

# CS61B Lecture #23

**Today:** Backtracking searches, game trees (*DSIJ*, Section 6.5)

# Searching by “Generate and Test”

- We've been considering the problem of searching a set of data stored in some kind of data structure: “Is  $x \in S$ ?”
- But suppose we *don't* have a set  $S$ , but know how to recognize what we're after if we find it: “Is there an  $x$  such that  $P(x)$ ?”
- If we know how to enumerate all possible candidates, can use approach of *Generate and Test*: test all possibilities in turn.
- Can sometimes be more clever: avoid trying things that won't work, for example.
- What happens if the set of possible candidates is infinite?

# Backtracking Search

- Backtracking search is one way to enumerate all possibilities.
- Example: *Knight's Tour*. Find all paths a knight can travel on a chess-board such that it touches every square exactly once and ends up one knight move from where it started.
- In the example below, the numbers indicate position numbers (knight starts at 0).
- Here, knight (N) is stuck; how to handle this?

6							
		5					
4	7						
	10		2				
8	3	0					
N		9		1			

# General Recursive Algorithm

```
/** Append to PATH a sequence of knight moves starting at ROW, COL
 * that avoids all squares that have been hit already and
 * that ends up one square away from ENDROW, ENDCOL. B[i][j] is
 * true iff row i and column j have been hit on PATH so far.
 * Returns true if it succeeds, else false (with no change to PATH).
 * Call initially with PATH containing the starting square, and
 * the starting square (only) marked in B. */
```

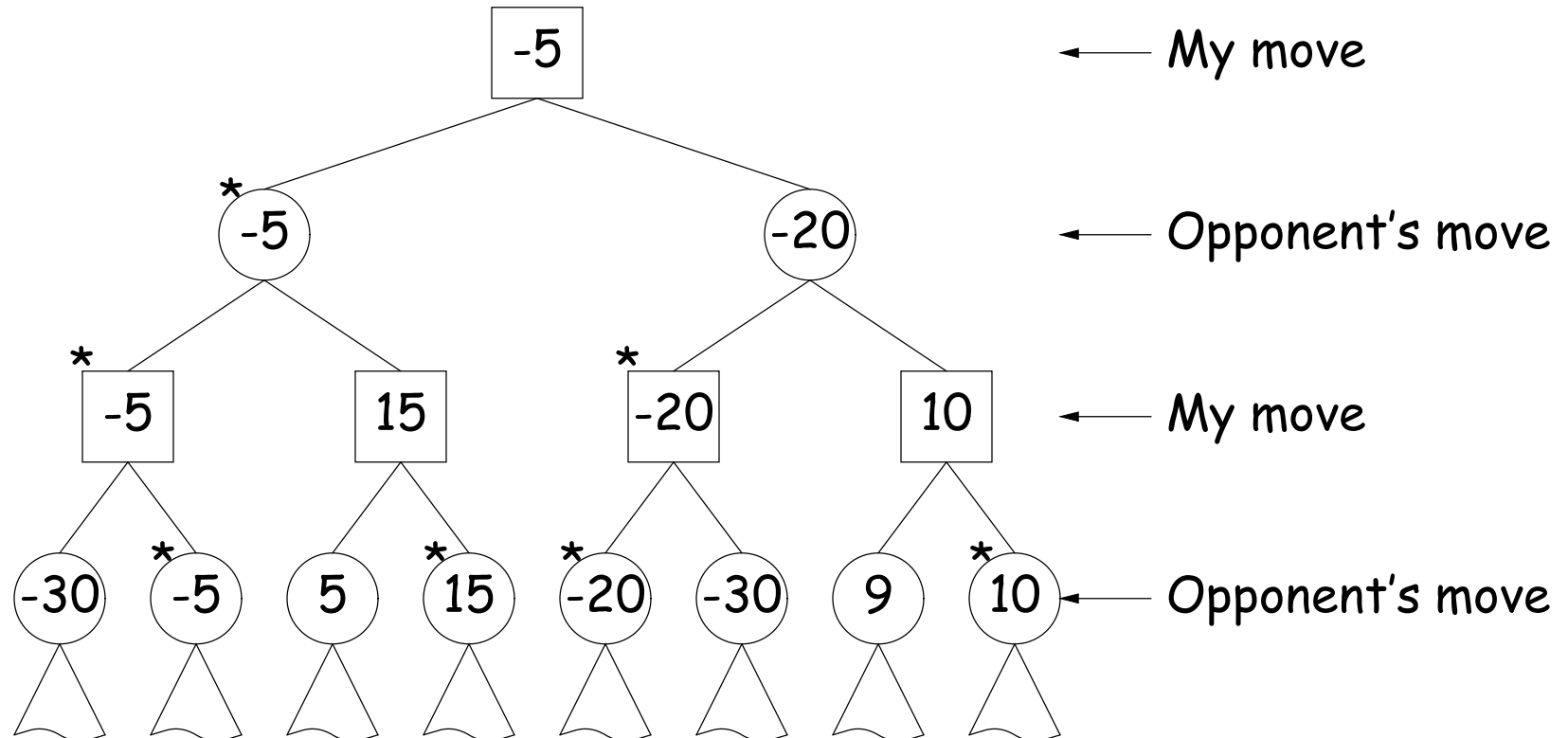
```
boolean findPath (boolean[][] b, int row, int col,
                  int endRow, int endCol, List path) {
    if (path.size () == 64)    return isKnightMove (row, col, endRow, endCol);
    for (r, c = all possible moves from (row, col)) {
        if (! b[r][c]) {
            b[r][c] = true; // Mark the square
            path.add (new Move (r, c));
            if (findPath (b, r, c, endRow, endCol, path)) return true;
            b[r][c] = false; // Backtrack out of the move.
            path.remove (path.size ()-1);
        }
    }
    return false;
}
```

