CS 540 Fall 2008 Homework 2

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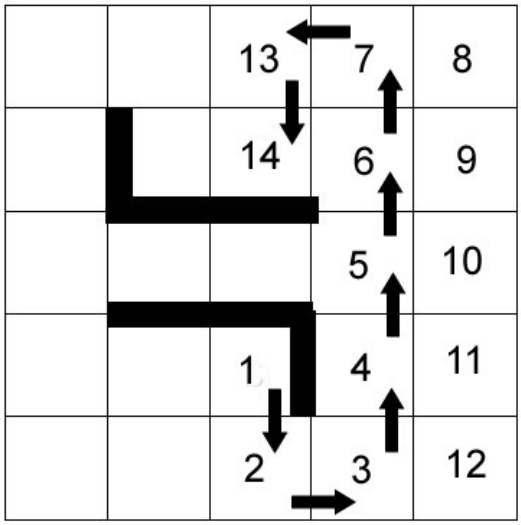
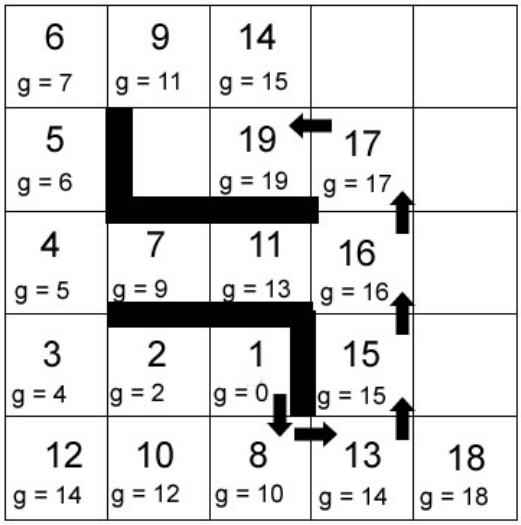
Late Days used: 0

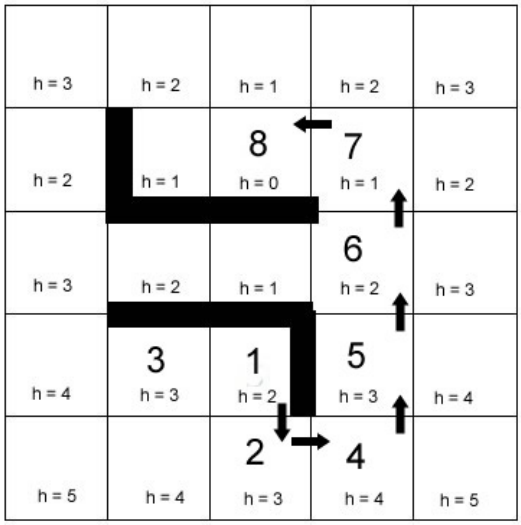
1.a) Depth First Search



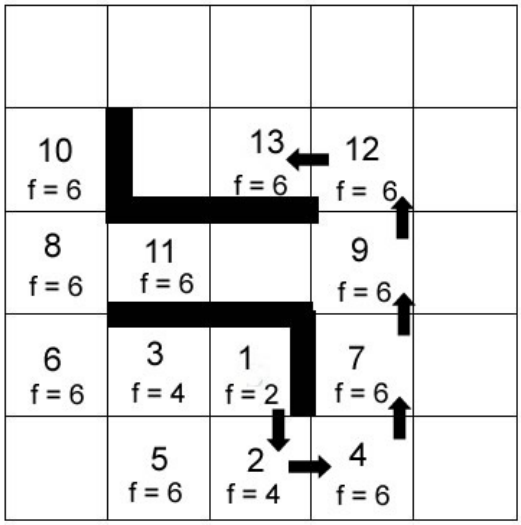
1.b) Uniform Cost Search



1.c) Greedy Best First Search



1.d) A^* Search



2.a) At any point in time, we must know the locations of both the robots, so our state description is (α, β) where α is the node in the graph at which robot A is currently located, and β is the node where the robot B is located. The initial state in our state space is (a, c) since the robot A starts at node a, and the robot B starts at node c. Similarly the goal state in our state space is (b, d).
Let us define $shortestPath(x, y)$ to be the length of the shortest path from node x to node y. Then a state (α, β) is *legal* if $shortestPath(\alpha, \beta) \geq t$. Note that if (a, c) and (b, d) are not legal, then there is trivially no solution. For a given state (α, β), the set of legal next states is given by:

