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BOOK CLUB SYNOPSIS

Deep Thinking:
Where Machine Intelligence Ends and Human Creativity Begins
Garry Kasparov

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Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins

Widely considered to be the history's greatest chess player, Garry Kasparov shot to fame in his early 20s as the youngest world champion to date. In 1997, Kasparov faced off with IBM computer "Deep Blue", which, in defeating him, alerted the world to the advancements of artificial intelligence.

The moment was considered to be more than a century in the making; Kasparov uses the pages of *Deep Thinking* to recount the event for the first time, and to look into the future of intelligent machines. *Deep Thinking* argues that humanity is at the precipice of reaching unforeseen advances with the help of our most remarkable creations.

ABOUT THE AUTHOR

Garry Kasparov is a global human rights activist, author, speaker and former world chess champion. His keynote lectures and seminars on strategic thinking, achieving peak performance and tech innovation have been acclaimed in dozens of countries. A frequent contributor to the *Wall Street Journal*, he is the author of two books, *How Life Imitates Chess* and *Winter is Coming*, each of which has been translated into more than a dozen languages. He is a Senior Visiting Fellow at the Oxford Martin School, working in cooperation with the Future of Humanity Institute. He lives in New York.

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intro

Hamburg, June 6, 1985. “I was inside a cramped auditorium, pacing around inside a circle of tables upon which rested thirty-two chessboards,” writes Garry Kasparov. “Across from me at every board was an opponent, who moved promptly when I arrived at the board in what is known as a simultaneous exhibition. ‘Simuls,’ as they are known, have been a staple of chess for centuries, a way for amateurs to challenge a champion, but this one was unique. Each of my opponents, all thirty-two of them, was a computer.” Kasparov—22 years old at the time—played for more than five hours, battling the machines provided by the four leading chess computer manufacturers. By year’s end he would be history’s youngest world chess champion: “I was fearless, and, in this case, my confidence was fully justified.” Kasparov achieved a perfect 32-0 score. According to the author, this was the golden age of human versus machine chess.

Fast forward 12 years to May 1997 in New York City, when Kasparov fought for his “chess life against just one machine, a $10 million IBM supercomputer nicknamed ‘Deep Blue.’” *Newsweek* magazine called this epic clash “The Brain’s Last Stand,” and the battle became the most famous human-machine competition in history.

Today, chess has changed so much that you can download free chess apps on your smartphone that can “crush any human Grandmaster.” And to turn the tables, notes Kasparov, “You can easily imagine a robot in my place in Hamburg, circling inside the tables and defeating thirty-two of the world's best human players at the same time." The robot would have more difficulty going from table to table than in calculating the chess moves. Proclaims Kasparov, "We have advanced further in duplicating human thought than human movement."

- **Moravec's Paradox:** What machines are good at is where humans are weak, and vice versa. Kasparov quotes roboticist Hans Moravec's observation: "It is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility." Within 10 years, the same observation applied to chess: The machines struggled with recognizing patterns and strategic planning—areas where Grandmasters excelled—but within seconds could calculate tactical complications that took humans days to work out.
- **Advanced Chess:** Building off of Moravec's Paradox, Kasparov created a match in 1998 in León, Spain, where players used a PC running the chess software of their choice alongside them, creating a machine-human partnership that resulted in the highest level of chess ever played. These competitions demonstrated that "chess still had a lot to offer the worlds of human cognition and artificial intelligence."

The dream of intelligent machines: A chess-playing machine has been a holy grail since long before it was possible to make one.

- In the 18th and 19th centuries, a chess-playing automaton, which featured a wooden figure moving the pieces, toured Europe and the Americas. "The Turk," as it was known, played against chess aficionados, including Napoleon Bonaparte and Benjamin Franklin. It turned out to be a hoax, as a human was hidden inside the cabinet under the table.
- Alan Turing wrote the first real chess program in 1952, processing a chess algorithm on pieces of paper, making himself the CPU that allowed his chess machine to play a competent game.
- In the Turing test, an experiment that followed Turing's first chess iteration and took his name, "the essence is whether or not a computer can fool a human into thinking it is human and if yes,

> it is said to have passed the Turing test." Even before Kasparov faced Deep Blue, some computers passed the test, and some games fought between these computers would have been comparable to the matches taking place in any strong human tournament.

Reflecting on Deep Blue, Kasparov believes that although artificial intelligence enthusiasts were pleased with the attention and result, the computer was "intelligent the way your programmable alarm clock is intelligent." He asserts: "Instead of a computer that thought and played chess like a human, with human creativity and intuition, they got one that played like a machine, systematically evaluating up to 200 million possible moves on the chess board per second and winning with brute number-crunching force." Kasparov admits that he found it difficult to re-examine every aspect of that infamous match with Deep Blue for the first time in 20 years. "There are many books about Deep Blue," he says. "But this is the first one that has all the facts and the only one that has my side of the story."

Machine and humans working together: "I'm receiving more and more requests to talk about artificial intelligence and what I call the human-machine relationship," writes Kasparov. Having met with one of the creators of IBM's Watson, as well as visiting companies such as Google, Facebook and Palantir, where algorithms are their lifeblood, he has listened "closely to the interests of the business world regarding intelligent machines. Much of this book is dedicated to addressing these concerns and separating inevitable facts from conjecture and hyperbole." Now a senior visiting fellow at the Oxford Martin School's Future of Humanity Institute, in this book he promises to "take some of the sophisticated, often arcane, expert research, predictions, and opinions and to serve as your translator and guide to their practical implications while adding my own insights and questions."

The folk legend of John Henry: The story of John Henry, the "steel-driving man" racing against the newly invented steam-powered hammer to plow through a mountain, shows the "pattern that has repeated over and over for centuries. People scoffed at every feeble attempt to substitute clumsy, fragile machines for the power of horses and oxen." Kasparov sees himself as the "John Henry of chess and artificial intelligence." Think of the changes they have produced: operatorless elevators, driverless cars, airports with self-check-in kiosks, iPads that take food orders and automated computer help desks. "John Henry won his race against the machine only to die on the spot, 'his hammer in his hand,'" writes Kasparov. "I was spared such a fate myself and humans are still playing chess, in fact more today than ever."

Artificial intelligence and looking ahead: "I remain an optimist," says Kasparov. "Artificial intelligence is on a path toward transforming every part of our lives in a way not seen since the creation of the internet, perhaps even since we harnessed electricity."

Kasparov closes his introduction with an outline of some the questions, observations and concerns from A.I. experts like Elon Musk and Stephen Hawking:

- When you program a machine, you know its capabilities. What if the machine programs itself? What might it do?
- How do you face your fears when you encounter something new—whether it's a ride in a driverless car or your new computer boss that issues an order at work?
- New jobs are being created—such as mobile app designers, drone pilots, 3-D print engineers and genetic counselors—and this trend will continue and accelerate.
- Robotics frees humans from routine work and allows them to use new technologies productively.

Concludes Kasparov: "Machines that replace physical labor have allowed us to focus more on what makes us human: our minds. Intelligent machines will continue that process, taking over the more menial aspects of cognition and elevating our mental lives toward creativity, curiosity, beauty, and joy. These are what truly make us human, not any particular activity or skill like swinging a hammer—or even playing chess."

A lifetime of chess triumphs: Kasparov was a chess prodigy who became the world's youngest champion at 22. His career took shape concurrently with the creation of chess playing computers.

- Grew up in Baku, Azerbaijan, which was part of the Soviet Union, where chess was officially promoted as a national pastime. Kasparov was recruited into the Soviet chess program at a very young age and trained in the school of former world champion Mikhail Botvinnik.
- 1983: Introduced to computers when he was given an Acorn computer and began playing a computer game called Hopper.
- 1984: Began his first match in September against world champion Anatoly Karpov. This marathon match dragged on for 48 games and five months before it was canceled by the World Chess Federation.
- 1985: Played his first public event against computers in a simultaneous exhibition in Hamburg on June 6, resulting in the 32-0 rout.
- 1985: Became the world champion in November when he defeated Karpov. At 22 years old, he was the youngest champion ever.
- 1987: His friendship with German chess fan and science writer Frederic Friedel led to the development of the professional chess software ChessBase. Kasparov tested it during a special exhibition.
- 1984-1990: Played five consecutive world champion matches against Karpov. This unprecedented series of contests elevated the game and brought it worldwide attention.
- 1989: Took on IBM's Deep Thought on October 22 in New York City, defeating it in a two-game match.
- 1996: On February 10, Kasparov lost the first of a six-game match to Deep Blue. By the end of the match, however, he defeated Deep Blue 4-2.

- 1997: The rematch between Kasparov and Deep Blue took place in New York City on May 3-11, he ultimately lost to Deep Blue 3.5-2.5. Deep Blue's victory was hailed as a milestone in artificial intelligence.
- 1998: Participated in an Advanced Chess game, where computers participated alongside the players.
- 2003: Played a drawn six-game match against a PC program called X3D Fritz, wearing a pair of 3-D glasses and making moves on a floating virtual reality board.
- 2003: Played a drawn six-game match against Deep Junior, the world's strongest chess program for personal computers.
- 2005: Retired from professional chess.

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CHAPTER ONE

THE BRAIN GAME

How long have humans been playing chess? Historians have identified an Indian precursor strategy game known as *chaturanga*, which dates to before the sixth century and spread through Persia, into the Arab and Muslim worlds and then into Europe. The modern game, which extended the ranges of the queen and bishop, appeared at the end of the 15th century in Europe. By the 18th century, the current rules of chess were defined. Kasparov writes, "This rich history includes thousands of games from great masters of centuries past, with each move, each brilliancy and each blunder, perfectly preserved in chess notation as if trapped in amber."

Chess's global heritage makes it unique, but it is hardly an elitist game. Surveys estimate that hundreds of millions of people around the world play. "The ability to play chess well has always had a special mystique as a representation of intelligence, a statement that applies equally to both human and machine players." He argues that although there is little to no proof connecting chess skills and general intelligence, players who exceed have the reputation of being strategic thinkers with advanced intellectual prowess.

Playing chess: In the following chapters, Kasparov describes phase by phase the numerous games he and others have played:

- The start—the opening phase—is a matter of study and recall for professionals. Openings are chosen from the player's personal mental library based on preparation and knowledge of opponents. Stronger players demonstrate superior pattern recognitions and a type of "packaging" of information recall that is referred to as "chunking."

