Question 3: It's Fight or FLIGHT [24 pts]

We're rewriting airport software to help the good folks at Sea-Tac keep track of flights. We will use the following typedef-ed structs:

```
typedef struct t {
  size_t hr;   // 0-23
  size_t min;  // 0-59
} Time;
```

```
typedef struct f {
  char *dest;  // destination airport
  Time dep;    // departure time
  Time arr;    // arrival time
} Flight;
```

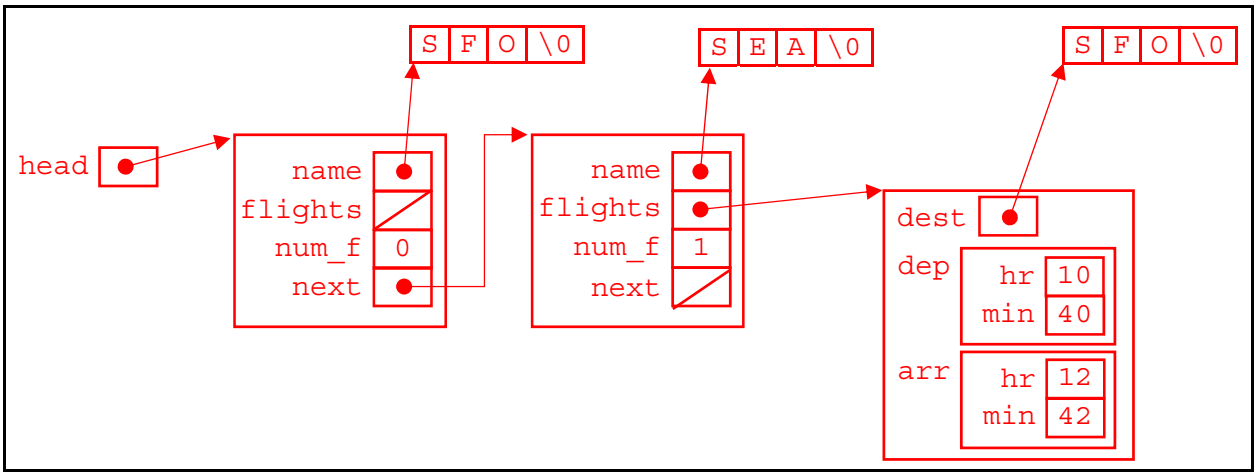
```
typedef struct a {
  char *name;
  Flight *flights;  // address of array of flights
  size_t num_f;     // number of flights in array
  struct a *next;
} Airport;          // node in linked list of airports
```

Each airport node holds a pointer to an array of `Flights` on the Heap and the length of that array is stored in `num_f`. **Pointers `name` and `dest` should also point to the Heap.** Assume we have the code shown below:

```
// Creates a new Airport (name: copied from argument, flights: NULL,
// num_f: 0, next: NULL) on the Heap and then pushes it to the front
// of our linked list of airports.
Airport *MakeAirport(char *name);

// Takes the provided Flight data and stores it in the flights array
// of the specified airport.  Needs to update flights and num_f.
void AddFlight(Airport *a, char *dest, Time dep, Time arr);
```

```
Airport *head = NULL;

int main(int argc, char **argv) {
  Time t1 = {10,40}, t2 = {12,42};
  head = MakeAirport("SEA");
  AddFlight(head, "SFO", t1, t2);
  head = MakeAirport("SFO");
  return EXIT_SUCCESS;
}
```

(A) Draw a memory diagram for our linked list of airports before `main()` returns: [9 pt]



(B) Complete the implementation of `AddFlight()`. Assume `stdio.h`, `stdlib.h`, and `string.h` are included. Assume arguments are valid, but check for other errors. [15 pt]

```
void AddFlight(Airport *a, char *dest, Time dep, Time arr) {
  // make more space for larger array
  // realloc works like malloc if a->flights == NULL
  a->flights = (Flight*) realloc(a->flights,
                                 (a->num_f+1)*sizeof(Flight) );
  // check for realloc error
  if (a->flights == NULL) {
    perror("flight malloc/realloc failed");
    exit(EXIT_FAILURE);
  }



  // malloc space for destination name
  a->flights[a->num_f].dest = (char*) malloc( (strlen(dest)+1)
                                             * sizeof(char) );
  // check for malloc error
  if (a->flights[a->num_f].dest == NULL) {
    perror("dest malloc failed");
    exit(EXIT_FAILURE);
  }

  // copy data into appropriate fields
  strcpy(a->flights[a->num_f].dest,dest);
  a->flights[a->num_f].dep = dep;
  a->flights[a->num_f].arr = arr;


  // update number of flights
  a->num_f++;

}
```

