

# Leveraging LLMs for Memory Forensics

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## A Comparative Analysis of Malware Detection

*Key takeaway: Memory forensics with LLMs is feasible: reasoning boosts detection, false positives remain high, and the human analyst remains responsible.*

Jan-Hendrik Lang & Thomas Schreck, September 16th - 17th, 2025

# Motivation



Windows PowerShell

Progress: 100.00 PDB scanning finished

PID	PPID	ImageFileName	Offset(V)	Threads	Handles	SessionId	Wow64	CreateTime	ExitTime	File output
980	2924	AggregatorHost	0xa8800003c240	3	-	0	False	2025-02-24 10:40:21.000000 UTC	N/A	Disabled
7408	820	svchost.exe	0xa88000041080	4	-	0	False	2025-02-24 10:40:56.000000 UTC	N/A	Disabled
4	0	System	0xce09fc486040 169	-	N/A	False	2025-02-24 10:40:12.000000 UTC	N/A	Disabled	
1716	820	svchost.exe	0xce09fc4d1080	10	-	0	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
1900	820	svchost.exe	0xce09fc4f1080	10	-	0	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
1728	820	svchost.exe	0xce09fc4f5080	6	-	0	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
72	4	Registry	0xce09fc524080	4	-	N/A	False	2025-02-24 10:40:08.000000 UTC	N/A	Disabled
1848	820	svchost.exe	0xce09fc591080	2	-	0	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
1860	820	svchost.exe	0xce09fc593080	5	-	0	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
1808	4	MemCompression	0xce09fc599040	42	-	N/A	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
1744	820	svchost.exe	0xce09fc5c8080	3	-	0	False	2025-02-24 10:40:15.000000 UTC	N/A	Disabled
528	4	smss.exe	0xce09ff4a9040	2	-	N/A	False	2025-02-24 10:40:12.000000 UTC	N/A	Disabled
5640	820	svchost.exe	0xce09ff662080	7	-	0	False	2025-02-24 10:40:39.000000 UTC	N/A	Disabled
2472	820	svchost.exe	0xce09ff6e1300	2	-	0	False	2025-02-24 10:40:16.000000 UTC	N/A	Disabled
632	624	csrss.exe	0xce09ff8c3140	10	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
820	700	services.exe	0xce0a001c3080	7	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
700	624	wininit.exe	0xce0a001ca080	1	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
708	692	csrss.exe	0xce0a001cd140	12	-	1	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
828	700	lsass.exe	0xce0a0081c080	9	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
756	692	winlogon.exe	0xce0a0084f140	6	-	1	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
912	756	fontdrvhost.ex	0xce0a0085a080	5	-	1	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
904	700	fontdrvhost.ex	0xce0a0085f2c0	5	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
972	820	svchost.exe	0xce0a008c7240	29	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
1016	820	svchost.exe	0xce0a009112c0	18	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
712	820	svchost.exe	0xce0a00968240	6	-	0	False	2025-02-24 10:40:13.000000 UTC	N/A	Disabled
560	756	dwm.exe	0xce0a009ed080 16	-	1	False	2025-02-24 10:40:14.000000 UTC	N/A	Disabled	
1112	820	svchost.exe	0xce0a00a5a240	5	-	0	False	2025-02-24 10:40:14.000000 UTC	N/A	Disabled
7928	972	ApplicationFra	0xce0a00a5c080	9	-	1	False	2025-02-24 10:41:23.000000 UTC	N/A	Disabled
1128	820	svchost.exe	0xce0a00a662c0	2	-	0	False	2025-02-24 10:40:14.000000 UTC	N/A	Disabled
1168	820	svchost.exe	0xce0a00a7a300	3	-	0	False	2025-02-24 10:40:14.000000 UTC	N/A	Disabled

