Kerberos Delegation Attacks

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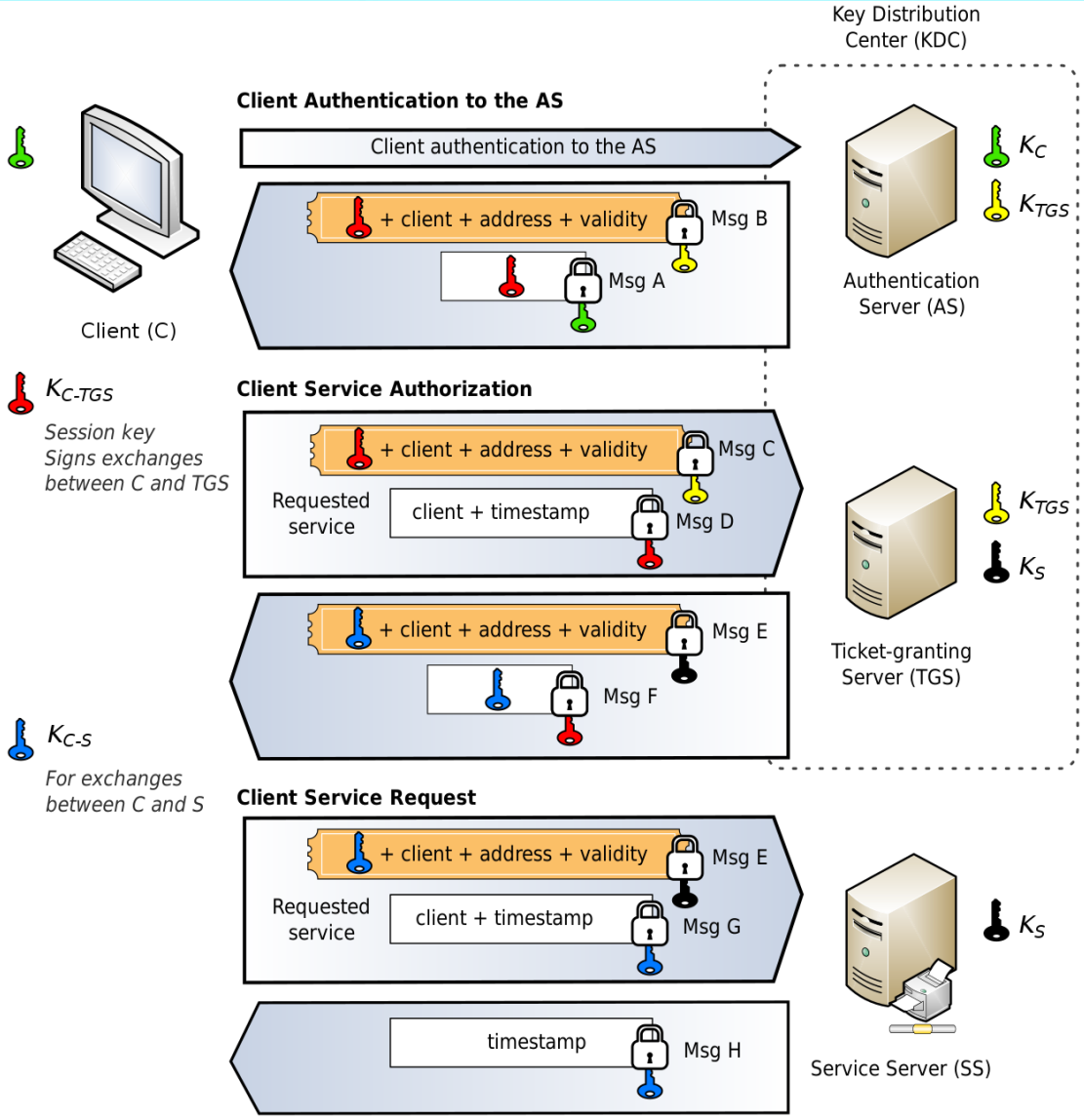
Kerberos 101



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

Not a real story

The **REAL STORY** behind Kerberos

Not a real story

- This is Bill
- 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

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
```

Getting tickets for rides

- Alice presents her day pass to the ticket office

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

Getting tickets for rides

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

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

- 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

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 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

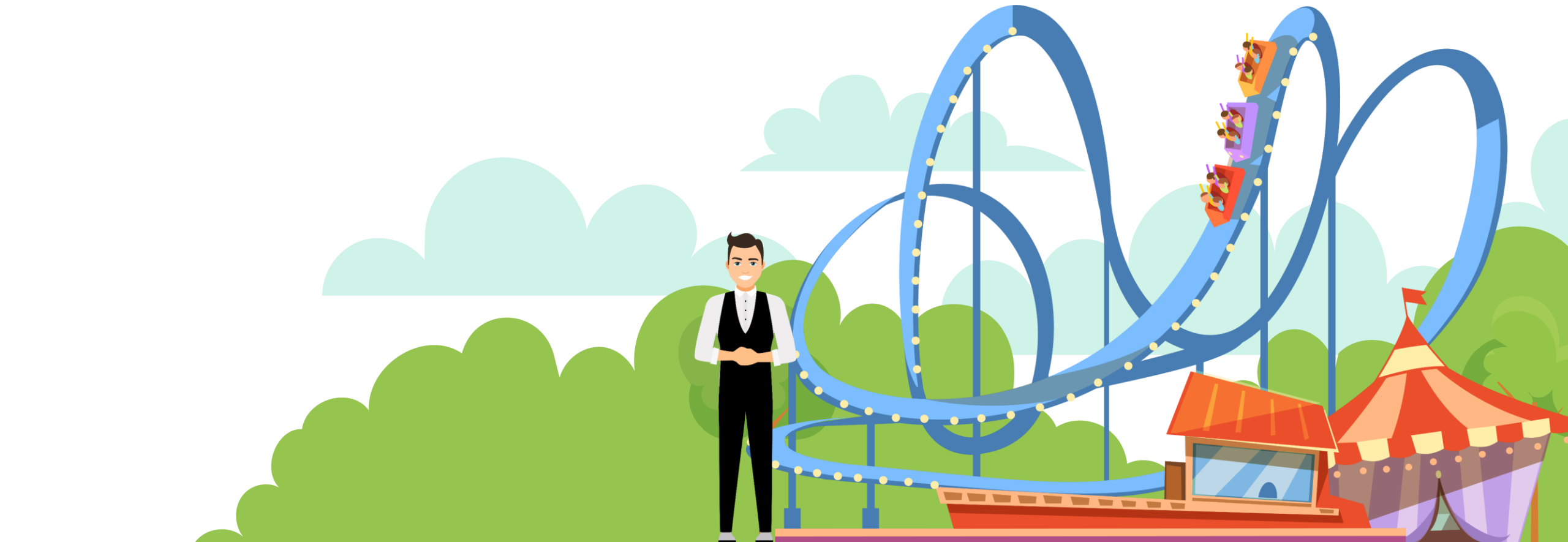
Ride@Rollercoaster

```
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

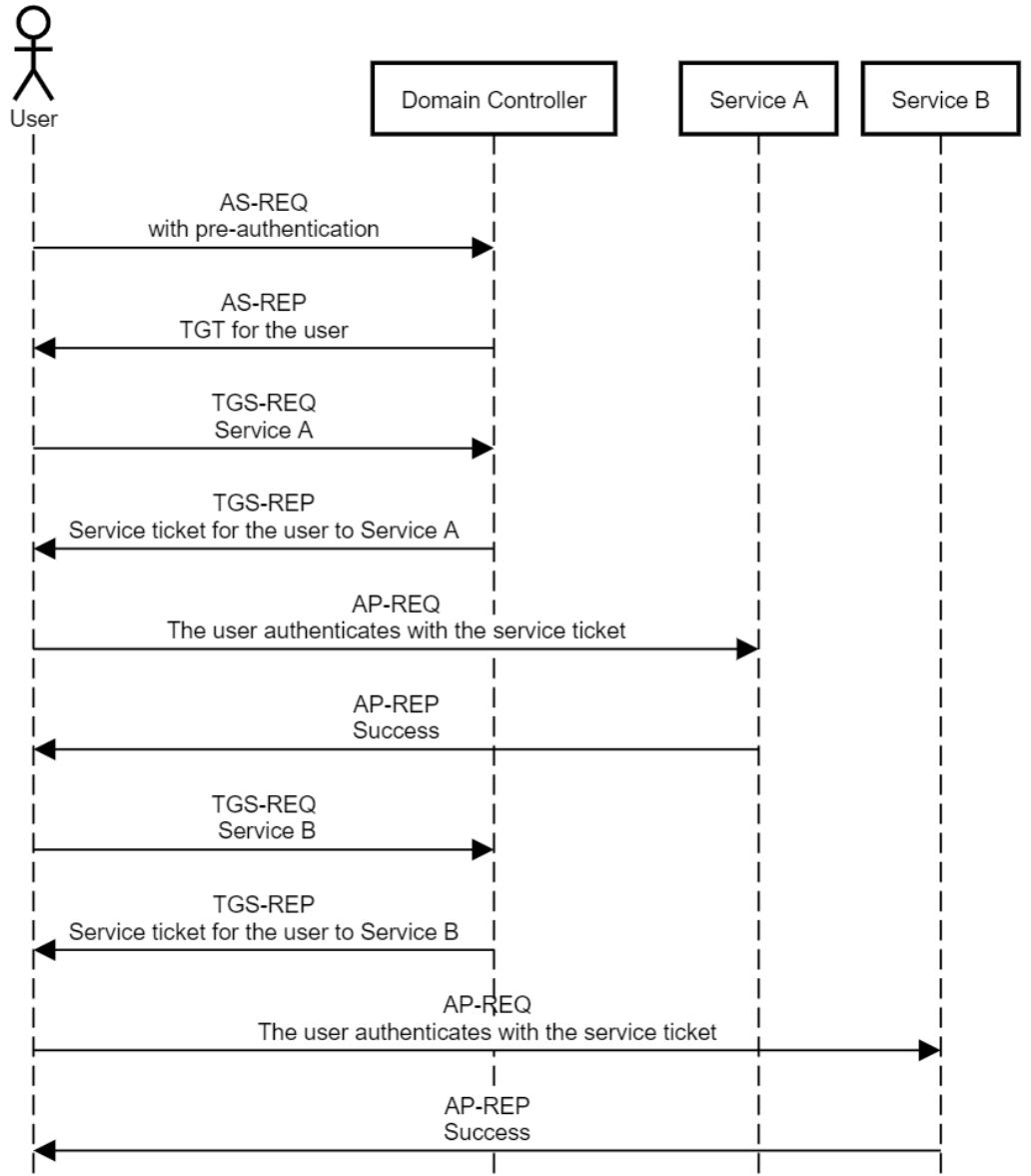
Ride@Rollercoaster

```
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
```

From Luna 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)*

Kerberos authentication flow



Can you crack the cipher?

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

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

Ride@Rollercoaster

Valid From: 4/4/75 9:00 AM
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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

Can you crack the cipher?

- If you obtain the ticket office's key, you can forge day passes
  - Same as obtaining the KRBTGT key and forging golden tickets
- If you obtain a ride operator's key, you can forge ride tickets
  - Same as compromising a service account and forging silver tickets
- Cracking a ride ticket to obtain the operator's key is the same as Kerberoasting
  - In Kerberoasting, the attacker obtains a service ticket and cracks the service account's password/key

A funny thing 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 funny thing 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 funny thing 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 funny thing 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
```

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

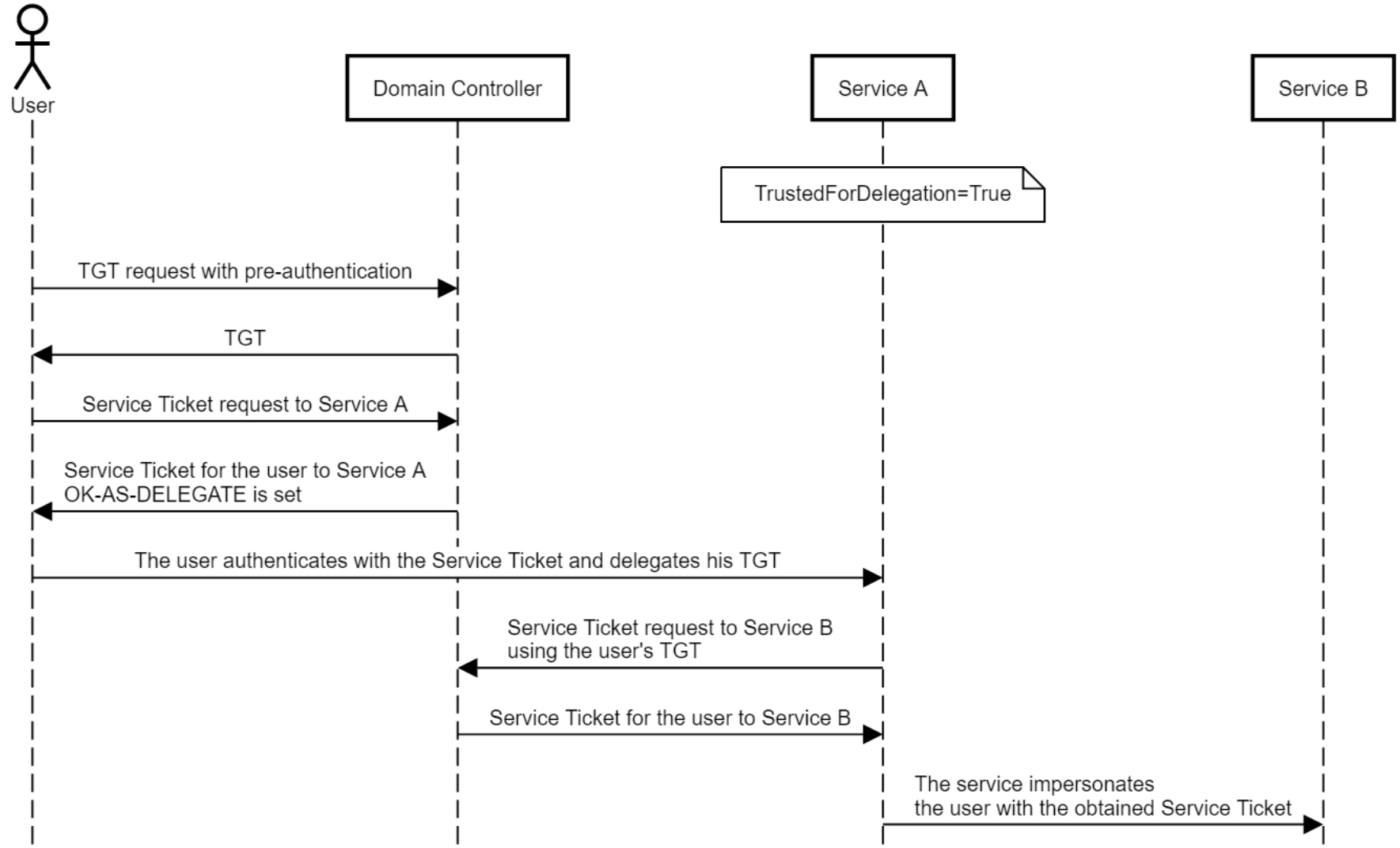
Beer@Luna Bar

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
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```

Day Pass

```
Valid From: 4/4/75 9:00 AM
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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

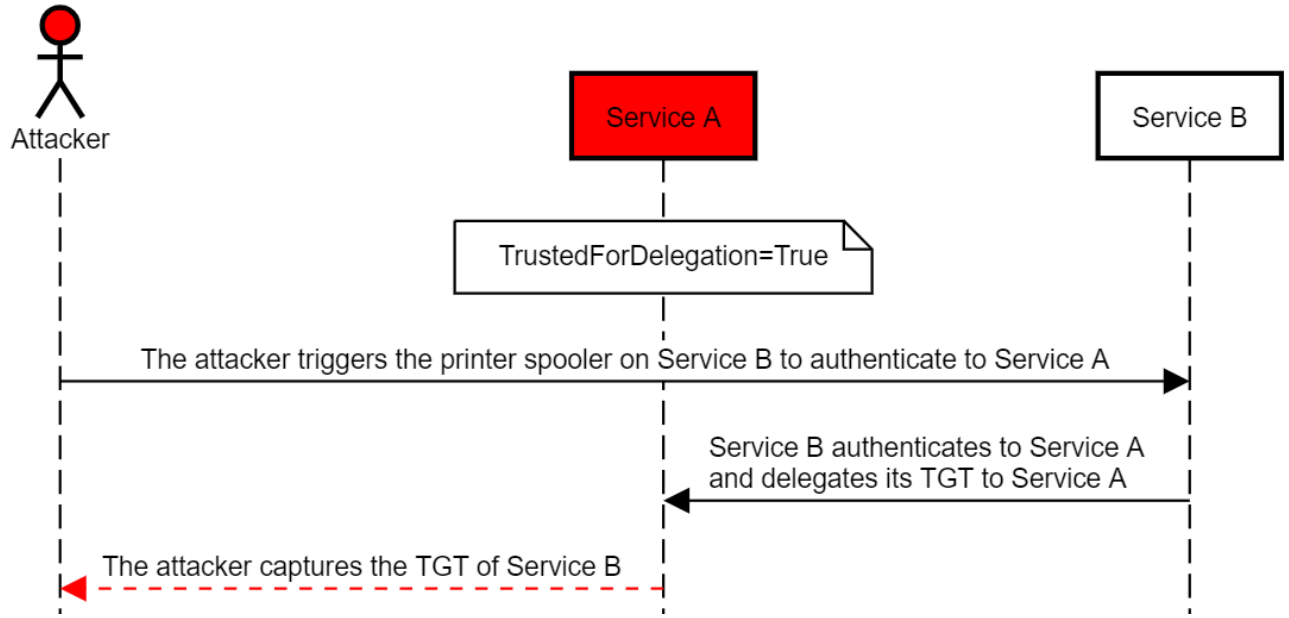
- If we compromise a service account or a host with TrustedForDelegation, we can take over any victim account that authenticates to it
- Where do victims come from?
  - Watering Hole
  - Social Engineering
  - Bring Your Own Victim?

