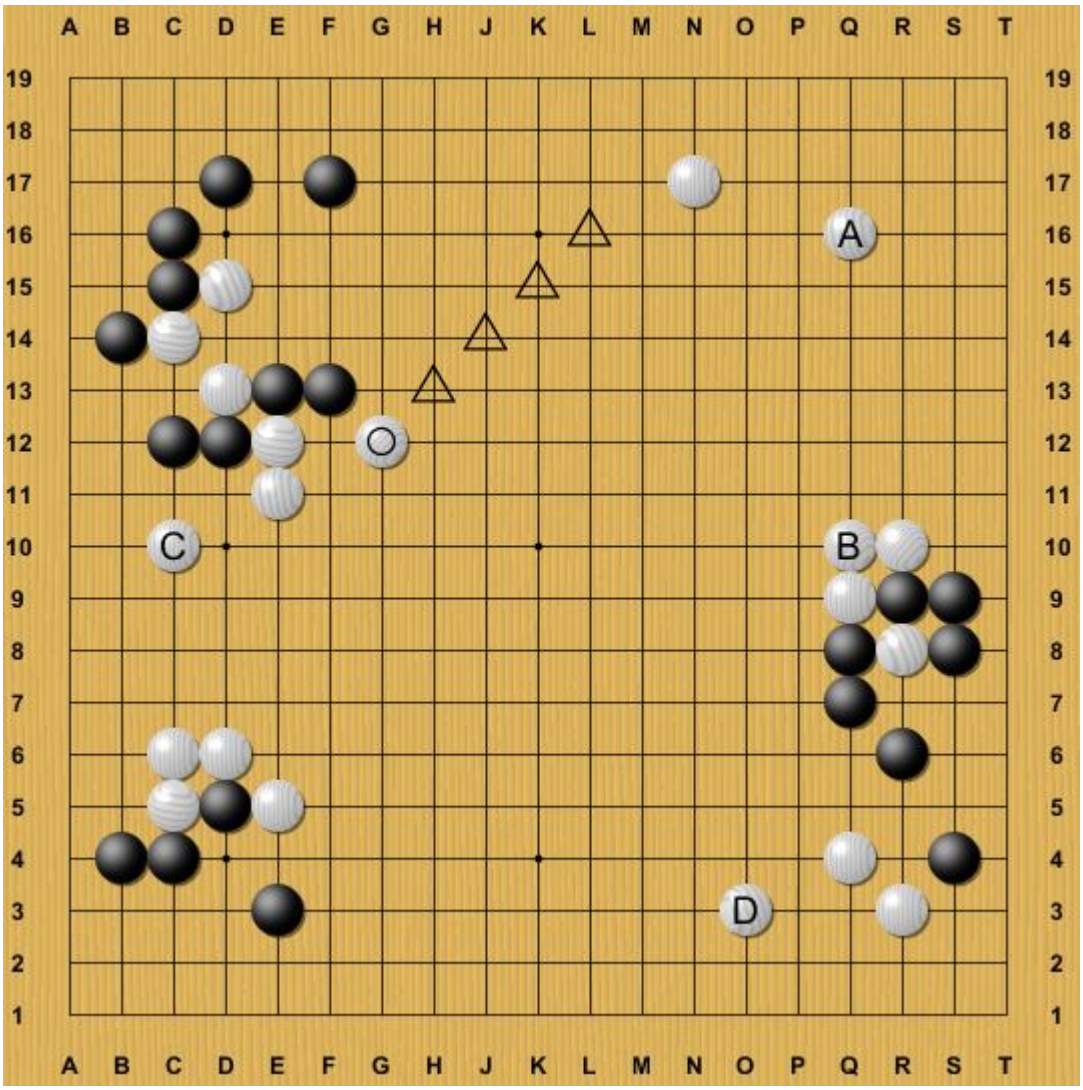
White can also block at 6, but then Black extends directly at 7. White has no way to deal with the corner, so this variation also fails.

Diagram 8



AlphaGo believes Black should choose the usual response and enter the 3-3 point, letting White seal in the corner with 3 and 5. The jump at 11 is just as valuable as before, and through 14, the position looks roughly equal.

Diagram 9

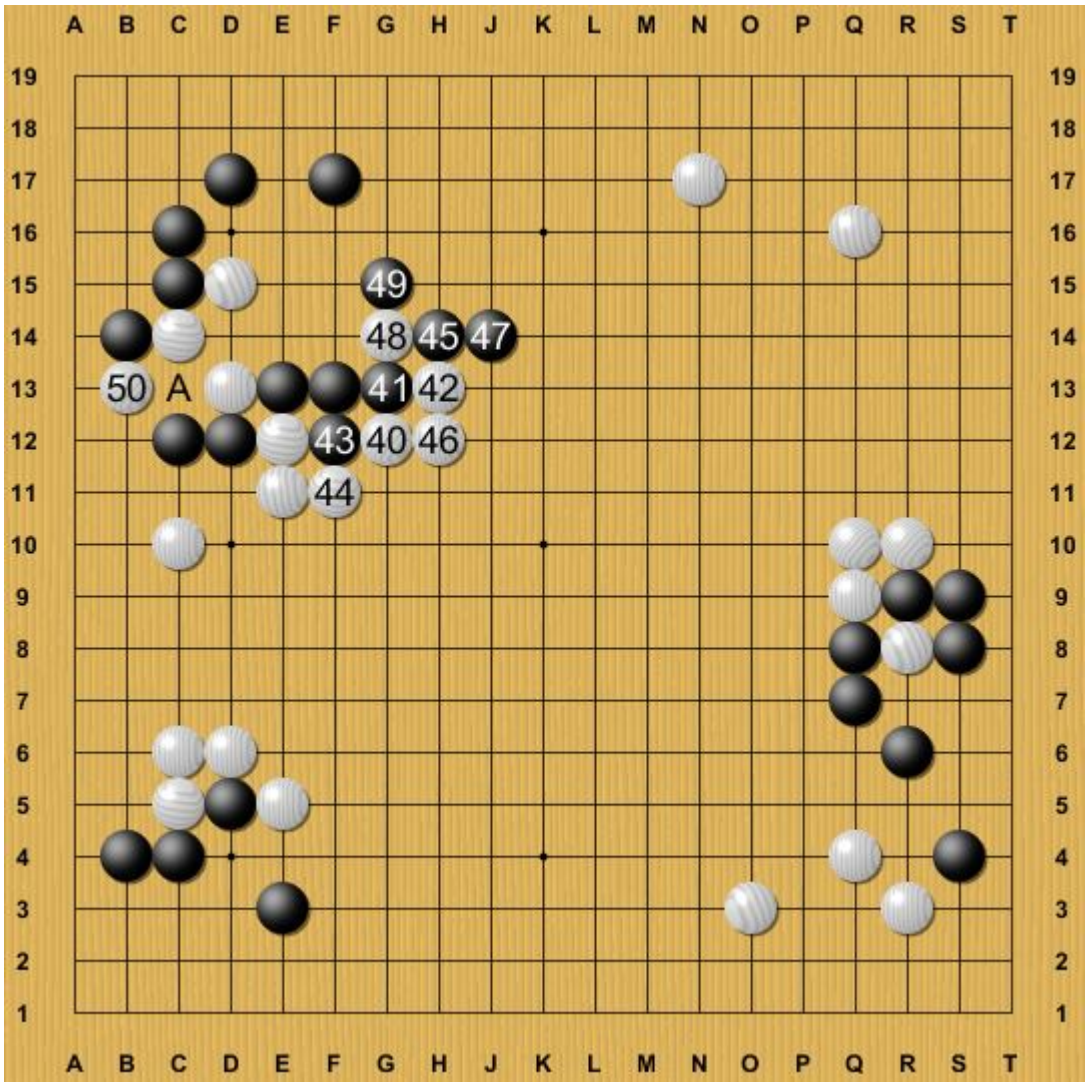


Here is a clearer way to explain the impact of White's jump at 40.

The gap between A and B on the right is fairly wide, so White must stay on guard against the possibility of invasion. On the left side, the group at C is not thin, but its potential for expansion is limited. The group at D is also difficult to develop because of Black's strength on the right. Although these groups were not very strongly related at first, after White 40, the left and right groups become loosely connected. Not only does this jump restrict Black's potential on the top, it also increases White's potential on the left. Finally, it begins to form an invisible web around the centre. If White can seal Black in on the right side, the entire centre will fall under White's influence.

One move that links all the groups together: now that's the essence of whole-board thinking!

Moves 40-50



Lee cautiously responded by extending at 41. When White haned at 42, Lee shook his head and grudgingly pushed in at 43. However, AlphaGo disliked Black 43, and instead suggested diagram 10.

Although 43 ensured that Black could successfully extend at 47, it also lost a liberty, making the cut of 48 more severe.

After move 48, Lee had 1 hour and 22 minutes, AlphaGo 1 hour and 34 minutes.

The unyielding Black 49 aimed to swallow up all of the white stones, but White's hane at 50 left a great deal of bad aji for Black due to the shortage of liberties. Lee's expression at this moment was grim, and he sighed heavily. It seemed as if Black would have to compromise with the cut at A. See diagram 11.

