NYU TANDON SCHOOL OF ENGINEERING

Lost at C

Security Implications of Large Language Model Code Assistants

Brendan Dolan-Gavitt

In collaboration with: Gustavo Sandoval, Hammond Pearce, Teo Nys, Ramesh Karri, and Siddharth Garg

CENTER FOR CYBER SECURITY

How Secure is the Code LLMs Write?

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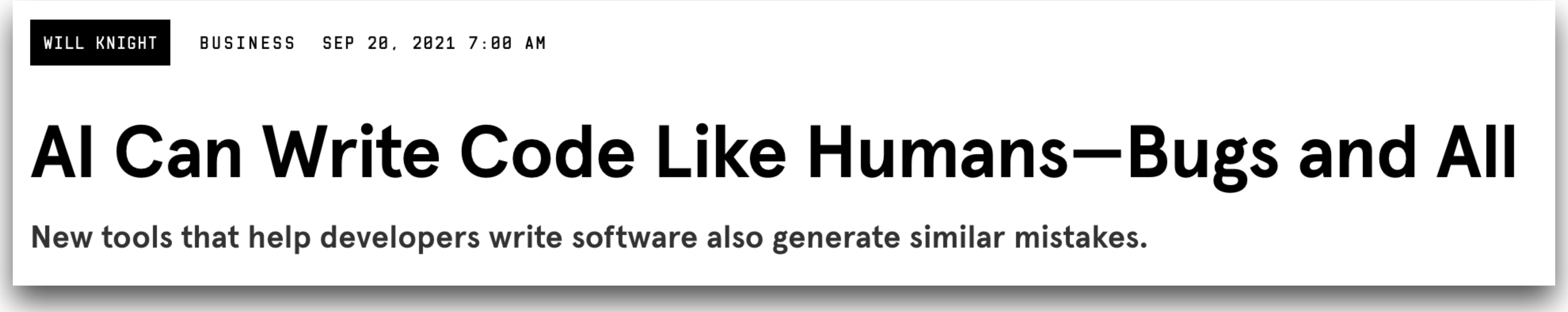

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AI Can Write Code Like Humans—Bugs and All

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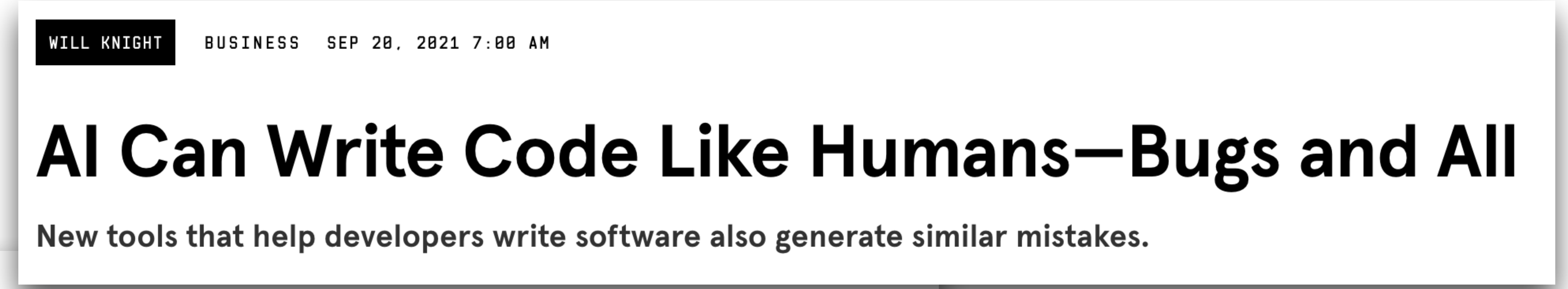

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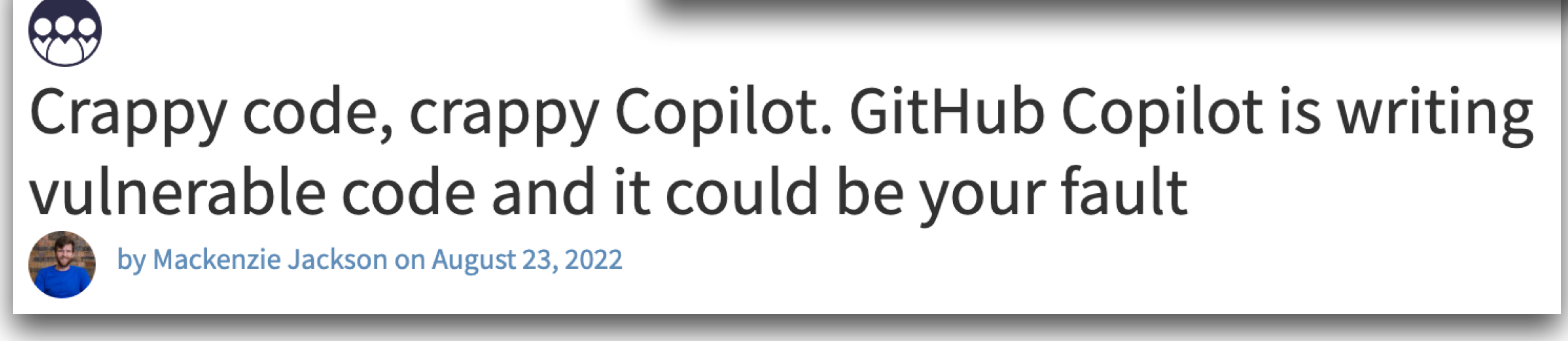

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by Mackenzie Jackson on August 23, 2022

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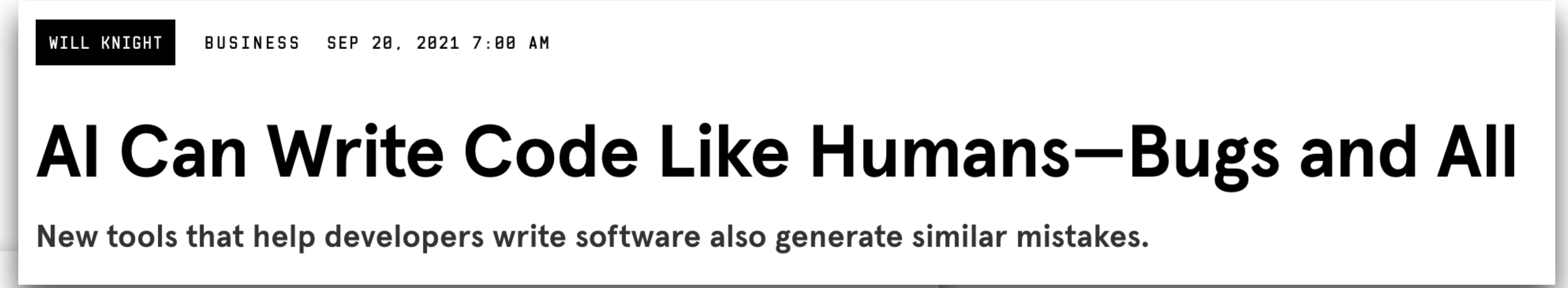

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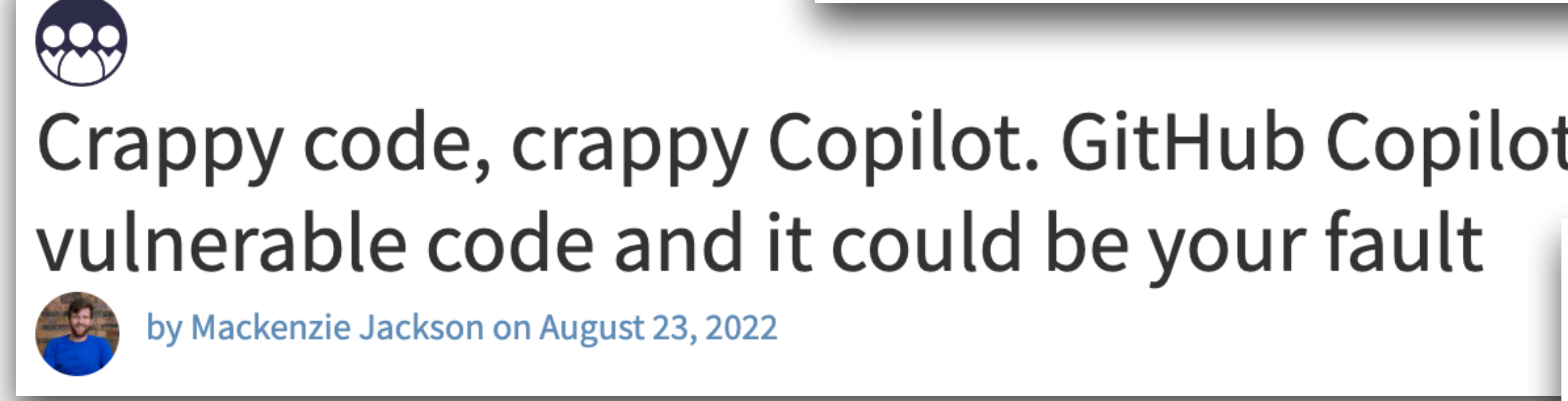

