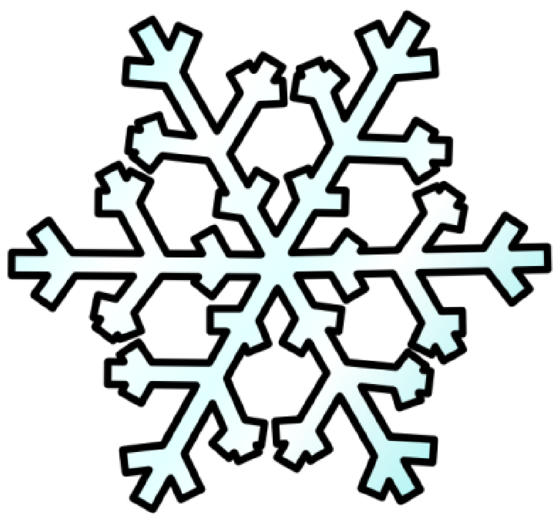
Instructions: This is a closed book, closed note exam. Calculators are not permitted. If you have a question, raise your hand and I will come to you. Please work the exam in pencil and do not separate the pages of the exam. For maximum credit, show your work.
Good Luck!

Your Name (***please print***) ____

1	2	3	4	5	total
30	30	35	25	30	150



Problem 1 (3 parts, 30 points) **Compilation and Optimization**

Part A (15 points) Perform at least **five** standard compiler optimizations on the following C code fragment by writing the optimized version (in C) to the right.

```
int foo(int g, int h) {

  int x = 64;

  int sum = 0;

  do {                                    ⇨

    sum += f(g-1, h%4, g+(h%4));

    g = x*g + h;

  } while (g<128);

  return (sum);

}
```

Briefly describe which standard compiler optimizations you applied:

1.

2.

3.

4.

5.

Part B (10 points) Optimize register usage by writing the following code fragment to the right (in MIPS). The optimized fragment must use the same number of instructions and perform the same operations, but the instructions may be in a different order. The result of the code fragment must be stored in \$2. Remember \$0 must always contain 0; it must not be overwritten. For maximum credit, the optimized version should use only registers \$0, \$1, \$2, and \$3. Partial credit will be given if more than this number of registers is used, as long as the code is still correct and equivalent to the unoptimized code to the left.

```
sub $6, $0, $3
sub $4, $0, $2
addi $7, $6, -1
addi $5, $4, -1        ⇨
and $8, $5, $3
and $9, $2, $7
or $2, $8, $9
```

Part C (5 points) The MIPS code fragment in Part B can be reduced to a single MIPS instruction that performs the equivalent computation on inputs \$2 and \$3. Complete the instruction below by filling in the appropriate operator. (Hint: try sample values of \$2 and \$3 to see what is computed for the resulting \$2.)

```
______ $2, $2, $3
```

Problem 2 (2 parts, 30 points) **Reverse Compilation**

Part A (15 points) In an unexpected move, Seattle-based ice cream vendor MicroSoftServe, producer of low-cal Fruity Stack PopSicles™, announced its merger with the BigBlueBunny company, maker of the popular Chocolate-T J Watson Bars™. The announcement was met with a flurry of excitement that these products will now be available in all Windows Ate My Lunch Cafes throughout the world.

Unfortunately, some of the control software for manufacturing these frozen treats is quite old and has survived only in MIPS assembly. You have been hired as a consultant to recover the original C source code. For the MIPS below, write a C subroutine that best matches the behavior. For full credit and to unfreeze BigBlueBunny's assets, write high level C; *do not transliterate*. For example, use the appropriate loop construct (`for`, `while`, or `do while`). Assume $1 holds an input variable **`Temp`** of type **`int`** and $2 holds an input variable **`MeltingPt`** of type **`int`**. Use the variable **`I`** of type **`int`** for register $3's value and assume the output **`I`** is returned in $3. $4 holds a constant and $5 is used for temporary, intermediate values. **`ChurnRPMs`** is a label to an address in the static data region of memory.

```
Label   Instruction
Cool:   addi $4, $0, 20
        addi $3, $0, 0
Loop:   slt  $5, $2, $1
        beq  $5, $0, Exit
        addi $1, $1, -1
        div  $1, $4
        mfhi $5
        sll  $5, $5, 3
        sw   $5, ChurnRPMs($3)
        addi $3, $3, 4
        j    Loop
Exit:   jr   $31
```

Part B (15 points) Assuming a **64-bit system**, show how the following global variables map into static memory. Assume they are allocated starting at address 3000 and all data types are **word aligned**. For each variable, draw a box showing its size and position in memory. Label the box with the variable name or element of an array (e.g., Name[0]).

```
int     x = 10;
double  D = 300.6;
float   F = 6.2;
float   *fp = &F;
double  *dp = &D;
```

