Ransomware

Ryan Warns

Outline

- Introductions
  - Me
  - FireEye
- Malware Analysis process
  - Goals and Process
- Ransomware
  - Implementations and Reverse Engineering
- Conclusion
- Q&A

Introduction

FLARE Offensive Task Force (OTF)

Ryan Warns

- Career trajectory:
  - Reversed malware
  - Wrote malware
  - Reversed malware
  - Repurposed malware
  - ???
- Presented at BlackHat, Infiltrate, CSW
- Fun fact: met wife on Counter-Strike
  - Also almost broke up with wife because of Counter-Strike ☺
- Gen 1 Cyberdawg
- Likes Windows Internals, Binary Exploitation, and long walks on the bach

FireEye/Mandiant

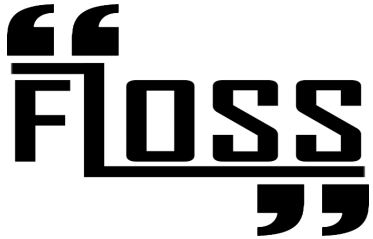
- 3 Main Services
- Consultancy
  - Red Teams
  - Incident Response
- Endpoint Security
  - Tools & Associated Monitoring
- Intelligence
  - Malware families, actors, APT groups, etc.

FLARE Team

- In-depth Reverse Engineering
  - Malware Analysis for hundreds of clients
  - Host and network decoders
  - Break things
- Tools
  - Internal and external
  - Make ourselves and investigators more efficient
  - Advance the overall community (Won Volatility contest, Malware Analysis Tools, CTF Hosting)
- Training – Internal and External
  - Black Hat, Private Companies, Internal Education, etc.
- Improve Detections and Context of Alerts
- FLARE On

Community Presence

- Get our **code** - https://github.com/fireeye/
- Read our **blog** - http://www.fireeye.com/blog
- Watch our **webinars** - https://www.brighttalk.com/search?q=flare
- Read our **whitepapers** - Synful Knock, WMI Defense and Offense
- Play with our free **tools** - https://www.fireeye.com/services/freeware.html
  - FLOSS, FakeNet-NG, FLARE VM



Malware Analysis & You

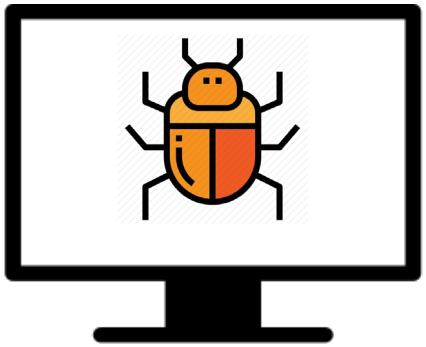
Malware Analysis

- Malware analysis is the **art of dissecting malicious software** to:
  - Understand how it works
  - Discover how to identify it
  - Plan to remove it

- Goals of malware analysis:
  - How can you detect malware within networks?
  - How can you tell if a host is infected?
  - What are the general capabilities of the malicious software?

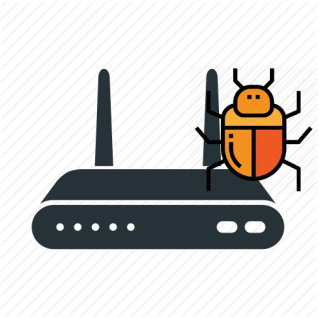
Malware Indicators – Host-Based

- Host-based indicators (HBIs) describe artifacts that malware leaves on a host
- Used to identify if an individual system is compromised
- HBIs can be anything unique about a sample:
  - File characteristics – size, hashes, names
  - Characteristics unique to the binary – strings, PDB paths
  - Changes made to the system – registry keys, created files, created directories
  - Other changes made to the system – named mutexes, started processes



Malware Indicators – Network-Based

- Network Based Indicators (NBIs) are unique characteristics of malware's communications over a network
- NBIs are used to identify infected systems on a network
- Network indicators are meant to identify unique details of network traffic
  - Domains and IP addresses
  - Protocols and ports
  - HTTP User-Agent strings
  - Unique patterns or data formats used by the sample



Malware Classifications - Capabilities

- When analyzing a sample it is useful to categorize malware into broad categories

- Sample categories:
  - **Backdoor/Remote Access Trojan (RAT)** – provides an attacker the ability to run commands on the infected system remotely
  - **Downloaders** –contacts a remote system to download additional binaries
  - **Ransomware** – encrypts files on a system to extort money from the infected
  - **Crypto Currency Miner** – uses a system's resources to mine crypto currency
  - **Credential Stealer** – extracts saved passwords from various locations on a system

