The Mutant and Monitor in Space: Automated Discovery of Windows RPC/COM Vulnerabilities

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WhoAmI

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Security Researcher, Cyber-Kunlun
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PhD in Cryptography, interested in all areas of Computer Science

Work in Defensive & Offensive security

Published many research in both Industry & Academia

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Some of my bugs

CVE-2018-20694,CVE-2018-20746,CVE-2018-20693,CVE-2018-20692,CVE-2018-20696,CVE-2018-20689,CVE-2018-20690,CVE-2018-10812,CVE-2019-6184,CVE-2019-6186,CVE-2019-6487,CVE-2019-1253,CVE-2019-1292,CVE-2019-1317,CVE-2019-1340,CVE-2019-1342,CVE-2019-1374,CVE-2019-8162,CVE-2019-1474,CVE-2019-18371,CVE-2019-18370,CVE-2020-0616,CVE-2020-0635,CVE-2020-0636,CVE-2020-0638,CVE-2020-0641,CVE-2020-0648,CVE-2020-0697,CVE-2020-0730,CVE-2020-3808,CVE-2020-0747,CVE-2020-0753,CVE-2020-0754,CVE-2020-0777,CVE-2020-0780,CVE-2020-0785,CVE-2020-0786,CVE-2020-0789,CVE-2020-0794,CVE-2020-0797,CVE-2020-0800,CVE-2020-0805,CVE-2020-0808,CVE-2020-0819,CVE-2020-0822,CVE-2020-0835,CVE-2020-0841,CVE-2020-0844,CVE-2020-0849,CVE-2020-0854,CVE-2020-0858,CVE-2020-0863,CVE-2020-0864,CVE-2020-0865,CVE-2020-0868,CVE-2020-0871,CVE-2020-0896,CVE-2020-0897,CVE-2020-0899,CVE-2020-0900,CVE-2020-0934,CVE-2020-0935,CVE-2020-0936,CVE-2020-0942,CVE-2020-0944,CVE-2020-0983,CVE-2020-0985,CVE-2020-0989,CVE-2020-1000,CVE-2020-1002,CVE-2020-1010,CVE-2020-1011,CVE-2020-1029,CVE-2020-1068,CVE-2020-1077,CVE-2020-1084,CVE-2020-1086,CVE-2020-1090,CVE-2020-1094,CVE-2020-1109,CVE-2020-1120,CVE-2020-1121,CVE-2020-1123,CVE-2020-1124,CVE-2020-1125,CVE-2020-1131,CVE-2020-1134,CVE-2020-1137,CVE-2020-1139,CVE-2020-1144,CVE-2020-1146,CVE-2020-1151,CVE-2020-1155,CVE-2020-1156,CVE-2020-1157,CVE-2020-1158,CVE-2020-1163,CVE-2020-1164,CVE-2020-1165,CVE-2020-1166,CVE-2020-1184,CVE-2020-1185,CVE-2020-1186,CVE-2020-1187,CVE-2020-1188,CVE-2020-1189,CVE-2020-1190,CVE-2020-1191,CVE-2020-1196,CVE-2020-1199,CVE-2020-1201,CVE-2020-1204,CVE-2020-1209,CVE-2020-1211,CVE-2020-1217,CVE-2020-1222,CVE-2020-1231,CVE-2020-1233,CVE-2020-1235,CVE-2020-1244,CVE-2020-1257,CVE-2020-1264,CVE-2020-1269,CVE-2020-1270,CVE-2020-1273,CVE-2020-1274,CVE-2020-1276,CVE-2020-1277,CVE-2020-1278,CVE-2020-1282,CVE-2020-1283,CVE-2020-1304,CVE-2020-1305,CVE-2020-1306,CVE-2020-1307,CVE-2020-1309,CVE-2020-1312,CVE-2020-1317,CVE-2020-1337,CVE-2020-1344,CVE-2020-1346,CVE-2020-1347,CVE-2020-1352,CVE-2020-1356,CVE-2020-1357,CVE-2020-1360,CVE-2020-1361,CVE-2020-1362,CVE-2020-1364,CVE-2020-5957,CVE-2020-1366,CVE-2020-1372,CVE-2020-1373,CVE-2020-1375,CVE-2020-1385,CVE-2020-1392,CVE-2020-1393,CVE-2020-1394,CVE-2020-1399,CVE-2020-1404,CVE-2020-1405,CVE-2020-1424,CVE-2020-1427,CVE-2020-1441,CVE-2020-0518,CVE-2020-1461,CVE-2020-1465,CVE-2020-1472,CVE-2020-1474,CVE-2020-1475,CVE-2020-1484,CVE-2020-1485,CVE-2020-1511,CVE-2020-1512,CVE-2020-0516,CVE-2020-1516,CVE-2020-1517,CVE-2020-1518,CVE-2020-1519,CVE-2020-1521,CVE-2020-1522,CVE-2020-1524,CVE-2020-1528,CVE-2020-1538,CVE-2020-8741,CVE-2020-1548,CVE-2020-1549,CVE-2020-1550,CVE-2020-1552,CVE-2020-1590,CVE-2020-1130,CVE-2020-16851,CVE-2020-16852,CVE-2020-1122,CVE-2020-1038,CVE-2020-17089,CVE-2020-16853,CVE-2020-16879,CVE-2020-16900,CVE-2020-16980,CVE-2020-17014,CVE-2020-17070,CVE-2020-17073,CVE-2020-17074,CVE-2020-17075,CVE-2020-17076,CVE-2020-17077,CVE-2020-17092,CVE-2020-17097,CVE-2020-17120,CVE-2021-1649,CVE-2021-1650,CVE-2021-1651,CVE-2021-1659,CVE-2021-1680,CVE-2021-1681,CVE-2021-1686,CVE-2021-1687,CVE-2021-1688,CVE-2021-1689,CVE-2021-1690,CVE-2021-1718,CVE-2021-1722,CVE-2021-24072,CVE-2021-24077,CVE-2021-3750,CVE-2021-24088,CVE-2021-26869,CVE-2021-26870,CVE-2021-26871,CVE-2021-26885,CVE-2021-28347,CVE-2021-28351,CVE-2021-28436,CVE-2021-28450,CVE-2021-31966,CVE-2021-34527,CVE-2021-42321,CVE-2021-36970,CVE-2021-38657,CVE-2021-40485,CVE-2021-41366,CVE-2021-42294,CVE-2021-42297,CVE-2021-43216,CVE-2021-43223,CVE-2021-43248,CVE-2022-21835,CVE-2022-21837,CVE-2022-21878,CVE-2022-21881,CVE-2022-21888,CVE-2022-21971,CVE-2022-21974,CVE-2022-21992,CVE-2022-23285,CVE-2022-23290,CVE-2022-24454,CVE-2022-29108,CVE-2022-24547,CVE-2022-23270,CVE-2022-26930,CVE-2022-29103,CVE-2022-29113,CVE-2022-38036,CVE-2022-35793,CVE-2022-35755,CVE-2022-35749,CVE-2022-35746,CVE-2022-34690,CVE-2022-21980,CVE-2022-22050,CVE-2022-22024,CVE-2022-22022,CVE-2022-30226,CVE-2022-30157,CVE-2022-29108,CVE-2022-21999,CVE-2023-21683,CVE-2023-21684,CVE-2023-21693,CVE-2023-21801,CVE-2023-23403,CVE-2023-23406,CVE-2023-23413,CVE-2023-24856,CVE-2023-24857,CVE-2023-24858,CVE-2023-24863,CVE-2023-24865,CVE-2023-24866,CVE-2023-24867,CVE-2023-24907,CVE-2023-24868,CVE-2023-24909,CVE-2023-24870,CVE-2023-24872,CVE-2023-24913,CVE-2023-24876,CVE-2023-24924,CVE-2023-24883,CVE-2023-24925,CVE-2023-24884,CVE-2023-24926,CVE-2023-24885,CVE-2023-24927,CVE-2023-24886,CVE-2023-24928,CVE-2023-24887,CVE-2023-24929,CVE-2023-28243,CVE-2023-28296,CVE-2023-29366,CVE-2023-29367,CVE-2023-32017,CVE-2023-32039,CVE-2023-32040,CVE-2023-32041,CVE-2023-32042,CVE-2023-32085,CVE-2023-35296,CVE-2023-35302,CVE-2023-35306,CVE-2023-35313,CVE-2023-35323,CVE-2023-35324,CVE-2023-36898,CVE-2023-36792,CVE-2023-36704,CVE-2023-36418,CVE-2023-36395,CVE-2023-36393,CVE-2023-35624,CVE-2023-21683,CVE-2023-29366,CVE-2023-46138,CVE-2023-42820,CVE-2023-42819,CVE-2024-21426,CVE-2024-29156,CVE-2024-26198,CVE-2024-21435,CVE-2024-21329,CVE-2024-21384,CVE-2024-20691,CVE-2024-21433,CVE-2024-20694,CVE-2024-0087,CVE-2024-0088,CVE-2024-30060,CVE-2024-29989,CVE-2024-38077,CVE-2024-38024,CVE-2024-38023,CVE-2024-38076,CVE-2024-38074,CVE-2024-38073,CVE-2024-35261,CVE-2024-38072,CVE-2024-38071,CVE-2024-38015,CVE-2024-43467,CVE-2024-43455,CVE-2024-38231,CVE-2024-38258,CVE-2024-43454,CVE-2024-38263,CVE-2024-38260,CVE-2024-38228,CVE-2024-43495,CVE-2024-43470,CVE-2024-38225