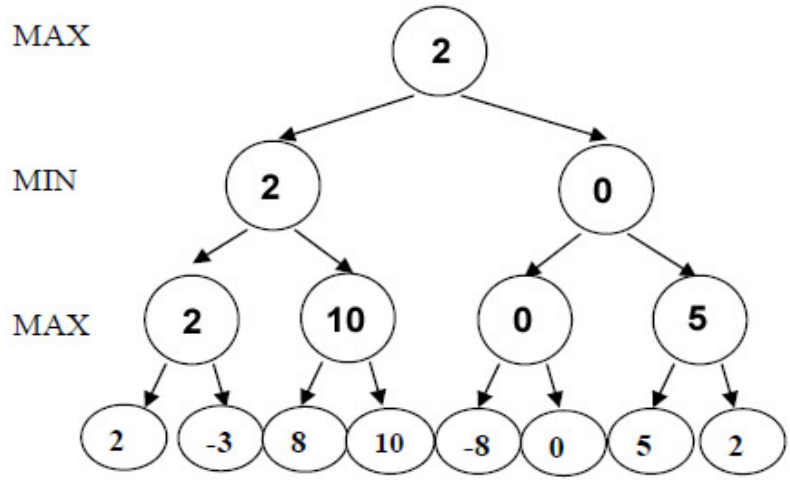
$$\{(\alpha', \beta) | \alpha' \text{ is a neighbor of } \alpha \text{ and } (\alpha', \beta) \text{ is legal.}\} \cup$$
$$\{(\alpha, \beta') | \beta' \text{ is a neighbor of } \beta \text{ and } (\alpha, \beta') \text{ is legal.}\}$$

Since the building graph is static, the shortest path between each pair of nodes can be precaculated and stored. The Floyd-Warshall algorithm can compute the shortest paths for all pairs of nodes in $O(n^3)$ time, where n is the number of nodes in the graph. Checking if a state is legal can then be done in constant time by looking up in the precalculated table.
2.b)Consider the following function:

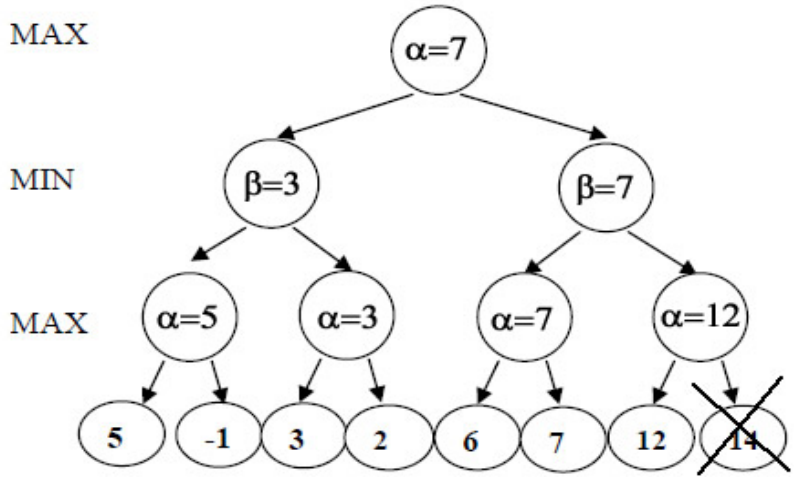
$$h(\alpha, \beta) = shortestPath(\alpha, b) + shortestPath(\beta, d).$$

When robot A is at position α, it needs at least $shortestPath(\alpha, b)$ steps to reach the destination. Similarly robot B needs at least $shortestPath(\beta, d)$ steps to reach the goal. Since at each step only one robot can move, h measures the least number of steps required for both robots to reach their destinations. Even the optimal solution cannot do better than this, so the A^* criteria is met.
Note that our definition of h doesn't incorporate t at all. There is no simple way we can incorporate t into our heuristic, because while computing all pairs shortest paths is easy, computing two paths such that they are always t nodes apart is considerably harder.