Diagram 10

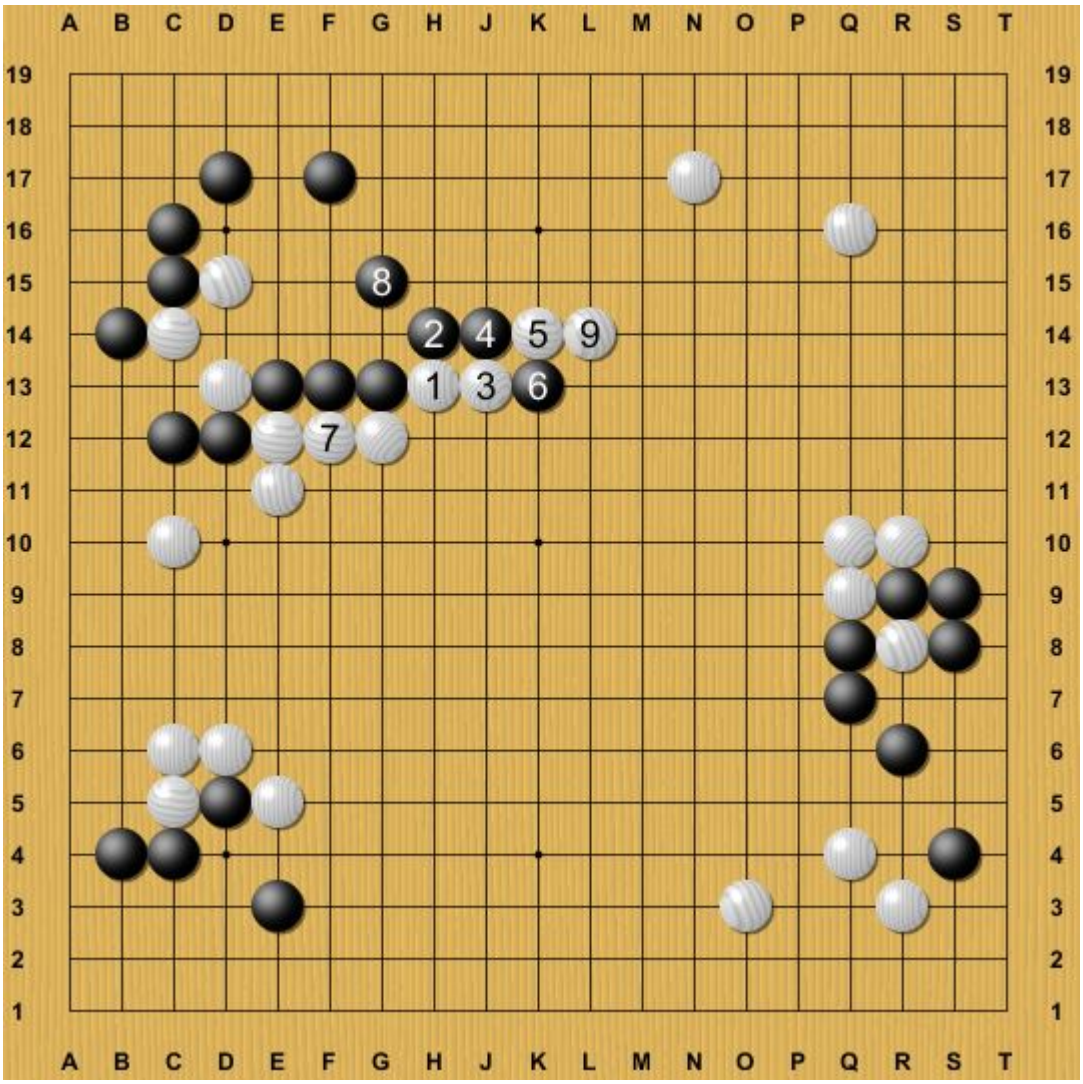
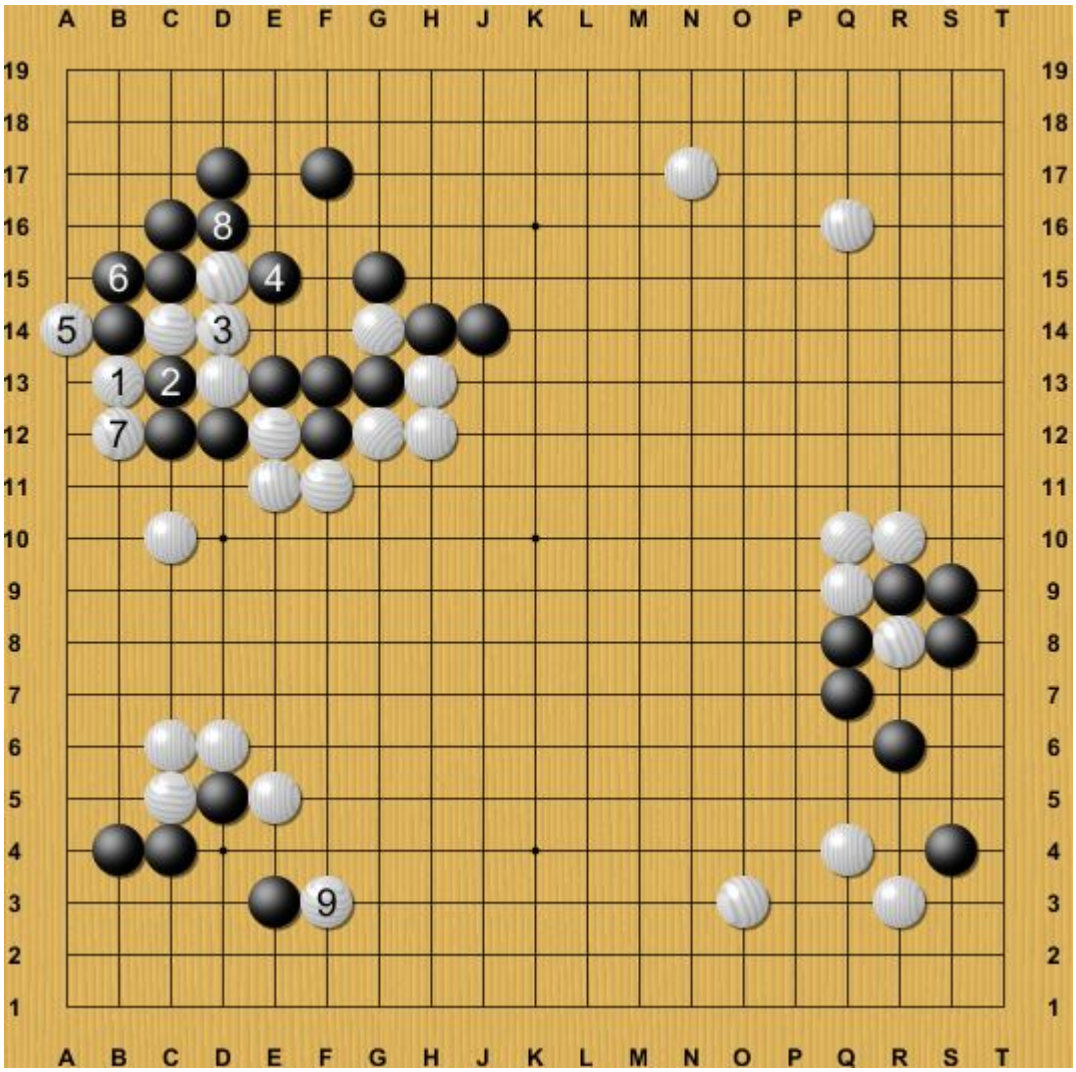


Diagram 10 will come as a great shock to everyone, as nearly every commentary states that White would answer 2 with the double hane at 4. Actually, AlphaGo planned to extend at 3 and play the sequence through 9! Of course, we cannot rule out the possibility that AlphaGo would have changed course and played at 4, should Black have chosen this in the real game. Either way, AlphaGo thinks this is better than the game for Black.

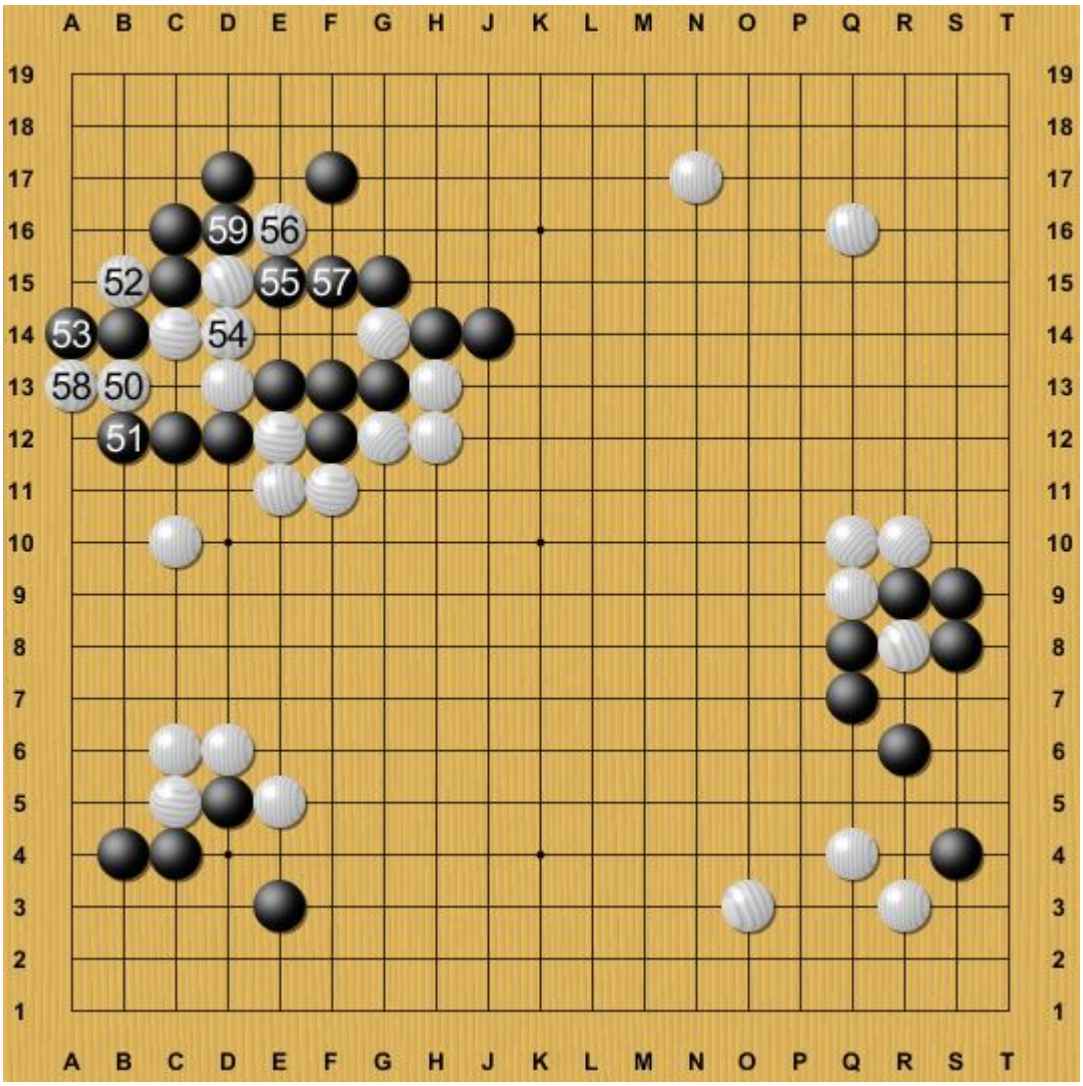
Diagram 11



Black's safest course of action is to cut immediately at 2, then clamp at 4. The four white stones are dead, but White has the tesuji of 5 and 7. Black loses at least ten points, and White has clearly gotten the better of this fight.

Note that White cannot play 5 at 6, or Black will answer at 5, leading to a two-stone edge squeeze where the entire White group dies.

