DIGITAL FORENSIC RESEARCH CONFERENCE

Inception: Virtual Space in Memory Space in Real Space - Memory Forensics of Immersive Virtual Reality with the HTC Vive

By

Peter Casey, Rebecca Lindsay-Decusati, Ibrahim Baggili, & Frank Breitinger

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Inception: Virtual Space in Memory Space in Real Space - Memory Forensics of Immersive Virtual Reality with the HTC Vive

Peter Casey, Rebecca Lindsay-Decusati, Ibrahim Baggili, & Frank Breitinger

Graduate Research Assistant & UNHcFREG Member

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University of New Haven
Cyber Forensics Research & Education Group

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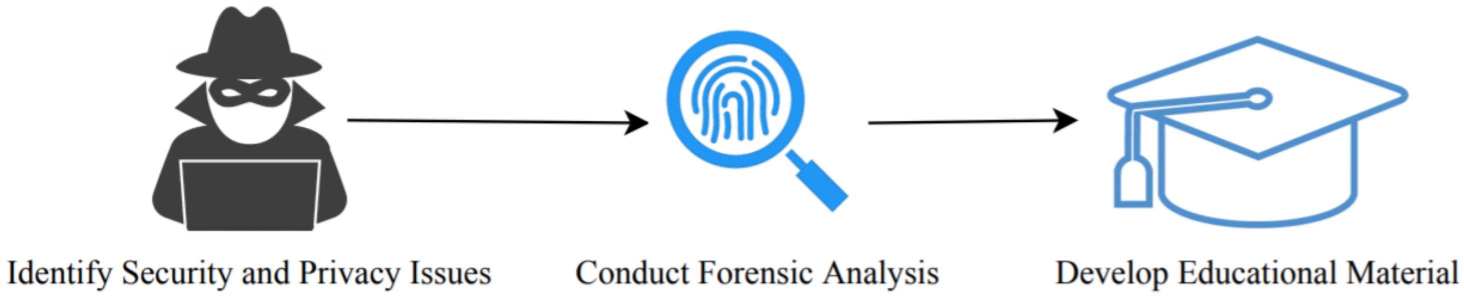
Background – Attacks against VR



- Overlay Attack
- Chaperone Attack
- Disorientation Attack
- Human Joystick
- Camera Exfiltration

Background – Forensics

- Surveyed nonvolatile artifacts
- Analyzed network traffic
- Steam (VR) and Oculus (Home)
- Select social VR applications
- Goal
  - Establish knowledge base of artifact location and content
  - Recreate a timeline of events

Problem

- Substantial amount of information resides only in memory.
  - Tracked device location / state
  - Virtual environment (VE) geometry and orientation

- What if a crime is committed in VR or a user is harmed while immersed?
- Chaperone, Disorientation, HJ attacks manipulate the live copy of the VE
- Can we recreate the VE from a memory dump?

Contributions

- To the best of our knowledge this is the primary account for specifically examining the memory forensics of VR systems.
- We share our analysis and findings that may impact future investigations involving VR systems.
- We employ and share a reusable methodology that may be adopted by others to create similar plugins.
- We construct an open source tool Vivedump, that may be used in the analysis of memory dumps of HTC Vive VR systems and share related datasets. The tool is a plug-in for the widely adopted Volatility framework.

Objective - Apparatus

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- Can we recreate the VE from a memory dump?
- HTC Vive
  - 2 x Controllers
  - 2 x Base stations
- Windows 10 Workstation
  - 8/16 GB Ram
  - Steam VR
  - DumpIt

Methodology - Recon

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- OpenVR - not quite open source…
- But we do have the function interfaces.
- **Step 1**: Review documentation and header files for relevant data sources.