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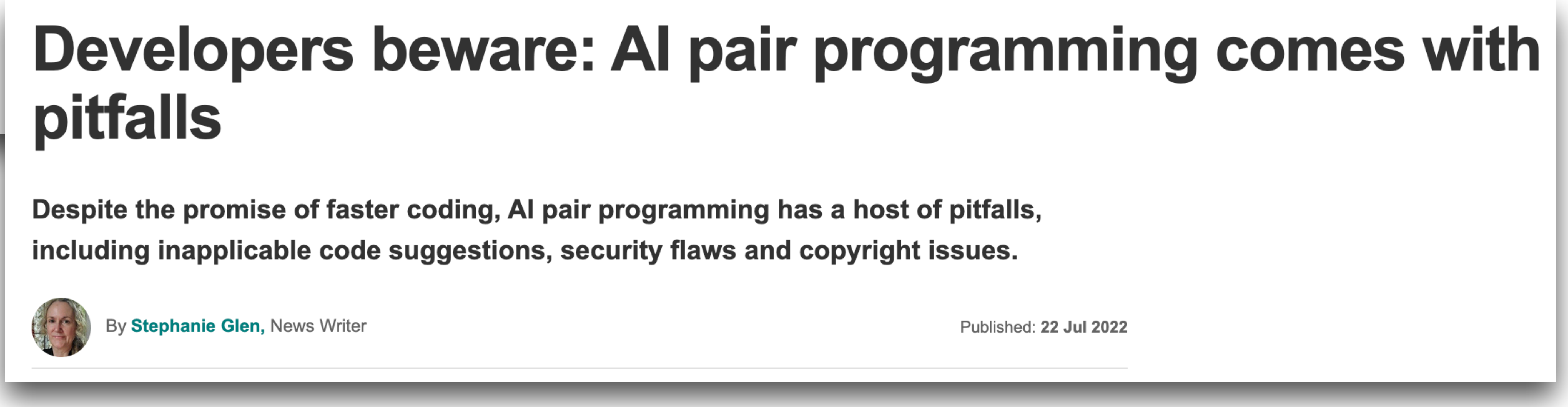

Developers beware: AI pair programming comes with pitfalls

Despite the promise of faster coding, AI pair programming has a host of pitfalls, including inapplicable code suggestions, security flaws and copyright issues.

By Stephanie Glen, News Writer

Published: 22 Jul 2022

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By Andrada Fiscutean

CSO | MAR 15, 2022 2:00 AM PDT

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GitHub Copilot Security Study: 'Developers Should Remain Awake' in View of 40% Bad Code Rate

By **David Ramel** 08/26/2021

Asleep at the Keyboard

Prior work at IEEE Security and Privacy 2022

- We did a systematic study of Copilot’s code completions in security-sensitive scenarios, measuring vulnerability rates with GitHub CodeQL
- Key findings:
  - Across all scenarios, **42%** of the generated programs were vulnerable
  - Features of the **prompt**, including comments, affects the rate of vulnerable code
  - The strongest predictor of whether Copilot will produce a vulnerability is the **presence of an existing vulnerability** in the prompt

But Wait!

Some objections from Reviewer #2

- In the real world, Copilot works with human assistance
- Maybe humans would spot and fix these mistakes?
- For that matter, maybe *unassisted* humans would write bugs at the same rate!
- **Strong reject**

Research Questions

- **RQ1**: Does the AI code assistant help novice users write better code in terms of ***functionality***?

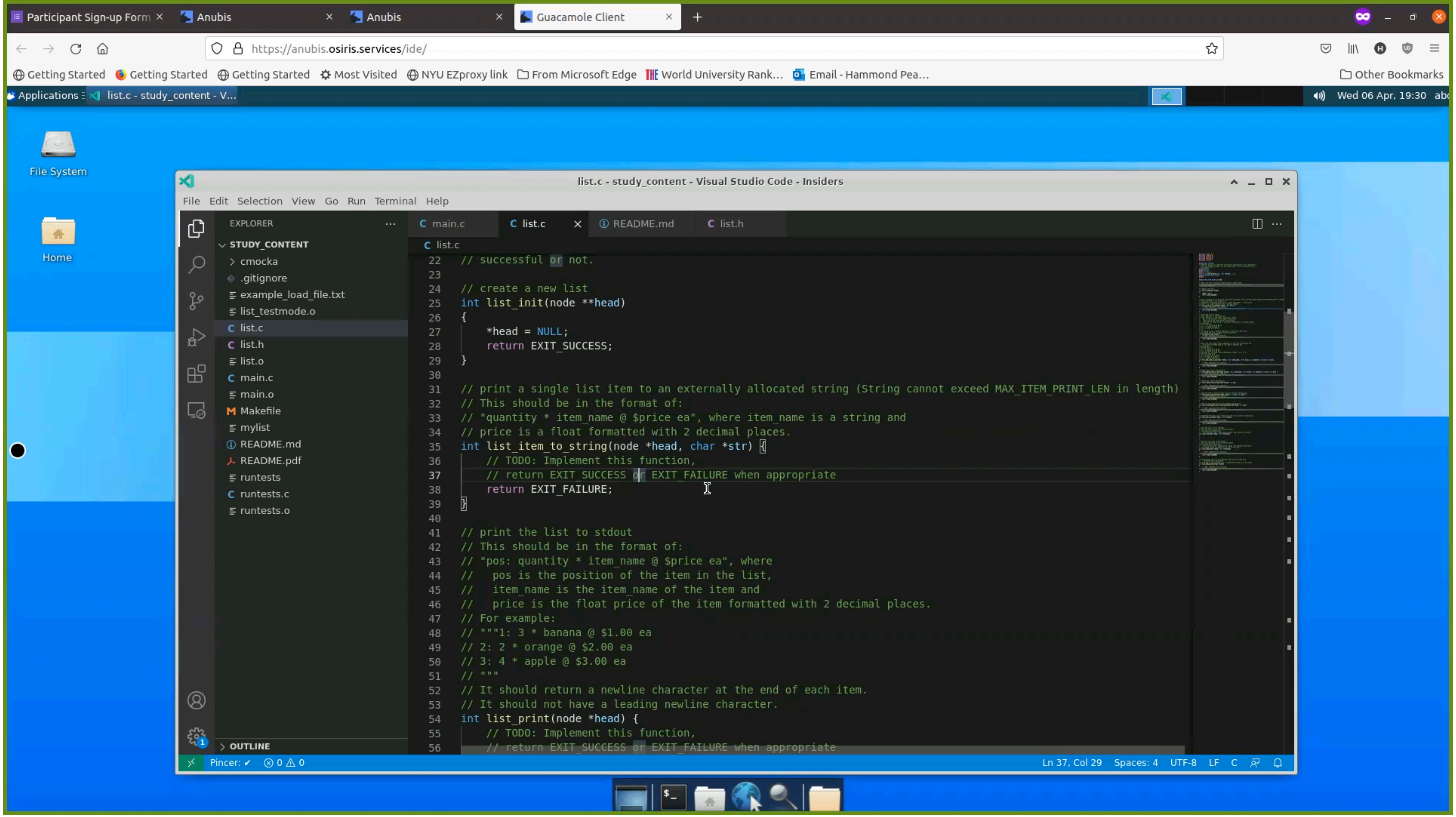
- **RQ2**: Is the code that novice users write with AI assistance more or less ***secure*** than the control group?

- **RQ3**: Are there systematic differences in the ***coding style*** of AI-assisted users and that of control group?

- **RQ4**: How do AI assisted users interact with potentially vulnerable code suggestions, i.e., where do bugs originate in an LLM-assisted system?

Study Environment

- **Goals**:
  - Minimize environment setup hassle
  - Log all the things
- Participants were asked to use our **Anubis** web-based IDE, which provides a VNC session to a Linux desktop with **VSCode** and a C compiler
- Created a VSCode plugin that mimics Copilot, but uses suggestions provided by the Codex API
- **Logged**: document snapshots every minute, prompt+suggestion data (including accepted/not accepted)



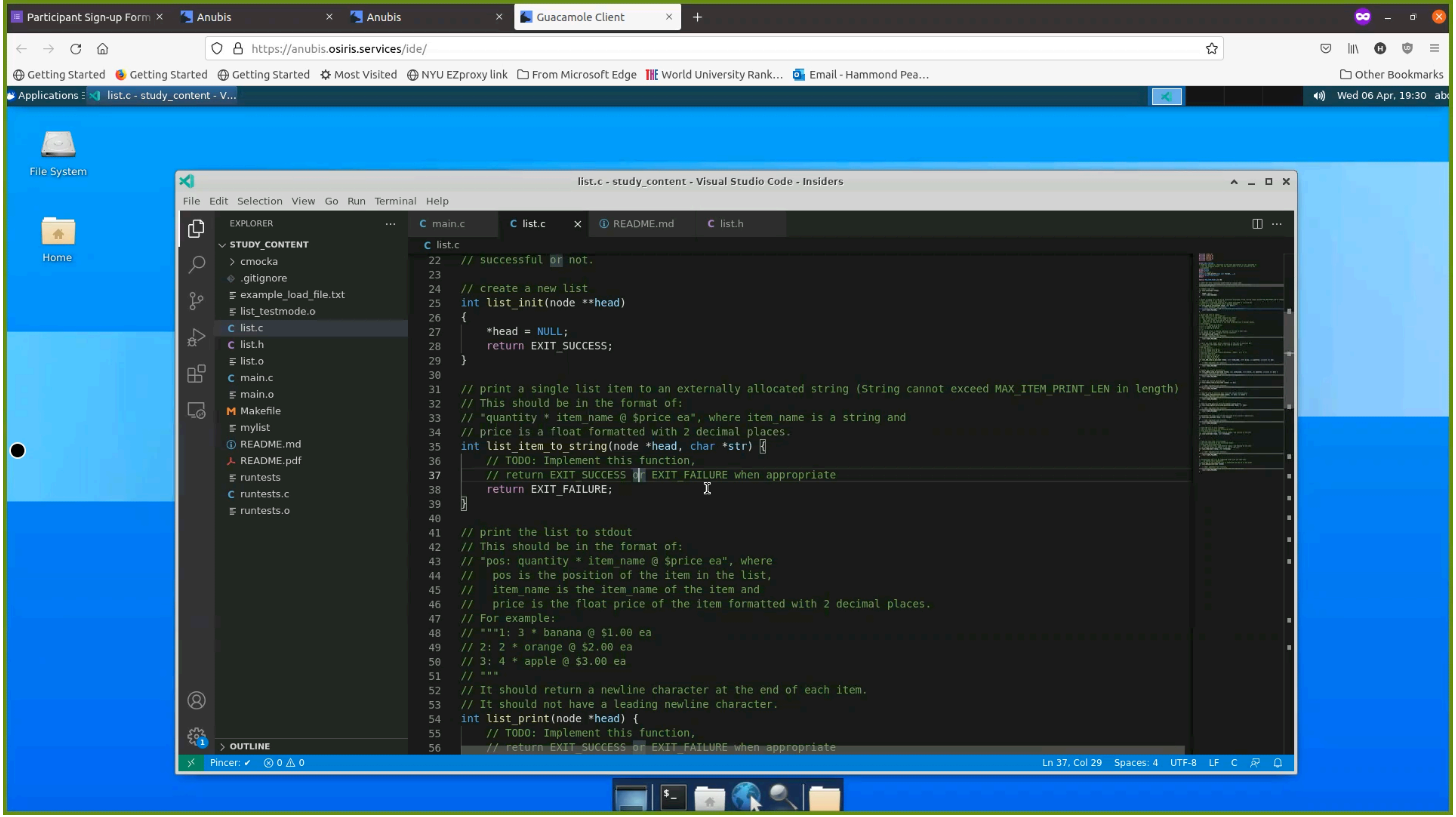
```c
// successful or not.

// create a new list
int list_init(node **head)
{
    *head = NULL;
    return EXIT_SUCCESS;
}

// print a single list item to an externally allocated string (String cannot exceed MAX_ITEM_PRINT_LEN in length)
// This should be in the format of:
// "quantity * item_name @ $price ea", where item_name is a string and
// price is a float formatted with 2 decimal places.
int list_item_to_string(node *head, char *str) {
    // TODO: Implement this function,
    // return EXIT_SUCCESS or EXIT_FAILURE when appropriate
    return EXIT_FAILURE;
}

// print the list to stdout
// This should be in the format of:
// "pos: quantity * item_name @ $price ea", where
//   pos is the position of the item in the list,
//   item_name is the item_name of the item and
//   price is the float price of the item formatted with 2 decimal places.
// For example:
// """1: 3 * banana @ $1.00 ea
// 2: 2 * orange @ $2.00 ea
// 3: 4 * apple @ $3.00 ea
// """
// It should return a newline character at the end of each item.
// It should not have a leading newline character.
int list_print(node *head) {
    // TODO: Implement this function,
    // return EXIT_SUCCESS or EXIT_FAILURE when appropriate
```

