HAL'S LEGACY: FIVE

"An Enjoyable Game": How HAL Plays Chess

Murray S. Campbell

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The chess scene in *2001* is just one example of the genius behind Clarke and Kubrick's screenplay. Although the game between HAL and astronaut Frank Poole is shown for only about thirty seconds, it conveys a great deal of information about HAL and the relationship between Frank and HAL. The fact that HAL can beat Frank at one of the world's oldest and most difficult games is clearly intended to establish HAL as an intelligent entity. But is this a correct conclusion? Does a machine need to be intelligent to play chess?

The question of whether HAL's chess ability demonstrates intelligence boils down to a question of *how* HAL plays chess. If, on the one hand, HAL plays chess in the "human style" - employing explicit reasoning about move choices and large amounts of chess knowledge - the computer can be said to demonstrate some aspects of intelligence. If, on the other hand, HAL plays chess in the computer style - that is, if HAL uses his computational power to carry out brute-force searches through millions or billions of possible alternatives, using relatively little knowledge or reasoning capabilities - then HAL's chess play is not a sign of intelligence.

This chapter attempts to resolve this question by examining in detail how HAL plays chess and by comparing HAL with Deep Blue, the world's current premier chess computer. I and my colleagues, Feng-hsiung Hsu and A. Joseph Hoane, Jr., developed Deep Blue at IBM's T. J. Watson Research Labs. It was the first machine in history to beat the human world champion, Garry Kasparov, in a regulation chess game. The chapter also examines the strengths and weaknesses of computer-style chess by looking at some of the games between Kasparov and Deep Blue. Finally, we discover that HAL's first error occurred in the chess game with Frank.

Before we analyze how HAL plays chess, we need to put his game with Frank into perspective by understanding the history of man-machine chess matches. What is the significance of a

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machine beating a human at a game like chess?

Frank versus HAL; Man versus Machine

HAL claims to be "foolproof and incapable of error." But, as we witness only one isolated game between Frank and HAL, how do we really know that HAL plays well? The answer can be determined, not so much by the game itself but by Frank's reaction to it.

Poole: Umm ... anyway, Queen takes pawn.

HAL: Bishop takes Knight's Pawn.

Poole: Lovely move. Er .. Rook to King One

HAL: I'm sorry, Frank. I think you missed it. Queen to Bishop Three. Bishop takes Queen. Knight takes Bishop. Mate.

Poole: Ah ... Yeah, looks like you're right. I resign.

HAL: Thank you for an enjoyable game.

Poole: Yeah. Thank you.

Having personally witnessed scores of amateur chess players lose to computers, I found Frank's reaction to losing to HAL extremely realistic. After HAL announces mate, Frank's pause is brief. This brevity is significant, because it demonstrates that Frank assumes HAL is right. He trusts that HAL has the details of the checkmate correct and does not take the time to confirm them for himself. Instead, Frank resigns immediately. Moreover, it is obvious from his tone of voice - or perhaps I should say from his complete lack of tone - that he never expected to win. In fact, Frank would have been utterly stunned if HAL had lost. No, playing chess with HAL is simply a way for Frank to pass the time on the eighteen-month journey to Jupiter. (As HAL is running virtually every aspect of the ship, there is little for the two, nonhibernating astronauts to do.) It is also clear from the dialogue, as well as from Frank's body language, that this is not a game between two competitors but one between two conscious entities - one of whom is vastly superior in intelligence to the other.

Clearly, Frank does not feel bad about losing to a computer, any more than a sprinter would feel bad about being outrun by a race car. Nor do we, the viewers, feel particularly sorry for Frank's loss. We don't mind HAL winning, because at this stage in the film we like HAL. The human relationship with chess computers hasn't always been so amicable though.

In many recent human-machine matches, the mood has been decidedly pro-human and anti-computer. In the first encounter between the human world champion (Kasparov) and the computer world champion (Deep Thought, Deep Blue's predecessor) in 1989, there was definite hostility toward the computer. When Kasparov pulled out the victory, the audience breathed an audible sigh of relief. In gratitude for "saving human pride," onlookers gave Kasparov a standing ovation.

