The State of Automated Bridge Play

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Abstract. *The game of Bridge provides a number of research areas to AI researchers due to the many components that constitute the game. Bidding provides the subtle challenge of potential outcome maximization while learning through information gathering, but constrained to a limited rule set. Declarer play can be accomplished through planning and inference. Both the bidding and the play can also be accomplished through Monte Carlo analysis using a perfect information solver. Double-dummy play is a perfect information search, but over an enormous state-space, and thus requires α-β pruning, transposition tables and other tree-minimization techniques. As such, researchers have made much progress in each of these sub-fields over the years, particularly double-dummy play, but are yet to produce a consistent expert level player.*

Keywords: Planning, HTN, Bridge, Card game.

1 Introduction

Before we had the computing power to write programs which dealt with full 52-card hands, interested researchers were devising algorithms for bidding and double dummy play for limited case-study.[Ber63, Was70] Then, in the early 80s, Throop released the first of his many editions of BridgeBaron$^{\text{TM}}$, which included the ability to play complete deals, along with a book narrating his travails.[Thr83] Subsequently as new AI techniques for search and planning were codified, many researchers explored the possibilities of applying those techniques to bridge as it provides a complex yet understandable game, where computers have yet to best humans on a regular basis.[Raj][1]

Many researchers have applied AI techniques to the problem of playing bridge, as similar to other games, it offers a partially-observable, stochastic, sequential, static, discrete, multi-agent environment to struggle with.[NR09]) Unlike poker, in which bluffing is a central component, deception and similar techniques techniques play a small part in bridge; the dominating issue is strategic play of the cards. Unlike chess, bridge offers a limited-depth search in bidding, and an exact-depth search in the play. As such, search-space minimization techniques can be powerful enough to produce an exact solution in

[1] Despite some early expectation of greatness.[Gin02]

reasonable time. [Gin96][2]

Bridge has 3 distinct types of problems: bidding, single-dummy play (imperfect-information), and double-dummy play (perfect information). Each of these have different rules, objectives, and inferences that can be drawn, such that research has tended to focus on only one aspect at a time. In this paper, I will primarily review the work of:

- Smith, Nau, & Throop and their work on planning
- Ginsberg and his work on partition search, and the use of Monte Carlo sampling in GiB
- Frank, Basin, Bundy, & others and their work on improved heuristic techniques in the play.

As well as these areas, the use of neural networks will be looked at.

2 Playing the hand

2.1 Declarer

In the play, declarer is faced with a goal of taking the optimal number of tricks with the combined assets of the two hands. Optimal may not mean maximal, as depending on the form of scoring, the declarer looking for the maximum expected value in the scoring format, may not mean the maximal number of tricks.[3]

When humans tackle a declarer problem, they often have a series of pre-canned 'plans' on how to take tricks, generally involving small building blocks like finessing and running a long suit, integrated into an overall plan of attack.[Kan02] One such common technique is to combine knowledge of how to play a single suit into a plan for the whole hand.

Smith et al. approached declarer play in just this fashion. Using a modified form of HTN[4] planning they explored complex hand analysis like finesse and cash-out, via simple building blocks like *LeadLow* and *PlayCard*.[SNT96] This approach was very successful, as it propelled Bridge Baron to a win at the inaugural 1997 World Computer Bridge Championships(WCBC).[SNT98b][5][6] However, basic tests suggested that the level of this improved robot was still less than that of an amateur bridge player.

Ginsberg introduced a new two-part approach: minimize the state space for perfect information search (see section 4), and then solve all problems through an expectation over Monte Carlo simulation. The set of draws in the Monte

[2] See section on Deep Finesse

[3] Based on the probabilities of achieving these outcomes, combined with the expected score under the format (imps/MPs/B-A-M).[Woo92]

[4] Hierarchical Task Network[GNT04]

[5] computerbridge.com

[6] incorporated into BridgeBaron

Carlo are done using only those consistent with the bidding and current play. This lead to wins at the 1998 and 1999 WCBC. Futher tests as a 'bot' on OKBridge[7] lead Ginsberg to conclude that GiB[8] was now better than a human amateur.[Gin02]

Frank & Basin and others described shortcomings with the Monte Carlo approach to solving an imperfect information problem as being prone to errors.[FB98b] They gave examples of *strategy-fusion* where a Monte Carlo algorithm incorrectly assumes that all the cards will be known at the time when a decision must be made.[9] In their work to eliminate this problem, they explored two techniques: *Vector-minimaxing* and *payoff-reduction minimaxing*. In theory, both should be able to make better heuristic decisions than raw Monte Carlo. However, the vector approach did not provide much improvement at an unreasonable speed-penalty. But, *prm* was shown to drastically reduce the chance of errors. However, this algorithm also appears to slow down the search engine to an unusable speed. Better results were obtained by Ginsberg simply by small heuristic modifications allowing for this problem.[Gin02]

2.2 Defense

While on the surface similar, defensive play is often done by humans in a very different manner from play. Since the dummy assets, and bidding are known, this often allows a defender to place the many of the missing high-cards, as well as postulate a small number of possible distributions, but to date no published work has attacked this differentiation in inferences available between the declarer and defensive play situations.

Frank et al did look at defensive play, but from a better tree search perspective.[FB98a] In this work they furthered the use of *prm* and introduced new heuristics of *Beta Reduction/Branch Ordering* and *Iterative Biasing*. Both are modelled after perfect-information search techniques, to be applied to an imperfect information tree. The combination of *prm* and *beta* proved to solve defensive problems at a much higher rate, but the cost of which was a ten-fold performance reduction, making the use of these techniques impractical.

