Lifting the Fog of War

Monitoring, Identifying and Mitigating MS-RPC Based Threats

whoami

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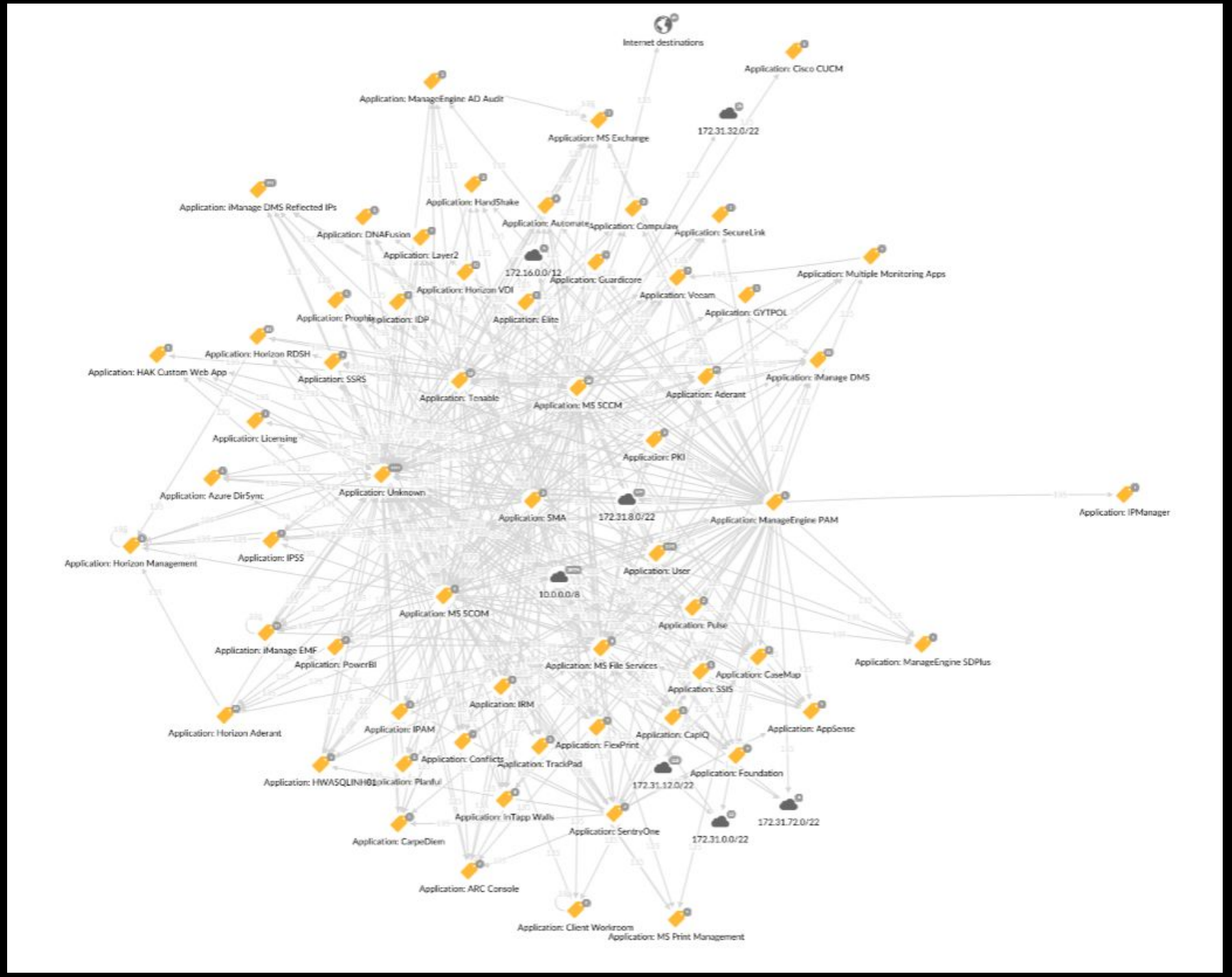
Background in DFIR and Windows internals

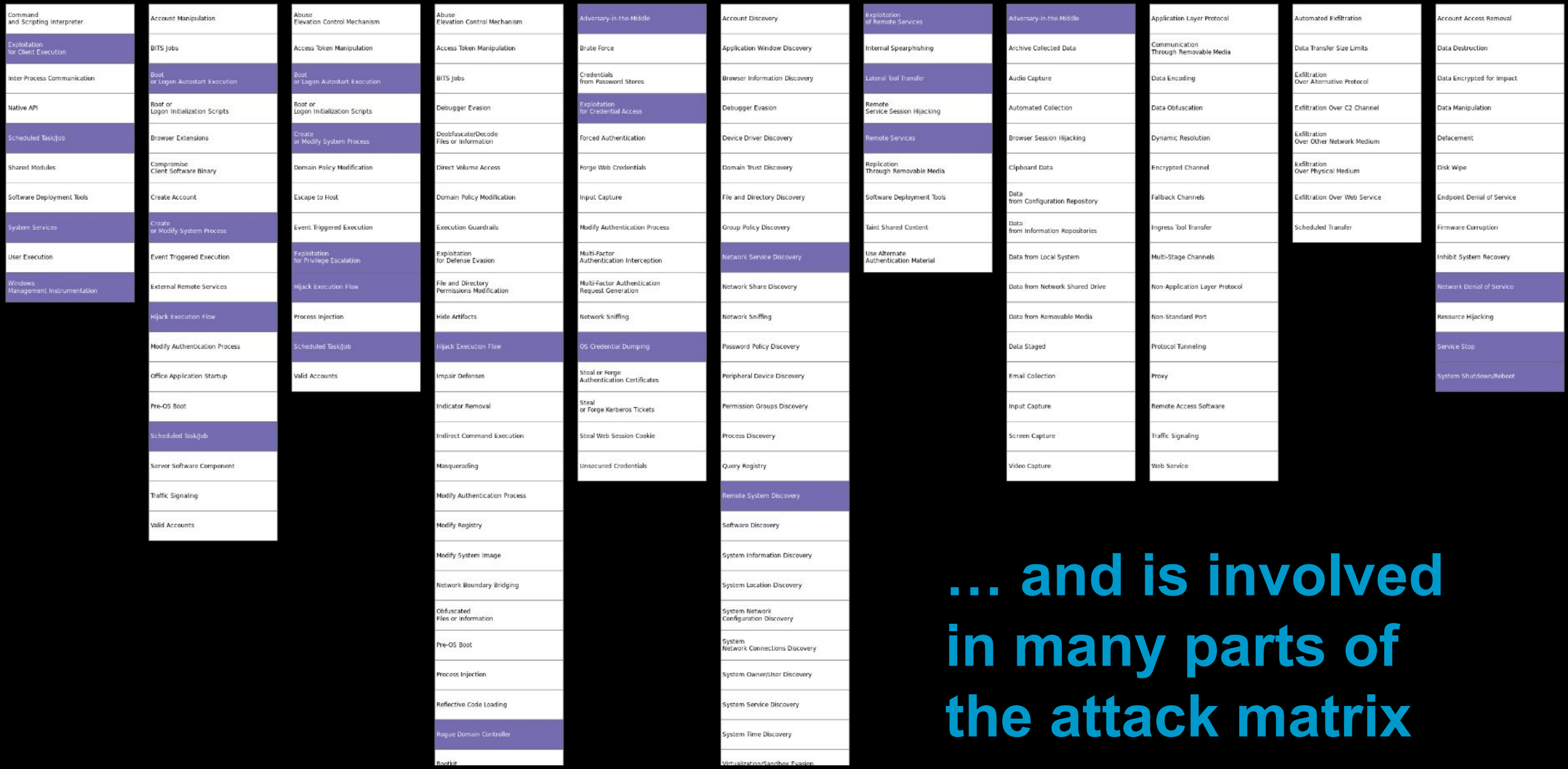
Agenda

- MS-RPC introduction and overview
- ETW introduction and overview
- Using ETW to detect MS-RPC based attacks
- Supplementing defense with RPC Filters

#define RPC

It’s everywhere in the network





… and is involved in many parts of the attack matrix

RPC Attacks are Hard to Detect

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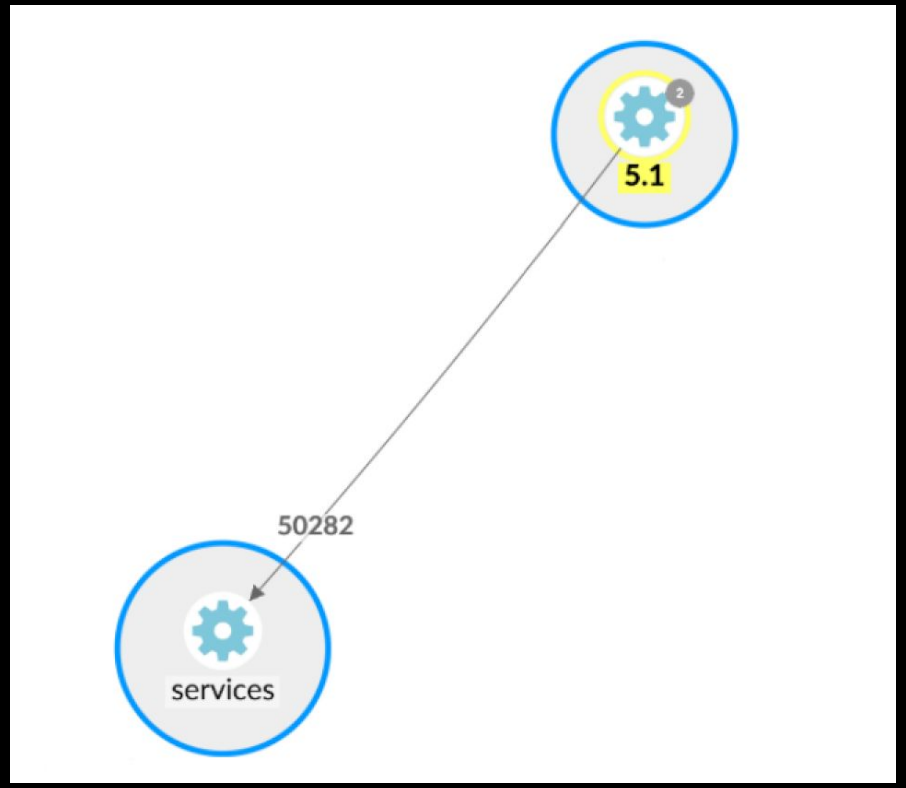
- Most RPC servers are running under svchost or protected processes
  - Difficult to match traffic to process or RPC server
- RPC traffic can occur over ephemeral ports
  - Can’t create FW rules in advance

Not Many (documented) Defense Options

- RPC Filters in the Windows Firewall
- ETW monitors aimed at researchers
  - RpcMon by CyberArk
  - RpcInvestigator by TrailOfBits
- RPC Firewall by ZeroNetworks
  - requires process injection & hooks

RPC without visibility



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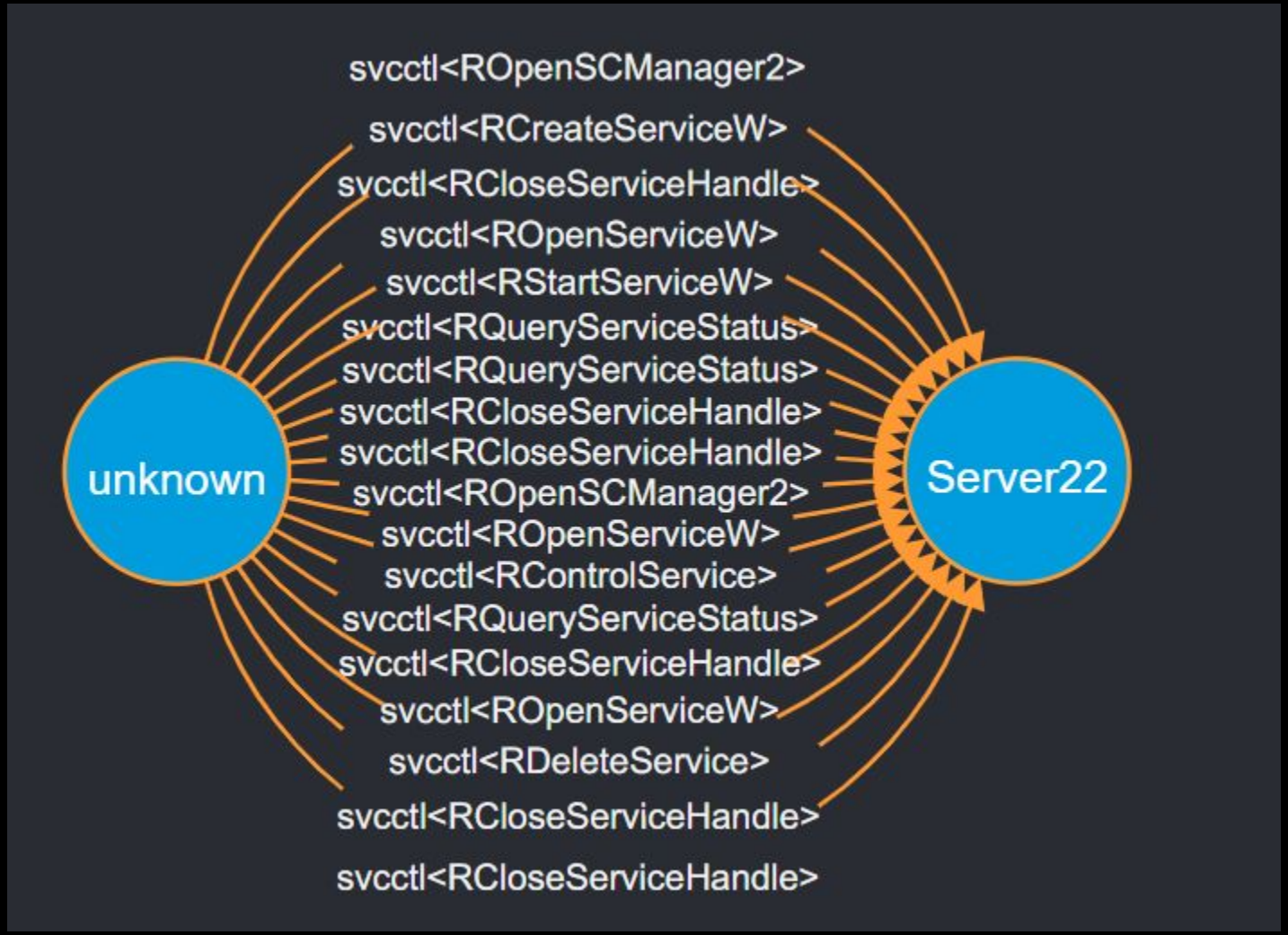
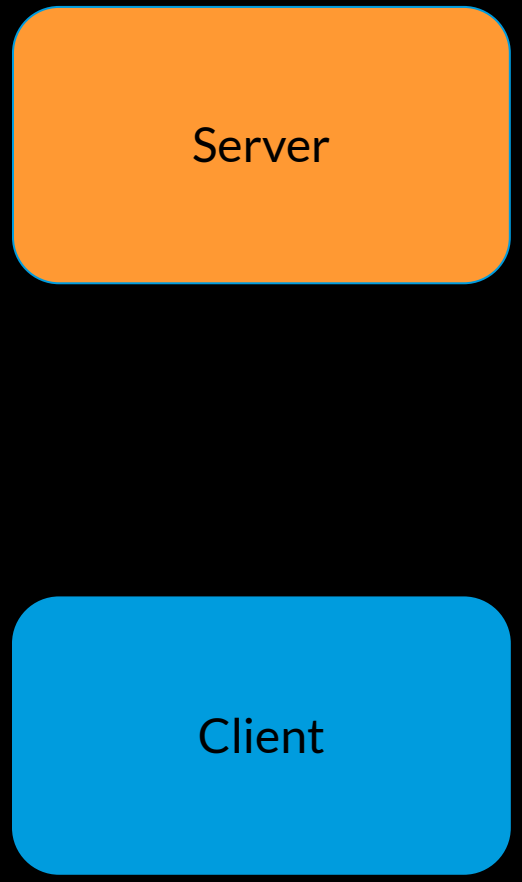