Kasparov couldn't, however, save humanity's pride indefinitely. In 1995 he lost a game of speed chess to a computer program called GENIUS3. Burying his head between his hands, Kasparov could not hide his despair; he stormed off the stage, shaking his head in disbelief. The loss, reported by newspapers and magazines around the globe, shocked the multitude of those - players and nonplayers alike - who believed that the strongest player in the history of the game would never suffer defeat at the hands of "a silicon monster." Although Kasparov was badly shaken by this upset, it was, after all, only speed chess - a game in which decisions are made within severe time constraints. (Speed chess allows each player only twenty-five minutes for the entire game, whereas players in regulation chess each have two hours to complete forty moves.)

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Pentominoes

Pento: A Program to solve the Pentominoes Problem

In February of 1996, Kasparov played Deep Blue in a six-game, full-length regulation match sponsored by the Association for Computing Machinery in celebration of the fiftieth anniversary of the computer. Before the match, Kasparov was quoted as saying, "To some extent this is a defense of the whole human race." When he lost the first game, his computer adviser, Frederick Friedel, openly acknowledged that Kasparov was devastated (see figure 5.1). Even though he rebounded to win the match, *Time* magazine called the first-game defeat an event larger than "world historical. It was species-defining."

Other grandmasters refuse to play against computers at all. Why? Perhaps because the idea of computer superiority in an arena as cerebral as chess is so disorienting; in Western culture, many consider chess the ultimate test of the human intellect. (It is interesting that Kubrick originally filmed the "chess scene" with a five-in-a-row board game called pentominoes but chose not to use it, believing that viewers would better appreciate the difficulties involved in a chess game.) Mathematicians have estimated that there are more possible chess positions than there are atoms in the universe. Therefore, skilled chess players must possess the ability to make difficult calculations and recognize a seemingly infinite number of patterns. Yet excellent chess play also requires imagination, intuition, ingenuity, and the passion to conquer. If a machine can beat a man at a game requiring as much creativity as chess does, what does that say about our "unique" human qualities?

For now, at least, we can rest assured that even though the best computers are better at chess than 99.999999 percent of the population, they do not actually play chess the way humans do. In the history of man's rivalry with machines, only one grandmaster-level computer has appeared to play like a human - and that computer is our fictitious friend HAL.

How HAL Plays Chess

By analyzing the game between Frank and HAL, we can uncover a number of clues about how HAL plays chess. As I explain in more detail below, HAL appears to play chess the way humans do. Even more important perhaps, the game reveals that HAL is not simply mimicking the way humans play; he actually understands how humans think.

The game in the screenplay is a real one played by two undistinguished players in Hamburg in 1913. Kubrick, a former Washington Square Park chess hustler and aficionado, selected a clever checkmate but was careful not to employ one too complex for viewers to grasp. He picked a position from a fairly obscure game - one obscure enough not to appear in the 600,000-game database of Deep Blue. I eventually located the game after being directed to an article written by Grandmaster Larry Evans on January 12, 1990 (HAL's birthday).

Evans makes the crucial point in his article that HAL should have said "Queen to Bishop six" (not three). HAL used the so-called descriptive notation system that describes moves from the viewpoint of the moving player. This contrasts with the algebraic-notation system used in the game score (see Appendix to chapter), in which moves are described from White's viewpoint. HAL used the incorrect viewpoint when giving his fifteenth move. Was the notation error a deliberate foreshadowing of the machine's fallibility or merely a writer's oversight? This is a question only Kubrick can answer. If Poole had been a little more attentive, he might have realized sooner rather than later that the HAL 9000 was indeed capable of error. But, like most chess players, he was focusing on the actual moves; he was not looking for errors because he had never even considered the possibility that HAL was capable of making one.

To better understand how HAL chooses to play against Frank, it is important to have some sense of Frank's chess background. Although the movie does not disclose his chess rating, it is easy enough to speculate about his skill level. He is a highly educated man who holds a doctoral degree, most likely in a field such as aerospace engineering or robotics. We can surmise that, as second in command on a top-secret space mission of unprecedented importance, Frank is well above average intelligence. Because he is a full-time astronaut, it is unlikely that he would have time to compete in professional chess tournaments; yet he clearly knows something about chess, for his game with HAL follows opening theory for eleven moves (see Appendix for a complete account of the game). Frank's chess rating may be in the expert range, making him strong enough to engage in an interesting game but certainly not experienced enough to handle HAL. (See figure 5.2 for an explanation of the rating scale.)

In the game itself, Frank plays White and HAL is Black. Frank chooses an unusual but perfectly sound variation of the well-known Ruy Lopez, or Spanish opening. HAL responds with very aggressive play, creating a situation that makes it very difficult for Frank to find the best moves. By the time the movie picks up the game, Frank has already made the losing move, and he goes down without much of a fight.

