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Bidding a bridge hand: a thesis on knowledge acquisition and application

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Bidding a Bridge Hand

A Thesis on Knowledge Acquisition and Application

by
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Abstract

Computerizing the game of Bridge has not yet met with much success. The efforts to date have fallen short of any reasonable technical proficiency. The game does appear to be perfectly suited for an expert system, however, since the game can be segmented into three contexts (Bidding, Play of the Hand, and Defense), each context can be described by a set of rules, and a series of inferences can be used to fire those rules. Each of the contexts is reviewed, then Bidding is chosen for further research.

This thesis claims that the set of all hands subdivides into 11 bidding classifications, based on a number of selection criteria. One of these subsets, Invitational Hands, is studied in detail Classic knowledge acquisition techniques are used to define Invitational Hands, assimilate the knowledge, then translate the facts, inferences, deductions and suppositions into a knowledge base. Changes in the state of the auction as bidding progresses are stored in state variables. These state variables are used to navigate the knowledge base to find the next bid. The interaction of state variable settings and facts firing rules in the knowledge base implement a frame architecture.

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Section 1

Introduction

This section introduces the problem of why decent Bridge playing software programs have yet to be written. It points out that the techniques needed to encode the logic already exist, and quotes an example of an algorithm to implement squeeze play. It identifies the three main parts of the game, Bidding, Play of the Hand, and Defense, and establishes that these can be represented in software.

The audience of this paper is presumed to have a working knowledge of the game of Bridge and its terminology. For those who don't, Appendix A contains the Glossary, which defines the terms used in this paper that have a unique definition in the Bridge vocabulary, and Appendix B contains a primer on the game.

An Introduction to Computers and Bridge

Why can't a computer play bridge at a competitive level? Software has been constructed that allows a machine to play world championship chess. Other games of skill such as 'Go' and 'Othello' have also been programmed to play credibly. The prevalence of deductive reasoning techniques, inferences, reasoning with uncertainty, and planning would seem to make the game a natural for a software application. The domain is finite, 52 cards and a set of clear rules governing their play. The solution space is large, however, since there are over six billion possible deals to contend with. Additionally, the bids, card play and defense procedures have been well documented in the literature. Indeed, one of the more complex card play techniques, the squeeze play, was translated into a series of PROLOG predicates and successfully tested against a number of card positions[1]. The objective of this system (referred to as **PYTHON**) was to demonstrate an application that encoded a set of rules into a logic programming format. The authors claimed a high degree of success with their program, that

> "...successfully solves all the examples posed in textbooks ([1], [2]). It performs better on these examples than some expert players of national standard of our acquaintance. More impressively, it discovered an error in a complicated squeeze position discussed by Goren [1]. ..."[1].

The steps for endplays, trump coups, elimination plays, finesses and other plays available to declarer, as well as ducking plays, hold-ups, unblocking plays, and various coups in the defenders' arsenal are easily defined. Bidding contains a grammar of 38 words with a specific ordering to their usage. Clearly, no component of the problem is beyond the reach of the normal procedures used in Artificial Intelligence applications. There are no major breakthroughs required in hardware or software.

One possible solution begins to materialize if we view the game of Bridge as a set of 3 interconnected entities, each quite different from the others. Bidding classifies hands and describes them within the rules and judgements of a Bidding system. The purpose of the Bidding system is to accurately forcast the trick-taking potential of the combined cards of the partnership without actually looking at both hands simultaneously. Play of the Hand uses the information gained from the bidding, inferences and facts from the way the defense is proceeding, and card playing techniques to play the cards in such a way as to make the contract. Defense uses the bidding, inferences about the way declarer is playing the hand, plus signals and technique to attempt to defeat the contract. Each area of the game requires inferential logic analysis and truth maintenance as facts replace inferences. Since each area of the game emphasises different skills, selection and application of paradigms appropriate to the particular phase of the game being exercised becomes necessary. The software construction task becomes one of building structures to accomodate the basics of each, then incrementally adding knowledge until the software attains the level of competency desired. The software structures are well documented. The trick, then, is acquiring, translating and implementing Bridge knowledge.

The skill of a Bridge player is directly proportional to his expertise. Hugh Kelsey discusses this in his book "**Bridge: The Mind of the Expert**":

> "Expertise in the play of the cards is a recognizable quality although, paradoxically, it may pass unnoticed in an average bridge game. As a general rule it takes an expert to

appreciate expert technique, which can be so far removed from the practice of the average player as to be totally incomprehensible to him. ..."[3].

"A bridge expert can be described in simple terms as a player who makes fewer mistakes than most. What we have to do, clearly, is to seek out the reasons why he makes fewer mistakes. There are a couple of qualities in particular without which no player can hope to become an expert. The first of these is what is known as 'card sense'. ...

"Success at bridge appears, in fact, to require a certain type of mind--a mind capable of assembling a wide range of data, analysing it and drawing the correct conclusions. It is the type of mind possessed by crossward enthusiasts, puzzle solvers and cypher experts. Bridge is above all an analytical game. ...

"In the expert, card sense is developed to an unusually high degree. Analytical power increases with use, and experience is a great asset. In most situations at the bridge table the expert has the advantage of 'having been there before'. From the vast backlog of bridge hands stored in his memory he can usually retrieve at least one that is relevant to the problem that he faces and apply the appropriate remedy."[4].

Card sense and expertise can be encoded by categorizing the differences in a number of similiar hands and building a mechanism to discern among the differences as appropriate. Each hand offers something different, so the more hands encountered, the more cases the software has to reference as it comes up with the next bid or play. Expertise is easily encoded, given enough exposure to experts and challenging, representative hands. Since a computer doesn't forget, lessons from past errors are always available. The computer would be very good at remembering, because the rules would become more complete as more cases are reviewed. Card sense is much more difficult. The perceptive factors going into table presence (timing, observing an opponent's mannerisms) and the psychological factors (intimidation, arrogance, anger, frustration) are tougher to capture, evaluate, and exert influence. It makes sense, then, to program expertise and evaluate the expert system's performance prior to undertaking the more elusive aspects. This parallels the human experience at the card table. One must first learn how to play the cards before he plays the opponents.

Section 2

Background

This section quotes reviews of Bridge software efforts to date, then elaborates on each of the areas of the game, Bidding, Play of the Hand, and Defense. A subset of Bidding is chosen as the area to model since the time involved in building a complete Bridge system is well beyond the scope of this work.

Survey of existing Bridge-playing software

Computers have not played the game well, to date. Of the many bridge-playing programs out there, only a few are mentioned in the literature. Jeff Reubens, a coeditor of **Bridge World** writes

> "Efforts to get a computer to play bridge have been abysmal failures. However, no shame attaches to the programmers. Writing a program to play well, even to play beyond a novice's level, seems to be a fiendishly difficult problem.
> "Because of this, many programs that allow the user to play with one or more computers as partner or opponent will be technical disappointments to Bridge World readers. ..."[12]

In August, 1986, the American Contract Bridge League reviewed a product called 'Bridgebrain' . After the caveat

> "Like other computer programs, *Bridgebrain* does not play high-level bridge. Because of the intricacies of the game of bridge, primarily the partnership angle, no random-deal program to date plays the game well." [5]

the reviewer describes some of the programming features, none of which are of interest to the study of building serious bridge software. In the review of *Micro Bridge Companion* in the November, 1990 issue, the reviewer writes

> "The computer program that plays bridge at a high level has yet to be written. Some say it can't be done -- that a computer cannot be programmed to have table feel, to recognize a psychic bid or even learn advanced plays like squeezes and coups.
> "Time will tell whether the various computer experts working on bridge programs can produce something the better-than-average player would like to have as a partner. For now, the most advanced bridge-playing program available is Bridge Baron IV, part of Tom Throop's Micro Bridge Companion."[6].

He mentioned that the software on occassion made decent plays, and had some nice ancillary features. Also mentioned in the same article was a very interesting bridge tool called *BASE II*. This software merits attention because it represents a significant advance in the currently defined state-of-the-art, even though it does not play, per se. The review states:

> "BASE II can also solve double dummy problems, create random deals for bidding practice and allow you to 'film' your favorite hands in bridge 'movies'. ...
> "Their creation is the first of what they expect to be increasingly sophisticated programs leading up to one that will play bridge at a level unseen in computers to date. ...

"The double dummy solver is also speedy, provided you don't give it too many cards to work with. ..."[7].

This product uses a generate and test strategy to solve the double dummy problems, hence the restriction on the number of cards. This is the first commercially available product that uses techniques more advanced than traditional serial programming. Also, BASE II contains a hand simulator and generator, a required tool for any serious bridge-playing software.

Components of the Game

There are three distinct phases to the game.

Bidding

There is a defined grammar in bidding consisting of 38 legal bids (spades, hearts, diamonds, clubs and no trump prefaced by a number from 1 to 7, pass, double, and redouble) and constraints on the sequence of the bids (pass may be bid at any time, double may only be bid by the opponent of the bidder, redouble can be bid only if double was the last non-pass bid, subsequent bids must be greater than preceding bids (1 club is the lowest, 7 no trump the highest)). This sparse grammar must define over 6 billion different hands, so clearly there is considerable overloading of the meaning of each bid. This requires an analysis of the context of each bid to determine its meaning. For instance, "pass" may describe radically different hands in different contexts:

1 heart - pass - ***pass***	indicates a hand of extreme weakness;
1 heart - 1 spade - 3 hearts (forcing) - 4 spades ***pass***	is played by some as a forcing pass, requiring partner to bid 5 hearts or double at his turn;
1 heart - 1 spade - ***pass***	denies sufficient values or sufficient interest to bid 2 hearts, 1 no trump, or double (usually played as showing the other two suits) but may have values to make a penalty double later in the auction;
3 hearts ***pass***	denies sufficient strength and shape to make an immediate bid over a 3 level

preempt, but may still have the values to bid game or slam if partner can act;

and so on. Additionally, there are many different bidding systems, each of which defines its own meaning to particular sequences. For instance:

1 club — in 'Standard bidding - 4 card majors' denies 22 high card points and a biddable 4 card major, unless the clubs are significantly longer. It also denies holding a balanced hand in the opening 1 no trump range (the range varies depending on partnership agreement);
in 5 card major systems (Standard, 2 over 1) it also denies a 5 card major suit holding unless the clubs are significantly longer than the major (by partnership agreement);
in strong club systems it promises a hand worth some minimum number of points (usually 16-17) with no reference to hand pattern;
in forcing pass systems it denies the value of an opening bid.

Factor in the subsequent bids and their meanings according to system, and the combinations of hand patterns to bids increase exponentially. Bidding systems by design seek to reduce the ambiguity associated with as many sequences as possible, but no bidding system has yet been designed that clarifies all the combinations. Judgement by the bidders plays an enormous role in determining what the bids mean as the auction progresses.

