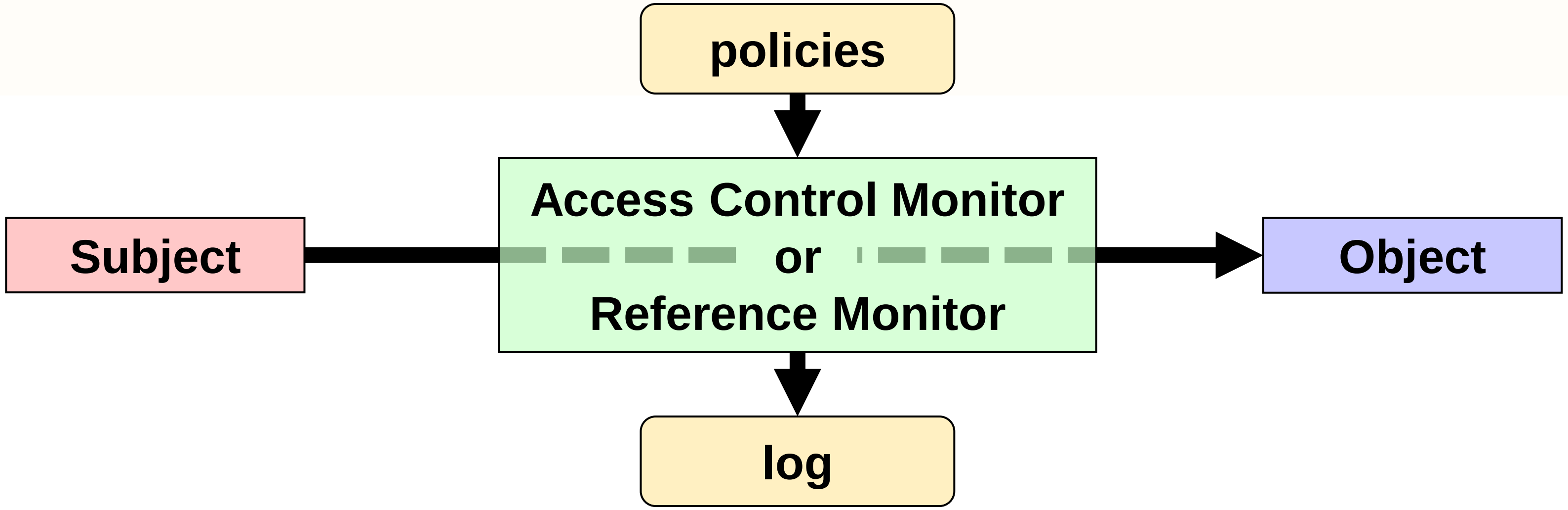
Access control models

Access types

- Physical access
  - Physical contact between a subject and the object of interest
    - Facility, room, network, computer, storage device, authentication token, etc.
  - **Out of scope of this course …**

- Informatic or electronic access
  - Information-oriented contact between a subject and the object of interest
    - Contact through request-response dialogs
  - Contact is mediated by
    - Computers and networks
    - Operating systems, applications, middleware, devices, etc.

Access control



- Definition
  - The policies and mechanisms that mediate the access of a subject to an object
- Normal requirements
  - Authentication
    - With some Level of Assurance (LoA)
  - Authorization
  - Accountability ➔logging

} AAA

Access control

- Subjects and objects
  - Both digital entities
  - Subjects can be something exhibiting activity :
    - Processes
    - Computers
    - Networks
  - Objects can be the target of an action :
    - Stored data
    - CPU time
    - Memory
    - Processes
    - Computers
    - Network
- An entity can be both subject and object

Least privilege principle

> Every program and every user of the system should operate using the least set of privileges necessary to complete the job
>
> J. H. Saltzer, M. D. Schroeder,
> The protection of information in computer systems, Proc. of the IEEE, 63(9) 1975

- Privilege:
  - Authorization to perform a given task
  - Similar to access control clearance
- Each subject should have, at any given time, the exact privileges required to the assigned tasks
  - Less privileges than the required create unsurpassable barriers
  - More privileges than the required create vulnerabilities
    - Damage resulting from accidents or errors
    - Potential interactions among privileged programs
    - Misuse of a privileges
    - Unwanted information flows
      - "need-to-know" military restrictions

