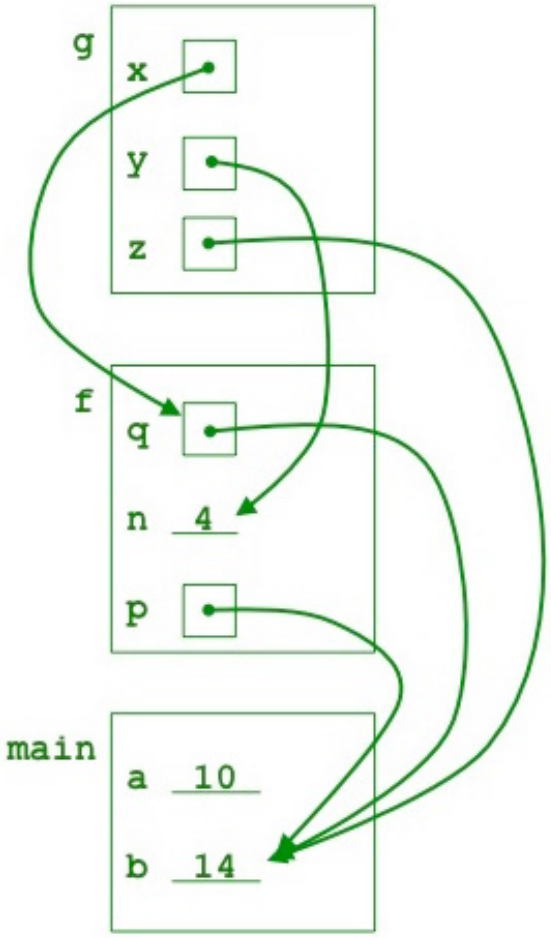
Question 5. (20 points) Pointy things. Consider the following program, which compiles and executes with no warnings or errors:

```
#include <stdio.h>

void g(int **x, int *y, int *z) {
  **x = 10;
  *x = z;
  // HERE!!! (see below) //
  printf("g: %d %d %d\n", **x, *y, *z);
}

void f(int *q, int n, int *p) {
  n = n+2;
  *p = *p**q;
  g(&q, &n, p);
  printf("f: %d %d %d\n", *p, *q, n);
}

int main() {
  int a = 7;
  int b = 2;
  f(&a, b, &b);
  printf("main: %d %d\n", a, b);
  return 0;
}
```



(a) (14 points) Draw a boxes 'n arrows diagram showing the memory layout and contents at the point just before the `printf` in function `g` is executed (marked with `HERE!!!` in the comment). Be sure your diagram clearly shows the values of all variables in all active functions and has a separate box or stack frame for each function. For each pointer, draw an arrow from the pointer to the variable that it references. Use the space below the code and/or to the right for your diagram.

(b) (6 points) What does this program print when it is executed?

```
g: 14 4 14
f: 14 14 4
main: 10 14
```

Question 1. (20 Points) Fixed Width Integers

For each of the following cases, decide what types the integer storing this information should have. (`int`, `unsigned int`, `int16_t`, `uint32_t`, ……)

A. We need to store the result of a general purpose string hashing function.
uint64_t
There are many possible input strings , so to account for this, the integer is 64 bits. The integer is also unsigned since the result from a hash can be treated as a bit pattern.

B. We need a variable to hold the length of a "normal" array
int
For most arrays that you encounter, the length won't exceed three digits, as such, an integer is fine to store the results.

C. We want to be able to assign a unique identifier to every American (population ~300 million)
int32_t
The number of possible values an int16_t can hold is too small to give a unique identifier to each person, so we must specify that it must be at least 32 bits to maintain uniqueness.

D. We need a variable to store intermediate results of performing multiplication with large numbers such as the speed of light (~300,000,000)
int64_t
The max integer value for int32_t is roughly 7 times the speed of light, since we are using very large numbers, we will need int64_t to hold these results.

