Intelligent Amazons Opponents

Henry Stern
Faculty of Computer Science
Dalhousie University
Halifax, NS, Canada
stern@cs.dal.ca

1 Introduction

"The Game of the Amazons" was invented in 1998 by Walter Zamkauskas of Argentina. A high branching factor with simple moves makes Amazons a popular game among combinatorial game theorists.

Amazons is a combinatorial game played on a 10 by 10 chess board. Each player has four *queens* which can be moved about the board. Each move consists of moving a queen along a straight line to a new square and then firing an *arrow* along a straight line and *destroying* the square where it lands. Queens and arrows may not move over queens or destroyed squares. Figure 1 illustrates the starting position for 10 by 10 Amazons.

Amazons has been played in tournaments since 1990 and much effort has been put into the development of computer programs that play the game.

There is much research in the field of writing computer opponents for the game of amazons. Amazons-playing programs such as Amazong [5], Antiope [10] and Aska compete against one another in tournaments such as the Jenazon Cup and The 7th Annual Computer Olympiad.

2 Problem Statement

I hypothesize that when humans play games such as chess or amazons, they make errors because they incorrectly evaluate options. To test this hypothesis, I will implement an amazons opponent using the *Territory and Mobility* (TM) Function [2]

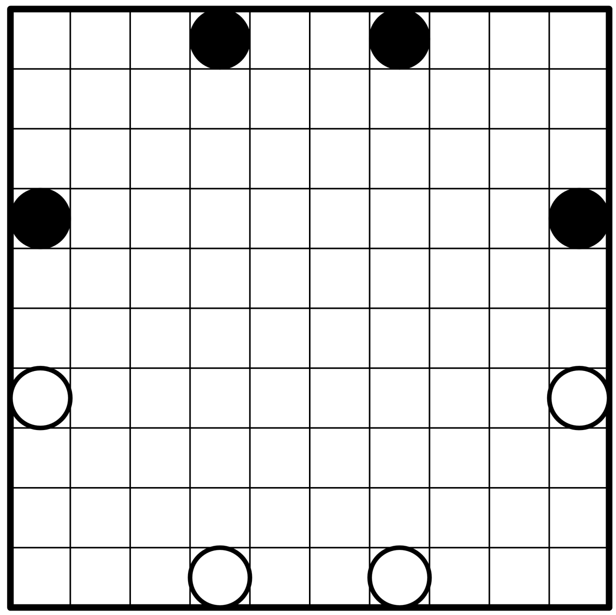

Figure 1: The starting position for 10 by 10 Amazons

from the Aska program. To simulate the computer incorrectly evaluating options, I will add Gaussian noise to the values returned by the evaluation function.

Once the opponent is implemented, I will conduct a limited user study where two human opponents will interact using a networked game client. There participants will be divided up into three groups. The first group will play against human opponents, the second will play against the TM function without Gaussian noise and the third will play against the TM function with Gaussian noise.

Each player will play three consecutive games. After each game, they will be required to write down whether they think that their opponent is human or a computer and how confident they are in their decision.

The results of this study will be rigourously analysed and can be used to develop a more comprehensive user study in the future. If my conjecture is shown to be true, it may be of use for computer opponents in other games as well.

3 Literature Survey

3.1 Exhaustive Search in Amazons

Elwyn Berlekamp was one of the first to begin an in-depth, general analysis [1] of Amazons. He computed thermographs of some of the subgames of n by 2 Amazons.

Geörg Snatzke resumed Berlekamp's work by performing a complete analysis of 11 by 2 Amazons [8] compiling a database of thermography and canonical game values of each subgame.

Martin Müller discovered that many Amazons positions can be shown to be isomorphic when viewed as a line graph [6]. Using this discovery, Müller completely solved 6 by 6 Amazons and found some interesting small game positions.

Snatzke continued the analysis of Amazons positions [9] and has completely solved 10 by 10 Amazons with two queens per side. As of the writing of this paper, it is the most comprehensive database of Amazons positions compiled.