Access control models

	O1	O2	…	Om-1	Om
S1		Access rights			
S2					
…					
Sn-1					
Sn					

- Access control matrix
  - Matrix with all access rights for subjects relatively to objects
  - Represents a conceptual model of the organization

Access control models

	O1	O2	…	Om-1	Om
S1		Access rights			
S2					
…					
Sn-1					
Sn					

▷ ACL-based mechanisms

- ACL: Access Control List (matrix column)
  - List of access rights for specific subjects
  - Access rights can be positive or negative
  - Default subjects may often be used
- Usually ACLs are stored along with objects
  - e.g. for file system objects.
- Rights are then mapped to specific actions
  - Same right may map to different actions on different contexts

Access control models

	O1	O2	…	Om-1	Om
S1		Access rights			
S2					
…					
Sn-1					
Sn					

▷ Capability-based mechanisms

- Capability: unforgeable authorization token (matrix row)
  - Contains object references and access rights
- Access granting
  - Transmission of capabilities between subjects
- Usually capabilities are kept by subjects
  - e.g. OAuth 2.0 access tokens

Access control kinds:
MAC and DAC

- Mandatory access control (MAC)
  - Access control policy statically implemented by the access control monitor
  - Access control rights cannot be tailored by subjects or object owners

- Discretionary access control (DAC)
  - Some subjects can update rights granted or denied to other subjects for a given object
    - Usually this is granted to object owners and system administrators

Access control kinds: Role-Based Access Control (RBAC)

D.F. Ferraiolo and D.R. Kuhn, "Role Based Access Control“, 15th National Computer Security Conference, Baltimore, October 1992

- Not DAC or MAC
  - Roles are dynamically assigned to subjects
    - For access control it matters the role played by the subject and not the subject’s identity
- Access control binds roles to (meaningful) operations
  - Operations are complex, meaningful system transactions
    - Not the ordinary, low-level read/write/execute actions on individual objects
  - Operations can involve many individual lower-level objects

Access control kinds:
RBAC rules (1/2)

- Role assignment:
  - All subject activity on the system is conducted through transactions
    - And transactions are allowed to specific roles
    - Thus all active subjects are required to have some active role
  - A subject can execute a transaction **iff**
    - it has selected
  - or
    - been assigned
    - a role which can use the transaction

