CIS 1200 Midterm II March 28, 2025

SOLUTIONS

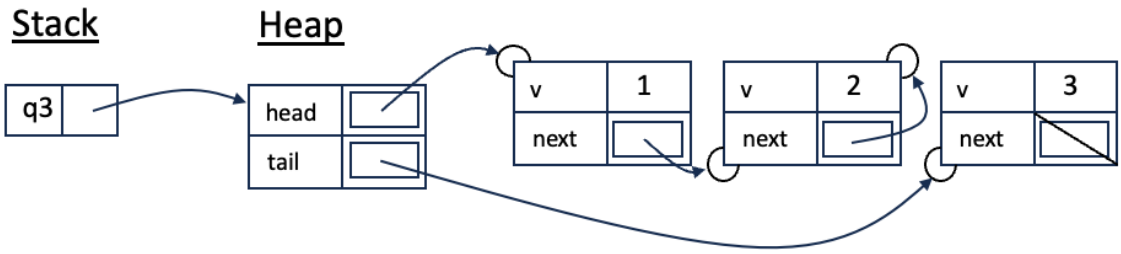
1. **Programming with Linked Queues** (44 points total)

   Recall the type definitions of the queue data structure:

```
type 'a qnode = { v: 'a;
                  mutable next: 'a qnode option }


type 'a queue = { mutable head: 'a qnode option;
                  mutable tail: 'a qnode option }
```

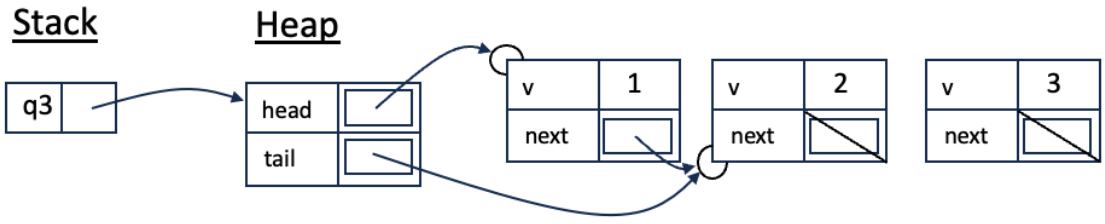
   We define an *almost-queue* to be a queue that contains a cycle. Here is an example:



   The goal for this problem is to define a function, called `remove_cycle`, that can convert an *almost-queue* to be a valid queue by truncating the queue at the problematic spot. (When given a *valid* queue, `remove_cycle` should not modify its argument.)

```
val remove_cycle : 'a queue -> unit
```

   After a call to `remove_cycle`, the first node in the queue that refers to itself or to any earlier node should be the *last* node in the queue. For example, calling `remove_cycle` with the queue above could result in the following ASM configuration.



1.1 (4 points) Recall the representation invariant for linked queues:

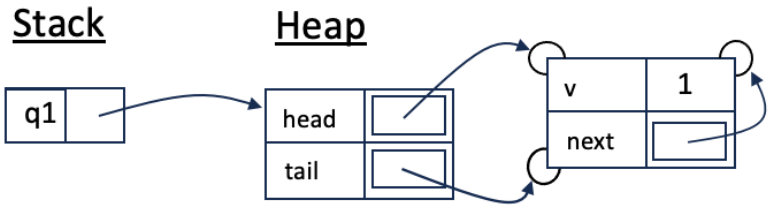
(1) `head` and `tail` are both tagged `None` or both tagged `Some`, and

(2) if `head = Some h` and `tail = Some t`, then

(2a) `t` is reachable from `h` by following `next` pointers

(2b) `t.next = None`

What part of this invariant does the *almost-queue* `q1` (shown below) break, if any? (Select "Valid" if no invariants are broken.)



☐ (1) ☐ (2a) ☒ (2b) ☐ This queue is valid.