The game provides sufficient evidence that HAL plays chess the way humans play chess. Early in the game HAL uses an apparently nonoptimal but very "trappy" move. The choice creates a very complex situation in which the "obvious" move is a losing blunder. If Frank had been able to find the best move, he would have gained the advantage over HAL. In leading Frank into this trap, HAL appears to be familiar with Frank's level of play, and we can assume that HAL is deliberately exploiting Frank's lack of experience. < /P>

The interesting point here is that present-day chess programs do not normally play trappy chess. They are almost always based on the *minimax principle*, which assumes that the opponent always makes the best move. (I discuss this principle in more detail later in the chapter.) A machine like Deep Blue, therefore, would only play the optimal move found in its search. The ability of HAL to play trappy moves is a sign of a sophisticated player who is familiar with the opponent's strengths and weaknesses.

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A second interesting point in the game occurs on move 13. The move played by HAL is clearly a winning move, but Deep Blue would have found a move that forces checkmate one move sooner. Current programs always prefer the shortest checkmate. Thus, either HAL is not able to calculate as deeply as Deep Blue does or he chooses a move based on "satisficing" criteria; that is, HAL saw that the move guaranteed a win, and so did not bother to search for a better move. Human chess players commonly follow this practice, which is another piece of evidence pointing to HAL's human style of play.

So how do we now that HAL understands how humans think? When HAL plays his spectacular fifteenth move, he surmises, undoubtedly correctly, that Frank had overlooked this move. Further, HAL did not point out to Frank the other possible variations to checkmate - only the most interesting line, the one that Frank would most appreciate. Although Frank need not have accepted HAL's queen sacrifice, a prosaic checkmate would have followed shortly anyway.

HAL's ability to play chess human style is what computer scientists in the 1960s might have expected. When *2001* was produced, the majority of artificial intelligence researchers probably believed that computers should play the way humans play: by using explicit reasoning about move decisions and applying large amounts of pattern-directed knowledge. It wasn't until the 1970s, after years of much hard work and little progress, that chess programmers tried a new strategy, which is still utilized in the 1990s. A brief history of computer chess and some of its key components is relevant to understanding how machines play today. Perhaps we should start with an even more basic question: Why develop a chess machine in the first place?

A Brief History of Computer Chess: The Early Days

In 1950, Claude Shannon, the founder of information theory, The Minimax Algorithm is a searching algorithm used for the AI in games like chess or tic-tac-toe, which Aasumes that each player always makes the best available move, and determines the best move for the computer.

proposed that developing a chess machine would be an excellent way to work on issues associated with machine intelligence. In his article, "A Chess-Playing Machine," Shannon states the case for developing such a machine: "The investigation of the chess-playing problem is intended to develop techniques that can be used for more practical applications. The chess machine is an ideal one to start with for several reasons. The problem is sharply defined, both in the allowed operations (the moves of chess) and in the ultimate goal (checkmate). It is neither so simple as to be trivial nor too difficult for satisfactory solution. And such a machine could be pitted against a human opponent, giving a clear measure of the machine's ability in the type of reasoning."

In fact, the practical applications that could result from development of a world-class chess machine are numerous. Complex tasks that may be solved by technologies derived from Deep Blue include problems in chemical modeling, data mining, and economic forecasting.

Fascination with the idea of a chess-playing machine, however, began more than two centuries ago, long before anyone thought of using a computer to solve large-scale problems. In the 1760s Baron Wolfgang von Kempelen toured Europe with the Maezal Chess Automaton, nicknamed the Turk. The machine was nicknamed the Turk because it played its moves through a turbaned marionette attached to a cabinet. The cabinet supposedly contained "the brain" of the machine; it was later discovered that the brain was actually a chess master of small stature.

The first documented discussion of computer chess is in *The Life of a Philosopher* by Charles Babbage (1845). Babbage, whose remarkable ideas in mathematics and science were far ahead of his time, proposed programming his Analytical Engine - a precursor of the computer - to play chess. A century later, Alan M. Turing, the British mathematician and computer scientist, developed a program that could generate simple moves and evaluate positions. Lacking a computer with which to run his program, Turing ran it by hand. Konrad Zuse, a German computer science pioneer, in his *Der Plankalkuel* (1945), described a program for generating legal chess moves. He even developed a computer, although he did not actually program it to play chess.

