About

Title:	Improving Digital Forensics and Incident Analysis in Production Environments by Using Virtual Machine Introspection
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Research Area:	System Security, Memory Forensics, Virtual Machine Introspection
Projects:	DINGfest (BMBF), ARADIA (DFG)

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Motivation

Motivation

Why do we need digital forensics?

- Traditional crime investigation
- Incident analysis
- Malware analysis

What are the challenges?

- Higher security standards (Access)[a]
- High amounts of data (Semantic Gap)
- Performance (Information Extraction)
- Stealthiness (Tracing)

[a] https://motherboard.vice.com/en_us/article/5984jq/cops-dont-look-iphonex-face-id-unlock-elcomsoft

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Types

- **Memory Forensics:** Forensics on (snapshots of) main memory to find sensitive information that is not stored on hard disk such as passwords, keys or rootkits
- **Virtual Machine Introspection:** Memory Forensics applied to running virtual machines

Advantages

- Access to raw, unencrypted data (e.g., key material)
- Isolation and forensic soundness
- Detailed tracing

Research Problems

Research Problems

A **Architecture:** How does a **generic approach** for computer forensics look like? What are the application requirements?

B **Data Acquisition:** How to gain **access** to the memory of production systems such as cloud environments or mobile devices?

C **Information Extraction:** How to **locate and extract** high level information efficiently from main memory?

D **Applications:** How to deploy and adapt VMI methods to the **requirements of real world use cases and modern computing systems**?

A How does a **generic approach** for computer forensics look like? What are the application requirements?

Requirements

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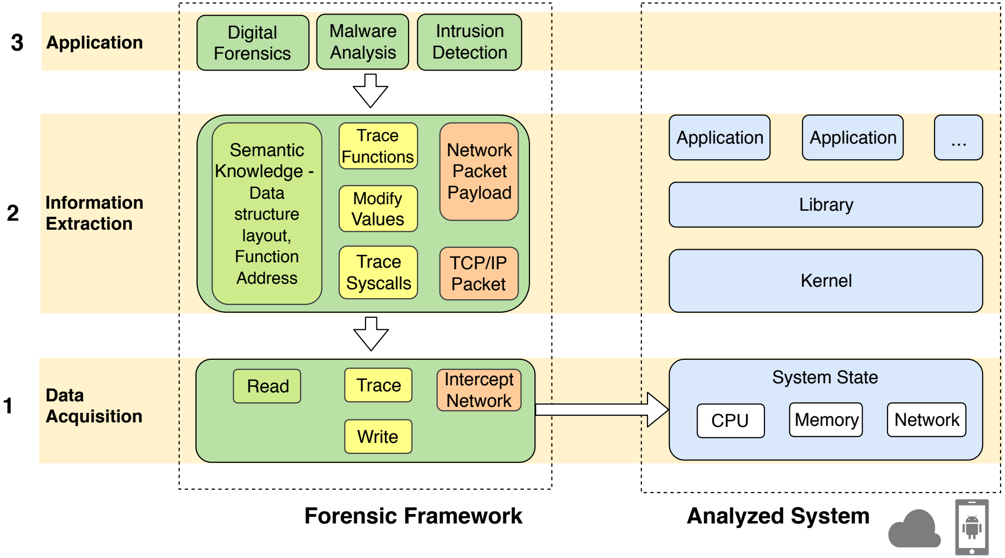
- **Off-line:** read memory and CPU registers, address translation
- **On-line:** write memory and CPU registers, control flow interception, manipulation, injection, access unmapped memory regions
- **File Access:** Read files (tmpfs, shm, encrypted fs)
- **Network Traffic Monitoring**

Application Requirements:

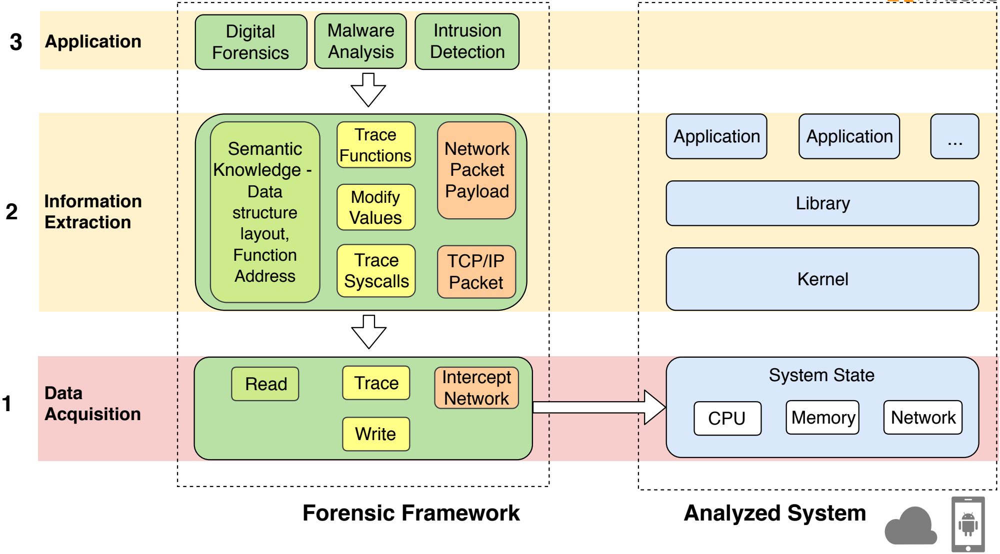
1. **Forensic Soundness:** Attackers MUST not interfere with the data acquisition process
2. **Security:** Forensic interface MUST not be a new attack surface
3. **Stealthiness:** Forensic analysis SHOULD NOT be noticeable from the analyzed system
4. **Stability:** Forensic analysis MUST NOT crash the analyzed system
5. **Platform Independence:** Forensic analysis SHOULD BE portable to other operating systems/hardware platforms
6. **Performance:** Forensic analysis SHOULD affect the performance of the analyzed system as little as possible
7. **Multiprocessor Support:** Tracing a system with multiple CPUs SHOULD be possible

Depending on the use case, some are more important than others

Architecture



Data Acquisition



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B How to gain **access** to the memory of production systems such as cloud environments or mobile devices?

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How to get access to the memory of production systems such as cloud environments or mobile devices?

Challenges:

- **Generic Interface** for different systems
- **Forensic Soundness:** access to raw untampered memory without using OS functions
- **Security:** do not introduce new attack surface

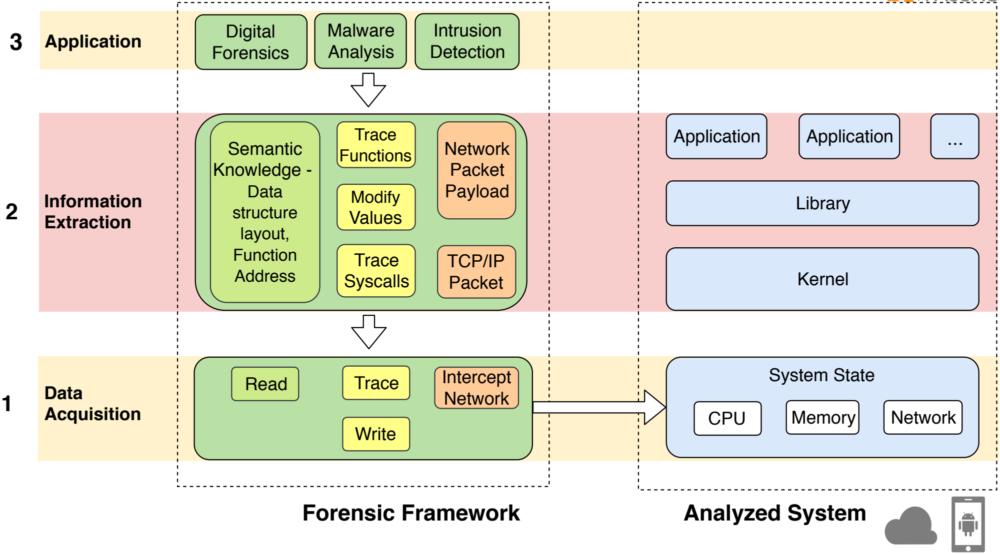
1. **Mobile Devices:**
   - **SOTA:**
     - Mobile devices have a high level of security
     - Coldboot attacks tools overwrite kernel data structures
   - **Contribution:** Minimal bare-metal application to access memory and transfer it to analysis PC[1]
2. **IaaS-based cloud computing:**
   - **SOTA:** No VMI support for cloud costumers
   - **Contribution:** Extended cloud management and the hypervisor so that cloud costumers can do VMI on their VMs[2]

[1] Taubmann, Benjamin et al. "A Lightweight Framework for Cold Boot Based Forensics on Mobile Devices." In: *ARES*. 2015.

