Preface

Thirteen years have passed since the classic book on computer chess, *Chess Skill in Man and Machine*†, appeared and seven years since a later expanded edition. In this time, the field of computer chess has made remarkable strides forward. In the early 1980s only the best computers were playing master level chess. Now store-bought machines are playing at master level and the best computers are occasionally beating top Grandmasters. It is a mere 40 years since Claude Shannon published the paper laying the foundations for computer chess, and already the long sought goal of artificial intelligence, to defeat the World Chess Champion, is in sight.

Part I of this book gives an excellent account of the most exciting recent advances in computer chess. It starts with a short history of computer chess, including some of the best man-machine and machine-machine games. In Part II, the secrets of three of the strongest chess programs around today are revealed. Actually, there are no real secrets here; all the programs are intensive applications of technology and known techniques. Part III describes some of the most promising new ideas that could lead to stronger programs of the future. In Part IV, the sometimes tenuous relationship between computer chess and artificial intelligence is examined.

Since the game of chess is steadily yielding to the onslaught of technology, Part V presents a description of the early attempts of computers to play the game of Go. There is the hope that Go will become the "*Drosophila* of artificial intelligence" where chess has failed.

Ken Thompson
Bell Laboratories
Murray Hill
May 1990

† Peter Frey (editor), Springer-Verlag, New York, 1977.

Foreword

During December 1989, in London, two opponents sat across from each other separated by a chessboard. After four tense games, International Master David Levy extended his hand in resignation; he had lost all four. Peter Jansen, a player of modest standards, accepted. Levy's opponent, however, was several thousand kilometers away in Pittsburgh, Pennsylvania, quietly sitting in a cold, dark room, oblivious to the historic event that had just unfolded. Jansen was the human representative for the chess playing machine *Deep Thought*. His job was to relay the machine's moves, as they were received through the phone lines. An era had ended; for twenty years Levy taunted the computer-chess community, daring them to defeat him. And now it was over, in a manner more decisive than most had imagined.

This marked the end of an era in many ways. Just a scant year before, the first human Grandmasters were defeated by their electronic counterparts. World Chess Champion Gary Kasparov, recognizing the strength of the budding computer prodigies, challenged *Deep Thought* to a match, which he won decisively. It is not yet time for machines to triumph over man completely, but it is clear that man's domination in this intellectual sport *par excellence* is rapidly drawing to a close. A new era of computer chess is about to dawn, one in which a combination of fast hardware and sophisticated software will conquer a domain thought to be uniquely human. It may still take a few years to defeat Kasparov, but inevitably the humans must concede.

In sight now is the long sought-after goal of artificial intelligence, a field of computer science devoted to creating the illusion of machine intelligence. The relationship of chess and artificial intelligence is long. Initially, the optimism of the field led to a prediction in 1958 that machines would defeat all humans within 10 years. Unfortunately, the complexity of the human thought processes and the difficulty of modeling this electronically were grossly under-estimated. The role of chess as a vehicle for exploring artificial intelligence has often been compared to the role of the fruit fly for genetics. Chess, the *Drosophila* (fruit fly) of artificial intelligence, has proven to be a fruitful application for investigating machine intelligence.

Just as computer chess enters its decisive era, a new successor *Drosophila* is emerging. The game of Go is arguably more difficult than chess. Not only does it have a larger space of possible board configurations (10^{100} versus 10^{43} for chess) but it does not appear to be easily amenable to the search-based methods successfully used for chess, needing more of a knowledge-based approach. Thus the end of one era for artificial intelligence is the dawning of a new, more challenging one.

We hope this book is timely. We have tried to present the state of the art in computer-chess research and outlined what still remains to be done before Gary Kasparov falls. As well, the emerging field of computer Go is highlighted. This area will receive a great deal of attention in the future.

This book was not possible without the help and support of a number of people. First and foremost, we would like to thank the authors of the chapters:

- Danny Kopec (University of Maine, Orono) for his review of advances in man-machine play.
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- Kiyoshi Shirayanagi (NTT Software Labs, Tokyo) for his proposal on knowledge-based search in Go.

To these contributions we have added our own brief history of computer chess and a report on the 6th World Computer Chess Championship, as well as a review of how contemporary programs compare on a standard test suite of problems.

Preparation of the manuscript was greatly aided by help from the following: Christine Vanzella, Monty Newborn and Jos Uiterwijk for making their photographs available, some of which are used here; Peter Fode and Tim Breitkreutz for assistance in typesetting the many diagrams for this book; Karen Gona for technical typing and editing; Patrick Schoo for supplying chess diagram software; Steve Sutphen for clarifying and simplifying the mechanism for inserting postscript figures; Carol Smith for considerable help in re-working troff macros to our needs; and Roy Hall of Cornell University for supplying a complete set of troff documentation macros for producing text to Springer-Verlag style specifications. The manuscript was prepared using facilities provided by the Department of Computing Science, University of Alberta.

