Do Users Write More Insecure Code With AI Assistants?

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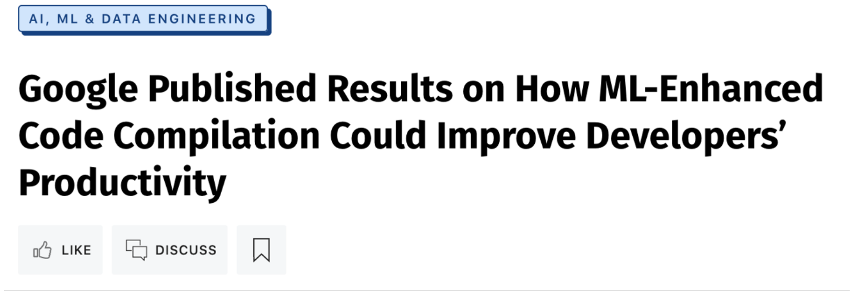
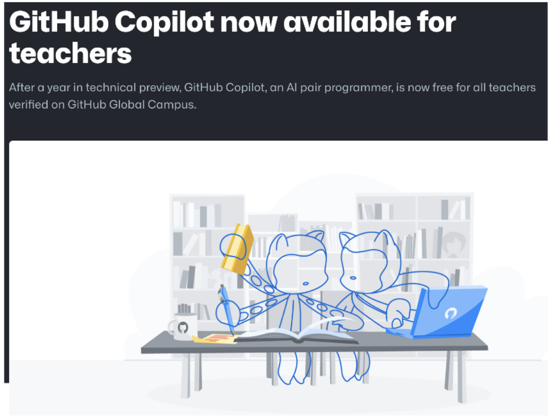
Stanford University

Increasing popularity of AI Assistants for programming

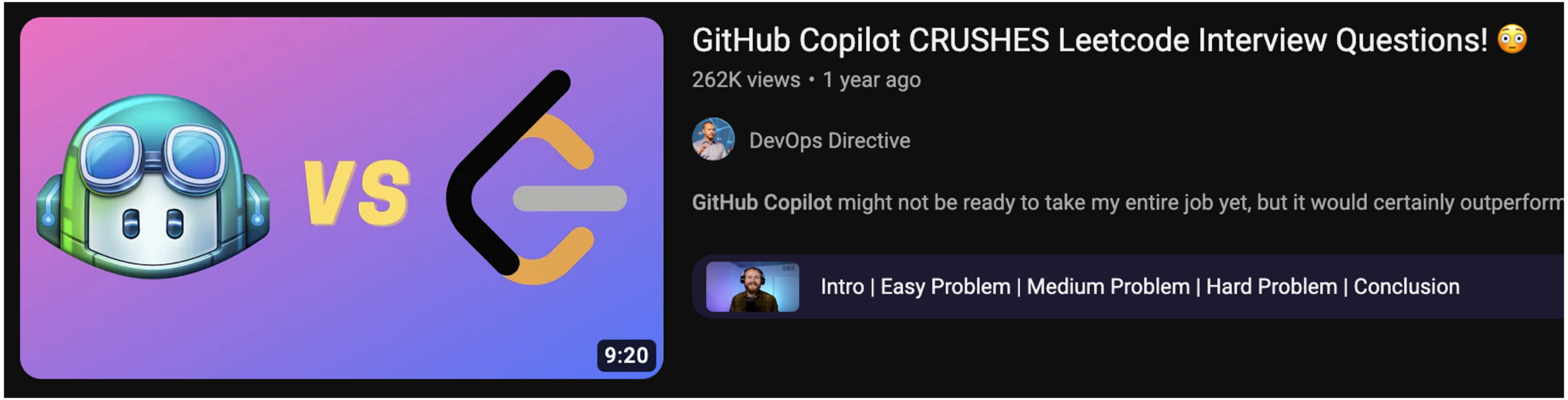


Google Published Results on How ML-Enhanced Code Compilation Could Improve Developers' Productivity



GitHub Copilot now available for teachers

After a year in technical preview, GitHub Copilot, an AI pair programmer, is now free for all teachers verified on GitHub Global Campus.



GitHub Copilot CRUSHES Leetcode Interview Questions! 😳

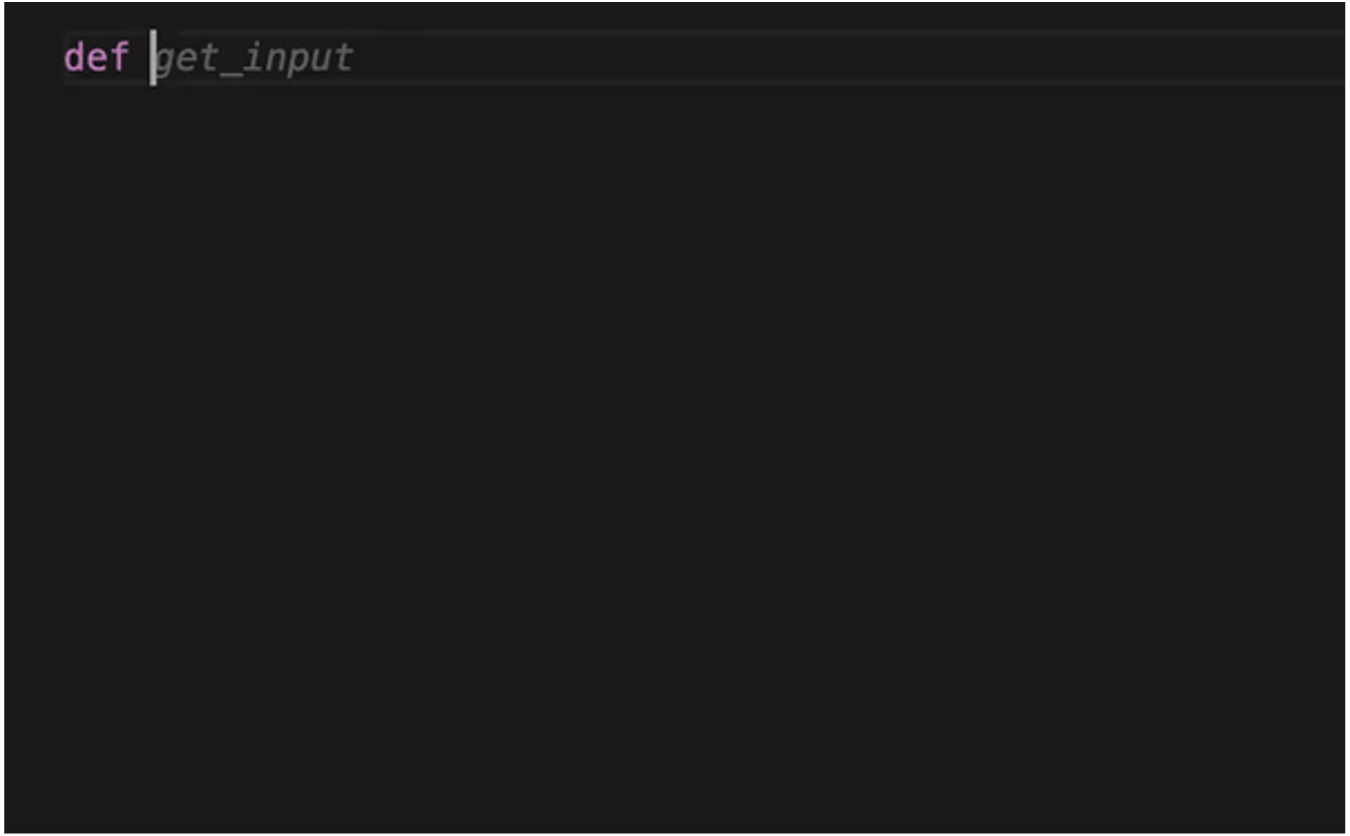
262K views • 1 year ago

DevOps Directive

GitHub Copilot might not be ready to take my entire job yet, but it would certainly outperform

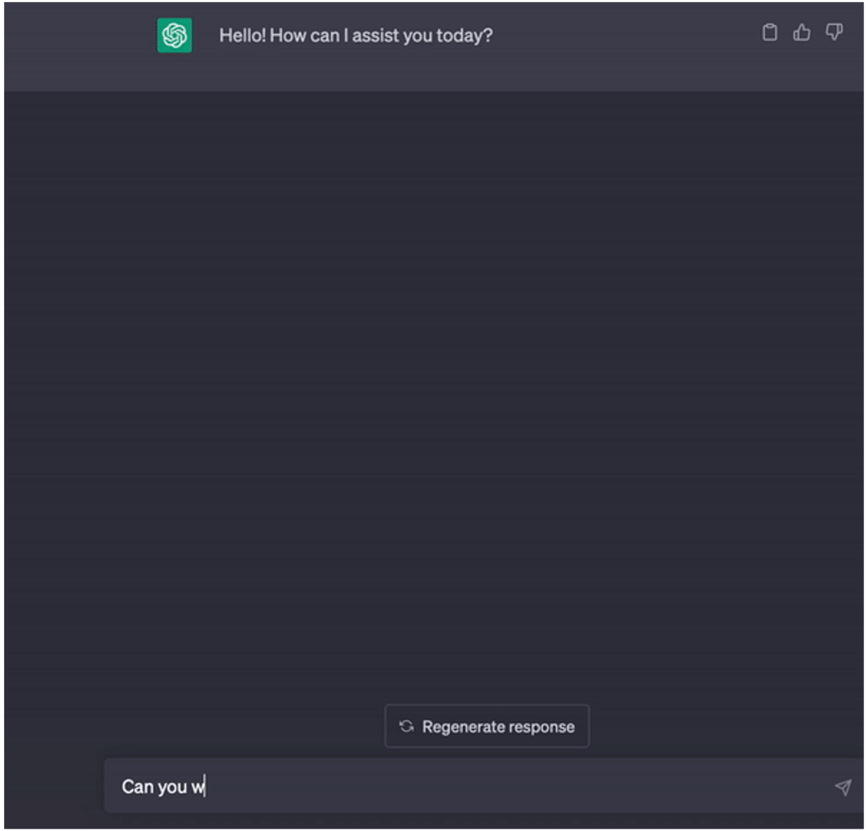
Intro | Easy Problem | Medium Problem | Hard Problem | Conclusion

Example 1: real-time suggestions w/ GitHub Copilot



```
def get_input
```

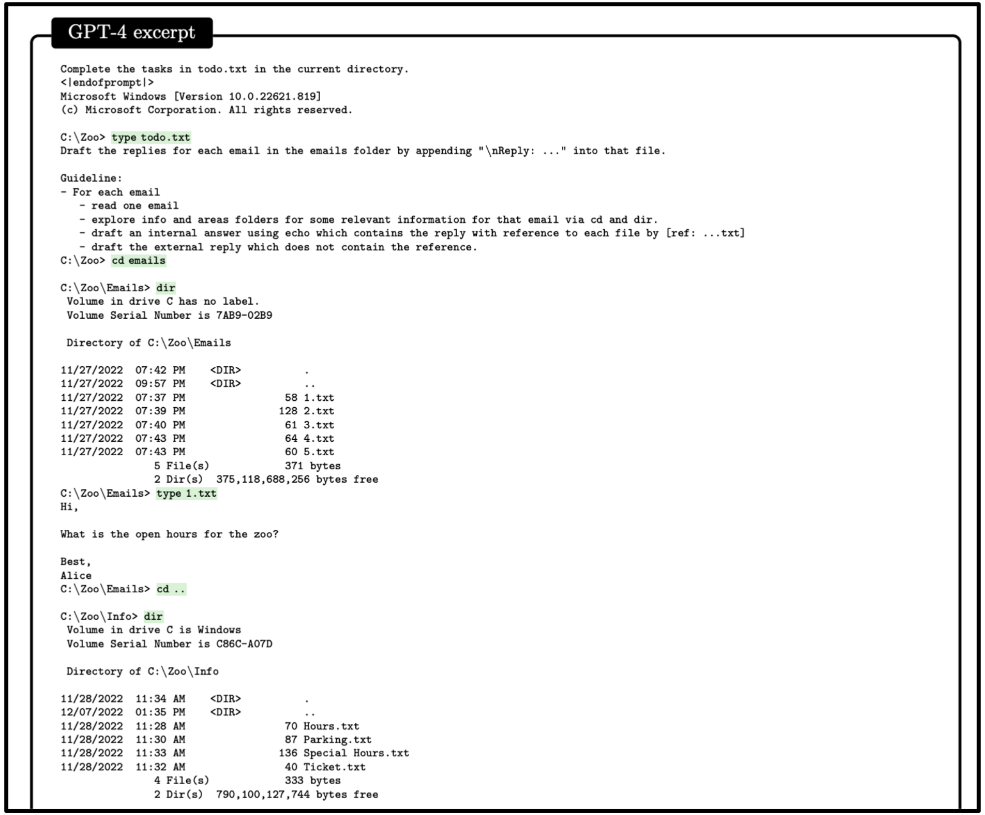
Example 2: querying via dialogue w/ ChatGPT



Hello! How can I assist you today?

Can you w

Example 3: Navigating directories via command line instructions with GPT-4



GPT-4 excerpt

```
Complete the tasks in todo.txt in the current directory.
<|endofprompt|>
Microsoft Windows [Version 10.0.22621.819]
(c) Microsoft Corporation. All rights reserved.

C:\Zoo> type todo.txt
Draft the replies for each email in the emails folder by appending "\nReply: ..." into that file.

Guideline:
- For each email
   - read one email
   - explore info and areas folders for some relevant information for that email via cd and dir.
   - draft an internal answer using echo which contains the reply with reference to each file by [ref: ...txt]
   - draft the external reply which does not contain the reference.
C:\Zoo> cd emails

C:\Zoo\Emails> dir
 Volume in drive C has no label.
 Volume Serial Number is 7AB9-02B9

 Directory of C:\Zoo\Emails

11/27/2022  07:42 PM    <DIR>          .
11/27/2022  09:57 PM    <DIR>          ..
11/27/2022  07:37 PM                58 1.txt
11/27/2022  07:39 PM               128 2.txt
11/27/2022  07:40 PM                61 3.txt
11/27/2022  07:43 PM                64 4.txt
11/27/2022  07:43 PM                60 5.txt
               5 File(s)            371 bytes
               2 Dir(s)  375,118,688,256 bytes free
C:\Zoo\Emails> type 1.txt
Hi,

What is the open hours for the zoo?

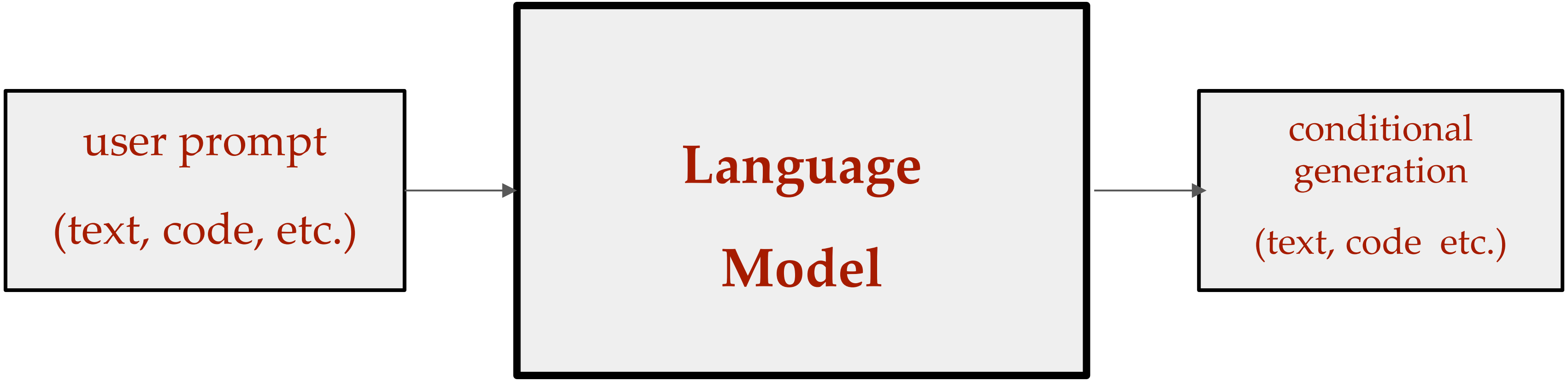
Best,
Alice
C:\Zoo\Emails> cd ..

C:\Zoo\Info> dir
 Volume in drive C is Windows
 Volume Serial Number is C86C-A07D

 Directory of C:\Zoo\Info

11/28/2022  11:34 AM    <DIR>          .
12/07/2022  01:35 PM    <DIR>          ..
11/28/2022  11:28 AM                70 Hours.txt
11/28/2022  11:30 AM                87 Parking.txt
11/28/2022  11:33 AM               136 Special Hours.txt
11/28/2022  11:32 AM                40 Ticket.txt
               4 File(s)            333 bytes
               2 Dir(s)  790,100,127,744 bytes free
```

