15-122: Principles of Imperative Computation, Spring 2024

Written Homework 5

Due on Gradescope: Monday 12th February, 2024 by 9pm

Name: ____

Andrew ID: ____

Section: ____

This written homework covers pointers, interfaces, and stacks and queues.

This is the first homework to emphasize interfaces. It's important for you to think carefully and be sure that your solutions respect the interface involved in the problem.

Preparing your Submission You can prepare your submission with any PDF editor that you like. Here are a few that prior-semester students recommended:

- **Kami**, **Adobe Acrobat Online**, or ***DocHub***, some web-based PDF editors that work from anywhere.
- ***Acrobat Pro***, installed on all non-CS cluster machines, works on many platforms.
- ***iAnnotate*** works on any iOS and Android mobile device.

There are many more — use whatever works best for you. If you'd rather not edit a PDF, you can always print this homework, write your answers *neatly* by hand, and scan it into a PDF file — *we don't recommend this option, though.*

Please do not add, remove or reorder pages.

Caution Recent versions of Preview on Mac are buggy: annotations get occasionally deleted for no reason. **Do not use Preview as a PDF editor.**

Submitting your Work Once you are done, submit this assignment on Gradescope. ***Always check it was correctly uploaded.*** You have unlimited submissions.

Question:	1	2	3	Total
Points:	4	6	2.5	12.5
Score:				

1. **Pointer Illustration**

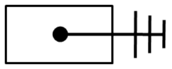
2pts

1.1 Clearly and carefully illustrate the contents of memory after the following code runs. Be explicit about default values and field names. We've drawn the contents of w, a pointer that points into allocated memory where the number 0 is stored.

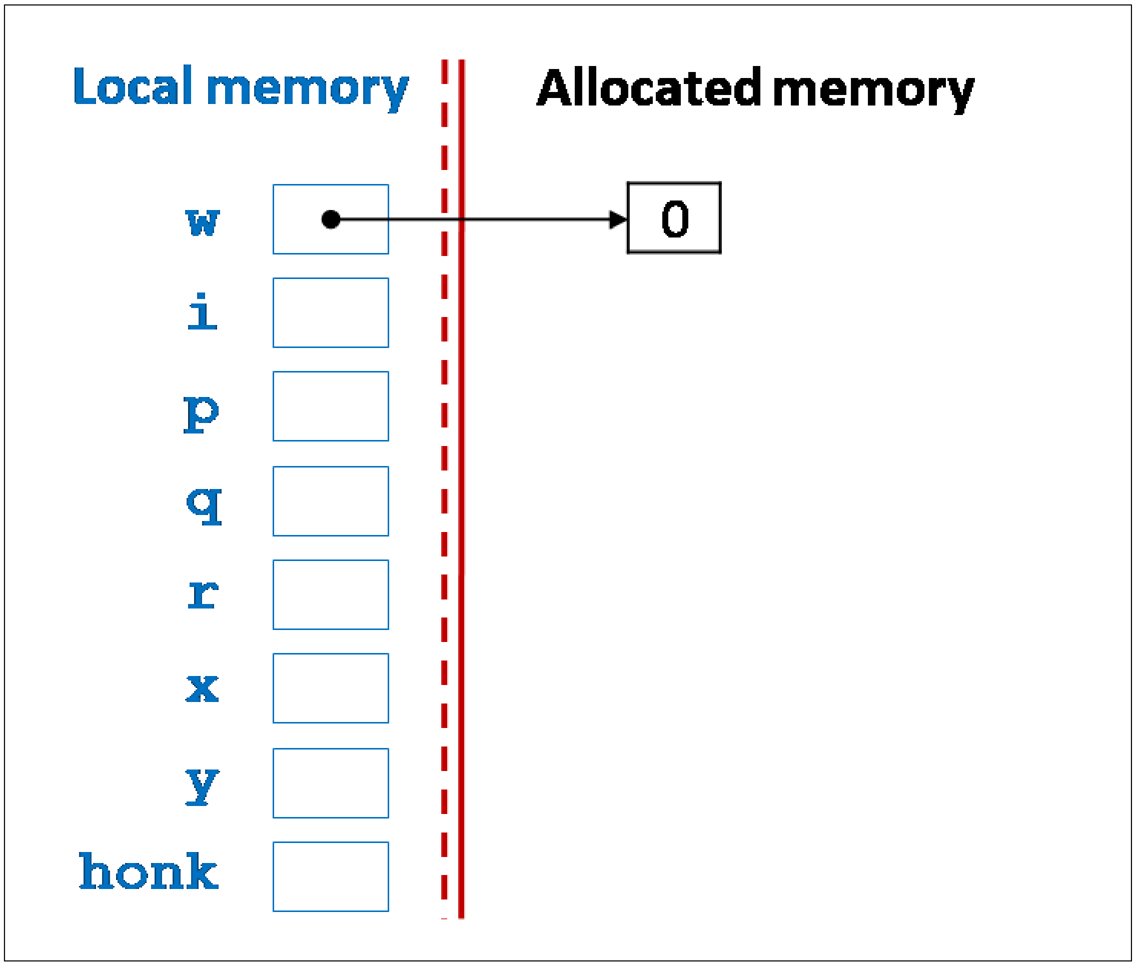
```
struct mascot {
  string name;
  int* age;
};

int main() {
  int* w = alloc(int);
  int i = -3;
  int* p = alloc(int);
  int* q = p;
  int* r = alloc(int);
  int** x = alloc(int*);
  int** y = x;
  struct mascot* honk = alloc(struct mascot);
  // ... to be continued ...
```

