Retrospective on the latest zero-days found in the wild

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- Likes reverse engineering (firmwares, kernels, etc.)
  - First person to participate in private Sony PlayStation BugBounty program ☺
- Finds zero-days exploited in the wild
  - CVE-2018-8174, CVE-2018-8453, CVE-2018-8589, CVE-2018-8611, CVE-2019-0797, CVE-2019-0859
- Finds supply chain attacks
  - ASUS “Operation ShadowHammer” and few others

Previously presented at:

Virus Bulletin, CanSecWest, SAS, BlueHat, TyphoonCon, ISC by Qihoo 360, AVAR, Code Blue, C3 …

Twitter: **@oct0xor**

Previously on BlueHat ...

BLUEHAT SHANGHAI 2019

Overview of the latest Windows OS kernel exploits found in the wild

30-May-19

We are ready to share the next chapter of our in the wild zero-day finding journey

BlueHat Shanghai 2019:

- 2 LPE's for the latest build of Windows 10 at the moment of discovery
- Sneak peek into exploitation framework that was used among many 0day exploits

BlueHat IL 2020:

- Detailed look into exploitation framework
  - Zero-days as a service
  - Hiding from AV vendors in the era of System Guard Runtime Attestation
- Information about some new LPE exploits that we found in 2019
- Information about full chain that we found in 2019: Chrome RCE + Windows EOP

In 2018 we caught 4 zero-days in the wild:

- May 2018 - CVE-2018-8174 - Windows VBScript Engine RCE Vulnerability
  Attack on Microsoft Office trough Internet Explorer
- October 2018 - CVE-2018-8453 - Win32k EOP Vulnerability
  First known exploit targeting Win32k in Windows 10 RS4
- November 2018 - CVE-2018-8589 - Win32k EOP Vulnerability
  Exploit targeted only Windows 7 SP1 32-bit but sophisticated framework is discovered
- December 2018 - CVE-2018-8611 - Windows Kernel EOP Vulnerability
  Lets to escape sandboxes of web browsers, reveals novel exploitation techniques

Two last exploits were a part of the same exploitation framework

Zero-day exploits is a multi-billion dollar industry

A few companies working in this area are well known and have a lot of publicity
Some others are not

We observe a rapid growth of entities who develop and sell exploits in volumes
Each with different business model

Some are picky to choose customers
There is a possibility that some are not, and those companies do greater harm
Zero-days used in the wild are to risky to be silent about if you encounter one

When products of such companies are used in the wild its just a matter of time until we or our industry partners stumble into one of them

We have found attacks with the use of unique exploitation framework

Attacks are conducted by several threat actors

Exploitation framework seemingly contained an armory of different exploits

Functionality of framework also includes:

- AV evasion
- Choosing appropriate exploit reliably
- Sophisticated direct kernel object manipulation

I am often asked:

"How do you even find zero-days? Don't they check that AV is installed?"

Probably it would be perfect if this was the case

It would mean that if you install AV then you will not be attacked with zero-day (If attacker cares about not burning zero-day of course)

Right now all PCs have AV installed by default (e.g. Windows Defender)

Imagine a product which is basically a collection of zero-days
There are two sides: manufacturer and customer

Manufacturer
It makes sense to protect zero-days because it's a valuable asset
They are shared with other and potentially new customers

Customer
Successes of operation is what matters the most
Depending on a license model customer might not care about wasting zero-day

One customer burns zero-day before others use it, everyone's loss?

Seems that protection of zero-day is a problem of manufacturer, if sold non-exclusive

AV evasion starts from the moment when shellcode is executed as a part of full chain

All API functions are executed using specially built trampolines or system calls
Framework searches for code patterns in text section of system libraries
Uses found gadgets to build fake stack and execute functions

```
/* build fake stack */
push   ebp
mov    ebp, esp
push   offset gadget_ret

push   ebp
mov    ebp, esp
push   offset gadget_ret
...
```

```
/* push args*/
...

/* push return address*/
push   offset trampilne_prolog

/* jump to function */
jmp    eax
```

Shellcode is used to execute embedded PE module

This embedded module is a central part of framework
It contains logic to execute exploits and backdoor

All API functions are executed using the same trampoline technique as in shellcode

