Research Institute
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A Scenario-Based Quality Assessment of Memory Acquisition Tools and its Investigative Implications

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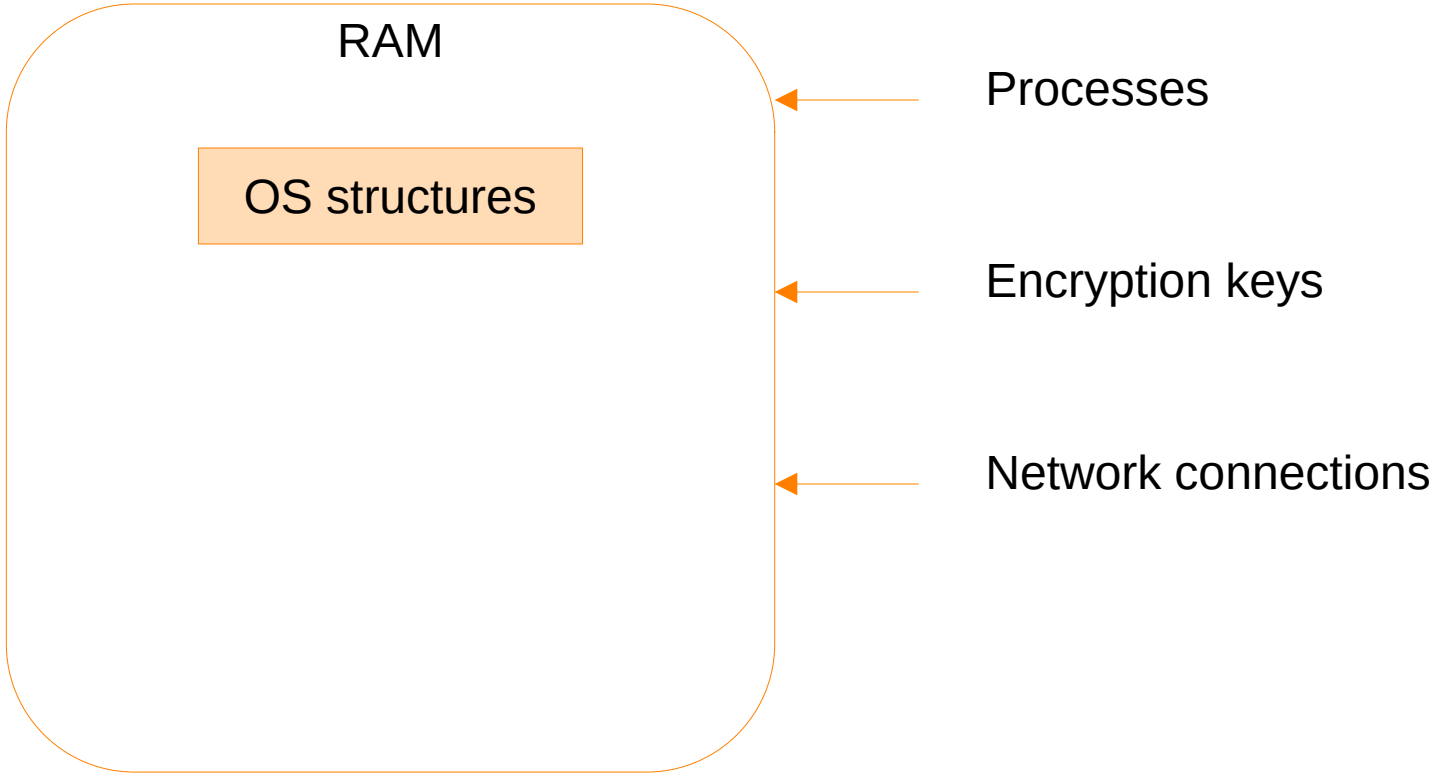
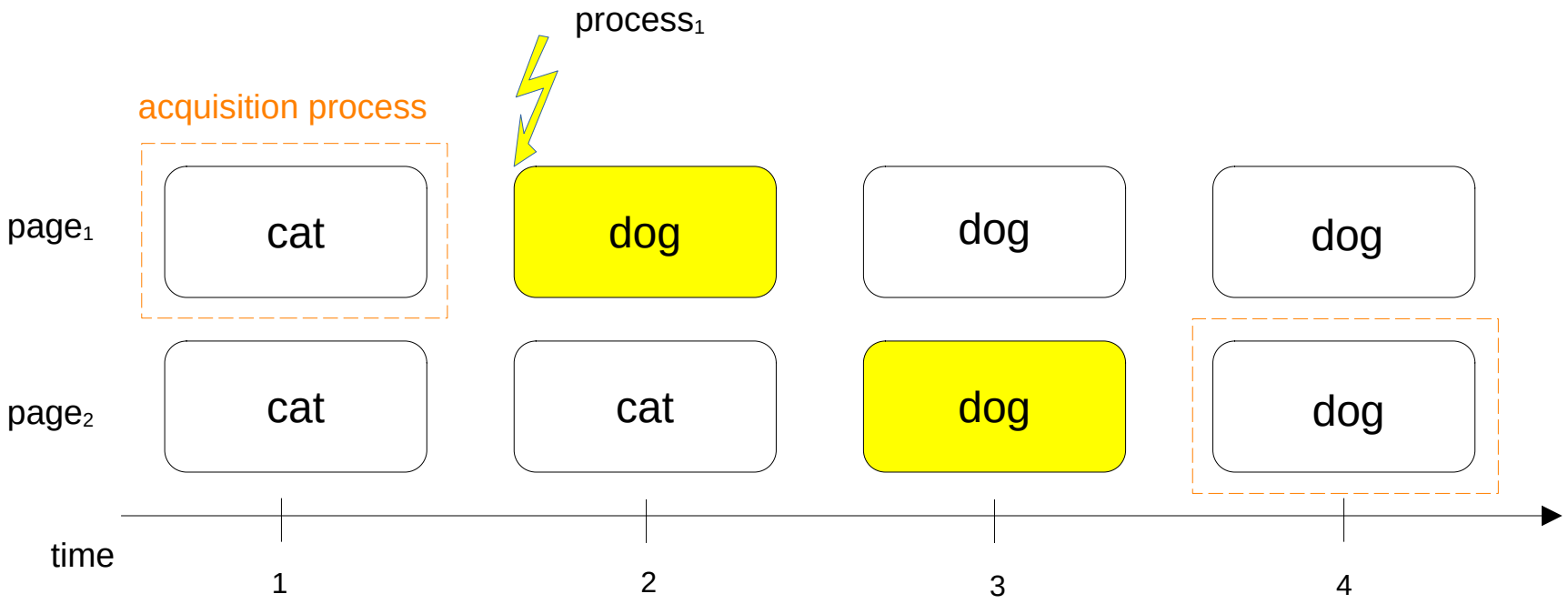
Motivation

