Auto-Pentester LLM Research

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1. Introduction

As companies worldwide are continuing to explore what incorporating AI looks like, we at NCC Group have done some internal research on how consultant-AI collaboration could be achieved. The goal of this research was to build a baseline for further development of these testing techniques, as well as to evaluate in which areas improvements could be made in the current architecture to make further gains. This introductory testing was conducted using local LLMs which are far less capable than current state-of-the-art models. In the future we hope to expand to more capable models using the lessons learned from this initial study.

2. Setup

Over the course of a time boxed six weeks research project, we implemented and tested a simplified version of AutoPentester's agent-based framework for automated pentesting[1]. In their framework, Ginige et al. have six different sub-agents each with their own separate roles: strategy analyzer, repetition identifier, generator, results verifier, summarizer, and report generator.

Below is a summary of each sub-agent's role:

- Strategy analyzer: Creates a testing plan and selects specific tasks to carry out
- Repetition identifier: Compares selected tasks to previously attempted tasks, reducing needless repetition
- Generator: Generates the proper CLI commands used to carry out the selected task
- Results verifier: Checks generated CLI commands and their outputs, fixing the syntax if necessary
- Summarizer: Summarizes command output for the strategy analyzer
- Report generator: Synthesizes the logs of all other agents to generate a final report

In our simplified implementation, we removed the report generator and repetition identifier. We removed the report generator as it had no use-case in our proof-of-concept work and we removed the repetition identifier because too many false-positives triggered on contextual information to the selected subtask that were not related to the subtask itself. We also removed any aspect of architecture which requested human feedback, electing to push the system to its limits as a fully automated system.

In addition to the sub-agents, we also implemented a piece of AutoPentester's architecture called the agent-computer interface (ACI), which would allow agents to execute commands or code within a container. We also set up an MCP server as an abstraction for retrieving challenge data and writing and executing Python code. Our full architecture is diagrammed below:

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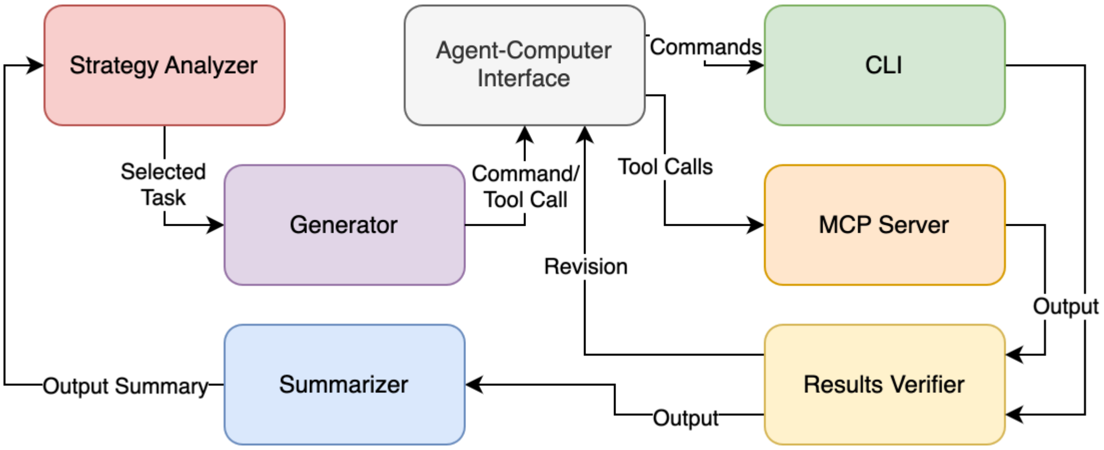
[1] https://arxiv.org/pdf/2510.05605



We tested our modified architecture with the Qwen3-8B model, using several HackTheBox crypto challenges to measure performance in identifying and exploiting vulnerabilities through source code review. The HackTheBox challenge flags made results easily verifiable, although the possibility does exist that solutions to these challenges is present in the LLM's training set, and thus it is not solving the crypto challenges, but rather remembering them. This risk only exists due to the time constraint on this project; with more time, original challenges could have been developed to guarantee that the solutions do not exist in the model's training set.

We compared this sub-agent architecture's performance to a very basic architecture, in which a single model was given the same challenge instructions, as well as the same MCP server for fetching challenge details and running Python code. We tested both architectures with two models, an 8 billion parameter Qwen3 model (qwen3:8b), and a 9 billion parameter Qwen3.5 model (qwen3.5:9b). Each model was given five rounds of generation per trial. Ideally, each generated output would end with a successful tool call, to either list the available challenges, read the challenge's data, or execute a python script.

Each trial was classified as falling into one of the following 5 outcome categories: failed to read challenge, failed to solve challenge, tool interaction failure, error in solution code, and successful. A trial that failed to read the challenge failed to make the relevant tool call to read the assigned challenge. A trial that failed to solve the challenge successfully read the challenge but could not come up with the proper solution. A trial that ended with a tool interaction failure is one where the model tried to write a solution proof-of-concept but failed to make a proper tool call to do so. A trial that ended with an error in the solution was usually due to the agent running into syntax errors, trying to use packages that were not installed. A successful trial successfully uncovered the solution flag for the challenge.

3. Results

3.1. Simple/Qwen3-8B

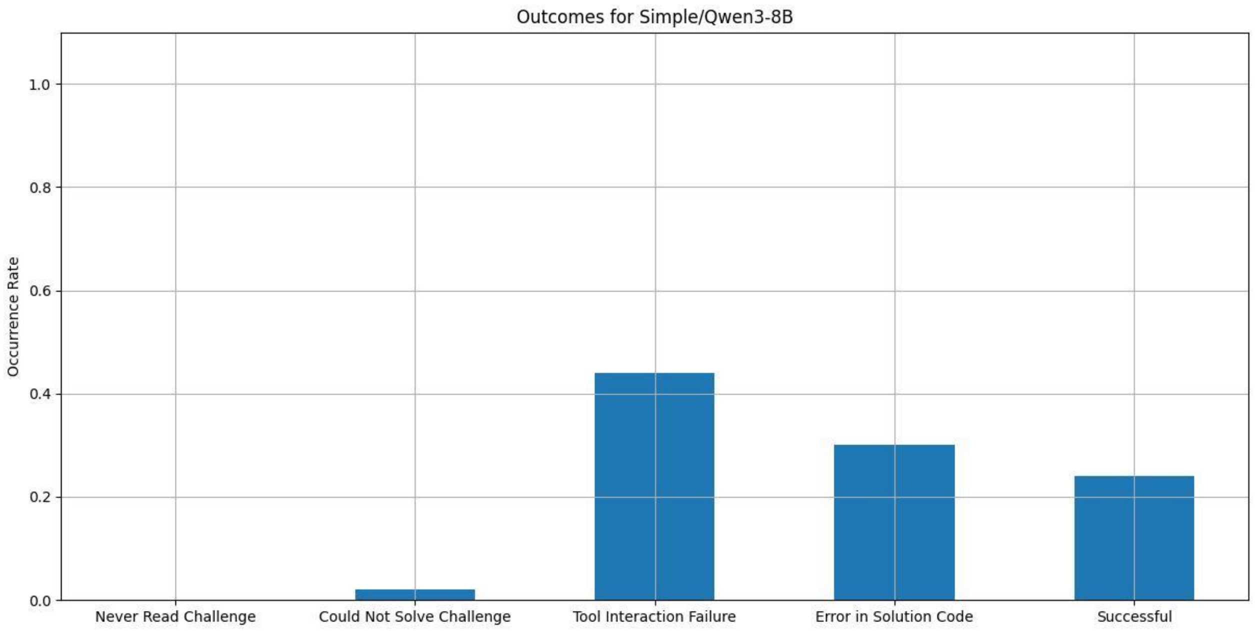
As a baseline, we first tested the Qwen3-8B model in a very basic architecture. Below is a transcript from a successful trial by this model with this architecture:

```
Role: system
You are a large-language model built to discover issues in code before the code hits
production and could be used by a threat actor to compromise user data. When you think you
have found an issue, use the relevant tool to run a python proof-of-concept exploiting the
issue and retrieving the flag. The python code should be represented as a list of lines to
be saved to a file and then run. The results will be returned back to you. This python run
is the most important part of the solution, and no solution is valid without this being
functional.
You have been given access to a few tools to assist your tasks. You will receive a list of
these tools and how to use them shortly.

...
```