## Another Kind of Search: Best Move

- Consider the problem of finding the *best* move in a two-person game.
- One way: assign a value to each possible move and pick highest.
  - Example: number of our pieces - number of opponent's pieces.
- But this is misleading. A move might give us more pieces, but set up a devastating response from the opponent.
- So, for each move, look at *opponent's* possible moves, assume he picks the best one for him, and use that as the value.
- But what if *you* have a great response to his response?
- How do we organize this sensibly?

# Game Trees, Minimax

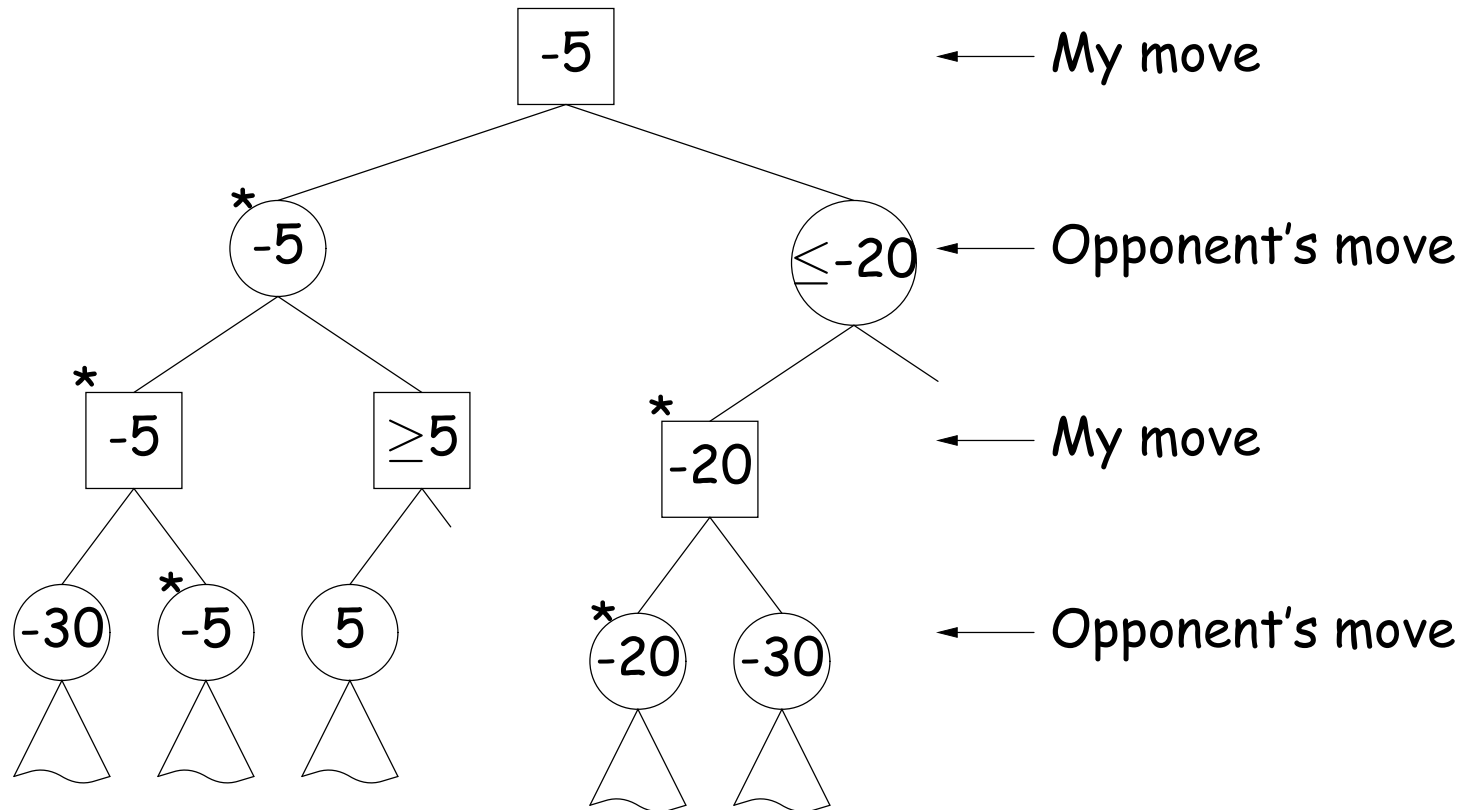
- Think of the space of possible continuations of the game as a tree.
- Each node is a position, each edge a move.



