Decompiling the Synergy:
An Empirical Study of Human–LLM Teaming in Software Reverse Engineering

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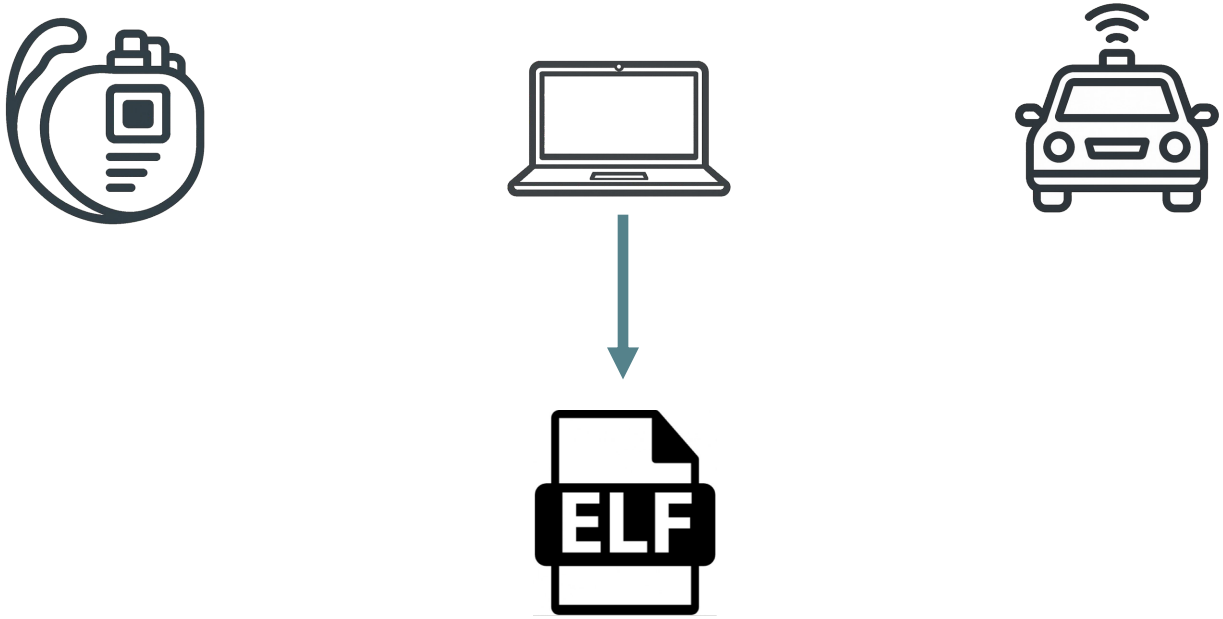
Università degli Studi di Padova

Arizona State University

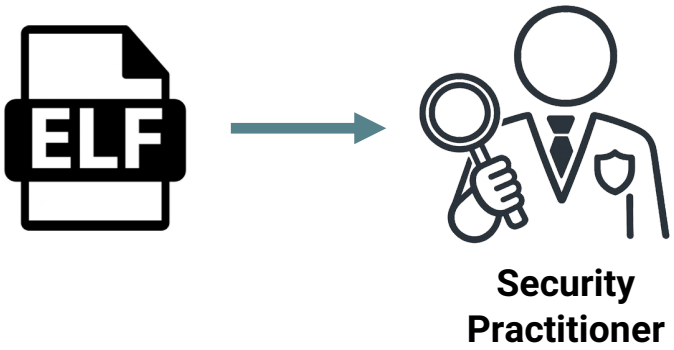
EURECOM
Sophia Antipolis

Securing Critical Software

Securing Critical Software



Securing Compiled Software



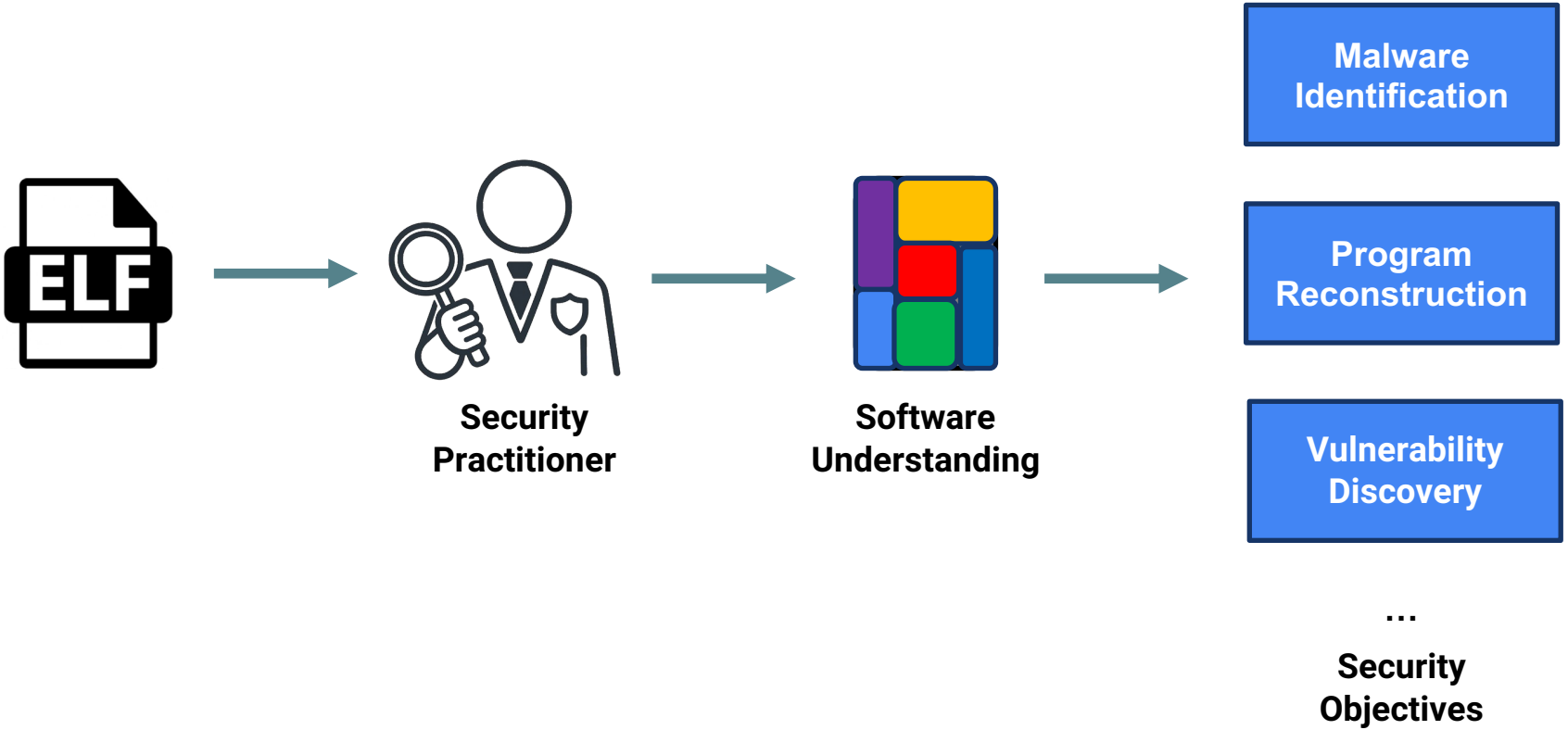
Securing Compiled Software

Security Practitioner

- Malware Identification
- Program Reconstruction
- Vulnerability Discovery
- ...