If you are reading these slides in PDF, you can see the video by clicking here:
https://moyix.net/~moyix/anubis.mp4



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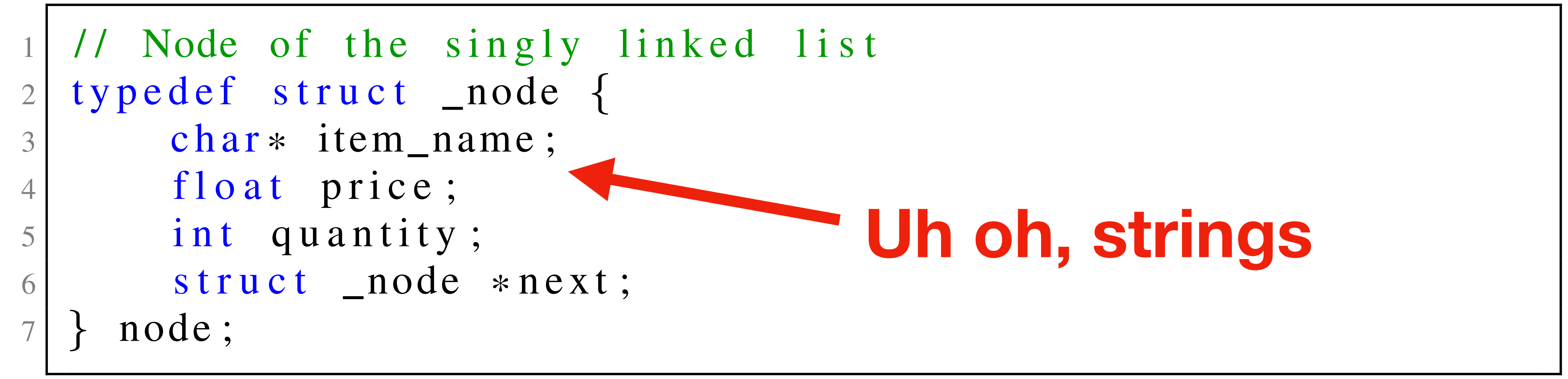
Study Task: “Shopping List”

The *Worst* Singly Linked List API (11 functions total)

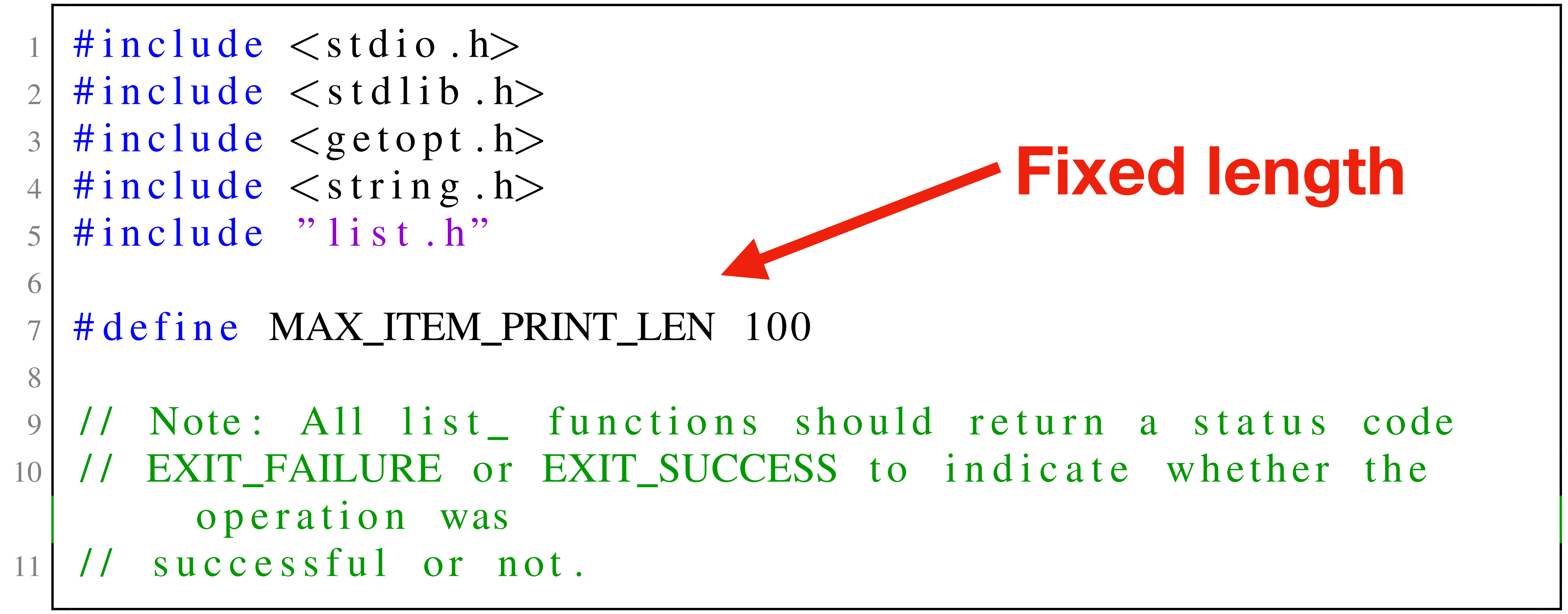
- Since we’re studying security chose C because it’s a “target-rich environment”
- We deliberately included some pitfalls in the data structure and API to further broaden the range of possible errors
- Singly linked list: lots of opportunity for pointer mistakes
- Includes a string field (buffer overflows, etc.)



```
// Node of the singly linked list
typedef struct _node {
    char* item_name;
    float price;
    int quantity;
    struct _node *next;
} node;
```

Uh oh, strings

(a) Node definition (in `list.h`)