Table 3: OpenVR Data Structures and Enumerators

Data	**Contents**
TrackedDevicePose_t	Pose and status of tracked device
HmdMatrix34_t	Tracked device tranformation matrix
ETrackedDeviceClass	Type of Device
ETrackedDeviceProperty	Static device properties
EVRState	Status of the overall system
EVREventType	Event types
EDeviceActivityLevel	Level of Hmd activity
VREvent_Notification_t	Notification related events
VREvent_Overlay_t	Overlay Events
VREvent_Ipd_t	Ipd change

Challenges – Plan

- Memory forensics: The path forward (Case and Richard, 2017)
- Future directions
  - Application specific analysis
  - Rapid updates – 17 versions of SteamVR in June
- Complex and robust system, solely RE effort not practical.

Methodology – Scenario Creation

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- How do we know what we are searching for in the first place?
- OpenVR Background application

Listing 1 : TrackedDeviePose_t

```
struct TrackedDevicePose_t
{
    HmdMatrix34_t mDeviceToAbsoluteTracking;
    HmdVector3_t vVelocity;
    HmdVector3_t vAngularVelocity;
    ETrackingResult eTrackingResult;
    bool bPoseIsValid;
    bool bDeviceIsConnected;
};
```

```
/** enum values to pass in to VR_Init to identify whether t
* draw a 3D scene. */
enum EVRApplicationType
{
    VRApplication_Other = 0,          // Some other kind of a
    VRApplication_Scene = 1,          // Application will sub
    VRApplication_Overlay = 2,        // Application only int
    VRApplication_Background = 3,     // Application should n
                                      // keep it running if e
    VRApplication_Utility = 4,        // Init should not try
                                      // interfaces (like IVR
    VRApplication_VRMonitor = 5,      // Reserved for vrmonit
    VRApplication_SteamWatchdog = 6,// Reserved for Steam
    VRApplication_Bootstrapper = 7, // Start up SteamVR

    VRApplication_Max
};
```

Methodology – Memory Scanning

- Tracking system information is rapidly updated and has high precision.
- Cheat Engine – *"Cheat Engine is an open source tool designed to help you with modifying single player games…"*
  - **Powerful Memory Scanner**
  - Extensive Lua scripting support