[2] Taubmann, Benjamin, Noelle Rakotondravony, and Hans P. Reiser. "CloudPhylactor: Harnessing Mandatory Access Control for Virtual Machine Introspection in Cloud Data Centers." In: *IEEE TrustCom-16*. 2016.

C How to **locate and extract** high level information efficiently from main memory?

Information Extraction



Data Extraction

How and when to locate and extract high level information efficiently from main memory?

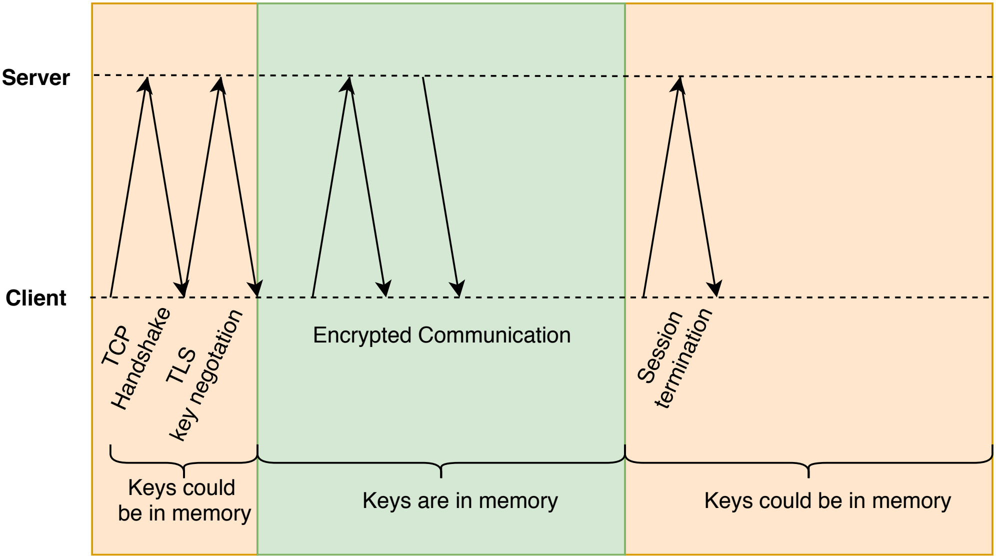
Example: Extracting sessions keys from memory in order to decrypt TLS encrypted network communication of

- Malware (in virtual machines)
- Persons using chat applications (mobile devices)

Requirements

- No modification of the application
- No modification of the network traffic
- Without knowing application logic
- Support of *perfect forward secrecy (PFS)*

Motivating Example



a **When to extract data?**

- state based (e.g., from network traffic)
- control flow based (e.g., when functions are called)
- time based (e.g., every second)

b **How to locate information?**

- the data (regular expression, entropy, etc.)
- the data structures storing the data (offset in data structures, type of data structure)
- the control flow (a function that directly accesses data)

c **How to get semantic knowledge?**

- From source code/debugging information
- By regenerating from main memory
- By regenerating from CPU instructions

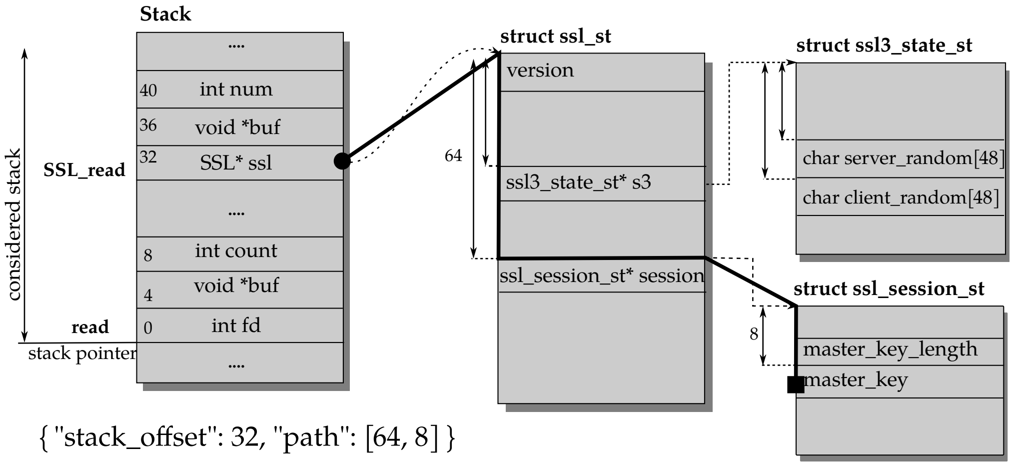


Figure: The contents on the stack when the `read` function is called by the `SSL_read` of OpenSSL function. The path from the starting point – the SSL pointer (black dot) to the MS (black square) – is marked bold and the corresponding. The computed path and the offset on the stack are noted on the bottom left side.