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This book grew out of the 6th World Computer Chess Championship held in Edmonton, May 28-31 1989, and the accompanying *New Directions in Game-Tree Search Workshop*. The Canadian Information Processing Society hosted the championship, and the Alberta Government Telephones was the principal sponsor. Financial support for the workshop was received from the Natural Sciences and Engineering Research Council of Canada and the University of Alberta. Without the backing of these organizations, the groundwork for this book would not have been possible.

Tony Marsland Jonathan Schaeffer

Edmonton, Alberta, Canada

In 1977, the computer-chess community formed the International Computer Chess Association (ICCA). For those wanting to keep abreast of this rapidly progressing field, we recommend subscribing to the quarterly *ICCA Journal* which follows the latest research advances and competitive results. Similarly, there is fledgling computer-Go association, whose publication is called the *Computer Go* Newsletter. For more information, contact:

ICCA c/o Dr. H.J. van den Herik Department of Computer Science University of Limburg, P.O. Box 616 6200 MD Maastricht The Netherlands	Computer Go c/o David Erbach 71 Brixford Crescent Winnipeg, Manitoba Canada R2N 1E1

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Part I. Man and Machine

This opening section puts computer chess into perspective with its past, present and future.

Tony Marsland recounts the past with his brief history of computer chess. The article highlights the major milestones in machine-machine competition. Danny Kopec provides a complementary article, surveying the milestones in man-machine play. The article culminates in *Deep Thought*'s unsuccessful challenge of Kasparov and the final defeat of David Levy.

The present state of chess programs is discussed in Jonathan Schaeffer's article on the 6th World Computer Chess Championship. The event brought the strongest chess programs in the world together to determine who was best - with some surprising and not-so-surprising results.

Finally, David Levy forecasts the future with his idea of what is needed to finally defeat the human World Champion. Although his paper contains a simple, yet powerful idea, the realization of it is quite difficult. Nevertheless, the type of knowledge engineering advocated by David is an important, promising area for future research.

1 A Short History of Computer Chess

T.A. Marsland

1.1 Review

Of the early chess-playing machines the best known was exhibited by Baron von Kempelen of Vienna in 1769. As might be expected, they were all conjurer's tricks and grand hoaxes, as Bell (1978) and Levy and Newborn (1982) explain. In contrast, around 1890 a Spanish engineer, Torres y Quevedo, designed a true mechanical player for KRK (king and rook against king) endgames. A later version of that machine was displayed at the Paris Exhibition of 1914 and now resides in a museum at Madrid's Polytechnic University (Levy and Newborn 1982). Despite the success of this electro-mechanical device, further advances on chess automata did not come until the 1940s. During that decade there was a sudden spurt of activity as several leading engineers and mathematicians, intrigued by the power of computers, began to express their ideas about computer chess. Some, like Tihamer Nemes of Budapest (Nemes 1951) and Konrad Zuse of Germany (Zuse 1945), tried a hardware approach, but their computer-chess works did not find wide acceptance. Others, like noted scientist Alan Turing, found success with a more philosophical tone, stressing the importance of the stored program concept (Turing *et al*. 1953).[1] Today, best recognized are Adriaan de Groot's 1946 doctoral dissertation (de Groot 1965) and the much referenced paper on algorithms for playing chess by Claude Shannon (1950). Shannon's inspirational work was read and re-read by computer-chess enthusiasts, and provided a basis for most early chess programs. Despite the passage of time, that paper is still worthy of study, and is again readily available as a reprint (Levy 1988, pp. 2-13).

1.2 Landmarks in Chess Program Development

The first computer-chess model in the 1950s was a hand simulation (Turing *et al*. 1953). Programs for subsets of chess followed (Kister *et al*. 1957) and the

This chapter is a revised and updated extract from "Computer Chess Methods," *Encyclopedia of Artificial Intelligence,* S.C. Shapiro (ed.), Wiley 1987, pp. 159-171.

[1] The chess portion of that paper is normally attributed to Turing, the draughts (checkers) part to Strachey, and the balance to the other co-authors.