In conjunction with databases of opening moves and the α-β search using a heuristic evaluation function, these solved games are used to develop strong computer Amazons players.

3.2 Game Tree Searching

The algorithm used for searching a game tree used in the above-mentioned papers is the *minmax* search shown in algorithm 1. The search alternates between searching for high and low game values imitating how two players with the intent of winning the game would play.

Algorithm 1 MINMAX: Minmax Search

Require: A node, N, in a game tree and d, the depth of the search.
Ensure: The estimated value of N, $\mathrm{E}(N)$.

```
if d = 0 then
    return E(N)
else
    Let N_1, N_2, ..., N_m be the successors of N.
    return max_{i∈1...m}{−MINMAX(N_i, d − 1)}
end if
```

The minmax search always returns the correct answer for a given game tree given a particular evaluation function but is very expensive as it iterates over the entire subtree. Amazons has an estimated average branching factor of 480 [2], so a 3-ply search would require $\mathcal{O}(480^3)$ operations.

The α-β search improves on the minmax by adding the concept of pruning. Rather than exhaustively searching through the entire game tree, the successors of N are ranked by the evaluation function and evaluated in order of best to worst. The function has two parameters, α and β. α is the best game value seen thus far and β is the lower bound for pruning. If the estimated value of a successor is below β, the algorithm terminates and returns the best value so far. The α-β search effectively eliminates poor moves from the search space.

3.2.1 Amazons Evaluation Functions

Since the Amazons game tree is so large, heuristic evaluation functions are used to prune branches from the game tree and apply a particular strategy to the play of a computer program.

The first evaluation function for Amazons, the *minimum stone ply* (MSP) function [4][1], focuses on controlling territory on the game board. The minimum number of moves for any player to destroy any given square on the board is computed and the position is ranked by the number of squares that a player "controls." Figure 2 illustrates computing the minimum stone ply function for a 5 by 7 game of Amazons.

An improved evaluation function, the *mobility-priority* (MP) function [3][2], focuses instead on preserving the *mobility* of the queens. The mobility of a queen is defined as the sum of the squares that it can move to. Different weights are assigned to the mobilities of the player's queens and those of the opponents. The position illustrated in figure 2 has a MP value of $8R_b - 8R_w$.

Neither the MSP nor the MP perform very well in practice. Beginner Amazons players can easily defeat a computer player using either function. A computer player using the MP evaluation function tends to place all four queens towards the centre of the board and the human player can easily capture all four corners and win the game. If capturing a particular piece of territory is critical to winning, the computer player using the MSP function will tend to rush all of its queens towards it sacrificing other territory.

Hashimoto further improved on the MSP and MP functions by combining them to make the *territory-mobility* function [2]. The territory-mobility function

[1] Written in Japanese. Cited by Iida in [2].

[2] Also written in Japanese and cited by Iida in [2].

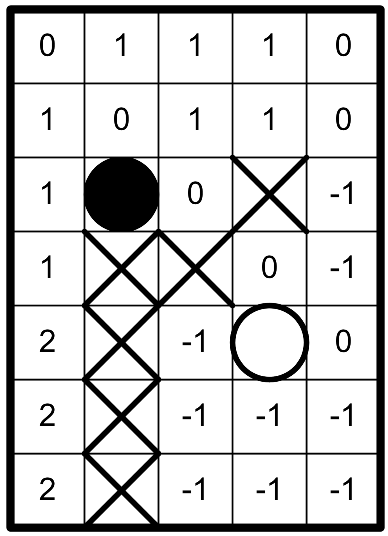

Figure 2: A game favouring black with a MSP value of 2

is a weighted sum of the MSP and MP functions. In practice, TM consistently wins against the MSP and MP functions, can defeat beginners and is highly competitive against middle-rank players.