MS-RPC Overview

Terminology you'll soon master

- Interface
- {M}IDL
- Transport
- Endpoint
- Binding

The RPC Client-Server Model



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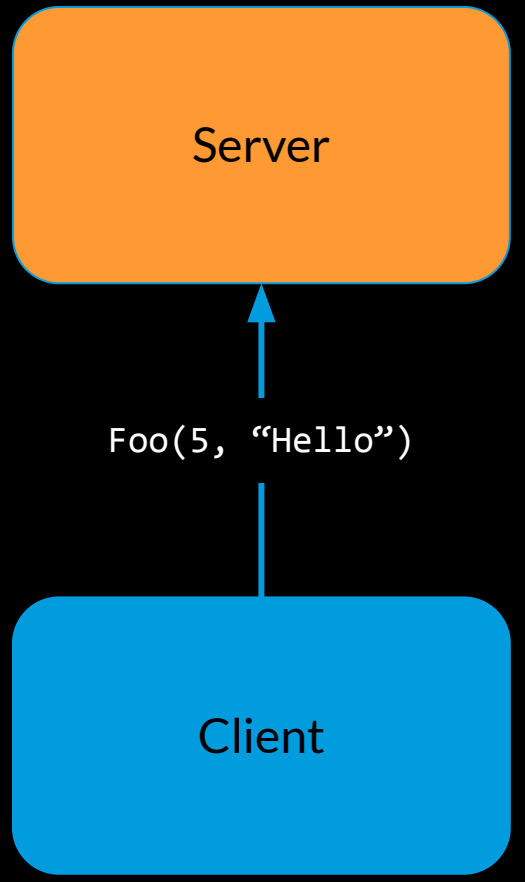
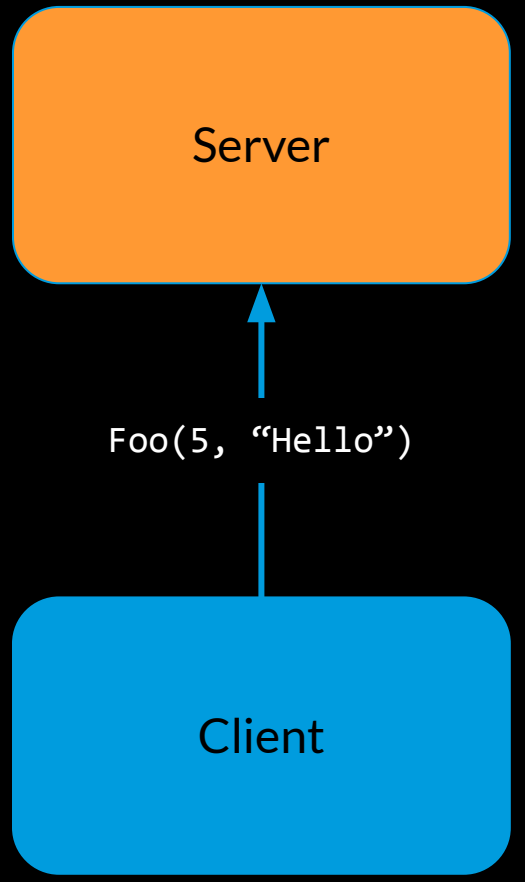


The RPC Client-Server Model

```
[
uuid(12345678-4000-2006-0000-2
0000000001a)
]

interface Test
{
void Foo([in] int number,
[in] char *message);
void Bar([out] int * result);
}
```



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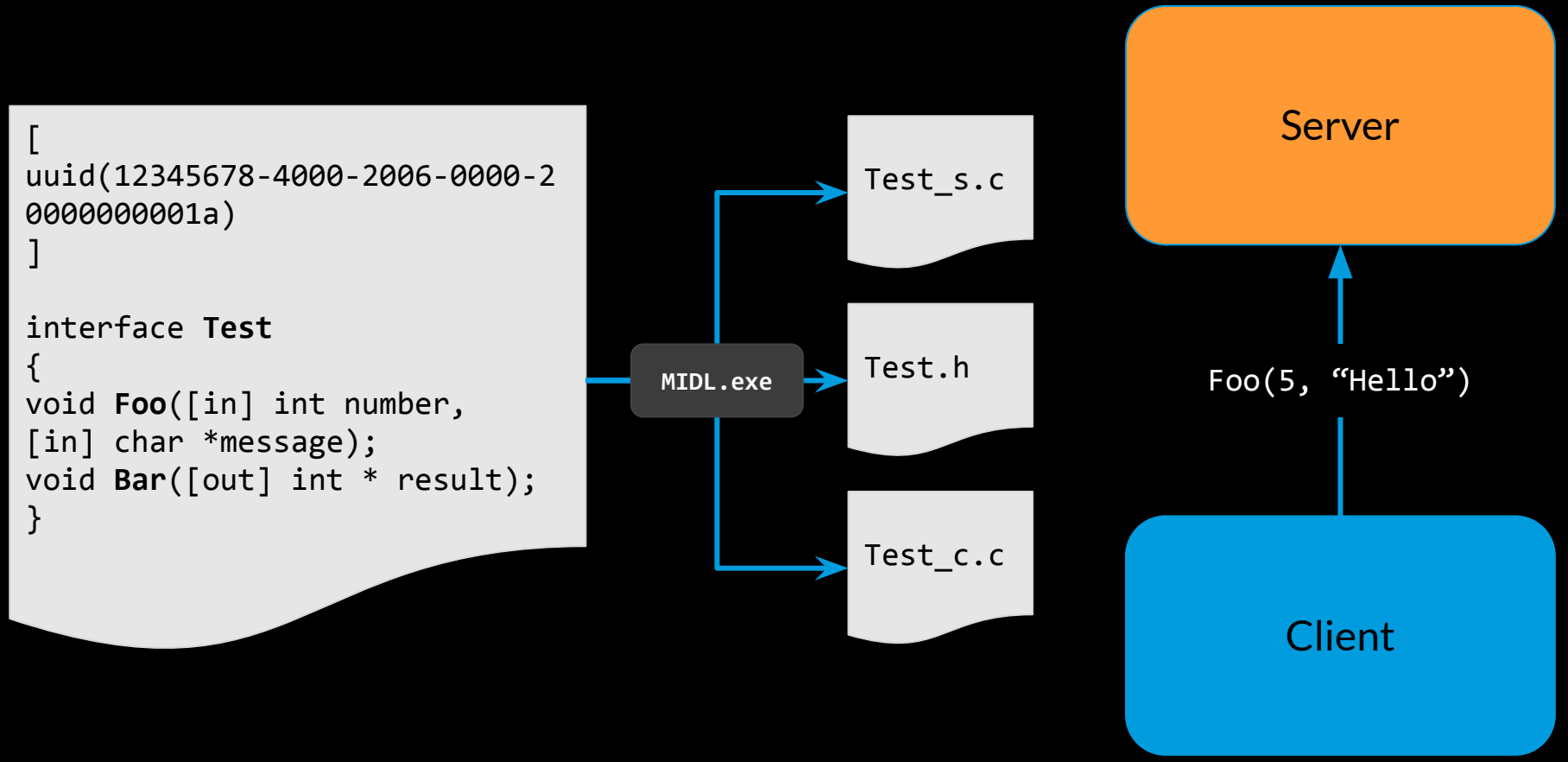

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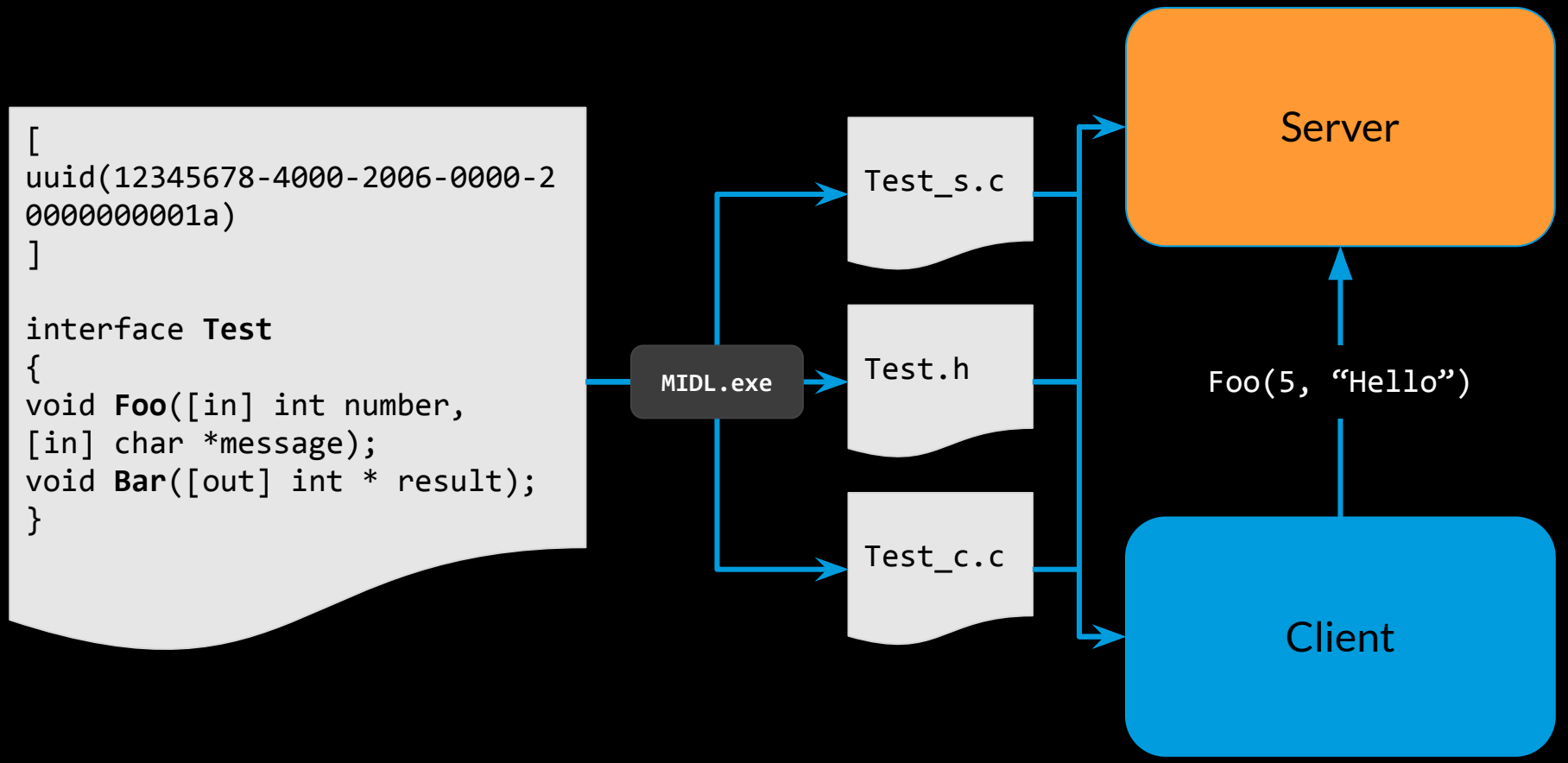


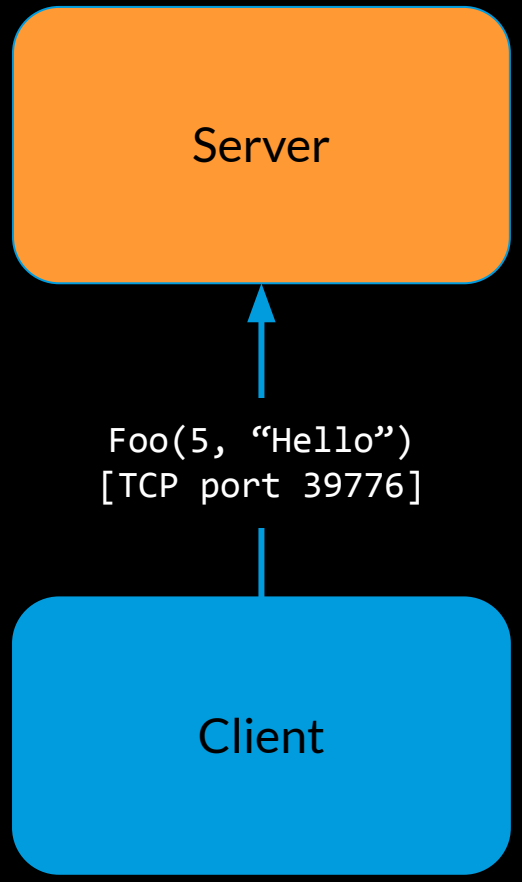
Endpoints

- The server registers an *endpoint* using a certain *transport*

Transports	Protocol Sequence	Endpoints
TCP	`ncacn_ip_tcp`	<port number>
Named pipe	`ncacn_np`	<pipe name>
UDP	`ncadg_ip_udp`	<port number>
ALPC	`ncalrpc`	<ALPC port>
HTTP	`ncacn_http`	<hostname>
Hyper-V socket	`ncacn_hvsocket`	<UUID>