- The evaluation aspect involves understanding and assessing what players see in their mind's eye; everyone has different opinions of given positions and moves. "All this visualization and evaluation must be verified by calculation, the 'I go here, he goes there, I go there' mechanics that novices rely on—and that many assume incorrectly to be what chess is all about."
- The executive process determines a course of action, and it decides *when* to decide. Since time can be limited in a serious game, players must decide when to make a certain move: "Your clock is ticking and your heart is racing!"
- Games can last for six or seven hours. Humans, unlike machines, must cope with various emotional and physical responses—including fatigue, hunger and distractions found in their surroundings—during each moment of the game.
- There is no luck element in chess; it is entirely an information game, since both sides know everything about the positions all the time. Everything is under the player's control.

What separates the good players from the great in chess? While some might try IQ tests as a measurement tool, Kasparov shares what he once said in a 1987 interview with Der Spiegel: "'The willingness to keep trying new things—different methods, uncomfortable tasks—when you are already an expert at something is what separates good from great."

Looking back on his career, Kasparov observes: "My matches against computers, which spanned nearly the entire twenty years I spent as the world's top-rated player, allowed me to think about chess as something other than a competition. Battling each new generation of chess machines meant participating in a hallowed scientific quest, sitting at the nexus of human and machine cognition, and holding up the banner for mankind." While he might have spurned the invitations to play against machines, he chose to face them because he was fascinated by both the machines and the experiment. "What could we learn from a strong chess machine? If a computer could play world-championship-level chess, what else could it do? Were they intelligent, and what did that that really mean? Could machines think, and what did the answers tell us about our own minds? Some of these questions have been answered while others are more passionately disputed than ever," he concludes.

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CHAPTER TWO

RISE OF THE CHESS MACHINES

Kasparov opens the chapter with an observation: "In 1968, when the *2001* book and movie were created, it was not yet a foregone conclusion that computers would come to dominate humans at chess, or anything else beyond rote automation and calculation." The dawn of the computer age began with utopian dreams and dystopian nightmares. "This is a critical point to keep in mind before we criticize or praise anyone for their predictions, and before we make our own. Every disruptive new technology, any resulting change in the dynamics of society, will produce a range of positive and negative effects and side effects that shift over time, often suddenly." Should you embrace these new challenges or resist them? Asks Kasparov: "Will we help shape the future and set the terms of our relationship with new technology, or will we let others force the terms on us?"

The fallacy of machine intelligence: Kasparov describes a fallacy of machine intelligence: If a machine can be taught to play chess well, then the secrets of human cognition will be unlocked. He is adamant that generations of scientific minds have fallen into this trap when contemplating machine intelligence.

- Humans confuse performance—the ability of a machine to replicate or surpass human results—with the method of how the results are achieved.
- Two versions of this fallacy romanticize and anthropomorphize machine intelligence. One version maintains that "the only way a machine will ever be able to do X is if it reaches a level of general

intelligence close to a human's." The other is that "if we can make a machine that can do X as well as a human, we will have figured out something very profound about the nature of intelligence."

- Machines don't have to operate the same way that the natural world does in order to be useful or surpass nature. Why then must computer brains work as human brains do to achieve results?
- "The mind goes beyond reasoning to include perception, feeling, remembering, and, perhaps most distinctively, *willing*—having and expressing wishes and desires."

How machines play chess: In 1949, Claude Shannon, an American mathematician, engineer and well-read chess player, wrote a paper called "Programming a Computer for Playing Chess." Shannon felt that chess could be a good scientific test bed because:

- The problem is clearly defined both in allowed operations—the moves—and the ultimate goal—checkmate.
- "Chess is neither so simple as to be trivial nor too difficult for satisfactory solution;"
- Chess requires "thinking" for skillful play. "A solution of this problem will force us either to admit the possibility of a mechanized thinking or to further restrict our concept of 'thinking,'" wrote Shannon. Kasparov elaborates on this point: "Since chess requires thinking, either a chess-playing machine thinks or thinking doesn't mean what we believe it to mean."
- "The discrete structure of chess fits well into the digital nature of modern computers."

Creating a chess program would therefore require rules, piece values, an evaluation function and possible search methods that the machine could employ. Shannon described the most fundamental element of search, called the "minimax" algorithm, which would look at possibilities and sort them from best to worst. Shannon also outlined two search techniques: "Type A" and "Type B."

- Type A should be thought of as "brute force," an exhaustive search method that looks at every possible move and variation, going deeper and deeper with each pass.

- Type B should be thought of as “intelligent search,” a relatively efficient algorithm that operates more like a human player who would focus on a few good moves rather than checking everything.

Chess programming’s main problem is the large number of possible continuations of play, what is known as the “branching factor.”

- While the game starts with each side having 16 pieces—eight pieces and eight pawns—there are more than 300 billion ways to play just the first four moves in chess game. Type A programming checks all of these.
- Extending this, there are approximately 40 legal moves in an average position. Replying to each move results in evaluating some 1,600 moves. “The average game lasts forty moves, leading to numbers that are beyond astronomical,” notes Kasparov. “The total number of legal positions in a game of chess is greater than the number of atoms in the universe.”

Knowing this, Shannon placed his faith in a Type B strategy. Kasparov writes, “But as it turned out, and not for the last time, the assumption that humanlike was better than brute force was largely wrong.”

How humans—and Kasparov—play chess: Kasparov asks that you imagine stepping into a bakery to select a pastry. You usually know what types of sweets you like to order and can quickly narrow your choices. If you see something that you haven’t seen before, you still have a sense of what it is, based on your recall of other pastries. “This is how strong human chess players start evaluating moves even before we start doing any calculation. The pattern-matching part of the brain has rung a bell to attract our attention to something interesting.” If you enter a bakery where you don’t recognize anything, then you will have to do a Type A search to decide what you want to buy.

Chess players form mental patterns throughout a match and, to ensure victory, must take into account the following:

- A Grandmaster can memorize tens of thousands of positions that can be broken down into component parts, rotated and twisted and they will still be useful. While some opening sequences have been memorized, says Kasparov, "Strong human players don't rely on recall as much as on a super-fast analogy engine."

- There are forced moves in chess such as in the case of "check" when the king is attacked.
- But there are also "candidate moves," where each position has several plausible choices, and a player strategizes based on moves. "Most of my search and evaluation time is spent on the main variation," notes Kasparov. "The human mind isn't a computer; it cannot progress in an orderly fashion down a list of candidate moves and rank them by a score down to the hundredth of a pawn the way a chess machine does."
- Humans learn that only a handful of moves make sense, and the stronger the player, the faster and more accurately the initial sorting is done.
- Human chess players rely on concentration, mental organization and also intuition.
- Humans have to worry about "psychological dramas. A game of chess is an intense competition, not a laboratory experiment. Under pressure, with a ticking clock, mental discipline breaks down."

The arrival of chess-playing machines and modern chess programming: Chess computing moved from the realm of imagination to reality in 1956 with the development of a chess program for Los Alamos' giant computer MANIAC 1. However, it was limited to using a reduced board of six-by-six squares without bishops. It first played against itself and then lost to a strong player, who had also played without a queen. Then it beat a young volunteer who had just learned to play chess. "It was the first time a human had lost to a computer in a game of intellectual skill."

There were still significant hurdles for the computers to complete. Programmers were forced to overcome a multitude of obstacles in their bid to create the perfect chess computer.

- While a group of researchers at Carnegie Mellon University declared in 1957 that they had found the secret to a Type B algorithm that would result in the defeat of a world champion in 10 years, it didn't happen until 1997. Chess was too complex, and the machines were too slow.

- The programmer has to add chess knowledge—such as the concept of checkmate and the values of pieces—to the machine's search algorithm, which results in trade-offs. "A chess program can either be faster and dumber or slower and smarter. It's a fascinating balancing act, and it took decades to create machines that were both smart enough and fast enough to challenge the world's best human players."
- Type A programs were soon favored as programs stopped focusing on moves that returned a lower value than the currently selected move. "Efficient brute force," writes Kasparov, "was dominant over every attempt to emulate human-style thinking and intuition in chess machines. Some chess knowledge was still necessary, but speed was king."

"All modern chess programs are based applying this alpha-beta pruning search algorithm to the basic minimax concept," he writes. "On this structure, the programmers build the chess evaluation function, tuning it for optimal results. The first programs using this technique, running on some of the fastest computers of the day, reached a respectable playing strength. By the late 1970s, programs running on early personal computers like the TRS-80 could defeat most amateurs."

Later, there was the development of Bell Laboratories' Belle, which could search approximately 180,000 positions per second and was capable of calculating outcomes up to nine half-moves ahead during a game. Between 1980 and 1983, Belle won almost every computer chess event. In 1988, Carnegie Mellon's HiTech hit a milestone when it received a Grandmaster rating, but HiTech was soon outdone by Deep Thought, created by students Murray Campbell and Feng-hsiung Hsu. In November 1988, Deep Thought defeated a Grandmaster in a regular tournament game. After Hsu's and Campbell's 1989 graduation, they brought Deep Thought to IBM, where it was renamed to reflect the company's nickname "Big Blue." As Kasparov notes, "Deep Thought became Deep Blue and the last great chapter of the machine chess story began."

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CHAPTER THREE

THE PLATINUM RULE OF FRIENDSHIP

"Human competition with machines has been part of the conversation about technology since the first machines were invented," writes Kasparov. Beginning with the Industrial Revolution and continuing through the robotics and information revolutions of today, the narrative has remained the same: people feel threatened by changing technology. They fear they are losing the race against the machine and are being rendered redundant. "Every profession will eventually feel this pressure, and it must, or else it will mean humanity has ceased to make progress," maintains Kasparov. "The transfer of labor from humans to our inventions is nothing less than the history of civilization." Every industry and every workforce will need to adapt. "There is no back, only forward," he says.

Kasparov outlines the realities of rapidly evolving technology:

- Companies globalize, and labor is fluid. You can't pick and choose when or where technological progress will stop. New technologies generate economic growth rather than impoverish people.
- It's more effective to educate and retrain workforces to adapt to change than to attempt to preserve the status quo or go backward.
- You can't throw away the downsides of globalization yet retain its benefits, as the two go hand-in-hand.