Security Objectives

Securing Compiled Software



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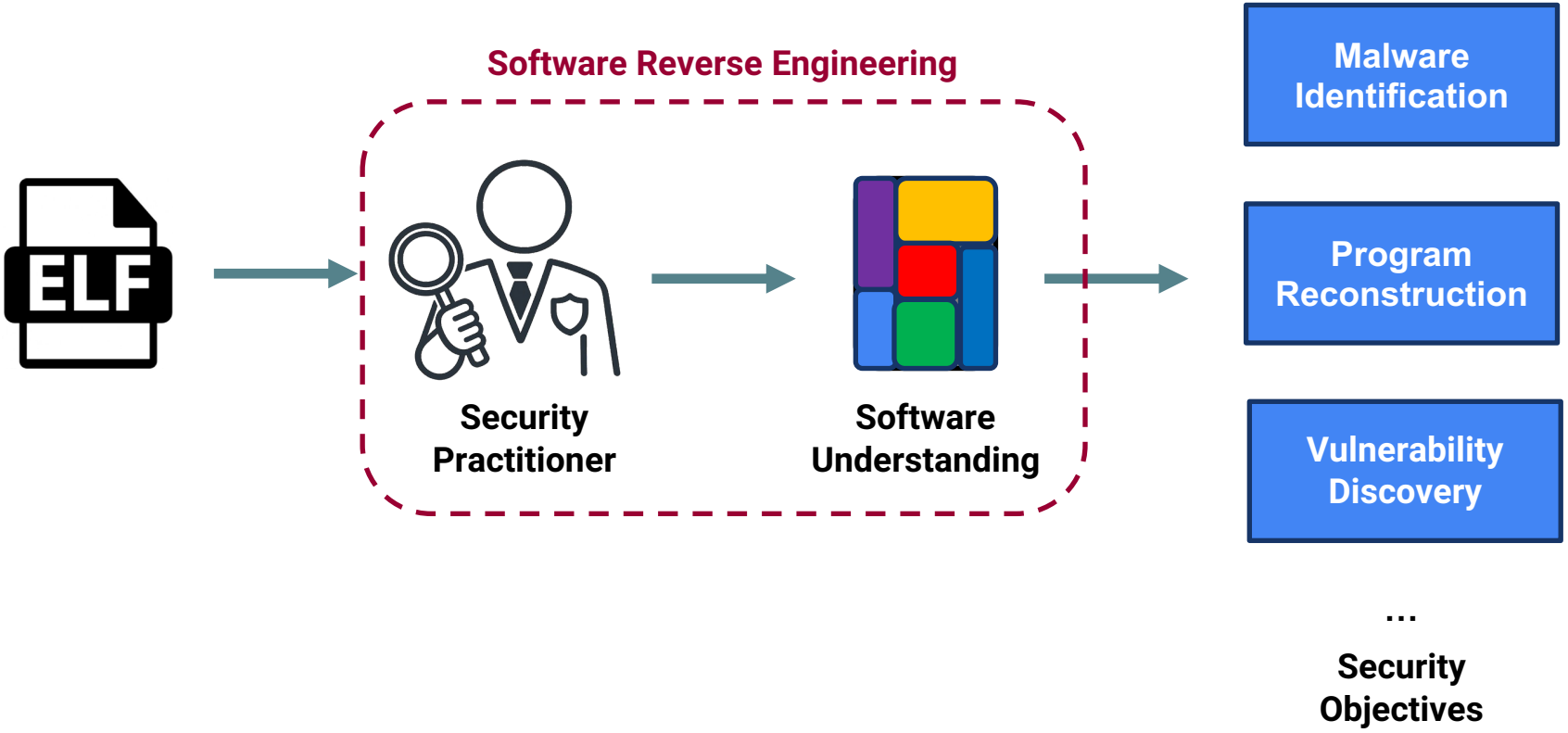

Reverse Engineering (RE)

Human dominated [1]

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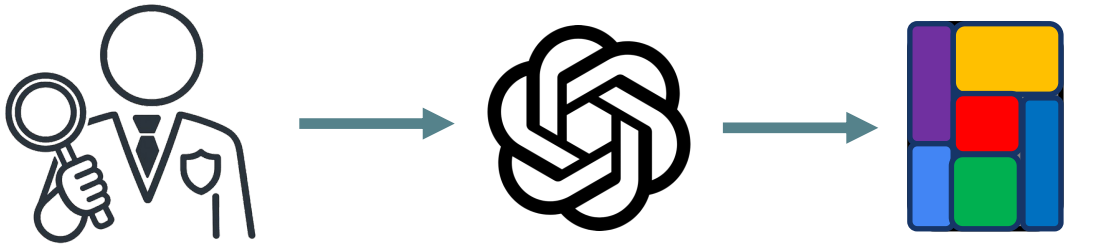
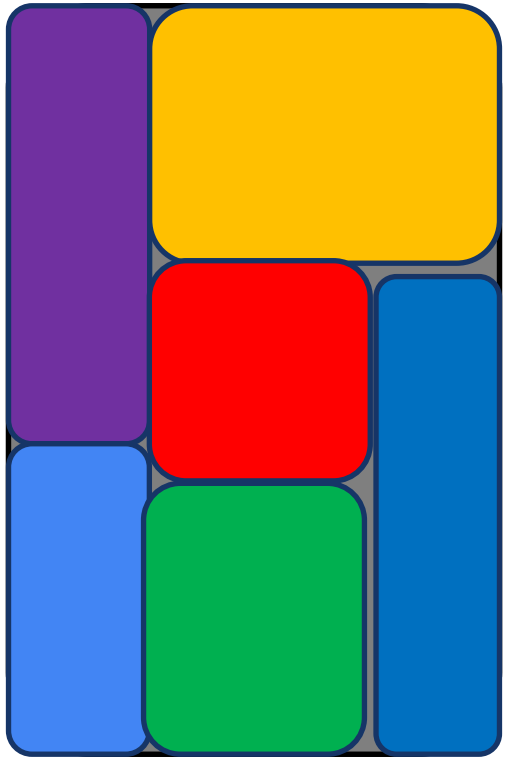
Modern Reverse Engineering: LLMs



Reverse Engineering Tasks



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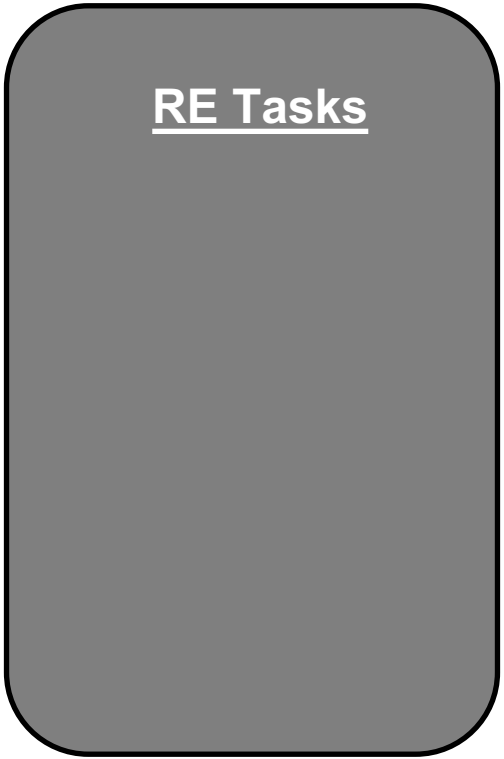