Well-Known Endpoints

Dynamic Endpoints



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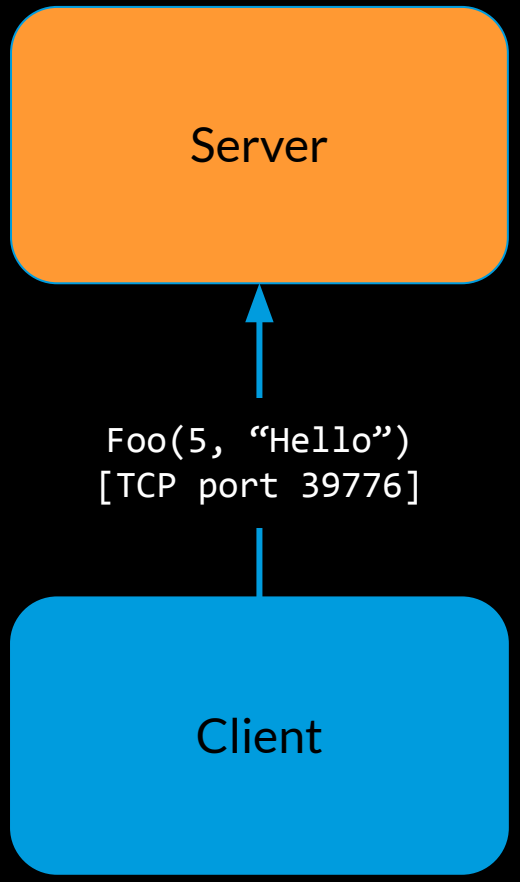

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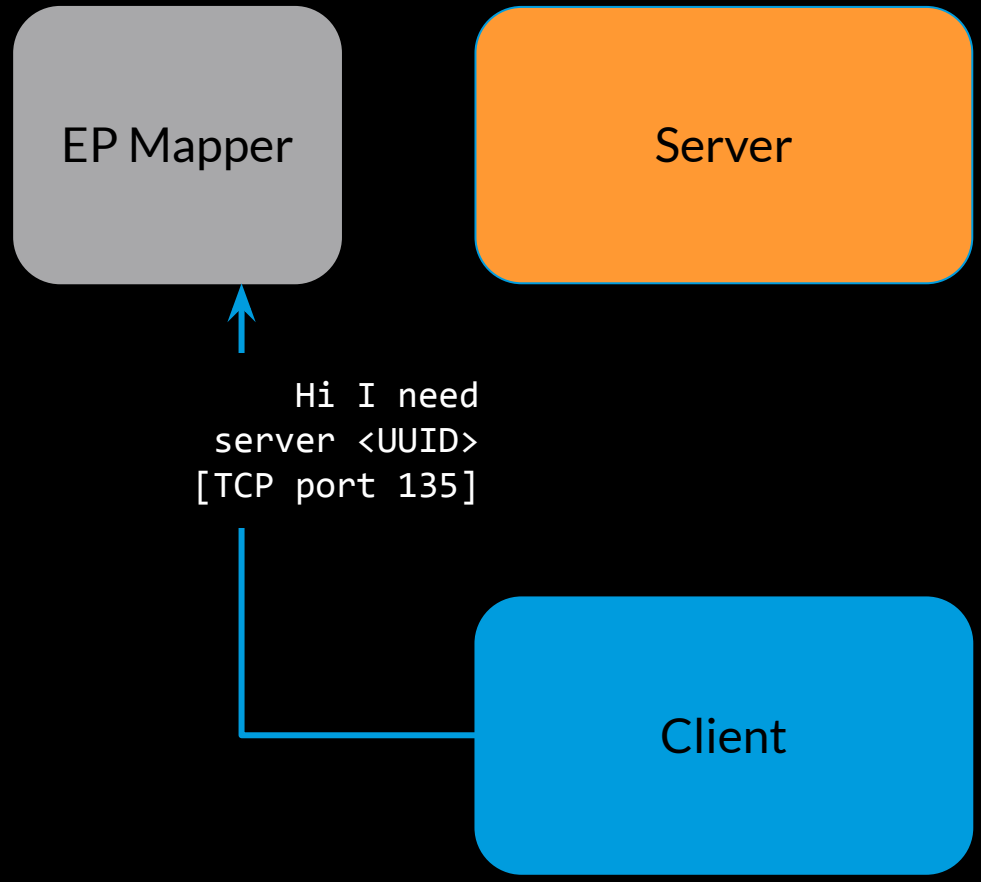

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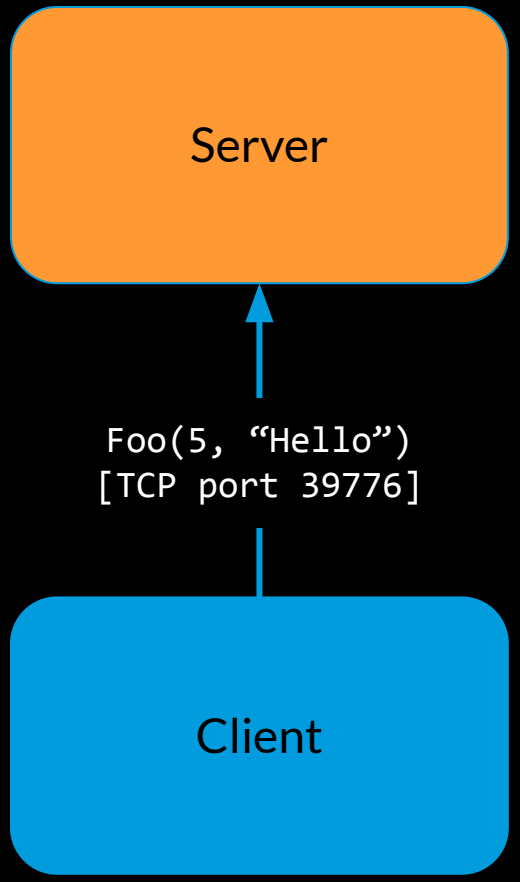

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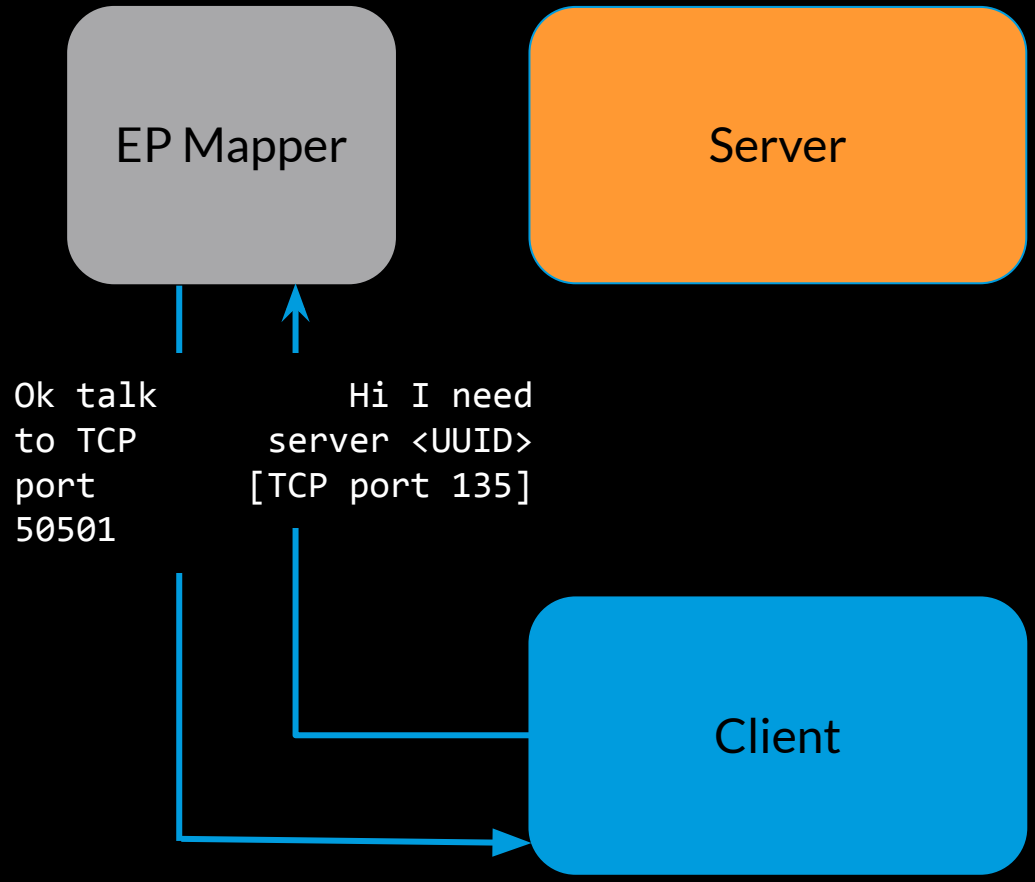

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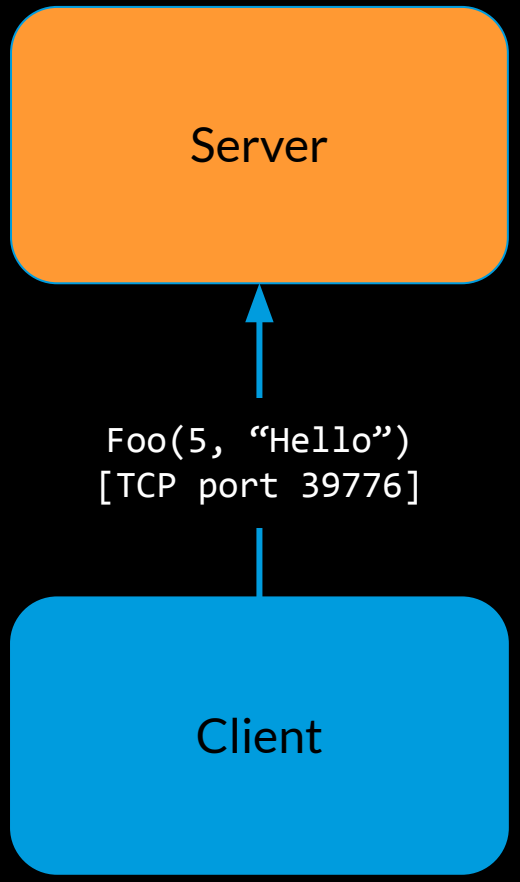