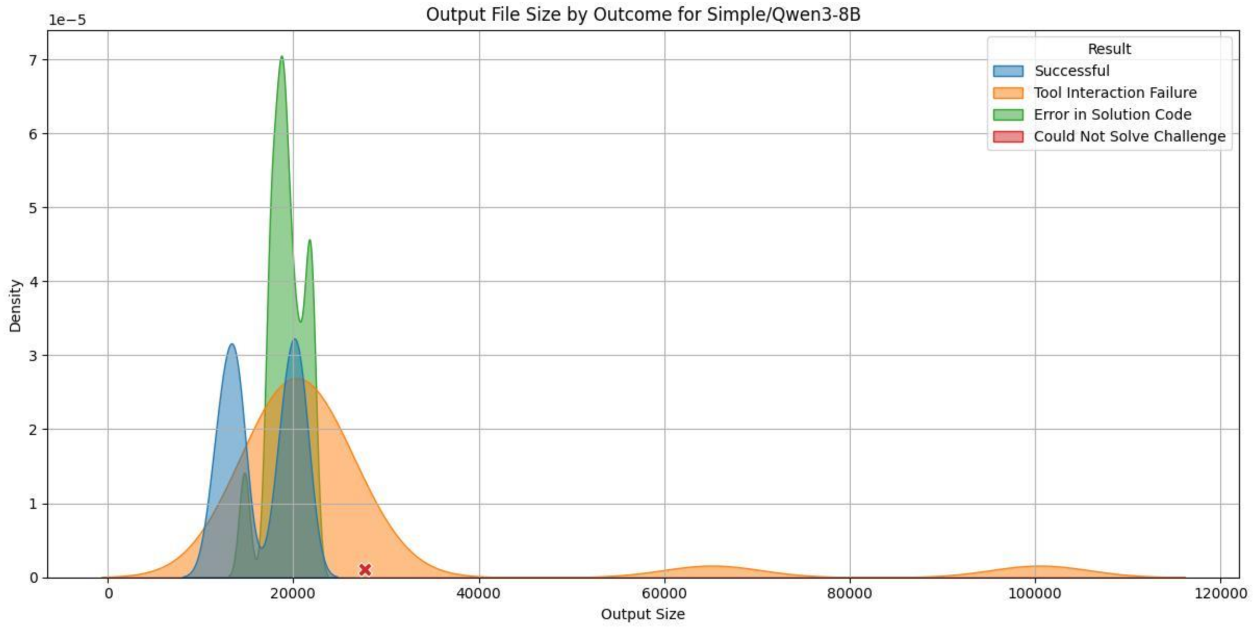
```
Following is a list of all available tools. Use these to select a challenge to solve, gather
more information about the problem, and attempt to solve it.

...

Role: user
Solve the "Last Dance" crypto challenge

Role: system
You have 5 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
{
    "name": "list_challenges"
}

Role: tool
{
    "result": [
        {
            "challenge_id": 0,
            "name": "Last Dance"
        },
        {
            "challenge_id": 1,
            "name": "Baby Time Capsule"
        },
        {
            "challenge_id": 2,
            "name": "Embryonic Plant"
        }
    ]
}

Role: system
You have 4 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
{
    "name": "read_challenge_data",
    "arguments": {
        "challenge_id": 0
    }
}

Role: tool
{
    "result": "<CODE>...</CODE>\n<OUTPUT>...</OUTPUT>\n<EXTRA>\n\n</EXTRA>"
}

Role: system
You have 3 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
```

```
Role: system
You have 2 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
{
    "name": "run_python",
    "arguments": {
        "challenge_id": 0,
        "code": [
            "with open(\"out.txt\", \"r\") as f:", "    data = f.read().splitlines()", "",
            "iv_hex, enc_msg_hex, enc_flag_hex = data[0], data[1], data[2]",
            "iv = bytes.fromhex(iv_hex)", "enc_msg = bytes.fromhex(enc_msg_hex)",
            "enc_flag = bytes.fromhex(enc_flag_hex)",
            "",
            "# Compute XOR of encrypted message and flag", "xor = bytes(a ^ b for a, b in
zip(enc_msg, enc_flag))",
            "",
            "# Known message", "message = b\"Our counter agencies have intercepted your
messages and a lot of your agent's identities have been exposed. In a matter of days all of
them will be captured\"",
            "",
            "# Recover flag", "flag = bytes(a ^ b for a, b in zip(xor, message))",
            "",
            "print(flag.decode())"
        ]
    }
}

Role: tool
{
    "result": "HTB{und3r57AnD1n9_57R3aM_C1PH3R5_15_51mPl3_a5_7Ha7}\n"
}

Role: system
You have 1 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant

The flag for the "Last Dance" challenge is:
HTB{und3r57AnD1n9_57R3aM_C1PH3R5_15_51mPl3_a5_7Ha7}
```

Aside from the empty response when there were three responses remaining, this was a perfect solution. The model successfully listed the valid challenges, read the challenge data corresponding to the one it was tasked with solving, diagnosed the solution, and solved the challenge with its tool call, recognizing the HTB flag when it was recovered. Overall, it successfully demonstrated a solution in 24% of its trials and came up with the correct solution in 98% of its trials. Below is a figure depicting the occurrence rate of each outcome across its trials:



The most common result was that the model failed to call the proper tool to run python code. The next most common result was an error in the solution code, usually due to trying to import a library that was not in the python environment. Instead of trying to solve the challenge without the library, the agent tried to install the package but was blocked from doing so. There was only one trial in which the agent failed to solve the challenge. We also measured the size of the output files logging the model output as a proxy for the length of the model output.



The cases when the agent failed to interact with the tool had the largest outputs. These would occur when the model would get stuck in a loop repeating its plan to itself several times in a row before finishing its response. This overthinking seemed to be a symptom of the model's failures, as any trial that submitted a solution to the run python tool was complete after only a bit more than 20 KB of output data.

Ultimately, we found the basic architecture to outperform the sub-agent architecture when using the Qwen3-8B model. Each agent had difficulty following system prompt instructions, beyond what prompt tuning would seem to address, which seemed to indicate that the Qwen3-8B model may not be performant enough to take advantage of this architecture. While the additional structure would conceivably help individual agents be able to address each part of the testing process more easily, too much information was lost in inter-agent communication for this architecture to be successful. Especially in the case of code review, too much information was lost between the summarizer and strategy analyzer for the system of sub-agents to successfully complete the challenges.