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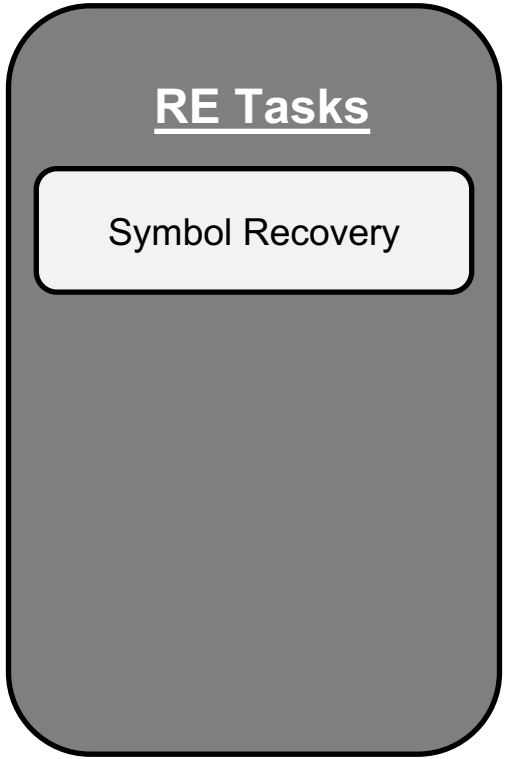

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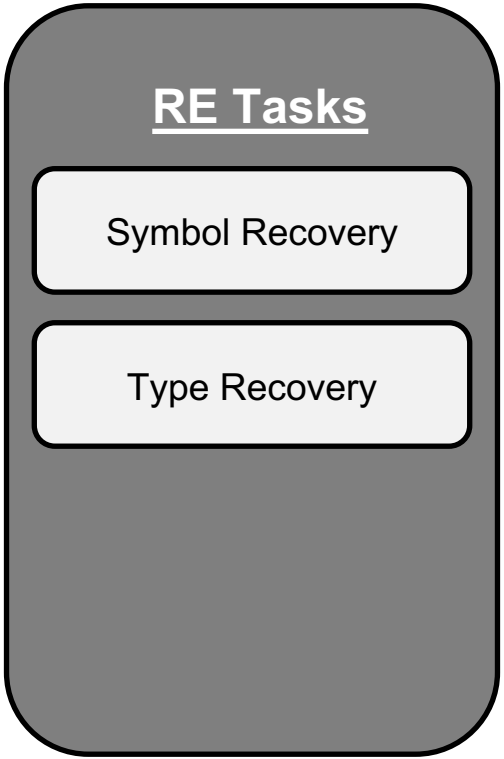
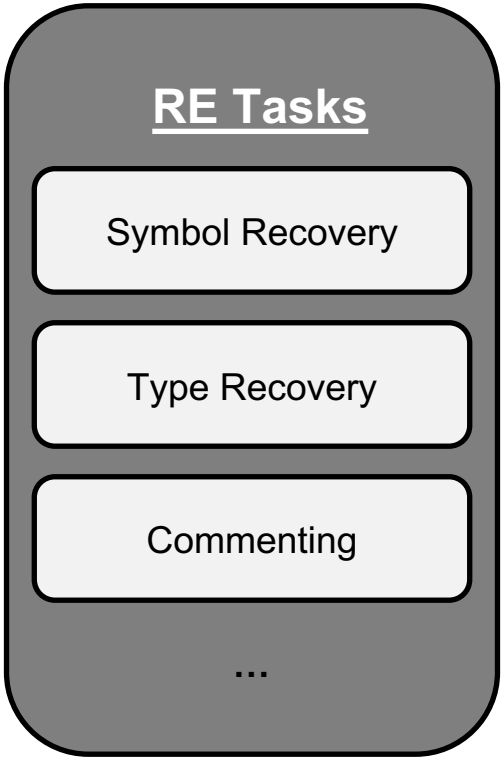
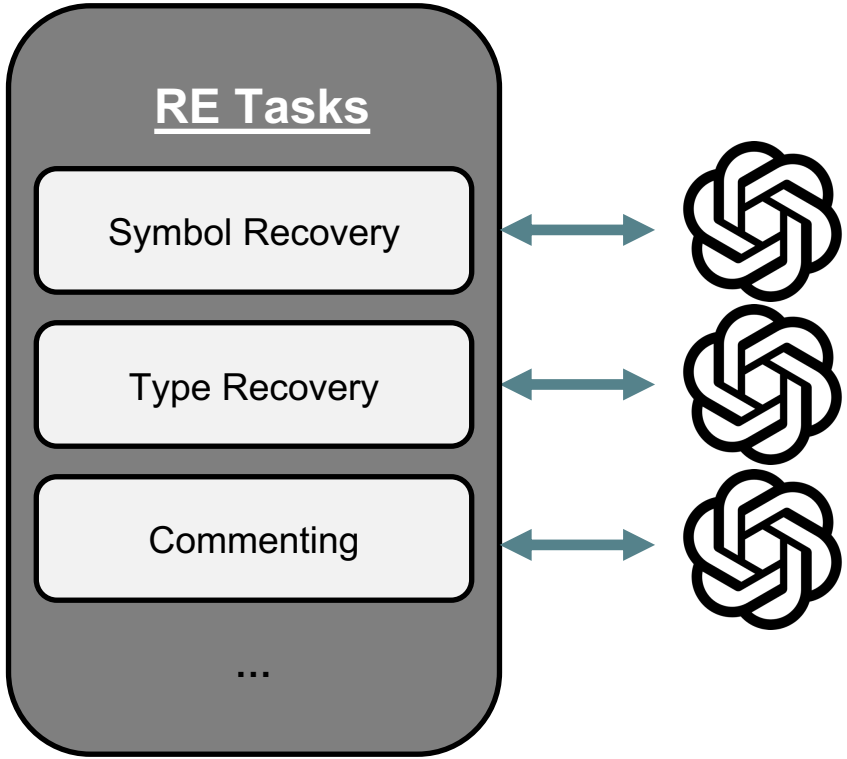