Hands are classified prior to a bid being utterred. The classification process involves accumulating and storing a number of facts about the hand, such as the vulnerability, who is the dealer, high card points, suit "texture", and suit distribution. The player then uses these facts to determine in what class the hand resides. The classifications I have identified are very weak, weak, minimum response, invitational response, minimum opener, intermediate opener, strong opener, very strong opener, forcing, weak two, and preemptive. He then selects bids within the context of the deduced class. There is no 1-to-1 mapping of bids to class. Each bid has a degree of ambiguity associated with it, with clarifications coming on subsequent rounds. For instance, in standard bidding, a bid of 1 club can mean an opening bid of 12-14 HCP without a biddable 5 card major, 18-19 points without a 5 card major, a 5+ card club suit with either a

balanced or unbalanced hand, or a 16-19 point two-suited hand with clubs as one of the suits, 5 different hand patterns in all, encompassing a range of 11-20 HCP. A t least 1 other bid is needed to remove the ambiguity.

Within each classification, a bidding system deals with uncontested auctions, competitive auctions, and preemptive auctions. In an uncontested auction, the partnership uses only their bidding system to establish the final contract. A competitive auction adds the element of the opponents competing for the contract, and a preemptive auction attempts to disrupt the normal bidding communication by using up an inordinate amount of bidding space. So the evaluation process for bidding a Bridge hand starts with evaluating a series of facts to establish a classification, then uses information from the auction to determine the state of the auction. The Bidding System is then used to derive a bid that best describes the evaluation to that point. This is a value-added exercise. The knowledge gain is incremental. Each new piece of information restricts the number of available final contracts and bids available.

Play of the Hand

Techniques exist to manipulate the cards in such a way as to reduce the number of losers or increase the number of winners. There are many plays available that a declarer can choose from, given the conditions that exist in a hand at any moment. When declarer evaluates a hand, he develops a plan based on the opening lead, dummy's thirteen cards, and the bidding. He counts winners (or losers), performs some truth maintenance ("Was partner's bidding accurate? Does the opening lead contradict inferences gained from the opponents' bidding?"), then establishes his first of potentially many plans to play the cards in such a way so as to maximize his gain. His expertise in card play dictates the number of available techniques at his disposal. He evaluates the card combinations in each suit, and uses the results of that evaluation to form a list of attributes that summarize the characteristics of his and dummy's

cards. He then uses those attributes to choose which card play techniques to implement. His choice of plays to choose from include

> cashing winners, simple finesses, double finesses, indirect finesses, obligatory finesses, long suit establishment, developing entries, hold up plays, conserving entries, unblocking, ducking, trump control, ruffing, trump postponement, trump substitutes, dummy reversals, safety plays, distribution considerations, end plays, eliminations, throw ins, Bath coup, Deschapelles coup, trump coup, simple squeezes, backward squeeze, pseudo squeeze, progressive (three suit) squeeze, double squeeze, Vienna coup[8], avoidance plays, removing entries to the danger hand[10], discovery plays, scissors coup, and Merrimac coup.

Also, there exist a number of card combinations which require special attention. Samples of these include

> J10x opposite Axx, Q10 opposite Ax, Q98 opposite A7x, A7xx opposite KJxx, AKQ10 opposite xxx, K10x opposite xxx, Axx opposite J9x[11], and Q109 opposite AJx[10].

When straightforward techniques are insufficient, a number of deceptive plays are available to the resourceful declarer. They include

> Inducing a defender to hold up a key card;
>
> ducking a trick unnecessarily;
>
> falsecarding to avert a ruff;
>
> falsecarding to induce a miscount;
>
> encouraging a defensive continuation;
>
> inducing a defender to smother his partner's honor;
>
> playing side suits early before a count of the hand is complete;
>
> choosing a card from a sequence to either encourage or discourage a cover;
>
> misleading discards;
>
> winning a trick with a higher card than necessary;
>
> persuading an opponent to surrender a trump trick;

taking critical finesses early[9];

inducing a defender to ruff a loser.

So, the competent declarer has a comprehensive list of tools at his disposal, some of which are mutually exclusive. The ability to select a viable strategy from such a vast list is entirely dependent on the declarer's ability to identify the attributes. Attribute identification can be described as the means needed to discover a piece of knowledge and figure out how to apply it. In order to build the attribute list and select which plays apply, a series of evaluations must be performed. These include

an evaluation of the soundness of the contract and the subsequent approach;

an analysis of the bidding;

an analysis of the opening lead;

the impact the opening lead has on the rest of the play;

an evaluation of the cards played by the defenders to date;

a construction of the unseen hand based on evidence and inferences available;

a consideration of the different card combinations that could be contained in the unseen hands;

an evaluation of making the wrong choice when presented one by the defense;

counting missing high cards and distributions.

More abstract evaluations include

table presence;

examining the defense's motives;

evaluating the evidence[2];

camouflage;

communications[13];

the time needed for an opponent to play a card;

skill level of the opponents.

The better the analysis, the more accurate the play control, selection and execution.

Defense

The plays available to the defenders are the same as to the declarer. The mechanics of invoking them are quite a bit different, however. Defenders are at a disadvantage, since the opponents have been able to land the contract, so proper defense relies more on supposition, trickery when appropriate, clear signalling and correct card selection more so than is needed by declarer. The defenders' prime tasks are to confuse and disrupt. In the foreward to their book 'The Art of Defence in Bridge', Reese and Trézel write

> "Defence is certainly the most difficult part of the game, because it calls for more imagination and experience than dummy play. It is seldom possible to form the sort of logical and comprehensive plan that is made by declarer who can see twenty-six cards in combination. Nevertheless, defence has an extensive technique. ..."[16].

The defense starts the play of the hand with the opening lead. Opening leads are dictated by the bidding, and are easily quantifiable. They include active leads, passive leads, blind leads against no trump, leading partner's suit, leads against slams[14], attacking leads against no trump, protecting leads against no trump, leading when partner doubles, attacking leads against trumps, protecting leads against trumps, ruffing leads against trumps[15], ace leads, suit preference leads. The best lead is selected after anaylzing the bidding and opening leader's hand.

After the opening lead, dummy's 13 cards are in view for the defenders, so subsequent play now involves more imagination, hypothesis and creativity. The defender assimilates the following facts:

he counts the high card points in his and dummy's hands;

he computes the remaining high card points in the other two hands;

he counts the suit distributions for his and dummy's hands, then notes the cards missing in each suit;

he reviews the bidding.

He then makes the following inferences:

he translates the message contained in partner's opening lead;

he hypothesizes the makeup of declarer's hand;

he determines which key cards partner must hold to maximize the gain.

The defender resolves conflicts arising from contradictory hypotheses by eliminating those which fail to benefit his side, then plays the appropriate card from his hand.

Each card played adds facts to the information already assimilated. Truth maintenance is then performed on the inferences, eliminating the ones proven to be false, and substituting more complete inferences for the ones remaining.

There are standard plays to win tricks, promote subsequent tricks, show attitude, count, or suit preference that are used as defaults or when more sophisticated plays are not apparent. More advanced, subtle techniques include

choosing between agressive leads;

determining when to cover an honor;

ducking to preserve an entry;

ducking to preserve a tempo;

ducking to preserve control;

refusing to overruff;

hold up combinations;

controlling the trump suit;

coercing declarer into using a stopper;

jettisoning a winner;

underruffing;

refusing to part with controlling cards in declarer's long suit;

establishing an entry in partner's hand;

blocking plays;

trump promotions;

hypothesising a specific card holding for partner then playing for that holding;

choosing a lead to prepare an unblock;[16]

choosing between the safe exit and breaking a new suit;

deducing partner's holding by his play of or failure to play a card;

cloaked suit preference;

planning the play of a card in tempo;

counting declarer's tricks;

promoting a trump trick by forcing declarer to ruff;

constructing declarer's hand based on the clues and inferences;

parting with known cards;

maintaining communications and timing;

taking over the defense when the correct line is not known to partner;

not ruffing losers;

ducking an ace when a singleton is led;

underleading an ace;

overtaking and switching;

evaluating partner's tendencies in competitive situations. [17]

These plays are readily implemented once the conditions have been identified. The problem in defense lies in recognizing those conditions.

Summary

Expertise in the game of Bridge requires a degree of skill in each of these areas. In order to play the game competently, one must know as much as possible about each. When starting off, a novice begins with a basic bidding system, knowledge of little more than the mechanics of the finesse, and rudimentary defensive techniques. As the player matures, conventions are added, treatments discussed. and a lot of work goes into Play of the Hand and Defense. Once

the player has established himself as competent, education in Play of the Hand and Defense taper off, since most of the common situations are now handled. The mechanics in Play of the Hand become rote, and Defense becomes much less opaque. Bidding, however, remains the biggest mystery, and the most difficult area to get right. Bidding questions haunt players well into the expert levels. A Bidding System's rules cover only a small percentage of the actual hands encountered. Judgement and expertise take over for the rest. The successful bidder can wield a bidding system like a scalpel, applying levels of sophistication in inference and logic to such a degree so as to elicit the most possible information from partner about his hand while giving the maximum amount about his own in order to arrive at precisely the right contract, while the typical bidder uses a system like a hammer, bludgeoning his way to average or incorrect contracts, using point count, suit distribution and a few conventions. Although building software to play the hand and defend poses interesting challenges, time and resource constraints dictate concertrating efforts in one area. I have, as a result, chosen Bidding as the topic of my research. The task this thesis describes is the attempt to capture the sophistication needed to attain a level of bidding expertise.

Section 3

Description of the Domain

This section describes the environment for a Bidding System. It introduces two concepts needed to analyze an auction (and central to this thesis): the Hand Classification and the State of the Auction. Examples are provided to show how different systems use the same analytical approaches to arrive at intermediate bids on their way to a final contract. Illustrations of bidding systems and conventions are supplied. Treatments are touched upon. The context preceding a bid is discussed to show the impact on the state of the auction and how that state affects succeeding bidding. The scope of the software is then limited to invitational hands in uncontested auctions. Finally , the chosen bidding system, **Bridge World Standard**, is discussed.

Overview

I have played Bridge at a tournament level with a degree of success for a number of years, so in preparing the descriptions that follow, I used my evaluation metrics. For purposes of encoding Bridge logic into an expert system, I have included two enhancements to traditional hand evaluation methods, **hand classification** and **state variables**. I submit that a hand's classification never changes throughout an auction. The classification results from collecting the facts concerning the thirteen cards being evaluated, and placing the hand in one of eleven categories ennumerated later in this section. Once classified, the bids for that hand come from the portion of the rule base dedicated to that class. The internal representation of a class can be thought of as a frame. The bids are chosen by analyzing the context of the auction, storing that context in slots, and identifying the existence of a filled slot by a state variable setting. The state variable settings are then responsible for navigating the portion of the knowledge base assigned to that class. When the appropriate spot is reached, the facts and the context are evaluated and stored, the next bid is generated, and new state variables are set. The evaluation is never repeated, since its results are stored in the slot, and are summarized by the state variable settings. While the facts and deductions stored in the slots serve no purpose for

future bidding, they have significant impact on Play of the Hand and Defense. The hand classifications and the description for each classification are arbitrary and may meet with some disagreement, but I view that as not relevant to this work. The classifications may change from player to player, or their boundaries may shift, depending on the player.

Preliminary Observations

Certain activities initiate each hand. Initially, the opponents' bidding system is scrutinized, and unfamiliar treatments are reviewed. After the hand is dealt, the cards are picked up and sorted into suits. The vulnerability is noted, as well as which hand is the dealer. In Rubber Bridge, part-scores are also considered.

