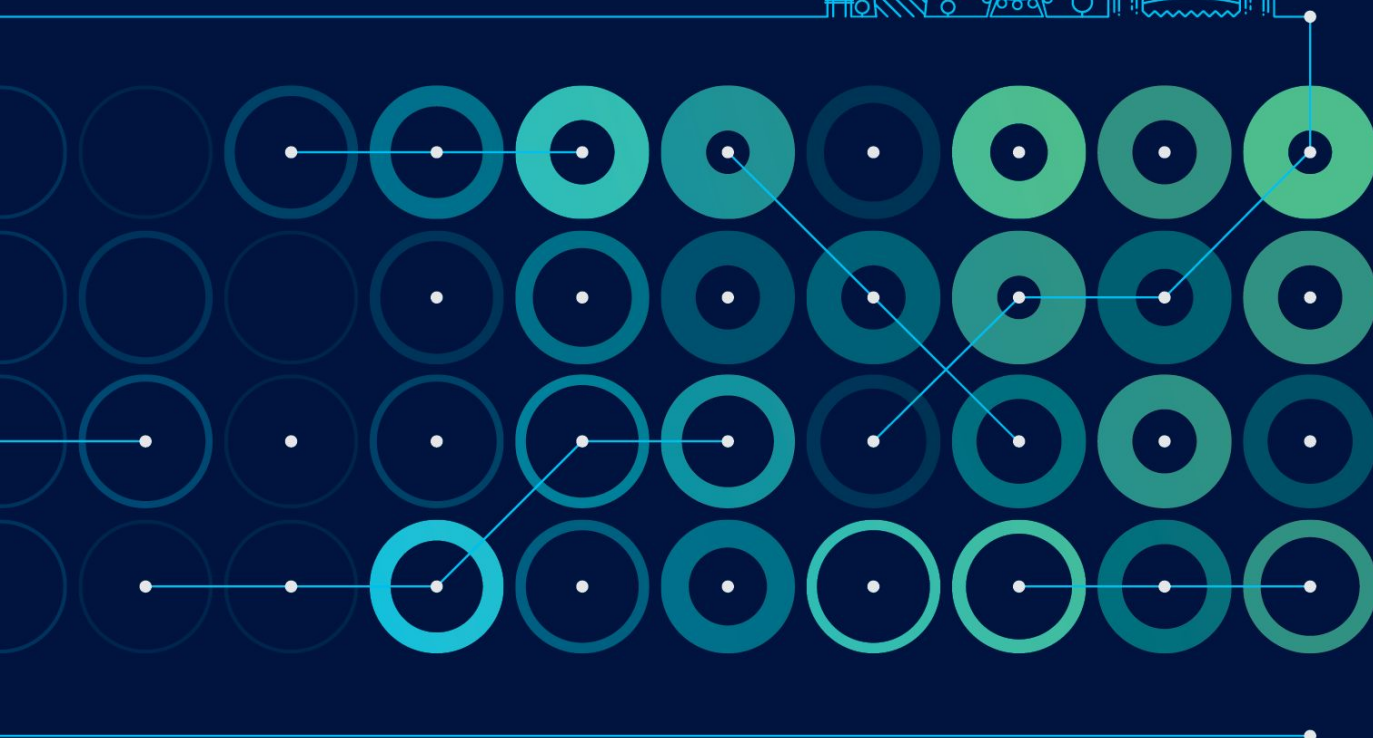




Google DeepMind

Challenge Match

8-15 March 2016



Game 2: “Invention”

Commentary by Fan Hui

Go expert analysis by Gu Li and Zhou Ruiyang

Translated by Lucas Baker, Thomas Hubert,
and Thore Graepel

Invention

AlphaGo's victory in the first game stunned the world. Many Go players, however, found the result very difficult to accept. Not only had Lee's play in the first game fallen short of his usual standards, but AlphaGo had not even needed to play any spectacular moves to win. Perhaps the first game was a fluke? Though they proclaimed it less stridently than before, the overwhelming majority of commentators were still betting on Lee to claim victory.

Reporters arrived in much greater numbers that morning, and with the increased attention from the media, the pressure on Lee rose. After all, the match had begun with everyone expecting Lee to win either 5-0 or 4-1.

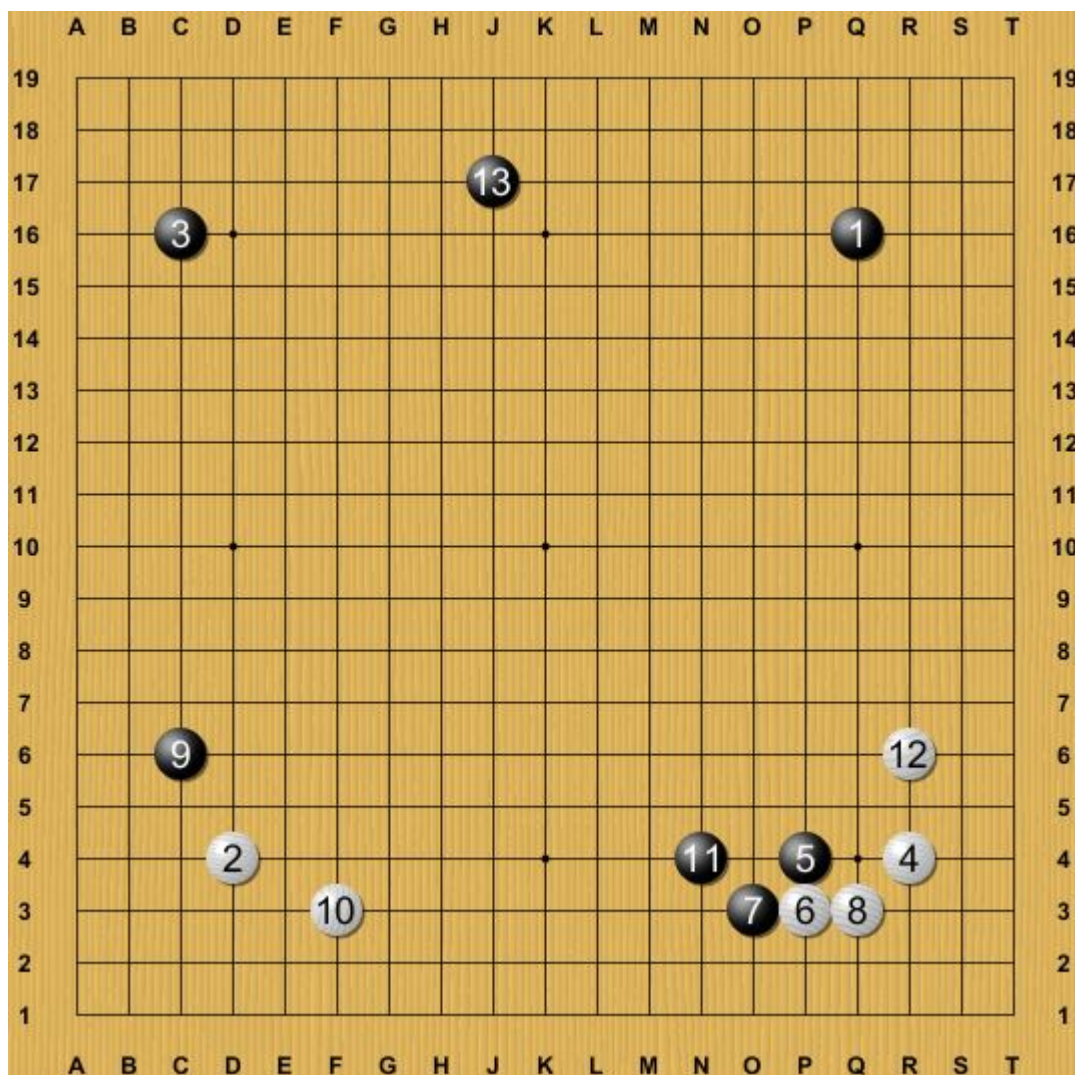
I entered the playing room fifteen minutes before the game to find Demis Hassabis already present, looking much more relaxed than the day before.

Four minutes before the starting time, Lee came in with his daughter. Perhaps he felt that she would bring him luck? As a father myself, I know that feeling well.

By convention, the media is allowed a few minutes to take pictures at the start of a major game. The room was much fuller this time, another reflection of the increased focus on the match.

Today, AlphaGo would take Black, and everyone was eager to see what opening it would choose. Whatever it played would represent what AlphaGo believed to be best for Black. Perhaps that opening would become the new fashion in the Go world?

Moves 1-13



Unlike the first game, AlphaGo played its first move after less than thirty seconds. Rarely does it decide so quickly.

Lee played White 2 in the lower left corner, on the diagonally opposing star point, indicating a strategic departure from the first game. Since the fighting had turned against him before, perhaps he wished to play a quieter and more solid opening this time. In that case, White 2 may have aimed to prevent AlphaGo from taking that point for Black, since this kind of cross-opening can easily turn violent.

When Black played the 3-4 point, I felt that AlphaGo would opt for the Chinese opening, one of its favorites.

Compared to the first game, Lee played much more slowly, pondering over each move. Many players had criticized him for playing too quickly in the first game, and the shift may have been partly in response to that. Sometimes changing pace is also a useful meta-tactic to disrupt the opponent's mindset, but of course this would have no effect on AlphaGo.

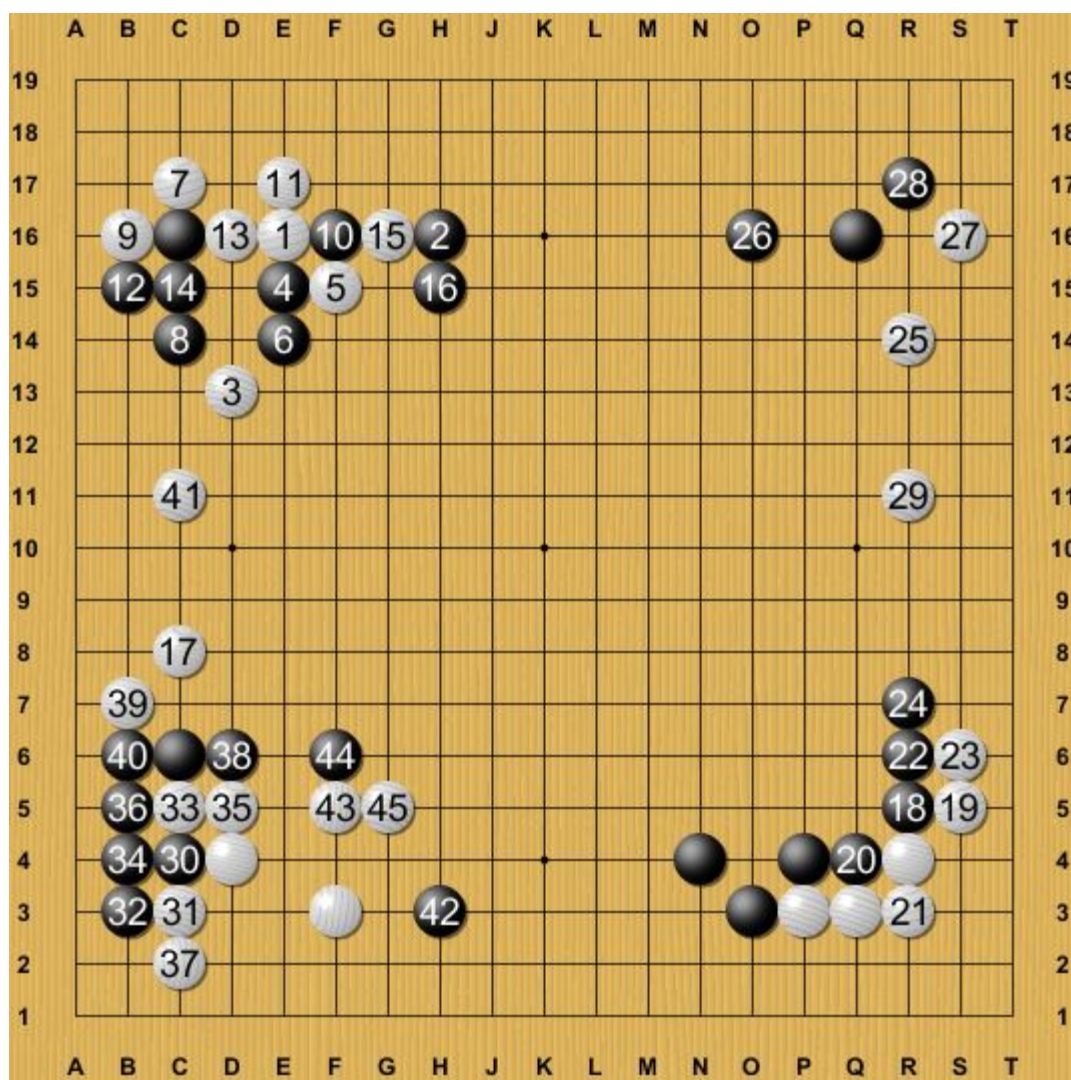
White took the remaining 3-4 point, and AlphaGo approached the lower right corner with 5.

I had heard that Lee was very fond of coffee, and always asked the staff to bring more as soon as his cup was empty. During this game, and the rest of the match, he fully lived up to his reputation.

Through 12, everything proceeded normally. Black 13 was the first truly startling move in the game - but firstly, and just as interesting, AlphaGo did not even think White should have finished the joseki with 12! If AlphaGo were White, it would have played diagram 1 instead. Gu Li and Zhou Ruiyang were just as shocked as I to see this sequence, and we began to wonder: could there be a problem with even such an established, fundamental joseki as this?

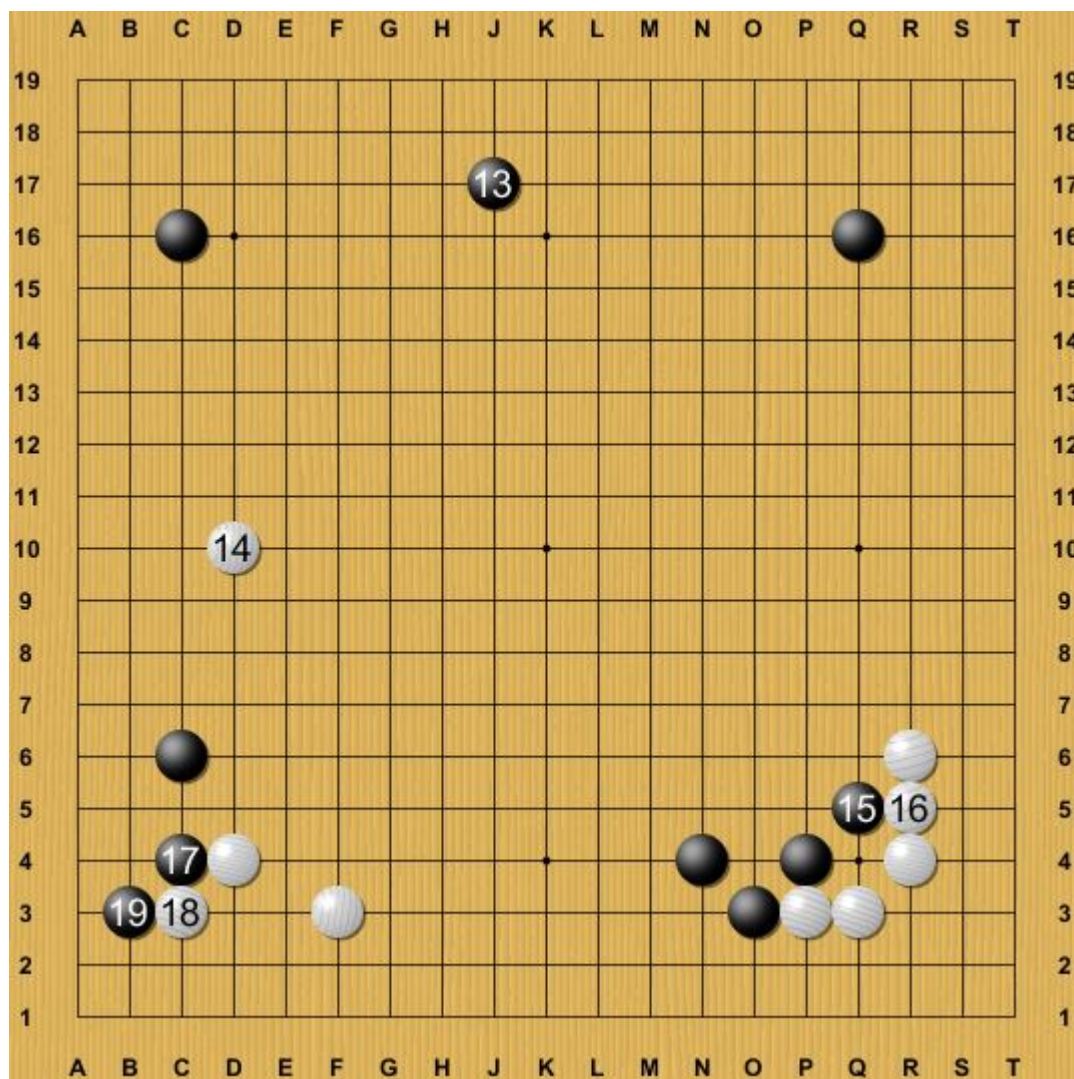
Move 13 came as an enormous surprise. Even here, Black can tenuki? It seems anything is possible for AlphaGo!

