CS 61C
Great Ideas in Computer Architecture

MT 1

PRINT your name: ______________________, ______________________
(last) (first)

I am aware of the Berkeley Campus Code of Student Conduct and acknowledge that any academic misconduct will be reported to the Center for Student Conduct, and may result in partial or complete loss of credit. I am also aware that Nick Weaver takes cheating personally and, like the Hulk®, you don't want to see him angry.

SIGN your name: ______________________________________

PRINT your class account login: cs61c-______ and SID: ____________________

Your Favorite TA's name: ______________________________________

Exam # for person sitting to your left: ____________

Exam # for person sitting to your right: ____________

You may consult one sheet of paper (double-sided) of notes. You may not consult other notes, textbooks, etc. Calculators, computers, and other electronic devices are not permitted.

You have 110 minutes. There are 6 questions, of varying credit (90 points total). The questions are of varying difficulty, so avoid spending too long on any one question. Parts of the exam will be graded automatically by scanning the **bubbles you fill in**, so please do your best to fill them in somewhat completely. Don't worry—if something goes wrong with the scanning, you'll have a chance to correct it during the regrade period.

If you have a question, raise your hand, and when an instructor motions to you, come to them to ask the question.

Do not turn this page until your instructor tells you to do so.

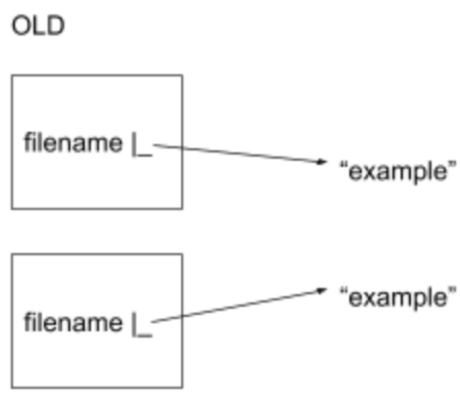
Question:	1	2	3	4	5	6	Total
Points:	15	18	20	15	15	7	90

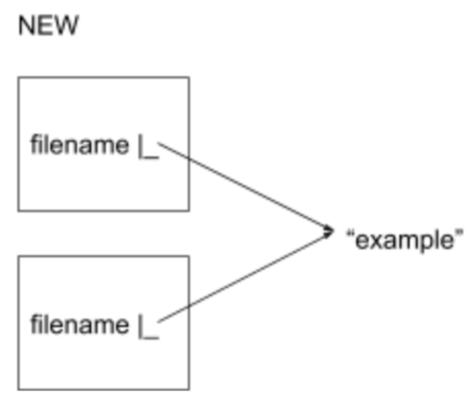
Problem 1 *Free's Company* (15 points)

In project 1-2 we asked you to allocate and free memory for an AST struct. Consider the following simplified struct.

```
typedef struct simple_ast {
    char *filename;
    int type;
    struct simple_ast **children;
    int size;
} simple_AST;
```

When Nick was testing the project, he found that he ran out of memory sooner than expected on large inputs. He attributed this to redundant malloc's for filenames.
To address this, Nick decides to make one malloc for filenames that are shared between nodes. The left image below shows what was assumed in the project, and the right image shows the new, single-malloc scheme.





(a) Nick decides to use the following function to free his ASTs.

```
void FreeAST (simple_AST *tree) {
     if (tree != NULL) {
          int i;
          for (i = 0; i < tree->size; i++) {
               FreeAST (tree->children [ i ]);
          }
          free (tree->children);
          free (tree->filename);
          free (tree);
          }
     }
```

In 1 sentence explain why Nicks free function will cause problems on the following input. You may assume all calls to malloc succeed.

```
char *filename = malloc (sizeof (char) * (strlen("ex") + 1));
strcpy (filename, "ex");
simple_AST *tree = MakeAST (...., filename);
simple_AST *child = MakeAST (...., filename);
AppendAST (tree, child);
FreeAST (tree);
```

Solution: The code above will make two calls to free on the same pointer (filename). We can't free the same memory twice, this might crash our program!

