CS 61 - Programming Assignment 05

Objective

The purpose of this final programming assignment is to test the limits of your LC3 skill by giving you a challenging implementation problem straight out of the textbook.

High Level Description

There is a server somewhere, called the Busyness Server. This server tracks whether 16 different machines connected to it are **busy (0)** or **free (1)**: this information is stored in a single LC-3 word (aka a "bit-vector").

You will write a menu-driven system that allows the user to query this bit-vector as to the availability of the 16 machines, in various combinations.

Before You Start Coding

This assignment is based on a variation of Question 9.9 (p. 242 of the textbook) – which will require that you first work through the following:

- Example 2.11 (p. 37)
- Question 2.36 (p. 46)
- Question 5.6 (p. 146)

(Note: I have lightly edited the wording of the following exerpts from the text for increased clarity)

Example 2.11

Suppose we have eight machines that we want to monitor with respect to their availability. We can keep track of them with an 8-bit BUSYNESS vector, where a bit is 1 if the unit is free and 0 if the unit is busy. The bits are labeled, from right (lsb) to left (msb), from 0 to 7.

The BUSYNESS bit vector 11000010 corresponds to the situation where only units 7, 6, and 1 are free, and therefore available for work assignment.

Suppose work is assigned to unit 7. We update our BUSYNESS bit vector by performing the logical AND, where our two operands are the current bit vector 11000010 and the bit mask 01111111. The purpose of the bit mask is to clear bit 7 of the BUSYNESS bit vector. The result is the bit vector 01000010.

Recall that we encountered the concept of bit mask in Example 2.7. Recall that a bit mask enables one to interact with some bits of a binary pattern while ignoring the rest. In this case, the bit mask *clears* bit 7 and *leaves unchanged* (ignores) bits 6 through 0.

Suppose unit 5 finishes its task and becomes idle. We can update the BUSYNESS bit vector by performing the logical OR of it with the bit mask 00100000. The result is 01100010.

Question 2.36

Refer to Example 2.11 (above) for the following questions.

A. What mask value and what operation would one use to *set* machine 2 to busy (0)? (Without changing the state of the other machines).
B. What mask value and what operation would one use to *set* machines 2 and 6 to free (1)? (Again, without changing the state of the other machines).
   Note: This can be done with a single operation.
C. What mask value and what operation would one use to *set* all machines to busy (0)?
D. What mask value and what operation would one use to *set* all machines to free (1)?
E. Develop a procedure to isolate the status bit of machine 2 as the "sign bit" (i.e. the msb). For example, if the BUSYNESS pattern is 0101 1100, then the output of this procedure is 10000000. If the BUSYNESS pattern is 0111 0011, then the output is 0000 0000. In general, if the BUSYNESS pattern is:

b7	b6	b5	b4	b3	b2	b1	b0

the output is

b2	0	0	0	0	0	0	0

Hint: What happens when you ADD a bit pattern to itself?

Question 5.6

Recall the machine busy example from Section 2.7.1. Assuming the BUSYNESS bit vector is stored in R2, we can use the LC3 instruction AND R3, R2, #1 to determine whether machine 0 is busy or not. If the result of this instruction is 0, then machine 0 is busy.

A. Write an LC3 instruction that determines whether machine 2 is busy.
B. Write an LC3 instruction that determines whether both machines 2 and 3 are busy.
C. Write an LC3 instruction that indicates whether none of the machines are busy.
D. Can you write a single LC3 instruction that determines whether machine 6 is busy? Is there a problem here?

The variation of Question 9.9 that you will implement in this assignment:

A. Check if *all* machines are busy; return 1 if all are busy, 0 otherwise.
B. Check if *all* machines are free; return 1 if all are free, 0 otherwise.
C. Check *how many* machines are busy; return the number of busy machines.
D. Check *how many* machines are free; return the number of free machines.
E. Check the *status* of a specific machine whose number is passed as an argument in R1; return 1 if that machine is free, 0 if it is busy.
F. Return the *number* of the first (lowest numbered) machine that is free.
   If no machine is free, return -1
   e.g. if the busyness vector is 0101 0100, then the first available machine is #2
   (the lsb is always considered #0)

Your Tasks

The assignment can be broken down into the following tasks:

1. Your main code block should call a MENU subroutine, which prints out a fancy looking menu with numerical options, allows the user to input a choice, and returns in **R1** the choice (i.e. 1, 2, 3, 4, 5, 6, 7) that the user made (if the user inputs a non-existent option, output an error message and re-print the menu until a valid entry is obtained).
   Here is the menu that you will be using for the assignment. It is given to you in the template at memory address **x6000**

   ```
   ***********************
   * The Busyness Server *
   ***********************
   1. Check to see whether all machines are busy
   2. Check to see whether all machines are free
   3. Report the number of busy machines
   4. Report the number of free machines
   5. Report the status of machine n
   6. Report the number of the first available machine
   7. Quit
   ```

2. Write the following subroutines:
   A. MENU
   B. ALL_MACHINES_BUSY
   C. ALL_MACHINES_FREE
   D. NUM_BUSY_MACHINES
   E. NUM_FREE_MACHINES
   F. MACHINE_STATUS
   G. FIRST_FREE

Subroutine Headers

The following headers have been provided to you in the given template.

```
;-----------------------------------------------------------------------
; Subroutine: MENU
; Inputs: None
; Postcondition: The subroutine has printed out a menu with numerical
;              options, captured the user selection, and returned it.
; Return Value (R1): The option selected:  #1, #2, #3, #4, #5, #6 or #7
;                 no other return value is valid
;-----------------------------------------------------------------------
```