- A so-called “Sputnik moment”—named for the launch of the Soviet satellite in 1957—galvanizes innovation as well as sparking fear. Embrace it rather than step away: “Any transformative effort on a national scale requires the focused minds of politicians, business leaders, and a plurality of citizens to support it,” says Kasparov.
- The U.S. needs government regulations that promote innovation rather than thwart it.

“Fighting to thwart the impact of machine intelligence is like lobbying against electricity or rockets,” Kasparov emphasizes. “Our machines will continue to make us healthier and richer if we use them wisely.” Humans compete not against machines but with themselves to improve their lives and their capabilities. “These challenges will require even more capable machines and people to build them and train them and maintain them—until we can make machines that do those things too, and the cycle continues.” As for himself, he says, “I was never one to duck a challenge, and being remembered as the first world champion to lose a match to a computer cannot be worse than being remembered as the first world champion to run away from a computer.”

How chess machines augment play: Strong chess machines, which might be analogous to steroids or other types of coping in physical sports, influence human play. Chess is concrete, and computers, moves and strategies can be exactly duplicated by humans. Kasparov poses these questions:

- What if machines showed us that some of the most popular chess moves were bad and how to beat them?
- Would humans become the automatons, regurgitating the moves learned from machines?
- Would the winner be the player with the strongest computer at home?
- Would there be an epidemic of computer-assisted cheating?

Kasparov’s early interest in chess machination focused on developing tools to help with his preparation, and he discussed his ideas with others. The groundbreaking program ChessBase, which ran on an

Atari ST and was released in 1987, had "the ability to collect, organize, compare and review games with just a few clicks." At the time, Kasparov called it "as revolutionary for the study of chess as the printing press." He started using it, finding that "[he] was able to bring up and review ... opponents' previous games in hours, a process that would have taken weeks without a computer." In a competition for which he had just two days of preparation, he was able to play a rematch and win. He notes, "That was when I knew I was going to be spending a lot of time in front of a computer for the rest of my career. I just didn't realize yet how much of that time would be spent playing against them."

Strong chess programs greatly democratized the game, since learning to play was no longer dependent upon access to coaches in countries where chess was already popular. These programs also brought about the emergence of younger players. "The key factor in producing elite chess talent is finding it early," observes Kasparov.

The long-running human versus computer chess rivalry—what it teaches about artificial intelligence and human cognition: Looking beyond the results (from the wins and losses) to the moves is key to understanding what computers and humans are best at and what their unique struggles are and why. Chess machines' progression—from weak to interesting to strong and ultimately superior to humans—has been repeated with other A.I. programs such as speech recognition, speech synthesis, self-driving cars and virtual assistants. "Then there comes another shift," observes Kasparov, "when a tool becomes something more, something more powerful than even its creators had in mind."

Man versus machine chess games: The first recorded game took place on April 4, 1963, in Moscow, when Soviet Grandmaster David Bronstein played a full game against a Soviet program running on a Soviet M-20 mainframe computer. "Bronstein's win was an urtext of the first generation of (strong) human versus machine chess: the computer gets greedy and is punished. Early programs' evaluation functions were heavily weighted toward material value. That is, which side has more pieces and pawns," writes Kasparov. This focus on grabbing pieces is how novices play. Beginners learn from experience that if a king is checkmated, it doesn't matter how many pieces the player has captured.

Humans learn from experience, but early chess machines couldn't. "Even well into the 1980s, if you timed it just right you could replay an entire game against a computer, beating it the same way move for move," says Kasparov.

The infancy of computer chess includes a number of since discontinued programs, false starts and algorithms which took decades to strengthen.

- In the early years, experts believed that it would be impossible to create a strong Type A (brute force) program. This was because computers were very good at chess calculations but poor at recognizing patterns and analogical evaluations, and they were slow.
- The first program to play competent chess was developed in the late 1950s at MIT: the Kotok-McCarthy program that ran on an IBM 7090 and included alpha-beta pruning to speed its search.
- The MacHack VI program, which was developed in the late 1960s and built on the Kotok-McCarthy program widened search and added a database of thousands of opening moves. It was the first computer program to play in a human chess tournament and received a chess rating. "The days of Type B programs were numbered," says Kasparov, "even more so than those of humans. Brute force was coming."
- Starting in 1987, ChessBase became synonymous with professional chess software.

Computers begin to dominate chess preparation: With the emergence of ChessBase and other programs, computers became key to preparation and success. All of Kasparov's preparation was done on his Compaq laptop, which was more efficient and lighter than lugging around paper notebooks and chess books. Grandmasters traveled to competitions with their laptops, and with the internet's widespread adoption, chess players could download the latest games shortly after they were played. New opening moves were imitated by players rapidly. Young players, using PC database programs, could now "plug into the fire hose of information," Kasparov describes. "How professional chess changed when computers and databases arrived is a useful metaphor for how new technology is adopted across industries and societies in general."

The chess machines are coming for the world champion: As chess machines evolved, it became clear that brute force—with a sufficiently speedy search—was adequate enough to play strong chess. The creators of the machines of the 1950s and 1960s struggled to figure out whether the machines would be based on Type A or Type B search. By the 1980s, the combination of faster hardware and 20 years' worth of programming improvements had fully merged. In 1986, David Levy, who is now the president of the International Computer Games Association, posed the inevitable question in the title of an article in *ICGA Journal*: "When Will Brute Force Programs Beat Kasparov?"

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CHAPTER FOUR

WHAT MATTERS TO A MACHINE?

Pablo Picasso reportedly said, “Computers are useless. They can only give you answers,” Kasparov concurs. “Computers are excellent tools for producing answers, but they don’t know how to ask questions, at least not in the sense that humans do.” Even the strongest chess program can’t explain why a brilliant move is made beyond elementary tactical sequences. A computer makes a move because it evaluates the option against its database rather than the type of analytical reasoning that people use. Kasparov quotes Dave Ferrucci, one of the creators of IBM’s A.I. project Watson, who says: “Computers *do* know how to ask questions. They just don’t know which ones are important.” Building on this assertion, Kasparov examines what a computer can and can’t do. The simplest program can perform automated digital note taking, posing scripted questions and recording the answers. Type in your questions or problem, and the help system identifies a key term such as “crash” to offer you helpful information.

The difference between strategy and tactics: It’s essential to understand your long-term goals—otherwise you could confuse them with reactions, opportunities or milestones. “Machines have no independent way to know if or why some results matter more than others unless they’ve been programmed with explicit parameters or have enough information to figure it out on their own,” says Kasparov. “What does it even mean to say something matters to a machine?”

In attempting to communicate chess strategy to computers, a number of questions and observations emerged:

- Machines have been programmed for results, and humans have established their values. But what if a machine is left to figure things out for itself?
- What would it mean if a chess machine, for example, had to figure out for itself that rooks are more valuable than bishops? "This opens up the possibility of not only creating a strong chess machine but also that humans will learn something new from what the machine discovers and how it discovers it."
- Genetic algorithms and neural networks are techniques used today to let different systems program themselves. In chess, however, they have not been found to be stronger than the traditional fast-searching programs and brute force. "Chess just isn't complex enough," says Kasparov. "For better or worse, chess just wasn't deep enough to force the chess-machine community to find a solution beyond speed."

AlphaGo: In 1990, computer scientists began advocating the game Go as a more promising target than chess for developments in A.I. In contrast to chess, Go's 19-by-19-inch board with its 361 black and white stones is too big of a matrix for brute force to crack and too subtle to be decided by the types of tactical blunders that define human losses to computers at chess. It wasn't until 2016 that Google's A.I. project DeepMind and its Go-playing offshoot AlphaGo defeated Lee Sedol, the world's top Go player. As an A.I. project, the methods used to create AlphaGo are more interesting than those that produced the top chess machines such as IBM's Deep Blue. "[AlphaGo] uses machine learning and neural networks to teach itself how to play better, as well as other sophisticated techniques beyond the usual alpha-beta search," says Kasparov. "Deep Blue was the end; AlphaGo is a beginning."

Machine intelligence: Generations of computer scientists and developers of artificial intelligence have based their work on the assumption that the human brain is itself a kind of computer. Therefore, the goal was to create a machine that successfully imitated human behavior, seeing neurons as switches and cortexes as memory banks. "It is a distraction from what makes human thinking so different from machine thinking."

From his point of view, the differences are understanding and purpose. Recognizing these differences has become a vital realization in applying human reason to the processes of computers.

- Applying context comes naturally to humans. For example, when someone tells you that "the chicken is too hot to eat," you will understand from the context whether the food needs to cool down, is too spicy, or that the bird is ill.
- Contrast that scenario with how a machine deals with information. It has to figure out what a chicken is, whether it is alive or dead, where it is and if it is edible. "Machine intelligence has to build context for every new piece of data that it encounters. It has to process a huge amount of information to simulate understanding."

Summing up: Kasparov concludes the chapter by making the following observations:

- "A medical diagnostic A.I. can dig through years of data about cancer or diabetes patients and find correlations between various characteristics, habits, or symptoms in order to aid in preventing or diagnosing the disease. Does it matter that none of it 'matters' to the machine as long as it's a useful tool?"
- "The trajectory so far has been as follows: We create a machine that follows strict rules in order to imitate human performance. Its performance is poor and artificial. With generations of optimization and speed gains, performance improves. The next jump occurs when the programmers loosen the rules and allow the machine to figure out more things on its own, and to shape or even ignore the old rules. To become good at anything, you have to know how to apply basic principles. To become great at it, you have to know when to violate those principles."
- "This isn't only a theory; it's also the story of my own battles against chess machines over two decades."

05

CHAPTER FIVE

WHAT MAKES A MIND

Chess is a competitive sport, and it comes down to win, lose or draw. Players experience intense psychological and physical exertion during a game and a crisis—whether it is delight, depression or recovery—after the game. "What sports science calls the 'stress response process' is at least as powerful in chess as it is in more physical sports," says Kasparov. The "pitched battle" aspect of human chess playing has resulted in a psychological approach to the game. German world champion Emanuel Lasker wrote that the best move was the one that made an opponent most uncomfortable: "To play the man, not the board."