3.3 The Turing Test

The *Turing Test* [11, 7] is a replacement to the question "Can machines think?" An *imitation game* is played involving three people. The *interrogator* converses via teletype with either the *man* or *woman* and is then tasked with deciding which of the two is the woman. The goal of the game is for the man to convince the interrogator that he is the woman and the man's performance is evaluated by how often the interrogator makes the wrong decision. Turing replaces the question "can machines think?" with the following:

> Let us fix our attention to one particular digital computer C. It is true that by modifying this computer to have an adequate storage, suitably increasing its speed of action and providing it with an appropriate programme, C can be made to play satisfactorily the part of A in the imitation, the part of B being taken by a man? [11, page 442]

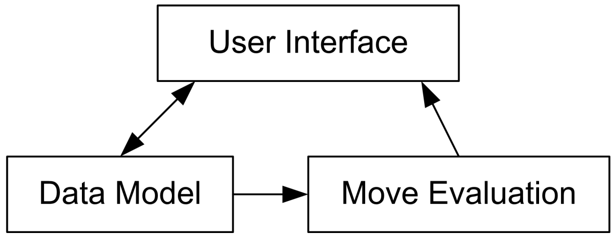

Figure 3: A data flow diagram showing how information propagates in the application.

The woman is replaced by the task being performed and the test is evaluated by how often the interrogator chooses the computer over the man.

4 Architecture

The Amazons-playing software consists of three modules: the data model, move evaluator and user interface. Figure 4 illustrates how data flows through the application. The user interface reads from the data model and sends any modifications. The user interface also reads from the move evaluator which, in turn, reads from the data model.

4.1 Data Model

A game board for Amazons can be represented by a $m \times n$ matrix. The cells of the matrix correspond to the particular position on the board and can be either empty, destroyed or contain a black or white Amazon.

No sanity checks are done on the board, leaving it very flexible. Using the implementation in my project, any game position on a board of size up to 10 by 10 with any number of Amazons may be represented.

If game values are to be cached in memory or secondary storage, the game position may be represented in its packed format consisting of 25 bytes. Since there are only four available states, each square may be represented by two bits allowing four squares to be stored in one byte. The board is stored in row order and is illustrated in figure 4.1.

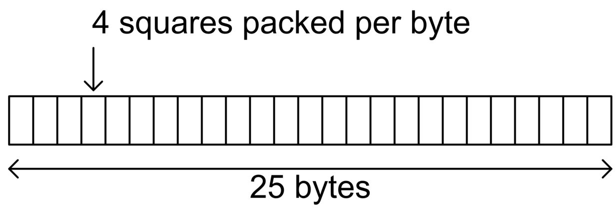

Figure 4: The packed binary format of a game board.

4.2 Move Evaluation

A randomized α-β search is used to make a decision about the optimal move. The territory-mobility function discussed by Iida [2] is used to estimate the value of individual game positions.

Due to the high branching factor of Amazons, it is not feasible to find the value of every sub-game of a particular position, let alone allow the α-β search to explore it. To cope with this problem and allow the tree to be searched to a reasonable depth, the branching factor is constrained by taking a random sampling of the available moves and then evaluating the best moves in that sample.

The above technique reduced the computing time for the opening move from 60 seconds on an AMD Athlon XP 2500+ to 12 seconds, a reasonable time to expect a user to wait for the computer to make its move.

To attempt to simulate a human's decision making process, Gaussian noise can be applied to the output of the territory-mobility evaluation function.

4.3 User Interface

Figure 4.3 shows the user interface for the Amazons-playing program. The user may click on any square on the board to change its state to empty, full, white or black. These changes are propagated throughout the application.

The user can instruct the program to search for a good move for either colour at any time. The territory weight, R, may be adjusted and the Gaussian noise on the evaluation function can be enabled or disabled.

After evaluating the available options, the best move is printed in the format $(sx, sy) \rightarrow (dx, dy)/(xx, xy)$ along with its estimated value and the real time required to find the move.