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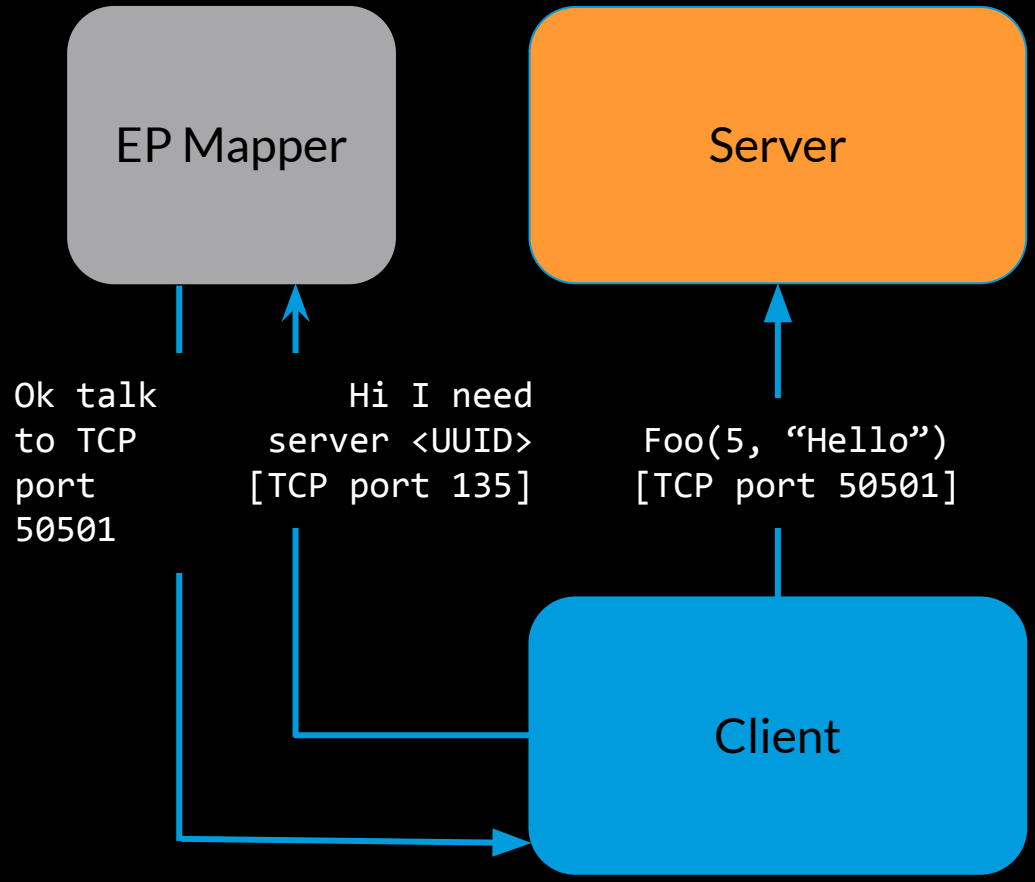
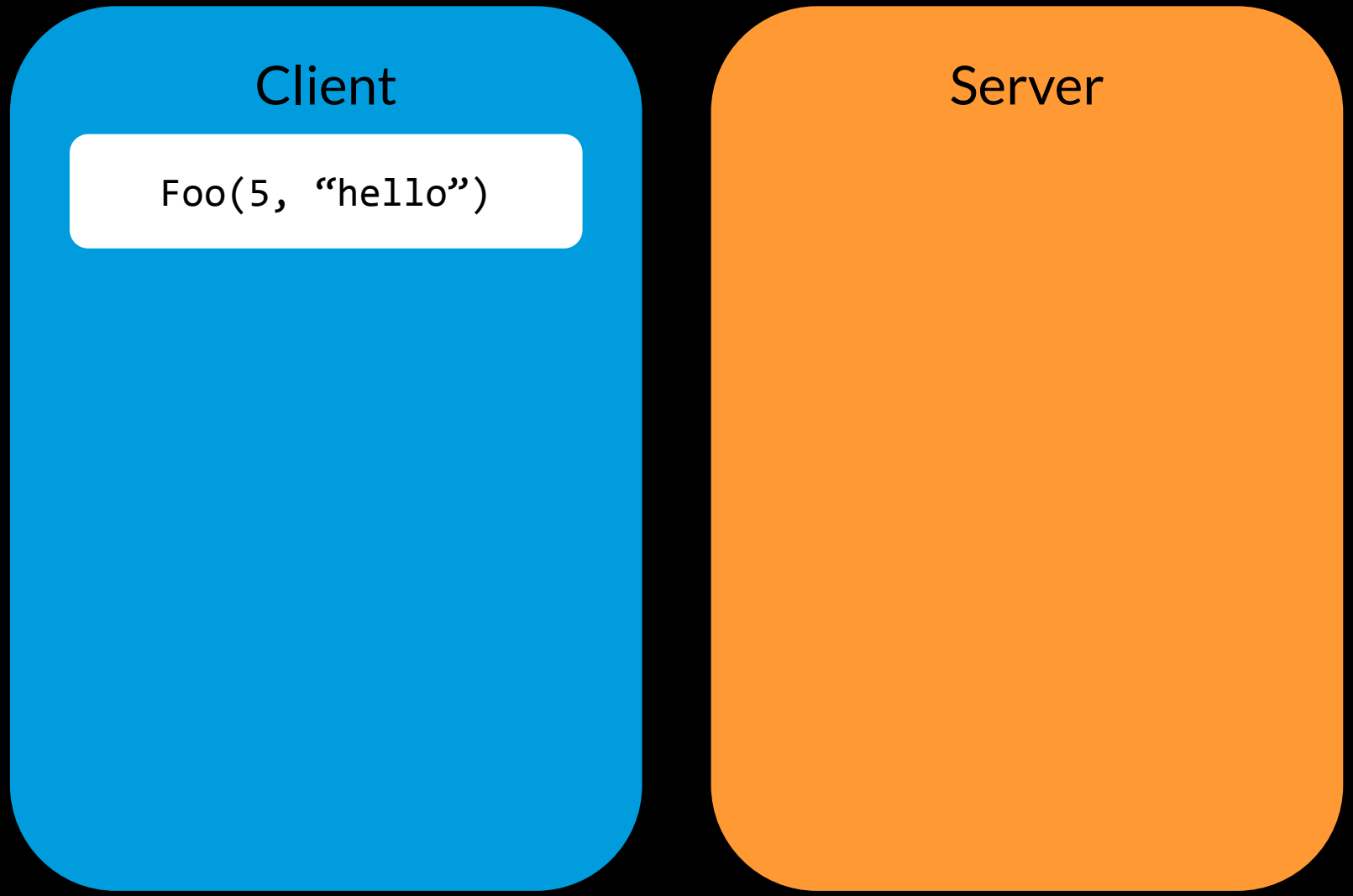


Binding

- The representation of a session between a client and a server
  - Practically, a handle
  - Client and server can manipulate binding data using designated functions
  - Used for authentication (among other things)

An RPC Call's Flow



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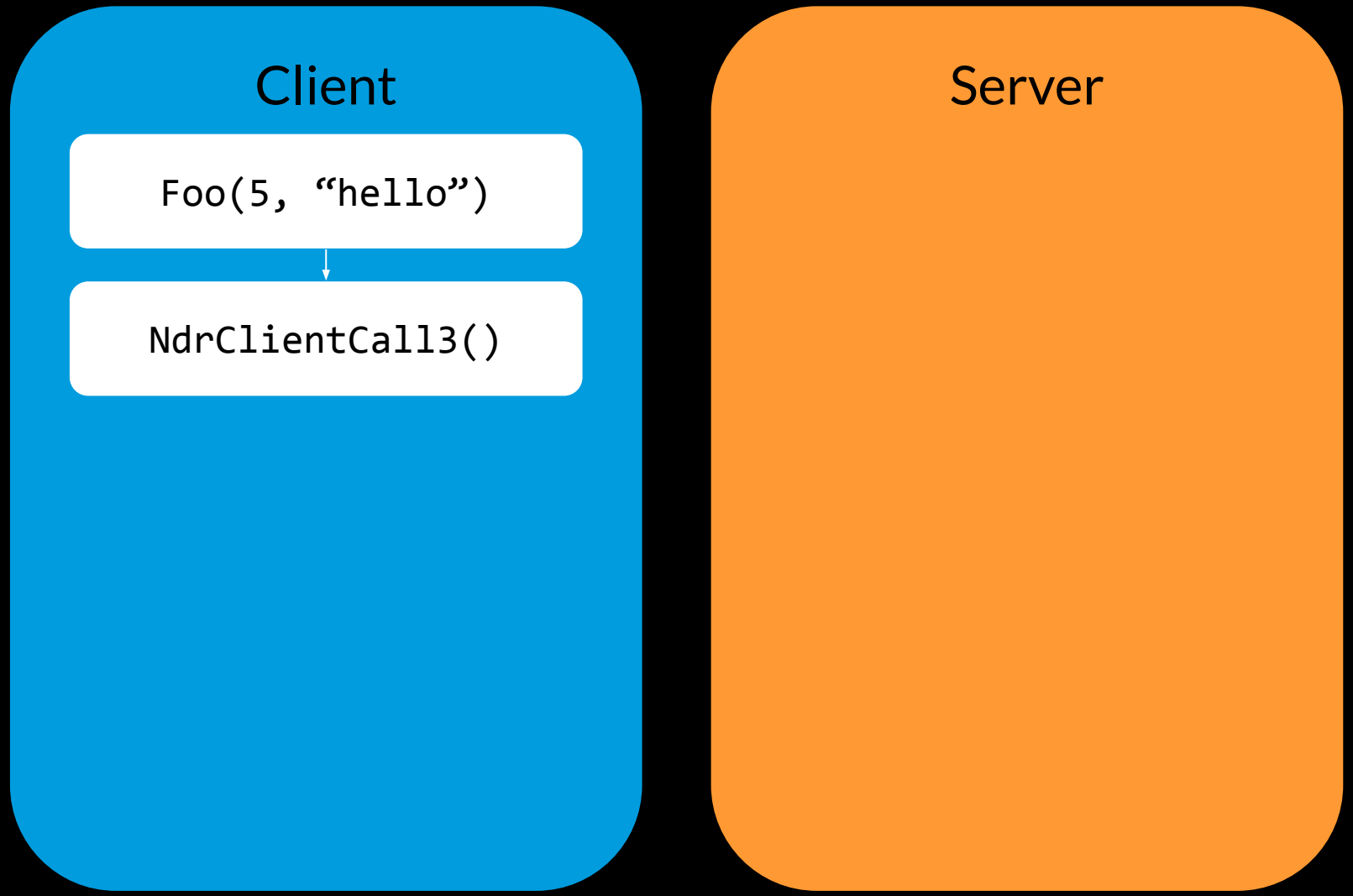

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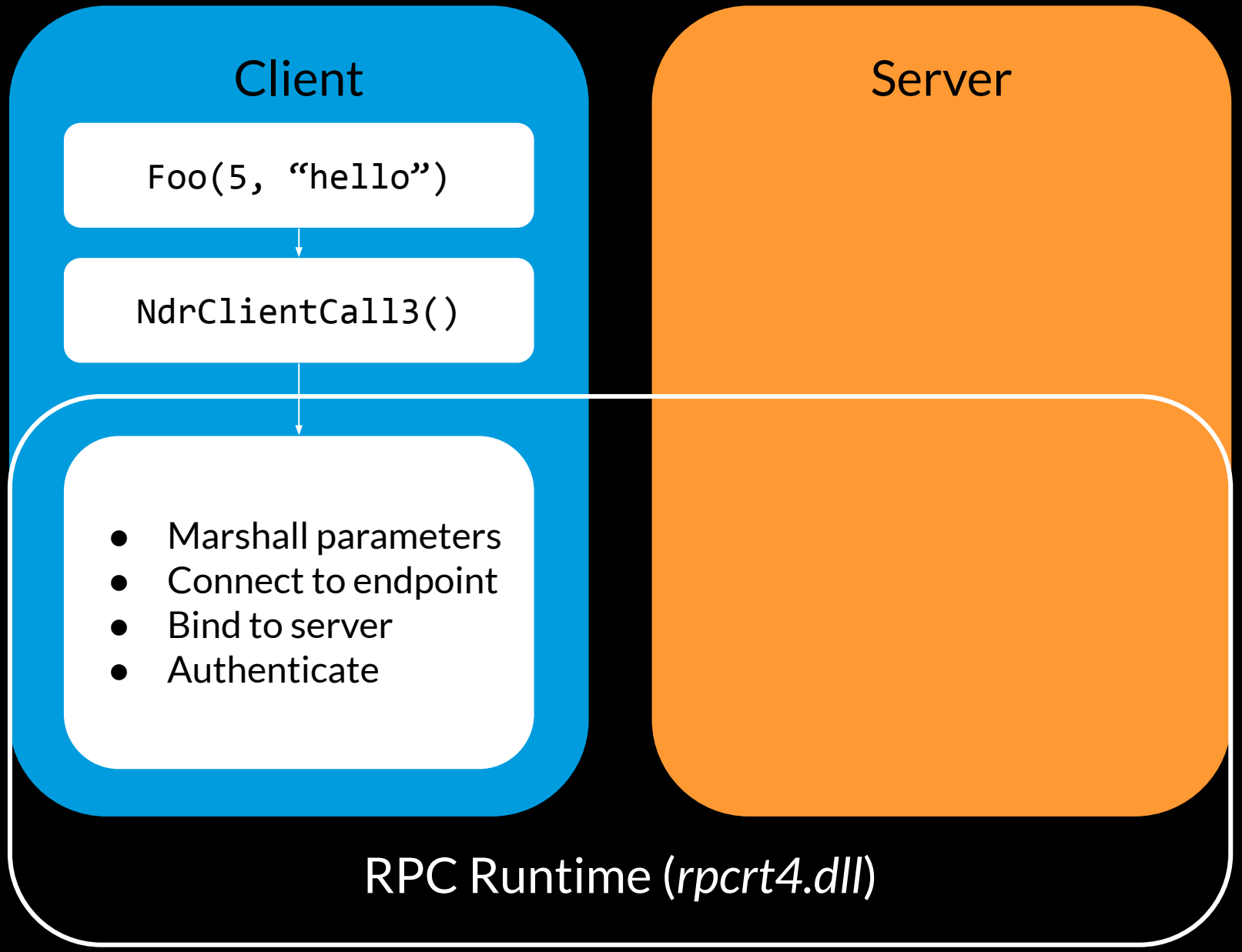

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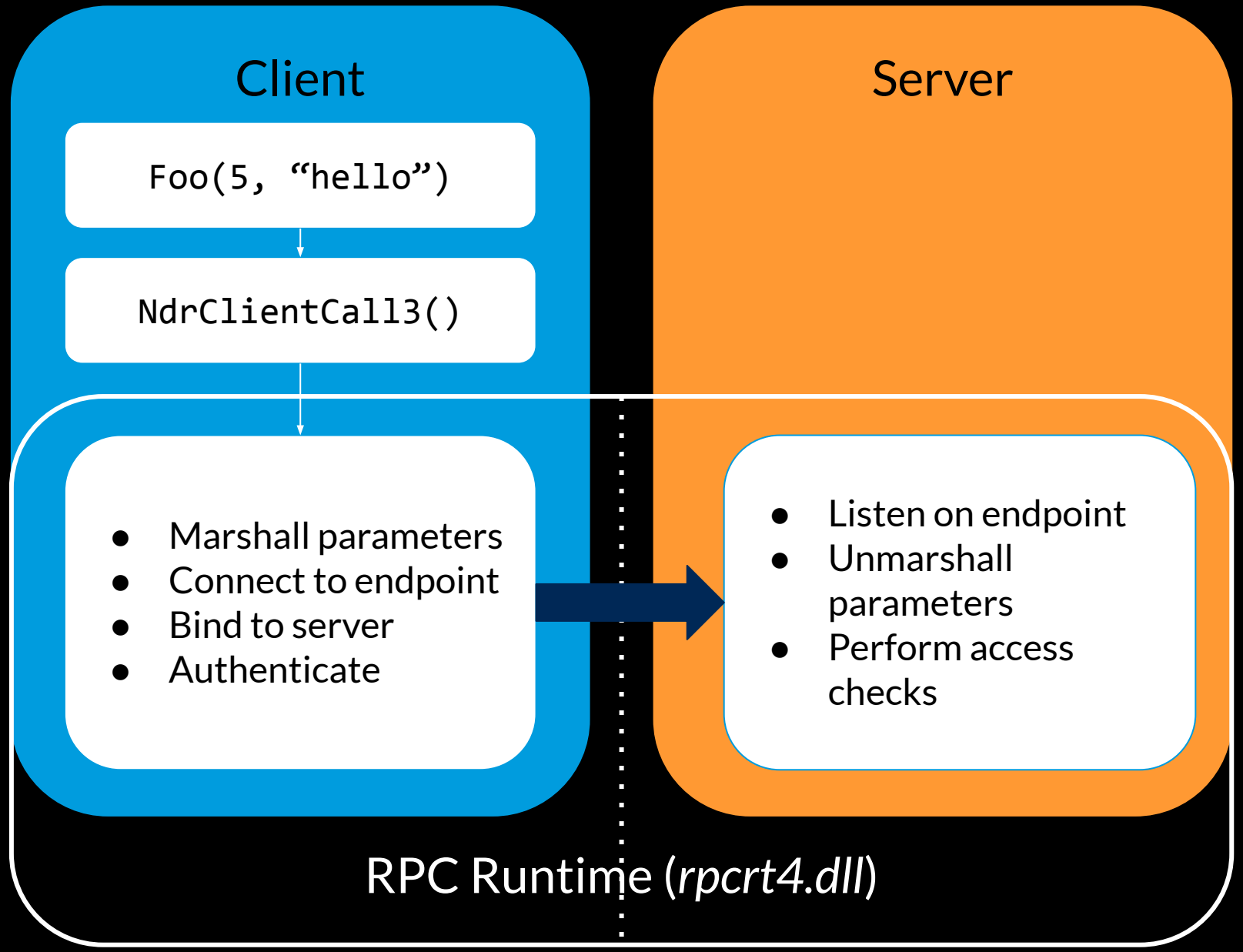