1.2 (10 points) Define the function `make_q1` that, when called, returns a queue that looks like `q1`. In other words, placing **`let`** `q1 = make_q1 ()` on the workspace should produce the stack and heap diagram shown above.

```
let make_q1 () : int queue =
      let q1n = { v = 1 ; next = None } in
      q1n.next <- Some q1n ;
      { head = Some q1n ; tail = Some q1n }
```

Consider the function `contains_qn`, shown below. When given a `'a qnode` and `'a qnode list`, this function returns **`true`** if the `'a qnode` is present within the list and **`false`** otherwise.

```
let rec contains_qn (e : 'a qnode) (l : 'a qnode list)  : bool =
  begin match l with
  | [] -> false
  | hd :: tl -> if e == hd then true else contains_qn e tl
  end
```

1.3 (4 points) Complete the following test case for `contains_qn`:

```
let test () : bool =
  let qn1 = { v = 1 ; next = None } in
  let qn2 = qn1 in
  let qn3 = { v = 3 ; next = Some qn1 } in

  contains_qn qn1 [ qn2 ; qn3 ] =  true
```

1.4 (5 points) Is `contains_qn` tail recursive?

☐ Tail Recursive ☐ Not Tail Recursive

1.5 (5 points) Now consider a mystery function that works with queues. Don't try to understand what this function does. Is this function tail recursive?

```
let mystery (q : bool queue) : bool =
   let rec loop (qno : bool qnode option) : bool =
      begin match qno with
      | None -> true
      | Some qn -> loop qn.next && qn.v
      end in
   loop q.head
```

☐ Tail Recursive ☒ Not Tail Recursive

1.6 (16 points) Now complete the implementation of `remove_cycle`. We have given you a start by defining the `loop` that traverses each node in the queue. This loop maintains a list of `qnodes` that have been previously encountered. If you encounter a `qnode` that is already contained in the list, then you have found a cycle!

In your solution, you may use `contains_qn` but no other library functions.

```
(* Given an almost-queue with a cycle, correct the queue by truncating
it when the first repeated element appears. *)
let remove_cycle (q: 'a queue) : unit =
let rec loop (qno: 'a qnode option) (l: 'a qnode list) =
  begin match qno with
  | None -> ()
  | Some qn ->
     (* look at following node *)
     begin match qn.next with
     | None -> ()
     | Some next_qn ->
```

```
        if contains_qn next_qn l then
          (* found a cycle, truncate queue *)
          (qn.next <- None; q.tail <- Some qn)
        else
          (* loop to next node, remembering this one *)
          loop qn.next (qn :: l)
```

```
     end
  end in
loop  q.head    []
```

2. **GUI library and Reactive Programming** (32 points total)

Suppose we would like to add a simple clock (a circle with an "hour hand" indicating the current time) to the widget library from homework 5. For example, Figure 1 shows clocks set at two different times: noon and five o'clock.

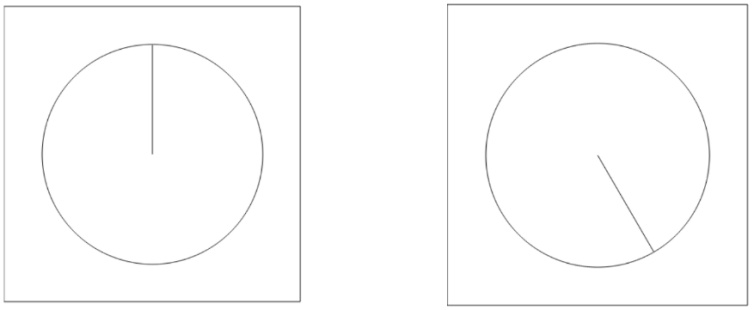


Figure 1: Clock widget at 12 o'clock (left) and 5 o'clock (right)

To do so, we will add a "clock constructor," with the following type to `widget.mli`:

```
val clock : int -> widget * notifier_controller * int value_controller
```

When given an initial time (a number between 1 and 12, inclusive) this function creates a clock widget plus a way to add event listeners to the clock widget (using a notifier controller) and a way to add change listeners for the clock's time (using a value controller).