(b) To fix this problem, Nick decides to take the following approach: he will keep any address he intends to free in a structure of unique elements. Then, once he has iterated through the whole tree, he will iterate through the structure and free each address. Nick creates the following structure for holding the addresses:

```
typedef struct shared_string {
    int size;
    int capacity;
    char **arr;
} shared_string_t;
```

Fill in the following function to add addresses to the lst. The function should *not* copy the strings themselves. Assume `contains` returns nonzero if the address is already in the list and zero otherwise.

```
void append_address (shared_string_t *lst, char *address) {
    if (! contains (lst, address)) {
        if (lst->size == lst->capacity) {

            ______________________________________________;

            ______________________________________________;

        }

        ____________________________;

        ____________________________;
    }
}
```

Solution:

```
void append_address (shared_string_t *lst, char *address) {
    if (! contains (lst, address)) {
        if (lst->size == lst->capacity) {
            lst->capacity *= 2;;
            lst->arr = realloc(
                lst->arr,
                sizeof(char*) * lst->capacity);
        }
        lst->arr[lst->size] = address;
        lst->size += 1;
    }
```

(c) Finally we will implement `FreeAST`. This function should free all memory associated with the given `simple_AST` and should *not* exhibit the problem you described in part (a). You may assume the existence of the following helper functions:

```
/* This function allocates memory for a shared_string_t and initalises
it.  It returns the pointer to the malloc'd memory.  You may assume all
calls to malloc succeed.  */

shared_string_t *create_list ();

/* This function frees the given simple_AST node and its children.  It
also adds each filename to the given shared_string_t struct so it can be
deleted later.  */

void FreeASTHelper (simple_AST *tree, shared_string_t *addr_list);
```

Fill in the remaining sections of `FreeAST`. Note the function should not leak any memory.

```
void FreeAST (simple_AST *tree) {
     if (tree != NULL) {
          shared_string_t *lst = create_list ();
          FreeASTHelper (tree, lst);
          int i;
          for (i = 0; i < lst->size; i++) {

               ______________________________________________;
          }

          ______________________________________________;

          ______________________________________________;
     }
}
```

Solution:
```
void FreeAST (simple_AST *tree) {
    if (tree != NULL) {
        shared_string_t *lst = create_list ();
        FreeASTHelper (tree, lst);
        int i;
        for (i = 0; i < lst->size; i++) {
            free(lst->arr[i]);
        }
        free(lst->arr);
        free(lst);
    }
}
```

Problem 2 *Remember-y Management* (18 points)

For this problem, assume all pointers are four bytes and all characters are one byte. Consider the following C code (all the necessary #includes are omitted). C structs are properly aligned in memory and all calls to malloc succeed.

```
int size = 0;
struct map_entry {
    char *key;
    char *value;
};

void add_entry(struct map_entry *m, char *k, char *v) {
    int *zero = NULL;
    m[size].key = k;
    m[size].value = v;
    size++;
}

void main(void) {
    struct map_entry *map = malloc(sizeof(struct map_entry) * 10);
    char *key = malloc(sizeof(char) * 10);
    char value[20];
    add_entry(map, "k", "v");
    add_entry(map, key, value);
}
```

(a) For each of the following, bubble the option that best describes where in the memory layout each variable is stored **You should select one answer per variable.**

(a) `zero`

- ● Stack
- ○ Static
- ○ Heap
- ○ Code

(b) `*map[0].key`

- ○ Stack
- ● Static
- ○ Heap
- ○ Code

(c) `map[1].value`

- ○ Stack
- ○ Static
- ● Heap
- ○ Code

(d) `add_entry`

- ○ Stack
- ○ Static
- ○ Heap
- ● Code

(e) Bubble the comparators that would make the following expressions evaluate to true. If there is not enough information in the problem to answer conclusively, select the last option. Assume malloced memory grows upward, allocating the first available address.