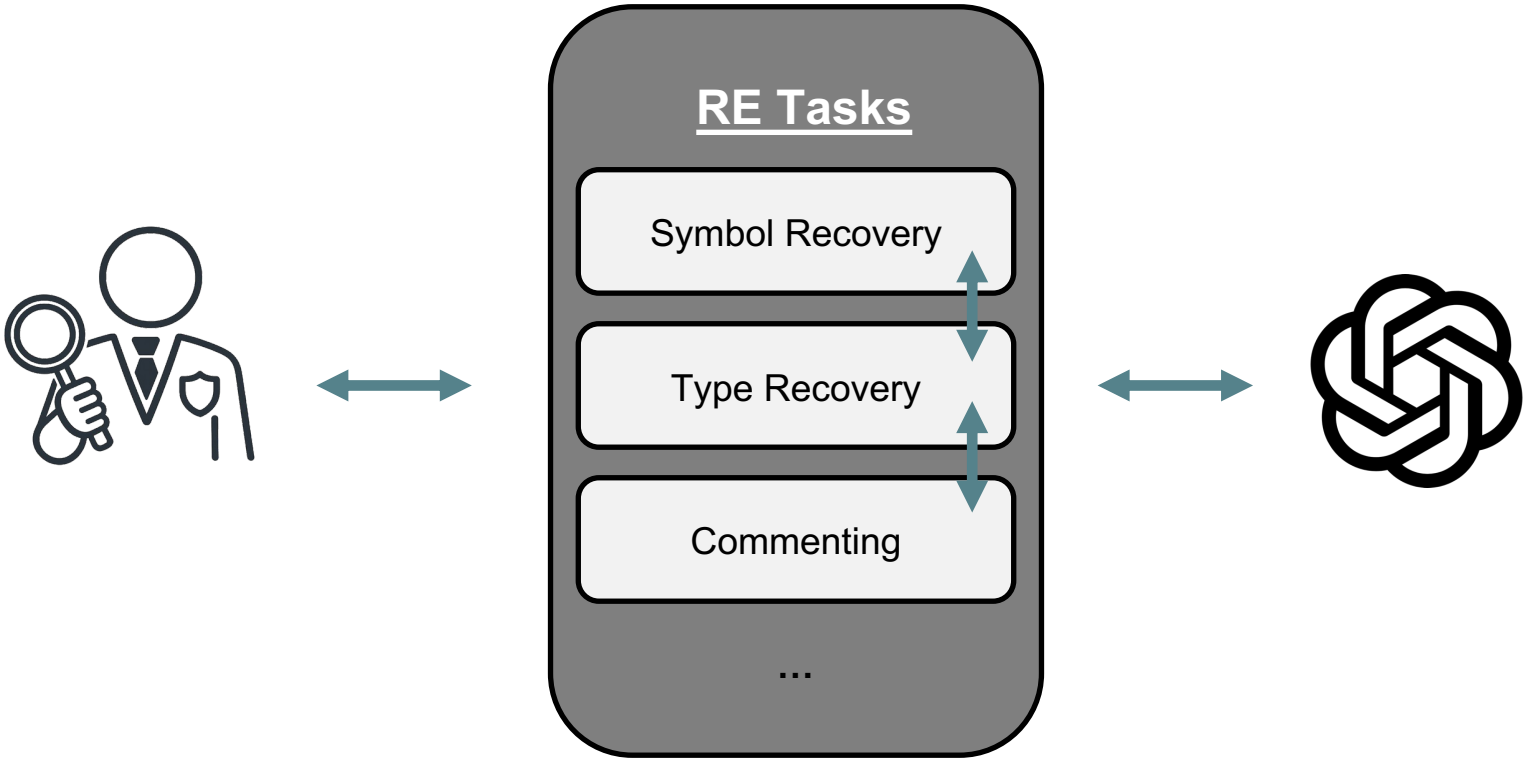
Reverse Engineering Tasks



Measuring LLMs for Specific RE Tasks



Our Work: Studying LLMs for End-to-End RE



Research Questions

How do practitioners **use** LLMs for RE?

How do LLMs **impact** RE performance?

Do LLM **collaboration** patterns impact RE performance?

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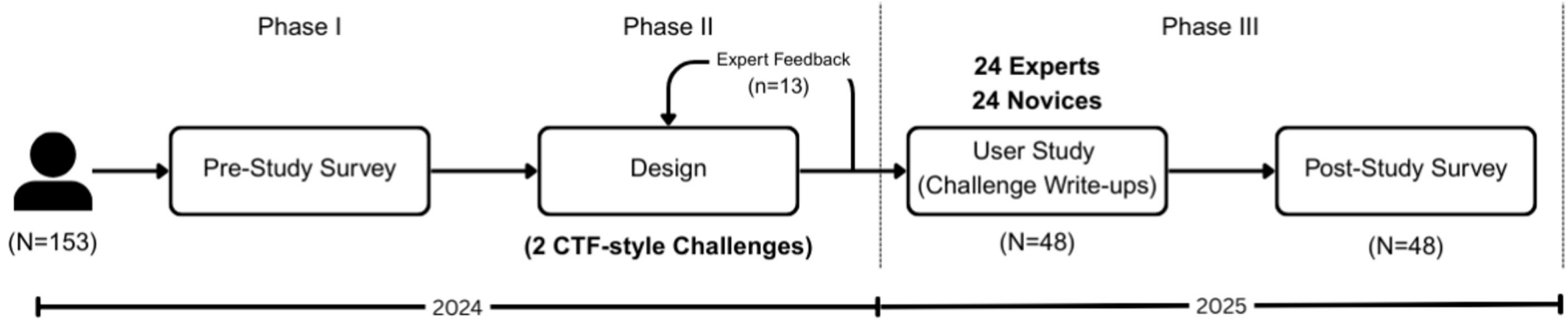
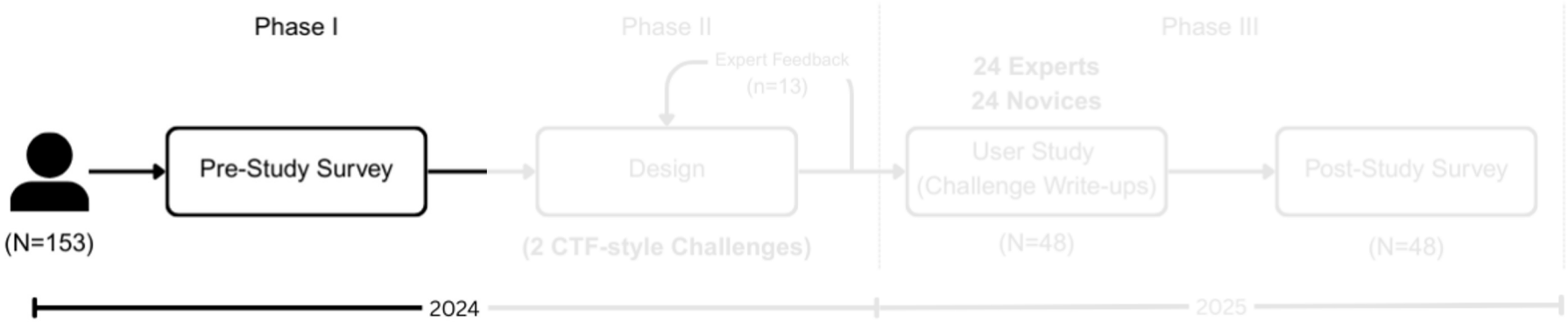
Study Design



Study Design



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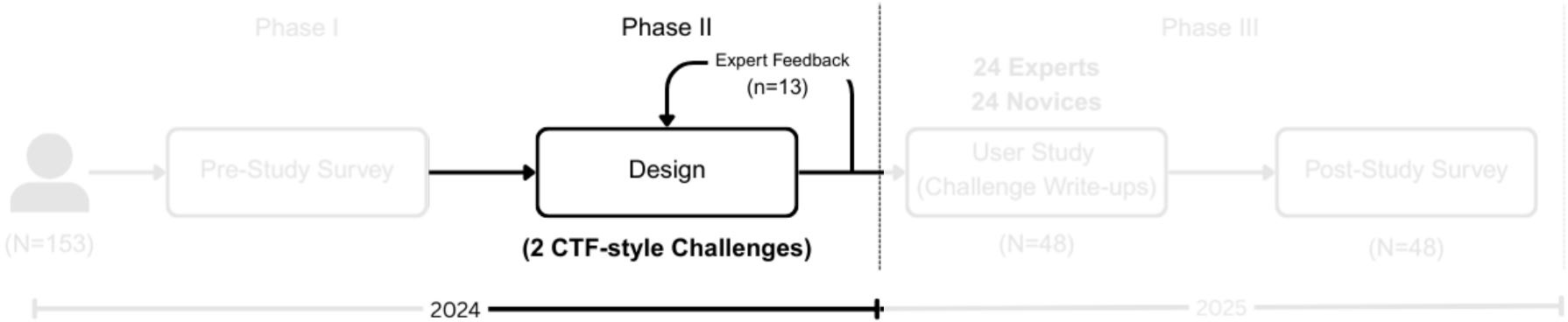