First, let's make sure that you understand the widget library. The following problem refers to the implementation of the `notifier` widget, reprinted in Appendix C.

2.1 (4 points) What is the type of the anonymous function defined on lines 12–14:

`event_listener` or `Gctx.gctx -> Gctx.event -> unit`

2.2 (4 points) When allocated in the heap, the closure for the anonymous function defined on lines 12–14, must include copies of the stack bindings for which of the following:

☒ `w` ☒ `listeners` ☐ `contents` ☐ `List.iter` ☐ `g` ☐ `e`

2.3 (14 points) Implement `clock`. For reference, the interface for the `Gctx` library appears in Appendix A and you may assume that `;; open Gctx` appears at the top of the module.

You should draw the clock as a 150×150 pixel ellipse centered in a 400×400 pixel canvas as the "clock face", plus a line from the center to the edge as the "clock hand". In your code, you may use `find_endpoint`, declared below. (You not need to implement this function.)

```
(* Calculate the correct position of the end of the "clock hand" at
   a given time. This position is a point on the circumference
   of a radius 150 circle centered at location (200,200). *)
let find_endpoint (time: int) : Gctx.position = ...

(** Create a clock widget *)
let clock (init : int) :
          widget * notifier_controller * int value_controller =

    (* value controller for the time *)
    let time = make_controller (init mod 12) in

    (* draw the clock face and clock hand *)
    let repaint (g : Gctx.gctx) : unit =
      let c : Gctx.position = (200,200) in  (* center *)
      let r : int = 150 in                  (* radius *)

      Gctx.draw_ellipse g c r r ;
      Gctx.draw_line g c (find_endpoint (time.get_value ()))
    in

    (* create the clock widget and its notifier controller *)
    let clock_w, nc =
       canvas (400, 400) repaint  in

    (* return the appropriate values *)
    (clock_w, nc, time)
```

Now, consider how a client might *use* the clock in an application. For reference, an excerpt of the `Widget` library interface appears in Appendix B. You may assume that `;; open Widget` appears at the top of the module.

2.4 (10 points) Say we would like to simulate an alarm clock. For example, let's create a label and put it next to the clock widget:

```
let clock_w, nc, vc = clock 12
let label_w, lc = label "Zzzzz"
let top = hpair clock_w (hpair (space (10,10)) label_w)
```

Use the clock's value controller below to make it so that when the time reaches 5, the label's string changes from `"Zzzzz"` to `"Wake up"`. (You do not need to change the string at any other time.)

```
vc.add_change_listener (fun x ->
   if x = 5 then lc.set_text "Wake up")
```

3. **Java arrays and strings** (20 points total)

The following questions refer to Java's `String` class. An excerpt of the documentation for this class is shown in Appendix D.

3.1 (4 points) What happens when the following code is executed in Java? (Select one.)

```
String[] s = {};
int result = s.length;
```

- ☒ The `s.length` expression returns 0.
- ☐ The expression `s.length` is skipped.
- ☐ A `NullPointerException` is thrown.
- ☐ The program does not compile.
- ☐ None of the above.

3.2 (4 points) What happens when the following code is executed in Java? (Select one.)

```
String s1 = "Java";
String s2 = new String("Java");
System.out.println(s1.equals(s2));
```

- ☒ The program prints **`true`**.
- ☐ The program prints **`false`**.
- ☐ The program prints `null`.
- ☐ The program does not compile.
- ☐ None of the above.

3.3 (4 points) What happens when the following code is executed in Java? (Select one.)

```
String s1 = "Java";
char[] a1 = s1.toCharArray();
char[] a2 = { 'J', 'a', 'v', 'a' };
System.out.println(a1 == a2);
```

- ☐ The program prints **`true`**.
- ☒ The program prints **`false`**.
- ☐ The program prints `null`.
- ☐ The program does not compile.
- ☐ None of the above.

3.4 (4 points) What happens when the following code is executed in Java? (Select one.)

```
String[] arr = { "Java", "OCaml"};
String last = arr[arr.length];
System.out.println(last);
```

- ☐ The program prints `"OCaml"`.
- ☐ The program prints `2`.
- ☐ The program prints `null`.
- ☒ An `ArrayIndexOutOfBoundsException` is thrown.
- ☐ None of the above.

