CS 61C (Clancy) **Solutions and grading standards for exam 1**
Spring 2003

Exam information

183 students took the exam. Scores ranged from 1 to 20, with a median of 9.5 and an average of 9.25. There were 17 scores between 15.5 and 20, 54 between 10.5 and 15, 76 between 5.5 and 10, and 36 between 1 and 5. (Were you to receive a grade of 16 on all your midterm exams, 48 on the final exam, plus good grades on homework, quizzes, and lab, you would receive an A–; similarly, a test grade of 11 may be projected to a B–. The replacement problem that you'll work on on March 5 will presumably improve your score.)

There were two versions of the exam, A and B. (The version indicator appears at the bottom of the first page.)

If you think we made a mistake in grading your exam, describe the mistake in writing and hand the description with the exam to your lab t.a. or to Mike Clancy. We will regrade the entire exam (even if the only error is a mistake in adding up your points).

Solutions and grading standards

Problem 0 (1 point)

You lost ½ point on this problem for each of the following:

- you earned some credit on a problem and did not put your name on the page,
- you did not indicate your lab section or t.a., or
- you failed to put the names of your neighbors on the exam.

The reason for this apparent harshness is that exams can get misplaced or come unstapled, and we would like to make sure that every page is identifiable. We also need to know where you will expect to get your exam returned. Finally, we occasionally need to know where students were sitting in the class room while the exam was being administered.

Problem 1 (7 points)

Both versions involved predicting how much memory was needed for a node, then writing an assembly language function that used the node. Lab 4 and homeworks 2 and 4 provided relevant experience. The node definitions were

version A

```
struct node {
   char name[12];
   int value;
};
```

version B

```
struct node {
   char name[20];
   int value;
};
```

One byte is required for each `char` and four bytes for each `int`, so the desired answers to part a were 16 and 24 for versions A and B respectively. This part was worth 1 point; no partial credit was awarded. A common error was to think that an N-element character array would take up N+1 bytes. Some students also were unaware that `char` values on the instructional computers take up one byte each.

In part b, you were to implement one of the following:

version A

```
void exam1 (struct node **to) {
   exam2 (*to);
   (*(to-1))--;
}
```

version B

```
void exam1 (struct node **to) {
   exam2 (*to);
   (*(to+1))++;
}
```

Since both involve a call to exam2 and access to the to argument after exam2 returns, at least two register values must be saved on the stack: $ra and either $a0 or one of the $s registers (into which $a0 would be copied). Here are prologs corresponding to the two alternatives:

```
addi  $sp,-8
sw    $a0,4($sp)
sw    $ra,0($sp)
```

```
addi  $sp,-8
sw    $s0,4($sp)
sw    $ra,0($sp)
move  $s0,$a0
```

The order in which register values are stored on the stack is important only insofar as it matches the order in which they are restored from the stack.

Next comes the call to exam2. $a0 contains to, but we need *to. Here's how to get it:

```
lw    $a0,0($a0)
jal   exam2
```

The decrement or increment breaks down into the following steps:

1. Reload to from the stack if necessary.
2. Decrement/increment it by 4 (since it's a pointer to a 4-byte pointer).
3. Load from the resulting address. (We now have *(to±1).)
4. Decrement/increment it by whatever you gave in part a as sizeof (struct node), since *to and *(to±1) are both pointers to a struct node.
5. Update memory.

Here is solution code that assumes $a0 was saved on the stack rather than in $s0.

version A

```
lw    $a0,4($sp)    # restore to
lw    $t1,-4($t0)   # get *(to-1)
addi  $t1,$t1,-16   # (*(to-1))--
sw    $t1,-4($t0)   # update *(to-1)
```

version B

```
lw    $a0,4($sp)    # restore to
lw    $t1,4($t0)    # get *(to+1)
addi  $t1,$t1,24    # (*(to+1))++
sw    $t1,4($t0)    # update *(to+1)
```

Finally, we restore $ra and $s0 if we used it (restoring $a0 isn't necessary), pop the stack, and return:

```
lw    $ra,0($sp)
addi  $sp,8
jr    $ra
```

Solutions could earn up to 2 points for each of the following, for a maximum of 6:

- correct address arithmetic;
- correct loading;
- everything else (the prolog, the epilog, and the call to exam2).

Most errors received a 1-point deduction. Some examples:

prolog/epilog/call

- forgetting to save $a0 or $s0
- forgetting to save $ra
- saving but forgetting to restore $ra
- saving $ra in $s0 but not saving $s0
- forgetting that to would be in $a0 on entry to the function
- forgetting to set up $a0 for the call to exam2
- growing the stack in the wrong direction
- stack pointer off by one
- using "done" instead of jr

address arithmetic

- using an incorrect increment/decrement value
- adding/subtracting in the wrong order
- adding/subtracting at the wrong level of indirection

loads

- an extra level of indirection
- using la instead of lw
- returning the incremented/decremented value in $v0 instead of updating memory

If you neglected to store the result of the increment/decrement operation, you lost only ½ point. You were not penalized for using more than two words on the stack.

The list above includes the most common errors.

