CS61B Lecture #34

Today: Backtracking searches, game trees.

Coming Up: Graph Structures: DSIJ, Chapter 12

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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?

![Chessboard diagram with numbers indicating position numbers](image-url)
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 '$\geq 5$' 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 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:

```java
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;
    }
}