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Decryption of TLS based communication

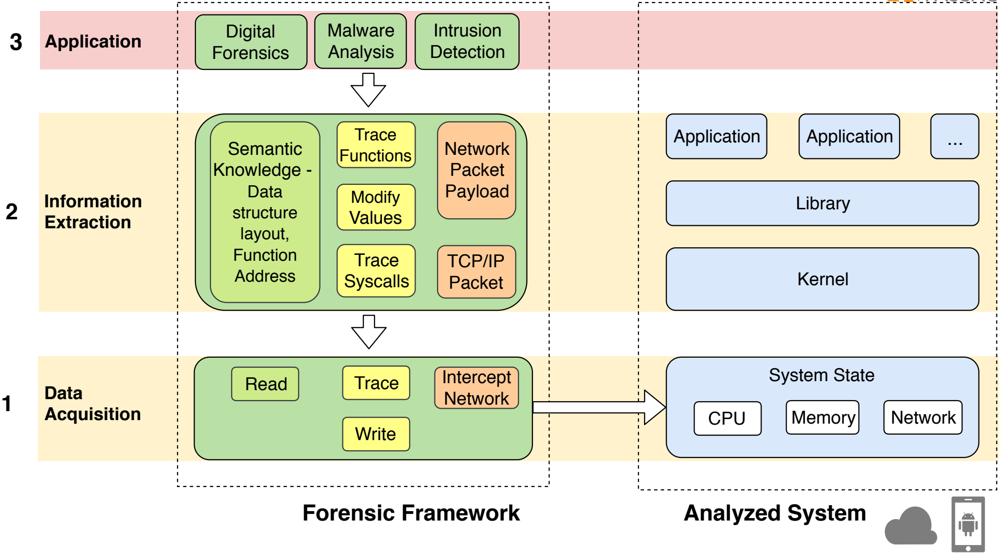
- **SOTA:** MitM based Proxy solutions
- **Contributions:**
  - Approach to extract TLS session keys from main memory of virtual machines[3]
  - Derive semantic knowledge about data structures from memory snapshots[4]
  - Improve performance of key extraction by intercepting the control flow of Android applications

[3] Taubmann, Benjamin et al. "TLSkex: Harnessing virtual machine introspection for decrypting TLS communication." In: *DFRWS EU*. 2016.

[4] Taubmann, Benjamin, Omar Al Abduljaleel, and Hans P. Reiser. "DroidKex: Fast Extraction of Ephemeral TLS Keys from the Memory of Android Apps." In: *DFRWS USA*. 2018.

D How to deploy and adapt VMI methods to the **requirements of real world use cases and modern computing systems**?

Applications and Requirements



How to deploy and adapt VMI methods to the requirements of real world use cases and modern computing systems?

Advantages:

- Stealthiness
- Isolation
- Forensic Soundness

Challenges:

- **Overhead:** VMI-based tracing can be slow
- **Level of detail:** Extraction of more information slows down the process
- **Large amount of information:** many logs

Intrusion Detection System

- **SOTA:** VMI-based tracing is too slow for production environments
- **Contribution:**
  - **Trade-off** between detailed tracing and performance: lightweight tracing to detect intrusions, heavyweight tracing for incident analysis[5][6]

Honeypots

- **SOTA:** SSH Honeypots are easy to detect
- **Contribution:** Implementation of a stealthy VMI-based honeypot[7]