first full working program was reported in 1958 (Bernstein *et al*. 1958). By the mid 1960s there was an international computer-computer match, later reported by Mittman (1977), between a program backed by John McCarthy of Stanford (developed by Alan Kotok and a group of students from MIT) and one from the Institute for Theoretical and Experimental Physics (ITEP) in Moscow (Adelson-Velsky *et al*. 1970). The ITEP group's program won the match, and the scientists involved went on to develop *Kaissa*,[2] which became the first World Computer Chess Champion in 1974 (Hayes and Levy 1976). Meanwhile there emerged from MIT another program, *Mac Hack Six* (Greenblatt, Eastlake and Crocker 1967), which boosted interest in artificial intelligence. Firstly, *Mac Hack* was demonstrably superior not only to all previous chess programs, but also to most casual chess players. Secondly, it contained more sophisticated move-ordering and position-evaluation methods. Finally, the program incorporated a memory table to keep track of the values of chess positions that were seen more than once. In the late 1960s, spurred by the early promise of *Mac Hack*, several people began developing chess programs and writing proposals. Most substantial of the proposals was the twenty-nine point plan by Jack Good (1968). By and large experimenters did not make effective use of these works; at least nobody claimed a program based on those designs, partly because it was not clear how some of the ideas could be addressed and partly because some points were too naive. Even so, by 1970 there was enough progress that Monroe Newborn was able to convert a suggestion for a public demonstration of chess-playing computers into a competition that attracted eight participants (Newborn 1975). Due mainly to Newborn's careful planning and organization this event continues today under the title "The North American Computer Chess Championship," with the sponsorship of the ACM.

In a similar vein, under the auspices of the International Computer Chess Association, a worldwide computer-chess competition has evolved. Initial sponsors were the IFIP triennial conference at Stockholm in 1974 and Toronto in 1977, and later independent backers such as the Linz (Austria) Chamber of Commerce for 1980, ACM New York for 1983, the city of Cologne in West Germany for 1986 and AGT/CIPS for 1989 in Edmonton, Canada. In the first World Championship for computers *Kaissa* won all its games, including a defeat of *Chaos* program that had beaten the favorite, *Chess 4.0*. An exhibition match between the new champion, *Kaissa*, and the eventual second place finisher, *Chess 4.0* the 1973 North American Champion, was drawn (Mittman 1977). *Kaissa* was at its peak, backed by a team of outstanding experts on tree-searching methods (Adelson-Velsky, Arlazarov and Donskoy 1988). In the second Championship at Toronto in 1977, *Chess 4.6* finished first with *Duchess* and *Kaissa* tied for second place. Meanwhile both *Chess 4.6* and *Kaissa* had acquired faster computers, a Cyber 176 and an IBM 370/165 respectively. The

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[2] Descriptions of *Kaissa*, and other chess programs not discussed here, can be found elsewhere, e.g., the books by Hayes and Levy (1976), and by Welsh and Baczynskyj (1985).

exhibition match between *Chess 4.6* and *Kaissa* was won by the former, indicating that in the interim it had undergone far more development and testing (Frey 1977). The 3rd World Championship at Linz in 1980 finished in a tie between *Belle* and *Chaos*. In the playoff *Belle* won convincingly, providing perhaps the best evidence yet that a deeper search more than compensates for an apparent lack of knowledge. In the past, this counter-intuitive idea had not found ready acceptance in the artificial intelligence community.

At the 4th World Championship (1983 in New York) yet another new winner emerged, *Cray Blitz* (Hyatt, Gower and Nelson 1985; Chapter 7 *Cray Blitz*). More than any other, that program drew on the power of a fast computer, here a Cray XMP. Originally Blitz was a selective search program, in the sense that it used a local evaluation function to discard some moves from every position, but often the time saved was not worth the attendant risks. The availability of a faster computer made it possible for *Cray Blitz* to switch to a purely algorithmic approach and yet retain much of the expensive chess knowledge. Although a mainframe program won the 1983 event, small machines made their mark and were seen to have a great future (Levy and Newborn 1982). For instance, *Bebe* with special-purpose hardware finished second (see also Chapter 12 *Learning in Bebe*), and even experimental versions of commercial products did well. The 5th World Championship (1986 in Cologne) was especially exciting. At that time *Hitech* seemed all powerful (see also Chapter 6 *Hitech*), but faltered in a better position against *Cray Blitz* allowing a four-way tie for first place. As a consequence, had an unknown microprocessor system, *Rebel*, capitalized on its advantages in the final round game, it would have been the first micro-system to win an open championship. Finally we come to the most recent event of this type, the 6th World Championship (1989 in Edmonton). Here the Carnegie Mellon favorite, *Deep Thought* won convincingly, even though the program exhibited several programming errors. Still luck favors the strong, as the full report of the largest and strongest computer chess event ever held shows in Chapter 3 *1989 World Computer Chess Championship*. Although *Deep Thought* dominated the world championship, at the 20th North American Tournament that followed a bare six months later it lost a game against *Mephisto*, and so only tied for first place with its deadly rival and stable-mate *Hitech*.

