CS 2110 Homework 6
Intro to Assembly

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1 Overview

The goal of this first assembly homework is to introduce you to programming in LC-3 assembly code. This will involve writing small programs, translating conditionals and loops into assembly, modifying memory, manipulating strings, and converting high-level programs into assembly code. There are four functions that we are requiring you to complete:

1. `gates.asm`
2. `reverse.asm`
3. `phone.asm`
4. `linkedlist.asm`

For some advice on debugging your assembly code, please check out section 3 below.

2 Instructions

2.1 Part 1: Gates

To start you off with this homework, we are implementing gates in assembly! Since the LC-3 only has the `AND` and `NOT` instructions, use DeMorgan's law to implement the functionality of the other gates. Store the result of the appropriate gate in the label `ANSWER`. Implement your assembly code in `gates.asm`
Pseudocode:

```
if (A > X) && (B < X)
    ANSWER = A NAND B
else if (A > X) && (B > X)
    ANSWER = A NOR B
else if (A < X) && (B < X)
    ANSWER = A OR B
else if (A < X) && (B > X)
    ANSWER = A AND B
else
    ANSWER = !A
```

Please note, your answer will be bitwise `NAND, NOR, OR, AND`

2.2 Part 2: Reverse

The second assembly function is to reverse an array in memory. Use the pseudocode to help plan out your assembly and make sure you are reversing it in place!
Pseudocode:

```
x = 0               //1st index of the array
y = length - 1      //last index of the array
while (x < y) {
    temp = ARRAY[x];
    ARRAY[x] = y;
    ARRAY[y] = temp;
    x++;
    y--;
}
```

2.3 Part 3: Phone Number

The third assembly function is to detect whether a given **null-terminated** string matches the specified US phone number string, and store the answer in the label `ANSWER`. The label `STRING` will contain the address of the first character of the phone number. Implement your assembly code in `phone.asm`

The US phone number string to match looks like this:

```
"(678) 555-2110"
```

Note! We are explicitly requiring that every valid number follow the above template *exactly*, except for the actual digits, which can be any digits in the range $[0, 9]$. A valid phone number should contain all special characters present in the above string—the **space**, **"**, **-**, **(**, and **)**—and a valid phone number shouldn't contain any excess characters which aren't present in the above string.

To check for these special characters, refer to the ASCII table below and remember that each of these characters is represented by a word in the LC-3's memory. This is a **null-terminated** string, meaning that a 0 should be stored immediately after the final character in memory (remember, 0 is different from '0').

After the program executes, the label `ANSWER` should contain 1 if the provided string matches the template, and 0 otherwise.

Char	Dec	Oct	Hex	Char	Dec	Oct	Hex	Char	Dec	Oct	Hex
(sp)	32	0040	0x20	@	64	0100	0x40	`	96	0140	0x60
!	33	0041	0x21	A	65	0101	0x41	a	97	0141	0x61
"	34	0042	0x22	B	66	0102	0x42	b	98	0142	0x62
#	35	0043	0x23	C	67	0103	0x43	c	99	0143	0x63
$	36	0044	0x24	D	68	0104	0x44	d	100	0144	0x64
%	37	0045	0x25	E	69	0105	0x45	e	101	0145	0x65
&	38	0046	0x26	F	70	0106	0x46	f	102	0146	0x66
'	39	0047	0x27	G	71	0107	0x47	g	103	0147	0x67
(	40	0050	0x28	H	72	0110	0x48	h	104	0150	0x68
)	41	0051	0x29	I	73	0111	0x49	i	105	0151	0x69
*	42	0052	0x2a	J	74	0112	0x4a	j	106	0152	0x6a
+	43	0053	0x2b	K	75	0113	0x4b	k	107	0153	0x6b
,	44	0054	0x2c	L	76	0114	0x4c	l	108	0154	0x6c
-	45	0055	0x2d	M	77	0115	0x4d	m	109	0155	0x6d
.	46	0056	0x2e	N	78	0116	0x4e	n	110	0156	0x6e
/	47	0057	0x2f	O	79	0117	0x4f	o	111	0157	0x6f
0	48	0060	0x30	P	80	0120	0x50	p	112	0160	0x70
1	49	0061	0x31	Q	81	0121	0x51	q	113	0161	0x71
2	50	0062	0x32	R	82	0122	0x52	r	114	0162	0x72
3	51	0063	0x33	S	83	0123	0x53	s	115	0163	0x73
4	52	0064	0x34	T	84	0124	0x54	t	116	0164	0x74
5	53	0065	0x35	U	85	0125	0x55	u	117	0165	0x75
6	54	0066	0x36	V	86	0126	0x56	v	118	0166	0x76
7	55	0067	0x37	W	87	0127	0x57	w	119	0167	0x77
8	56	0070	0x38	X	88	0130	0x58	x	120	0170	0x78
9	57	0071	0x39	Y	89	0131	0x59	y	121	0171	0x79
:	58	0072	0x3a	Z	90	0132	0x5a	z	122	0172	0x7a
;	59	0073	0x3b	[	91	0133	0x5b	{	123	0173	0x7b
<	60	0074	0x3c	\	92	0134	0x5c	|	124	0174	0x7c
=	61	0075	0x3d	]	93	0135	0x5d	}	125	0175	0x7d
>	62	0076	0x3e	^	94	0136	0x5e	~	126	0176	0x7e
?	63	0077	0x3f	_	95	0137	0x5f				