But embedded module also contains additional AV evasion logic

Implementation for this logic is quite strange
A dedicated function checks if special libraries are present in exploited process
List of libraries depends on version of operating system
In case if library is found in process exploits are not executed

Older builds

```
switch ( windows_version_id )
{
case WIN_10:
        libs = {“emet.dll”, “emet64.dll”}; break;
case WIN_8_1:
case WIN_8:
case WIN_7_SP1:
case WIN_7:
case WIN_XP:
        // BitDefender
        libs = {“avcuf32.dll”, “avcuf64.dll”}; break;
default:
        libs = {};
}
```

Newer builds

Same thing with small modifications:

Now library names are checked using CRC chksum over wide strings

For WIN_10 new libs added:
“avcuf32.dll”, “avcuf64.dll”, “mbae.dll”, “mbae64.dll”, +1 unknown library

In other cases:
“mbae.dll”, “mbae64.dll”, +1 unknown library

This check takes place before execution of EOP exploits, additional check happens after

RCE exploit may be triggered more than once

For reliable exploitation a proper mutual exclusion is required

Otherwise execution of multiple instances of EOP exploit will lead to BSOD

Use of **CreateMutex()** function may arouse suspicion

Framework uses quite interesting trick to implement custom mutex

Exploitation framework – Reliability


```
HANDLE heap = GetProcessHeap();

HeapLock(heap);

while ( HeapWalk(heap, &Entry) )
{
 if (Entry.wFlags & PROCESS_HEAP_ENTRY_BUSY
  && Entry.cbData == size
  && memcmp(Entry.lpData, data, size))
 {
  return -1;
 }
}

HeapUnlock(heap);

void* buf = HeapAlloc(heap, HEAP_ZERO_MEMORY, size);
memcpy(buf, data, size);
```

Look for special memory block
If it exists, then exploit is running

If memory block is not found,
create it and we have a mutex

Framework module may come with multiple exploits (embedded or received remotely)

Each elevation of privilege exploit is implemented as a module with special interface

Exploits check version of operating system to find out if exploit supports target

Framework tries different exploits until it finds the one that succeeds

```
while ( !found )
{
 get_exploit(&exploit)

 if ( execute_exploit(exploit, ...) )
 {
  found = 1;
 }

 if ( ++count >= 10 )
  break;
}
```

Maximum number of EOP exploits is hardcoded to 10

Each exploit contained a debug information that reveals codename of exploit

Developers granted each elevation of privilege exploit with a girl name

We have found 4 exploits:

- **Alice** - CVE-2018-8589
- **Christine** - CVE-2015-2360
- **Dana** - CVE-2019-0797
- **Jasmine** - CVE-2018-8611

Naming pattern:

- **Alice** - CVE-2018-8589
- ...
- **Christine** - CVE-2015-2360
- **Dana** - CVE-2019-0797
- ...
- **Jasmine** - CVE-2018-8611

```
while ( !found )
{
 get_exploit(&exploit)

 if ( execute_exploit(exploit, ...) )
 {
  found = 1;
 }

 if ( ++count >= 10 )
  break;
}
```

A B C D E F G H I J

In English alphabet ‘J’ has an index 10

Jasmine also looks like the most modern exploit

We looked, but could not find any more exploits from this framework

But we shared this information with our partner

Using information that we provided, our partner was able to find more zero-days

Vulnerabilities were fixed ☺

We believe that the main purpose of this framework is a full chain attacks

We succeeded in analysis of elevation of privilege exploits and backdoor module

But our knowledge about remote code execution exploits is limited

However, we are aware that this framework was observed to be used as a payload for Adobe Flash zero-day CVE-2018-5002

http://blogs.360.cn/post/cve-2018-5002-en.html

https://unit42.paloaltonetworks.com/unit42-slicing-dicing-cve-2018-5002-payloads-new-chainshot-malware/

In 2019 we caught 4 zero-days in the wild:

- March 2019 - CVE-2019-0797 - Win32k EOP Vulnerability
- April 2019 - CVE-2019-0859 - Win32k EOP Vulnerability
- November 2019 - CVE-2019-13720 - Google Chrome Use-After-Free in Audio
- December 2019 - CVE-2019-1458 - Win32k EOP Vulnerability

Race condition in win32k.sys driver

Abused in “Dana” elevation of privilege exploit
The last 0day that was used by exploitation framework and discovered by us