In spite of these earlier precedents, it was Shannon's efforts that laid the groundwork for actual research, and he is generally considered the "father of computer chess." Shannon's work was based, in turn, on the findings of John von Neumann and Oskar Morgenstern, game theorists who devised a minimax algorithm by which the best move can be calculated.

Key Components of a Chess Program

The minimax algorithm can be thought of as consisting of two parts: an evaluation function and the minimax rule. An *evaluation function* for any chess position produces a number that measures the "goodness" of the position. Positions with positive values are good for White, and negative values are good for Black. The higher the score, the better it is for White, and vice versa. The *minimax rule* allows the evaluation function values to be used. It simply states that, when White moves, White chooses the move that leads to the maximum value, and when Black moves, Black chooses the move that leads to the minimum value.

In theory, the minimax algorithm allows one to play "perfect" chess; that is, the player always makes a winning move in a won position or a drawing move in a drawn position. Of course, perfect chess is just a fantasy; chess is far too vast a game for perfect play, except when there are only a few pieces on the board. In practice, chess programs examine only a limited number of moves ahead - typically between four and six.

Although minimax is very effective, it is also quite inefficient. In the opening position in a chess game, White has twenty moves, and Black has twenty different replies to each of these - thus there are four hundred possible positions after the first move. After two moves there are more than twenty thousand positions, and after five moves the number of potential chess positions is into the trillions. Even today's fastest computers cannot process this many positions. The *alpha-beta algorithm* improves the minimax rule by greatly reducing the number of positions that must be examined. Instead of exploring trillions of positions after five moves, the computer only needs to analyze millions.

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The Modern Era of Computer Chess

The principles of the minimax and alpha-beta algorithms were well understood in the 1960s. When *2001* made its screen debut in 1968, however, the very best computer chess program was only as strong as the average tournament player. Still, many computer scientists believed that building a world-class chess machine was a fairly straightforward problem, one that would not take long to solve.

The earliest approach to solving it involved emulating the human style of play. It is now clear that this was an extraordinarily difficult way to tackle computer chess. Even though chess seems to be a simple and restricted domain, people use many different aspects of intelligence in top-level play,including calculation of possible outcomes, sophisticated pattern recognition and evaluation, and general-purpose reasoning. Significant progress in computer chess did not occur until 1973, when David Slate and Larry Atkin wrote a well-engineered brute-force chess program called Chess 4.0. Since then, almost all good chess programs have been based on their work.

The Slate/Atkin program remained the best chess-playing computer program throughout the 1970s; it gained in strength with each new, faster generation of computer hardware. It was observed in practice, and verified by experiment, that every fivefold speedup in computer hardware led to a two-hundred-point increase in the program's rating as it approached the master level. Subsequent chess-playing machines pushed the computer chess ratings higher and higher - in large part due to faster hardware, although software was also improving rapidly. The Slate/Atkin program reached the expert level (2,000) by 1979; in 1983 Belle, a machine from AT&T Bell Labs, used specially designed chess hardware to reach the master's level (2,200); then came Cray Blitz, which ran on a Cray supercomputer, and Hitech, which dedicated a special-purpose chip to each of the sixty-four squares on a chessboard. Recognizing this trend, Ray Kurzweil predicted that a computer would beat the world champion around 1995. All these machines were finally surpassed by Deep Thought, which began playing in 1988 (see figure 5.3). Designed and programmed by a group of graduate students (myself included), Deep Thought was the first machine to defeat a grandmaster in tournament play; it was capable of searching up to seven hundred thousand chess positions per second. Deep Thought eventually led to Deep Blue, still the world's best chess-playing machine.

How Deep Blue Plays Chess

The objectives of the Deep Blue project were to develop a machine capable of playing at the level of the human world chess champion and to apply the knowledge gained in this work to solving other complex problems. To accomplish these goals, a significant increase in processing power was necessary. Today Deep Blue is capable of searching up to two hundred million chess positions per second. Its ability to search such an extraordinary number of positions prompted Kasparov to comment that "quantity had become quality." In other words, the computer is able to search so deeply into a position that it can discover difficult and profound moves. Although Deep Blue uses a variety of techniques to achieve its high level of chess play, the heart of the machine is a *chess microprocessor* (see figure 5.4).

