Realization of a skillful bridge bidding program*

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INTRODUCTION

The problem of bidding at contract bridge is an “intellectual” task which has never before been performed skillfully by a computer program. Only Carley1 has made the attempt to handle this problem and his program used a very crude treatment; as a result, inferior contracts were produced because bidding requires many fine lines of distinction which his approach could not make.

Slightly more work has been done on other problems related to bridge. Berlekamp2 has done work on the double-dummy problem for play of the hand, but double-dummy is a perfect information situation and bears little resemblance, beyond the rules for legal play of the cards, to the actual game of bridge. Furthermore, his program was limited to no trump contracts and to contracts in which the declarer was to take almost all of the tricks so that the number of cases (and hence the size of the search tree) remained fairly small.

More recently, Riley and Throop3 are developing an interactive bridge playing program. Their program does only play of the hand, given the final contract. It is considerably more sophisticated than Carley’s program in that it attempts to determine an overall strategy for the play of the hand rather than the isolated, one-trick-at-a-time method used by Carley. Because it ignores the bidding, however, the Riley-Throop program is unable to determine the likely location of cards held by the opposition which might have been inferred from competitive bidding, thus causing the program to lose tricks which would not be lost with proper application of such information. Some of the more advanced play situations appear to be beyond the scope of their present program as well. However, it seems that the program can still be improved, especially by extending it to react to bidding information.

In addition to the fact that bridge bidding is intellectually interesting and has never before been competently accomplished by a computer program, there are numerous other reasons for studying the task. First, bridge bidding requires a certain degree of generality, with a vast number of bidding systems and conventions in current use. In addition, the goal of bridge bidding is not as well defined as the goals of many other tasks. Thus, there can exist numerous techniques to reach any given contract and there is not always a final contract which is clearly superior to all others.

Second, bridge bidding is a task of imperfect information, since each player is aware of the exact location of only thirteen of the fifty-two cards in the deck. Lack of perfect information is characteristic of a large number of problem-solving environments, from corporate decision-making to play-calling in a football huddle.

Third, bridge bidding is a partnership task. Each player must react to both partner and the opposition, distinguishing between friendly and hostile information, a process which requires a considerable amount of judgment in a human. The partnership aspect of bidding resembles the process of negotiation or arbitration or even an auction.*

Fourth, bridge bidding allows the investigation of

* Contract bridge is a modification of a game called auction bridge.
programming techniques which can be valuable in many application areas. A task language for bridge bidding was designed using the DEFINE capability of Burroughs B5500 ALGOL so that a person familiar with the game is able to read and understand programs written in that language, despite possible inability to write the program. In addition, one decision-making model, chosen for its speed and efficiency, was employed almost exclusively, with the intent of discovering the extent to which it can be used.4

Fifth, bridge bidding is a significant intellectual problem. The proliferation of books on the subject of bridge bidding and the popularization of the Goren point-count bidding system5 have mistakenly led many persons to believe that the task of bridge bidding is rendered trivial by simple adherence to the rules advanced by one of these books and that skill in this field is proportional to the ability to memorize and apply the many different rules. Indeed, skillful bridge bidding possesses many opportunities for the exercise of “judgment” and “imagination”, since no bridge bidding “system” specifies action to be taken in all cases and most systems do not adequately treat competitive bidding.

For all these reasons, then, bridge bidding is an excellent subject for research and investigation.

PARTNERSHIP BIDDING

The initial goal of the research was to design a program which would bid very skillfully in the situation in which only the two members of one partnership make bids (non-competitive or “partnership” bidding), with the opponents passing at each turn to bid. A partnership must be skillful in non-competitive situations as a prerequisite toward skill in competitive situations, since competitive bidding is designed, in part, to make it difficult for the opposition to explore their combined holding thoroughly enough to reach an optimal contract. Accordingly, the program was designed so that it could be extended to competitive bidding and eventually to other related tasks.

The program was further initially limited to the Schenken system of bidding,6,7 chosen primarily because of personal preference and familiarity. This restriction was also made with the eventual extensions in mind. The final initial restriction was to base the scoring system on match-point scoring in duplicate bridge. This last constraint is considerably less significant than the others, since it in no way prevents the program from performing any task; it does, however, have a slight effect upon the program’s performance when another method of scoring is used.

The structure of the program is based on the idea of classes of bidding sequences, each class encompassing a large number of possible sequences. A bidding sequence (for partnership bidding) may be defined as the ordered set of bids by two partners from the opening bid to the first pass made by a member of the partnership. There are more than $10^9$ of these distinct bidding sequences possible, making the problem one of classifying sequences and handling different classes in appropriately different ways.