From the machine's viewpoint, the physiological and psychological demands of chess playing are inconsequential. Machines don't get overconfident or distracted, suffer from fatigue or anxiety as the timer ticks down, nor do they need to stretch their legs or take restroom breaks. Machines don't get upset when they break down, while their crash can be very disturbing to their human competitors. "[The machine] is only a human puppet, relaying the moves of an algorithm," says Kasparov. "If chess is a war game, how can you motivate yourself to go to war against a piece of hardware?"

Motivation is also a key factor in successful elite chess games, as competitors have to maintain an intense level of concentration for extended periods of time. This cognitive skill or talent will vary based on the individual. "The ability to push yourself, to keep working, practicing and studying more than others is itself a talent," Kasparov notes. “Reaching peak human performance requires maximizing every aspect of our abilities wherever we can, including preparation and training, not only while at the chessboard or in the boardroom.”

Facing a computer opponent: Computers do have distinct strengths and weaknesses—far more distinct than any equally strong human player would have. They cannot play strategically, but they are too accurate tactically for a human to exploit those subtle weaknesses today.

In the past, human players who were aware of machine handicaps could develop anti-computer strategies:

- Humans can look at a chessboard, for example, and think in generalities such as “My king is weak” or “His knight is in a threatening position.” By contrast, if a computer’s brute force algorithm cannot reach deep enough to see a position in its search tree, it doesn’t exist. Humans competing with computers must discard said generalities to outmaneuver their programmed opponent.
- Another anti-computer strategy involved playing passively and solidly until the computer created weaknesses in its own position. “Having no concept of biding its time, machines would advance pawns, put pieces out of position, and generally wander without a plan unless there were concrete targets to attack or defend.”
- Later programming techniques allowed computers to fantasize by looking at hypothetical positions, but this slowed down its main search.

Of the human versus machine chess games of the 1980s, “I can say that they did not play good chess,” Kasparov notes. “But they were increasingly dangerous because humans make so many mistakes of the kind that computers are perfectly designed to exploit. In purely chess terms, a human versus machine game is asymmetrical warfare. Computers are very good at sharp tactics in complex positions while that is a human’s greatest weakness. Humans are very good at planning and what we call ‘positional play,’ the strategic and structural considerations and quiet maneuvering.”

The culture of chess: In 1989, A.I. pioneer Donald Michie observed that "Chess is a culture shared among colleagues who form a human community, however adversarial the game may be in itself. After play, opponents commonly analyze the fine points together, and many find in the tournament room the mainstream of their social life. Robot intruders contribute only brute force, not interesting chess ideas." Notes Kasparov, "Being crushed by a robot that experiences no satisfaction, no fear, no interest at all is difficult to process." Add to that the player's experience of interacting with the programmers and engineers who handle the machines who might huddle around the screen to see what the computer had been processing. What is the relationship of the chess player to them? Reflecting on this, Kasparov recalls world champion Bobby Fischer's retort to a fan after a difficult win: "'Nice game, Bobby!' Fischer answered, 'How would you know?'"

The stage was set for the great human-computer chess clash once computers began crossing the ratings threshold. "Experts" are rated 2000-2200, the "Master" designation is applied to players with a ranking of 2200-2500, while Grandmasters are rated 2500 and higher. By 1983, the computer Belle had achieved a master rating, breaking 2200 in 1983. HiTech achieved a rating of 2400 in 1987, and Deep Thought followed (2500 in 1989), raising the bar in competitions that they continued to win. In 1988, Deep Thought beat a Grandmaster, repeating that feat in 1989 when it crushed another strong Grandmaster 4-0. "It was 1989," Kasparov recalls, "and the machines had finally arrived. It was time for me to enter the arena."

06

CHAPTER SIX

INTO THE ARENA

As Kasparov moved to the center stage of chess, having defeated world champion Anatoly Karpov in 1985, developments in artificial intelligence were enabling computers to play chess at the Grandmaster level. Artificial intelligence over the years underwent a resurgence, with its pioneers working on natural language, self-teaching machines and understanding abstract concepts. Computer chess developers focused on the alpha-beta search algorithm, speed and "data—lots and lots of data." A machine could be given many examples to process—instead of a set of rules to follow, which is how humans typically learn a second language—and then be asked to figure out the rules. Today's Google Translate, for example, is powered by machine learning. "As one Google Translate engineer put it, 'When you go from 10,000 training examples to 10 billion training examples, it all starts to work. Data trumps everything.'"

Yet the machines also had their limitations. Kasparov recalls a scene in the 1984 movie *Starman,* in which an alien explorer, "an extraterrestrial version of general purpose machine learning," comes to Earth and learns by watching the humans around him. When Starman is driving a car, he speeds through an intersection, causing a crash and the following dialogue with his passenger Jenny:

> **STARMAN:** Okay?
>
> **JENNY:** Okay? Are you crazy? You almost got us killed! You said you watched me, you said you knew the rules!
>
> **STARMAN**: I do know the rules.

JENNY: Oh, for your information, pal, that was a yellow light back there!

STARMAN: I watched you very carefully. Red light stop, green light go, yellow light go very fast.

JENNY: You'd better let me drive.

"Computers, like visiting aliens, don't have common sense or any context that they aren't told or cannot build. Starman was not wrong, exactly; he just didn't have enough data to figure out that accelerating at a yellow light requires much more context. Even the petabytes of data used by Watson and the billions of examples that pour into the bottomless maw of Google Translate, often lead to strange results. As is usually the case in science, what goes wrong teaches us more than what goes right."

A machine learning system is only as good as its data: Machine learning works, "but for how long?" asks Kasparov. "The law of diminishing returns is already having an impact. Getting a machine system to a 90 percent effectiveness rate may be enough to make it useful, but it's often even harder to get it from 90 percent to 95 percent, let alone to the 99.99 percent you would want before trusting it to translate a love letter or drive your kids to school."

Playing against computers is problematic because they change quickly and often: Grandmasters prepare by studying their opponents' games deeply, looking for weaknesses and focusing on openings, for example. But this is complicated for the player who faces a computer opponent.

Computer opponents apply a range of methods human players never encounter. These strategies include:

- For opening moves, computers rely on a database of moves derived from human play, what is known as an "opening book." The books have evolved over the years, but essentially the computer follows it "more or less blindly until it 'runs out of book' and has to think for itself."
- A computer opponent short-circuits a human player's extensive preparation. "Even if you go over every game the machine has played, the operator can simply load an entirely new opening book, or change a few values. And it will play them perfectly, since it has none of the human concerns over recall."

- If the operator of the computer tweaks a few values in the computer, it can play more aggressively than it did in a previous game: "There could be six different machine 'personalities' stored away so you never really face the same opponent twice in a match of six games."
- Computers keep getting stronger—the faster the computer's search speed, the stronger its playing strength: "Faster means deeper and deeper means stronger and that was all that mattered."

Kasparov's 1989 two-game match against Deep Thought: Deep Thought, which had six processors and could search over 2 million positions per second, was playing at a Grandmaster-level 2500, while Kasparov had recently broken the long-standing 2785 record of world champion Bobby Fischer. Kasparov was unafraid and well-prepared, having reviewed the machine's previous games, which its developers had provided the day before the match. The games were played at a relatively brisk pace of 90 minutes per side, with Kasparov winning both games.

"My first foray into serious man-machine chess had been an easy and enjoyable success and even the local tabloids covered the match. 'Red Chess King Quick Fries Deep Thought's Chips,' wrote the *New York Post*." After the match, Kasparov learned that the computer had played with a "castling bug," a glitch in its code that weakened its play, and also that the operator had adjusted the machine between games to make it play more slowly.

"I honestly don't recall any particular psychological impact of playing my first serious games against a computer opponent. It was different, but not yet ominous. I think I was so confident that I did not feel the usual tension I would have against a Grandmaster. It felt more like a friendly exhibition, or a sort of science experiment. This wouldn't be the case in the coming years, however, as the machines got stronger and began to appear in serious tournaments where money and prestige were at stake, not merely the future of humanity."

07

CHAPTER SEVEN

THE DEEP END

In the previous chapters, Kasparov concentrated on exploring artificial intelligence, machine learning and the developments in computer chess and their relationships to humans. In the following chapters, his focus switches to his career and game playing, while still analyzing machine versus human intelligence. He begins by stating, "I hate losing. ... To be the best in any competitive endeavor you have to hate losing more than you are afraid of it." He points out that today's online databases can bring up nearly all the serious games that he played since he was 12 years old—more than 2,400 games. Of those, he only lost approximately 170 times, and one Grandmaster has written, "Beating Garry Kasparov at chess is considerably more difficult than climbing Mount Everest or becoming a dollar billionaire."

Why start the chapter with a discussion of losing? "I want to get all this out of the way because my attitude about losing inevitably comes up in any discussion of my match with the IBM supercomputer Deep Blue. To be more precise, my rematch with Deep Blue in 1997." Although Kasparov beat Deep Blue in their first match in 1996, "when the 1996 match is remembered at all, it's because [his] loss in game one was the first time a machine had beaten the world champion in a classical time control game."

This was not the first time that Kasparov had lost to a computer. In playing "rapid" games—which allow between 15 to 30 minutes per player—as well as even shorter "blitz" and "bullet" chess, he had succumbed because "the faster the game, the greater the advantage for a computer against a human. ... Without the time to calculate properly against a machine that is checking millions of positions per second, a blitz game can quickly become a bloodbath."

Machines, data and privacy issues: Kasparov is intrigued by the thought that chess programs might be able to detect patterns and habits in human games and subsequently display a human player's vulnerabilities. Yet he notes that this has not been a direction that computer chess has gone. In other parts of daily life, data—such as texts, emails, social media posts, search history, and shopping history—are analyzed by companies like Facebook and Amazon. "People would be unnerved by seeing that analysis reflected back at them, perhaps revealing uncomfortable truths. There are countless privacy issues to be negotiated anytime such data is accessed, of course, and that trade-off will continue to be one of the main battlefields of the A.I. revolution. I would want to know what a machine says about my chess, or my mental and physical health, but would I want anyone else to know?"

Although people may cringe at what is revealed, Kasparov believes that "the desire for services wins out over a vague desire for privacy ... [and that] technology will continue to make the benefits of sharing our data practically irresistible." As the data-gathering tools become increasingly powerful—and through the internet of things, for example, people have microsensors in their plumbing, their food and even their bodies—this trend will continue to accelerate. "It will happen both voluntarily in exchange for services and due to the increasing public and private demand for security." Therefore, as the amount of data increases, it is critical that we monitor where that data goes and how it is used. "Privacy is dying, so transparency must increase," he argues.