3.5 (4 points) Which of the following is a valid way of creating a Java array with values `"1"`, `"2"`, and `"3"`? (Select all that apply, or "None of the above".)

- ☒ `String[] arr = {"1", "2", "3"};`
- ☐ `String arr = new String(new char[]{'1', '2', '3'});`
- ☐ `String[] arr = new int[]{1, 2, 3};`
- ☒ `String[] arr = { new String("1"), new String("2"), new String("3")};`
- ☐ None of the above.

4. **Programming with Java Arrays** (24 points total)

   Recall that in Java, two dimensional arrays are represented as arrays of arrays. This means that in a 2D array of type `int[][]` there is no guarantee that the inner arrays are all the same length, or even nonnull.

   For this problem, you will write a static function, called `extractRectangle` that copies a rectangular section starting from the upper-left corner of some input array.

```
/* Copy a rectangular array of size h * w from the input, starting at
   the upper left corner. Returns null if any part of the input is null,
   h or w is negative, or if the input array does not contain enough
   values. */
public static int[][] extractRectangle(int h, int w, int[][] input);
```

   For example, the following test case demonstrates what happens when a rectangle can be extracted.

```
@Test
public void testExtractRectangle_validInput() {
    int[][] input = {
            {1, 2, 3},
            {4},
            {7, 8, 9, 10}
    };
    int[][] expected = {
            {1},  // truncate first row
            {4}   // copy entire second row
                  // omit third row
    };
    assertArrayEquals(expected, Exam.extractRectangle(2, 1, input));
}
```

   And this test case demonstrates that the copy needs to start at the upper left corner. The method returns `null` because there are not enough values in the first row of the array.

```
@Test
public void testExtractRectangle_tooSmall() {
    int[][] input = {
            {1, 2},    // need to have 3 values, but only 2 present
            {4, 5, 6},
            {7, 8, 9}
    };
    assertNull(Exam.extractRectangle(2, 3, input));
}
```

4.1 (4 points) Fill in the expected result when a zero-by-zero rectangle is requested. (This should be a 2D array of size 0×0.)

```
@Test
public void testRectangle0() {
    int[][] input = {
        {1, 2},
        {4, 5, 6},
        {7, 8, 9, 10}
    };
    int[][] expected =
        {}

    assertArrayEquals(expected, Main.extractRectangle(0, 0, input));
}
```

4.2 (4 points) Complete a test case that demonstrates when the function should return **`null`** when requesting a zero-by-zero rectangle.

```
@Test
public void testRectangle1() {

    int[][] input =
        null
    ;

    assertNull(Main.extractRectangle(0,0,input));
}
```

4.3 (16 points) Now implement the method. Your method should never throw an `ArrayIndexOutOfBounds` exception or a `NullPointerException`. If either of these would happen, the method should return `null` instead.

```
public static int[][] extractRectangle(int h, int w, int[][] input) {
    if (input == null || w < 0 || h < 0 || h > input.length) {
        return null;
    }
    int[][] output = new int[h][w];
    for (int i = 0; i < h; i++) {
        // make sure the row is not null and has enough values
        if (input[i] == null || w > input[i].length ) {
            return null;
        }
        // copy the prefix of the row
        for (int j = 0; j < w; j++) {
            output[i][j] = input[i][j];
        }
    }
    // make sure none of the remaining rows are null
    for (int i = h; i < input.length; i++) {
        if (input[i] == null) {
            return null;
        }
    }
    return output;
}
```

Scratch Space

*Use this page for work that you do not want us to grade. If you run out of space elsewhere in the exam and you **do** want to put something here that we should grade, make sure to put a clear note in the normal answer space for the problem in question.*