The various classes of sequences can be defined on the basis of different types of opening bids. Each type of opening bid is designed to give a certain characterization of the opening bidder’s hand and, generally, to distinguish it in structure and strength. For example, the opening bid of one heart is of the same type as an opening bid of one spade, but of a different type than opening bids of one no trump or two hearts.

The major classes may now be defined as the set of all sequences beginning with a certain type of opening bid. Thus, a program structure evolves. There is a procedure OPENBID,* a procedure RESPOND, and eight “sequence procedures” ONECLUBSEQ, ONEBIDSEQ, ONENOSEQ, WEAKTWOSEQ, TWODYMISEQ, TWONOSEQ, PREEMPTSEQ, and THREECLUBSEQ, defining the major classes for the Schenken system. All of these sequence procedures are similar, each representing individual bidding sequences beginning with a given type of opening bid. In addition, there are three special sequence procedures, BLACKWOOD, GERBER, and STAYMAN, corresponding to special bridge bidding conventions, which may be called from any of the sequence procedures. With this basic set of procedures, the problem of non-competitive bidding can be adequately handled.

The decisions to create sequence procedures based on the opening bid and to isolate the initial response into a separate procedure are based on the fact that the two most important bids in a bidding sequence are the first two, particularly the opening bid. If the opening bidder makes an incorrect bid, an incorrect interpretation will be made of his hand. And the error will be magnified if the opening bid is of a different type than the proper opening bid, rather than just a different bid of the same type. Future bids can clarify this initial error, but can rarely make the contents of the hand as clear as it would be with the proper initial bid. The program structure reflects this statement in that an opening bid of the wrong type will cause the program to enter the wrong sequence procedure.

* Capitalized words refer to program designators.
The flow of control for partnership bidding is from OPENBID to RESPOND to the appropriate sequence procedure. Control remains within one of the sequence procedures throughout the remainder of the bidding unless one of the three special convention sequences is entered, in which case control remains there for the rest of the bidding. Error recovery, if necessary, is handled automatically within the sequence procedure in control.

Partnership bridge bidding may be envisioned as a giant tree structure in which each path in the structure represents a possible bidding sequence and in which each vertex represents a possible bid. Consider the root of the tree to be the point immediately prior to the opening bidder's bid. Then there are thirty-five branches at the first level (one for each legal opening bid), and each succeeding level has fewer branches from each vertex, corresponding to the number of remaining legal bids at that point. The longest path is of length thirty-six (beginning with one club, then each possible bid in succession, then a pass); the shortest is of length two (any legal bid followed by a pass), ignoring the case in which both partners pass.

Since this tree has more than $10^{19}$ paths, a number of simplifying assumptions are necessary in order to make the task feasible. First, a much smaller tree may be constructed using the previously defined notion of classes. In this reduced tree, the first level has only eight branches, one for each type of opening bid. Then, for each of the eight opening bids, the responses may be divided into several types, creating subclasses, and these subclasses may be divided still further throughout the tree. In addition, the tree may be arbitrarily severed at a length of ten or eleven, since few realistic bidding sequences contain more bids. These assumptions permit a huge reduction in the size of the tree, leaving it with about fifty subclasses which, when subdivided, leave several thousand paths down the tree.

The number of paths may be reduced still further by observing that a great number of bidding sequences, while superficially different, are really quite similar in many bidding systems, with only slight differences in meaning or slight differences in the estimated strength of the partnership. Thus, two paths of the tree can be merged into one by treating sequences of different subclasses identically, creating a new form of structure, a loop-free directed graph.

It was then necessary to connect the vertices so that the network could be traversed. Each vertex was given a marker which a member of the partnership could use to mark his place in the structure at each turn. With this approach, a sequence of markers could uniquely identify a path through the graph. Each player, however, can only use markers that he has found. (It may be that the program's partner is a human who doesn't even know about the internal representation of the bidding and who, in any event, certainly doesn't find or use any markers.) Thus, each bidder begins at the point at which he last found a marker and each partner discovers the same set of markers, since they are following the same path.

