

15 SEP 2010

Reference: Government Contract No. N00014-09-C-0050, “Enhancing Simulation-based Training Adversary Tactics via Evolution (ESTATE)”  
Charles River Analytics Contract No. C08098

Subject: Contractor’s Status Report: Quarterly Status Report #7  
Reporting Dates: 6/15/2009 – 9/15/2010

Dear Dr. Hawkins,

The following is the Contractor’s Quarterly Status Report for the subject contract for the indicated period. During this reporting period we have concentrated on Task 4: Develop Trainee Model Processing.

## 1. Summary of Progress

### 1.1 Strategy Visualization in the MoneyBee Dataset

During our previous reporting period, our analyses indicated that under the MoneyBee experiment, students were learning through challenges, solving more difficult problems in less time as they gained experience. Our next step was then to understand the strategies employed by students to create models of different players for future experimentation.

#### 1.1.1 Strategy Visualization Method

To understand the strategies employed, we improved upon our graph-based visualization of the strategy space to focus on perceptual methods for presenting the paths taken by players through the game state space. These visualizations are presented in Figure 1 through Figure 4 in Appendix A.

Each of the visualizations presents a single representative challenge problem in the MoneyBee dataset. In this case, the challenge problem faced is 8 coins that add up to 82 cents. The correct solution is 2 of each coin: 2 quarters, 2 dimes, 2 nickels, and 2 pennies. Each game state is represented by a node with a four digit number (QDNP), signifying the number of quarters, nickels, dimes, and pennies.

Our visualization technique uses a combination of node color, node brightness, and edge thickness to perceptually reveal elements of the strategy space. First, each node in the game state graph is color coded. Green nodes indicate valid states on the way to the correct solution state.

## Report Documentation Page

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Yellow nodes have gone over the number of coins needed, but still are below the target coin value. Red nodes have violated both conditions, where the number of coins and the current coin value you are above the solution state. The Blue node is the goal state. Second, each node's brightness is determined by how often that node is visited during play. Nodes that are visited less are scaled darker. Bright green nodes, therefore, are visited most often. Third, an edge is placed between the transitions between game states, either by the player adding a coin (black arrowhead), removing a coin (gray arrowhead), or resetting the game (arrow to 0000 node). The width of each edge is scaled based on the frequency of how often that transition occurs.

Each visualization is constrained to players who were faced with this problem during a particular session. For example, Figure 1 shows the outcome for players who encountered this problem during their first session, or early on in their learning process. Figure 4 shows the outcome for players who encounter this problem in their fourth session, meaning they had encountered more problems before this. Based on our previous analysis, we had discovered that players do perform better in later sessions over earlier sessions.

### **1.1.2 Analysis of Strategy Visualizations**

Several trends emerge when comparing the visualizations across sessions. First, the number of game states explored rapidly decrease, indicating that novice players are inconsistent among one another while expert players develop common strategies. Second, the number of game states visited with violations also decreases, indicating that expert players can preemptively or reactively identify violating states and recover from them gracefully. Third, there is a decrease in the amount of backtracking or resets. Finally, it is clear that explicit dominant strategies emerge early on and grow stronger in later sessions.

Now, let us look at each session individually. Figure 1 displays the results for players who encountered this challenge during their first session. While the number of states visited is large, dominant paths emerge. Specifically, there are four dominant paths that emerge. One dominant path follows the path of adding two of each coin in sequence, starting from the largest denomination to the smallest denomination. In other words, adding two quarters, then two dimes, then two nickels, and two pennies. Alternatively, the other dominant paths begin follow the same initial path before diverging. In this case, one of each coin is added in sequence, starting from the largest denomination to the smallest denomination, arriving at the 1111 game state. From here, the path diverges equally into three directions. One direction is to repeat this process, adding one of each coin in sequence, starting from largest denomination to the smallest. Alternatively, another path repeats the initial process, but adds from the smallest denomination to the largest denomination in sequence. The final path can add one coin of increasing denominations, but begins at the nickel, followed by dime and quarter before finishing with the penny. All three of these strategies can be seen as variants of a higher-level strategy, that of adding one of each coin in a sequence (largest to smallest denomination) followed by a repeat of this process (largest to smallest or smallest to largest denomination).