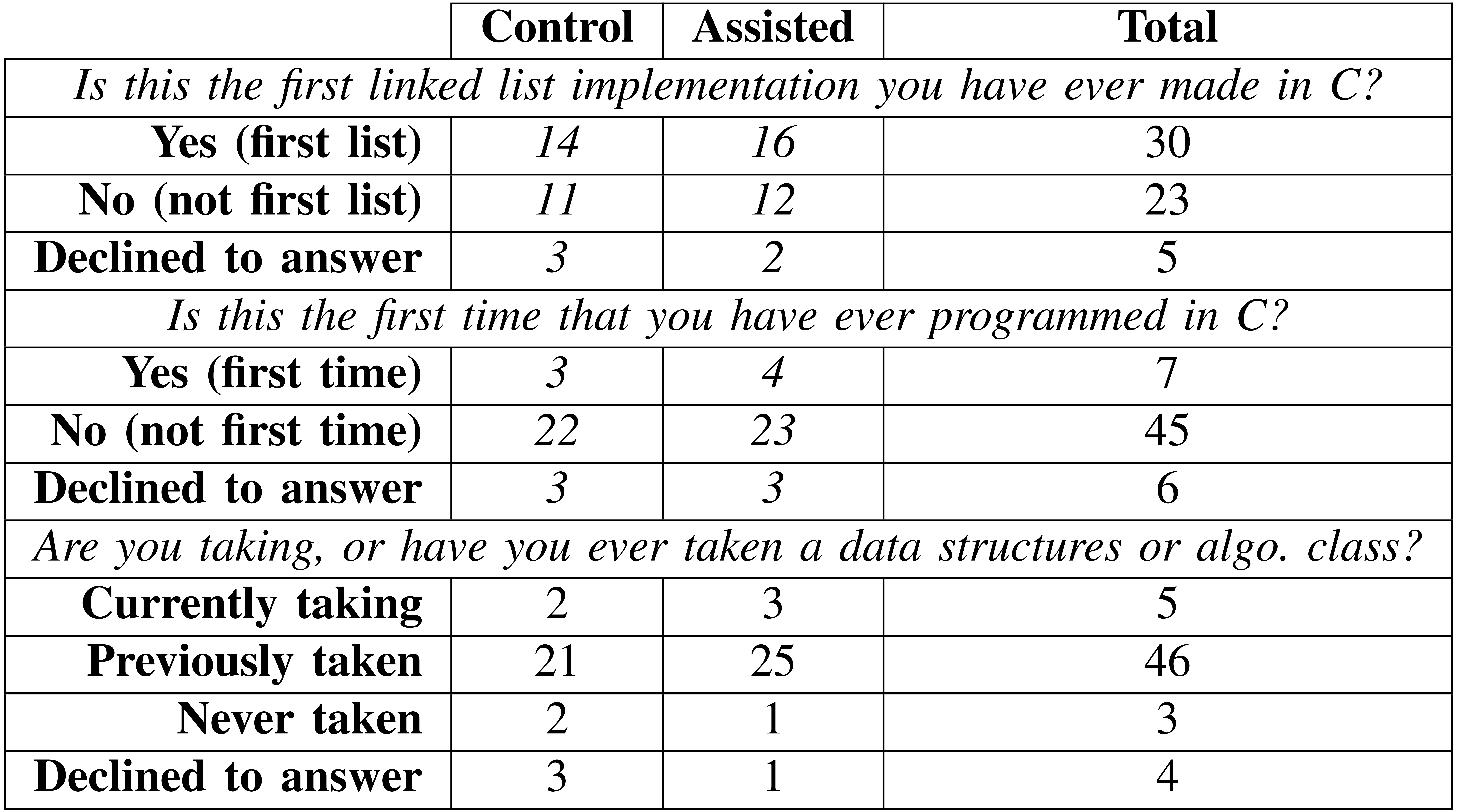
```
#include <stdio.h>
#include <stdlib.h>
#include <getopt.h>
#include <string.h>
#include ”list.h”

#define MAX_ITEM_PRINT_LEN 100

// Note: All list_ functions should return a status code
// EXIT_FAILURE or EXIT_SUCCESS to indicate whether the
     operation was
// successful or not.
```

Fixed length

(b) `#includes` and implementation hints (in `list.c`)

Participant Demographics

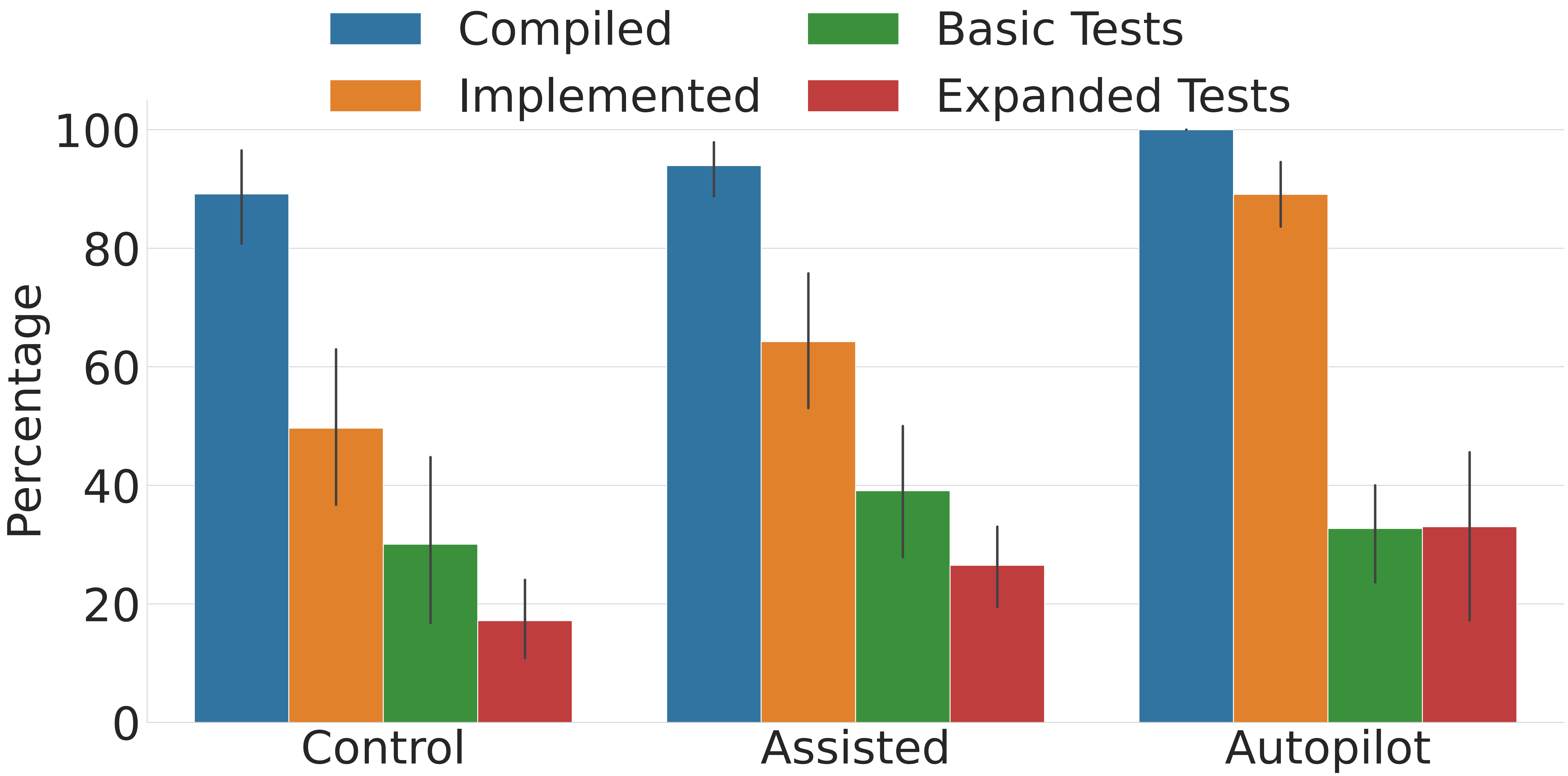
Experience Level



	Control	Assisted	Total
Is this the first linked list implementation you have ever made in C?			
Yes (first list)	*14*	*16*	30
No (not first list)	*11*	*12*	23
Declined to answer	*3*	*2*	5
Is this the first time that you have ever programmed in C?			
Yes (first time)	*3*	*4*	7
No (not first time)	*22*	*23*	45
Declined to answer	*3*	*3*	6
Are you taking, or have you ever taken a data structures or algo. class?			
Currently taking	2	3	5
Previously taken	21	25	46
Never taken	2	1	3
Declined to answer	3	1	4

