IMPORTANT: Explain your answer briefly. Do not just write a short answer or fill the assembly code.

1. [10pts] The following code fragment has a potential vulnerability.

```
void* copy_elements(void *ele_src[], int ele_cnt, size_t ele_size) {
    /*
     * Allocate buffer for ele_cnt objects, each of ele_size bytes
     * and copy from locations designated by ele_src
     */
    void *result = malloc(ele_cnt * ele_size);
    if (result == NULL)
             /* malloc failed */
             return NULL;
    void *next = result;
    int i;
    for (i = 0; i < ele_cnt; i++) {
        /* Copy object i to destination */
        memcpy(next, ele_src[i], ele_size);
             /* Move pointer to next memory region */
             next += ele_size;
    }
    return result;
}
```

   A. [4pts] Write possible values for ele_cnt and ele_size to crash the application/system. Explain the reason.

   B. [6pts] Write extra C codes to add before the malloc call to prevent the crash.

2. [10pts][floating point data representation]

A. [4pts] Assume variables x, f, and d are of type `int`, `float`, and `double`, respectively. (Neither f nor d equals to +infinity, -infinity, or NaN). For each of the following expressions, either argue that it is always true or give a counterexample if it is not.

```
A-1) x == (int) (double) x

A-2) f == -(-f)

A-3) 1.0/2 == 1/2.0

A-4) d*d >= 0.0

A-5) (f+d) – f == d
```

B. [3pts] Write the rounded binary numbers for the following values. They should be rounded to nearest 1/4 (2 bits fright of binary point, and must use "round-to-even" rule.

Explain the advantage of such "round-to-even" rule, compared to round-down or round-up.

10.00011 => ______________
10.00110 => ______________
10.11100 => ______________
10.10100 => ______________

C. [3pts] Explain how a floating point compare instruction (fcmp) can be implemented for the IEEE fp format. How will it be different from the integer compare instruction (cmp)?

3. [5pts] In the following code fragment, argue whether b and c always have the same value or not.

```
typedef union {
  float f;
  unsigned u;
} bit_float_t

float bit2float (unsigned u) {
  bit_float_t arg;
  arg.u = u;
  return arg.f;
}

unsigned  a = random();
float b = bit2float(a);
 float c = (float) a;
```

4. [8pts] Answer the two questions for the following C function and the corresponding assembly code.

```
long rfun(unsinged long x) {

   if ( ______________________ )
       return ________________;

   unsigned long nx = _____________;
   long rv = rfun(nx);
   return ____________;
}
```

```
rfun:
     pushq     %rbx
     moveq     %rdi, %rbx
     movl      $0, %eax
     testq     %rdi, %rdi
     je        .L2
     shrq      $2, %rdi
     call      rfun
     addq      %rbx, %rax
.L2:
     popq      %rbx
     ret
```

A. [3pts] What value in the C code does rfun store in %rbx?

B. [5pts] Fill in the missing expressions in the C code.

5. [7pts] The following two C code fragments show two different ways of supporting 2D data structures.

```
#define ZLEN 5
typedef int zip_dig[ZLEN];

#define PCOUNT 4
zip_dig pgh[PCOUNT] =
  {{1, 5, 2, 0, 6},
   {1, 5, 2, 1, 3 },
   {1, 5, 2, 1, 7 },
   {1, 5, 2, 2, 1 }};

int get_pgh_digit
  (int index, int dig)
{
  return pgh[index][dig];
}
```

```
zip_dig cmu = { 1, 5, 2, 1, 3 };
zip_dig mit = { 0, 2, 1, 3, 9 };
zip_dig ucb = { 9, 4, 7, 2, 0 };

#define UCOUNT 3

int *univ[UCOUNT] = {mit, cmu,
ucb};

int get_univ_digit (size_t index,
size_t digit){

  return univ[index][digit];

}
```

A. [4pts] Complete the following assembly codes for the two access functions. (explain your answer)

```
1)________________________
addl %rax, %rsi
movl  2)__________, %eax
ret
```

```
salq    $2, %rsi
addq    3)__________, %rsi
4)___________________________
ret
```

B. [3pts] Discuss the pros and cons of the two approaches.

6. Find the minimum number of operations to implement the given functions.

- Points will not be given if functions are implemented more than your minimum number of operations.
- You should justify your solution by implementing the functions.
- Assignment operator '=' is legal. But it will not be counted as an operator.

(1) addOK [5pts]

Description	Determine if can compute x+y without overflow
Examples	addOK(0x80000000,0x80000000) = 0 addOK(0x80000000,0x70000000) = 1
Legal Ops	! ~ & ^ | + << >>

The minimum number of operations to implement this function is _______.

int addOK(int, int)
{
 	
}

8. [10pts] Solve the following problems with the given assembly code.