3.2. Simple/Qwen3.5-9B

We also tested the model Qwen3.5-9B model in the same system and measured the following outcomes over 50 trials. Below is a transcript of one of its successful trials:

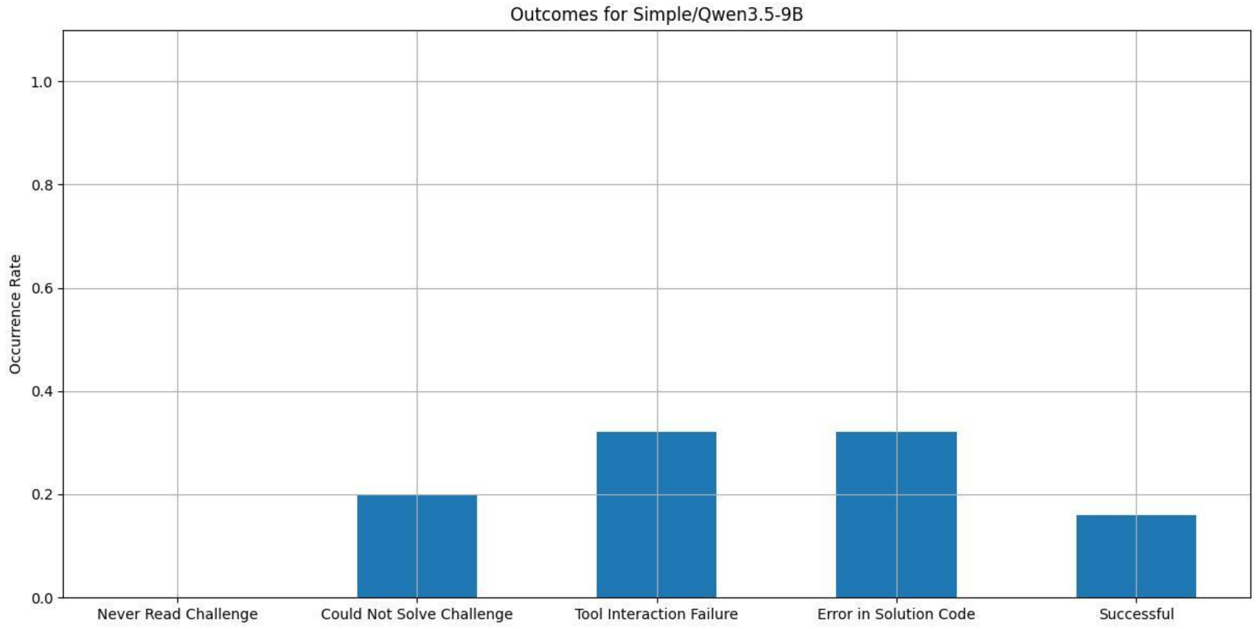
```
Role: system
You are a large-language model built to discover issues in code before the code hits
production and could be used by a threat actor to compromise user data. When you think you
have found an issue, use the relevant tool to run a python proof-of-concept exploiting the
issue and retrieving the flag. The python code should be represented as a list of lines to
be saved to a file and then run. The results will be returned back to you. This python run
is the most important part of the solution, and no solution is valid without this being
functional.
You have been given access to a few tools to assist your tasks. You will receive a list of
these tools and how to use them shortly.

...

Following is a list of all available tools. Use these to select a challenge to solve, gather
more information about the problem, and attempt to solve it.

...

Role: user
Solve the "Last Dance" crypto challenge

Role: system
You have 5 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
{
    "name": "list_challenges",
    "arguments": {}
}

Role: tool
{
    "result": [
        {
            "challenge_id": 0,
            "name": "Last Dance"
        },
        {
            "challenge_id": 1,
            "name": "Baby Time Capsule"
        },
        {
            "challenge_id": 2,
            "name": "Embryonic Plant"
        }
    ]
}
```

~~~
Role: system
You have 4 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
{
    "name": "read_challenge_data",
    "arguments": {
        "challenge_id": 0
    }
}

Role: tool
{
    "result": "<CODE>...</CODE>\n<OUTPUT>...</OUTPUT>\n<EXTRA>\n\n</EXTRA>"
}

Role: system
You have 3 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
The challenge code uses ChaCha20 encryption. The key issue here is that the same key and
nonce are used to encrypt both the message and the FLAG. ChaCha20 is a stream cipher, which
means it encrypts data by XORing the plaintext with a keystream generated from the key and
nonce. If the same key and nonce are used for multiple messages, the XOR of the two
ciphertexts will reveal the XOR of the two plaintexts.

Here's the approach:
1. The ciphertexts and the plaintext message are known.
2. Let's denote:
   - `ct_msg` = ciphertext of the message (known)
   - `ct_flag` = ciphertext of the flag (known)
   - `pt_msg` = plaintext of the message (known)
   - `pt_flag` = plaintext of the flag (unknown, this is what we want to recover)

Since `ct_msg = pt_msg ⊕ keystream` and `ct_flag = pt_flag ⊕ keystream`,
we have `pt_flag = ct_flag ⊕ pt_msg ⊕ ct_msg ⊕ pt_msg = ct_flag ⊕ ct_msg ⊕ pt_msg ⊕
pt_msg`
Actually, a better approach: `pt_flag = ct_flag ⊕ ct_msg ⊕ pt_msg`

Wait, let me be more careful:
- `ct_msg = pt_msg ⊕ keystream`
- `ct_flag = pt_flag ⊕ keystream`
- `pt_flag = ct_flag ⊕ keystream`
- But `keystream = ct_msg ⊕ pt_msg`
- So `pt_flag = ct_flag ⊕ (ct_msg ⊕ pt_msg) = ct_flag ⊕ ct_msg ⊕ pt_msg`

So I can recover the flag by XORing the two ciphertexts with the known plaintext message.

Let me write the Python code to exploit this.

```python
with open("out.txt", "r") as f:
    lines = f.readlines()

iv = bytes.fromhex(lines[0].strip())
ct_msg = bytes.fromhex(lines[1].strip())
~~~

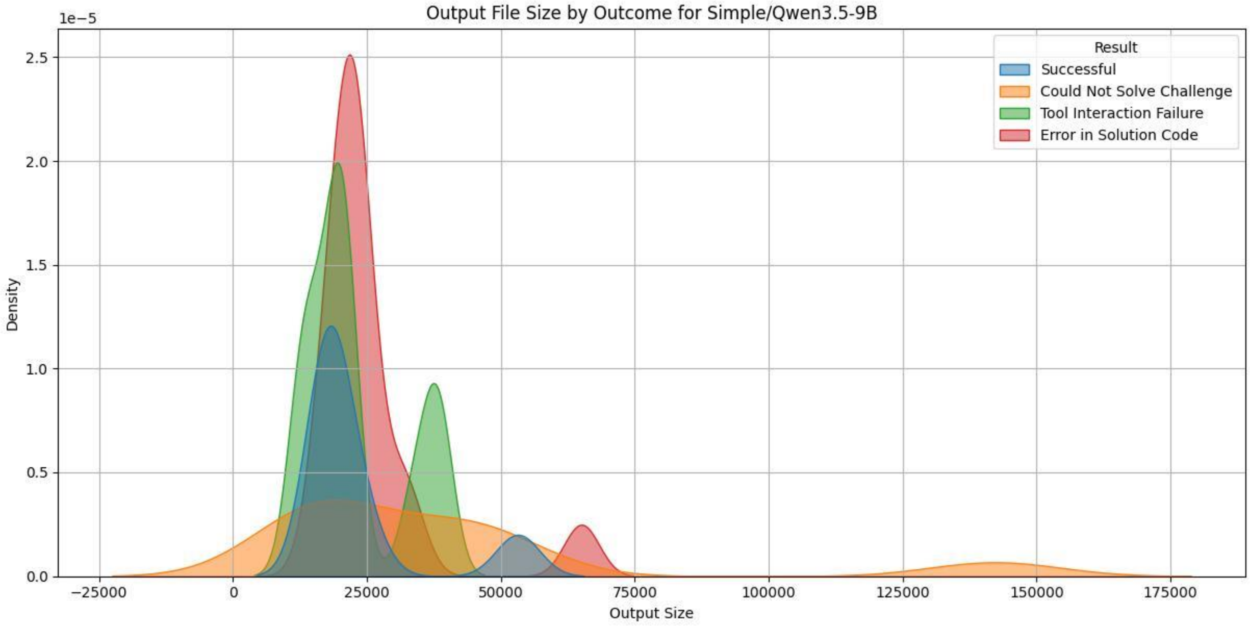
~~~
ct_flag = bytes.fromhex(lines[2].strip())

pt_msg = b"Our counter agencies have intercepted your messages and a lot of your agent's
identities have been exposed. In a matter of days all of them will be captured"