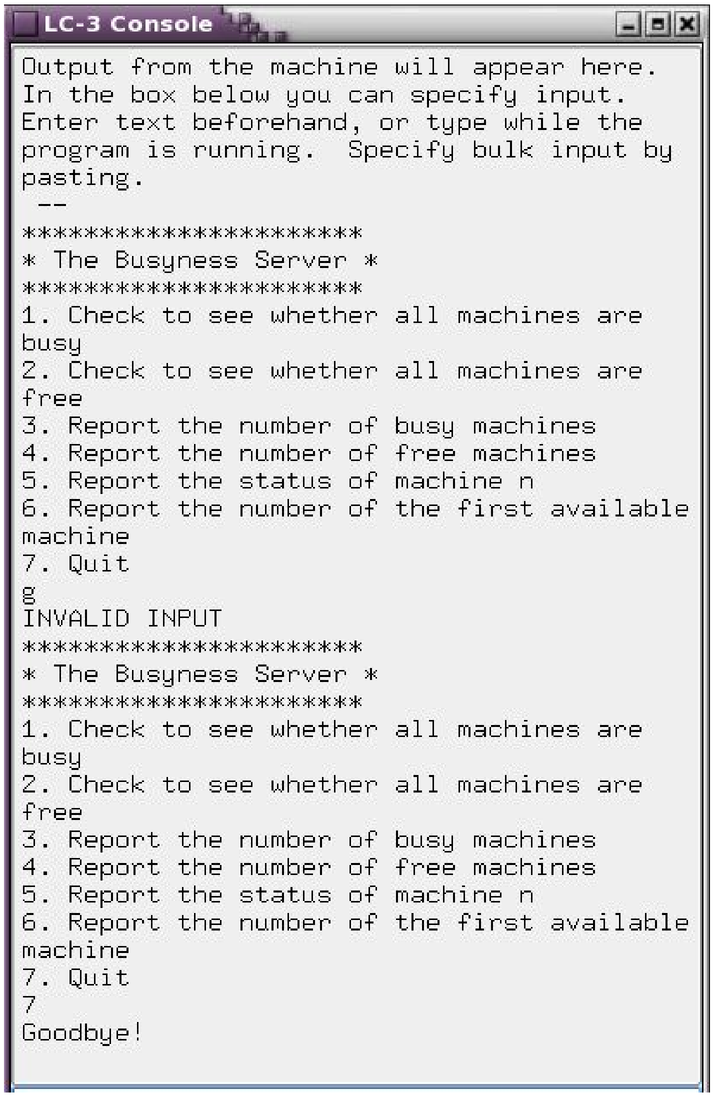
```
;--------------------------------------------------------------------
; Subroutine: ALL_MACHINES_BUSY
; Inputs: None
; Postcondition: The subroutine has returned a value
;               indicating whether all machines are busy
; Return value (R2): 1 if all machines are busy,    0 otherwise
;--------------------------------------------------------------------

;--------------------------------------------------------------------
; Subroutine: ALL_MACHINES_FREE
; Inputs: None
; Postcondition: The subroutine has returned a value
;               indicating whether all machines are free
; Return value (R2): 1 if all machines are free, 0 otherwise
;--------------------------------------------------------------------

;--------------------------------------------------------------------
; Subroutine: NUM_BUSY_MACHINES
; Inputs: None
; Postcondition: The subroutine has returned the number of busy machines.
; Return Value (R2): The number of machines that are busy
;--------------------------------------------------------------------

;--------------------------------------------------------------------
; Subroutine: NUM_FREE_MACHINES
; Inputs: None
; Postcondition: The subroutine has returned the number of free machines
; Return Value (R2): The number of machines that are free
;--------------------------------------------------------------------

;--------------------------------------------------------------------
; Subroutine: MACHINE_STATUS
; Input (R1): Which machine to check
; Postcondition: The subroutine has returned a value
;               indicating whether or not machine (R1) is busy
; Return Value (R2): 0 if machine (R1) is busy, 1 if it is free
;--------------------------------------------------------------------

;--------------------------------------------------------------------
; Subroutine: FIRST_FREE
; Inputs: None
; Postcondition: The subroutine has returned a value
;               indicating the lowest numbered free machine
; Return Value (R2): the number of the free machine
;--------------------------------------------------------------------
```

Expected/ Sample output

Output

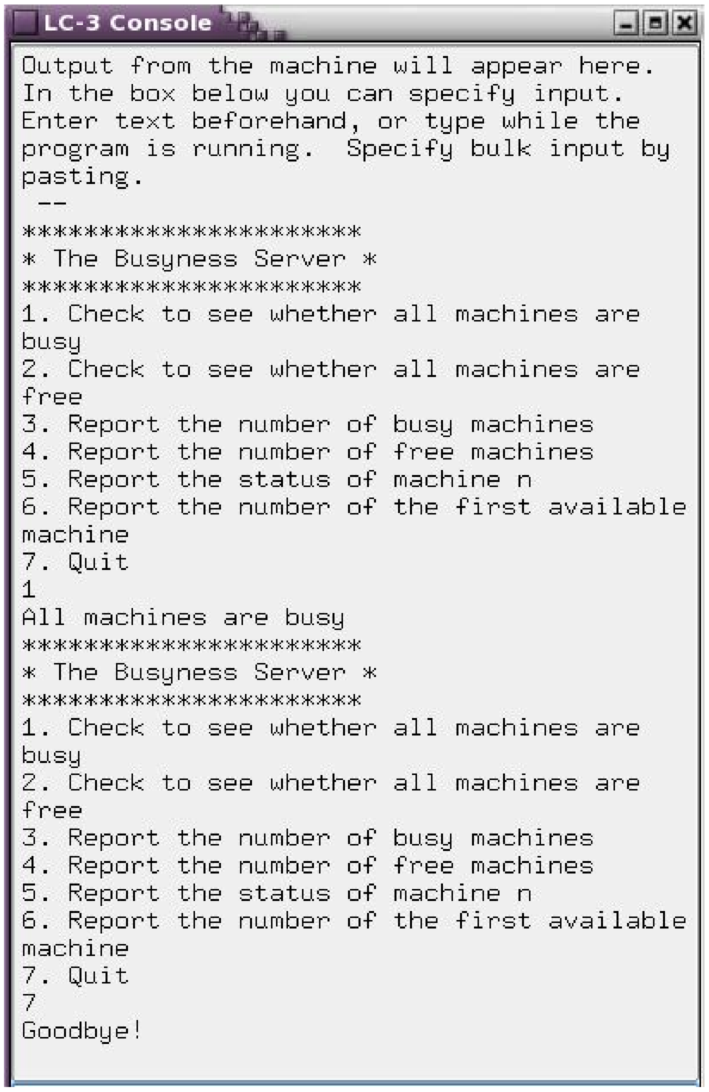
- See provided template and examples below.