Agenda

- Introduction
- ALPC Internals
- XALPC Fuzzing
- XALPC Monitoring
- Summary


Introduction

Background

RPC/COM is an important attack surface for Windows

- RCE, LPE and Sandbox Escape

Previous vulnerability research focused on existing pattern

- Race condition, File Redirection etc.
- Requiring significant time and effort investment

Motivation

Fuzzing RPC/COM Server in Windows

Creating custom corpus and fuzzers for each interface

Reverse engineering process proves inefficient and cumbersome

Our solution: XALPC

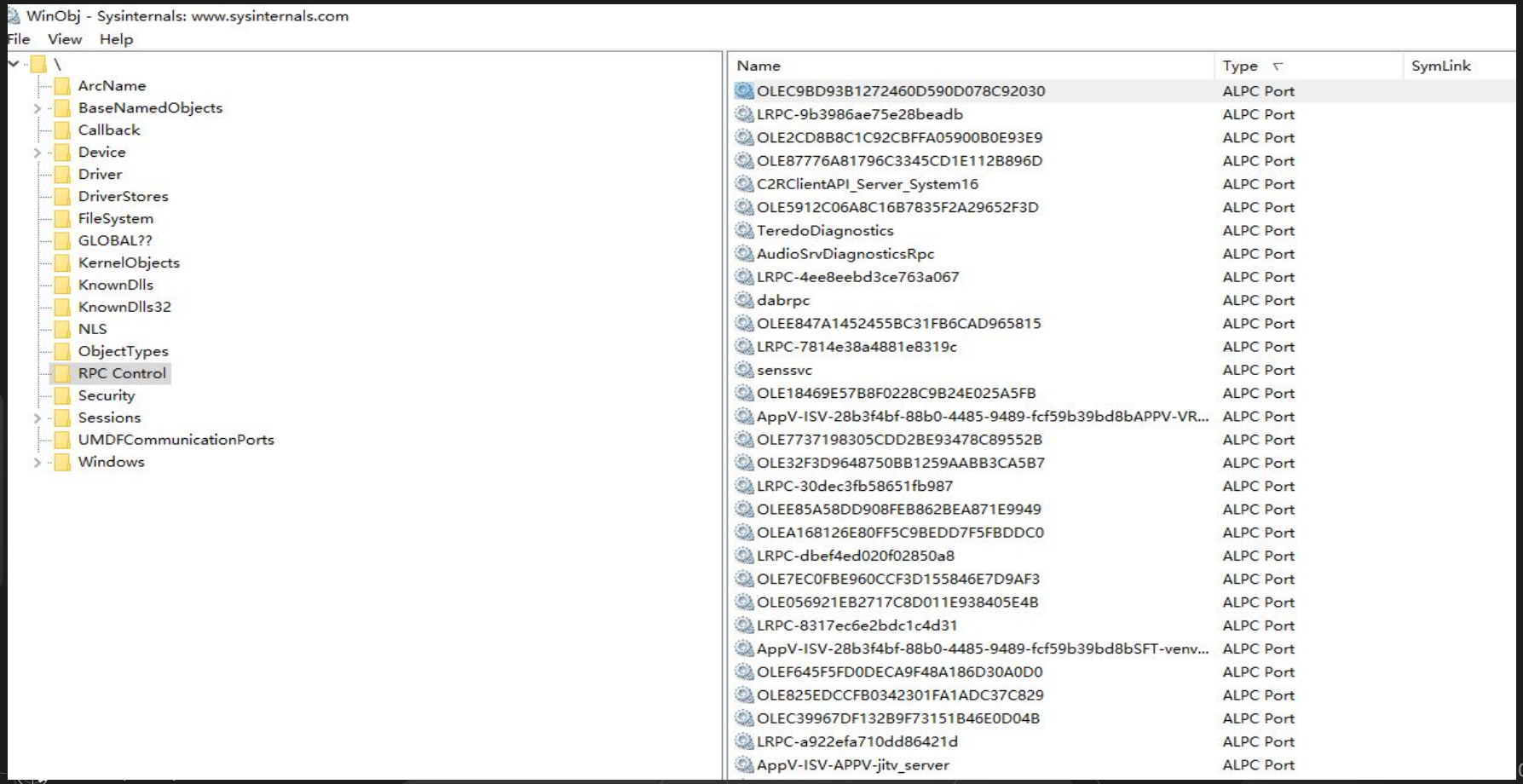
A cutting-edge RPC/COM fuzzing and monitoring tool to hunting system-wide RPC/COM vulnerabilities