Moves 50-59



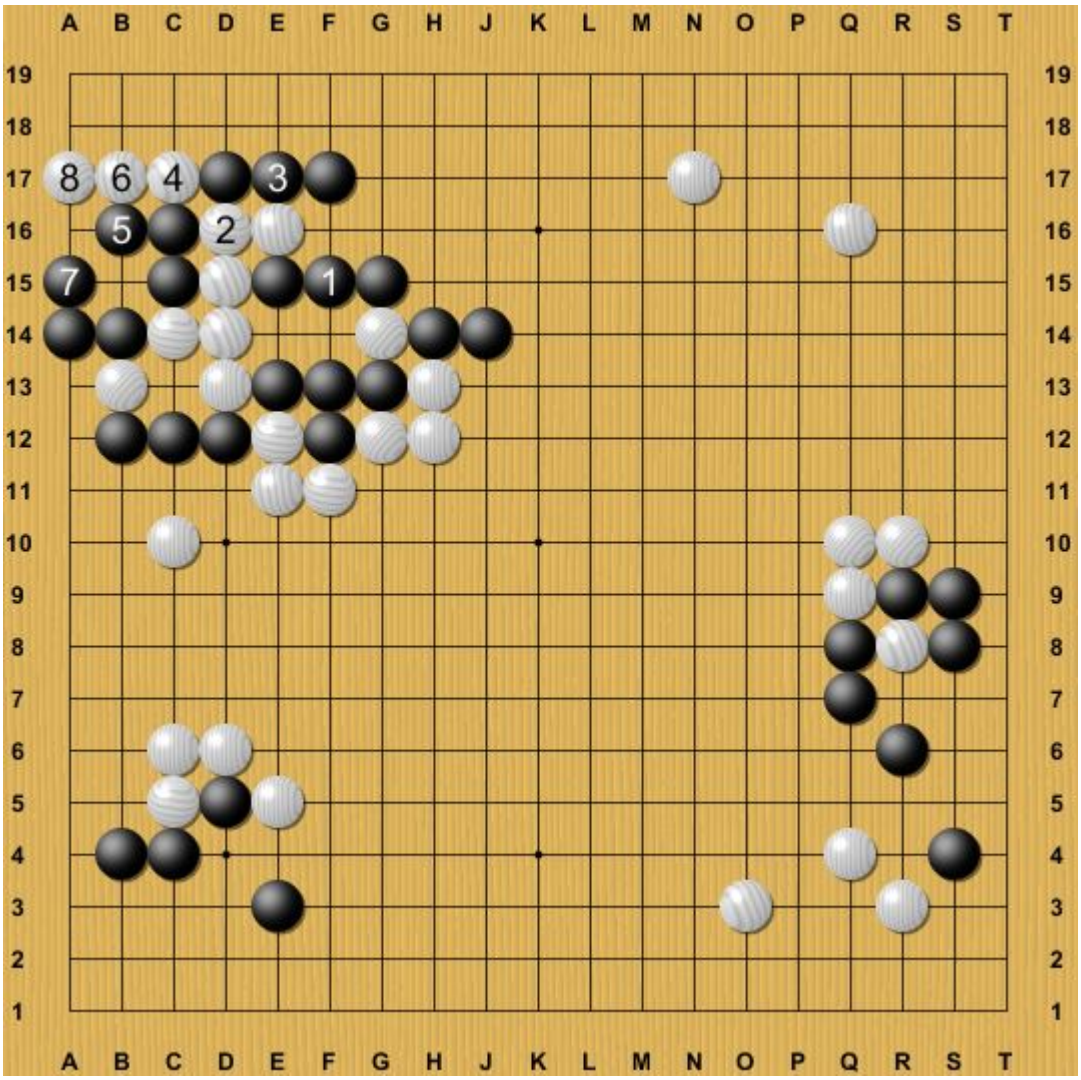
The fight grew more complicated, but Lee appeared to be at a disadvantage. If White managed to get out, the game would be decided on the spot. In fact, things seemed to be heading in that direction. White 54 is excellent move order, and after the exchange of 56 for 57, many of the live commentaries had already discovered a problem for Black. See diagrams 12 and 13.

Shockingly, at this moment AlphaGo chose to exchange 58 for 59, and White's group simply died! Had AlphaGo made another critical blunder?

Studying the data, I found that AlphaGo was not confused the way it had been in game 4. In fact, the win rate had barely changed at all. Of course, from the human perspective of seeking the best moves, AlphaGo's choice was a foolish one. From a global perspective, however, White is by no means behind, and as we will soon see, the dead stones are far from meaningless.

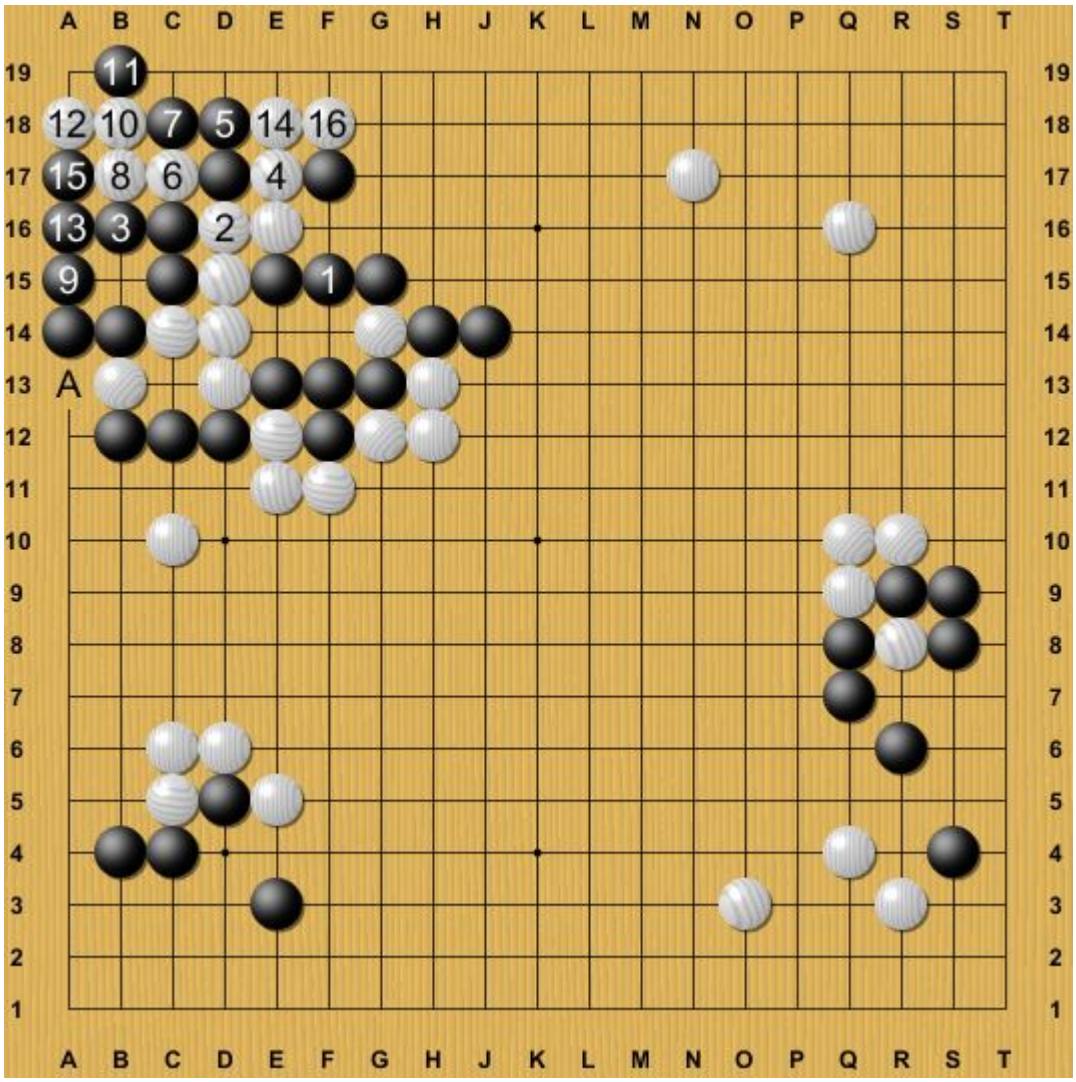
Regardless, Lee had just gone from hell to paradise. He looked as if he sensed another sudden reversal at hand. Perhaps this was the cause of his tremendous blunder just a few moves later.

Diagram 12



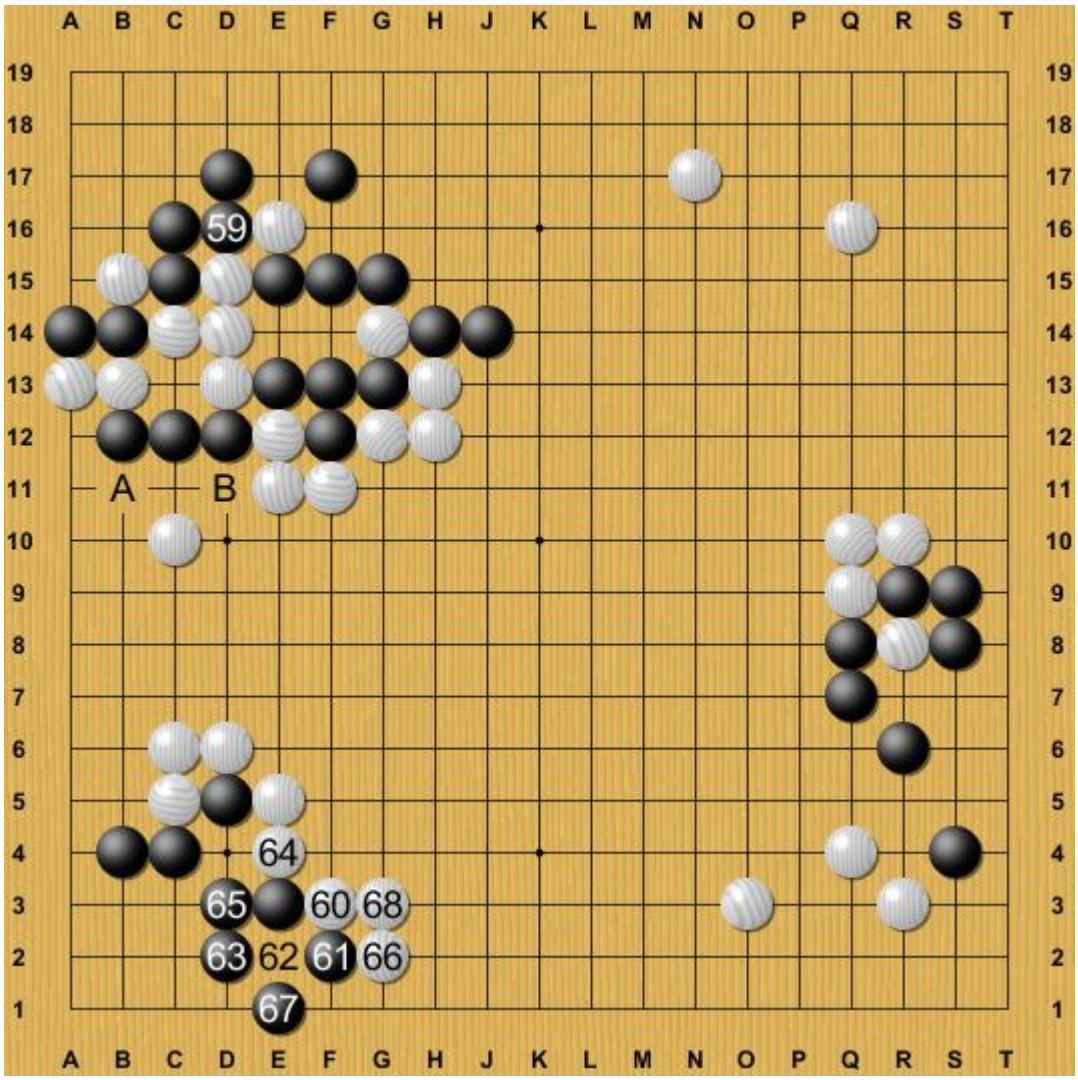
White's connection at 2 is very severe. Black cannot start filling liberties with 3, or else White 4 through 8 will kill the black stones on the side.