Consider a hypothetical structure such as that in Figure 1 and assume that the program is bidding both hands of a partnership. The opening bidder first enters the sequence procedure at A as a result of the opening bid and can then make a bid based on the previous information. The responder then jumps to the same sequence procedure and can move one level down the graph (to point B) based on his partner's last bid to the point at which he must make a bid. He finds the marker at this point, then goes into the bidding process. At his next turn, he will return directly to the marker at B, follow the last two bids (his own and partner's last) down the graph, find the new marker, and make a new bid. In the meantime, the opener, who has not yet picked up a marker, reenters the sequence procedure at A, where he must move down two levels, which he can do based on his own last bid and his partner's last bid. Now he finds the marker

* An exception: STAYMAN can call BLACKWOOD.
at C and makes a bid. This process continues throughout the bidding sequence, with each partner finding the marker and moving down two levels based on the last round of bidding to the point at which a new marker is found and a new bid is made.

Each vertex represents a point at which a bid must be made, a decision-making point. The bridge bidding program attempts to bid in the same manner as a human would, using the same decision-making criteria, since the size of the task is too great to allow programming a completely specified set of rules. The order in which various conditions and alternatives are tested were chosen to correspond closely to the way in which a human bridge expert would select a bid. The program, in effect, simulates human judgment by considering the same conditions and making the same evaluations as a human.

One of the major mechanisms of the bidding process for each player is a running estimate of partnership strength. At each turn to bid, each player reestimates the minimum and maximum number of points held by the partnership, based on information gained from the bidding up to that point. The early versions of the program used a static evaluation for each player's hand, based on high card and distributional points, computed at the time the hand was first dealt and never changed. This was the figure used in computing the strength of the partnership. Although this scheme worked fairly well, it tended to be inaccurate in extreme cases.

To counteract these inaccuracies, a dynamic evaluation scheme was adopted. Each time it is a player's turn to bid, REVALUEHAND is called, which recomputes his point count, awarding extra points on the basis of length in his partner's bid suite(s) and shortness in his unbid suite(s), and subtracting points from his hand for shortness in partner's suite(s). Further adjustments are made if the partnership agrees on a trump suit. This dynamic scheme results in a more accurate evaluation of the true partnership strength, which, in turn, yields more aggressive bidding when the strength of the two hands coincides and more cautious bidding when the opposite is true.

The overall process for partnership bidding is now completed. Following the opening bid, the responder evaluates his own hand, evaluates the strength of the partnership, and makes a bid. Then, until one of the partners passes, each player finds the correct point in the proper sequence procedure, reevaluates his hand, makes a new estimate of the combined strength of the partnership based on his own new valuation and any additional information gained from partner's last bid, then picks up the marker and makes a bid.

COMPETITIVE BIDDING

There are several significant differences between partnership and competitive bidding. In the partnership case, the bidder always tries to make an offensive bid; the competitive case requires the bidder to consider both offensive and defensive action. In competitive bidding, a partnership must be prepared for the opponents' attempt to interrupt a perfectly normal and logical bidding sequence with an intervening bid. The partnership must also develop methods to reach their best contract after their opponents have opened the bidding. These differences and others make skillful competitive bidding considerably more difficult than skillful non-competitive bidding.

Competitive bidding is further complicated by the existence of a huge number of bidding conventions, very few of which are universally accepted as being standard. For example, if the opening bidder bids one no trump and left-hand-opponent bids two clubs, the two club bid, a priori, can be interpreted as being a natural bid or any of several special conventional bids. The partnership using the two club bid, as well as their opponents, must understand the meaning of that bid, since future bidding action is highly dependent on its actual meaning. The competitive bidding portions of the program, then, have to be able to both make and interpret a large number of conventional bids.

Since the program was initially designed with the intent of eventually incorporating competitive bidding, the modifications to perform this task could be made directly, without any major structural changes. A procedure INTERVIEW was created which establishes the bidding conventions to be used by each partnership. Procedures OVERCALL and RESPONDTOOVERCALL, corresponding to OPENBID and RESPOND respectively, complete the organization of the first round of bidding.

After conventions are selected, the dealer bids first. If and when one of the players makes an opening bid (using OPENBID), OVERCALL is called for the left-hand-opponent. Next, RESPOND is called for opener's partner. The fourth player completes the first round of bidding by using either RESPONDTOOVERCALL or OVERCALL depending on whether or not his partner made an overcall.

The partnership which opened the bidding then uses the previously defined sequence procedures, which have been modified for competitive bidding. The opposition (the overcalling side) cannot use these procedures as easily, since many of their bids are conventional and cannot be treated in the same manner. In addition, when bidding on a hand becomes very competitive and all four players have made bids, the
original sequence procedures tend to break down, particularly when one of the players has passed once or has doubled an opponent’s contract for penalties. For these reasons, a supervisory procedure NEXTBIDDER was created. The responsibility of NEXTBIDDER is to determine whether or not the original sequence procedures are still usable and, if not, to provide the mechanism whereby a player can make a meaningful bid.