Figure 1: ASCII Table — Very Cool and Useful!

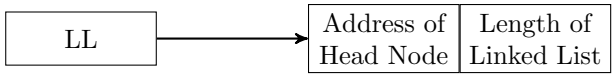
Suggested Pseudocode:

```
templateString = "(000) 000-0000";      //null-terminated template string
i = 0;                                  //1st index of the string
j = 15;                                 //expected length of string with null terminator
while (i < j) {
    if (i == 0 || i == 4 || i == 5      //checking for non-numeric characters,
               || i == 9 || i == 14) {  //including null terminator at i == 14
        if (STRING[i] != templateString[i]) {
            ANSWER = 0;
            return;
        }
    } else {
        if (STRING[i] < '0' || STRING[i] > '9') {
            ANSWER = 0;
            return;
        }
    }
    i++;
}
ANSWER = 1;
```

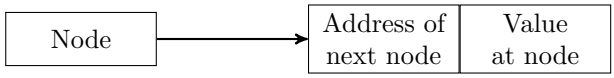
2.4 Part 4: Find in Linked List

For the final problem, your goal is to find a particular element in a linked list and replace its value with the length of the list. In order to do so, look at the two labels we have given you:

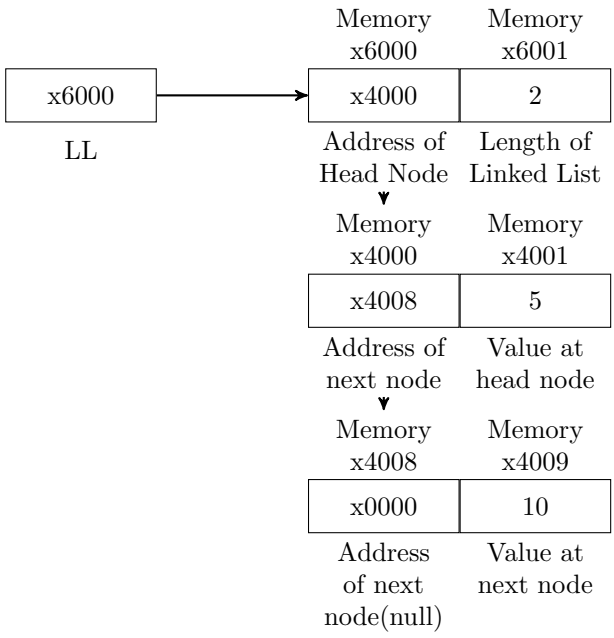
- Data: The data to be found and replaced
- LL: The address of a Linked List object. Similar to Java, our linked list is an object with two attributes - head and length. These two attributes are stored in memory like so:



Every node in our linked list is another object with two attributes - next node and value. These two attributes are stored in memory like so:



So together, our data structure would look something like this:



Now that you understand what data structure we are dealing with, we have provided the following pseudocode to help you begin your coding! This code will be implemented in the `linkedlist.asm` file.

```
length = LL.length
curr = LL.head //HINT: What can an LDI instruction be used for?
while (curr != null) {
    if (curr.value == data) {
        curr.value = length;
    } else {
        curr = curr.next
    }
}
```