Diagram 1



This is the variation AlphaGo anticipated. Of course, this is only one of many possibilities, but we can clearly see that AlphaGo plays some well-known joseki, meaning that it agrees with at least some of modern joseki theory.

Moves 13-19



After seeing Black 13, Lee sank into deep contemplation. Compared to his confident appearance in game 1, he now seemed much more prudent. He even declined the opportunity to attack the three stones in the lower right, opting instead to bide his time and split the left side at 14. However, AlphaGo thinks Black should have played at the bottom as in diagram 2.

After Black 13, AlphaGo's win rate was 49.7%, so it thought the game more or less in equilibrium.

Next, the peep at 15 stunned the Go world for the second time in two moves! Any Go teacher would say that such a crude move cannot possibly be good, and would criticize any student who played it. Then again, AlphaGo never worried about other people's opinions.

As we walk the path of improvement, we must study and experience all aspects of the game: joseki, fuseki, shape, and direction, just to name a few. After we absorb this knowledge, we learn over time to apply it flexibly. But to reach the level of grandmasters, even this is not enough! As we gain experience, our knowledge fetters our creativity. To truly throw off these shackles and liberate ourselves from what we have learned, we must discard labels of "right" and "wrong." In their place, we must consider the essence of Go: the role of each stone, and

the relationships between them. Only in this way can we reach the level where invention prevails over tradition. AlphaGo began from the same fundamentals as humans, but the rigid attachment to knowledge is simply not in its nature. Thus, it is only natural that AlphaGo possesses a talent for creativity.

In the history of Go, I can think of two periods when a decisive shift occurred in Go theory. The first was the age of Go Seigen. The most famous example of his innovation is perhaps the game in which he opened on the star point, the tengen, and the 3-3 point, in a time when no other professional player would think of starting anywhere besides the 3-4 point. But beyond that, he showed us that Go, even at the highest level, can be played in any style one likes. Out of that age of 3-4 points, a hundred other styles blossomed and grew, including the Chinese opening we know today. However, many joseki and fuseki still remained purely theoretical.

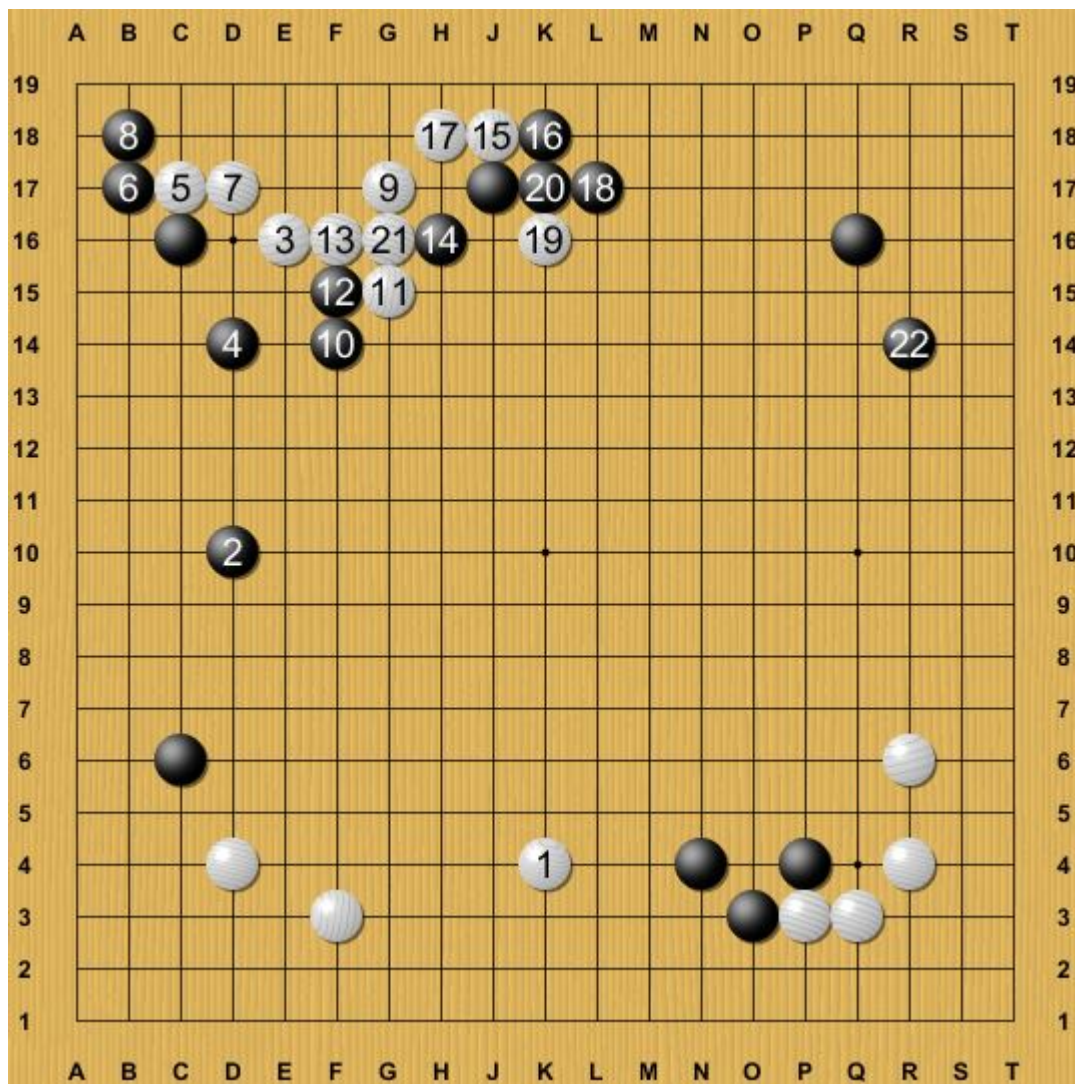
The second such period was the age of Lee Changho and the Korean style. This movement was by no means the work of one person, but it was Lee Changho's rise that inspired Korean players to doubt established theory, and experiment with ever-bolder departures from the prevailing style. At first, many of these moves were called "crude" or simply "bad," but the results spoke for themselves. As research progressed, many older joseki were disproved and discarded. We realized that many of these joseki had been established not by study, but by old grandmasters who had claimed that one way or another was the right one. The more we explored the new variations, the more fatal weaknesses were exposed in the old ones. These discoveries liberated us, stimulating the development of more and more new styles and variations. In the final analysis, this period marked a great advancement in our understanding of Go, simply because we had the courage to try new things.

However, the emergence of the Internet has stimulated ever-faster development and progress. As the strength gap between players shrinks, so too does the apparent window for innovation. But Go is a rich, abundant world - can we truly say that we have reached its limits? Perhaps AlphaGo can usher in a third wave of exploration and invention. When we are brave enough to defy theory, only then can we Go players call ourselves "free." Even from the perspective of amateurs and fans, wouldn't this spirit make Go that much more fascinating to witness?

In fact, it is gratifying to note that since AlphaGo played 15, more and more professionals no longer find it so crude. Quite often, professionals find themselves wanting to exchange this move after the opportunity has disappeared, so many players have started trying to work it in earlier. It seems we have already gained some courage!

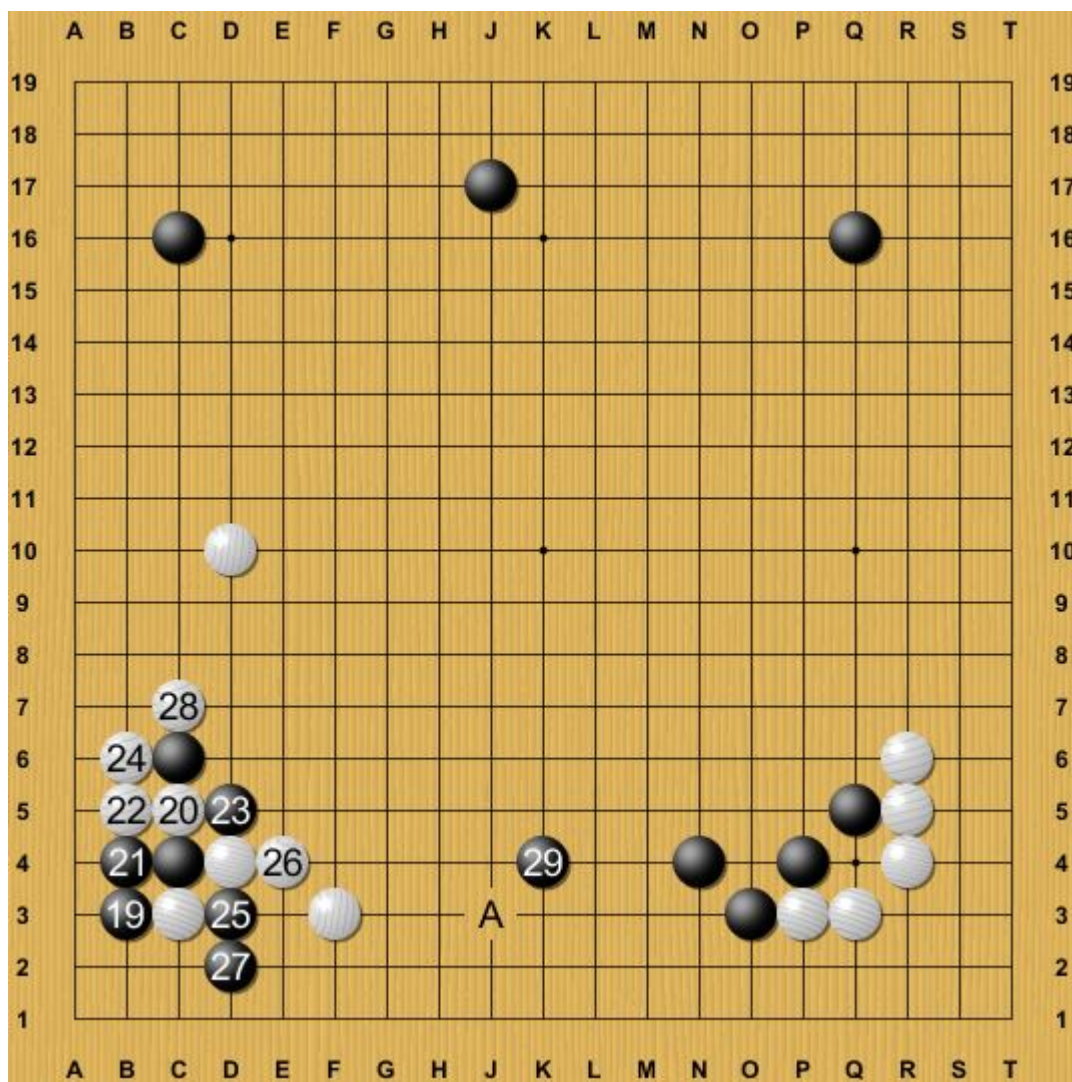
Getting back to the game, following Black's peep at 15, 17 through 19 were all standard moves.

Diagram 2



As Black did not finish the joseki at the bottom, White naturally has the option to pincer there. AlphaGo suggests Black would tenuki once more to build up the right with 2, after which the sequence to 22 would lead to a balanced game. This would have been more keeping with Lee's style, but perhaps Lee adopted a more defensive stance as a probe to sound out AlphaGo's strategy.

Moves 19-29



When Black connected with 21, Lee nodded. He seemed to be reaffirming his decision to play on the left side.

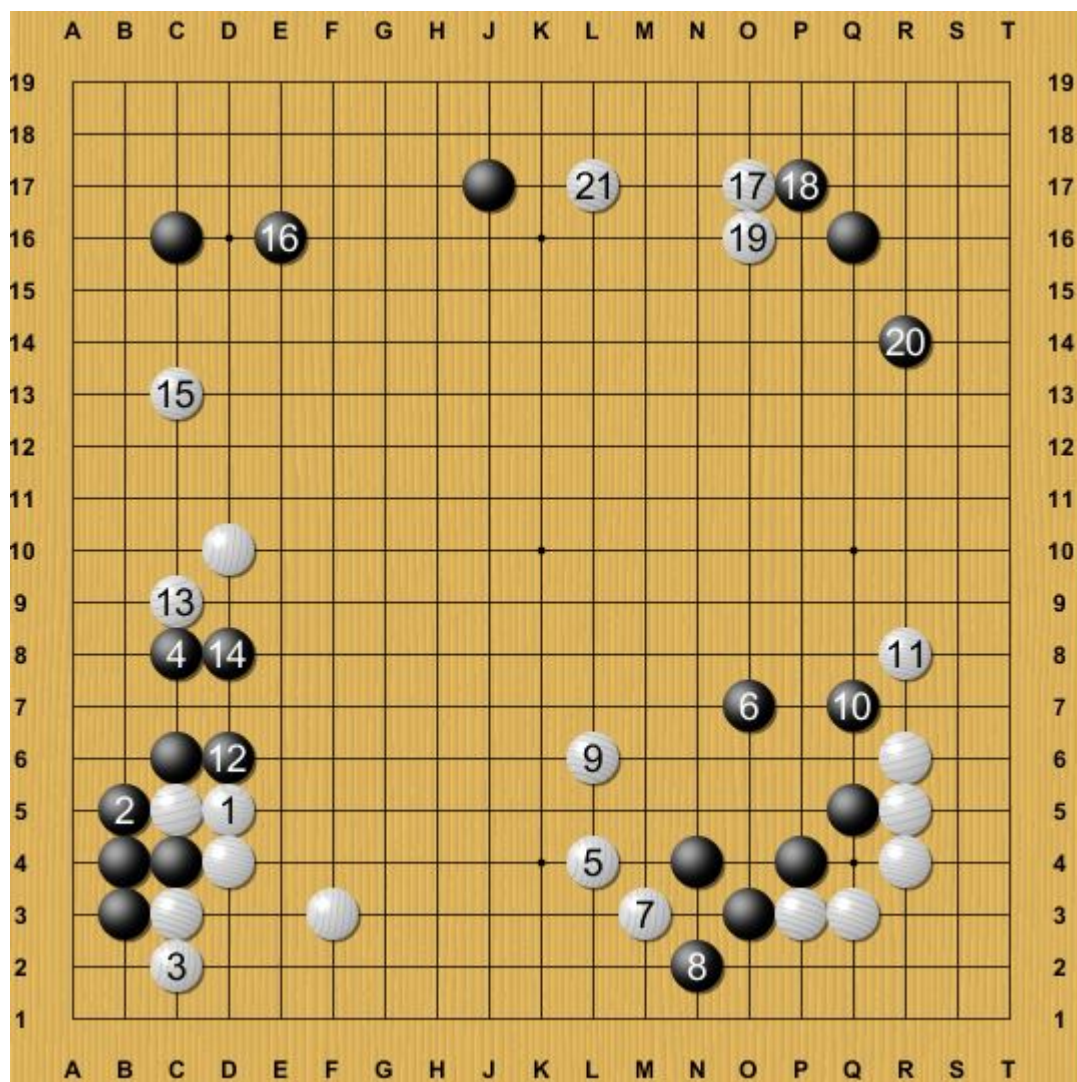
White chose the block at 22, but AlphaGo prefers the connection in diagram 3.

The moves through 28 form a classic joseki.

Taking the initiative on the bottom, AlphaGo once again smashed convention with the beautiful two-space jump at 29! According to Nie Weiping, when he saw this move, he exclaimed, "Hats off to AlphaGo!" The rationale behind this move is not difficult to understand: since Black already has a stone at 27, the lower side has lost much of its value, and the normal extension at A would be less efficient in view of White's thickness on the left. Furthermore, although Black 29 takes less territory than A, it gives Black more potential to expand in the center while restricting White's influence there. The real beauty of this move lies not just in the move itself, but in the way it demonstrates AlphaGo's ability to adapt joseki according to context. It is this sense of flexibility that deserves recognition.

At move 29, Lee Sedol had 1 hour and 40 minutes left, AlphaGo 1 hour and 43 minutes.