The PC chess revolution: By 1992, some of the computer chess programs for personal computers had surpassed the strength of many of the stand-alone chess machines. Although they were slower than specialized hardware machines such as Deep Blue, these Type A brute force programs compensated by being much smarter than common programs and by having optimized programming techniques that extended search far deeper than could be done by a simple exhaustive search. Among the developments:

- In the “null” move technique, the program tells the engine to “pass” for one side—to evaluate a position as if one player could make two moves in a row. If the position has not improved after moving twice, then the first move can be assumed to be a dud and discarded from the search tree, reducing its size and making it more efficient. Notes Kasparov: “It’s elegant and a little ironic that algorithms designed on the principle of exhaustive search are augmented by being less exhaustive.” Contrast this with human strategic thinking, which involves setting long-term goals and milestones.
- The Monte Carlo tree search allows machines to extend their thinking into the hypothetical outside of the direct search tree, simulating entire games played out from positions in the search and recording them as wins, draws or losses. It stores the results and moves toward more favorable outcomes.
- Computer programs had their own DNA, and if you studied them, you could prepare for them as you did against another Grandmaster.

In 1992 and 1994, Kasparov played against the computer program Fritz 3, losing the latter time in a blitz tournament. “Then began the script that would become all too familiar to human players facing machines for the next decade. I played one lazy move and it counterattacked,” he says. “It was only blitz, with five minutes per side, but it was still the first victory over the world chess champion in a serious game by a machine. If not the moon landing, it was at least the launch of a small rocket.”

In 1994, Kasparov played two games against the program Chess Genius, losing the first and agreeing to a draw in the second in a queen-plus-knight endgame. “Both games with Genius reflected the unique nature of computer chess, especially the second game,” says Kasparov. “Chess players have the most trouble visualizing the moves of knights because their move is unlike anything else in the game, an L-shaped hop instead of a predictable straight line like the other pieces. Computers, of course, don’t visualize anything at all, and so manage every piece with equal skill.” Instead of facing human players with similar limitations, now chess’s greatest player had to face a computer opponent with incredibly complex tactical abilities.

A disturbing new dimension was added to the psychological and physical demands of play: "the new sensation of always wondering if your opponent might be seeing something you could scarcely imagine was very disturbing. It created a terrible tension in complex positions, a sense of dread that at any moment a shot could ring out in the dark," says Kasparov. This feeling led him and other players facing a computer opponent to double- and triple-check their calculations instead of trusting their instincts as they would against other people. "After a lifetime at the chessboard, you have no choice but to become a creature of habit," says Kasparov. "Those habits were all disrupted when playing against a machine. I didn't like it, but I also wanted to prove I could overcome these handicaps, and to prove that I was still the best chess player in the world, human or machine."

Boots, bugs, crashes and reboots: Rumors about a match between Kasparov and Deep Blue started in early 1995, since by then the latter was beating versions of Fritz. But was Deep Blue ready? Computer play meant contending with bugs, crashes, disconnected phone lines, interrupted internet connections, loose circuits, power failures, cold restarts and opening book errors. Says Kasparov: "In nearly every Deep Blue game description I can find from this period there are resets, crashes, reboots and disconnects." This need to periodically restart demonstrated how computer chess would wildly differ from conventional competitions.

- Operator intervention is required to get the machine into the game. With the restart, the machine may make a different move than it did before the crash.
- With the vagaries of computer chess thinking, the machine could take more time after a reboot and find an improvement or make a different move that turned out to be better.

Enter Deep Blue: When Kasparov played Deep Blue in Philadelphia on February 10, 1996, he recalls, "I was confident, but worried about the lack of information available about this new version's capabilities. Not the technical specifications, which were useless to me, but what mattered to a Grandmaster's preparation: games. The version I was facing had never played publicly before, so I really had no idea what it was capable of."

- This version could search 100 million positions per second, which meant that its master rating might be more than 2700; Kasparov's at the time was 2800+.
- IBM had hired a Grandmaster to work with the programming team to prepare Deep Blue's opening book and to serve as its second during the match in case any book adjustments were needed.

"I've had twenty years to come up with a good way to describe what it's like for a world champion chess player to play against a world-champion-level chess machine," writes Kasparov. "I'm still not sure I've succeeded. Directly competing against a computer at the highest level of a human discipline is a unique experience." When the game began, it stopped, as Deep Blue wasn't yet up and running, and it took a few minutes for this bug to be squashed. Kasparov found this distracting: "As a believer in chess as a form of psychological, not just intellectual, warfare, playing against something with no psyche was troubling from the start."

There are numerous descriptions online and in print of the plays that followed. Kasparov singles out this reflection on the game by *Time* magazine's Charles Krauthammer in 2001:

> Late in the game, Blue's king was under savage attack by Kasparov. Any human player under such assault by a world champion would be staring at his own king trying to figure out how to get away. Instead, Blue ignored the threat and quite nonchalantly went hunting for lowly pawns at the other end of the board. In fact, at the point of maximum peril, Blue expended two moves—many have died giving Kasparov even one—to snap one pawn. It was as if, at Gettysburg, General Meade had sent his soldiers out for a bit of apple picking moments before Pickett's charge because he had calculated that they could get back to their positions with a half-second to spare.
>
> In humans, that is called sangfroid. And if you don't have any sang, you can be very froid. But then again if Meade had known absolutely—by calculating the precise trajectories of all the bullets and all the bayonets and all the cannons in Pickett's division—the

> time of arrival of the enemy, he could indeed, without fear, have ordered his men to pick apples.
>
> Which is exactly what Deep Blue did. It had calculated every possible combination of Kasparov's available moves and determined with absolute certainty that it could return from its pawn-picking expedition and destroy Kasparov exactly one move before Kasparov could destroy it. Which it did.
>
> It takes more than nerves of steel to do that. It takes a silicon brain. No human can achieve absolute certainty because no human can be sure to have seen everything. Deep Blue can.

On move 37, Kasparov held out his hand to resign, and for the first time in chess history, a computer had defeated the world chess champion. "It was the best that I had ever seen a machine play, against me or anyone else and, at least at the moment of my loss, I even considered the possibility that it might be too strong to beat," he writes. Later, he recalls asking his unofficial chess advisor, "What if this thing is invincible?"

The machine wasn't: Kasparov won the match 4-2, and as he played he found that he could target its weaknesses and avoid its strengths. Kasparov notes:

- In game four, he wasn't just playing chess but was making specific adjustments to playing against a machine whose capabilities in certain areas far exceeded his or anyone else's.
- Deep Blue crashed in game four just when Kasparov was preparing a dangerous attack. Says Kasparov: "I was furious, ripped out of my state of deep concentration, at a key moment in the game." By the time the game ended (in a draw), Kasparov was exhausted. He would experience fatigue during the next two games as well.
- In the last game, Deep Blue stumbled further as it found itself making moves that got it into trouble and not knowing what to do next. "It didn't know, as a Grandmaster would, that certain pieces belong on certain squares in certain openings," writes Kasparov. "This is exactly the sort of generalized, analogous thinking that humans use all the time."

Reflecting on the match a month later in *Time* magazine, Kasparov wrote that his ability to adapt his strategy may have been his biggest advantage against Deep Blue: “I could figure out its priorities and adjust my play. It couldn’t do the same to me. So although I think I did see some signs of intelligence, it’s a weird kind, an inefficient, inflexible kind that makes me think I have a few years left.” He had, as he notes, “exactly 450 days, until the rematch on May 11, 1997. I was the last world champion to win a match against a computer.”

08

CHAPTER EIGHT

DEEPER BLUE

In this chapter, Kasparov discusses the preparations for his rematch with Deep Blue and its importance to IBM. He begins, however, by stating that the creation of the super-fast hardware machine Belle actually signaled the end of the evolution of chess machines. The winning concept of speed, brute force and optimization had been found. Through internet collaboration on programming techniques that brought about improvements in search, databases and processing speed, he notes that "chess engines running on PCs were improving so quickly that the millions of dollars of custom chess chips and supercomputing power in Deep Blue would be surpassed by an off-the-shelf engine running on a business-class Windows server in just six years."

The importance to IBM of Deep Blue's rematch, from Kasparov's point of view, lay in its "investing in a great quest, in taking part in an exciting competition that brings together pop culture and high technology." IBM spent hundreds of millions of dollars in publicity that most likely translated into products and sales. The company's stock rose seven percent as a result of the rematch. "There cannot be a better way to capture market share than to capture people's imaginations," Kasparov says.

As for Deep Blue itself, "hardware-based machines are frozen in time without massive continued investment. The prize of beating the world champion in a match for the first time made the investment worth it for

IBM, but there wasn't much to be done with Deep Blue after that if it wasn't going to play chess, other than to send a few pieces to the Smithsonian."

Kasparov underestimated how much IBM was willing to invest in Deep Blue—he thought that it would take a few more years of development to reach his 2800 level. He writes: "In the span of one week, the name Deep Blue had become practically synonymous with artificial intelligence, bringing IBM with it to the forefront of a hot tech sector, at least in the public eye." IBM would sponsor the rematch (the first had been low key and sponsored by the Association for Computing Machinery and part of a scientific experiment) with much more hoopla. "I underestimated that with so much on the line, IBM wasn't only building a chess machine to beat me at the board, but a machine to beat me, period."

Analyzing his play in the first match: If Kasparov failed to recognize the significance to IBM of the rematch, another problem was his loss of objectivity about his own play. Kasparov made a crucial mistake in underestimating just how his opponent's team would impact their matches.

- He credited his own play for his success rather than the poor play of his opponent: "The Deep Blue team would learn more from their losses than I learned from my wins and they would use what they learned to target my weaknesses while strengthening their own. They would address the machine's specific insufficiencies, not only double its speed."
- He didn't realize that his play in the match was "mediocre at best, and that only Deep Blue's unique weaknesses in the final two games masked this fact."
- He hadn't accounted for how different humans and machines are when it comes to chess strength. A Grandmaster's rating is based on the balance of performance over hundreds of games, and Grandmasters will have strengths and weaknesses in different parts of the game. Deep Blue had been weak in its evaluation ability during the match, and IBM focused on this weakness as it strengthened Deep Blue. "I failed to take this into account when

I estimated much it could improve in a little over a year," he admits. IBM hired several Grandmasters to tune up Deep Blue and fabricated a new set of chess chips with the new evaluation function built in.