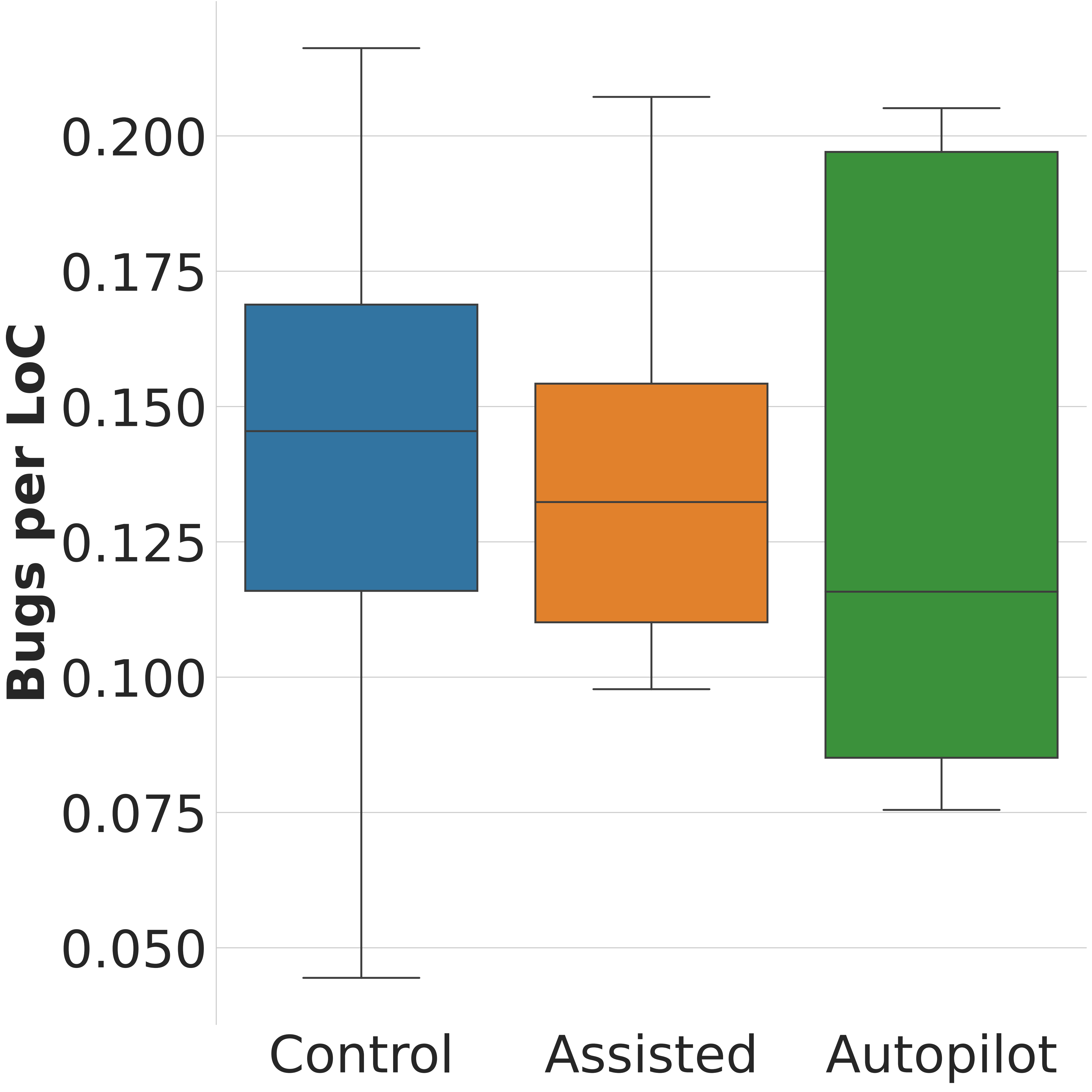
Functionality Results

Rise of the Machines

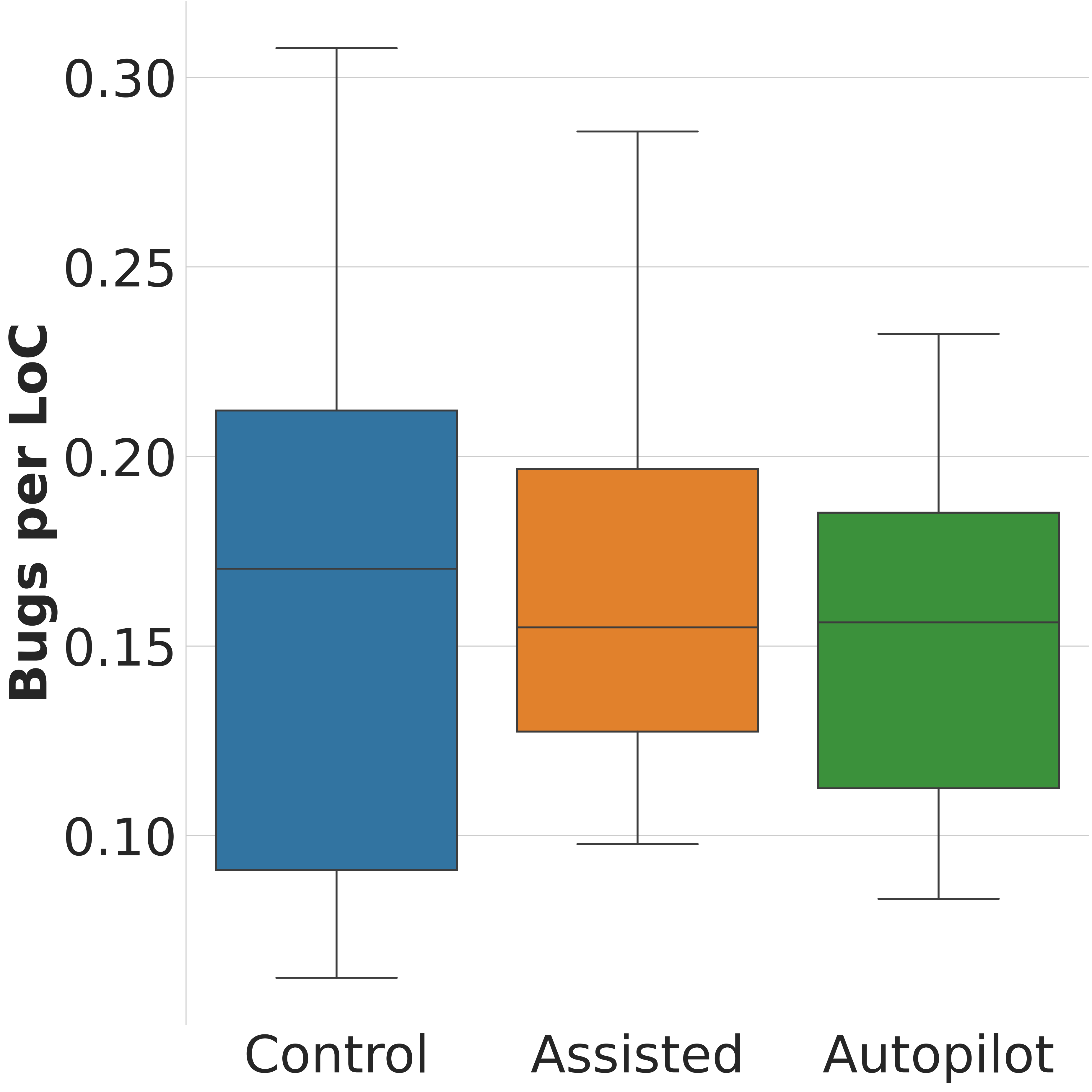


Security Results

Number of vulnerabilities per line of code



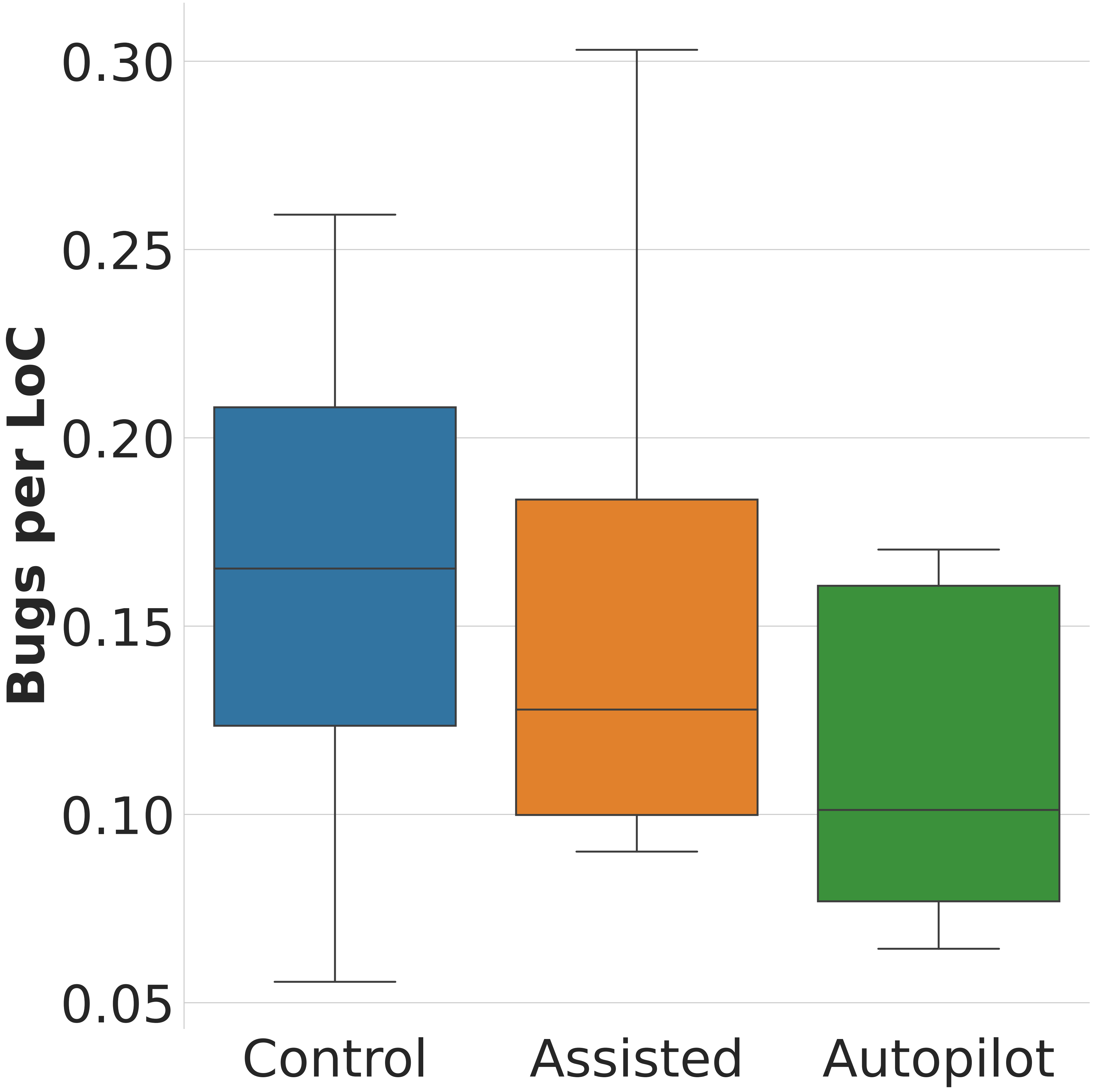
CWEs/LoC for *compiling* code



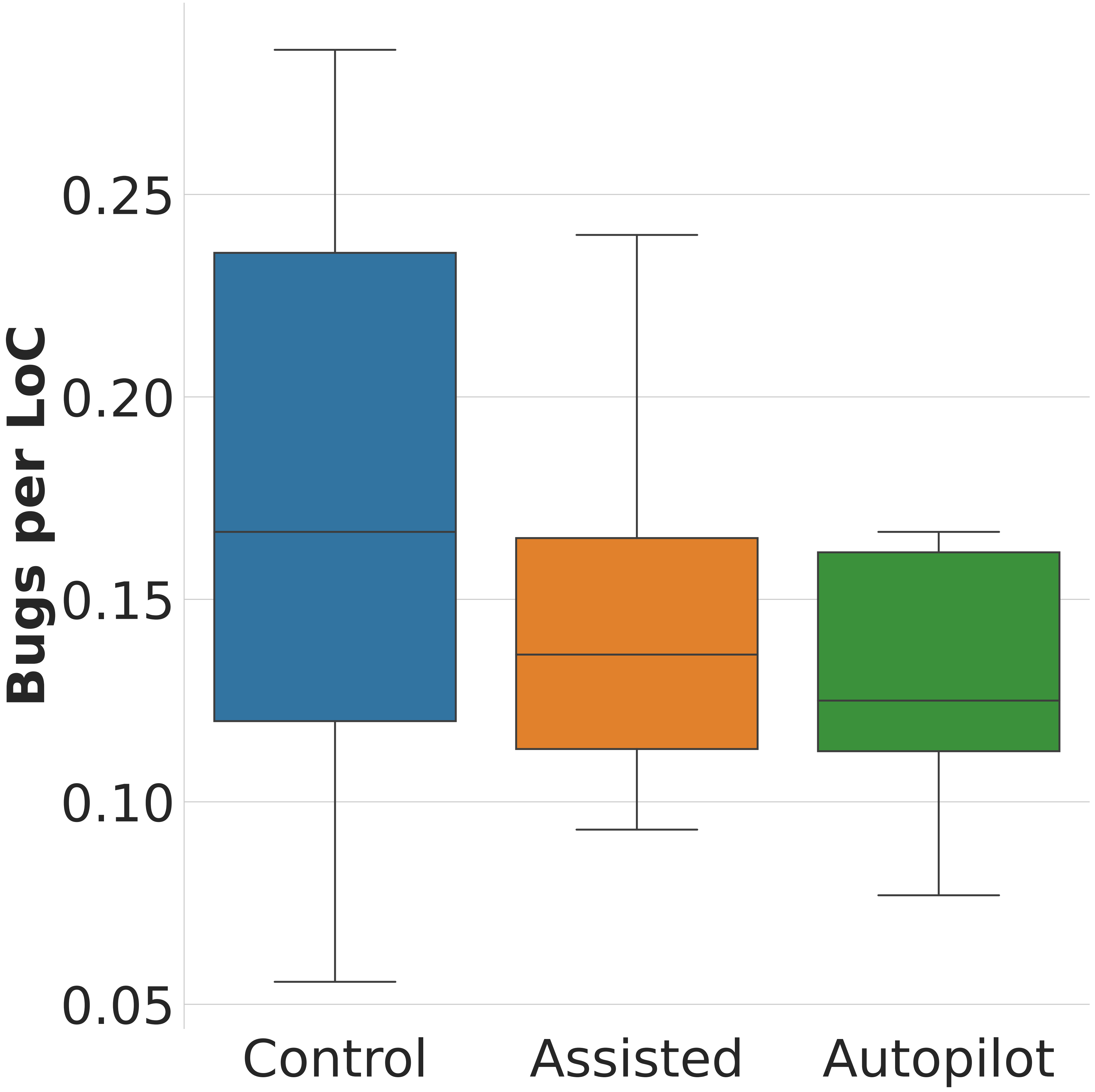
CWEs/LoC, code that *passes the basic unit test*