Main memory



Motivation

Inconsistencies

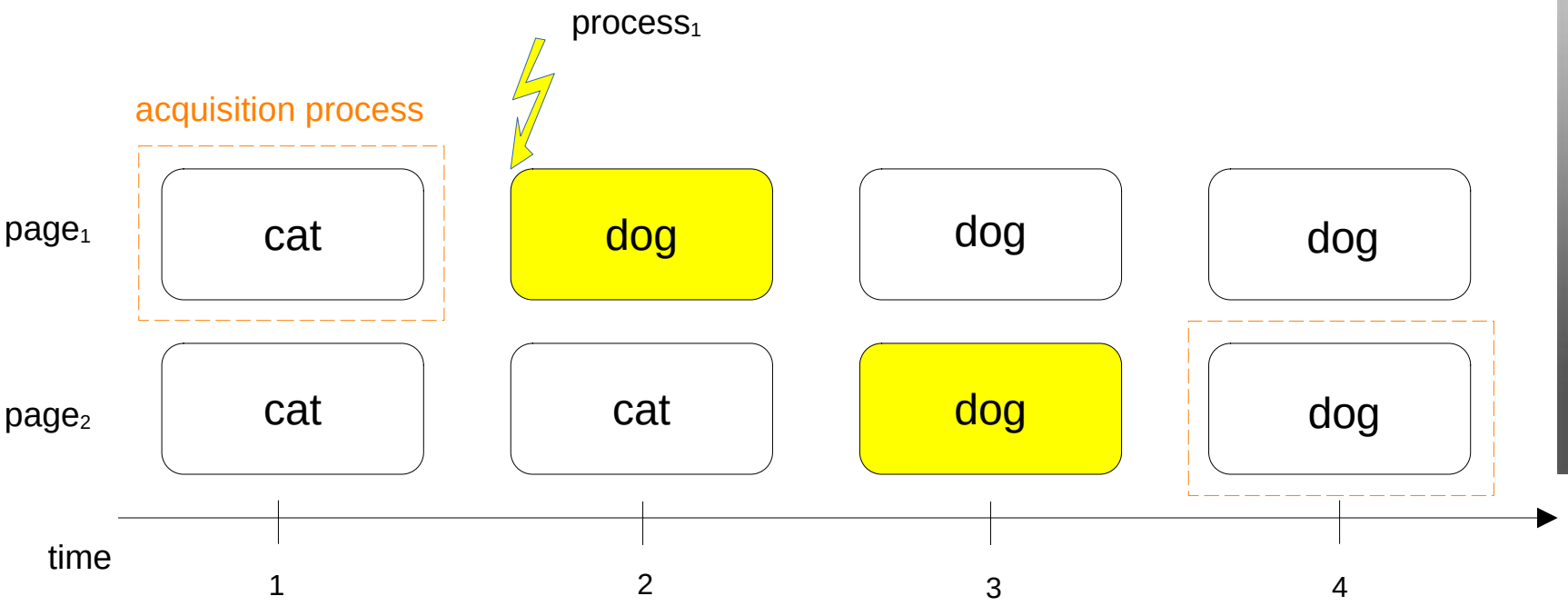


expected result

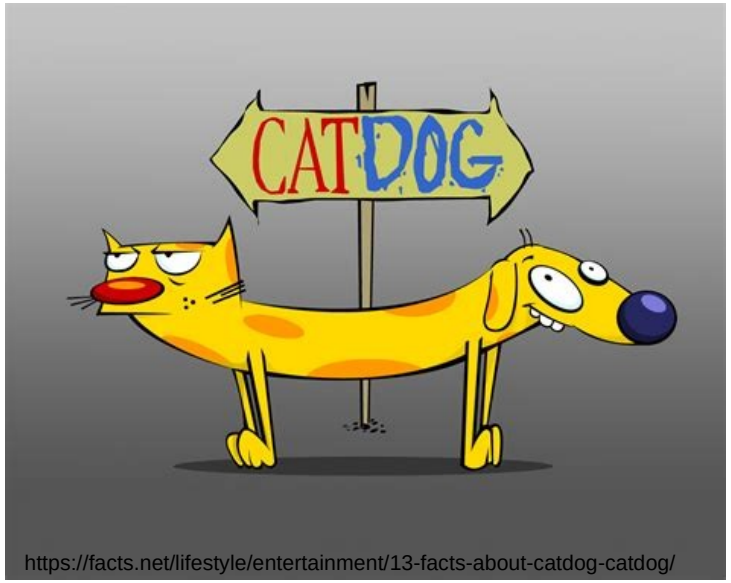
Image generated with ChatGPT

Motivation

Inconsistencies



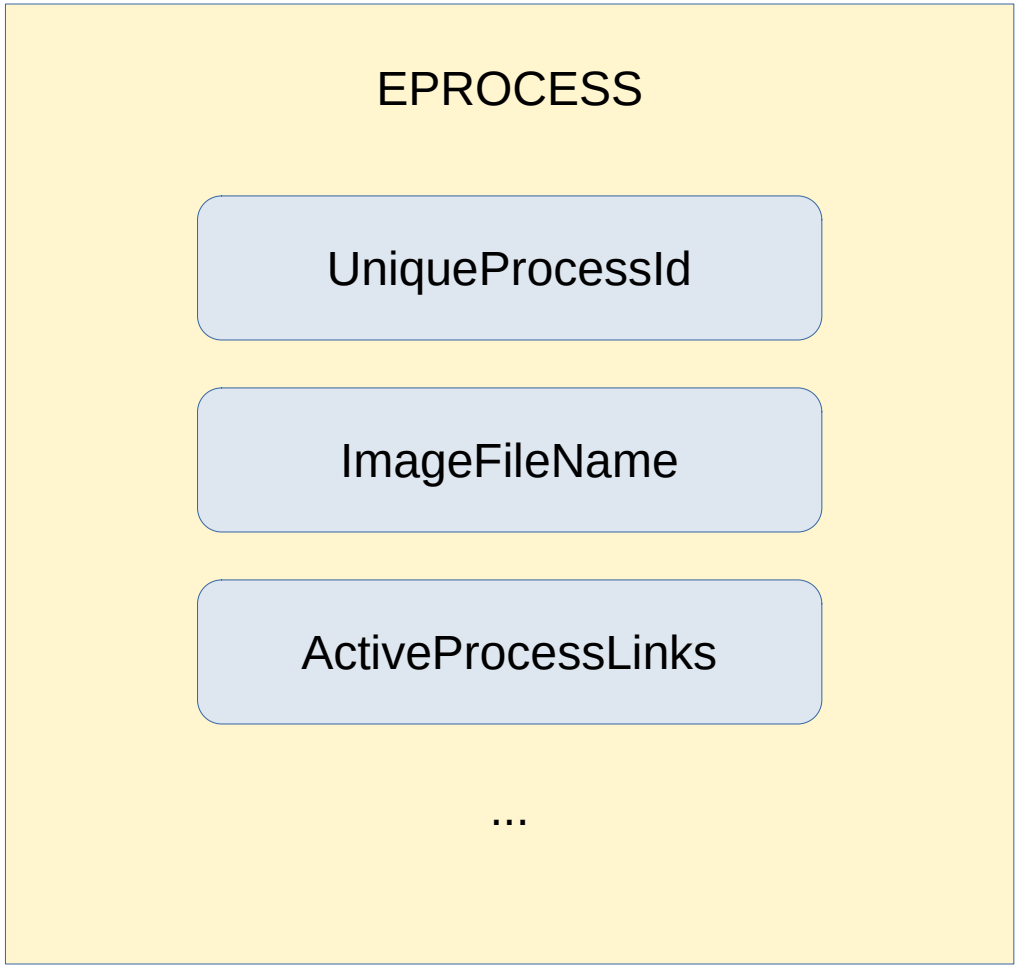
actual result



Motivation