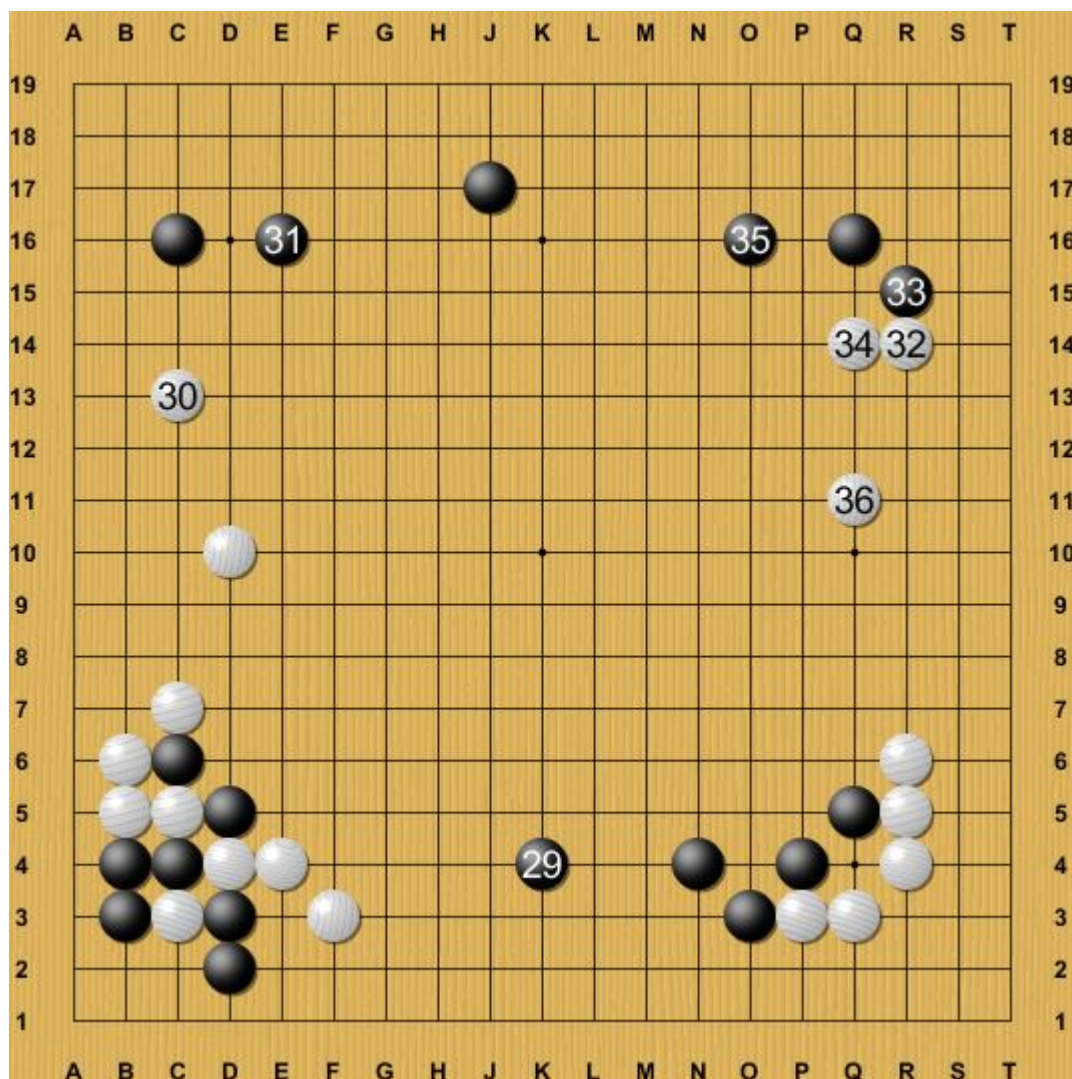
Diagram 3



AlphaGo thinks White should connect outside at 1, earning sente to come back and attack the four black stones with 5. Through 21, this would be a balanced game.

Gu Li and Zhou Ruiyang thought that while this variation merits consideration, there is nothing wrong with the game.

Moves 29-36



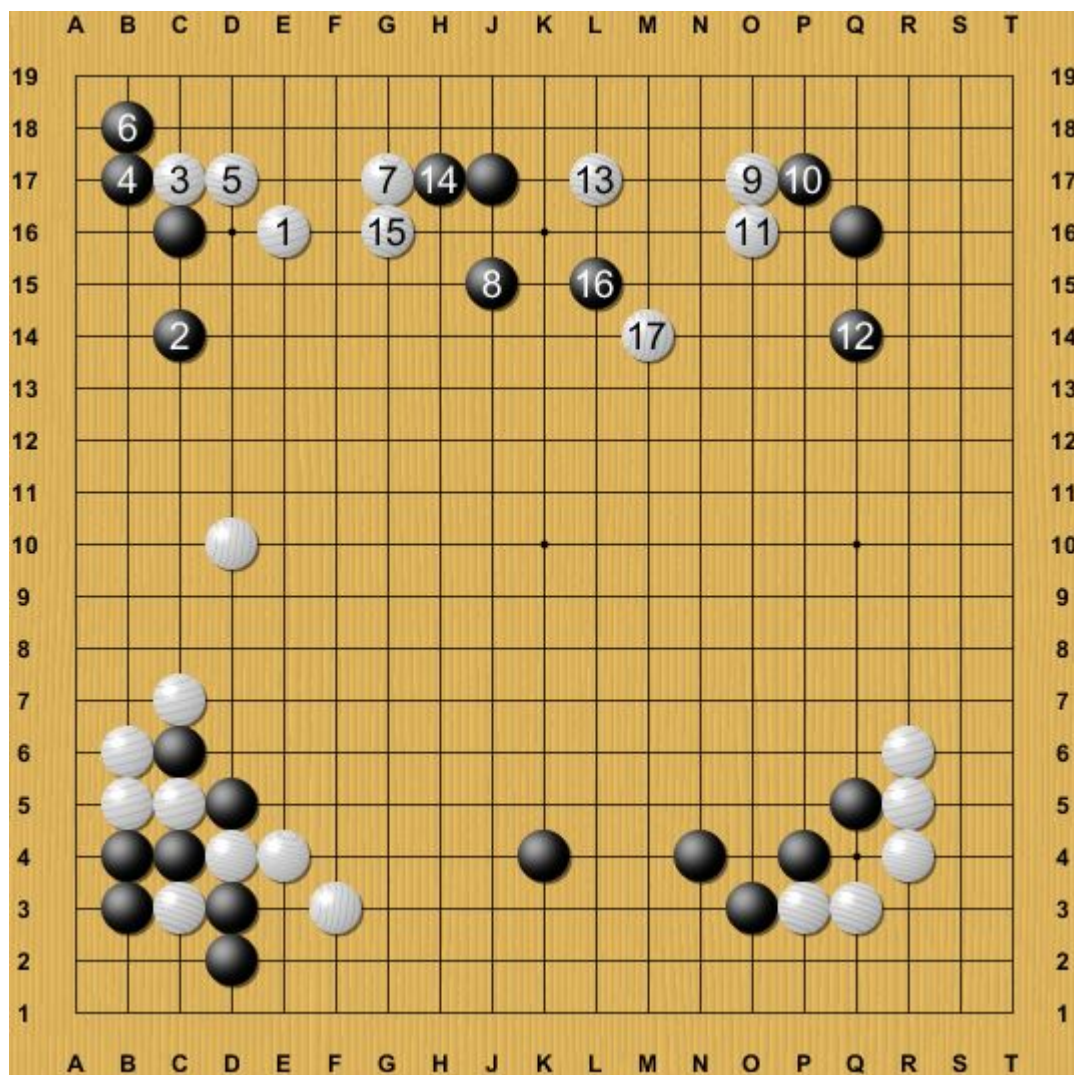
The exchange of White 30 for Black 31 looks normal, but AlphaGo's win rate clearly increased, so it must think this benefits Black! See diagram 4 for AlphaGo's suggestion.

After Black enclosed the corner at 31, Lee Sedol briefly hesitated over the direction of play in the upper right. He eventually chose to approach from below at 32.

The kick at 33 was a good choice for Black. White was already solid on the right, so the loss from strengthening White further was minimal, and 33 prevented White from invading the corner. See diagram 5.

Through 36, both sides played normally.

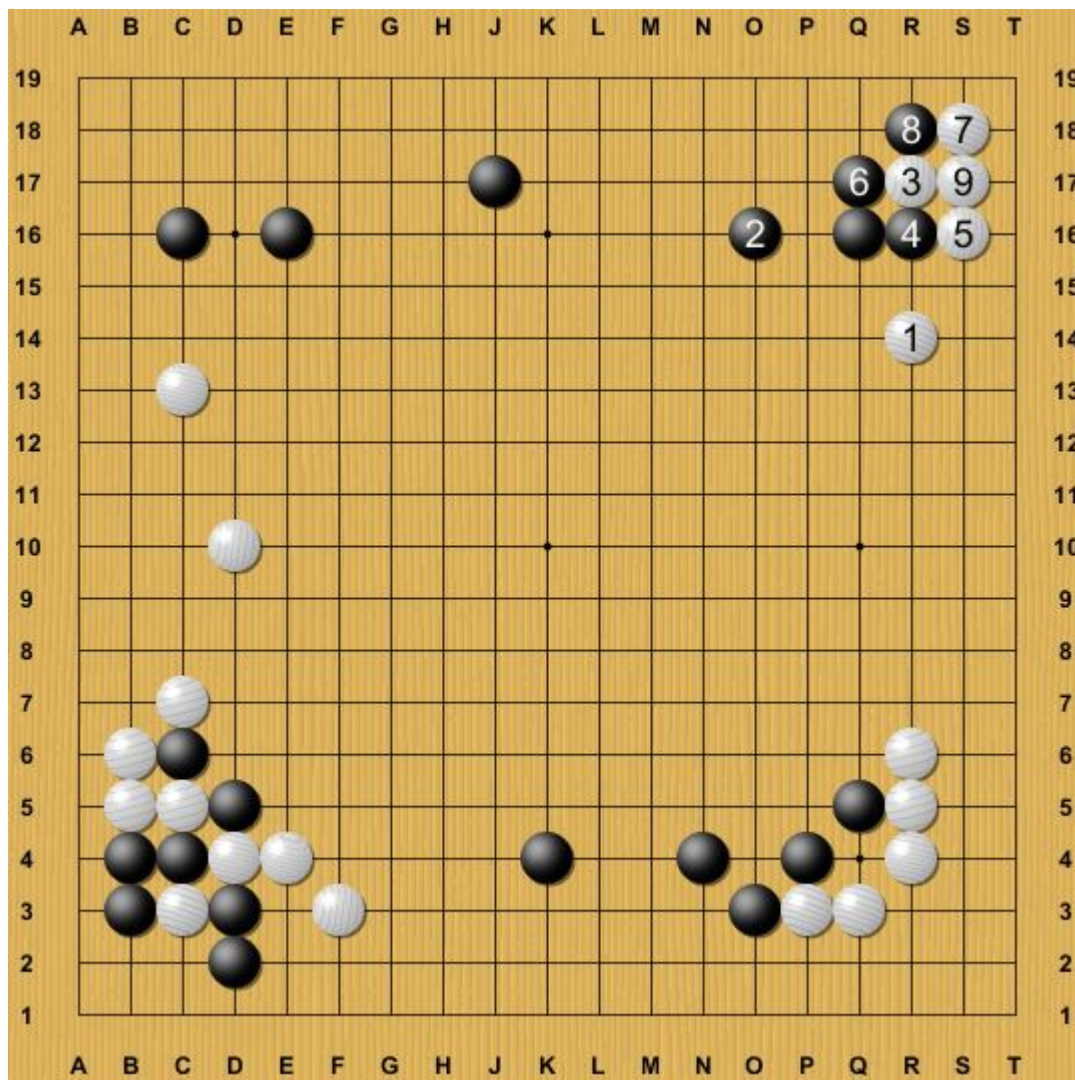
Diagram 4



AlphaGo thinks the upper side is more valuable, so White should approach directly with 1. Black will extend on the third line with 2, and through 17, a fight develops.

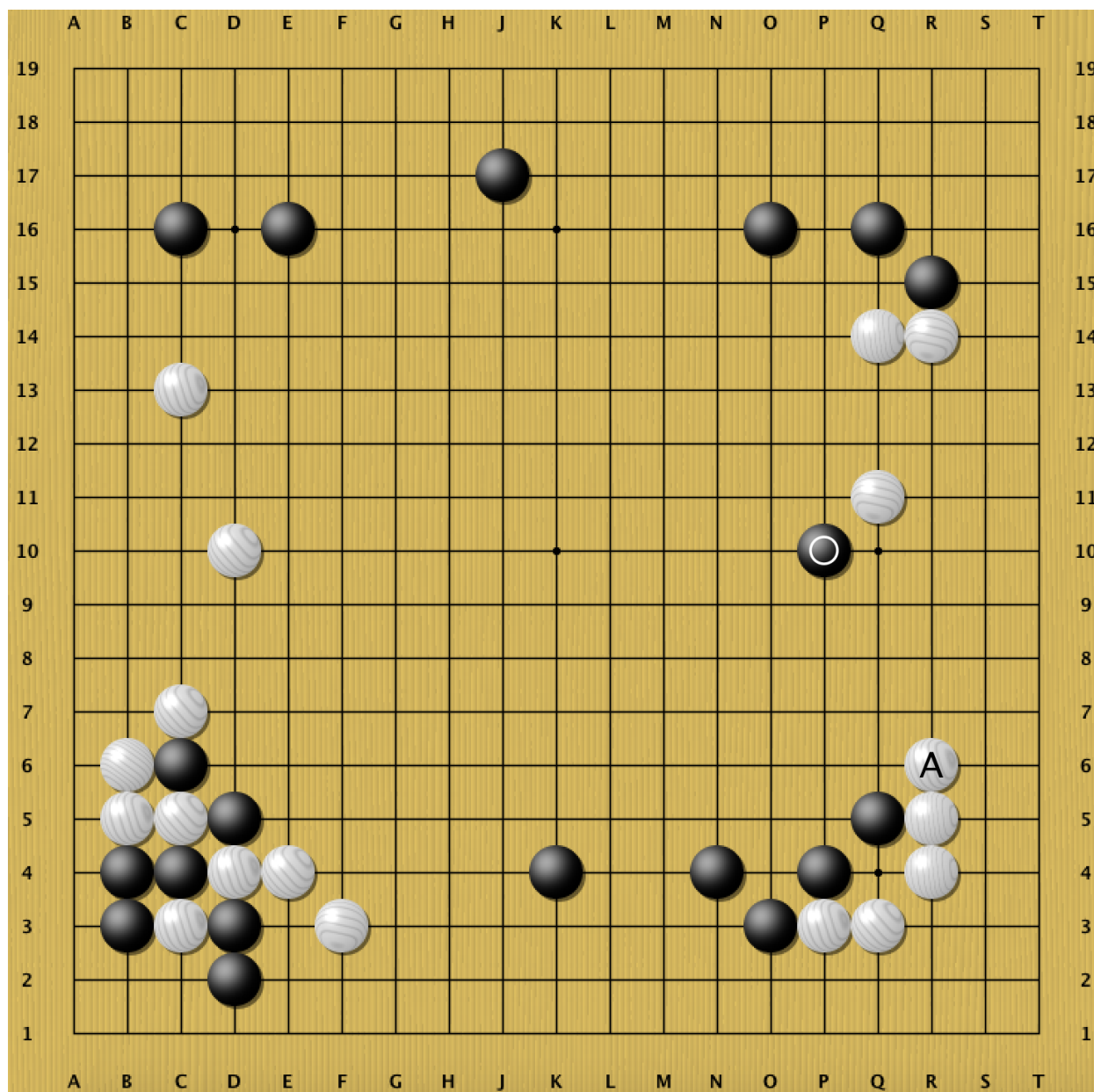
Gu Li and Zhou Ruiyang disagreed with Black 8, suggesting that Black defend directly at 9, since it is hard to see the practical value of the jump at 8. Nonetheless, they found AlphaGo's suggestion for the direction of play quite interesting.

Diagram 5



If Black jumps directly, White will take the 3-3 point straightaway. As the right side is uninteresting, Black has no choice but to protect the top with 6 and 8, but this outcome is clearly inferior to the game.

Moves 37



This figure has only one move: Black 37! This move proved so stunning that, when it appeared on the screen, many players thought the stone had been put down in the wrong place.

Because my main duty was to count the score at the end of the game, I had nothing in particular to do in the meantime. However, for such a historic event, it would be a terrible shame if there were no one to record the scene in the playing room, so I took this role upon myself. Though I had no prior experience, my aim was simple: to capture the atmosphere, the players' expressions, even their gestures, and in this way to communicate the experience of the match.

On seeing Black 37, I wrote down the following: "*Here?! This goes beyond my understanding. Globally, there's nothing wrong with it, it's going in the right direction...and AlphaGo always pays special attention to coordinating the stones. It seems anything is*

possible in Go! Everyone will be talking about this move! A human would never dare play it, it's too difficult to estimate. But AlphaGo can. Perhaps this move is a sign of its confidence."