Methodology – Memory Scanning

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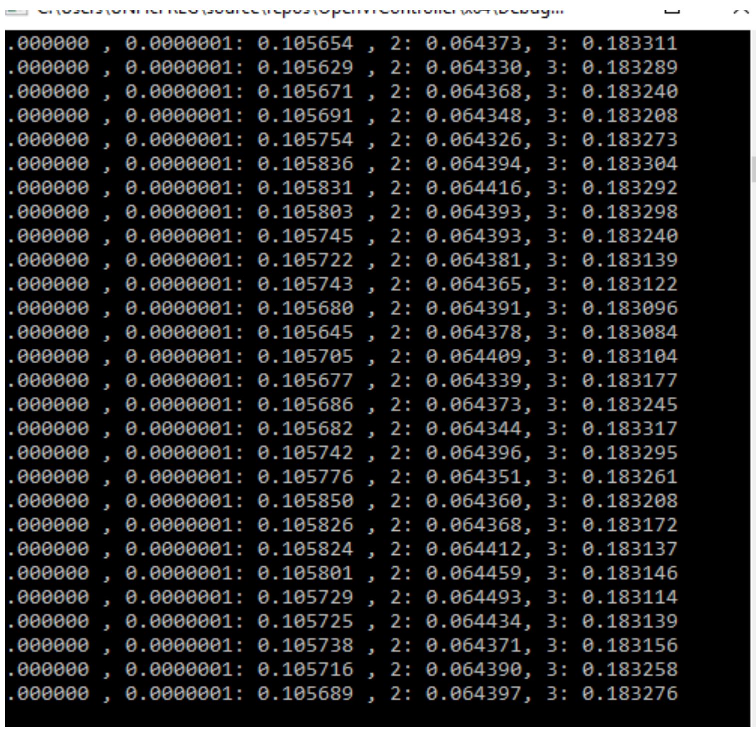
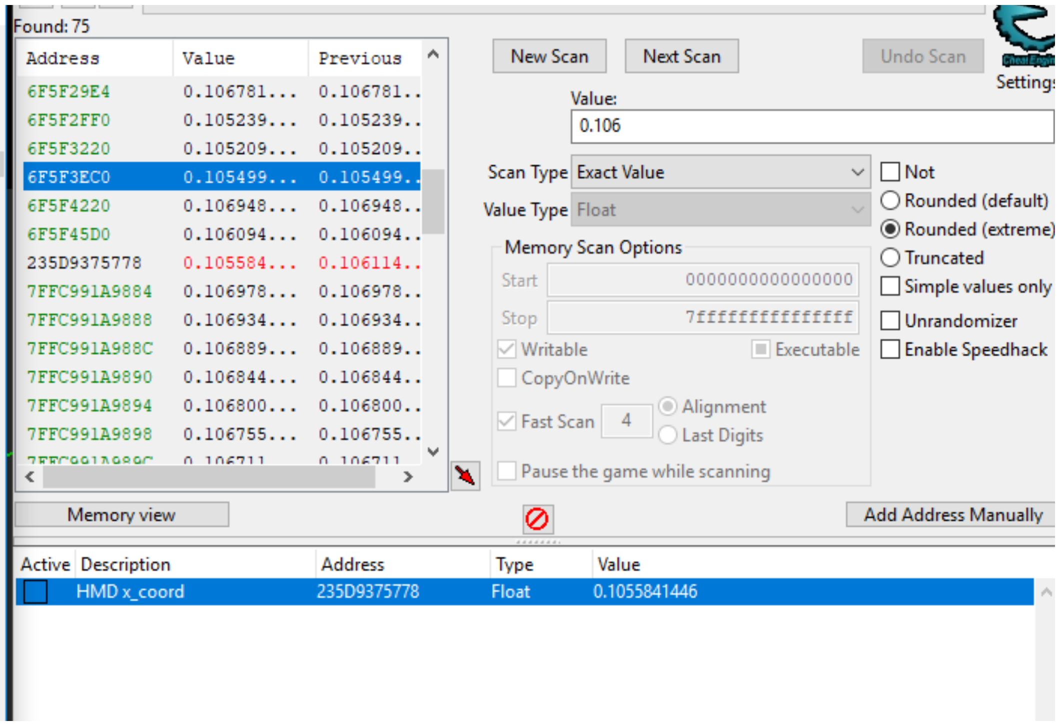
- Search
- Reduce
- Modify
- Repeat





Methodology – Static Reference

- How to reliably locate data in a memory dump?
- Work backwards from data to a static reference.
- Two strategies:
  - Attach debugger and monitor reads and writes to address
  - Search for pointer chains.

Base Address	Offset 0	Offset 1	Offset 2	Offset 3	Offset 4	Points to:
"vrmonitor.exe"+001F78A0	68					235D9375778
"THREADSTACK1"-00000...	2C0	0	50	8	68	235D9375778
"THREADSTACK1"-00000...	2C0	0	50	8	68	235D9375778
"THREADSTACK1"-00000...	2C0	0	50	8	68	235D9375778
"vrclient_x64.dll"+00220F...	60	30	50	8	68	235D9375778
"vrclient_x64.dll"+002278...	38	90	50	8	68	235D9375778
"vrmonitor.exe"+001F7798	668	90	50	8	68	235D9375778
"vrclient_x64.dll"+00227B...	18	C0	50	8	68	235D9375778
"vrclient_x64.dll"+00227B...	20	C0	50	8	68	235D9375778
"vrclient_x64.dll"+00227B...	18	C0	50	8	68	235D9375778
"vrclient_x64.dll"+002221...	D8	C0	50	8	68	235D9375778
"THREADSTACK1"-00000...	428	C0	50	8	68	235D9375778
"vrclient_x64.dll"+002250...	18	C0	50	8	68	235D9375778
"vrclient_x64.dll"+00223C...	618	C0	50	8	68	235D9375778
"vrclient_x64.dll"+002250...	20	C0	50	8	68	235D9375778
"vrclient_x64.dll"+00223C...	620	C0	50	8	68	235D9375778
"vrclient_x64.dll"+002250...	28	C0	50	8	68	235D9375778
"vrclient_x64.dll"+00223C...	628	C0	50	8	68	235D9375778
"vrclient_x64.dll"+002250...	30	C0	50	8	68	235D9375778
"vrclient_x64.dll"+00223C...	630	C0	50	8	68	235D9375778