Hand Classification

The high card points are counted, and the distribution is observed. The texture of each suit is considered, as well as the major suit holdings. Quick tricks are counted. These factors determine which classification the hand belongs to. A hand can reside in only one class, and cannot move to a different class. High card points are counted first; then the other metrics are factored in to arrive at a class. For instance, it is entirely possible for a 12 HCP hand to open with a forcing bid, if the hand holds 9 tricks, or not open at all if the hand contains a smattering of disconnected Kings, Queens and Jacks. It is also possible to adjust a hand value downward if the distribution, suit texture and honor cards warrant it. I propose the following eleven classifications:

1. preemptive - This classification is defined by a suit length longer than 6 cards, with an adjusted HCP range between 0-10 pts, and most of the high card strength within the suit. The bidding with these types is usually obstructive, since the goals with these hands are to a) rob the opponents of the bidding space needed to conduct a scientific

auction, and b) describe to partner a hand with a long suit and little defense outside the suit;

2. weak two - This classification usually has a suit length of 6 cards and an adjusted HCP range of 3-10 points. A structured weak two usually has three of the top 5 honors, and little outside the suit. An unstructured weak two does not require this suit strength;

3. very weak This classification is described by a hand with 0-4 adjusted HCP. The only occassions where this hand would bid would be when a) partner opened with a forcing bid, b) partner opened with a preempt and the holding in partner's suit is greater than a singleton(advancing the preempt), or c) partner opened a major suit, the holding in that suit is at least 5 cards, and there is an outside singleton or void. In this case, a game bid by this hand is likely to succeed because of the additional ruffing tricks available. If it fails, the bid usually preempts the opponents out of their best spot;

4. weak - This classification is described by a hand in the 4-6 adjusted point range. The decision to respond to partner's opening bid is based on suit texture and distribution. With nothing of significance, this hand passes. Hands in this classification are never good enough to accept a game invitation in an uncontested auction, and are good enough to bid in competitive auctions only when very good distribution exists;

5. minimum - This classification is described by a hand in the 6-9 adjusted HCP range. It will always respond to partner's opening bid. It may accept a game invitation with distributional extras, but would decline the invitation most of the time;

6. invitational - This classification is described by a hand in the 9-12 adjusted HCP range that is not good enough to open the bidding in first or second seat. Some hands qualify for third seat openers, but none qualify for fourth seat openers. These hands invite game, accept almost all game invitations, invite slams opposite some strong hands, most very strong hands, and all forcing hands;

7. minimum opener - This classification is described by a hand in the 11- 14 adjusted point range with a combination of quick tricks, major suit holdings, suit texture and HCP to warrant opening the bidding. The fewer HCP in the hand, the more the other factors are considered. A 13 point hand is always opened. An 11 point hand is opened if there are three quick tricks or the major suit texture and length are good. This hand pattern will rarely accept a game invitation;

8. intermediate opener - This classification is described by a hand in the 15-17 adjusted HCP range. This hand makes a game try over a minimum response unless the auction dictates a misfit, and always accepts game tries;

9. strong opener - This classification is described by a hand in the 18-19 adjusted HCP range. With a fit for partner's hand, this hand will bid game. It is possible for this hand to stop short of game, but rare;

10. very strong opener This classification is described by a hand in the 20-21 adjusted HCP range. This hand will not be in game only if partner is very weak, and cannot respond to the opening bid;

11. forcing opener - This classification is described by a hand with at least 22 HCP. or a hand that has at least 9 playing tricks. This hand forces partner to

bid at least twice below the level of game. It is possible, but extremely rare for this hand to stay out of game.

The choice of hand classification influences the judgement used in bidding the hand. It, like the other ancillary information gathered is used to make decisions once the auction commences. The preliminary work is now complete, and the auction is ready to begin.

Defining the State of the Auction

The state of the auction is defined as the information made available about the characteristics of how the cards are distributed after each bid is made. The state of any particular deal includes information and inferences about the distribution of suits and specific cards around the table.

Auction Groupings

A hand changes state every time a bid is issued. Initially, the state is undefined. Only four separate preliminary analyses exist, the classification for each hand. After the dealer begins the auction, the state of the auction transforms with each subsequent bid until the final contract is decided. States are set by the partnership as the auction progresses (although it is possible for a player to make a unilateral action to set a state without regard for partner's holding (opening a 7 level bid, for instance)). There are four groupings that bidding actions fall into. Each of these represents a path to reach the correct final state:

1. uncontested auctions - This group consists of bids from only one partnership. The desired final state is to locate the proper part-score, game or slam contract. State changes are initiated only by one side, so more emphasis is placed on the accuracy of the bidding system;
2. contested auctions This group involves the participation of both partnerships. Each side strives to maximize the number of points taken or minimize the number of points lost on a given deal. This

group creates the most state changes, since each bid transforms the auction and requires additional evaluation. An element of risk is introduced here. Since a goal in competitive auctions is to get the opponents too high, bids are often made to coerce the opponents into bidding too high. The risk occurs when the opponents double correctly;

3. defensive bids — This group consists of bids injected into an otherwise uncontested auction that suggests a defense to partner or requests a particular opening lead. This added information transforms the state of the auction by calling attention to a condition that would otherwise be unknown. This action is a double-edged sword, however, since both sides may use the information gained to their best advantage;

4. disruptive bids — This group consists of bids designed to disrupt the opponents' auction by depriving them of bidding space. Bids that suggest a sacrifice to partner reside here as well. By altering the state of the auction in such a way so as to remove available bidding space, the opponents are forced to choose between guessing the contract at a high level or doubling the disruptors. Contracts determined by disruptive tactics are almost always doubled, almost always go down, but are designed to take advantage of the scoring in order to minimize the number of points lost.

Bidding Systems

Each partnership uses a Bidding System. These systems range from very simple to extremely complex. The function of the Bidding System is to map bids to a set of hand attributes. This is a one to many relationship, since one bid can be used to describe many different hand patterns, yet each hand pattern has only one bid within the context of a given auction. The bids are, as a result, context sensitive, since one bid in isolation does not fully describe a hand, and a bid's meaning changes based on what bids preceded it. A two heart opening bid describes a hand that resides in either the very strong classification or preemptive classification, or weak two classification, or minimum opener classification, or intermediate opener classification, depending on how the bid is defined in the Bidding System. A two heart response to partner's one-level minor suit opening is strong in some bidding systems, weak in others. Two hearts over partner's one spade bid shows a good hand in most systems and usually forces partner to bid again. In some systems the bid is game force, in others, game invitation. A two heart bid after the opponents have overcalled at the one level usually means something different if the overcall was in a lower ranking suit (diamonds) than in the higher ranking suit (spades). Two hearts over the opponents two level preempt means something else as well. The complexity (and the uncertainty) increase the higher the bidding gets.

Each bidding system is structured by using an overall approach which defines the meaning of most basic bids. Additionally, conventions are incorporated which give specialized meanings to certain sets of bids, and treatments are used which further elaborate the meanings behind certain sequences. Some of the more popular Bidding Systems include

Standard American - 4 card majors - a bidding system refered to a "straight Goren" or "Momma-Poppa" bridge because it is the most common of bidding systems by casual players. Highlights of this system include major suit openings at the one level with at least 4

cards to an honor, two level openings as strong and forcing, invitational two-over-one responses, and sound preempts;

Standard American 5 card majors - the same basic system as 4 card majors with the additional requirement that a major suit 1 level opening has at least 5 cards in the suit;

Two-over-one Game Force - two level bids in a lower ranking suit are forcing to game after partner's one level opening, weak two bids except for two clubs (which is the forcing bid in the system), many other treatments such as bypassing biddable minor suits to respond in a four card major, weak preempts, and elaborate conventions after a one no trump opening;

Big Club system - where one club is the strong opening bid, and usually defines a hand with at least 16 HCP without regard to distribution, a two club opening describes an 11 - 15 HCP hand with at least 5 clubs, and many other nuances.

Bidding systems can incorporate zero to many conventions. A convention assigns non-standard meanings to bids, and is invoked by a certain sequence. Examples of popular conventions include

Blackwood - a convention that requests partner to tell how many aces or how many kings he holds. The purpose of the convention is to verify that enough first and second round controls exist to

be able to bid either a small or grand slam. The sequence is initiated by a four no trump bid and the responses are five clubs (0-4 aces), five diamonds (1 ace), 5 hearts (2 aces), 5 spades (three aces), 5 no trump (two aces and a useful void), and 6 of anything but the trump suit (1 ace and a void in the suit bid). If the four no trump bidder next bids five no trump, the responder tells how many kings he holds (6 clubs = 0-4, 6 diamonds = 1, 6 hearts = 2, 6 spades = 3). There are many variations to basic Blackwood that alter the responses;

Splinter bids — a double jump shift by responder indicating a singleton or void in the suit bid, support for partner's suit, game going and slam invitational values (e.g. 1h-4c);

Inverted minors — reversing the natural order of raising partner's minor suit opening, to conserve bidding space and investigate the possibility of playing 3 no trump. In standard bidding, 1c-2c is a minimum raise, 1c-3c is a limit raise. Inverted minors reverse these meanings, allowing the two level for further investigation;

Stayman — a two club bid after a one no trump opener, or a three club bid after a two no trump opener, asking the no trump bidder if he holds a four card major. The purpose of this bid is to play in

a four-four major suit fit, since this combination usually provides one more trick than a no trump contract;

Jacoby transfers — a bid used to uncover a 5-3 major suit fit after a no trump opener. It also has the added feature of keeping the no trump hand hidden. Over a one no trump opening, a two diamond response forces the opener to bid two hearts, a two heart response forces the opener to bid two spades. Transfer bids are also used after a two no trump opener one level higher. Extensions to this convention include minor suit transfers;

Michaels cue bid — a convention used by an opponent of the opening bidder allowing him to show a two-suited hand. In the auction 1c-2c or 1d-2d, the overcaller is showing the majors. 1h-2h shows spades and one of the minor suits, 1s-2s shows hearts and one of the minor suits. The purpose of this bid is to allow partner to pick the proper spot for a sacrifice if his hand warrants, since the Michaels bidder usually has few defensive values;

Negative doubles - a convention used by the partner of the opening bidder after an overcall has occurred, showing at leat one (and usually two) of the other suits. For instance, 1c-1h-double would show four

spades and imply four diamonds (at least), and 1c-1h-1s would show 5 spades.

Treatments

Treatments are more specific to the partnership, and involve assigning a meaning to certain bidding sequences. Examples of treatments used include suppressing a biddable diamond suit when partner opens 1 club if a good four card major exists, unless the diamond suit is at least 6 cards long, treating a four card major headed by no higher than the 10 as a three card suit, and treating all 4-3-3-3 distributions as no trump-type hands, even if the four card suit is a major.

Establishing the Optimum Contract

The goal of bidding a hand in an uncontested auction is to arrive at a contract that (when played correctly) maximizes the number of points gained. There are bonus points awarded for slams, games, part-scores and rubbers, depending on the type of game (Rubber Bridge or Duplicate). This maximum is arrived at by analyzing each of the state change that occur whenever partner bids. Competitive auctions add the additional consideration of minimizing the number of points lost. If the opponents can make the vulnerable four spade contract they have bid they would receive 620 points at Duplicate (120 for the tricks and 500 for the game bonus), so bidding five clubs and going down 3 not vulnerable (500 points) turns out to be a good sacrifice. However, going down 4 (800 points), or going down at all when the opponents can't make their contract loses.