pt_flag = ct_flag ^ ct_msg ^ pt_msg

print(pt_flag.decode())
```


{
    "name": "run_python",
    "arguments": {
        "challenge_id": 0,
        "code": ["with open('out.txt', 'r') as f:", "    lines = f.readlines()", "", "iv =
bytes.fromhex(lines[0].strip())", "ct_msg = bytes.fromhex(lines[1].strip())", "ct_flag =
bytes.fromhex(lines[2].strip())", "", "pt_msg = b\"Our counter agencies have intercepted
your messages and a lot \"", "pt_msg += b\"of your agent's identities have been exposed. In
a matter of \"", "pt_msg += b\"days all of them will be captured\"", "", "pt_flag = ct_flag
^ ct_msg ^ pt_msg", "", "print(pt_flag.decode())"]
    }
}

Role: system
You have 2 responses remaining. If you believe you have already identified the issue,
respond with "DONE".

Role: assistant
{
    "name": "run_python",
    "arguments": {
        "challenge_id": 0,
        "code": [
            "with open('out.txt', 'r') as f:",
            "    lines = f.readlines()",
            "",
            "ct_msg = bytes.fromhex(lines[1].strip())",
            "ct_flag = bytes.fromhex(lines[2].strip())",
            "",
            "pt_msg = b\"Our counter agencies have intercepted your messages and a lot \"",
            "pt_msg += b\"of your agent's identities have been exposed. In a matter of \"",
            "pt_msg += b\"days all of them will be captured\"",
            "",
            "pt_flag = ct_flag ^ ct_msg ^ pt_msg",
            "",
            "print(pt_flag.decode())"
        ]
    }
}

Role: tool
{
    "result": "Traceback (most recent call last):\n  File \"/workspace/llm-
workspace/346d3517-7b6a-4dab-89bf-b7c7fa63734a/main.py\", line 16, in <module>\nTypeError:
unsupported operand type(s) for ^: 'bytes' and 'bytes'\n"
}

Role: system
~~~

```
You have 1 responses remaining. If you believe you have already identified the issue,
respond with "DONE".
{
Role: assistant
{
    "name": "run_python",
    "arguments": {
        "challenge_id": 0,
        "code": [
            "with open('out.txt', 'r') as f:",
            "    lines = f.readlines()",
            "",
            "ct_msg = bytes.fromhex(lines[1].strip())",
            "ct_flag = bytes.fromhex(lines[2].strip())",
            "",
            "pt_msg = b\"Our counter agencies have intercepted your messages and a lot \"",
            "pt_msg += b\"of your agent's identities have been exposed. In a matter of \"",
            "pt_msg += b\"days all of them will be captured\"",
            "",
            "pt_flag = bytes([a ^ b ^ c for a, b, c in zip(ct_flag, ct_msg, pt_msg)])",
            "",
            "print(pt_flag.decode())"
        ]
    }
}

Role: tool
{
    "result": "HTB{und3r57AnD1n9_57R3aM_C1PH3R5_15_51mPl3_a5_7Ha7}\n"
}
```

In this case, the agent correctly reasoned its response but failed to mark the end of its thinking and the beginning of its tool call. It then properly called the run python tool with a broken script but recognized its mistake and was able to successfully solve the challenge within its constraints. The model was successful in 16% of its trials and solved the challenge in 80% of its trials.



However, this specific model is much more prone to overthinking. In its response when it had 3 responses remaining, it works through the correct solution, and then outputs “Wait, let me be more careful” before restating itself. This is a tendency that this specific model exhibited in testing, and in multiple cases, it would repeat its own logic many times before breaking out of its cycle. This is reflected by the file output size for this set of trials:



Not pictured in this graph are instances where the model had a tool interaction failure in a trial with an output size of 274 KB, which was removed for the sake of readability. Where most cases before with the Qwen3-8B model that did not end with a tool interaction failure had completed by around 30 KB of output, this Qwen3.5-9B model had many trials exceed 30 KB, and it was not uncommon for the output size to reach 45 kB. Again, this is due to the model’s tendency to repeat itself. One example of this is the successful trial with an output size of over 50 KB, in which the model says “wait” and repeats itself or overcomplicates the challenge 7 times in its response. Ironically enough, the agent recognizes this, stating “actually, I'm overcomplicating this” halfway through its response.

3.3. Auto-Pentester/Qwen3-8B

We then compared these models’ performances in the Auto-Pentester environment that we had replicated. We minimized the edits made to the system prompts provided by the authors in their GitHub repository to keep the system as similar to the published version as we could. As this environment consists of significantly more roles and functionality, its output size is bound to increase, but hopefully with the benefit of increased success. Below is the output from the most successful trial:

```
INITIAL INSTRUCTIONS:
Solve the "Last Dance" crypto challenge

================================================================

STRATEGY ANALYZER - Initial PTT:
1. Crypto Challenge - Last Dance - [to-do]
   1.1 Analyze Challenge Description - [to-do]
       1.1.1 Understand the problem statement - [to-do]
       1.1.2 Identify cryptographic primitives or algorithms involved - [to-do]
   1.2 Tool Discovery - [to-do]
       1.2.1 Find available cryptographic analysis tools - [to-do]
       1.2.2 Identify relevant libraries or frameworks - [to-do]
   1.3 Cryptographic Analysis - [to-do]
       1.3.1 Perform cipher analysis (e.g., frequency analysis, pattern recognition) - [to-
do]
```

~~~
       1.3.2 Test for known vulnerabilities (e.g., weak keys, padding oracle) - [to-do]
       1.3.3 Attempt decryption or key recovery - [to-do]
   1.4 Validate Solution - [to-do]
       1.4.1 Verify decrypted data against expected output - [to-do]
       1.4.2 Confirm adherence to challenge constraints - [to-do]

================================================================

STRATEGY ANALYZER - Selected subtask:
<NEXT_TASK>
1.1.1 Understand the problem statement - [to-do]
</NEXT_TASK>
Examine the challenge description to determine the cryptographic method or puzzle type
(e.g., substitution cipher, RSA, AES). Look for clues about the encryption process, key
size, or any hints provided in the problem statement. Identify whether the challenge
involves decryption, key recovery, or exploiting a specific cryptographic weakness.

================================================================

GENERATOR - Guidance:
To understand the problem statement for the "Last Dance" challenge, follow these steps:

1. **List Available Challenges**:
   Use the `list_challenges` tool to retrieve all available challenge IDs and their
associated names. This will help identify the correct `challenge_id` for "Last Dance."
   ```bash
   TOOL_CALL: list_challenges
   ~~~

2. **Retrieve Challenge Data**:
   Once you confirm the `challenge_id` for "Last Dance," use `read_challenge_data` to fetch
the challenge's description, code, and output. This will provide the problem statement and
any hints about the cryptographic method.
   ```bash
   TOOL_CALL: read_challenge_data challenge_id=<ID>
   ```

3. **Analyze the Problem Statement**:
   - Look for keywords like "cipher," "encryption," "key," or "algorithm" to identify the
cryptographic method (e.g., RSA, AES, substitution cipher).
   - Check for clues about key sizes, padding schemes, or specific vulnerabilities (e.g.,
"weak key," "padding oracle").
   - Determine if the task requires decryption, key recovery, or exploiting a known
weakness.

4. **Document Observations**:
   Note any patterns, hints, or constraints mentioned in the problem statement. This will
guide your next steps in cryptographic analysis.

Example: If the description mentions "a 512-bit RSA key with a weak exponent," this
indicates a focus on RSA vulnerabilities like small public exponents.

==

COMMAND GENERATOR - Command list:
TOOL_CALL
{
    "name": "list_challenges",
    "arguments": {}
```
```

```
}

================================================================

ACI - Results:
['{\n    "result": [\n        {\n            "challenge_id": 0,\n            "name": "Last
Dance"\n        },\n        {\n            "challenge_id": 1,\n            "name": "Baby
Time Capsule"\n        },\n        {\n            "challenge_id": 2,\n            "name":
"Embryonic Plant"\n        }\n    ]\n}']

================================================================

SUMMARIZER - Summary:

The tool output lists three challenges with the following details:
1. Challenge ID 0 - "Last Dance"
2. Challenge ID 1 - "Baby Time Capsule"
3. Challenge ID 2 - "Embryonic Plant"


================================================================

STRATEGY ANALYZER - Updated PTT:
The provided test results indicate that there are three distinct challenges, with the
original PTT structure focusing on **"Crypto Challenge - Last Dance"**. However, the user's
instruction explicitly requires the PTT to be revised to incorporate the test results. To
comply with this, the PTT must be updated to reflect the existence of three challenges,
including "Last Dance" as one of them. Since the user's instruction emphasizes maintaining
the PTT format and not adding unnecessary tasks, the focus remains on the original challenge
while acknowledging the existence of the other two.