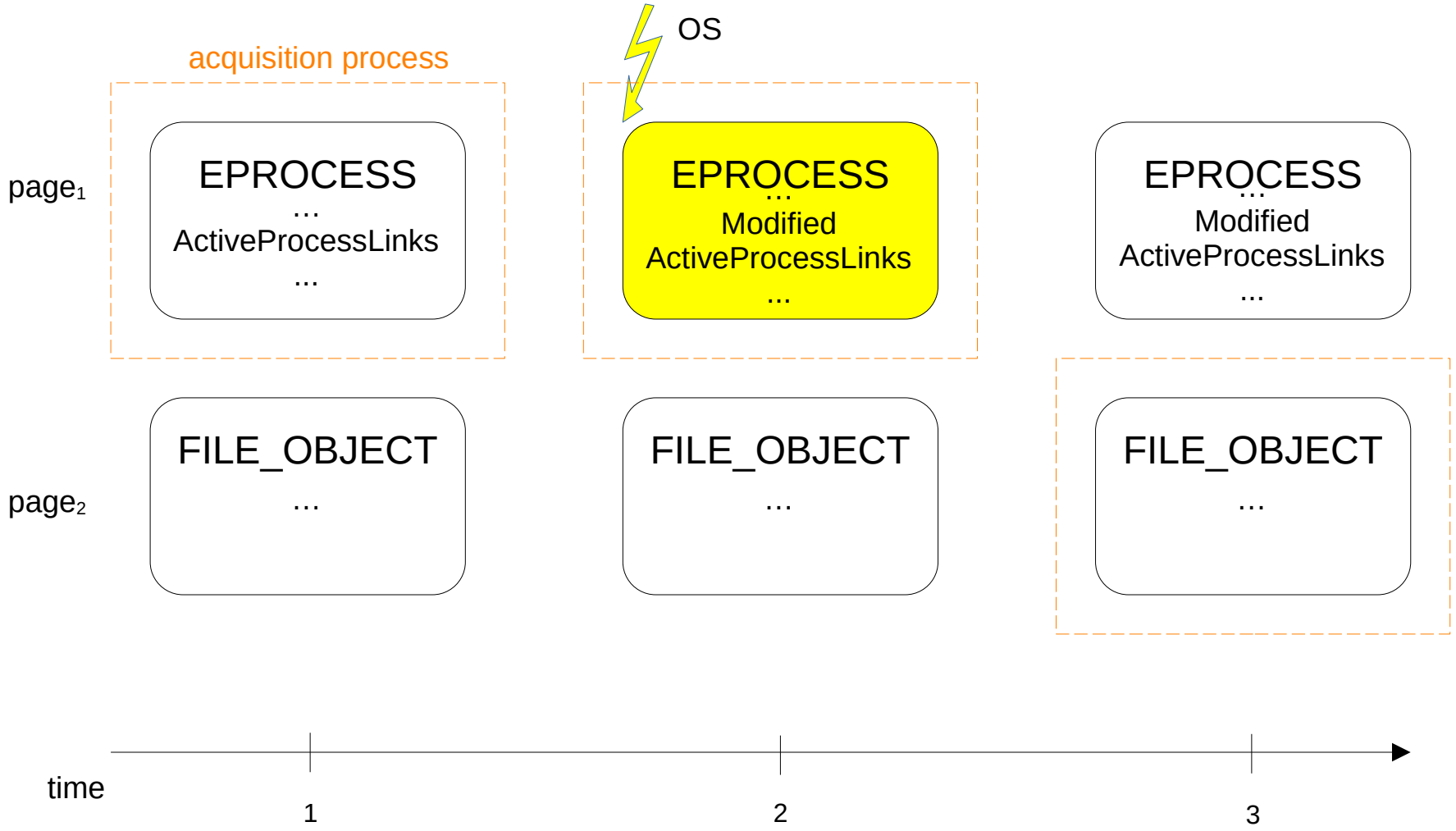
EPROCESS

- OS structure in Windows OS
- Information about (running) process



Motivation

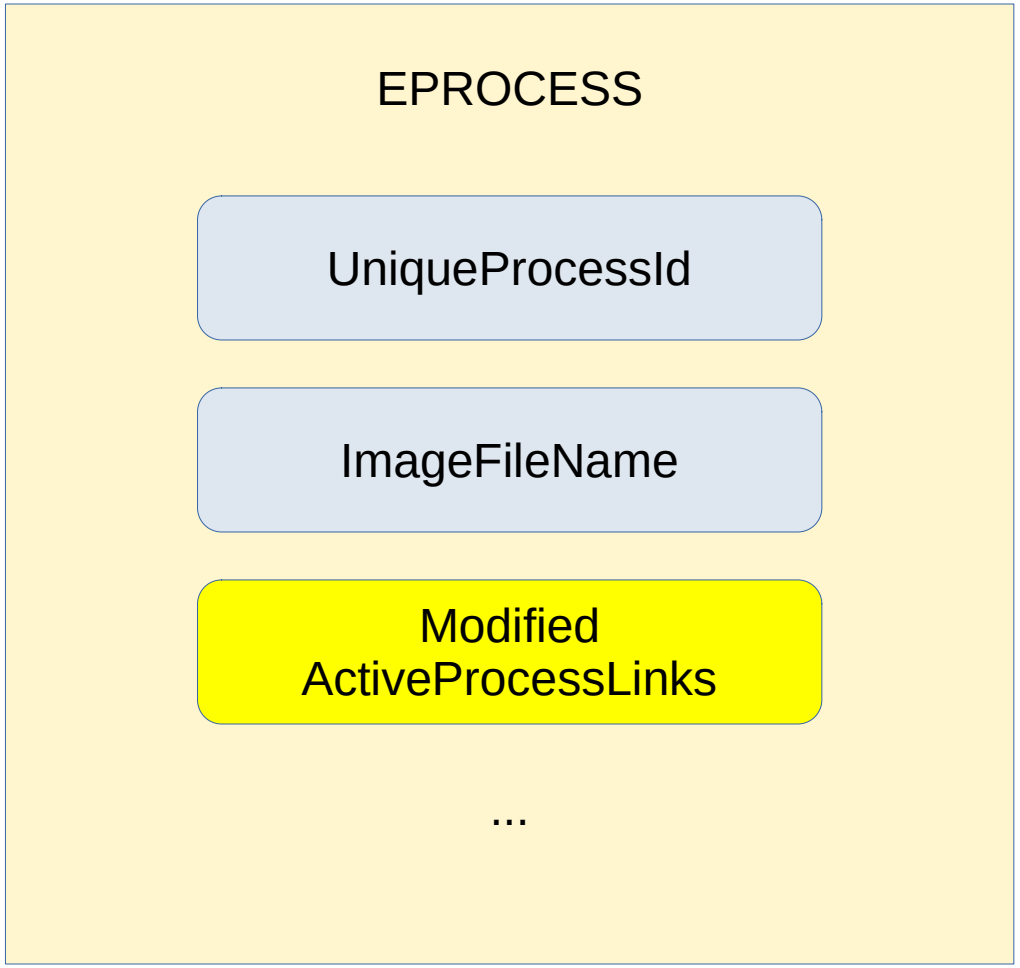
EPROCESS



Motivation

EPROCESS

- Memory dump contains modified EPROCESS structure
- Modification for example removal from list
- Volatility plugin pslist does not find process



Contributions

- Automated, scenario-based methodology to compare memory acquisition tools
- Measurement results for four tools and four scenarios
- Data set consisting of 1600 memory dumps