The players in a partnership, then, must correctly interpret the state of the auction in order to arrive at the optimum contract on a given set of hands. Armed with a bidding system constrained by the hand classification, each does his best to translate the bids into a state, analyze how that state determines what additional information is needed, and map the request

for more information (or the final contract) into a bid. Since a bidding system is usually defined only for a few rounds of bidding, judgement and supposition are more heavily relied upon to define the state of the auction the more complex the auction becomes. It is the capture of this judgement and supposition in software that is of interest.

Each of the eleven hand classifications constrain the logic behind bidding in a different way. After partner has opened one heart, for example, the hand that falls into the very weak classification has a different agenda than the hand classified as invitational. However, the process of analyzing partner's bid, considering the hand classification and prior bids, then coming up with an appropriate bid is the same for each class. Since each bid changes the state of the auction, the final goal is never known until the final bid is made. For instance, assume partner opens the bidding in first seat. If a hand is held that falls into the 'forcing' category, the goal is slam, and bids are made to determine if a grand slam can be successful. Conversely, if a hand falls into the 'minimum' classification, a part score becomes the goal, and bids are made to determine the correct part score. If partner jump shifts after hearing the minimum bid, the goal shifts from part score to bidding the correct game, since partner has changed the state of the auction. The work this thesis describes involves programming the judgement and logic associated with hands in the 'invitational' classification. Additionally, the logic in determining a bid in a competitive auction is the same as in an uncontested auction, except that state changes are more frequent (since at lesast one opponent is bidding), the use of two extra bids is factored into the logic (double and redouble), bids of "pass" can have an additional meaning attached to it ("forcing pass") . The techniques used in translating these additional conditions into rules in the rule base pattern the techniques used in translating the positions in the uncontested auctions. Also, there are times when a bid in a competitive auction is just a "best guess" Programming these guesses makes sense after the knowledge base has matured. So the scope of this thesis has arbitrarily been limited to invitational hands in uncontested auctions. The bidding system followed is "**Bridge World Standard**", which is a

composite bidding system compiled by the editors of **The Bridge World** by polling the Bridge experts in this country for thoughts on system structure, conventions and treatments[18].

Analyzing the State of the Auction for Invitational Hands

Hands in the Invitational classification are not opened in first , second or fourth seat. Certain hands can be opened in third seat, but will pass any invitational bid, so all game and slam sequences are ruled out. So opening bid logic is not addressed. The activity in this classification occurs when partner opens the bidding. Partner initiates the auction, and that action serves as the initial state variable setting that triggers the code associated with the appropriate slot needing to be filled, based on the facts of the hand. When no further state variables are set, the auction ends and the final contract is set.

The following table lists the current state of the auction (which is established by accumulating the results of the bidding to that point), the next action (which lists the possible actions for the invitational hand given the current state) and the next state resulting from that action. Each bid causes a state change in the auction. The auction continues to change states until a final contract is reached. Subsequent bids are dependent upon the current state of the auction for their meanings, and are constricted by the current state of the auction. A bid has a meaning only within the context of the bids preceding it.

Current State	Next Action	Next State
partner opens 1 minor	show a four + card major or the other minor	partner must bid
	bid no trump	game invitation issued
	double raise partner's minor	game invitation issued
	single raise partner's minor	inverted minor raise
partner opens 1 major	raise the major	game invitation issued
	bid forcing no trump	partner must bid
	bid new suit	partner must bid
	bid two no trump	game invitation issued
partner opens 1 nt	bid 3 nt	auction ends
	bid 2 clubs	Stayman Convention
	bid 2 diamonds or hearts	Jacoby Transfers
	bid at the 3 level	game force
partner opens 2 clubs	show a 5 + card suit with 2/3 top honors	2 club sequences
	bid 2nt	
	bid 2 diamonds	
partner opens weak 2	raise to game with useful distribution	auction ends
	pass	auction ends
partner opens 2nt	bid 3nt	auction ends
	bid 3 clubs	Stayman Convention
	bid 3 diamonds or hearts	Jacoby Transfer
partner opens a 3 level preempt	raise to game with useful distribution	auction ends
	pass	auction ends
partner opens 3nt	pass with stoppers in the suits other than partner's	auction ends
	bid 4 clubs	auction ends or partner bids 4d, auction ends
partner opens a 4 level minor suit preempt	raise to 5 with good distribution	auction ends
partner opens a 4-level major suit or higher preempt	pass	auction ends
partner must bid	limit raise in second suit	game invitation issued
- partner bids a new suit at the one level	limit raise in first suit	game invitation issued
	bid 1 nt	auction can end
	bid two nt	game invitation issued
	jump rebid	game invitation issued
	bid fourth suit	fourth suit forcing

Current State	Next Action	Next State
game invitation issued		
partner passes	auction ends	no further action
partner raises to game	auction ends	no further action
- partner bids a new suit at the three level	bid game in either of partner's suits or no trump	game force
partner bids 3 nt	bid game in partner's suit	game force
	pass	auction ends
- partner bids 4 nt	respond Roman Keycard Blackwood with the last bid suit as trumps	Blackwood Convention
partner bids a suit at the 4 level	bid cheapest first round control	Cue bidding Sequences
- partner bids a suit at the 5 level	rebid the trump suit at the 5 level if there is more than one loser in the suit, at the 6 level otherwise	auction ends
inverted minor raise		
- partner rebids suit	pass	no further action
- partner bids no trump	raise to three with max or extra length in suit	auction ends
- partner bids a suit	with a stopper in the suit bid, bid no trump or another suit	inverted minor
	rebid the minor	auction ends
Stayman Convention		
- partner bids diamonds	bid three no trump	auction ends
- partner shows a major suit fit	bid four of the major	auction ends
- partner denies a major suit fit	bid three no trump	auction ends
Jacoby Transfers		
- 2 club state does not exist	bid three no trump or four of the major, depending on the suit length	auction ends
- 2 club state does exist	bid 5 no trump or 6 of the major	slam force
game force		
partner bids game	pass	auction ends
partner passes	auction ends	no further action
partner bids another suit	bid the cheapest first round control	Cue bidding sequences

Current State	Next Action	Next State
2 club sequences		
partner bids his suit at the two level	raise with a fit	game force, slam invitational
	bid no trump	game force, slam invitational
	rebid a long suit	game force, slam invitational
partner rebids two no trump	raise to 6nt	auction ends
	bid a new suit	game force, slam invitational
	bid 3 clubs	Stayman Convention
	bid 3 diamonds or 3 hearts	Jacoby Transfer
	bid 4 clubs	Gerber Convention
- partner bids his suit at the three level	bid cheapest first or second round control at the four level	Cue bidding Sequences
	rebid three no trump	game force, slam
partner rebids his suit at the three level	raise with a fit	invitational
	bid three no trump	
- partner bids a new suit at the three level	raise partner's first or second suit	game force, slam invitational
	bid 3 no trump	game force, slam invitational
- partner bids three no trump	bid 6 no trump	auction ends
partner raises	bid 4 no trump	Blackwood Convention
- partner bids his suit at the four level	bid cheapest first or second round control	Cue bidding Sequences
- partner bids 4nt	respond Roman Keycard Blackwood using the last bid suit as the trump suit	Blackwood Convention
- partner bids a suit at the 5 level	rebid the trump suit at the 5 level if there is more than one loser in the suit, at the 6 level otherwise	auction ends
auction can end		
partner bids	raise partner's suit	game invitation issued
	bid two no trump	game invitation issued
- partner passes	auction ends	no further action
fourth suit forcing		
partner raises, min	bid game with max	auction ends
	raise to 3 with a semi max	game invitation issued
	pass	auction ends
- partner raises, max	bid game	auction ends
- partner denies, min	pass	auction ends
	bid two no trump	game invitation issued
- partner denies, max	raise partner's suit	game force
	bid three no trump	game force

Current State	Next Action	Next State
game force		
partner bids game	pass if 2 club state disabled	auction ends
	raise suit	slam invitational
	bid 4 nt	Blackwood Convention
- partner bids a new suit at the four level	bid the cheapest first round control	Cue bidding Sequence
- partner bids a new suit at the 5 level	rebid the trump suit at the 5 level if there is more than one loser in the suit, at the 6 level otherwise	auction ends
partner bids 4nt	respond Roman Keycard Blackwood using the last bid suit as the trump suit	BlackwoodConvention
Blackwood Convention		
- partner bids the nt	respond with the appropriate number of controls	Blackwood Convention
- partner responds to the nt ask	next level if all controls are accounted for	Blackwood Convention
	bid the suit below the trump suit	Blackwood Convention
- partner rebids the trump suit after responding to an ask	pass	auction ends
partner bids the suit below the trump suit	bid the trump suit	auction ends
Cue bidding Sequences	bid the next higher control if all lower controls are accounted for	Cue bidding Sequences
	rebid the trump suit	auction ends
	bid slam in the trump suit	auction ends
	bid no trump	Cue bidding Sequences
Gerber Convention	bid the next higher level if all 1st round controls accounted for	Gerber Convention
	rebid no trump	auction ends
	bid slam in no trump	auction ends
slam force		
- partner bids slam in a suit or nt	pass	auction ends
- partner bids a new suit	bid 6 or 7 of the suit	auction ends
slam invitational		
- partner bids game	bid one level higher	slam invitational
- partner passes	auction ends	no further action
- partner bids a new suit	cue bid the cheapest appropriate control	Cue bidding sequences
partner bids 4nt	respond Roman Keycard Blackwood using the last bid suit as the trump suit	Blackwood Convention

Section 4

Implementation Details

This section describes the hardware and software tools used to construct the knowledge base. It describes how the Object Oriented paradigm was followed. It lists the classes and corresponding header files used to construct the Bidder and the Explanation facility. The methods for enhancement through knowledge acquisition are illustrated. The resulting structure forms a frame. Testing and debugging procedures are discussed.

System Architecture

This software was written using Turbo C++ [19] in an MS-DOS[20] environment on an 8086-based machine. C++ was chosen because of it's ability to model the Object Oriented programming paradigm, since this work naturally divided into a series of classes and subclasses. MS-DOS and the 8086-based machine were chosen simply as a matter of convenience. All machine-specific and operating system specific calls are contained within the class used for communication.

Class Definitions

Four entities are modelled in this design: a **Dealer**, a **Bidding System**, a **State Analyzer**, and a **Message System**.

Class **Deal** controls the activity relating to the distribution of the cards and the auction control. It finds out which hand the computer is to play, asks if there is to be another hand, determines which player is the dealer, what board number is being played, and what the vulnerability is. It deals out the four hands, and keeps track of the cards. It records the bids in the bid table and stops the auction after three successive passes. It uses the following functions:

void Bid() - controls the bidding sequence

char Get_dealer(board_num) - returns the dealer based on the hand number

int Get_vulnerability(board_num) - returns the vulnerability given the board number.

