# Chapter 1

# Introduction

Efficiently parallelizing the Alpha-Beta search algorithm is difficult in general [Sch89a], but it is made more difficult by *narrow game trees*, which have a low branching factor. This thesis examines the problem of parallelizing the game tree search of the *Chinook* checkers[1] (8 x 8 draughts) playing program [SCT92,STL93]. Two recurring themes are how the low branching factor of checkers game trees makes it difficult to create sufficient amounts of parallel work and how the branch-and-bound nature of Alpha-Beta search makes it difficult to complete the work efficiently in parallel.

Although pioneering work in artificial intelligence (AI) and machine learning by Arthur Samuel used the game of checkers as the application domain [Sam59,Sam67], researchers have largely ignored computers checkers for the past 34 years. One notable exception is the *Duke* checkers program [Tru78]. Of course, there have been commercially available checkers programs, but the technical lessons from those projects have not been widely published. In truth, much of the published work in computer game playing in the past three decades has been in computer chess.

Whereas chess game trees are wide and have the potential for a relatively high *degree of parallelism* [SuG91], checkers game trees are narrow and have less work available for parallel processing at each node. Chess game trees have a relatively high average branching factor of 35 to 40 [Gil78]. This thesis reports that checkers game trees in the proposed test suite have an average branching factor of 2.84, which is over an order of magnitude less than in chess. As parallel processors are added to the game tree search strategy, they quickly exceed the degree of parallelism available at a node in a narrow game tree.

The situation is further complicated by the fact that the Alpha-Beta tree search algorithm is a special case of the branch-and-bound family of algorithms. As with other branch-and bound

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[1] For a brief summary of the rules of checkers, see Appendix A.

algorithms, Alpha-Beta has the ability to logically eliminate portions of the search tree based on the results obtained by searching other subtrees. Therefore, searching subtrees in non-optimal order, through poor work scheduling or because searches are done in parallel without the benefit of information from an earlier search, may result in unnecessary computation.

## 1.1 A Brief History of *Chinook*

*Chinook* is a checkers program developed at the University of Alberta. The project began in June 1989 with Joe Culberson, Jonathan Schaeffer and Duane Szafron and over the years, a variety of individuals have become involved in the effort. The project has the short-term goal of developing an interactive program capable of defeating the human world checkers champion and the long-term goal of solving the game of checkers.

Towards the short-term goal, the program has had some significant successes. In August 1990, *Chinook* won the Mississippi State Open (human) checkers tournament and placed second in the U.S. National Open behind World Champion Dr. Marion Tinsley. In both tournaments, *Chinook* defeated human checkers grandmasters. More importantly, by placing second in the U.S. National Open, behind the World Champion, *Chinook* earned the right to play for the World Championship in a 40-game match. *Chinook* is the first computer program to earn the right to contest for such a title.

*Chinook* is not invincible and has also had some setbacks. Since August 1990, *Chinook* has lost one competitive game to another computer program, and it has narrowly lost exhibition matches against human grandmasters. In August 1992, Dr. Tinsley and *Chinook* played the 40-game match for the Man Versus Machine World Draughts Championship in London, England, sponsored by Silicon Graphics International. Dr. Tinsley defeated *Chinook* with 4 wins, 2 losses and 33 draws.[2] To *Chinook*'s credit, its two wins represent only the 8th and 9th losses by Dr. Tinsley in over 40 years of competitive play.

For the August 1992 match, a parallel version of *Chinook*, *ParaChinook*, was implemented for the Silicon Graphics SGI 4D/480, 8-processor, shared memory multiprocessor. Each processor had a clock speed of 33 MHz and the common random access memory was 256 megabytes. However, the results presented in this thesis were actually obtained on a BBN TC2000 shared memory multiprocessor. The TC2000 version of *ParaChinook* is the August

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[2] The 40th game was not played because with a 2 game lead, Dr. Tinsley had already won the match.

1992 program, ported to the new computer to take advantage of the larger number of processors and with minor improvements added as a result of the on-going research.

The long-term goal of the *Chinook* project is to prove the game theoretic value of the game of checkers. From the initial board position, either one player can force a win or neither player can force a win. Proving the game would determine if it is a win for Black, a win for White or is a draw. There is strong empirical evidence that the game is a draw. The state space contains $5 \times 10^{20}$ nodes [SCT92] and proving the game of checkers would set a milestone as one of the largest combinatorial search spaces to be solved.

An important component of the both the short and long term goals is the endgame databases computed through retrograde analysis [Tho86,LSL93]. Currently, *Chinook* has a database of all of the endgames with 7 pieces or less on the board, the so-called 7-piece databases, and the game theoretic value of each position. By looking up a position in the database, it is possible to determine the position's value with perfect accuracy. In late-July 1993, all of the materially balanced (i.e. equal number of pieces of each colour), and thus the most useful, 8-piece databases were completed. Because the endgame databases represent perfect information, they will play a crucial role in solving the game. The endgame databases have already played a major role in *Chinook*'s success in tournament play and in the August 1992 match with Dr. Tinsley.

The short-term goal remains unfulfilled, but *may* be close at hand as a re-match with Dr. Tinsley is possible in late 1993 or early 1994. The addition of the entire materially balanced 8-piece databases, of which only 40% was available in August 1992, will significantly improve *Chinook*'s playing strength. The long-term goal, which once seemed very distant, is also made more attainable by the completion of the key 8-piece databases.

### 1.2 Overview of the Thesis

This thesis describes the parallelization of *Chinook*'s Alpha-Beta search. The depth-first Principal Variation Splitting (PVSplit) algorithm [MaC82], popular with computer chess researchers, formed the basis of the first *ParaChinook*. However, the poor performance of PVSplit led to the development of the Principal Variation Frontier Splitting (PVFSplit) algorithm, which is a variation of PVSplit. The parallel performance of both PVSplit and PVFSplit is evaluated on a BBN TC2000 shared memory multiprocessor, using a test suite of 20 positions. The issues of starvation and stragglers are discussed, quantified and addressed. It is concluded that any PVSplit-based algorithm will suffer from poor speedups on the narrow

checkers game trees. However, a hybrid approach using both a non-depth-first search algorithm and PVFSplit may be promising for a future version of *ParaChinook*.

The thesis begins by reviewing the concepts of sequential Alpha-Beta game tree search. It is a non-exhaustive survey of the large body of research in Alpha-Beta search and game playing programs. It then surveys the research on parallel Alpha-Beta search and discusses the *ParaChinook* implementation of Principal Variation Splitting and the experiments used to evaluate parallel performance. It discusses Principal Variation Frontier Splitting, which is based on PVSplit, but improves on its parallel performance. It also addresses the issue of stragglers and their impact on performance. Finally, the thesis concludes with a discussion of the experimental results and possibilities for future work.