Question 3: C Preprocessor [6 pts]

Consider the following code in a file called `spooky.c`:

```
#include <stdlib.h>
#include <stdint.h>
#include <stdio.h>

#define TRIPLE(x) x * 3
#ifdef DDEBUG
#define CONST 4
#else
#define CONST 2
#endif

int main(int argc, char **argv) {
  int32_t x = TRIPLE(2);
  int32_t y = TRIPLE(10 + CONST);
  printf("%d, %d\n", x, y);
  return EXIT_SUCCESS;
}
```

When compiled with `gcc -Wall -std=c11 -DDEBUG -o spooky spooky.c`, what does the executable `spooky` output when run?

6, 16

Note that the flag -DDEBUG defines the symbol DEBUG, not the symbol DDEBUG, so the second number should not be 22. Also recall that the preprocessor does simple text substitution, but does not override order of operations – so expanding TRIPLE to 10 + 2 * 3 would evaluate to 16, not 36. Making both mistakes would lead to the second number being 42.

CSE 333 Midterm Exam 7/25/16 Sample Solution

Question 6. (20 points) Not quite the traditional what-does-it-print question. Consider the following C++ program, which, as is usual, compiles and executes with no errors.

```
#include <iostream>
using namespace std;

int f(int &n, int *pa, int &k, int *pb) {
  k = pb[1];
  pb[2] = pa[1];
  n = *pb**pa;
  return k+1;
}

int main() {
  int a = 1;
  int &b = a;
  int ray[4] = { 10, 11, 12, 13 };
  int *p = ray;
  int *q = &ray[1];

  *p = f(ray[2], p, b, q);

  cout<< "a = " << a << ", b = " << b << ", *q = " << *q << endl;
  cout<< "ray = ";
  for (int k = 0; k < 4; k++)
    cout << ray[k] << " ";
  cout << endl;

  return 0;
}
```

What output does this program produce when it runs? (You are not required to draw a boxes-n-arrows diagram, but you might find doing so to be very helpful, and it might help us if we need to assign partial credit to a not-completely-perfect answer.)

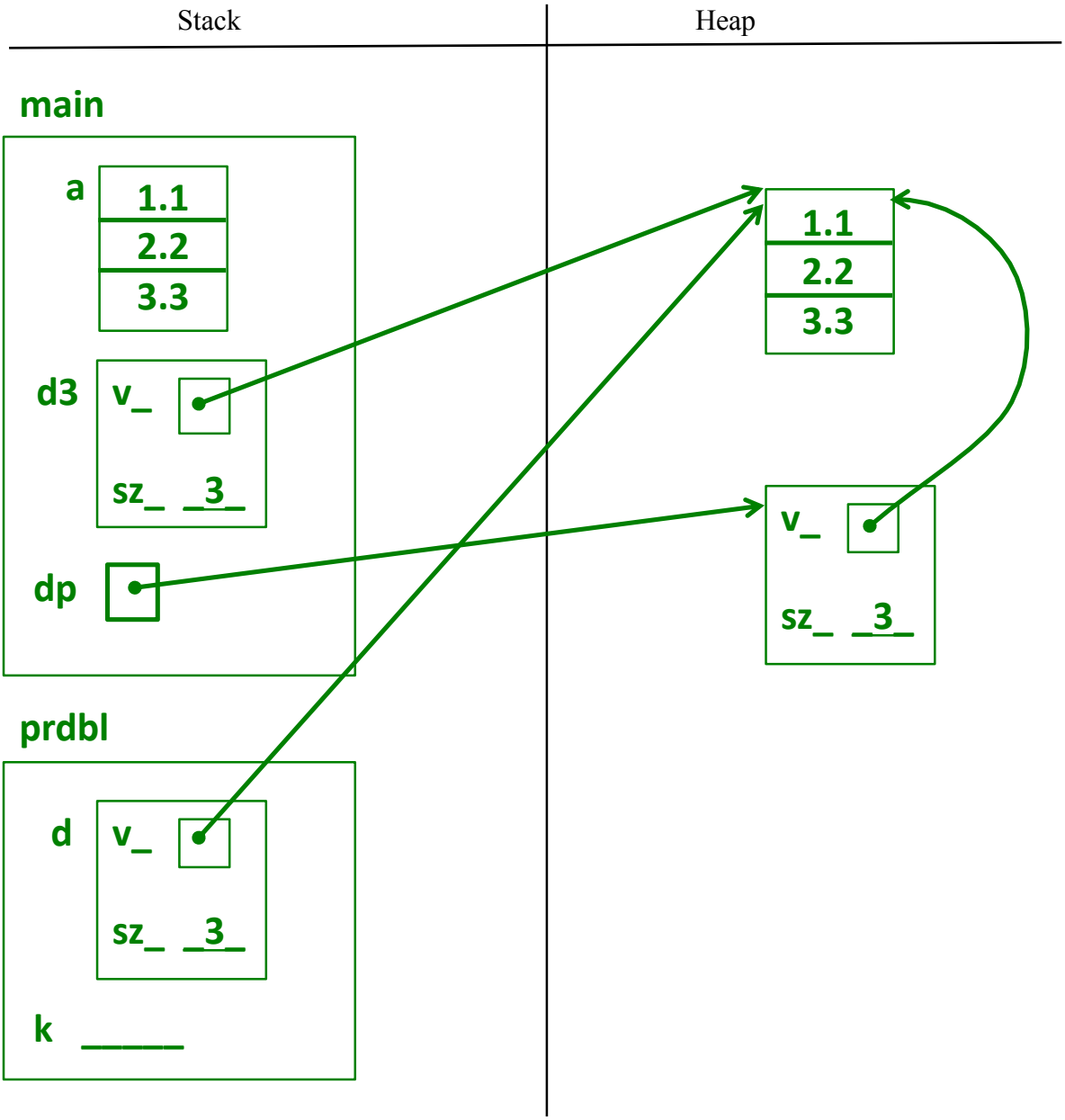
```
a = 12, b = 12, *q = 11
ray = 13 11 110 11
```