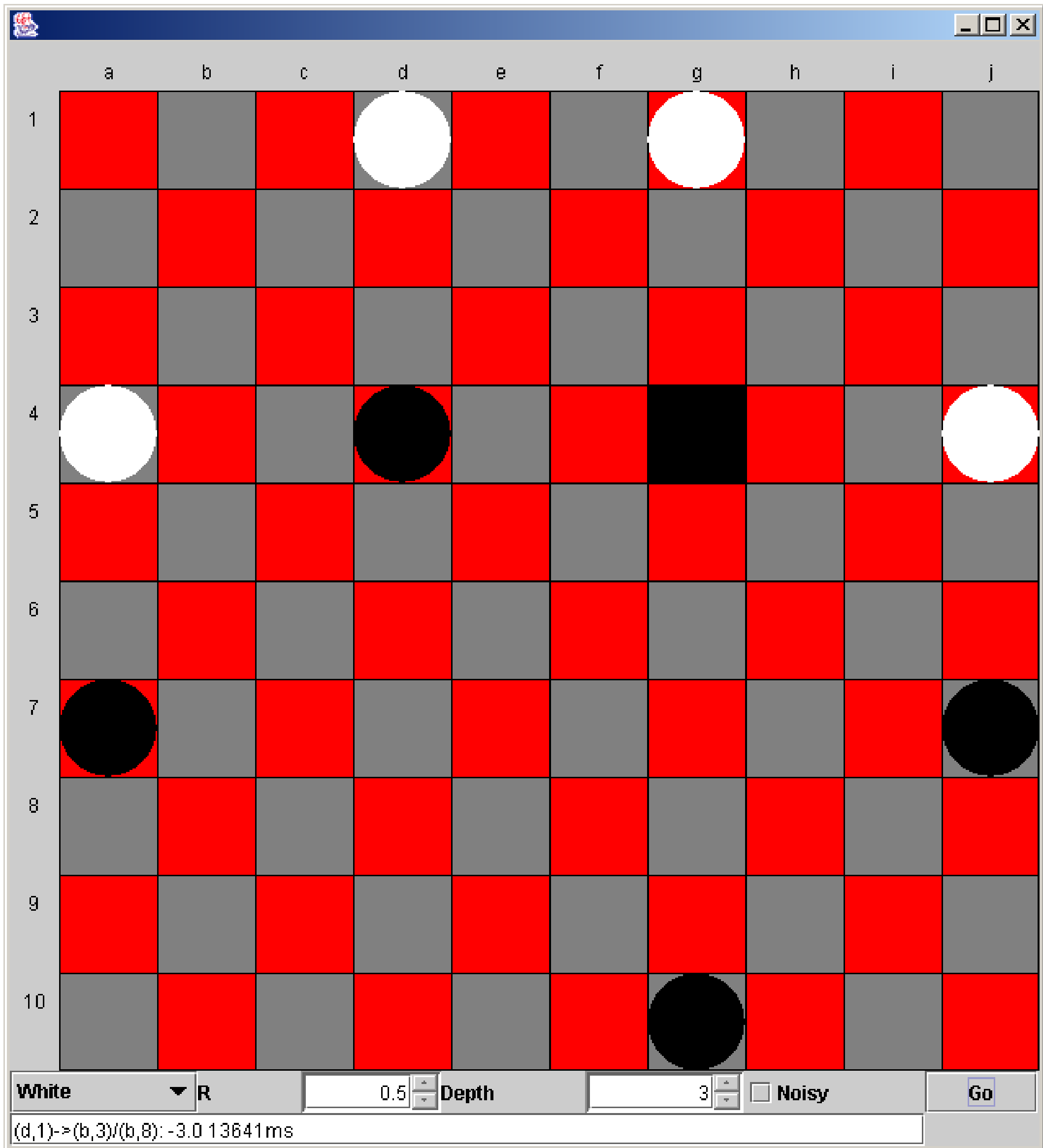

Figure 5: A screen shot of the Amazons-playing software suggesting a questionable move.