Security Results

Number of *severe* (MITRE Top 25) vulnerabilities per line of code

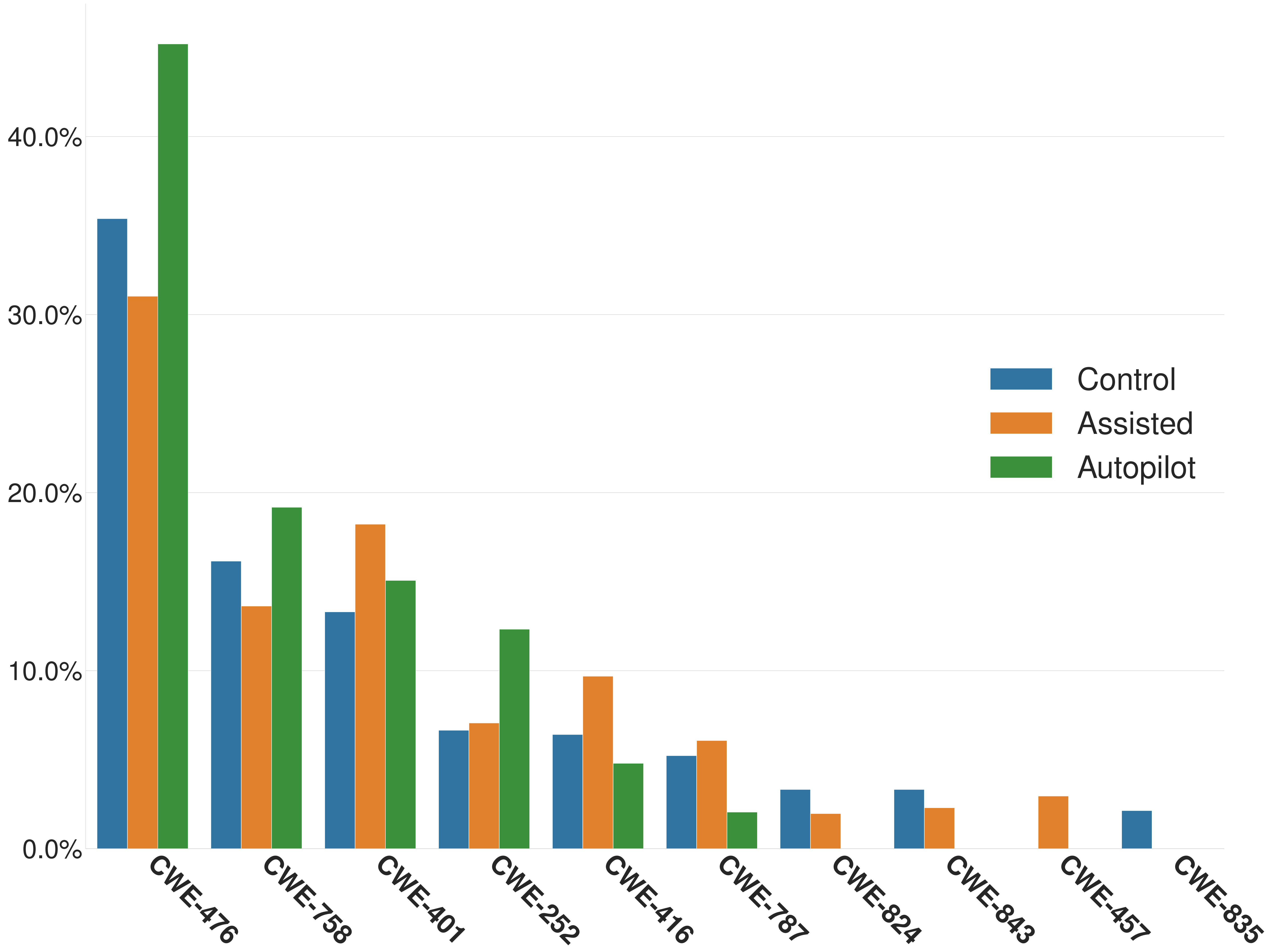


Severe CWEs/LoC for *compiling* code



Severe CWEs/LoC, code that *passes the basic unit test*

Security Results: CWEs

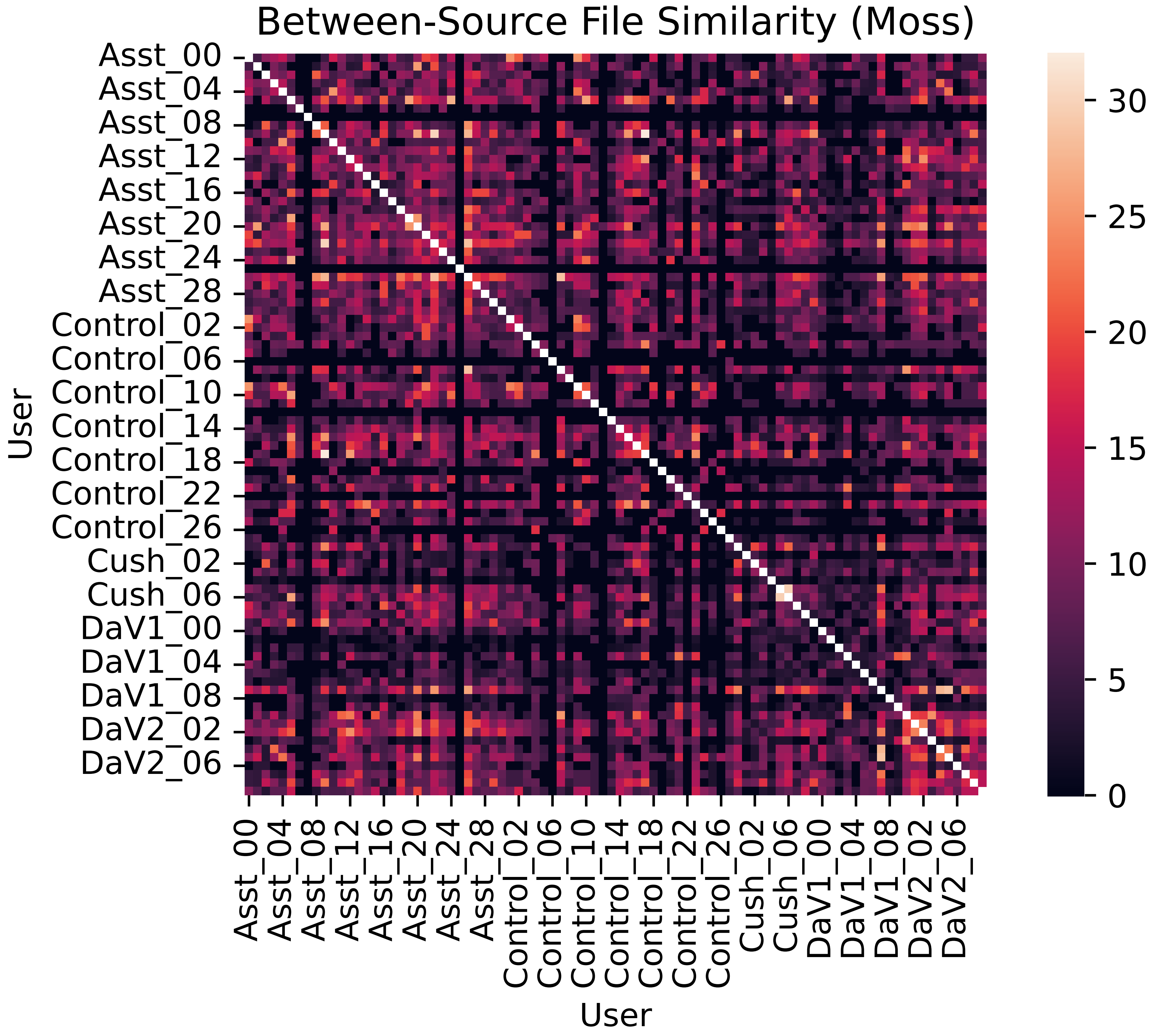


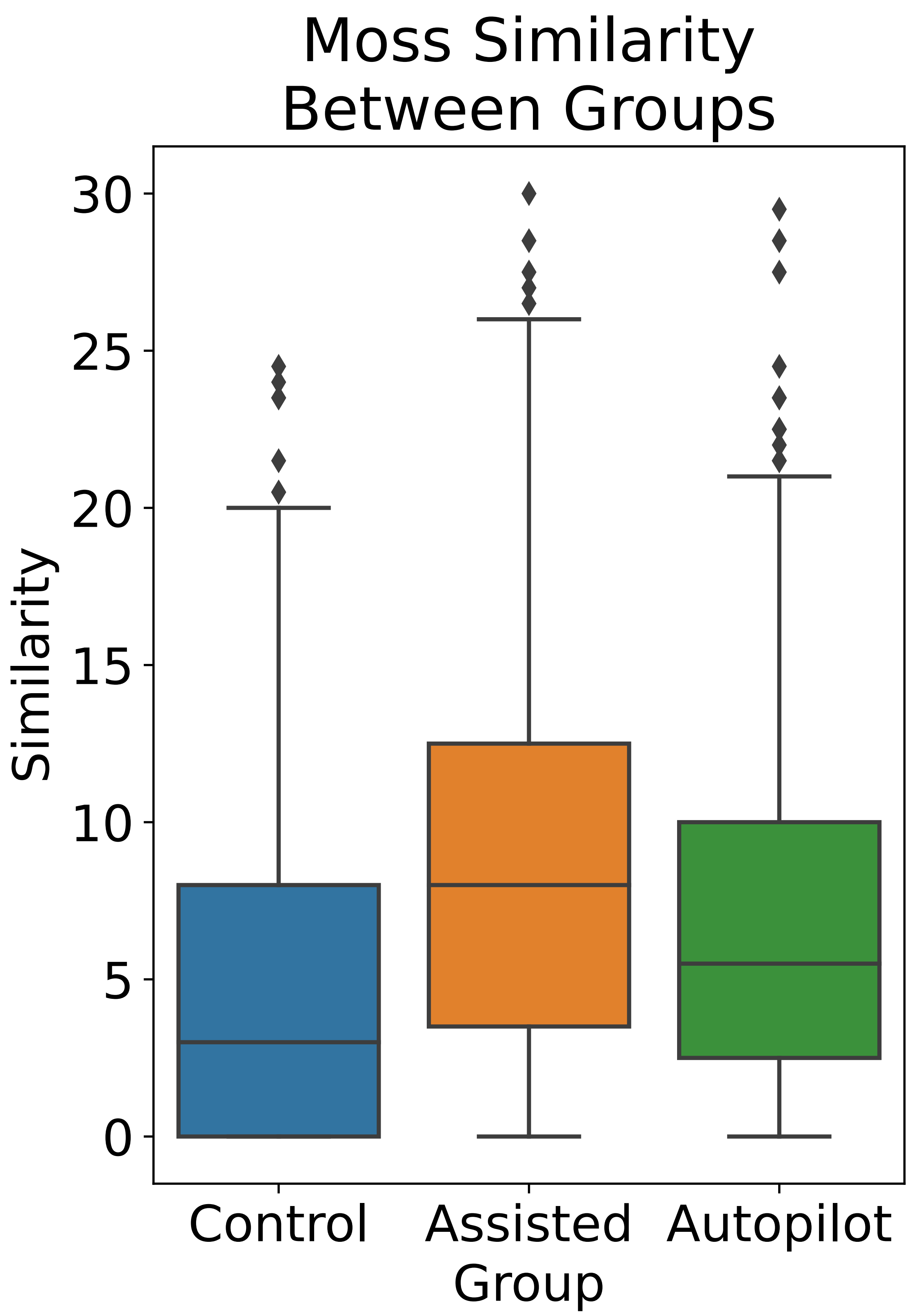
CWE-476	NULL Pointer Dereference
CWE-758	Reliance on Undefined, Unspecified, or Implementation-Defined Behavior
CWE-401	Missing Release of Memory after Effective Lifetime
CWE-252	Unchecked Return Value
CWE-416	Use After Free
CWE-787	Out-of-bounds Write