- He continued to see the games as scientific experiments rather than as chess competitions.

The gloves come off: The friendliness and open attitude that had been on display at the first match in Philadelphia disappeared. "With IBM in charge from top to bottom, this chumminess had been replaced by a policy of obstruction and even hostility," writes Kasparov. A Deep Blue project manager told *The New York Times* in August 1996: "We're not conducting a scientific experiment anymore. This time, we're just going to play chess." In the past, Kasparov felt mutual respect. Not this time: "It was clear IBM didn't want my respect or my partnership; they wanted my scalp."

Before the first match, IBM had provided Kasparov with details about all the games Deep Blue had played. This time, although he was aware that several Grandmasters had played training games with Deep Blue, IBM did not share any information. "We were told that since those were not official games, as specified in the match rules, they were under no obligation to share them with me," remarks Kasparov. "Deep Blue would be a black box until game one."

By Kasparov's own admission, he furthermore addled himself by agreeing to a schedule which proved problematic. He did not insist on a rest day between games five and six so that they could be held on a weekend, possibly improving attendance and coverage.

"IBM had performed a simple equation when they decided to go all-in to win. Despite the Deep Blue team's tremendous efforts, it wasn't clear to them that they would be able to get the machine up to my 2820 level. And by the time the match started, even with the new evaluation-tweaking tools and the opening book, they couldn't make Deep Blue play any better. But there was always the chance that I could be induced to play worse. Deep Blue didn't have to play at a 2800 level to beat me if I didn't play at that level myself. And so began the games within the games."

09

CHAPTER NINE

THE BOARD IS IN FLAMES!

For the rematch in May 1997, IBM took over several floors of the Equitable Center in midtown Manhattan. Deep Blue's main system was on-site with several backup systems connected to it. The staging area for the match was a small room with a VIP seating section of about 15 chairs, and there was a separate large auditorium on another floor where people could watch on large video screens and follow the live commentary, which included the computer Fritz 4. But Kasparov had no team room: His team would have to sit with the press or in the audience. As the games got underway, Kasparov says, "I was a veteran of seven world championship matches and I knew that I had to push back against the increasingly antagonistic match organization or I would feel psychologically crushed."

The match constituted just six games played over a period of days, in contrast to other world championships that stretched for weeks or even months, with as many as 16 or 24 games played. "[Y]ou had time to experiment, to try different ideas. In only six games there would be no time to recover from an unforced error." In the days before the match began, he was shocked to learn that a number of Grandmasters were assisting IBM: "[T]hey had been working with a big team of Grandmasters, maybe they were really teaching it to play chess!"

The complicated asymmetries in human-machine chess: While preparing for a match, Kasparov worked with a team, but when he walked onto a stage, it was just himself, his opponent and their memorized opening moves. “Deep Blue didn’t have to worry about forgetting any of the thousands of opening lines it had been fed by its Grandmaster tutors.”

Having learned from his experience in New York with Deep Blue, Kasparov’s later encounters with human-machine chess would include stricter regulations to attempt to level the playing field and address some of the complicated asymmetrical problems.

- There would be limitations to how many variations could be added or altered to the machine’s opening book between games, and the human player would be provided a relatively recent version of the engine a short time in advance to compensate for the lack of published games.
- Additional regulations would address thornier issues of fair play and secrecy that had no perfect solution. For example, if the machine crashed or had some other problem during the game, should the human player be informed?
- There should be a detailed log of all the human interactions with the computer during the game, not only those of the operator.
- The potential for distractions when playing against a machine is enormous and not always recognized.

Let the games begin: Before the match got underway, Kasparov says he was in a “metaphorical darkness” regarding Deep Blue’s capabilities. “I was bitter over having been stonewalled about seeing any of its games. What was I supposed to base my preparation on?” Given his lack of information, he decided to play more “passively” than he would have preferred so that he could get a sense of the machine’s strengths and weaknesses. This “anti-computer” strategy meant playing conservatively for a long-term advantage that the computer would be unable to find in its game-tree search. The human player selects moves that in the short term appear sub-optimal, so the player can exploit known weaknesses in the way the computer evaluates positions. Despite this more limiting strategy, Kasparov says that he was “genuinely confident” based on how much he thought IBM had been able to improve Deep Blue.

Game one: Based on the player's drawing for the order of the games, Kasparov started the first game, which gave him a playing advantage. While he would have preferred to use the sharp openings that he had applied against other Grandmasters, he had to be practical, though he felt "there [would be] two big problems with following my main lines against Deep Blue."

1. If the machine could just regurgitate from its opening database and its knowledge of Kasparov's past games, it would be given a "free pass" to the middle game where it excelled. "[Kasparov] hoped to exploit its inability to plan or to play strategically by getting it out of its book as early as possible, even if the position was not objectively great for [him]." Also, whatever during these opening moves, he would get a chance to see which playing style the machine would utilize.
2. Many of Kasparov's favorite openings led to "sharp, open positions where we would be closer to the territory where Deep Blue played at a 3000 level and further from the closed, maneuvering positions where it played much worse." He believed his chances were better "in an anti-computer bog than in a pitched battle on the open plains."

In the course of playing the game, Deep Blue did make a few mistakes. However, Kasparov notes, "Computers could often be led into creating weaknesses in their positions, but they were also incredibly good at protecting those weaknesses." As for his game play at this point, he says, "I had to keep reminding myself not to rush, that I needed to find out as much as I could about my opponent's abilities. My priority was to limit the machine's counterplay."

And then the pitched battle began, prompting one commentator to remark, "The board is in flames!'" Deep Blue played aggressively. "My plan for a quiet fact-finding mission in game one had been blown to hell by the aggressive machine. I was pinning my hopes on my superior evaluation ability. Deep Blue liked its material advantage and well-placed pieces." Ultimately, Deep Blue overestimated its material advantage, exchanging queens when it shouldn't have. "It was a classic computer mistake: it was happy with the status quo but couldn't see that it would have no ability to improve its position." Deep Blue lost the game, but "it had been a real battle, a rich game of chess," Kasparov says. "This Deep Blue was a worthy opponent."

Game two: "Had I been in the possession of even a dozen of Deep Blue's games to get a sense of its capabilities I would have felt comfortable playing my usual openings and preparing for it like I would any Grandmaster opponent," says Kasparov. "Without anything on which to base concrete preparation, it felt best to stick with flexible positions where I didn't have to add worrying about opening novelties to the long list of things I had to worry about." He also was concerned about conserving his own strength: "Playing against a machine was exhausting because I was obliged to look at possibilities I wouldn't normally consider, and to double-check every calculation." Again, he made a choice to play the game that went against his own natural style: "While I was playing anti-computer chess, I was also playing anti-Kasparov chess."

Kasparov's games with Deep Blue forced him to confront the vast differences between the human-style of play at which he excelled, and that of a supercomputer upon which his methodology often did not apply.

- When playing against a human opponent, players may practice "psychological gamesmanship," hashing out openings at a rapid pace, for example, or holding back and appearing to pause to think, even when they know what they are going to do. Machines, however, are not able to do the same.
- While Deep Blue was "immune to gamesmanship," Kasparov discovered that "it was very much capable of employing it itself." In some moves, Deep Blue, which had also opened the game, took time to think; it had been programmed to surprise Kasparov. Spanish Grandmaster Miguel Illescas, who had worked with the computer programmers, explained in a 2009 interview in *New in Chess*, "We gave Deep Blue a lot of knowledge of chess openings but we also gave it a lot of freedom to choose from the database with statistics." Illescas speculated that "'[Kasparov] was never sure whether the computer was playing theory or thinking for itself."
- Another dimension was added to the game—a second surprise as it were—but Kasparov didn't discover this until Illescas's 2009

revelations about Deep Blue. "Of course we also built in some tricks for [Kasparov]. For certain moves there was a delay or some moves it played immediately. In some positions we bet that [Kasparov] would play the best move, and if he does, let's reply immediately. This has a psychological impact, as the machine becomes unpredictable, which was our main goal."

- As the game progressed, Kasparov saw that the Deep Blue of game two was far different than the opponent he'd faced in game one. Instead of the purposeless shuffling exhibited previously, Deep Blue maneuvered behind the lines expertly, preparing for an eventual breakthrough.
- Even though Deep Blue's plays were sometimes mediocre, Kasparov recalls, "I became so concerned with what it might be capable of that I was oblivious to how my problems were more due to how badly I was playing than how well it was playing."
- Ultimately, Kasparov resigned; Deep Blue was the winner.

Reflecting on the game, which Kasparov says is one of the most heavily scrutinized chess games in history, he says: "The entire game had been a demoralizing experience and I just wanted to get as far from the board as possible. My mind was already racing, wondering how in the hell the time-wasting computer from game one had achieved this positional masterpiece in game two. That I was already thinking about anything other than the game was a typical human frailty that we just cannot avoid. It felt physically painful to keep looking at what I was sure was a totally lost position. I wanted to resign with at least a little dignity left and to save some energy for the next game instead of continuing in a hopeless cause."

The psychological toll: This loss was one of the worst that Kasparov had ever experienced. "It made me question everything," he says. "The dramatic increase in the quality of Deep Blue's play, the decision to play anti-computer chess instead of my own game, how I had been fooled into believing I would have some of Deep Blue's games to study before the match." His confidence was shaken, and this uncertainty deepened when Yury Dokhoian, one of his team members, told him that his analysis of the game showed that the final position of the game had been a draw: "'Perpetual check. Queen to e3. Draw.'" As he learned of this outcome, so had millions of chess players around the world—the armchair analysts following the game—and they shared their results on the internet. “I had lost one of the worst games in my life in front of the entire world and now I was finding out that I had resigned in a drawn position for the first time in my life. I was in disbelief,” says Kasparov. “It was a crushing blow, as if I had lost the game twice.”