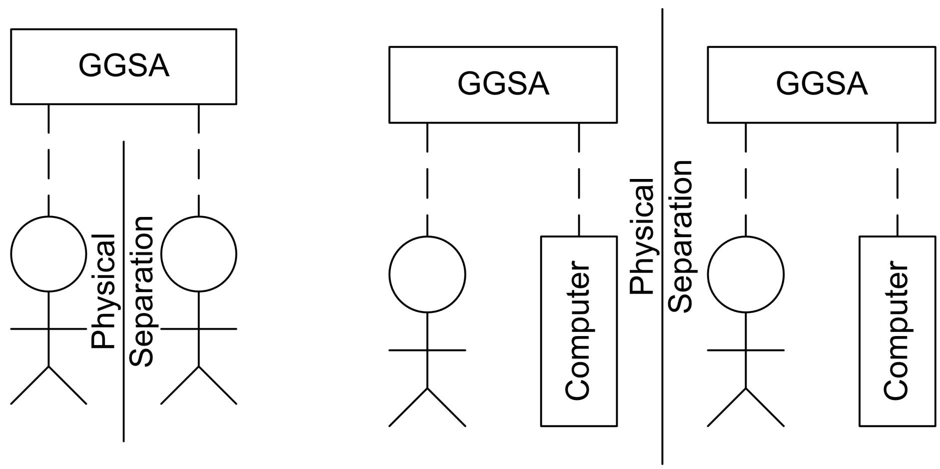

Figure 6: Experimental configuration.

5 User Study Design

The user study is to be held in a lab with three partitioned areas. In each of two of these areas, one participant will interact with an unknown opponent and play three games of Amazons. After each game, the participant marks on their evaluation form whether they think that their opponent is human or a computer and their level of confidence to that effect.

The participants will interact using the *Generic Game Server Applet* (GGSA). The configuration of this experiment is depicted in figure 6.

The participants are to be divided into three groups. The first group will play against human opponents, the second will play against the territory and mobility (TM) function without Gaussian noise and the third will play against the TM function with Gaussian noise.

Since the computer opponent can manipulate the interface faster than the human can and the human can decide initial moves faster than the computer opponent can, a human operator acts as an intermediary between the two players. For all groups, the human operator relays all moves back and forth between the two players.

The participants will complete four forms: the informed consent form (figure 7), the pre-activity form (figure 8), the post-activity form (figure 9) and the post-game form (figure 10).

DALHOUSIE University

Informed Consent Form

Evaluating intelligent Amazons computer opponent.

Principal Investigators: Mr. Henry Stern, Computer Science Graduate Student

Contact Person: Mr. Henry Stern, Faculty of Computer Science, stern@cs.dal.ca

We invite you to take part in a research study at Dalhousie University. Taking part in this study is voluntary and you may withdraw from the study at anytime. There will be no repercussions from choosing not to participate in this study. The study is described below. Participating in the study may not benefit you directly, but we might learn how to design better computer support for co-located collaboration that would benefit others. You will be asked to participate in one 1-hour session. You may terminate your participation in the study at any time without prejudice. You should discuss any questions you have about this study with the principal investigators who will be administering the study.

The purpose of this study is to evaluate the ability of a computer game opponent to mimic the behaviour of a human opponent playing the game of Amazons. At the beginning of your session, you will be asked to fill out a background questionnaire detailing your previous experience with the game of Amazons and other board games both on the computer and on the tabletop. You will then be asked to perform a series of 3 games against an unknown opponent interacting with them using a computer terminal. After each game, you will be given another questionnaire that will ask questions about the opponent in the game just completed. After all games have been completed, you will be given a final questionnaire detailing your overall satisfaction with the study and asking for general comments

Interactions during the session will be recorded by project researchers (in the room with you), using field notes and electronic logs. All personal and identifying data will be kept confidential. Anonymity will be preserved in any presentation of textual data in journals or at conferences. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance to University policy for 5 years post publication.

In the event that you have any difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact Human Research Ethics / Integrity Coordinator at Dalhousie University's Office of Human Research Ethics and Integrity for assistance: ph.(902) 494-1462, email: patricia.lindley@dal.ca.

"*I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I hereby consent to take part in the study. However, I understand that my participation is voluntary and that I am free to withdraw from the study at any time without prejudice.*"

Participant	**Researcher**
Name: ____________________	Name: ____________________
Signature: ________________	Signature: ________________
Date: _____________________	Date: _____________________

Figure 7: Informed consent form.