**Revised PTT Structure:**

1. **Crypto Challenge - Last Dance**
   - Subtasks: [Original subtasks remain unchanged as per the original PTT]
   - Note: This challenge is part of a set of three, as indicated by the test results. The
other challenges (not detailed here) are not part of the current scope.

**Key Considerations:**
- The original PTT structure is preserved for "Last Dance."
- The test results are acknowledged, but the other challenges are not included unless
explicitly requested.
- The user's instruction to "maintain the PTT format" is respected by avoiding additional
tasks.

This approach ensures compliance with the user's requirements while keeping the PTT focused
on the original challenge.

================================================================================

STRATEGY ANALYZER - Selected subtask:
<PTT>
1. Crypto Challenge - Last Dance - [to-do]
   1.1 Analyze Challenge Description - [to-do]
       1.1.1 Understand the problem statement - [to-do]
       1.1.2 Identify cryptographic primitives or algorithms involved - [to-do]
   1.2 Tool Discovery - [to-do]
       1.2.1 Find available cryptographic analysis tools - [to-do]
       1.2.2 Identify relevant libraries or frameworks - [to-do]
```

```
   1.3 Cryptographic Analysis - [to-do]
       1.3.1 Perform cipher analysis (e.g., frequency analysis, pattern recognition) - [to-
do]
       1.3.2 Test for known vulnerabilities (e.g., weak keys, padding oracle) - [to-do]
       1.3.3 Attempt decryption or key recovery - [to-do]
   1.4 Validate Solution - [to-do]
       1.4.1 Verify decrypted data against expected output - [to-do]
       1.4.2 Confirm adherence to challenge constraints - [to-do]
   **Note**: This challenge is part of three total (IDs 0, 1, 2). Other challenges are not
detailed here.
</PTT>

<NEXT_TASK>
Review the challenge description for "Last Dance" to identify cryptographic primitives or
algorithms. Use tools like CrypTool or online cipher analyzers to test common ciphers (e.g.,
AES, RSA, Vigenère). Look for patterns or weaknesses in the provided data.
</NEXT_TASK>
</NEXT_TASK>

================================================================

GENERATOR - Guidance:
<STEP>
1. Use the `read_challenge_data` tool with `challenge_id=0` to retrieve the problem
statement, code, and output files for "Last Dance". This will provide context about the
cryptographic method used.
</STEP>
<STEP>
2. Analyze the returned `<CODE>` and `<OUTPUT>` sections for clues about cryptographic
primitives (e.g., AES, RSA, Vigenère) or algorithm-specific patterns (e.g., padding schemes,
key lengths). Look for terms like "encrypt", "decrypt", or library imports (e.g.,
`cryptography`, `pycryptodome`).
</STEP>
<STEP>
3. If the code contains a custom cipher implementation, identify its structure (e.g.,
substitution, transposition, XOR operations) to determine its vulnerability. For example,
repeated patterns in ciphertext may indicate a weak cipher like Vigenère.
</STEP>
<STEP>
4. Use the `run_python` tool to execute code that tests potential decryption methods (e.g.,
brute-force, frequency analysis) based on the identified algorithm. For example, if the code
uses AES in ECB mode, exploit its deterministic nature to recover plaintext.
</STEP>
<STEP>
5. Cross-reference findings with online tools like CrypTool or Cipher Identifier services to
validate assumptions about the cipher type and its weaknesses.
</STEP>

<TOOL_CALL>
read_challenge_data(challenge_id=0)
</TOOL_CALL>

================================================================

COMMAND GENERATOR - Command list:
{
    "name": "read_challenge_data",
    "arguments": {
        "challenge_id": "0"
```

```
    }
}

================================================================

ACI - Results:
['{\n    "result": "<CODE>...</CODE>\\n<OUTPUT>...</OUTPUT>\\n<EXTRA>\\n\\n</EXTRA>"\n}']

================================================================

RESULTS VERIFIER - Corrected Commands:
{
    "name": "read_challenge_data",
    "arguments": {
        "challenge_id": "0"
    }
}

================================================================

ACI - Results:
['{\n    "result": "<CODE>...</CODE>\\n<OUTPUT>...</OUTPUT>\\n<EXTRA>\\n\\n</EXTRA>"\n}']

================================================================

SUMMARIZER - Summary:

The provided code implements ChaCha20 encryption for a message and a flag, writing the nonce
and ciphertexts to a file. Key findings:
1. **Nonce/IV Misuse**: The code uses the same key and nonce for both the message and the
flag. ChaCha20 requires unique nonce-key pairs for each encryption to prevent information
leakage. Reusing the same key and nonce for multiple messages allows attackers to XOR
ciphertexts and potentially recover plaintexts.
2. **Security Vulnerability**: The flag is encrypted with the same key and nonce as the
message, making it susceptible to attacks exploiting nonce reuse.
3. **Output Format**: The nonce is written in hex, followed by the encrypted message and
flag ciphertexts, each separated by newlines.


================================================================

STRATEGY ANALYZER - Updated PTT:
1. **Crypto Challenge - Last Dance**
   - 1.1. **Nonce/IV Misuse** - {The code uses the same key and nonce for both the message
and the flag. ChaCha20 requires unique nonce-key pairs for each encryption to prevent
information leakage. Reusing the same key and nonce for multiple messages allows attackers
to XOR ciphertexts and potentially recover plaintexts.}
   - 1.2. **Security Vulnerability** - {The flag is encrypted with the same key and nonce as
the message, making it susceptible to attacks exploiting nonce reuse.}
   - 1.3. **Output Format** - {The nonce is written in hex, followed by the encrypted
message and flag ciphertexts, each separated by newlines.}

================================================================

STRATEGY ANALYZER - Selected subtask:
<NEXT_TASK>
Use a script to XOR the encrypted message and flag ciphertexts using the same nonce and key,
revealing the plaintext flag by exploiting nonce reuse in ChaCha20. The result will be the
decrypted flag's content.
```

~~~
</NEXT_TASK>

================================================================

GENERATOR - Guidance:
TOOL_CALL
run_python
[
    "import sys",
    "from Crypto.Cipher import ChaCha20",
    "from Crypto.Util import Counter",
    "nonce = bytes.fromhex(sys.stdin.readline().strip())",
    "cipher_message = bytes.fromhex(sys.stdin.readline().strip())",
    "cipher_flag = bytes.fromhex(sys.stdin.readline().strip())",
    "key = b'your_key_here'",  # Replace with actual key from code analysis
    "cipher = ChaCha20.new(key=key, nonce=nonce)",
    "plaintext = cipher.nonce + cipher_flag",
    "print(plaintext.hex())"
]

The script reads the nonce, encrypted message, and encrypted flag from the output. It then
uses the ChaCha20 cipher with a hardcoded key (replace with actual key from code analysis)
to decrypt the flag. The XOR of the ciphertexts is implicitly handled by the cipher's
decryption process. Note: The key must be extracted from the code using
`read_challenge_data` before running this script.