Examples



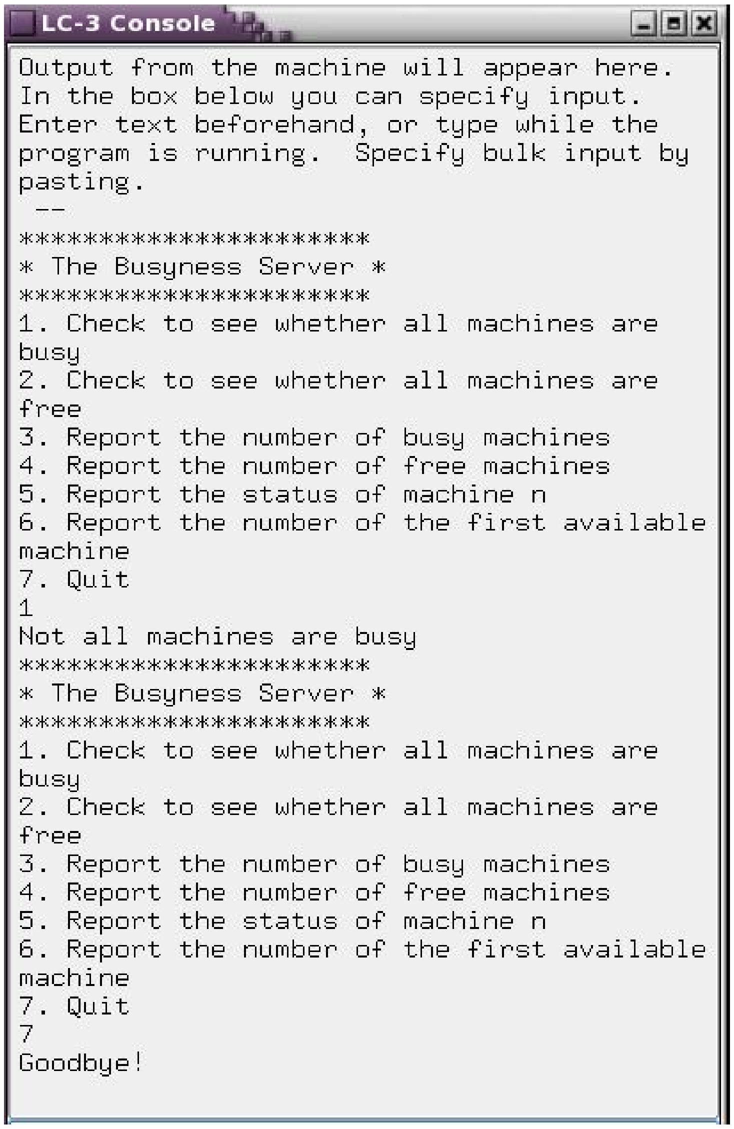
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
g
INVALID INPUT
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Wrong Input for menu, BUSYNESS = x0000)



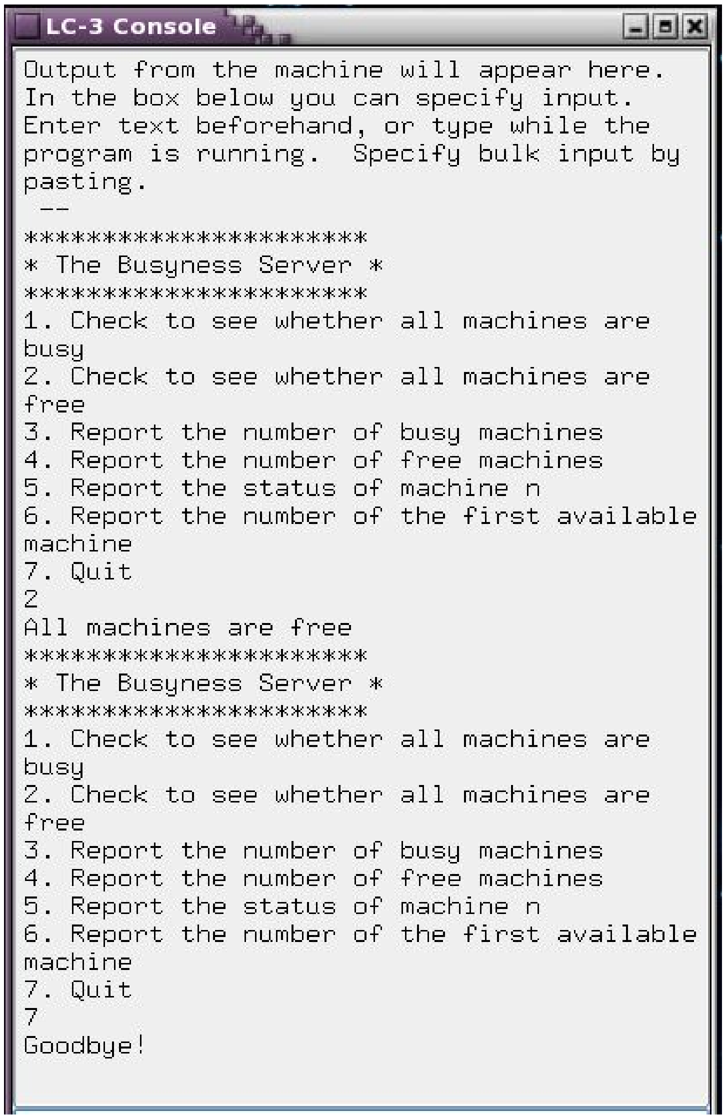
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
1
All machines are busy
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 1, BUSYNESS = x0000)