Method

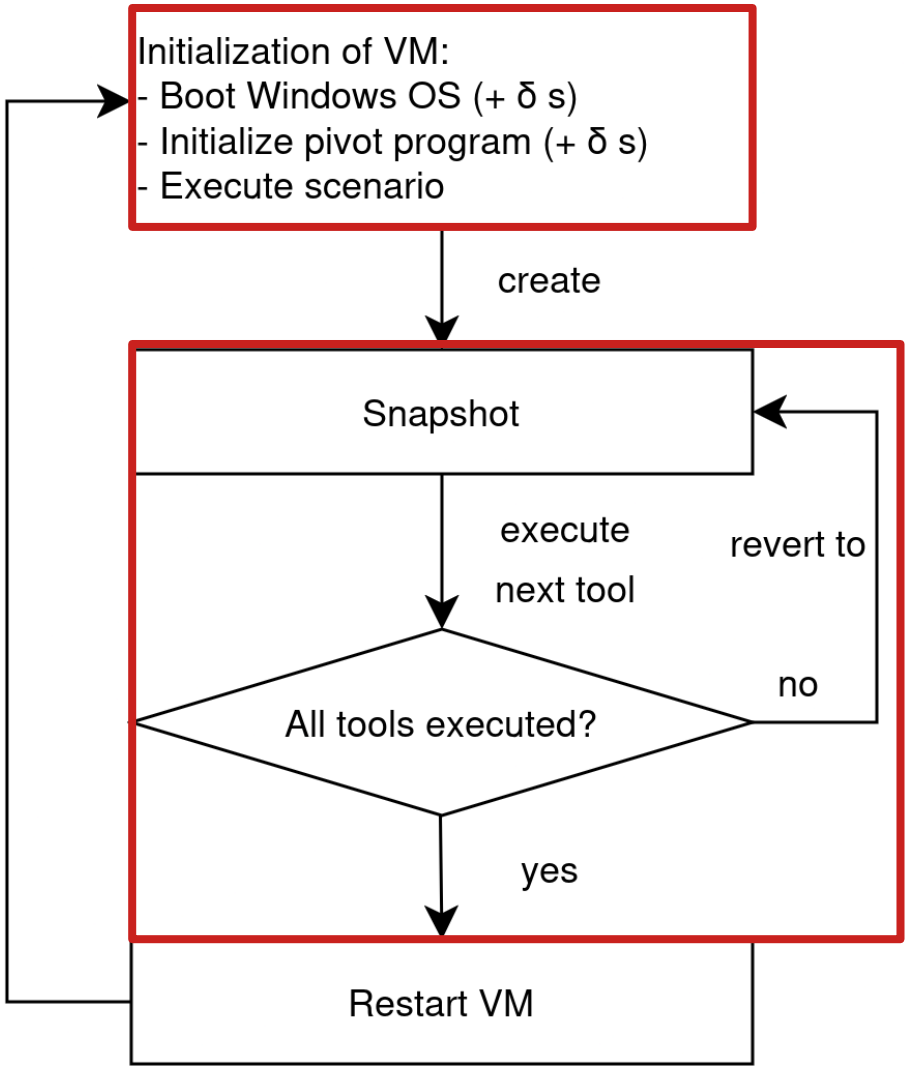
RAM acquisition tools

Tool name	Version	Open/closed source	Commercial/free
Belkasoft RAM Capturer	downloaded 07.02.2024	closed	free
FTK Imager	v4.7.1	closed	free
Magnet RAM Capture	v1.2.0	closed	free
WinPmem	winpmem_mini v4.0 RC2	open	free

Method

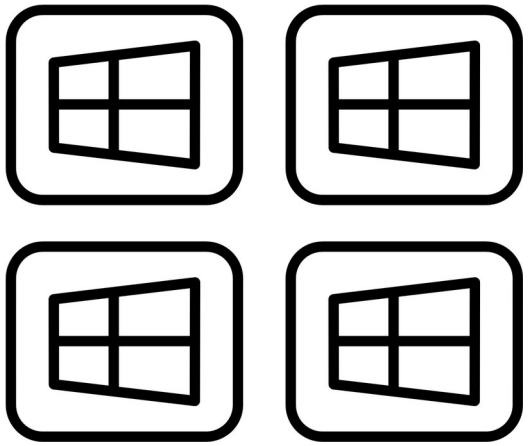
RAM acquisition tools

- Initialization: δ = 60 seconds
- 100 times per tool per scenario = 400 dumps
- In summary 1600 memory dumps
- Subset can be found here: https://zenodo.org/records/14260323

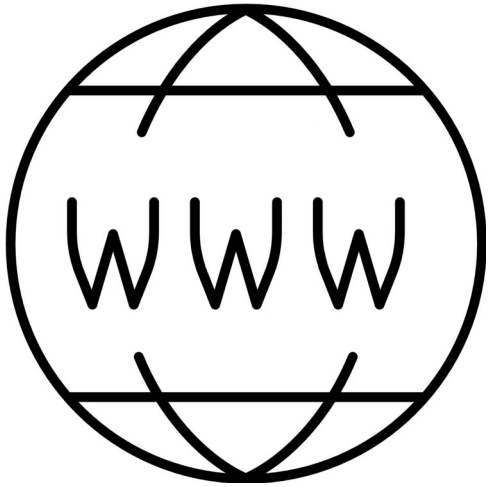


Method

Scenarios



Process



Network connection

VeraCrypt key

jpg

Analysis

Tools

Scenario	Structured analysis tool	Unstructured analysis tool
Executed software	Volatility *pslist*	Volatility *psscan*
Active ssh connection	Volatility *netlist*	Volatility *netscan*
Opened VeraCrypt container	-	*aeskeyfind*
Opened file (jpg)	-	Volatility *filescan*