Deal has a child, class **Hand**. **Hand** formats and analyzes the cards passed to it from **Deal**. It counts the high card points and quick tricks, determines the texture for each suit (the quality of the spot cards), and classifies the hand. It passes this information to the Bidding System,

receives the next bid from the Bidding System, then passes this information back to **Deal**. It used the following functions:

int Count_HCP()

int Compute_texture(suit)

int Count_Quick_tricks()

int Classify_hand() - determines the hand class based on HCP and Quick tricks

int Evaluate_shape() - stores suit lengths

int Format_card() - changes the card input by the user to a numerical representation

int Load_cards() - loads the card into the internal array

int Prompt_next_bid() prompts the user for the next bid

int Compute_next_bid() queries the Bidding System for the next bid

void Identify_controls() identifies the aces and kings in case cue bidding is invoked.

Two transgressions were committed while modelling the **Bidder** and the **State Analyzer**. Most of the Bidding System and corresponding treatments were hard-coded, since only Bridge World Standard was used. The code was incorporated into the State Analyzer, instead of being placed in its own class. These transgressions bypassed design issues that need to be considered once the system expands to include other classes and bidding systems. A further discussion of this point is contained within the Enhancements paragraph of Section 5. The aberrations to coding theory were included solely to expedite the knowledge base construction.

Class **Bidder** comprises the State Analyzer. It is responsible for directing which subclass generates the next bid, since the Invitational classification is implemented as a child of **Bidder**. This class contains the data elements that serve as the state variables. After the bid has been determined, **Bidder** passes the bid to **Deal** for storage and future retrieval. This class also identifies partner and retrieves his bid. It uses the following functions:

int Get_bid() - switches processing to the proper subclass and returns the bid to **Hand**

void Get_partner()

int Get_partners_bid().

Class **Invitational** holds the logic to evaluate the state variables, alter them, and communicate with the Bidding System to generate the next bid for hands classified as Invitational. It is where the knowledge base resides. The rule base is written in C++, which means the basic structures are if-then-else and case statements. The bidding system becomes 'smarter', then, by augmenting a given set of statements with additional enhancements/constraints. For example, a piece of logic when originally entered went something like this:

```
switch (partners_bid)
{
    ...case FOUR_DIAMONDS:
        if (partners_first_bid = = ONE_DIAMOND)
        {
            if (my_diamond_length > 1)
                bid = FIVE_DIAMONDS;
            else
                bid = PASS;
        } ...
}
```

In testing, a hand came up that fit this example and pointed out a more sophisticated evaluation, so the knowledge base was enhanced as follows:

```
switch (partners_bid)
{
    ...case FOUR_DIAMONDS:
        if (partners_first_bid = = ONE_DIAMOND)
        {
            if (my_diamond_length > 1)
            {
                if(my_diamond_texture > JX) or (I have an outside singleton or void)
                    bid = SIX_DIAMONDS;
                else
                    bid = FIVE_DIAMONDS;
            }
            else
                bid = PASS;
```

```
        } ...
    }
```

Errors were corrected in a similiar fashion.

The knowledge base structure is represented as slots in a frame. The code segments are activated by the state variable settings. Some state variable settings lead to other state variable settings, some lead to code fragments. For instance, If no bid has been made, partner's first bid is fetched. Assume partner bids 2 clubs. The next bid is determined, then the game force and slam invitational state variables are set to 'Y'. When partner's next bid is retrieved, the processing branches to the game force sequences. If no suit has been determined, processing remains in the game force code segment until a suit is settled upon. The 'suit established' state variable is now set, and processing branches to the slam invitational area. This in turn can branch to cue bidding sequences, Blackwood, asking bids, or whatever else is encoded. The determinant is the path built to the code segments based on the state variable settings. So, each slot can be reentered as many times as it takes to either set the next series of state variables or end the auction. The sequence of processing these variables is EXTREMELY important, since incorrect positioning results in incorrect processing. This class uses the following functions:

int Next_bid(partners_bid) returns the next bid

int Get_partnership_action(partners_bid) controls non first bid logic

int Respond_to_partners_opening_bid(partners_bid)

int Partner_rebids(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner rebids his suit'

int Partner_jump_rebids(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner jumps in his suit'

int Partner_double_jump_rebids(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner double jumps in his suit'

int Partner_bids_a_new_suit(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner shows two suits'

int Single_raise(my_last_bid, partners_last_bid, partners_bid)

returns the next bid based on the state 'partner shows a fit for my suit'

int Double_raise(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner shows a fit for my suit and a good hand'

int Triple_raise(my_last_bid, partners_last_bid, partners_bid)

returns the next bid based on the state 'partner shows a fit for my suit and a forcing hand'

int Partner_reverses(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner shows a strong, unbalanced hand'

int Partner_jump_shifts(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner shows a forcing, unbalanced hand'

int Partner_splinters(my_last_bid, partners_last_bid, partners_bid)

returns the next bid based on the state 'partner shows a forcing, hand with a fit for my suit and a singleton'

int Partner_preempts(my_last_bid, partners_last_bid, partners_bid)

- returns the next bid based on the state 'partner shows a long suit and a weak hand'

int Check_diamond_fit(partners_bid) - checks for a secondary diamond fit

int Check_club_fit(partners_bid) - checks for a secondary club fit

int Game_force_sequences(my_last_bid, partners_last_bid,partners_bid)

- bidding sequences after the state variable 'game force' has been set

int Cue_bid_sequences(my_last_bid, partners_last_bid,partners_bid)

- bidding sequences after the state variable 'cue bid' has been set

int Two_club_sequences(my_last_bid, partners_last_bid,partners_bid)

- bidding sequences after the state variable 'two club sequences' has been set

void Check_for_all_aces()

char Check_for _missing_controls(partners_bid)

checks for all aces and kings up to the last bid

int Establish_trump_suit(my_last_bid, partners_last_bid,partners_bid)

int Check_for partners_signoff(partners_bid) - determines if partner has ended the auction

int Analyze_state(partners_bid, my_last_bid)

- switches to appropriate logic based on state variable settings.

The Bidding System translates states into bids by using state variable settings, context, classification, and hand distribution. For instance, given partner's opening bid of one club using Bridge World Standard, a classification of 'Invitational', and a hand pattern of 5 spades, 4

hearts, 1 diamond and 3 clubs, the Bidding System would return '1 spade'. With one fewer spade the Bidding System would return the bid of '1 heart'.

Class **Conventions** represents the part of the Bidding System that resides in a separate class. Since most bidding systems use the same conventions in the same manner, this class can be used by all bidding systems without modification. This class responds to requests for bids from the **State Analyzer**. It returns the appropriate bid given the conditions passed it. New conventions are implemented by adding the code to this class and establishing the necessary state variables in the **State Analyzer**. The following conventions were incorporated into this work:

int Fourth_suit_forcing(partners_bid, my_last_bid, partners_last_bid)
determines if partner forces to game, invites game, or makes a minimum rebid

int Blackwood_sequences(partners_bid, my_last_bid, partners_last_bid)

- implements the Roman Key Card version of the Blackwood Convention

int Jacoby_sequences(partners_bid, my_last_bid, partners_last_bid)
implements Jacoby Transfers

int Stayman_sequences(partners_bid, my_last_bid, partners_last_bid)

int Inverted_minors(partners_bid, my_last_bid)
generates the appropriate bid in the inverted minor sequence given partner's last bid.

Class **Message** handles screen to program and program to screen communication. It contains environment-specific code to create the displays. There are two message arrays contained within Message. One array stores the prompts issued by the program and the user responses. The other array stores the messages generated by the program as the decision tree is being traversed. This second array acts as an explanation facility, since messages are sent by the **State Analyzer** and **Conventions** whenever a function is entered and when a decision is reached. The **Message** class accepts three types of strings - one single string, two concatenated strings, and a string concatenated with an integer. The message displays are

controlled by the knowledge base. After the base has been traversed, class **Deal** issues a command to **Message** to print the accumulated messages.

The functions this class incorporates are:

void Explain__int(value, text *) - concatenates a string and an integer
void Explain__1string(text *) stores a single string
void Explain__2string(text *) - concatenates two strings
void Align__screen() - clears out the message arrays when full
void Print__screen()
void Print__prompt(prompt *) prints the prompt generated from the program
void Clear__prompts().

Knowledge Acquisition, Testing and Debugging

The knowledge acquisition occurred incrementally. I picked a specific hand pattern within the domain, determined the appropriate rules and the state variable settings needed to fire them, inserted them into the expert system, tested, debugged and enhanced as more or better evaluations became apparent. So the knowledge base was refined and enlarged through experience and exposure to differing conditions. Since the knowledge base was constructed using my expertise, a test suite from live conditions was needed. I chose representative hands from a collection of about 50 tournament hand records I possess. Each hand was selected using the following criteria:

- it had to fall into the Invitational class (good 8 to a bad 12 HCP, no outlandish suit distributions)

  partner had to have a hand that could open the bidding in first or second seat (since no third seat logic was incorporated)

  the auction had to be uncontested.

These constraints eliminated about 80% of the hands, on average, but I was still able to get close to 300 hands. Next, I recorded my best guess for a reasonable auction looking at both hands. Finally, I submitted them to the software, one hand at a time. I input the hand that fit the listed criteria, so the computer bid that hand and I bid the other. Whenever a hand was bid

reasonably, I went on to the next. If an error occurred, or if logic needed to be enhanced, I stopped the proccess and made the necessary corrections and coding entries. The explanation facility coded into the software allowed me to locate the functions that needed changing rather easily. Periodically, I would review the tests already completed to ensure those hands previously completed were still bid correctly. I wanted to avoid fixes and enhancements that clobbered something else.

This approach pointed out three items of interest:

- Since I was both the expert and developer, the methods I used to encode my logic had a number of missing pieces, pieces that I normally never think about. For example, there are auctions where partner makes the same bid, one time it's forcing, and another time it's not. The difference is in the context of what occurred prior to the bid. 1c-1h-3c if not a forcing auction, but 1d-1h-3c is. I know this when I'm at the table, but the software didn't until I told it;

  I discovered that better bids were available than what I had first considered, so in effect, the software surpassed my abilities in these areas once the logic was coded (refer to the earlier 1d-1 anything-4d example);
- the ordering of the processing for the state variables is very important. I spent a fair amount of time resequencing them.

The major problem with this approach is that there is always the hand lurking out there that has not been considered. Eventually, through numerous iterations of the process of bidding a hand, analyzing erroneous or substandard sequences, then enhancing the corresponding rules, the knowledge base stabilizes, and default bids built into the system activate less frequently. The knowledge base reaches the point of handling the mundane hands rather quickly, and further testing contributes very little. The ability to handle the exceptional hands increase dramatically as they are encountered, studied, and encoded, however, and the net knowledge gain is cumulative, since the knowledge base doesn't forget. This parallels the human process

at the table. The more hands that are analyzed, the more sophisticated the logic applications to future hands.

Section 5

Conclusions

This section summarizes the results from the research. It discusses the effectiveness of incremental knowledge acquisition and application, comments on the physical environment used, and advocates the Object Oriented paradigm as a workable methodology. The usefulness of the hand classification and state variable concept is reiterated. Potential enhancements are listed. Finally, the position is stated that bidding software is doable using a knowledge base and frame structure.