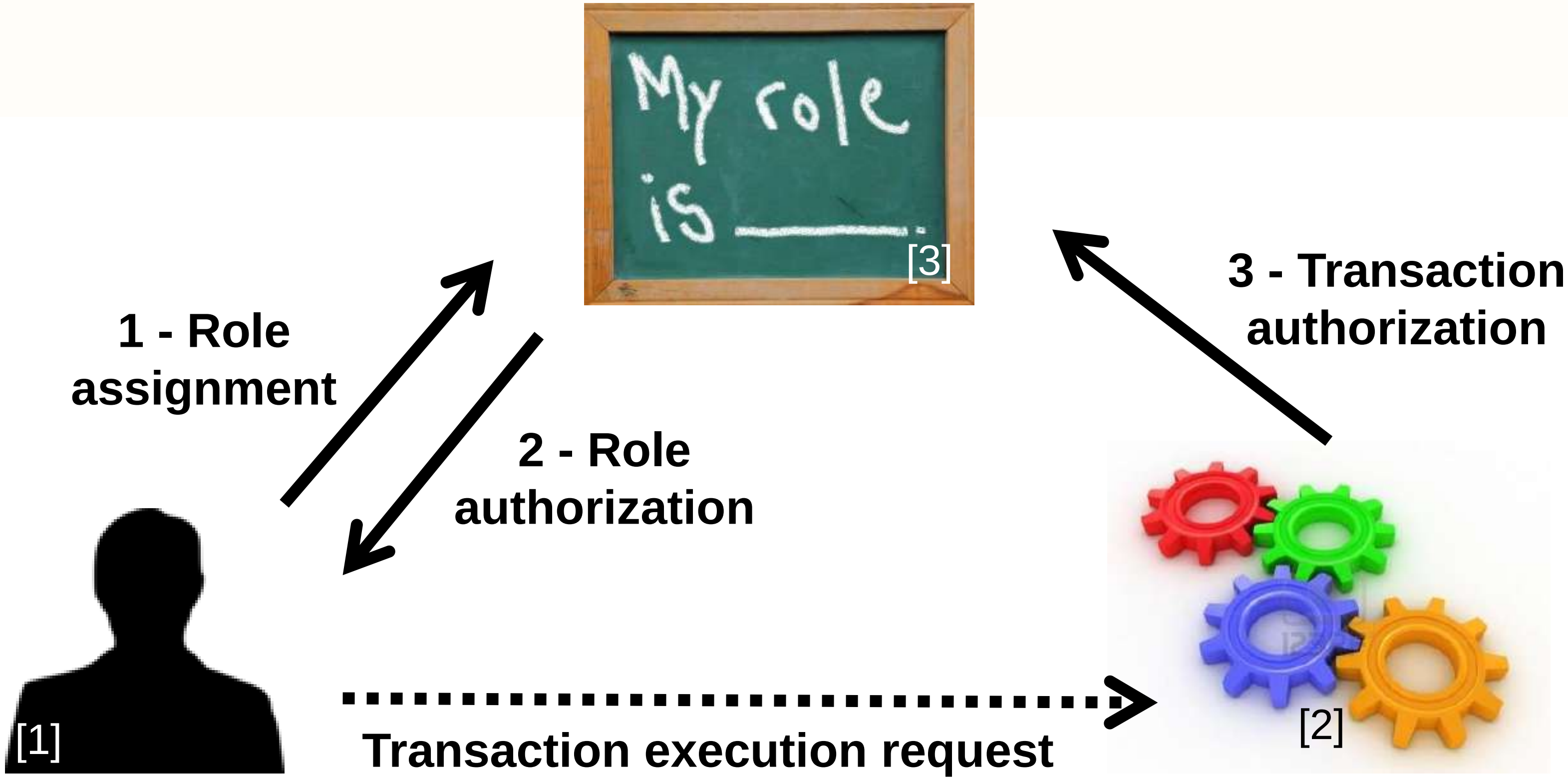
Access control kinds: RBAC rules (2/2)

- Role authorization:
  - A subject's active role must be authorized for the subject

- Transaction authorization:
  - A subject can execute a transaction **iff**
    - the transaction is authorized through the subject's role memberships

    and
    - there are no other constraints that may be applied across subjects, roles, and permissions

RBAC rules



1 - Role assignment

2 - Role authorization

3 - Transaction authorization

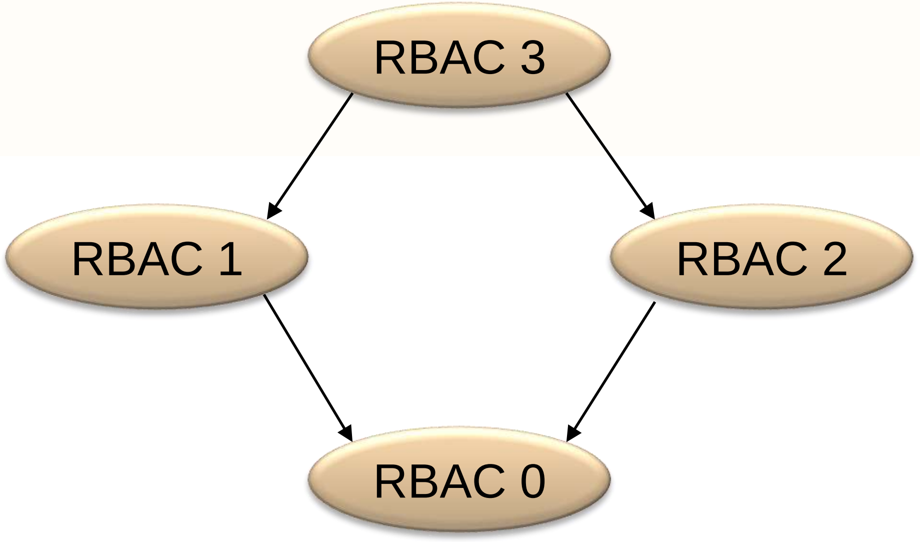
Transaction execution request (on behalf of a given role)