- Numbers are the values we guess for the positions (larger means better for me). Starred nodes would be chosen.
- I always choose child (next position) with maximum value; opponent chooses minimum value ("Minimax algorithm")

# Alpha-Beta Pruning

- We can *prune* this tree as we search it.



- At the ' $\geq 5$ ' position, I know that the opponent will not choose to move here (since he already has a  $-5$  move).
- At the ' $\leq -20$ ' position, my opponent knows that I will never choose to move here (since I already have a  $-5$  move).

# Cutting off the Search

- If you could traverse game tree to the bottom, you'd be able to force a win (if it's possible).
- Sometimes possible near the end of a game.
- Unfortunately, game trees tend to be either infinite or impossibly large.
- So, we choose a maximum *depth*, and use a heuristic value computed on the position alone (called a *static valuation*) as the value at that depth.
- Or we might use *iterative deepening* (kind of breadth-first search), and repeat the search at increasing depths until time is up.
- Much more sophisticated searches are possible, however (take CS188).



## Some Pseudocode for Searching

```
/** A legal move for WHO that either has an estimated value >= CUTOFF
 * or that has the best estimated value for player WHO, starting from
 * position START, and looking up to DEPTH moves ahead. */
Move findBestMove (Player who, Position start, int depth, double cutoff)
{
    if (start is a won position for who) return WON_GAME; /* Value  $\infty$  */
    else if (start is a lost position for who) return LOST_GAME; /* Value  $-\infty$  */
    else if (depth == 0) return guessBestMove (who, start, cutoff);

    Move bestSoFar = REALLY_BAD_MOVE;
    for (each legal move, M, for who from position start) {
        Position next = start.makeMove (M);
        Move response = findBestMove (who.opponent (), next,
                                      depth-1, -bestSoFar.value ());
        if (-response.value () > bestSoFar.value ()) {
            Set M's value to -response.value (); // Value for who = - Value for opponent
            bestSoFar = M;
            if (M.value () >= cutoff) break;
        }
    }
    return bestSoFar;
}
```

# Static Evaluation

- This leaves static evaluation, which looks just at the next possible move:

```
Move guessBestMove (Player who, Position start, double cutoff)
{
    Move bestSoFar;
    bestSoFar = Move.REALLY_BAD_MOVE;
    for (each legal move, M, for who from position start) {
        Position next = start.makeMove (M);
        Set M's value to heuristic guess of value to who of next;
        if (M.value () > bestSoFar.value ()) {
            bestSoFar = M;
            if (M.value () >= cutoff)
                break;
        }
    }
    return bestSoFar;
}
```