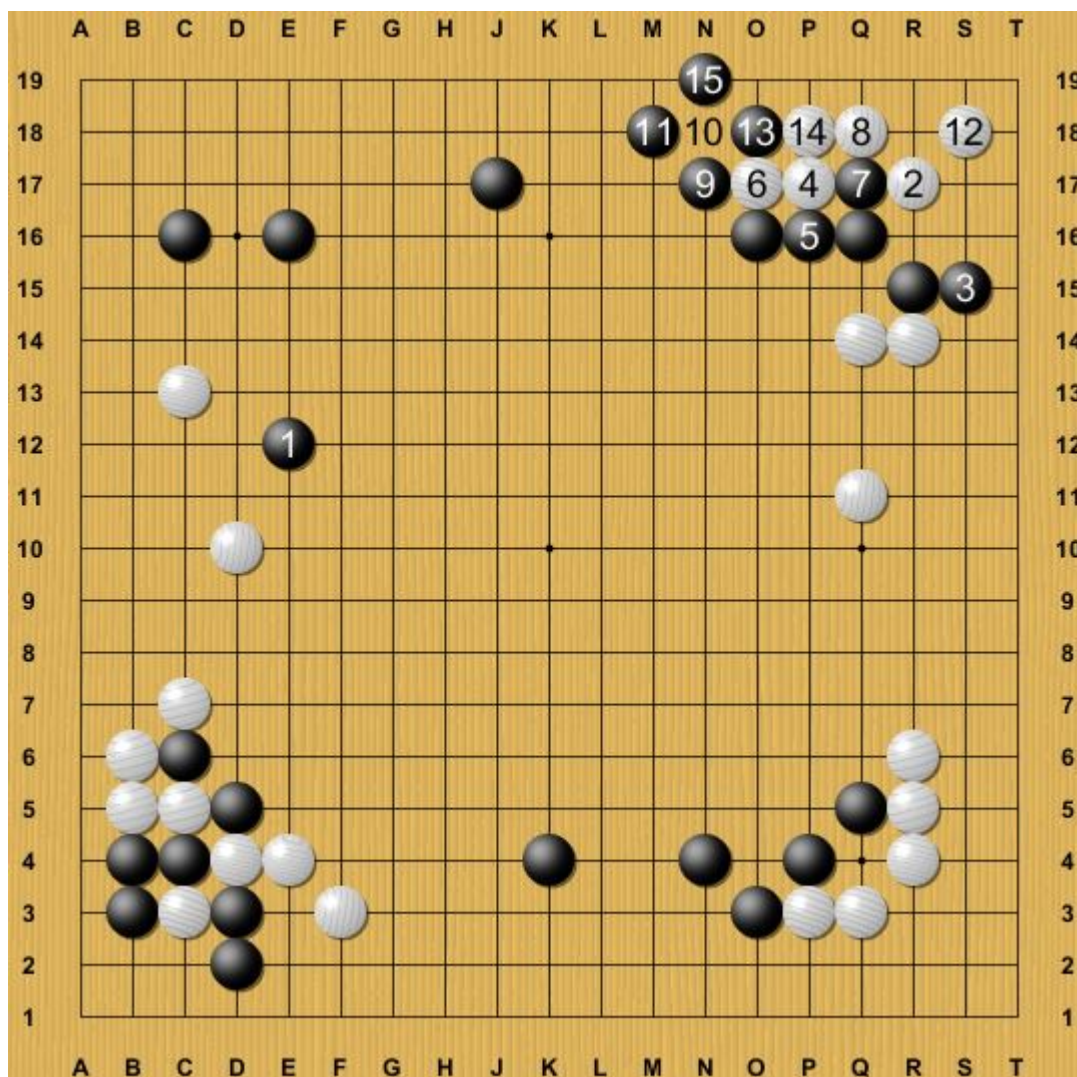
This move made a deep impression on me during the game. I experienced first confusion, then shock, and finally delight. It reminded me of an old Chinese saying: "A beginner plays the corners, an average player the sides; but a master controls the center." These days, due to the convergence of strengths and the pressure of competition, something close to the opposite is true, with most players focusing on the corners and sides. In contrast, AlphaGo's talent for central control is second to none. Perhaps, through AlphaGo, we too can become the "masters" of which the proverb speaks.

Returning to the game, we may say that Black 37 casts an invisible net across the board. Together with the lower side, Black's shoulder hit creates potential all across the center. Although it helps White make territory on the right, the presence of White A means that a Black invasion there would not have been valuable anyway. Of course, Black should be reluctant to give away fourth-line territory too easily, but one must give to get.

After the match, when I examined the data back at DeepMind, I saw that AlphaGo had not even been thinking about 37 only a few moves before. It had been expecting diagram 6, and its data indicated that a human player would hardly consider the shoulder hit a possibility. It was only when White played 36 that AlphaGo discovered 37, and boldly decided that this move would work even better.

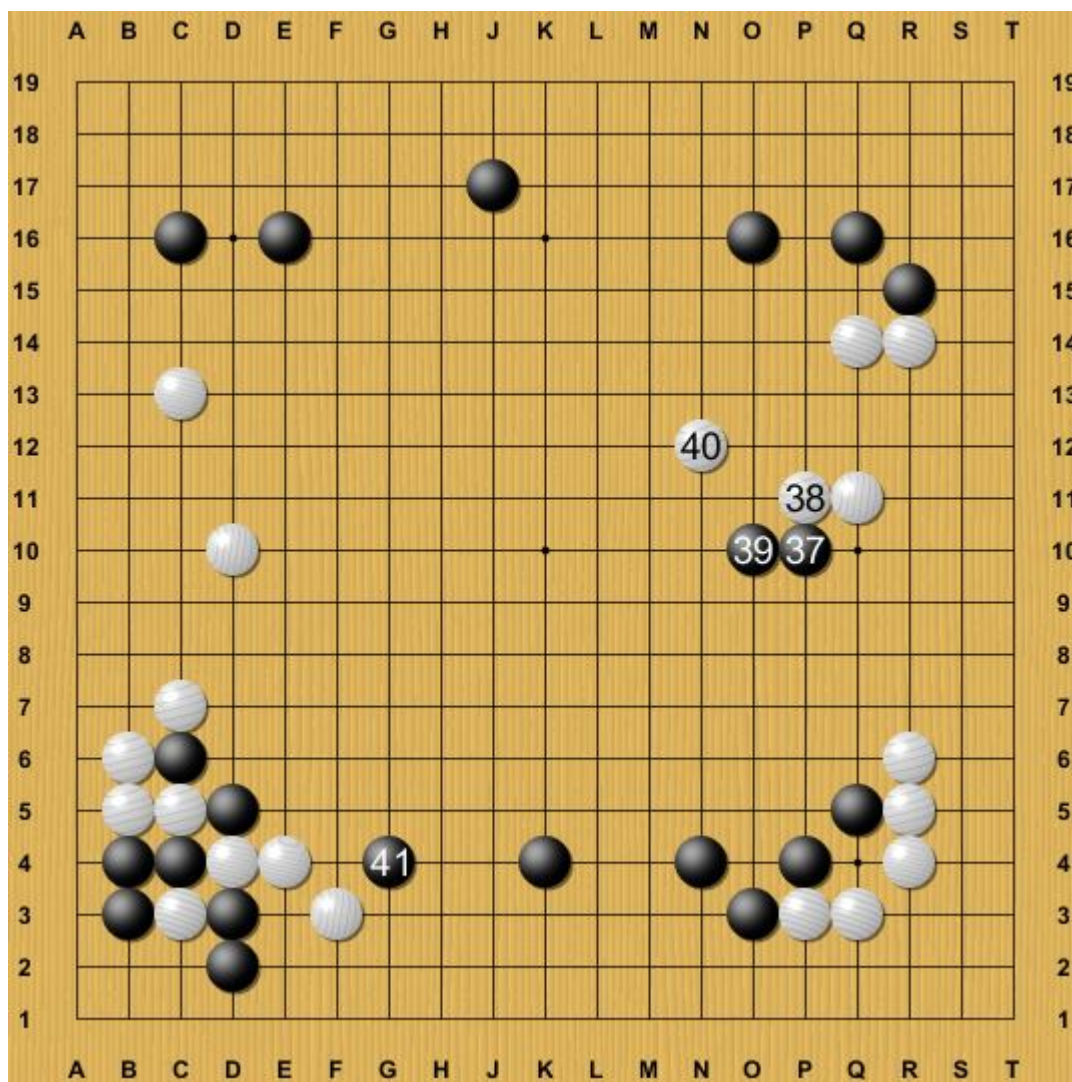
The pace of the game was much slower than the previous day, so Lee had already gone out to smoke before 37. The minute he caught sight of AlphaGo's reply, he stared blankly at the board. Then he smiled, sat down, and started thinking. The longer he thought, the more serious his expression became, while the clock ran down little by little.

Diagram 6



Black originally planned to jump at 1, a move that has appeared in a number of professional games lately. White enters at the 3-3 point and lives in the corner. This is an interesting strategy, and Gu Li mentioned that many top players have also chosen to play this way. Through 15, the result is equal.

Moves 37-41



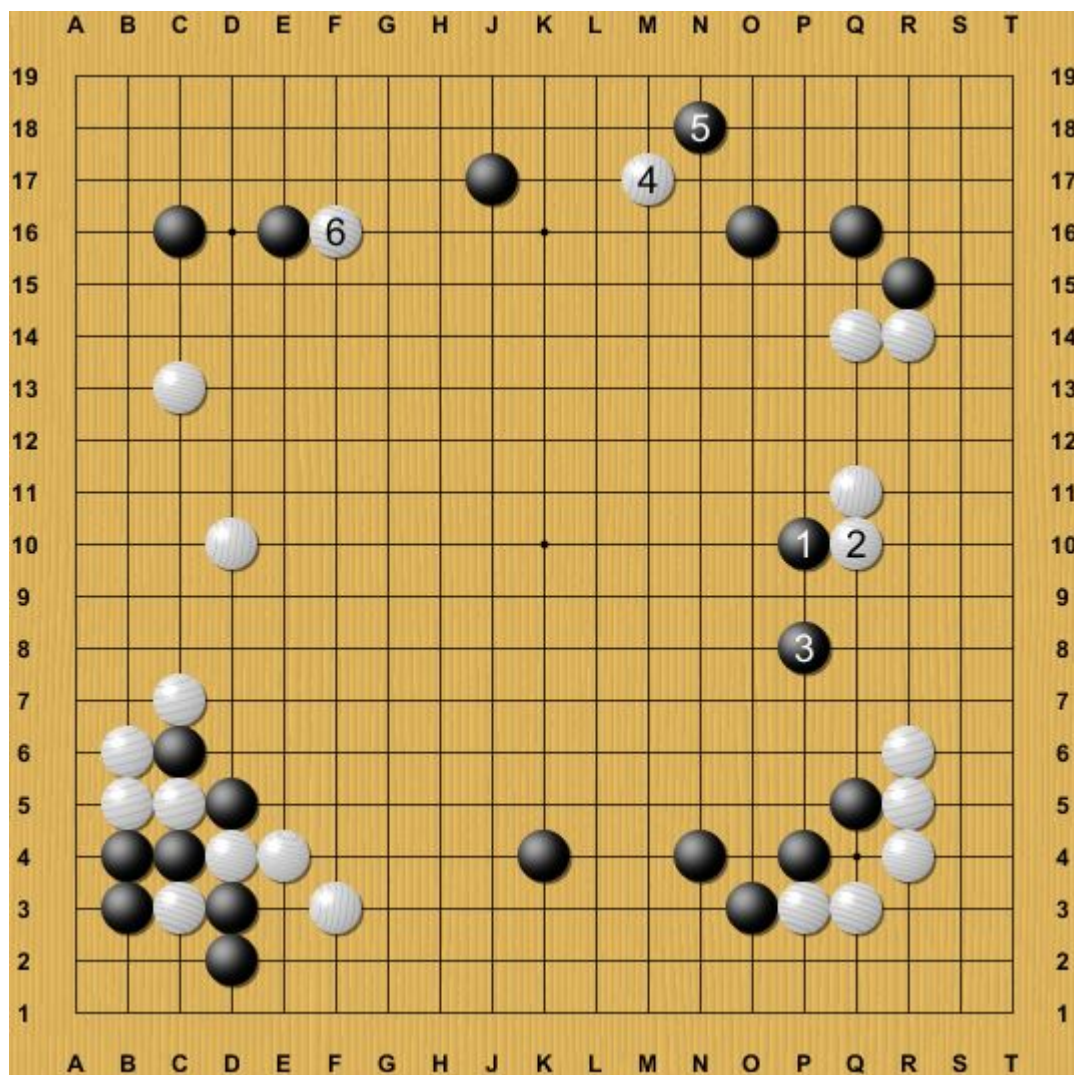
After twelve minutes of thought, Lee finally pushed up at 38. Perhaps he was feeling the pressure, as the direction of this move is clearly problematic: White is helping Black build up the bottom. See diagram 7.

Even after 39, AlphaGo thought the knight's move at 40 was inappropriate, and recommended diagram 8 instead. It seems that 37 not only helped Black on the board, but also threw Lee off balance psychologically.

At this point, AlphaGo's win rate reached 55%.

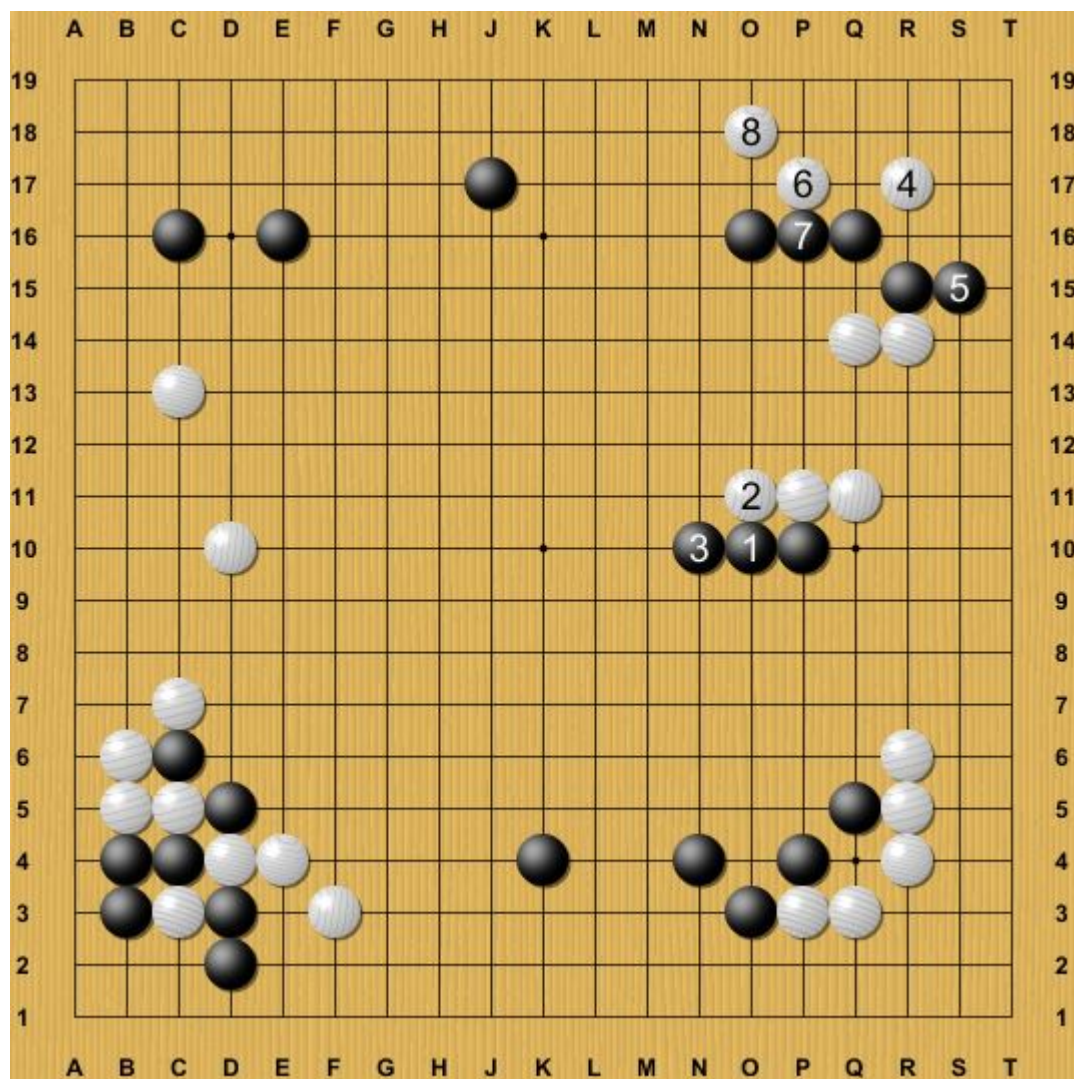
Black 41 further restricted White's potential on the left, while enlarging Black's in the center.