Diagram 13



Black can put up a stronger fight with the atari at 3, but Black's shortage of liberties leaves a great deal of aji in the corner. Through 16, Black proves unable to kill, as White can always cut off three stones with the atari at A.

Moves 59-68

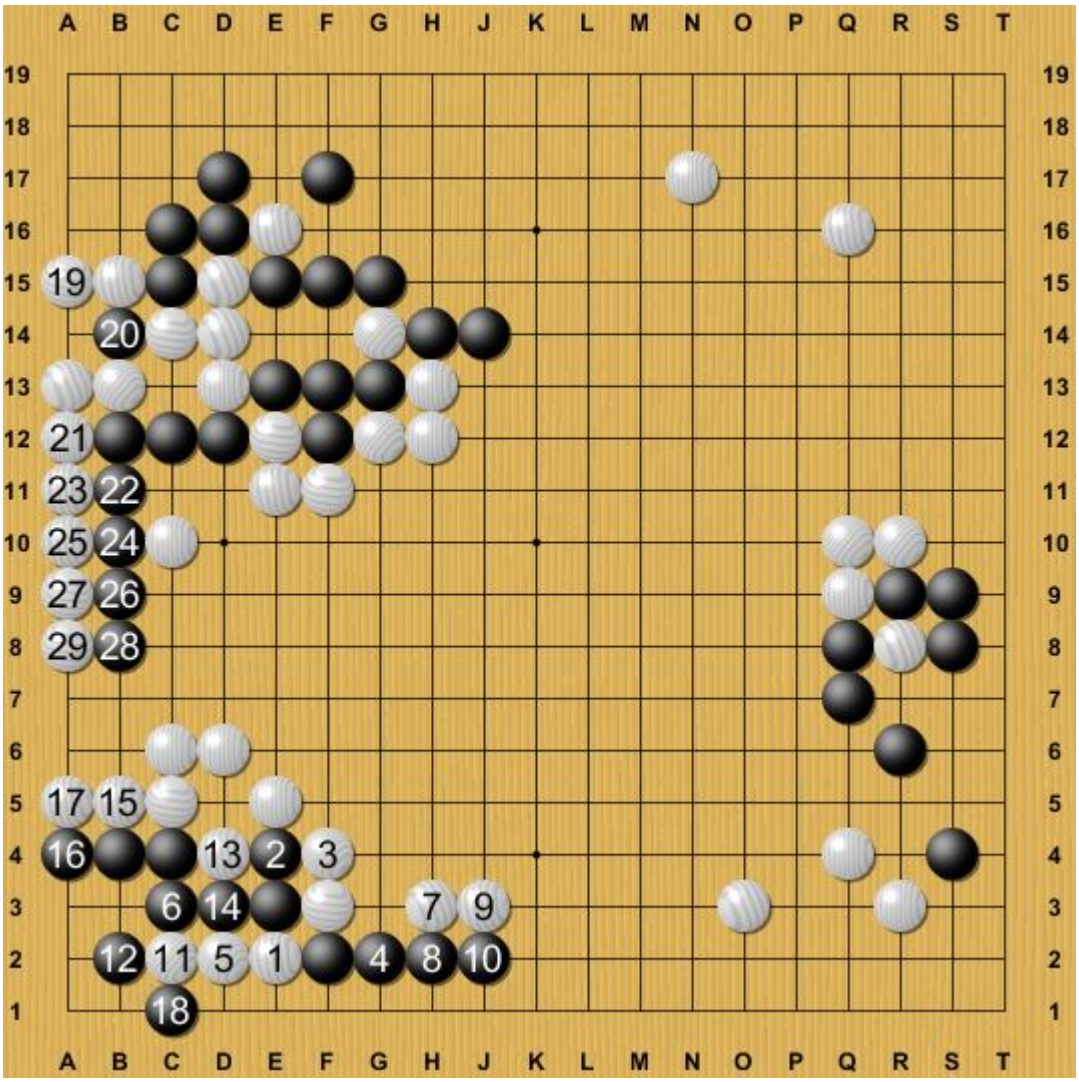


White 60 was extremely large. We have already analyzed this move, and earlier it would have failed for White. However, due to the change on the left side, Black's refutation no longer works! See diagram 14. This may have been the compensation White was looking for by sacrificing the stones on the left.

With the sequence to 68, White reaped a large profit on the bottom. Black was completely sealed into the corner, while White had built a powerful formation on the outside. Considering that White's moves at A and B had also become sente, the thickness of the upper wall was almost perfect. AlphaGo may have missed the chance to wrap up the game, but on the whole White was not doing badly at all. At this point, AlphaGo's win rate had already climbed above 70%.

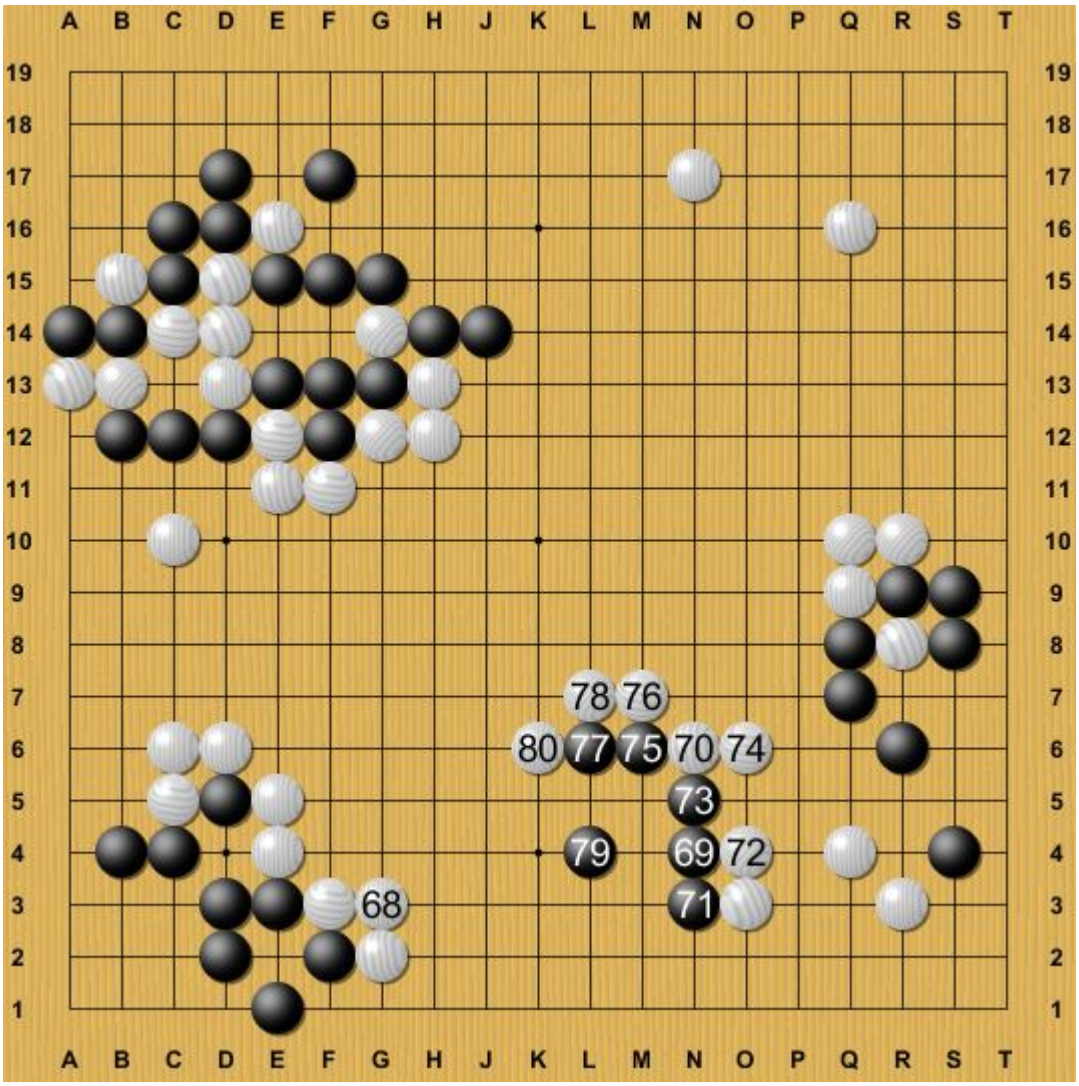
At the same time, Lee Sedol was equally pleased, still basking in the warm afterglow of Black's profits on the left.

Diagram 14



This sequence starts out exactly like diagram 7. The only difference is that, after the forcing move at 15, White can suddenly resurrect the dead stones on the left! When White plays 19, Black must throw in at 20 to avoid falling short of liberties in the semeai, but now White can connect up along the first line. Through 29, Black's stones on the outside are completely wiped out.