[1] From http://www.clker.com/clipart-24011.html
[2] From http://www.123rf.com/photo_12115593_three-dimensional-colored-toothed-wheels.html
[3] From http://www1.yorksolutions.net/Portals/115255/images/MyRoleIs.jpg

RBAC:
Roles vs. groups

- Roles are a collection of permissions
  - The permissions are granted to the subjects that, at a given instant, play the role
  - A subject can only play a role at a given time
- Groups are a collection of users
  - And permissions can be granted both to users and groups
  - A subject can belong to many groups at a given time
- The session concept
  - Role assignment is similar to a session activation
  - Group membership is ordinarily a static attribute

RBAC variants



- RBAC 0
  - No role hierarchies
  - No role constraints
- RBAC 1
  - RBAC 0 w/ role hierarchies (privilege inheritance)
- RBAC 2
  - RBAC 0 w/ role constraints (separation of duties)
- RBAC 3
  - RBAC 1 + RBAC 2

NIST RBAC model

- Flat RBAC
  - Simple RBAC model w/ user-role review
  - Role provides specific permissions for the user
- Hierarchical RBAC
  - Flat RBAC w/ role hierarchies (DAG or tree)
  - General and restricted hierarchies, where Roles gain additional permissions from other roles
- Constraint RBAC
  - RBAC w/ role constraints for separation of duty
  - Static: Conflicting Roles cannot be assigned
  - Dynamic: Subject cannot activate conflicting Roles within session
- Symmetric RBAC
  - RBAC w/ organization wide permission-role review
  - Allows review of a subject roles to prevent bloat

Access control kinds: Context-Based Access Control (CBAC)

- Access rights have an historical context
  - The access rights cannot be determined without reasoning about past access operations
  - Example:
    - Stateful packet filter firewall
- Chinese Wall policy
  - Conflict groups
  - Access control policies need to address past accesses to objects in different members of conflict groups

D.F.C. Brewer and M.J. Nash, "The Chinese Wall Security Policy “, IEEE Symposium on Security and Privacy, 1989

Access control kinds: Attribute-Based Access Control (ABAC)

- Access control decisions are made based on attributes associated with relevant entities