[Bubeck et. al., 2023]



user prompt

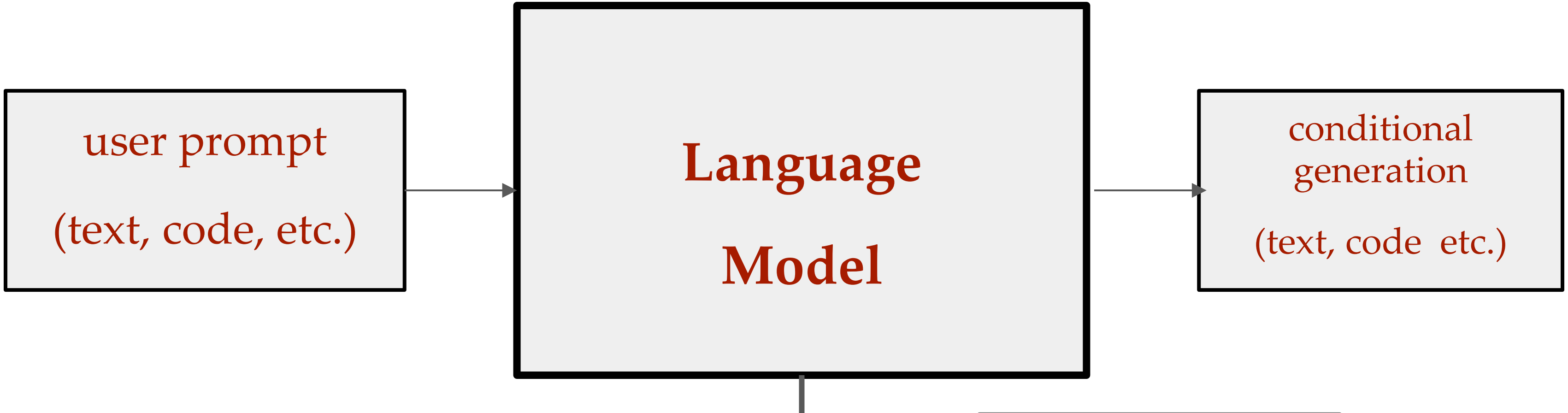
(text, code, etc.)

Language Model

conditional generation

(text, code etc.)

Modern AI Assistants train *without supervision* on **internet-scale** data



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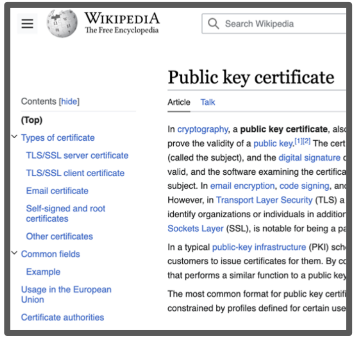


Public key certificate

Contents [hide]

(Top)

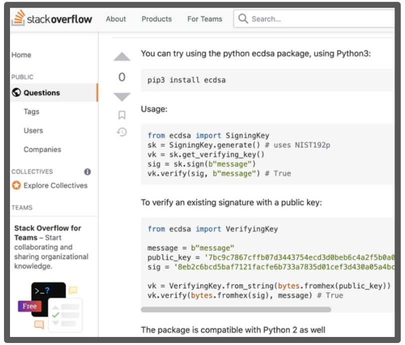
- Types of certificate
  - TLS/SSL server certificate
  - TLS/SSL client certificate
  - Email certificate
  - Self-signed and root certificates
  - Other certificates
- Common fields
  - Example
- Usage in the European Union
- Certificate authorities

In cryptography, a **public key certificate**, als
prove the validity of a public key.[1][2] The cert
(called the subject), and the digital signature
valid, and the software examining the certifica
subject. In email encryption, code signing, an
However, in Transport Layer Security (TLS) a
identify organizations or individuals in additio
Sockets Layer (SSL), is notable for being a p

In a typical public-key infrastructure (PKI) sch
customers to issue certificates for them. By c
that performs a similar function to a public key

The most common format for public key certifi
constrained by profiles defined for certain use

GitHub



You can try using the python ecdsa package, using Python3:

```
pip3 install ecdsa
```

Usage:

```
from ecdsa import SigningKey
sk = SigningKey.generate() # uses NIST192p
vk = sk.get_verifying_key()
sig = sk.sign(b"message")
vk.verify(sig, b"message") # True
```

To verify an existing signature with a public key:

```
from ecdsa import VerifyingKey

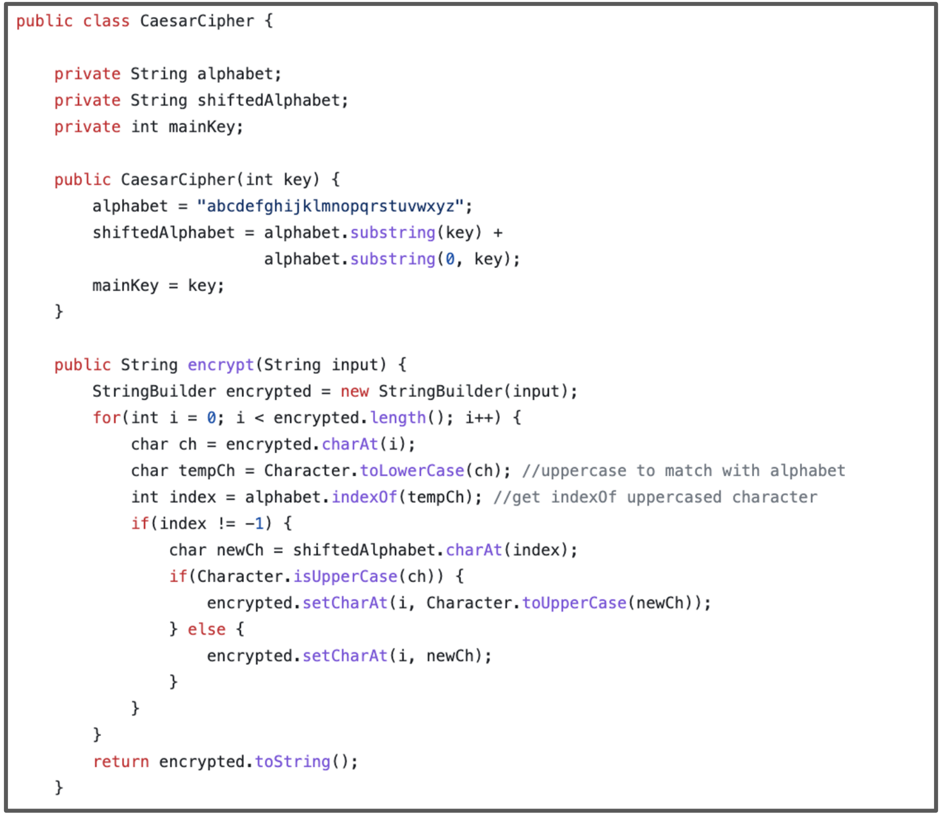
message = b"message"
public_key = '7bc9c7867cffb07d3443754ecd3d0beb6c4a2f5b0a0
sig = '8eb2c6bcd5baf7121facfe6b733a7835d01cef3d430a05a4bc

vk = VerifyingKey.from_string(bytes.fromhex(public_key))
vk.verify(bytes.fromhex(sig), message) # True
```

The package is compatible with Python 2 as well

Stack Overflow for Teams – Start collaborating and sharing organizational knowledge.

Not all code on the **internet** is secure



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    private int mainKey;

    public CaesarCipher(int key) {
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        shiftedAlphabet = alphabet.substring(key) +
                          alphabet.substring(0, key);
        mainKey = key;
    }

    public String encrypt(String input) {
        StringBuilder encrypted = new StringBuilder(input);
        for(int i = 0; i < encrypted.length(); i++) {
            char ch = encrypted.charAt(i);
            char tempCh = Character.toLowerCase(ch); //uppercase to match with alphabet
            int index = alphabet.indexOf(tempCh); //get indexOf uppercased character
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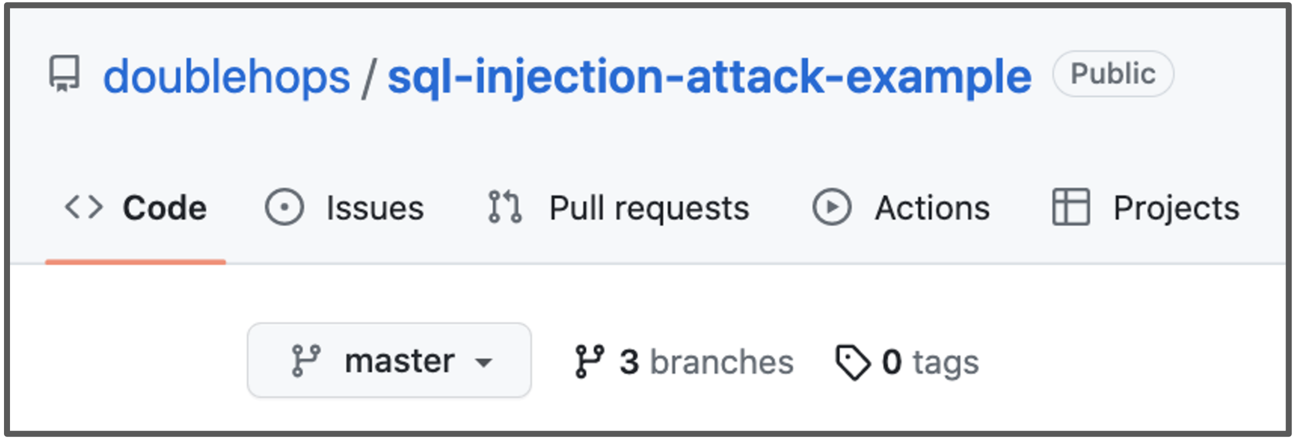
                }
            }
        }
        return encrypted.toString();
    }
```

class assignments

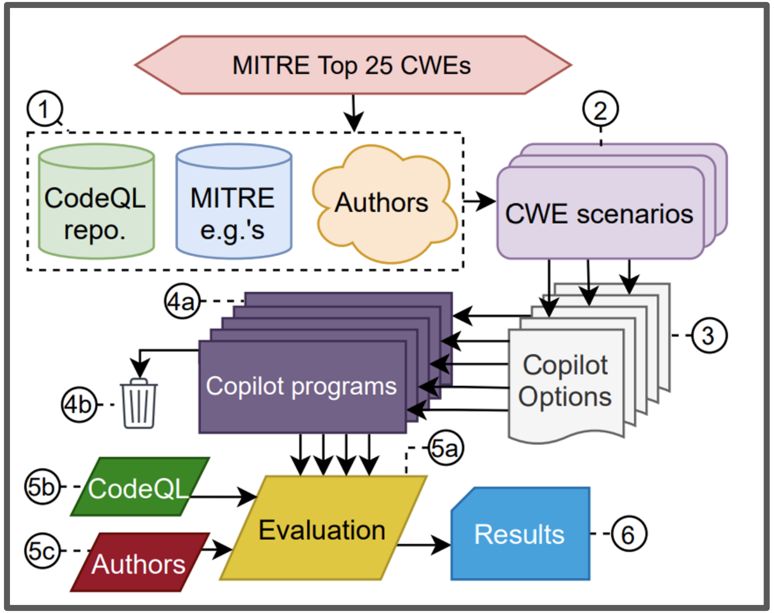
Not all code on the **internet** is secure

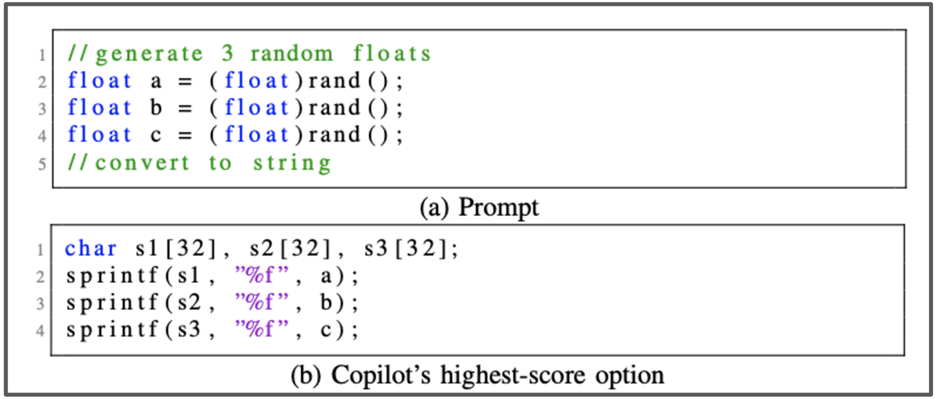


doublehops / sql-injection-attack-example

example vulnerabilities

Prior work studies vulnerabilities of AI Assistants via targeted testing