Moves 68-80



White's aim to build up the bottom was clear, so Lee played the shoulder hit at 69 to reduce White's potential. Some commentators felt that Black 69 went too deep, but AlphaGo would have made the same choice in Black's position.

White 70 was the only move to start the attack, and the battle intensified up to move 78. Suddenly, Lee hesitated. Instead of extending at 80, he turned back towards safety, making an eye with 79. Should Black have risked the life of the group to extend out into the center? See diagram 15.

If Lee were to play ten games from this exact position, he would have played the extension in perhaps nine of them. After the game, he must have asked himself, when it would have been so much his style to seek life in the centre, how could he possibly have chosen to back down? There are no doubt many causes, but the sense of superiority born of Black's unexpected gains on the left side must be the main one.

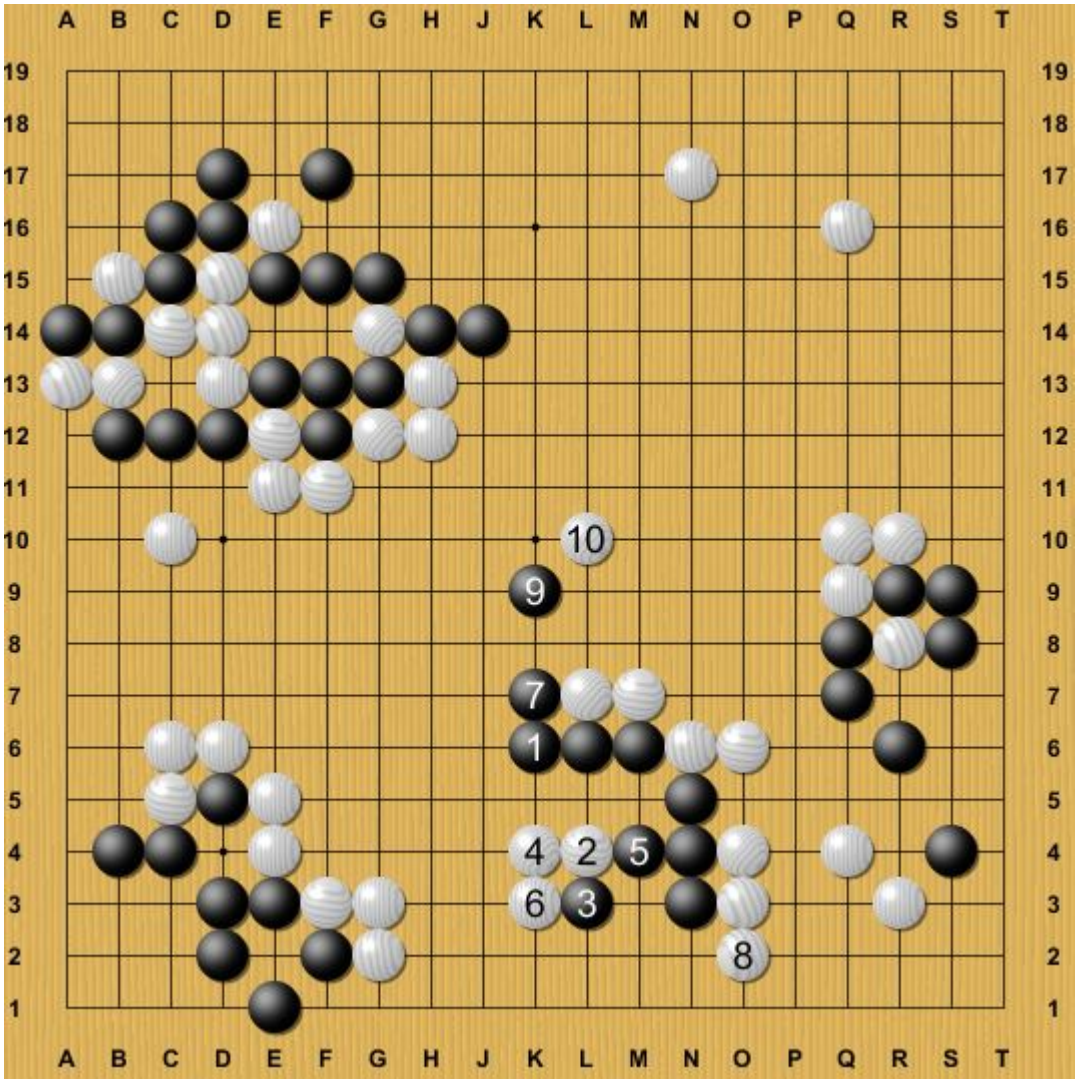
Besides this, White 76 and 78 would have taken immense courage for a human to play. White would be in deep trouble if Black lived inside White's moyo, so a human player would experience great doubt and hesitation before attacking this way. In contrast, AlphaGo's

constant, unfeeling rhythm can easily unnerve its opponents. This may well be the most difficult aspect of playing against AlphaGo.

Black 79 was perhaps the move that Lee regretted most from the entire match. If he had extended at 80, would it have changed the outcome? Sadly, we will never know. The French have a proverb: "With enough 'ifs', one could fit Paris in a bottle."

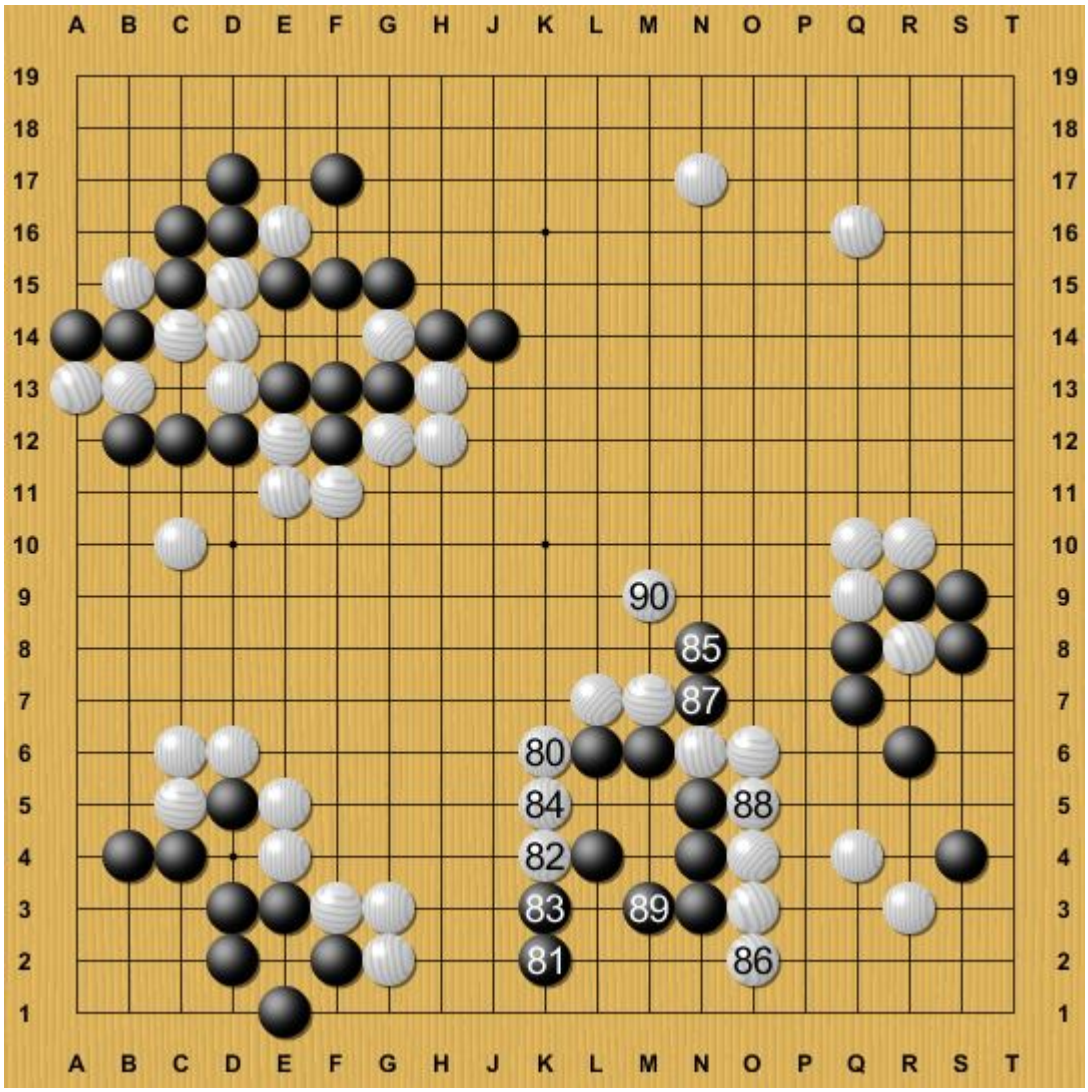
When White haned at 80, AlphaGo's win rate climbed to 76%.

Diagram 15



AlphaGo thinks Black should extend at 1. White attacks Black with 2 through 10, and while Black is still not safe, it looks unlikely that White can kill everything. This way, the outcome remains uncertain.