Designed over a period of several years, this chip was built to search and evaluate up to two million chess positions per second. By itself, however, the chip cannot play chess. It requires the control of a general-purpose computer to make it work. Deep Blue runs on an IBM SP2 supercomputer with thirty-two separate computers (or nodes) that work in concert. For the match against Kasparov, each SP2 node controlled up to eight chess chips, while the entire SP2 system had about 220 chess chips that could be run in parallel. The old saying about too many cooks spoiling the broth is also applicable to parallel computers. A lot of processors won't do much good unless they can all be kept busy doing useful work. In fact, parallelizing a chess program efficiently has proven to be a very difficult problem. For the match with Kasparov, Deep Blue looked at an average of close to one hundred million positions per second.

Nonetheless, a purely brute-force machine would have little chance against a player like Kasparov. Although grandmasters require very little actual calculation of variations for most moves, there are typically a few key points in a game where they must calculate the possible variations very deeply. Often these calculations far surpass what brute-force search could hope to attain. To overcome this problem, Deep Blue employs a technique called *selective extensions*, which enables the computer to search critical positions more deeply.

One of the questions most commonly asked about a chess computer is, "How deep does it search?" In the early days of the computer chess, most programs searched all lines to roughly the same depth, and this question was relatively easy to answer. The fact that Deep Blue employs sophisticated selective searches complicates the issue considerably. When asked how deeply Deep Blue searches, one can give at least three answers; minimum depth (six moves in typical middle game positions); average depth (perhaps eight moves); and maximum depth (highly variable, but typically in the ten-to-twenty-move range).

Yet, although Deep Blue's speed and search capabilities enable it to play grandmaster-level chess, it is still lacking in general intelligence. It is clear that there are significant differences between the way HAL and Deep Blue play chess.

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How HAL Compares with Deep Blue

As we mentioned earlier, there is considerable evidence that HAL plays chess in the human style. In fact, given that Kubrick and Clarke chose a game between two humans as the model for the Frank Poole-HAL game, it would have been extraordinary if HAL had not played in the human style. Deep Blue, on the other hand, is a classic brute-force-based machine, albeit it has considerable search selectivity. So a comparison between HAL and Deep Blue must begin by comparing computer and human styles of chess playing.

The difference is actually quite subtle and would probably be detected only by persons experienced with computer play. A computer engaged in an electronic dialogue is said to have passed the Turing test if the computer's conversation is indistinguishable from that of a human being. At the present time, no computer has ever passed the Turing test. HAL, by comparison, would pass with flying colors - and later turn around and try to kill the person administering the test!

Drawing on this analogy, one could devise a Turing test for computer chess programs. That is, a chess machine would pass the chess-restricted Turing test if the person playing the machine could not determine whether or not he or she was playing against another person or a machine. Most players would find it difficult to discern whether or not a Deep Blue game was played by a human or a computer. This was proven in an informal experiment conducted by Frederic Friedel, Kasparov's computer adviser. Friedel showed Kasparov a series of games in a tournament played by Deep Thought and several grandmasters. Without identifying the players, Friedel asked Kasparov to pick out the moves made by the computer. In a number of cases Kasparov mistook the computer's moves for those of a human grandmaster, or vice versa. In general, only chess players who have considerable experience playing against computers can identify computer moves.

A specific example demonstrates the difference between the human style of play and the computer style of play: the fact that chess programs exhibit a lack of understanding of the role of timing in chess. Concepts involving *never*, *eventually*, or *any time* can be very difficult for computer programs. For example, a weapon in the arsenal of most strong human players is the idea of a *fortress* - a position where a player who has fewer or less-powerful pieces, can create an impenetrable position in which the opponent can never make progress (see figure 5.4). In the 1996 Kasparov-Deep Blue match, Kasparov was able to clinch a draw in the fourth game by means of a sacrifice that created a fortress (see figure 5.5). Although Deep Blue can be programmed to identify many different specific fortresses, detecting the general case of a fortress is still beyond its capabilities and presents us with a complicated pattern-recognition problem worthy of further research.

Another difference between human and computer styles of play can be seen by examining a position involving the ability to reason. At the conclusion of the historic match, Kasparov visited our research lab and showed us a position from which he was absolutely certain that Black would eventually checkmate. Kasparov could not say precisely how many moves it would take, and he was curious to see how Deep Blue would analyze the position. Even after several minutes of search, however, Deep Blue did not see the checkmate. Sometimes search is a very poor substitute for reasoning.