Diagram 7



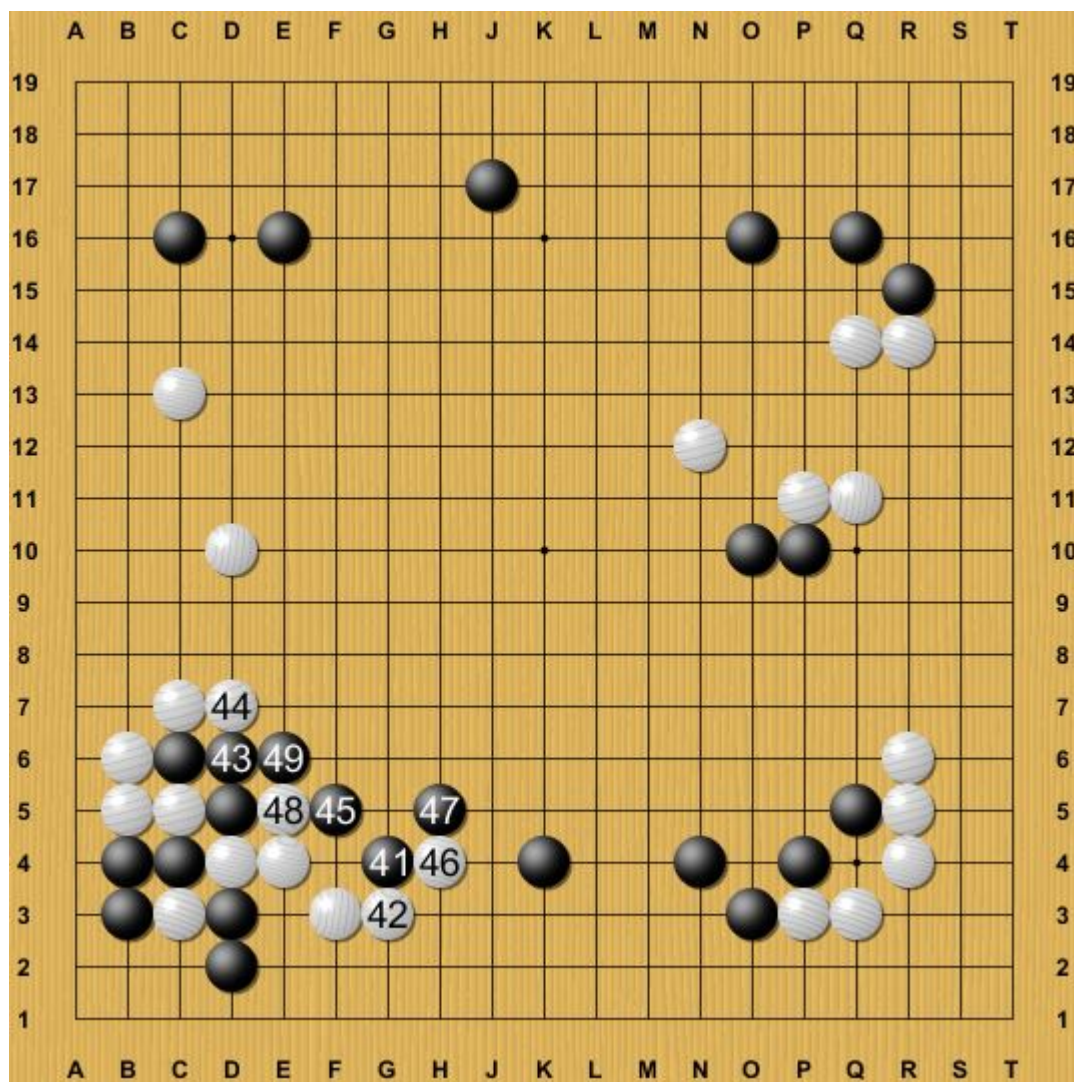
AlphaGo believes White should push at 2, and Black will answer with the jump at 3. White can now invade with 4. Shi Yue suggested the same, and this variation appears to be the professional consensus on how White should have replied.

Diagram 8



Since White has already chosen to push, AlphaGo believes White should push again, then take the 3-3 point. Notably, AlphaGo prefers the kosumi at White 8 to crawling as in diagram 6. Perhaps, because Black is not as developed on the upper side, the corner profit is relatively more important here.

Moves 41-49

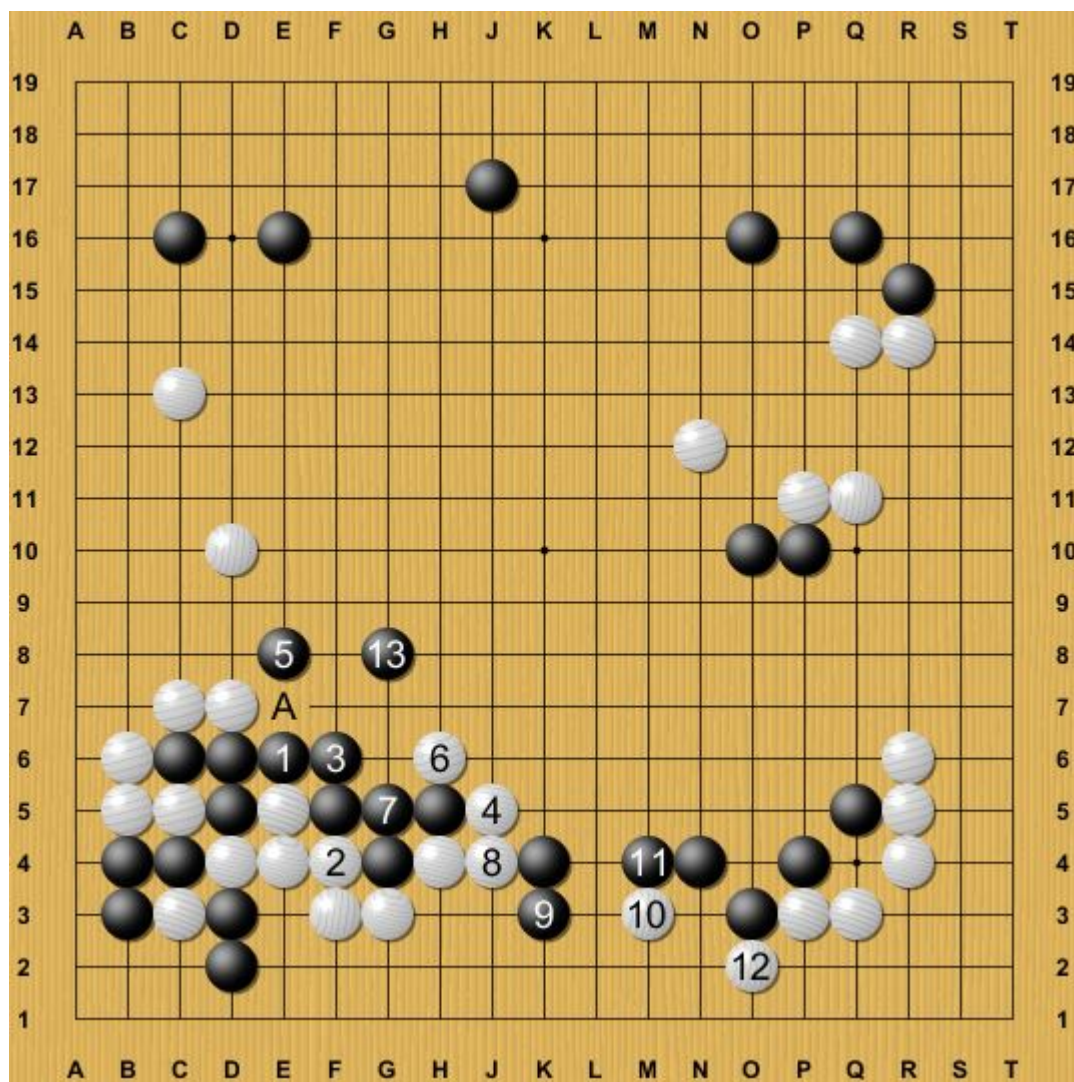


At move 42, Lee had 1 hour and 16 minutes, AlphaGo 1 hour and 34 minutes.

Connecting at 43 was a definite overplay for AlphaGo. After White pushed at 44, even AlphaGo's own win rate suffered a rare decline.

Lee Sedol stared at the board with a scowl, evidently confused by AlphaGo's strategic slip. Drawing on the lessons of the first game, he remained cautious, taking time to verify each move. When Black blocked at 49, AlphaGo's win rate fell to 50%. This may have been Lee's only chance to wrest control of the game. See diagram 9.

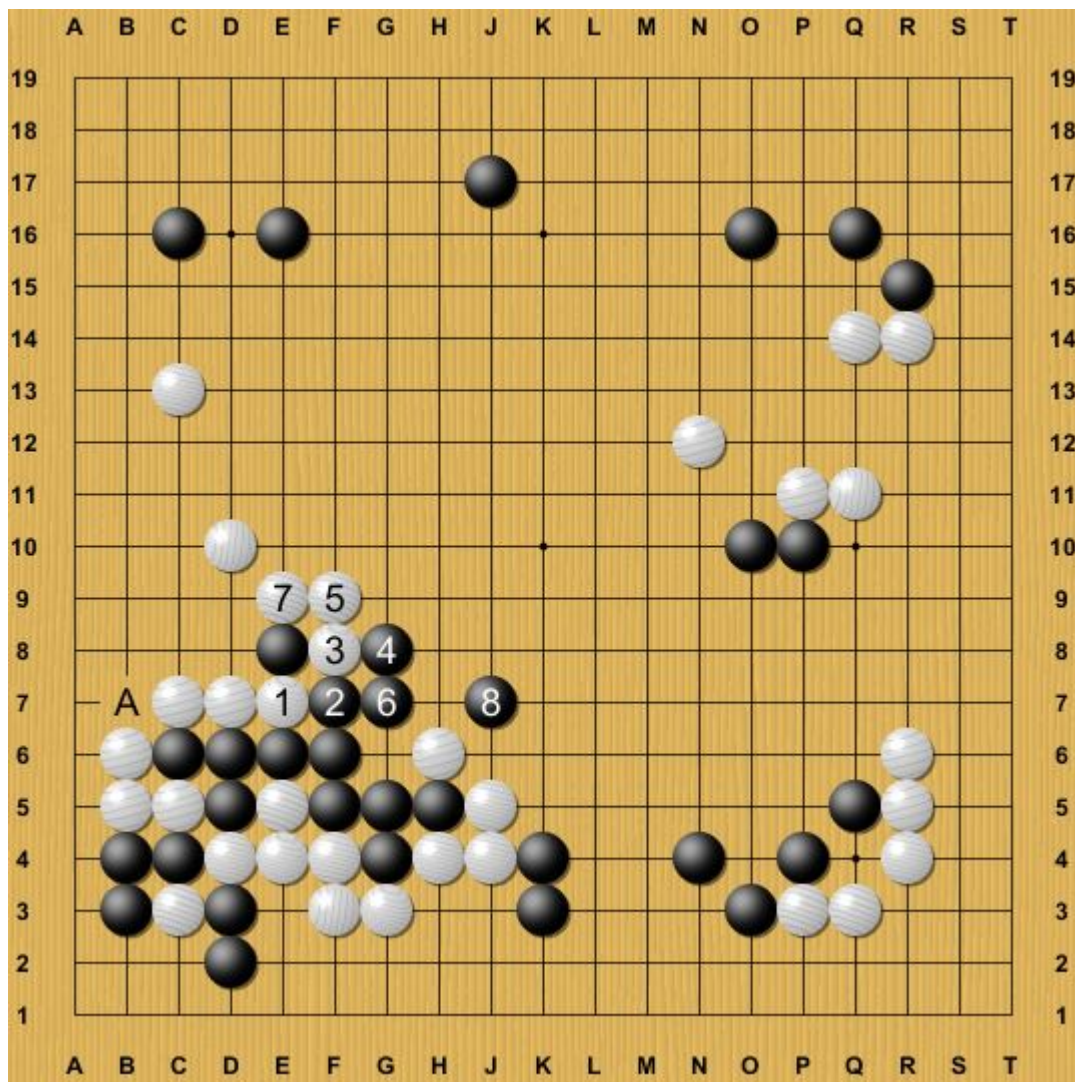
Diagram 9



White 2 is crude but effective. Black must connect with 3, and escape with the tesuji at 5, but White takes sente to switch to the bottom with 10. Black must let White connect, and through 13, the result favors White.

Note that White cannot use 10 to cut at A. See diagram 10.

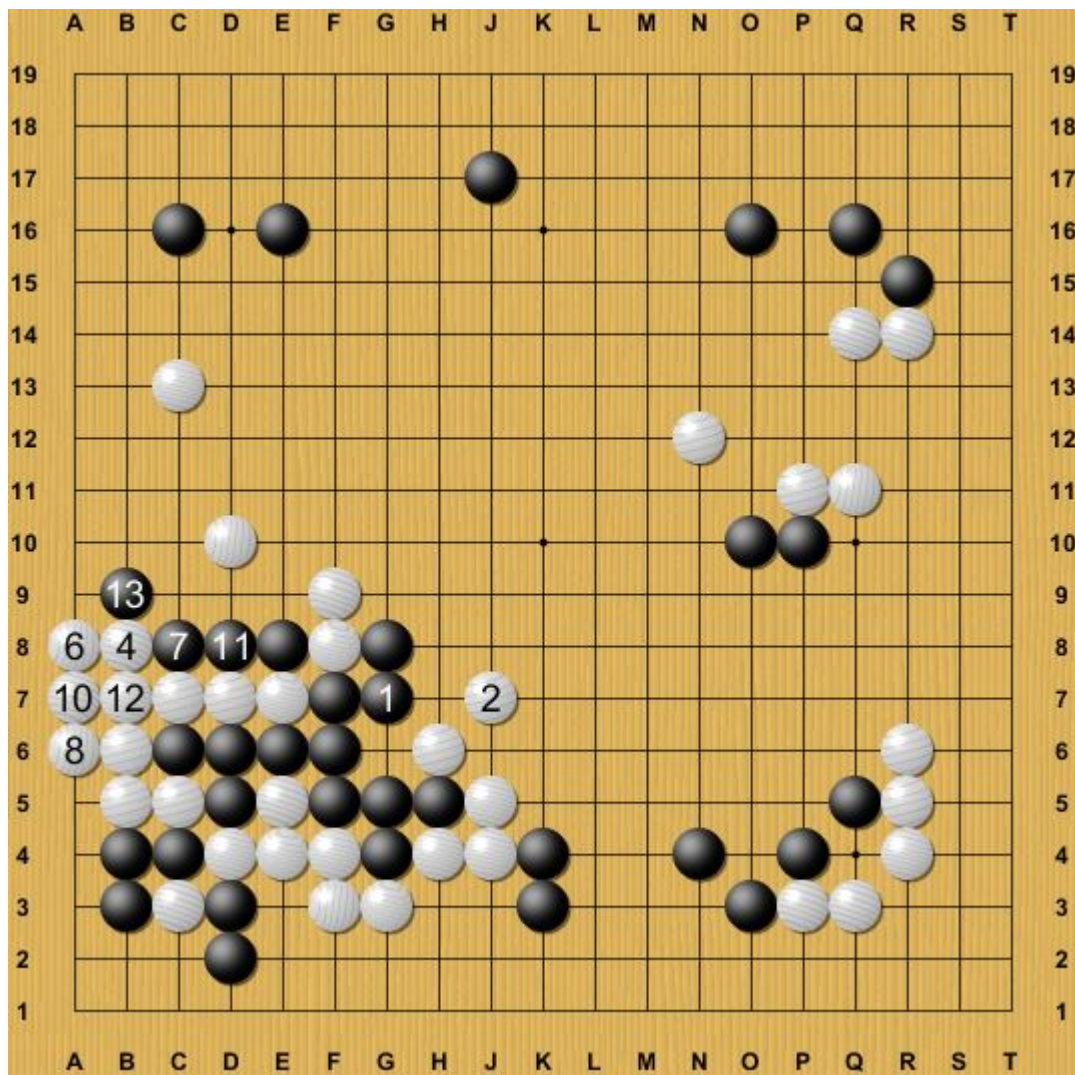
Diagram 10



If White cuts, after Black ataris and connects, White must capture at 7 to protect the cutting point at A. Black can now attach at 8, and White will be hard-pressed to handle the group at the bottom.

Diagram 11 shows the consequences if White omits 7.