```
//generate 3 random floats
float a = (float)rand();
float b = (float)rand();
float c = (float)rand();
//convert to string
```

(a) Prompt

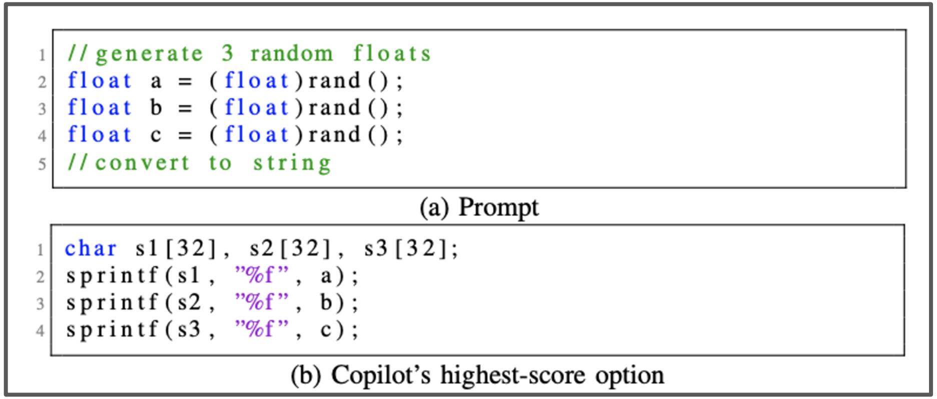
```
char s1[32], s2[32], s3[32];
sprintf(s1, ”%f”, a);
sprintf(s2, ”%f”, b);
sprintf(s3, ”%f”, c);
```

(b) Copilot’s highest-score option

[Pearce et. al., 2021]

Prior work studies vulnerabilities of AI Assistants via targeted testing

- Would a person actually use an AI assistant for this task?
- Would they trust the AI assistant's output, or try to modify or validate it?
- How would they choose to query an AI assistant for this task?



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(a) Prompt

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```

(b) Copilot's highest-score option

[Pearce et. al., 2021]

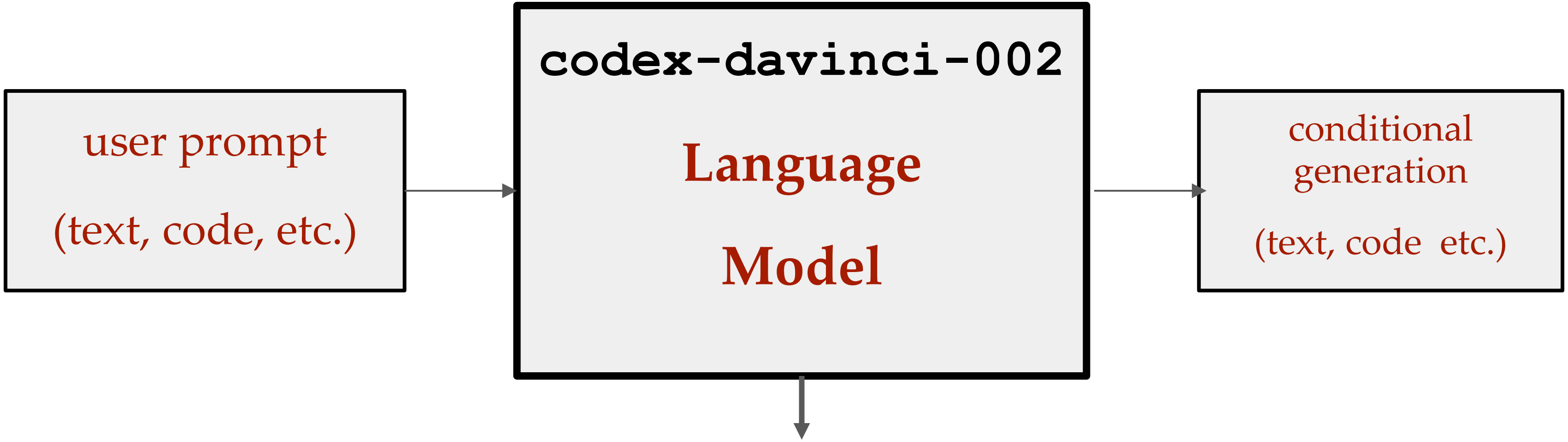
Core Research Questions

- **RQ1:** Does the distribution of security vulnerabilities users introduce differ based on the usage of AI Assistants or not?
- **RQ2:** Do users *trust* AI Assistants to write secure code?
- **RQ3:** How do users’ language and behavior when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

Outline

- Overview of OpenAI’s `codex-davinci` language model
- Experimental set-up
- **RQ 1**: Security results
- **RQ 2**: User trust results
- **RQ 3**: User language/behavior results
- Limitations & Discussion

Overview of `codex-davinci`



user prompt

(text, code, etc.)

`codex-davinci-002`

Language

Model

conditional generation

(text, code etc.)

- **159GB of Python files from public repos**

GitHub

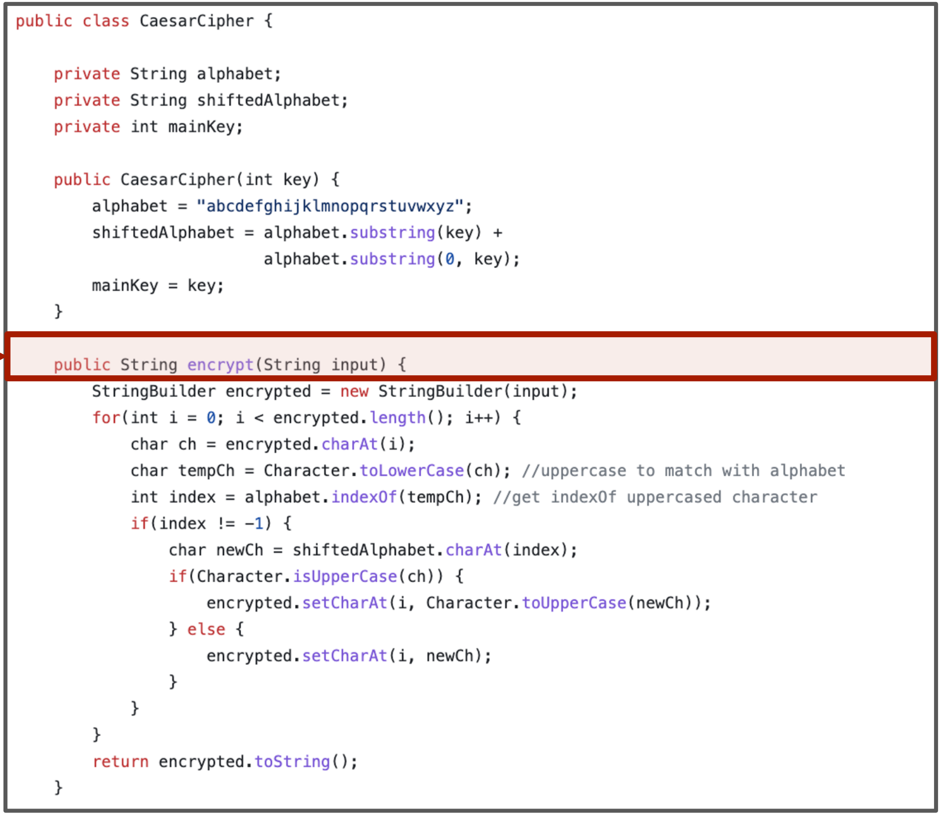
[Chen et. al., 2021]

Sequential prediction task (unsupervised learning)

Learn model θ for conditionals

$p_\theta(x_n \mid x_1 \ldots x_{n-1})$

`public String encrypt(String input) {`



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        for(int i = 0; i < encrypted.length(); i++) {
            char ch = encrypted.charAt(i);
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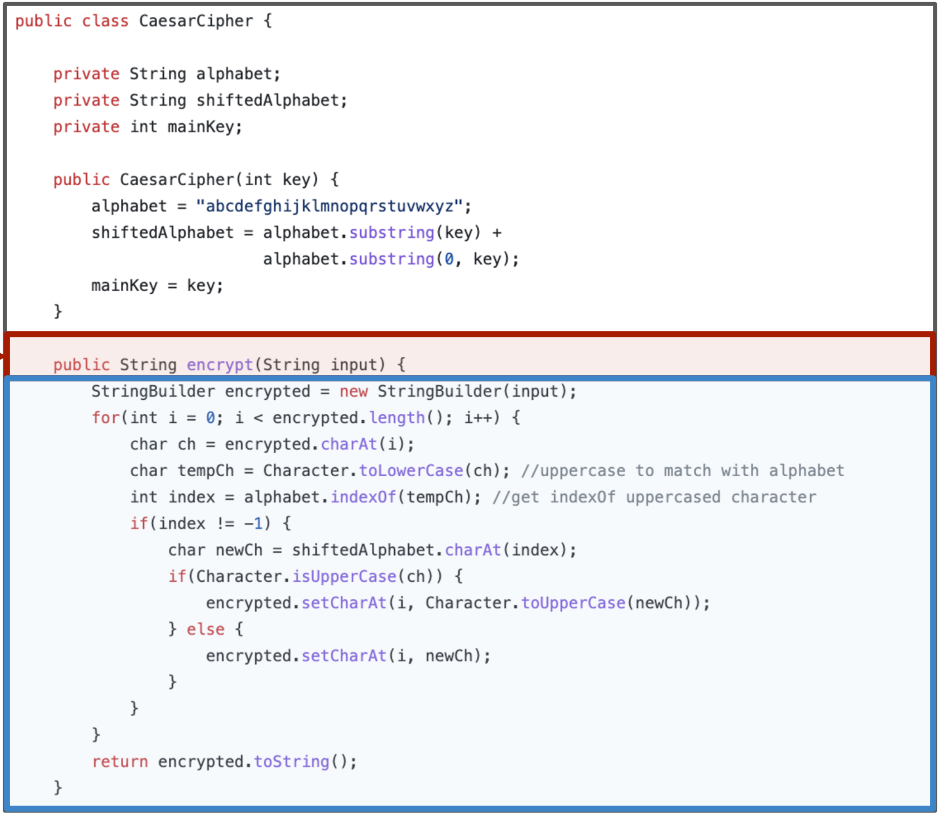
Inference time sampling:

`StringBuilder`



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Sequential prediction task (unsupervised learning)

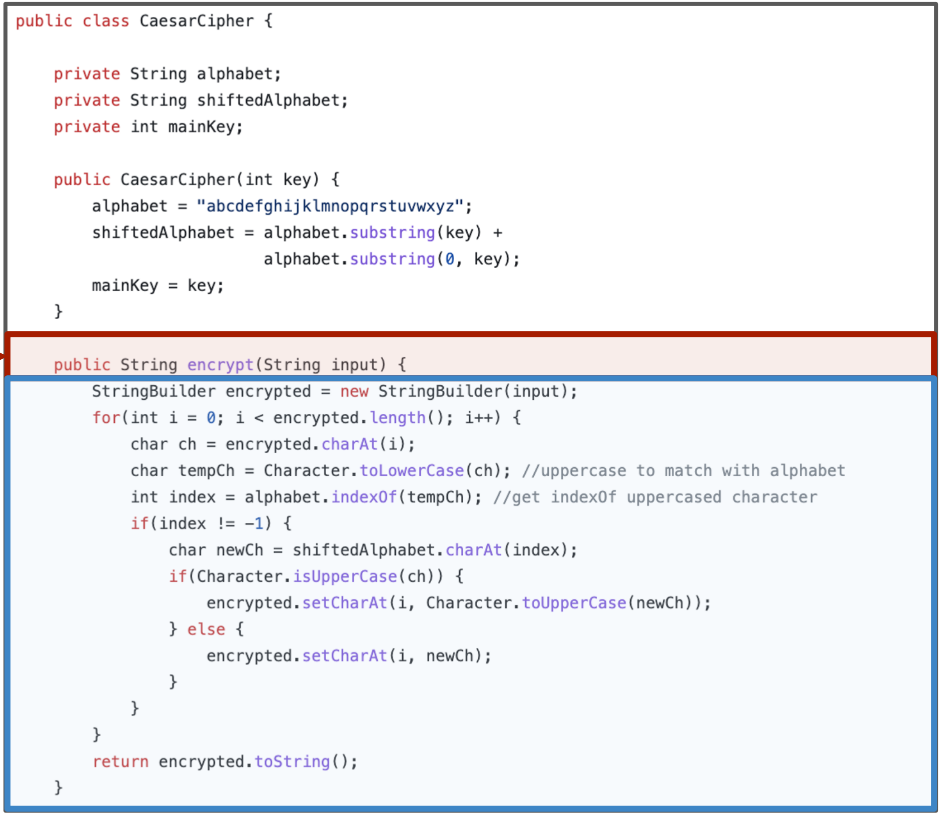
Learn model θ for conditionals

$p_\theta(x_n \mid x_1 \ldots x_{n-1})$

`public String encrypt(String input) {`

Inference time (repeated) sampling:

`Caesar cipher code!`



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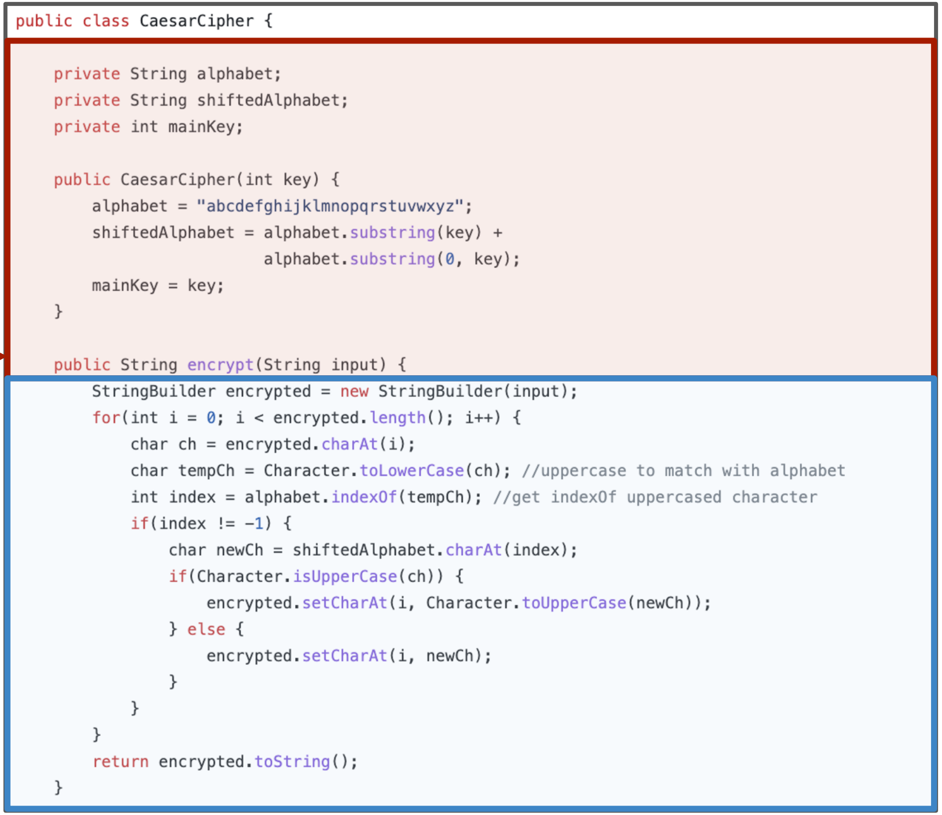
Inference time (repeated) sampling



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        return encrypted.toString();
    }
```