Moves 80-90

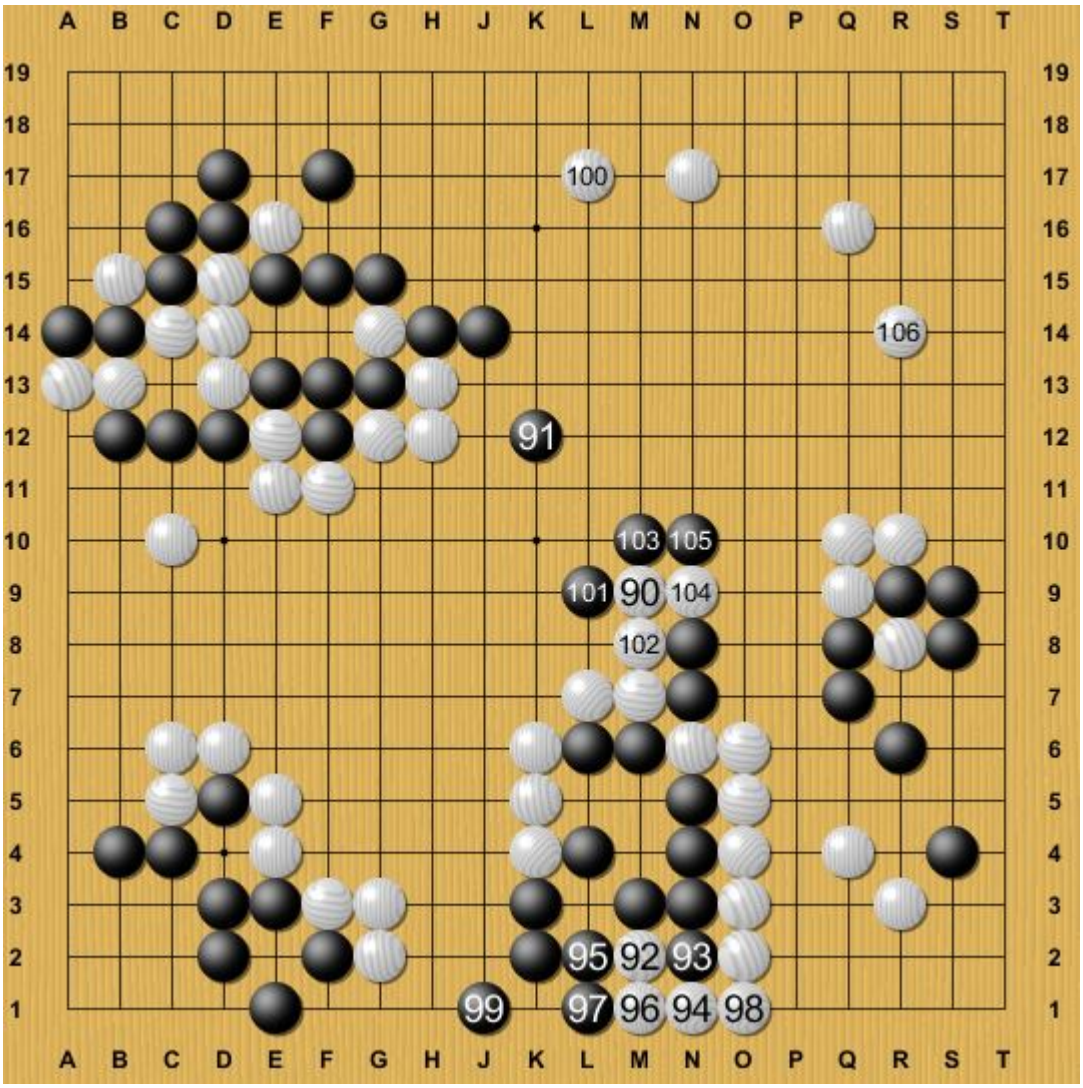


When White haned at 80, the centre and left side became White territory, and Black was forced to make a painstaking life at the bottom.

Lee Sedol suddenly realized his plight. With 85 and 87, he attempted to reduce White's influence, but only achieved the opposite. Not only did White gain points while making life with 86 and 88, but after White 90, it was plain to see that Black's two stones were facing the wrong direction. Truly, blessings do not come in pairs, and misfortunes never come singly.

At this moment, AlphaGo’s win rate was 84%. Lee had 46 minutes left on the clock, AlphaGo 1 hour and 9 minutes.

Moves 90-106

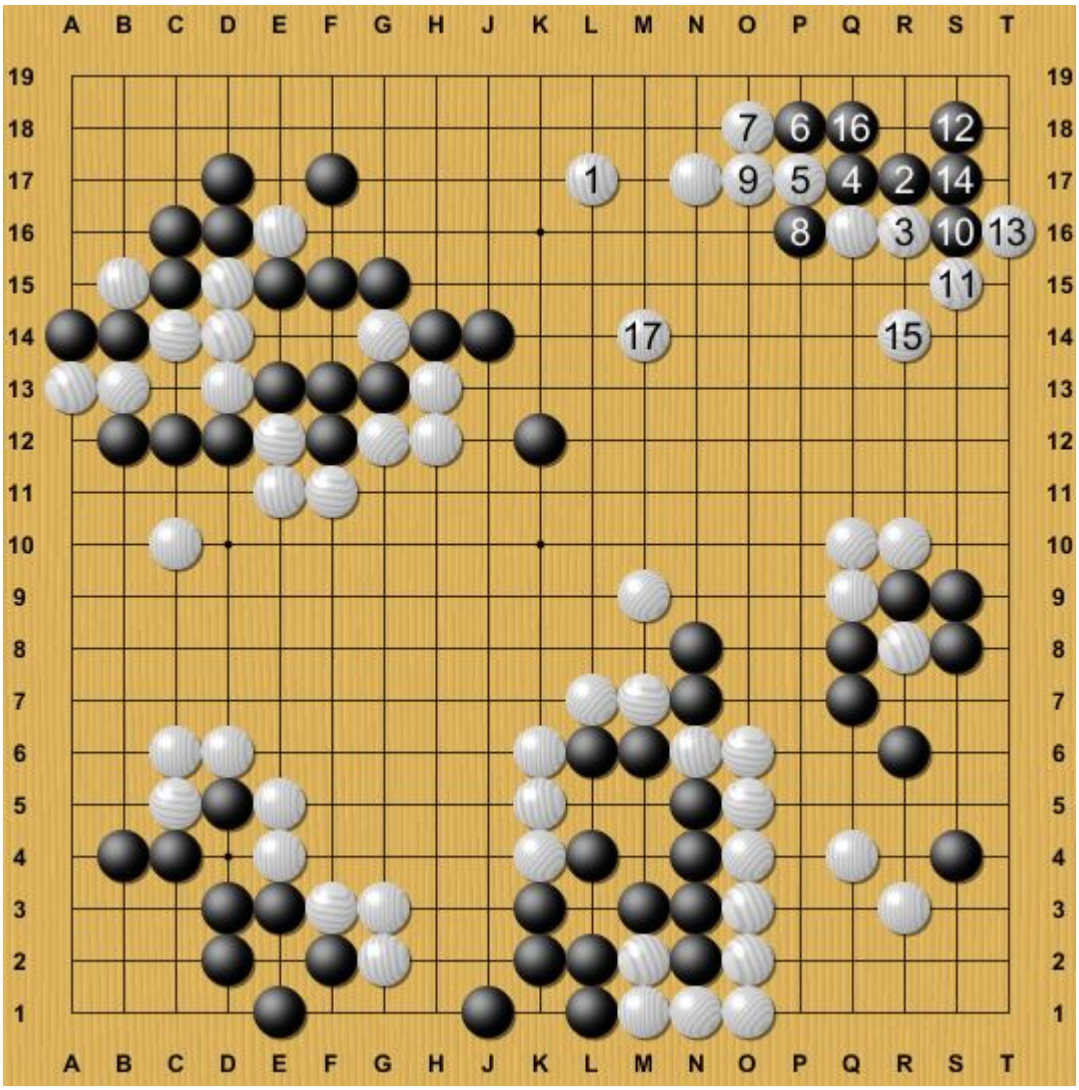


AlphaGo never gets too attached to its own territory, and when Black played the knight's move at 91, White showed no inclination to protect the centre. Instead, after some exchanges at the bottom, White chose the one-space jump at 100. This solid way of playing could only mean AlphaGo felt very optimistic about the outcome.

AlphaGo thought Black's way of playing with 101 through 105 was no good - see diagram 16. In any case, Black faced a very difficult game no matter what.

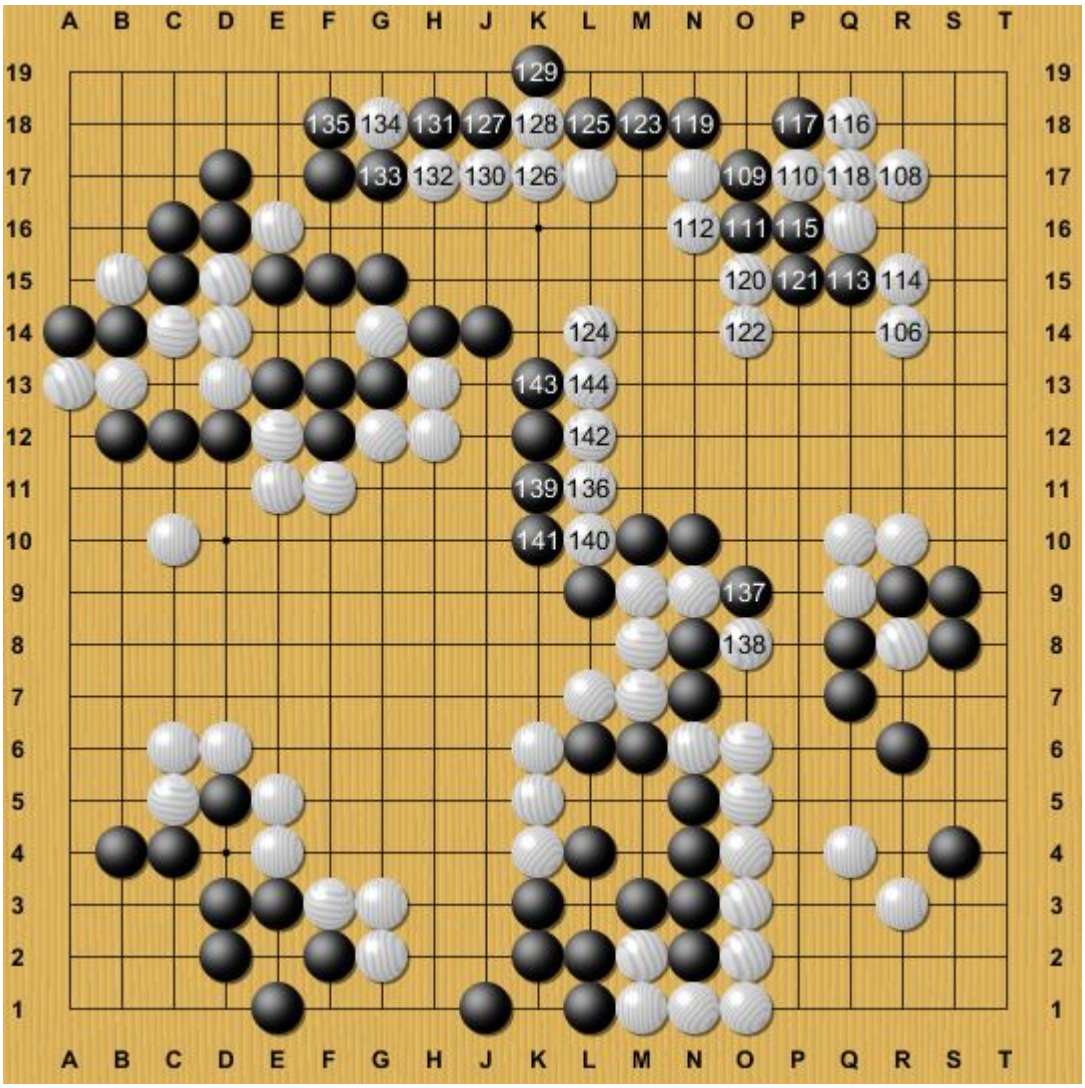
When White protected the corner with 106, AlphaGo’s win rate stood at 86%. Lee had 29 minutes left, AlphaGo 57 minutes.