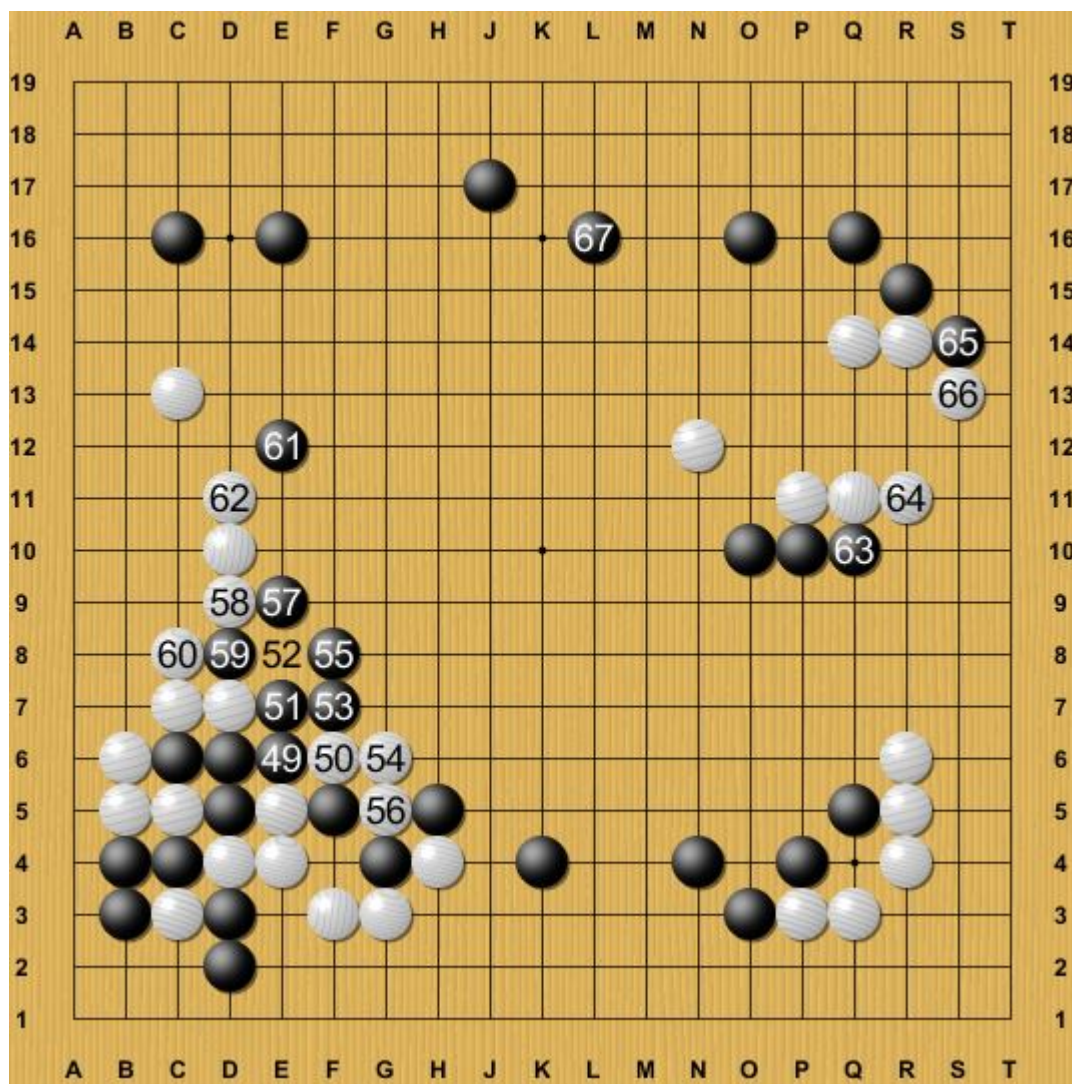
Diagram 11



3=12, 5=10, 9=12

If White tries for the outside, the cut at 3 sets up a fatal two-stone edge squeeze. After 13, White is dead.

Moves 49-67



Regrettably, Lee missed the crucial opportunity and chose the atari at 50 instead. When Black extended at 51, AlphaGo's win rate shot up to 59%!

However, Lee looked unconcerned. Through 62, Black had gained nothing locally while White had captured two stones at the bottom, and furthermore the center group was not yet safe. By this reasoning, White should at least not have been worse off. Globally speaking, however, Black had reduced White's left side in sente, made the profitable exchange of 61 for 62, and come away with the initiative to take the last big point at the top. Overall, it would be hard not to call this a strategic success for Black.

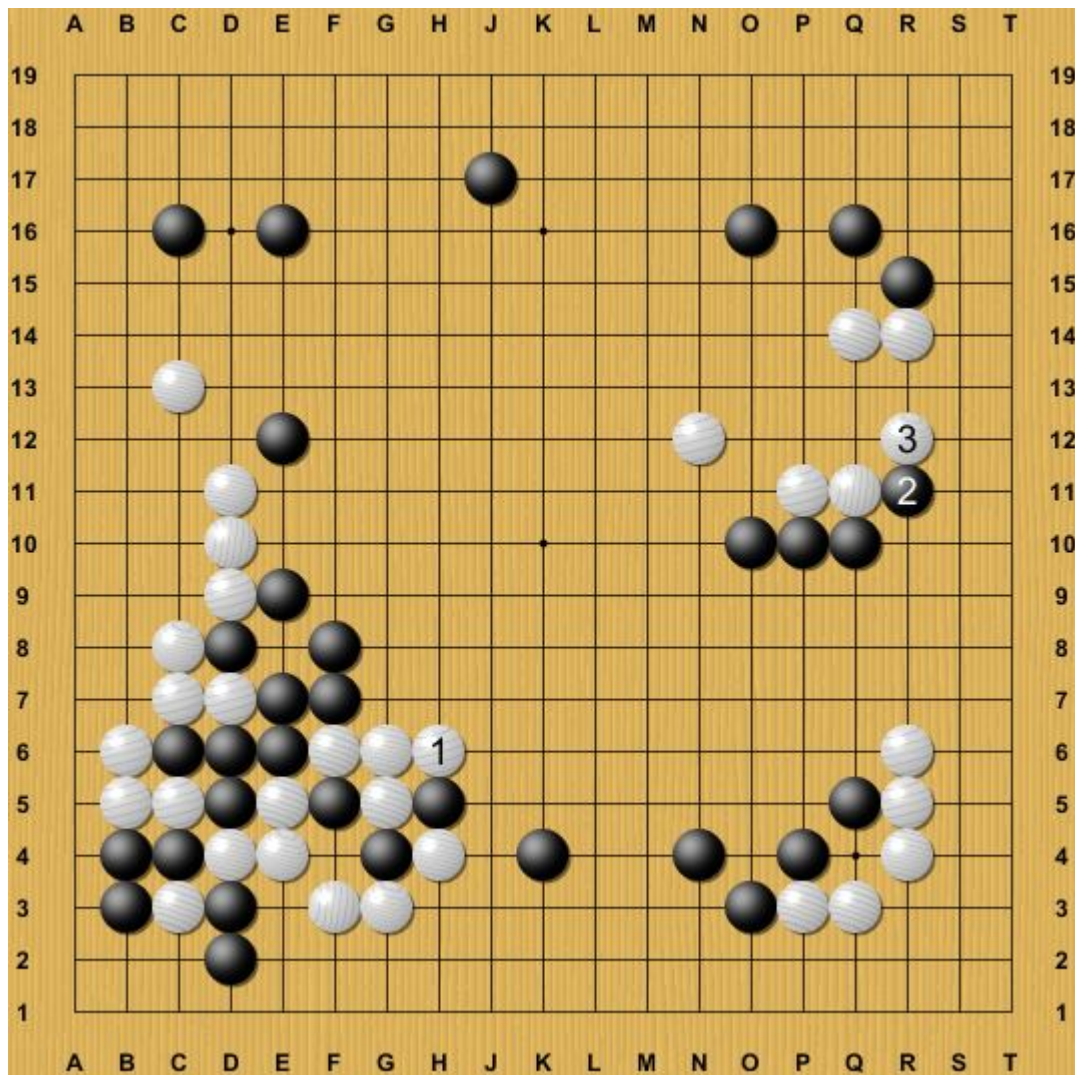
Many of the professionals in the commentary room did not understand Black's way of playing, but after game 1, they were hesitant to pass judgment.

After 63, Lee spent a few minutes in thought, and patiently descended with 64. AlphaGo felt this move was too soft, as did Gu Li and Zhou Ruiyang, and would have chosen diagram 12 instead.

At move 66, Lee Sedol had 59 minutes, AlphaGo 1 hour and 21 minutes.

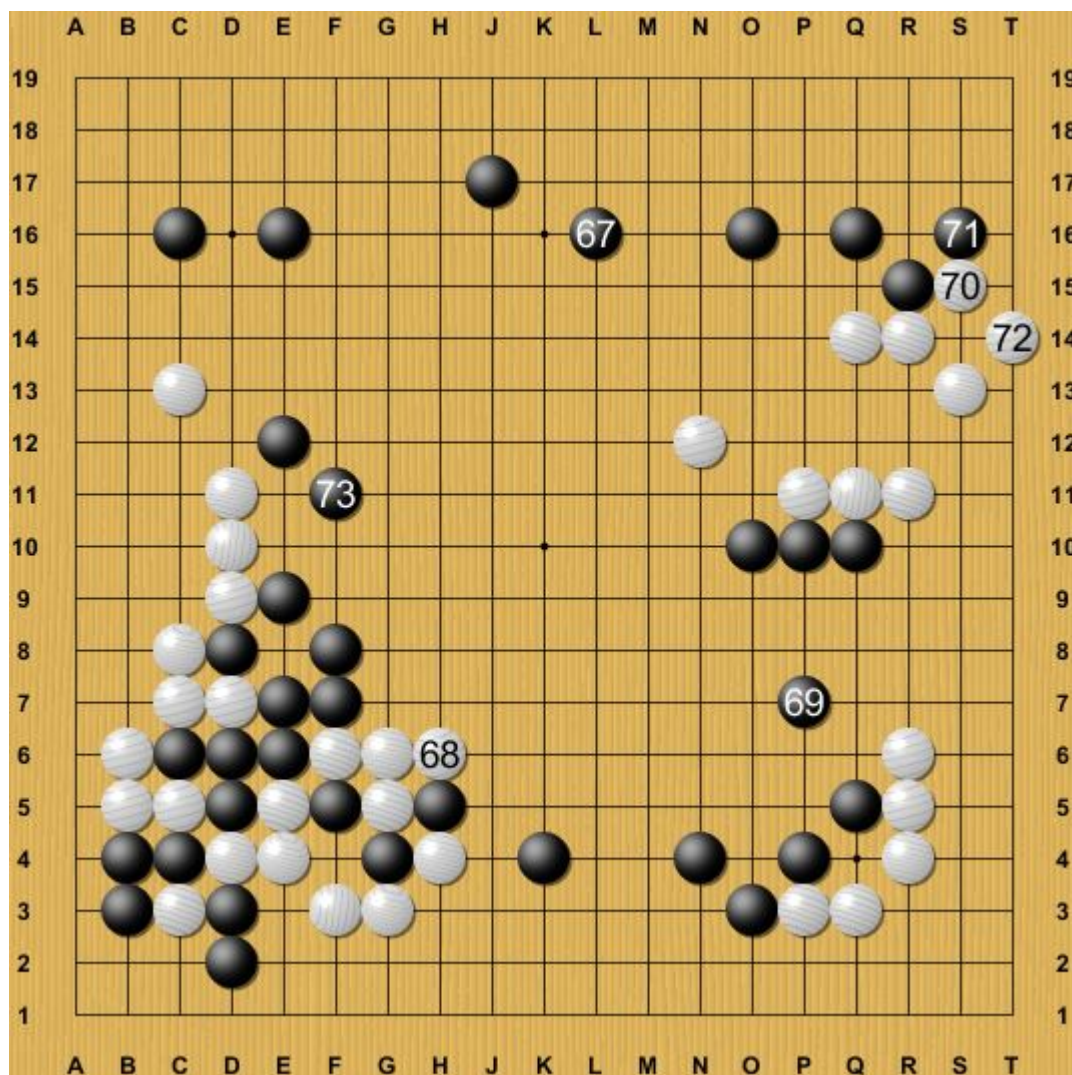
Move 67 put Black clearly in the lead.

Diagram 12



AlphaGo thinks White should come back to the center immediately, as the hane at 2 is nothing to be afraid of. Although Gu Li and Zhou Ruiyang were unsure about White 1, they agreed that the hane is not very severe.

Moves 67-73

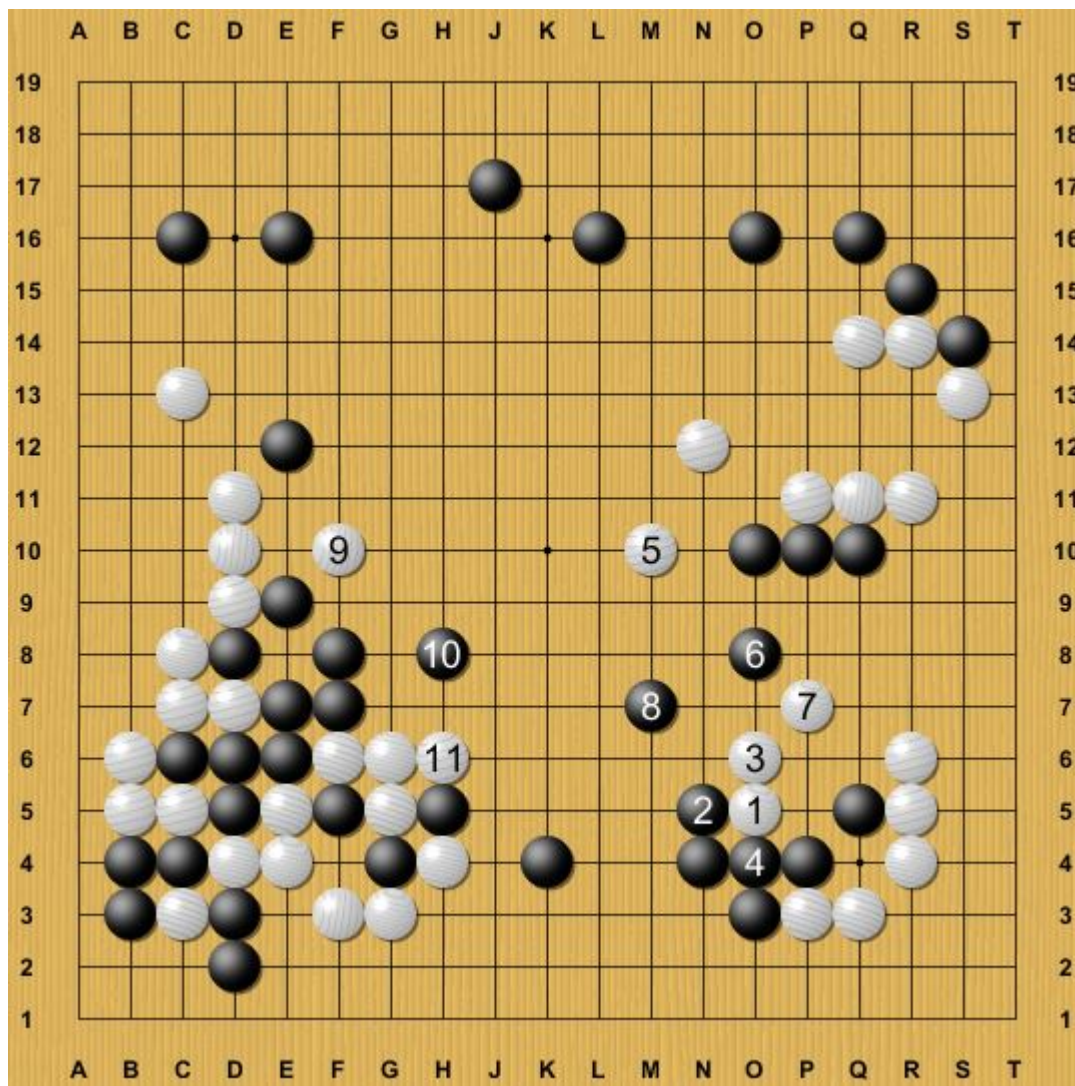


Lee followed with several more slow moves, perhaps still misled by White's apparent gains on the left. 68 was one such move - see diagram 13. Next, taking a stone on the second line was even slower. Moves 70 and 72 left a deep impression on Gu Li and Zhou Ruiyang, who felt that Lee must have thought White ahead to play like this. See diagram 14.

For AlphaGo, the outlook was continually improving. When Black played 73, its win rate reached 64%.

For a human player, Go requires the capacity to feel. The better the player, the more effectively their feelings steer them towards good moves and away from bad ones. However, if we rely too much on feeling, it begins to obscure rational calculation and judgment. After the AlphaGo match, Lee Sedol won nine consecutive games. When asked for his secret, he replied, "Do not rely on instinct. Calculate with the utmost precision." That may be the lesson he drew from this game.

