CSC 261  
Lab 2: Uninformed Search  
Fall 2013

Assigned: Tuesday 10 September 2013

Due: Monday 16 September 2013, 11:59 p.m.

Objectives:

- Understand details of **uninformed search** algorithm implementations
- Explore **performance implications** of various search algorithms
- Practice reading and programming to specified **interfaces**
- Reinforce programming with **higher-order procedures** in Scheme
- Apply principles of good science **writing**

Collaboration:

- Problem 1 (programming) will be completed in pairs assigned by the instructor.
- Problem 2 (analysis) must be completed individually.

1 Introduction

In this assignment, you will complete a general framework for implementing a variety of uninformed search algorithms, measuring their efficiency and solution quality. While the textbook gives a graph search version of most specific search algorithm implementations, we will be using a general tree search algorithm, which may be found below.

**Algorithm 1** General tree-search algorithm requiring a starting state for a problem as well as a method for organizing nodes in the frontier.

```scheme
function Tree-Search(start, problem, Enqueue) returns a solution, or failure
    node ← Node-Init(start)
    if Goal(start) then return Solution(node)

    frontier ← Queue(node)
    do
        if Empty(frontier) then return failure
        node ← POP(frontier)
        if Goal(problem, State(node)) then return Solution(node)
        frontier ← Enqueue( Expand(problem, node), frontier)
```

```scheme
function Expand( problem, node ) returns a set of nodes
    successors ← []
    for each action in Actions( problem, State(node) )
        if Contains( Path(node), Result(action,node) ) then continue
        successors ← [ Child-Node(problem, node, action) | successors ]
```

Many search algorithms can be implemented using this general structure. The only difference between various search algorithms is in how they order (enqueue) nodes on the frontier. Thus the Enqueue parameter is actually a procedure that implements the ordering criterion that determines the precise search algorithm.

Note that the call to Contains ensures no state will be repeated within any given solution. Unfortunately, this is not the same as making sure no state is examined more than once anywhere in the search tree.
2 Code and environment

For this assignment, you will need to copy some starter code from the MathLAN directory:

```
~weinman/courses/CSC261/code/search
```

Note that Scheme is not all that intelligent about dealing with relative paths. Thus, any Scheme `load` commands that are issued will be relative to the working directory. You should not change the code’s `load` commands to use absolute paths, as this makes running your code more difficult for grading purposes.

2.1 General search

2.1.1 Search routines: `search.scm`

The file `search.scm` contains skeletons and specifications for many of the procedures you are to write. In order to promote code reuse, the search routines take a generic kind of value we’re calling a problem and operates on a node type. Both of these are described below.

2.1.2 Generic search problems: `problem.scm`

Like the text, a problem requires the ability to define a goal state, a method for generating successors (states that result from the actions available at a given state), and a cost for taking an action in a given state. Thus, we can create a problem by passing in these three procedures to a procedure `make-problem` that encapsulates them all. Once these are tied together, the general procedure `problem-expand-node` (akin to `Expand` above and already written for you) has everything needed to generate the list of potential actions and their resulting states. The accompanying 6-P documentation has further detail.

2.1.3 Representing search tree nodes: `node.scm`

To find the solution to a problem, it is important to keep track of various aspects of our search. We do this by means of a node type. As in AIMA Section 3.3.1, a node encapsulates an action, the state resulting from that action, the “parent” node preceding it in the search tree, and a path cost for taking the action from the parent. We also add to this structure the (estimated) total cost of the solution through this node (to be used in the next assignment), and the depth of the node in the search tree. All of this information is packaged together in type we call a node.

In addition, we will need to create a start node, the root of our search tree, using an initial state and any heuristic procedure for the problem; this is what the procedure `node-init` does. Note that the parent of the initial node is null.

Some of the searches (including the uniform-cost-search provided) may require you to sort the successor nodes and/or queue by some criterion. Thus a simple insertion sort has been provided for you in `sort.scm`.

2.2 Jumping

In addition to the 8-puzzle sliding block problem described in AIMA Section 3.2.1, you will apply your search routines to another problem faced by the lesser-known archaeologist Illinois Smith. Trapped in the Temple of Fumes, Dr. Smith must hop across a wide chasm with only a handful of supports to step upon along the way. He wants to minimize the total number of hops it takes him to reach the other side because the eponymous noxious cloud is quickly descending upon him. The last hop is to a narrow bridge where he will make a sharp left turn to the exit; he must therefore land on it precisely.

Unfortunately, Noisey (as his friends call him), faces this challenge often, so we generalize it by the number of evenly-spaced supports \( N \) along the chasm.

**States:** Dr. Smith may be in one of \( N + 1 \) positions, \( p \), with \( p = 0 \) indicating the start, and \( p = N \) indicating the far side of the chasm. His momentum \( m \) (the amount he most recently jumped) will also be important. Formally, the state at time \( t \) is the pair \( s_t = (p_t, m_t) \).
**Initial state:** The initial state is $p_0 = 0$ and $m_0 = 0$.

**Actions:** Dr. Smith can only leap to the first position $p = 1$ from the starting location. However, he must account for momentum so that on a subsequent leap he may leap just as far, up to two farther or slow down by jumping one less than his previous move. Formally,

$$a(s_t) = \{m_{t-1} - 1, m_{t-1}, m_{t-1} + 1, m_{t-1} + 2\}, t > 1$$

with the added restriction that he may not move backward.