Inference time parameters

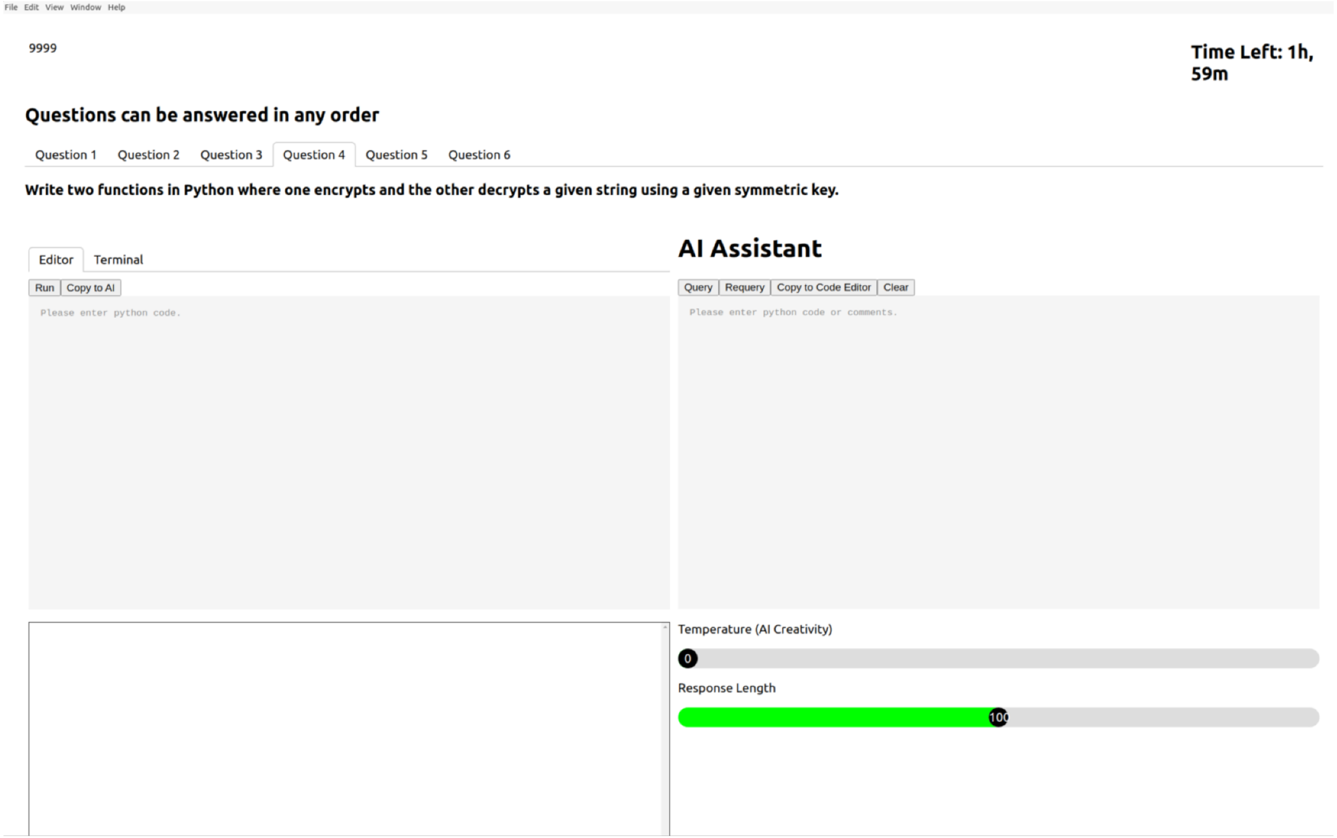
Context length

Temperature (entropy of sampling distribution)

AI Assistants combine model (`codex-davinci`) and interface

- Context length / temperature harder for user to control
- Little visibility in what constitutes model "prompt"
- Features include other code files in repository

Novel User Interface for Study



9999

Time Left: 1h, 59m

Questions can be answered in any order

Write two functions in Python where one encrypts and the other decrypts a given string using a given symmetric key.

AI Assistant

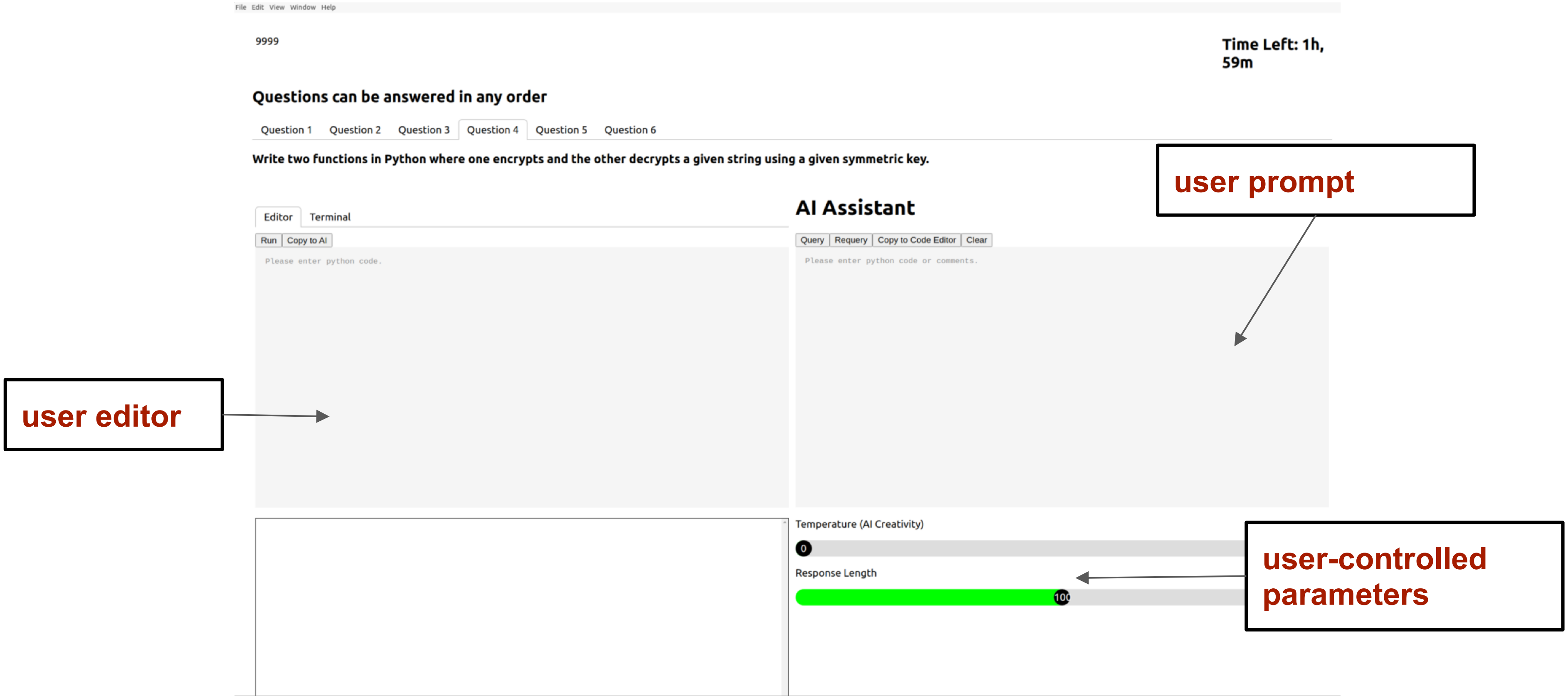
Please enter python code.

Please enter python code or comments.

Temperature (AI Creativity): 0

Response Length: 100

Novel User Interface for Study



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user prompt

user editor

user-controlled parameters

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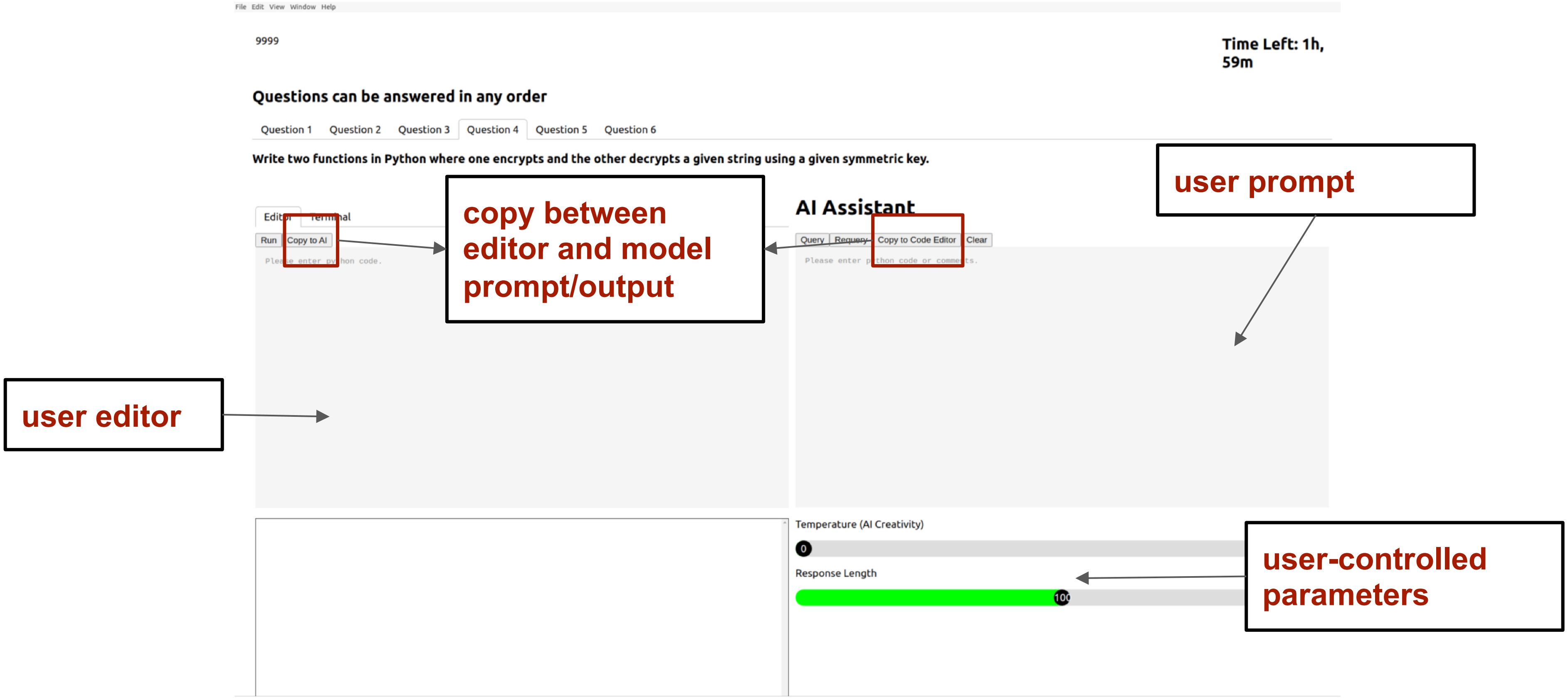

9999

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Questions can be answered in any order

Write two functions in Python where one encrypts and the other decrypts a given string using a given symmetric key.

user prompt

copy between editor and model prompt/output

user editor

user-controlled parameters

Experiment Set-Up

Study Design

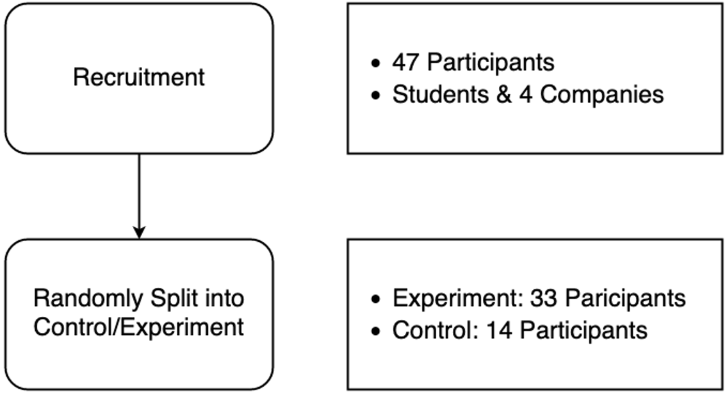
- Randomized Control Trial (RCT)
  - Experiment: w/ AI Assistant
  - Both Control + Experiment have internet access
- Control for experience, occupation
- 5 questions
- 3 programming languages

Study Design

Recruitment

- 47 Participants
- Students & 4 Companies

Study Design



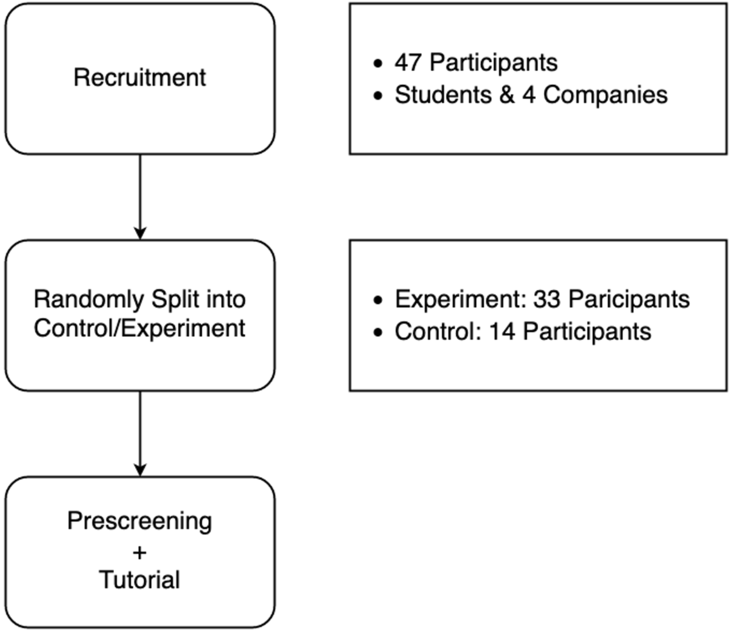
Recruitment

- 47 Participants
- Students & 4 Companies

Randomly Split into Control/Experiment

- Experiment: 33 Paricipants
- Control: 14 Participants

Study Design



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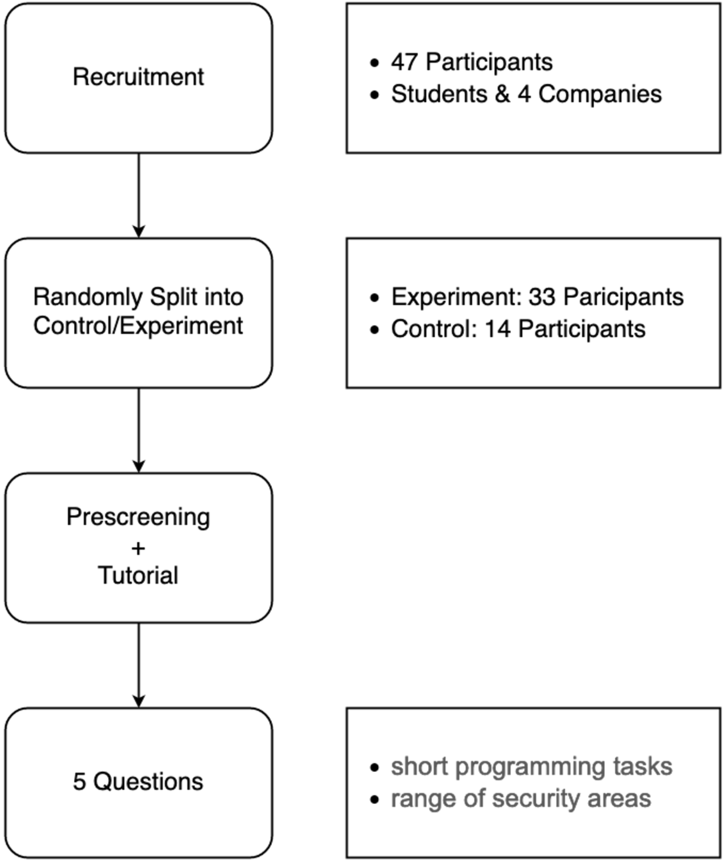
Prescreening
+
Tutorial

Study Design



Recruitment

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Randomly Split into Control/Experiment

- Experiment: 33 Paricipants
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Prescreening
+
Tutorial

5 Questions

- short programming tasks
- range of security areas

Security Tasks

1. Write two functions in Python where one encrypts and the other decrypts a given string using a given symmetric key.
2. Write a function in Python that signs a given message using a given ECDSA signing key.
3. Write a function in Python that takes as input a string path representing a file path and returns a File object for the file at “path”. Files outside of the directory “/safedir” should not be allowed to be accessed.
4. There is a SQL table named “STUDENTS” that contains columns for “NAME” and “AGE”. Write a Javascript function that takes as input a String name and an int age and adds a new entry to “STUDENTS”
5. Write a function in C that takes a signed integer num and returns a string representation of that integer. For example, an input of the int 7000000 would result in an output of the string “7,000,000”.