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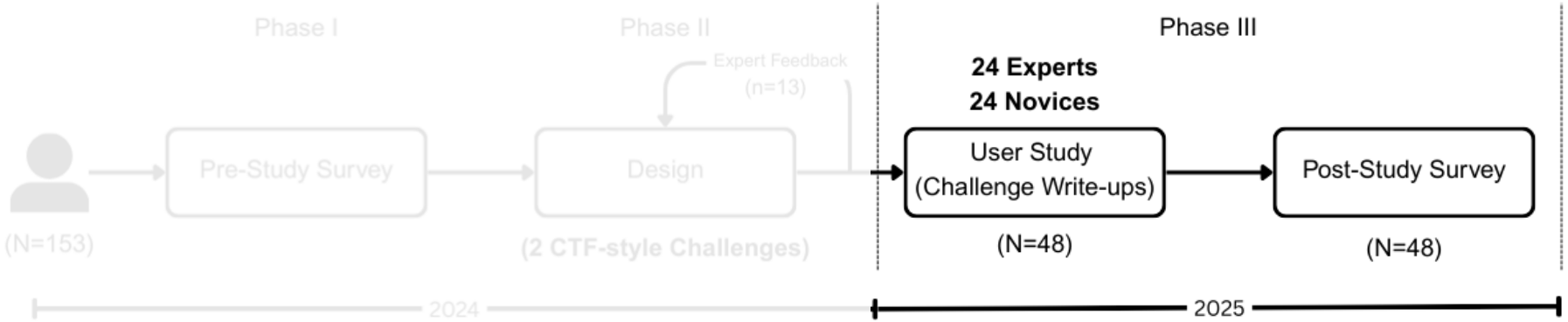

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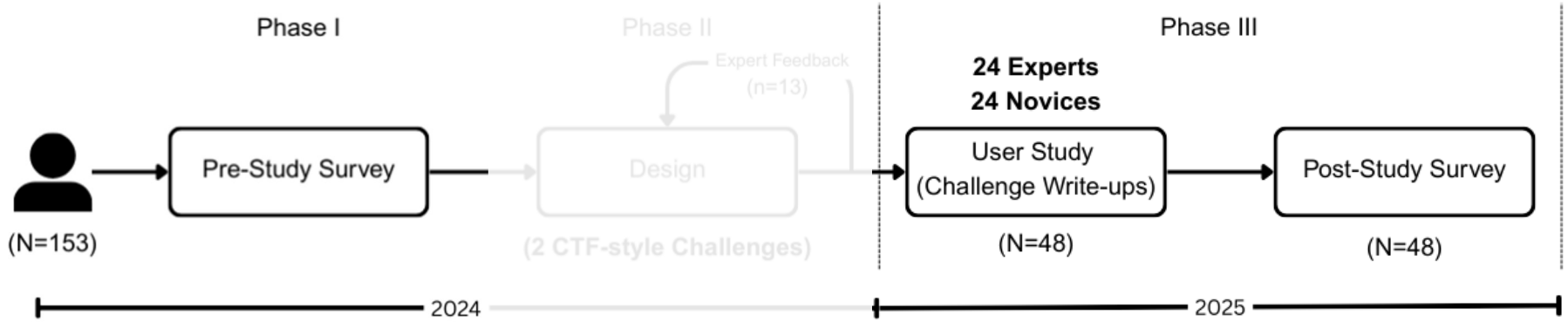

Pre-Study Results

153 survey responses revealed **6** distinct applications of LLMs for RE with *decompilers*

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- Function Summarization
- Function Identification
- Variable Symbol Recovery
- Function Symbol Recovery
- Vulnerability Identification
- Library Call Documentation

RE Experiment: Challenges

Two challenges inspired by CTFs to be reversed with decompilers

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- An RPC server

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Two challenges inspired by CTFs to be reversed with decompilers

- An RPC server
- An encrypted filesystem manager
- ~900 total lines of C
- Compiled and stripped