3000				
3004				
3008				
3012				
3016				
3020				
3024				
3028				
3032				
3036				

Problem 3 (5 parts, 35 points) **Pointers and Arrays**

Consider a hash table that is implemented using the following struct definitions.

```
typedef struct Entry {
   int            Key;
   int            Value;
   struct Entry *Next;
} Entry;

typedef struct {
   Entry          **Buckets;
   int            NumBuckets;
} HashTable;
```

Part A (4 points) Write a single C statement to allocate a `HashTable` structure and to declare a variable named **`MyHT`** that is a pointer to the newly allocated `HashTable` structure.

Part B (3 points) Write a single C statement to set the **`NumBuckets`** field to 5 in the `HashTable` structure pointed to by **`MyHT`**.

Part C (6 points) Assuming a 32-bit system, what are the following values?

`sizeof(HashTable) =` ______________ `sizeof(Entry) =` ______________

Part D (12 points) Complete the C subroutine called `CalculateSize` shown below. It should take a pointer to a `HashTable` named **`HT`** and return the total number of Entries in the given `HashTable`. (Assume that the referenced `HashTable`'s `Buckets` have been allocated and initialized, and several `Entry` structures have already been inserted into it.) Be sure to declare and initialize any additional local variables you may need.

```
int CalculateSize(HashTable *HT) {
  int Size = 0;









  return(Size);
}
```

Part E (10 points) Write the MIPS code implementation of the dynamically allocated array access below in the smallest number of instructions. A pointer to the array (declared below) is stored in `$3`. Variables **`W`**, **`X`**, **`Y`**, **`Z`**, and **`R`** reside in `$4`, `$5`, `$6`, `$7`, and `$2` respectively. Modify only registers `$1` and `$2`.

```
int      Array[8][5][4][16];       /* array declaration */
R = Array[Z][Y][X][W];             /* implement this */
```

Label	Instruction	Comment

Problem 4 (3 parts, 25 points) **Garbage Collection**

Below is a snapshot of heap storage. Values that are pointers are denoted with a "$". The heap pointer is $6168. The heap has been allocated contiguously beginning at $6000, with no gaps between objects.

addr	value	addr	value	addr	value	addr	value	addr	value	addr	value
6000	16	6032	12	6064	0	6096	16	6128	12	6160	0
6004	33	6036	28	6068	4	6100	6172	6132	$6024	6164	0
6008	$6132	6040	$6120	6072	$6004	6104	16	6136	9	6168	0
6012	16	6044	$6080	6076	8	6108	5	6140	$6072	6172	0
6016	80	6048	16	6080	$6024	6112	$6148	6144	20	6176	0
6020	8	6052	$6092	6084	$6052	6116	8	6148	6046	6180	0
6024	25	6056	$6024	6088	4	6120	32	6152	8	6184	0
6028	$6004	6060	0	6092	$6080	6124	$6024	6156	26	6188	0

Part A (10 points) Suppose the stack holds a local variable whose value is the memory address $6052 and register $3 holds the address $6004. No other registers or static variables currently hold heap memory addresses. List the addresses of all objects in the heap that are *not* garbage.

Addresses of

Non-Garbage Objects: ______________________________

Part B (5 points) If a reference counting garbage collection strategy is being used, what would be the reference count of the object at address $6004?

Reference count of object at $6004 = ______________________________

Part C (10 points) If the local variable whose value is the address $6052 is popped from the stack, which addresses will be reclaimed by each of the following strategies? If none, write "none."

Reference Counting:	
Mark and Sweep:	
Old-New Space (copying):	

Problem 5 (2 parts, 30 points) Activation Frames

Consider the following C code fragment:

```
typedef struct {
   int x;
   int y;
} pair;

int Bar() {
   int         M = 3;
   int         N = 4;
   pair        P;
   int         Q[] = {10, 20, 30};
   int         Foo(int, pair *, int *);
   P.x = 5;
   P.y = 6;
   N = Foo(M, &P, Q);
   return(N);
}

int Foo(int A, pair *B, int *C) {
   int         D = 25;
   int         E;

   C[2] = C[1] + A;
   E = B->y + D;
   return(E);
}
```

Part A (15 points) Describe the current state of the stack <u>just before `Foo` returns to `Bar`</u>. Fill in the unshaded boxes to show `Bar's` and `Foo`'s activation frames. Include a symbolic description and the actual value (in decimal). For return addresses, show only the symbolic description; do not include a value. *Label the frame pointer and stack pointer*.

address	description	Value
9900	**RA of Bar's caller**	
9896	**FP of Bar's caller**	
SP, Bar's FP 9892		
9888		
9884		
9880		
9876		
9872		
9868		
9864		
9860		
9856		
9852		
9848		
9844		
9840		
9836		
9832		

Part B (15 points) Write MIPS code fragments to implement the subroutine `Foo` by following the steps below. Do not use absolute addresses in your code; instead, access variables relative to the frame pointer. Assume no parameters are present in registers (i.e., access all parameters from `Foo`'s activation frame).