Participant Number ________

1. Sex - Male: _______ Female: _________

2. Relationship to other participant (please check one):
   - ___ Friend
   - ___ Classmate/colleague
   - ___ Family
   - ___ None
   - ___ Other

3. Do you have any prior experience with the game of Amazons? (circle one)

   YES NO

4. Have you played games with the other participant in the past? (circle one)

   YES NO

5. a) How often do you play games? (please circle one)

   NEVER VERY OFTEN

   0 1 2 3 4

   b) When you play games, do you usually play them on the: (check one):
   - ___table top?
   - ___computer?

6. How often do you use computers? (please circle one)

   NEVER VERY OFTEN

   0 1 2 3 4

7. Other comments:

Figure 8: Pre-activity form.

Participant Number _________

1. Did you enjoy this activity?

   DID NOT ENJOY AT ALL REALLY ENJOYED

   0 1 2 3 4

2. Were you satisfied with how well your opponent played the game?

   NOT SATISFIED VERY SATISFIED

   0 1 2 3 4

3. Would you be interested in playing this game again?

   NOT SATISFIED VERY SATISFIED

   0 1 2 3 4

4. Other comments:

Figure 9: Post-activity form.

Participant Number _________

1. a) After the first game, do you think that you are playing: (check one)
___a human?
___a computer?

b) How confident are you in this?

NOT CONFIDENT VERY CONFIDENT

0 1 2 3 4

2. a) After the second game, do you think that you are playing: (check one)
___a human?
___a computer?

c) How confident are you in this?

NOT CONFIDENT VERY CONFIDENT

0 1 2 3 4

3. a) After the third game, do you think that you are playing: (check one)
___a human?
___a computer?

d) How confident are you in this?

NOT CONFIDENT VERY CONFIDENT

0 1 2 3 4

Figure 10: Post-game form.

6 Preliminary Evaluation

In preparation of running the user study, many games of Amazons were played against the computer opponent. The log of one such game is shown in section 9. The human opponent involved was Billy Biggs, a masters student in the Faculty of Computer Science at Dalhousie University.

Billy allows the computer to go first. The computer opens up with a fairly aggressive move that could have been better-chosen. Billy responds by forcing the computer to be on the defensive, blocking two avenues of attack.

Play continues with both players building fortifications on the left-hand side of the board. Move 11, made by the computer seems particularly clever, further building on the square-shaped section of territory. Move 12, made by Billy begins to box the computer into the bottom-right corner. By move 15, the board is divided up into three well-defined regions with the computer able to control one and the other two open.

At move 17, disaster strikes. The computer makes an obviously poor move. It moves a queen down a long corridor into a small area already containing one of its queens and effectively sealing itself in. A human would not have made such an obviously poor move. Billy capitalizes and seals the computer in with move 20.

Move 21, made by the computer is interesting. It makes an aggressive move towards Billy's queen in the top corner, pushing it back towards the edge of the board.

Move 23 is another bad move made by the computer. It captures a square in its own territory and moves a queen to a square with an escape route that Billy will not open. A human opponent would realize this.

Play continues with both sides making good moves, capturing territory. The game is almost completely decided by move 31. The computer makes move 33, separating the board into two disjoint partitions.

The game ends at move 40, a decisive win for Billy with 45 captured squares to the computer's 7. Billy's comments on the performance of the computer opponent was that it "did alright but did not challenge [him]." The computer did not adjust its strategy based on moves that he made and always acted defensively. He described the computer player as behaving like "it knew something that [he] didn't" about the game and simply ignored whatever he did.

7 Conclusions and Future Work

The territory and mobility function does not seem to perform well even without Gaussian noise. Before the computer opponent can be used in a blind test, it needs drastic improvements.

These improvements include better pruning in the α-β search and heuristics that involves some longer-term strategies. For humans, it is obvious how to respond to certain situations making it very easy to search a high number of plies ahead in the game tree. The α-β search does not take advantage of this at all and looks at too many moves, preventing it from searching deep enough.