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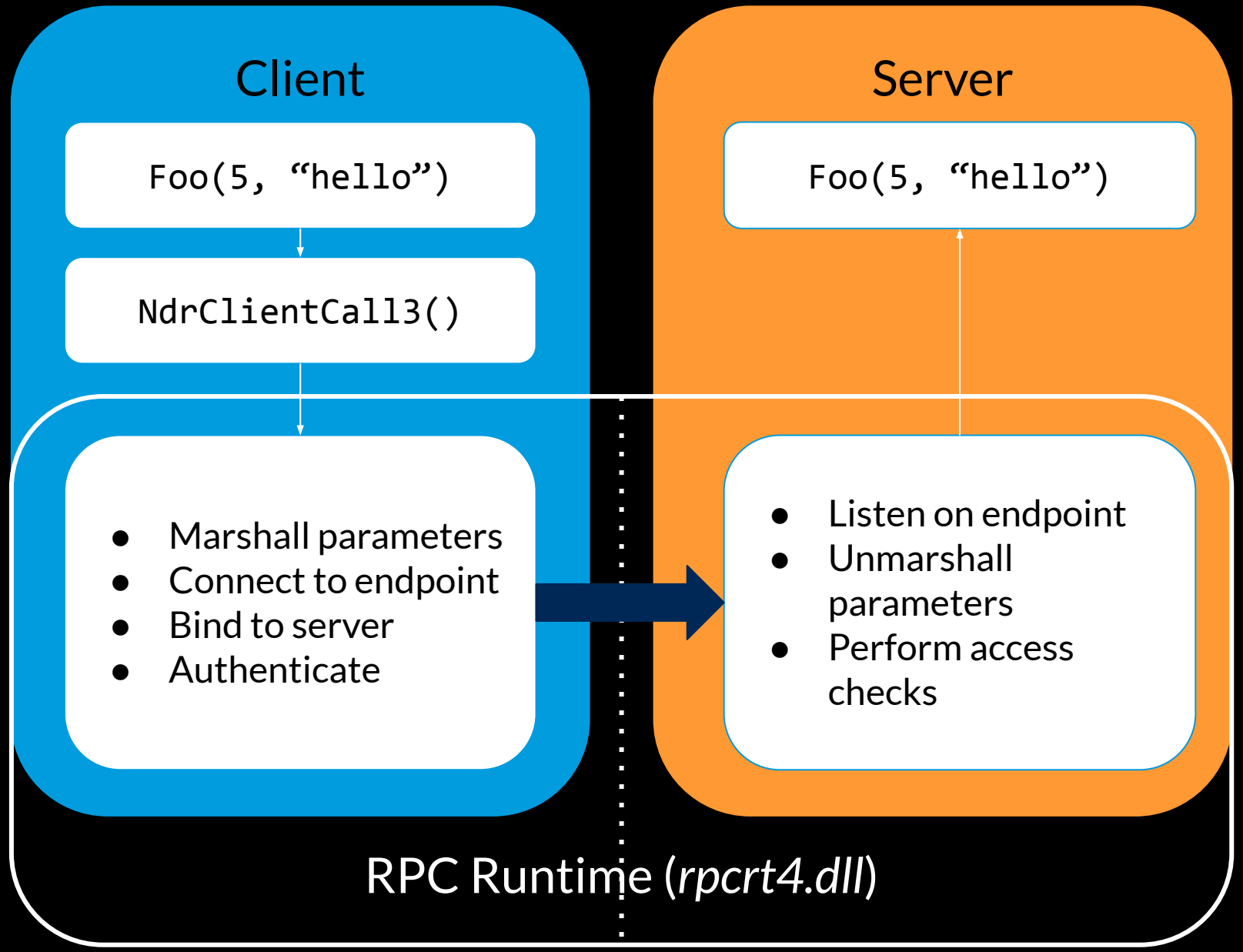

Zooming In

IDL:

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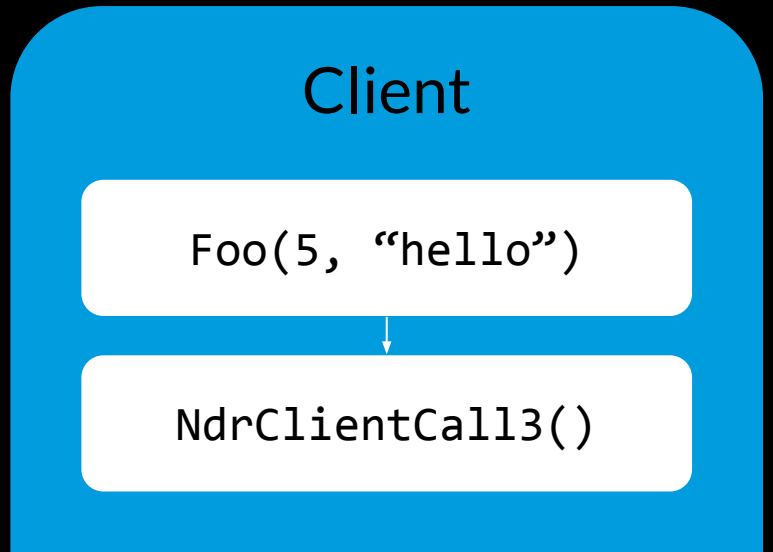

Zooming In

IDL:

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void Foo([in] int number,
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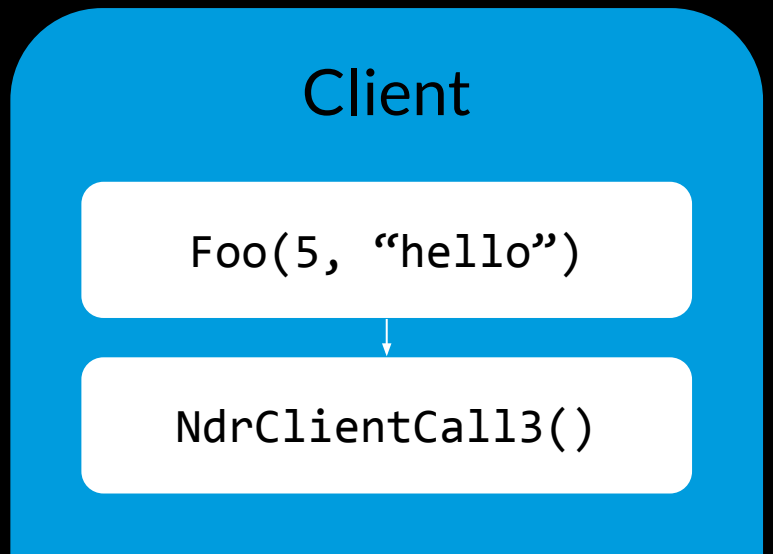
```

Test_c.c:

```
void Foo(
  handle_t IDL_handle,
  int number,
  unsigned char *message) {

  NdrClientCall3(
  (PMIDL_STUBLESS_PROXY_INFO
  )&Test_ProxyInfo, 0, 0,
  IDL_handle, number, message);
}
```



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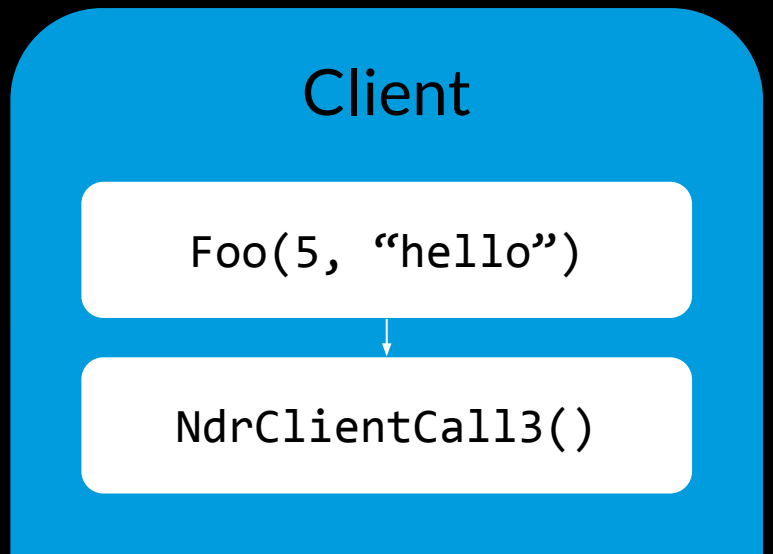
Opnum



Quick Recap

- Interface – describes server functionality [UUID]
- Transport – the communication medium [protocol sequence]
- Endpoint – destination to connect to [port, pipe name, etc.]
- Binding – represents a client-server session [binding handle]

RPC Visibility

#define ETW

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  - Providers define a schema for their events so consumers can parse them
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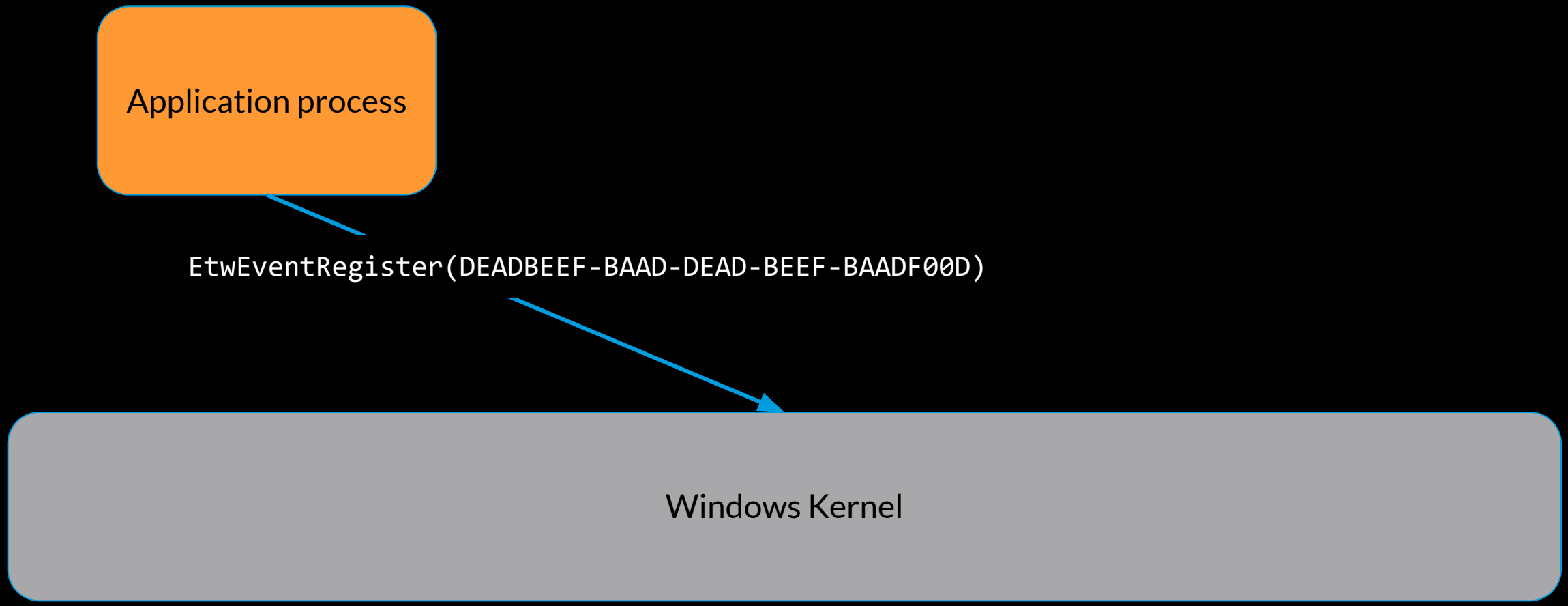
  - Providers define a schema for their events so consumers can parse them
  - Both providers and consumers need to register with the ETW
- UM logic implemented in ntdll, transfers control to kernel

Provider <> Consumer



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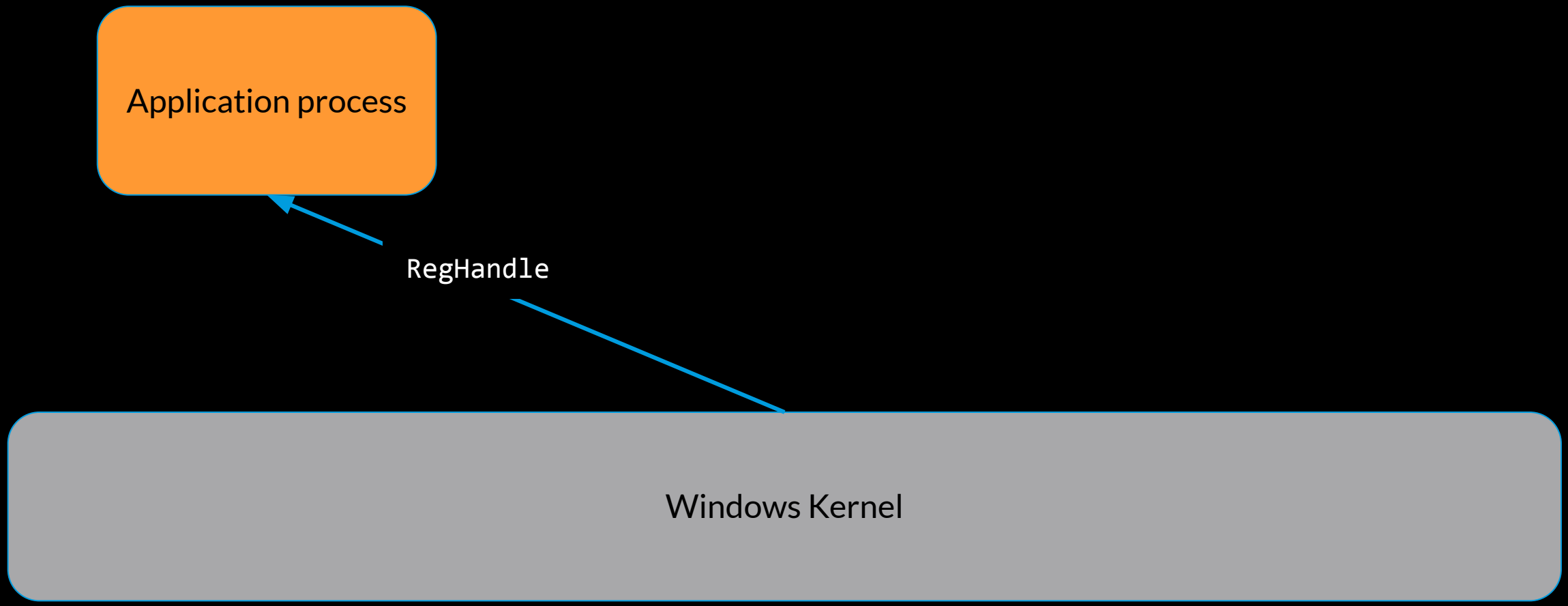

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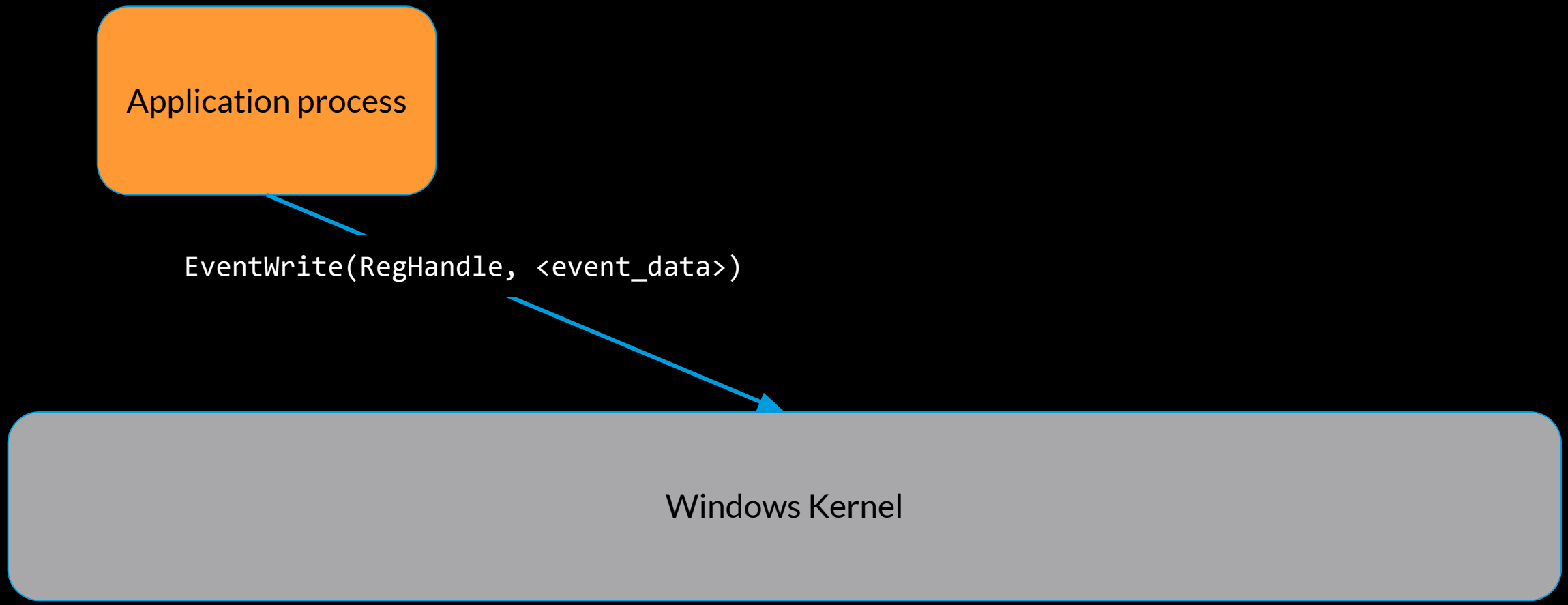

Provider <> Consumer

Application process

<event_data>

Windows Kernel

Context is Important

- Since events need to hop the kernel boundary, it is a waste to send them when no consumers are tracing events

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- Providers can define a callback to the kernel, to be notified about the state of the provider
- If there are no consumers, the provider is considered disabled and can skip event writing