The loss led Kasparov to confront the next stage of competing with a computer, which involved studying Deep Blue’s previous games with human opponents, now that he’d come up short. Two key takeaways emerged from the devastating loss:

- Had he been playing another Grandmaster, Kasparov believes that this wouldn’t have happened because he would have assumed that his opponent saw what he did. But when your opponent is a computer that is capable of checking 200 million positions per second and playing a powerful game against a world champion, “the assumptions were different,” he says. “I couldn’t play normally; I had to give the machine the benefit of the doubt in certain positions.”
- The worst scenario for a chess player is to let a single loss linger and subsequently cost more than the game’s one point, and this is what happened to Kasparov: “Continued attention on game two would only serve to make it impossible to put it behind me, ruining my focus for the rest of the match.” Facing another four games, Kasparov says, “I didn’t feel like playing chess anymore. I didn’t know my opponent at all. Was it the computer that made weak pawn moves in game one? Was it the strategic mastermind that had played game two like an anaconda? Or was it buggy and error prone, capable of missing a relatively simple repetition draw.”

Game three: This game ended in a draw with Deep Blue playing tamely. An angry Kasparov expressed his resentment to the press post game, clearly asking to see the printouts of what had happened. “I didn’t know what had happened and I admitted it. I couldn’t understand how a machine could play so well and then make a blunder that seemed elementary, and I said so. I challenged them to explain it to me and to the world, to release the printouts and remove all the doubts, but they wouldn’t. Why not?” An angry Kasparov expressed his resentment to the press post game, clearly asking to see the printouts of what had happened.

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CHAPTER TEN

THE HOLY GRAIL

Kasparov explores the final three games of the match in this chapter. Throughout the match, he had to grapple with the computer's inconsistency and unexpected moves, combined with his rapidly draining energy, demoralization and mental exhaustion. In game five, for example, he writes that a "strange but weak move by Deep Blue" turned out to be ultimately more effective than a good move because of how it affected him psychologically. "I never got a sense of what to expect, never felt sure of how to play, and I let it ruin my concentration." After game five ended in a draw as had game four, he says, "For the second game in a row I felt shattered, certain I had squandered a winning opportunity and disgusted with the low quality of my play."

He starts the chapter, however, not with a focus on the games themselves, but with an assertion: "There is a long and ugly history of recriminations and accusations of foul play and worse during world championship matches." After citing numerous examples, he writes, "You can either believe that there is a great deal of treachery at the top level of chess, that some Grandmasters are as paranoid as the stories say, or that gamesmanship and off-the-board maneuvers are a standard element of an all-out psychological war. Or you may select 'all of the above' and join the consensus." Why open the chapter in this way? Kasparov has strong opinions about his battle with Deep Blue and IBM that he expands upon.

- There was "human intervention" involved, as Deep Blue's operators could fix bugs, reboot the machine after crashes and alter its book and evaluation function between games, for example. This type of intervention would be limited in future games, as it was judged to be to the machine's advantage.

- What impact did a reboot have after a crash? Kasparov later learned that "a system restart changes everything from the perspective of reproducibility. The memory tables the machine uses to retain positions are lost and there will never be a way to confirm that the machine would make the same moves again." Does a restart mean that the machine could come back with a better move? And what is the emotional impact on the human player who has to wait out the restart?
- Deep Blue had to be manually restarted in games three and four. In 2016, Kasparov spoke to A.I. and machine-learning expert Noel Sharkey, who expressed his feelings about the storied match: "'I've been annoyed about it for years,' he told me. 'I was very excited about the prospect of an A.I. system beating you but I wanted it to be a fair contest and it wasn't. The crashes? All the connected systems they put in? How do you monitor that? They could change software or hardware between moves. I can't say IBM cheated but I can't say that they didn't.'"

Kasparov believes that "IBM was willing to push the boundaries of ethical behavior to improve Deep Blue's chances in any way." He draws on the 2009 revelations of Grandmaster Illescas, who reported that there were daily morning meetings with "all the team, the engineers, the communication people, everybody." Illescas had shared with the group that Kasparov spoke to his teammate Dokhoian after games and commented that he wanted to know what they say. "Can we change the security guard, and replace him by someone that speaks Russian? The next day they changed the guy, so I knew what they spoke about after the game." Remarks Kasparov: "Perhaps not that important in practice, but it's a bombshell in exposing the lengths IBM went to in order to gain any competitive advantage."

In retrospect, Kasparov says that Deep Blue's moves in game two, which had left him feeling lost and crushed, were unique for that time. Within five years commercial engines running on Intel servers, however, could reproduce all of the computer's moves, including the more "humanlike" ones that so flummoxed him. "Had I played better defense instead of collapsing and resigning, game two would have been considered a very impressive game for a machine but nothing more, no matter the eventual result."

Kasparov believes that his lack of information about Deep Blue's games was critical to his approach. Had he known about the machine's ability to make uncharacteristic positional approaches as seen in game two, he says he would have reacted in a completely different way. Concludes Kasparov: "Keeping Deep Blue completely hidden was the strongest move of the match, but it was played by IBM, not either of the participants."

The chess endgame: In 1977, a computer scientist generated a database through retrograde analysis—essentially solving chess backward, starting from checkmate and working backward—and, thus, the endgame tablebase was introduced into chess playing. "It was a revolutionary contribution to computer chess, where the subtleties of endgame play had long been a machine weakness," says Kasparov. "With tablebases, all that started to change. Instead of calculating all the way, a machine only had to reach a tablebase position to know if it was winning, losing, or a draw. It was like gaining second sight." The massive data storage required made tablebases impractical for most computer engines in the beginning. Tablebase use became more commonplace, however, as new data generation and compression techniques came along and as hard drives got bigger.

Humans haven't found chess tablebases as useful as machines have. Observes Kasparov: "Tablebases are the clearest case of human chess versus alien chess, and of the huge difference in how humans and machines achieve results. A decade of trying to teach computers how to play endgames was rendered obsolete in an instant thanks to a new tool. This is a pattern we see over and over in everything related to intelligent machines. It's wonderful if we can teach machines to think like we do, but why settle for thinking like a human if you can be a god?" Kasparov was not aware of Deep Blue's knowledge of tablebases and later learned that it had access to them and used them briefly in its search in game four.

Game six: This was a game of firsts, writes Kasparov: "The shortest loss of my career. It was the first classical match loss of my career. It was the first time a machine had defeated the world champion in a serious match." He entered the game in a tie, 2.5. to 2.5, without a rest day, knowing that he would have little energy for a long fight.

- By the seventh move, Kasparov sensed that the game was over. "I went through the motions of trying to defend a position that would be very difficult against any Grandmaster and, I knew, was absolutely hopeless against Deep Blue."
- He played the next moves on "autopilot" and resigned on the 19th move with the entire match lasting less than an hour.
- Deep Blue's coach Illescas, in his 2009 interview about this game, later revealed that IBM's team had entered into Deep Blue's instructions a particular variation on a move that it was to employ in response to one of Kasparov moves. Writes Kasparov: "Two paragraphs after Illescas says IBM had hired Russian speakers to spy on me, he says the team entered this critical line into Deep Blue's book that morning? An obscure variation that I had only discussed with my team in the privacy of our suite at the Plaza Hotel that week in New York?" Kasparov later notes that another Grandmaster recalled that the controversial move was entered a month ahead—another reason why Deep Blue's logs should have been released at the time of play.

Deep Blue retires: The famed computer never played another game. Kasparov believes that a loss to him in a rematch would have been embarrassing. "It beat the champion and retired, Fischer-like, becoming as much myth as machine." Its retirement did not sit well with chess fans and the computer chess community. Frederic Friedel commented to *The New York Times*: "Deep Blue's victory over Kasparov was a milestone in artificial intelligence…But it's a crime that IBM didn't let it play again. It's like going to the moon and returning home without looking around." Deep Blue, according to a member of the IBM team, was kept in the lab until 2001, when it was finally powered down. "'Half was donated to the Smithsonian (in 2002) and the other half to the Computer History Museum (in 2005). … It was still a respectable supercomputer.'"

Summing up, Kasparov writes: “I have been asked, ‘Did Deep Blue cheat?’ more times than I could possibly count, and my honest answer has always been ‘I don’t know.’ After twenty years of soul-searching, revelations, and analysis, my answer is now ‘no.’ As for IBM, the lengths they went to win were a betrayal of fair competition, but the real victim of this betrayal was science.”

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CHAPTER ELEVEN

HUMAN PLUS MACHINE

Deep Blue's triumph over Kasparov led to its own obsolescence, since it never played again. Deep Blue had only proved that smarter programs on faster machines could beat the human world chess champion. "This did not mean that super-strong chess machines did not have an impact, only that their impact was limited to the chess world," says Kasparov. "The good news is that what happens in the chess world is frequently a useful preview for the rest of the world." In this chapter, he focuses on where he and his "beloved game" have been on the "cutting edge of the rapidly changing relationship between humans and machines. As the curtain fell on a decade of human versus machine competition, it was time for human plus machine collaboration to take center stage."

Nearly everything a modern human does involves the use of technology. Increasingly, humans are using machines to supplement fundamental cognitive functions such as memory. Why remember phone numbers when you have them stored in your smartphone and computer? Why write a letter when email, texts, Facebook posts or a personal blog do the trick? Why search for information in books or do mathematic calculations?

"Following in the grand tradition of nearly every new technology, nobody started to panic about the potential downsides of cognitive outsourcing until kids starting doing it, and doing it in ways that their parents didn't understand." Millennials have created their own slang and symbols, spend hours on social media rather than "irl"—in real life—and can't remember phone numbers. Observed *New York Times* columnist David Brooks about what is referred to as "the outsourced brain": "I had thought that the magic of the information age was that it allowed us to know more, but then I realized the magic of the information age is that it allows us to know less. … You may wonder if in the process of outsourcing my thinking I am losing my individuality. Not so. … It's merely my autonomy that I'm losing."

Kasparov notes this shift, yet recognizes the gaps in our technological evolution leave room for continued advancement:

- People have gained time that they don't know what to do with yet. Writes Kasparov: "We have gained incredible powers, virtual omniscience, but still lack the sense of purpose to apply them in ways that satisfy us."
- People wonder if an overreliance on machine memory shuts down other ways of understanding the world. Getting information from a phone is no different than turning to encyclopedias, a telephone book or a librarian: "It is only the next stage of how our technology allows us to create and to interact with more information faster and faster—and it won't be the last stage." But in doing so, people have to be careful not to substitute "superficial knowledge for the type of understanding and insight that is required to create new things."