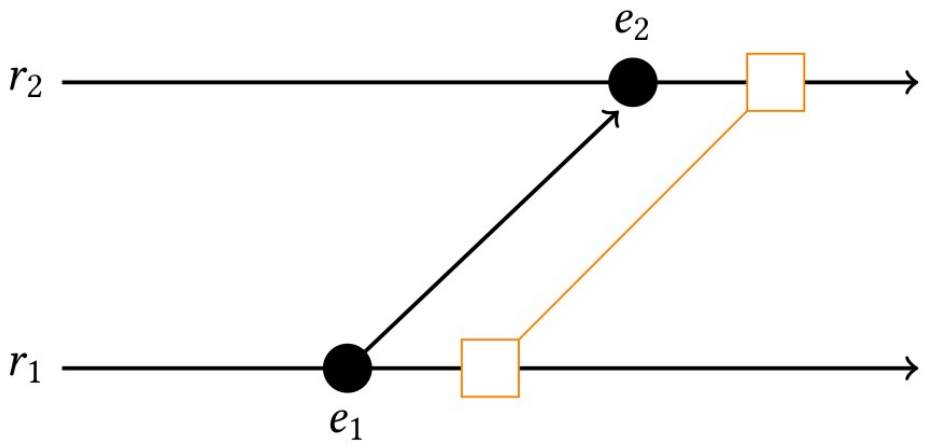
Background

Inconsistency indicators

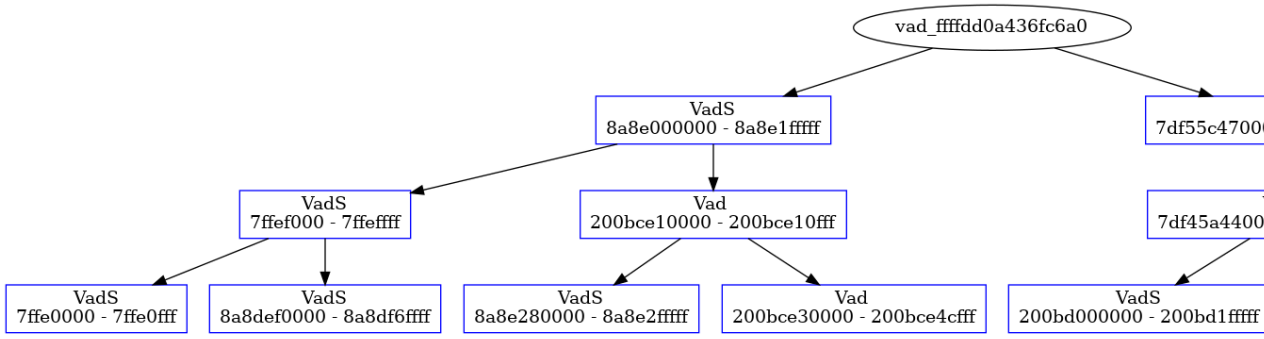
- Two different inconsistency indicators

  1) Causal inconsistency
     - Cause-effect relationships
     - Vector clocks
     - Pivot program

  2) VAD inconsistency
     - VAD tree
     - VadCount
     - Volatility3 plugin



Causally consistent memory snapshot



Part of VAD tree of smss.exe

Analysis

Technical results - Process

	Belkasoft	FTK	Magnet	WinPmem	Ideal
Process (structured)	96/100	96/100	69/100	94/100	10/10
Process (unstructured)	100/100	100/100	100/100	100/100	10/10
Mean VAD inconsistencies	685	785	1909	684	0
Mean causal inconsistencies	18	17	50	20	0

Analysis

Technical results – Network connection

	Belkasoft	FTK	Magnet	WinPmem	Ideal
ssh connection (structured)	98/100	98/100	90/100	94/100	9/10
ssh connection (unstructured)	100/100	98/100	92/100	96/100	10/10
Mean VAD inconsistencies	739	1135	2734	952	0
Mean causal inconsistencies	28	31	56	34	0

Analysis

Technical results – VeraCrypt key

	Belkasoft	FTK	Magnet	WinPmem	Ideal
VeraCrypt key	100/100	100/100	99/100	100/100	10/10
Mean VAD inconsistencies	510	907	2494	513	0
Mean causal inconsistencies	19	23	50	19	0

Analysis

Technical results – Opened file

	Belkasoft	FTK	Magnet	WinPmem	Ideal
Opened jpg file	49/100	49/100	99/100	45/100	10/10
Mean VAD inconsistencies	501	1066	1538	746	0
Mean causal inconsistencies	16	11	41	15	0