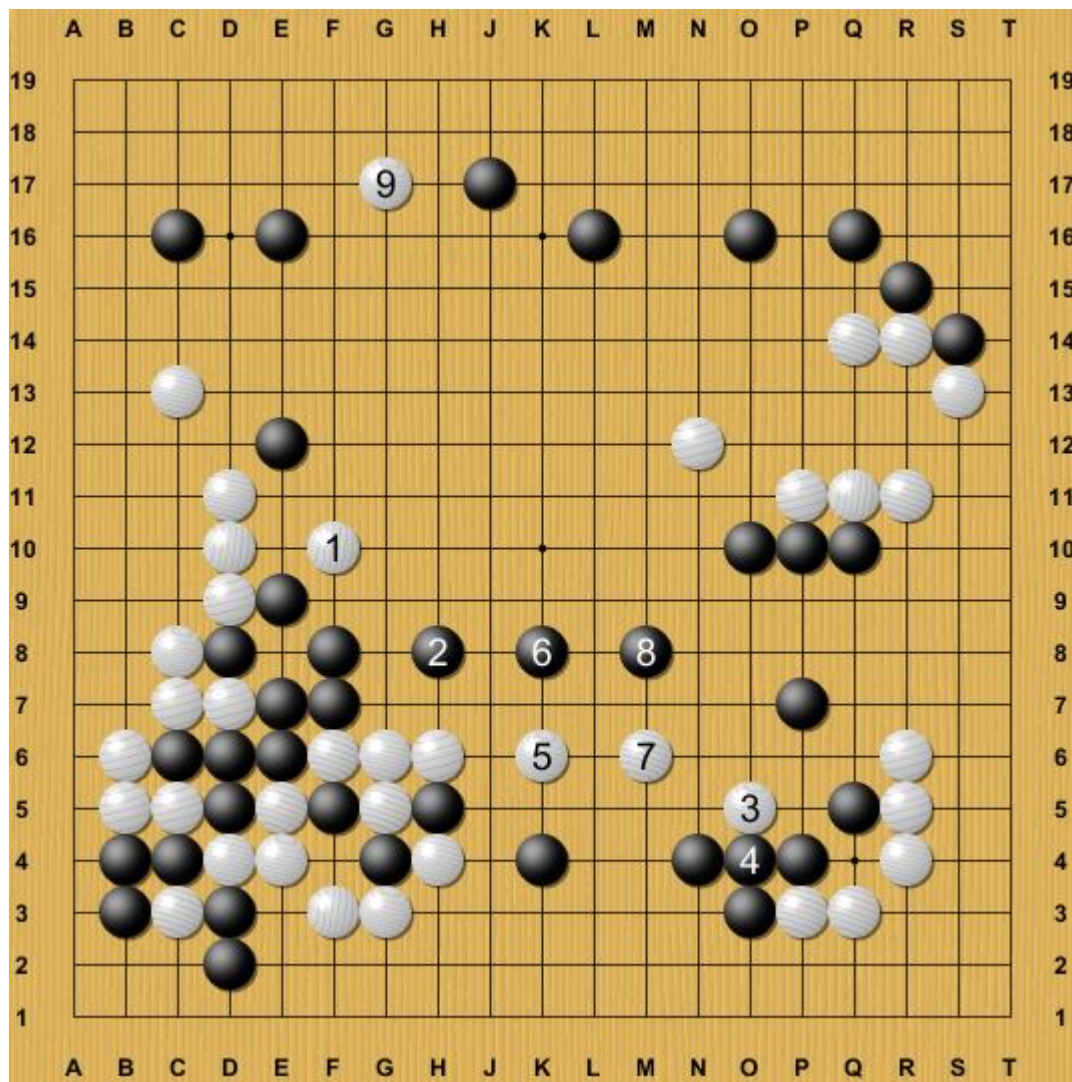
Diagram 13



AlphaGo thinks that White should first attack the three black stones on the right, then break into the center with 9. This way, Black's center is much weaker.

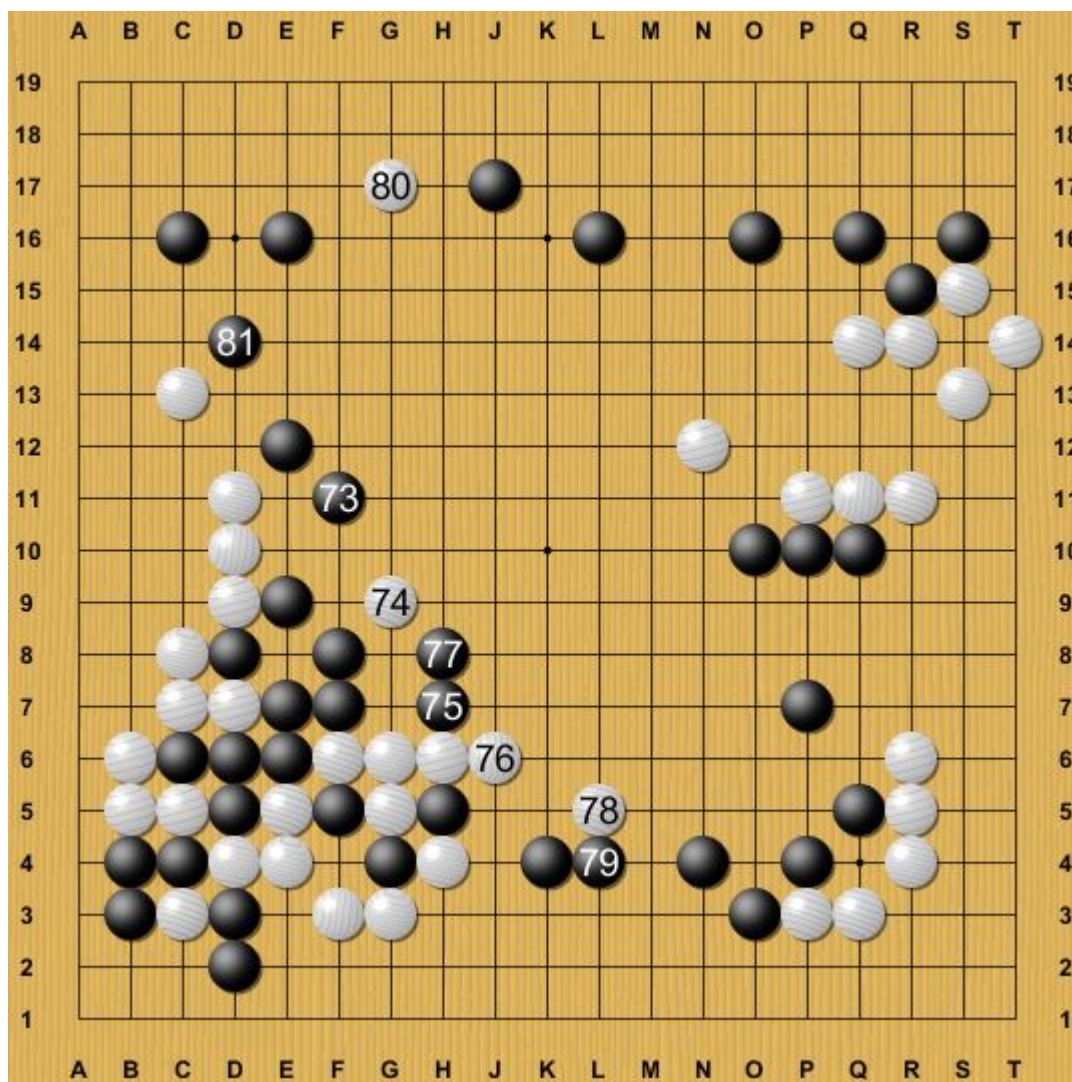
Both Gu Li and Zhou Ruiyang preferred this to the game.

Diagram 14



Even now, White should attack the center. AlphaGo thinks the jump at 1 is critical. Through 8, although Black connects, the center is clearly not as good as in the game. When White invades with 9, the position looks balanced, and both sides are in for a long battle.

Moves 73-81



After Black protected with 73, White's attack at 74 became much less severe. On seeing 75, Lee finally seemed to wake up. He sighed, and made the necessary extension at 76. After 77, Black's advantage was obvious.

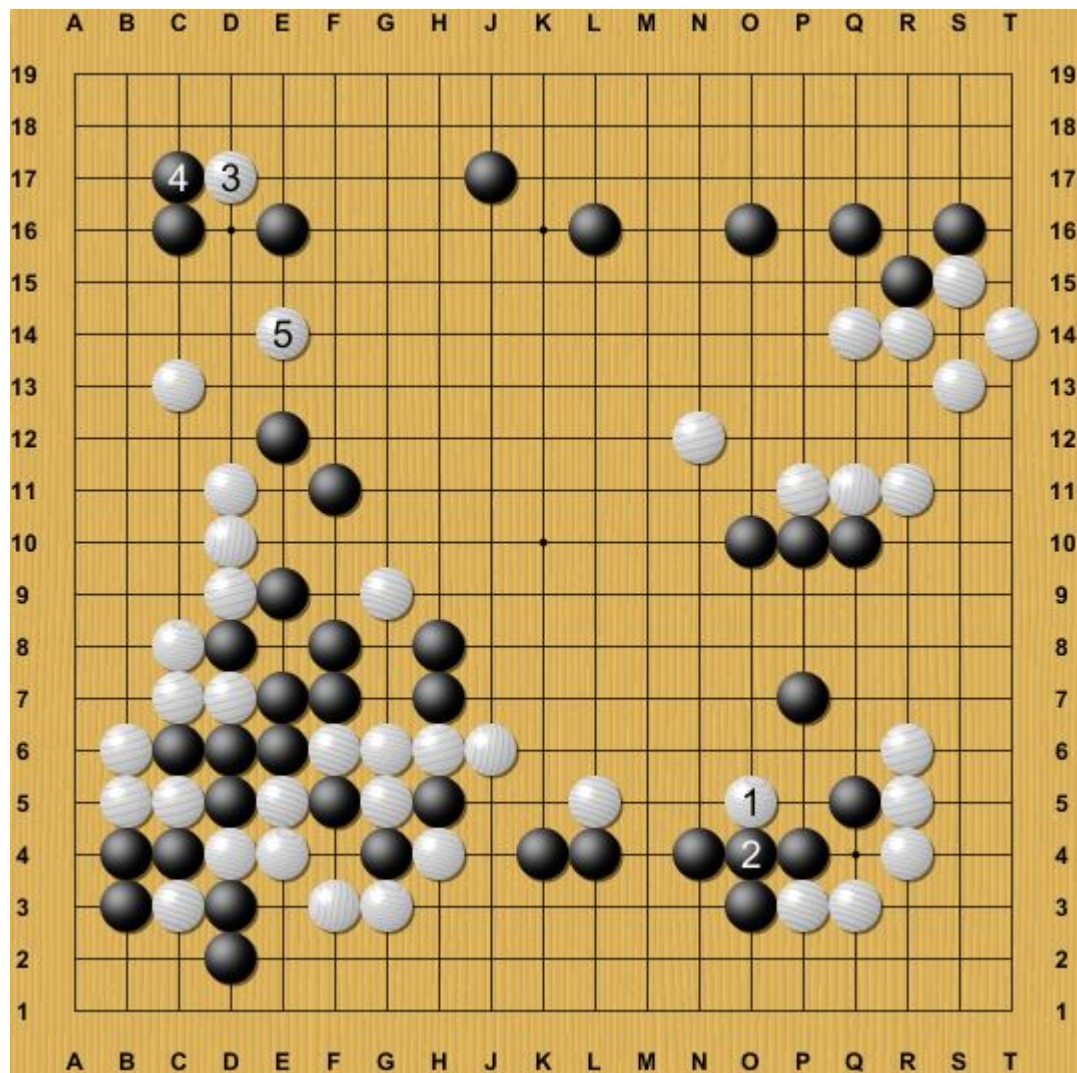
Seeking a comeback, Lee launched the do-or-die invasion at White 80! However, AlphaGo thinks White should remain patient, as in diagram 15.

At move 80, Lee Sedol had 50 minutes, AlphaGo 1 hour and 12 minutes.

Just as everyone was debating how Black should answer locally, AlphaGo played the shoulder hit at 81, reinforcing the center while subtly pressuring White's invading stone. It felt like a breath of fresh air - truly, an amazing example of whole-board thinking!

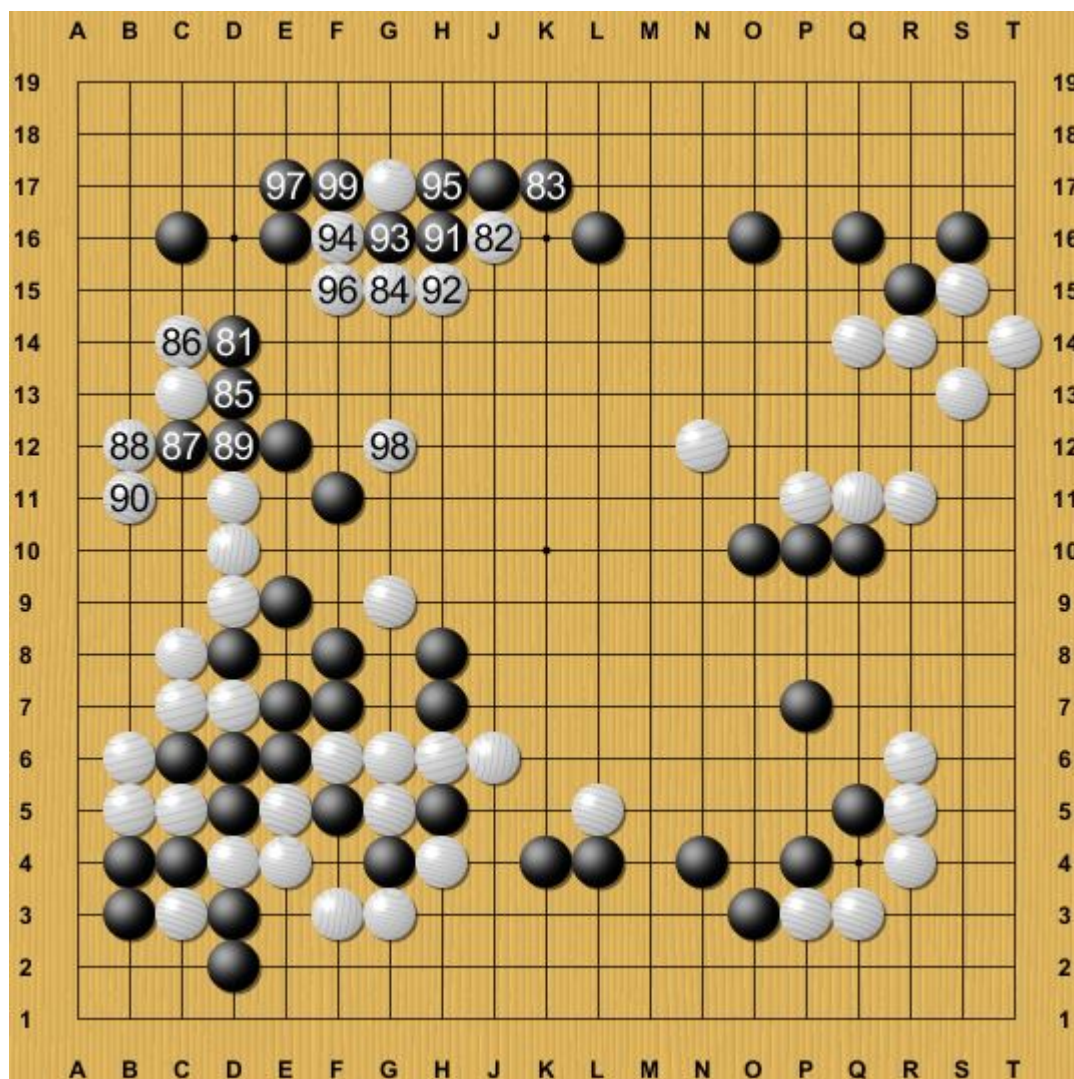
Not only did Black 81 connect up the center, it completed a huge wall. Although Black had done nothing to attack White directly, the invisible pressure was suffocating! The saying normally goes "attack is the best form of defence," but in this case, defence was the best form of attack.

Diagram 15



AlphaGo thinks White should exchange 1 and 3, then jump out into the center with 5 to disrupt Black's thickness. This way might have given White more opportunities to turn the game around.

Moves 81-99



Facing 81, Lee sobered up completely. He sighed, his face reddening.

Because Black's center potential is so great, White can no longer be satisfied with living locally. The attachment at 82 aimed to get out, and 83 was a calm response.

At move 83, Lee had 41 minutes remaining, AlphaGo 1 hour and 10 minutes.