Methodology – Static Reference

- References originating from the stack, unreliable.
- DLL functions operated on data passed to them
- Most reliable candidate pointer chains originate directly from executable – **vrmonitor.exe**

Listing 2 : Disassembly of Base Address Access

```
48 8b 05 25 d6 10 00        MOV RAX, [RIP+0x10d625]
48 85 c0                    TEST RAX, RAX
75 2a                       JNZ + 2a
snip
```

Methodology – Yara Signatures

- YARA - *"is a tool aimed at (but not limited to) helping malware researchers to identify and classify malware samples"*
- Develop signatures based on referencing op-codes.
- [Volatility Plugin & malware analysis]() – Thomas Chopitea

```
YARA_HMD = {
    'hmd_pointer': 'rule hmd_pointer { strings: $p = {48 8b 05 25 D6 10 00} condition: $p}',
}

YARA_HMD_ACTIVITY = {
    'hmd_activity': 'rule hmd_activity { strings: $p = {48 8b 05 55 A4 13 00} condition: $p}',
}
```

http://virustotal.github.io/yara/

Plugin Development

Algorithm 2 Vivedump: Locate target data

```
y ← yara.compile(rule)                         ▷ Base address signature
r ← [offset1, offset2, ...]                    ▷ Route
for task ∈ processList do
    if task = vrmonitor.exe then
        for vad ∈ getProcessVad do
            m ← y.match(vad)                   ▷ Address of YARA match
            for offset ∈ r do                  ▷ Traverse route
                m ← dereference(m) + offset
            end for
            return m                           ▷ Address of target data
        end for
    end if
end for
```

- Optimization – limit search to related process

http://virustotal.github.io/yara/

Data Interpretation

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- C++ Standard – *"Non-static data members of a (non-union) class with the same access control are allocated so that later members have higher addresses within a class object."*
- Enumerators – if not explicitly set, assume default implementation

Listing 1 : TrackedDeviePose_t

```
struct TrackedDevicePose_t
{
      HmdMatrix34_t mDeviceToAbsoluteTracking;
      HmdVector3_t vVelocity;
      HmdVector3_t vAngularVelocity;
      ETrackingResult eTrackingResult;
      bool bPoseIsValid;
      bool bDeviceIsConnected;
};
```

```
enum ETrackingResult
{
    TrackingResult_Uninitialized            = 1,
    TrackingResult_Calibrating_InProgress   = 100,
    TrackingResult_Calibrating_OutOfRange   = 101,
    TrackingResult_Running_OK               = 200,
    TrackingResult_Running_OutOfRange       = 201,
};
```

Visualization

Data Reliability

- TrackedDevicePose array always available
- TrackedDevice Class route may be misleading
- Correlate device states between structures

Data Structure	YARA Signature	Route
TrackedDevicePose Array	48 8b 05 25 D6 10 00	0x10D62C
—- HmdMatrix34_t		+ 0x5C
—- ETrackingResult		+ 0xA4
—- bPoseIsValid		+ 0xA8
—- bDeviceIsConnected		+ 0xAA
HMD State	48 8b 05 55 A4 13 00	0x13A45C, 0x1E0, 0x 0B8, 0x68
—- HMD Activity		+ 0x10
TrackedDevice Class	48 8b 05 55 A4 13 00	0x13A45C, 0x190, 0x8, 0x510, 0x3E0, 0x120

Future Work

- Expand supported recoverable features
- Version Detection
- Application update recovery
- Emulation

Questions

Peter Casey

(pgrom1@unh.newhaven.edu)

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