3 Debugging

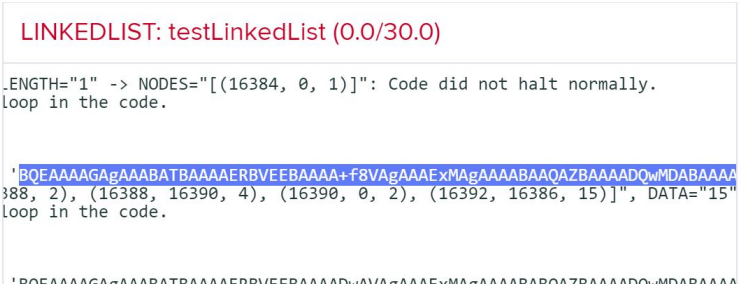
When you turn in your files on gradescope for the first time, you might not receive a perfect score. Does this mean you change one line and spam gradescope until you get a 100? No! You can use a handy tool known as tester strings.

1. First off, we can get these tester strings in two places: the local grader or off of gradescope. To run the local grader:
   - Mac/Linux Users:
     (a) Navigate to the directory your homework is in. **In your terminal, not in your browser**
     (b) Run the command `sudo chmod +x grade.sh`
     (c) Now run `./grade.sh`
   - Windows Users:
     (a) On **docker quickstart**, navigate to the directory your homework is in
     (b) Run `./grade.sh`

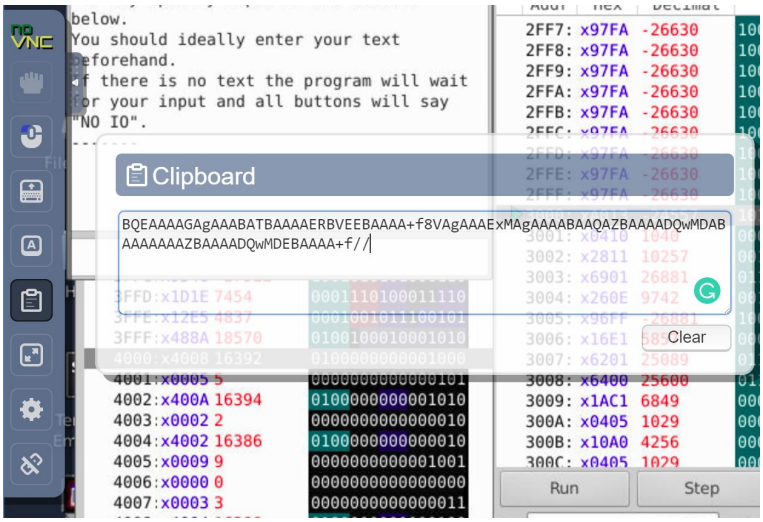
   When you run the script, you should see an output like this:

Copy the string, starting with the leading 'B' and ending with the final backslace. Do not include the quotations.

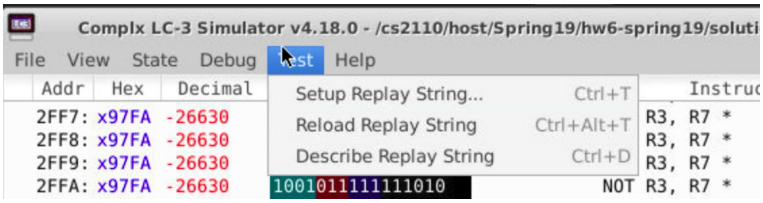
Side Note: If you do not have docker installed, you can still use the tester strings to debug your assembly code. In your gradescope error output, you will see a tester string. When copying, make sure you copy from the first letter to the final backslace and again, don't copy the quotations.



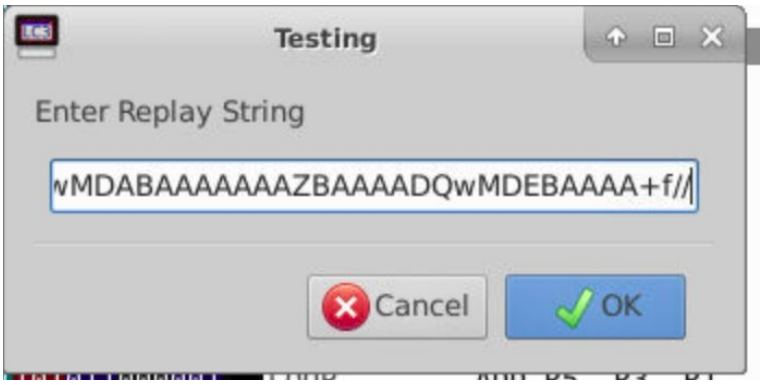
2. Secondly, navigate to the clipboard in your docker image and paste in the string.