ALPC Internals

ALPC Internals

- ALPC (Advanced Local Procedure Call)
  - Inter-process communication on Windows
  - Server listening on an ALPC port
  - Client connecting to that port
- Widely used in Windows
  - COM/RPC/ALPC Server depend on it for IPC

ALPC Port


WinObj - Sysinternals: www.sysinternals.com
File View Help
\
ArcName
BaseNamedObjects
Callback
Device
Driver
DriverStores
FileSystem
GLOBAL??
KernelObjects
KnownDlls
KnownDlls32
NLS
ObjectTypes
RPC Control
Security
Sessions
UMDFCommunicationPorts
Windows
Name
Type
SymLink
OLEC9BD93B1272460D590D078C92030 ALPC Port
LRPC-9b3986ae75e28beadb ALPC Port
OLE2CD8B8C1C92CBFFA05900B0E93E9 ALPC Port
OLE87776A81796C3345CD1E112B896D ALPC Port
C2RClientAPI_Server_System16 ALPC Port
OLE5912C06A8C16B7835F2A29652F3D ALPC Port
TeredoDiagnostics ALPC Port
AudioSrvDiagnosticsRpc ALPC Port
LRPC-4ee8eebd3ce763a067 ALPC Port
dabrpc ALPC Port
OLEE847A1452455BC31FB6CAD965815 ALPC Port
LRPC-7814e38a4881e8319c ALPC Port
senssvc ALPC Port
OLE18469E57B8F0228C9B24E025A5FB ALPC Port
AppV-ISV-28b3f4bf-88b0-4485-9489-fcf59b39bd8bAPPV-VR... ALPC Port
OLE7737198305CDD2BE93478C89552B ALPC Port
OLE32F3D9648750BB1259AABB3CA5B7 ALPC Port
LRPC-30dec3fb58651fb987 ALPC Port
OLEE85A58DD908FEB862BEA871E9949 ALPC Port
OLEA168126E80FF5C9BEDD7F5FBDDC0 ALPC Port
LRPC-dbef4ed020f02850a8 ALPC Port
OLE7EC0FBE960CCF3D155846E7D9AF3 ALPC Port
OLE056921EB2717C8D011E938405E4B ALPC Port
LRPC-8317ec6e2bdc1c4d31 ALPC Port
AppV-ISV-28b3f4bf-88b0-4485-9489-fcf59b39bd8bSFT-venv... ALPC Port
OLEF645F5FD0DECA9F48A186D30A0D0 ALPC Port
OLE825EDCCFB0342301FA1ADC37C829 ALPC Port
OLEC39967DF132B9F73151B46E0D04B ALPC Port
LRPC-a922efa710dd86421d ALPC Port
AppV-ISV-APPV-jitv_server ALPC Port

ALPC API

ALPC Server

- NtAlpcCreatePort
- NtAlpcAcceptConnectPort
- NtAlpcSendWaitReceivePort

ALPC Client

- NtAlpcConnectPort
- NtAlpcDisconnectPort
- NtAlpcSendWaitReceivePort

ALPC Message

ALPC Message include two parts

PORT_MESSAGE: the header and data of the message

ALPC_MESSAGE_ATTRIBUTES: Attributes header and data for advanced features

```
typedef struct _PORT_MESSAGE
{
    ULONG u1;
    ULONG u2;
    union
    {
        CLIENT_ID ClientId;
        Float DoNotUseThisField;
    };
    ULONG MessageId;
    union
    {
        ULONG ClientViewSize;
        ULONG CallbackId;
    };
} PORT_MESSAGE, *PPORT_MESSAGE;
```

NDR Engine

Network Data Representation (NDR) Engine

- The marshaling engine of the RPC and DCOM components
- Actual data in ALPC message is marshalled and unmarshalled by NDR

Online Document

- https://learn.microsoft.com/en-us/windows/win32/rpc/rpc-ndr-engine


XALPC Fuzzing

How to fuzz ALPC effectively?

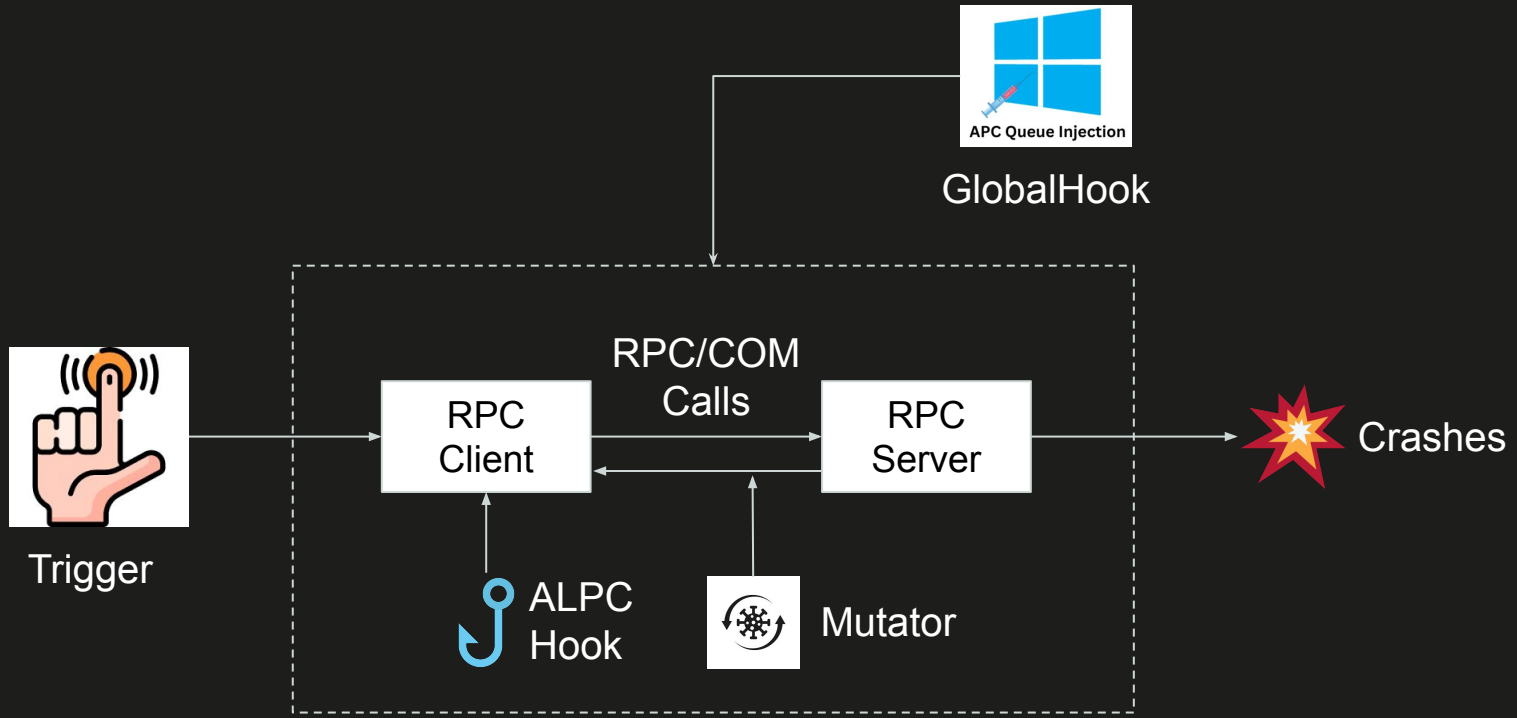
Challenges

1. ∞ Huge amounts of ALPC messages system-wide.
2. 🎯 How to mutate the message sent to ALPC Server?
3. 🎯 How to trigger more hidden ALPC messages?