- A sample may implement any combination of the above behaviors

Malware Analysis is *Iterative*

- Malware Analysis is *not*:
  - Static Analysis tells me the first 30%
  - Dynamic Analysis tells me the next 40%
  - Disassembly/Debugging tells me the rest

- Rather:
  - Maybe Static Analysis tells me 90%
  - … or Dynamic Analysis tells me nothing
  - … or on my 500th backdoor you open the command handler in IDA and know instantly

FIREEYE™

Ransomware Anatomy

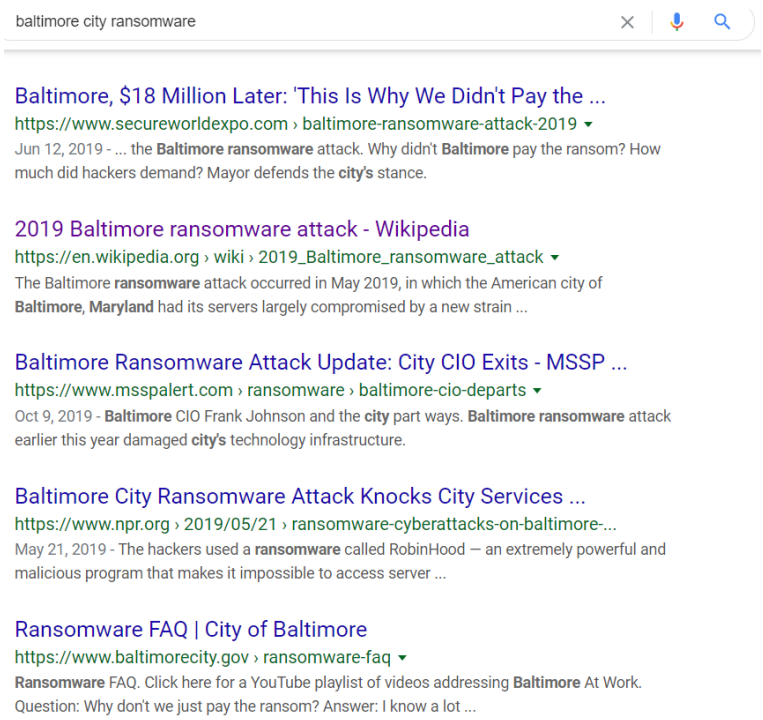
Ransomware

- Ransomware:
  - Iterates through files on an infected system
  - Encrypts or destroys them
  - May use a custom or standard encryption algorithm
  - May (not) extort victims for decryption keys

Ransomware? Who cares?

- FLREQ-9937 - ELF backdoor (with full symbols), using fake TLS handshake.
- FLREQ-9939 - DRAGONJUICE recon tool.
- FLREQ-9918 - MILUM backdoor
- FLREQ-9944 - BOOSTPIPE/SANDPIPE/THINPIPE code comparisons
- FLREQ-9953 - NSIS installer, acts as CobaltStrike Beacon dropper
- FLREQ-9955 - PROLOCK ransomware
- FLREQ-9961 - PROLOCK ransomware
- FLREQ-9958 - PROLOCK unlocker/decryptor
- FLREQ-9974 - Prolock Decryptor re-implementation request
- FLREQ-9810 - GINGERYUM dropper
- FLREQ-9952 - SADFLOWER/LOWKEY/FRONTMAN code comparison
- FLREQ-9929 - MAZE ransomware
- FLREQ-9962 - MAZE ransomware
- FLREQ-9959 - MAZE ransomware decryptor utility
- FLREQ-9981 - MAZE ransomware
- FLREQ-9984 - MAZE ransomware
- FLREQ-9977 - doppelpaymer ransomware
- FLREQ-9954 - Ploutus-D ATM malware
- FLREQ-9538 - Tyupkin ATM malware

Ransomware? Who cares?



Ransomware - Analysis

- We see ransomware all the time
  - *All* the time
- Common questions:
  - What *extension* does the ransomware use when renaming files
  - Can we extract the *ransom note*
  - Can the files be decrypted *after* the sample has run?

Ransomware - Analysis

- Q&A Time
- You're given a sample with our usual questions, and are asked to write a report
- You, probably, don't have an encyclopedic knowledge of encryption algorithms
- **Where do you start?**

Ransomware - Analysis

- 1) Iterates through files on an infected system
- 2) Opens, encrypts, and writes files

- Think: If I were writing a ransomware, how would I do this?
  - Then think: where do I look to find this in the binary?