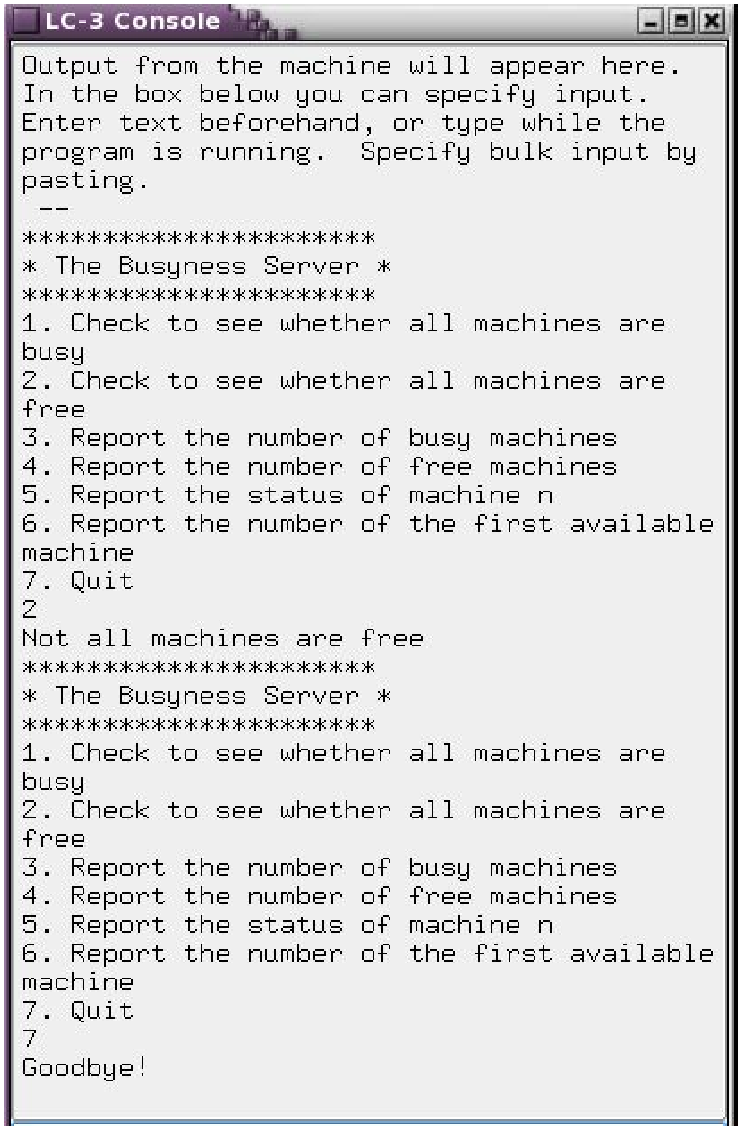
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
1
Not all machines are busy
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 1, BUSYNESS = xABCD)



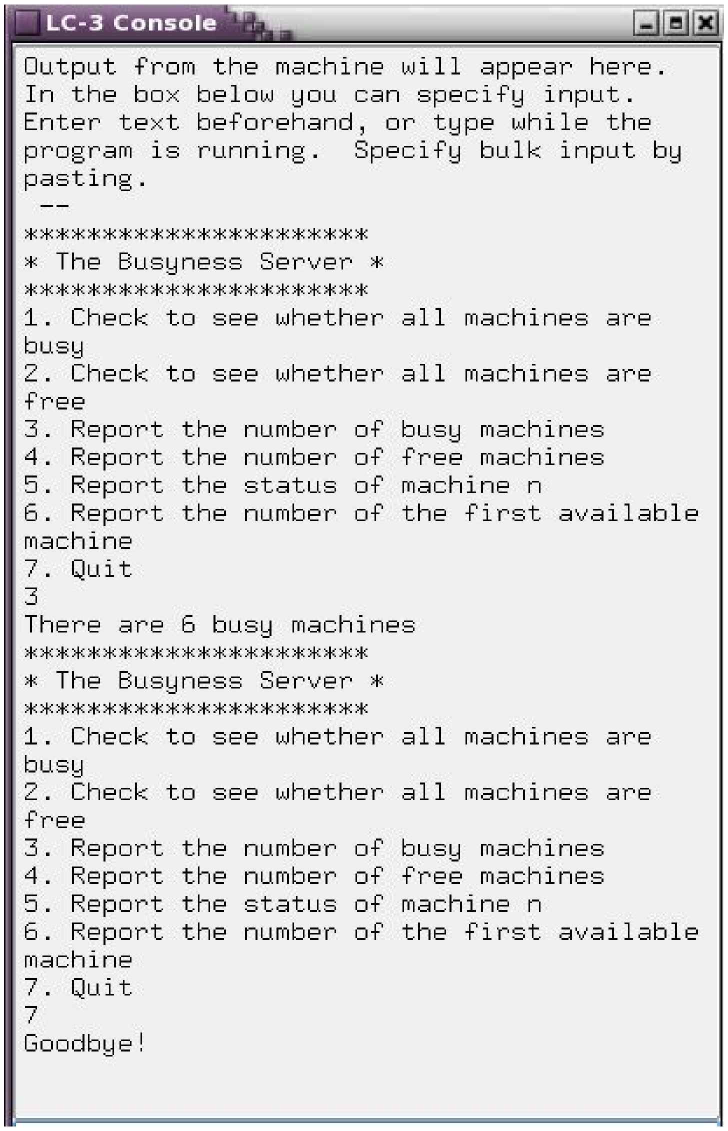
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
2
All machines are free
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 2, BUSYNESS = xFFFF)