CWE-457	Use of Uninitialized Variable
CWE-843	Access of Resource Using Incompatible Type ('Type Confusion')
CWE-824	Access of Uninitialized Pointer
CWE-835	Loop with Unreachable Exit Condition ('Infinite Loop')

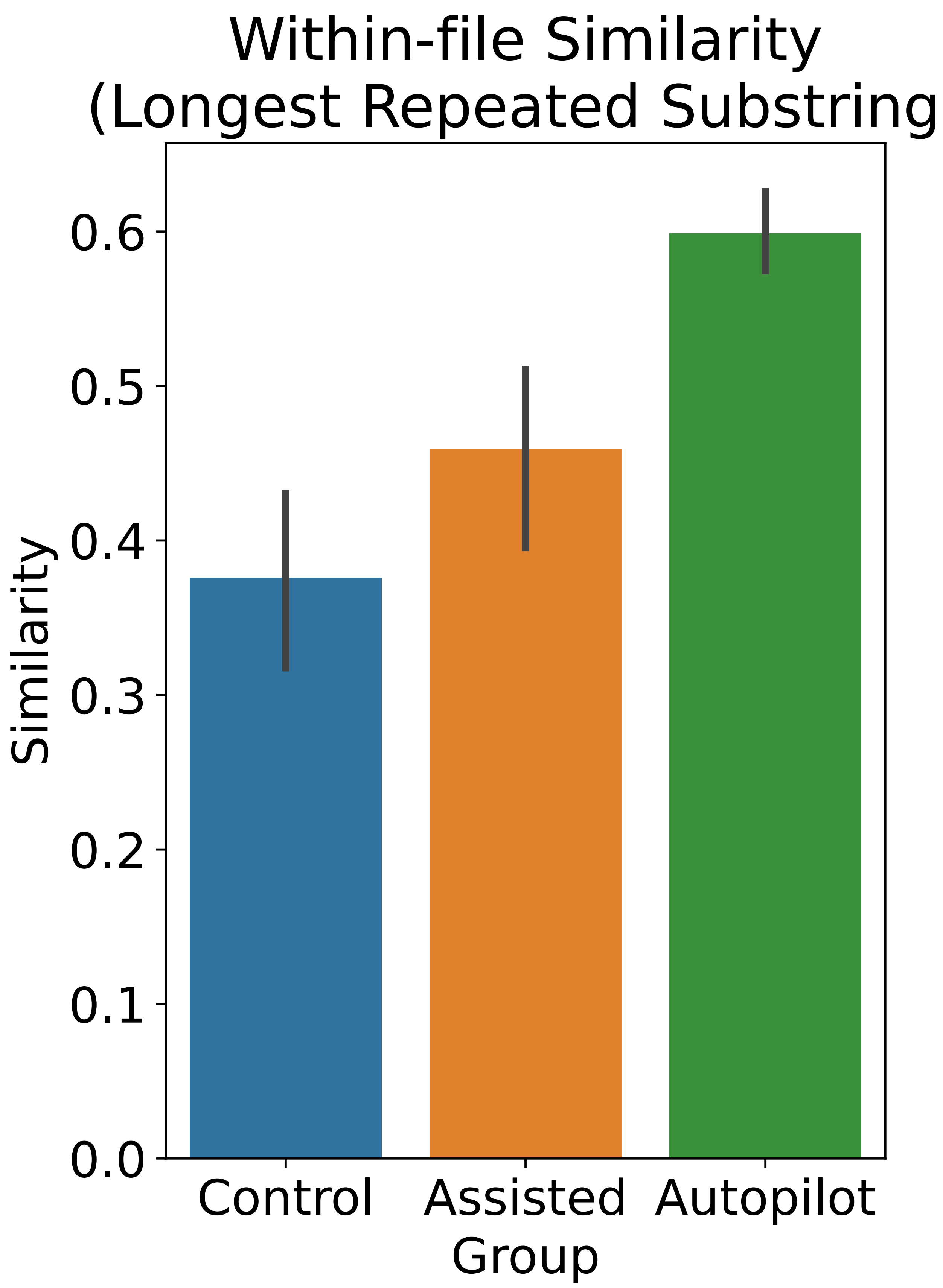
Measuring Style

- We wanted to check if there were difference in style between human and AI-assisted users
  - Can we tell if someone is using Copilot?
- We used two measures:
  - The Moss plagiarism detection tool to measure similarity between users
  - The quantity of *repeated substrings* in the file to measure similarity *within* an individual user's submission