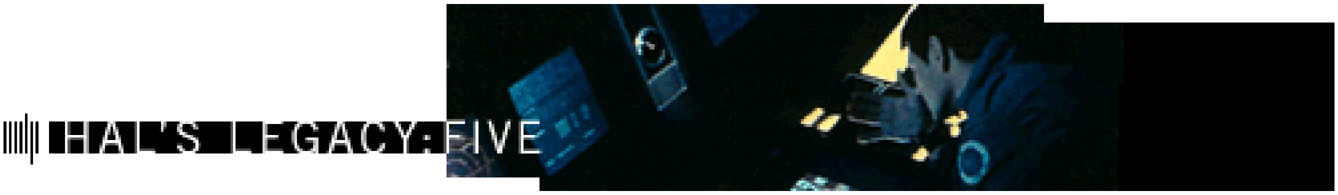
There is, of course, another obvious difference between the human style (HAL) and the computer style (Deep Blue) of play: Humans have emotion. One of the supposed advantages of computers over humans in a game like chess is that computers lack emotion. They are not embarrassed by previous mistakes, they don't slump dejectedly in their chairs when they get into a bad position. One wonders, then, whether HAL's emotional side possibly influenced his style of play (see chapter 13).

When HAL thanks Frank for "an enjoyable game," this is more than simply a pleasing platitude entered into HAL's system by his programmers. Because he possesses both emotion and general intelligence, HAL has the ability to enjoy a good game of chess. Alas, while Deep Blue is sometimes capable of playing magnificent, world-class chess, it is unable to appreciate its own moves.

How, one might speculate, would Deep Blue fare in a match against HAL? Deep Blue could find all the moves HAL plays to finish off the game with Frank in a fraction of a second.

Clearly, both machines are tactically very strong. However, given HAL's general intelligence, one suspects it would be able to avoid most of the typical computer mistakes to which brute-force machines like Deep Blue are susceptible. On the other hand, Deep Blue's search strategy could be a strength; it might find counterintuitive moves that would probably be dismissed by a humanlike search. I suspect it would be a very interesting match, in which each computer would gain its fair share of wins.

The idea of HAL losing a game, however, brings up an interesting point. Throughout the film, HAL consistently asserts that he is "incapable of error." Given the overwhelming complexity of the game, it is not plausible for HAL to play perfect chess, as this would require HAL to have solved all possible chess problems. So, if HAL does not play perfect chess, there must be some winning positions in which HAL fails to play a winning move - or drawn positions in which he doesn't find the drawing move. In the normal sense of the word, these would constitute errors. HAL's own interpretation of the word *errorr* remains mysterious.



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Man versus Machine today

In one six-game match, the 1996 Kasparov-Deep Blue "showdown" demonstrated both the great strengths and the great weaknesses of 1990s computer chess machines. The diagram in figure 5.6 illustrates how quantity can indeed become quality.

This position was taken from Game 1 of the match. Deep Blue's move23 was **P-Q5** (or d5 in algebraic notation). This strong move completed thedemolition of Kasparov's pawn structure; all Black's pawns were soon isolated and unable to support each other. Kasparov knew that 23. **P-Q5** was a strong move, but he did not expect it from a computer, because it involved a pawn sacrifice - something computers are often reluctant to do. However, Deep Blue, in analyzing the position, saw deeply enough to realize that 23. **P-Q5** was only a temporary pawn sacrifice; that is, it saw that it would later win back the pawn and retain all the other advantages.

As figure 5.7 illustrates, however, computers can sometimes lack basic chess concepts that are understood even by amateur players. The diagram shows the final position in Game 6 of the match. Although Deep Blue was actually a pawn ahead, its pieces were all trapped, or immobilized. Deep Blue had not recognized the danger in this position many moves earlier, when there was still a chance to avoid it. If Deep Blue had not resigned, Kasparov could have won easily by, for example, opening up the king side and attacking the undefended king. The human ability to reason about permanently trapped pieces was a deciding factor in this game.

Although the competitive aspects of human-versus-computer play attract considerable attention, cooperation between man and machine is becoming more and more common. Many grandmasters use PC chess programs to help them analyze chess positions. And players can now learn more about chess endgames by studying computer-generated endgame databases that demonstrate perfect play in positions with five or fewer pieces on the board. But, perhaps most notably, Kasparov feels that the 1996 match with Deep Blue helped him understand more about chess. This may be a sign of things to come.