# Motivation



```
Windows PowerShell
Progress: 100.00 PDB scanning finished
Offset Proto LocalAddr LocalPort ForeignAddr ForeignPort State PID Owner Created
0xa880000acaa0 TCPv4 192.168.241.129 49696 104.126.37.137 443 CLOSE_WAIT 6688 SearchApp.exe 2025-02-24 10:40:44.000000 UTC
0xce09fc48d050 TCPv4 0.0.0.0 49668 0.0.0.0 0 LISTENING 2204 spoolsv.exe 2025-02-24 10:40:16.000000 UTC
0xce09fc48d470 TCPv4 0.0.0.0 445 0.0.0.0 0 LISTENING 4 System 2025-02-24 10:40:16.000000 UTC
0xce09fc48d470 TCPv6 :: 445 :: 0 LISTENING 4 System 2025-02-24 10:40:16.000000 UTC
0xce09fc48db50 TCPv4 192.168.241.129 139 0.0.0.0 0 LISTENING 4 System 2025-02-24 10:40:15.000000 UTC
0xce09ff3fe730 TCPv4 0.0.0.0 49668 0.0.0.0 0 LISTENING 2204 spoolsv.exe 2025-02-24 10:40:16.000000 UTC
0xce09ff3fe730 TCPv6 :: 49668 :: 0 LISTENING 2204 spoolsv.exe 2025-02-24 10:40:16.000000 UTC
0xce09ff5705c0 TCPv4 192.168.241.129 49698 204.79.197.222 443 CLOSED 6688 SearchApp.exe 2025-02-24 10:40:45.000000 UTC
0xce09ff7f05d0 TCPv4 0.0.0.0 135 0.0.0.0 0 LISTENING 1016 svchost.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f05d0 TCPv6 :: 135 :: 0 LISTENING 1016 svchost.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f0890 TCPv4 0.0.0.0 49665 0.0.0.0 0 LISTENING 700 wininit.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f0890 TCPv6 :: 49665 :: 0 LISTENING 700 wininit.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f09f0 TCPv4 0.0.0.0 49666 0.0.0.0 0 LISTENING 1340 svchost.exe 2025-02-24 10:40:14.000000 UTC
0xce09ff7f0b50 TCPv4 0.0.0.0 49666 0.0.0.0 0 LISTENING 1340 svchost.exe 2025-02-24 10:40:14.000000 UTC
0xce09ff7f0b50 TCPv6 :: 49666 :: 0 LISTENING 1340 svchost.exe 2025-02-24 10:40:14.000000 UTC
0xce09ff7f1390 TCPv4 0.0.0.0 49667 0.0.0.0 0 LISTENING 1332 svchost.exe 2025-02-24 10:40:14.000000 UTC
0xce09ff7f1650 TCPv4 0.0.0.0 49667 0.0.0.0 0 LISTENING 1332 svchost.exe 2025-02-24 10:40:14.000000 UTC
0xce09ff7f1650 TCPv6 :: 49667 :: 0 LISTENING 1332 svchost.exe 2025-02-24 10:40:14.000000 UTC
0xce09ff7f17b0 TCPv4 0.0.0.0 49665 0.0.0.0 0 LISTENING 700 wininit.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f1bd0 TCPv4 0.0.0.0 135 0.0.0.0 0 LISTENING 1016 svchost.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f1d30 TCPv4 0.0.0.0 49664 0.0.0.0 0 LISTENING 828 lsass.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f1e90 TCPv4 0.0.0.0 49664 0.0.0.0 0 LISTENING 828 lsass.exe 2025-02-24 10:40:13.000000 UTC
0xce09ff7f1e90 TCPv6 :: 49664 :: 0 LISTENING 828 lsass.exe 2025-02-24 10:40:13.000000 UTC
0xce0a00cacd10 UDPv4 192.168.241.129 138 * 0 4 System 2025-02-24 10:40:15.000000 UTC
0xce0a00cad030 UDPv4 192.168.241.129 137 * 0 4 System 2025-02-24 10:40:15.000000 UTC
0xce0a00edb220 UDPv4 0.0.0.0 0 * 0 1096 svchost.exe 2025-02-24 10:40:16.000000 UTC
0xce0a00edb220 UDPv6 :: 0 * 0 1096 svchost.exe 2025-02-24 10:40:16.000000 UTC
0xce0a00edb860 UDPv4 0.0.0.0 5353 * 0 1096 svchost.exe 2025-02-24 10:40:16.000000 UTC
0xce0a00edb860 UDPv6 :: 5353 * 0 1096 svchost.exe 2025-02-24 10:40:16.000000 UTC
```