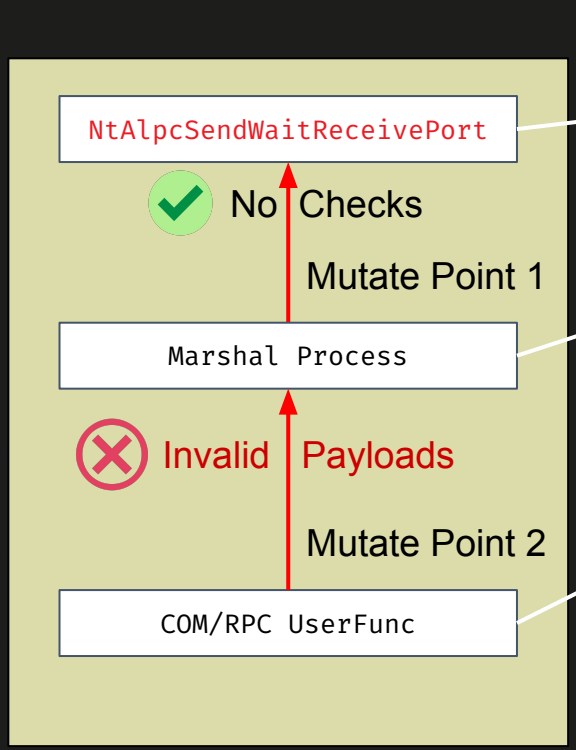
XALPCFuzz

Proposing a hook-based framework to fuzz Windows RPC/COM messages live & at scale.

XALPCFuzz - Design



XALPCFuzz - Where to hook & mutate

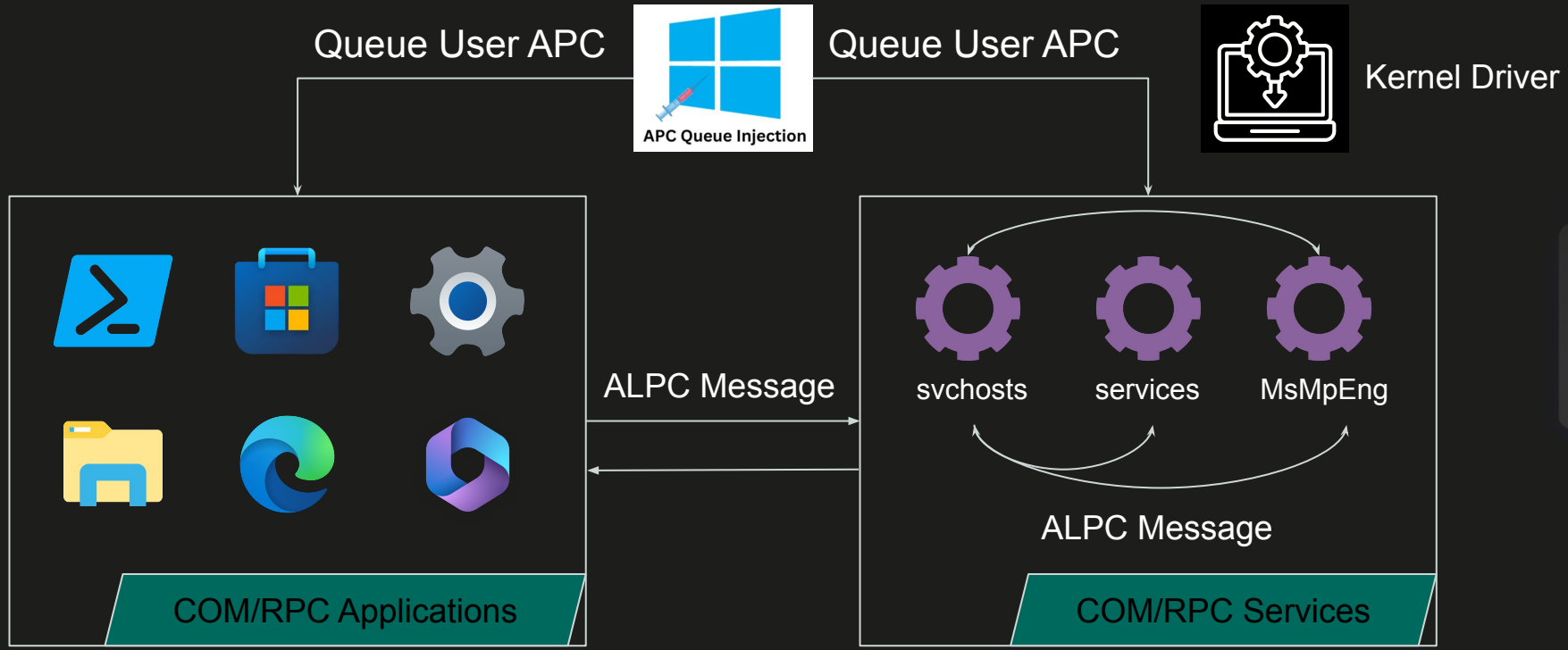


RPC Client


```
Call Site
ntdll!NtAlpcSendWaitReceivePort
RPCRT4!LRPC_BASE_CCALL::DoSendReceive+0x156
RPCRT4!LRPC_CCALL::SendReceive+0x76
RPCRT4!NdrpClientCall3+0x63c
RPCRT4!NdrClientCall3+0xed
sechost!LsaLookupOpenLocalPolicy+0x49
sechost!LookupAccountSidInternal+0xe2
sechost!LookupAccountSidLocalW+0x25
advapi32!GetAccountName+0x9a
advapi32!CreateRpcBinding+0xb1
advapi32!OpenRemoteExtObjectLibrary+0x17
advapi32!OpenExtObjectLibrary+0x970
advapi32!QueryV1Provider+0xc7
advapi32!QueryExtensibleData+0x427
advapi32!PerfRegQueryValueEx+0xbd3
advapi32!PerfRegQueryValue+0x3b
KERNELBASE!BaseRegQueryValueInternal+0x4af
KERNELBASE!RegQueryValueExW+0x128
```