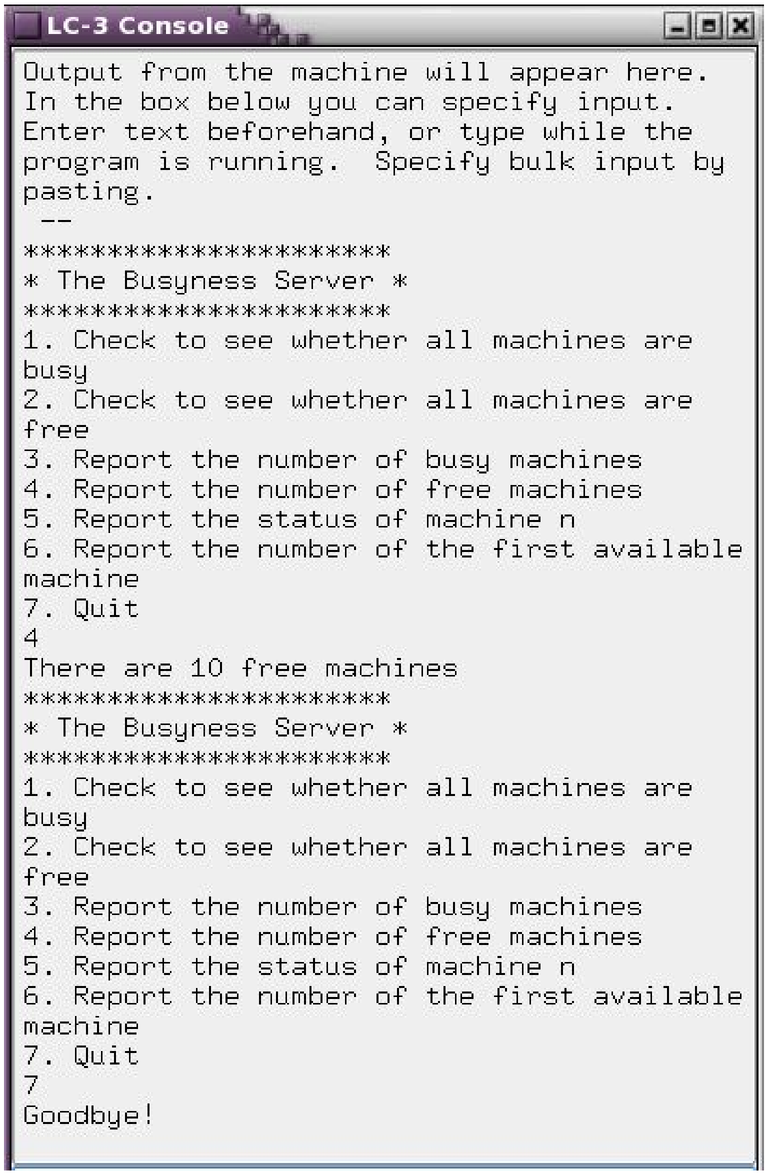
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
2
Not all machines are free
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 2, BUSYNESS = xABCD)



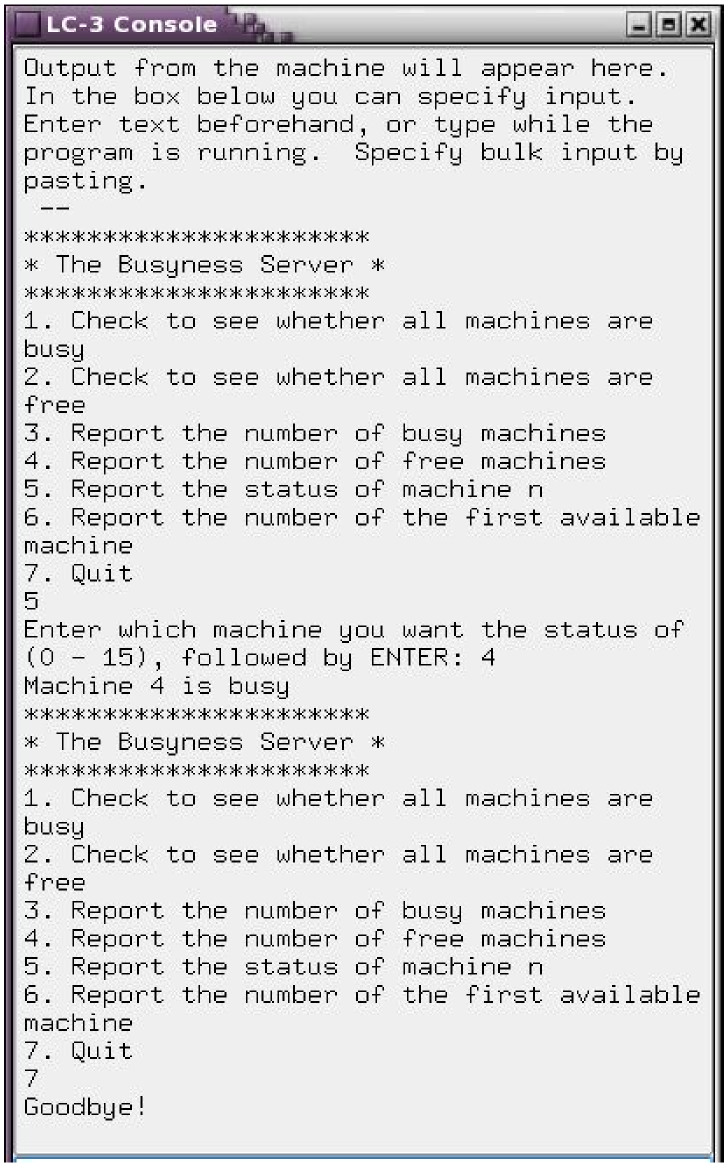
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
3
There are 6 busy machines
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

Option 3, BUSYNESS = xABCD)



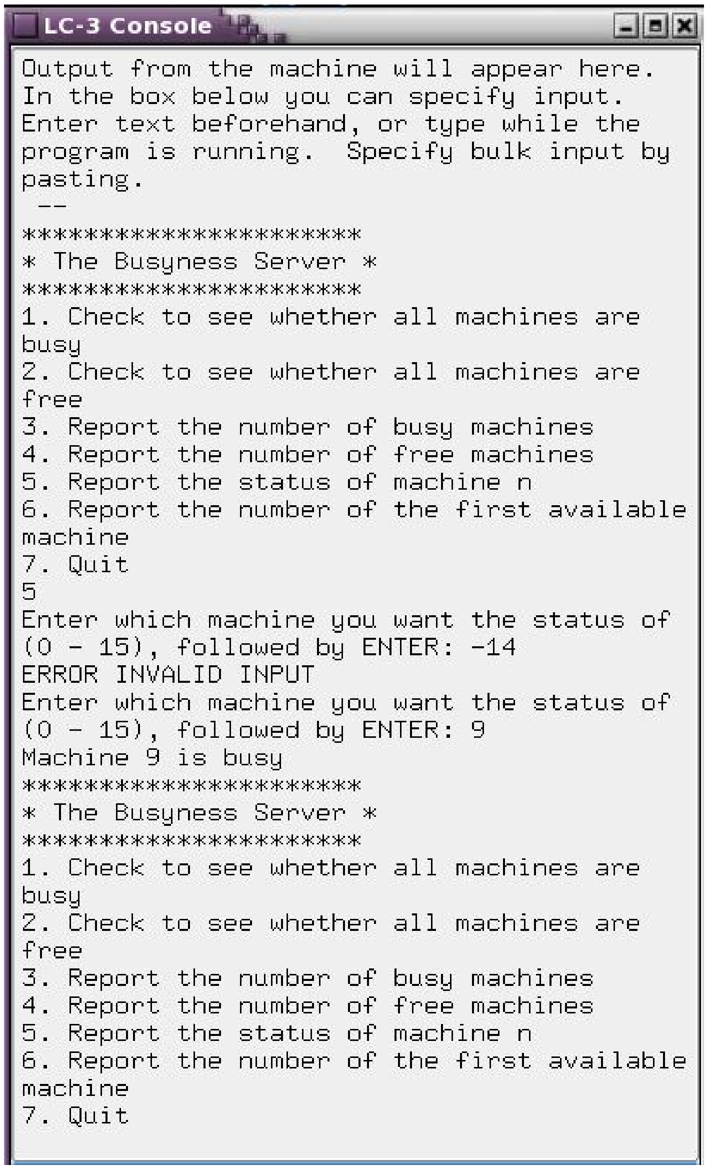
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
4
There are 10 free machines
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 4, BUSYNESS = xABCD)