RE Experiment: Workflow

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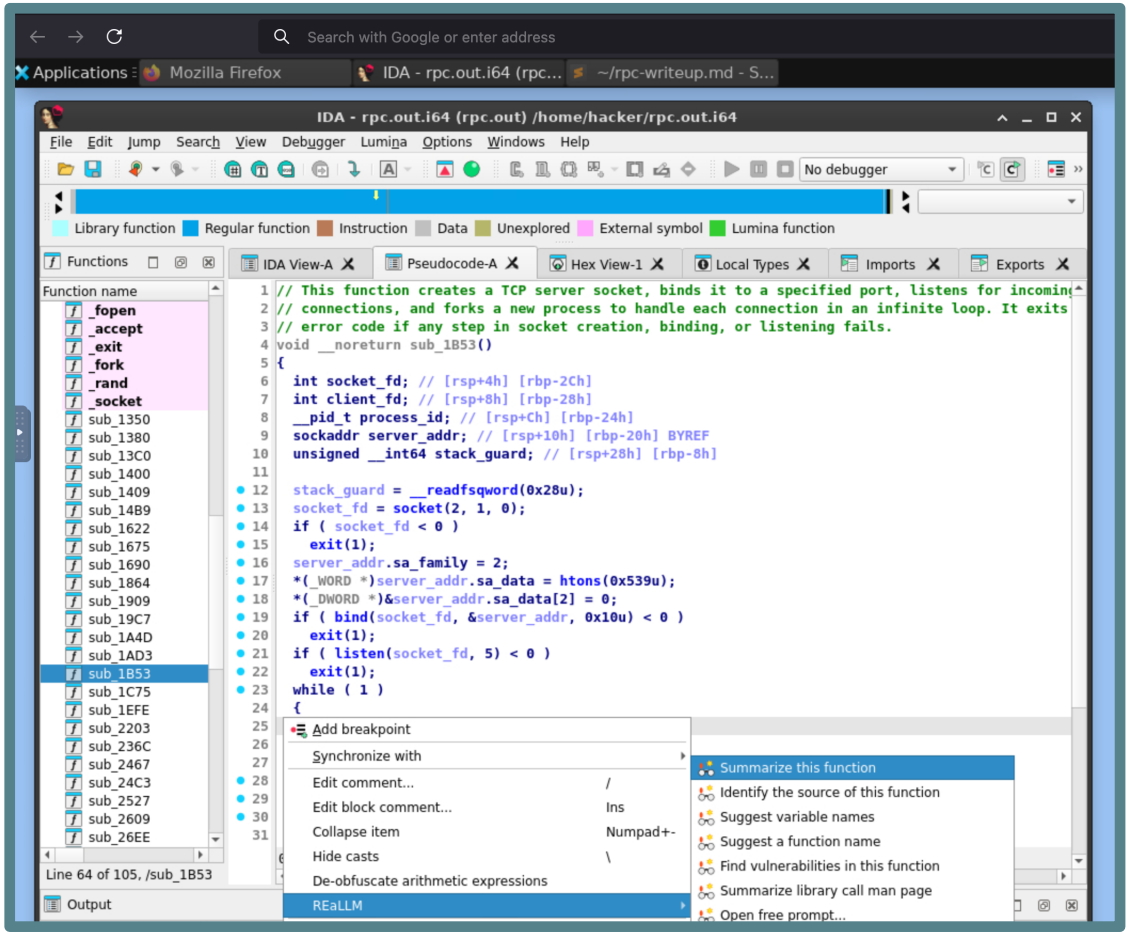
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~/rpc-writeup.md - S...
IDA - rpc.out.i64 (rpc.out) /home/hacker/rpc.out.i64
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No debugger
Library function Regular function Instruction Data Unexplored External symbol Lumina function
Functions
IDA View-A
Pseudocode-A
Hex View-1
Local Types
Imports
Exports
Function name
_fopen
_accept
_exit
_fork
_rand
_socket
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sub_14B9
sub_1622
sub_1675
sub_1690
sub_1864
sub_1909
sub_19C7
sub_1A4D
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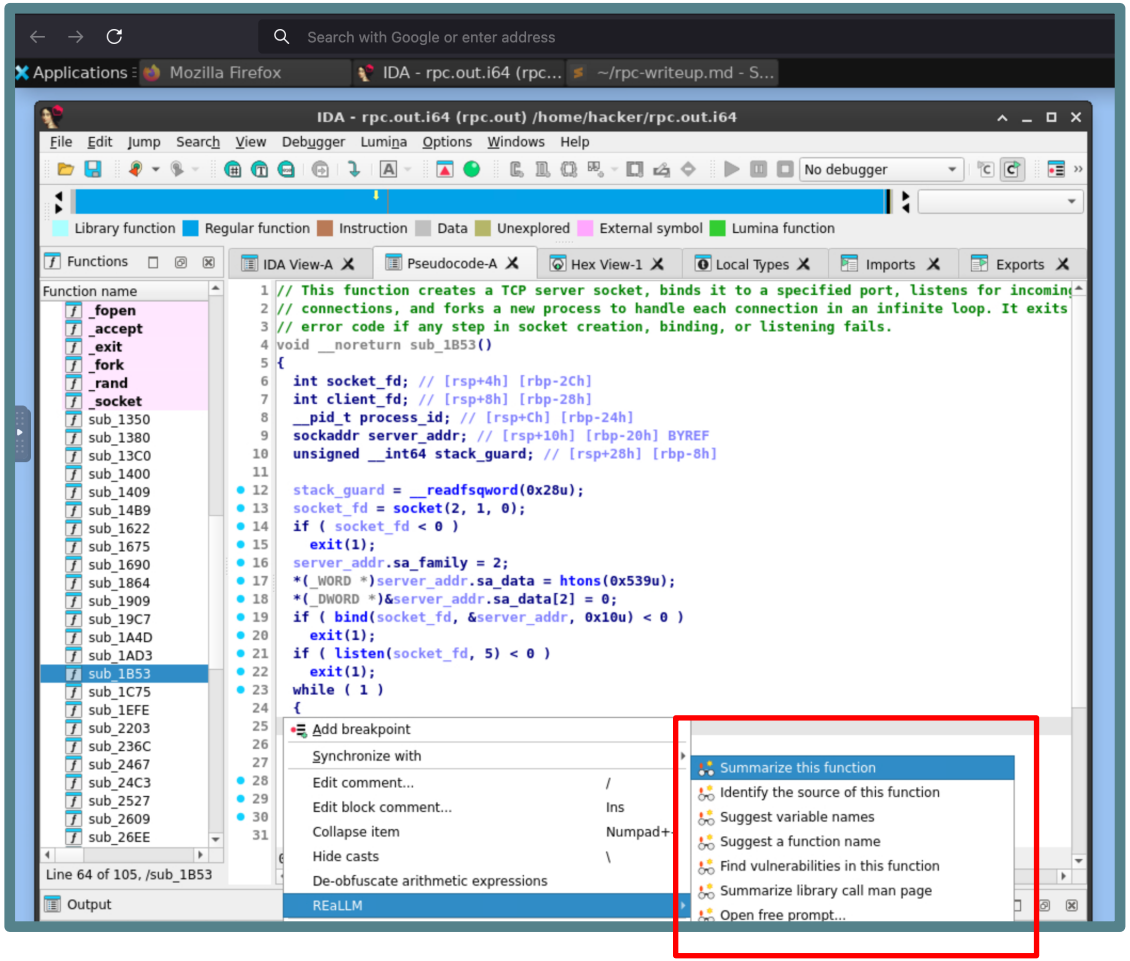
Line 64 of 105, /sub_1B53
// This function creates a TCP server socket, binds it to a specified port, listens for incomin
// connections, and forks a new process to handle each connection in an infinite loop. It exits
// error code if any step in socket creation, binding, or listening fails.
void __noreturn sub_1B53()
{
int socket_fd; // [rsp+4h] [rbp-2Ch]
int client_fd; // [rsp+8h] [rbp-28h]
__pid_t process_id; // [rsp+Ch] [rbp-24h]
sockaddr server_addr; // [rsp+10h] [rbp-20h] BYREF
unsigned __int64 stack_guard; // [rsp+28h] [rbp-8h]
stack_guard = __readfsqword(0x28u);
socket_fd = socket(2, 1, 0);
if (socket_fd < 0)
exit(1);
server_addr.sa_family = 2;