The Boolean variable OKTORAISE, computed by NEXTBIDDER for each bidder at each turn, incorporates many of the tests needed for successful competitive bidding. OKTORAISE is true if the bidder (or the partnership in certain cases) has sufficient strength to bid at the current level of the bidding, despite intervening bids by the opposition. If OKTORAISE is false, the bidder will, as a rule, pass or attempt to double an opposing contract.

Additional modifications were also necessary. First among these was the inclusion of doubles and redoubles. The program has to make both penalty and takeout doubles, as well as interpret doubles by other players correctly. Procedures TAKEOUTDOUBLE and PENALTYDOUBLE return the value “true” if the hand meets the conditions to make a takeout double or a penalty double. Takeout doubles make bidding more difficult since they indicate a wide range of strength. Redoubles are much more easily treated since the vast majority of them are made by responder following a takeout double of the opening bid.

Another set of modifications was necessary to handle cue bidding, one of the most sophisticated areas of bridge bidding. Many different meanings can be assigned to a cue bid depending on the exact situation: an overwhelmingly strong hand, control of the enemy’s bid suit, asking for control of the enemy’s suit, an ace-showing bid, or a general purpose forcing bid when no other useful bid is available. Since cue bids force partner to bid, special checks for cue bids had to be included within the decision-making mechanism.

Many of these checks were made by the Boolean array BIDBYWHO, which also checked to see that both partnerships are not bidding the same suit. Since two players on opposing sides will often have the same strongest suit, one of the players will have to suppress mentioning that suit once the other player has bid it, unless he has some suspicion that the opposition bid is psychic or artificial.**

Some change was also made in the means for evaluating partnership strength. First, REVALUEHAND was expanded to credit extra points for shortness in the opponents’ bid suit(s) and to subtract points for apparently worthless honor cards in their suit(s). Second, running estimates of the minimum and maximum strength of the opponents were established for each player. These estimates are only lightly considered, since the natural tendency is to believe one’s partner rather than the opposition. However, this information is useful when trying to decide to double the opponents or whether to bid a close contract.

There were a number of options available for handling continuing bids by the overcalling side (the side which did not make the opening bid). One constraint was that the overcalling side might really have the stronger hands and would need to have sequence procedures which were as powerful and versatile as those of the opening side. Another factor was that there are a very large number of overcalls which, if improperly grouped, could lead to an unmanageable number of subsequences.*

Several observations were made which allowed great simplification and eventual solution of the problem. First, the easiest way to have the powerful sequence procedures of the opening side available to the overcalling side was to use them directly as much as possible. Second, in order to use them, the overcalls somehow had to be equated to opening bids. Third, extra provisions were necessary to handle the special conventions and to make the overcall sequences resemble opening bid sequences. (Note that, in actual bidding, there is only one sequence; for purposes of explication, however, two distinct subsequences, one for each partnership, may be considered.)

The above observations were implemented in stages. It became clear that whatever the overcall, the overcall sequence would be highly dependent on the opening bid (rather than the overcall), at least for the first couple of bids. Thus, OVERCALL and RESPONDTOOVERCALL were organized in much the same way as RESPOND, setting up major divisions based on the type of opening bid.

Next, overcalls were divided into classes. In doing so, it was seen that regular (simple) overcalls and takeout doubles indicate approximately the strength as an opening bid of one of a suit, that direct no trump overcalls are very similar to strong no trump openings, that weak jump overcalls are similar to preemptive or weak two bids, and that strong jump overcalls and cue bids are roughly equivalent to strong opening two bids in strength. This division showed that many overcalls

** This inference is very difficult even for the expert human bidder and currently beyond the scope of the program.

* Epstein* calculates the number of competitive bidding sequences to be of the order of $10^4$, compared with $10^8$ for partnership bidding.
could be treated very similarly to certain types of opening bids and that, for these cases at least, the same basic sequence procedures could be used for both the opening side and the overcalling side, simply by providing a set of markers for each partnership in each sequence procedure.

This approach was successful for most, but not all, of the competitive cases. In particular, it failed to cover the highly conventional bids, such as unusual no trumps, Michaels cue bids, and Astro. This failure resulted from the very specialized nature and very limited applicability of these conventional bids; in other words, the approach was satisfactory for all but the most specialized conventions. To solve this problem, the overcalling side treated the opening bids as belonging to one of three classes: strong opening bids, weak opening bids, and no trump openings. Then, three new sequence procedures were constructed to handle the competitive situation, particularly the special cases. These new sequence procedures, named OVERONESEQ, OVERPREESEQ, and OVERNTSEQ, call the regular sequence procedures whenever possible, making the remaining decisions themselves.