Ransomware – File Encryption

- Multiple approaches to encrypting files
  - Creates new files, adds extension, deletes or overwrites the old
    - `ReadFile`
    - `WriteFile`
    - `DeleteFile`
    - `MoveFile`
  - In-place encryption, no new file or extension
    - `CreateFileMapping`
    - `MapViewOfFile`
    - `FlushViewOfFile`

```
loc_10002265:
                lea     edx, [esp+2E4h+Dest]
                push    offset Source ; ".WNCRY"
                push    edx ; Dest
```

A Quick Detour – The Windows API

- Application Programming Interface (API)
  - The source code interface provided by an operating system or library that defines the services provided by said operating system or library
  - **TL;DR** This is how you talk to Windows
- Every user application (**including malware**) must leverage the Windows API to do work
- Windows has evolved over the years, but many of the core Windows APIs have been largely unchanged for 30 years
  - Microsoft's commitment to backwards compatibility
- The Windows API is documented in the MSDN Library.
  - Available online or can be installed locally through versions of Visual Studio

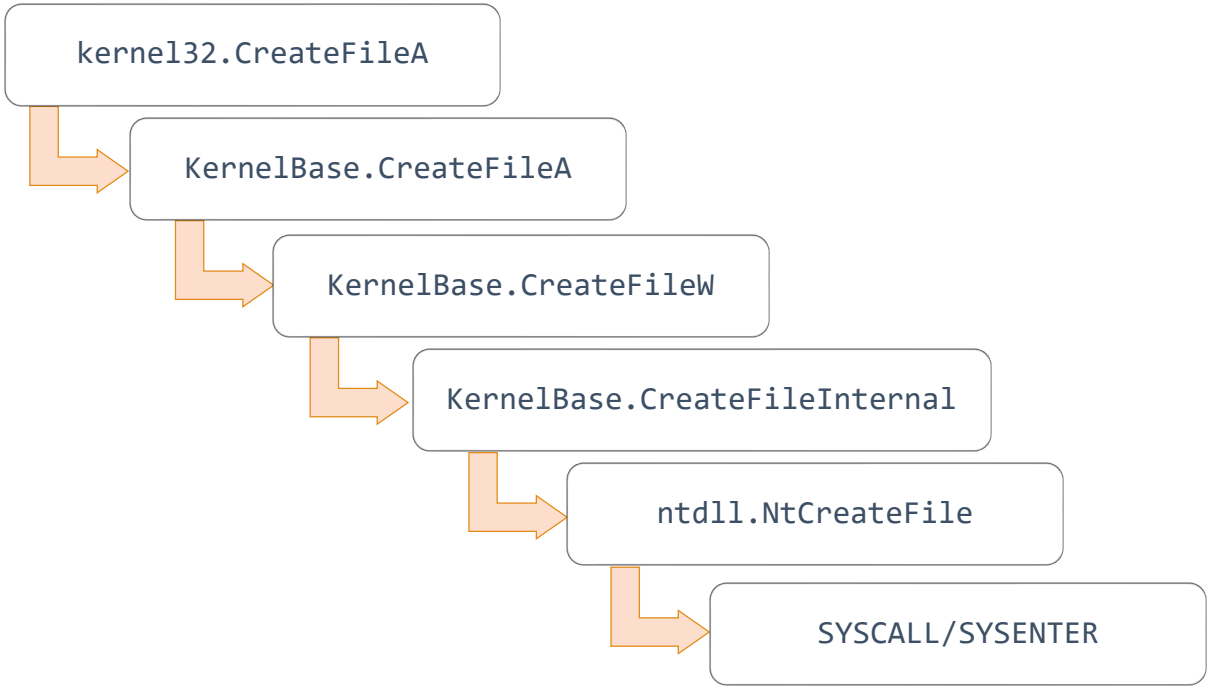
A Quick Detour – Subsystem DLLs

- Different subsystem DLLs provide different groups of functionality
- The main ones you will see are:
  - msvcrt.dll, msvcr1XX.dll – C runtime libraries, POSIX APIs
  - kernel32.dll – most vanilla APIs to manage files, processes, etc
  - kernelbase.dll – internal implementations for kernel32 APIs
  - wininet.dll and ws2_32.dll – upper- and lower-level networking functions
  - user32.dll and gdi32.dll – upper- and lower-level GUI functions
  - ntdll.dll – low-level OS management functions

A Quick Detour – The Windows API

- Internally, the Windows Kernel uses Unicode strings (UTF16-LE)
  - For international language support
- Many functions found in the Windows API have two versions:
  - An "`A`"-suffix version that uses narrow (ASCII) strings
  - A "`W`"-suffix version that uses wide (Unicode) strings
- Examples:
  - CreateFileA
  - CreateServiceW
  - RegSetValueExA
- Application developers choose to support Unicode in the program code
  - The same goes for malware authors