```
void Penablecallback(
    [in] LPCGUID SourceId,
    [in] ULONG IsEnabled,
    [in] UCHAR Level,
    [in] ULONGLONG MatchAnyKeyword,
    ULONGLONG MatchAllKeyword,
    [in, optional] PEVENT_FILTER_DESCRIPTOR FilterData,
    [in, optional] PVOID CallbackContext
)
```

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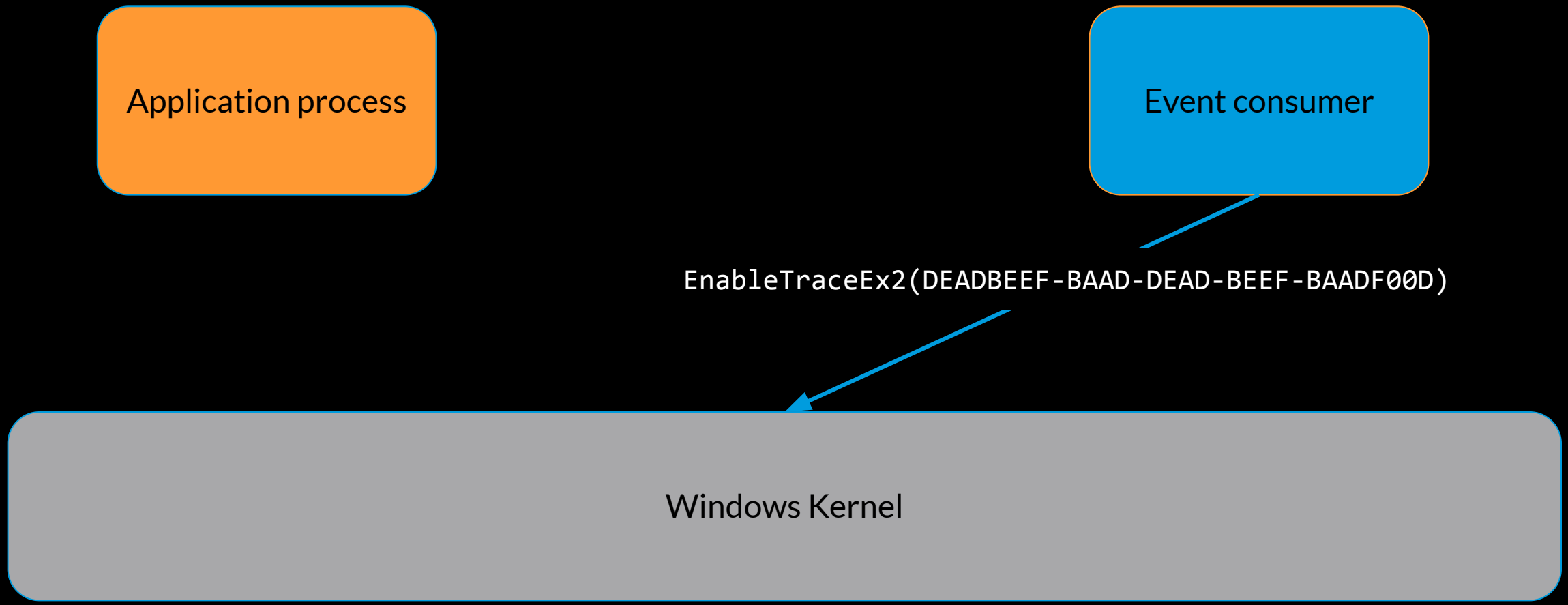

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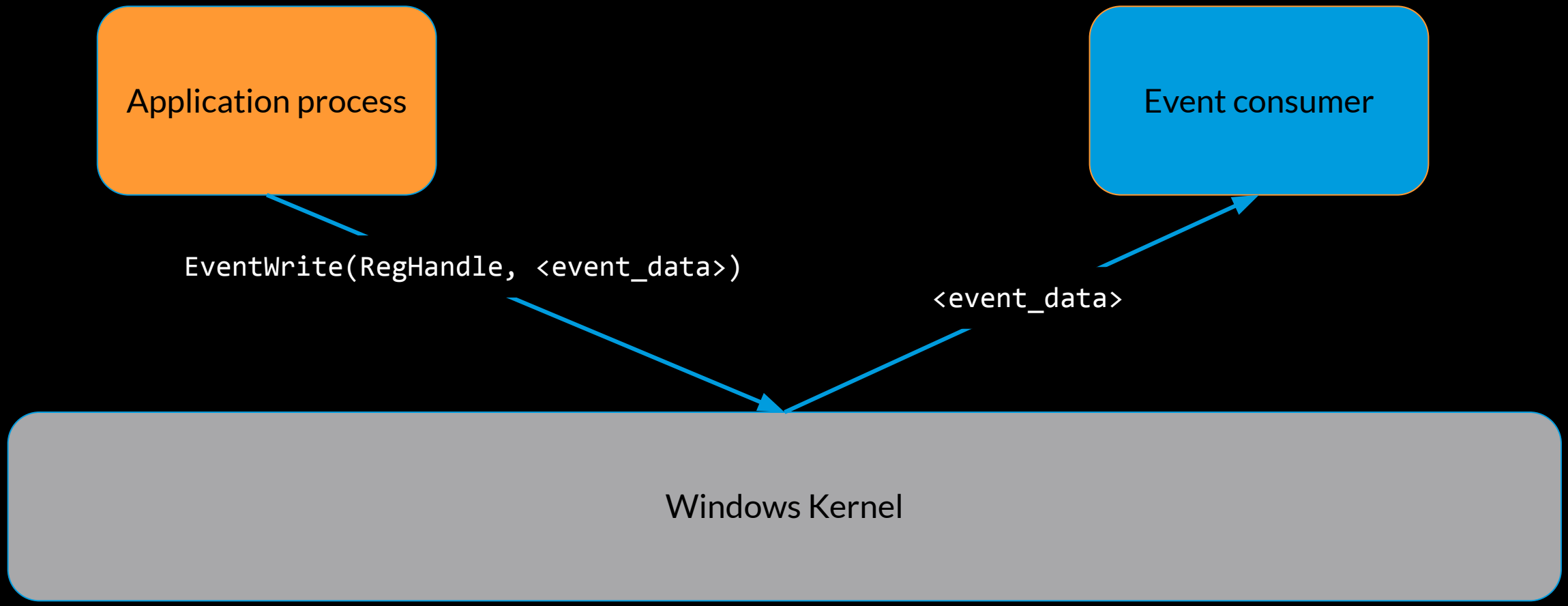

RPC ETW Provider

- Microsoft-Windows-RPC[1] {6ad52b32-d609-4be9-ae07-ce8dae937e39}
- Implemented in the runtime *rpcrt4.dll*
  - Since event routing is handled in the kernel, multiple processes can write to the same provider
- 13 different events
  - Event ids 5,7 — Client call start/stop
  - Event ids 6,8 –- Server call start/stop

[1] https://github.com/repnz/etw-providers-docs/blob/master/Manifests-Win7-7600/Microsoft-Windows-RPC.xml

Call Start Schema

```
<template tid="RpcServerCallStartArgs_V1">
      <data name="InterfaceUuid" inType="win:GUID"/>
      <data name="ProcNum" inType="win:UInt32"/>
      <data name="Protocol" inType="win:UInt32"/>
      <data name="NetworkAddress" inType="win:UnicodeString"/>
      <data name="Endpoint" inType="win:UnicodeString"/>
      <data name="Options" inType="win:UnicodeString"/>
      <data name="AuthenticationLevel" inType="win:UInt32"/>
      <data name="AuthenticationService" inType="win:UInt32"/>
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</template>
```

Additional Useful Event Headers

- ActivityId — a UUID that can be used to track event chains (Call start, stop, error)
- ProcessId — the PID of the process that sent the trace event
- Timestamp — the time the trace event was generated

Attack Detection?

Server Trace Events Are Lacking