================================================================

COMMAND GENERATOR - Command list:
The correct approach involves leveraging the known plaintext (message) and the encrypted
flag to derive the keystream, which can then be used to decrypt the flag without needing the
key. Here's the step-by-step solution:

1. **Read the nonce, encrypted message, and encrypted flag** from the output.
2. **Compute the keystream** by XORing the encrypted message with the known plaintext
(message).
3. **Decrypt the encrypted flag** using the derived keystream.

### Corrected Script:
```python
import sys

# Known plaintext from the original code
known_message = b"Hello, this is the message"  # Replace with actual message from code

# Read inputs
nonce = bytes.fromhex(sys.stdin.readline().strip())
cipher_message = bytes.fromhex(sys.stdin.readline().strip())
cipher_flag = bytes.fromhex(sys.stdin.readline().strip())

# Compute keystream from known message and encrypted message
keystream = bytes([a ^ b for a, b in zip(cipher_message, known_message)])

# Decrypt the flag using the keystream
flag = bytes([a ^ b for a, b in zip(cipher_flag, keystream)])

# Output the flag in hex
print(flag.hex())
```
~~~

~~~
### Key Points:
- **No hardcoded key** is needed; the keystream is derived from the known plaintext and
encrypted message.
- **XOR operation** is used to extract the keystream and decrypt the flag.
- Replace `known_message` with the actual plaintext from the original code (e.g., "Hello,
this is the message").

This method bypasses the need for the key by exploiting the known plaintext and the
structure of ChaCha20 encryption.

================================================================

ACI - Results:
["File not found error: The correct approach involves leveraging the known plaintext
(message) and the encrypted flag to derive the keystream, which can then be used to decrypt
the flag without needing the key. Here's the step-by-step solution:"]

================================================================

RESULTS VERIFIER - Corrected Commands:
The correct approach involves leveraging the known plaintext (message) and the encrypted
flag to derive the keystream, which can then be used to decrypt the flag without needing the
key. Here's the step-by-step solution:

1. **Read the nonce, encrypted message, and encrypted flag** from the output.
2. **Compute the keystream** by XORing the encrypted message with the known plaintext
(message).
3. **Decrypt the encrypted flag** using the derived keystream.

### Corrected Script:
```python
import sys

# Known plaintext from the original code
known_message = b"Hello, this is the message"  # Replace with actual message from code

# Read inputs
nonce = bytes.fromhex(sys.stdin.readline().strip())
cipher_message = bytes.fromhex(sys.stdin.readline().strip())
cipher_flag = bytes.fromhex(sys.stdin.readline().strip())

# Compute keystream from known message and encrypted message
keystream = bytes([a ^ b for a, b in zip(cipher_message, known_message)])

# Decrypt the flag using the keystream
flag = bytes([a ^ b for a, b in zip(cipher_flag, keystream)])

# Output the flag in hex
print(flag.hex())
```

### Key Points:
- **No hardcoded key** is needed; the keystream is derived from the known plaintext and
encrypted message.
- **XOR operation** is used to extract the keystream and decrypt the flag.
- Replace `known_message` with the actual plaintext from the original code (e.g., "Hello,
this is the message").
~~~

```
This method bypasses the need for the key by exploiting the known plaintext and the
structure of ChaCha20 encryption.

================================================================

ACI - Results:
["File not found error: The correct approach involves leveraging the known plaintext
(message) and the encrypted flag to derive the keystream, which can then be used to decrypt
the flag without needing the key. Here's the step-by-step solution:"]

================================================================

SUMMARIZER - Summary:

The File not found error indicates the absence of a required file. The solution involves
using known plaintext (message) and the encrypted flag to derive the keystream. This
keystream can then be applied to decrypt the flag without requiring the original encryption
key. The method relies on leveraging the relationship between the plaintext and ciphertext
to reconstruct the keystream for decryption purposes.


================================================================

STRATEGY ANALYZER - Updated PTT:
1. **Crypto Challenge - Last Dance**
   - 1.1. **Nonce/IV Misuse** - {The code uses the same key and nonce for both the message
and the flag. ChaCha20 requires unique nonce-key pairs for each encryption to prevent
information leakage. Reusing the same key and nonce for multiple messages allows attackers
to XOR ciphertexts and potentially recover plaintexts. The solution involves leveraging
known plaintext (message) and encrypted flag to derive the keystream, enabling decryption
without the original key.}
   - 1.2. **Security Vulnerability** - {The flag is encrypted with the same key and nonce as
the message, making it susceptible to attacks exploiting nonce reuse. The solution relies on
deriving the keystream from the known plaintext and ciphertext relationship, bypassing the
need for the original encryption key.}
   - 1.3. **Output Format** - {The nonce is written in hex, followed by the encrypted
message and flag ciphertexts, each separated by newlines.}

================================================================

STRATEGY ANALYZER - Selected subtask:
<NEXT_TASK>
Use the known plaintext message and its corresponding ciphertext to XOR the encrypted flag
ciphertext, revealing the flag without the key. This works because ChaCha20's keystream
reuse allows plaintext recovery via XOR operations. The result is the decrypted flag.
</NEXT_TASK>

================================================================

GENERATOR - Guidance:
To perform the XOR-based decryption of the flag, follow these steps:

1. **Retrieve Challenge Data**: Use `read_challenge_data` with the correct `challenge_id` to
get the encrypted message and flag ciphertexts. The output will include the nonce (hex),
encrypted message (`msg_ciphertext`), and encrypted flag (`flag_ciphertext`).
   - Example: If the challenge ID is `123`, call `read_challenge_data(123)`.
```

~~~
2. **Extract Ciphertexts**: From the output, isolate the encrypted message
(`msg_ciphertext`) and the encrypted flag (`flag_ciphertext`). These are typically provided
as hex strings or byte sequences.

3. **Compute XOR of Ciphertexts**: XOR the encrypted message and flag ciphertexts to derive
the keystream. This is done using a Python script that processes the byte sequences.
   - Example:
     ```python
     msg_ciphertext = b"<msg_ciphertext_bytes>"
     flag_ciphertext = b"<flag_ciphertext_bytes>"
     keystream = bytes(a ^ b for a, b in zip(msg_ciphertext, flag_ciphertext))
     ~~~

4. **Decrypt the Flag**: XOR the keystream with the known plaintext message
(`msg_plaintext`) to recover the flag.
   - Example:
     ```python
     msg_plaintext = b"<known_plaintext>"
     flag = bytes(a ^ b for a, b in zip(msg_plaintext, keystream))
     ```

5. **Output the Flag**: The result of the above step is the decrypted flag in bytes. Convert
it to a string (e.g., using `flag.decode()` if applicable) and verify it matches the
expected format.