**Transition model:** A given jump distance will take Dr. Smith to the appropriate support.

**Goal test:** Dr. Smith must land precisely on the last position because the chasm still yawns beyond it. Also, so that his momentum doesn’t carry him past the bridge, his last hop must also be from the last support before the bridge ($p = N - 1$).

**Path cost:** Each step has unit cost.

### 2.3 Summary

The following gives a table of function/procedure equivalencies between the pseudo-code and the provided Scheme code.

<table>
<thead>
<tr>
<th>Pseudo code</th>
<th>Scheme</th>
<th>File</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODE-INIT</td>
<td>(node-init state heuristic)</td>
<td>node.scm</td>
</tr>
<tr>
<td>GOAL</td>
<td>((problem-goal? problem) state)</td>
<td>problem.scm</td>
</tr>
<tr>
<td>EXPAND</td>
<td>(problem-expand-node problem node heuristic)</td>
<td>problem.scm</td>
</tr>
</tbody>
</table>

For now, we will ignore the heuristic parameter, which is used on the next assignment. For now, you can simply use

```
(lambda (state) 0)
```

as a basic state evaluation function that always returns zero.

Here is an example that uses breadth-first and uniform-cost search to solve a 25 step chasm for Dr. Smith.

```
(load "jump.scm")
(load "search.scm")
(define course-length 25)
(define start (jump-start-state course-length))
(define bfs-sol (breadth-first-search start (jump-problem course-length)))
(define ucs-sol (uniform-cost-search start (jump-problem course-length)))
(display (list ’bfs (length (car bfs-sol)) (cadr bfs-solution))) (newline)
(display (list ’ucs (length (car ucs-sol)) (cadr ucs-solution)))
```

This produces the following output:

```
(bfs 9 6207)
(ucs 9 9684)
```

In the event you do not complete Problem 1, or you wish to benchmark your implementations, a complete compiled version is provided, which you may copy to a new directory:

```
$ mkdir complete
$ cp -R ~weinman/courses/CSC261/code/searchc ./complete
$ dracket complete/complete.scm &
```
3 Lab assignment

Problem 1 - Writing search algorithms [40 points]

12 additional points will be allotted for testing and code formatting considerations.

Part A [12 points]

Implement the routine `search`, as defined in `search.scm`. This is the general tree search algorithm as given above. Note that the `problem` parameter may be used with the routines given in `problem.scm`, in particular `problem-goal?` and `problem-expand-node`.

Per the specification, you will need to track expansions, a count of the number of times you call the problem’s successor function `problem-expand-node`. When you have found a node that is a solution, `search` should return

```
(list (node-extract-actions node) expansions)
```

As an example, the procedures `depth-first-search` and `uniform-cost-search` both call `search` with a specific enqueueing procedure. Both of these searches are uninformed, so we use the always-zero heuristic given above.

Part B [4 points]

Write the procedure `breadth-first-search` by calling your `search` routine with an appropriate enqueueing procedure. (Hint: Follow the example of `depth-first-search`.)

Part C [4 points]

Write the procedure `depth-limited-search` by calling your `search` routine with an appropriate enqueueing procedure. (Hint: Do not enqueue a node whose depth exceeds the given limit.) The procedure `(node-depth node)` from `node.scm` will be helpful. Your implementation need not distinguish between cutoff and standard failures.

Part D [8 points]

Write and document the procedure `iterative-deepening-search` by repeatedly calling your `search` routine with an appropriate enqueueing procedure. (Hint: Use `depth-limited-search`.)

Problem 2 - Analysis [40 points]

In this problem, you will do some comparative analysis of your search routines by writing a single, integrated essay. The Part A/B/C structure below is simply to help you organize your efforts.

Note that, while `random-eight-puzzle-state` calls `random` to produce their states, you can make your results repeatable by using the procedure `(random-seed seed)` to set the seed of the random number generator.

Part A

Generate a fairly easy eight-puzzle state and a short jump problem. Run each search algorithm on both, creating two tables (one for each problem) listing the number of nodes expanded to find a solution, and the total number of actions in the solution. Be sure to specify the specifics of each problem or how they were generated.

Part B

Generate the hardest eight-puzzle problem and longest jump problem you feel like waiting for solutions to under most search algorithms. Run your search algorithms again, adding rows to the tables you created above. Be sure to specify the specifics of each problem or how they were generated.
Part C

Using the data you have generated, answer the following questions:

• How do the number of nodes expanded compare among the search algorithms? How does this comparison vary with problem difficulty (if at all)?

• How do the solution costs compare among the search algorithms? How does this comparison vary with problem difficulty (if at all)?

Draw some conclusions about the relative efficiency and effectiveness of these search algorithms on these problems.

Note that a complete analysis will feature coherent paragraphs, a brief introduction stating the purpose and context, as well as your overall conclusions. It should be nicely formatted and feature a logical organization, complete sentences, and proper grammar, spelling, and punctuation. The audience is your peers in this class; they do not know a priori what problems you examined, nor what your results or conclusions may be. Be sure to include your name, mailbox, and a title. Acknowledge any parties responsible for the search source code used for analysis.

What to turn in

Programming Assignment

Your joint submission should include the following

• Your completed search.scm file

• A short driver program that demonstrates your search algorithm implementations applied to a simple problem (i.e., one that does not take long to run).

• A single PDF containing (merged)
  
  – Your Scheme files
  – A transcript of your driver program’s output

Files in any other format will receive a zero.

Analysis

Your individual submission should be only a PDF of your analysis. Files in any other format will receive a zero.