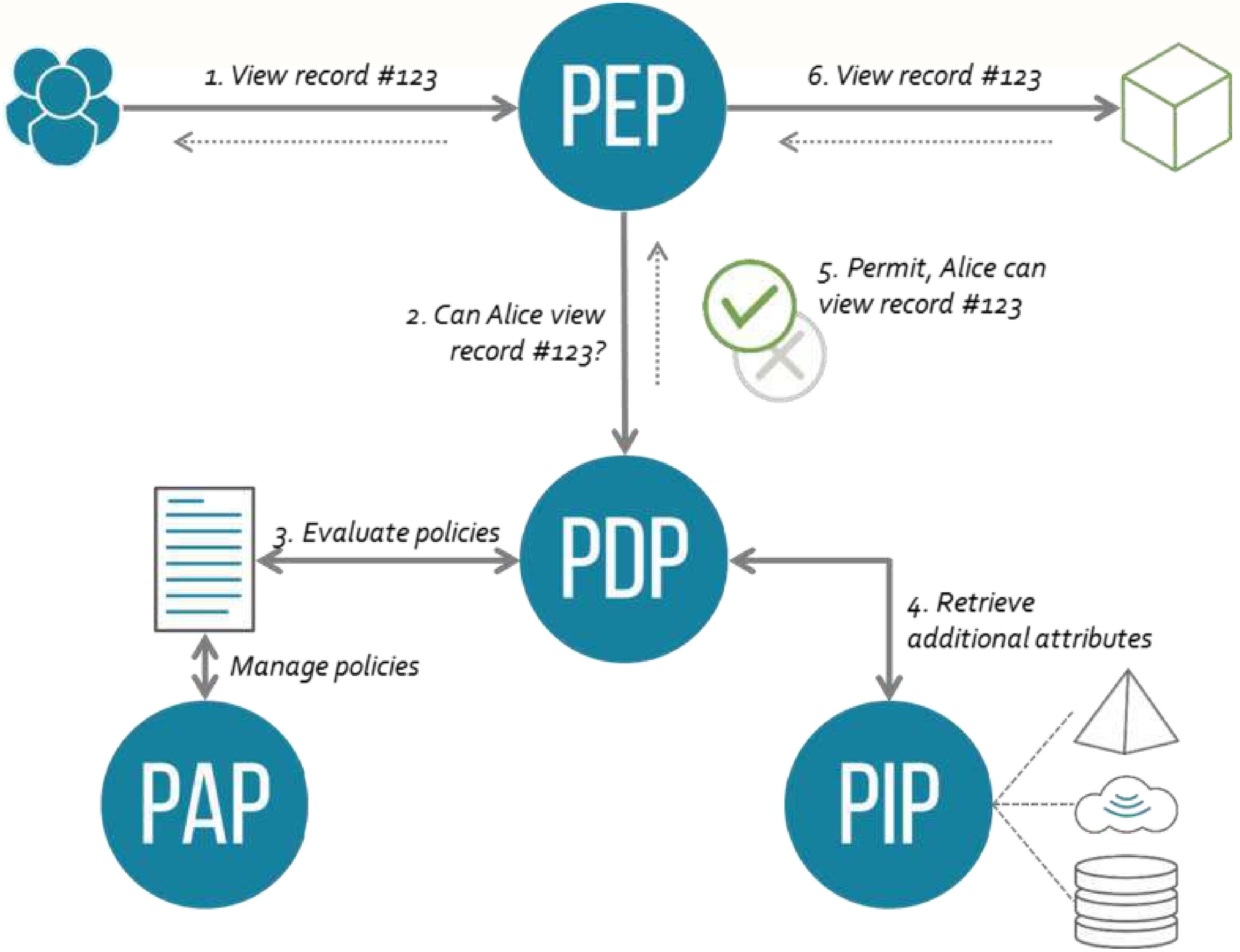
- OASIS XACML architecture
  - Policy Administration Point (PAP)
    - Where policies are managed
  - Policy Decision Point (PDP)
    - Where authorization decisions are evaluated and issued
  - Policy Enforcement Point (PEP)
    - Where access requests to a resource are intercepted and confronted with PDP’s decisions
  - Policy Information Point (PIP)
    - Provides external information to a PDP

XACML:
Access control with PEP and PDP

- A subject sends a request
  - Which is intercepted by the Policy Enforcement Point (PEP)
- The PEP sends the authorization request to the Policy Decision Point (PDP)
- The PDP evaluates the request against its policies and reaches a decision
  - Which is returned to the PEP

  - Policies are retrieved from a Policy Retrieval Point (PRP)
  - Useful attributes are fetched from Policy Information Points (PIP)
  - Policies are managed by the Policy Administration Point (PAP)

XACML big picture


1. View record #123
PEP
6. View record #123
2. Can Alice view record #123?
5. Permit, Alice can view record #123
3. Evaluate policies
PDP
4. Retrieve additional attributes
Manage policies
PAP
PIP

From https://en.wikipedia.org/wiki/XACML

Break-the-glass access control model

- It may be required to overcome the established access limitations
  - e.g. in a life threatening situation

- The subject may be presented with a break-the-glass decision upon a deny
  - Can overcome the deny at their own responsibility
  - Logging is fundamental to prevent abuses
    - Subject may have to justify action, after using the elevated right

Separation of duties

R.A. Botha, J.H.P. Eloff, “Separation of duties for access control enforcement in workflow environments”, IBM Systems Journal, 2001

- ▷ Fundamental security requirement for fraud and error prevention
  - Dissemination of tasks and associated privileges for a specific business process among multiple subjects
  - Often implemented with RBAC
- ▷ Damage control
  - Segregation of duties helps reducing the potential damage from the actions of one person
  - Some duties should not be combined into one position