Once the computer opponent can make good decisions without noise, it can be tested with Gaussian noise and the user study can be run.

8 Acknowledgements

I would like to thank Billy Biggs for his time in helping me test the computer Amazons opponent.

9 Game Log

Move	Territory Mobility	Billy Biggs
1,2	$a7 \to e3/e5$	$g1 \to g9/d9$
3,4	$g10 \to d7/b5$	$g9 \to e7/e9$
5,6	$d10 \to b10/j10$	$a4 \to c4/e6$
7,8	$j7 \to j9/g9$	$c4 \to c5/d5$
9,10	$d7 \to c6/e8$	$j4 \to j8/i8$
11,12	$e3 \to f4/f9$	$d1 \to g4/g3$
13,14	$f4 \to e3/f3$	$c5 \to c3/c5$
15,16	$j9 \to h9/h2$	$g4 \to g8/h8$
17,18	$b10 \to h10/b10$	$g8 \to g4/f4$
19,20	$c6 \to c7/d6$	$g4 \to g8/f8$
21,22	$e3 \to d3/d2$	$g8 \to j5/g8$
23,24	$h9 \to i9/h9$	$j5 \to f1/e2$
25,26	$h10 \to c10/g10$	$c3 \to a5/c3$
27,28	$c10 \to a8/b8$	$a5 \to a4/e4$?? d4?
29,30	$c7 \to a5/a6$	$a4 \to b4/a4$
31,32	$a8 \to b9/d7$	$e7 \to c9/e7$
33,34	$a5 \to c7/a5$	$b4 \to d4/e3$
35,36	$c7 \to b6/c7$	$f1 \to c1/c2$
37,38	$b9 \to a9/b9$	$d4 \to c4/d4$
39,40	$b6 \to b7/a7$	$c9 \to c8/d8$

References

[1] Elwyn R. Berlekamp. Sums of $n \times 2$ amazons. In F. Thomas Bruss and Lucien le Cam, editors, *Game Theory, Optimal Stopping, Probability and Statistics: Papers in honor of Thomas S. Ferguson. Institute of Mathematical Statistics Lecture Notes—Monograph Series*, volume 35, pages 1–34, Beechwood, Ohio, 2000. Institute of Mathematical Statistics.

[2] T. Hashimoto, N. Sasaki, Y. Kajihara, J. Yoshimura, and H. Iida. An evaluation function for amazons. In H.J. van den Herik, editor, *Advances in Computer Chess 9*, pages 191–202. Universiteit Maastricht, Maastricht, The Netherlands, 2001.

[3] Y. Kajihara and H. Iida. Programming of amazons. In *Proceedings of the 40th Programming Symposium*, page 103, Tokyo, Japan, 1999. Information Processing Society of Japan.

[4] Y. Kotani. An evaluation function for amazons. In *Proceedings of the 40th Programming Symposium*, pages 104–105, Tokyo, Japan, 1999. Information Processing Society of Japan.

[5] Jens Liberum. Amazong. `http://www.math.unibas.ch/~lieberum/amazong/amazong.html`, Last accessed June 10, 2003.

[6] Martin Müller and Theodore Tegos. Experiments in computer amazons. In Richard Nowakowski, editor, *More Games of No Chance*, pages 243–260. Cambridge University Press, 2002.

[7] Ayse Pinar Saygin, Ilyas Cicekli, and Varol Akman. Turing test: 50 years later. In *Minds and Machines*, volume 10, pages 463–518, 2000.

[8] Raymond Gëorg Snatzke. Exhaustive search in the game amazons. In Richard Nowakowski, editor, *More Games of No Chance*, pages 261–278. Cambridge University Press, 2002.

[9] Raymond Gëorg Snatzke. New results of exhaustive search in the game amazons. *Theory of Computer Science*, 2003.

[10] Theodore Tegos. Antiope. `http://www.cs.ualberta.ca/~tegos/amazons/antiope/index.html`, Last accessed June 10, 2003.

[11] Alan Turing. Computing machinery and intelligence. *Mind*, 59(236):433–460, 1950.