Question 5. (26 points) One of the summer interns is trying to learn C++ and has written the following class that stores an array of doubles and a main program that uses it.

```
class Doubles {
public:
  // construct Doubles given array and # elements
  Doubles(double *vals, uint32_t size)
         : v_(new double[size]), sz_(size) {
    for (uint32_t k = 0; k < size; k++)
      v_[k] = vals[k];
  }

  // destructor, other standard operations
  ~Doubles() { delete[] v_; }
  Doubles(const Doubles &other) = default;
  Doubles &operator=(const Doubles &other) = default;

  // "getter" functions
  double   get(uint32_t k) const { return v_[k]; }
  uint32_t length() const        { return sz_; }

private:
  double* v_;     // heap-allocated array
  uint32_t sz_;   // size of array
};

// print data in a Doubles object
void prdbl(Doubles d) {
  ///// ***>>>> here <<<<*** /////
  cout << "[ ";
  for (uint32_t k = 0; k < d.length(); k++)
    cout << d.get(k) << " ";
  cout << "]" << endl;
}

int main() {
  double a[] = { 1.1, 2.2, 3.3 };
  Doubles d3(a,3);
  Doubles* dp = new Doubles(d3);
  prdbl(d3);
  prdbl(*dp);
  delete dp;
  return 0;
}
```

Please answer the questions about this class on the next page and **remove this page from the exam. This page will not be scanned for grading.**

Question 5. (cont.) (a) (12 points) Draw a *precise* diagram showing the contents of memory the **first time** execution reaches the comment ///// ***>>>> here <<<<*** ///// at the beginning of function `prdbl`. Your diagram should clearly show the contents of the individual stack frames for `main` and `prdbl` and the contents of heap storage, with appropriate arrows from pointers to values that they reference. Then continue with the question on the next page.



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Question 5. (cont.) (b) (3 points) When the program is executed it crashes. Exactly where does it crash, when, and why? (what is the problem?) (Be brief but precise!)

The code crashes on exit from the *second* call to `prdbl` when it attempts to delete the array of `doubles` on the heap a second time.

There are multiple `Doubles` objects, all of which share the same array of `doubles` on the heap because the default copy constructor does a shallow copy of the object data and does not create a new array for each object. This includes the call-by-value objects created when `prdbl` is called.

When these objects are deleted the destructor deletes the array on the heap resulting in dangling pointers for all other objects constructed from the original one (`d3`). The second time a `Doubles` object is deleted, a double delete error occurs, and this happens when the local parameter object is deleted at the end of the second call to `prdbl`.

(Grading note: explanations did not need to be this detailed for full credit as long as they pinpointed the exact problem and location.)