# Motivation



```
Windows PowerShell
Volatility 3 Framework 2.8.0
Progress: 100.00 PDB scanning finished
Pid Process Base InLoad InInit InMem MappedPath
4 System 0x77120000 False False False \Windows\SysWOW64\ntdll.dll
4 System 0x7ff94c150000 False False False \Windows\System32\vertdll.dll
4 System 0x7ff94c190000 False False False \Windows\System32\ntdll.dll
528 smss.exe 0x7ff94c190000 True True True \Windows\System32\ntdll.dll
528 smss.exe 0x7ff70d350000 True False True \Windows\System32\smss.exe
632 csrss.exe 0x10e6ab80000 False False False \Windows\System32\de-DE\csrss.exe.mui
632 csrss.exe 0x10e6ab90000 False False False \Windows\System32\de-DE\winsrv.dll.mui
632 csrss.exe 0x7ff949810000 True True True \Windows\System32\csrssrv.dll
632 csrss.exe 0x7ff74ff70000 True False True \Windows\System32\csrss.exe
632 csrss.exe 0x7ff9497d0000 True True True \Windows\System32\winsrv.dll
632 csrss.exe 0x7ff949790000 True True True \Windows\System32\sxssrv.dll
632 csrss.exe 0x7ff949560000 True True True \Windows\System32\sxs.dll
632 csrss.exe 0x7ff9497a0000 True True True \Windows\System32\winsrvext.dll
632 csrss.exe 0x7ff9497f0000 True True True \Windows\System32\basesrv.dll
632 csrss.exe 0x7ff94a330000 True True True \Windows\System32\kernel32.dll
632 csrss.exe 0x7ff949c60000 True True True \Windows\System32\cfgmgr32.dll
632 csrss.exe 0x7ff9499a0000 True True True \Windows\System32\gdi32full.dll
632 csrss.exe 0x7ff949830000 True True True \Windows\System32\ucrtbase.dll
632 csrss.exe 0x7ff949c30000 True True True \Windows\System32\win32u.dll
632 csrss.exe 0x7ff949ba0000 True True True \Windows\System32\bcryptprimitives.dll
632 csrss.exe 0x7ff949cb0000 True True True \Windows\System32\KernelBase.dll
632 csrss.exe 0x7ff94a110000 True True True \Windows\System32\msvc_p_win.dll
632 csrss.exe 0x7ff94bf20000 True True True \Windows\System32\user32.dll
632 csrss.exe 0x7ff94ba30000 True True True \Windows\System32\combase.dll
632 csrss.exe 0x7ff94aac0000 True True True \Windows\System32\rpcrt4.dll
632 csrss.exe 0x7ff94c190000 True True True \Windows\System32\ntdll.dll
632 csrss.exe 0x7ff94c120000 True True True \Windows\System32\gdi32.dll
700 wininit.exe 0x7ff61bb20000 True False True \Windows\System32\wininit.exe
```



- **Expertise-Intensive:** requires deep specialist knowledge & manual effort
- **Data Overload:** numerous plugin outputs, subtle IoCs to correlate
- **Steep Learning Curve:** difficult for less-experienced analysts
- **Memory Forensics Importance:** essential for detecting fileless malware & APTs
- **Analyst Fatigue:** overload increases errors and slows detection
- **Underexplored AI Potential:** unclear if LLMs can reduce effort while preserving accuracy



- 1. Detection Performance:** How do different LLMs perform in detecting malware from Volatility3 data?
- 2. Impact of Reasoning:** Do reasoning-enabled (“thinking mode”) configurations yield statistically significant improvements in detection quality?
- 3. Limitations & Error Sources:** What drives false positives and false negatives, and can adding baseline system knowledge reduce these errors?



- **Proof-of-Concept Prototype Goals**

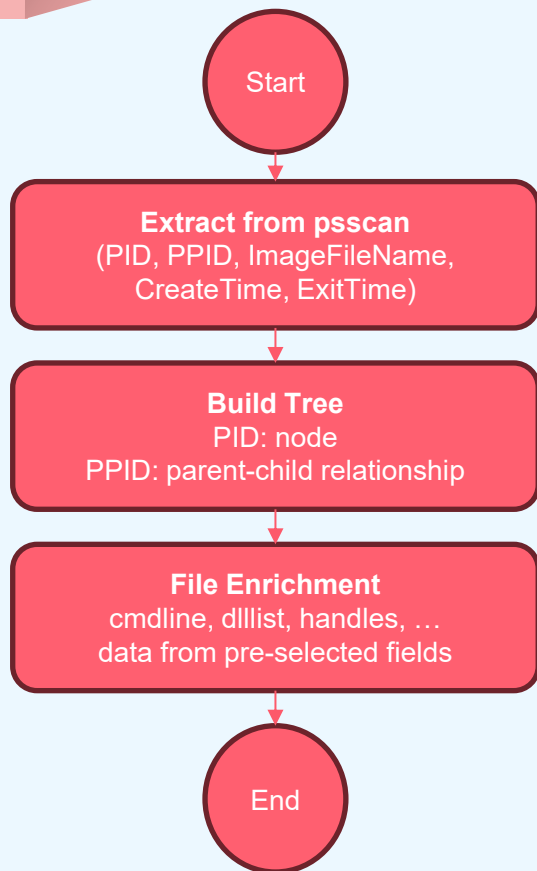
- Volatility3 automated
- Volatility3 output prepared for an LLM
- forwarding the processed output to an LLM and displaying the results
- to recognize anomalies on its own in the best case