3 Bidding

In the play, there is no ambiguity in the meaning of each card, and thus with perfect information the game can be played optimally. No such guarantee exists in the bidding, as there is a limited script of bids that can be applied to describe various hand-types. Different systems have strengths and flaws, but having perfect information does not guarantee the systemic ability to reach the optimal scoring contract. Also, especially in competitive auctions, many situations are reached in the auction which do not have an exact meaning according to the

[7]okbridge.com

[8]Ginsberg intelligent Bridge

[9]A good example exists in [FB98a] pp 54-55

agreed upon bidding system. Therefore, experts are forced to improvize using agreed upon rules and the heuristic of experience. Such improvisation across a large field of possibilities using only is a daunting task for a computer.

The GiB method is akin to its play method: draw hand layouts consistent with the auction and use a bid database to determine suitability. Once a set is obtained, each is solved via the double-dummy solver, and the decision is made via probability. This method assumes that both partner and the opponents will both play and bid optimally, and thus does not take into account tactical or destructive bids which the opponents might make to obstruct.

Amit and Markovitch tried a slightly different approach, by combining Monte Carlo sampling with a learning algorithm over a training set and method. The key to this approach was an understanding of the partnership requirements of the bidding phase, they engaged a method of co-training, such that both partners learn with each other rather than separately. The results of this were quite promising, as over a set of 2000 training deals, the bidding system was able to improve from worse than GiB, to better. [AM06]

Other attempts to model bidding include Jamroga [Jam99], who used a first-order language approach, Yegnanarayana et al[YKS96], who modelled the decision process in bidding using neural networks, and Ando, Kobayashi, and Uehara, who furthered the techniques of abduction as proposed by Uehara[Ueh95] to a framework of agent competition.

4 Double Dummy

Even under perfect information, the average branching factor of a full 52-card deal of bridge makes the state-space too large to solve problems, even using α-β pruning. Ginsberg used transposition and zero-window methods and added a new method he dubbed partition search. The reduction in branching factor observed was $b \rightarrow b^{0.76}$. Transposition tables deal with the symmetry of a game such as bridge, thus reducing the total number of positions that require studying. Zero-window search is a search-space minimizing technique which tightly binds the values used for α-β after making an initial 'good' move[10]. Ginsberg's Partition Search is a method where cards whose rank is irrelevant to the set of outcomes are reduced to 'x's, just as a human player would do. In doing so, the number of expanded branches is reduced to a searchable size. [Gin96]

Mossakowski et al tried a solution using Neural Networks to recognize hand patterns with some success.[MM04] They plan to extend the work to the play and bidding.

In the bridge community, the best known solver is DeepFinesse. Authored by William Bailey, this program is used by the ACBL to provide double-dummy analysis for every set of deals, as well as by GiB and BridgeBase to provide on the fly analysis as to which lines of play will be successful. The author is reported to have used α-β, transposition tables, and an aggressive heuristic pruner, to

[10] A good heuristic function makes this more profitable

achieve an average of 6-seconds to solve a hand given a contract and declarer.[11] Unfortunately, Bailey has yet to publish any deeper insight into his work.

5 Current bridge playing programs

Over the last five years, two programs have reigned as champions of the WCBC: Jackbridge and Wbridge5. Jack bridge written by Kuijf and Heemskerk from the Netherlands won in 2006 and 2009. Wbridge5, written by Yves Costel from France won in 2005, and 2007-8. Both programs are rumoured to be written using a customization of the Monte Carlo and double-dummy techniques proposed by Ginsberg.[NR09]

Several other programs and their author information can be found at Al Levy's website.[12]

6 Shortcomings and Future Work

Computer bridge players have surpassed humans in the time they take to solve double-dummy problems, and the best programs are attaining expert status as card players. They do not yet handle all the nuances of deceptive play, and due to the constrained medium for exchange as well as the tactical and destructive considerations, computer bidding is still a work in progress.

There is still work to be done in the area of logic, in grasping the possibility of opponent not playing optimally, and why they might do so. When one is faced with a choice of plays, rather than always choosing the one with the highest probability under the assumption that an opponent will play perfectly, often an expert will make a play which gives that opponent an opportunity to make a mistake. The application of epistemic knowledge may also be interesting, as in the previous problem, it would be of aid to model the information that is known by our opponent, and thus apply a probability to the chance that they will go wrong.

Another expert skill discussed in bridge literature is the ability to make a declarer claim.[Kan02] From as few as two up to the full thirteen cards per hand, an expert can often make an unconditional claim that states an order of play regardless of the distribution of the opponents hands. On occasion even a conditional claim will be made suggesting a number of tricks in each case. A human generally does this via combining simple knowledge of executing tricks via single suit plays into a full plan. No attempt appears to have been made or at least published to solve this sub-problem. Doing so would be useful to all phases of bridge as at any point, as if a problem evolves to a claim, only the state space problem of learned combinations of the two hands would be searched.

With all these problems and sub-problems, it appears researchers still have a lot of work ahead of them to create a bridge player to rival the top experts.

[11] http://query.nytimes.com/gst/fullpage.html?res=9C02E3DB163FF937A15750C0A9639C8B63&fta=y

[12] http://www.computerbridge.com

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Links

- Bridge Baron. http://www.bridgebaron.com
- Deep Fineese. http://www.deepfinesse.com
- Jack Bridge. http://www.jackbridge.com
- Richard Pavilicek's suit break calculator http://www.rpbridge.net/xsb2.htm
- Wbridge5 http://www.wbridge5.com
- World Computer Bridge http://computerbridge.com