Incremental Knowledge Acquisition

The technique of adding knowledge to the expert system incrementally proved to be useful in defining the logic in a bidding system. Most bidding systems define a general approach, assign meanings to some bids, and leave the rest of the possibilities to the users of the system to work out. Working out the rest of the possibilities takes years, with questionable results for most players. Only the best can invent bids on the fly to describe extremely complex situations. Most spend their bridge lives unable to grasp the sophisticated analysis needed to properly evaluate the full trick-taking potential of the more elegant hand patterns that exist. The incremental technique is suited for this because it allows for the continuous development of more elaborate reasoning processes as well as breaking the domain of bidding system logic into small, manageable pieces. When a hand of interest is presented, the hand can be bid with the knowledge already programmed, an analysis can be completed to discover additional considerations, and these considerations can be added to the knowledge base. This process builds upon itself rather nicely. After the most basic bidding sequences are defined, the more challenging are added. This process theoretically could continue until the analytical limits of the expert are reached.

Knowledge Base Construction

There must be better alternatives to coding the knowledge base and frame structure than C + +. The major disadvantage is the syntax of the language. Since some of the logic is

rather deeply nested, a brace or a semi-colon in the wrong spot means hours of debugging. Pointer errors are another distraction. Putting in a couple of lines of code, waiting for the compiler to finish (usually about 20 minutes -- a faster processor would help here) testing the code then having to reboot because of a failure to dereference a pointer is somewhat aggravating. An environment that handled these details would be greatly appreciated.

The Object Oriented paradigm proved to be very useful, both as a way to think about the problem and as an architectural medium for ease in future expansion. Hand classifications subdivide themselves nicely into sub-classes of a bidding system. Inheritance makes sense, because there are attributes to hands that apply to all classes, yet each class handles those attributes differently. Even though only one hand classification was modelled, the techniques employed could easily be used to model the other classes as well. The state variables in this work were stored in the parent class strictly as a programming convenience. As more classes are programmed, the variables would reside within each child class, making the implementation of the frame paradigm more accurate.

Classifying a hand prior to bidding, then maintaining that the classification never changes is somewhat controversial. Bridge players observe that their hand 'grows' or 'shrinks' during an auction. They like to think that their minimum opener transforms into a strong forcing hand after partner has made a few particularly appealing bids. However, the cards don't change. The high card points and suit textures don't change. What does change is the estimation of the trick-taking potential of the two combined hands. Grouping the hand patterns into classes, then compiling knowledge specifically related to that classification makes sense, then. It also provides a vehicle for modular code.

State variables also pattern the thought process Bridge players go through when evaluating the auction. Is the sequence forcing? Can a minimum bid be passed? When exploring the slam

possibilities, are any key Aces or Kings missing? The answers to these questions influence the next bid. Since bidding is represented by filled slots in a frame, and the incomplete slots store the code fragments that derive the bids, the state variables summarize the activity that occurred as a slot became complete. Ordering is important, since a series of states have to be traversed to arrive at the correct segment. Improper ordering requires code duplication to avoid errors. However, code duplication usually means the effort to 'smarten up' the knowledge base will fail.

The physical medium chosen was inadequate, simply because of the size of the code segments that needed to be processed. The 8 Mhz 8086 processor was showing its age. The executable file for the stripped down version I built was about 250,000 bytes. Some optimization might be in order, but since this was one of eleven identified classes, the executable files for the complete bidding system could run over 2 million bytes. The programming included over 30,000 lines of source code in 12 modules (a great deal of the code was in include files; the actual source data sets were closer to 10,000 lines). Also, DOS' 64K segment limit was reached in a couple of data sets. Enough addressable memory to use the larger memory models included with Turbo C + + (>1 meg) would help significantly.

Enhancements

There is quite a bit of work that can be done on this program:

1. Add third seat opening bidding logic
   - This should be relatively easy. On a third seat major suit opener, incorporate the logic to find out if partner opened light. If yes, sign off below game. If no, use existing logic for first and second seat openers;
2. Add competitive auction logic
   - This is quite a bit more involved. Additional states have to be considered. Three bids, pass, double and redouble take on additional meanings. The Law of Total

Tricks needs to be considered. There are a number of conventions to add, as well. The level of competition needs to be factored in. Does one opponent throw in a bid to suggest a lead from his partner, or do the opponents compete to the 5 level? Are the opponents sacrificing? Phantom sacrificing? Can they make their contract? If our contract goes down, will the loss be a gain (losing fewer points by sacrificing than defending)?

3. Decouple the **State Analyzer** and **Bidding System**

   This can be accomplished after the knowledge base has stabilized and all the states have been categorized, since the Bidding System will need a definition of what partner's bids mean. The State Analyzer would be responsible for providing those meanings, and the Bidding System would determine which bid to present. To make this completely universal, the Bidding System would need a user interface that would allow the user to input a bid given the sets of conditions found in the **State Analyzer**. The State Analyzer then continues in its role as an inference engine, executing the logic that sets the states.

4. Add the logic for the remaining classes

   - Although the first frame took a fair amount of time, the others should proceed more rapidly if steps 1-3 are completed. A pattern would now be available for building the subclasses, and the time spent in coming up with a workable design would not have to be undertaken again. The process for extracting the logic and codifying it is intensive, however, and will take a non-trivial effort per class.

5. Establish a more suitable environment

   - A knowledge base constructor with a first rate debugger that can support inductive reasoning methods on a fast machine would be perfect. Scanning the hands into a file then reading the file instead of inputting each would help as well.

Final Comments

This work demonstrates the techniques needed to capture the logic associated with bidding a Bridge hand. The incremental knowledge acquisition method used in this work allows for progressive software enhancement as more becomes known about the domain and the knowledge associations become more complex. The knowledge is encapsulated into classes, so that growth can occur in one area without affecting another. The algorithms presented here show that Bridge logic can be captured and represented. The major obstacle is the amount of time needed to construct the representations.

A Bridge-bidding software program exhibiting a high degree of efficiency is doable, given the time to acquire and code the knowledge, sufficient testing criteria to uncover flaws and promote enhancements, and access to people who are recognized experts on bidding to augment the knowledge base. The software will be deficient wherever hunches are exploited, but will be superior in judging the best course of action based on past occurrences. This work should indicate that the software can be constructed, if one wants to put in the time. There are tasks that are 'easy' to program, such as the bidding rules in the rule base. There are tasks that are more involved, such as defining meaningful state variables and ordering them properly. There are tasks that are hard to program, such as observations and table presence. Work relating to the hard stuff should be tabled until work on the easy stuff is complete and evaluated favorably.

Appendix A

Glossary of Bridge Terms

Auction	The process by which the contract is established.
Balanced hand	A hand containing no singletons or voids.
Bidding	One of 38 allowable phrases, used within the context of a Bidding system. The purpose is to identify the number of tricks a partnership can take.
Bidding system	An agreement by which a bid either describes a certain card holding or requests specific information about partner's holdings. The meanings of the bids are dependent on the bidding that has previously occurred, so that one bid can have many different meanings.
Board	A device used in Duplicate Bridge to keep each of the four hands intact for each deal. The players remove the hands from the slots, then insert the hands into the slots after play has completed. The board containing the four hands is then passed to the next set of players.
Book	6 tricks.
Card Sense	The ability of a player to reason logically given facts, clues and inferences within the domain of the rules of the game and a deck of playing cards.
Competitive Auction	An auction where both sides are competing for the final contract.
Contract	The number of tricks needed to succeed. The tricks needed is defined a book plus contract level (e.g. a 4 spade contract to be fulfilled requires winning at least 10 tricks (6 + 4).
Controls	Winners in a suit. An Ace is a first-round control, a King is a second-round control. In a trump contract, a void in a suit other than trumps is a first round control, and a singleton is a second round control.
Convention	A meaning given to a bid other than the generally accepted meaning (e.g. after a 1 no trump opening, a bid of 2 clubs by the opener's partner is the *Stayman* convention, asking partner if he has a four card major suit. It says nothing about clubs. If this convention were not played, 2 clubs would show a club suit (the standard meaning)).
Danger hand	A defender who can cash a number of established tricks if he gets the lead.
Declarer	The person playing the hand. Declarer is the first of the partnership to name the suit (or no trump) in the bidding.
Discard	Playing a card other than the suit led and other than a trump.

Double — A bid that increases the value of the contract if the contract is made, or the value of the penalty if declarer goes down. This bid is valid when used by the opponents of the person who made the last bid other than pass or redouble.

Doubleton — Two cards in a suit.

Dummy — Partner to declarer. Dummy's cards are tabled face up after the opening lead has been made, so that everyone sees an additional 13 cards.

Duplicate Bridge — A form of the game where all contestants play the same hands. For each hand the scores are compared. The partnership with the best (or least worst) score gets the most matchpoints. The matchpoint awards for each board are totalled to determine the winner, second place, etc.

Entry — A winning card that allows access to the hand that played it. The Ace of trumps in dummy is an entry to that hand, and the next trick would be started from dummy after the Ace is played.

Falsecard — A play of a card that misinformes the opponent to the true holding.

Finesse — A Play of the Hand technique where declarer plays a card that might win a trick (e.g. declarer leads a small card toward the AQ of a suit in dummy. If LHO plays a small card and declarer plays the Queen, he wins two tricks when LHO has the King, one trick if RHO has the King).

First Seat — The hand that opens the auction with a pass or bid. First seat is the dealer.

Fit — At least 8 cards in the suit between the two hands.

Forcing Pass — A bid of "pass" in a competitive auction that, given the correct context, forces partner to either bid or double at his turn, depending on his card holding in the opponents' suit and potential defensive tricks.

Fourth Seat — The hand to the right of the dealer, and is the last to bid in the opening round of bidding.

Game — A 3, 4, or 5 no trump, 4 or 5 of a major, or 5 of a minor suit contract. Point bonuses are awarded for bidding and making game. Game scores = 100 points for 3 no trump, 5 clubs or 5 diamonds, and 120 points for 4 hearts or 4 spades.

Game Force — A bid issued within a context that forces the partnership to continue bidding until game is reached.

Game Invitation — A bid, usually one level below game, that requests partner to reevaluate his cards to see if there are extra distributional or trick-taking values other than what has been described so far. If so, partner is expected to bid game.

Gerber Convention — a convention used to discover the number of aces and kings a side holds after one member of the partnership has opened in no trump. Gerber is initiated by bidding 4 clubs after a 1 nt or 2 nt opening, or after 2c, some bid, 2nt.

Going Down — Capturing fewer than the number of tricks contracted for, resulting in a score for the opponents.

Half-stoppers — see **Stoppers**.

HCP — High Card Points. Ace = 4, King = 3, Queen = 2, Jack = 1. This system was popularized by Charles Goren and is the most popular basic hand evaluation method in use today.

Hold up — A play where declarer waits to take a winner in the opponents' suit, so as to exhaust one of the opponents of all of his cards in that suit. Then, if that opponent later gains the lead, he cannot return that suit to his partner.

Honors — Ace, king, queen, jack or ten of a suit.