In addition to the two dominant strategies, there are other major features of the data for first session games. First, players move into violating game states. Both in going over the number of coins (yellow nodes) and going over the target total amount (red nodes). Furthermore, backtracking is evident (indicated by the number of grey arrows moving up the tree), including

full resets (grey arrows from advanced game states back to the 0000 game state) when violations are identified. Finally, some traces indicate circuitous routes to the goal state, using more coins indicated than necessary and then removing them to arrive at the goal state.

There is noticeable difference in the results of traces of second session games of this challenge when compared to the first session games. As illustrated in Figure 2, adding a quarter as the first move is much more prevalent. Additionally, the two of each coin in decreasing denomination is the dominant strategy. However, closer inspection does illustrate the alternative strategy of one of each coin in decreasing denominations, however, once arriving at the 1111 game state, the strategies split equally between adding one of each coin in decreasing denominations (1111 → 2111 → 2211 → 2221 → 2222) or increasing denominations (1111 → 1112 → 1122 → 1222 → 2222). This seems to indicate that more experienced players have developed some common strategies for attempting problems. Additionally, there are fewer violations, much less backtracking, a limited number of resets, and less circuitous routes to the goal state.

Moving to third session games, as shown in Figure 3, reveals a major shift. There is a major reduction in the number of paths taken. The number of branches at a given node is often only one, indicating that players either (a) have a plan in mind when making a move, or (b) can identify the next best move at each game state. The quarter-first move still dominates and the “add two of each coin in sequence from largest denomination to smallest denomination” strategy is noticeable. The interesting feature of the third session games is that no violating states are visited nor is there any backtracking.

The fourth session games in Figure 4 exhibit a dramatic result. Adding a quarter first (and second) is the only initial move. At this point, the “add two of each coin in sequence from largest denomination to smallest denomination” is the dominant strategy. However, we do see some deviation in some traces, backtracking when entering violating states or pressing forward and removing the violation to arrive at the game state. However, the state space of visited nodes is dramatically small and driven in primarily one path. This indicates that experienced players converge on a dominant strategy.

This visualization method has proved instrumental to analyzing the strategies employed by players with various levels of expertise. Our next step would be to analyze other challenge problems to develop a common set of strategies by players that we can model for experimentation purposes. We can then perform experiments using our simulated trainee models to present challenges that will push players to adapt their strategies.

## 2. Scheduled Items

In the next reporting period we plan to address the following items:

- Analyze additional MoneyBee challenge problem data using the developed visualization technique to elicit common strategies for simulated trainee model development
- Design and begin implementation of a simulation of 1) trainees attempting challenges, 2) assess trainee skill and strategy, and 3) challenges evolving.

Sincerely,

A handwritten signature in blue ink, appearing to read "Brad Rosenberg", with a large, sweeping flourish underneath.