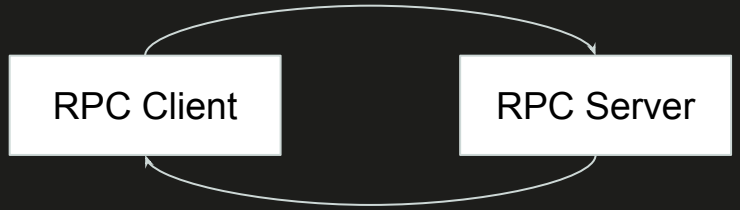
Local RPC Call Stack

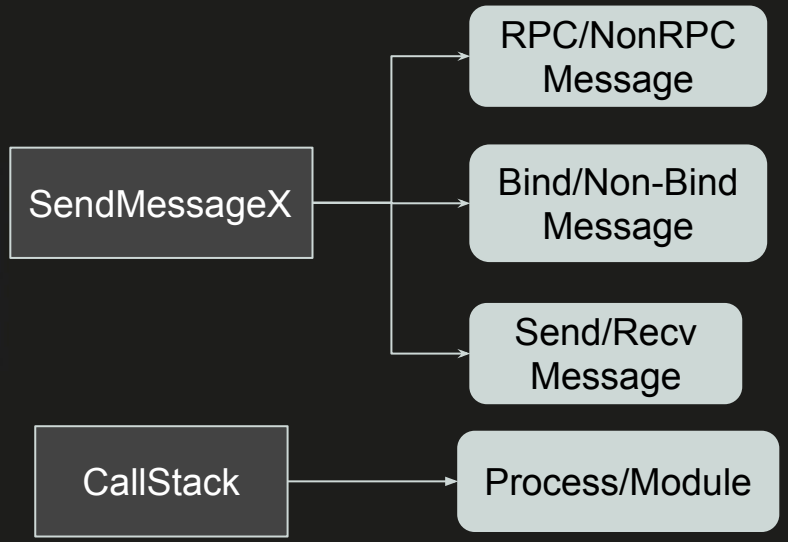
XALPCFuzz - Deploy globally



XALPCFuzz - Filter messages & processes

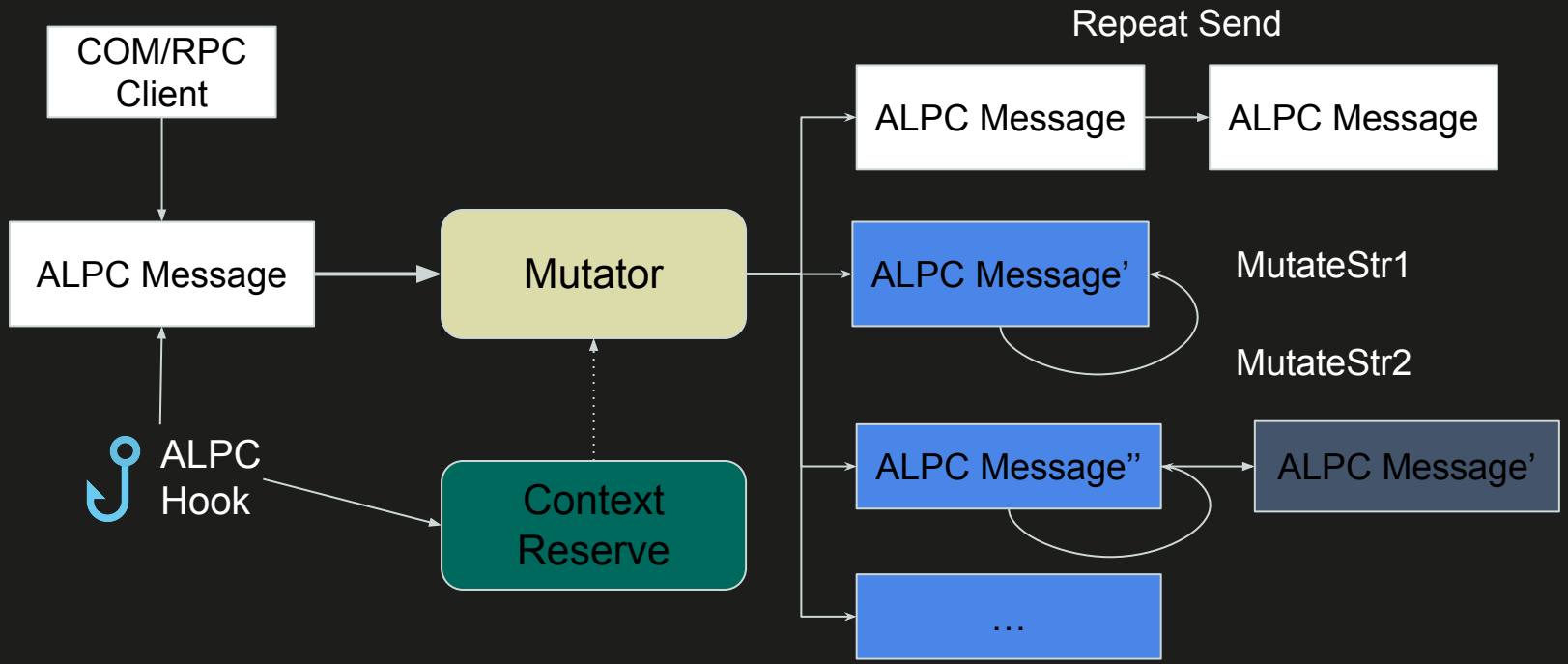
ALPC MessageType is PPORT_MESSAGE.
When the ALPC call contains an RPC message, SendMessageX contains marshalled RPC body.