- **Result**

- Development of a Streamlit app
- Available at: <https://github.com/jan-hendrik-lang/MemoryInvestigator>

- **Features**

- Automation Volatility3 Version 2.8.0
- Display and search of data as table and graph
- Preparation of the data as a user-defined tree-of-table<sup>1</sup> for further use of the LLM
- LLM-supported analysis of the tree-of-table
- Dynamic creation of a RAG using PDF files or Malpedia Thread Reports



### Volatility3 Modules:

- Process modules like *psscan*, *cmdline*, *dlllist*.
- Network modules like *netscan*.
- Malware-specific plugins like *malfind*, *processghosting*, *suspicious\_threads*.
- Privilege and persistence indicators like *getsids* and *svcdiff*.





### Processes

- **System (pid=4, ppid=0)**
  - SID: S-1-5-18, S-1-5-32-544, ...
  - ldrmodules: ntdll.dll [InInit=False, InLoad=False, InMem=False]
  - netscan: UDPv4, 192.168.10.210:137 → LISTENING
- **Registry (pid=92)**
  - SID: S-1-5-18, S-1-5-32-544, ...
  - ldrmodules: ntdll.dll [InInit=False, InLoad=False, InMem=False]
  - netscan: UDPv4, 192.168.10.210:137 → LISTENING
- **smss.exe (pid=328)**



### System Message:

You are a forensic RAM analyst assistant specializing in Windows memory analysis. Analyze the JSON tree of Windows memory artifacts to detect intrusions or malicious activities. Cross-check your findings with known threats and provide clear, specific reasons for flagging any anomalies (e.g., unusual parentchild relationships, code injection, execution from nonstandard locations). If you are unsure, ask clarifying questions, and if you don't know, say so. Generate a structured forensic report highlighting confirmed threats while minimizing noise. Data: *"Tree-of-Table Data"*

**User Message:** Analyze the data and determine whether there is an anomaly.



- **Test Scenarios:**

- Clean Image,
- Process Injection (msfvenom),
- PowerShell Empire,
- QuasarRAT (Remote Access Trojan),
- MassLogger (keylogger),
- DarkCloud (trojan),
- LockBit (ransomware),
- LokiBot (stealer).

- **LLMs for Comparison:**

- OpenAI GPT-4o,
- OpenAI o1,
- Google Gemini 2.0 Flash,
- Google Gemini 2.0 Flash-Thinking,
- Grok 3,
- Grok 3 with enabled thinking mode.



Build Test  
Enviroment

Select  
Malware

Execute  
Malware

Take  
Memory  
Image

Analyse  
with LLMs  
(240 trails)