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 (not only over SMB)
  - 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)

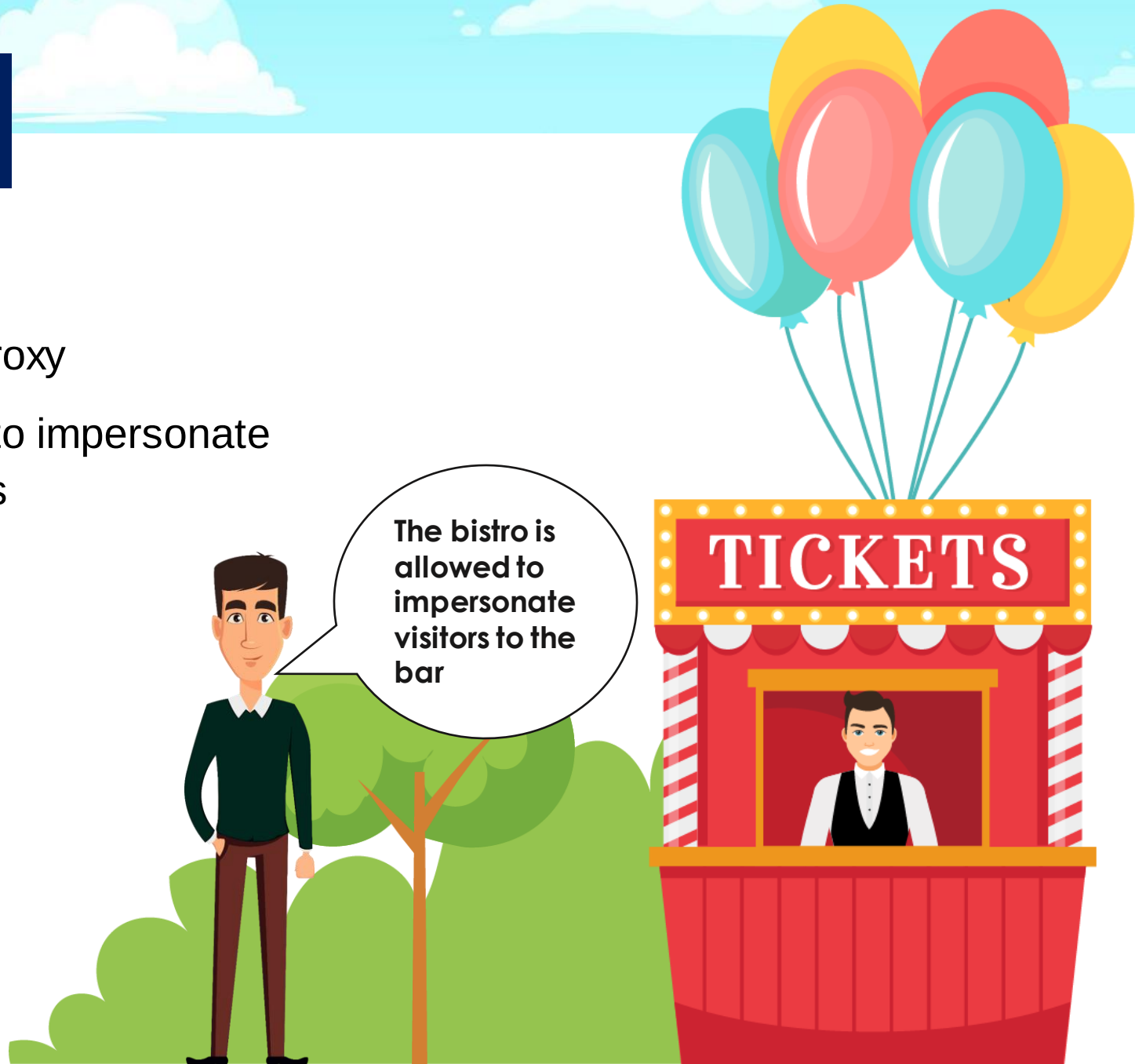


PetitPotam

- Discovered by Gilles Lionel (@topotam77)
- Inspired by The Printer Bug
- Abuses methods in the Encrypting File System Remote (EFSRPC) Protocol that allow providing the remote system with a UNC path, and it will connect back to access it
  - EfsRpcOpenFileRaw - patched
  - Still unpatched: EfsRpcEncryptFileSrv, EfsRpcDecryptFileSrv, EfsRpcQueryUsersOnFile, EfsRpcQueryRecoveryAgents, EfsRpcRemoveUsersFromFile, EfsRpcAddUsersToFile…
- Connects back to the provided path
- The service runs as LOCAL SYSTEM
- The service is configured to start automatically by default

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

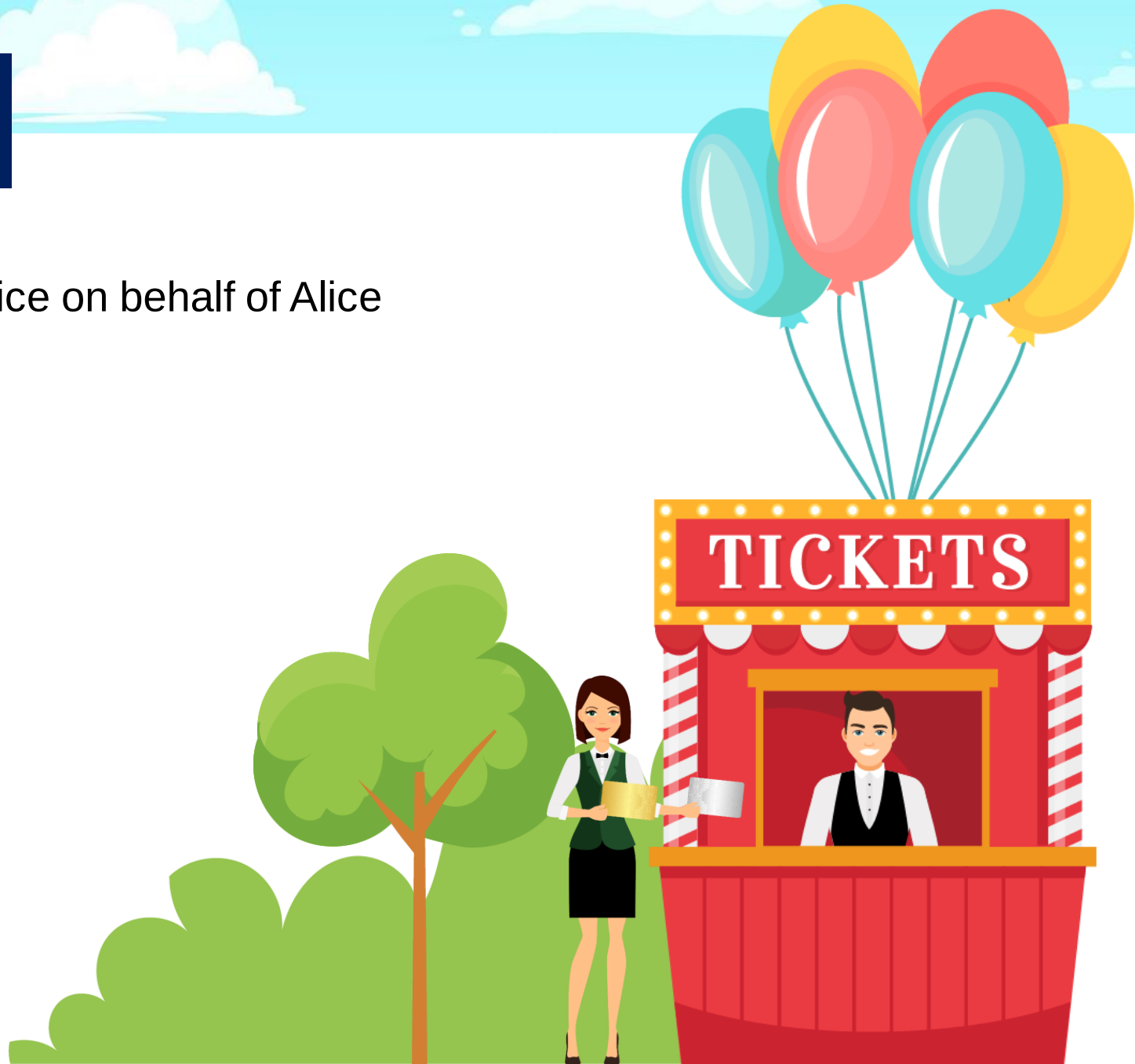
- Alice presents her lunch ticket to the waitress at the bistro
- The waitress decrypts the ticket and validates it

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

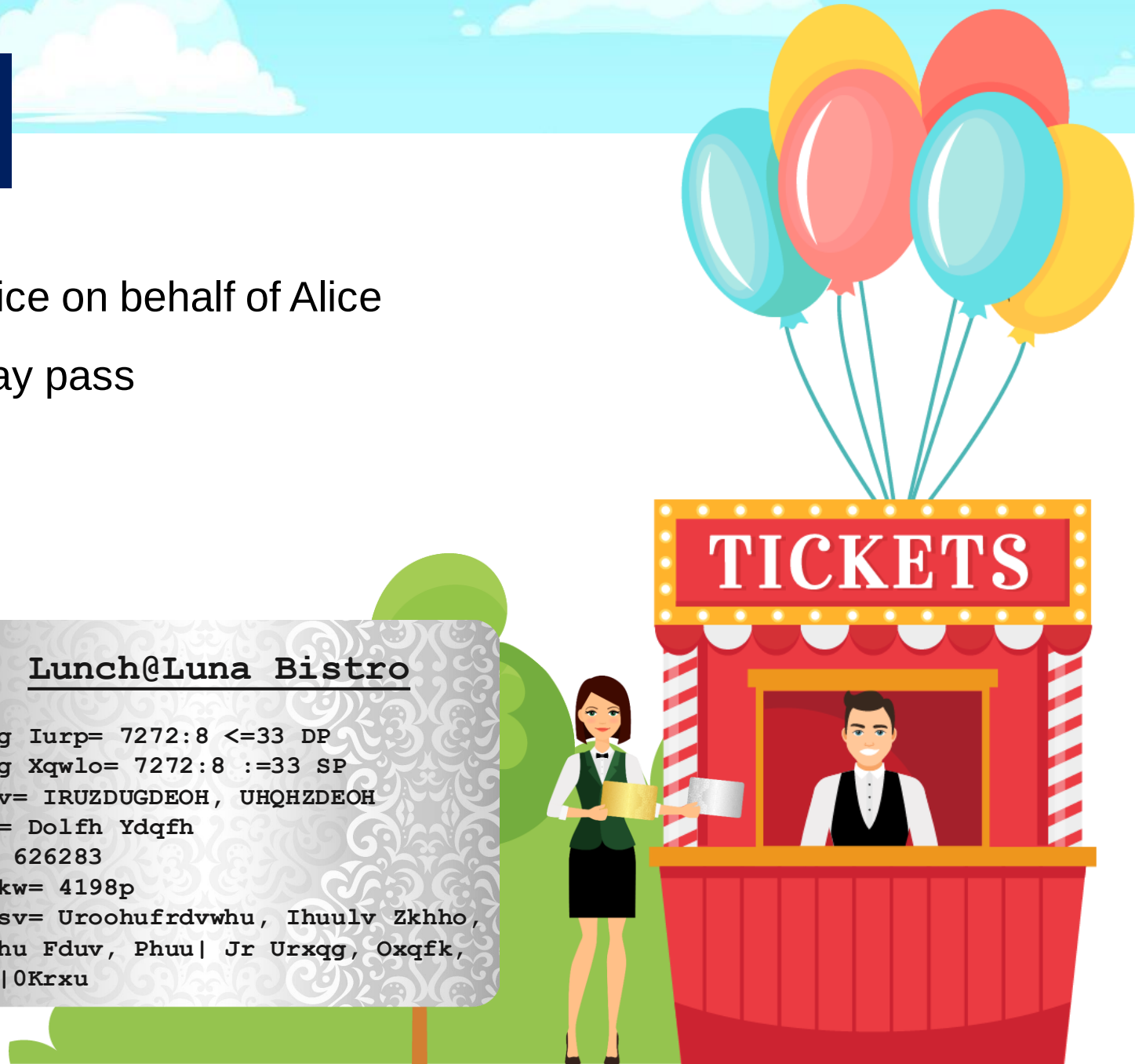
- The waitress goes to the ticket office on behalf of Alice
- The waitress presents **her own** day pass and Alice's bistro ticket

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 Zkho,
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 Zkho,
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