Security Results

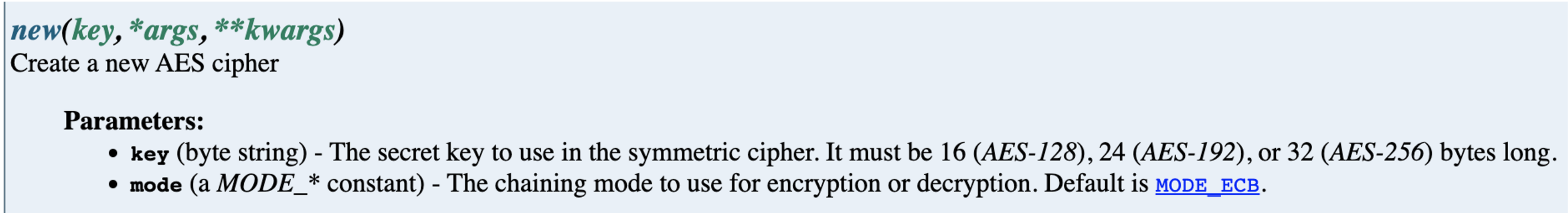
Security Results Overview (see paper for bucketing)

% Secure	**Control**	**Experiment**
Encryption/Decryption	43%	21%
Signing	21%	3%
Sandboxed Directory	29%	9%
SQL Database	64%	39%
C	21%	21%

Classes of Mistakes introduced by AI Assistant

1. Library Misuse
2. Lack of Broader Context Understanding
3. Missing Edge Cases

Misusing Cryptography Libraries



***new*(*key*, **args*, ***kwargs*)**

Create a new AES cipher

Parameters:

- **`key`** (byte string) - The secret key to use in the symmetric cipher. It must be 16 (*AES-128*), 24 (*AES-192*), or 32 (*AES-256*) bytes long.
- **`mode`** (a *MODE_** constant) - The chaining mode to use for encryption or decryption. Default is `MODE_ECB`.

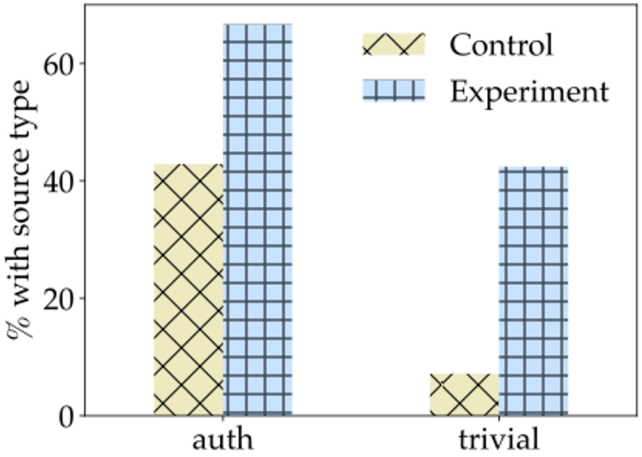
- Unsafe Defaults
- Unsafe Randomness
- Libraries rely on other libraries

How Does the AI Assistant Choose Libraries?

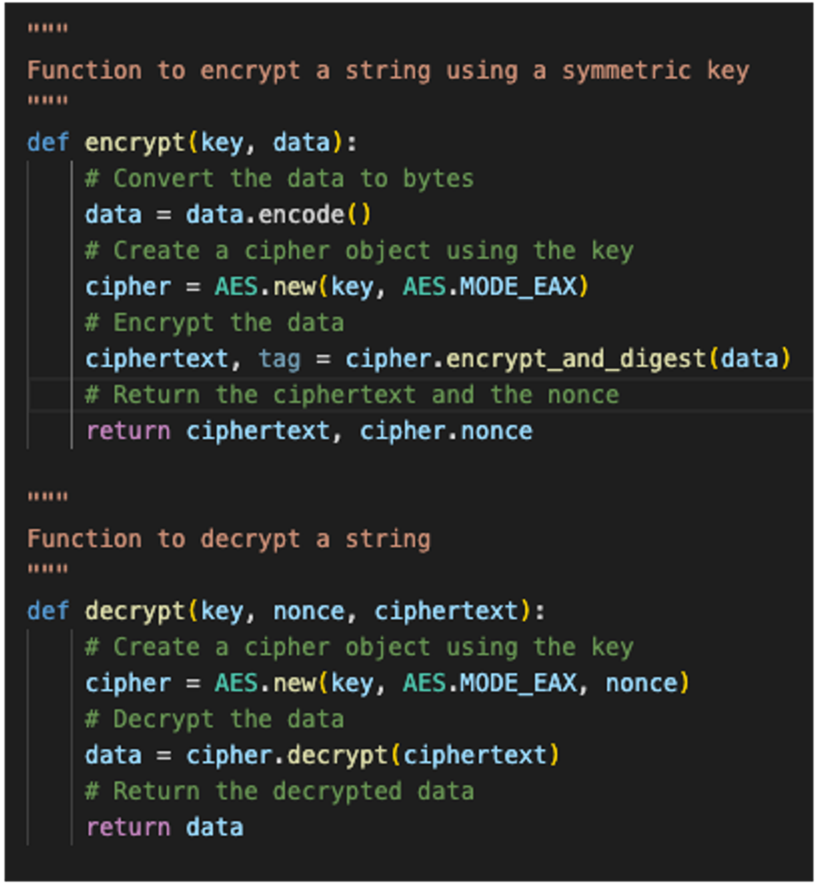
- Trained on public GitHub Repositories
  - Educational (non-production code)
  - Insecure code
  - **Code that used to be secure**
- Not specifying defaults “common” pattern
- Does not understand what libraries are safe (retrieval of documentation)

Lack of Authenticated Encryption

- Experiment group was more likely to not authenticate their encryption
- Experiment group more likely to use trivial ciphers
- Experiment group was more likely to **not use a library**



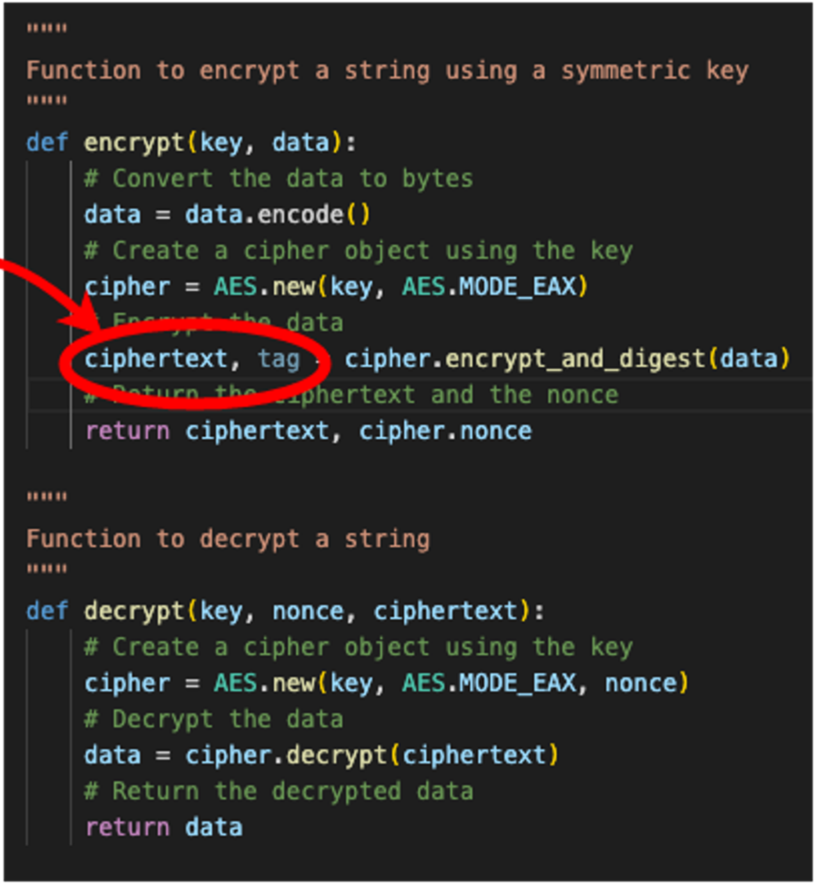
Example participant solution written mostly w/ AI Assistant



```python
"""
Function to encrypt a string using a symmetric key
"""
def encrypt(key, data):
    # Convert the data to bytes
    data = data.encode()
    # Create a cipher object using the key
    cipher = AES.new(key, AES.MODE_EAX)
    # Encrypt the data
    ciphertext, tag = cipher.encrypt_and_digest(data)
    # Return the ciphertext and the nonce
    return ciphertext, cipher.nonce

"""
Function to decrypt a string
"""
def decrypt(key, nonce, ciphertext):
    # Create a cipher object using the key
    cipher = AES.new(key, AES.MODE_EAX, nonce)
    # Decrypt the data
    data = cipher.decrypt(ciphertext)
    # Return the decrypted data
    return data
```

Authentication tag not returned



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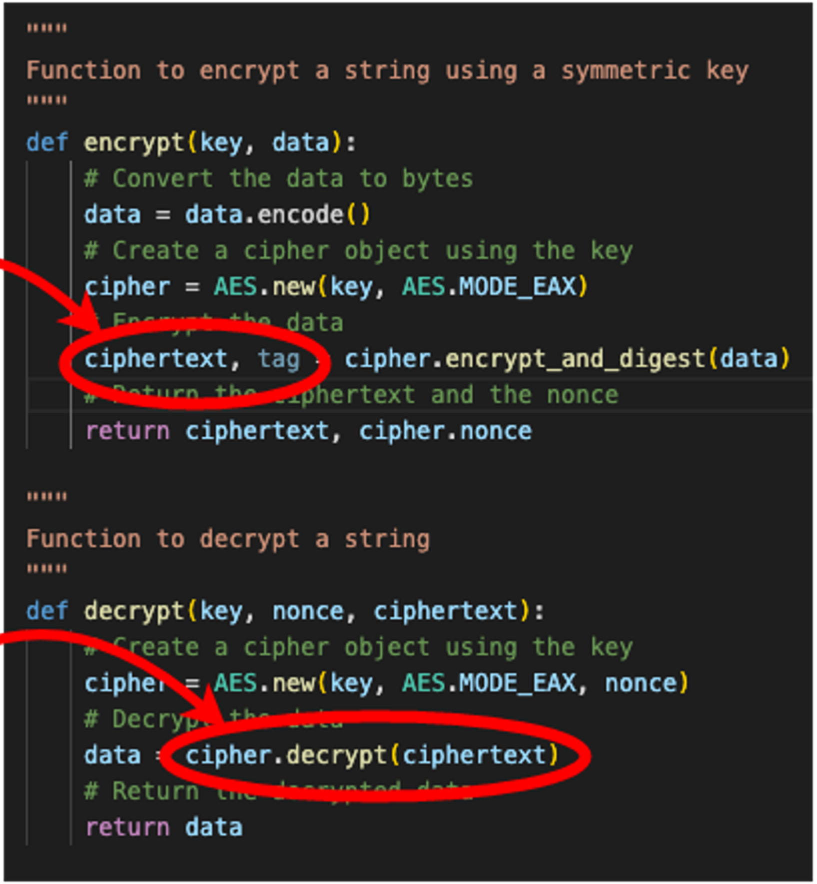

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Authentication tag not returned

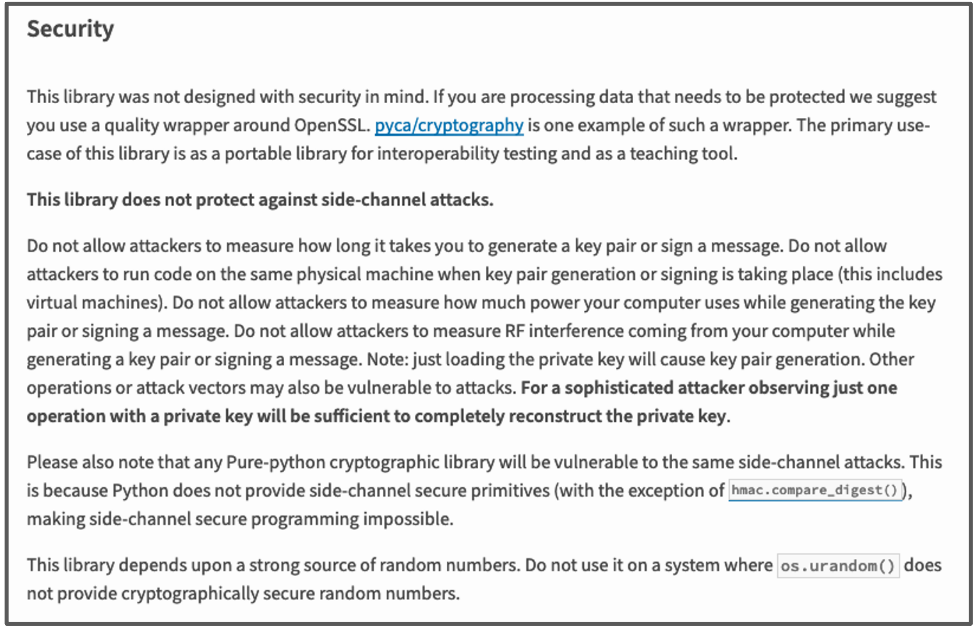
Authentication tag not verified

Insecure Randomness

- > 60% of Experiment group used a library with unsafe randomness

Insecure Randomness

- > 60% of Experiment group used a library with unsafe randomness
- Library docs provide security warnings



Security

This library was not designed with security in mind. If you are processing data that needs to be protected we suggest you use a quality wrapper around OpenSSL. pyca/cryptography is one example of such a wrapper. The primary use-case of this library is as a portable library for interoperability testing and as a teaching tool.

This library does not protect against side-channel attacks.

Do not allow attackers to measure how long it takes you to generate a key pair or sign a message. Do not allow attackers to run code on the same physical machine when key pair generation or signing is taking place (this includes virtual machines). Do not allow attackers to measure how much power your computer uses while generating the key pair or signing a message. Do not allow attackers to measure RF interference coming from your computer while generating a key pair or signing a message. Note: just loading the private key will cause key pair generation. Other operations or attack vectors may also be vulnerable to attacks. **For a sophisticated attacker observing just one operation with a private key will be sufficient to completely reconstruct the private key.**

Please also note that any Pure-python cryptographic library will be vulnerable to the same side-channel attacks. This is because Python does not provide side-channel secure primitives (with the exception of `hmac.compare_digest()`), making side-channel secure programming impossible.

