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?

General Recursive Algorithm

```java
/** 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 (int 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.

\[
\begin{array}{c}
\text{-5} \\
\text{-5} \\
\text{-5} \\
\text{-5} \\
\text{-5} \\
\text{-20} \\
\text{15} \\
\text{-20} \\
\text{10} \\
\text{-30} \\
\text{-5} \\
\text{5} \\
\text{-30} \\
\text{-5} \\
\text{-30} \\
\text{9} \\
\text{10} \\
\end{array}
\]

- 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.

\[
\begin{array}{c}
\text{-5} \\
\text{-5} \\
\text{-20} \\
\text{15} \\
\text{-20} \\
\text{10} \\
\text{-30} \\
\text{-5} \\
\text{5} \\
\text{-30} \\
\end{array}
\]

- 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

```java
/** 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:

```java
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);
    }
}
```

```java
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;
    }
}
```