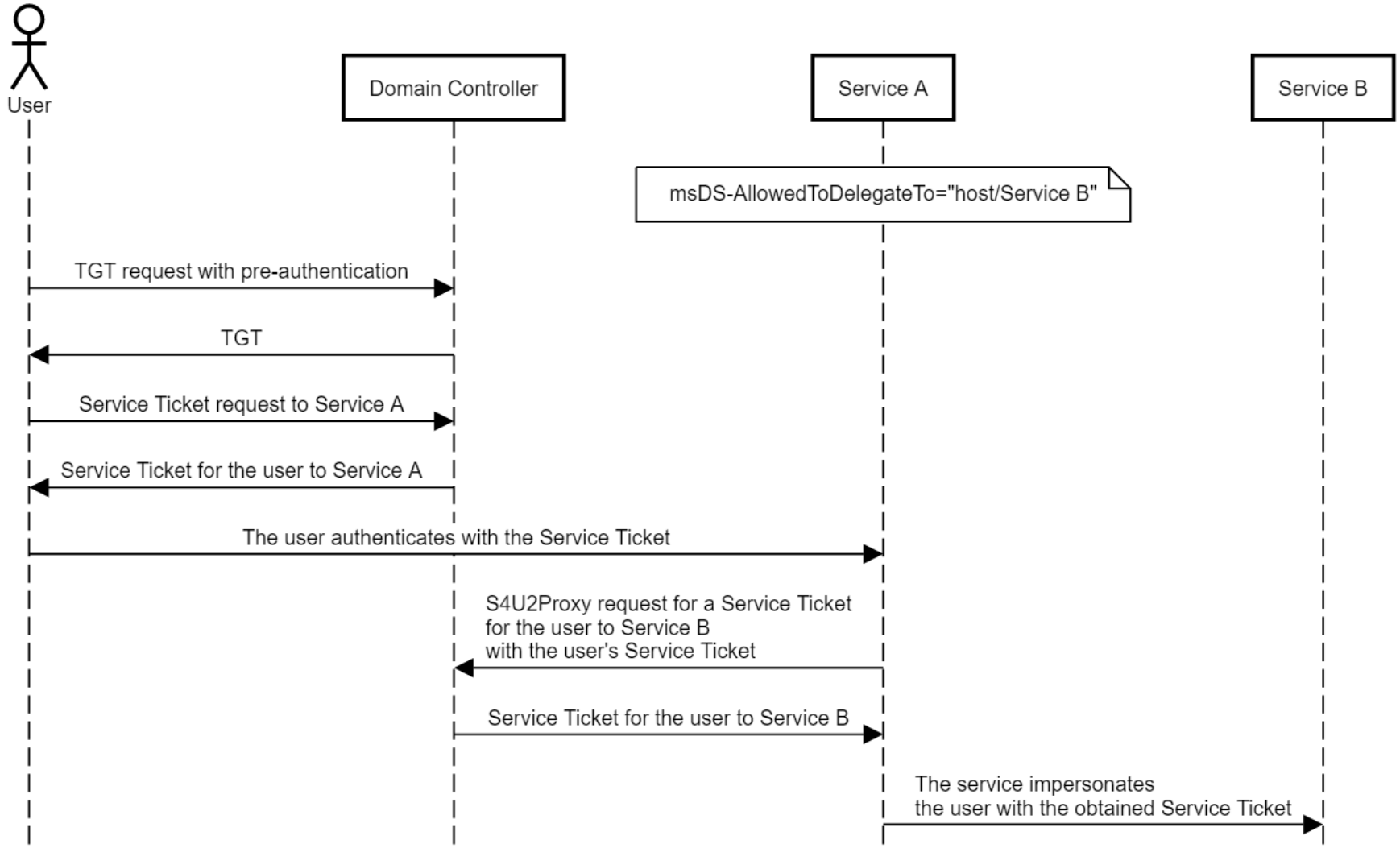
Beer@Luna Bar

```
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 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!

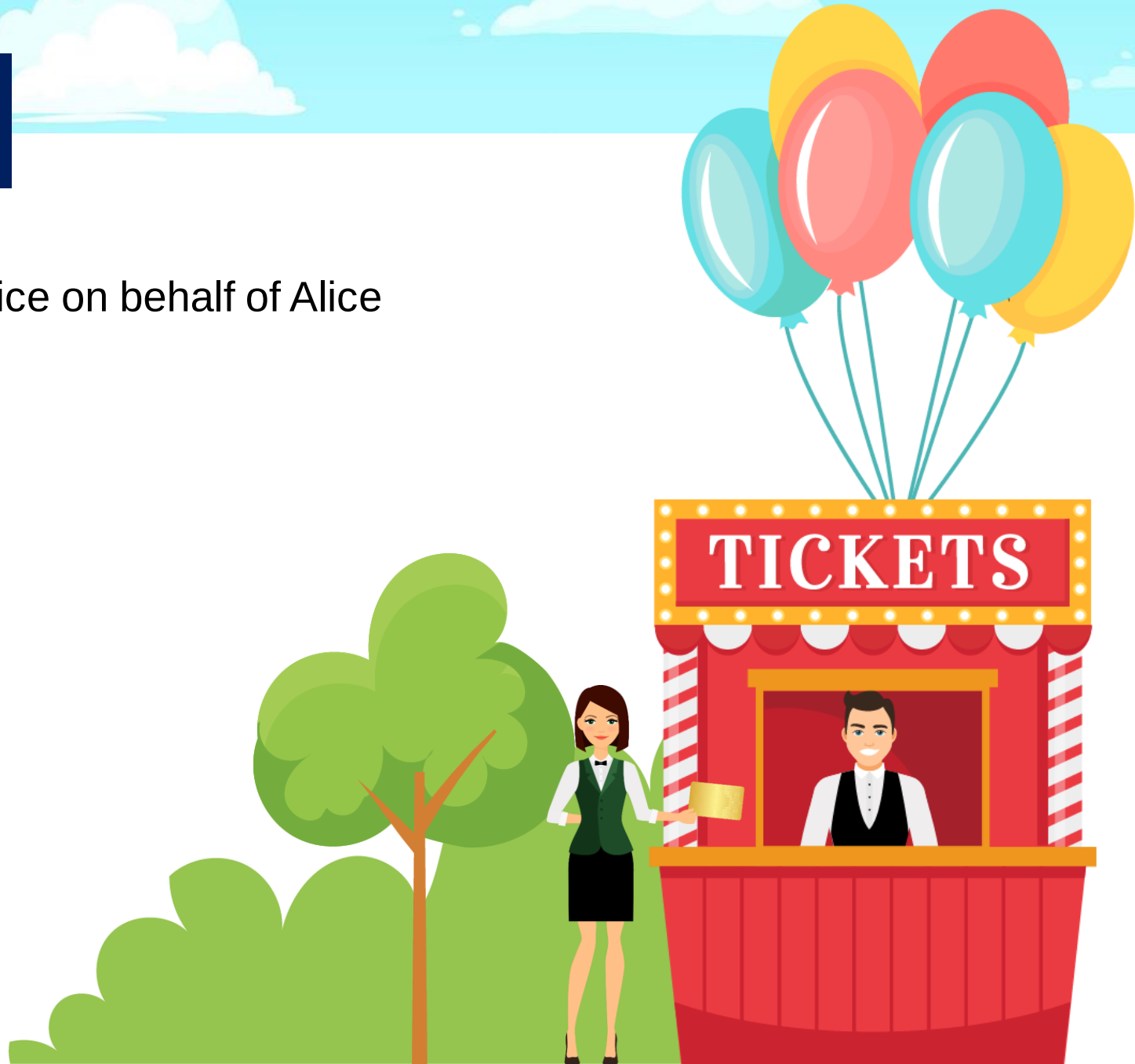
- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar

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

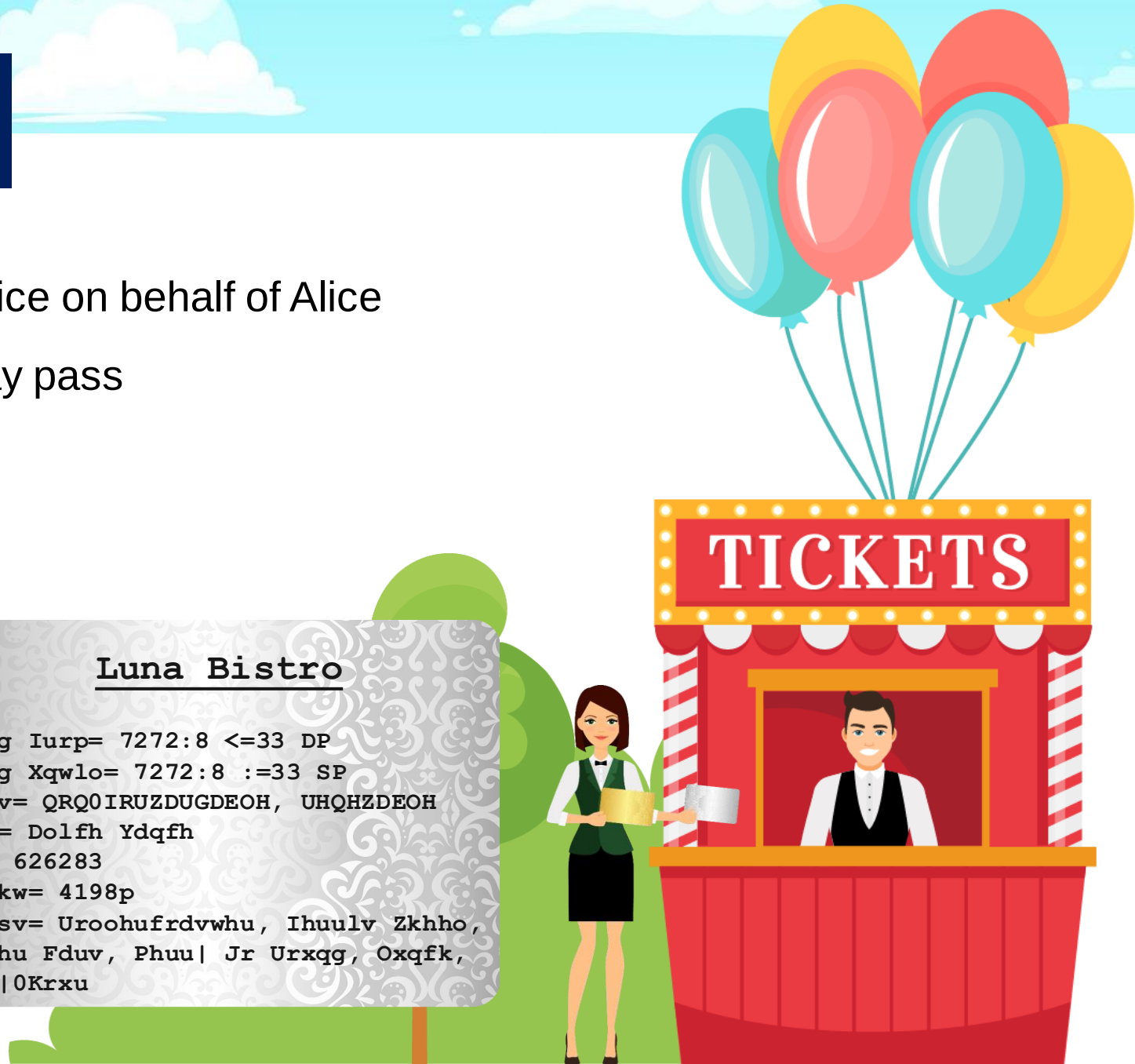
- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and Alice's bistro ticket

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
GRE= 626283
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!

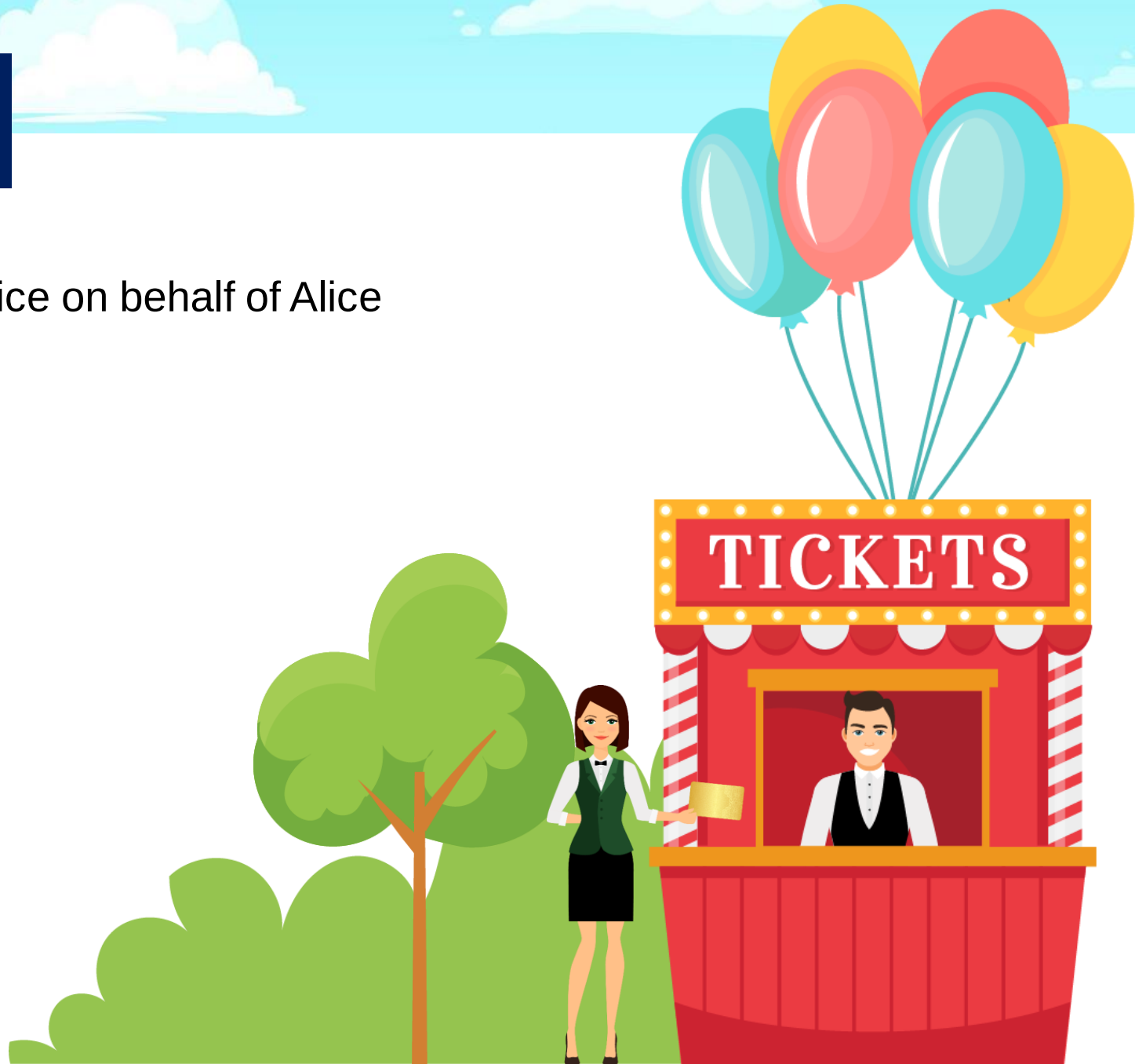
- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar

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 Zkho,
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 Zkho,
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: 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: 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

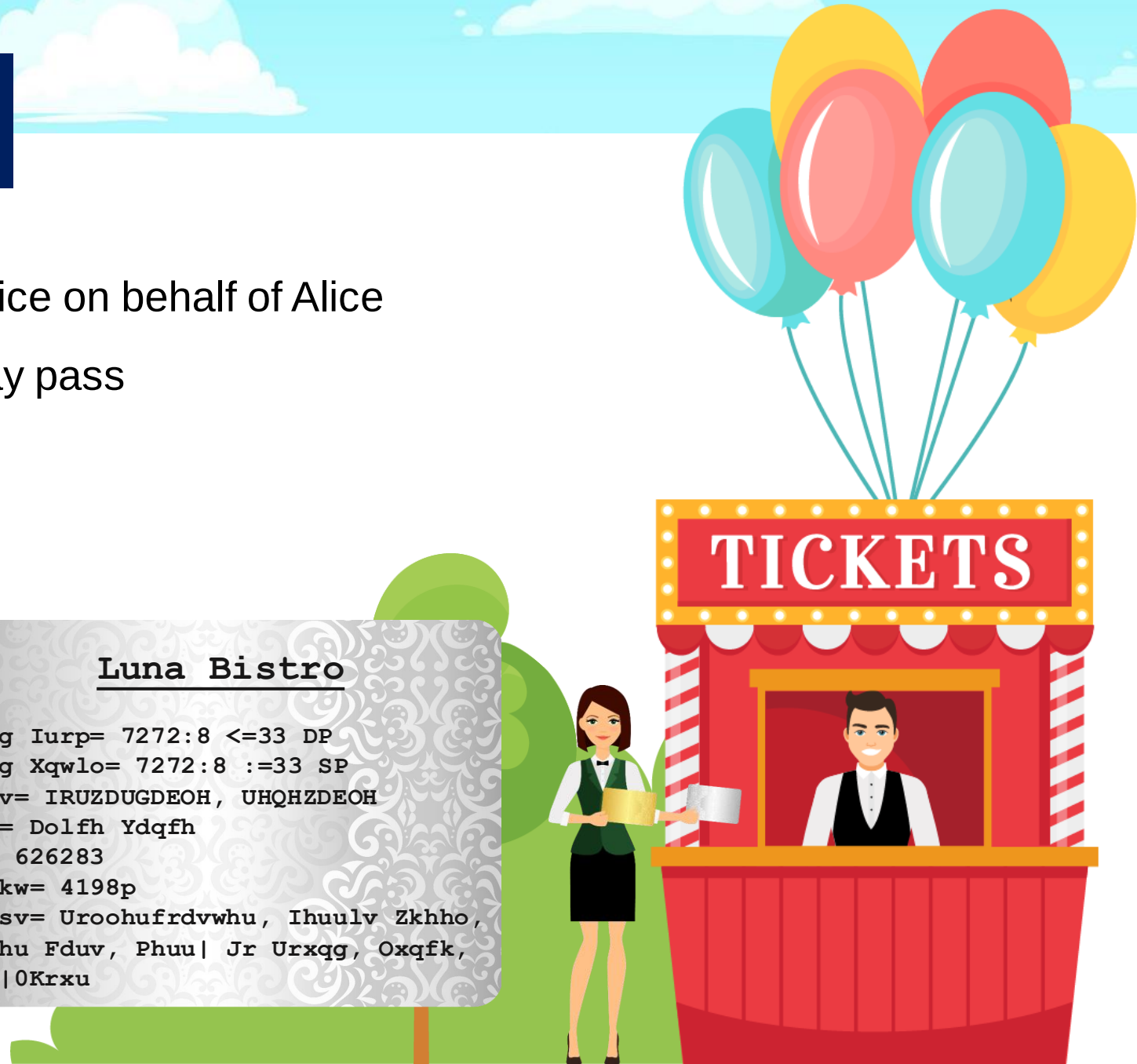
- The waitress goes to the ticket office on behalf of Alice
- The waitress presents her own day pass and Alice's bistro ticket

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 Zkho,
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

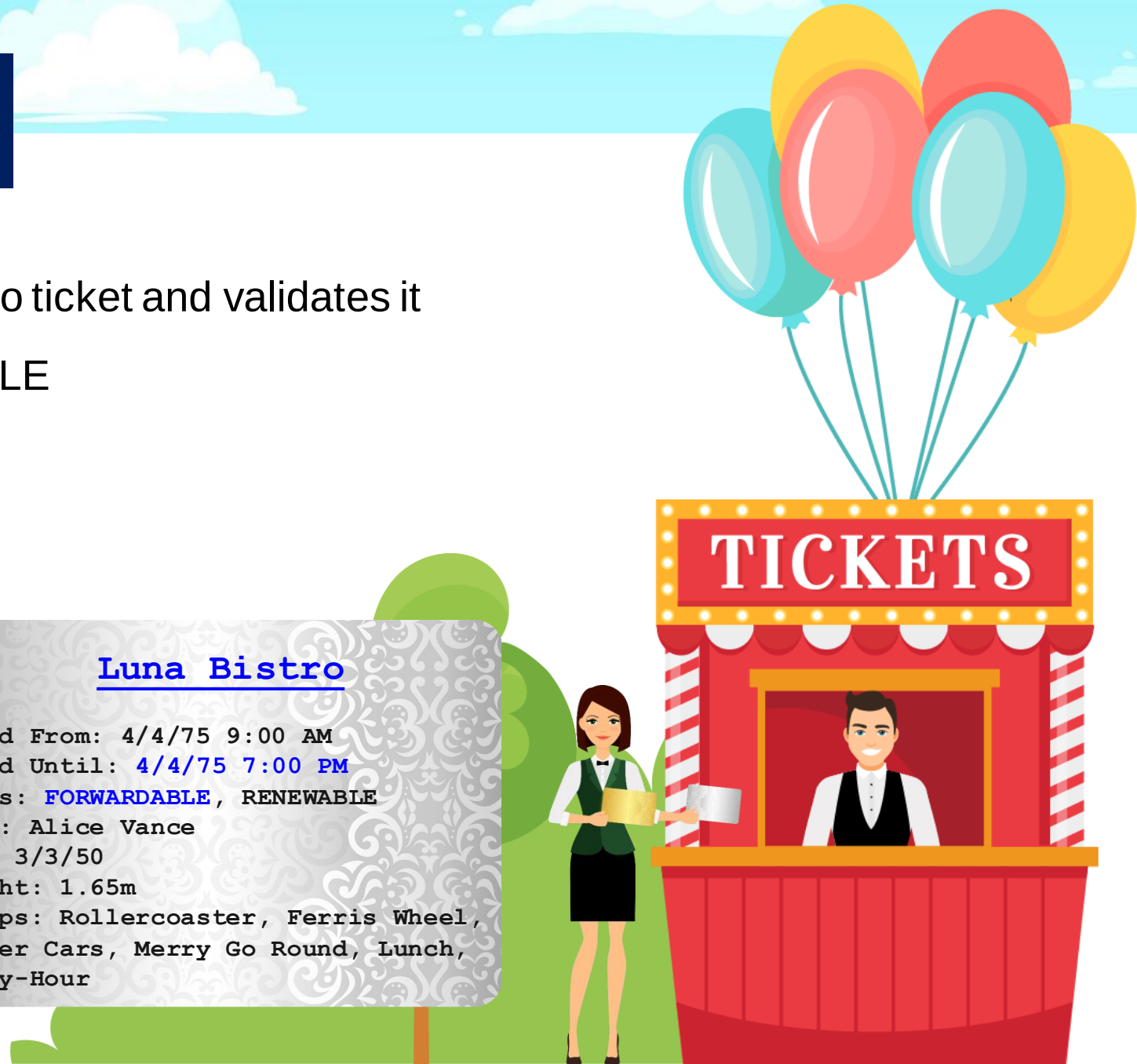
```
Valid From: 4/4/75 9:00 AM
Valid Until: 4/4/75 7:00 PM
Flags: FORWARDABLE, RENEWABLE
Name: Luna Bistro
Groups: Kitchen, Bistro, Staff
```

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 Zkho,
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

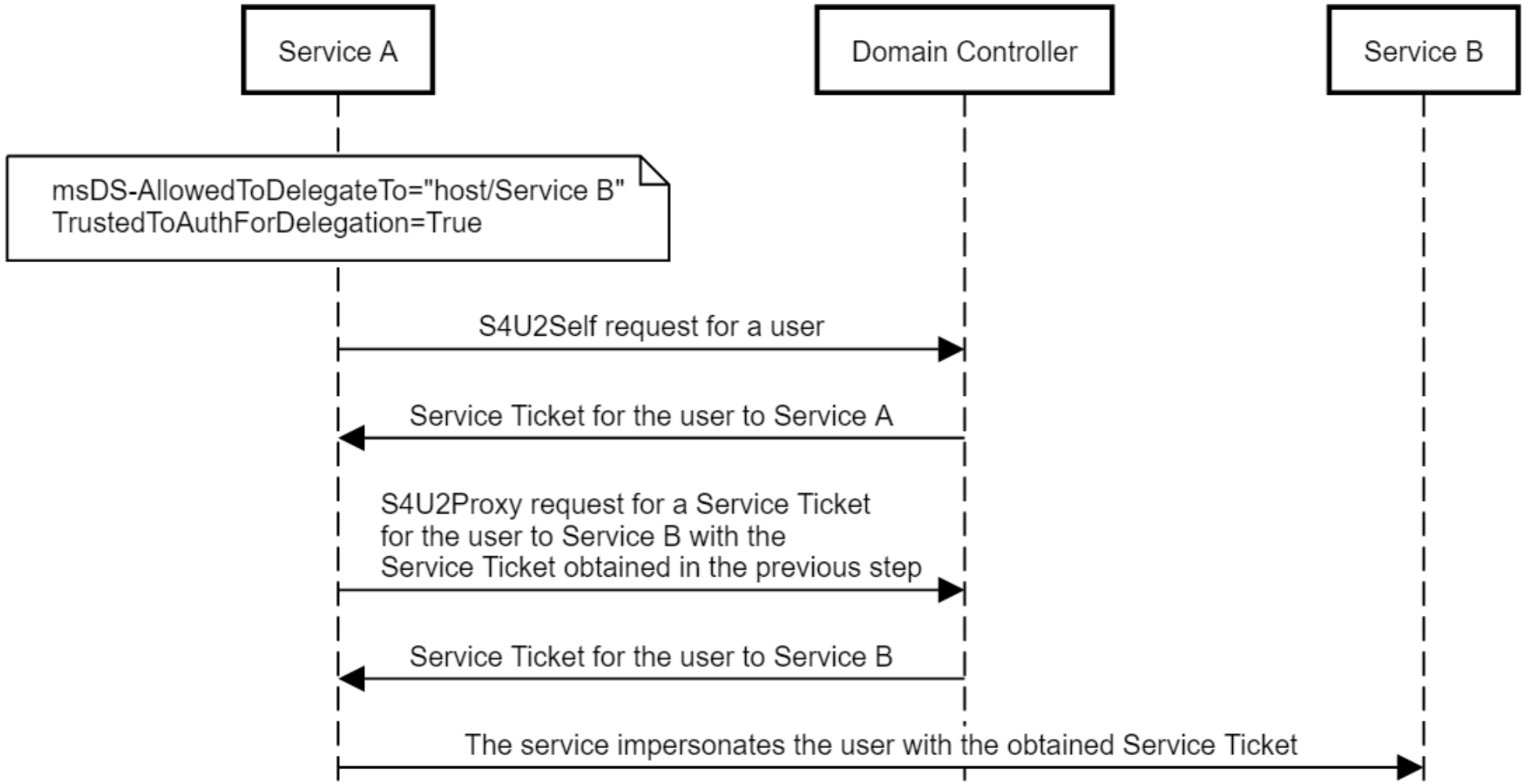
Beer@Luna Bar

```
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



TrustedToAuthForDelegation

- TrustedToAuthForDelegation flag
- Requires the SeEnableDelegation privilege
  - Only domain admins have that by default
- Also called “protocol transition”
- Does not require the user to be present

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

TrustedToAuthForDelegation is dangerous

- The waitress can follow this procedure even if Alice is not present

The Bronze Bit

- The ticket is encrypted using a symmetric cipher and the waitress knows the key

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

The Bronze Bit

- The ticket is encrypted using a symmetric cipher and the waitress knows the key
- The waitress can flip the NON-FORWARDABLE flag, encrypt it, and follow the same process