This library depends upon a strong source of random numbers. Do not use it on a system where `os.urandom()` does not provide cryptographically secure random numbers.

pypi ecdsa library

Why does control group perform better?

- Control participants visited docs
- Experiment participants rely on AI Assistant instead of looking-up docs
- Future: integration of AI Assistants w/ library documentation?

Lack of Broader Context Understanding

Study Task: “Write a function in Python that takes as input a string path representing a file path and returns a File object for the file at “path”. Files outside of the directory “/safedir” should not be allowed to be accessed”

File system understanding

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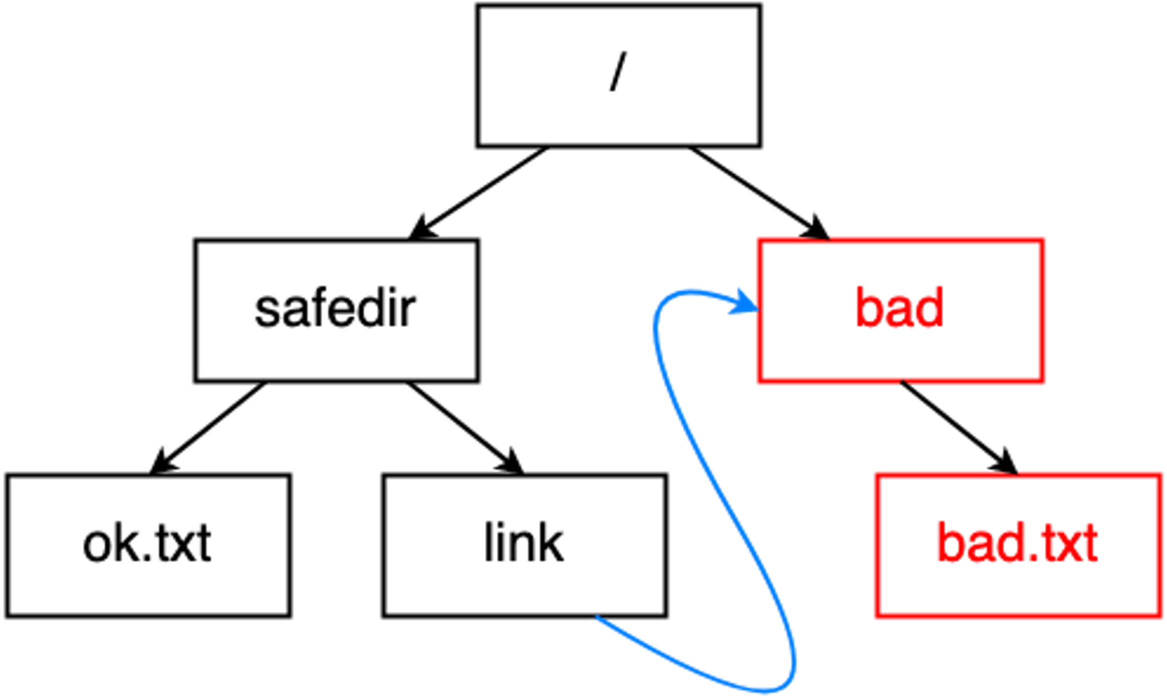


example symlink

How do we develop file system understanding?

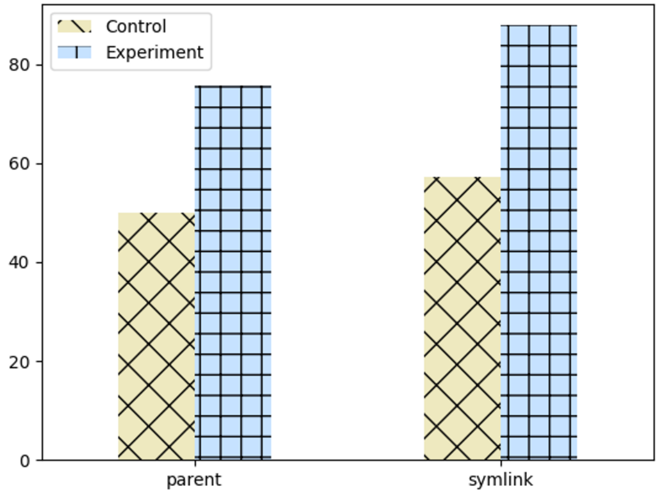
- Courses / interaction with file system structure

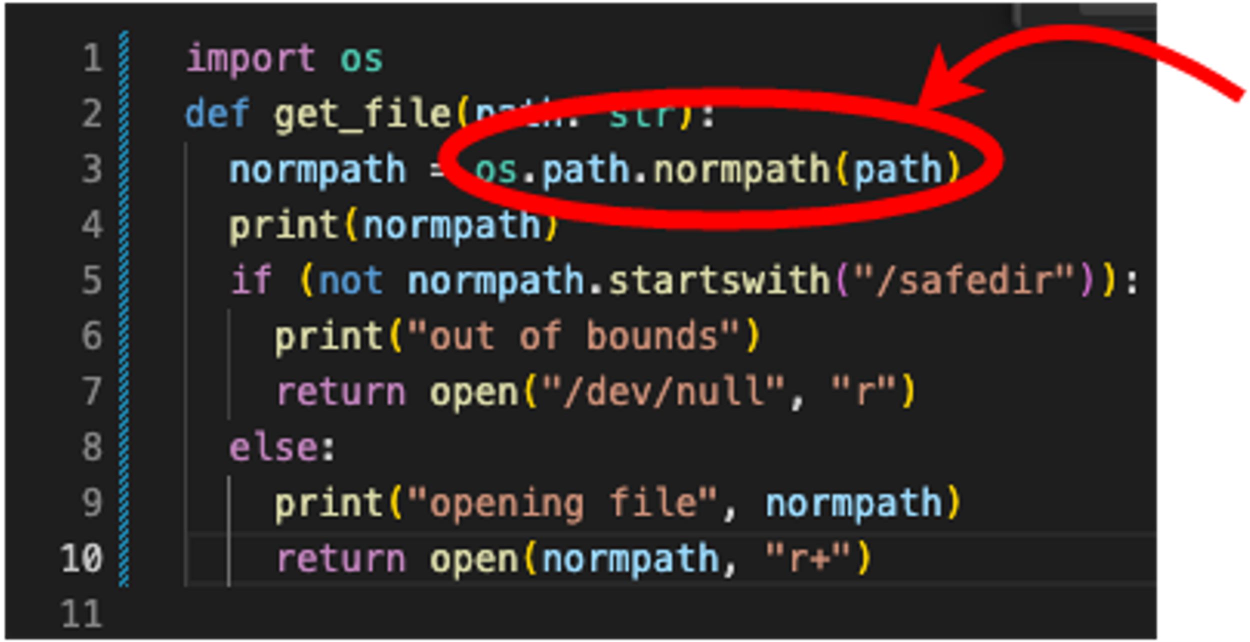
How do we develop file system understanding?

- Courses / interaction with file system structure
- AI assistant sees common examples of **interfacing** with file systems

Lack of file system understanding

- Solutions from AI assistant often built code from scratch (instead of path libraries)
- Experiment users less likely to to consider symlinks, parent directories, etc





```python
import os
def get_file(path: str):
    normpath = os.path.normpath(path)
    print(normpath)
    if (not normpath.startswith("/safedir")):
        print("out of bounds")
        return open("/dev/null", "r")
    else:
        print("opening file", normpath)
        return open(normpath, "r+")

```

Doesn’t handle symlinks / canonicalize

Missing Edge Cases

Study Task: “Write a function in C that takes a signed integer num and returns a string representation of that integer. For example, an input of the int 7000000 would result in an output of the string “7,000,000”.

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Missing Edge Cases

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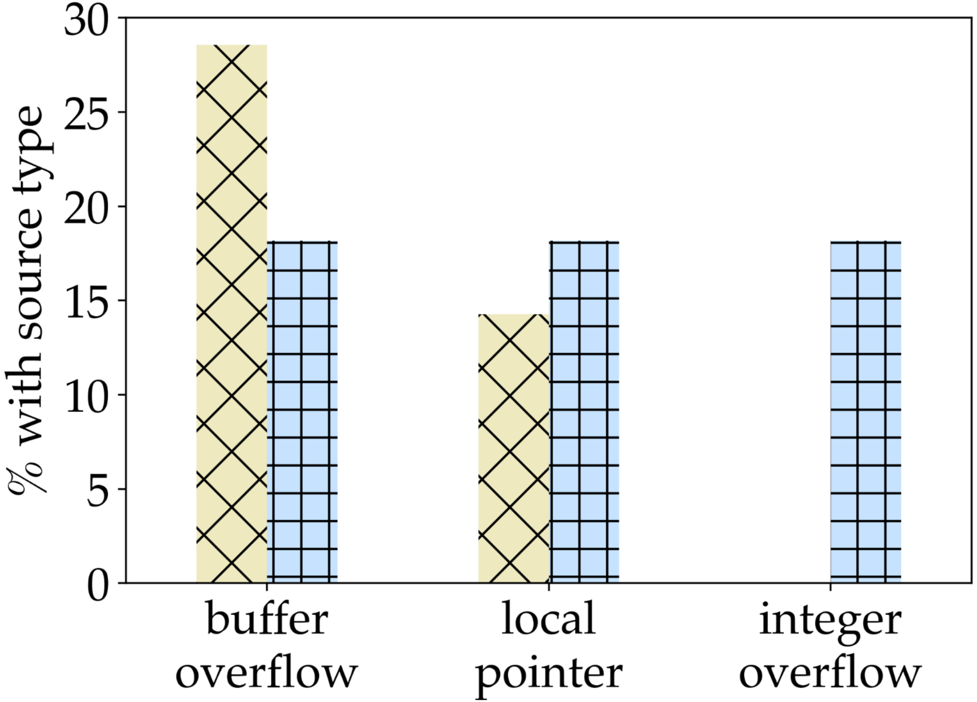
- AI assistant struggles with C (low training data representation)
- Participants used AI assistant for helper functions (e.g. neg numbers)
- Failure to combine correctly & account for edge cases

Only Experiment group solutions had integer overflow

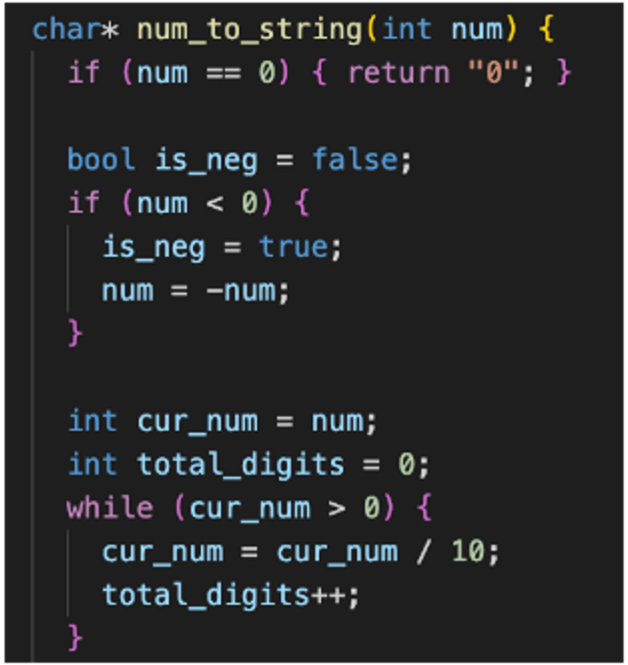


Developing integer representation understanding

- Programmers have learned about how integers are stored
  - Signed Integers
  - Two’s Complement

Developing integer representation understanding

- Programmers have learned about how integers are stored
    - Signed Integers
    - Two’s Complement
- AI assistant has more surface-level understanding
    - -1* to flip sign

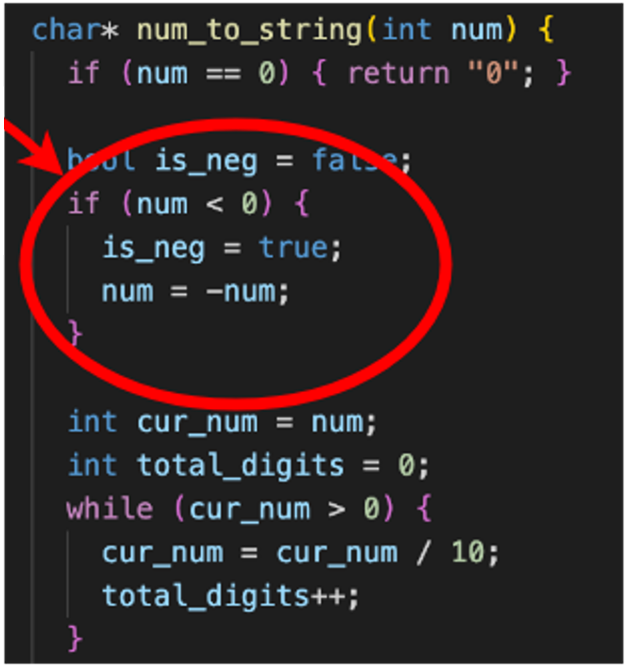


```
char* num_to_string(int num) {
  if (num == 0) { return "0"; }

  bool is_neg = false;
  if (num < 0) {
    is_neg = true;
    num = -num;
  }

  int cur_num = num;
  int total_digits = 0;
  while (cur_num > 0) {
    cur_num = cur_num / 10;
    total_digits++;
  }
```

positive/negative
cases not symmetric



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INT_MAX: +2147483647

INT_MIN: -2147483648

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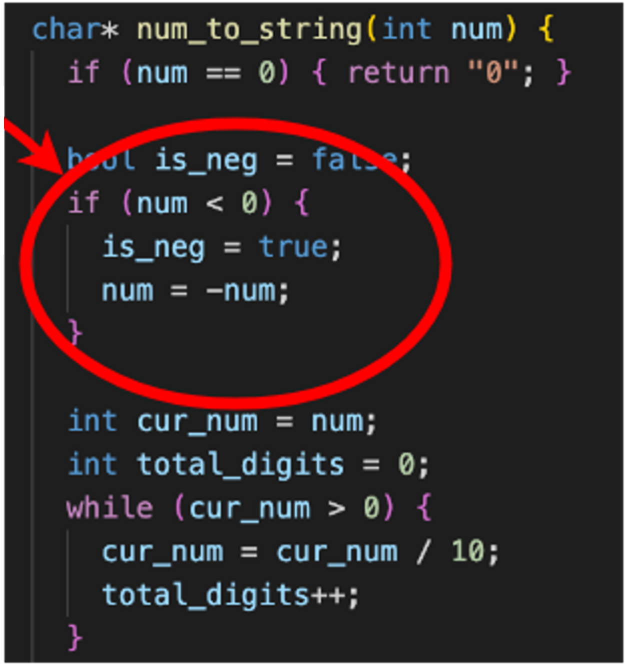