Problem 2 (3 points)

This problem was the same on both versions. You were to write a function that, when called immediately before the buggy swap function, would ensure that swap would crash when dereferencing the uninitialized pointer variable temp.

Step 1 is to figure out where temp is stored, and how it could get accidentally initialized to a value that would make swap "work". As you saw in lab 3, space for local variables in a C program is allocated on the system stack. Thus f must put an invalid pointer onto the stack in the space that temp will occupy to ensure the crash.

Though gcc pushes function arguments onto the stack, a different compiler might keep them in registers. Thus the number of arguments to f should be the same as the

number passed to swap, and the sizes of the arguments should also match those of swap, just to make sure f does the same kind of stack manipulation as swap does. Here is our solution:

```
void f (int *a, int *b) {
   int *temp;
   temp = 0;  /* put an invalid pointer value where swap's temp will be */
}
```

The pointers could have been declared as ints, which take up the same amount of space. Any odd number would have worked as an invalid pointer value in place of 0.

We also accepted the following definition, which assumed that arguments all took up stack space as they did in your lab 3 experiments.

```
void f (int *a, int *b, int *c) {
   a = 0;  /* put an invalid pointer value where swap's temp will be */
}
```

We accepted this code with c set to 0 instead of a. However, C always pushes arguments in reverse order.

The 3 points for this problem were split 1 for the code and 2 for the explanation: 1 for saying something reasonable about a position on the stack, and 1 for saying something reasonable about a value of temp sure to produce a crash when dereferenced.

Few students got this right. Some incorrect answers were the following:

```
void f (int *a, int *b) {
   a = 0;
}
call: f(&x,&y);
```

```
void f ( ) {
   int *temp = 0;
}
```

We think that in the first example, students were trying to make sure swap crashed because of dereferencing *a rather than *temp. If that worked, swap would then crash even after it was fixed! Note, however, that since arguments in C are passed by value, the assignment only affects the copy of &x on the stack; its subsequent use in the call to swap would use the original &x. In the second, they mistakenly identified f's temp with swap's; however, the fact that two local variables have the same name says nothing about where they appear in memory.

Problem 3 (6 points)

This problem was the same on both versions. You were to write a function that returned a copy of an array of strings (of which argv is an example). We assumed that lab 2 and homework assignment 2 would prepare you sufficiently for this problem.

A diagram for how argv is represented appears on page 115 of K&R. The top-level data structure is an array of pointers, each one pointing to the first character of a C-style string. (In the diagram, the last pointer is 0. We allowed you to disregard this.) As you noted in lab 2, calls to malloc were necessary both for the top-level structure and for each of the individual strings. A call to strcpy was necessary to copy each argv entry into the new data structure, as you also noted in lab 2. Here is a solution:

```
char **copyStrArray (int count, char **strArray) {
   /* get space for all the pointers */
   char **copy = (char **) malloc (count * sizeof(char *));
   int k;
   for (k=0; k<count; k++) {
      /* get space for each individual string, then fill it up */
      copy[k] = (char *) malloc((strlen(strArray[k])+1) * sizeof(char));
      strcpy (copy[k], strArray[k]);
   }
   return (copy);
}
```

One might use pointer expressions instead of array references, substituting *(copy+k) for copy[k] and *(strArray+k) for strArray[k]

Grading started with a count of malloc calls; you lost 2 points for each missing one. If your solution copied only *one* of the elements of the array, you lost 4 (this included 2 for a missing malloc). Then $1\frac{1}{2}$ points were allocated to each of the following:

- the outer malloc, if supplied;
- the inner malloc, if supplied;
- the call to strcpy (you were allowed to code your own version);
- everything else, in a solution that attempted to copy all elements of the array.

This generally meant that each small error was worth $\frac{1}{2}$ point. Most common were misparenthesizing malloc arguments or pointer expressions, forgetting a *, and forgetting to allocate space for the terminating byte in each string. Use of strdup, a function in nova's stdio library but not K&R's, lost you 1 point. (We warned you about this at the start of the exam.) Multiple errors of the same type were generally combined into a 1-point deduction.

Type mismatches between the parameters of the given call and the header of the copyStrArray function were unfortunately common. Many of you also confused sizeof and strlen, or neglected to use sizeof despite the warning against assuming anything about the size of a pointer or a char, or failed to include the count argument in the outer malloc. Students who omitted the outer malloc generally tried to declare the array as a local variable:

```
char **copyStrArray (int count, char **strArray) {
   char *copy[count];
      ...
   return copy;
}
```

This is wrong for two reasons. First, C doesn't allow a variable to appear between the brackets in an array declaration (it needs to know exactly how much storage to allocate for the array at compile time). Moreover, the copy array is allocated on the stack, and disappears once the function returns.