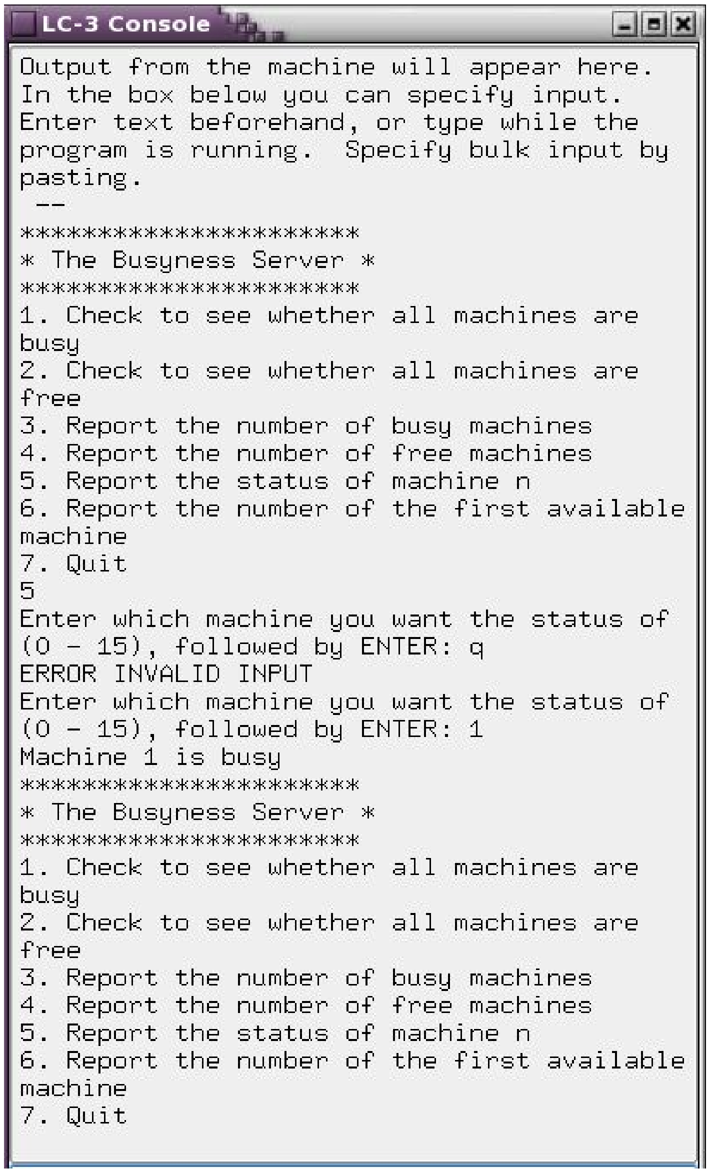
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
5
Enter which machine you want the status of
(0 - 15), followed by ENTER: 4
Machine 4 is busy
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 5, BUSYNESS = x0000 with correct input)



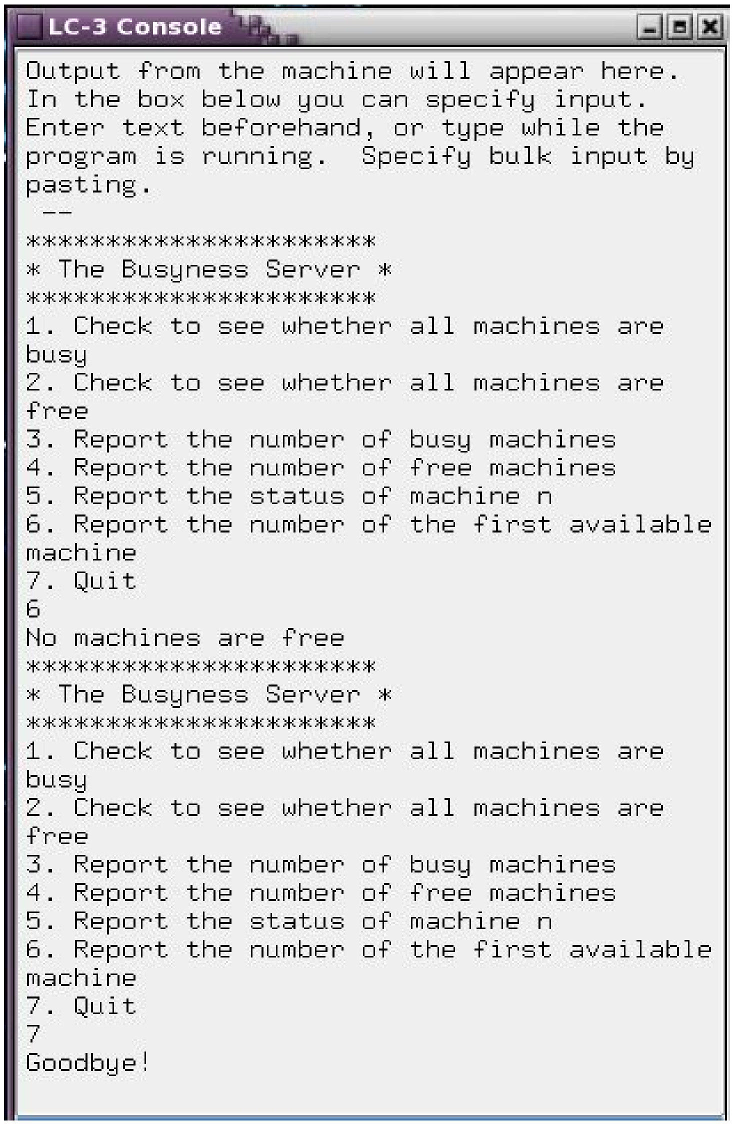
```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
5
Enter which machine you want the status of
(0 - 15), followed by ENTER: -14
ERROR INVALID INPUT
Enter which machine you want the status of
(0 - 15), followed by ENTER: 9
Machine 9 is busy
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
```

