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1  (*
2           CS51 Lab D
3           Improving Debugging Skills
4  *)
5
6  (*=====
7 Readings:
8
9     This lab has no prerequisite textbook reading.
10
11 Objective: In this lab, you'll improve your debugging skills by
12 applying fundamental debugging ideas to improving code.
13
14     In the exercises that follow, some functions may have bugs, so that
15     their behavior may not match the intended behavior described in the
16     comments. Your job is to find and fix all of the bugs.
17 =====)
18
19 (*=====
20 Part 0: Important aspects of debugging
21
22 You may not have thought explicitly about the debugging process, but
23 doing so can provide you with valuable skills in the process. Here are
24 some of the major aspects of the debugging process.
25
26 Identification
27
28     Read error messages in detail. They often provide not just the
29     nature of the error, but an approximate location.
30
31     Set up unit tests for individual functions. Unit tests can
32     identify bugs in your code by finding cases that don't match
33     the behavior you intended. Try to specify unit test cases that
34     cover all of the important paths through the code. A good
35     technique is to put the unit tests in a separate file that
36     references the file with the functions to be tested. Then,
37     whenever you make changes to the functions, you can rerun the
38     test file to make sure that you haven't introduced bugs in
39     previously working code.
40
41 Localization
42
43     When you first identify a bug, you may not know where in the
44     code base the bug actually lives. You'll need to localize the
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45     bug -- finding its location in the code base.  
46  
47     In tracking down problems in larger codebases, eliminate  
48     portions of the code to generate the minimal codebase that  
49     demonstrates the problem. Breaking the code into smaller parts  
50     can allow localization to one of the parts, as they can be  
51     unit-tested separately.  
52  
53     Simplification  
54  
55     When confronted with an error exhibited on a large instance,  
56     try to simplify it to find the minimal example that exhibits  
57     the problem.  
58  
59     Reproduction  
60  
61     Try alternate examples to see which ones exhibit the problem.  
62     The commonalities among the examples that exhibit the problem  
63     can give clues as to the problem.  
64  
65     Diagnosis  
66  
67     Verify that invariants that should hold in the code actually  
68     do, with assertions or other constructs. (The `Absbook.verify`  
69     function can be especially useful in verifying invariants of  
70     the arguments and return value.) Conduct experiments  
71     to test your theory of what has gone wrong.  
72  
73     Correction  
74  
75     Generate git commits to save a version of the code so that you  
76     can confidently make changes to the code while you are  
77     experimenting, knowing that you'll be able to return to  
78     earlier versions.  
79  
80     Maintenance  
81  
82     Code that was once working can become buggy as changes are  
83     made either to the code itself or to code that it uses. It's  
84     thus helpful to retest code when changes are made to it or its  
85     environment. Fortunately, unit test files are ideal for this  
86     process. Rerunning the unit tests liberally allows us to  
87     verify that working code hasn't regressed to a buggy state.  
88     (The process is referred to in the literature as "regression  
89     testing" for this reason. See  
90     <https://en.wikipedia.org/wiki/Regression\_testing>.)
```

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91      *)
92
93
94 (*=====
95 Part 1: Some finger exercises in debugging
96
97 In this part, we'll provide implementations of a few simple
98 functions. These functions may or may not have bugs in them. You'll
99 proceed through four steps:
100
101 1. Read the function definition, including the top-level comment, to
102    give you an idea of what the function is intended to do.
103
104 2. Write a full set of unit tests for each of the functions in the
105    file 'part1_tests.ml'. The comments introducing each function may
106    give information about the intended behavior of each function.
107
108 3. Once you've written all of the unit tests, compile and run the
109    unit tests
110
111     % ocamlbuild -use-ocamlfind part1tests.byte
112     % ./part1tests.byte
113
114 4. For each of the functions, find a value for the function's
115    argument that expresses the bug, if there is one. (If you've built
116    your unit tests well, they should uncover such a value directly.)
117    Record the bug-inducing value by let-defining the corresponding
118    '-bug' value to be 'Some v' where 'v' is the bug-inducing value if
119    there is one, or 'None' if the function is not buggy.
120
121 5. Revise each function to eliminate any bugs that you found. While
122    you're at it, you should probably deal with any warnings that
123    arise as well.
124
125 We've done the first of these exercises, the 'abs' function, for you
126 to give you the idea.
127
128 1. ORIGINAL VERSION
129
130 (* abs x -- Returns the absolute value of the integer 'x' *)
131 let abs x =
132     if x < ~-1 then ~- x else x
133
134 2. UNIT TESTS (These would be added to 'part1tests.ml'.)
135
136 unit_test (abs 0 = 0) "abs zero";

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137     unit_test (abs 1 = 1) "abs one";
138     unit_test (abs max_int = max_int) "abs maxint";
139     unit_test (abs min_int = min_int) "abs minint";
140     unit_test (abs (-0) = 0) "abs zero";
141     unit_test (abs (-1) = 1) "abs neg one";
142     unit_test (abs (-max_int) = max_int) "abs neg maxint";
143     unit_test (abs (-min_int) = min_int) "abs neg minint";

144
145     3. COMPILE AND RUN

146
147     % ocamlbuild -use-ocamlfind part1tests.byte
148     % ./part1tests.byte
149     ...
150     abs zero passed
151     abs one passed
152     abs maxint passed
153     abs minint passed
154     abs zero passed
155     abs neg one FAILED      <-- This'll be helpful!
156     abs neg maxint passed
157     abs neg minint passed
158     ...