CSE 333 Midterm Exam 2/12/16 Sample Solution

Question 1. (12 points) Preprocessor. Consider the following C (*not* C++ files).

```
======
func.h
======
#ifndef _FUNC_H_
#define _FUNC_H_
#define FUN(a,b) a*b
#endif
```

```
======
nums.h
======
#ifndef _NUMS_H_
#define _NUMS_H_
#ifdef BIG
typedef long int num;
#else
typedef int num;
#endif
#define NBR 3
#endif
```

```
======
test.c
======
#include <stdio.h>
#include "nums.h"
#include "func.h"

#define BIG

num compute(int x) {
  return FUN(x+1,NBR);
}

int main() {
  printf("%d\n", compute(2));
  return 0;
}
```

(a) (10 points) Give the output produced by the preprocessor (`cpp -P test.c`) when it reads and processes the file `test.c`. Ignore the `#include <stdio.h>` line – it will insert the declarations from `stdio.h` and do nothing further. Otherwise, your answer should show all of the output from the preprocessor. There are no preprocessor errors in this program, and the resulting program compiles and executes without errors.

```
typedef int num;
num compute(int x) {
  return x+1*3;
}
int main() {
  printf("%d\n", compute(2));
  return 0;
}
```

(b) (2 points) What does this program print when it is compiled and executed?

```
5
```

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.)

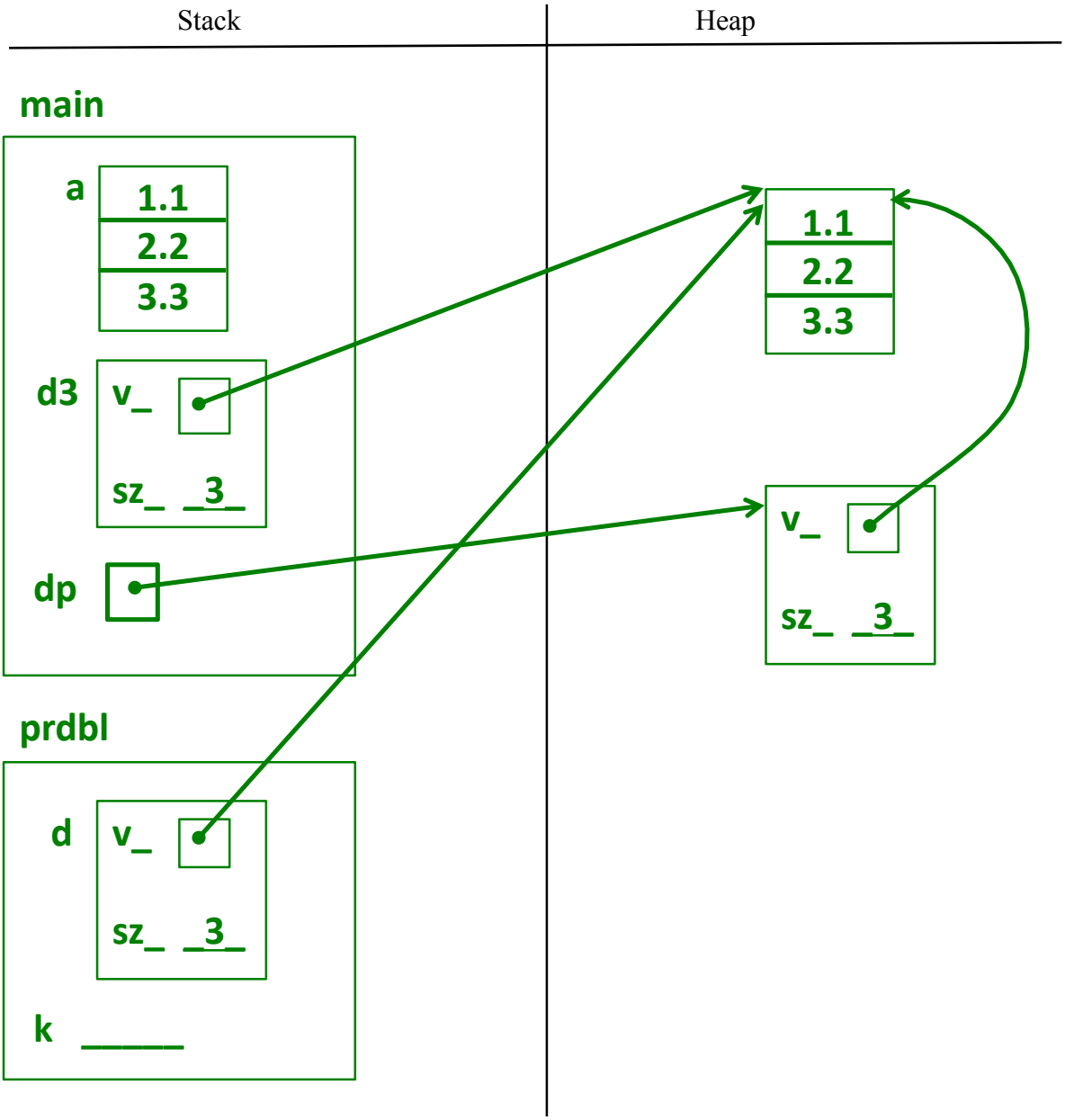
```
a = 12, b = 12, *q = 11
ray = 13 11 110 11
```