From the foregoing one might reasonably assume that most computer chess programs have been developed in the USA, and yet for the past two decades Canadian participation has also been active and successful in providing supplementary support. Two programs, *Ostrich* and *Wita*, were at the inauguration of computer-chess tournaments at New York in 1970, and their authors went on to produce and instigate fundamental research in practical aspects of game-tree search (for example, Marsland and Campbell 1982; Campbell and Marsland 1983; Newborn 1985,88a,89; Marsland and Popowich 1985; Marsland, Reinefeld and Schaeffer 1987). Before its retirement, *Ostrich* (McGill University) participated in more championships than any other program. Its contemporary, renamed *Awit* (University of Alberta), had a checkered career as a Shannon type-B (selective search) program, finally achieving its best result with a second place tie at New York in 1983. Other active programs have included *Ribbit* (University of Waterloo), which tied for second at Stockholm in 1974, *L'Excentrique* and *Brute Force*. Currently the strongest Canadian program is *Phoenix* (University of Alberta), a multiprocessor-based system using workstations (Schaeffer 1989a,b), which tied for first place with three others at Cologne in 1986.

While the biggest and highest performing computers were being used in North America, European developers concentrated on microcomputer systems. Especially noteworthy are now the Hegener & Glaser products with the *Mephisto* program developed by Richard Lang of England, and the *Rebel* program by Ed Schröder from the Netherlands.

1.3 Implications

All this leads to the common question: When will a computer be the unassailed expert on chess? This issue was discussed at length during a panel discussion at the ACM 1984 National Conference in San Francisco. At that time it was too early to give a definitive answer, since even the experts could not agree. Their responses covered the whole range of possible answers with different degrees of optimism. Monty Newborn enthusiastically supported "in five years," while Tony Scherzer and Bob Hyatt held to "about the end of the century." Ken Thompson was more cautious with his "eventually, it is inevitable," but more pessimistic was Tony Marsland who said "never, or not until the limits on human skill are known." Even so, there was a sense that production of an artificial Grandmaster was possible, and that a realistic challenge would occur during the first quarter of the 21st century. As added motivation, Edward Fredkin (MIT professor and well-known inventor) has created a special incentive prize for computer chess. The trustee for the Fredkin Prize is Carnegie Mellon University and the fund is administered by Hans Berliner. Much like the Kremer prize for man-powered flight, awards are offered in three categories. The smallest prize of $5000 was presented to Ken Thompson and Joe Condon, when their *Belle* program earned a US Master rating in 1983. The second prize of $10,000 for the first program to achieve a USCF 2500 rating (players who attain this rating may reasonably aspire to becoming Grandmasters) was awarded to *Deep Thought* in August 1989 (for more details see Chapter 5 *Deep Thought*), but the $100,000 for attaining world-champion status remains unclaimed. To sustain interest in this activity, Fredkin funds are available each year for a prize match between the currently best computer and a comparably rated human.

One might well ask whether such a problem is worth all this effort, but when one considers some of the emerging uses of computers in important decision-making processes, the answer must be positive. If computers cannot even solve a decision-making problem in an area of perfect knowledge (like chess), then how can we be sure that computers make better decisions than humans in other complex domains—especially in domains where the rules are ill-defined, or those exhibiting high levels of uncertainty? Unlike some problems, for chess there are well established standards against which to measure performance, not only through the Elo rating scale (Elo 1978) but also using standard tests (Kopec and Bratko 1982) and relative performance measures (Thompson 1982). (See also Chapter 13 *The Bratko-Kopec Test Revisited*.) The ACM-sponsored competitions have provided twenty years of continuing experimental data about the effective speed of computers and their operating system support. They have also afforded a public testing ground for new algorithms and data structures for speeding the traversal of search trees. These tests have provided growing proof of the increased understanding about how to program computers for chess, and how to encode the wealth of expert knowledge needed.

Another potentially valuable aspect of computer chess is its usefulness in demonstrating the power of man-machine cooperation. One would hope, for instance, that a computer could be a useful adjunct to the decision-making process, providing perhaps a steadying influence, and protecting against errors introduced by impulsive short-cuts of the kind people might try in a careless or angry moment. In this and other respects it is easy to understand Donald Michie's support for the view that computer chess is the "*Drosophila melanogaster* (fruit fly) of machine intelligence" (Michie 1980).

What then has been the effect of computer chess on artificial intelligence (AI)? First, each doubter who dared assert the superiority of human thought processes over mechanical algorithms for chess has been discredited. All that remains is to remove the mysticism of the world's greatest chess players. Exactly why seemingly mechanical means have worked, when almost every method proposed by reputable AI experts failed, remains a mystery for some. Clearly hard work, direct application of simple ideas and substantial public testing played a major role, as did improvements in hardware/software support systems. More than anything, this failure of traditional AI techniques for selection in decision-making, leads to the unnatural notion that many "intellectual and creative" activities can be reduced to fundamental computations. Ultimately this means that computers will make major contributions to Music and Writing; indeed some will argue that they have already done so. Thus one contribution of computer chess has been to force an initially reluctant acceptance of "brute-force" methods as an essential component in "intelligent systems," and to encourage growing use of search in problem-solving and planning applications.