Exploit code is written to support next OS versions:

- Windows 10 builds 10240, 10586, 14393, 15063
- Windows 8.1
- Windows 8

Win32k driver contains code for DirectComposition API

DirectComposition

- Introduced in Windows 8
- Lets to combine and animate elements
  - Bitmap composition with transforms, effects, and animations
  - Combine bitmaps of different sources (GDI, DirectX…)
  - Using tree like structure similar to Visual Tree in XAML
- Relatively new part of Win32k but already was exploited before

https://docs.microsoft.com/en-us/windows/win32/directcomp/directcomposition-portal
https://cansecwest.com/slides/2017/CSW2017_PengQiu-ShefangZhong_win32k_dark_composition.pdf

Look for NtDComposition* syscalls

```
dq offset NtDCompositionAddCrossDeviceVisualChild
dq offset NtDCompositionAddVisualChild
dq offset NtDCompositionBeginFrame
dq offset NtDCompositionCommitChannel
dq offset NtDCompositionConfirmFrame
dq offset NtDCompositionConnectPipe
dq offset NtDCompositionCreateAndBindSharedSection
dq offset NtDCompositionCreateChannel
dq offset NtDCompositionCreateConnection
dq offset NtDCompositionCreateDwmChannel
dq offset NtDCompositionCreateResource
dq offset NtDCompositionCurrentBatchId
dq offset NtDCompositionDestroyChannel
dq offset NtDCompositionDestroyConnection
dq offset NtDCompositionDiscardFrame
dq offset NtDCompositionDuplicateHandleToProcess
dq offset NtDCompositionDwmSyncFlush
dq offset NtDCompositionConnectPipe
dq offset NtDCompositionGetConnectionBatch
dq offset NtDCompositionGetDeletedResources
dq offset NtDCompositionGetFrameLegacyTokens
dq offset NtDCompositionGetFrameStatistics
dq offset NtDCompositionGetFrameSurfaceUpdates
dq offset NtDCompositionOpenSharedResource
```

NtDCompositionDiscardFrame

```
ExAcquirePushLockSharedEx((char *)connection + 0xB8, 1i64);
for ( i = (volatile signed __int32 *)*((_QWORD *)connection + 0x16)
      i != (volatile signed __int32 *)((char *)connection + 0xA8);
      i = (volatile signed __int32 *)*((_QWORD *)i + 1) )
{
  if ( *((_QWORD *)i + 6) == frameId )
  {
    _InterlockedIncrement(i - 2);
    frame_ptr = (__int64)(i - 2);
    frame = (DirectComposition::CCompositionFrame *)(i - 2);
    status = 0;
    break;
  }
}
ExReleasePushLockSharedEx((char *)connection + 0xB8, 1i64);
v24 = status;
if ( status >= 0 )
{
  ...
  if ( !_InterlockedDecrement((volatile signed __int32 *)frame_ptr) )
  {
    if ( *(_DWORD *)(frame_ptr + 64) != 3 )
      DirectComposition::CCompositionFrame::Discard(frame);
    Win32FreePool((void *)frame);
  }
}
DirectComposition::CConnection::RemoveCompositionFrame(connection, frameId);
```

Find frame by ID

Free frame

NtDCompositionDestroyConnection

```
void __fastcall DirectComposition::CConnection::Disconnect(DirectComposition::CConnection *this)
{
  ...
  v1 = this;
  v2 = 0;
  DirectComposition::CCriticalSection::AcquireExclusive(*(DirectComposition::CCriticalSection **)(*((_QWORD *)this + 17)
                                                                                                 + 24i64));
  DirectComposition::CCriticalSection::AcquireExclusive(*((DirectComposition::CCriticalSection **)v1 + 1));
  if ( *((_DWORD *)v1 + 0x21) )
  {
    *((_DWORD *)v1 + 0x21) = 0;
    v2 = 1;
  }
  DirectComposition::CConnection::DiscardAllCompositionFrames(v1);
  DirectComposition::CBatchSharedMemoryPoolSet::FreeAllPools((DirectComposit                    0xC0));
```

Free all frames

Execution of NtDCompositionDiscardFrame and NtDCompositionDestroyConnection simultaneously leads to a use-after-free