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.

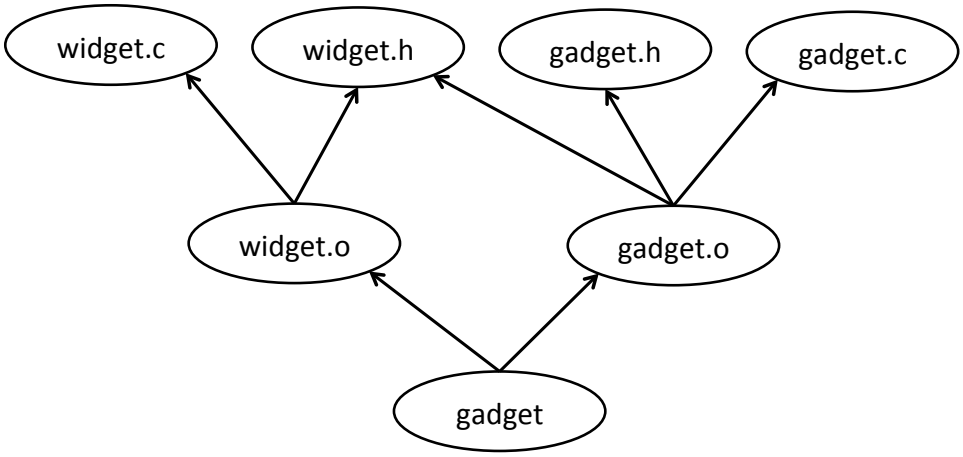
Question 5. (cont.) (d) (8 points) What really needs to be done to fix this class so it works properly and behaves appropriately for a C++ class? Give the changes needed below by listing which functions (methods) need to be changed in the original code and writing the correct code below.

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;
}
```

Make and related things. We have the following diagram that describes the dependencies between the various files that are involved in building an executable program named `gadget`.



Question 2. (9 points, 3 each) What can we conclude from the above diagram? In the statements below, **circle** the number of the *best* choice in each group of possible answers:

(a) The `widget.c` source file:

(i) **Definitely** contains a `#include "widget.h"` preprocessor directive.

(ii) **Might** contain a `#include "widget.h"` preprocessor directive, but might not.

(iii) **Does not** contains a `#include "widget.h"` preprocessor directive.

(b) The `gadget.c` source file:

(i) **Definitely** contains a `#include "widget.h"` preprocessor directive.

(ii) **Might** contain a `#include "widget.h"` preprocessor directive, but might not. **(`gadget.h` might `#include widget.h` to create the dependency.)**

(iii) **Does not** contains a `#include "widget.h"` preprocessor directive.

(c) The `main` function for this program:

(i) **Definitely** is implemented (defined) in the `gadget.c` source file.

(ii) **Might** be implemented (defined) in the `gadget.c` source file, but might not.

(iii) **Is not** implemented (defined) in the `gadget.c` source file.

(more about this diagram on the next page)

Question 4. (22 points) The program on this page and the next opens two files, one for reading and one for writing, and copies the contents of the first file to the second. Your job is to complete the code by filling in the blanks lines with the correct POSIX I/O function calls to handle the files (open, close, read, write).

Here is a summary of some key POSIX I/O functions for your reference.