Life of a Windows API Call – Opening a File



- Transition to kernel mode

Life of a Windows API Call – `CreateFileA`

```
__stdcall CreateFileA(x, x, x, x, x, x, x) proc near
                                        ; DATA XREF: .text:1000140C↑o
                                        ; .text:off_10002D54↑o

UnicodeString   = LSA_UNICODE_STRING ptr -8
lpFileName      = dword ptr  8
dwDesiredAccess = dword ptr  0Ch
dwShareMode     = dword ptr  10h
lpSecurityAttributes= dword ptr  14h
dwCreationDisposition= dword ptr  18h
dwFlagsAndAttributes= dword ptr  1Ch
hTemplateFile   = dword ptr  20h

                mov     edi, edi
                push    ebp
                mov     ebp, esp
                push    ecx
                push    ecx
                mov     edx, [ebp+lpFileName]
                lea     ecx, [ebp+UnicodeString] ; DestinationString
                call    Basep8BitStringToDynamicUnicodeString(x,x)
                test    eax, eax
                jz      short loc_100171D6
                push    esi
                push    [ebp+hTemplateFile] ; hTemplateFile
                push    [ebp+dwFlagsAndAttributes] ; dwFlagsAndAttributes
                push    [ebp+dwCreationDisposition] ; dwCreationDisposition
                push    [ebp+lpSecurityAttributes] ; lpSecurityAttributes
                push    [ebp+dwShareMode] ; dwShareMode
                push    [ebp+dwDesiredAccess] ; dwDesiredAccess
                push    [ebp+UnicodeString.Buffer] ; lpFileName
                call    CreateFileW(x,x,x,x,x,x,x)
                mov     esi, eax
                lea     eax, [ebp+UnicodeString]
                push    eax             ; UnicodeString
                call    ds:RtlFreeUnicodeString(x)
                mov     eax, esi
                pop     esi

loc_100171D0:                           ; CODE XREF: CreateFileA(x,x,x,x,x,x,x)+49↓j
                mov     esp, ebp
                pop     ebp
                retn    1Ch
```

- Disassembly of `CreateFileA()`
  - Windows 7 x86, KernelBase.dll
- The ASCII version is a wrapper around the Unicode version
- On Windows 7 and higher, core Windows APIs are forwarded to a new subsystem DLL, `KernelBase.dll`

Ransomware - Analysis

- 1) Iterates through files on an infected system
- 2) ~~Opens~~, encrypts~~, and writes files~~

- Think: If I were writing a ransomware, how would I do this?
  - Then think: where do I look to find this in the binary?

Ransomware Analysis

- Ransomware can iterate files using the following APIs:
  - `FindFirstFile`
  - `FindNextFile`
- File extension comparison occurs after a file is located using these functions

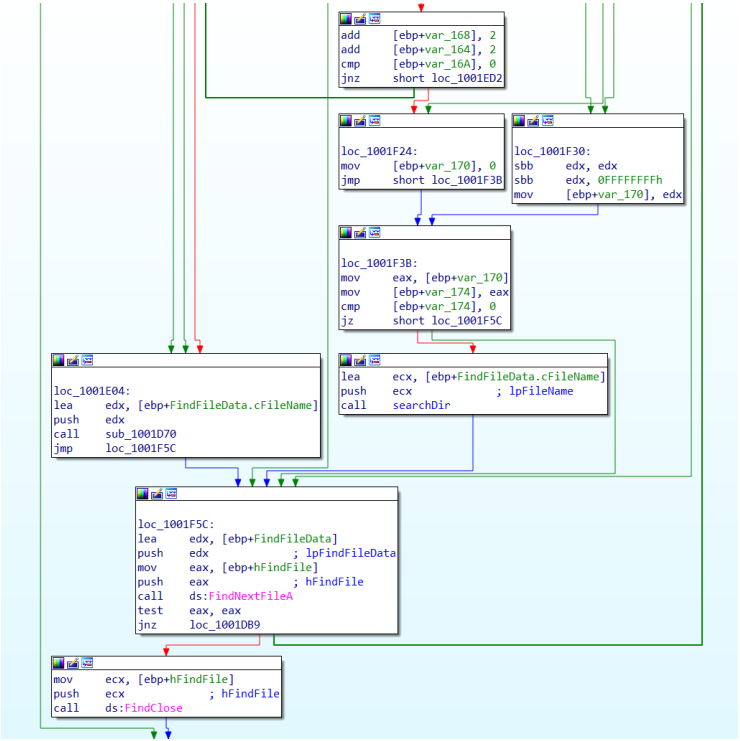
```
C++

typedef struct _WIN32_FIND_DATAA {
  DWORD    dwFileAttributes;
  FILETIME ftCreationTime;
  FILETIME ftLastAccessTime;
  FILETIME ftLastWriteTime;
  DWORD    nFileSizeHigh;
  DWORD    nFileSizeLow;
  DWORD    dwReserved0;
  DWORD    dwReserved1;
  CHAR     cFileName[MAX_PATH];
  CHAR     cAlternateFileName[14];
  DWORD    dwFileType;
  DWORD    dwCreatorType;
  WORD     wFinderFlags;
} WIN32_FIND_DATAA, *PWIN32_FIND_DATAA, *LPWIN32_FIND_DATAA;
```