Brad Rosenberg  
Principal Investigator

## Appendix A: MoneyBee Visualizations

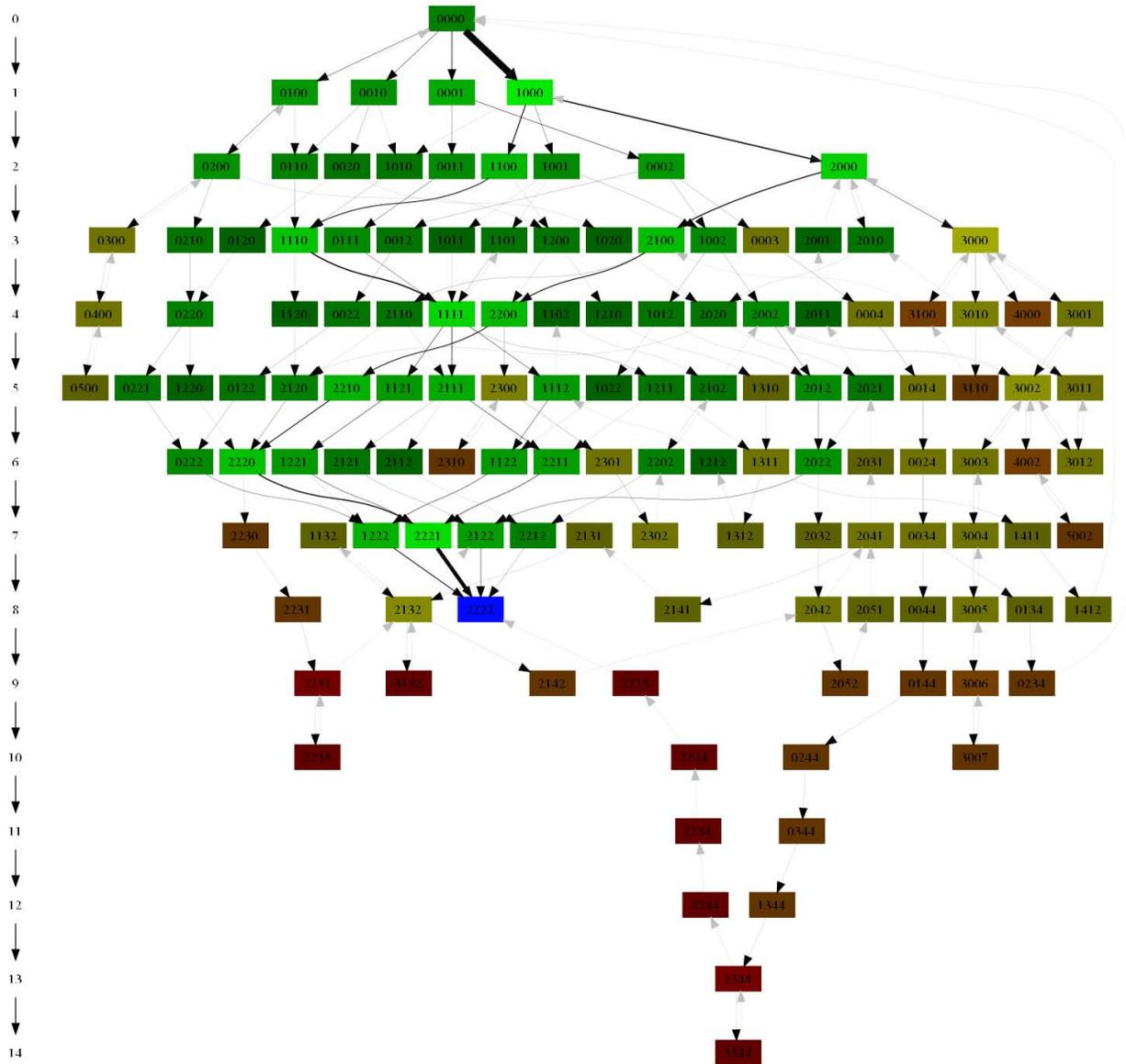