(Option 5, BUSYNESS = x0000 with incorrect input example #1)

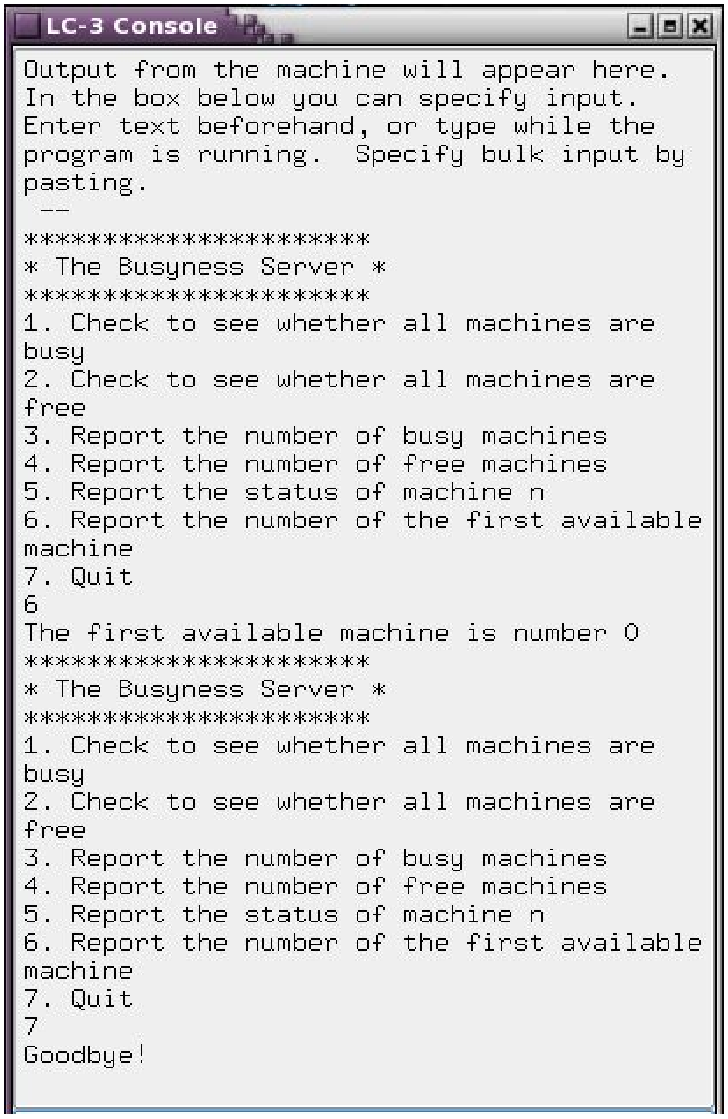


```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
5
Enter which machine you want the status of
(0 - 15), followed by ENTER: q
ERROR INVALID INPUT
Enter which machine you want the status of
(0 - 15), followed by ENTER: 1
Machine 1 is busy
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
```

(Option 5, BUSYNESS = x0000 with incorrect input example #2)


```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
6
No machines are free
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 6, BUSYNESS = x0000)


```
Output from the machine will appear here.
In the box below you can specify input.
Enter text beforehand, or type while the
program is running.  Specify bulk input by
pasting.
 --
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
6
The first available machine is number 0
**********************
* The Busyness Server *
**********************
1. Check to see whether all machines are
busy
2. Check to see whether all machines are
free
3. Report the number of busy machines
4. Report the number of free machines
5. Report the status of machine n
6. Report the number of the first available
machine
7. Quit
7
Goodbye!
```

(Option 6, BUSYNESS = xABCD)

Notes:

- As always, you must echo all inputs (no "ghost writing").
- When an invalid input is detected: Output the error message and reprompt the user for input
- **NO** leading zeros on output numbers *(you must still echo any leading zeros the user inputs)*
- When outputting **positive** response there is **no sign** *(though a '+' sign may be used on input)*

REMEMBER: all outputs must be newline terminated

Your code will obviously be tested with a range of different busyness vectors: Make sure you do likewise!

Uh...help?

This is actually not a difficult assignment, just a bit long – but we'll give you some hints anyway :)

<u>Really, Really Important</u>

- **1 means free; 0 means busy**
- Store the BUSYNESS vector at the memory address **given to you in the template.**
    - The grader will test different values using this address

Hint 01
Remember the algorithm for printing a number out in binary. Remember how to examine each individual bit of a 16-bit value (i.e. any number in a register).

Hint 02
Steal the headers we wrote and use them to help guide your step-by-step completion of the assignment (yay - endorsed micro-plagiarism?)

Hint 03 – sub A (MENU)
The MENU subroutine gets a **single** character from the user. You do **NOT** have to press enter for the character to be accepted. The moment the user enters a character, it will be echoed, and the subroutine will try and validate the input; if valid will return the option value, if not then an error message should be outputted and start the process from the beginning.

Hint 04 – subs B & C
Notice that if a machine is free, then it is NOT busy. If a machine is busy, then it is NOT free - emphasis on the keyword "NOT" :)

Hint 05 – subs D & E
If N = the total number of machines (16),
and X = the total number of free machines,
and Y = the total number of busy machines,

then X = 16 – Y and Y = 16 – X
- in other words, you only need to implement one of these subroutines in full :)

Hint 06 – subs F & G

From the specs:

```
; Postcondition: The subroutine has returned a value
;              indicating the lowest numbered free machine
```

In other words, The FIRST machine is machine 0 (the lsb, or rightmost bit);
the LAST machine is machine 15 (the msb, or leftmost digit)

Machine IDs:

```
MSB                                           LSB
 |                                              |
[15 14 13 12]  [11,10,9,8] [7,6,5,4] [3,2,1,0]
```

Subroutine F (MACHINE STATUS): The only acceptable values are between **0** and **15**.

Examples of valid input:	Examples of invalid input:
● 12	● -12
● 0	● 16
● 0003	● +2g
● +4	● g

Hint 07
Do not forget to follow all of the steps of the subroutine construction process.

Hint 08
Did we mention that **1 means free; 0 means busy ?**

Hint 09
To implement your menu-driven system, implement an infinite loop that works like this:

```
while( true )
{
  choice = menu()      ; call MENU subroutine

  if (choice == 1)
    R2 = all_machines_busy()  ; call ALL_MACHINES_BUSY subroutine
    if (R2 == 1)
      Print “All machines are busy”[
    else
      Print “Not all machines are busy”

  else if (choice == 2)
    [similar]

  else if (choice == 3)
    R2 = num_busy_machines()  ; call NUM_BUSY_MACHINES subroutine
    Print “There are “, (R2), “ machines busy”


  else if (choice == 4)
    [similar]

  else if (choice == 5)
    Print “Which machine do you want the status of (0 - 15)?”
    ; NOTE: you may want to build a “helper” subroutine
    ; to obtain validated input here
    R1 = <validated user entry from #0 to #15>
    R2 = machine_status(R1)   ; call MACHINE_STATUS and pass R1
    if (R2 == 1)
      Print “Machine “, (R1), “ is free”
    else
      Print “Machine “, (R1), “ is busy”

  else if (choice == 6)
    R2 = first_machine_free() ; call FIRST_Free subroutine
    if (R2 == <come up with a sentinel value> )
      Print “No machines are free”
    else
      Print “The first available machine is number”, (R2)

  else if (choice == 7)
    Print “Goodbye!”
    HALT
}
```

Submission Instructions

Submit to GitHub

Comments/Feedback

Do a "Git pull" to download the results.html file for detailed feedback.

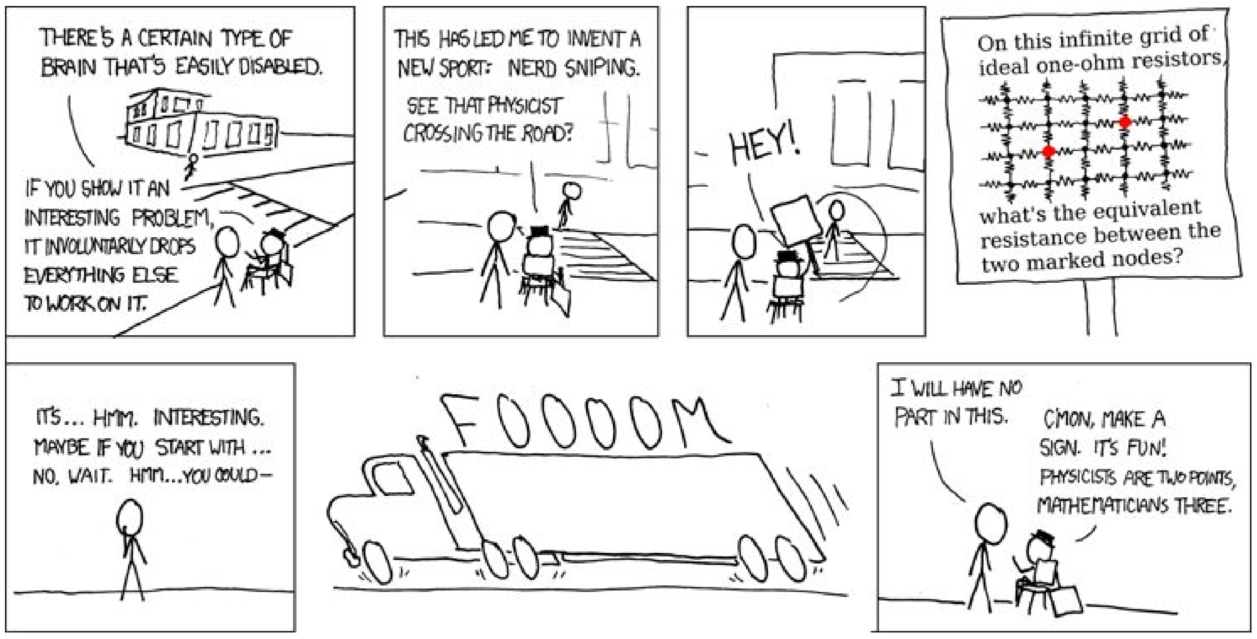
Rubric

- The autograder will attempt to assign partial credit for each test (like those described in the expected output section above), and will report which tests passed and which failed.
  To pass the assignment, you need a cumulative score of >= 8/10.
  HOWEVER: after certain errors in your output (run-time errors, missing newlines, etc), the autograder will be unable to proceed, resulting in a grade of 0/10, with no partial credit.

  This should not be a problem: the problematic output will usually be clearly highlighted in the feedback, so you can fix & resubmit, and hopefully get past the blockage.
  (Unless, of course, you waited until one hour before the deadline to submit, in which case you're stuck with the 0/10 - but you would never do that, would you?)

- **You must use the template we provide** - if you make *any* changes to the provided starter code, the autograder may not be able to interpret the ouput, resulting in a grade of 0.

One last XKCD comic for the quarter!


THERE'S A CERTAIN TYPE OF BRAIN THAT'S EASILY DISABLED.
IF YOU SHOW IT AN INTERESTING PROBLEM, IT INVOLUNTARILY DROPS EVERYTHING ELSE TO WORK ON IT.
THIS HAS LED ME TO INVENT A NEW SPORT: NERD SNIPING.
SEE THAT PHYSICIST CROSSING THE ROAD?
HEY!
On this infinite grid of ideal one-ohm resistors, what's the equivalent resistance between the two marked nodes?
IT'S... HMM. INTERESTING. MAYBE IF YOU START WITH ... NO, WAIT. HMM...YOU COULD—
FOOOOM
I WILL HAVE NO PART IN THIS.
C'MON, MAKE A SIGN. IT'S FUN! PHYSICISTS ARE TWO POINTS, MATHEMATICIANS THREE.

Source: http://xkcd.com/356/