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
```

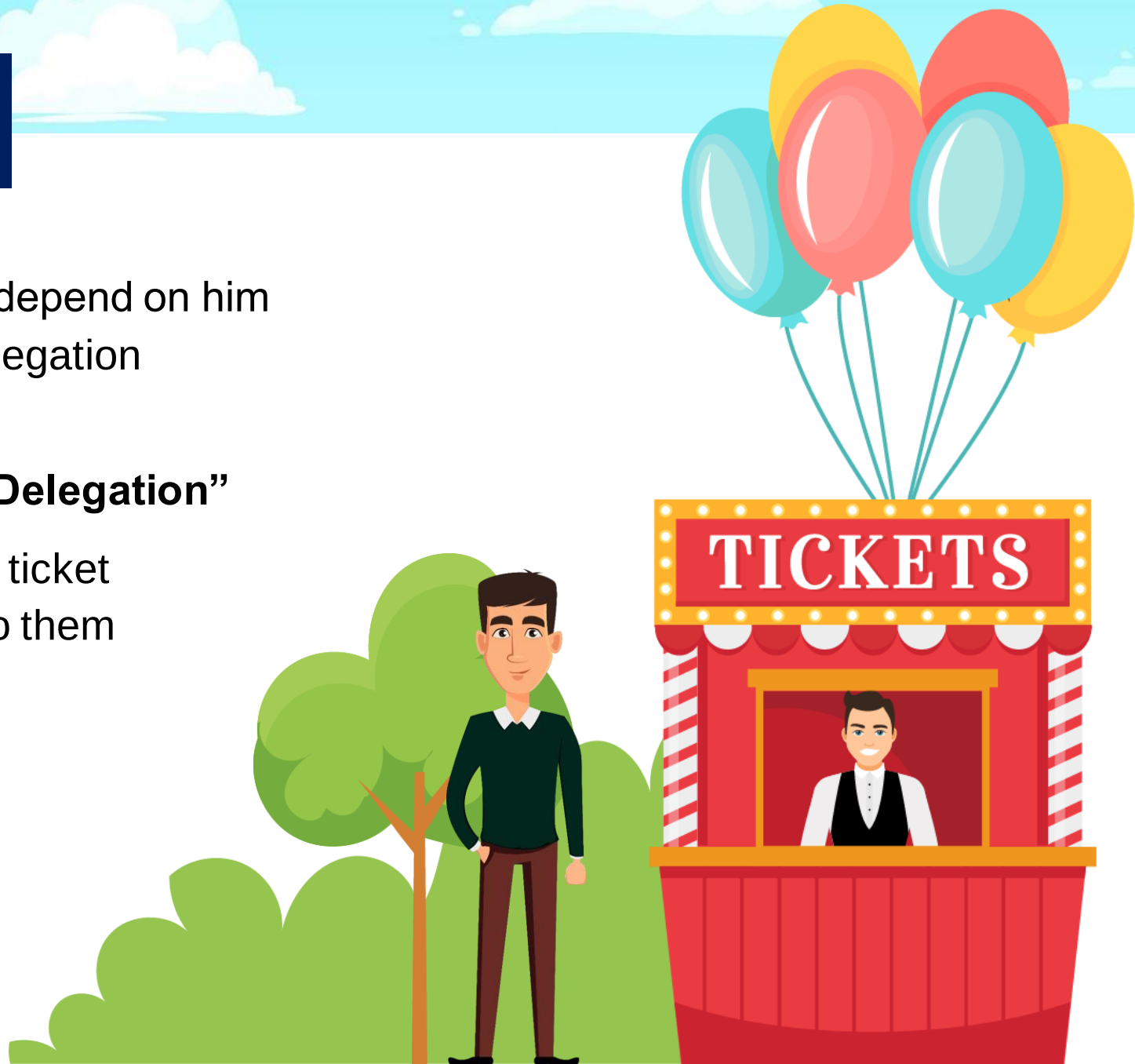
The Bronze Bit

- The ticket is encrypted using a symmetric cipher and the waitress knows the key
- The waitress can flip the NON-FORWARDABLE flag, encrypt it, and follow the same process
- The waitress can get herself a drink even if Alice is not present

- This attack was viable against Active Directory until it was patched by Microsoft in CVE-2020-17049
  - Discovered by Jake Karnes (@jakekarnes42)

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!

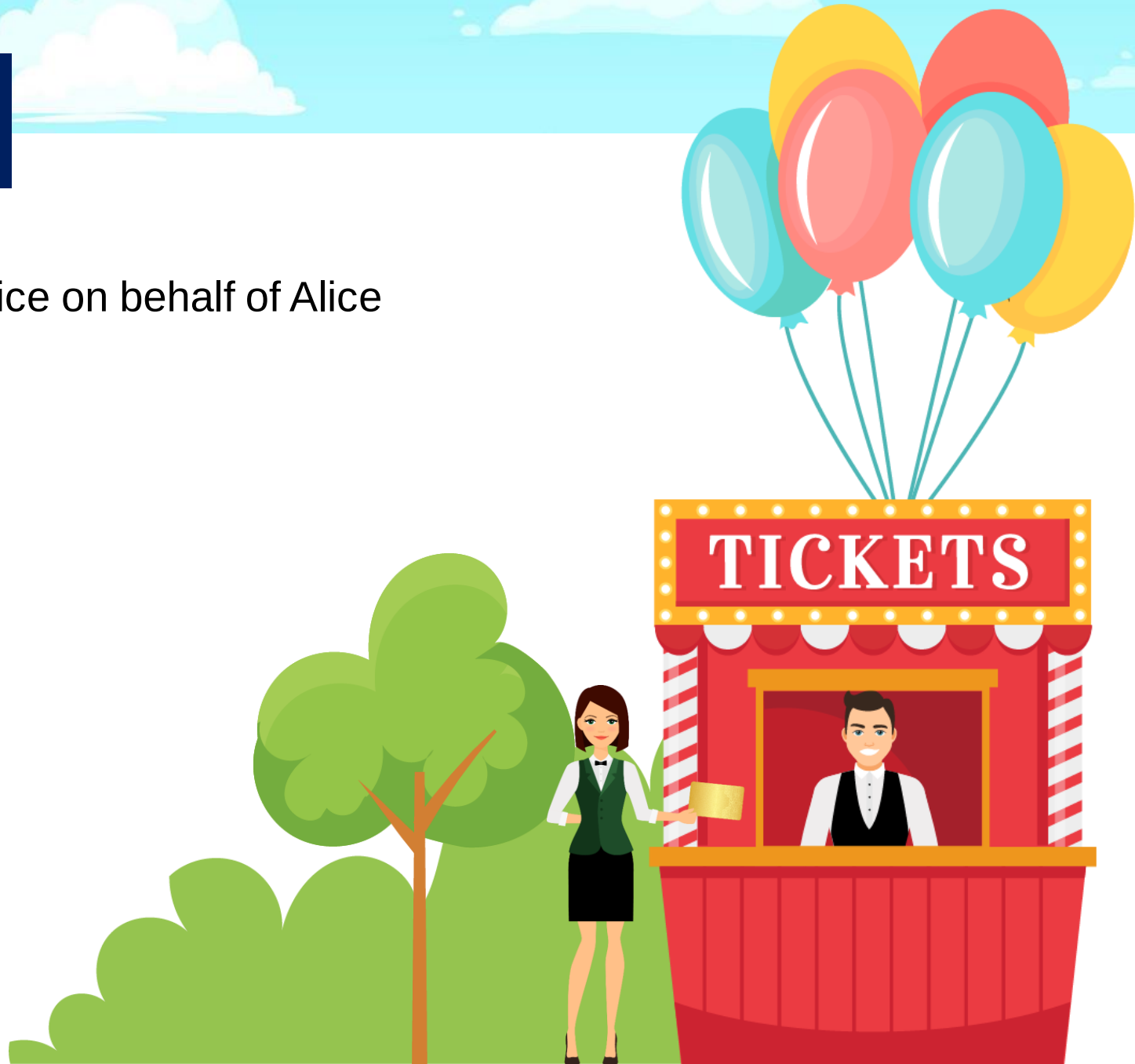
- Alice goes to the bistro and wants to order a burger and a beer
- The burger is served at the bistro and the beer is served at the bar

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
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 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
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Luna Bistro

```
Ydolg Iurp= 7272:8 <=33 DP
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Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
GRE= 626283
Khljkw= 4198p
Jurxsv= Uroohufrdvwhu, Ihuulv Zkho,
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

```
Ydolg Iurp= 7272:8 <=33 DP
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Iodjv= QRQ0IRUZDUGDEOH, UHQHZDEOH
Qdph= Dolfh Ydqfh
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Jurxsv= Uroohufrdvwhu, Ihuulv Zkho,
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
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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

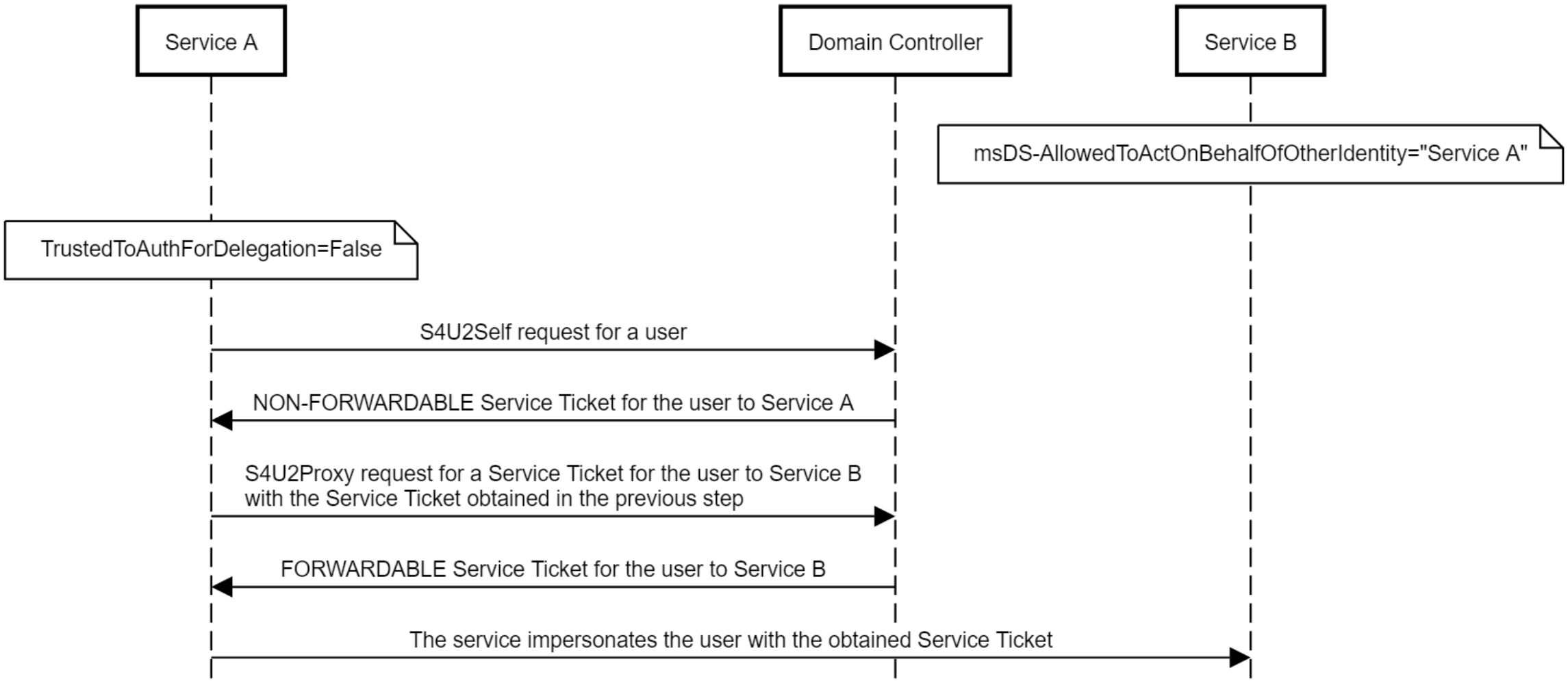
Beer@Luna Bar

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

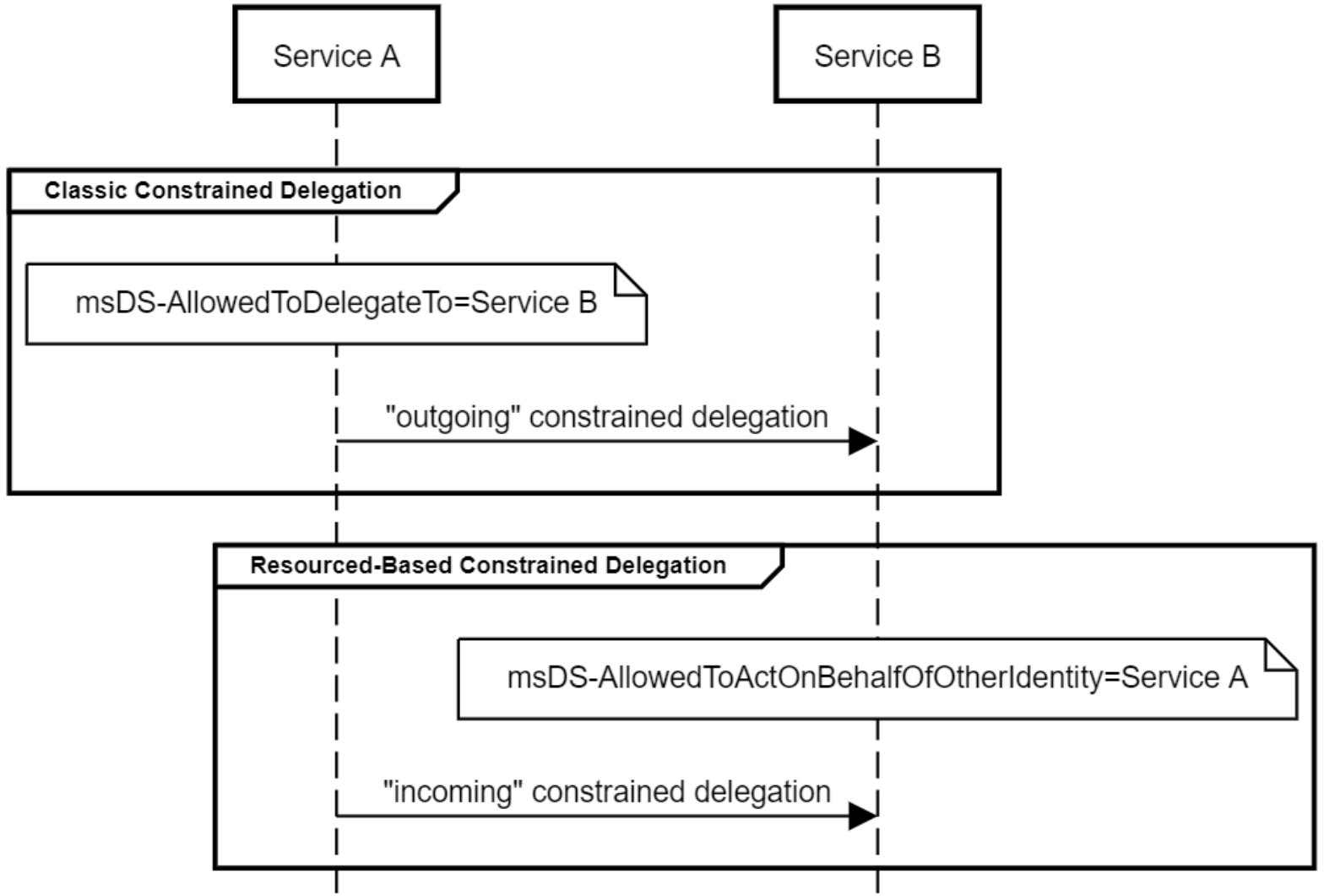


Resource-based constrained delegation

- 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 is always possible
Requires the SeEnableDelegation privilege	No special privileges required

DACL-Based AD Attacks

- Initial attack paths were primarily the Credential Shuffle
- More advanced attacks progressed to abusing delegated AD rights
  - If you compromise an account that has delegated rights over other objects, how can you abuse it?

Object	Abuse
User	Password Reset, Targeted Kerberoasting, *Shadow Credentials*
Group	Add User
Domain	DCSYNC
GPO	GPO-Based Attacks (e.g. scheduled task)
Computer	Read LAPS Password, *Shadow Credentials*, **RBCD**

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 Zkho,
Expshu Fduv, Phuu| Jr Urxqg, Oxqfk,
Kdss|0Krxu
```

RBCD is dangerous

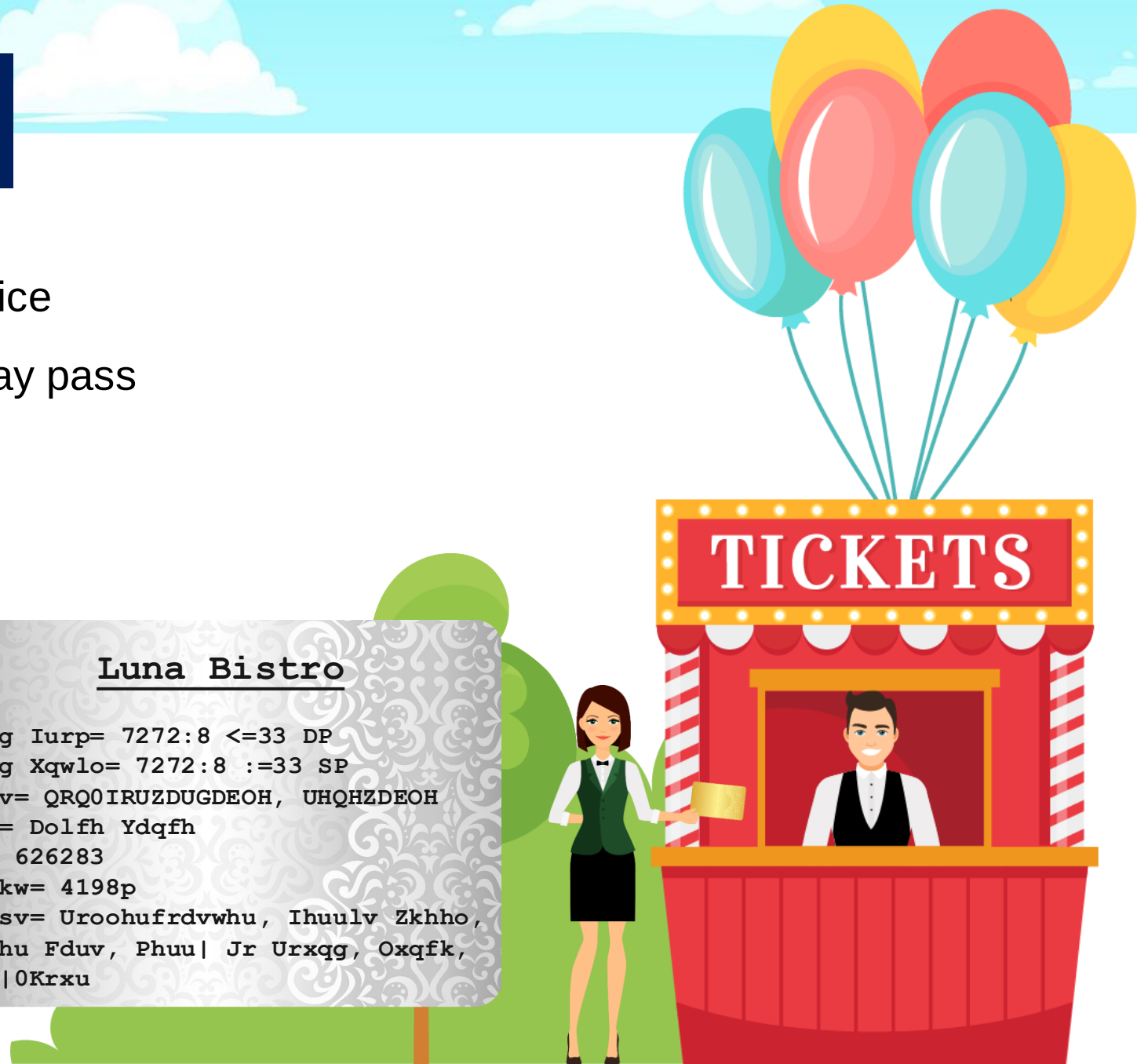
- The waitress goes to the ticket office
- The waitress presents **her own** day pass and Alice's bistro ticket