(c) (3 points) Our summer intern has been googling and thinks that something called the "Rule of 3" is the reason for the crash. The intern proposes replacing the destructor with the following code to match the copy constructor and assignment:

```
~Doubles() = default;
```

Will the program run without crashing if this is done? Why or why not? (briefly)

Yes, it will run without crashing since the array that is shared will never be deleted. There will be a memory leak, because the heap array is never deleted, but there won't be double-delete errors.

Question 5. (cont.) (d) (8 points) What really needs to be done to fix this class so it works properly and behaves appropriately for a C++ class? Give the changes needed below by listing which functions (methods) need to be changed in the original code and writing the correct code below.

We should create a proper copy constructor and assignment operator for `Doubles` so that each instance of the class has its own private copy of the array. Replace the `default` versions with the following or something equivalent:

```
Doubles(const Doubles &other)
  : v_(new double[other.sz_]), sz_(other.sz_) {
  for (uint32_t k = 0; k < sz_; k++)
    v_[k] = other.v_[k];
}

Doubles &operator=(const Doubles &other) {
  if (this == &other)
    return *this;
  delete [] v_;
  v_ = new double[other.sz_];
  sz_ = other.sz_;
  for (uint32_t k = 0; k < sz_; k++)
    v_[k] = other.v_[k];
  return *this;
}
```

Question 1: You MAKE Me Whole [12 pts]

For the following questions, you may use the variable `CFLAGS = -Wall -g -std=c11`.

(A) We have a file `oneA.c` that includes `oneA.h`. Write a Makefile target to produce the executable `oneA`. [3 pt]

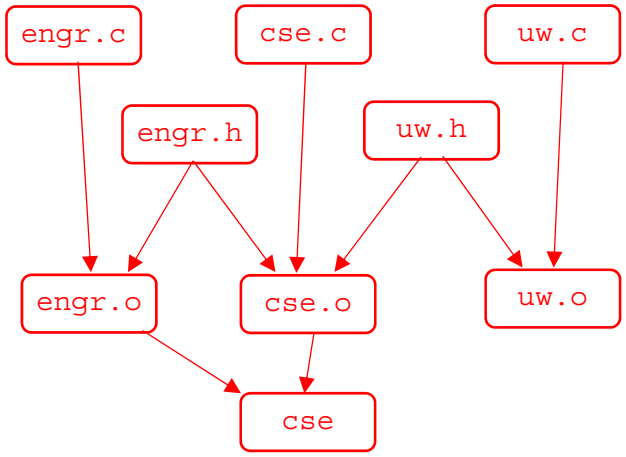
```
oneA: oneA.c oneA.h
      gcc -Wall -g -std=c11 -o oneA oneA.c
      OR
      gcc $(CFLAGS) -o oneA oneA.c
```

Recall that targets can execute multiple commands. The `touch` command updates the timestamp on a file to the current time (and creates the file if it did not previously exist).

(B) Draw out a corresponding directed acyclic graph for the Makefile on the left. [4 pt]

```
cse: cse.o engr.o
     gcc $(CFLAGS) -o cse *.o

cse.o: cse.c engr.h uw.h
     touch engr.o
     gcc $(CFLAGS) -c cse.c

engr.o: engr.c engr.h
     gcc $(CFLAGS) -c engr.c

uw.o: uw.c uw.h
     gcc $(CFLAGS) -c uw.c

clean:
     rm -f *.o *~ cse
```

Note: direction of arrows didn't matter as long as consistent.



(C) A likely dependency error should be apparent from part B. Describe the fix. [2 pt]

Add `uw.o` to the source list in the `cse` target.

(D) Even with the dependency fix from part C applied, running `make clean` then `make` results in a linking error! *Briefly* describe why this happens. [3 pt]

`make clean` removes all object files. In addressing the target `cse`, we first run the commands in the `cse.o` target, which creates an *empty*, but "updated" `engr.o` file. Therefore, we don't run the `engr.o` target commands and there is an error when linking to the empty `engr.o` file.

Question 5: C File I/O [14 pts]

a) [6 pts] Suppose you are using the C standard library to write 1024 total bytes to disk. To do so, you invoke the fwrite() function repeatedly, writing N bytes each time until all 1024 bytes are written.