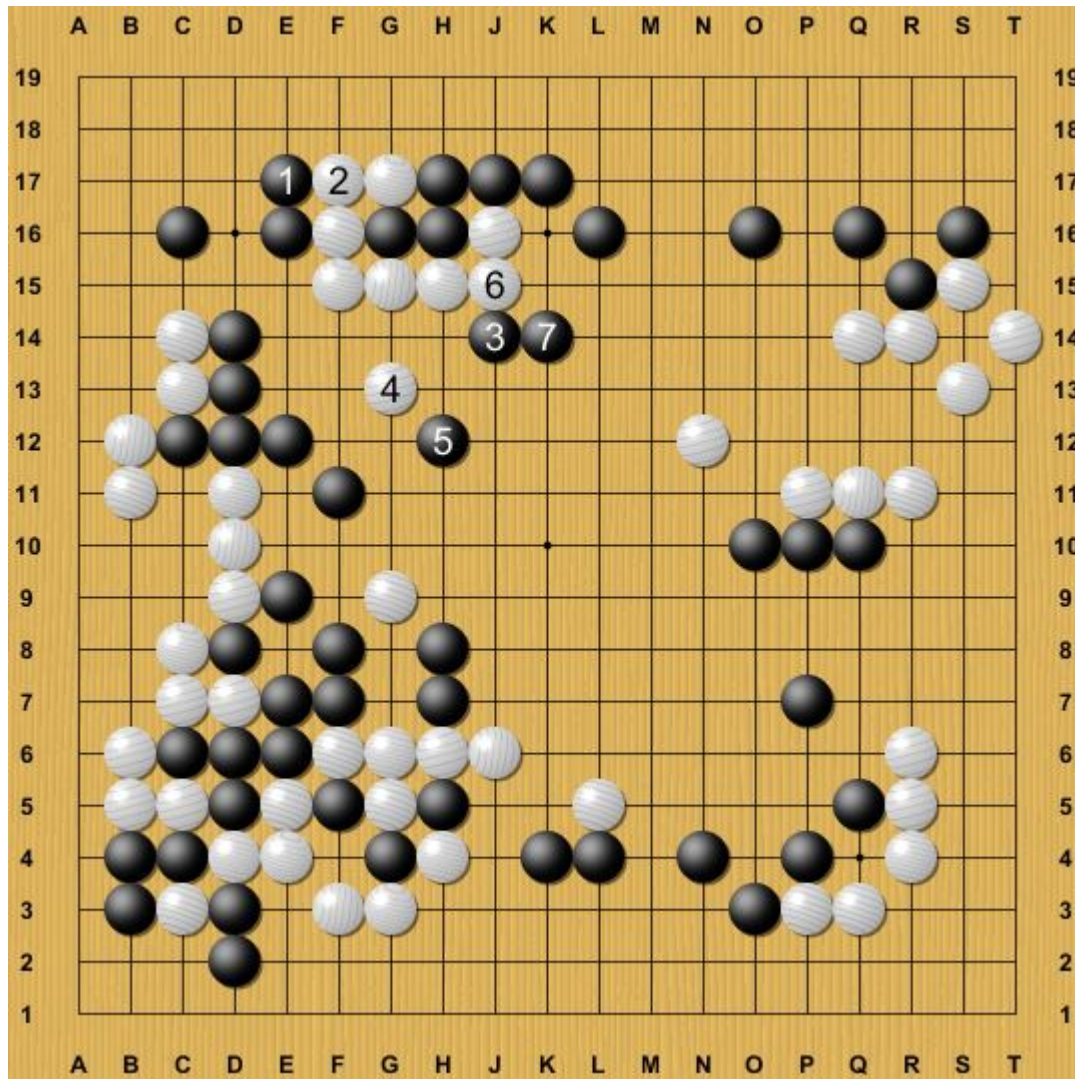
Black 85 was very solid. Up to 90, Black not only compressed White's territory on the left, but also reinforced the connection between the center and the corner.

After the hane at 91, it became difficult for White to save the initial invasion stone.

For 98, White had no choice but to escape, since connecting would have meant the death of the whole group. See diagram 16.

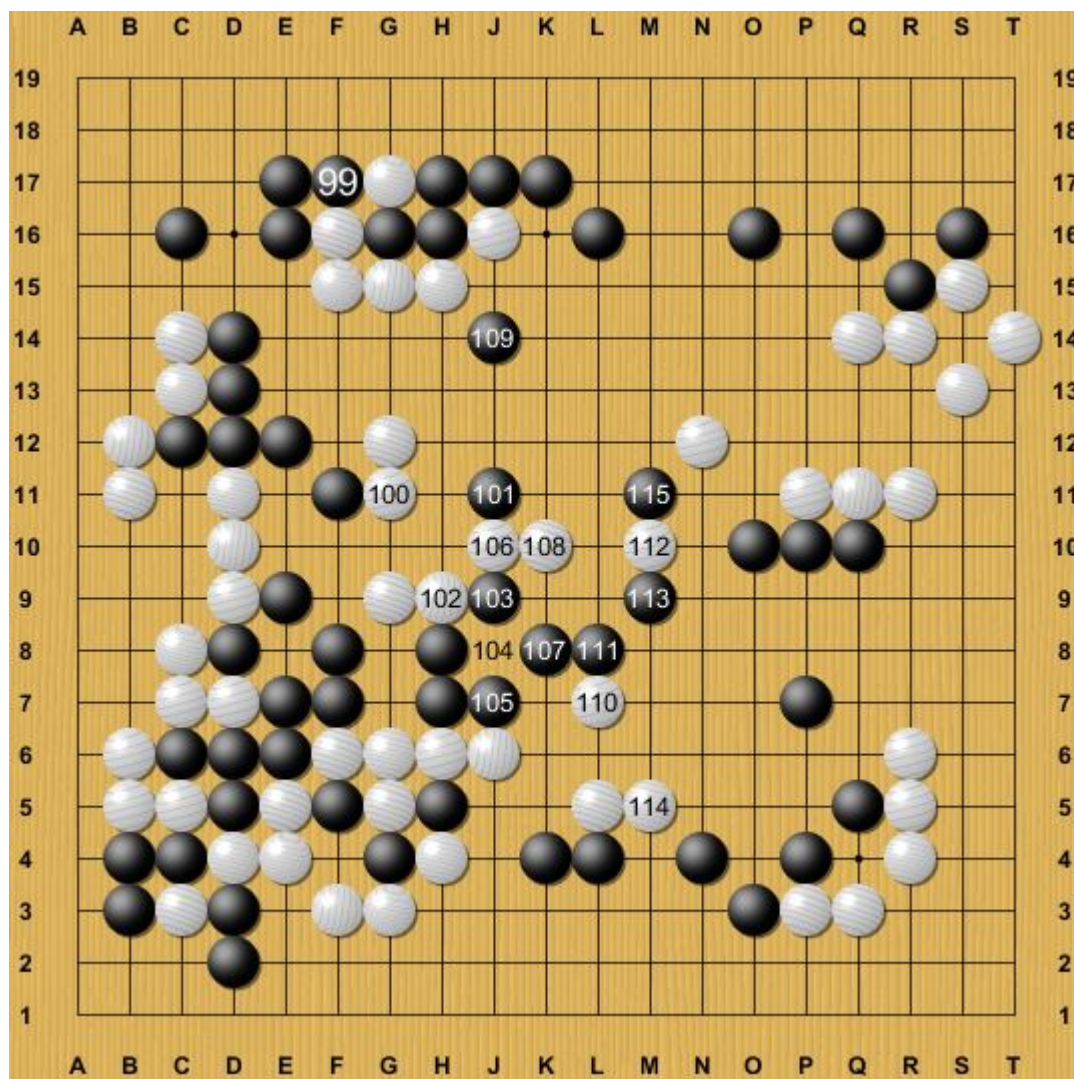
At move 99, AlphaGo's win rate reached 73%.

Diagram 16



If White connects at 2, Black 3 traps the whole group. After 7, White is dead.

Moves 99-115



After Black 99, Lee had no real chance of winning.

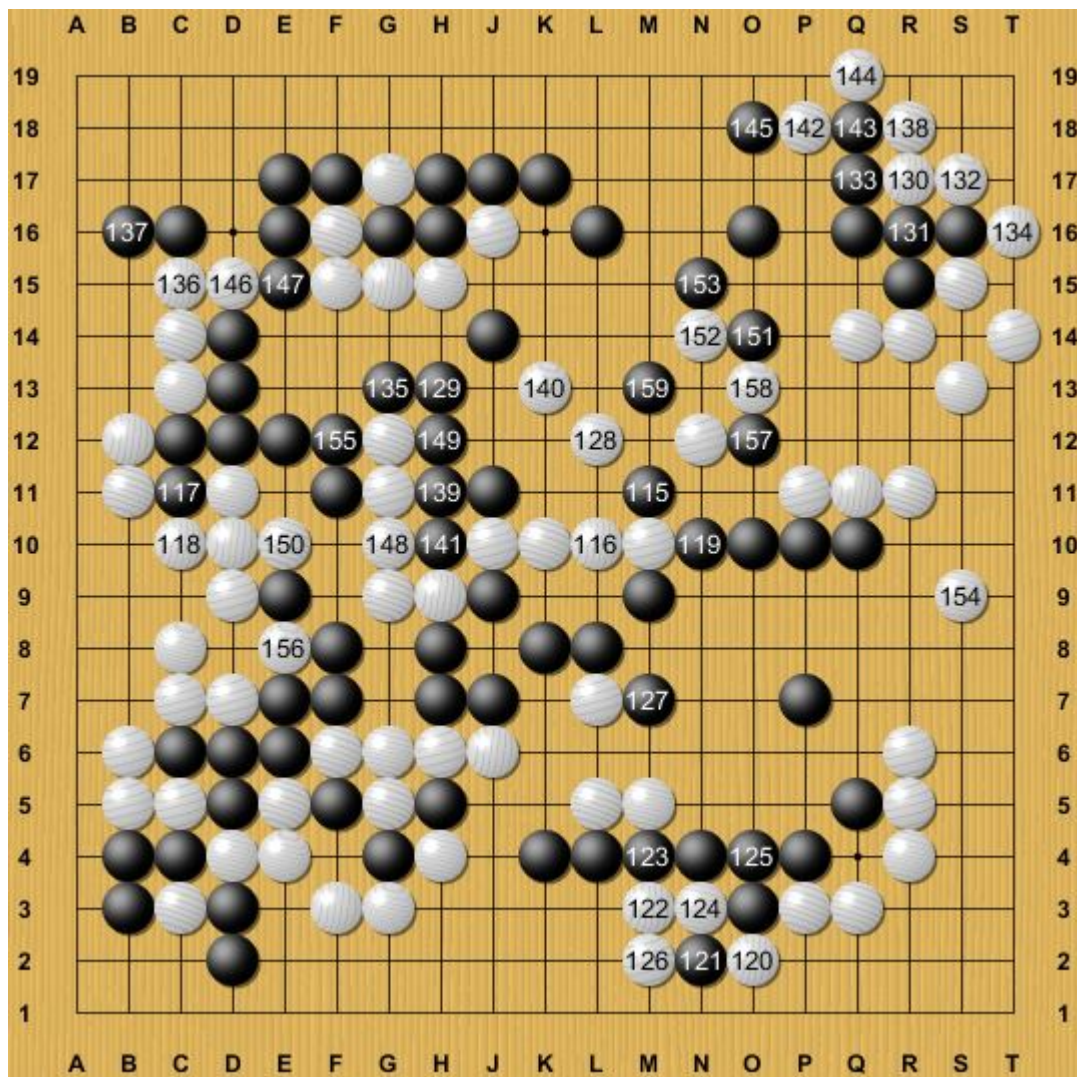
We have all had the experience of playing a game where we are behind. Against a person, the best hope is to stay calm and patiently await the opponent's mistakes. After all, to err is human. Against AlphaGo, of course, this strategy is futile. It is calmer than you, more patient than you, and, by the time you realize you are in trouble, the game is already decided.

Lee had just experienced this painful process, the desperation of knowing one's fate while being helpless to change it. But, as a professional Go player, he could only steel himself and press on.

At move 109, AlphaGo's win rate reached 78%.

At move 115, Lee had 10 minutes, AlphaGo 48 minutes.

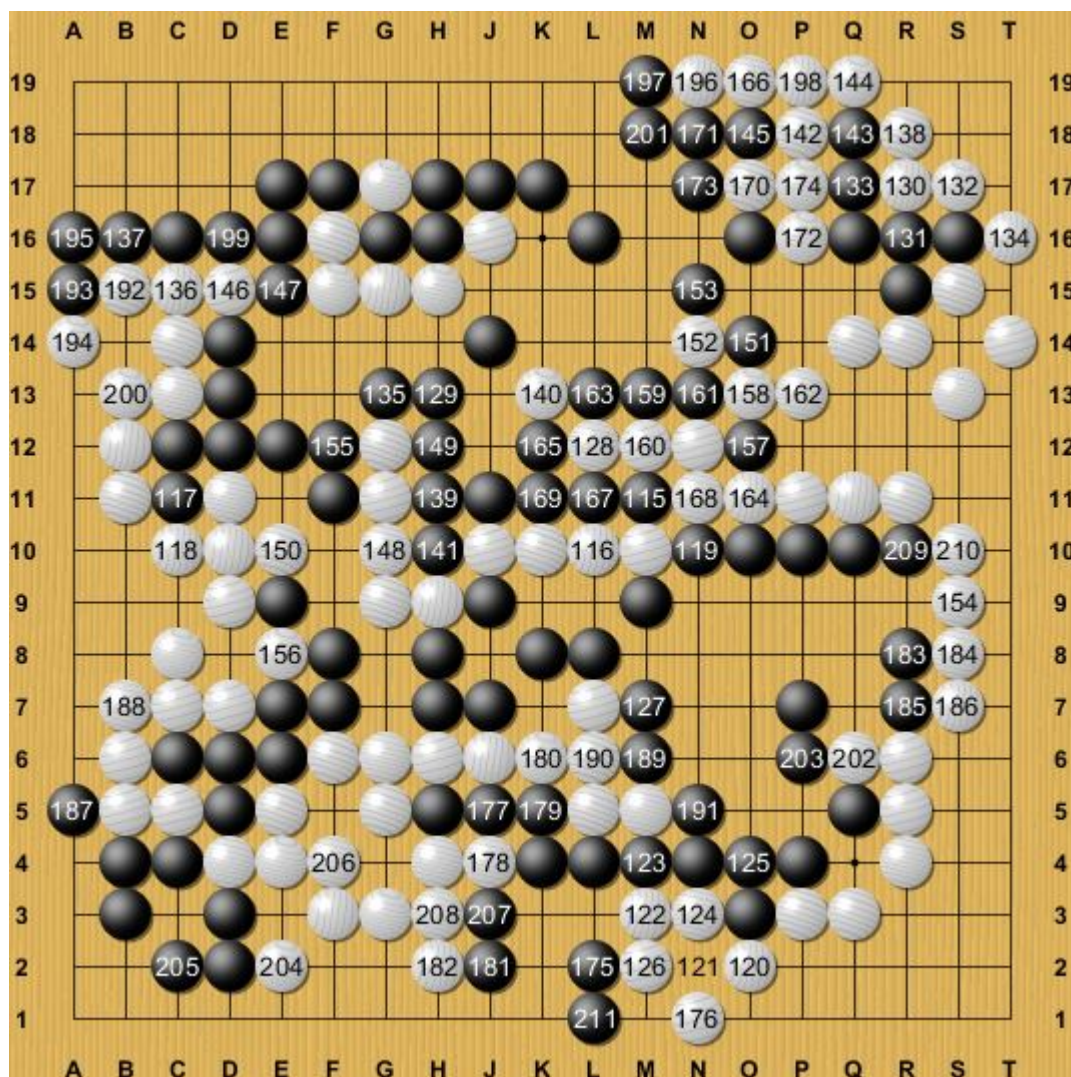
Moves 115-159



AlphaGo never went for the kill in the center, instead nibbling away at White's stones bit by bit. Although it looked as if White had destroyed much of Black's territory at the top and bottom, the actual score tilted ever more strongly in Black's favor.

Even though the result was already decided, the beautiful tesuji at Black 159 is worth remembering! With this move, White's center collapsed.

Moves 159-211



As the game neared its end, Lee continually recounted the score, looking for some sort of miracle. But he searched in vain: as the world had already realized, AlphaGo had won.

After playing on doggedly in byo-yomi, Lee Sedol resigned at move 211. In that moment, I heard the reluctance in his voice, and saw the regret etched upon his face.

During the press conference, Lee's voice was choked with emotion, and he repeated many times how impressed he was with AlphaGo's near-perfect play. The way he spoke, it seemed as if he bore the weight of the entire Go world on his shoulders.

Although AlphaGo's play in the first two games had verged on perfection, the match was not yet over. Behind Lee's trembling voice there stood a firm conviction: "I may have lost the second game, but there is still a third game left to play."

At the end of this game, the entire Go world was left astonished and bewildered. Perhaps the time had come to rethink our understanding of AlphaGo, and of ourselves.