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 Zkho,
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 Zkho,
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
```

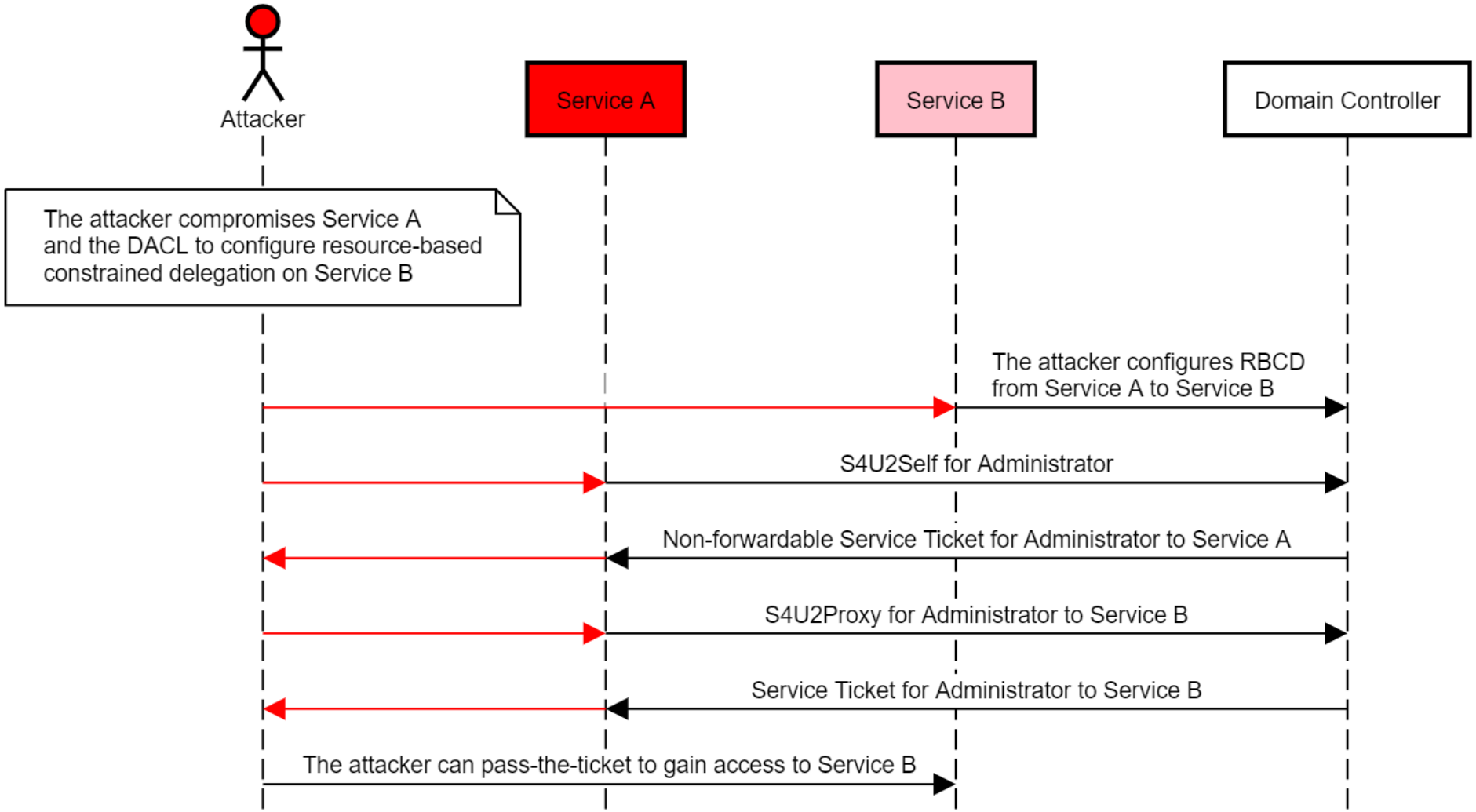
RBCD is dangerous

- The waitress gets a drink

Generalized RBCD abuse

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

Generalized RBCD abuse



Attack Primitives Recap

- Capture TGTs through unconstrained delegation
- The “Printer Bug”
- S4U2Self and S4U2Proxy
- TrustedToAuthForDelegation
- Abuse classic constrained delegation to compromise services
- Generalized DACL-based computer object takeover primitive through resource-based constrained delegation
- MS-DS-Machine-Account-Quota
- The service name on the tickets is not encrypted

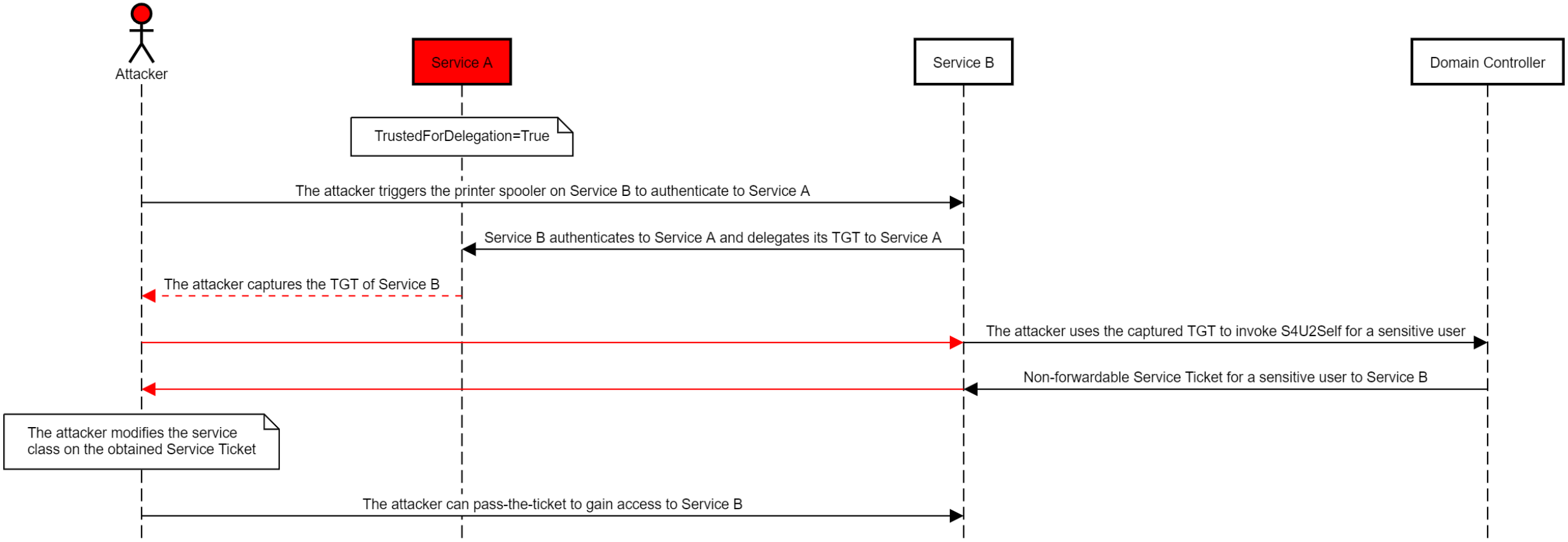
S4U2Silver

- 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

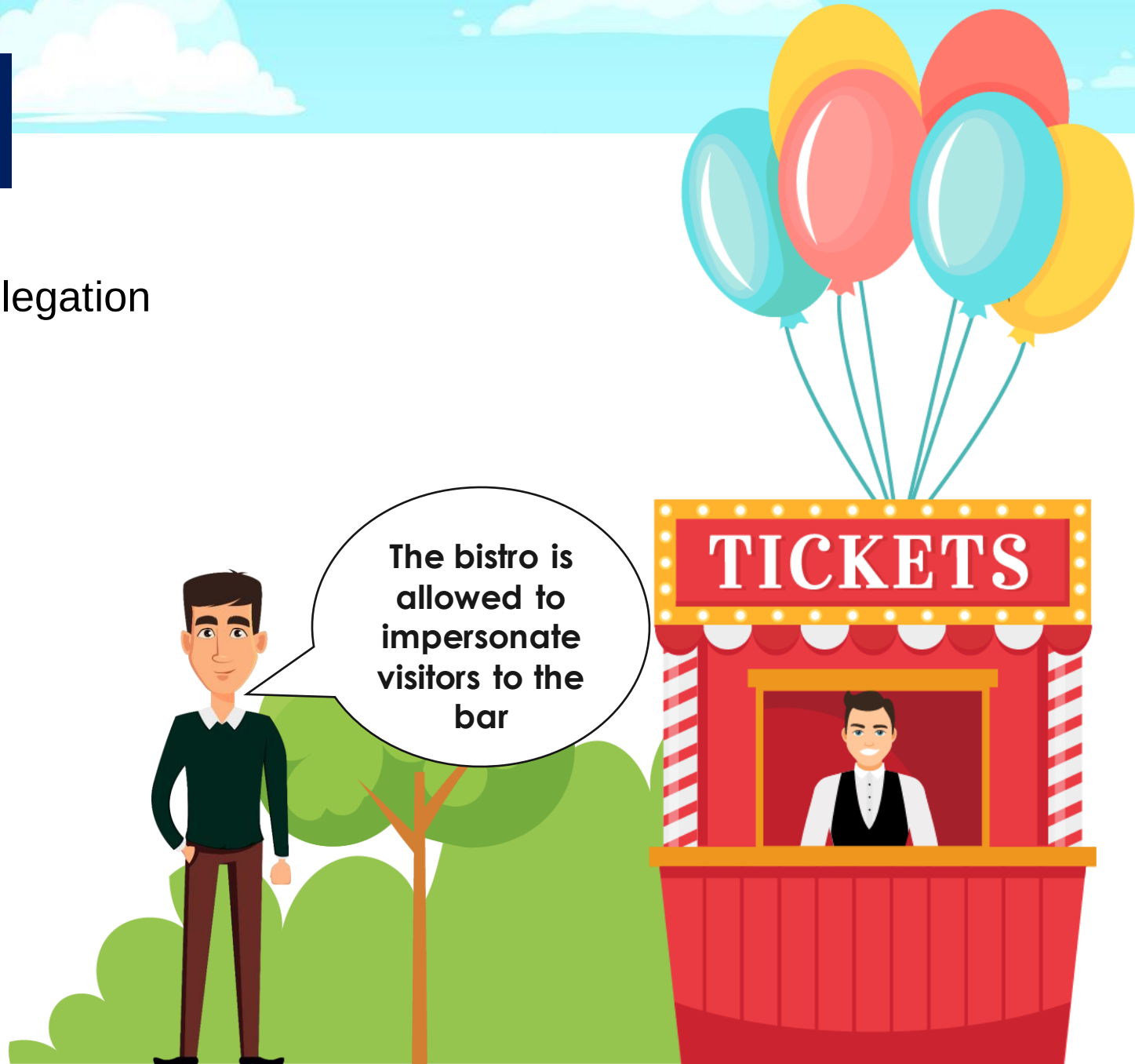
- Use the “printer bug” to coerce authentication from the target host to a compromised host with unconstrained delegation
- Obtain the target host’s TGT
- Use the target host’s TGT to invoke S4U2Silver for an admin user to the target host
  - Can impersonate sensitive users as well

RCE with unconstrained delegation



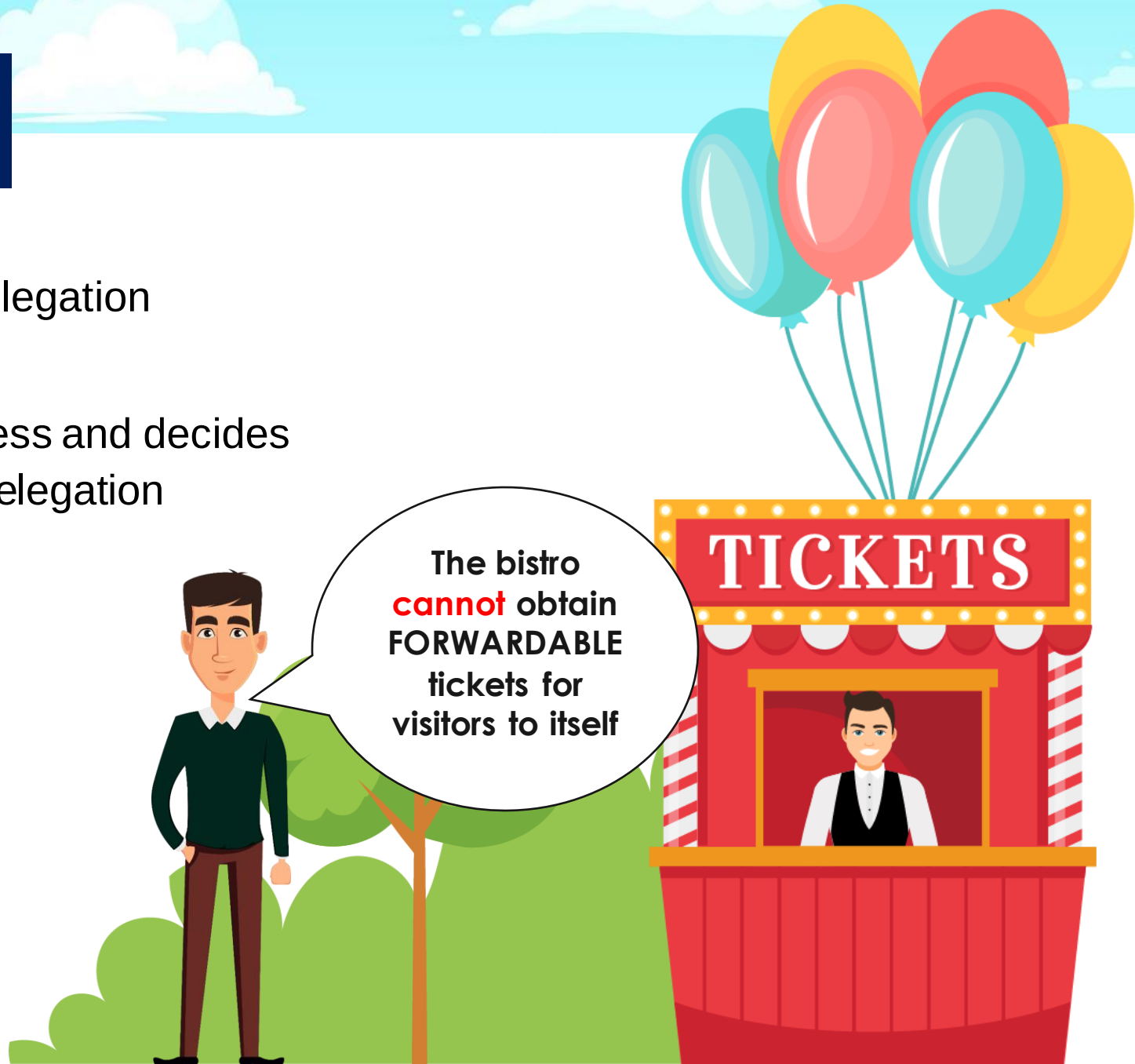
Did Bill make a mistake?

- 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?

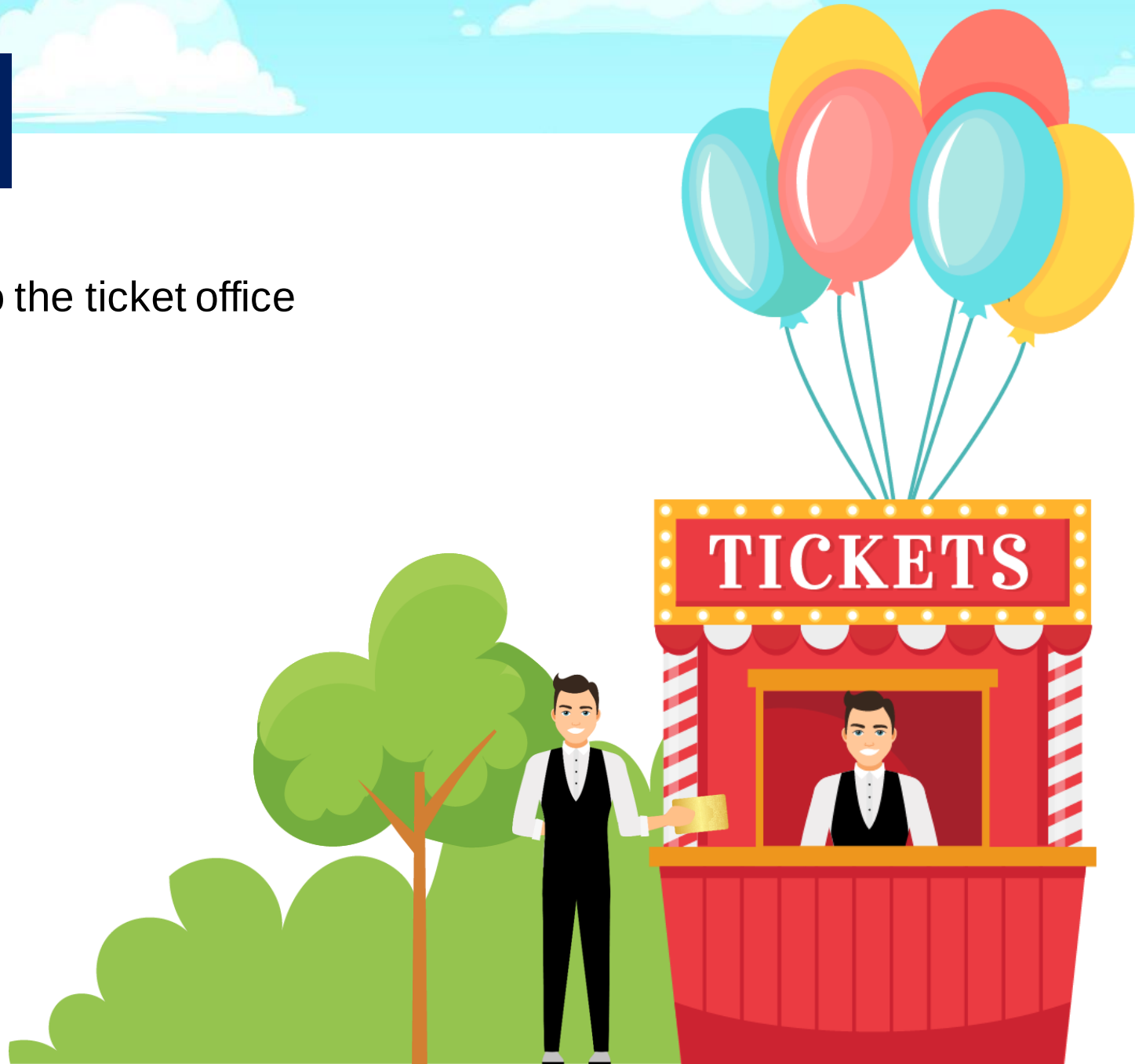
- The waitress is thirsty
- The waitress conspires with the rollercoaster operator

TrustedToAuthForDelegation bypass

- The waitress sets RBCD from the rollercoaster to the bistro

TrustedToAuthForDelegation bypass

- The rollercoaster operator goes to the ticket office

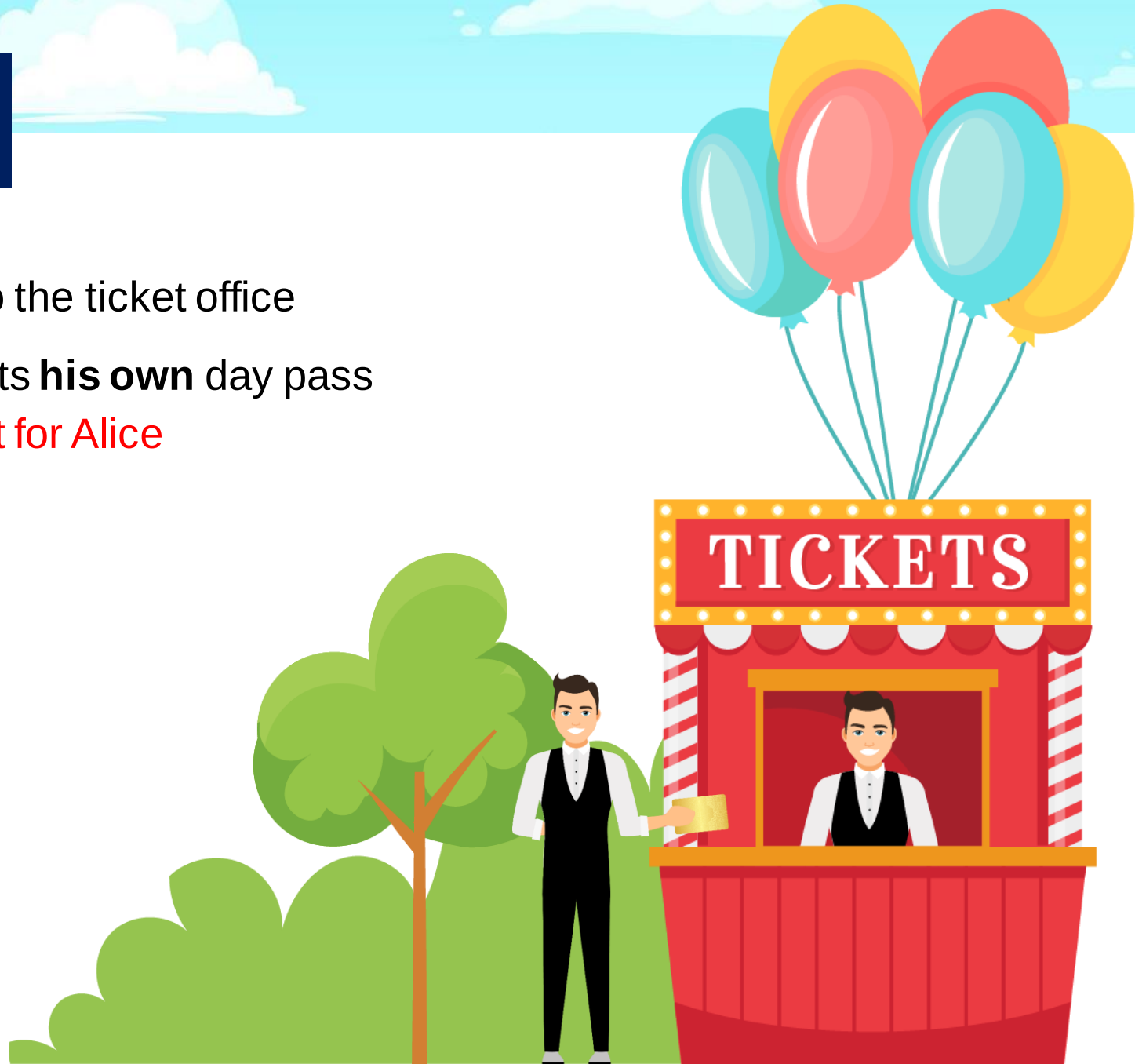


TrustedToAuthForDelegation bypass

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

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 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
```