You may draw a variable or memory location containing NULL either as



or as

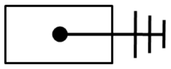


2pts

1.2 The code in the previous task continues as follows:

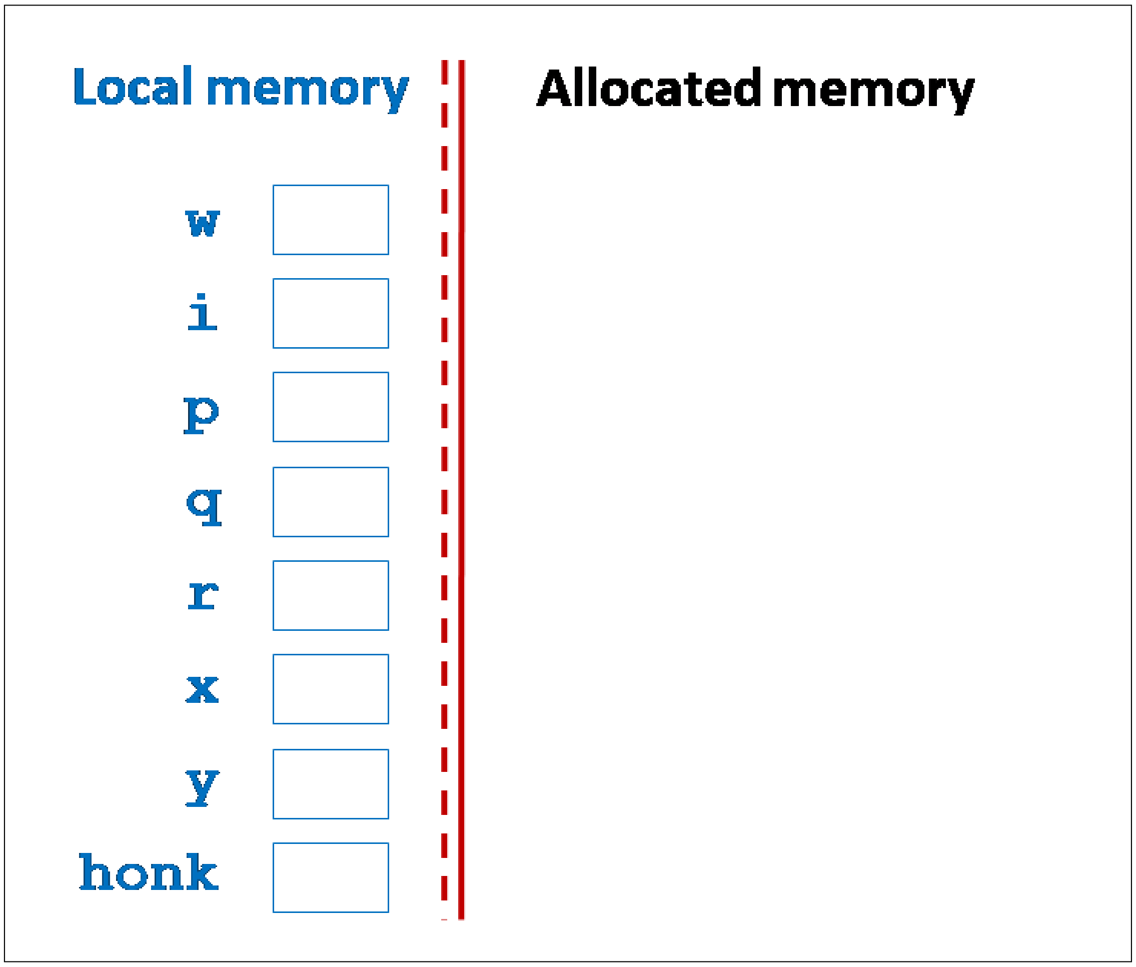
```
  // Continued from the previous task
  *r = i + 7;
  *x = q;
  **y = *r - i;
  p = NULL;
  honk->age = r;
  i = *q + **x + *w;
  return 0;
}
```