### Performance Metrics:

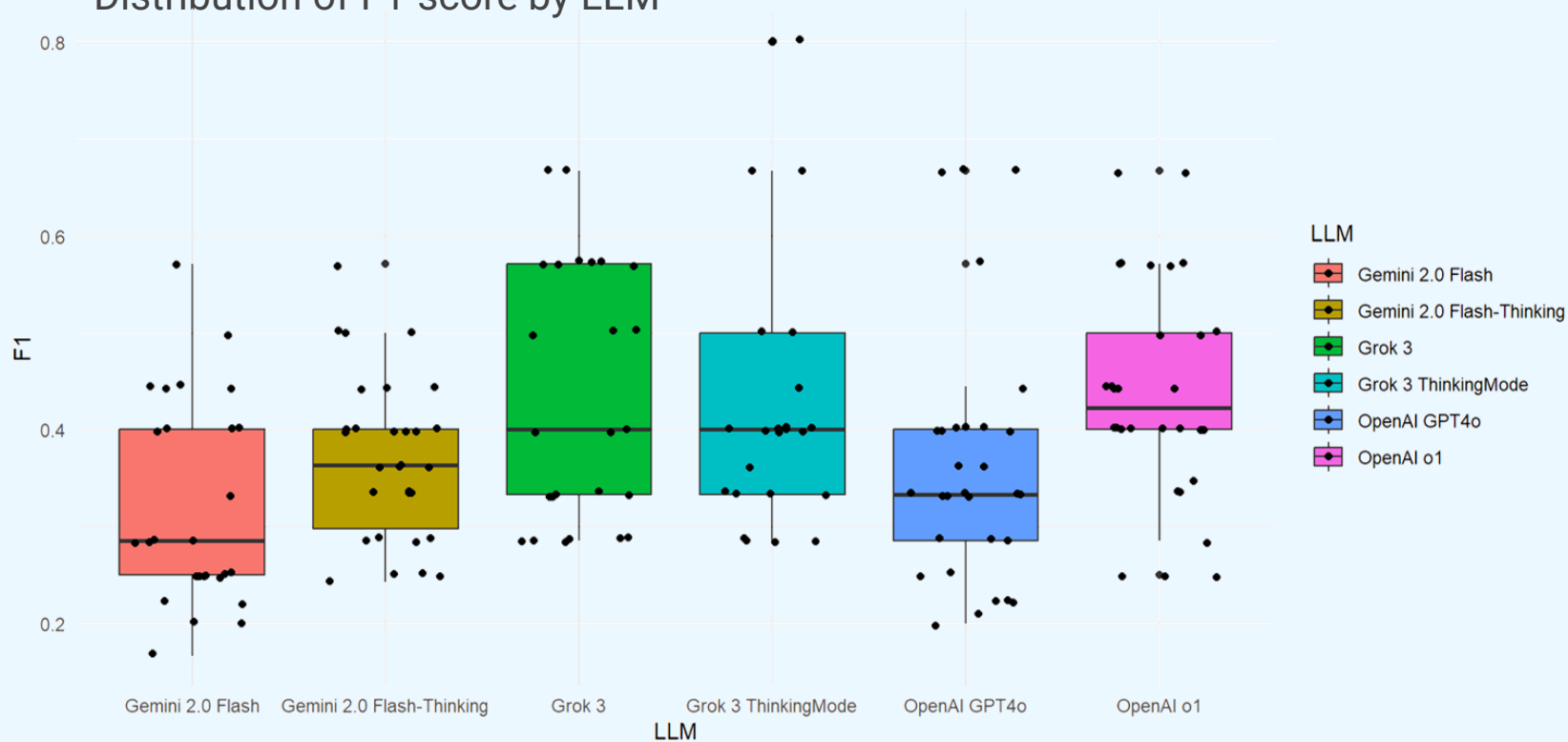
- Accuracy,
- Precision,
- Recall,
- F1-score,
- ANOVA,
- t-tests.



- **Experiment scale:** 240 trials (8 scenarios × 1 image × 6 LLMs × 5 runs)
- **Detection:** All LLMs found malicious evidence in most scenarios
- **Reasoning helps:** “Thinking” modes consistently outperformed standard modes
- **Different strengths:** Models excel at different artifact types (e.g., network vs. script decoding)
- **Performance pattern:** Very high recall (often  $\approx 100\%$ ) — low precision (precision often  $< 20\%$ )
- **Blind spot:** LockBit IoCs were outside available inputs → missed detections
- **Common FP source:** malfind outputs (e.g., MsMpEng.exe) frequently mis-flagged



## Distribution of F1-score by LLM





- **Dataset Scope:** one memory image per scenario; limited to Windows 10
- **Data Coverage:** only selected Volatility3 plugins; no registry hives, EVTX logs, or raw strings
- **Model Dependence:** results bound to specific LLM versions & modes (non-deterministic behavior)
- **Precision Gap:** high false positive rate; not suitable as a standalone detection system
- **Generalizability:** performance on other OS, larger datasets, or different attack techniques remains untested



- **Broader Data Sources:** include registry hives, event logs, and memory strings
- **Improve Precision:** integrate baseline system<sup>2</sup> knowledge to filter benign processes
- **Advanced LLM Integration:** fine-tune models on forensic data; evaluate next-gen LLMs
- **User Studies & Deployment:** measure analyst time savings, detection gains, usability
- **Tool Enrichment:** expand from Volatility3 towards MemProcFS or Velociraptor
- **Protocol Experimentation:** test Model Context Protocol (MCP) as an alternative to tree-of-tables





- **Feasibility & Value:** LLMs can sift memory data and highlight likely IoCs
- **Recall vs. Precision:** strong recall, but very low precision (many false alarms)
- **Context Matters:** success depends on the breadth of forensic input data
- **Human Essential:** analysts remain critical due to false positives & blind spots
- **LLMs as Support:** assist in triage, improve interpretability, not a replacement

## Contact Details

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## GitHub Repo:

[https://github.com/  
jan-hendrik-lang/  
MemoryInvestigator](https://github.com/jan-hendrik-lang/MemoryInvestigator)

# AI be like:



# everything is malware