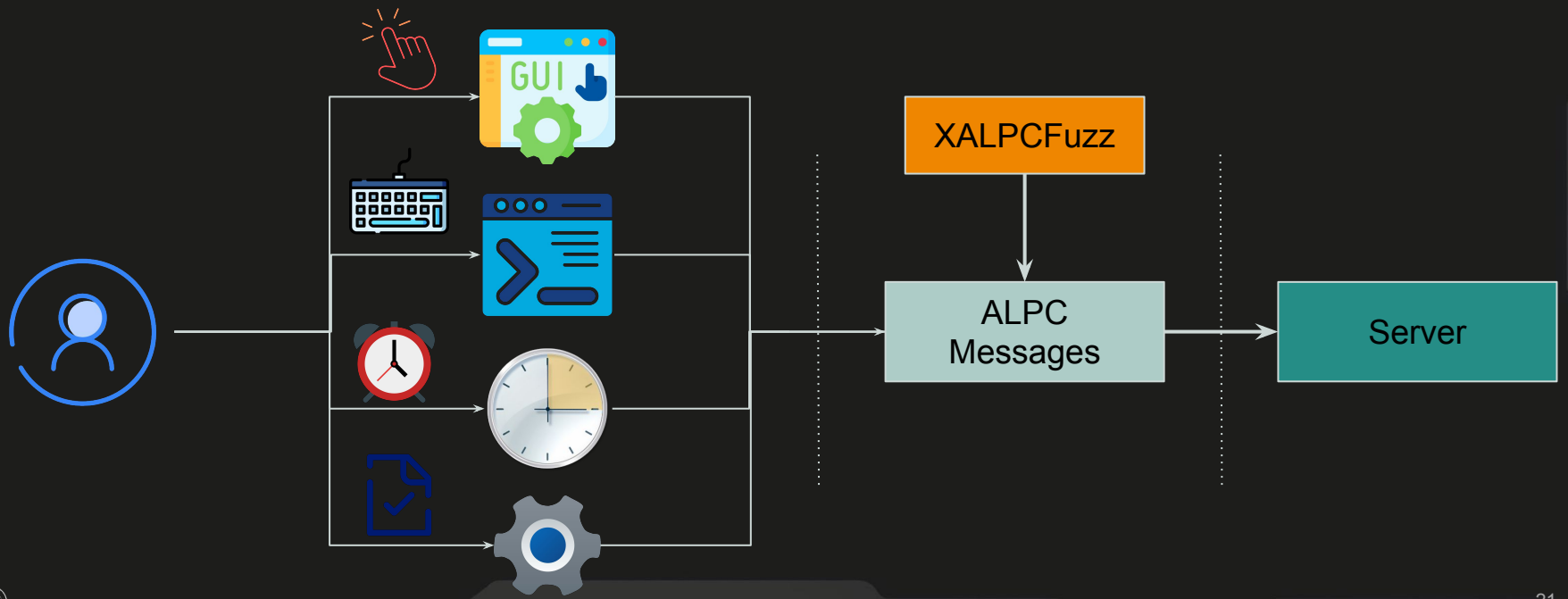

```
NTSTATUS NtAlpcSendWaitReceivePortFilter(
 HANDLE PortHandle,
 ULONG Flags,
 PPORT_MESSAGE SendMessageX,
 PALPC_MESSAGE_ATTRIBUTES SendMessageAttributes,
 PPORT_MESSAGE ReceiveMessage,
 PSIZE_T BufferLength,
 PALPC_MESSAGE_ATTRIBUTES
ReceiveMessageAttributes,
 PLARGE_INTEGER Timeout
)
```

XALPCFuzz - Mutation Strategy



XALPCFuzz - Trigger

Trigger is an important component in this scenario.
We use it to generate more ALPC messages as mutation seeds.



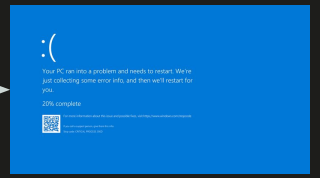
Case Study

Launch
Powershell.exe

Replace Mutator: 0xffff

XALPC-Mutator

InitProcess:
Send ALPC



BSOD

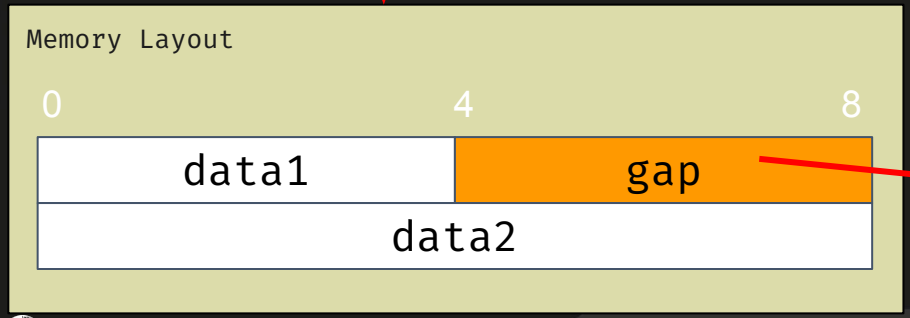

XALPC Monitoring

Why Monitor

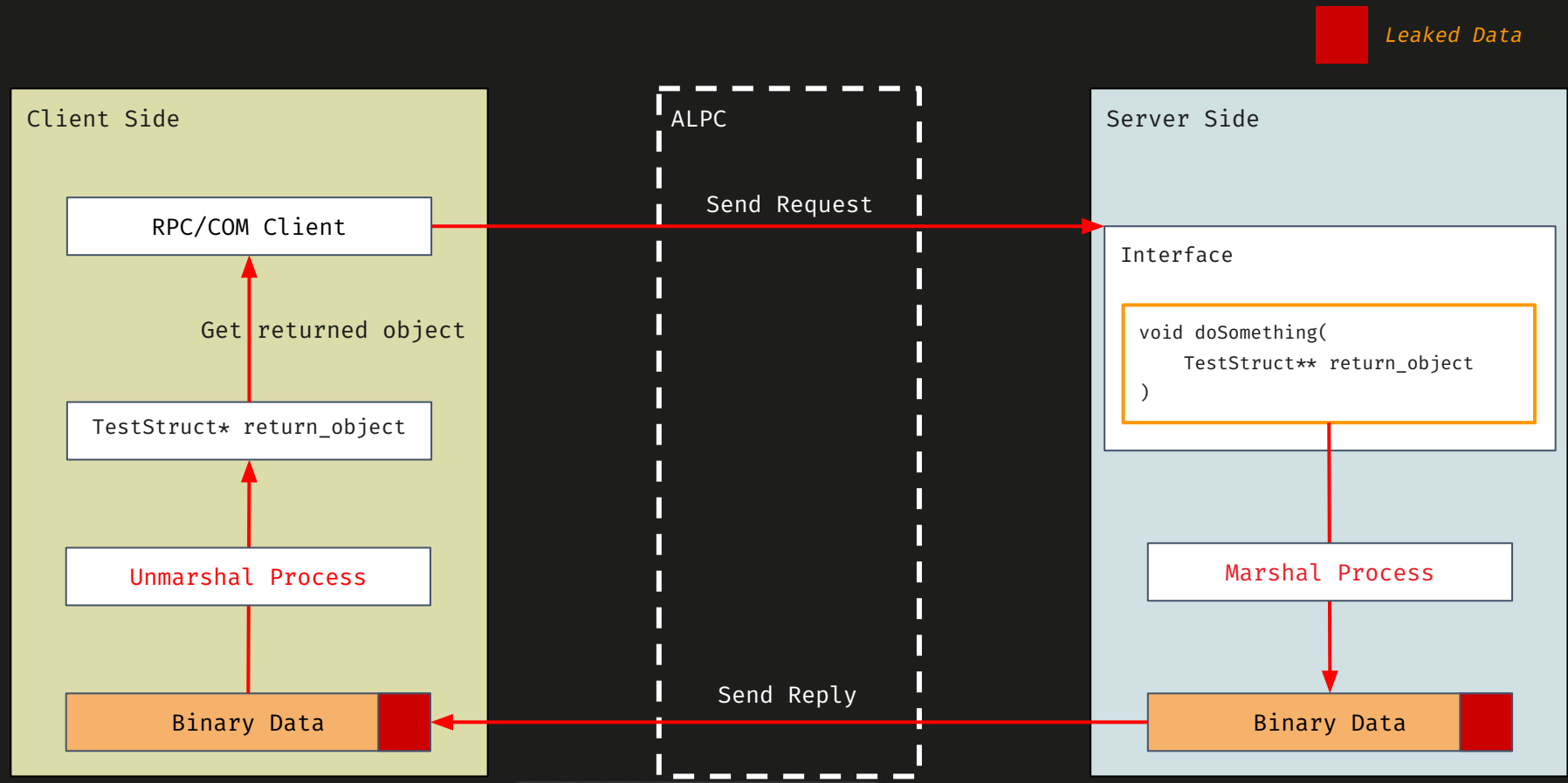
- Typical uninitialized memory

```
typedef struct TestStruct{
      DWORD data1;
      ULONG64 data2;
};
```