First, write code to properly set `Foo`'s frame pointer and to allocate space for `Foo`'s local variables and initialize them if necessary.

label	instruction	Comment

`C[2] = C[1] + A;`

label	instruction	Comment

`E = B->y + D;`

label	instruction	Comment

`return(E); (compute return value, deallocate locals, and return)`

label	instruction	Comment

MIPS Instruction Set (core)

instruction	***example***	***meaning***
	arithmetic	
add	add \$1,\$2,\$3	\$1 = \$2 + \$3
subtract	sub \$1,\$2,\$3	\$1 = \$2 - \$3
add immediate	addi \$1,\$2,100	\$1 = \$2 + 100
add unsigned	addu \$1,\$2,\$3	\$1 = \$2 + \$3
subtract unsigned	subu \$1,\$2,\$3	\$1 = \$2 - \$3
add immediate unsigned	addiu \$1,\$2,100	\$1 = \$2 + 100
set if less than	slt \$1, \$2, \$3	if (\$2 < \$3), \$1 = 1 else \$1 = 0
set if less than immediate	slti \$1, \$2, 100	if (\$2 < 100), \$1 = 1 else \$1 = 0
set if less than unsigned	sltu \$1, \$2, \$3	if (\$2 < \$3), \$1 = 1 else \$1 = 0
set if < immediate unsigned	sltui \$1, \$2, 100	if (\$2 < 100), \$1 = 1 else \$1 = 0
multiply	mult \$2,\$3	Hi, Lo = \$2 * \$3, 64-bit signed product
multiply unsigned	multu \$2,\$3	Hi, Lo = \$2 * \$3, 64-bit unsigned product
divide	div \$2,\$3	Lo = \$2 / \$3, Hi = \$2 mod \$3
divide unsigned	divu \$2,\$3	Lo = \$2 / \$3, Hi = \$2 mod \$3, unsigned
	transfer	
move from Hi	mfhi \$1	\$1 = Hi
move from Lo	mflo \$1	\$1 = Lo
load upper immediate	lui \$1,100	\$1 = 100 x 2^{16}
	logic	
and	and \$1,\$2,\$3	\$1 = \$2 & \$3
or	or \$1,\$2,\$3	\$1 = \$2 | \$3
and immediate	andi \$1,\$2,100	\$1 = \$2 & 100
or immediate	ori \$1,\$2,100	\$1 = \$2 | 100
nor	nor \$1,\$2,\$3	\$1 = not(\$2 | \$3)
xor	xor \$1, \$2, \$3	\$1 = \$2 ⊕ \$3
xor immediate	xori \$1, \$2, 255	\$1 = \$2 ⊕ 255
	shift	
shift left logical	sll \$1,\$2,5	\$1 = \$2 << 5 (logical)
shift left logical variable	sllv \$1,\$2,\$3	\$1 = \$2 << \$3 (logical), variable shift amt
shift right logical	srl \$1,\$2,5	\$1 = \$2 >> 5 (logical)
shift right logical variable	srlv \$1,\$2,\$3	\$1 = \$2 >> \$3 (logical), variable shift amt
shift right arithmetic	sra \$1,\$2,5	\$1 = \$2 >> 5 (arithmetic)
shift right arithmetic variable	srav \$1,\$2,\$3	\$1 = \$2 >> \$3 (arithmetic), variable shift amt
	memory	
load word	lw \$1, 1000(\$2)	\$1 = memory [\$2+1000]
store word	sw \$1, 1000(\$2)	memory [\$2+1000] = \$1
load byte	lb \$1, 1002(\$2)	\$1 = memory[\$2+1002] in least sig. byte
load byte unsigned	lbu \$1, 1002(\$2)	\$1 = memory[\$2+1002] in least sig. byte
store byte	sb \$1, 1002(\$2)	memory[\$2+1002] = \$1 (byte modified only)
	branch	
branch if equal	beq \$1,\$2,100	if (\$1 = \$2), PC = PC + 4 + (100*4)
branch if not equal	bne \$1,\$2,100	if (\$1 ≠ \$2), PC = PC + 4 + (100*4)
	jump	
jump	j 10000	PC = 10000*4
jump register	jr \$31	PC = \$31
jump and link	jal 10000	\$31 = PC + 4; PC = 10000*4