3. Next, go to the Test Tab and click Setup Replay String

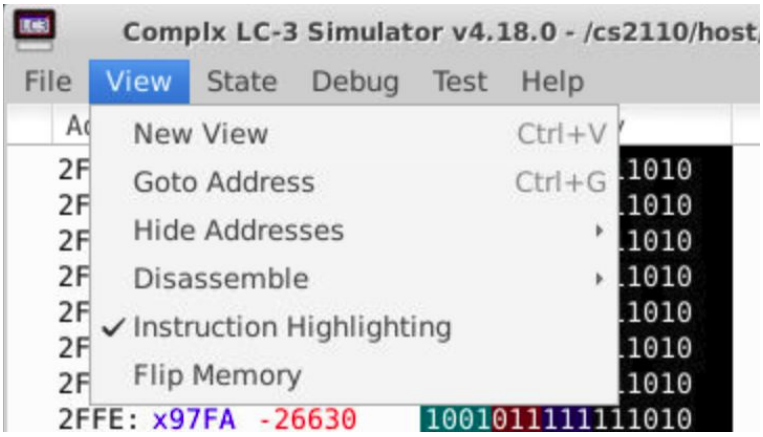


4. Now, paste your tester string in the box!

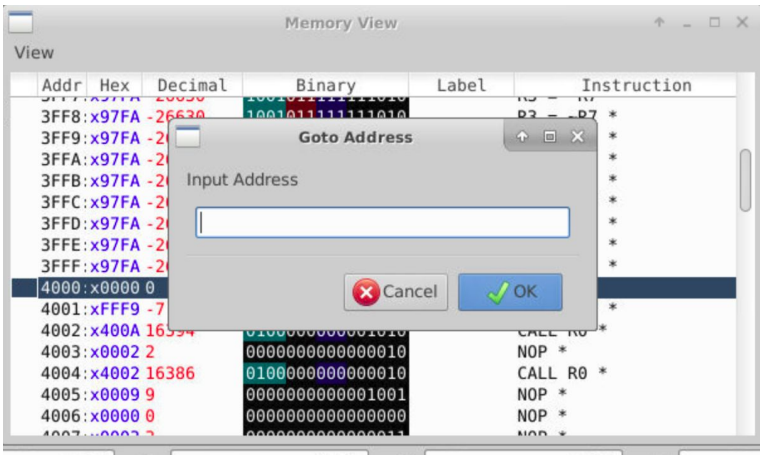


5. Now, complx is set up with the test that you failed! The nicest part of complx is the ability to step through each instruction and see how they change register values. To do so, click the step button. To change the number representation of the registers, double click inside the register box.

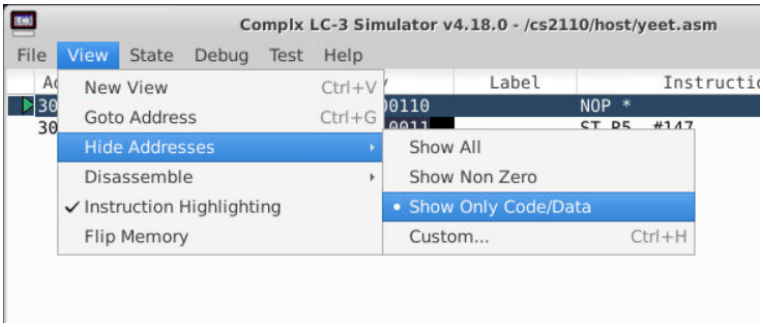
6. If you are interested in looking how your code changes different portions of memory, click the view tab and indicate 'New View'



7. Now in your new view, go to the area of memory where your data is stored by CTRL+G and insert the address



8. One final tip: to automatically shrink your view down to only those parts of memory that you care about (instructions and data), you can use View Tab → Hide Addresses → Show Only Code/Data. Just be careful: if you misclick and select Show Non Zero, it *may* make the window freeze (it's a known Complx bug).