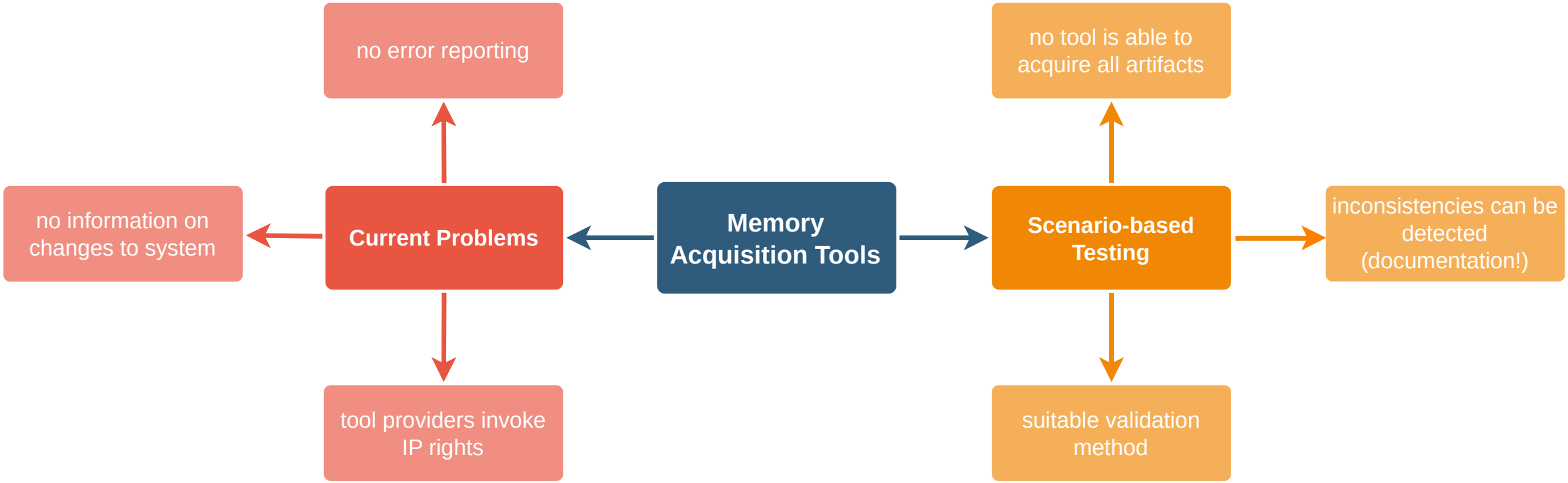
Analysis

Validation requirements for memory acquisition

- ISO17025 standard for testing/calibration of forensic laboratories
- Methods and tools in memory forensics derived primarily from forensic guidelines
- Both define rather broad and imprecise conditions for memory acquisition
- No validation scenarios or measurements given

Analysis

Procedural results



Summary

- Inconsistencies have greater impact on structured analysis methods
- Unstructured methods are more robust, but no context
- Artifacts of opened (jpg-)files difficult
- Scenario-based testing can help in assessing limitations of tools

Future Work

Questions?

- Experiments with unstructured analysis methods
- Quality of memory analysis tools
- Additional inconsistency indicators and their relationship
- Artifacts of opened files

Subset of dataset can be found here:
https://zenodo.org/records/14260323

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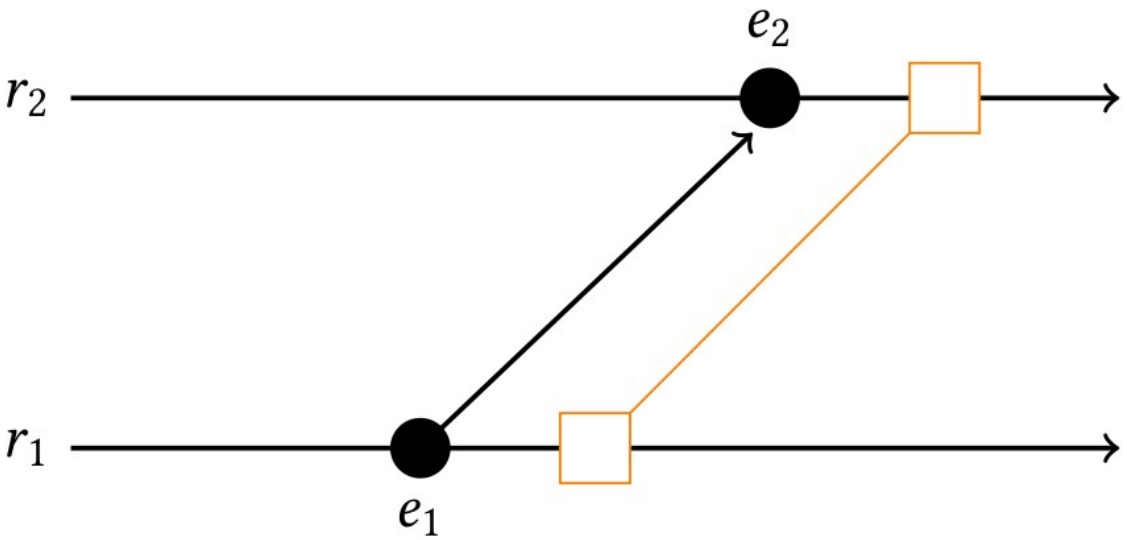
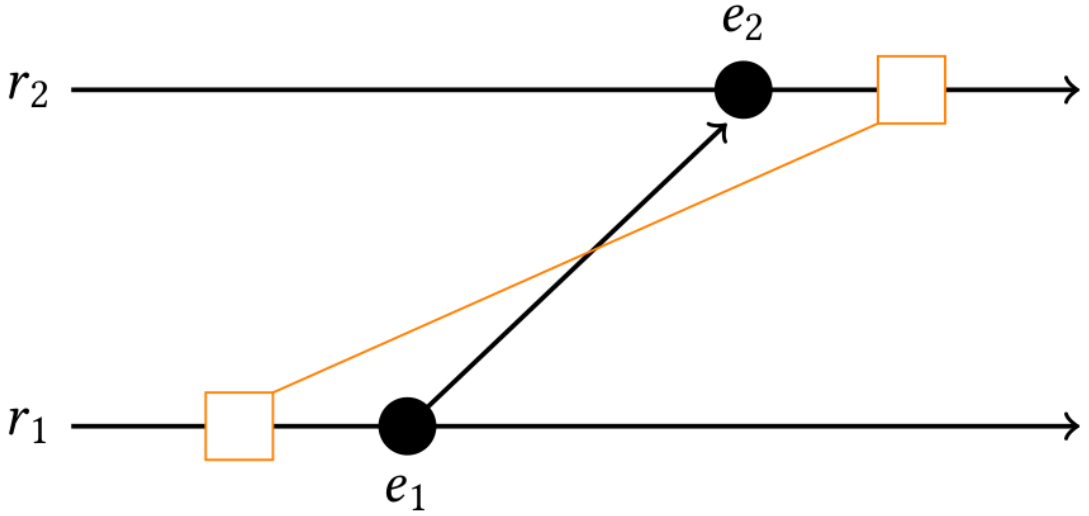
Background

Causal consistency

- 2 memory regions r1, r2
- 2 events e1, e2
- Orange rectangle = memory acquisition process
- X axis = time