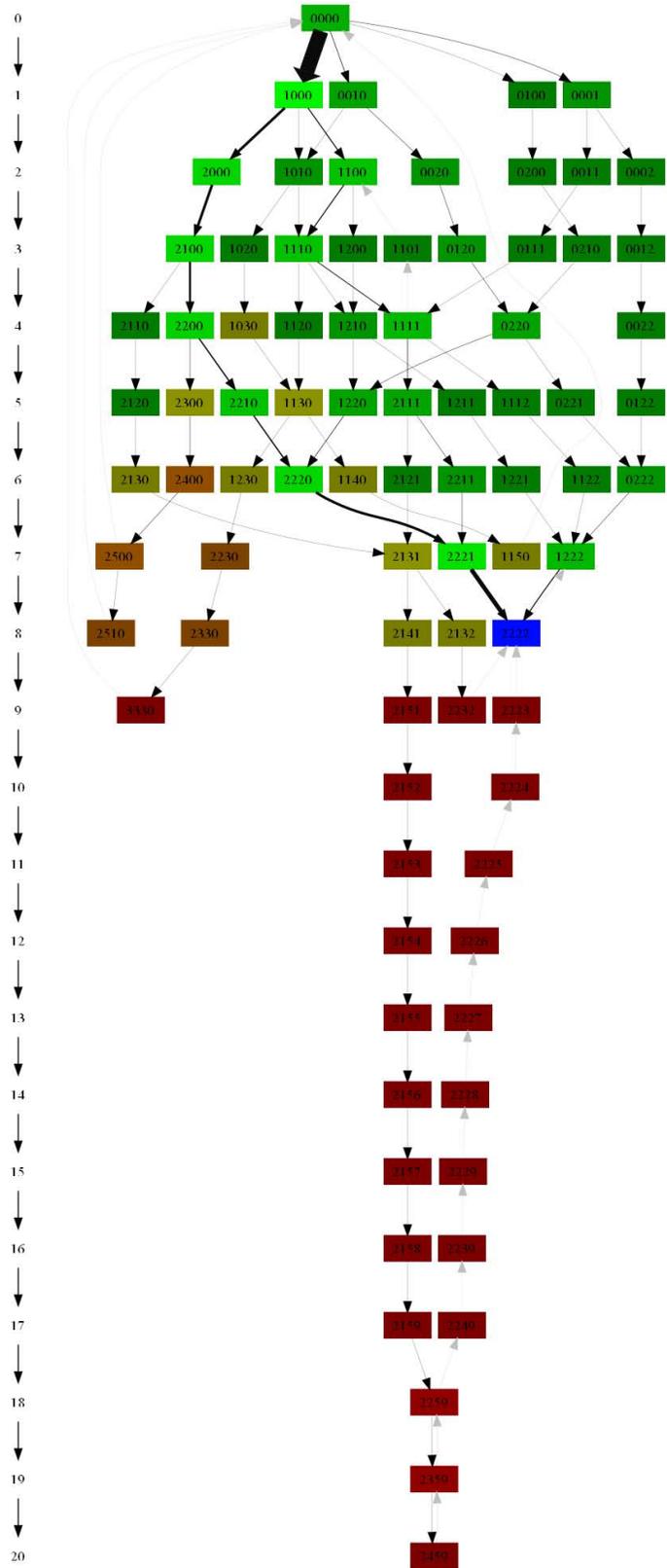
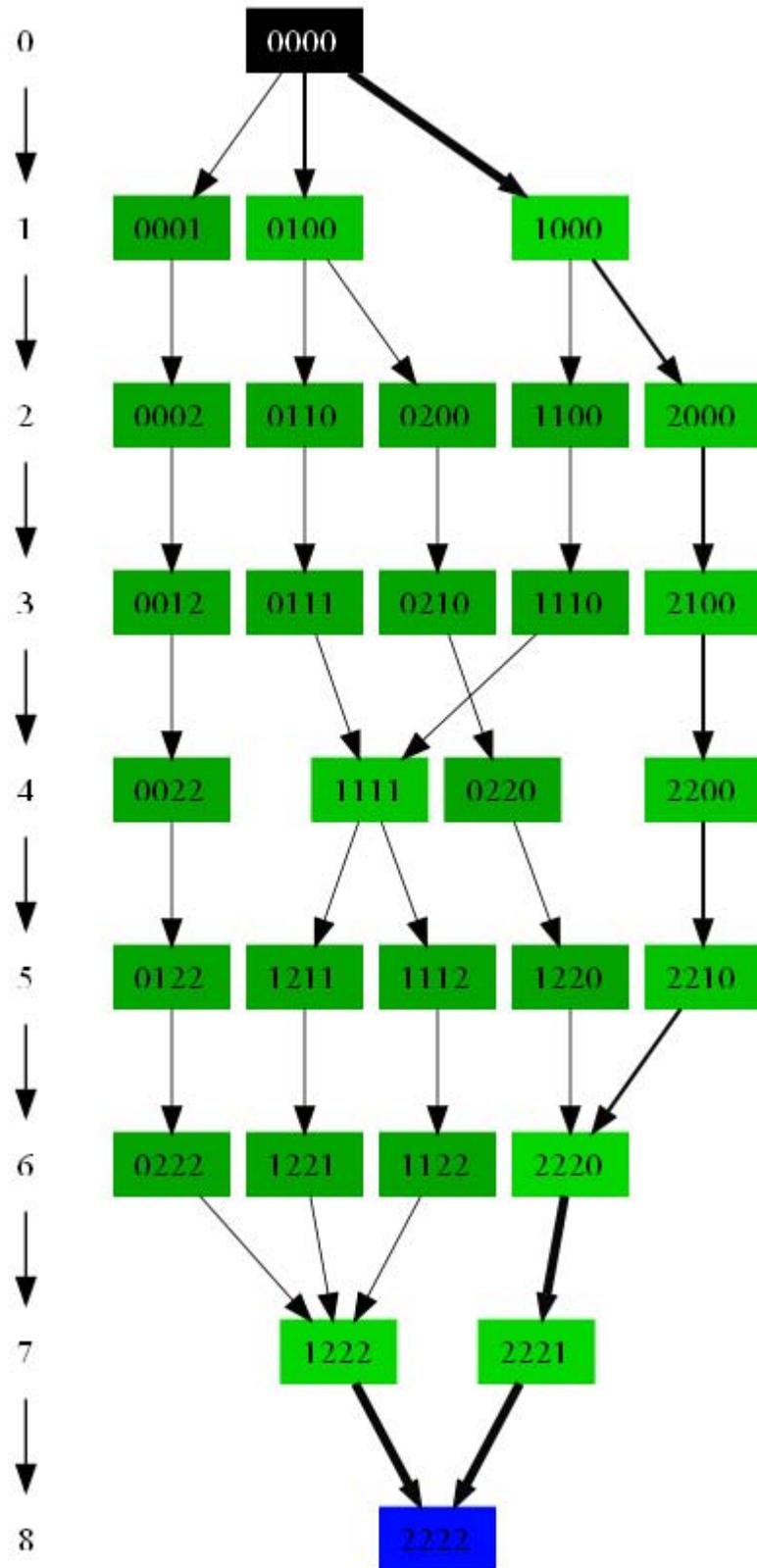