*(_WORD *)server_addr.sa_data = htons(0x539u);
*(_DWORD *)&server_addr.sa_data[2] = 0;
if (bind(socket_fd, &server_addr, 0x10u) < 0)
exit(1);
if (listen(socket_fd, 5) < 0)
exit(1);
while (1)
{
Add breakpoint
Synchronize with
Edit comment... /
Edit block comment... Ins
Collapse item Numpad+-
Hide casts \
De-obfuscate arithmetic expressions
REaLLM
Summarize this function
Identify the source of this function
Suggest variable names
Suggest a function name
Find vulnerabilities in this function
Summarize library call man page
Open free prompt...
Output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Library function Regular function Instruction Data Unexplored External symbol Lumina function
Functions
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Pseudocode-A
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_exit
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sub_13C0
sub_1400
sub_1409
sub_14B9
sub_1622
sub_1675
sub_1690
sub_1864
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if (bind(socket_fd, &server_addr, 0x10u) < 0)
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Synchronize with
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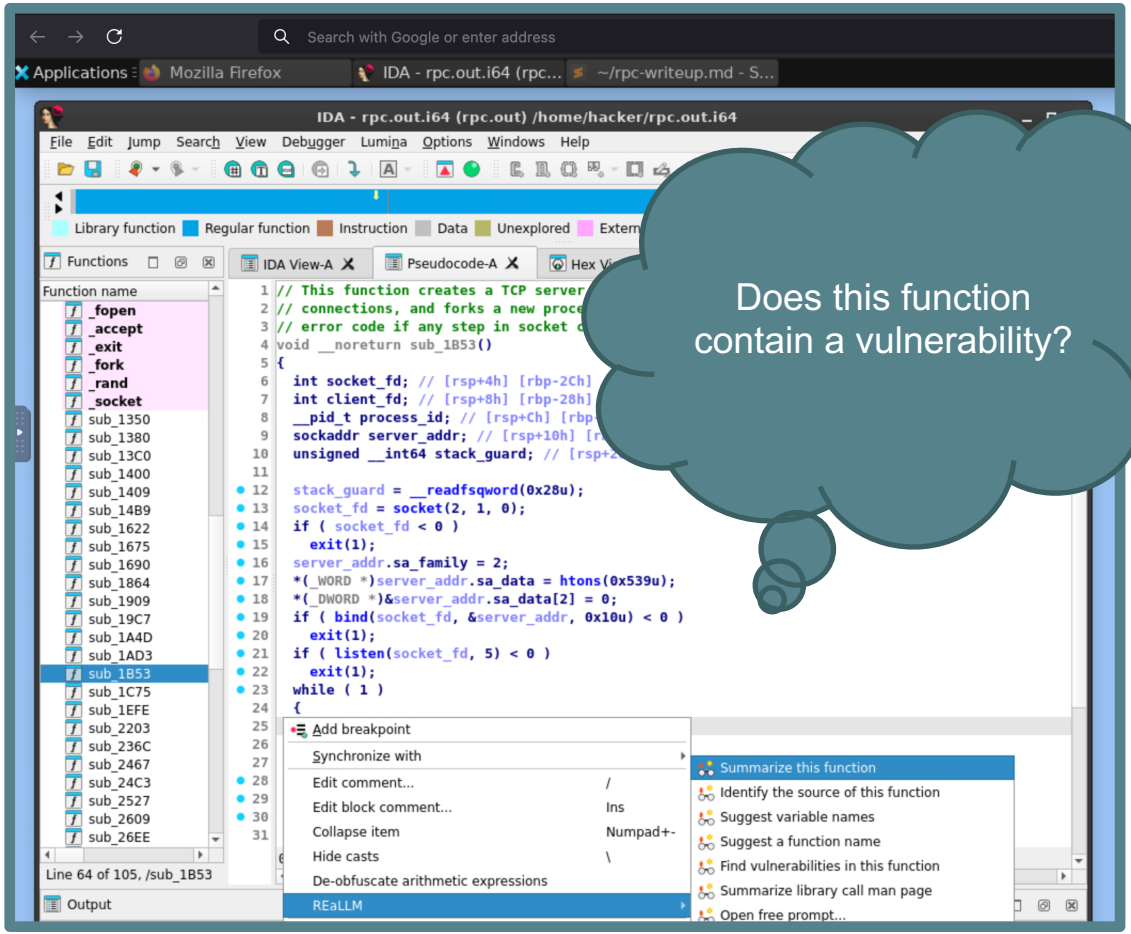
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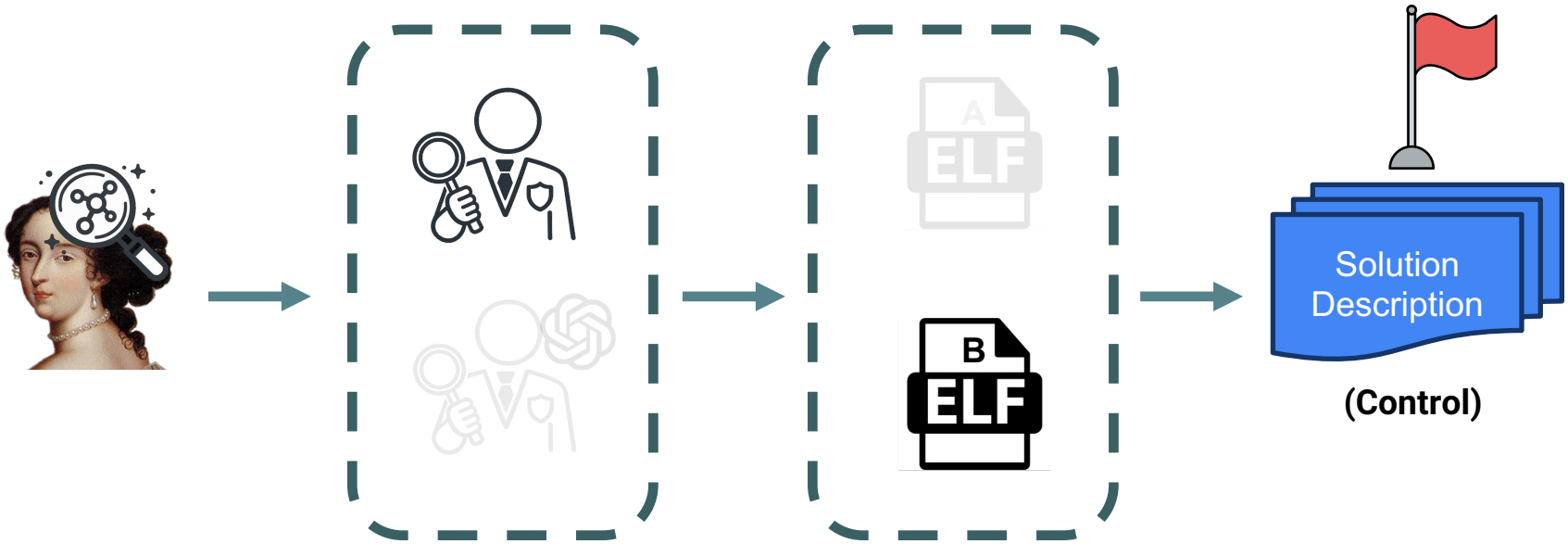
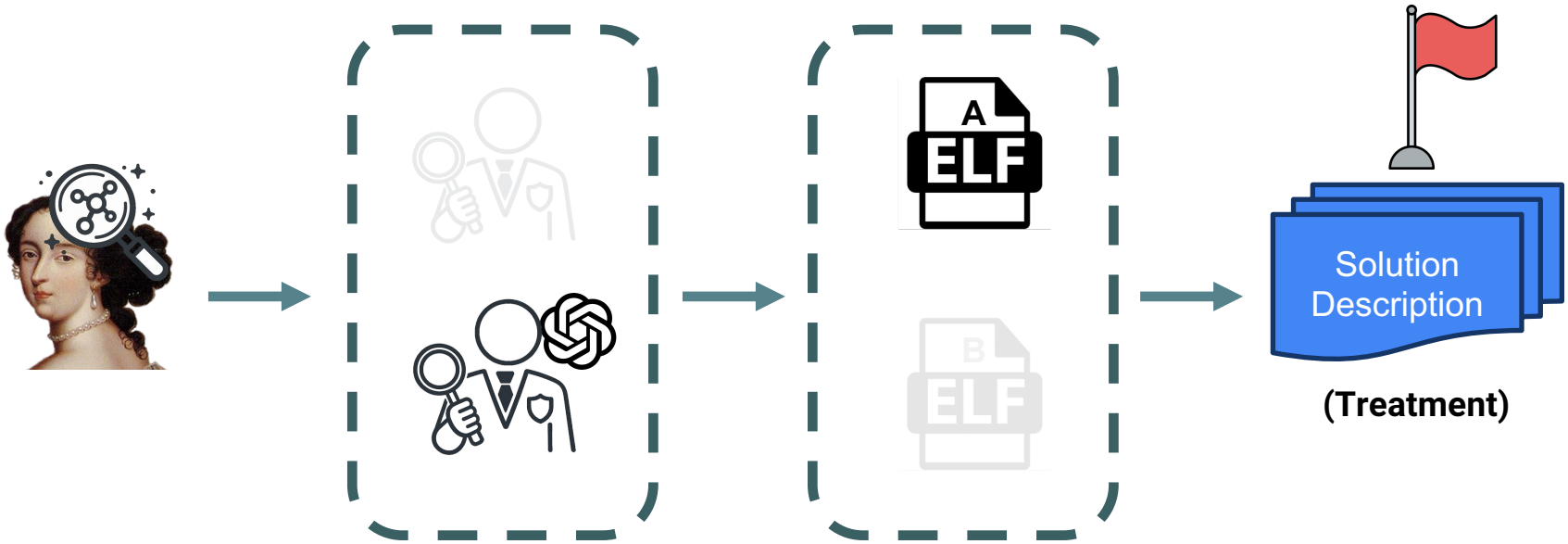
Output
Does this function contain a vulnerability?