4 Deliverables

Turn in the files `gates.asm`, `reverse.asm`, `phone.asm`, and `linkedlist.asm` on Gradescope by February 24th by 11:55pm.

Note: Please do not wait until the last minute to run/test your homework, history has proved that last minute turn-ins will result in long queue times for grading on Gradescope. You have been warned.

5 LC-3 Assembly Programming Requirements

5.1 Overview

1. Your code must assemble with **NO WARNINGS OR ERRORS**. To assemble your program, open the file with Complx. It will complain if there are any issues. **If your code does not assemble you WILL get a zero for that file.**

2. **Comment your code!** This is especially important in assembly, because it's much harder to interpret what is happening later, and you'll be glad you left yourself notes on what certain instructions are contributing to the code. Comment things like what registers are being used for and what less intuitive

lines of code are actually doing. To comment code in LC-3 assembly just type a semicolon (;), and the rest of that line will be a comment.

3. Avoid stating the obvious in your comments, it doesn't help in understanding what the code is doing.

   Good Comment

   ```
   ADD R3, R3, -1          ; counter--
   BRp LOOP                ; if counter == 0 don't loop again
   ```

   Bad Comment

   ```
   ADD R3, R3, -1          ; Decrement R3
   BRp LOOP                ; Branch to LOOP if positive
   ```

4. **DO NOT assume that ANYTHING in the LC-3 is already zero.** Treat the machine as if your program was loaded into a machine with random values stored in the memory and register file.

5. Following from 3. You can randomize the memory and load your program by doing File - Randomize and Load.

6. Use the LC-3 calling convention. This means that all local variables, frame pointer, etc... must be pushed onto the stack. Our autograder will be checking for correct stack setup.

7. Start the stack at xF000. **The stack pointer always points to the last used stack location.** This means you will allocate space **first**, then store onto the stack pointer.

8. Do NOT execute any data as if it were an instruction (meaning you should put .fills after **HALT** or RET).

9. Do not add any comments beginning with @plugin or change any comments of this kind.

10. **Test your assembly.** Don't just assume it works and turn it in.

6 Rules and Regulations

6.1 General Rules

1. Starting with the assembly homeworks, any code you write must be meaningfully commented. You should comment your code in terms of the algorithm you are implementing; we all know what each line of code does.

2. Although you may ask TAs for clarification, you are ultimately responsible for what you submit. This means that (in the case of demos) you should come prepared to explain to the TA how any piece of code you submitted works, even if you copied it from the book or read about it on the internet.

3. Please read the assignment in its entirety before asking questions.

4. Please start assignments early, and ask for help early. Do not email us the night the assignment is due with questions.

5. If you find any problems with the assignment it would be greatly appreciated if you reported them to the author (which can be found at the top of the assignment). Announcements will be posted if the assignment changes.

6.2 Submission Conventions

1. All files you submit for assignments in this course should have your name at the top of the file as a comment for any source code file, and somewhere in the file, near the top, for other files unless otherwise noted.

2. When preparing your submission you may either submit the files individually to Canvas/Gradescope or you may submit an archive (zip or tar.gz only please) of the files. You can create an archive by right clicking on files and selecting the appropriate compress option on your system. Both ways (uploading raw files or an archive) are exactly equivalent, so choose whichever is most convenient for you.

3. Do not submit compiled files, that is .class files for Java code and .o files for C code. Only submit the files we ask for in the assignment.

4. Do not submit links to files. The autograder does not understand it, and we will not manually grade assignments submitted this way as it is easy to change the files after the submission period ends.

6.3 Submission Guidelines

1. You are responsible for turning in assignments on time. This includes allowing for unforeseen circumstances. If you have an emergency let us know **IN ADVANCE** of the due time supplying documentation (i.e. note from the dean, doctor's note, etc). Extensions will only be granted to those who contact us in advance of the deadline and no extensions will be made after the due date.

2. You are also responsible for ensuring that what you turned in is what you meant to turn in. After submitting you should be sure to download your submission into a brand new folder and test if it works. No excuses if you submit the wrong files, what you turn in is what we grade. In addition, your assignment must be turned in via Canvas/Gradescope. Under no circumstances whatsoever we will accept any email submission of an assignment. Note: if you were granted an extension you will still turn in the assignment over Canvas/Gradescope.