3.a) Minimax algorithm



3.b) Alpha Beta Pruning



4.1) Basic Alpha Beta Pruning Source Code

```
import java.util.Vector;
// CS 540 : HW2
// author: priyananda( shenoy@cs.wisc.edu )
// date: 5 Oct 2008
// random quote: [Fight Club] Tyler Durden: We're a generation of men raised by women.

/**
 * Basic Alpha Beta Pruning using iterative deepening.
 */
public class AlphaBetaPlayer extends CheckerPlayer implements CheckerBoardConstants
{
    public AlphaBetaPlayer(String name)
    {
        super(name);
    }
    //overridden method to compute the best next move
    public void calculateMove(int[][] bs, int whosTurn)
    {
        this.chosenMoveValue = Integer.MIN_VALUE;
        this.chosenMove = null;

        //iterative deepening. 100 is some arbitrary number which will never
        //be reached.
        for(int depth = 1 ; depth < 100 ; ++depth ){
            //this finds best solution for the given depth cutoff and
            //stores it in tempSolution/tempValue
            findBestSolutionWithinDepth(bs, whosTurn, depth);

            if(this.tempValue > this.chosenMoveValue){
                this.chosenMoveValue = this.tempValue;
                this.chosenMove = this.tempSolution;
            }
            if(Utils.debug)
                System.out.printf(
                    "Done␣with␣depth␣limit␣%d\nI␣pruned␣the␣tree␣%d␣time(s)\n",
                    depth, pruneCount
                );
        }
    }
    //depth-0 is always maximizing.
    private void findBestSolutionWithinDepth(int [][] bs,int whosTurn, int depth)
    {
        this.depthCutOff = depth;
        this.pruneCount = 0;

        this.tempSolution = null;
        this.tempValue = Integer.MIN_VALUE;

        for(Object m : Utils.getAllPossibleMoves(bs, whosTurn)){
            Move currentMove = (Move)m;
            int [][] bsnew = Utils.copyBoardState(bs);
            Utils.executeMove(whosTurn, currentMove, bsnew);
            int kidValue = alphaBetaPrune(
                bsnew,
                whosTurn,
                1, //initial depth
                Integer.MIN_VALUE, //alpha
                Integer.MAX_VALUE  //beta
            );
            if(this.tempSolution == null || kidValue > this.tempValue){
                this.tempSolution = currentMove;
                this.tempValue = kidValue;
            }
        }
    }
    //main method which implements alpha-beta minimax search
    private int alphaBetaPrune(int [][] bs,int whosTurn, int depth, int alpha, int beta)
    {
        if(depth >= this.depthCutOff)
            //reached the end of cutoff, stop
            return evaluateBoard(bs, whosTurn);

        //if i am a minimizing node, then the other player has to move.
        Vector kids = Utils.getAllPossibleMoves(bs,
```

```
            isMax(depth,whosTurn) ? whosTurn : otherPlayer(whosTurn)
        );
        if(kids.size() == 0)
            //this is a dead end. just return the current value.
            return evaluateBoard(bs, whosTurn);

        //is this node a max node or min node
        if(isMax(depth, whosTurn)){
            int i;
            for(i = 0 ; i < kids.size() && alpha < beta; ++i ){
                Move currentMove = (Move)kids.elementAt(i);
                int [][] bsnew = Utils.copyBoardState(bs);
                Utils.executeMove(whosTurn , currentMove, bsnew);
                int kidAlpha = alphaBetaPrune(bsnew,whosTurn,depth+1,alpha,beta);
                if( kidAlpha > alpha )
                    alpha = kidAlpha;
            }
            pruneCount += kids.size() - i;
            return alpha;
        }else{
            int i;
            for(i = 0 ; i < kids.size() && alpha < beta; ++i ){
                Move currentMove = (Move)kids.elementAt(i);
                int [][] bsnew = Utils.copyBoardState(bs);

                //when the current node is minimizing, the other
                //player is to move.
                Utils.executeMove(
                    otherPlayer(whosTurn),
                    currentMove,
                    bsnew
                );
                int kidBeta = alphaBetaPrune(bsnew, whosTurn,depth+1, alpha, beta);
                if( kidBeta < beta )
                    beta = kidBeta;
            }
            pruneCount += kids.size() - i;
            return beta;
        }
    }

    private boolean isMax(int depth, int whosTurn)
    {
        if(depth % 2 == 0)
            //even depth is maximizing
            return true;
        else
            //odd depth is minimizing
            return false;
    }
    //this simplifies many things, like the current player always maximizes
    protected int evaluateBoard(int [][] bs,int whosTurn)
    {
        int ret = Utils.scoreCheckerBoard(bs, whosTurn);
        return (whosTurn == RED_PLAYER) ? ret : -ret;
    }
    //simple helper function to get the opposite player
    private int otherPlayer(int whosTurn)
    {
        return whosTurn == RED_PLAYER ? BLACK_PLAYER : RED_PLAYER;
    }

    //best solution found so far
    private int chosenMoveValue = -1;
    //solution found for current depth iteration
    private Move tempSolution;
    private int tempValue;

    //now many nodes were pruned in current depth iteration
    private int pruneCount = 0;
    private int depthCutOff = 0;
}
```

4.2) Static Board Evaluation function.
The value of a particular state of the board is calculated as follows. A positive value implies advantage for the Red player, and a negative value for the Black player.

$$value(B) = (\sum_{r \in RED} value(r)) - (\sum_{b \in BLACK} value(b))$$

where $value(B)$ is the value of the game, calculated as the difference between the collective values of the Red and Black pieces. The value of each piece $value(p)$ is calculated as:

$$value(p) = \begin{cases} 10 + dof(p) + attacks(p) & \text{p is a pawn.} \\ 25 + dof(p) + attacks(p) & \text{p is a king.} \end{cases}$$

Each of the terms is explained in more details below:

1. Each piece has a *base value*, which is chosen to be 10 for pawns and 25 for kings.

2. $dof(p)$ measure the *degree of freedom* each piece has. Note that this measures the static freedom each piece has, not considering other pieces. All it serves to do is to give piece in the middle of the board a slightly more importance than those on the edges. For a pawn, this can be any of $\{0, 1, 2\}$, and for a king $\{0, 1, 2, 3, 4\}$.