C code

```
void phase(char *input)
{
   int i;
   int numbers[6];
   read_six_numbers(input, numbers);
   for(i = 1; i < 6; i++) {
     if ( [                    ] )
       explode_bomb();
   }
}
```

Assembly

```
Dump of assembler code for function phase:
  0x000055555555522a <+0>:    push   %rbp
  0x000055555555522b <+1>:    push   %rbx
  0x000055555555522c <+2>:    sub    $0x28,%rsp
  0x0000555555555230 <+6>:    mov    %fs:0x28,%rax
  0x0000555555555239 <+15>:   mov    %rax,0x18(%rsp)
  0x000055555555523e <+20>:   xor    %eax,%eax
  0x0000555555555240 <+22>:   mov    %rsp,%rbp
  0x0000555555555243 <+25>:   mov    %rsp,%rsi
  0x0000555555555246 <+28>:   callq  0x555555555820 <read_six_numbers>
  0x000055555555524b <+33>:   mov    %rsp,%rbx
  0x000055555555524e <+36>:   add    $0x14,%rbp
  0x0000555555555252 <+40>:   jmp    0x55555555525d <phase+51>
  0x0000555555555254 <+42>:   add    $0x4,%rbx
  0x0000555555555258 <+46>:   cmp    %rbp,%rbx
  0x000055555555525b <+49>:   je     0x55555555526f <phase+69>
  0x000055555555525d <+51>:   mov    (%rbx),%eax
  0x000055555555525f <+53>:   lea    0x2(%rax,%rax,2),%eax
  0x0000555555555263 <+57>:   cmp    %eax,0x4(%rbx)
  0x0000555555555266 <+60>:   je     0x555555555254 <phase+42>
  0x0000555555555268 <+62>:   callq  0x5555555557fa <explode_bomb>
  0x000055555555526d <+67>:   jmp    0x555555555254 <phase+42>
  0x000055555555526f <+69>:   mov    0x18(%rsp),%rax
  0x0000555555555274 <+74>:   xor    %fs:0x28,%rax
  0x000055555555527d <+83>:   jne    0x555555555286 <phase+92>
  0x000055555555527f <+85>:   add    $0x28,%rsp
  0x0000555555555283 <+89>:   pop    %rbx
  0x0000555555555284 <+90>:   pop    %rbp
  0x0000555555555285 <+91>:   retq
  0x0000555555555286 <+92>:   callq  0x555555554ed8
End of assembler dump.
```

A. Fill the C statement in the blank, based on the corresponding assembly codes. [5pts]

B. What is the solution if the first number of the solution is “1”? [5pts]

10. [7pts] Solve the following problems with the given C code and assembly code

C code

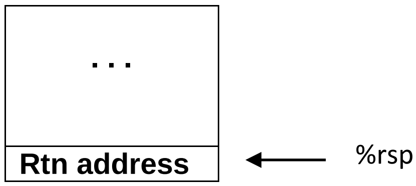
long mul(long *p,long val)
{
    long x=*p;
    long y=x*val;
    *p=y;
    return x;
}
long call_mul(long x)
{
    long v1=10;
    long v2=mul(&v1,300);
    return x+v2;
}

Assembly

mul:
    movq (%rdi), %rax
    imul %rax, %rsi
    movq %rsi, (%rdi)
    ret
call_mul:
    subq $16, %rsp
    movq $1000, 8(%rsp)
    [ ]
    [ ]
    call mul ←
    addq 8(%rsp), %rax
    addq $16, %rsp
    ret

A. [3pts] Fill the assembly code in the blank(Assembly) [3pts]

B. [4pts] Assume that the program starts with the call_mul function. Draw the stack frame when the program **finishes executing "`call mul`" instructions.**



Initial Stack Structure

11. [13pts] Answer the questions related to the following C and assembly codes.

```
/* Get string from stdin */
char *gets(char *dest)
{
   int c = getchar();
   char *p = dest;
   while (c != EOF && c != '\n') {
      *p++ = c;
      c = getchar();
   }
   *p = '\0';
   return dest;
}
```

```
void call_echo()
{
        echo();
}
void echo()
{
          char buf[8];
          gets(buf);
          puts(buf);
}
```

```
00000000004006cf <echo>:
  4006cf:  48 83 ec 18          sub    $0x18,%rsp
  4006d3:  48 89 e7             mov    %rsp,%rdi
  4006d6:  e8 a5 ff ff ff       callq  400680 <gets>
  4006db:  48 89 e7             mov    %rsp,%rdi
  4006de:  e8 3d fe ff ff       callq  400520 <puts@plt>
  4006e3:  48 83 c4 18          add    $0x18,%rsp
  4006e7:  c3                   retq
00000000004006e8 <call_echo>:
  4006e8:  48 83 ec 08          sub    $0x8,%rsp
  4006ec:  b8 00 00 00 00       mov    $0x0,%eax
  4006f1:  e8 d9 ff ff ff       callq  4006cf <echo>
  4006f6:  48 83 c4 08          add    $0x8,%rsp
  4006fa:  c3                   retq
```

A. [2pts] Find an input for “gets” to change the return address set by “call <echo>” instruction in the stack to 0x0 (8B).

B. [2pts] Describe how an attacker can execute a short sequence of instructions in the example by exploiting the vulnerability.

C. [2pts] Explain how the stack address randomization can thwart the attack?

D. [3pts] Explain how return-oriented programming (ROP) works and how it can allow the attacker to bypass the non-executable permission setting on the stack and to execute a sequence of instructions the attacker wants to run?

E. [4pts] Fill the blacks in the following assembly code which adds the stack canary protection.

```
00000000004006cf <echo>:
  40072f:  sub    $0x18,%rsp
  400733:  mov    %fs:0x28,%rax
  40073c:  mov    %rax,0x8(%rsp)
  400741:  xor    %eax,%eax
  400743:  mov    %rsp,%rdi
  400746:  callq  4006e0 <gets>
  40074b:  mov    %rsp,%rdi
  40074e:  callq  400570 <puts@plt>
  400753:  _______________________
  400758:  _______________________
  400761:  je     400768 <echo+0x39>
  400763:  callq  400580 <__stack_chk_fail@plt>
  400768:  add    $0x18,%rsp
  40076c:  retq
```