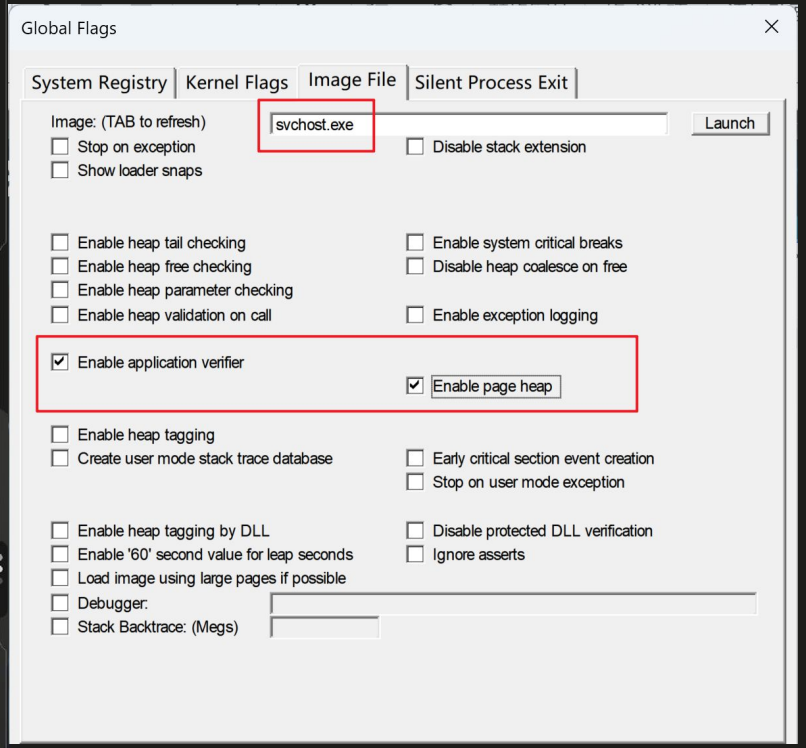
```
void doSomething(TestStruct** return_object){
      TestStruct* object = (TestStruct*)malloc( sizeof(TestStruct) );
      object→data1 = 0;
      object→data2 = 0;

      *return_object = object;  // return object to the caller
}
```



Leak Uninitialized Data



Detect Leaked Memory



Without Page Heap (filled with unpredictable value)

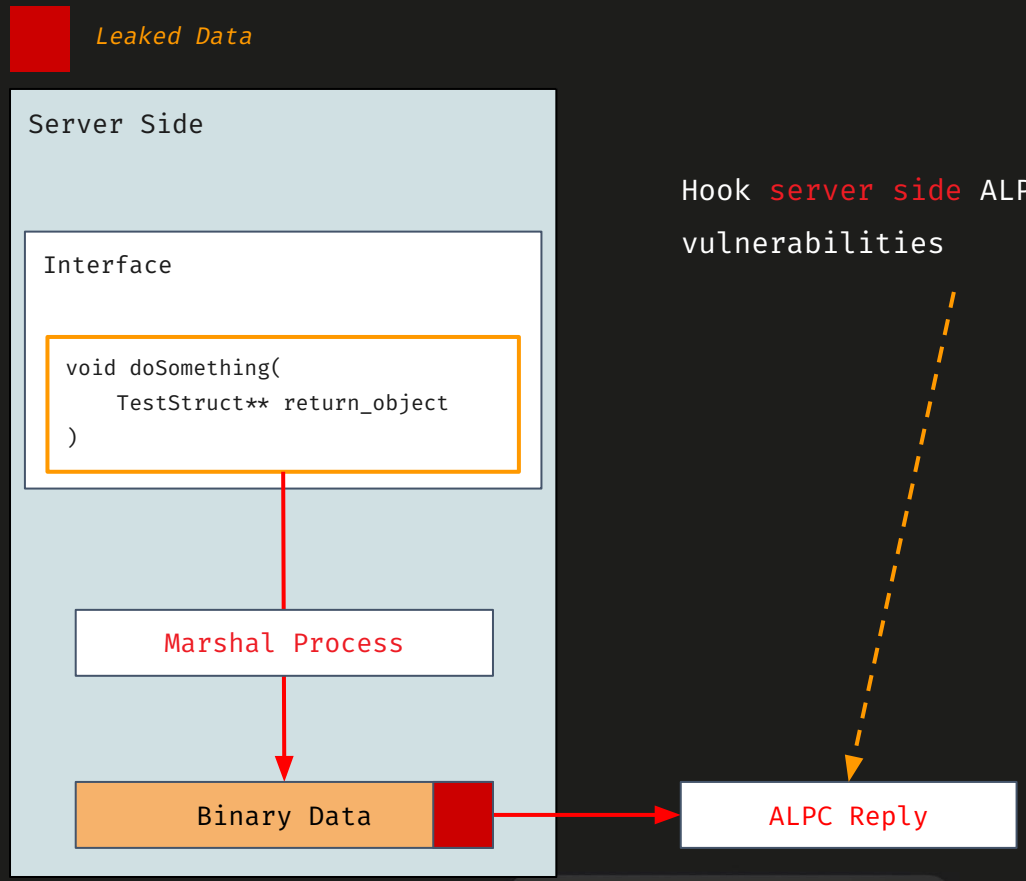
```
0:003> db 0000024F932B1290
0000024f`932b1290  50 01 2a 93 4f 02 00 00-30 fd 2a 93 4f 02 00 00  P.*.O...0.*.O...
0000024f`932b12a0  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
0000024f`932b12b0  00 00 00 00 d1 00 00 00-00 00 00 00 00 00 00 00  ................
0000024f`932b12c0  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
0000024f`932b12d0  01 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
0000024f`932b12e0  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
0000024f`932b12f0  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
0000024f`932b1300  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
```

With Page Heap (filled with fixed value)

```
0:021> db 000002f0`f3f7e9b8
000002f0`f3f7e9b8  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7e9c8  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7e9d8  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7e9e8  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7e9f8  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7ea08  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7ea18  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
000002f0`f3f7ea28  e0 e0 e0 e0 e0 e0 e0 e0-e0 e0 e0 e0 e0 e0 e0 e0  ................
```

Treat 0×e0e0 as a signature

Install ALPC Hooker



Hook server side ALPC reply API to detect the vulnerabilities

Effective, but not enough!