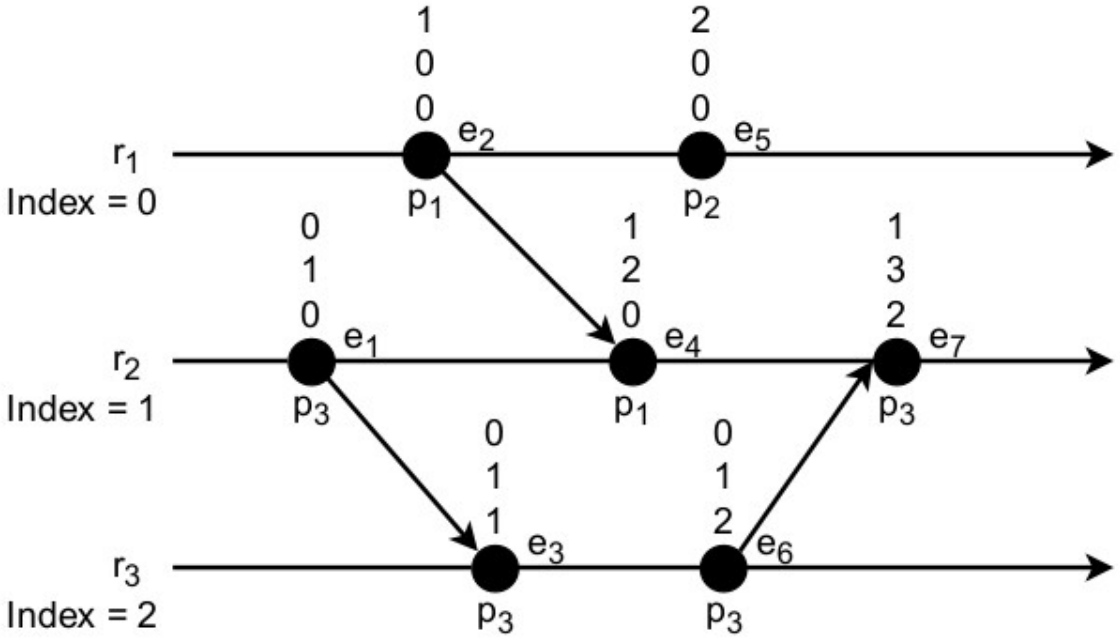
Causally consistent memory snapshot



Causally inconsistent memory snapshot

Vector clocks

- Each memory region is assigned a row in a vector
- Index is updated each time event happened in memory region (local counter)
- Processes save vector clocks and update them



Background

Virtual Address Descriptor (VAD) Tree

- Adelson-Velsky/Landis (AVL) tree
- Allocated memory for each process
- 3 node types
- VadCount

Type	Abbreviation
MMVAD_SHORT	VadS
MMVAD	Vad
MMVAD_LONG	VadL

```
typedef struct _RTL_AVL_TABLE {
  RTL_BALANCED_LINKS            BalancedRoot;
  PVOID                         OrderedPointer;
  ULONG                         WhichOrderedElement;
  ULONG                         NumberGenericTableElements;
  ULONG                         DepthOfTree;
  PRTL_BALANCED_LINKS           RestartKey;
  ULONG                         DeleteCount;
  PRTL_AVL_COMPARE_ROUTINE      CompareRoutine;
  PRTL_AVL_ALLOCATE_ROUTINE     AllocateRoutine;
  PRTL_AVL_FREE_ROUTINE         FreeRoutine;
  PVOID                         TableContext;
} RTL_AVL_TABLE;
```

Method

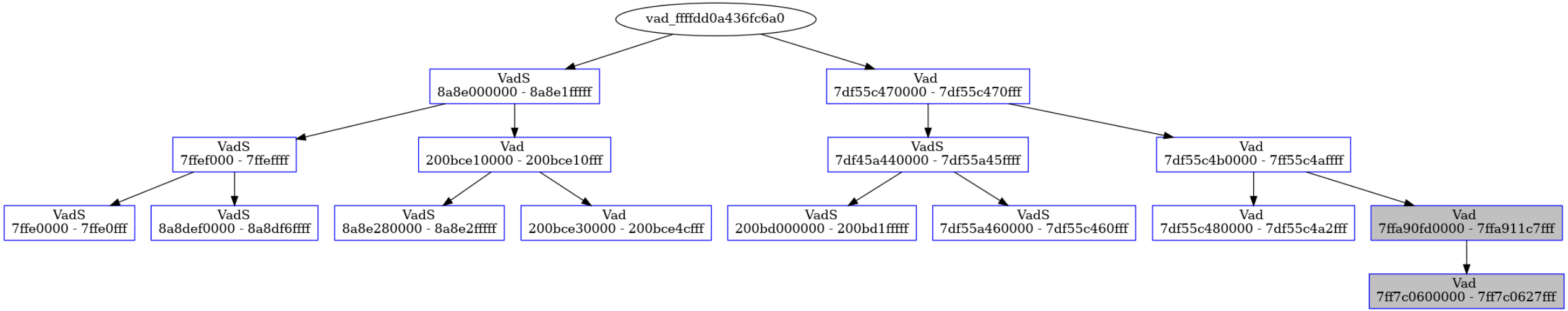
Volatility 3 VadDiff plugin

PID	Process	VadCount	Count	Difference
92	Registry	82	73	9
452	csrss.exe	182	176	6
540	csrss.exe	113	114	1
588	winlogon.exe	95	94	1
668	services.exe	62	61	1
684	lsass.exe	153	152	1
780	svchost.exe	156	152	4
888	svchost.exe	92	78	14
400	svchost.exe	74	72	2
812	svchost.exe	57	53	4
1096	dwm.exe	254	279	25
1368	svchost.exe	111	105	6
1384	svchost.exe	102	103	1
1416	svchost.exe	67	68	1
1448	svchost.exe	117	116	1
1676	svchost.exe	78	76	2

...

Background

Virtual Address Descriptor (VAD) Tree



Background

Virtual Address Descriptor (VAD) Tree