CS61B Lecture #34

Today: Backtracking searches, game trees.

Coming Up: Graph Structures: *DSIJ*, Chapter 12

Public Service Announcement: The Student Advocate's Office is effectively a campus public defender—an executive, non-partisan office of the student government offering representation, help, and advice to any student or student group involved in a dispute with the University. For assistance with residency applications and appeals, financial aid applications, withdrawals and enrollment, grade appeals, cheating accusations, sexual assault, discrimination, and other University grievances, see their web page at advocate.berkeley.edu.

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 chessboard 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

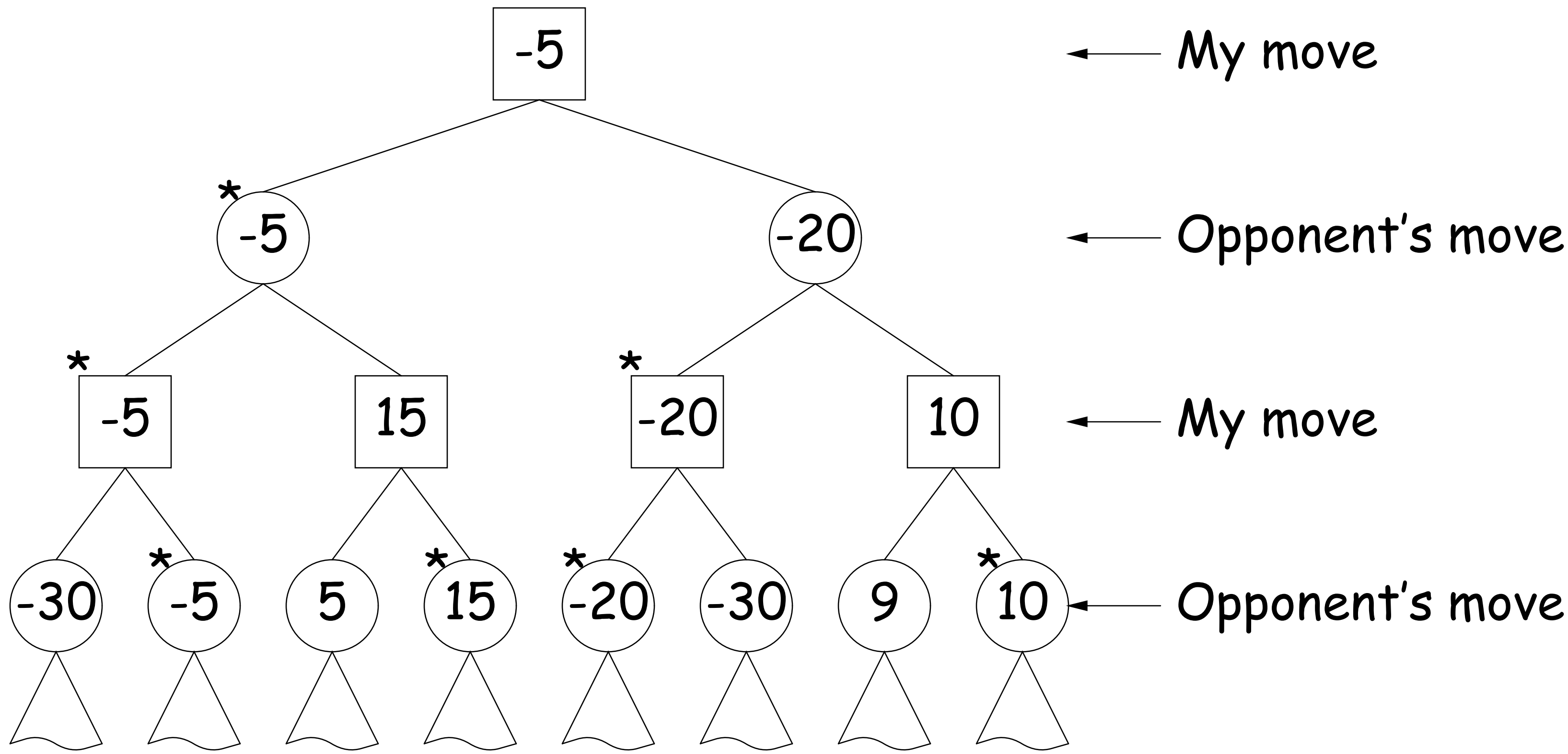
```
/** Append to PATH a sequence of knight moves starting at ROW, COL
 *  that avoids all squares that have been hit already and
 *  that ends up one square away from ENDROW, ENDCOL. B[i][j] is
 *  true iff row i and column j have been hit on PATH so far.
 *  Returns true if it succeeds, else false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

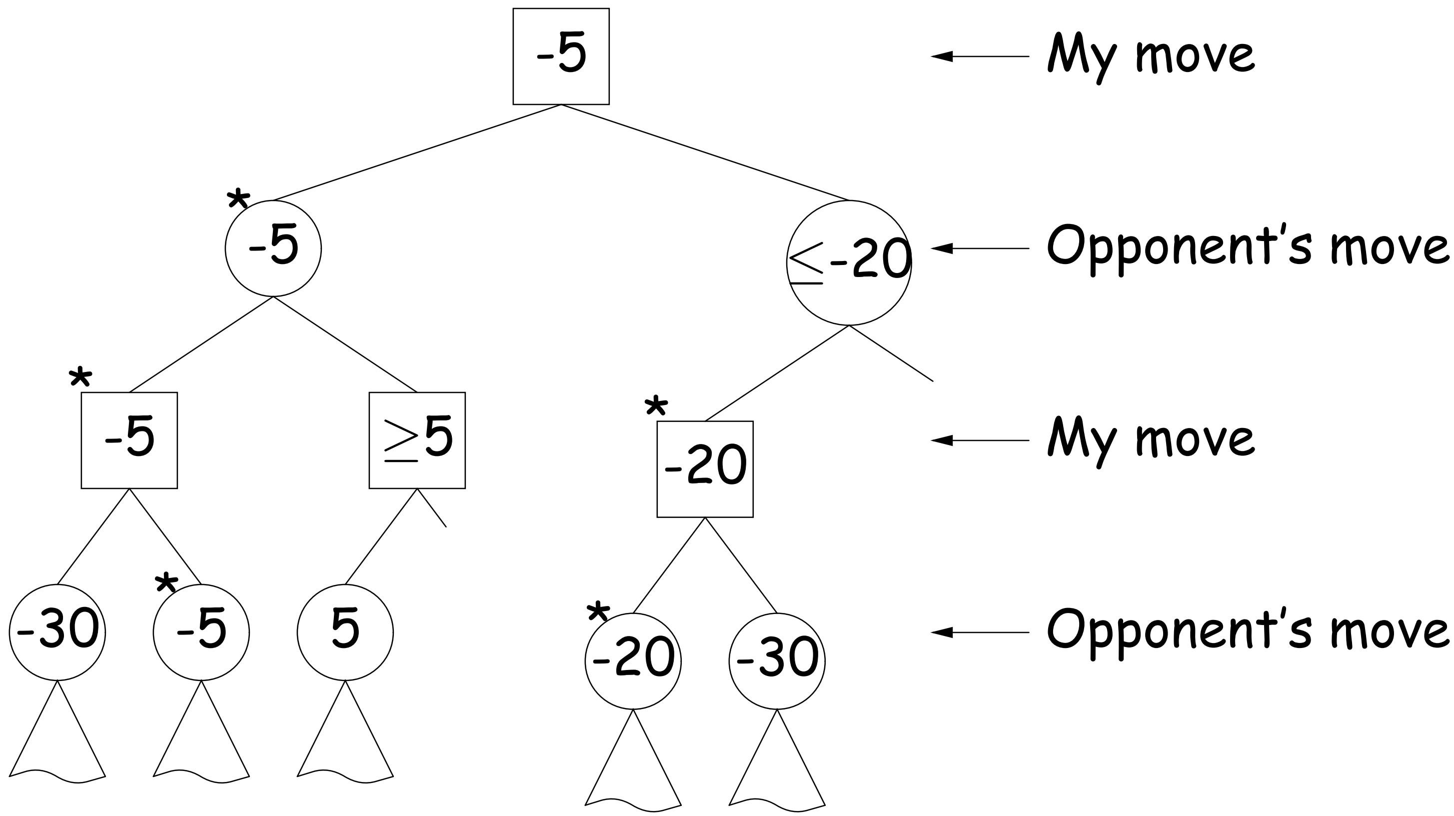
- Think of the space of possible continuations of the game as a tree.
- Each node is a position, each edge a move.



- 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 '≥ 5' position, I know that the opponent will not choose to move here (since he already has a -5 move).
- At the '≤ -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 CANT_MOVE;
  else if (start is a lost position for who) return CANT_MOVE;
  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;
}
```

Coroutines (redone from Lecture #32, slide 10)

- A *coroutine* is a kind of synchronous thread that explicitly hands off control to other coroutines so that only one executes at a time. Can get similar effect with threads and mailboxes.
- Example: recursive inorder tree iterator:

```
class TreeIterator extends Thread {
  Tree root; Mailbox r;
  TreeIterator (Tree T, Mailbox r) {
    this.root = T; this.dest = r;
  }
  public void run () {
    traverse (root);
    r.deposit (End marker);
  }
  void traverse (Tree t) {
    if (t == null) return;
    traverse (t.left);
    r.deposit (t.label);
    traverse (t.right);
  }
}
```

```
void treeProcessor (Tree T) {
  Mailbox m = new QueuedMailbox ();
  new TreeIterator (T, m).start ();
  while (true) {
     Object x = m.receive ();
     if (x is end marker)
        break;
     do something with x;
  }
}
```