(a) `map __ zero`

- ● `>`
- ○ `==`
- ○ `<`
- ○ `Not enough information`

(b) `key __ &size`

- ● `>`
- ○ `==`
- ○ `<`
- ○ `Not enough information`

(c) `map __ key`

- ○ `>`
- ○ `==`
- ● `<`
- ○ `Not enough information`

(d) `value __ &zero`

- ● `>`
- ○ `==`
- ○ `<`
- ○ `Not enough information`

(e) How many bytes of memory are leaked by this program?

Solution: 90 Bytes

Problem 3 ***AST: Another Stupid Tree*** **(20 points)**

In this problem, we will revisit a simplified version of the AST from Project 1-2. Our version is shown below. We are interested in implementing a function that searches our AST for a given piece of data and, when found, replaces the data with a value returned by `(*f)(data)`. We will search for and replace ever occurrence of the data inside our tree.

```
Struct AST_Simple {
    Struct AST_Simple **children;
    int size;
    int data;
}

void SearchAST (struct AST_Simple *ast, int data, int (*f)(int)) {
    int i = 0;
    /* If the AST is NULL, no match */
    if (ast == NULL) {
        return;
    }

    /* If the head node contains our data, we found a match */
    if (ast->data == data){
        ast->data = (*f)(data);
    }

    /* Search for the data within the children nodes */
    for (; i < ast->size; i++){
        searchAST(ast->children[i], data, f);
    }
}
```

```
# Arguments follow the RISC-V calling convention
SearchAST:
         # Prologue
    addi sp sp _________
    sw ___________________
    sw ___________________
    sw ___________________
    sw ___________________
    sw ___________________
         # Preserve and set arguments
    add s3 x0 x0
    mv s0 a0
    mv s1 a1
    mv s2 a2
         # Start computing
IfOne:
    bne ______________
    j ___________________
IfTwo:  # Have we found what we're looking for?
    lw t0 ______________
    bne ___________________
    ____________________________
    ____________________________
    ____________________________
Loop:     # Check our children
    lw t0 ______________
    bge ___________________
    lw t0 ______________
    slli t1 ______________
    add t2 ______________
         # Prepare for recursive call
    lw a0 ______________
    ____________________________
    ____________________________
    jal ___________________
    ____________________________
    j ___________________
Done:      # Epilogue
    lw ___________________
    lw ___________________
    lw ___________________
    lw ___________________
    lw ___________________
    addi sp sp _________
    jr ra
```

Solution:

```
SearchAST:
    # Prologue:  We use s0-s3 so need to save them
    # Plus we need to save RA
    addi sp sp -20
    sw s0 0(sp)
    sw s1 4(sp)
    sw s2 8(sp)
    sw s3 12(sp)
    sw ra 16(sp)

    # Preserve and set arguments
    # Note that this also ends up setting which vars
    # end up in which registers
    add s3 x0 x0 # x = 0
    mv s0 a0 # s0 = ast
    mv s1 a1 # s1 = data
    mv s2 a2 # s2 = f

    # Start computing
    # The first if represents the case "if ast == 0 return"
    # So in assembly we write "if AST != 0 go to next if"
    # where the body of the if is "skip-to-the-end" (Done)
IfOne:
    bne s0 x0 IfTwo # Could have also used a0
    j Done

IfTwo:  # Have we found what we're looking for?
    # Structure layout is:
    # 0 = children, 4 = size, 8 = data
    # So load ast->data, and if it isn't
    # equal, skip the rest of the if
    # We can use a0/s0 and a1/s1 because
    # for now, they are the same values
    lw t0 8(a0/s0)
    bne t0 s1/a1 Loop

    # OK, data == ast->data, so we
    # need to call F(data)
    mv a0 t0 # could also be from s1/a1
    jalr ra a2/s2 0 # call F
    sw a0 8(s0) # Replace ast->data
```

```
Loop:     # Check our children
     lw t0 4(s0) # Load ast->size
     bge s3 t0 Done # if i >= size we return
     lw t0 0(s0) # load ast->children
     slli t1 s3 2 # t1 == i << 2 to create byte offset to i'th child
     add t2 t1 t0 # Pointer addition to get &(lst->children[i])

     # Prepare for recursive call
     lw a0 0(t2) # now load ast->children[i] to a0
     mv a1 s1 # and make sure a1 is set...
     mv a2 s2 # and a2...
     jal ra SearchAST # and now recurse
     addi s3 s3 1 # and increment i
     j Loop # and continue the loop

Done:      # Epilogue:  restore saved registers, ra
     lw s0 0(sp)
     lw s1 4(sp)
     lw s2 8(sp)
     lw s3 12(sp)
     lw ra 16(sp)
     addi sp sp 20
     # Return to caller
     jr ra
```