Jacoby Transfer — a bidding convention designed to allow the no trump opener play the hand. If (after a 1 no trump opening) the responder has a 5 + card heart suit, he bids 2 diamonds, forcing the opener to bid 2 hearts. Wlth 5 spades responder bids two hearts, and opener bids two spades. Over a 2 no trump opening, the same bids are made at the three level.

Jump shift — bidding a new suit one level higher than required (e.g. 1h-1s-3c) to show a strong, forcing hand.

Law of Total Tricks — A metric used for evaluating the trick taking potential for hands in competitive auctions. The law states that the number of trumps a side holds equates to the number of tricks the combined hands can take.

Limit Raise — A bid that establishes a trump suit and issues a game invitation to partner. It describes a hand with values less than an opening bid, but better than a minimum raise.

Major Suit — Spades or hearts.

Merrimac Coup — The play of an unnecessarialy high card to force the opponent to win the trick prematurely.

Minimum raise	A bid that describes a fit for partner's suit but cautions partner against bidding on unless he has extra values.
Minor Suit	Diamonds or clubs.
No Bid	See **Pass**.
No Trump	The rank of a card within a suit is the only consideration for determining the winner of a trick(e.g. the club 3 beats the club 2, the club 2 beats the spade Ace if clubs were led, the spade 2 beats the club Ace if spades were led).
Opening bidder	The first person to bid something other than *Pass*.
Opening Leader	The person to the left of declarer. This operson initiates Play of the Hand by playing a card from his hand face up on the table.
Opening Light	Opening the bidding with less than the minimum opening requirements of 12 + points and 2 1/2 quick tricks. This is usually associated with opening bids from third seat.
Overcall	A bid made by one of the opponents of the *Opening Bidder*.
Part-score	A score on a completed contract that totals less than 100 points.
Pass	A bid that does not elevate the level of the contract. An auction is completed after three successive passes following a bid other than Pass, or four passes.
Phantom Sacrifice	Bidding a sacrifice against the opponents' contract when the opponents cannot make their contract (e.g. bidding 5 hearts after the opponents have bid 4 spades, only to find at the end of the hand that 4 spades could not be made).
Preempt	A bid that advances the bidding a number of levels. It's purpose is two-fold: (1) to describe a hand that holds a lot of cards in one suit and would take a number of tricks if that suit were trumps, and (2) to use up bidding space that the opponents need to accurately describe their hands.
Quick tricks	A metric for evaluating the strength of the aces, kings and queens in a hand. Ax = 1, AK = 2, AQ = 1 1/2, KQ = 1, Kx = 1/2.
Rank	A designation for the relative order of the suits. Clubs carries the lowest ranking, then Diamonds, then Hearts, then Spades, then No Trump. Since each bid must be greater than the last (excepting Pass, Double or Redouble) a bid must be in a suit of a higher rank than the last bid or of a higher level if the suit bid is of equal or lower rank.

Redouble	A bid t t doubles again the value of the contract if it is made defeated. This bid is valid only after a double and is used by the opponents of the person who doubled.
Response	The bid issued by the partner of the opening bidder. This person is called the *responder.*
Reverse	A sequence by the opening bidder where two suits are bid in reverse order. The Reverse is used to show a strong, unbalanced hand (e.g. 1c-1s-2h is a reverse).
Roman Key Card Blackwood	A variation of Blackwood where the King of trumps counts as a 5th key card. The responses to 4nt are 5 clubs (0 or 3 key cards), 5 diamonds (1 or 4 key cards), 5 hearts (2 key cards without the trump Queen) and 5 spades (two key cards with the trump Queen).
Rubber Bridge	he original form of Contract Bridge, where the two partnerships compete to try to win rubbers. A rubber is awarded to the side who first completes two games. Points are assigned for winning a rubber, more points for winning two games before the opponents can win one.
Ruffing	Playing a trump when unable to follow suit.
Sacrifice	A bid designed to lead to a final contract that will usually be doubled and go down. The points lost through this action are hopefully less than the points lost if the opponents can bid and make their normal contract.
Second Seat	The hand to the left of the dealer.
Scissors Coup	A technique where a suit the opponents might use to transfer the lead between their two hands is eliminated, thus cutting their communication.
Simple raise	See **Minimum Raise**.
Singleton	A holding of one card in a suit.
Slams	A 6 or 7 level contract. 6 level contracts are called *small* slams, 7 level contracts are called *grand* slams.
Spot cards	Cards other than the ace, king, queen, or jack. The ten is considered both a spot card and an honor.
Squeeze play	A card play technique that requires a defender who holds a winner in one suit and a guard in another to part with one, establishing an additional trick for declarer. There are many variations.
Standard Bidding	A bidding system popular with most casual partnerships whereby an opening no trump range is 15-17 points or 16-18, a major suit is opened at the 1 level with 5 cards or 4

	cards, depending on partnership preference, and a two over 1 bid does not force to game.
Stayman Convention	a bid after a no trump opening that asks whether opener has a four card major. The purpose of the bid is to play in a 4-4 major suit fit rather than no trump. After a 1nt opening, 2 clubs is Stayman. Opener bids 2 hearts or 2 spades, 2 diamonds if he does not have one, and 2 hearts if he holds four cards in both. After a 2 no trump opening, the same bids are made at the three level.
Stoppers	cards that can take tricks in the opponents' suit, preventing them from taking enough tricks consecutively in the suit to defeat the no trump contract. Stoppers include A. Kx, Qxx, J10xx. Half-stoppers include K, Qx, Jxx.
Texture	Name given to the high spot cards within a suit. A hand is rich in texture if it contains tens, nines and eights, poor in texture if the suits contain twos, threes and fours.
Third Seat	The hand opposite the dealer. Third seat opening bidding requirements in most systems are somewhat less stringent than in other positions.
Trick	The play of one card from each of the four hands. There are 13 tricks per hand.
Trump	A suit designated by the final contract to hold trick taking preeminence over the other suits(e.g. if hearts are trump, the heart 2 is higher than the spade, diamond, or club Ace).
Trump postponement	Delaying pulling the opponents' trumps in order to establish another suit.
Trump substitute	Using an established side suit to extraxt an opponent's trumps, by forcing him to ruff or conceding a discard.
Two-over-one	A two level response in a suit of a lower rank to a one level bid (e.g. one spade - two clubs).
Two-suited hand	A hand containing at least 9 cards in two suits. The cards are distributed as near equally as possible (e.g. 9 cards are distributed 5-4, 10 cards are distributed 5-5, 11 cards are distributed 6-5).
Unblocking	Playing an unnecessarialy high card to promote a lower card in partner's hand.
Uncontested Auction	A bidding sequence where the opponents pass at every opportunity prior to the final contract being set.
Vienna Coup	A form of squeeze play where declarer cashes a winner, promoting a card to a winner in the hand of an opponent

who holds a guard in another suit. He is then squeezed out of either the winner or the guard.

Void — A holding of zero cards in a specific suit.

Vulnerable — An element of scoring that increases the points received for a game or slam being bid and made, and the points lost for going down in a contract. The points allocated to a doubled and redoubled contract are also proportionally increased. In rubber bridge, a side is vulnerable after it has won a game.

Appendix B

A Primer on the Basics of Bridge

Contract Bridge is a partnership game for four, played with a standard 52 card deck. Each of the 4 suits (spades, hearts, diamonds, clubs) has 13 cards, ranging from Ace (high) to 2 (low).

The partners sit across the table from each other, then the cards are dealt out. Each person receives 13 cards. After the cards are arranged in each hand, the first phase of the game, the *bidding*, begins.

The person who dealt begins the auction with either a 'pass' or a bid. The purpose of bidding is to determine how many tricks a partnership can take with a particular suit as trumps. A trick is a round of four cards, one from each person, placed face up on the table in turn. The trick is won by the person who plays the highest card in the suit led. The 2 of trump is higher than the Ace of the non-trump suit.

The bidding establishes the contract and the declarer. The contract equates to how many tricks the side must take over and above the book. The book is 6 tricks, so a contract of 4 spades must take 10 tricks (6 for the book and 4 for the bid) to be successful. The person who first named the trump suit is the declarer, and will play the hand. His partner's hand is called the Dummy. After the opening lead is made, the dummy is displayed, all 13 cards face up. Declarer then plays both hands to try to make his contract. The opponents of the declarer are the Defenders. Their task is to prevent declarer from making his contract. The defender to the left of declarer is the opening leader. He places one of his cards face up on the table, then play commences. Each player must play a card of the same suit, if possible. If all players follow suit, the highest card wins the trick, and initiates play to the next trick. If a player cannot follow suit, he may play any other card in his hand. If he plays a trump, and everyone else follows suit, he wins a trick. If he trumps and someone else plays a higher trump, he loses the trick. If he plays a card other than a trump, he is said to have discarded. The card he plays will not win the trick, regardless of its rank.

There are five strains in which to play contracts: one for each of the suit as trumps, and no trump. No trump contracts, as the name implies, involve tricks that are won on rank within suit only -- no trumping is allowed. So, at a no trump contract for instance, if South led the 4 of clubs, West played the 8 of clubs, North played the 2 of diamonds (because he couldn't follow suit) and East played the Ace of hearts, West would win the trick at no trump because he played a higher ranking card in the same suit. If the contract were in diamonds, North would win the trick. If hearts, East would win.

In Rubber Bridge, the goal of the game is to accumulate the most points at the end of a session. One way to accumulate points is to win the rubber. The rubber is won by winning two games. A game is scored any time a contract's value is greater than or equal to 100 points. The game contracts are 3 no trump, 4 hearts, 4 spades, 5 clubs, and 5 diamonds. Part-score contract totals are accumulated until 100 points is reached or exceeded. Overtricks do not count in the scoring toward game (called 'Below the Line', but count toward the overall score. The same is true for slam bonuses, rubber bonuses, and bonuses for doubled and redoubled contracts that are made. Another way to accumulate points is by defeating the contract. For a more complete explanation, refer to Charles Goren's 'The Complete Book of Bridge'[21].

Appendix C

Bridge World Standard

Bridge World Standard is the chosen bidding system for the research in this thesis.[22]

Bridge World Standard

Bridge World Standard is a system based on the majority preferences of approximately 125 leading experts and thousands of BRIDGE WORLD *readers. The methods used in the system were determined by polls: a clear expert preference determined the systemic treatment; close questions were decided by the readers' vote.*

Because it is a consensus system, BWS is rarely used by regular partnerships. It is, however, very valuable in forming casual partnerships-if both partners know the system, they need discuss only theose areas in which individual preferences do not conform to the BWS treatment.

Bridge World Standard is also used as a foundation for voting in the Master Solvers' Club. To avoid differences based on varied systematic approaches, and thereby give more meaning to all the answers and markings, the North-South players are assumed to have agreed on Bridge World Standard.