Ransomware – Putting it Together

```
void doBadFileThings(char *dirToSearch)
{
    HANDLE hFind;
    WIN32_FIND_DATAA data;

    hFind = FindFirstFileA(dirToSearch, &data);

    if (hFind != INVALID_HANDLE_VALUE)
    {
        do
        {
            if(strstr(data.cFileName, ".jpg") ||
                strstr(data.cFileName, ".doc") ||
                strstr(data.cFileName, ".docx"))
            {
                doRansomWare(data.cFileName);
            }
            else if(data.dwFileAttributes & FILE_ATTRIBUTE_DIRECTORY &&
                    strcmp(".", data.cFileName) &&
                    strcmp("..", data.cFileName))
            {
                doBadFileThings(data.cFileName);
            }
        } while (FindNextFile(hFind, &data));

        FindClose(hFind);
    }
}
```

API example – Search a Directory (x86 - 1)

API example – Search a Directory (x86 - 2)



API example – Search a Directory

Ransomware - Analysis

- 1) ~~Iterates through files on an infected system~~
- 2) ~~Opens~~, encrypts~~, and writes files~~

- Think: If I were writing a ransomware, how would I do this?
  - Then think: where do I look to find this in the binary?

Ransomware - Encryption

- Q&A time:

- If you were writing a ransomware how would you design it? What algorithm(s) would you use? Any other steps you would take?

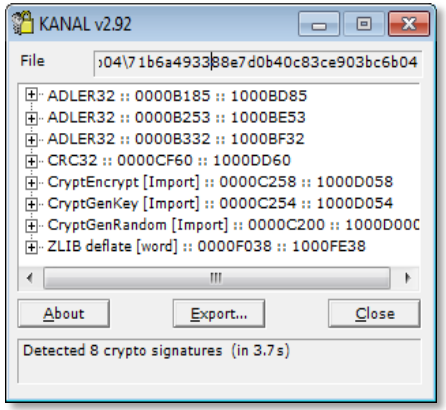
Encryption Approaches

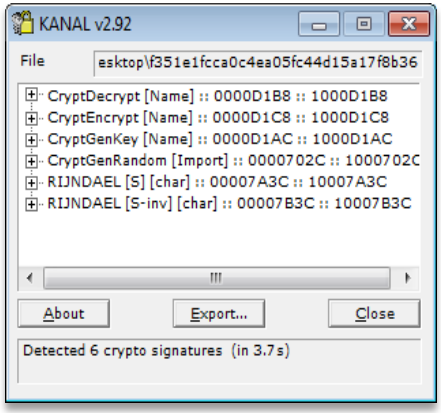
- Symmetric
  - Single private key to encrypt and decrypt (e.g., RC4, AES, DES)
  - Possible scenarios:
    - Generate private key and send to C2 server
    - Request private key from C2 server
  - Advantage
    - Fast
  - Disadvantage
    - Protecting the key is difficult

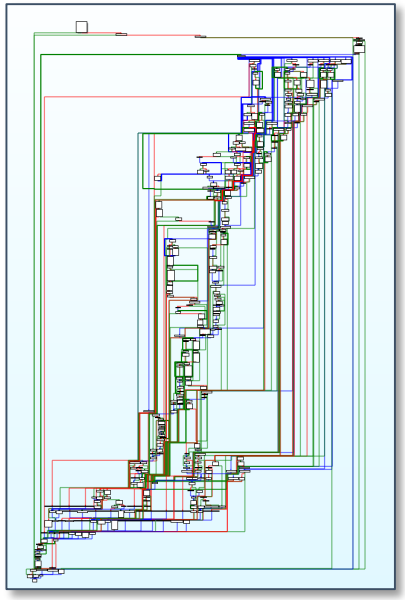
- Asymmetric
  - Uses public key to encrypt, private key to decrypt (e.g., RSA, Diffie-Hellman, ECC)
  - Possible scenarios:
    - Generate public/private key pair on system, transmit to C2
    - Encrypt files with an embedded or downloaded public key
  - Advantage
    - Key protection
  - Disadvantage
    - Slow