Give a value of N such that the code would be more efficient with buffering turned on than turned off (assume a buffer size of 512 bytes). Briefly explain why.

```
Any value between 1 (inclusive) and 512 (exclusive).

If each fwrite call writes 1 byte of data, without buffering we would
need to make 1024 accesses to disk to write all of the data. With
buffering, 512 of those bytes would be saved up before writing it all to
disk at once, requiring only 2 accesses to disk. Since disk accesses take
a relatively enormous amount of time, any value of N less than 512 would
be improved with buffering turned on.
```

Give a value of N such that the code would be more efficient with buffering turned off than turned on. Briefly explain why.

```
Any value between 512 (inclusive) and 1024 (inclusive).

If we write the data using a single fwrite call writing all 1024 bytes at
once, we only require one disk access. With buffering, things would be
slightly slower because we would write 512 bytes to disk at once,
incurring 2 disk accesses. Note that even for a value between 512 and
1024, for which it would be necessary to make 2 disk accesses anyway, it
would still be slightly slower to use buffering because it would require
copying the data to an intermediate buffer and then writing to disk (but
still use 2 disk accesses).
```

b) [8 pts] Suppose you have a file on disk called `midterm_soln.txt` with a guaranteed size of exactly 50 bytes. The following is a partially-implemented POSIX read loop that reads in those 50 bytes from the file and copies them into a buffer called `buf`. Complete the code so that after the last line, `buf` contains those 50 bytes. Make sure to clean up the open file descriptor.

```
#include <fctnl.h>
#include <unistd.h>
#define BUFFER_SIZE 50

char buf[BUFFER_SIZE];
int bytes_left = BUFFER_SIZE;
int fd = open("midterm_soln.txt", O_RDONLY);

while (1) {
  ssize_t res = read(fd, buf + (BUFFER_SIZE - bytes_left),
        bytes_left );
  if (res == 0) {
    break;
  } else if (res == -1) {
    if (errno != EINTR ) {
      perror("read error");
      exit(1);
    }
  } else {

    bytes_left -= res ;
  }
}
  close(fd) ; // Clean up the fd
```

CSE 333 18au Midterm Exam Nov. 2, 2018

Sample Solution

Question 5. (16 points) Constructor madness. Consider the following C++ program which does compile and execute successfully. On the next page, write the output produced when it is executed.

```
#include <iostream>
using namespace std;

static int idnum = 1;   // global var: next obj id number

class obj {
public:
  obj() {                    // default constructor
    id_ = idnum; idnum++;
    cout << "obj " << id_ << ": default constructor" << endl;
  }
  obj(int n) {               // int constructor
    id_ = idnum; idnum++;
    cout << "obj " << id_ << ": int constructor" << endl;
  }
  obj(const obj & other) {  // copy constructor
    id_ = idnum; idnum++;
    cout << "obj " << id_ << ": copy constructor from " <<
                                              other.id_ << endl;
  }
  obj& operator=(const obj & other) {  // assignment operator
    cout << "obj " << id_ << ": assignment operator from " <<
                                              other.id_ << endl;
    return *this;
  }
  ~obj() { // destructor
    cout << "obj " << id_ << ": destructor" << endl;
  }
private:
  int id_;    // this obj's id number
};

int main() {
  obj a;          // output is obj 1: default constructor
  obj b(a);
  obj c = 5;
  obj d = c;
  a = c;
  b = 5;
  cout << "done!" << endl;
}
```

Please write your answer on the next page and **remove this page from the exam. This page will not be scanned for grading.**

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CSE 333 18au Midterm Exam Nov. 2, 2018

Sample Solution

Queston 5 (cont.) On this page, write the output produced when the program from the previous page is executed. It does compile and execute successfully.

Note that when an object is constructed, the constructor stores a unique integer `id_` number, and operations on each object print out that object's `id_` number when they are executed. The first object's `id_` number is 1, and each new object has an `id_` number that is 1 greater than the previous object.

Also note that the constructors and assignment operations ignore their arguments. That, of course, would not happen in real code, but for this question it was done to save space since the values of the arguments are not needed to trace the program's execution.

The first output line is written for you. Write the rest of the program's output after that.

Output:

```
obj 1: default constructor
obj 2: copy constructor from 1
obj 3: int constructor
obj 4: copy constructor from 3
obj 1: assignment operator from 3
obj 5: int constructor
obj 2: assignment operator from 5
obj 5: destructor
done!
obj 4: destructor
obj 3: destructor
obj 2: destructor
obj 1: destructor
```

Note: for the assignment `b=5`, the compiler has to construct an `obj` temporary using the class `obj int` constructor, and then use that temporary object as the source value for the assignment to `b`. The compiler then generates code to automatically destroy the temporary. When we ran the program, the destructor code for the temporary executed right after the assignment, but it could have happened any time before the program terminated. Solutions that showed the destructor executing anywhere after the assignment received proper credit.