DiscardAllCompositionFrames may be executed at a time when the NtDCompositionDiscardFrame syscall is looking for a frame to release or has already found it

Exploit uses two distinct exploitation techniques

1) Abuse of GDI Palettes
   - Windows 10 builds 10240, 10586
   - Windows 8.1
   - Windows 8

2) Abuse of Windows
   - Windows 10 builds 14393, 15063

Abuse of GDI Palettes

1) Grooms heap using pallets, their addresses are leaked via GdiSharedHandleTable
2) Keeps a couple of pallets allocated next to each other
3) Uses vulnerability to free pallet #1, reclaim memory and overwrite cEntries field
   SetPaletteEntries on pallet #1 can be used to overwrite *pFirstColor of pallet #2
5) Arbitrary memory R/W using GetPaletteEntries / SetPaletteEntries

```
typedef struct _PALETTE
{
  ULONG        cEntries;
  ...
  PALETTEENTRY   *pFirstColor;
  ...
} PALETTE, *PPALETTE;
```

https://sensepost.com/blog/2017/abusing-gdi-objects-for-ring0-primitives-revolution/
https://github.com/sensepost/gdi-palettes-exp

Abuse of Windows

1) Grooms heap using NtUserCreateInputContext and CreateWindowExW
   - Window kernel address (win32k!tagWND) is leaked via user32!gSharedInfo
2) Uses vulnerability to free window, reclaim memory and overwrite *strName field
3) Arbitrary memory R/W using InternalGetWindowText / NtUserDefSetText

```
typedef struct tagWND
{
   ...
   LARGE_UNICODE_STRING strName;
   ...
}
```

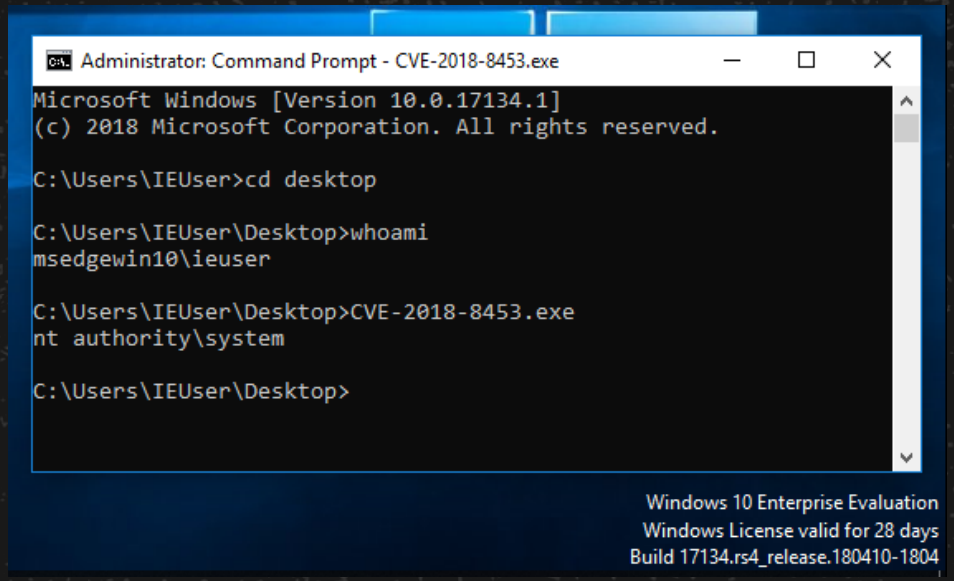
In this framework each elevation of privilege exploit provides interfaces for DKOM

```
class Kernel_IO
{
   ReadQword(...)          WriteQword(...)
   ReadDword(...)          WriteDword(...)
   ReadWord(...)           WriteWord(...)
   ReadBytes(...)          WriteBytes(...)
   ...
   SetAddress(...)
}
```

A special functionality for execution of kernel shellcode is also provided

Almost every EOP exploit that we observe use data-only exploitation

The most common scenario: walk EPROCESS structures and steal SYSTEM token



But this exploitation framework uses DKOM to get kernel code execution

A sophisticated functionality that is not commonly observed in EOP exploits

In that case its worth taking a closer look on actual implementation and kernel shellcode

We also are lucky to see evolution of this functionality in framework

First is implementation observed among early variants

Step 1:

Shellcode is put into some kernel object whose kernel address is possible to leak

- E.g. CreateAcceleratorTableW + user32!gSharedInfo

Step 2:

Duplicate handle to current thread, parse EPROCESS->ObjectTable to get address of KTHREAD

Get KTHREAD->SchedulerApc, verify it using type from nt!_KOBJECTS and address of KTHREAD

Address of KAPC.NormalRoutine is stored for later use

Step 3:

Resolve base addresses of page table entries and page directory entries

- In Windows 10 build 10586 and below PT/PD entries are at fixed addresses
  - PT_BASE = 0xFFFFF68000000000
  - PD_BASE = 0xFFFFF6FB40000000
- In other cases base addresses are resolved heuristically from kernel image

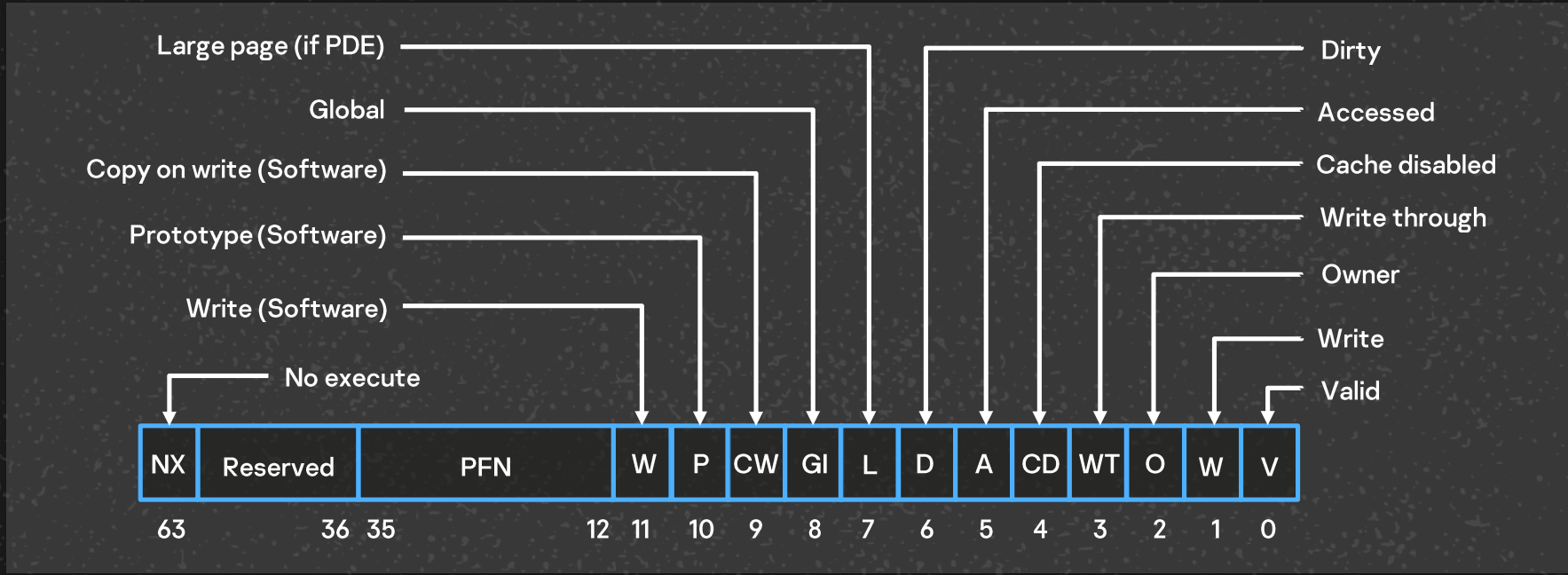
Accessing page directory entry for VA:

- PDE_ADDRESS = PD_BASE + ((VA >> 18) & 0x3FFFFFF8)

Accessing page table entry for VA:

- PTE_ADDRESS = PT_BASE + ((VA >> 9) & 0x7FFFFFFF8)

Exploitation framework – From R/W to code execution in kernel level



Modification of NX bit makes page executable

Owner bit is also interesting: it indicates kernel/user page

Step 4:

KAPC.NormalRoutine is overwritten with shellcode address

Current thread is suspended to get shellcode executed

Step 5:

KAPC.NormalRoutine original value is restored

Current thread is resumed

Kernel shellcode borrows a lot from open source Blackbone project
Code is very similar to BlackBoneDrv/Inject.c

Backdoor module is injected and executed inside chosen process (e.g. svchost.exe)

Injection is achieved exactly like in BlackBoneDrv:

- Reflective PE loading from kernel
- User code is executed using trampolines and creation of worker thread

Blackbone source code is known to be used in malware
Probably that's the reason why in newer variants this part was re-done

https://github.com/DarthTon/Blackbone

In newer variants the following technique is used

Step 1:

Dummy thread with SignalObjectAndWait is created and executed

EPROCESS->ObjectTable is parsed to get address of KTHREAD

Step 2:

Thread stack base and thread stack limit values are retrieved

Stack is parsed in search of address belonging to kernel image .text section

Bytes at correct return address should be equal to 8B D8 89 44

Step 3:

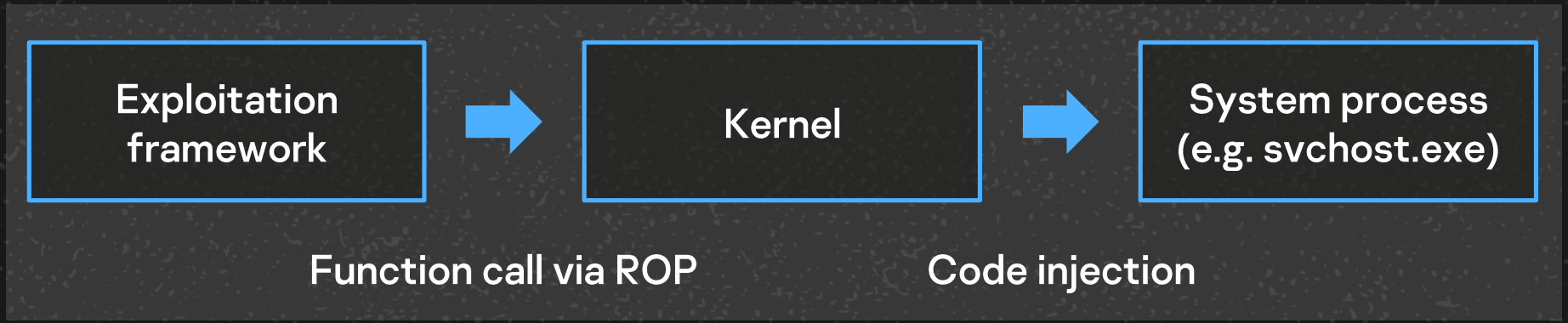
When correct address is found a ROP chain is build and written to the stack

Event to thread is fired to get ROP chain executed

In this case kernel shellcode is never used

This technique lets to execute any kernel function from user level!

Exploitation framework – From R/W to code execution in kernel level



DKOM lets to use many interesting techniques other than stealing SYSTEM token

Advanced threat actors already using them

Living in kernel land have a number of advantages

It's the same level where AV products live

Possible attacks on System Guard Runtime Attestation

We are likely to see more malicious uses of direct kernel object manipulation

http://alex-ionescu.com/Publications/OPCDE/octagon.pdf
https://www.microsoft.com/security/blog/2018/04/19/introducing-windows-defender-system-guard-runtime-attestation/

CVE-2019-0859 - Use-After-Free in win32k.sys driver

Root cause: Ability to set improper extra data with SetWindowLongPtr

ASLR bypass: HMValidateHandle

Exploitation primitive: Windows

CVE-2019-1458 - Arbitrary Pointer Dereference in win32k.sys driver

Root cause: Ability to set improper extra data with SetWindowLongPtr

ASLR bypass: CreateAcceleratorTableA + user32!gSharedInfo / GdiSharedHandleTable

Exploitation primitive: Bitmaps

https://securelist.com/new-win32k-zero-day-cve-2019-0859/90435/
https://securelist.com/windows-0-day-exploit-cve-2019-1458-used-in-operation-wizardopium/95432/

The vast majority of exploits found in the wild support only older builds of OS
Windows 10 is commonly supported, but only older builds

Exploits for CVE-2018-8453 and CVE-2018-8611 are unique there
They exploited the latest builds at the moment of discovery
More information about them in our slides for BlueHat Shanghai 2019