3. $attacks(p)$ counts the number of pieces this piece can attack. It doesn't consider multiple jumps.For a pawn, this can be any of $\{0, 1, 2\}$, and for a king $\{0, 1, 2, 3, 4\}$.

To get an idea of the performance of this function against the basic one, 10 games were played between the basic player and this implementation, with the evaluation function being the only difference between the implementations. Out of 10, 6 games were won by the enhanced implementation, 3 by the basic one, and 1 game got stuck. To ensure that the same games are not replayed, a small random component of ± 2 was added to the evaluation function. This has a significant effect especially in the initial few moves where the board is equally good for both players.
Strengths of implementation: Favouring states which have higher attack potential is a hueristic which works most of the time. We can think of this as an approximate look-ahead into the next state, and counting how many next states will result in a enemy capture.

Weaknesses of implementation: Since this is an approximate heuristic, we can always find situations where this leads to a bad situation. Since the weights of the factors are arbitrary, there is no statistical guarantee that this function will perform better than any other implementation. In some situations, the weight given to attack potential is far too less, but in some other situations, it is too less, since in one move a piece can attack only one other piece. Also, the degree of freedom should have weight much less than attack potential in most cases, but there is no simple way of figuring out what the weight should be.
The source code for the evaluation function is given below:

```
protected int scoreCheckerBoard(int [][] bs,int whosTurn)
{
    int redValue = 0;
    int blackValue = 0;
    for(int i = 0 ; i < Utils.BOARD_WIDTH; ++i)
        for(int j = 0; j < Utils.BOARD_HEIGHT; ++j){
            switch(bs[i][j]){
                case RED_PAWN:
                    redValue += 10; //base
                    redValue += isValid(i-1,j-1) + isValid(i-1,j+1); //dof
                    redValue += canAttack(bs,i - 1,j - 1, i - 2, j - 2, BLACK_PLAYER) +
                                canAttack(bs,i - 1,j + 1, i - 2, j + 2, BLACK_PLAYER); //attacks
                break;
                case RED_KING:
                    redValue += 25; //base
                    redValue += isValid(i-1,j-1) + isValid(i-1,j+1) +
                                isValid(i+1,j-1) + isValid(i+1,j+1); //dof
                    redValue += canAttack(bs,i - 1,j - 1, i - 2, j - 2, BLACK_PLAYER) +
                                canAttack(bs,i - 1,j + 1, i - 2, j + 2, BLACK_PLAYER) +
                                canAttack(bs,i + 1,j - 1, i + 2, j - 2, BLACK_PLAYER) +
                                canAttack(bs,i + 1,j + 1, i + 2, j + 2, BLACK_PLAYER); //attacks
                break;
                case BLACK_PAWN:
                    blackValue += 10; //base
                    blackValue += isValid(i+1,j-1) + isValid(i+1,j+1); //dof
                    blackValue += canAttack(bs,i + 1,j - 1, i + 2, j - 2, RED_PLAYER) +
                                  canAttack(bs,i + 1,j + 1, i + 2, j + 2, RED_PLAYER); //attacks
                break;
                case BLACK_KING:
                    blackValue += 25;
                    blackValue += isValid(i-1,j-1) + isValid(i-1,j+1) +
                                  isValid(i+1,j-1) + isValid(i+1,j+1); //dof
                    blackValue += canAttack(bs,i - 1,j - 1, i - 2, j - 2, RED_PLAYER) +
                                  canAttack(bs,i - 1,j + 1, i - 2, j + 2, RED_PLAYER) +
                                  canAttack(bs,i + 1,j - 1, i + 2, j - 2, RED_PLAYER) +
                                  canAttack(bs,i + 1,j + 1, i + 2, j + 2, RED_PLAYER);//attacks
                break;
            }
        }
    return redValue - blackValue + ((int)(Math.random() * 4) - 2);
}
//returns 1 if the location is valid
private int isValid(int i,int j)
{
    if(i >= 0 && i < BOARD_WIDTH)
        if(j >= 0 && j < BOARD_HEIGHT)
            return 1;
    return 0;
}
//can i jump over enemy piece at (x1,y1) to empty location (x2,x2)
private int canAttack(int [][] bs,int x1, int y1, int x2, int y2, int otherPlayer)
{
    if(isValid(x1, y1) == 0 || isValid(x2, y2) == 0 ) return 0;
    if(Utils.getOwner(bs[x1][y1]) == otherPlayer && bs[x2][y2] == BLANK) return 1;
    return 0;
}
```