Issues we meet

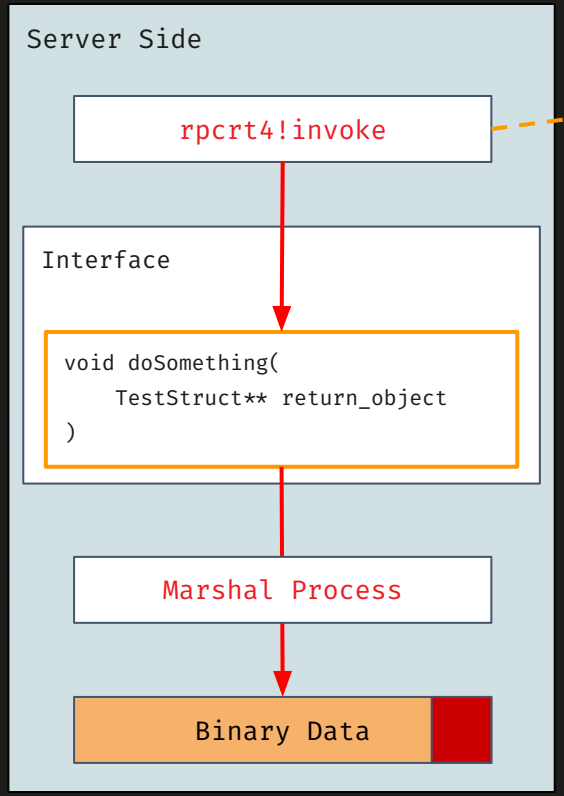
Several vulnerabilities reported, but hard to reproduce

We don't have enough information related to the vulnerable function at ALPC level

- Hard to locate the vulnerable function
  - ALPC call stack is separated from the vulnerable function, we can’t get the function name from the stack
- Hard to locate the vulnerable parameters for complex interface
  - For interfaces with multiple Out parameters, we don't know which parameter caused the info leak.
  - Much time of Reverse Engineering is required.

```
HRESULT VulnerableFunction(
      [In] int arg1,
      [Out] struct1* arg2,
      [Out] struct2* arg3,
      [Out] struct3* arg4,
      [Out] struct4* arg5,
      [Out] struct5* arg6
);
```

Solution



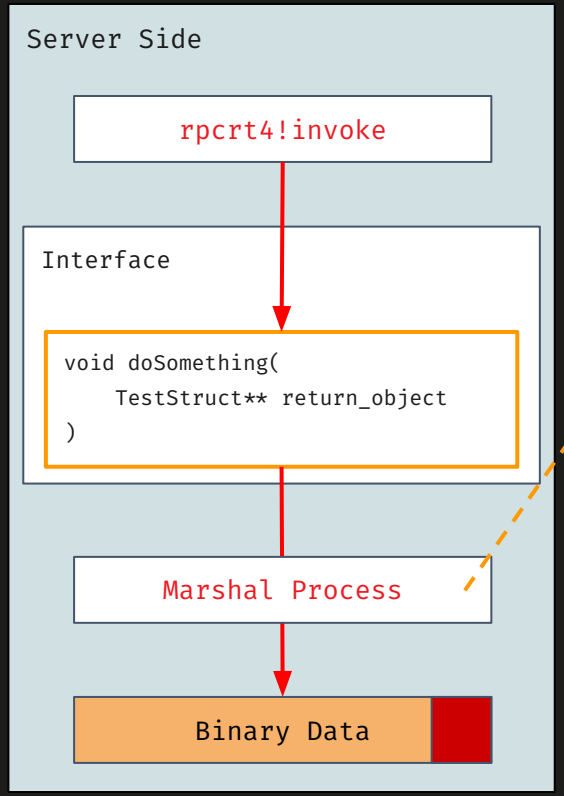
- For challenge 1

  Hook the entry point to get the function address, store the value at global position

```
__int64 __fastcall Invoke(
        __int64 (__fastcall *a1)(__int64, __int64, __int64, __int64),
        const void *a2,
        __int64 a3,
        unsigned int a4)
{
  void *v4; // rsp
  __int64 vars0[4]; // [rsp+0h] [rbp+0h] BYREF

  v4 = alloca(8 * ((a4 + 1) & 0xFFFFFFFE));
  qmemcpy(vars0, a2, 8i64 * a4);
  RpcInvokeCheckICall(a1);
  return a1(vars0[0], vars0[1], vars0[2], vars0[3]);
}
```

rpcrt4!invoke

Solution



- For challenge 2
  - Hook the Marshal Process
    - Detect the leaked data
    - Identify which parameters cause the info leak
    - Read the function address from the global position

```
index = 0;
Foreach param in params:
        index++;
        CallMarshalHandler( param, marshal_buffer );
        if DetectUninitializedMemory( marshal_buffer ) == True:
                // ok, we find the vul
                func_addr = g_func_addr;
                ReportVul( func_addr, index, … );
```

pseudocode

Case Study

CVE-2023-35325 Windows Print Spooler Information Disclosure Vulnerability

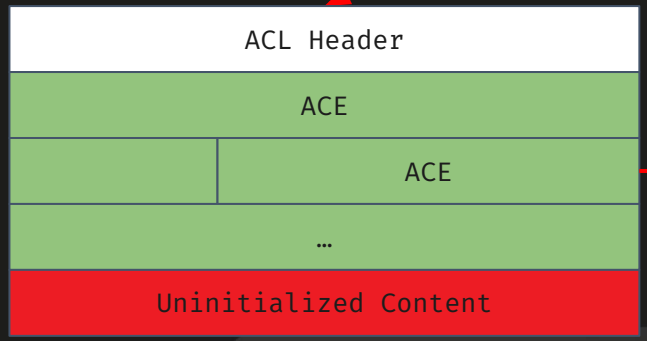
```
BOOL GetPrinter(
  _In_  HANDLE  hPrinter,
  _In_  DWORD   Level,
  _Out_ LPBYTE  pPrinter,
  _In_  DWORD   cbBuf,
  _Out_ LPDWORD pcbNeeded
);
```

RPC Interface

Forget to empty

```
acl_buffer = operator new(total_acl_size);

InitializeAcl(acl_buffer, total_acl_size, 2u)

[ ... ]

for (int idx=0; idx< ace_count; idx++){
    AddAce(acl_buffer, 2u, 0×FFFFFFFF, ace, ace_size);
}
```

localspl!DuplicateAclWithPermission



Return back to caller


Summary

XALPC

XALPC Fuzzing

- Hook-based framework to fuzz Windows RPC/COM messages
- Automatically mutating ALPC message to discover vulnerabilities

XALPC Monitoring

- ALPC level monitor
- Monitor and identify leaked memory information in ALPC messages

10+ CVE found.

Let’s Talk?

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