Finding vulnerabilities is much more easier than developing novel techniques for them

The majority of 0day exploits that we found in the wild recently are kernel exploits

We also look for RCE zero-days, but there are some complications

Our technologies are aimed at detection and prevention of exploitation

Exploit detection != zero-day finding
- Additional analysis is always required
- Lack of information

At first signs of exploitation there already might be nothing in memory
- All scripts were just-in-time compiled and freed from memory
- There are no interfaces available to kindly ask a browser for those scripts

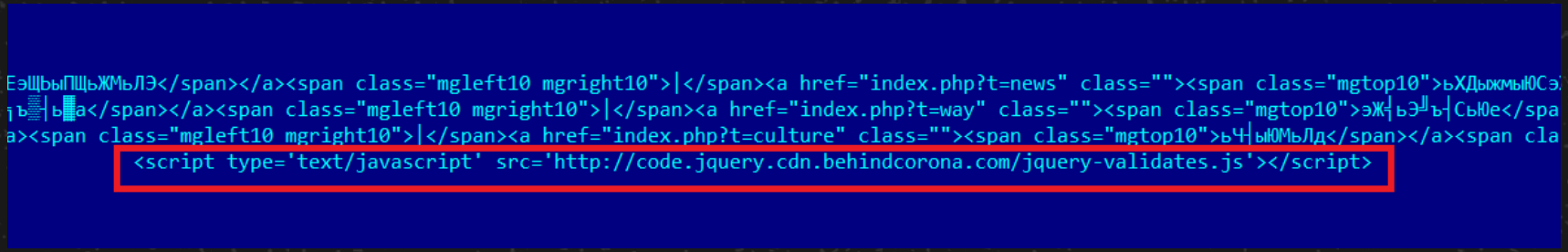
We work on those problems and zero-days gets found

Google Chrome Use-After-Free in Audio

Originally exploit supported only Chrome version 76 and 77
But we were able to fix exploit for the upstream versions and prove that its 0day

We call those attacks “Operation WizardOpium”
No definitive link with any known threat actors
Weak code similarities with Lazarus attacks (high chance of false alarm)
The profile of attack is more similar to DarkHotel attacks

Waterhole-style injection on a Korean-language news portal



Multiple redirects and layers of obfuscation and encryption

Actual exploit is split into multiple RC4 encrypted chucks

Key for actual payload is appended to GIF image

Vulnerability actually is a race condition that results in Use-After-Free (UaF)

1) Exploit triggers UaF to leak pointer (AudioFloatArray)
    - Defeats ASLR and makes it possible to retrieve others useful pointers
2) Memory is sprayed with attempt to reuse freed buffer
3) Control over AudioFloatArray lets to achieve arbitrary R/W
4) Exploit comes with huge WebAssembly object with “dummy” logic
5) V8 compiles WASM bytecode to native code and puts in into RWX section
6) RWX section is overwritten with shellcode
7) Exploit uses FileReader technique to trigger execution of shellcode

- Technique is very similar to the one used in Chrome 72 FileReader UaF exploit

Detailed write-up will be published at securelist.com

Just the tip of the iceberg: zero-days found in the wild in 2019

CVE-2019-7286

CVE-2019-2215

CVE-2019-1132

CVE-2019-1458

CVE-2019-18187

CVE-2019-0808

CVE-2019-7287

CVE-2019-0859

CVE-2019-5786

CVE-2019-0880

CVE-2019-0676

CVE-2019-0797

CVE-2019-0803

CVE-2019-11707

CVE-2019-3568

CVE-2019-0703

CVE-2019-13720

CVE-2019-1367

CVE-2019-1429

CVE-2019-11708

https://googleprojectzero.blogspot.com/p/0day.html

Thanks to Microsoft and Google for handling our findings very fast

Sharing detailed information about vulnerabilities is important
- Particular thanks to Microsoft Active Protection Program (MAPP) team
- Details about our findings were shared with partners, similar vulns were found

Sharing insights about threat actors brings great results
- More in the wild zero-days gets found

Right now making zero-days is hard, but not hard enough yet; huge money involved

Exploits will act more stealthy on platforms with good visibility
- Better AV checks / evasion
- Novel uses of DKOM to bypass System Guard Runtime Attestation

Thank you!

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