Rollercoaster

```
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 presents **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
```

Rollercoaster

```
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 presents **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
```

Rollercoaster

```
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 rollercoaster 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 rollercoaster 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

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 Zkho,
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

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

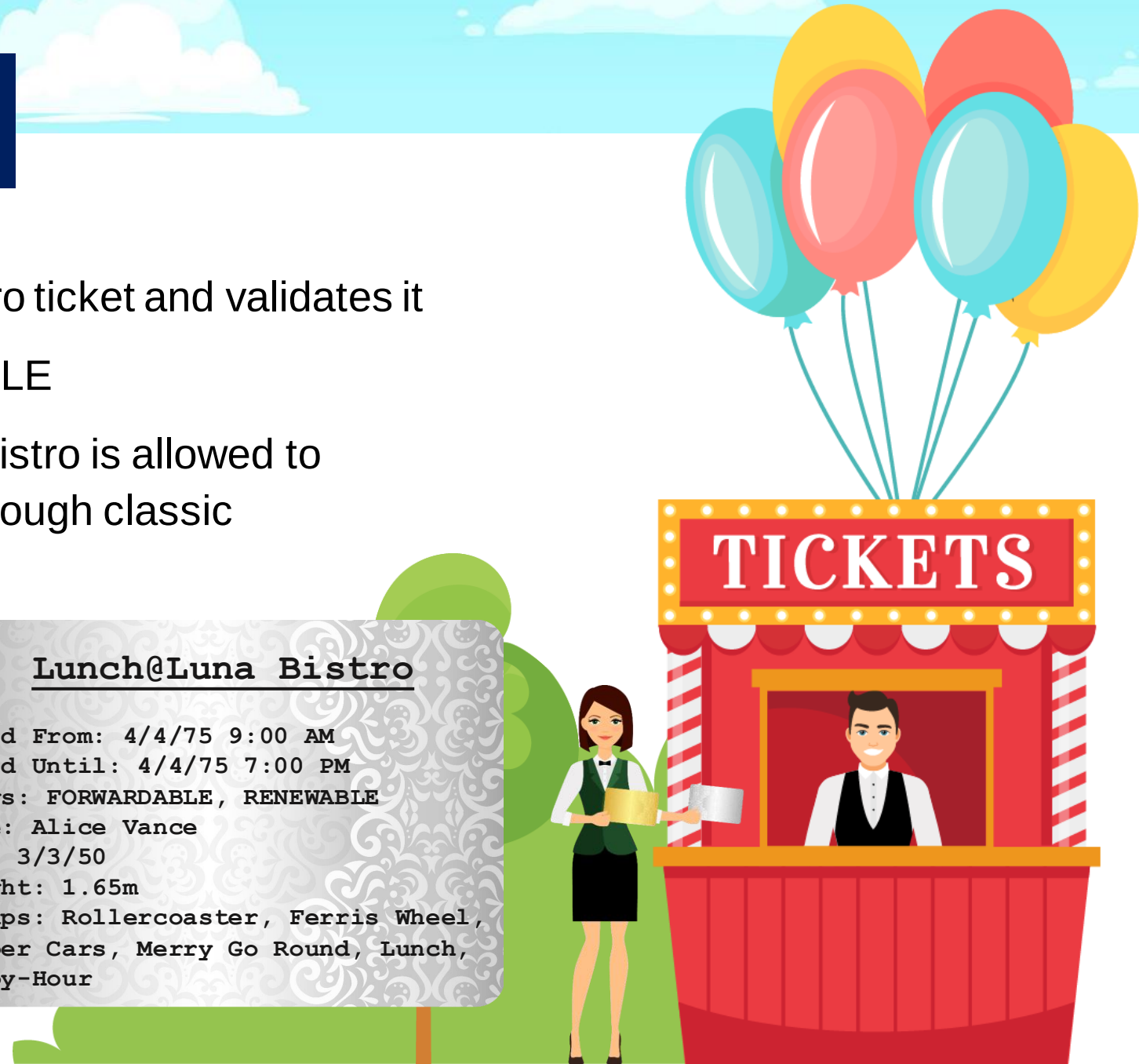
- The ticket office decrypts the bistro ticket and validates it
- The bistro ticket is FORWARDABLE
- The ticket office verifies that the bistro is allowed to impersonate visitors to the bar through classic constrained delegation

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
```

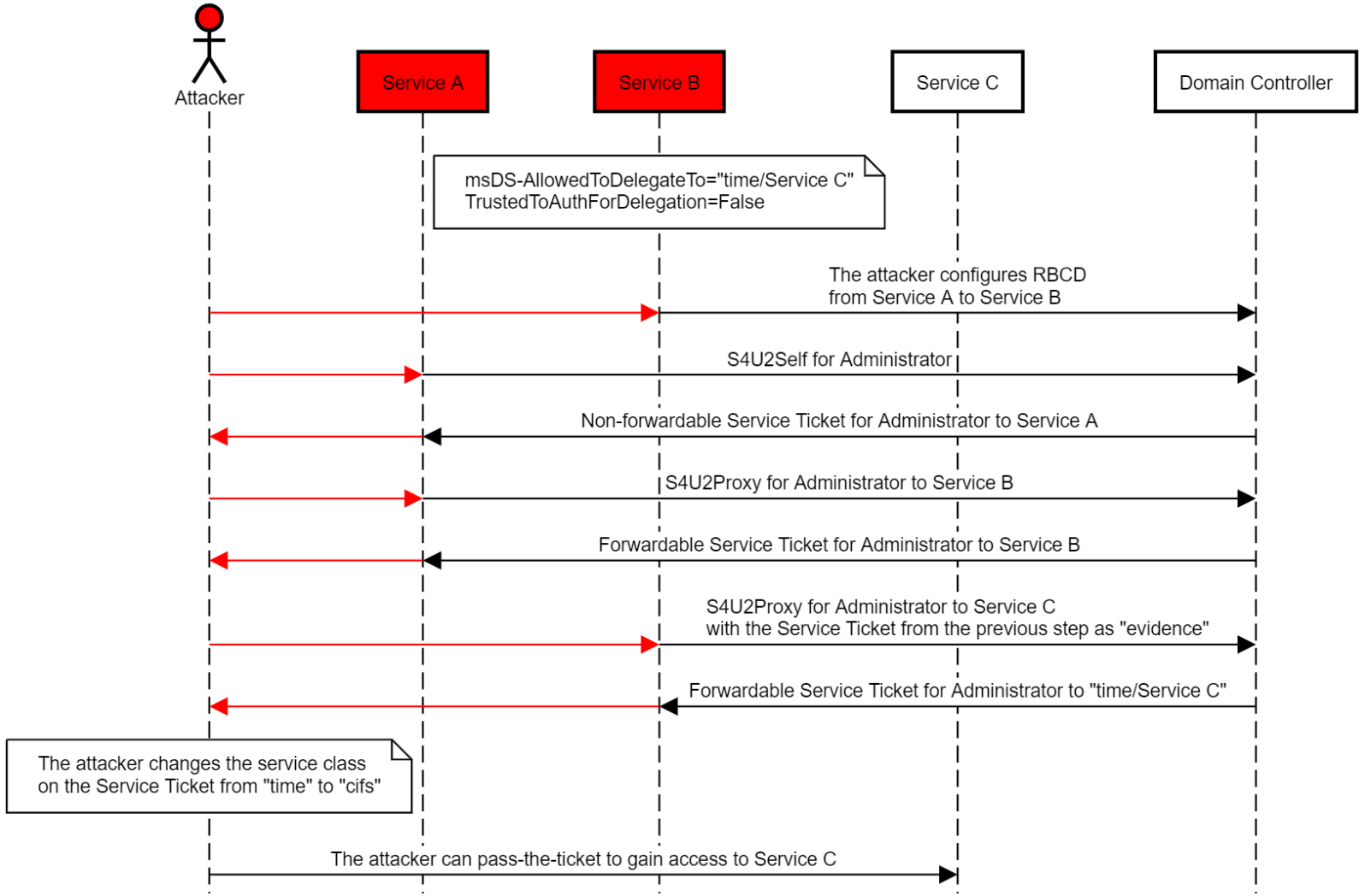
TrustedToAuthForDelegation bypass

- The waitress gets a drink

TrustedToAuthForDelegation bypass

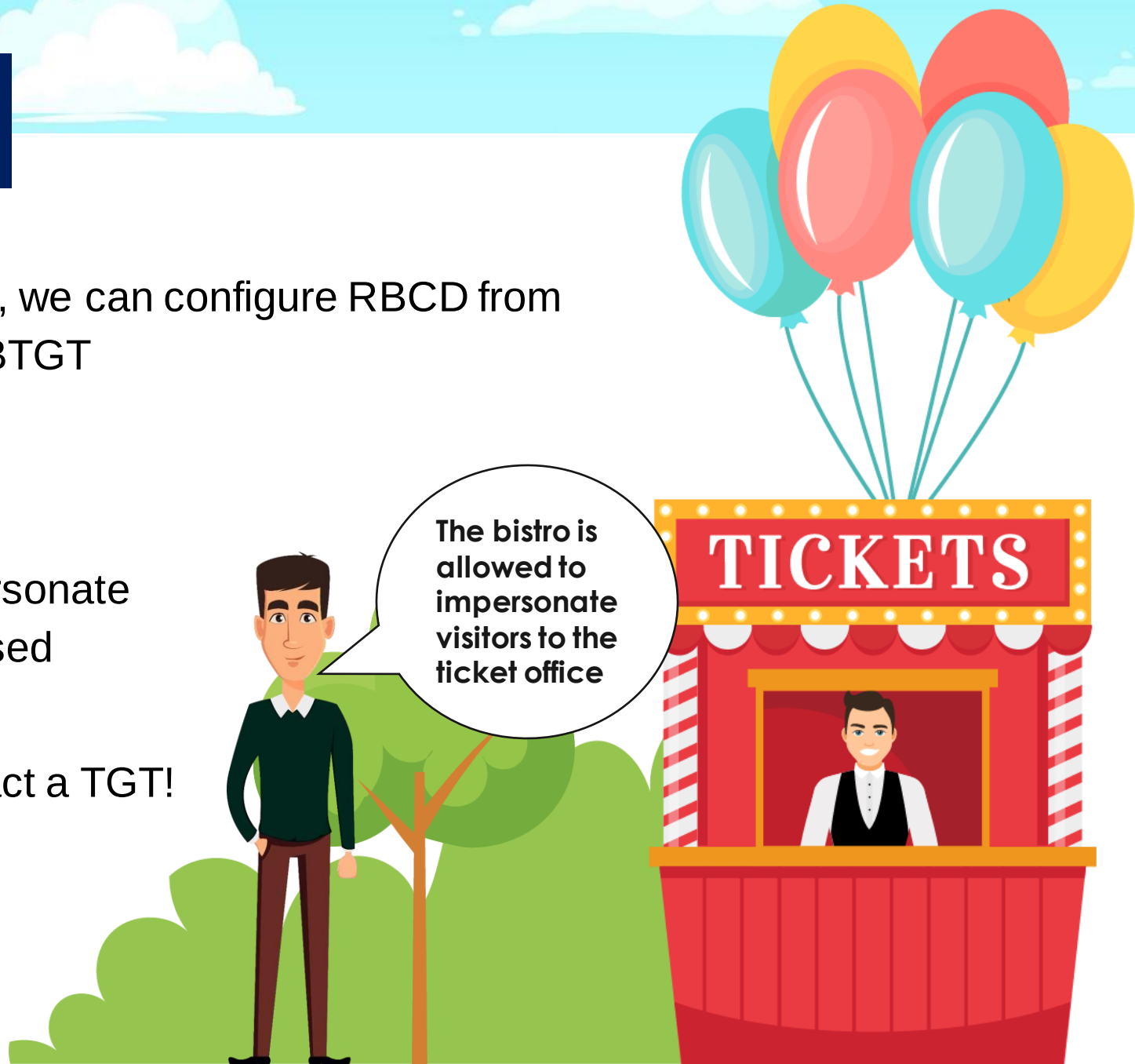
- Every resource has the right to configure RBCD for itself
- RBCD doesn’t require TrustedToAuthForDelegation to be set to perform protocol transition
  - S4U2Proxy for RBCD doesn’t require a forwardable service ticket
- S4U2Proxy always produces a forwardable service ticket
  - Even if provided with 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

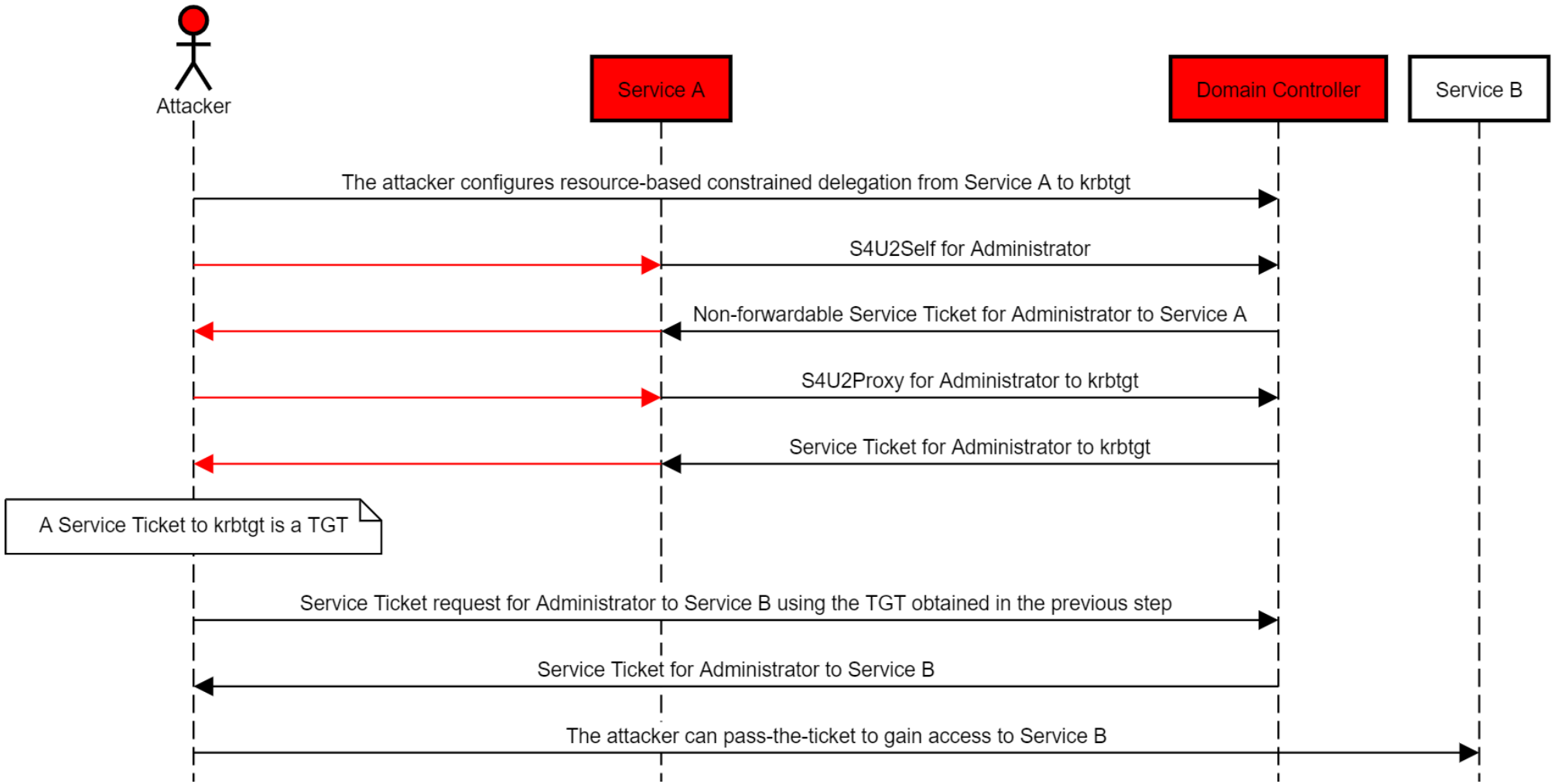


Unconstrained domain persistence

- Once we compromise the domain, we can configure RBCD from any compromised account to KRBTGT
  - The account must have a SPN
  - Can create a new account
- Perform a full S4U attack to impersonate users from the chosen 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

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- The waitress picks a random number – 4321

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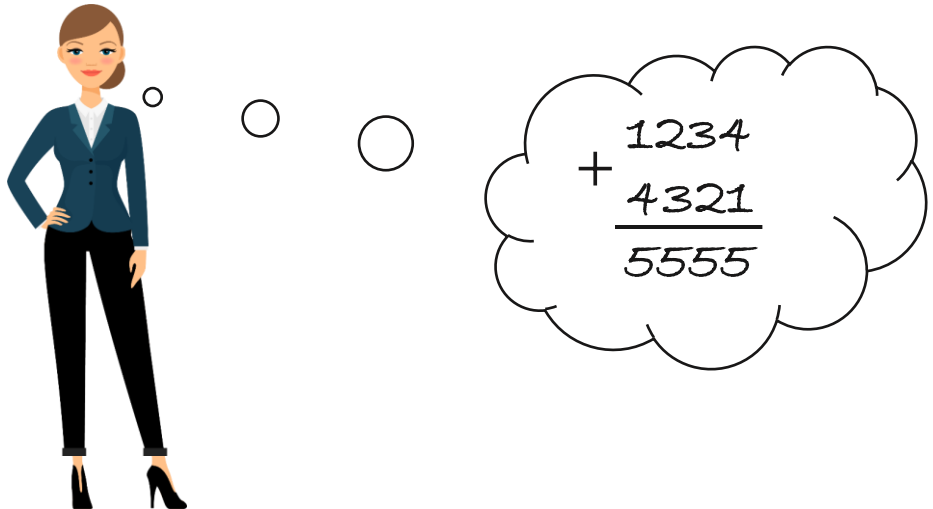
- Alice is presented with a challenge
- Alice calculates the response