The overall program organization can now be summarized very simply. Following convention selection and the first round of bidding, control passes to the supervisory procedure NEXTBIDDER. For each player in turn, NEXTBIDDER calls REVALUEHAND, checks to see if the sequence procedures are still valid for his partnership, and then either calls one of the eight sequence procedures for the opening side, calls one of the three new sequence procedures for the overcalling side (which may then call another sequence procedure), or uses its own methods to make a bid. This procedure retains control until the bidding is ended by three consecutive passes.*

EXTENSIONS OF THE BASIC PROGRAM

A number of extensions were then made to the existing program, including the ability to use other bidding systems, the ability to solve bridge bidding puzzles, and the ability to play with up to three human players. These extensions produced a large amount of generality within the domain of bridge bidding.

The program at first bid only according to the Schenken system, which is less popular among bridge players than Standard American bidding. The extended program contained four basic bidding systems: Standard American, Goren (from which Standard American has been derived), Schenken, and Kaplan-Sheinwold. In addition, many variations on these systems were allowed and a large number of defensive conventions were implemented. This choice of systems was made since an overwhelming majority of bridge players in the United States use one of these systems. In addition, basic bids from the different systems may be combined, as long as no contradictions are created.**

The biggest effect of the addition of the new bidding systems was observed in those sections of the program handling the first round of the bidding and in those where the strength of the partnership was evaluated. Most of the difference among the systems could be incorporated into the estimates of partnership strength. Much of the rest of the program was only slightly altered.

Additional care had to be taken for those situations in which the opening bid may be partially artificial, such as a “short club” in Standard American bidding. Of the eight sequence procedures, only ONEBIDSEQ was significantly affected by these changes, as a result of the greater range of strength indicated by an opening bid of one of a suit in bidding systems other than Schenken’s.

Each of the systems has some special quirks that must be specially treated, though, and each of these special conventions was separately handled, creating most of the programming work necessary to implement each additional bidding system.

Defensively, most of the common conventions were made available. At least three alternatives were provided for each defensive situation. Several other possible defensive devices, such as unusual no trumps and Michaels cue bids, were also included. The limits were rather arbitrarily drawn.

The second major extension of the program was made to enable it to bid with people. In its first version, it would bid each hand using only information normally available to that bidder. The result of the program’s bidding all four hands is that the program always “understood” the meaning of the other bids. When the program bids with humans, the problem of communication becomes significant, illustrating two major considerations in a partnership game: the amount of faith to place in partner’s action and the amount of credence to give to the opposition.

In bidding with one to three humans, the program

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* An exception: when the left-hand-opponent of the opener passes and the overcall follows the response, RESPONDTOOVERCALL is called for the left-hand-opponent at his next turn rather than a sequence procedure.

** Procedure INTERVIEW prevents such contradictions.
must interpret all bids as accurately as possible, given the bidding systems of both partnerships. It is important to note that a bad bid by a human might not only tend to confuse the program, but might also confuse any human player. The program tends to put considerably more faith in its partner's bids than in bids made by the opposition.

The inclusion of human players is handled by interactive procedures. Each partnership must decide on its conventions and so inform the opponents, corresponding to the convention cards used in duplicate bridge games. The program interviews both partnerships, which allows it to assign the proper meaning to bids made by the humans. Other interactive procedures allow humans to supply a hand for the program to bid, as well as letting the program shuffle and deal hands by means of random number generation. There are facilities for replaying any hand and for varying the number of hands being bid by humans.

The third major extension to the basic program allows the program to solve bridge bidding puzzles: given a hand, a bidding sequence, and the vulnerability, make the “best” bid. This is a somewhat harder task than merely bidding the same hand at each turn with three human players. Whereas the program previously had to interpret the other three players’ bidding, in this case, it must also interpret its own previous bids. In numerous cases, the bids, supplied for previous rounds do not conform to what the program would have bid on its own. (Humans have the same difficulty.) Thus, the program must reconstruct the entire bidding sequence by going through the sequence one bid at a time and computing the strength of each hand and partnership.

PROGRAM PERFORMANCE

Skill at bridge bidding was established as a major goal of the program development. It is trivial to write a computer program to make legal bids; it is vastly more difficult to achieve a high level of competence in bidding. Hence, particular attention was given to skill at all stages—first in partnership bidding, next in competitive bidding, and finally in a variety of bidding systems. As a result, the program is a highly skillful bidder, capable of using a variety of conventions to reach contracts which are often superior to those reached by expert human players. Justifying this assessment of the program’s ability is the aim of this section.