159     - : unit = ()

160
161     3. BUGGY VALUE

162
163     let abs_bug = -1

164
165     4. REVISED VERSION

166
167     (* abs x -- Returns the absolute value of the integer `x` *)
168     let abs x =
169         if x < 0 then ~- x else x
170     *)

171
172     (*.....*)
173     (* last_element lst -- Returns the last element of `lst` as an option;
174        'None' if there is no last element *)
175     let rec last_element lst =
176         match lst with
177         | [] -> None
178         | [x] -> Some x
179         | _ :: tail -> last_element (List.tl tail)

180
181     let last_element_bug = failwith "last_element_bug not defined"
182

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```
183 (*.....*)
184 (* sum_to_n n -- Returns the sum of integers from 1 to `n` *)
185 let rec sum_to_n n =
186   if n = 0 then n
187   else n + sum_to_n (n - 1)
188
189 let sum_to_n_bug = failwith "sum_to_n_bug not defined"
190
191 (*.....*)
192 let describe_list lst =
193   match lst with
194   | [] -> "Empty list"
195   | _ :: _ -> "Multiple list"
196   | [x] -> "Singleton list"
197
198 let describe_list_bug = failwith "describe_list_bug not defined"
199
200 (*=====
201 Part 2: Debugging set operations
202
203 In this part, you will apply your debugging skills to debugging an
204 implementation of set operations (union, intersection, etc.).
205
206 ****
207 In this lab, sets of integers will be represented as `int list`s
208 whose elements are in *sorted order* with *no duplicates*. All
209 functions can assume this invariant and should deliver results
210 satisfying it as well.
211 ****
212
213 To get you started on debugging, we've placed a few unit tests for
214 some of the functions in the file `part2_tests.ml`. Compile and run
215 these tests to see how the functions are working so far.
216
217 % ocamlbuild -use-ocamlfind part2_tests.byte
218 % ./part2_tests.byte
219
220 What do you notice? Does this give you an idea on where to start
221 debugging?
222
223 =====
224 Part 2A: Some utilities for checking the sorting and no-duplicates
225 conditions.
226 *)
227
228 (* is_sorted lst -- Returns 'true' if and only if `lst` is a sorted
```

```

229     list *)
230 let is_sorted (lst : 'a list) : bool =
231   lst = List.sort Stdlib.compare lst ;;
232
233 (* dups_sorted lst -- Returns the number of duplicate elements in
234   `lst`, a sorted list of integers. For example
235
236   # dups_sorted [1;2;5;5;5;5;5;5;6;7;7;9] ;;
237   - : int = 6
238 *)
239 let rec dups_sorted (lst : 'a list) : int =
240   match lst with
241   | [] -> 0
242   | [_] -> 0
243   | first :: second :: rest ->
244     if first = second then 1 else 0
245     + dups_sorted rest
246
247 (* HINT: The `dups_sorted` function already fails two of the tests in
248   the testing file `part2_tests.ml`. Examine the failing cases one at
249   a time. What is it about the first case that causes it to fail? Can
250   you find a simpler case that fails? What is the minimal example
251   that fails? Does that help you repair the first buggy test case?
252   Then turn your attention to the second case. Did you fix that bug
253   too, or is it still around? If it's still around, you'll need to
254   fix that too. *)
255
256 (* is_set lst -- Returns `true` if and only if lst represents a set,
257   with no duplicates and elements in sorted order. *)
258 let is_set (lst : 'a list) : bool =
259   is_sorted lst && dups_sorted lst = 0 ;;
260
261 =====
262 Part 2B: Set operations -- member, union, and intersection
263
264 Below we provide code for computing membership, intersections, and
265 unions of sets represented by lists with the stated invariant.
266
267 Check out the unit tests for these in `part2_tests.ml`. Augment the
268 tests until you're satisfied that you've fully tested these functions,
269 making any needed changes as you go.
270
271 We'll test them further on larger examples in the next part, Part
272 2C. *)
273
274 (* member elt set -- Returns `true` if and only if `elt` is an element

```

```

275     of `set` (represented as above). Search can stop early based on
276     sortedness of `set`. *)
277 let rec member elt set =
278   match set with
279   | [] -> false
280   | hd :: tl ->
281     if elt = hd then true
282     else if elt < hd then false
283     else member elt tl ;;
284
285 (* union set1 set2 -- Returns a list representing the union of the
286   sets `set1` and `set2` *)
287 let rec union s1 s2 =
288   match s1, s2 with
289   | [], [] -> []
290   | _hd :: _tl, [] -> s1
291   | [], _hd :: _tl -> s2
292   | hd1 :: tl1, hd2 :: tl2 ->
293     if hd1 < hd2 then
294       hd1 :: union tl1 s2
295     else
296       hd2 :: union tl2 s1 ;;
297
298 (* HINT: This function has no tests in the testing file. Maybe you
299 should add some. *)
300
301 (* intersection set1 set2 -- Returns a list representing the
302   intersection of the sets `set1` and `set2` *)
303 let rec intersection s1 s2 =
304   match s1, s2 with
305   | [], _ -> []
306   | _, [] -> []
307   | hd1 :: tl1, hd2 :: tl2 ->
308     if hd1 = hd2 then hd1 :: intersection tl1 tl2
309     else if hd1 > hd2 then intersection tl1 s2
310     else intersection s1 tl2 ;;
311
312 (*=====
313 Part 2C: Scaling up the testing
314
315 The file `labD_examples` contains a couple of larger examples of sets
316 represented as lists (`example1` and `example2`). The `part2_tests.ml`
317 file contains a few tests based on these larger examples, which are
318 commented out at the moment. Uncomment them now and rerun the unit
319 tests. What do you notice?
320
```

321 More bugs to debug. Where do you think the problems lie? Remaining  
322 bugs in the functions above? In the examples? In the tests themselves?  
323  
324 You're on your own to figure out what's going on and correct the  
325 problems, wherever they might be.  
326 \*)