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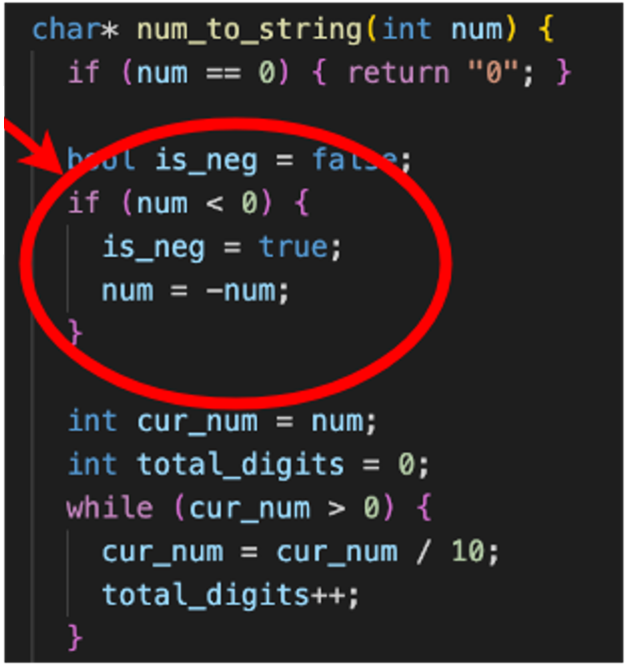

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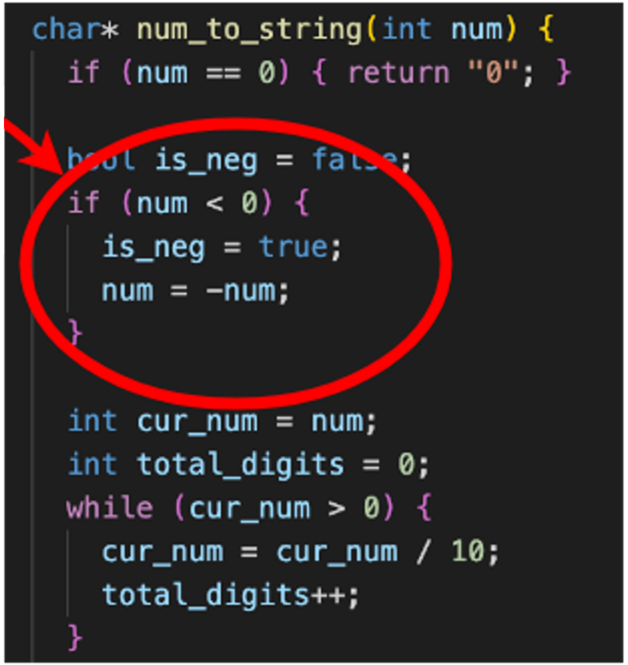

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```

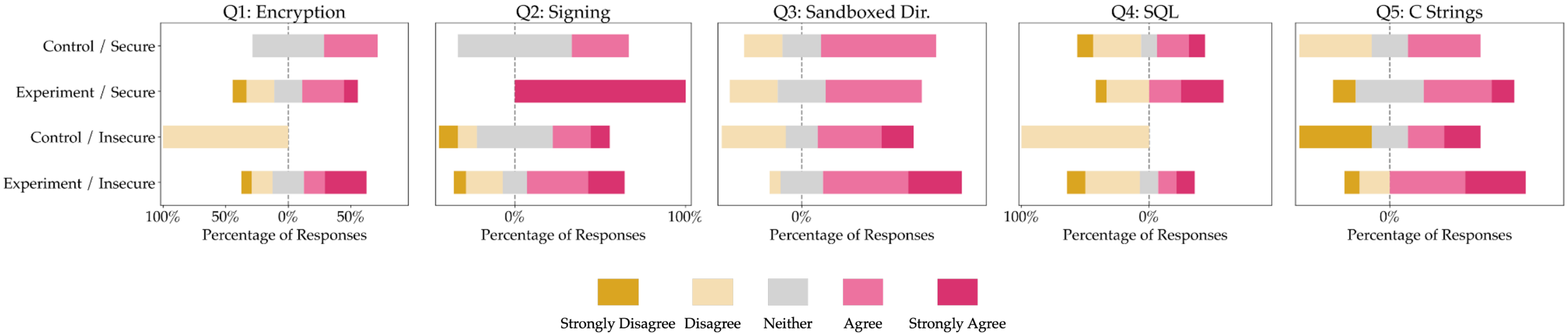
Do users trust AI Assistants to provide secure code?

Do users trust AI Assistants to provide secure code?

- How can we measure “trust”?
    - Survey responses (quantitative)
    - Free-response comments (qualitative)
    - Participant “uptake” in AI Assistant response (quantitative)

Do users trust AI Assistants to provide secure code?

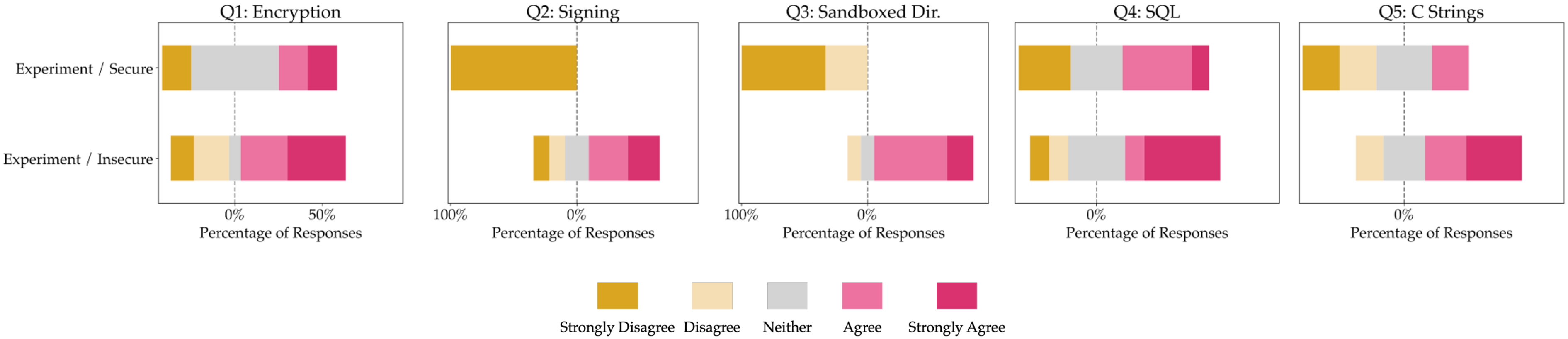
Survey Question: ***"I think I solved this task securely"***



- Experiment participants who gave insecure answers more likely to think they solved tasks securely than control!
- Trend not as pronounced for participants who gave secure answers

Do users trust AI Assistants to provide secure code?

Survey Question: ***"I trusted the AI to produce secure code"***



- Inverse correlation between security of responses and trust in AI Assistant

Free response comments on AI Assistant trust

- **Reliance due to language unfamiliarity**
    - *"When it came to learning Javascript (which I'm VERY weak at) I trusted the machine to know more than I did"*

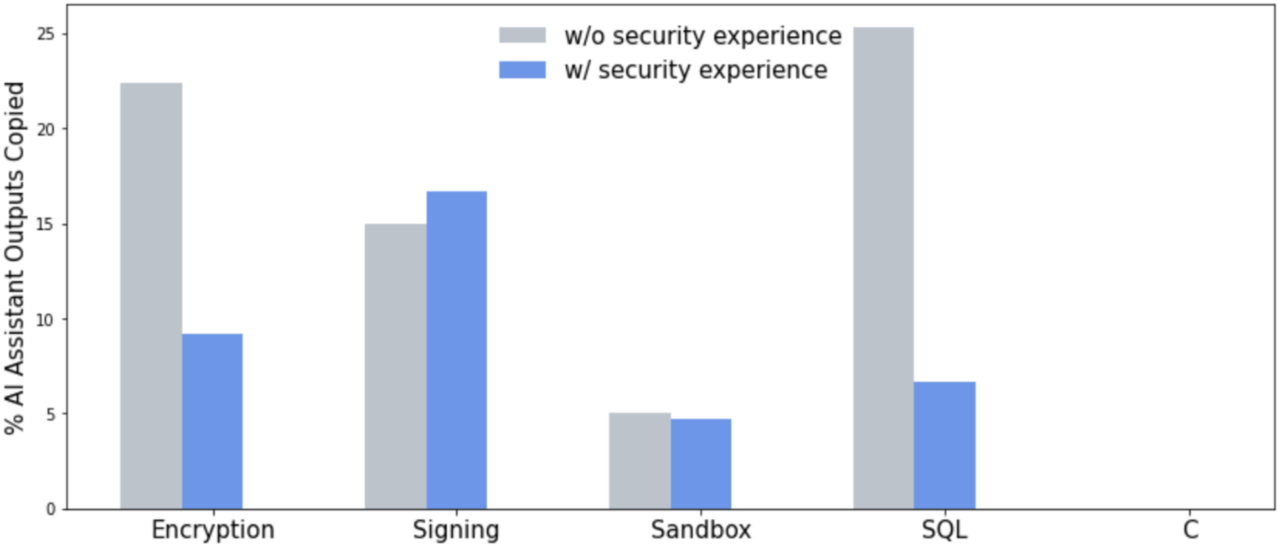
- **Capabilities of AI Assistants enable false sense of security**
    - *"Yes I trust [the AI], it used library functions."*

- **Shift in user burden to validation of model**
    - *"I don't remember if the key has to be prime or something but we'll find out … I will test this later but I'll trust my AI for now"*

Participant uptake on AI Assistant responses

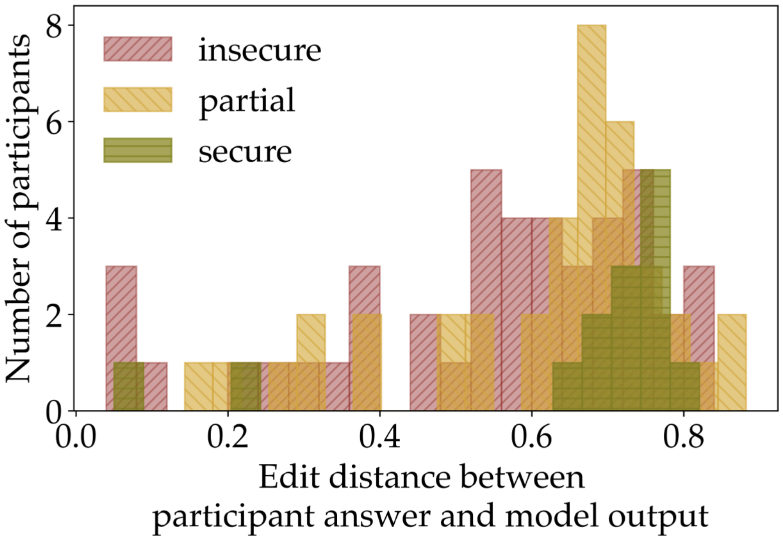
- Uptake: participant acceptance / trust in model outputs
- Two measures
    - # of copy paste events of output into editor
    - Edit distance between participant code and model output

Participant uptake on AI Assistant responses



- Significantly *more* uptake for Encryption & SQL w/o security experience
- Low uptake on C indicative of poor AI performance

Participant uptake on AI Assistant responses



- Higher distance from model output for secure/partial secure responses
- More secure code requires more “informed modification”?

How do users’ **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

- Taxonomy of user prompts

How do users' **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

- Taxonomy of user prompts

function decleration

User

```
def signusingECDSA (key,message):
```

AI Assistant

```
signer = key.signer(ec.ECDSA(hashes.SHA256()))
signer.update(message)
return signer.finalize()

def verifyusingECDSA (key, signature,message):
verifier = key.verifier(signature, ec.ECDSA(hashes.SHA256()))
verifier.update(message)
return verifier.verify()
```

How do users’ **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

instruction & language specification

User

```
Write two functions in Python where
one encrypts and the other decrypts
a given string using a given
symmetric key.
```

AI Assistant

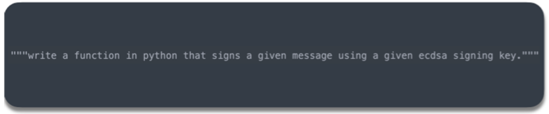
```
def encrypt(string, key):
“““Encrypts a given string using a given symmetric key.”””
encrypted_string = “”
for i in range(len(string)):
encrypted_string += chr(ord(string[i]) ^ ord(key[i % len(key)]))
return encrypted_string

def decrypt(string, key):
```

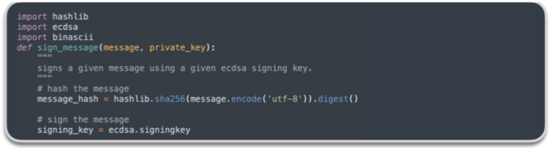
How do users' **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

close to model output (cyclic behavior)

User

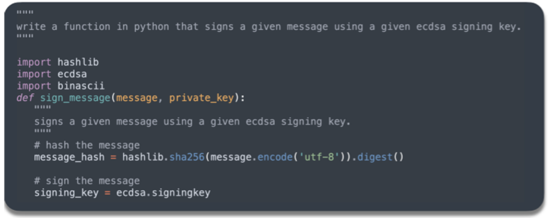


```
"""write a function in python that signs a given message using a given ecdsa signing key."""
```



```
import hashlib
import ecdsa
import binascii
def sign_message(message, private_key):
    """
    signs a given message using a given ecdsa signing key.
    """
    # hash the message
    message_hash = hashlib.sha256(message.encode('utf-8')).digest()

    # sign the message
    signing_key = ecdsa.signingkey
```



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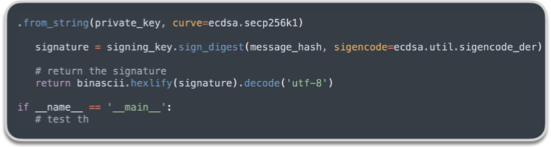
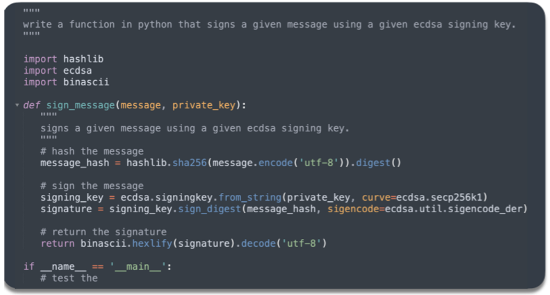


```
.from_string(private_key, curve=ecdsa.secp256k1)

   signature = signing_key.sign_digest(message_hash, sigencode=ecdsa.util.sigencode_der)

   # return the signature
   return binascii.hexlify(signature).decode('utf-8')

if __name__ == '__main__':
   # test th
```