"Using our machines to acquire and retain more knowledge cannot be a bad thing on its own. The question is whether or not there is a type of cognitive opportunity cost. I reject the notion that everything must be a zero-sum game in which for every cognitive gain there is a corresponding loss. Big changes in how we manage our minds can, and often do, result in net positives. As with other aspects of what I call upgrading our mental software, self-awareness is the vital ingredient."

The computer's influence on chess games: It's now possible to have a Grandmaster-strength computer in your home or in your pocket, which has led to the appearance of strong chess players worldwide rather than solely in countries where chess has traditionally flourished. "It didn't only affect *who* plays chess, however. Chess machines have also had an impact on *how* human chess is played," says Kasparov.

- A player's earliest influence can easily be a machine, which doesn't care about style, patterns or established theory. "The heavy use of computers for practice and analysis has contributed to the development of a generation of players who are almost as free of dogma as the machines with which they train."
- Chess moves are increasingly seen as good if they work and bad if they don't. "Although we still require a strong measure of intuition, guidelines, and logic to play well, humans today are starting to play chess more like computers."
- One consequence of this playing style, which Kasparov has seen in younger players who rely on chess programs, is that they don't want to puzzle out a move and explain why it is good or bad. "The kids want to skip all that and just start at the good part, where the previous analysis and old games tell them to go, before thinking for themselves," he says. "That's exactly how machines play, by using an opening book, a database of Grandmaster games and theory. Humans playing this way have the same drawbacks. What if there's an error in the book? What if you're following along blindly and your opponent has prepared a nasty novelty down the line you're following?" Kasparov agues. "It's not enough to know the best moves; you must also know why those moves are the best."

Human machine collaboration can help people be more creative—or less—depending on how they use digital tools: Databases are based on whole games—not just opening lines. Chess players who follow a database need to find ways to make improvement, and that should start earlier, digging into the established moves to find better ones, not where the database ends. Innovation—not imitation—is needed. "And so it is with chess thinking, business thinking, and with pursuing innovation in general," Kasparov says. "The earlier on in the development tree you look, the bigger the potential for disruption is, and the more work it will take to achieve. If we only rely on our machines to show us how to be good imitators, we will never take the next step to becoming creative innovators."

- Grandmasters using their ability to prepare with engines and databases have played riskier, more experimental opening variations in their matches.

- The best chess players now are younger, since they can access millions of games in a database. Ukrainian-born Sergey Karjakin, today's youngest Grandmaster, achieved the title when he was 12 years old, and today's world champion Magnus Carlsen became a grandmaster at 13.
- Technology can make training more efficient. The teens and preteens, notes Kasparov, "accelerate the process by plugging into a digital fire hose of chess information and making full use of the superiority of the young mind to retain it all."

With the global spread of cell phones and the internet, Kasparov is convinced that technology will enable people all over the world to become entrepreneurs, scientists or whatever they wish to be. Here, again, chess has shown just how its devotees are embracing these advances as it "sneaks through the cracks of cultural, geographic, technological and economic barriers, disguised as an innocuous pastime. Again and again it serves as a model for everything from artificial intelligence to online gaming to problem solving and gamification in education. … Kids are capable of learning far more, far faster, than traditional education methods allow for," he says. "They are already doing it mostly on their own, living and playing in a far more complex environment than the one their parents grew up in."

The challenge for educators: "Kids thrive on connections and creation and they can be empowered by today's technology to connect and create in limitless ways," says Kasparov. Yet many classrooms still look like they did a century ago. He questions if teachers or books are the best source of information when youngsters can instantly access the sum of all human knowledge merely from a device in their pockets. "[Kids] must be given the methods and means to teach themselves. This means creative problem-solving, dynamic collaboration online and off, real-time research, and the ability to modify and make their own digital tools." He continues, "The prevailing attitude is that education is too important to take risks. My response is that education is too important *not* to take risks. We need to find out what works and the only way to do that is to experiment. ... [Kids] are already doing it on their own. It's the adults who are afraid."

Using the computer as a partner in championship chess and the wider world: In 1995, before the Deep Blue battle, Kasparov played against India's Viswanathan Anand and incorporated the computer engine Fritz 4 into his preparation routine, using it as a fact-checking calculator as he worked out extremely tactical positions without risking oversight. And it proved useful during the long stretch of games. Emotions played a key role in both Anand's and his playing—Anand was dejected, and Kasparov elated after game 10, when Kasparov played a novel move that he had worked out. Defeats take time to recover from. "Our emotions rule over our cognition in countless ways, many of which we cannot explain," he says.

Humans may look for a pattern in the flip of a coin, although logically there isn't one, and may convince themselves that past events somehow influence present ones. "Machines don't look for patterns in randomness, or at least if they do, they don't find any the way our minds often do," observes Kasparov. "Just like chess Grandmasters do at the board, we rely on assumptions and heuristics to make sense of the complexity around us. We do not calculate every decision by brute force, checking every possible outcome," he says. "But when [human assumptions are] isolated by researchers, or exploited by advertisers, politicians and other con artists, you can see how we could all use a little objective oversight, which is where our machines can help us. Not only by providing the right answers, but by showing us how idiosyncratic and easily influenced our thinking can be. Becoming aware of these fallacies and cognitive blind spots won't prevent them entirely, but it's a big step toward combating them."

Digital tools make checklists and goalposts easy to use in disciplined thinking and strategic planning despite their potential for enabling human dependence. "In chess analysis, having an engine peeking over your shoulder while you work is very useful, but it can enslave you and intimidate you if it's on all the time," observes Kasparov. "Human plus machines can keep you honest, as long as you are honest with your machines."

Advanced Chess: In 1998 in León, Spain, Kasparov experimented with playing a match against Bulgarian Grandmaster Veselin Topalov, and each had a computer running the chess software of his choice during the game. A player's advantage would come not from the database but in creating a new idea during the game. "We could concentrate on strategic planning instead of spending so much time on laborious calculations," writes Kasparov. "Human creativity was even more paramount under these conditions, not less." The match itself ended in a 3-3 draw, despite the fact that the previous month Kasparov had defeated Topalov in a match of regular rapid chess 4-0. "My advantage in calculating tactics had been nullified by the machine," says Kasparov.

The encroachment of machines on the game of chess was years in the making, having been applied in a number of competitive experiments:

- For many years, Advanced Chess games were played in León, and the computer screens were mirrored for the audiences as if the Grandmasters had hidden cameras inside their minds that revealed how they were thinking.
- The experiment morphed into other types of chess games, including a freestyle tournament in 2005 where the winner turned out not to be a Grandmaster using a state-of-the-art PC, but two amateur Americans who worked with three computers at the same time. Of this feat Kasparov concluded in various writings: "*weak human + machine + better process* was superior to a strong computer alone and, more remarkably, superior to a *strong human + machine + inferior process*." This formulation is often referred to as "Kasparov's law."

How do you get humans and machines working together in a way that makes the most of the strength of each without slowing the computer to a crawl? IBM and other companies are now working on intelligence amplification which uses information technology as a tool to enhance human decisions instead of replacing them with autonomous A.I. systems."

How the future will appear with respect to humans balancing personal cognition with A.I. will require some critical breakthroughs:

- The need for a new generation of intelligent tools that will perform as human-machine and machine-human interpreters.
- Understanding how to interact with machines that are entering the decision-making space.

Kasparo concludes: “Our algorithms will continue to get smarter and our hardware faster. Soon, even the strongest humans will be more of a hindrance than a help to the world’s best chess machines, for example. ... To keep ahead of the machines, we must not try to slow them down because that slows us down as well. We must speed them up. We must give them, and ourselves, plenty of room to grow. We must go forward, outward, and upward.”

CONCLUSION:
ONWARD AND UPWARD

"Our technology is not concerned about good or evil. It is agnostic," writes Kasparov. "The ethics are in how we humans use it, not whether or not we should build it." Throughout the book, he has considered the contradictions that technology presents humanity. "I am optimistic on most days, worried on others, and mostly afraid only that we may not have the foresight, imagination, and determination we need to do what must be done."

Reflecting on the importance of his battles against machines, Kasparov notes, "The 1996-2006 window during which human-machine chess was truly competitive felt like a long time to me because I was on the front line. From a distance, it's a good example of how human time scales and human capabilities are rendered practically insignificant compared to accelerating technological progress."

Following his competition with Deep Blue, Kasparov played against two other leading engines—Deep Junior and Deep Fritz—and the results were draws, even though the rules had been adjusted to be more equitable to humans. In 2006, world champion Vladimir Kramnik lost to another version of Fritz with even more favorable regulations. Says Kasparov: "Any subsequent competitions would require ways of handicapping the machines."

The "competition dot"—the period on the historical timeline when humans and machines end the struggle for supremacy—has to give way to moving ahead. "The most important conclusion is not found near the competition dot, but what comes after it, on that long line into eternity," he says. "Once tasks can be done better (cheaper, faster, safer) by machines, humans will only ever do them again for recreation or during power outages. Once technology enables us to do certain things, we never give them up." Kasparov maintains that although we cannot be sure of what changes this new technology will bring, he is hopeful. "I trust the young people who are growing up with it. I trust that they will find surprising new ways to use technology the way my generation used computers and satellites and how every generation has used technology to fulfill human ambitions."

Kasparov concludes the book by saying, "I hope you will take this section as a reading list and as an invitation to take an active role in creating the future you want to see." He offered parting advice for humanity to best leverage the tech of tomorrow:

- The more that people believe in technology's positive future, the greater the chance of this outcome. People choose what the future looks like through their actions and beliefs.
- Humans will need every bit of ambition to stay ahead of technology. "We are fantastic at teaching our machines how to do our tasks, and we will only get better at it."
- Technology excels at removing the difficulty and uncertainty from people's lives, so they must continue to strive for more difficult and uncertain challenges.

"I have argued that our technology can make us more human by freeing us to be more creative, but there is more to being human than creativity," says Kasparov. "We have other qualities the machines cannot match. Machines cannot dream, not even in sleep mode. Humans can, and we will need our intelligent machines in order to turn our grandest dreams into reality. If we stop dreaming big dreams, if we stop looking for a greater purpose, then we may as well be machines ourselves."

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