Several methods are used to illustrate the skill and capabilities of the program. First, the program’s bidding on some randomly dealt sample hands will be shown and discussed; second, the results of a non-competitive bidding contest will be given; third, a summary of the program’s performance against two experienced human bridge players will indicate the program’s skill in competitive bidding; last, the program’s attempts on some bridge bidding puzzles will be discussed.

The bridge bidding program was tested on thousands of randomly dealt hands and continually modified on the basis of its performance on these hands. Every bid on every deal was studied to be certain that the program bid quickly and accurately to the best contract on those hands for which the best contract is relatively obvious, observed the widely accepted rules for describing various distributions and strengths, and made generally “reasonable” bids. In competitive bidding, the program will use all of the specified defensive conventions in addition to the partnership bidding system and can adequately handle highly complicated bidding sequences.

For example, the program bid all the hands on the deal shown in Figure 2, producing a great deal of competition. East will bid up to the four level on the

```
NORTH
S- 4 0 6 4
H- 10 9 6
D- 5 3
C- 0 7 5

WEST
S- J 9 7
H- A 0 8 5 2
D- 10 6 8
C- A 8

SOUTH
S- K 10 8 5 2
H- K J 7 4
D- 9
C- K 4 2

Figure 2—A complicated bidding sequence utilizing the redouble; all hands bid by program
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Figure 3—Preemptive bidding as a defensive measure; all hands bid by program

<table>
<thead>
<tr>
<th>NORTH</th>
<th>SOUTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>S&lt;sup&gt;-&lt;/sup&gt; 7</td>
<td>S&lt;sup&gt;-&lt;/sup&gt; 0 J 10 8 6</td>
</tr>
<tr>
<td>H&lt;sup&gt;-&lt;/sup&gt; 10 5 6 2</td>
<td>H&lt;sup&gt;-&lt;/sup&gt; K</td>
</tr>
<tr>
<td>D&lt;sup&gt;-&lt;/sup&gt; A K J 9 7 6 3</td>
<td>D&lt;sup&gt;-&lt;/sup&gt; 0 10 5 4 8</td>
</tr>
<tr>
<td>C&lt;sup&gt;-&lt;/sup&gt; 9</td>
<td>C&lt;sup&gt;-&lt;/sup&gt; 0 8</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>WEST</th>
<th>EAST</th>
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</thead>
<tbody>
<tr>
<td>S&lt;sup&gt;-&lt;/sup&gt; A 5 4 3</td>
<td>S&lt;sup&gt;-&lt;/sup&gt; X 9 8</td>
</tr>
<tr>
<td>H&lt;sup&gt;-&lt;/sup&gt; 0 4 3</td>
<td>H&lt;sup&gt;-&lt;/sup&gt; A J 9 7 5</td>
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<tr>
<td>D&lt;sup&gt;-&lt;/sup&gt; 8</td>
<td>D&lt;sup&gt;-&lt;/sup&gt; 0</td>
</tr>
<tr>
<td>C&lt;sup&gt;-&lt;/sup&gt; A J 7 4 3</td>
<td>C&lt;sup&gt;-&lt;/sup&gt; K 10 6 5 8</td>
</tr>
</tbody>
</table>

The monthly contest “Challenge the Champs” in *Bridge World* is an excellent means for evaluation of non-competitive bidding. In this contest, two expert bridge partnerships are matched against one another. The editors select ten hands and determine point awards in advance for each possible contract based on the likely result in a good duplicate game, i.e., a duplicate game at a regional or national tournament. By using these scoring awards, it is possible to compare the program directly with the expert players bidding the hands each month. The emphasis is on partnership bidding, with competition either nonexistent, or playing a minor part. “Challenge the Champs” was an excellent measure since it provided an independent evaluation of the program’s performance on partnership bidding. Its only drawback is that the scoring awards are only estimates and not substantiated by results in actual play.

“Challenge the Champs” was highly useful in the development of the bridge bidding program. Since the contest is keyed to duplicate bridge results, as is the program, the program could be tested and improved using its ratings, helping to indicate the distinctions that must be made in choosing a bid. The first eighteen months of these hands (January, 1967, through June, 1968) were used in this manner with all major program revisions being tested against the hands to see if there was a net improvement in skill. The following twelve months’ hands were then used to actually measure the program’s ability. The program had never before bid these hands, nor had any changes been made in the program especially for this test. The program bid these hands according to three different bidding systems: Schenken, Standard American, and Kaplan-Sheinwold.
The average scores of the program in comparison with the human players competing in the match on an overall basis were as follows:

<table>
<thead>
<tr>
<th>Experts</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winning Partnership</td>
<td>65.7</td>
</tr>
<tr>
<td>Losing Partnership</td>
<td>57.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bridge Bidding Program</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schenken System</td>
<td>58.2</td>
</tr>
<tr>
<td>Standard American System</td>
<td>51.2</td>
</tr>
<tr>
<td>Kaplan-Sheinwold System</td>
<td>50.0</td>
</tr>
</tbody>
</table>

The editors of *Bridge World* consider a score above seventy to be outstanding, with a score above sixty excellent, and anything above fifty to be above average. Thus, the program performed as well or better than the average using all three systems, despite the fact that the program had still not reached the final stage of development. In particular, the defensive bidding sections had not been thoroughly tested, vulnerability was not yet properly taken into account, and there were several coding errors in sections of the program handling Standard American and Kaplan-Sheinwold bidding, since they were added long after the program was operational.