A Appendix: GUI Gctx interface (excerpt)

```
(** A widget-relative position *)
type position = int * int

(** A width and height paired together. *)
type dimension = int * int

(** Display text at the given position *)
val draw_string : gctx -> position -> string -> unit

(** Draw a line between the two specified positions *)
val draw_line : gctx -> position -> position -> unit

(** Draw an ellipse, centered at position with given x and y radii. *)
val draw_ellipse : gctx -> position -> int -> int -> unit
```

B Appendix: GUI Widget Interface (excerpt)

```
(* Widget *)

type widget = {
  repaint : Gctx.gctx -> unit;
  handle : Gctx.gctx -> Gctx.event -> unit;
  size : unit -> Gctx.dimension;
}

(** A horizontal group of widgets *)
val hlist : widget list -> widget

(****************************************)
(** {1 Label Widgets }                  *)
(****************************************)

(** A record of functions that allows us to read and write the string
associated with a label. *)
type label_controller = { get_label : unit -> string;
  set_label : string -> unit }

(****************************************)
(** {1 Event Listeners }                *)
(****************************************)

(** An event listener processes events as they "flow" through
the widget hierarchy. *)
type event_listener = Gctx.gctx -> Gctx.event -> unit

(** Performs an action upon receiving a mouse click. *)
val mouseclick_listener : (unit -> unit) -> event_listener
```

```
(****************************************)
(** {2 Notifier }                       *)
(****************************************)

(** A notifier_controller is associated with a notifier widget.
It allows the program to add event listeners to the notifier.*)

type notifier_controller = { add_event_listener : event_listener -> unit; }

val notifier : widget -> widget * notifier_controller

(****************************************)
(** {3 Canvas }                         *)
(****************************************)

(** A widget that allows drawing to a graphics context *)

(** Canvases are just widgets with an associated notifier_controller.
   The repaint method of a canvas is a parameter of the widget
   constructor.*)
val bare_canvas : Gctx.dimension -> (Gctx.gctx -> unit) -> widget
val canvas      : Gctx.dimension -> (Gctx.gctx -> unit) ->
                                        widget * notifier_controller

(****************************************)
(** {4   Value controller             } *)
(****************************************)

(** A controller for a value associated with a widget.

    This controller can read and write the value. It also allows
    change listeners to be registered by the application. These listeners are
    run whenever this value is set. *)
type 'a value_controller = {
  add_change_listener : ('a -> unit) -> unit;
  get_value           : unit -> 'a;
  change_value        : 'a -> unit
  }

(** A utility function for creating a value_controller. *)
val make_controller : 'a -> 'a value_controller
```

C Appendix: Notifier widget implementation

This code uses the following function from the `List` library.

```
val iter : ('a -> unit) -> 'a list -> unit
```

```
1  (** A notifier widget is a widget "wrapper" that doesn't take up any
2     extra screen space -- it extends an existing widget with the
3     ability to react to events. It maintains a list of of
4     event_listeners that eavesdrop on the events propagated through the
5     notifier widget.
6     When an event comes in to the notifier, it is passed to each
7     event_listener in turn, and then passed to the child widget. *)
8  let notifier (w: widget) : widget * notifier_controller =
9    let listeners = {contents = []} in {
10     repaint = w.repaint;
11     handle =
12       (fun (g: Gctx.gctx) (e: Gctx.event) ->
13          List.iter (fun h -> h g e) listeners.contents;
14          w.handle g e);
15     size = w.size
16   },{
17     add_event_listener =
18       fun (newl: event_listener) ->
19         listeners.contents <- newl :: listeners.contents
20   }
```

D Appendix: Java String class documentation

Constructors	
`String(String original)`	Initializes a newly created `String` object so that it represents the same sequence of characters as the argument; in other words, the newly created string is a copy of the argument string.
`String(char[] value)`	Allocates a new String so that it represents the sequence of characters currently contained in the character array argument.
Methods	
`int` `length()`	Returns the length of this string.
`char``[] toCharArray()`	Converts this string to a new character array.
`boolean` `equals(Object obj)`	Compares this string to the specified object. The result is true if and only if the argument is not null and is a String object that represents the same sequence of characters as this object.