```
int open(const char *name, int mode);
      mode is one of O_RDONLY, O_WRONLY, O_RDWR
int creat(const char *name, int mode);
      create a new file
int close(int fd);
ssize_t read(int fd, void *buffer, size_t count);
      returns # bytes read or 0 (eof) or -1 (error)
ssize_t write(int fd, void *buffer, size_t count);
      returns # bytes written or -1 (error)
```

Below is the code you are to complete. You should assume that all necessary header files have been `#include`d and you do not need write any other `#includes`.

```
#define SIZE 1024
int main(int argc, char** argv) {
  int fd1, fd2;
  char buf[SIZE];
  ssize_t rlen, total, wlen;

  if (argc != 3) {
    fprintf(stderr, "Usage: ./a.out <file1> <file2>\n");
    exit(1);
  }
  // open first file for reading

  fd1 = open(argv[1], O_RDONLY);
  if (fd1 == -1) {
    fprintf(stderr, "Could not open file for reading\n");
    exit(1);
  }
  // create the second file
  fd2 = creat(argv[2], 0777);
  if (fd2 == -1) {
    close(fd1);
    fprintf(stderr, "Could not create file for writing\n");
    exit(1);
  }
```

(code continued on next page)

Question 4. (cont.) Continued from previous page.

```
  // Copy all data from fd1 to fd2
  do {
      // read next data from fd1 into buf

      rlen = read(fd1, buf, SIZE);
      if (rlen == -1) {
        if (errno != EINTR) {
          close(fd1);
          close(fd2);
          perror(NULL);
          exit(1);
        }
        continue;
      }
      // Write newly read data from buf to fd2
      total = 0;

      while ( total < rlen ) {

        wlen = write(fd2, buf + total, rlen - total);
        if (wlen == -1) {
          if (errno != EINTR) {
            close(fd1);
            close(fd2);
            perror(NULL);
            exit(1);
          }
          continue;
        }

        total += wlen;
      }
  } while ( rlen > 0 );
  // Close input and output files
  close(fd1);
  close(fd2);
  return 0;
}
```

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.**

(continued on next page)

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.

Question 2. (19 points) The following header file defines a class that holds a pair of integers and includes a constructor and functions for accessing the values.

```
#ifndef _Pair_h_
#define _Pair_h_
template <class T>
class Pair {
 public:
  // Construct a Pair with given first and second values
  Pair(~~int~~ T first, ~~int~~ T second)
      : first_(first), second_(second) { }

  // accessors: return first and second items from Pair
  ~~int~~ T first()  const { return first_;  }
  ~~int~~ T second() const { return second_; }

 private:
  // instance variables
  ~~int~~ T first_;
  ~~int~~ T second_;
};

#endif  // _Pair_h_
```

(a) (6 points) We would like to generalize this class so it can be used to store any pairs of values as long as the values have the same type (i.e., pairs of `int`s or pairs of `string`s, etc.)

Show the changes needed to make this a generic class where the element type is a type parameter instead of `int`. You should write your changes and additions in the above code. Hint: you'll need to start by adding `template <class T>` (or `template <typename T>`, which is equivalent) at the beginning of the class definition.

(Changes shown in green bold above)

(continued on the next page)

Question 2. (cont.) We would now like to add an addition (+) operator to the generic `Pair` class on the previous page. If (a,b) and (c,d) are `Pair` values, then (a,b)+(c,d) should yield a new `Pair` containing (a+c, b+d). Neither of the original `Pair` objects should be modified. You do not need to check that addition (+) is defined on the items stored in a `Pair` – that is handled for you by the compiler when the addition operator is used.

(b) (5 points) Write the function declaration (not the implementation) to be added to the header file `Pair.h` for the new `operator+`.

```
// return a new Pair that is the element-wise sum of
// this and other

Pair<T> operator+(const Pair<T> &other) const;
```

(You did not need to supply a comment, although that would be expected in a real project.)

(c) (8 points) Give the code to implement this new addition operator as it would appear in a separate file `Pair.cc` containing definitions of functions not implemented in `Pair.h`. Hint: the implementation needs to begin with `template <class T>`.

```
template <class T>

Pair<T> Pair<T>::operator+(const Pair<T> &other) const {

  return Pair<T>(first_ + other.first_,

                 second_ + other.second_);

}
```

(The file containing this template would have to `#include` the `Pair.h` header, and client code would need to include both the header and implementation to use it. That wouldn't make any difference in how the template is written and was not considered while grading.)