Opening Bids and Responses

1 NT: good 15 to bad 18

Jacoby transfers (splinter rebids; game raise is a slam try*); two spades shows minors*; Texas transfers*;Stayman (major rebid invitational; minor rebid forcing); three of a minor weak*; Gerber*

2 NT: good 20 to bad 22 (small doubleton acceptable)

Jacoby transfers; three spades shows minors; Texas transfers*; Gerber*; High Gerber*

Two clubs artificial, strong

Natural responses (positive response requires good suit); two diamonds neutral

Weak two-bids

Two notrump (asks for feature if maximum) and new suit responses forcing

Weak "gambling" three-bids

3 NT: gambling (little or no outside strength); 4 diamonds response artificial

Five card majors in first or second position

One-notrump response forcing; two-over one promises rebid; limit jump raises (four trumps); two notrump strong raise (asks shortness)*; three notrump natural, 16-17*; passed hand responses: one notrump 6-12; two clubs strong raise*; three clubs natural*

Responses to minor-suit openings:

Single raise strong, 10 pts. up, denies major; jump raise weak; 1 club 1 NT: 8-10; two notrump natural, game force*;up the line may be ignored with moderate hand; two club response to 1 diamond does not promise a rebid

Partnership Bidding

Splinter raises:

Double jump shift after major opening; single jump in fourth suit if one level above a reverse; single jump in third suit if four level, or reverse; double jump in fourth suit; four of opener's minor after new suit rebid; jump shift by two diamond responder to two clubs

Slam methods:

Roman key-card Blackwood with trump-queen ask; DOPI*; five notrump (2 keys) or higher response with void

Cheapest-weakest response to grand-slam force

Gerber after one-notrump or two-notrump opening, or one notrump or two notrump rebid

Other methods

Cheaper minor second negative response after two clubs, through three diamonds*

Fourth-suit bidding: nonforcing by passed hand: game force if reverse or at the three level

Opener's suit over suit reverse promises a rebid; responder's reverse game force

All non jump-shift secondary jumps by one-over-one responder invitational

Opener's jump rebid to four of original minor is strong raise

Unbid minor forcing and artificial after one-notrump rebid, requests support

Three clubs artificial, may be preclude to signoff, after two-notrump jump by opener

Raise to three of major preemptive

Competitive Bidding*

Negative double:

after suit opening; through three spades (including opener's suit); after one notrump opening, at the three level; unlimited; suggests length in unbid major; of one heart shows four spades; of one spade after minor suit opening shows four or more hearts

Repeat same-suit double by negative doubler for takeout

Weak jump responses after overcall of minor opening

Jump cue-bid over overcall is splinter

Cue-bid over overcall is forcing raise

Over unusual notrump: clubs for hearts; diamonds for spades; unbid suit nonforcing

Over minor Michaels: unbid suit nonforcing; major suit shows stopper

Over major Michaels: cue-bid in enemy major is limit raise or better; new suit forcing

When an opponent doubles partner's suit bid: change of suit forcing at the one level only; Jump shift nonforcing; two notrump limit raise or better; double jump in new suit splinter

Lebensohl after two-level overcalls of one notrump

Jump cue-bid by opener is splinter raise

Defensive Bidding*

Michaels cuebids (in minor: majors; in major: other major plus unspecified minor) in direct position over suit one bids and over one-notrump response

Direct jump cue-bid natural over minor, asks stopper over major

Takeout doubles of preemptive openings through four hearts; otherwise for penalty

Maximal overcall double of raised suit

Pass and ppull strong in forcing situations

Reopening 1 NT, 10-14; 2 NT, 18-19

In fourth seat over a response: one-notrump and cue-bids natural

After 1 NT overcall: two clubs Stayman; jumps invitational

Landy (three-club response forcing), over one-notrump (both positions)

Direct two-notrump unusual for lower unbid suits, unlimited

New-suit bids forcing after cue-bids

Llght, shaped takeout doubles permissible; new-suit rebid *very* strong

Preemptive single-jump overcalls and jump raises of overcalls

Responsive doubles after takeout doubles and at the two level after an overcall

Cue-bid by advancer forcing until a suit is bid twice, or game

Lebensohl after double of weak two-bid

Opening Leads*

Against suit contracts; third from even; low from odd

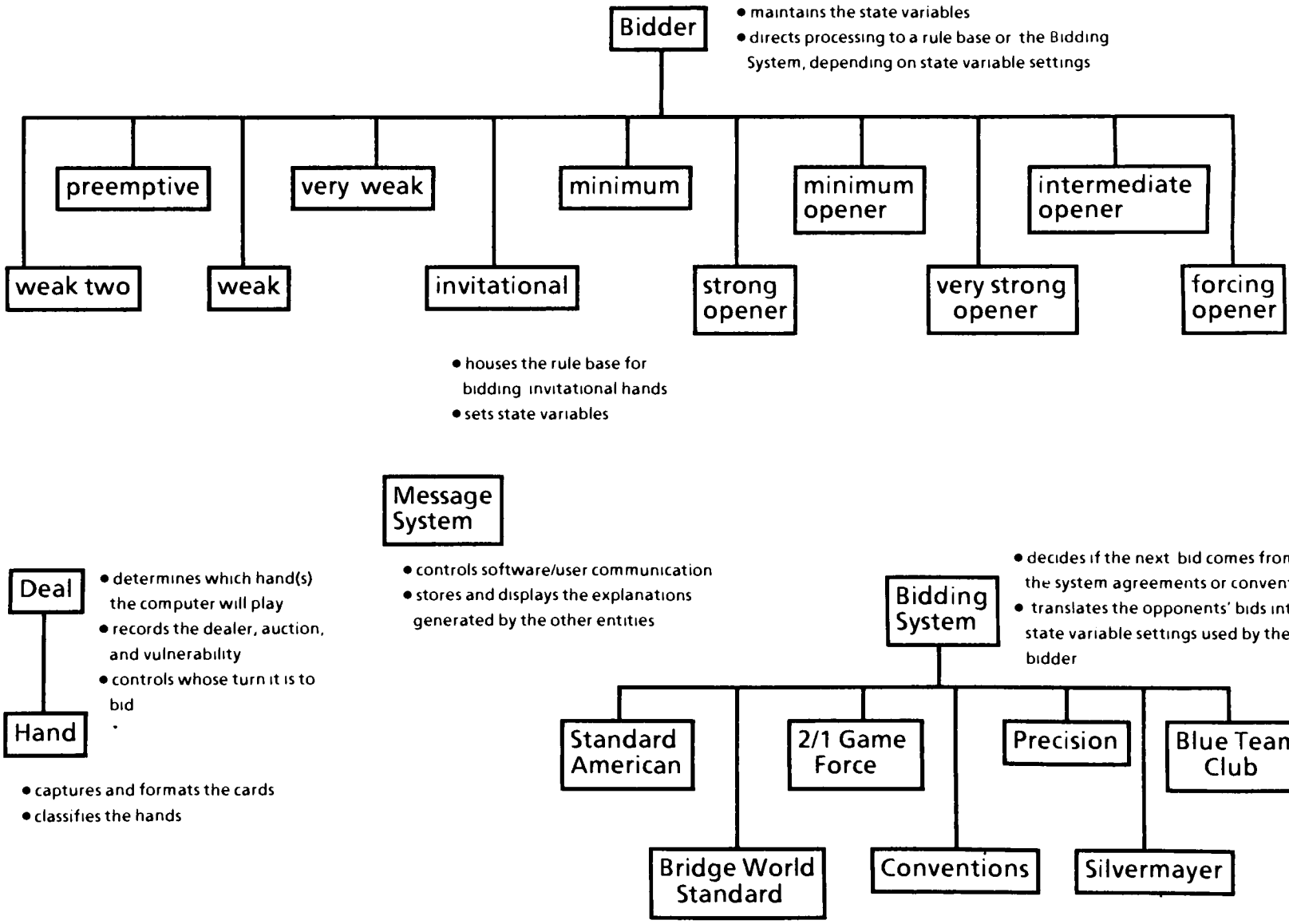
All other leads old-fashioned

* denotes features of BWS not yet implemented

Appendix D

Class Structure and Frame Diagram

Class Structure



Frame for Invitational Hands

Data Slots:

high card points
distribution:
- spades
- hearts
- diamonds
- clubs

dealer
texture:
- spades
- hearts
- diamonds
- clubs

vulnerability
quick tricks
partner's first bid

Procedural Slots:

Auction Ends
- *Determine if partner ended the auction*

My First Bid
- *Evaluate partner's opening*

Partners Second Bid
- *Evaluate partner's second bid*

Game Force = 'Y'
Trump Suit
- *Establish trump suit*

Cuebid = 'Y'
- *Get next cuebid*

Splinter = 'Y'
- *Get next cuebid*

Blackwood = 'Y'
- *Blackwood sequences*

Jacoby = 'Y'
- *Jacoby sequences*

Stayman = 'Y'
- *Stayman sequences*

Asking bid = 'Y'
- *Asking bid sequences*

Game Invitation = 'Y'
- *Generate game bid*

Fourth Suit Forcing = 'Y'
- *Evaluate partner's Fourth suit response*

Inverted minor = 'Y'
- *Evaluate partner's Inverted minor response*

Jacoby = 'Y'
- *Jacoby sequences*

Stayman = 'Y'
- *Stayman sequences*

Generate next bid
- *Partner Rebids*
- *Partner Bids a New Suit*
- *Single Raise*
- *Partner Preempts*
- *Two Club Sequences*

References

[1] Leon Sterling and Yossi Nygate. Python: an expert squeezer. Journal of Logic Programming Jan-May 1990. vol 8 no 1-2, pp21-39.

[2] H. W. Kelsey. Bridge: The Mind of the Expert. Faber and Faber, Ltd., London. 1981

[3] Ibid p9

[4] Ibid pp11-12

[5] The Contract Bridge Bulletin, vol 52 no 8. August, 1986. p 19.

[6] The Contract Bridge Bulletin, vol 56 no 11, November, 1990. p 26.

[7] Ibid pp 24-25.

[8] Louis H. Watson, Watson's Classic Book on the Play of the Hand at Bridge. Sterling Publishing Co., Inc, New York, New York. 1958.

[9] Terence Reese and Roger Trézel. Snares and Swindles in Bridge. Fredrich Fell Publishers, Inc., New York, New York. 1976.

[10] Terence Reese and Roger Trézel. Those Extra Chances in Bridge. Fredrich Fell Publishers, Inc., New York, New York. 1978.

[11] Mike Lawrence. How to Play Card Combinations. Devyn Press, Inc., Louisville, KY. 1988.

[12] Jeff Reubens, Computer Products II. The Bridge World November, 1989 vol 61 no 2, p 24.

[13] H. W. Kelsey. Advanced Play at Bridge. Faber and Faber Ltd., London. 1968.

[14] Hugh Kelsey and John Matheson. Improve Your Opening Leads. Victor Gollancz Ltd., London. 1979.

[15] John Mallon. Opening Leads and Signals. Collin Books, New York, New York. 1964.

[16] Terence Reese and Roger Trézel. The Art of Defence in Bridge. Fredrich Fell Publishers, Inc., New York, New York. 1979.

[17] Mike Lawrence. Dynamic Defense. Devyn Press, Inc., Louisville, KY. 1985.

[18] The Bridge World, published monthly by Bridge World Magazines, Inc., 39 West 94th St., New York, NY 10025-7124

[19] Turbo C + + is a product of Borland International.

[20] MS-DOS is a product of Microsoft Corporation.

[21] Goren's New Bridge Complete, Bantam Doubleday Dell Publishing Group, Inc. New York, New York. c.1985. pp.685-689.

[22] The Bridge World, December, 1984. pp 24-25.