Figure 1: Strategy Visualization for Session 1 Games



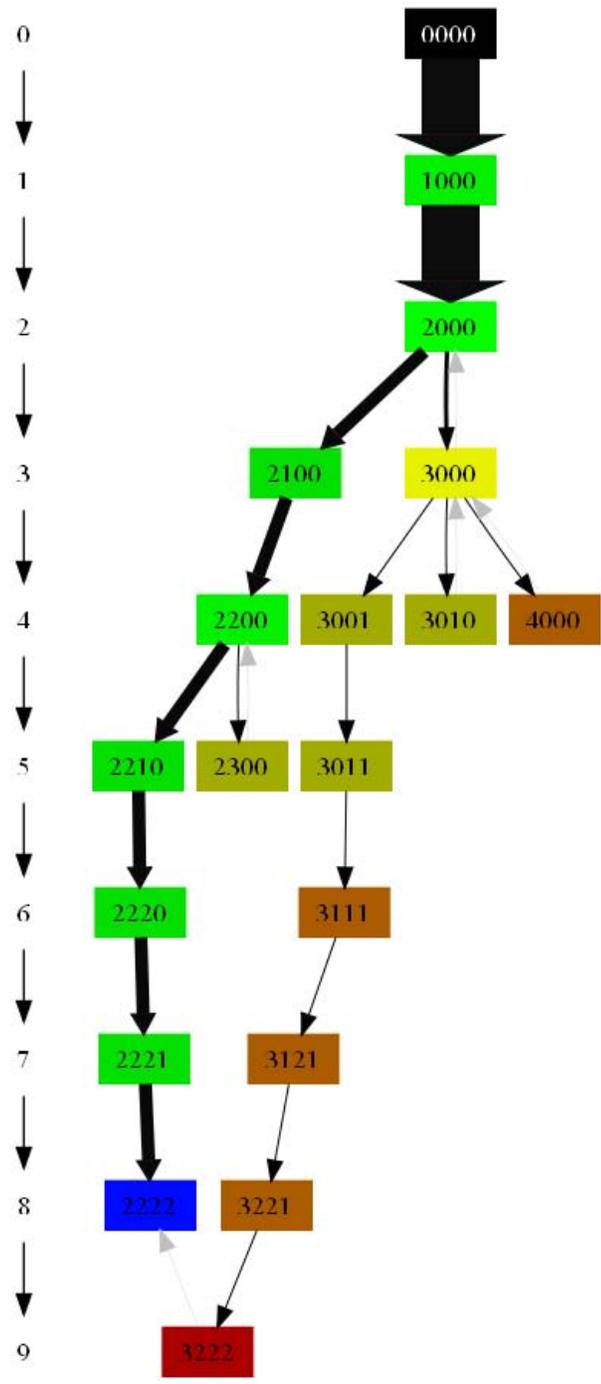
**Figure 2: Strategy Visualization for Session 2 Games**

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**Figure 3: Strategy Visualization for Session 3 Games**

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**Figure 4: Strategy Visualization for Session 4 Games**