Tools – Crypto Identification

- Recognize complex functions that may be part of the encryption/decryption process
  - Avoid reversing these function and instead hunt for constants and strings
- PEiD
  - KANAL plugin identifies encryption constants and APIs
  - Generate an IDC script to markup IDA disassembly







Tools – Crypto Identification

- PEiD IDA Pro markup

```
.rdata:10007B3C      db  52h ; R ; RIJNDAEL [S-inv] [char]
.rdata:10007B3C                  ; RIJNDAEL (AES): inverse SBOX (for decryption)
.rdata:10007B3D      db    9
```

- FindCrypt IDA plugin

```
10007C3C: found const array Rijndael_Te0 (used in Rijndael)
1000803C: found const array Rijndael_Te1 (used in Rijndael)
1000843C: found const array Rijndael_Te2 (used in Rijndael)
1000883C: found const array Rijndael_Te3 (used in Rijndael)
10008C3C: found const array Rijndael_Td0 (used in Rijndael)
1000903C: found const array Rijndael_Td1 (used in Rijndael)
1000943C: found const array Rijndael_Td2 (used in Rijndael)
1000983C: found const array Rijndael_Td3 (used in Rijndael)
Found 8 known constant arrays in total.
```

Crypto Identification

github.com/kokke/tiny-AES-c/blob/master/aes.c

x86 and x64... | Using DbgHelp thr... | set/modify/restore... | The path to becom... | Using PowerShell t... | Why You No Longe... | compatibility - 16-b...

```
// This can be useful in (embedded) bootloader applications, where ROM is often limited.
static const uint8_t sbox[256] = {
  //0     1    2      3     4    5     6     7      8    9     A      B    C     D     E     F
  0x63, 0x7c, 0x77, 0x7b, 0xf2, 0x6b, 0x6f, 0xc5, 0x30, 0x01, 0x67, 0x2b, 0xfe, 0xd7, 0xab, 0x76,
  0xca, 0x82, 0xc9, 0x7d, 0xfa, 0x59, 0x47, 0xf0, 0xad, 0xd4, 0xa2, 0xaf, 0x9c, 0xa4, 0x72, 0xc0,
  0xb7, 0xfd, 0x93, 0x26, 0x36, 0x3f, 0xf7, 0xcc, 0x34, 0xa5, 0xe5, 0xf1, 0x71, 0xd8, 0x31, 0x15,
  0x04, 0xc7, 0x23, 0xc3, 0x18, 0x96, 0x05, 0x9a, 0x07, 0x12, 0x80, 0xe2, 0xeb, 0x27, 0xb2, 0x75,
  0x09, 0x83, 0x2c, 0x1a, 0x1b, 0x6e, 0x5a, 0xa0, 0x52, 0x3b, 0xd6, 0xb3, 0x29, 0xe3, 0x2f, 0x84,
  0x53, 0xd1, 0x00, 0xed, 0x20, 0xfc, 0xb1, 0x5b, 0x6a, 0xcb, 0xbe, 0x39, 0x4a, 0x4c, 0x58, 0xcf,
  0xd0, 0xef, 0xaa, 0xfb, 0x43, 0x4d, 0x33, 0x85, 0x45, 0xf9, 0x02, 0x7f, 0x50, 0x3c, 0x9f, 0xa8,
  0x51, 0xa3, 0x40, 0x8f, 0x92, 0x9d, 0x38, 0xf5, 0xbc, 0xb6, 0xda, 0x21, 0x10, 0xff, 0xf3, 0xd2,
```

Ransomware - Encryption

- The Windows API provides a cryptographic API implementing different algorithms
  - CryptAcquireContext – creates a crypto "object" to use during a crypto session
  - CryptCreateHash – creates a hash "object" to use during crypto session
  - CryptDeriveKey – key generations
  - CryptHashData – guess
  - CryptEncrypt/CryptDecrypt – guess
- There are other functions available to set:
  - Encryption mode (as applicable)
  - The IV
  - Padding

Ransomware – Encryption (Win API in C)