You may draw a variable or memory location containing `NULL` either as



or as

Update the diagram you drew in the previous task to show the state of memory as the function returns.



2. **Implementing an Image Type Using a Struct**

   In a previous programming assignment, you implemented image manipulations that passed around an array of pixels together with a width and a height as a representation of an image.

   In this question, we want to write a library that packages an abstract type of images (`image_t`) and some basic operations to work with them. Your first job is to complete the interface of this library. Your interface should support *any representation* of images (not just the one you saw in the programming assignment). Some constraints on what constitutes a valid image:

   - neither the width nor the height of the image could be 0,
   - their product should be at most `int_max()`.

   You may assume the client has access to the pixel interface and some basic image utility functions reproduced in appendices A and B at the end of this homework. Feel free to use the added function `pixel_equal` if you need it.

1pt **2.1** Complete the interface for the image data type. Add appropriate preconditions and postconditions for each image operation to ensure the client can't use the interface unsafely. The postconditions should give the client enough information to prove the safety of subsequent calls. *(You may not need all the lines we provided.)*

```
// typedef ______* image_t;


__________ image_getwidth(___________________________________)

    __________________________________________________________

    __________________________________________________________

    __________________________________________________________


__________ image_getheight(__________________________________)

    __________________________________________________________

    __________________________________________________________

    __________________________________________________________
```

1pt **2.2** (Continued)

```
__________ image_getpixel(image_t A, int r, int c)
```

```
void image_setpixel(image_t A, int r, int c, pixel_t q)
```

1pt **2.3** (Continued)

```
__________ image_new(__________ w, __________ h)
```

In the implementation of the image data type, we have the following concrete type definitions:

```
struct image_header {
    int width;
    int height;
    pixel_t[] data;
};
typedef struct image_header image;
typedef image* image_t;
```

And the following data structure invariant:

```
bool is_image(image* A) {
  return A != NULL
      && A->width > 0
      && A->height > 0
      && A->width <= int_max() / A->height
      && is_arr_expected_length(A->data, A->width * A->height);
}
```

The client does not need to know about this function, since it is the job of the implementation to preserve the validity of the image data structure. But the implementation must use this specification function to assure that the image is valid before and after any image operation.