Problem 4 ***Do you see what IEC?*** **(15 points)**

(a) IEC Prefixes

1. The human genome is approximately 3,200 Mega-base pairs. How many base pairs is 3,200 Mega-base pairs? For credit you must format your answer using powers of 10 (ie _ * 10 ^_).

   ____

   Solution: $3,200 * 10^6$ base pairs

2. Ram wants to sell you a floppy disk with 8 (marketing) KIBIbytes memory for 16 dollars. Sruthi also wants to sell you a floppy disk, with 8 (marketing) KILObytes memory for 10 dollars.

   (a) For Rams floppy disk, how many bytes are on the floppy disk? Do not simplify.

____________________________ Bytes

Solution: 8192 Bytes

(b) For Rams floppy disk, how many bytes per dollar?

____________________________ Bytes per dollar

Solution: 512 Bytes per dollar

(c) For Sruthis floppy disk, how many bytes are on the floppy disk? Do not simplify.

____________________________ Bytes

Solution: 8000 Bytes

(d) For Sruthis floppy disk, how many bytes per dollar?

____________________________ Bytes per dollar

Solution: 800 Bytes per dollar

(b) Number Representation

1. Because Moores Law is dead, its time to try storing data in something alive. A DNA strand is composed of a linear sequence of chemical base pairs, and we can consider each of its 4 base pairs (A, C, T, G) as a "digit" How many unique values can be stored in an X-base pair DNA strand? Your answer should contain the variable X.

   ______________________________ unique values

   Solution: 4^X unique values

2. Assume we use DNA to store data in base-4, unsigned. A = 0, C = 1, T = 2, and G = 3, with the most significant base pair first. *Use the number-equivalent of each base to format your answers below.*

   (a) How do we store the decimal (base-10) number 36 in DNA?

   ____

   Solution: 10_01_00
   $0dTCA$ (or $0dATCA$)

   (b) How do we store the binary (base-2) number $0b01111100$ in DNA?

   ____

   Solution: 01_11_11_00
   $0dCGGA$

   (c) How do we store the hexadecimal (base-16) number $0x7AB$ in DNA?

   ____

   Solution: $0x7AB$ == 0b0111_1010_1011 == 0b01_11_10_10_10_11
   $0dCGTTTG$ (or $0dA...ACGTTTG$)

   (d) Convert GATTACA to binary

   $0b$______________________________

Solution: 0b11_00_10_10_00_01_00 == 0b11001010000100

Problem 5 ***More Poorly Written Instructions (Project 1-3)*** **(15 points)**

As much as we love working in RISC-V, TAs and students everywhere are tired of having to transcribe 32-bits for every instruction. We'd like to invent a new machine language based on RISC-V that uses fewer bits overall.

To make this change possible, our reduced instruction set will contain *only* the following instructions:

1. add
2. addi
3. beq
4. jal

Additionally, we will group together all immediate bits and place them at the end of the instruction. If we rearrange the *standard RISC-V SB-type* to match our immediate adjustment, it would look like the following:

rs2	rs1	func3	opcode	imm[11:0]

The instructions beq and jal will encode the entire immediate necessary for control flow and do not append a trailing zero. We would like to continue to support the use of all 32 registers.