The LUNA Protocol

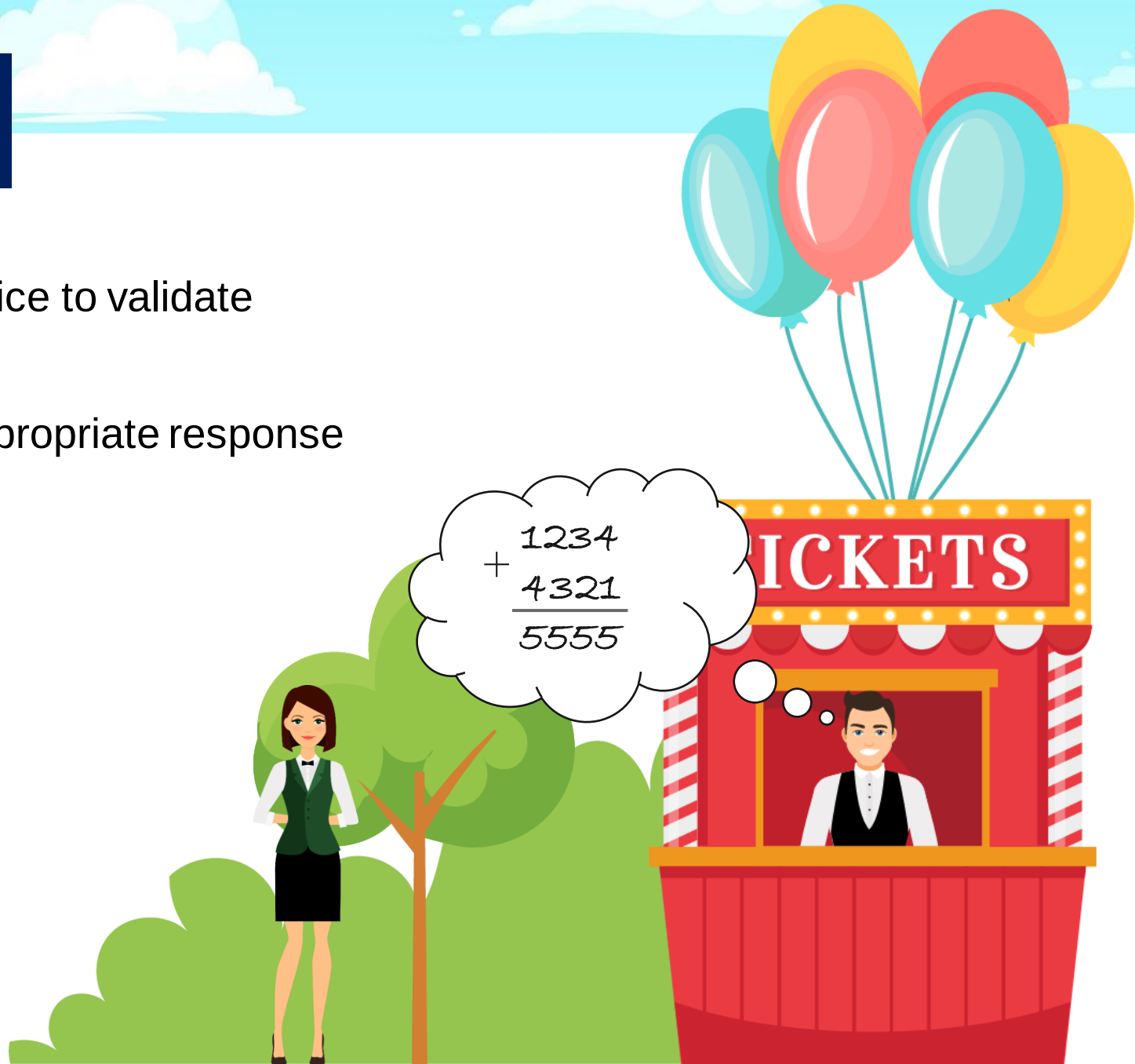
- Alice's secret code is 1234
- Alice asks to authenticate
- The waitress picks a random number – 4321
- Alice is presented with a challenge
- Alice calculates the response

The LUNA Protocol

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

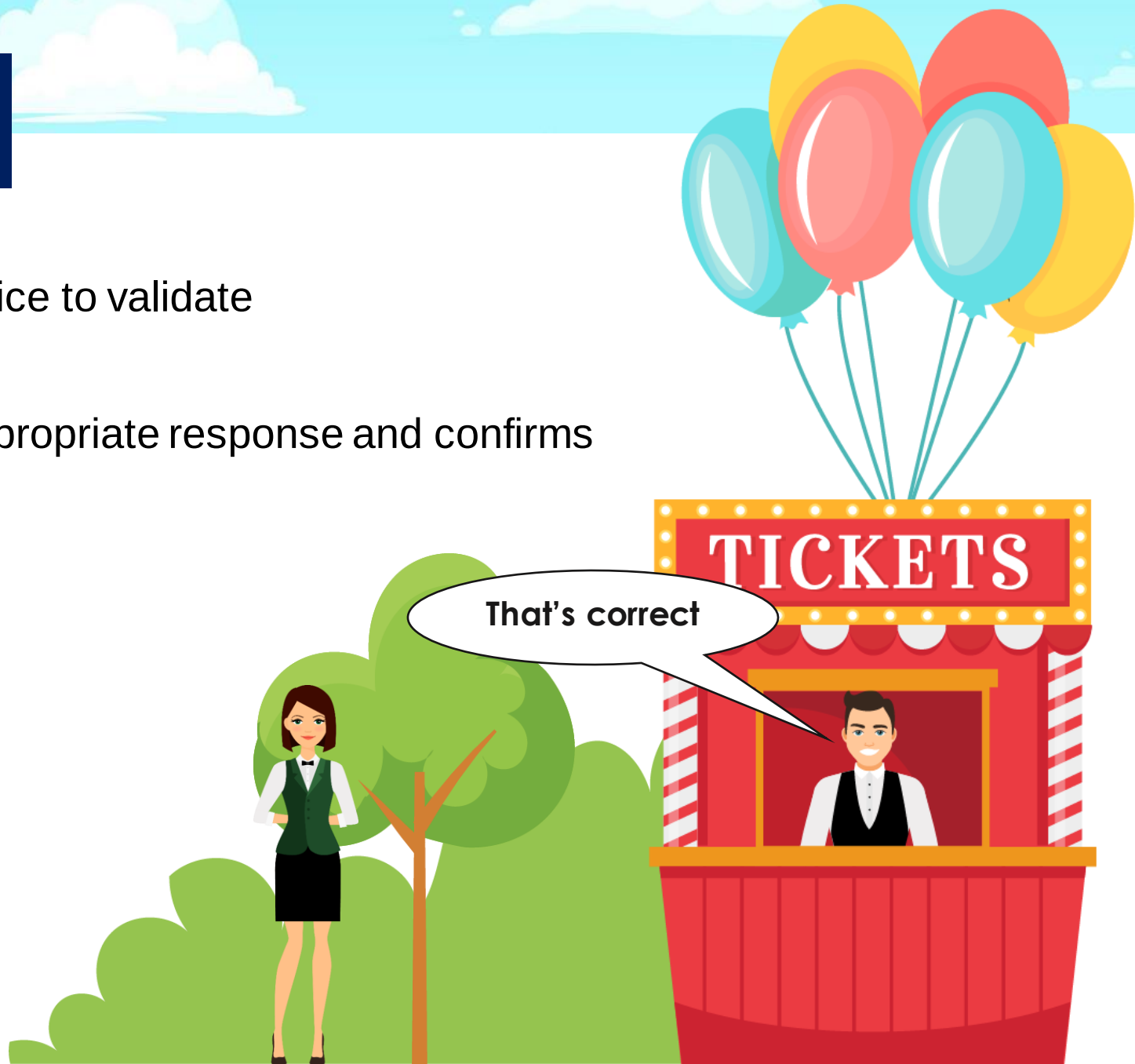
The LUNA Protocol

- 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

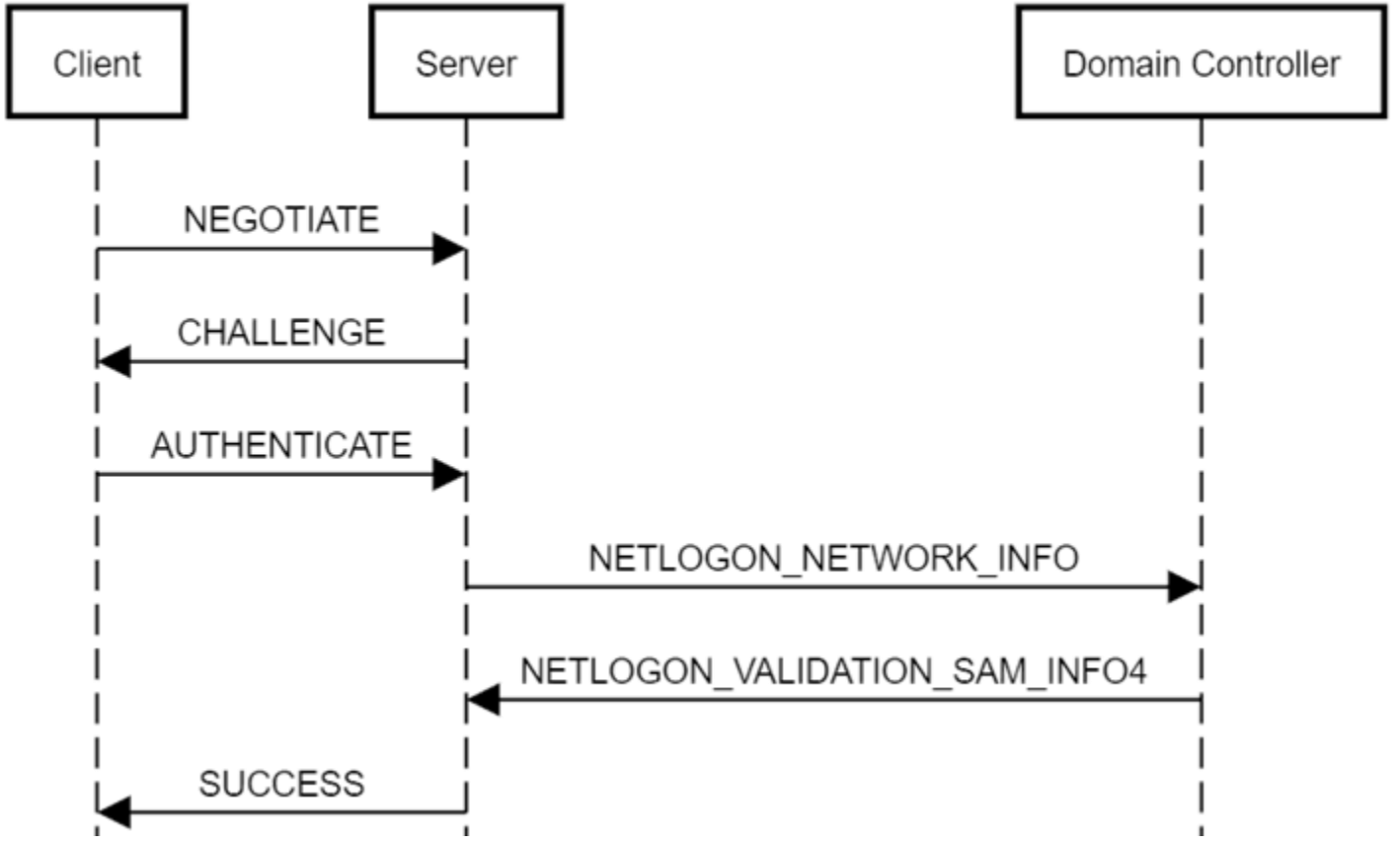
- The waitress confirms

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

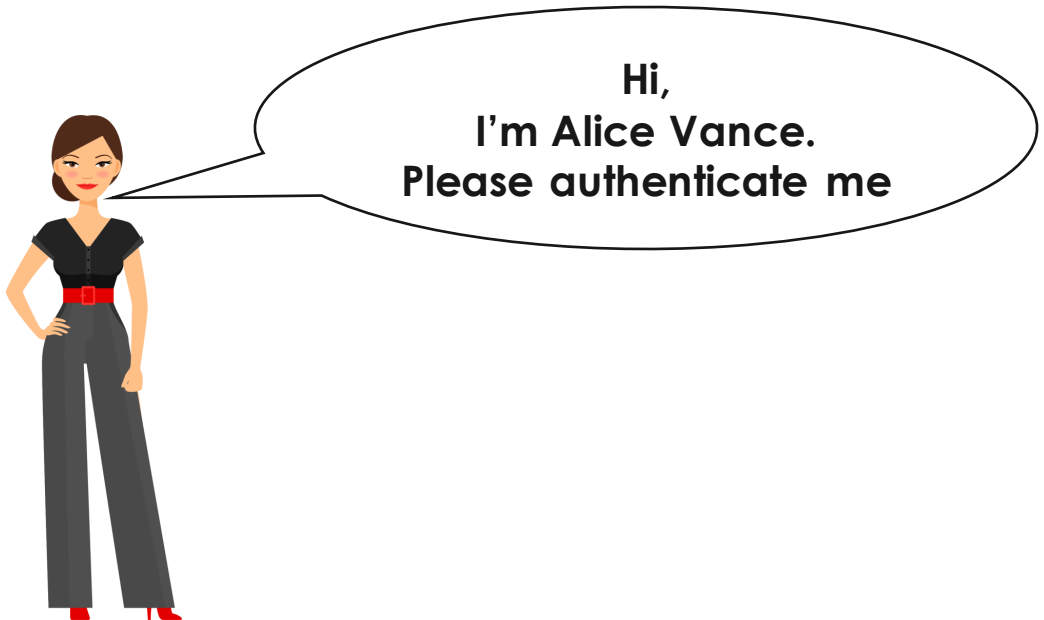
- Eve waits at the entrance for a visitor to arrive
- Alice arrives
- Eve pretends to work at the bistro

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

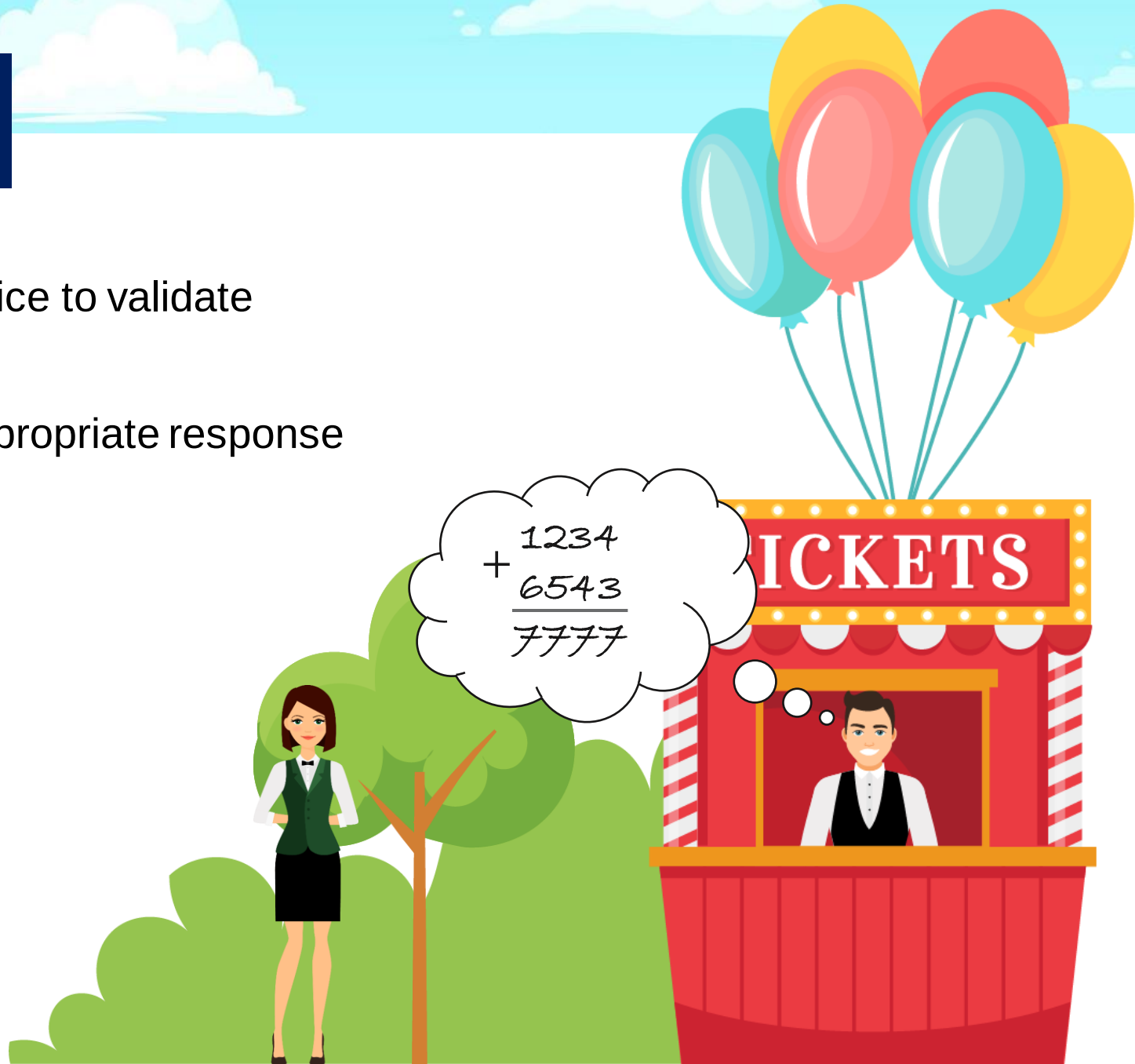
- Eve relays Alice’s response to the waitress inside