Note that the type `pixel_t` is abstract and can only be manipulated using the functions listed in Appendix A.

1.5pts

2.4 Write an implementation for `image_setpixel`, assuming pixels are stored in the pixel array in the exact same way they were stored in the programming assignment. Include any necessary preconditions and postconditions for the implementation.

1.5pts

2.5 Write an implementation for `image_getheight`. Include any necessary preconditions and postconditions for the implementation.

3. **Stacks, Queues, and Interfaces**

1pt **3.1** Consider the following interface for `stack_t` that stores elements of type `string`:

```
/* Stack Interface */
// typedef ______* stack_t;

bool stack_empty(stack_t S)  /* O(1), check if stack empty */
/*@requires S != NULL; @*/;

stack_t stack_new()          /* O(1), create new empty stack */
/*@ensures \result != NULL; @*/
/*@ensures stack_empty(\result); @*/;

void push(stack_t S, string x) /* O(1), add item on top of stack */
/*@requires S != NULL; @*/;

string pop(stack_t S)          /* O(1), remove item from top */
/*@requires S != NULL; @*/
/*@requires !stack_empty(S); @*/
```

Write a client function `stack_bottom(stack_t S)` that returns the bottom element of the given stack, assuming the stack is not empty. The final stack should be identical to the initial stack. For this task, use only the interface since, as a client, you do not know how this data structure is implemented. Do not use any stack functions that are not in the interface (including specification functions like `is_stack` since these belong to the implementation).

```
string stack_bottom(stack_t S)
//@requires S != NULL;
//@requires !stack_empty(S);
{



}
```

Below is the queue interface from lecture (with elements of type `string`).

```
// typedef ______* queue_t;

bool queue_empty(queue_t Q)          /* O(1) */
/*@requires Q != NULL; @*/;

queue_t queue_new()                  /* O(1) */
/*@ensures \result != NULL; @*/
/*@ensures queue_empty(\result); @*/;

void enq(queue_t Q, string e)          /* O(1) */
/*@requires Q != NULL; @*/;

string deq(queue_t Q)                  /* O(1) */
/*@requires Q != NULL; @*/
/*@requires !queue_empty(Q); @*/ ;
```

The following is a client function `queue_size` that is intended to compute the size of the queue while leaving the queue unchanged.

```
int queue_size(queue_t Q)
//@requires Q != NULL;
//@ensures \result >= 0;
{
  int size = 0;
  queue_t C = Q;
  while (!queue_empty(Q)) {
    enq(C, deq(Q));
    size++;
  }
  while (!queue_empty(C)) enq(Q, deq(C));
  return size;
}
```

0.5pts

3.2 In one or two sentences, explain why `queue_size` does not work.

1pt **3.3** Give a corrected version of `queue_size`.

```
int queue_size(queue_t Q)
//@requires Q != NULL;
//@ensures \result >= 0;
{
















}
```

A Appendix: the pixel interface

See your *pixels* programming assignment for the contracts these functions obey and what they do. However, *don't assume the implementation in the assignment*.

```
// typedef _______ pixel_t;

int get_red(pixel_t p);
int get_green(pixel_t p);
int get_blue(pixel_t p);
int get_alpha(pixel_t p);

pixel_t make_pixel(int alpha, int red, int green, int blue);

// Returns true if p and q are the same pixel, false otherwise
bool pixel_equal(pixel_t p, pixel_t q);  // ADDED
```

B Appendix: image utility functions — `imageutil.c0`

See your *images* programming assignment for the contracts these functions obey and what they do. However, *don't assume the implementation in the assignment*.

```
bool is_valid_imagesize(int width, int height);

int get_row(int index, int width, int height);
int get_column(int index, int width, int height);

bool is_valid_pixel(int row, int col, int width, int height);

int get_index(int row, int col, int width, int height);
```