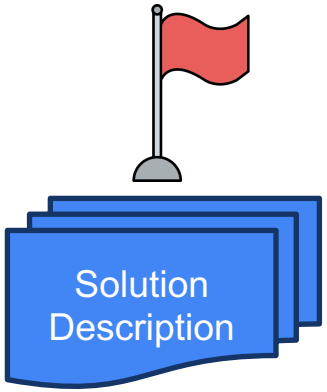
RE Experiment: Control



RE Experiment: Treatment



RE Experiment: Scoring



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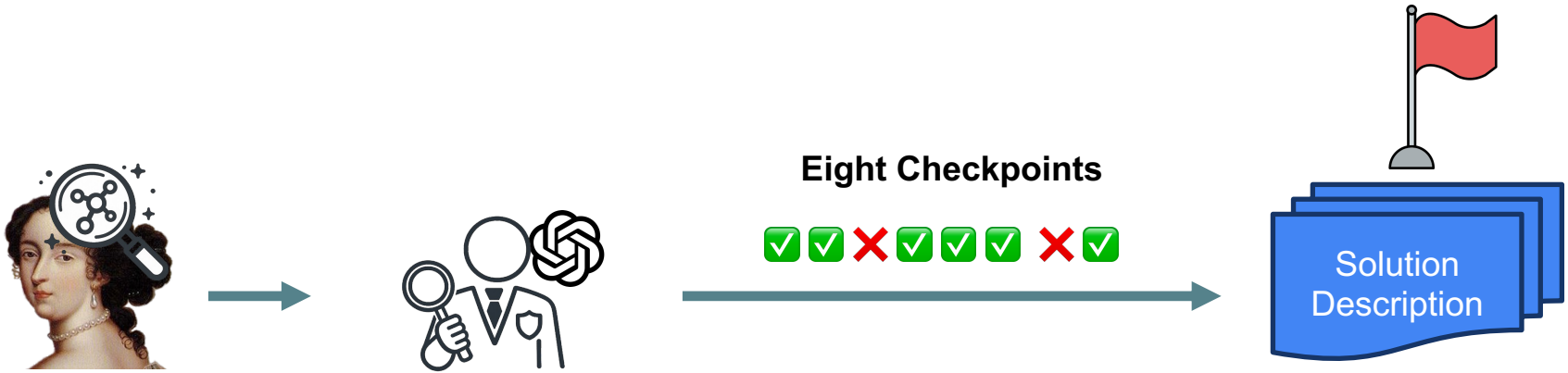
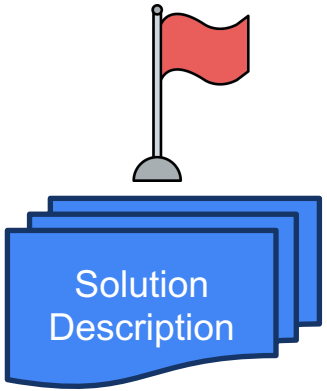


RE Experiment: Scoring

Eight Checkpoints

✅✅❌✅✅✅❌✅



Software Understanding Rate: ✅ Checkpoints / Time

Experiment Overview

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48 Participants: 24 Experts, 24 Novices

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109 Hours of recorded reverse engineering

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1,517 LLM Queries

- Experts: 728
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Novices approached expert levels of reversing with a **2x increase** in understanding rates while using LLMs.

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- Often due to function summarization.

```
__int64 __fastcall sub_2609(unsigned int a1, unsigned int *a2,
__int64 a3)
{
  unsigned int v4; // [rsp+20h] [rbp-18h]
  unsigned int v5; // [rsp+24h] [rbp-14h]
  unsigned int v6; // [rsp+28h] [rbp-10h]
  unsigned __int64 i; // [rsp+30h] [rbp-8h]

  v4 = *a2;
  v5 = a2[1];
  v6 = -1640531527 * a1;
  for ( i = 0; i < a1; ++i )
  {
    v5 -= (((v4 >> 5) ^ (16 * v4)) + v4) ^ (*(_DWORD *)(4LL *
((v6 >> 11) & 3) + a3) + v6);
    v6 += 1640531527;
    v4 -= (((v5 >> 5) ^ (16 * v5)) + v5) ^ (*(_DWORD *)(4LL *
(v6 & 3) + a3) + v6);
  }
  *a2 = v4;
  a2[1] = v5;
  return v5;
}
```

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    v6 += 1640531527;
    v4 -= (((v5 >> 5) ^ (16 * v5)) + v5) ^ (*(_DWORD *)(4LL *
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  }
  *a2 = v4;
  a2[1] = v5;
  return v5;
}
```

“This function decrypts one 64-bit block using TEA (Tiny Encryption Algorithm).”

Results: Low Expert Improvement

Experts had **negligible** reversing improvements with LLMs.

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- Same LLM usage as novices, but for less benefit.

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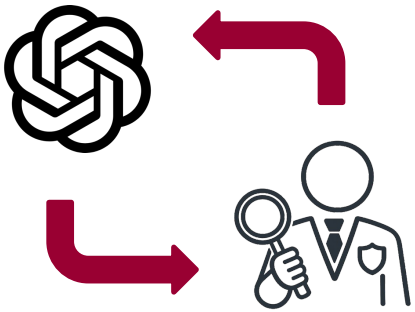
Experts had **negligible** reversing improvements with LLMs.

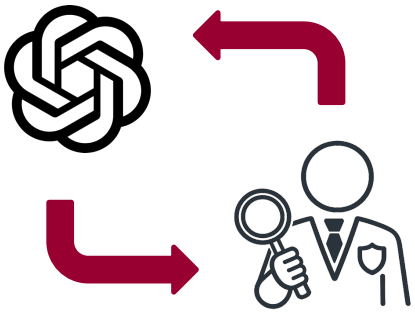
- Same LLM usage as novices, but for less benefit.
- Experts may require a **different collaboration model.**

Results: Wasted Collaboration



Results: Wasted Collaboration

Collaborating more on single functions with LLMs resulted in **lower understanding rates** on average.



Results: First Look Prevails

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- Compressible information either compressed quickly or never did.

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1,517 LLM Responses

3 detected hallucinations (<1%)

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1,517 LLM Responses
3 detected hallucinations (<1%)

3 vulnerability hallucinations caused…

- Caused a minimum **231% understanding rate slowdown**
- All participants encountering it **submitted an incorrect solution early**!

Summary

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We created a methodology to quantify the understanding of software in reverse engineering illuminating **18 findings**.

We open-sourced our platform, challenges, and LLM tool used in our study.

Open Science

Online RE Human Study Platform:
https://github.com/mahaloz/dec-synergy-study

Maintained LLM Tool:
https://github.com/mahaloz/DAILA
680 GitHub Stars
~1000 PyPI installs a month

Questions?

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https://zionbasque.com
https://github.com/mahaloz/dec-synergy-study
https://github.com/mahaloz/DAILA