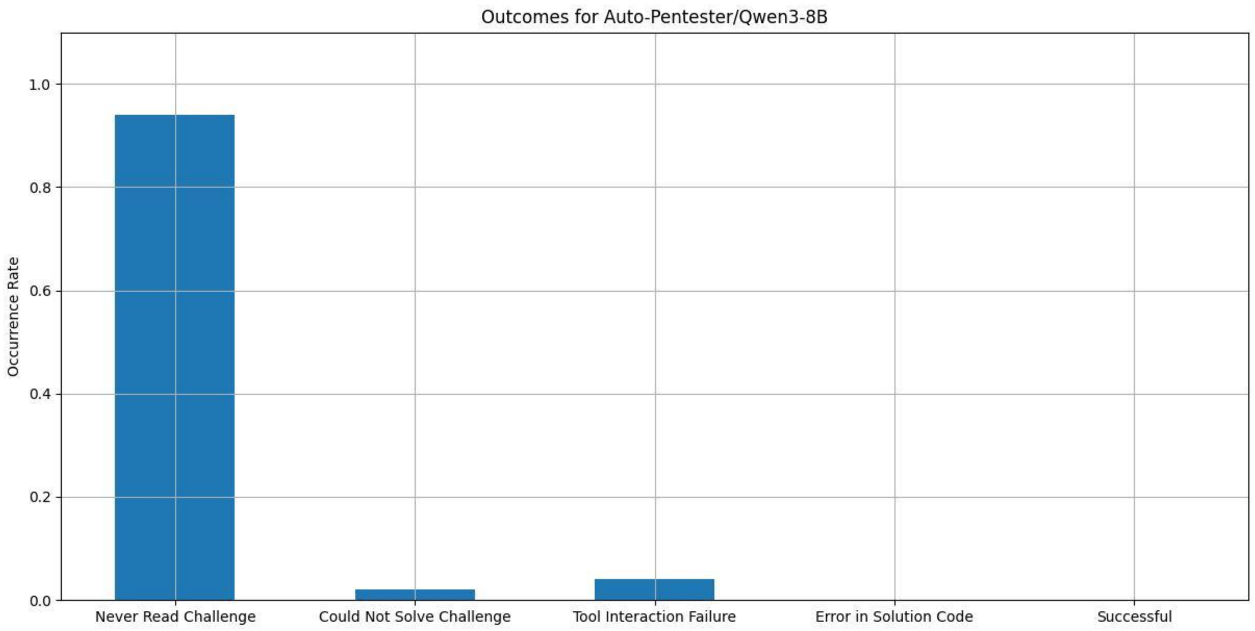
Tool Calls:
- Use `read_challenge_data(<challenge_id>)` to fetch the ciphertexts.
- Use `run_python` with the script above to perform the XOR operations and retrieve the
flag.

Note: Ensure the `challenge_id` is correct. If unsure, first use `list_challenges` to
identify valid IDs.

==

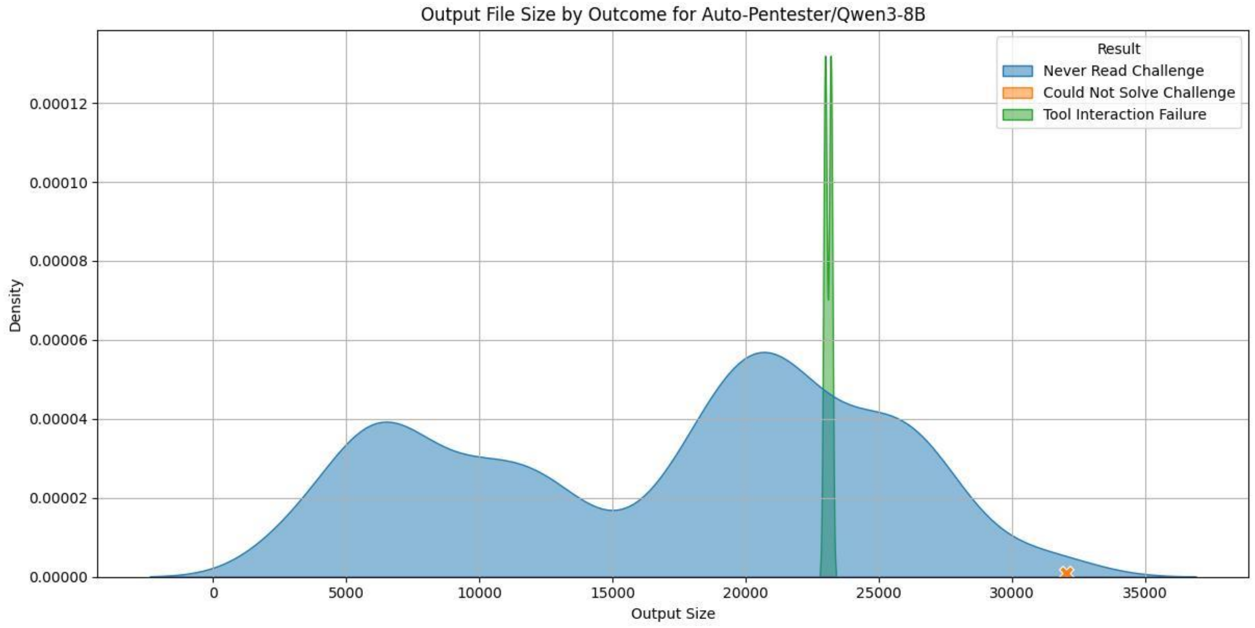
COMMAND GENERATOR - Command list:
TOOL_CALL
read_challenge_data
{
    "challenge_id": 0
}

==
```

No trial in this architecture successfully called the run python tool. Most trials did not even successfully read the challenge data. Below is a breakdown of the 50 trial outcomes:
```



As can be seen, only 6% of trials were able to read the challenge data. No trials were able to submit code to the run python tool, and as such, none were successful. The vast majority of trials failed to make the proper tool call to read the challenge data, a category of outcomes that the previous architecture never encountered.

We believe this is likely due to the necessary context to fix mistakes not being properly passed through the pipeline effectively enough for the agents to correct their mistakes. Additionally, the system prompts used by this architecture were likely created and tuned to a more performant model than Qwen3-8B. While modifying the tools' individual prompts would have been an interesting facet to study, that was outside of the scope for this study. Below is a breakdown of the output file size for this architecture:

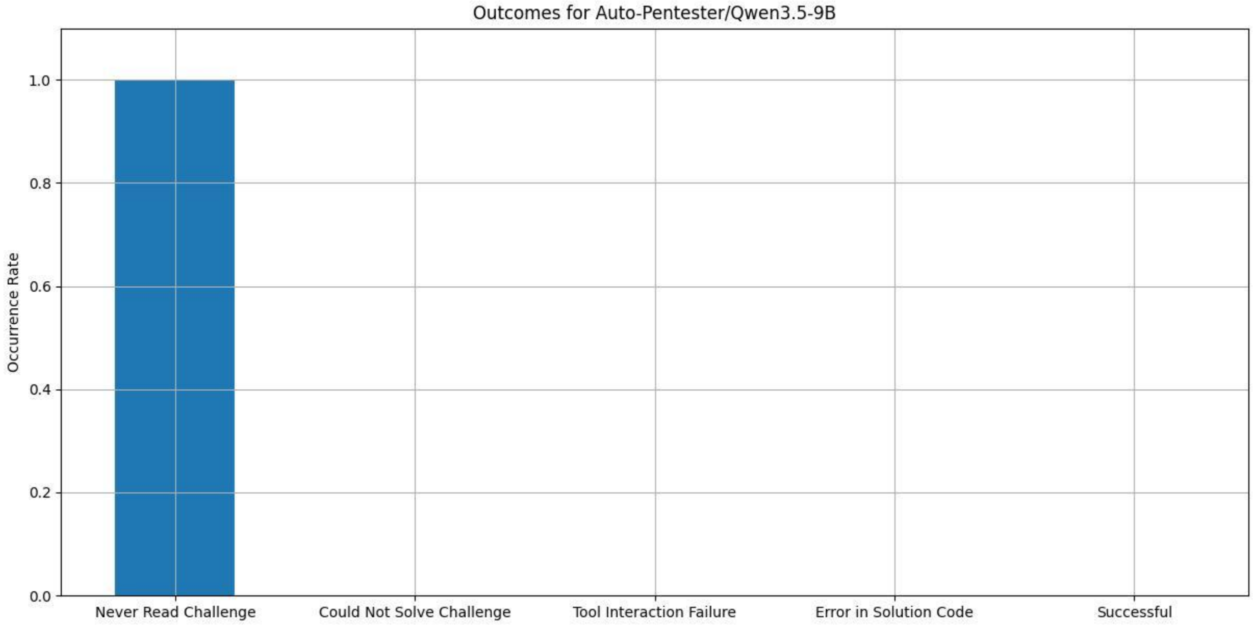


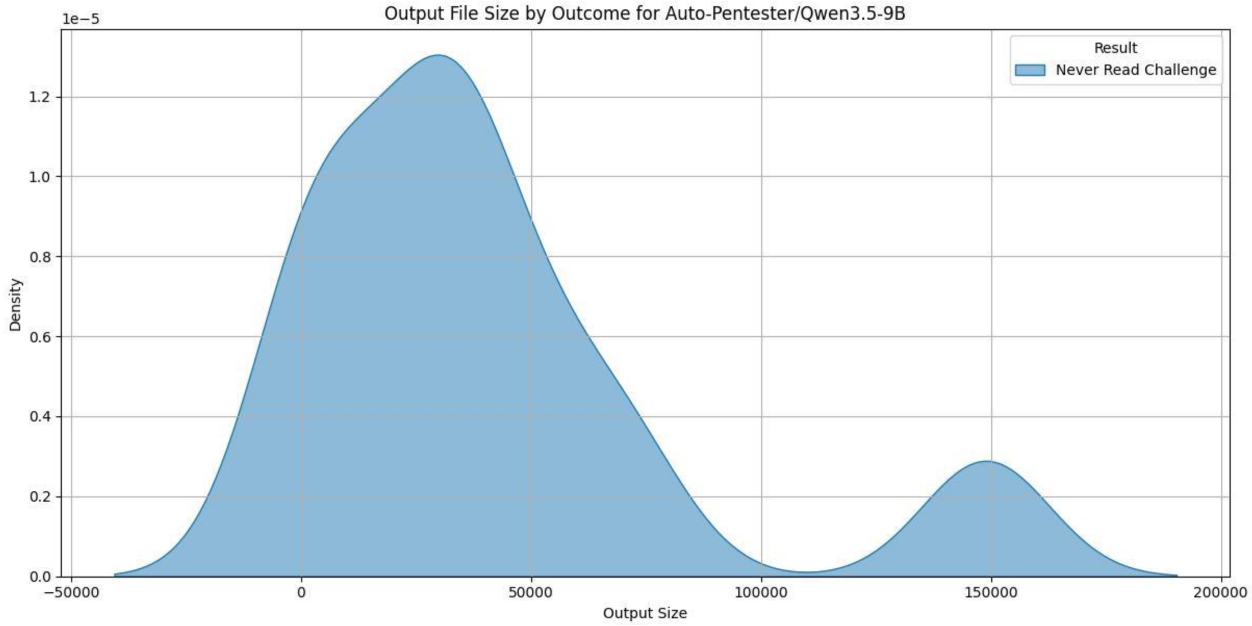
While this may seem promising, that given more time to output, the architecture may be more performant, the data that is saved to the output files for this architecture is very different. Firstly, a bug was fixed that repeated every agent's output. Secondly, no system prompts were included in the output from this architecture. Finally, not pictured are multiple trials with an output size of over 4 MB. Instead of comparing this chart to previous output file size charts, in terms of raw numbers, it is more interesting to examine the overall shape. For the simple architecture, the output file sizes were generally consistent, resulting in sharp, concentrated peaks generally low variance. However, for this more complex system, there was far more variance, with much flatter peaks. This shows the inconsistency of outputs by this system, and that it was not built for the models used for this study, without considerable adaptation or modification.

3.4. Auto-Pentester/Qwen3.5-9B

None of the 10 trials for the Auto-Pentester architecture with the Qwen3.5-9B model successfully read the challenge data. This portion was shortened to 50 trials because of the previously discussed tendency of Qwen3.9-9B to repeat itself. This was the first instance of trials that had to be manually stopped because the agent appeared to truly get stuck repeating itself.

While this could be remedied by stopping text generation after a set number of tokens, the mere presence of this problem illustrates that this architecture was not built for this specific model. Again, it would have been interesting to examine how significantly the system prompts would need to be modified to fit the architecture of this model, but that was outside of the scope of this initial study. For the sake of completeness, below are the graphs of the outcome distribution and file output size for the Qwen3.5-9B model in the Auto-Pentester architecture:

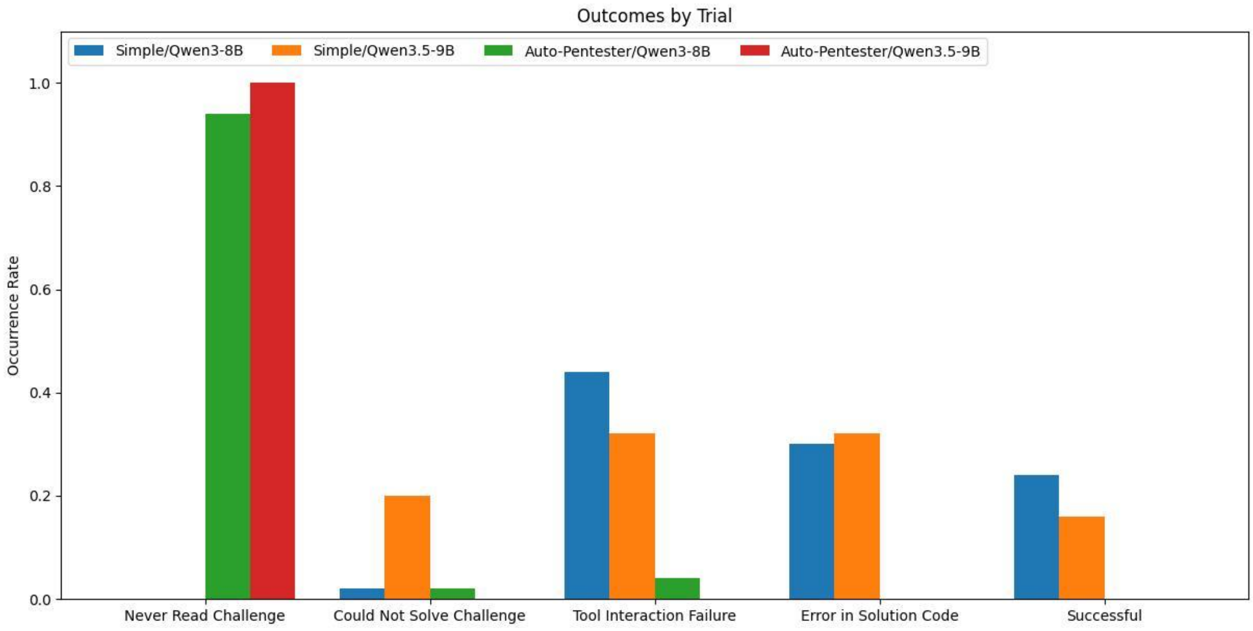




The Qwen3.5-9B model had a wider range of output sizes, ranging from 887 B, where it gave up, to an unknown quantity after the generation was manually stopped after the trial ran for several hours.

4. Comparison of Architectures

Below is a breakdown of each model and architecture's outcome distribution across the five measured outcomes:



As previously stated, the Auto-Pentester architecture was very clearly not built for the Qwen-class models under 10 billion parameters. A significant amount of time was spent tuning the system prompts for the simple architecture for the Qwen3-8B model, so in that respect, the simple architecture had an advantage over the Auto-Pentester architecture. Additionally, modifying the system prompts for the Qwen3.5-9B model likely could have reduced its tendency to overthink, albeit not remove the problem altogether, so in that respect, the Qwen3-8B model also had an advantage.

5. Conclusion

Our research study leads us to believe that the most important facet of an automated security tool is to ensure to fit the model to its surrounding architecture. Even within the same class of model, there are significant differences between model versions that significantly change the success rates of the model within the same architecture. In the future, we plan in studying the impact of model size on models that are properly fit into their architecture. We also plan on experimenting with replacing the summarizer with a couple other information distillation techniques, such as indexing returned code into a vector database and including the ‘N’ nearest code snippets for the strategy analyzer’s context or providing access to libraries such as pyscope[2] via the ACI to allow sub-agents to retrieve targeted information. We also plan to compare this to returning the output raw, instead of summarized, and seeing whether this positively or negatively impacts the architecture. We then plan to extensively test variations of these architectures in an ablation study to determine the most important contributions to successful architectures.

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[2] https://pypi.org/project/pyscope/