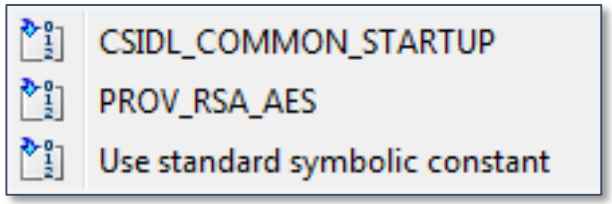
```
if(!CryptAcquireContext(
    &hProv,
    NULL,
    MS_ENH_RSA_AES_PROV,
    PROV_RSA_AES,
    CRYPT_VERIFYCONTEXT))
{
    printf("Error %x during CryptAcquireContext!\n", GetLastError());
    goto Cleanup;
}

if(!CryptCreateHash(hProv, CALG_SHA_256, 0, 0, &hHash))
{
    printf("Error %x during CryptCreateHash!\n", GetLastError());
    goto Cleanup;
}

if(!CryptHashData(hHash, (PBYTE)wszPassword, cbPassword, 0))
{
    printf("Error %x during CryptHashData!\n", GetLastError());
    goto Cleanup;
}

if (!CryptDeriveKey(hProv, CALG_AES_256, hHash, CRYPT_EXPORTABLE, &hKey))
{
    printf("Error %x during CryptDeriveKey!\n", GetLastError());
    goto Cleanup;
}
```

Ransomware – Encryption (Win API in IDA)

- The Windows API provides a cryptographic API implementing different algorithms
  - `CryptAcquireContext`

```
push    0                   ; dwFlags
push    18h                 ; dwProvType
push    0                   ; szProvider
push    0                   ; szContainer
mov     eax, [ebp+phProv]
push    eax                 ; phProv
call    ds:CryptAcquireContextW
```

```
push    0                   ; dwFlags
push    PROV_RSA_AES        ; dwProvType
push    0                   ; szProvider
push    0                   ; szContainer
mov     eax, [ebp+phProv]
push    eax                 ; phProv
call    ds:CryptAcquireContextW
```



`PROV_RSA_AES` includes RSA, RC4, AES, MD5, etc.

MSDN is your Friend

`dwProvType`

Specifies the type of provider to acquire. Defined provider types are discussed in Cryptographic Provider Types.

Name	Value	Meaning
PROV_RSA_FULL	0x00000001	Supports both digital signatures and data encryption. It is considered a general purpose CSP. The RSA public key algorithm is used for all public key operations.
PROV_DSS	0x00000003	Supports hashes and digital signatures. The signature algorithm specified by the PROV_DSS provider type is the **Digital Signature Algorithm (DSA)**.
PROV_RSA_AES	0x00000018	Supports the same as PROV_RSA_FULL with additional AES encryption capability.
PROV_DSS_DH	0x0000000D	A superset of the PROV_DSS provider type with Diffie-Hellman key exchange.
PROV_DH_SCHANNEL	0x00000012	Supports both Diffie-Hellman and Schannel protocols.
PROV_RSA_SCHANNEL	0x0000000C	Supports both RSA and Schannel protocols.
PROV_MS_EXCHANGE	0x00000005	Designed for the cryptographic needs of the Exchange mail application and other applications compatible with Microsoft Mail.

Ransomware - Encryption

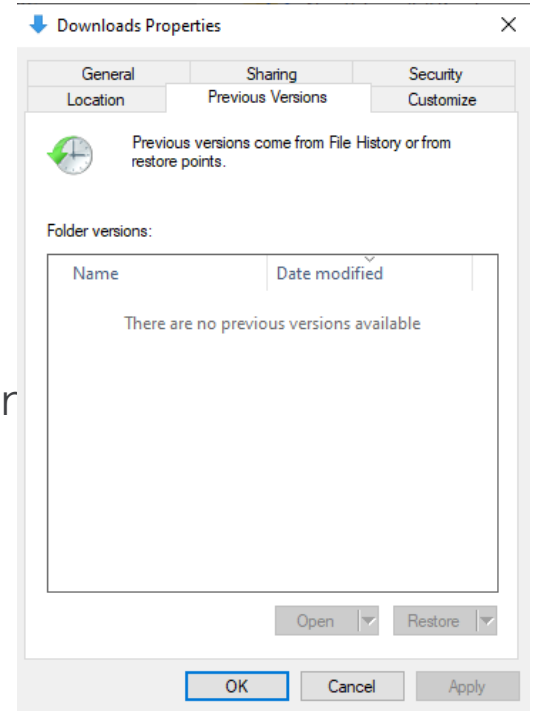
- The most common implementation for ransomware:
  - C2 server generates a PKI pair (e.g. RSA)
  - Ransomware binary contains the public key
  - Iterate all files on the system
    - Exclude/target certain extensions
  - For each file, generate a unique symmetric (e.g. AES) encryption key
  - Encrypt the file using AES
  - Encrypt the *AES key* using the *RSA key*
  - Embed/append the encrypted AES key in the encrypted file
  - Rename the file to the ransom extension

What if we use nonstandard algorithms?