The Future of Computer Chess

Early optimism in the field of artificial intelligence led people to believe that the chess problem would be relatively easy to solve. In the late 1950s, Herbert Simon, one of the founding fathers of artificial intelligence, predicted that it would take only ten years for a machine to become world champion. Despite his expertise in the field, Simon was off by at least thirty years. After Kasparov lost a regulation game to Deep Blue, many people mistakenly assumed that the chess-playing problem had finally been solved. It is becoming more and more apparent, however, that chess mastery requires an intriguing mixture of skills: pure calculation, sophisticated evaluation, learning, and a generalized reasoning capability. Although a machine like Deep Blue excels in calculation, at present it still lacks many other skills essential to consistent world-class chess play. Until computers possess the ability to reason, strong human chess players will always have a chance to defeat a computer-style opponent.

Given recent advances in hardware speed and algorithms, I believe Kasparov's loss to a machine in a regulation match was inevitable. Kasparov still has the advantage in that he has the ability to adapt quickly to weaknesses in a computer opponent, a skill that current chess-playing machines lack. With continued progress, however, it is likely that we will see the end of competitive matches between man and machine sometime in the next century. Certainly competitive chess will continue: man against man; machine against machine. Ultimately, though, the computer's superiority over human players will be so great that the only value in man-versus-machine play would be the instructional benefit it provides human players, or - as in *2001* - ts recreational use on journeys to faraway planets. The applications that have been, and will continue to be derived from developing a world-class chess machine will advance our use of computers as tools for solving other complex problems. Even so we are still decades away from creating a computer with HAL's capabilities.

Acknowledgments

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Murray S. Campbell is a research scientist at the IBM T. J. Watson Research Center in Yorktown Heights, New York, and one of the original memers of the Deep Blue computer chess group. He was the recipient of an IBM Outstanding Innovation Award for his work on the Deep Blue project. Deep Blue and its predecesors have won many awards and distinctions: the first computer to defeat a grandmaster in tournament play, the Fredkin Prize for the first grandmaster-level chess computer, the OMNI Challenge Prize, and first computer to defeat world chess champion Garry Kasparov in a regulation game. The programs developed by Campbell and his colleagues have also won numerous ACM International and World Computer Chess championships.

Campbell received his doctorate from Carnegie-Mellon University and his masters from the University of Alberta. He has been involved in computer chess research for more than fifteen years and is himself an expert chess player and the former chess champion of Alberta. He has coauthored a number of papers on computer chess, including a Mephisto Award-winning paper on selective searcch algorithms. His principal research interest is the use of brute-force search as a means of solving complex problems. Other interests include data-mining and parallel-search algorithms.

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GMT: Kasparov vs Deep Blue

IBM T.J. Watson Research Center

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HAL'S LEGACY: FIVE

Appendix

When *2001* was filmed, descriptive notation of chess moves was still quite common; nowadays algebraic notation is the standard worldwide. In algebraic notation every square on the chessboard has a unique name, as shown in figure 5.8. Moves are written with the letter for the piece first, followed by the destination square for the piece. For pawn moves there is no piece symbol. As in descriptive notation, kingside castling is denoted 0-0.

Kubrick and Clarke used the game Roesch-Schlage, Hamburg, 1913 as the source of the chess position and moves played between Frank and HAL. Here is the record of the full game.

White, played by Frank, moves first; HAL is Black.

1. **e4 e5** 2. **Nf3 Nc6** 3. **Bb5**

These moves signal the Ruy Lopez, one of the most popular openings in grandmaster play.

3... **a6** 4. **Ba4 Nf6** 5. **Qe2**

Frank chose the Worall variation. This move is much less common than the standard 5. 0-0.

5... **b5** 6. **Bb3 Be7** 7. **c3 0-0** 8. 0-0 d5 9. **exd5?!**

The notation ?! means "a dubious move." 9. exd5 is quite risky, and the move 9. d3 is the almost universal choice among top players.

9.... **Nxd5!?**

The **!?** notation means "an interesting move." HAL plays an extremely aggressive and trappy move, perhaps having learned after many games with Frank that such aggression usually pays off. Opening books recommend the move 9. ... **Bg4** in this position.

10. **Nxe5 Nf4** 11. **Qe4 Nxe5** 12. **Qxa8??**

This is the losing move. If Frank had played 12. **d4** he would have had a small advantage, which is why 9. .. **Bg4** is generally considered to be the best move. Here is one clue to HAL's method of playing chess: he chooses a nonoptimal move at move 9, which creates a difficult situation for Frank, one in which it is easy to make a mistake. Current computer chess programs are just beginning to take such considerations into account.