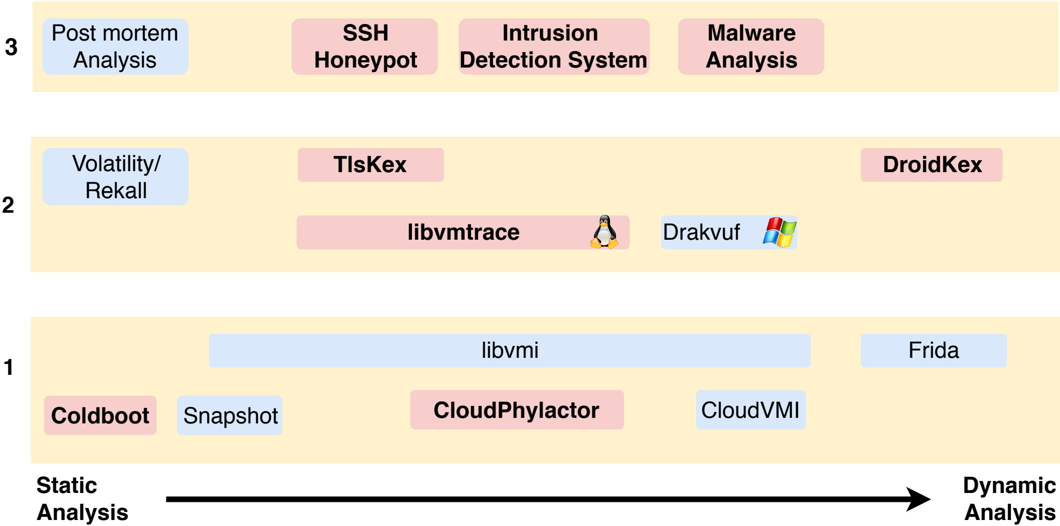
[5] Andres Fischer et al. "CloudIDEA: A Malware Defense Architecture for Cloud Data Centers." In: *C&TC 2015*. 2015.

[6] F. Menges, F. Böhm, M. Vielberth, A. Puchta, B. Taubmann, N. Rakotondravony, T. Latzo. "Introducing DINGfest: An architecture for next generation SIEM systems." In: *GI Sicherheit 2018 (Short Paperbt)*.

[7] Stewart Sentanoe, Taubmann, Benjamin, and Hans P. Reiser. "Sarracenia: Enhancing the Performance and Stealthiness of SSH Honeypots using Virtual Machine Introspection." In: *NordSec 2018*. 2018.

Summary

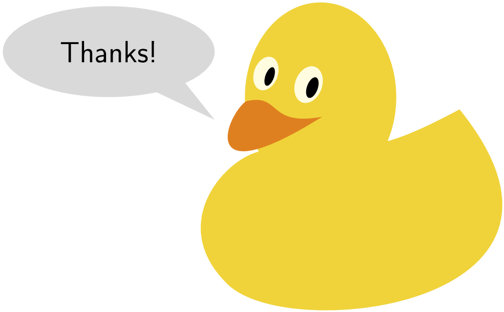
Contributions (bold red)



Conclusion

We showed:

- that TLS connections of virtual machines can be dencrypted
- that SSH sessions of a virtual machine can be monitored
- how VMI can be used in cloud environments and on mobile phones


Thanks!

Publications

[1] Taubmann, Benjamin, Manuel Huber, Lukas Heim, Georg Sigl, and Hans P. Reiser. "A Lightweight Framework for Cold Boot Based Forensics on Mobile Devices." In: *ARES*. 2015.

[2] Taubmann, Benjamin, Noelle Rakotondravony, and Hans P. Reiser. "CloudPhylactor: Harnessing Mandatory Access Control for Virtual Machine Introspection in Cloud Data Centers." In: *IEEE TrustCom-16*. 2016.

[3] Taubmann, Benjamin, Christoph Frädrich, Dominik Dusold, and Hans P. Reiser. "TLSkex: Harnessing virtual machine introspection for decrypting TLS communication." In: *DFRWS EU*. 2016.

[4] Taubmann, Benjamin, Omar Al Abduljaleel, and Hans P. Reiser. "DroidKex: Fast Extraction of Ephemeral TLS Keys from the Memory of Android Apps." In: *DFRWS USA*. 2018.

[5] Andres Fischer, Thomas Kittel, Bojan Kolosnjaji, Tamas K Lengyel, Waseem Mandarawi, Hans P Reiser, Taubmann, Benjamin, Eva Weishäupl, Hermann de Meer, Tilo Müller, and Mykola Protsenko. "CloudIDEA: A Malware Defense Architecture for Cloud Data Centers." In: *C&TC 2015*. 2015.

[10] F. Menges, F. Böhm, M. Vielberth, A. Puchta, B. Taubmann, N. Rakotondravony, T. Latzo. "Introducing DINGfest: An architecture for next generation SIEM systems." In: *GI Sicherheit 2018 (Short Paperbt)*.

[0] Stewart Sentanoe, Taubmann, Benjamin, and Hans P. Reiser. "Sarracenia: Enhancing the Performance and Stealthiness of SSH Honeypots using Virtual Machine Introspection." In: *NordSec 2018*. 2018.

[6] Taubmann, Benjamin and Bojan Kolosnjaji. "Architecture for Resource-Aware VMI-based Cloud Malware Analysis." In: *SHCIS'17*. 2017.