- Malware authors may attempt to "trick" analysts by using custom algorithms
  - These algorithms are not cryptographically sound, obviously
- From one sample I worked on:
  - GetComputerName -> Hash -> Take last 8 bytes
  - GetVolumeSerial -> Hash -> Take last 4 bytes
  - Rolling XOR between these two hashes
  - Concatenate with the target file name
  - Use result from 4 to create an MD5 hash
  - Take 8 characters from an MD5 hash and turn it into an AES key
  - Encrypt

Ransomware – Odds and Ends

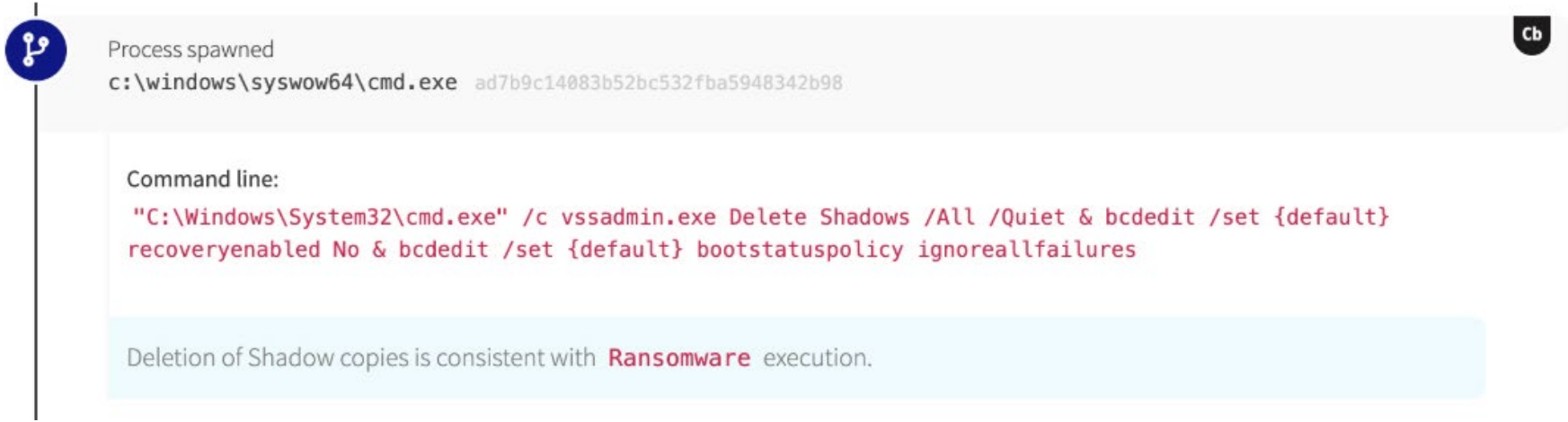
- Ransomware commonly use VSSADMIN to…
  - … delete shadow copies (e.g. previous versions)
- All malware commonly uses a named synchronization object (e.g. mutex) to check for infection)
- May use bcdedit to modify system restoration
- May beacon to a C2 to note an infection
- May use benign files to checkpoint when a directory has beer been encrypted
  - May be a way to "vaccinate" a system
  - e.g. .lock files found in a directory
- Common to see target extension strings to be obfuscated



Mutex Creation

```
v0 = OpenMutexA(0x1F0001u, 0, "windows_7_windows_10_check_running_once_mutex");
if ( v0 )
  return CloseHandle(v0);
CreateMutexA(0, 1, "windows_7_windows_10_check_running_once_mutex");
```

Destroying Backups



Ref: https://redcanary.com/blog/its-all-fun-and-games-until-ransomware-deletes-the-shadow-copies/

Ransomware – Wrapping up

- The ransomware note is also a source of intelligence
  - Contact information (e-mail? TOR?)
  - Payment information (BTC? FIAT?)
  - Languages
  - Locations
- All of this information is useful for creating a profile against the malware author

Ransomware – Wrapping up

- For ransomware *network based indicators* would include:
  - Any C2s contacted to alert the user of infection
  - If the ransom note contains a URL (e.g. onion address)

Ransomware – Wrapping up

- For ransomware the *host-based indicators* would include:
  - Renamed file extension
  - Any intermediate or .locked files
  - Modifications of registry keys (persistence), or deletion of system restore capability
  - Named mutexes to prevent re-infection

Conclusion

FLARE Offensive Task Force (OTF)

Ransomware - Encryption

- Malware analysis is an iterative process
  - Some tools are specialized for different samples
- Thorough understanding of the Windows API makes reversing easier
- Ransomware analysis is focused on encryption algorithms used and possibility of decryption
- Combining the above allows you to take short cuts to skip over superfluous details when reverse engineering binaries

Questions