Diagram 16



Taking the 3-3 point is very big for Black, but through 17, White's right side is not small either.

Moves 106-140



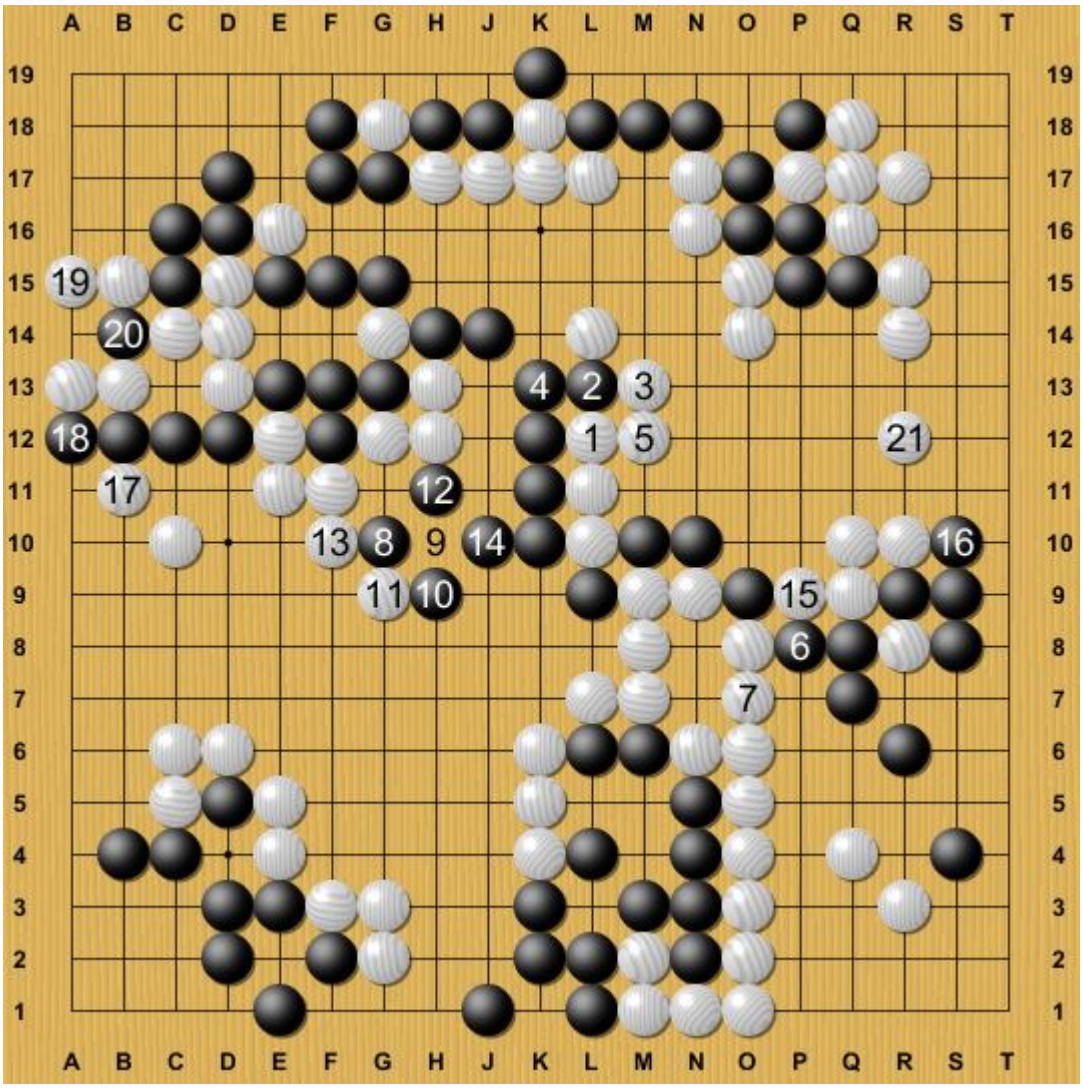
107=118

Lee tried everything to get back in the game, but to no avail. Although Black lived and connected out following the invasion at 107, White gained strength on the outside. Afterwards, White struck at the vital point with 136, slowly building further potential in the centre.

Many commentators felt that Black 143 was too passive, and that Lee should have wedged at 144. AlphaGo agreed, but White was winning either way. See diagram 17.

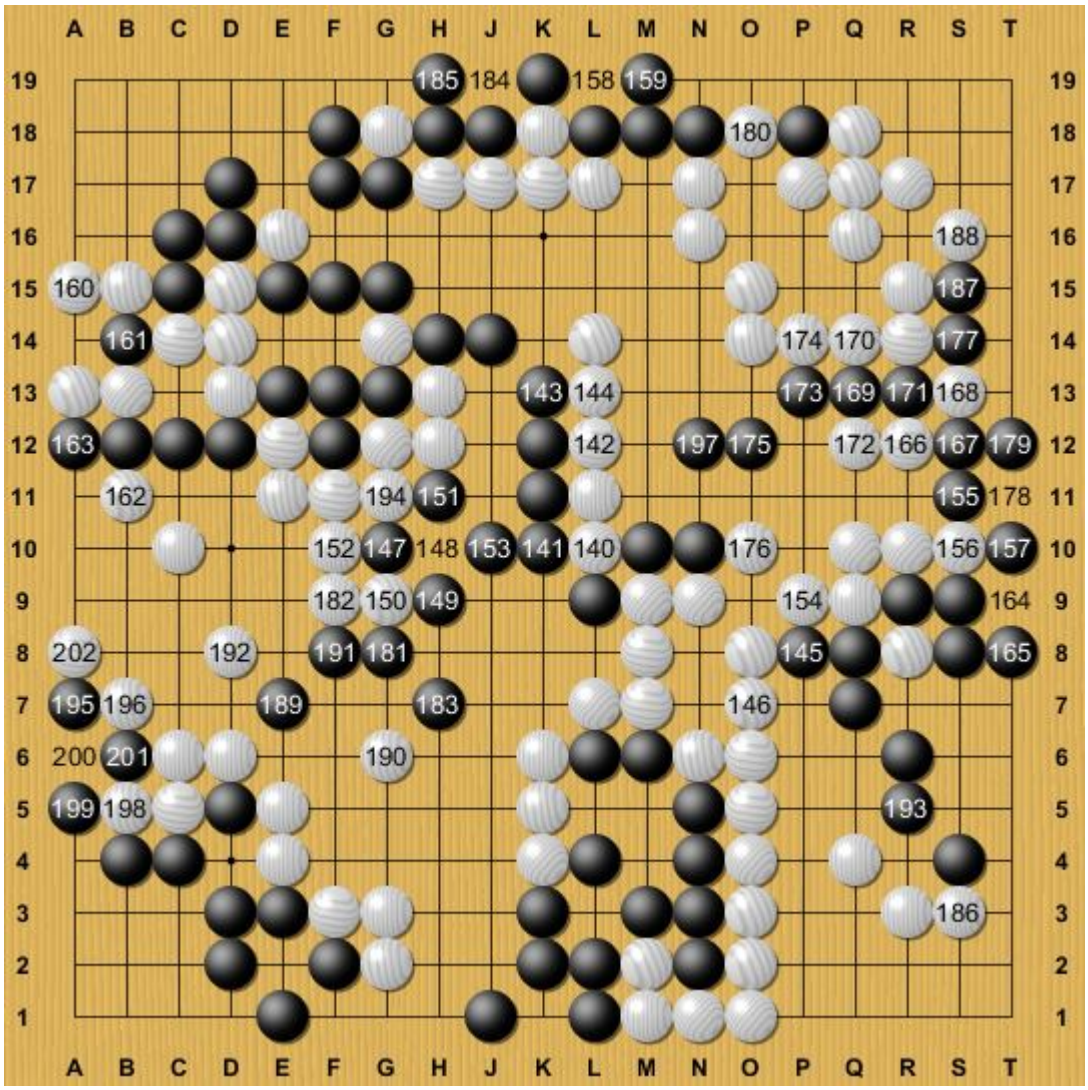
At move 144, AlphaGo's win rate reached 92%.

Diagram 17



This is the sequence AlphaGo had planned. The gap is small, but AlphaGo's endgame analysis is trustworthy, and White can be confident of the win.