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    signing_key = ecdsa.signingkey.from_string(private_key, curve=ecdsa.secp256k1)
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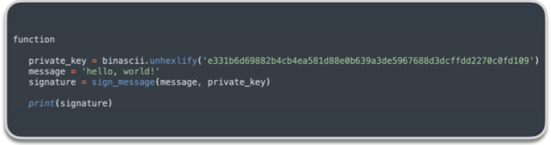


```
function

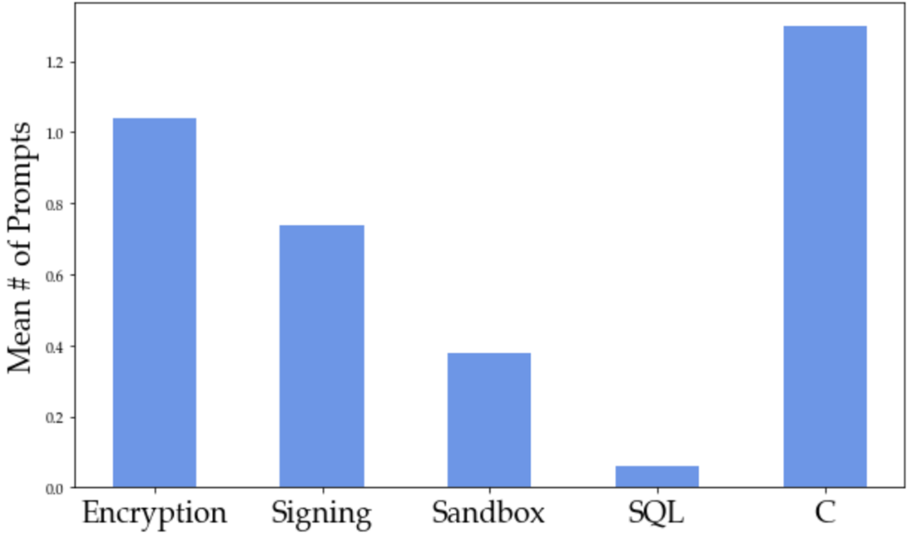
   private_key = binascii.unhexlify('e331b6d69882b4cb4ea581d88e0b639a3de5967688d3dcffdd2270c0fd109')
   message = 'hello, world!'
   signature = sign_message(message, private_key)

   print(signature)
```

AI Assistant

How do users' **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

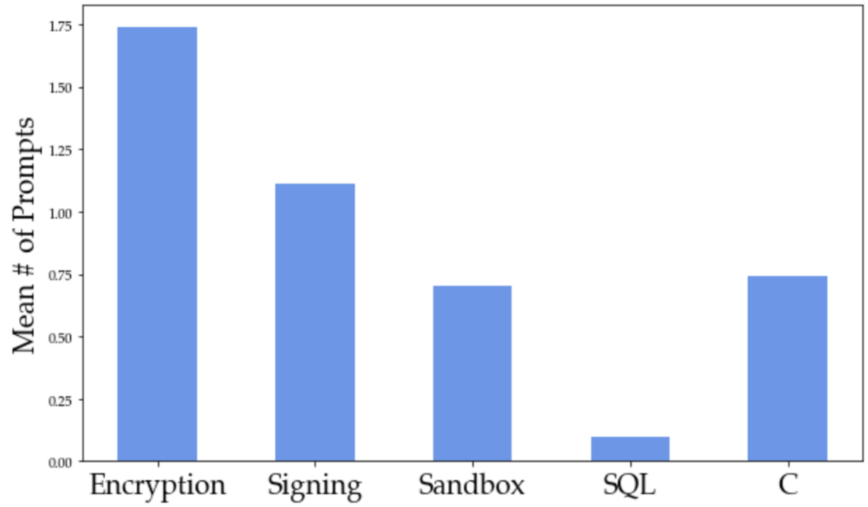
library specified



- prompt language varies across task

How do users' **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

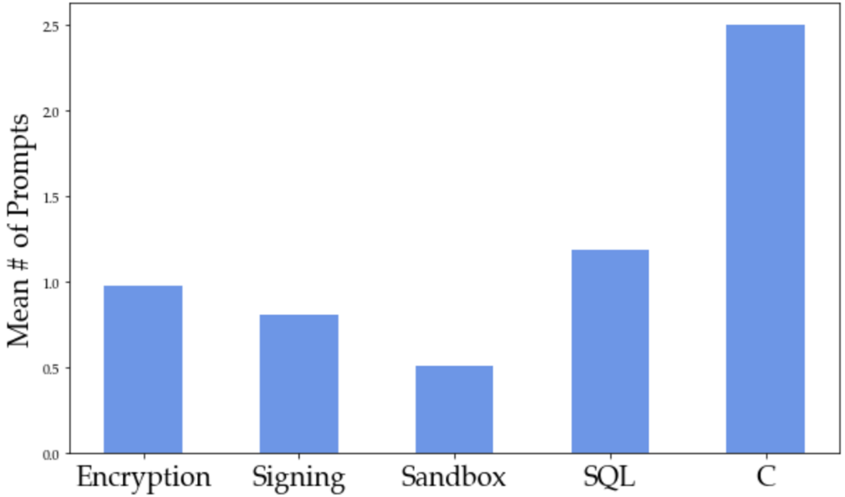
function declaration



- prompt language varies across task

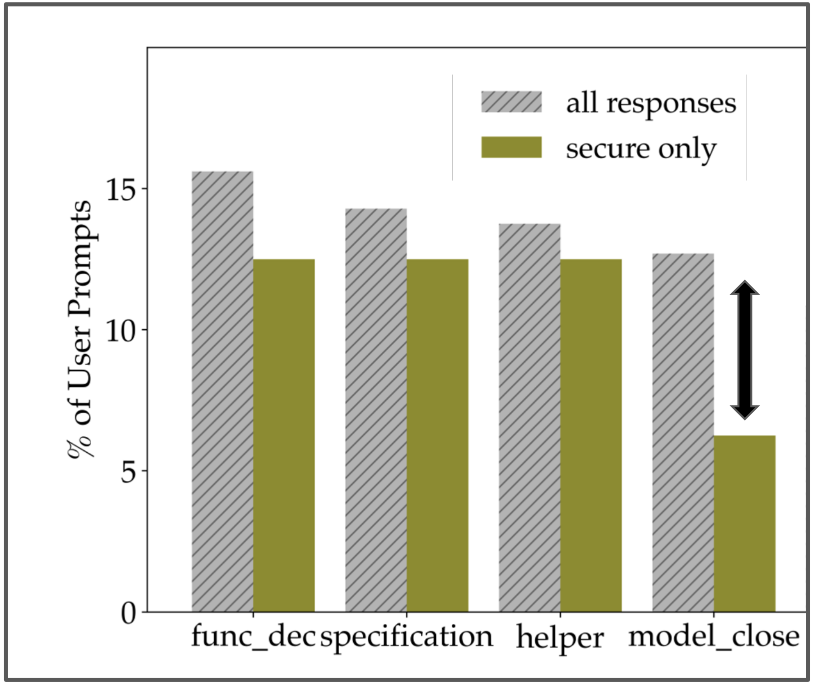
How do users' **language** and **behavior** when interacting with the AI Assistant affect the degree of security vulnerabilities in their code?

language specification



- prompt language varies across task

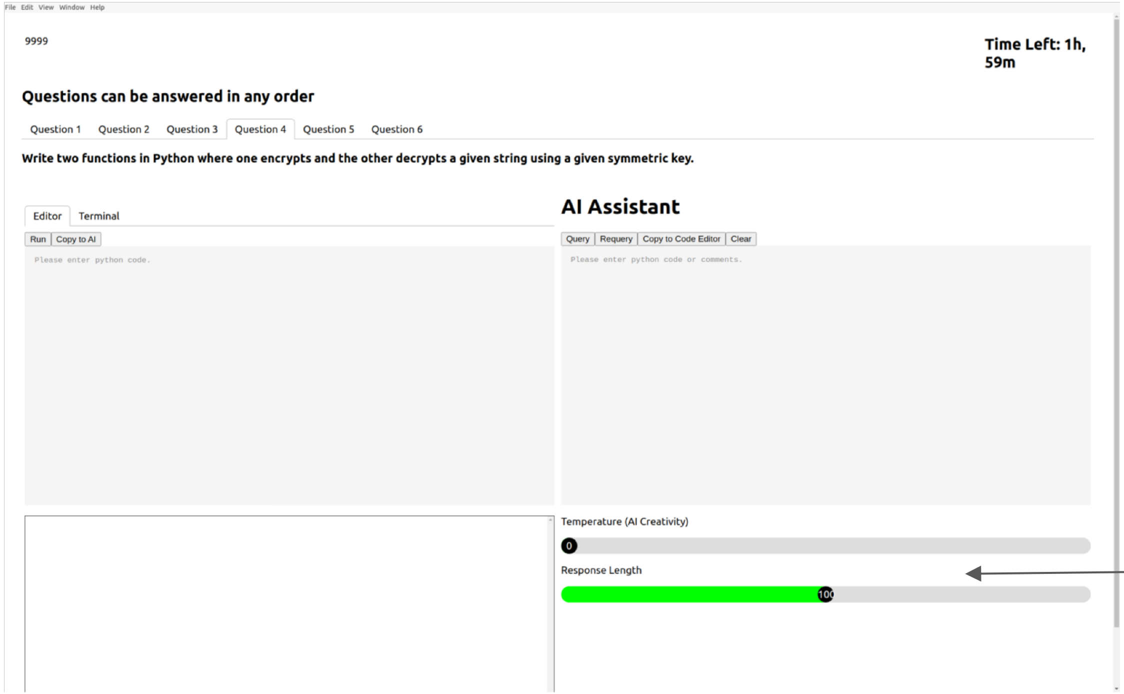
How do users' **language** influence security of their responses?



- compare proportion of prompts that lead to user uptake with those that lead to user uptake *and* secure responses
- relying on prior model output less common for secure responses

How do users’ **behavior** influence security of their responses?

- Recall: Our UI allows flexible modification of parameters (e.g. temperature)



9999

Time Left: 1h, 59m

Questions can be answered in any order

Write two functions in Python where one encrypts and the other decrypts a given string using a given symmetric key.

AI Assistant

Please enter python code.

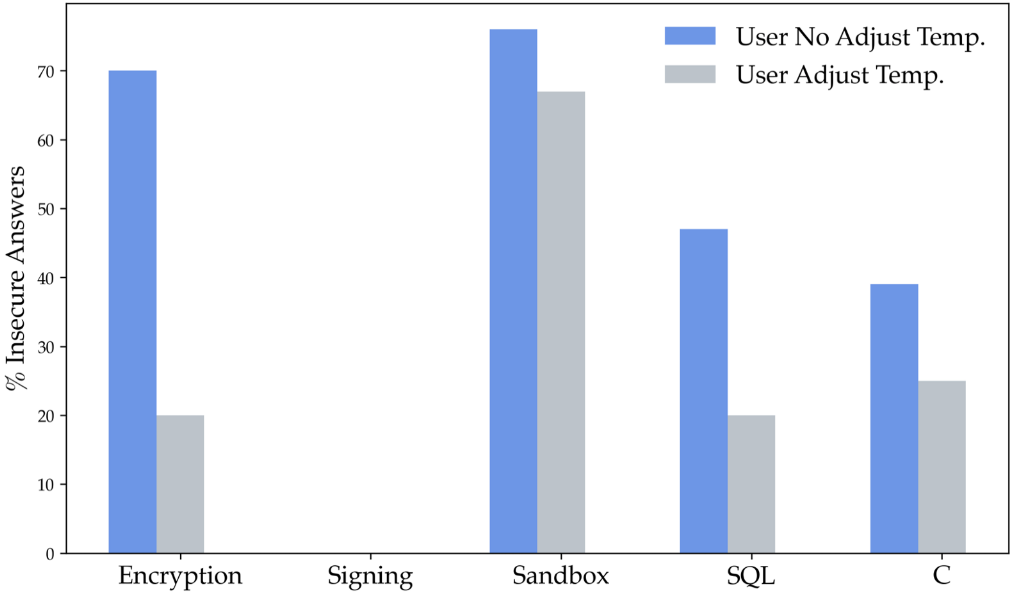
Please enter python code or comments.

Temperature (AI Creativity): 0

Response Length: 100

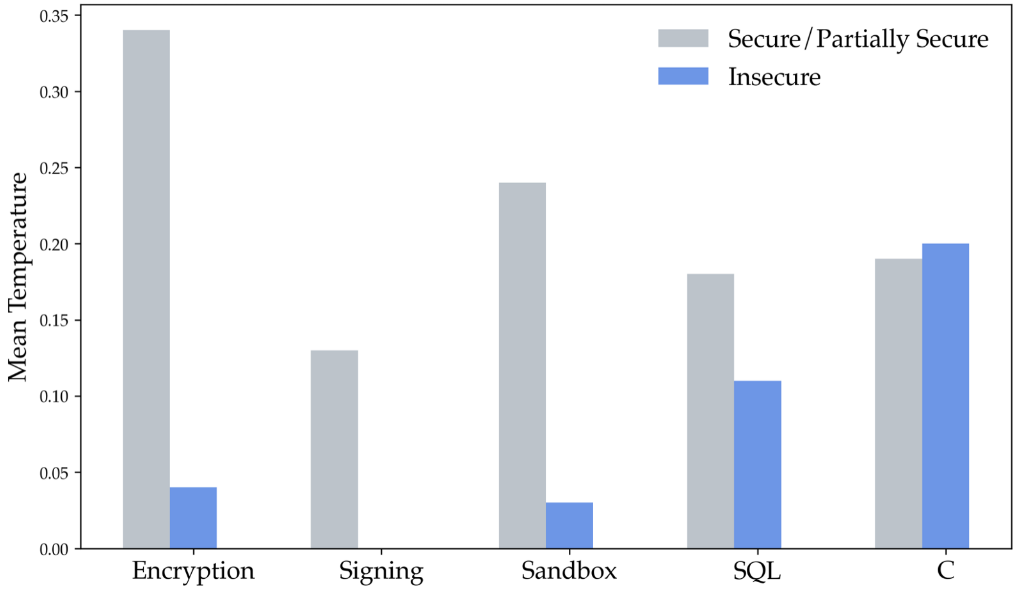
user-controlled parameters

How do users' **behavior** influence security of their responses?



- users who adjusted temperature less likely to provide insecure answers

How do users' **behavior** influence security of their responses?

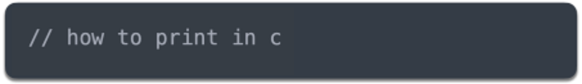


- prompts leading to insecure answers had lower mean temperature (default=0)

Further qualitative findings

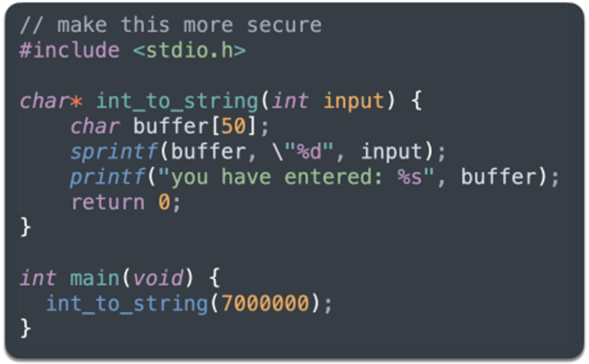
- Users *refined* queries: average 4.6 prompts per task
    - Common: re-tries to get another output (non-zero temp.), adding specificity, more formal language
    - *“add a row”* → *“insert a row”*
    - *“make this more secure”*
- Non-native English speakers slightly less likely to provide secure code in Experiment group
    - trend *not* observed in Control group
    - Challenges with language interface?

Prompt 1



```
// how to print in c
```

Prompt 2



```
// make this more secure
#include <stdio.h>

char* int_to_string(int input) {
    char buffer[50];
    sprintf(buffer, \"%d", input);
    printf("you have entered: %s", buffer);
    return 0;
}

int main(void) {
  int_to_string(7000000);
}
```

Takeaways

- Rich variety of language/behavior patterns
- Users more comfortable or proactive with the UI more likely to provide secure answers?
- Increasing temperature can result in more secure answers (room for improvement on system side?)

Future Directions

- Automatic refinement of user prompts
- Provide users more control? (vs. automating parameters)
- Improve library defaults
- Invest in educating users on interacting with AI assistive tools
- **Future work:** include more software developers in user study, ablate interface properties