```
if ( (Microsoft_Windows_RPCEnableBits & 2) != 0 )
      McTemplateU0jqqzzzqqq_EtwEventWriteTransfer(
        *(_QWORD *)(*((_QWORD *)this + 38) + 80i64),
        (__int64)&RpcServerCallStartEvent,      // Event descriptor
        (__int64)v4 + 84,                       // Interface UUID
        *((_DWORD *)this + 95),                 // Opnum
        v25[48],                                // Transfer protocol id
        0i64,                                   // Network address
        *(const wchar_t **)(*(_QWORD *)(*((_QWORD *)this + 38) + 80i64) + 32i64),// Endpoint
        0i64,                                   // Options
        v25[32],                                // Authentication level
        v25[36],                                // Authentication service
        0);                                     // Impersonation level
```

OSF_SCALL::DispatchHelper

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OSF_SCALL::DispatchHelper

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  - Tamper with ETW events via hooks/memory manipulation
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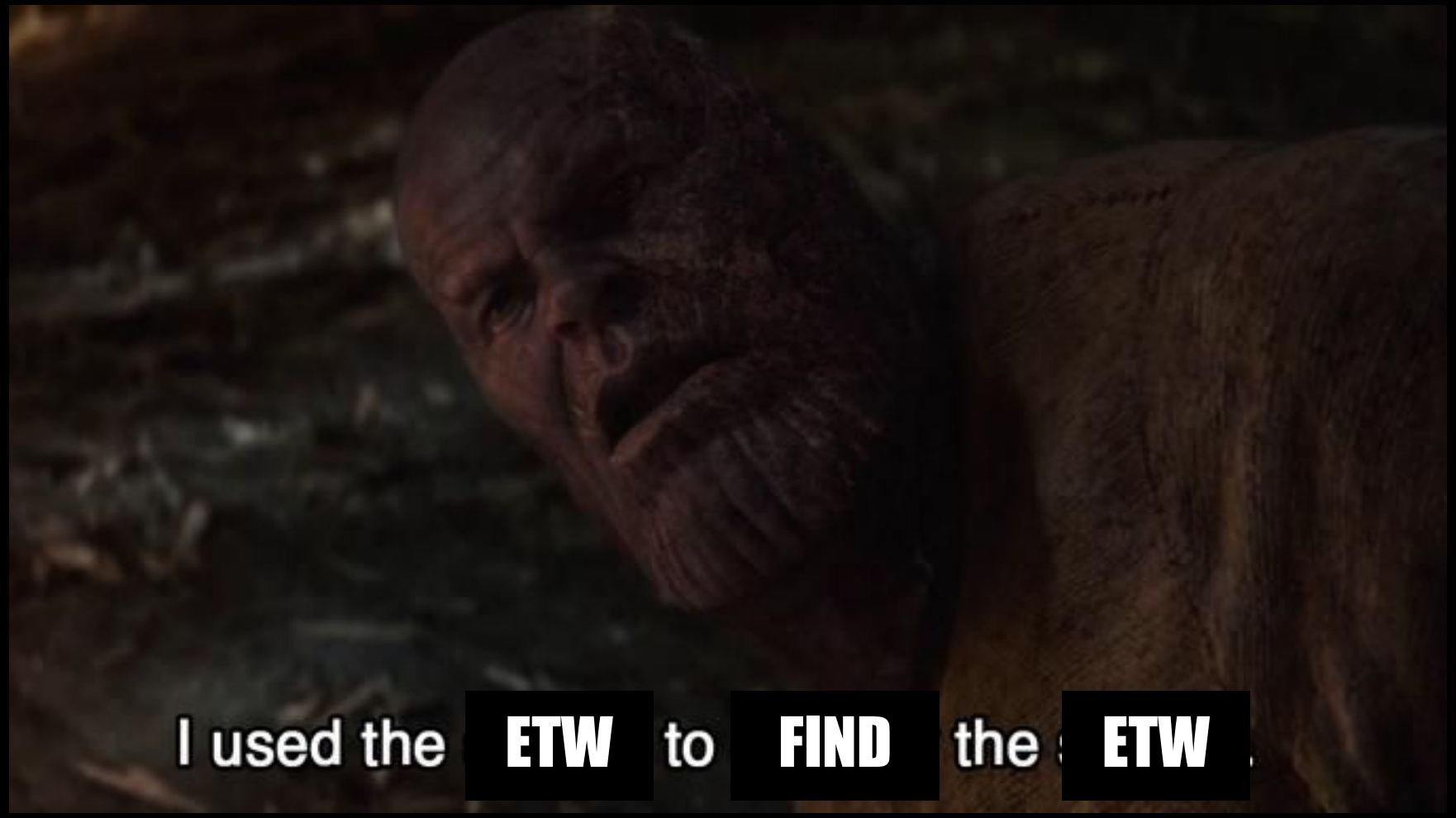
  - Generate RPC traffic without the OS (i.e Impacket)

ETW to the Rescue, Again



TCP ETW

event 1017 — TcpAcceptListenerComplete

```
<template tid="TcpAccpetListenerRouteLookupFailureArgs">
    <data name="LocalAddressLength" inType="win:UInt32"/>
    <data name="LocalAddress" inType="win:Binary"  length=”LocalAddressLength”/>
    <data name="RemoteAddressLength" inType="win:UInt32"/>
    <data name="RemoteAddress" inType="win:Binary"  length=”RemoteAddressLength”/>
    …
</template>
```

Address binary field := AF, IP, port

https://github.com/repnz/etw-providers-docs/blob/master/Manifests-Win10-17134/Microsoft-Windows-TCPIP.xml

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SMB ETW

event 500 — Smb2ConnectionAcceptStart

```
<template tid="Smb2ConnectionAcceptStart">
    <data name="ConnectionGUID"
                inType="win:GUID"/>
    <data name="AddressLength"
                inType="win:UInt32"/>
    <data name="Address"
                inType="win:Binary"
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</template>
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          length=”AddressLength”/>
</template>
```

event 8 — Smb2RequestCreate_V2

```
<template tid="Smb2RequestCreate_V2">
    …
    <data name="Filename"
          inType="win:UnicodeString"/>
    …
    <data name="ConnectionGUID"
          inType="win:GUID"/>
    <data name="TreeConnectGUID"
          inType="win:GUID"/>
</template>
```

https://github.com/repnz/etw-providers-docs/blob/master/Manifests-Win10-17134/Microsoft-Windows-SMBServer.xml

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```

https://github.com/repnz/etw-providers-docs/blob/master/Manifests-Win10-17134/Microsoft-Windows-SMBServer.xml

SMB ETW

event 500 — Smb2ConnectionAcceptStart

```
<template tid="Smb2ConnectionAcceptStart">
    <data name="ConnectionGUID"
          inType="win:GUID"/>
    <data name="AddressLength"
          inType="win:UInt32"/>
    <data name="Address"
          inType="win:Binary"
          length=”AddressLength”/>
</template>
```

event 8 — Smb2RequestCreate_V2