Moves 140-202

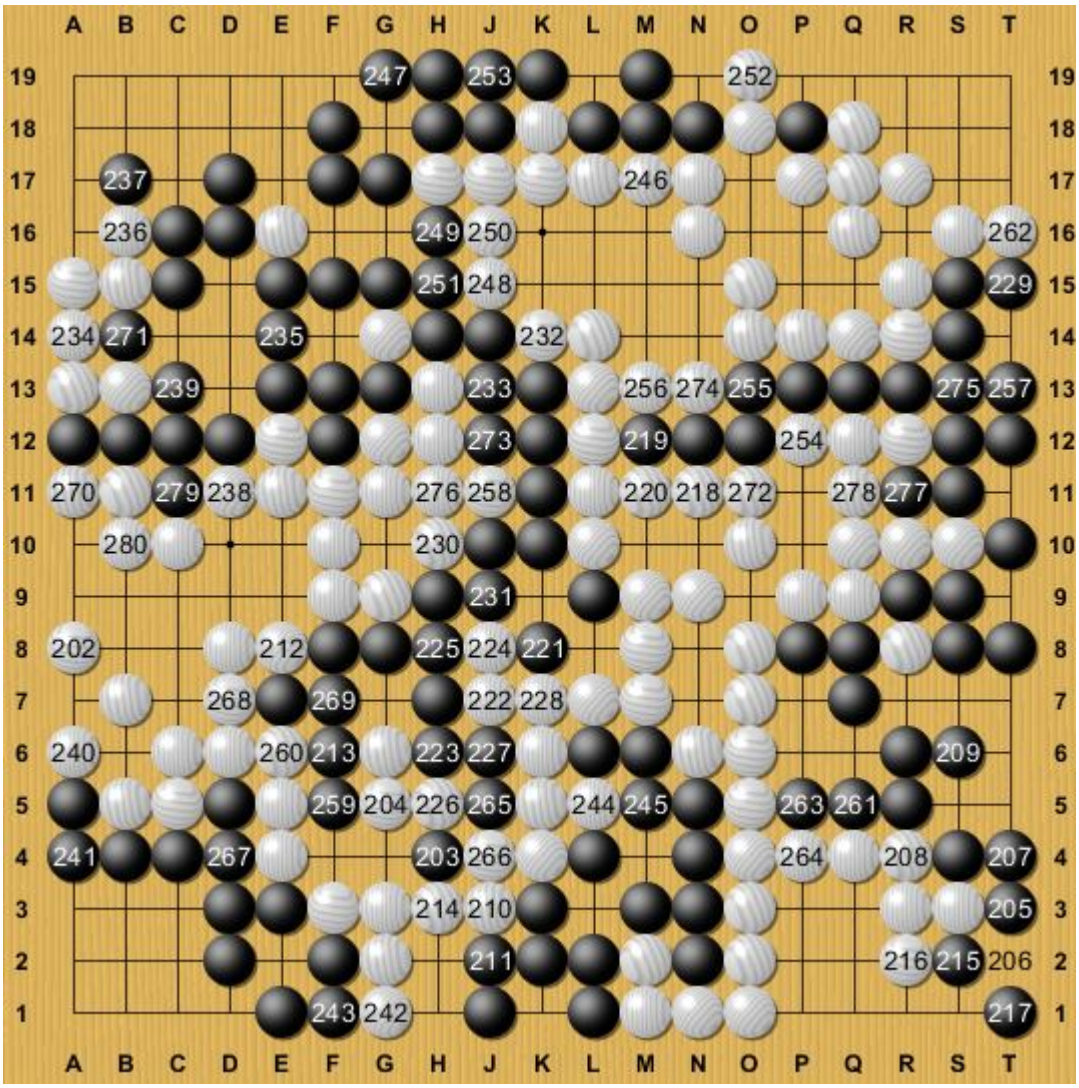


As the endgame began, Lee looked fiercely for an opportunity, exhausting every possible resource. But no matter what he did, White remained a little bit ahead.

At move 150, Lee entered byo-yomi.

White 180 concluded the last major exchange, and Black was still a few points short. Lee must have recognized now that there was no way to win.

Moves 202-280

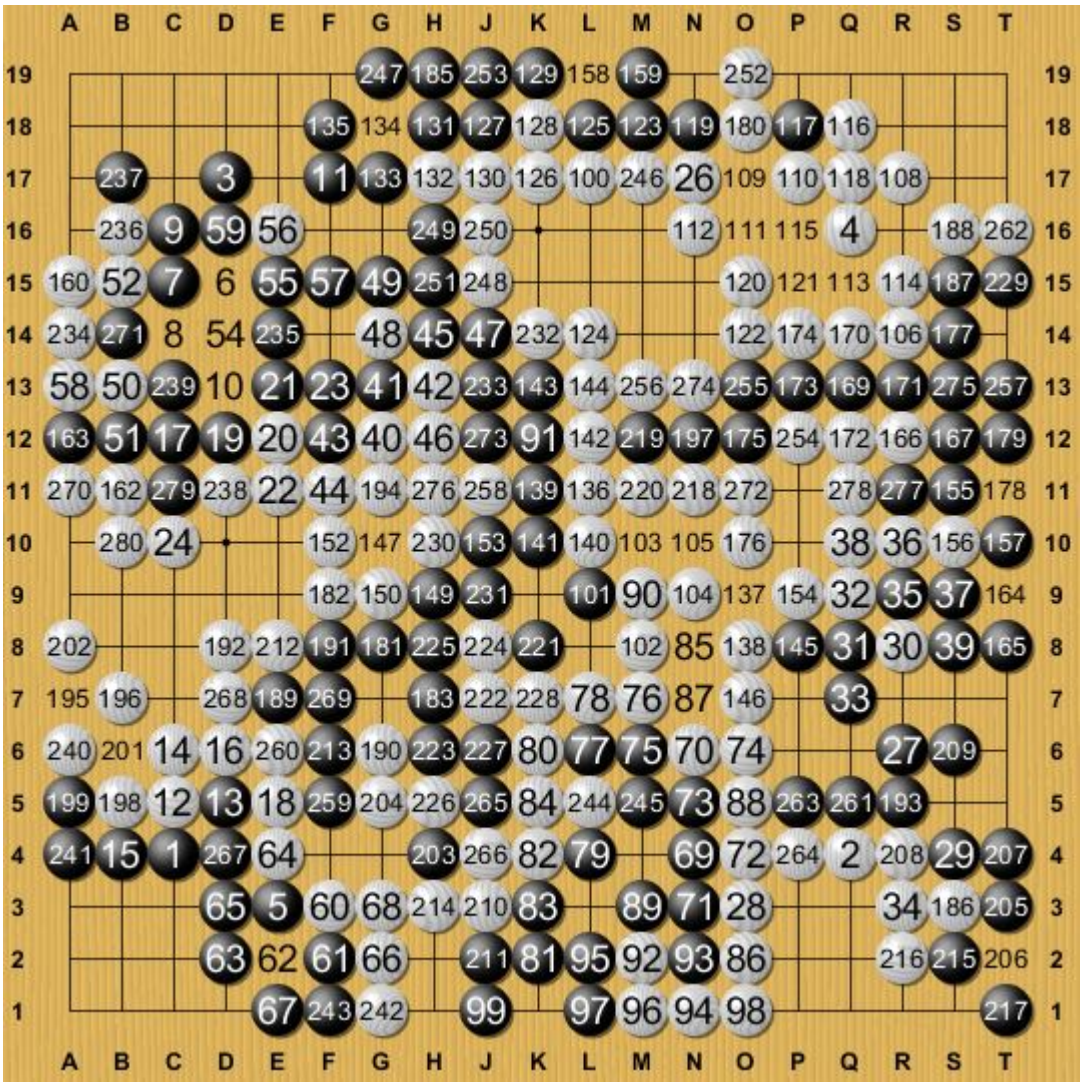


256=275

The endgame stretched out endlessly, making this by far the longest game of the competition. Even AlphaGo entered byo-yomi in the late endgame. However, the result had long since been decided.

Just as I began to believe we would finally have a game come down to counting, Lee resigned at move 280. In that moment, he looked utterly helpless.

Full Game, 1-280



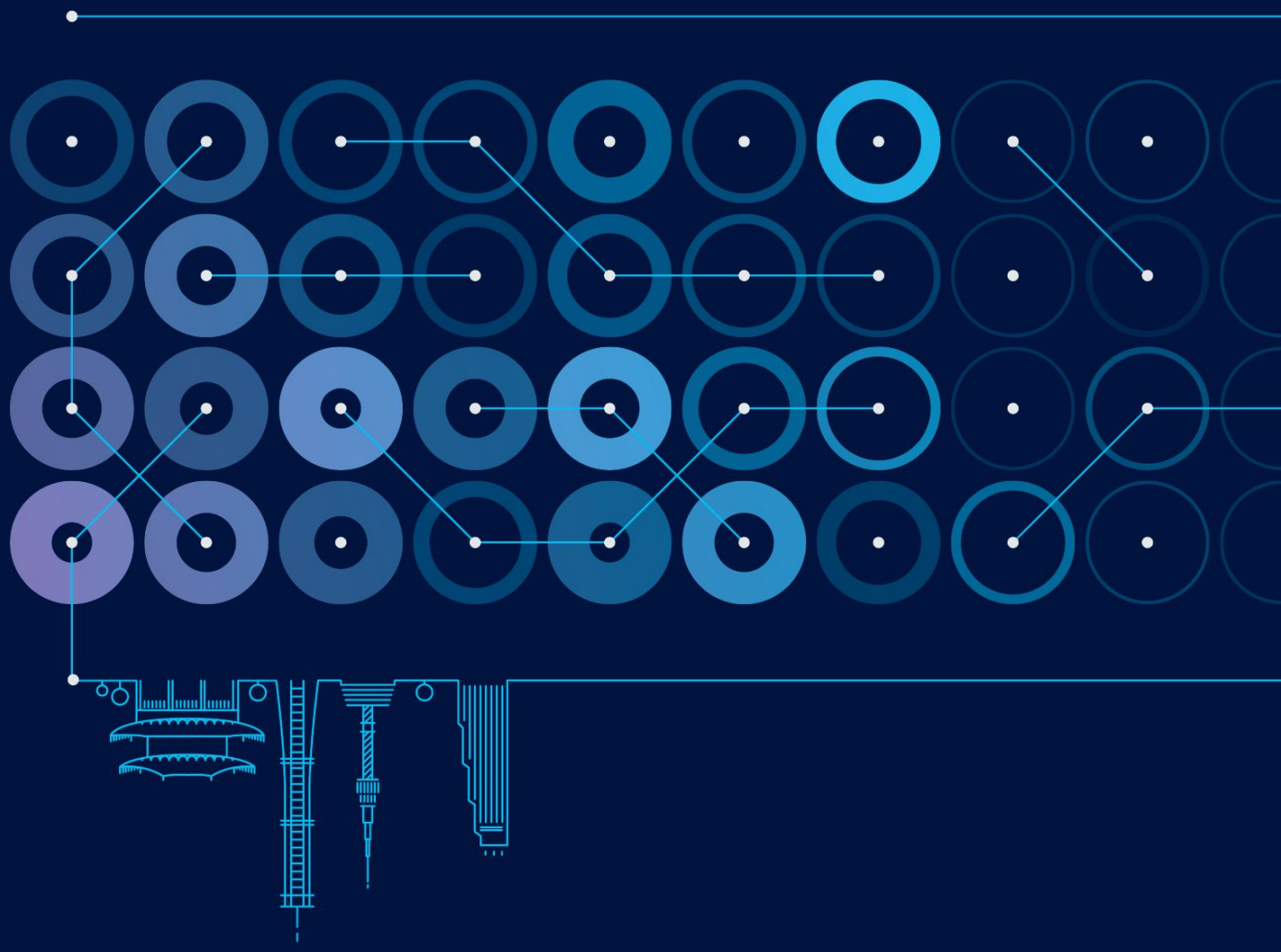
107=118, 148=230, 151=276, 161=271, 168=275, 184=253, 200=240

In the end, the result of the match was a 4-1 victory for AlphaGo.

It was an unforgettable story, this week of intense competition between man and machine. Even now, when I recall the scene, I am just overwhelmed by emotion as I was then. I believe the most important contribution of this match is not the result, but rather the opportunity it has given us to rethink our understanding of Go, and of ourselves.

I would like to finish this commentary with a quote from Eric Schmidt, the executive chairman of Alphabet, spoken at the press conference in Seoul before the match:

“The winner here, no matter what happens, is humanity."



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