When the program had evolved sufficiently to reduce these weaknesses, the same hands were run again with the program's results considerably improved, as follows:

<table>
<thead>
<tr>
<th>Percentage Improvement</th>
<th>Percent</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schenken System</td>
<td>2.5</td>
<td>59.7</td>
</tr>
<tr>
<td>Standard American System</td>
<td>15.2</td>
<td>59.0</td>
</tr>
<tr>
<td>Kaplan-Sheinwold System</td>
<td>13.2</td>
<td>56.6</td>
</tr>
</tbody>
</table>

The great improvements in the Standard American and Kaplan-Sheinwold systems can also be attributed to a general improvement in the program, as evidenced by the improved performance of the Schenken System. In this later version of the program, both the Schenken and Standard American systems beat both human partnerships four times, lost to both twice, and finished in the middle the remaining six times. The Kaplan-Sheinwold system won three times, lost three times, and finished in the middle six times. The program has undergone further improvement since these results were obtained, but any general evaluation based on a third attempt on these hands would be biased since some of the improvements in the program were made specifically with respect to bidding problems uncovered in the contest. Even with just the above results, however, it seems fair to say that the program achieves the level of human experts in partnership bidding.

One example of the program's performance on "Challenge the Champs" is shown in Figure 4 (Deal 3 of January, 1969), which shows the three systems each reaching the very good contract of six no trump. The Standard American sequence, using the strong three no trump opening, bids directly to the slam. Using the Schenken system, the program began with the Big Club, then jumped in no trump to show additional strength. The Kaplan-Sheinwold sequence is more complex, beginning with the artificial two club asking bid, followed by the four club ace-asking bid, followed by the four heart bid, asking for kings. Missing a king, West stops at six no trump. Although the top scoring award was given to the contract of six clubs, the six no trump contract was second best

![Figure 4](https://www.computerhistory.org)
Figure 5—Program (East-West) bidding grand slam during bidding contest

and far superior to the contracts reached by the expert human bidders.

Although the results on “Challenge the Champs” provided substantial evidence of the program’s ability, they were almost entirely partnership bidding and the true test of the bridge bidder’s skill comes on competitive sequences. Thus, some test of the program’s competitive bidding ability had to be designed. Duplicate bridge tournaments were the obvious source for hands to use for testing purposes. The only drawback to using actual results is that the program would have to compete against human opponents (or another program) in order to obtain an accurate evaluation.*

A bidding contest was set up, matching the bridge bidding program against two human players who have

played as duplicate bridge partners many times. One of the two players is a Life Master, with approximately 1000 master points; the other player has nearly a hundred. Hands were obtained from the American Contract Bridge League national tournament held at Cleveland in March, 1969, along with all of the scoring information from the actual tournament.

In the absence of play of the hand, some means for evaluating the bidding alone had to be found. One such means is to consider the average score made by those partnerships bidding a particular contract and to compare it with the average score for other contracts on the same deal. Since this method eliminates play of the hand, it penalizes those partnerships which play the hand skillfully and rewards those partnerships which do not play so well. No other method for evaluating bidding alone, however, seemed to be quite as feasible, and this method was agreeable to all concerned.

The author chose the entire set of thirty hands from the Women’s Finals at the national tournament for this contest. The Finals include the top female bridge players in the country, with many partnerships having been eliminated in the two session qualifying round for the Finals.

The contest was conducted in two sessions, with fifteen hands being bid in each session. The program bid according to the Schenken system in the first session and Standard American in the second session. The human players used a Standard American system with some more advanced conventions.

Each hand was scored so that the best score on each hand was twenty-five points and the worst score was zero (matchpointed with a twenty-five top). Scoring is such that the sum of the scores of both partnerships for each hand totals twenty-five, i.e., a seventeen for North-South means an eight for East-West. Twenty-seven of the thirty hands were bid to final contracts which had been reached in the actual tournament. On the remaining three hands, the author and the two human players analyzed the entire deal to determine the probable result for each partnership, assuming intelligent play of the hand by both sides. Only one of these three results favored the program. The overall results were as follows:

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<th></th>
<th>Human Players</th>
<th>Bidding Score</th>
<th>Program Percent</th>
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<tr>
<td>Hands 1–15</td>
<td>219.75</td>
<td>155.25</td>
<td>41.4</td>
</tr>
<tr>
<td>(Schenken)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands 16–30</td>
<td>168.75</td>
<td>206.25</td>
<td>55.0</td>
</tr>
<tr>
<td>(Standard)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>388.50</td>
<td>361.50</td>
<td>48.2</td>
</tr>
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* If the program competed against itself, it would simultaneously obtain both good and bad results, i.e., the final contract would be good for North-South if and only if it was bad for East-West. The expected result of such a contest would be a tie, regardless of the skill exhibited.
Thus, the program was victorious in one session, defeated in one session, and narrowly defeated overall. Even in victory, the human players were held to a percentage that would not be sufficient to win most duplicate bridge tournaments. The program’s overall loss could have been averted by a swing of just fourteen points, which is available on every deal.

During the contest, the program successfully bid a grand slam (Figure 5) despite intense competition from the human opponents, who used preemptive bidding up to the four level, depriving the program of considerable room to explore for a contract. Note that a sizable amount of investigation by the program came at the six level. This deal, on which the program got twenty-one of the twenty-five points possible, was the best result achieved by the program on its own bidding, and acknowledged by the author and the opponents to be the program’s most spectacular bidding performance.

The bridge bidding program made a very creditable showing, very nearly defeating two experienced duplicate bridge players. In discussing the program’s performance with the opponents, it was estimated that the program was slightly more skillful than the average duplicate bridge player at competitive bidding.

As a last test of the program’s ability, the program was given some bidding problems to solve. Bridge bidding problems are designed, in general, to evaluate skill on intermediate bids; there are some difficulties with such problems, however, which can make them somewhat unsuited for evaluation purposes.

First, as noted, the given previous bidding sequence does not always agree with the bids the program would have made. The program will then try to “correct” its previous bidding error, producing a poor answer to the puzzle.

Second, the specifications for the problems sometimes assume a scoring system other than matchpoints or conventions which are unknown to the program. In these cases, the program does not perfectly understand some of the bids given to it and is unaware of some of the special conventional bids it is expected to make in solving the puzzles.

When tested on problems which had neither of these shortcomings, the program’s performance was quite respectable. The problems, however, served to outline several areas in which the program’s bidding is weakest. One area in particular is that of cue bidding, which experts use more frequently than does the program, especially when exploring for slams. The program is also still fairly weak in adjusting for vulnerability and in making successful penalty doubles. Combining the evaluations obtained from all the different tests, it also appears that the program has a tendency to be cautious in slam bidding, rarely bidding grand slams, along with a tendency to be slightly aggressive in contracts at lower levels. Last, the program is unable to make psychic bids and has only limited success at counteracting psychic bids made by the opposition.

As a summary result of all these tests, it is fair to conclude that the bridge bidding program is quite skillful, performing at a near-expert level in non-competitive bidding and somewhat better than the average duplicate bridge player in competitive bidding. In addition, the program is able to provide fairly good solutions to bridge bidding problems. Furthermore, these results were achieved using more than one bidding system skillfully, a talent not possessed by many human players.

CONCLUSION

The bridge bidding program, then, is a contribution to the small quantity of skillful artificial intelligence programs. In addition, the programming methods used in the development of the program are useful tools for other applications. The decision-making procedures, for example, are written in the Bridge Bidding Language which represents virtually all of the important conceptual and strategic notions of the task. Using this language, it is very easy to transfer a bridge expert’s bidding technique to program code. The extensible language features which yielded a Bridge Bidding Language from Burroughs B5500 Extended ALGOL could be similarly used to devise other task languages.

The program was also constructed with the goal of having generality within the specific domain of bridge bidding, as can be seen from the program’s ability to bid according to various systems and conventions and to handle tasks such as solving bridge bidding problems. It is hoped that this work will help lead to the creation of computer programs which are skillful over a wide range of problems.

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