The “LUNA Relay” attack

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

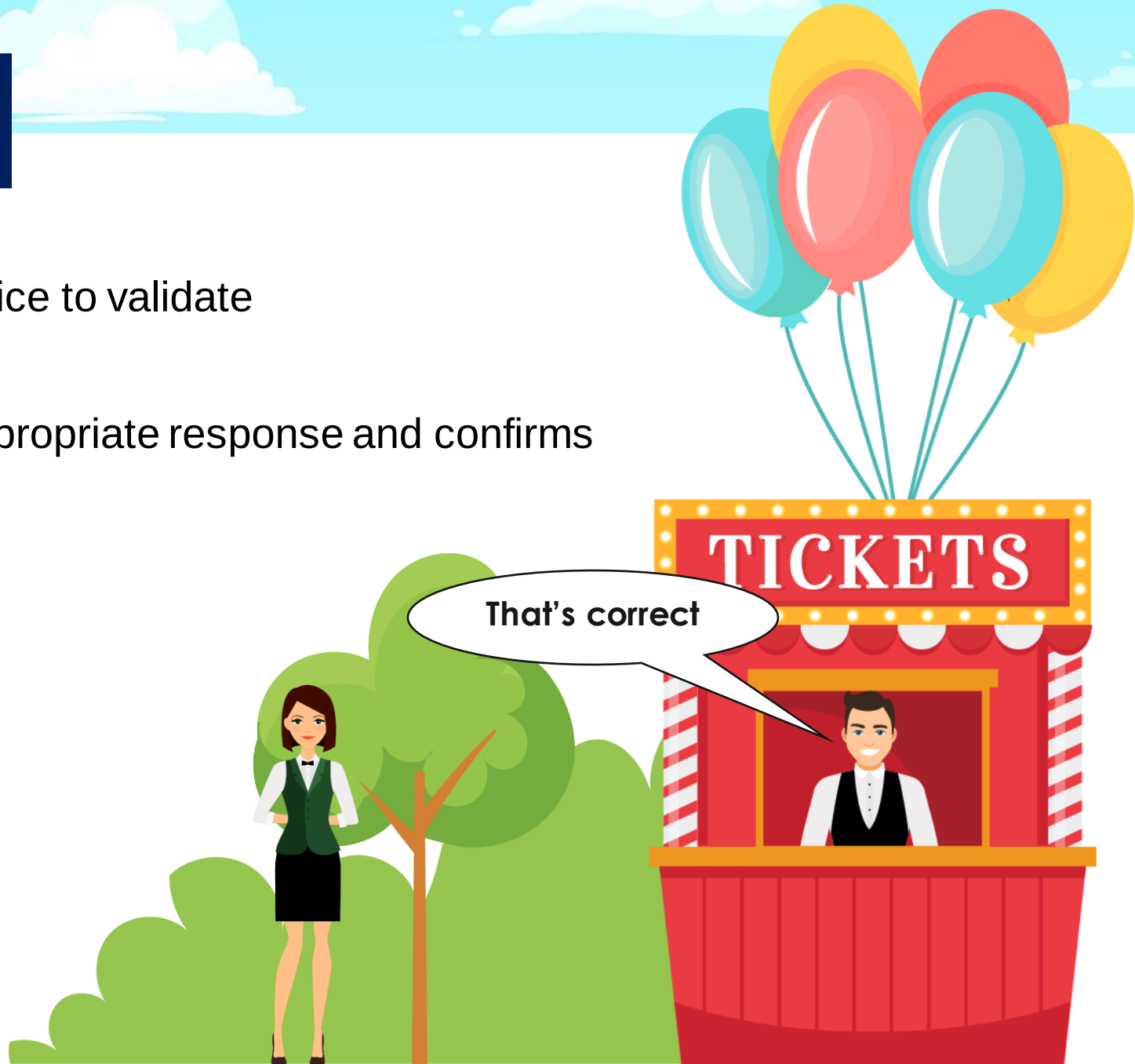
The “LUNA Relay” attack

- 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

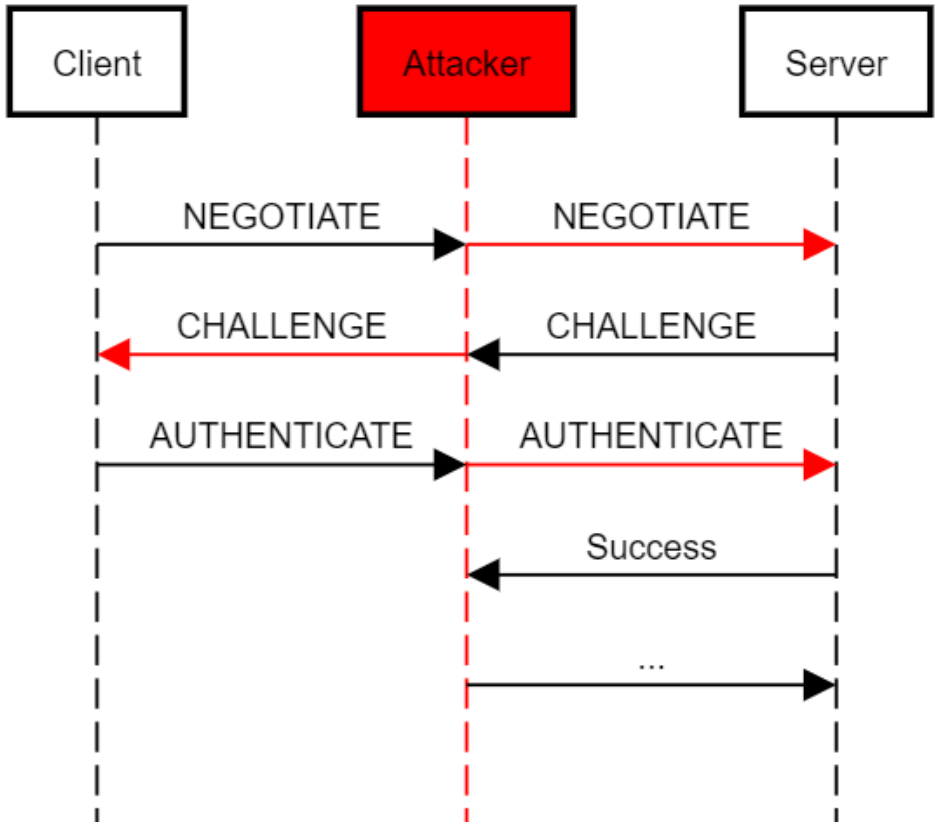
- The waitress confirms
- The waitress can now proceed with S4U2Self to determine whether Alice is entitled for lunch
- And with S4U2Proxy, if required

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

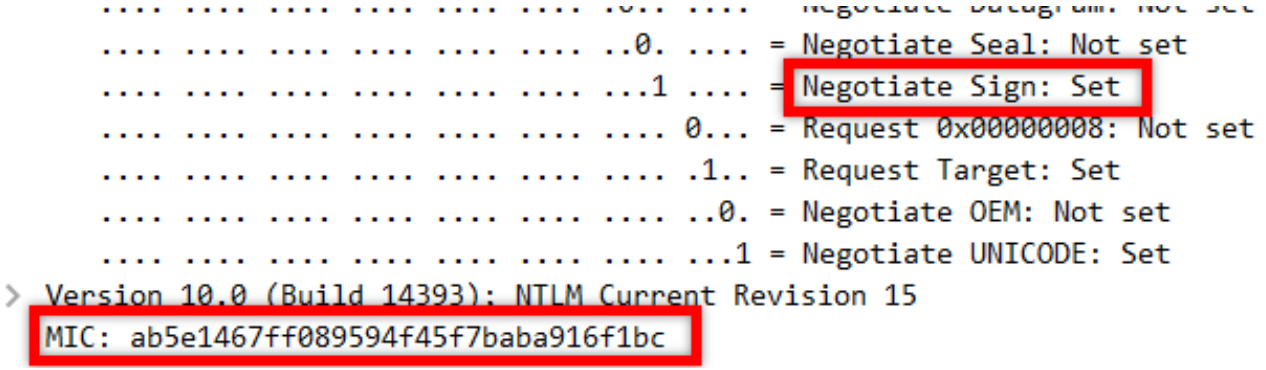
NTLM Relay 201

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

```
> Host name: DC1
> Session Key: 4df63818fff3dc782895bb89240d52e4
v Negotiate Flags: 0xe2888215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version, N
    1... .... .... .... .... .... .... .... = Negotiate 56: Set
    .1.. .... .... .... .... .... .... .... = Negotiate Key Exchange: Set
    ..1. .... .... .... .... .... .... .... = Negotiate 128: Set
    ...0 .... .... .... .... .... .... .... = Negotiate 0x10000000: Not set
    .... 0... .... .... .... .... .... .... = Negotiate 0x08000000: Not set
    .... .0.. .... .... .... .... .... .... = Negotiate 0x04000000: Not set
    .... ..1. .... .... .... .... .... .... = Negotiate Version: Set
    .... ...0 .... .... .... .... .... .... = Negotiate 0x01000000: Not set
    .... .... 1... .... .... .... .... .... = Negotiate Target Info: Set
    .... .... .0.. .... .... .... .... .... = Request Non-NT Session: Not set
    .... .... ..0. .... .... .... .... .... = Negotiate 0x00200000: Not set
    .... .... ...0 .... .... .... .... .... = Negotiate Identify: Not set
    .... .... .... 1... .... .... .... .... = Negotiate Extended Security: Set
    .... .... .... .0.. .... .... .... .... = Target Type Share: Not set
    .... .... .... ..0. .... .... .... .... = Target Type Server: Not set
    .... .... .... ...0 .... .... .... .... = Target Type Domain: Not set
    .... .... .... .... 1... .... .... .... = Negotiate Always Sign: Set
    .... .... .... .... .0.. .... .... .... = Negotiate 0x00004000: Not set
    .... .... .... .... ..0. .... .... .... = Negotiate OEM Workstation Supplied: Not set
    .... .... .... .... ...0 .... .... .... = Negotiate OEM Domain Supplied: Not set
    .... .... .... .... .... 0... .... .... = Negotiate Anonymous: Not set
    .... .... .... .... .... .0.. .... .... = Negotiate NT Only: Not set
    .... .... .... .... .... ..1. .... .... = Negotiate NTLM key: Set
    .... .... .... .... .... ...0 .... .... = Negotiate 0x00000100: Not set
    .... .... .... .... .... .... 0... .... = Negotiate Lan Manager Key: Not set
    .... .... .... .... .... .... .0.. .... = Negotiate Datagram: Not set
    .... .... .... .... .... .... ..0. .... = Negotiate Seal: Not set
    .... .... .... .... .... .... ...1 .... = Negotiate Sign: Set
    .... .... .... .... .... .... .... 0... = Request 0x00000008: Not set
    .... .... .... .... .... .... .... .1.. = Request Target: Set
    .... .... .... .... .... .... .... ..0. = Negotiate OEM: Not set
    .... .... .... .... .... .... .... ...1 = Negotiate UNICODE: Set
```

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

```
NTLM Secure Service Provider
   NTLMSSP identifier: NTLMSSP
   NTLM Message Type: NTLMSSP_AUTH (0x00000003)
 > Lan Manager Response: 0000000000000000000000000000000000000000000000000
   LMv2 Client Challenge: 0000000000000000
 v NTLM Response: fab944b1e97292271dc573962264cb990101000000000000...
      Length: 358
      Maxlen: 358
      Offset: 166
   v NTLMv2 Response: fab944b1e97292271dc573962264cb990101000000000000...
         NTProofStr: fab944b1e97292271dc573962264cb99
         Response Version: 1
         Hi Response Version: 1
         Z: 000000000000
         Time: Jan  5, 2019 23:35:10.204626900 UTC
         NTLMv2 Client Challenge: fb183405a8eb6fc7
         Z: 00000000
       > Attribute: NetBIOS domain name: SHENANIGANS
       > Attribute: NetBIOS computer name: SERVICEA
       > Attribute: DNS domain name: shenanigans.labs
       > Attribute: DNS computer name: ServiceA.shenanigans.labs
       > Attribute: DNS tree name: shenanigans.labs
       > Attribute: Timestamp
       v Attribute: Flags
            NTLMV2 Response Item Type: Flags (0x0006)
            NTLMV2 Response Item Length: 4
            Flags: 0x00000002
       > Attribute: Restrictions
       > Attribute: Channel Bindings
       > Attribute: Target Name: cifs/172.31.15.17
       > Attribute: End of list
         Z: 00000000
         padding: 00000000
```

Drop the MIC et al.

- Discovered by Marina Simakov (@simakov_marina) and Yaron Zinar (@YaronZi)
- 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 a 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

- Reflective relay used to be a RCE vector
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- 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
- 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
  - Target hosts that don't support MIC – XP/2003 and prior
  - **A client that doesn't negotiate signing – WebClient, including WebDAV**

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 you control such a URI?
  - Compromise one
  - Make your own

ADIDNS

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

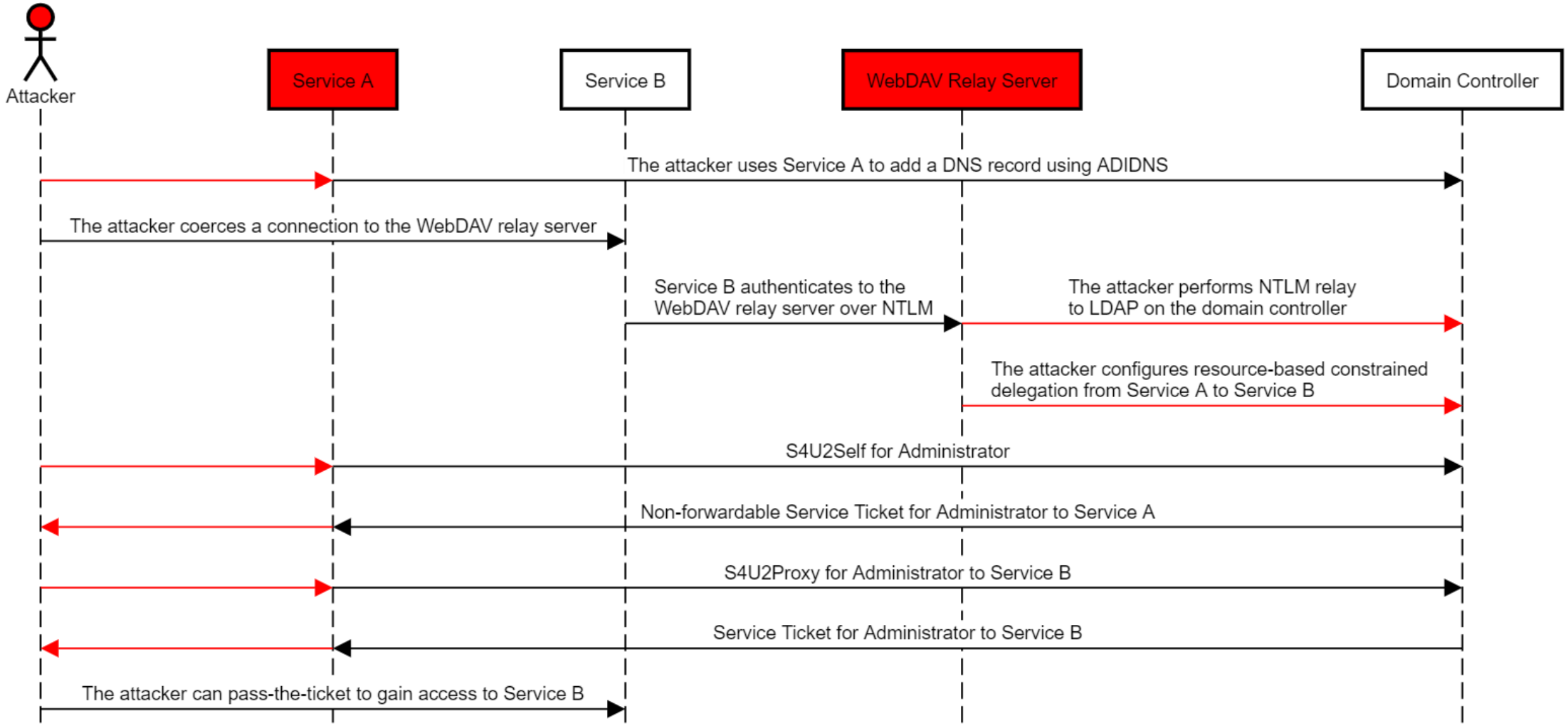
Remote Code Execution

- 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

Remote Code Execution

- Compromise an account with an SPN or create one
- Add an ADIDNS record, if required
- Use The Printer Bug or PetitPotam (or other primitives, such as xp_dirtree) to coerce 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

Remote Code Execution

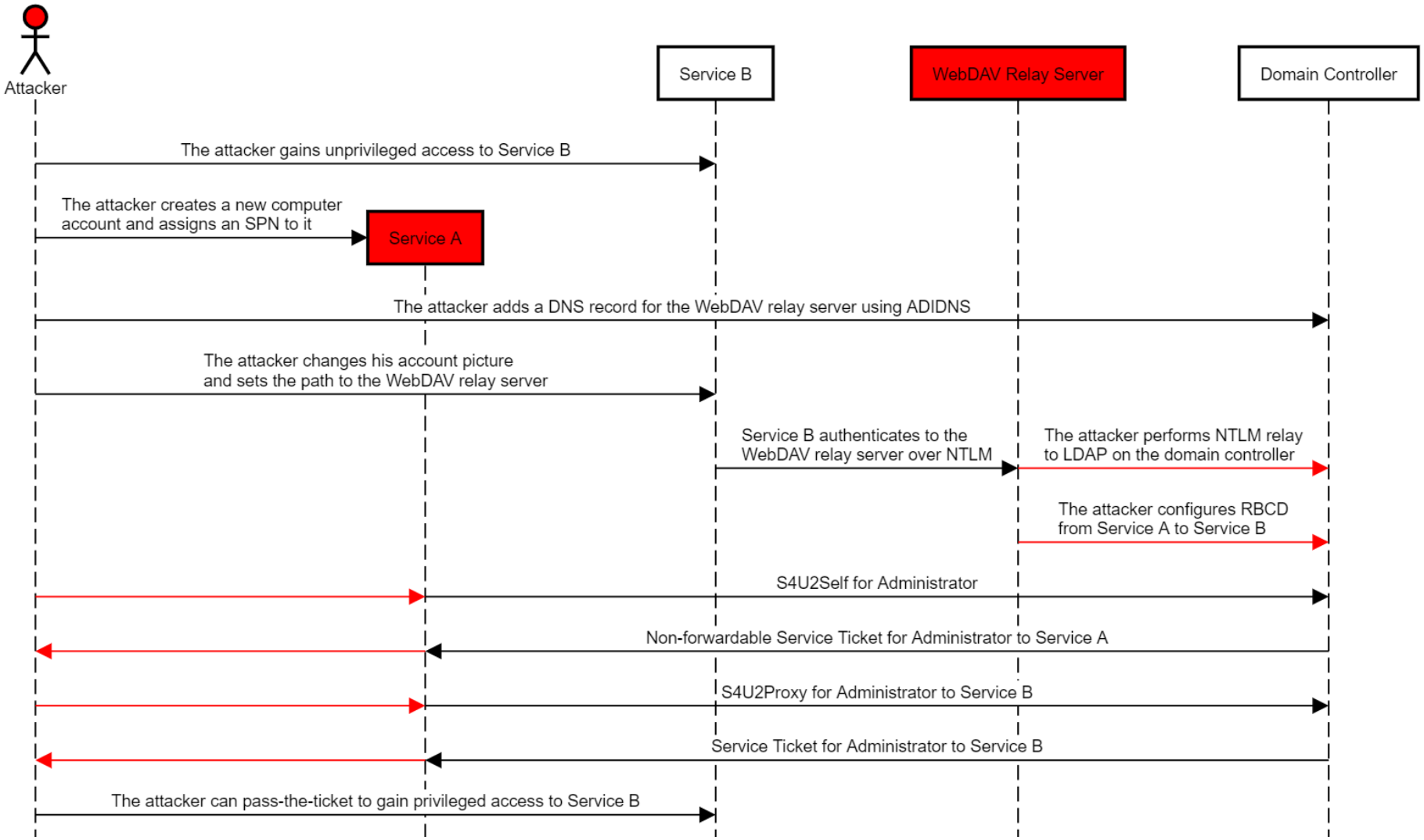


Windows 10/2016/2019 LPE

- When users change their account profile picture or the lock screen picture, ultimately SYSTEM opens the file to read its attributes
- 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



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

Server-Side Request Forgery

- Often, we find internal applications that are vulnerable to SSRF
- If they run as SYSTEM, Network Service, or a virtual account, we can relay them to LDAP and perform the same attack chain
    - Very common and very useful!
- If they run as a dedicated service account and the application supports Kerberos authentication, you can impersonate users to the service
    - Less common, but may allow compromising the host through the application

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 Bill abolished unconstrained delegation altogether
- 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
- Enforce 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

Resources

- S4U2Pwnage
- Wagging the Dog
- A Case Study in Wagging the Dog: Computer Takeover
- Another Word on Delegation
- Trust? Years to earn, seconds to break
- Active Directory Security Risk #101: Kerberos Unconstrained Delegation

Thank You!

Elad Shamir

(@elad_shamir)