12.... **Qd3!**

Deep Blue would see this strong move in about one second. Frank no longer has any real defense.

13. **Bd1 Bh3**

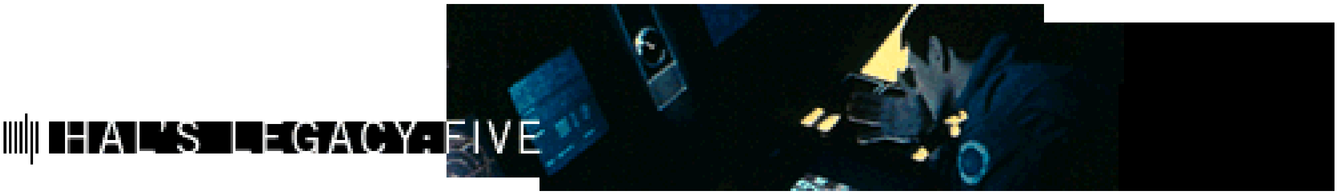
According to Deep Blue, 13. ... **Nh3** would have forced a checkmate one move sooner. The position after 13. ... **Bh3**is where the movie picks up the game (see figure 5.9).

14. **Qxa6**

This allows a checkmate in five moves. All the moves HAL plays in the movie would be found in a fraction of a second by Deep Blue.

14. .. **Bxg2** 15. Re1 Qf3!, and White resigns (see figure 5.10).

A pretty queen sacrifice to finish the game. HAL gives the continuation16. **Bxf3 Nxf3** mate.There were various ways to postpone the checkmate a couple of moves (e.g., 16. **Qc8 Rfc8** 17. **h4 Nh3** 18. **Kh2 Ng4 mate**).



Further Reading

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Peter W. Frey, ed. *Chess Skill in Man and Machine*, 2nd ed. New York: Springer-Verlag, 1983. A classic collection of early papers, including the much-studied paper by Slate and Atkin on the Chess 4.5 program.

Feng-hsiung Hsu, Thomas Anantharaman, Murray Campbell, and Andreas Nowatzyk. "A Grandmaster-level Chess Machine." *Scientific American* 263,4 (October 1990). A review of the history of computer chess and a description of the Deep Thought chess machine, the predecessor to Deep Blue.

David Levy and Monty Newborn. *How Computers Play Chess*. New York: Computer Science Press, 1991. A broad overview of computer chess from its historical development to basic tips on how to write a chess program.

T. Anthony Marsland and Jonathan Schaeffer, eds. *Computers, Chess, and Cognition*. New York: Springer-Verlag, 1990. A fairly technical collection of papers, this book describes advances in computer chess through 1989 and examines the relationship between computer chess and artificial intelligence. It includes detailed descriptions of Cray Blitz, Hitech, and Deep Thought.

Claude Shannon. "Programming a computer for playing chess." *Philosophical Magazine* 41 (1950): 256-75. The original and still much-referenced paper.

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EXPLORATIONS

Celebrating HAL's Birthday

This site was produced on an Apple Macintosh system, and proofed on an IBM Aptiva running WIN95. The following software was used:
Barebones Software BBedit 4.0.1
Adobe Photoshop 3.0.5
Equilibrium Debabilizer 1.6.5
Avid/Digidesign Sound Designer 2.3
Netscape Navigator 2.02 and 3.0.1
Imagery was scanned and corrected on a Linotype-Hell Saphire scanner, using LinoColor lite software.

Credits
This Website is the product of a collaborative effort between a number of people involved with the evolution, development, and production of HAL's Legacy: 2001's Computer as Dream and Reality.

Benjamin Williams of Blue Period. was responsible for the graphic design of the site. Matt Wise provided Java council.

Marney Smyth was the project manager for the Web treatment of HAL's Legacy: 2001's Computer as Dream and Reality. She is Producer/Editor with the Digital Projects Lab at the MIT Press, where she is also responsible for the development of online resources in the fields of cognitive and brain sciences.

Bob Prior, Acquisition Editor at the MIT Press for HAL's Legacy: 2001's Computer as Dream and Reality, has been an enthusiastic and energetic supporter of the site's development, and a most generous source of ideas and innovative links.

Michael Rutter, Assistant Acquisitions Editor at the MIT Press, performed the daunting task of running interference between Production, Design, and WebTeam schedules. Indefatigable in commitment, as he is graceful under pressure!

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