1. Lets say we decide to remove the funct3 and funct7 fields so that our R-type format looks like the following:

opcode	rd	rs1	rs2

How many bits do we need to represent each of the following fields?

```
Opcode: __________ bits

rd: __________ bits

rs1: __________ bits

rs2: __________ bits
```

Solution:

```
Opcode:  2 bits
rd:  5 bits
rs1:  5 bits
rs2:  5 bits
Because we only have four instructions, there's only log(4)=2 bits
```

```
needed for the opcode. However, we still need to support all 32
registers, meaning log(32) = 5 bits for rd, rs1, and rs2.
```

2. Using the values in your previous answer (and assuming all instructions must be the same total size), how many bits would we have for the immediate field in an I type instruction?

   `Imm:` ________ `bits`

Solution: `Imm: 5 bits`

```
From the previous part, we know that instructions must be 17 bits.
I-type instructions have opcode, rd, rs1, and imm. Resulting in
16 - 2 - 5 * 2 = 5 bits.
```

3. Because we only have 4 instructions, we cant represent all of our instruction types. Which types are missing from our language? Mark all that apply.

- ○ R
- ○ I
- ● S
- ○ SB
- ● U
- ○ UJ

Solution:

```
We know that add is R-type, addi is I-type, beq is SB-type,
and jal is UJ-type. Meaning we don't have S-type and U-type.
```

4. For the following question, mark the statement as true or false and give a tweet-length justification. (if true, mention which two formats). Assume we consider all register fields (rs1, rs2, rd) the same.

   Two of our instruction formats have the exact same field ordering

- ● True
- ○ False

____

____

____

Solution: Both I and SB types have the same arrangement of fields: opcode, register, register, immediate

5. Now assume our instructions match the format above but are 8 bits in length. If we have 2 bits of the opcode and 2 bits for registers (which may or may not reflect answers in previous parts), convert the following instructions.

Opcodes	
$0b00$	add
$0b01$	addi
$0b10$	beq
$0b11$	jal
Registers	
$0b00$	zero
$0b01$	ra
$0b10$	s0
$0b11$	t0
Labels	
One	One byte forward
Two	Two bytes forward
BOne	One byte backward
BTwo	Two bytes backward

(a) `addi zero, ra, -1`

____

Solution: 0b01000111. We go opcode, rd, rs1, rs2/imm.
This means $0b01|0b00|0b01|0b11 = 0b01000111$.

(b) $0b10101110$

____

Solution: `beq s0 t0 BTwo`. We check the opcode, $0b10$, which means it is beq. rs1 and rs2 are $0b10$ and $0b11$, respectively are s0 and t0.
Our imm is $0b10$, which equals -2, meaning we want to go two bytes back.

Problem 6 ***CALL: Crammed At the Last Lecture*** **(7 points)**

(a) Mark the following as either True or False

1. The linker reads in one or more object files and generates an executable or library.

   ● True ○ False

2. The assembler may remove pseudo instructions before passing the file to the linker, though this step is optional because pseudo instructions are understood by machines.

   ○ True ● False

3. The 61Ccc compiler you wrote in projects 1-1 and 1-2 is considered a complete compiler in that it converts c-like files to assembly code.

   ○ True ● False

4. Executable files generated by CALL are machine-dependent.

   ● True ○ False

(b) Consider an assembler that analyses code top-to-bottom in a single pass. Which of the following isolated blocks of code exhibit the forward reference problem? Bubble all that apply.

●

```
LOOP:
    beq t0 t1 END
    addi t0 t0 1
    sw t0 0(s0)
    j LOOP
END:
```

●

```
CALL:
    jal ra F
    la a0 CALL
F:
    addi sp sp -4
    sw s0 0(sp)
```

○

```
    add t0 t0 x0
    addi t1 x0 3
REDO:
    addi t0 t0 1
    slli s1 t0 2
LOOP:
    bne t0 t1 REDO
    add s0 s1 x1
    lw t0 0(s0)
    j LOOP
```

○

```
F_X:
    mv t0 a0
    addi t0 t0 4
    lw a1 0(t0)
    jr ra
G_X:
    mv a0 s0
    jal ra F_X
```

Figure 1: This Space Deliberately Left Blank