```
<template tid="Smb2RequestCreate_V2">
    …
    <data name="Filename"
        inType="win:UnicodeString"/>
    …
    <data name="ConnectionGUID"
        inType="win:GUID"/>
    <data name="TreeConnectGUID"
        inType="win:GUID"/>
</template>
```

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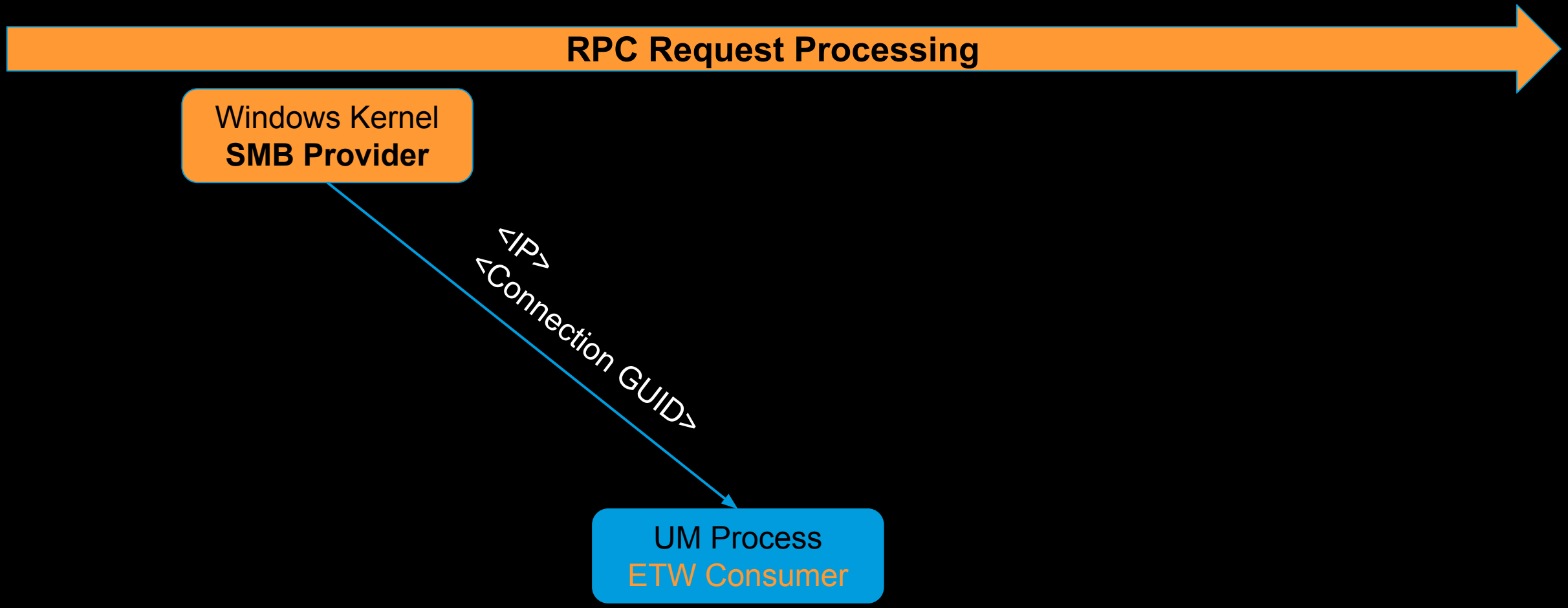
Matching Flows

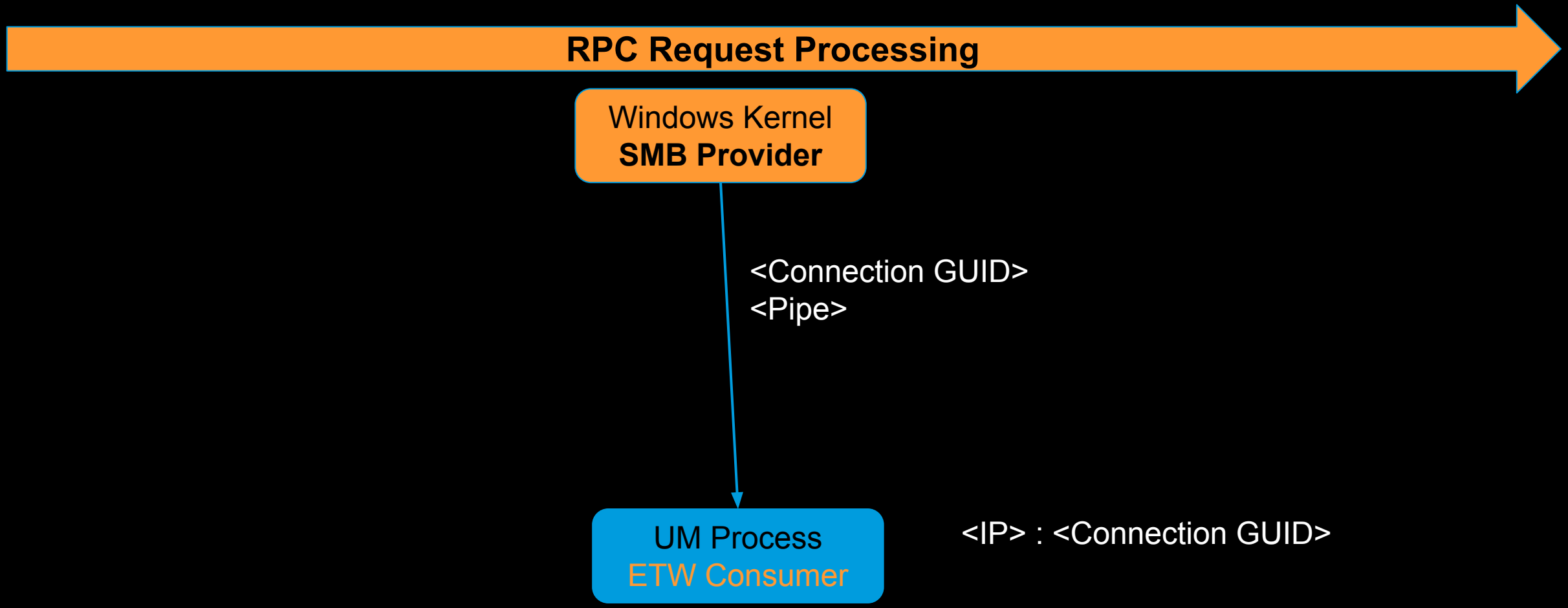


Matching Flows

UM Process
ETW Consumer

<IP> : <Connection GUID>

Matching Flows



Matching Flows

UM Process
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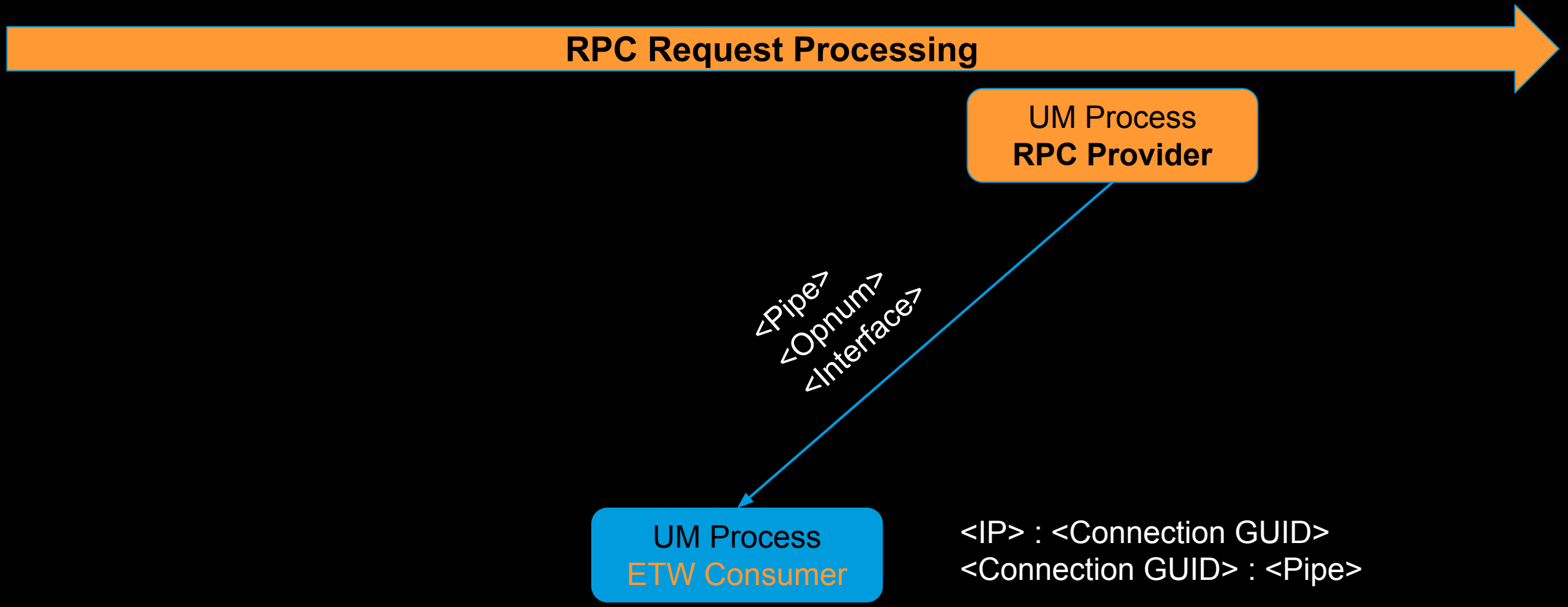
<IP> : <Connection GUID>
<Connection GUID> : <Pipe>

Matching Flows



Matching Flows

UM Process
ETW Consumer

<IP> : <Connection GUID>
<Connection GUID> : <Pipe>
<Pipe> : <Interface, Opnum>

Matching Flows

Machine <IP> connected over <Pipe> to request operation <Opnum> of the interface <Interface>

RPC Visibility

- Python script[1] with pywintrace
- Subscribe to the SMB, TCP and RPC providers
- Send results to Neo4J for easy visualization and querying
  - Could be extended to use other databases

[1] https://github.com/akamai/akamai-security-research/rpc_visibility

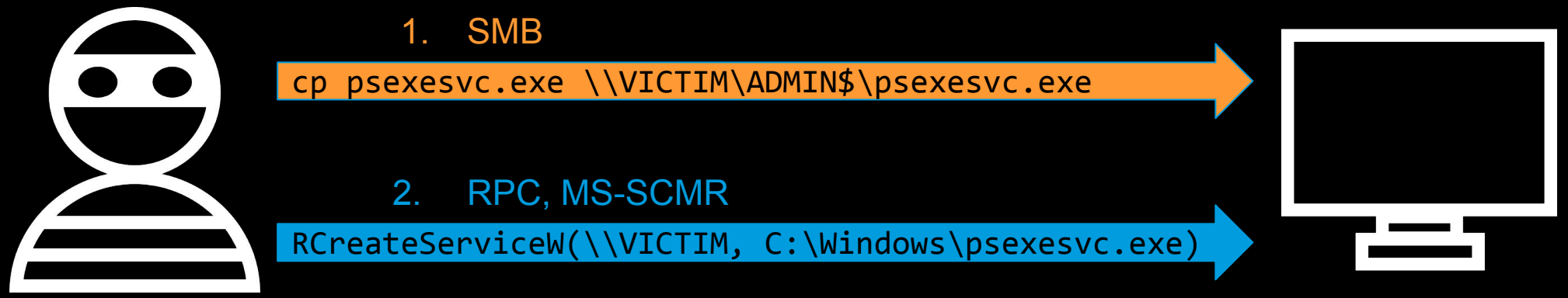
Attack Detection

Demo Time

RPC Visibility VS PSExec

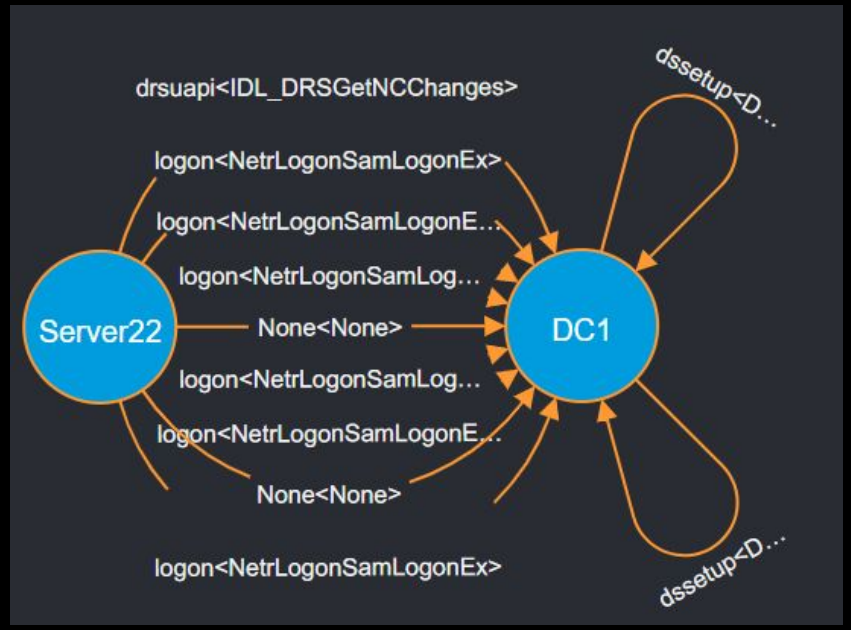
PSExec

- Both a general name for attack technique and a sysinternals tool
- Copy service PE to remote machine's ADMIN$ share
- Tell the SCM (using MS-SCMR) to run a service from the copied binary
  - 0xC — RCreateServiceW



DCSync

- Connect to a DC and pretend to be another DC
  - Request replication of the credential database
- Uses the Directory Replication service (MS-DRSR)
  - 0x3 — IDL_DRSGetNCChanges



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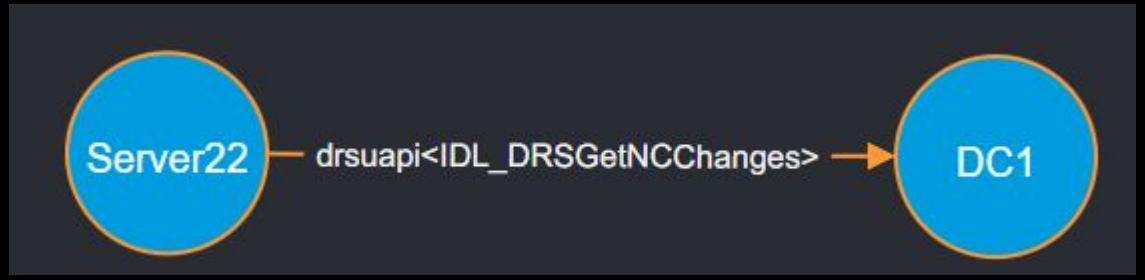
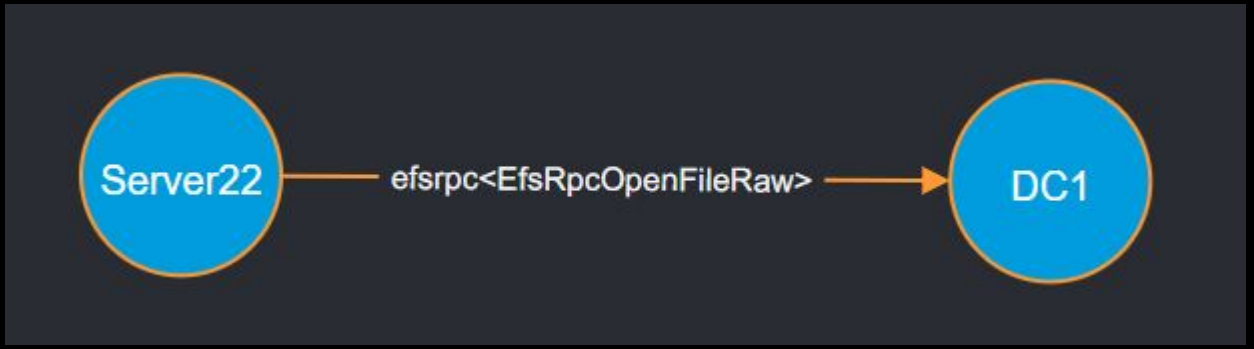


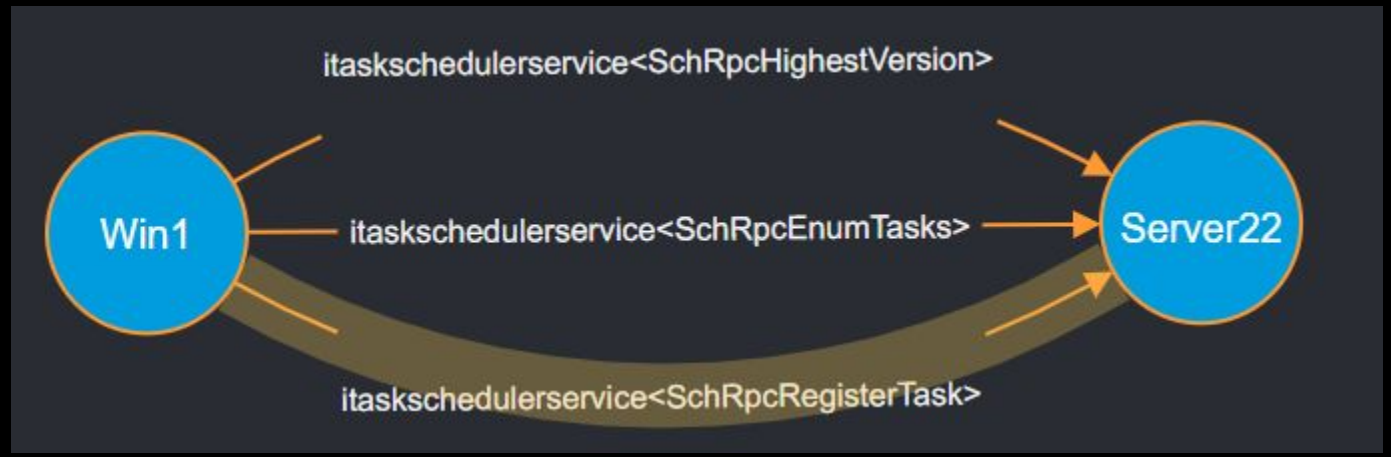
PetitPotam

- Tell the EFS service to open a remote file
  - Triggers an SMB connection with authentication that can be relayed
- Uses the MS-EFSR interface
  - 0x0 — EfsRpcOpenFileRaw
  - 0x4 — EfsRpcEncryptFileSrv



Task Scheduler

- Create a scheduled task remotely
  - MITRE T1053.005
- Uses the Task Scheduler Service Remoting protocol MS-TSCH
  - 0x1 — SchRpcRegisterTask



Remote WMI

- Use WMI to execute a binary remotely
- Implemented over MS-DCOM
  - Another layer of encapsulation
  - Can’t easily tell which operation was requested

Determining WMI maliciousness

- Check the opnums in each malicious operation, compared to benign
  - Heuristic based approach, has to be configured for each technique

WMIC process call create

Interface Name	Opnums
iwbemservices	24, 6
iremunknown2	5, 3
iwbemlevel1login	6, 3
iwbemloginclientid	3
iremotescmactivator	4
iobjectexporter	5

WMIC process get

Interface Name	Opnums
iwbemservices	20
iremunknown2	5, 3
iwbemlevel1login	6, 3
iwbemloginclientid	3
iremotescmactivator	4
iobjectexporter	5
iwbemwcosmartenum	3
iwbemfetchsmartenum	3

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WMIC process call create

Interface Name	Opnums
iwbemservices	ExecMethod
	GetObject

WMIC process get

Interface Name	Opnums
iwbemservices	ExecQuery
iwbemwcosmartenum	Next
iwbemfetchsmartenum	GetSmartEnum

Drawbacks

- Still only metadata based detection
- Can’t differentiate between “good” and “bad” flows
  - Detection has to be context dependent
  - Will have to be heuristics based analysis
- No blocking, visibility only
- Can’t handle DCOM with certainty

Incident Response & Mitigation

#define RPC Filters

- Filtering mechanism part of the Windows Firewall
- Exposed through *netsh* or via WinAPI
- Available since Windows Vista

```
netsh rpc filter>show filter
Listing all RPC Filters.
---------------------------------
filterKey: ac65a4a0-0ab9-11ee-b826-8038fb83bd95
displayData.name: RPCFilter
displayData.description: RPC Filter
filterId: 0x2e0773
layerKey: um
weight: Type: FWP_EMPTY Value: Empty
action.type: block
numFilterConditions: 1

filterCondition[0]
        fieldKey: if_uuid
        matchType: FWP_MATCH_EQUAL
        conditionValue: Type: FWP_BYTE_ARRAY16_TYPE Value: 367abb81 35f19844 f09832ad 03100038
```

Layers? Is it a cake?

- Filtering can occur at different parts of the RPC connections
- Pre-defined layers tell the FW where to apply the rule
  - FWPM_LAYER_RPC_UM — connection to interface
  - FWPM_LAYER_RPC_EPMAP — connection to the endpoint mapper
  - FWPM_LAYER_RPC_EP_ADD — new endpoint registration

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```

Filter fields

- src & dst IP
- RPC endpoints (port/named pipe)
- RPC interface UUID
- User token

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Full list + notes in our GH

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- Block RPC interfaces once an attack is detected/suspected
  - Emergency anti-lateral movement button

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  - If no one is using SCMR, why should it be left open?
- Block RPC interfaces once an attack is detected/suspected
  - Emergency anti-lateral movement button
- Restrict compromised users using RPC filters

Summary

- The RPC ETW provider is a treasure trove of information
- Use it to to get the gist of what is going on in the network, and detect potential malicious activity
- Respond to incidents with RPC filters, or use them to mitigate the risk beforehand

Thanks for listening

Questions?

References

- Our  repository for all things RPC, including the RPC Visibility script
- RPC tools by other researchers
  - RpcMon by CyberArk
  - RpcInvestigator by TrailOfBits
  - RPC Firewall, requires process injection & hooks
- A Definitive Guide to the RPC filters, by our research team
- Useful readings:
  - Jonathan Johnson of SpecterOps, Utilizing RPC Telemetry
  - Carsten Sandker, Offensive Windows IPC Internals 2: RPC
  - James Forshaw, How to secure a Windows RPC Server, and how not to.