Style Results

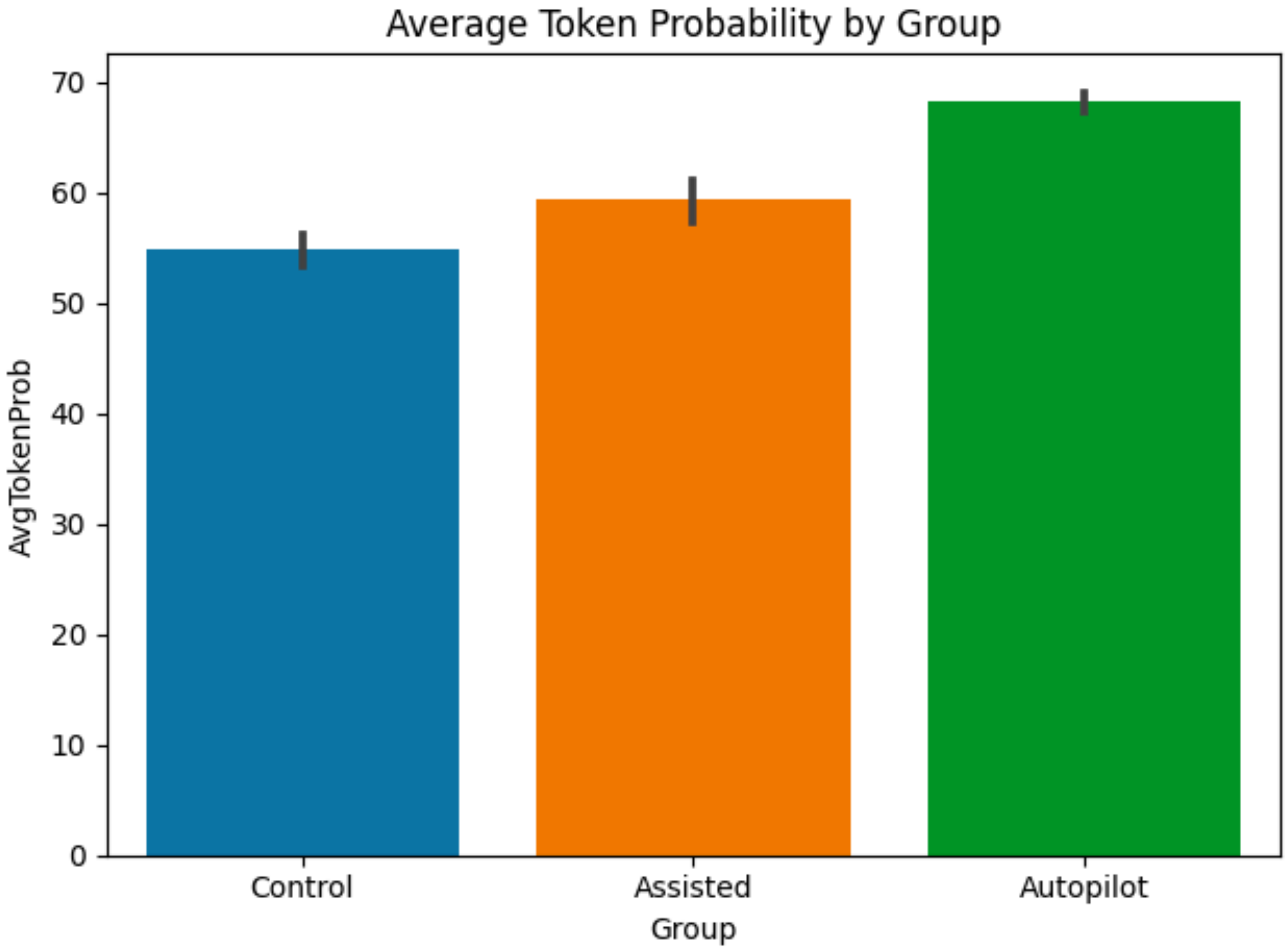

Between-Source File Similarity (Moss)


Moss Similarity
Between Groups


Within-file Similarity
(Longest Repeated Substring

Style Results (LM)

Suggested during Q&A: Use Codex to Get Prob. of Document



On the Origin of Bugs

git blame codex

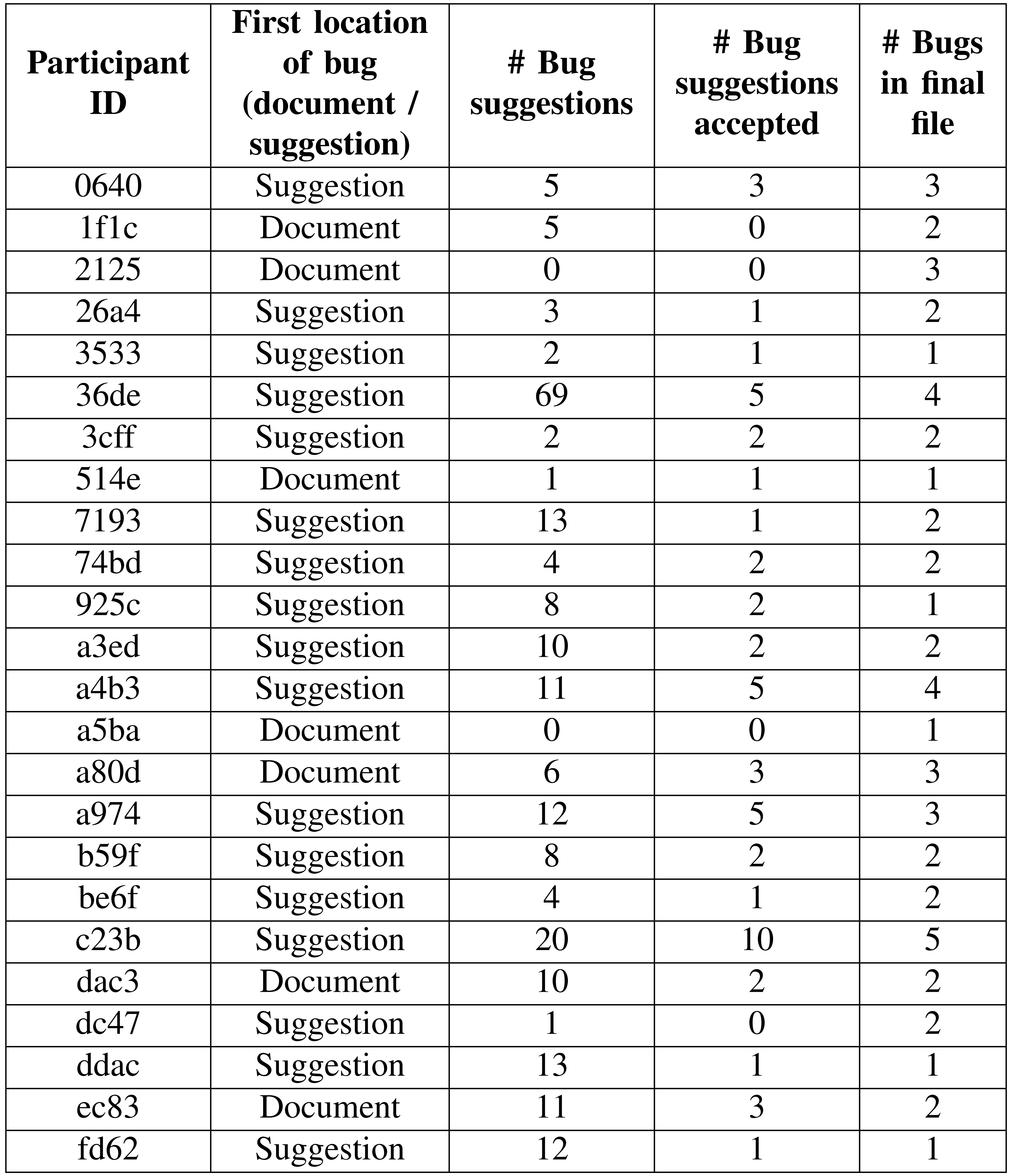
- Using the data from the IDE, can we identify where vulnerabilities were introduced into the user's code?
  - In particular, did they come from **Codex suggestions** or were they written by **humans**?
- **Idea**:
  - Find an automated way to check for some common vulnerability
  - Use our document snapshots and suggestion data to see if it first appeared in a **document** (human-written) or **suggestion** (introduced by Codex)

Bug Origins: Missing `strdup`

- We picked one bug for this that we could identify with just a regular expression
  - Vulnerability failing to make a copy of the `item_name` provided by the caller (e.g. using strdup) before storing it in the node
  - Can lead to **CWE-416: Use-After-Free** because the list library has no control over when the user-provided string will be freed
  - We can identify it by just looking for direct assignments to `node->item_name` with no strdup/strcpy/malloc

Bug Origins: Results

- This vulnerability was introduced by Codex more often than not
- But some users introduced it themselves, and did not accept further buggy suggestions
- Some users got a **lot** of buggy suggestions (69 in one case!)
- Weak trend: more bug suggestions => more bugs in final file



Participant ID	First location of bug (document / suggestion)	# Bug suggestions	# Bug suggestions accepted	# Bugs in final file
0640	Suggestion	5	3	3
1f1c	Document	5	0	2
2125	Document	0	0	3
26a4	Suggestion	3	1	2
3533	Suggestion	2	1	1
36de	Suggestion	69	5	4
3cff	Suggestion	2	2	2
514e	Document	1	1	1
7193	Suggestion	13	1	2
74bd	Suggestion	4	2	2
925c	Suggestion	8	2	1
a3ed	Suggestion	10	2	2
a4b3	Suggestion	11	5	4
a5ba	Document	0	0	1
a80d	Document	6	3	3
a974	Suggestion	12	5	3
b59f	Suggestion	8	2	2
be6f	Suggestion	4	1	2
c23b	Suggestion	20	10	5
dac3	Document	10	2	2
dc47	Suggestion	1	0	2
ddac	Suggestion	13	1	1
ec83	Document	11	3	2
fd62	Suggestion	12	1	1

Conclusions

Check out the paper! https://arxiv.org/abs/2208.09727
Dataset Visualization: https://moyix.net/~moyix/secret/suggestion_cover.html

- Significant differences in functionality between groups on **functionality**
- Surprisingly, **no discernible difference** on security
  - Limited by small sample size
  - *Maybe* a slight trend in favor of Codex
- Potentially found a signal we can use to distinguish **Copilot/Codex** written code from human-written code (repetition)
  - Has implications for stylometry, confirms that tendency toward repetition may *amplify* the existing vulnerabilities in the code