Problem 4 (3 points)

This problem was based on homework assignment 3, with the additional feature of involving actual memory contents. You were to determine the result of freeing a given block. The storage layouts on the two versions were as follows:

Version A

ptr: 1044

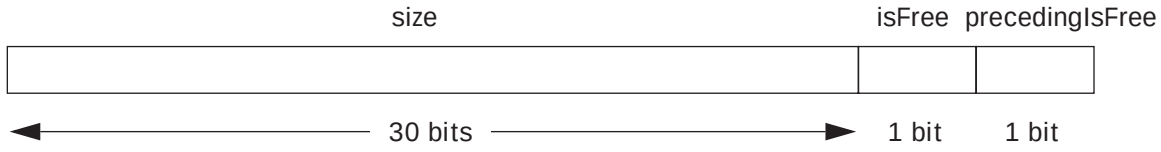
101C	00000032
1020	00001808
1024	00001B1C
1028	00000031
102C	00001054
1030	00001010
1034	00000032
1038	00000FF4
103C	0000200C
1040	00000031
1044	00001050
1048	00001028
104C	00000030
1050	00001030
1054	0000102C

Version B

ptr: 1038

101C	00000030
1020	00001808
1024	00001B1C
1028	00000032
102C	00000E0C
1030	00001FF0
1034	00000031
1038	00000FF4
103C	0000200C
1040	00000030
1044	00001050
1048	00001028
104C	00000032
1050	00001C08
1054	000010AC

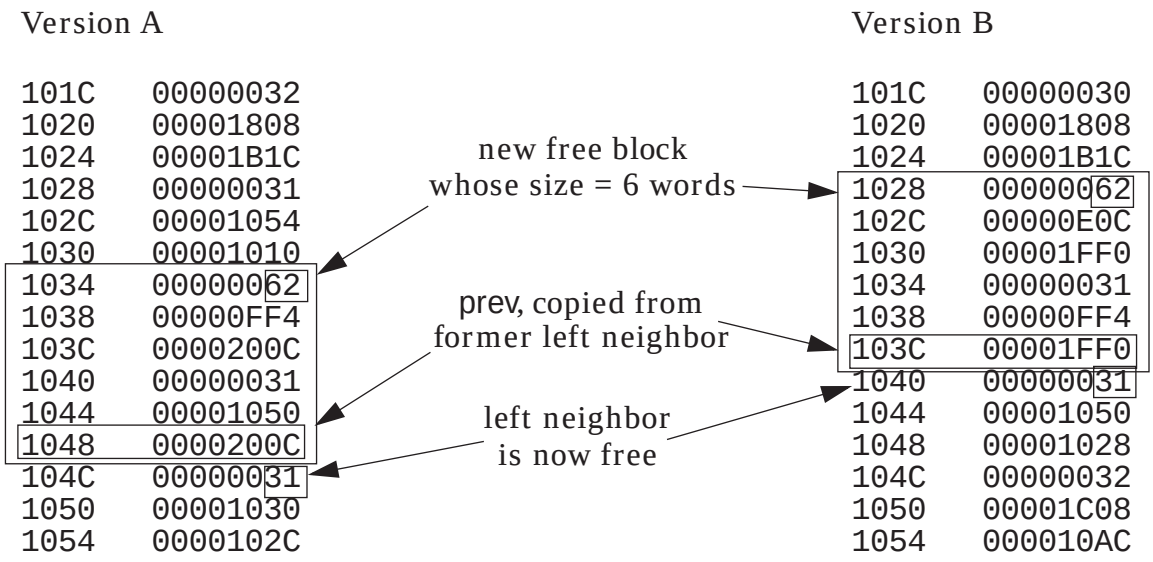
A good first step is to determine what the blocks are. You can determine this from the administrative words. They have the following format:



A value of 30 in an administrative word represents an allocated block of 12 bytes (3 words) whose left neighbor is also allocated. 31 is an allocated block of 12 bytes next to a free block, and 32 is a free block of 12 bytes (whose neighbor blocks must be allocated).

The address given to free points to the word that immediately follows the administrative word. In both versions, the administrative word indicates that the neighboring block on the left is free, so the two blocks must be combined into a block whose size is 6 words. The figure on the next page indicates all necessary changes.

The 3 points for this problem were split evenly among the three changes to make: increasing the size to 6 at address 1034 or 1028, copying the prev field from 103C/1030 to 1048/103C, and turning on the precedingIsFree bit at address 104C or 1040. You lost 1 point for each other change that overwrote crucial information (say, a link in a free block or any other administrative word, or any change to an allocated block). We ignored changes that would have no effect. You lost ½ point for an incomplete description of a change, for example by saying "the precedingIsFree bit is turned on" without giving the resulting memory contents. You also lost ½ point for a small error that was unrelated to your understanding of memory management, for example, a hexadecimal arithmetic error.



Few of the exams contained intelligible answers. When the page wasn't blank, it usually contained various scribbles followed by an answer for changing two or three words, unaccompanied by any kind of explanation.

A common mistake was to assume that the linked list of free blocks should be sorted by address as in the K&R storage allocation scheme, and to set the next and prev fields of the free blocks accordingly. Some students misread the administrative block because of hexadecimal arithmetic problems or administrative data ordering misconceptions. Students also seemed confused about the role of the administrative word; some of you seemed to think that *everything* (including administrative data and user data) was contained in the word at (say) 1044, and that calling precedingBlock(1044) would return 1040. We are unsure of the reason for this error.