3. There is a 6-hour grace period added to all assignments. You may submit your assignment without penalty up until 11:55PM, or with 25% penalty up until 5:55AM. So what you should take from this is not to start assignments on the last day and plan to submit right at 11:54AM. You alone are responsible for submitting your homework before the grace period begins or ends; neither Canvas/Gradescope, nor your flaky internet are to blame if you are unable to submit because you banked on your computer working up until 11:54PM. The penalty for submitting during the grace period (25%) or after (no credit) is non-negotiable.

6.4 Syllabus Excerpt on Academic Misconduct

Academic misconduct is taken very seriously in this class. Quizzes, timed labs and the final examination are individual work.

Homework assignments are collaborative, In addition many if not all homework assignments will be evaluated via demo or code review. During this evaluation, you will be expected to be able to explain every aspect of your submission. Homework assignments will also be examined using computer programs to find evidence of unauthorized collaboration.

What is unauthorized collaboration? Each individual programming assignment should be coded by you. You may work with others, but each student should be turning in their own version of the assignment. Submissions that are essentially identical will receive a zero and will be sent to the Dean of Students' Office of Academic Integrity. Submissions that are copies that have been superficially modified to conceal that they are copies are also considered unauthorized collaboration.

You are expressly forbidden to supply a copy of your homework to another student via electronic means. This includes simply e-mailing it to them so they can look at it. If you supply

an electronic copy of your homework to another student and they are charged with copying, you will also be charged. This includes storing your code on any site which would allow other parties to obtain your code such as but not limited to public repositories (Github), pastebin, etc. If you would like to use version control, use github.gatech.edu

6.5 Is collaboration allowed?

Collaboration is allowed on a high level, meaning that you may discuss design points and concepts relevant to the homework with your peers, share algorithms and pseudo-code, as well as help each other debug code. What you shouldn't be doing, however, is pair programming where you collaborate with each other on a single instance of the code. Furthermore, sending an electronic copy of your homework to another student for them to look at and figure out what is wrong with their code is not an acceptable way to help them, because it is frequently the case that the recipient will simply modify the code and submit it as their own. Consider instead using a screen-sharing collaboration app, such as `http://webex.gatech.edu/`, to help someone with debugging if you're not in the same room.

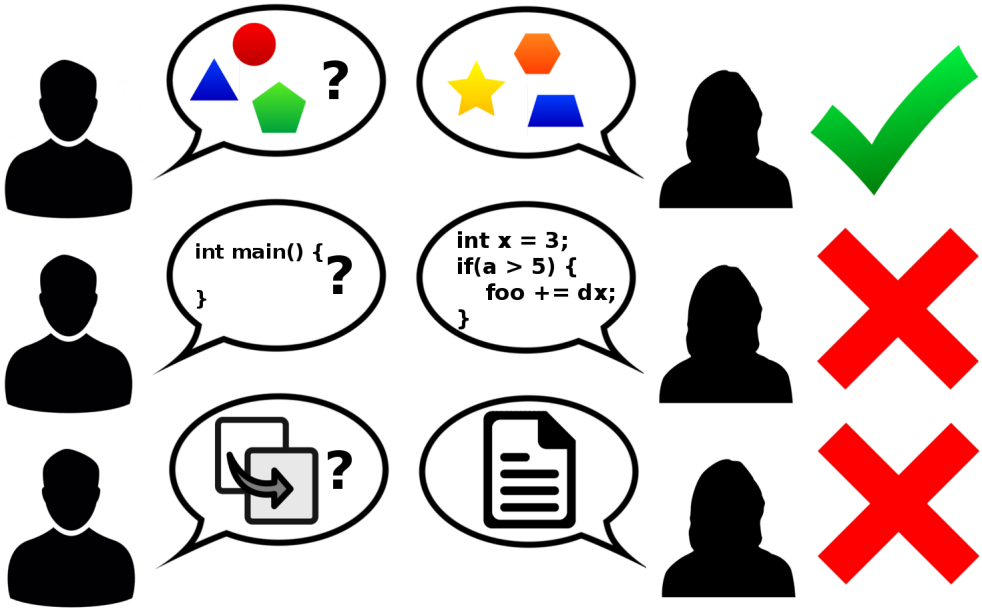


Figure 2: Collaboration rules, explained colorfully