Segregation of duties:

ISACA (Inf. Systems Audit and Control Ass.) matrix guideline

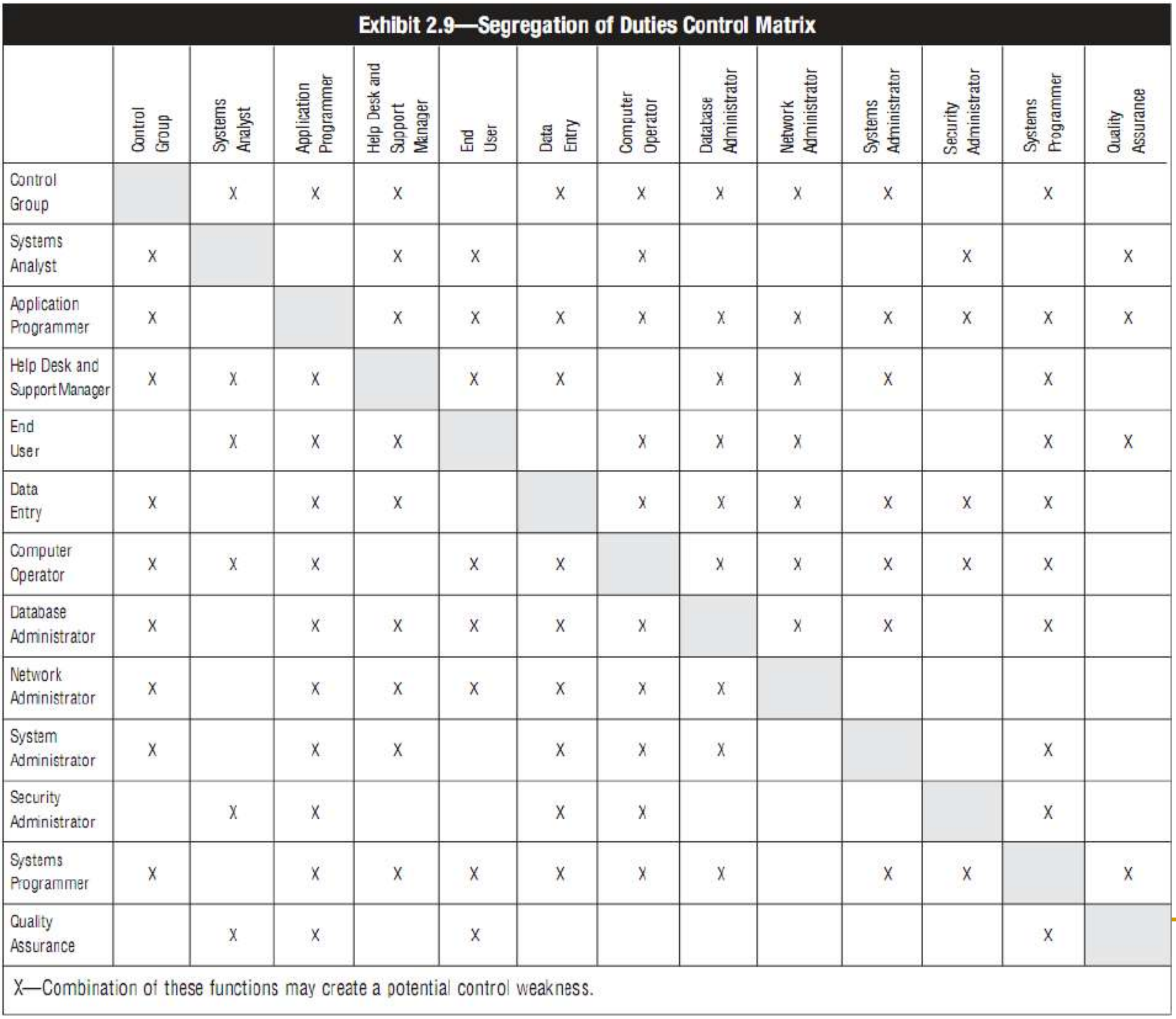


Exhibit 2.9—Segregation of Duties Control Matrix

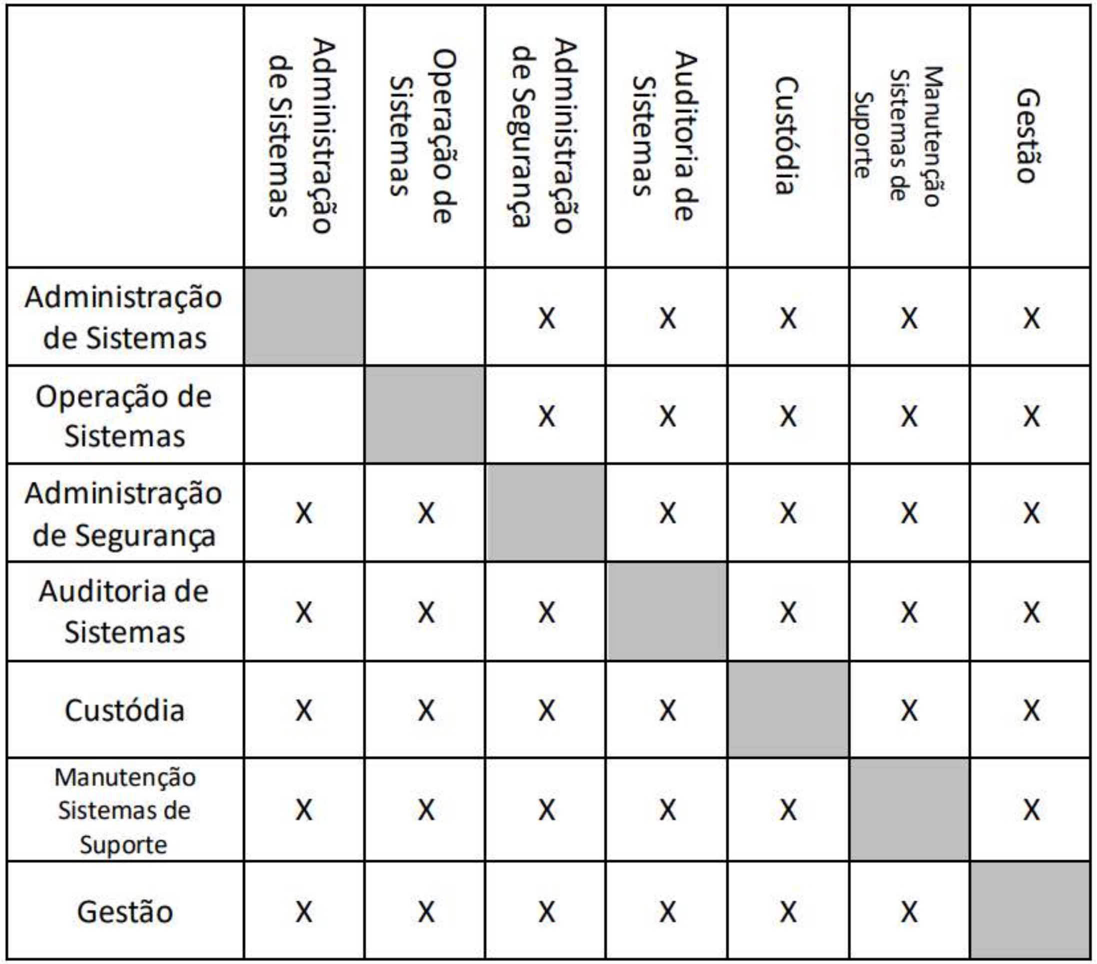
	Control Group	Systems Analyst	Application Programmer	Help Desk and Support Manager	End User	Data Entry	Computer Operator	Database Administrator	Network Administrator	Systems Administrator	Security Administrator	Systems Programmer	Quality Assurance
Control Group		X	X	X		X	X	X	X	X		X	
Systems Analyst	X			X	X		X				X		X
Application Programmer	X			X	X	X	X	X	X	X	X	X	X
Help Desk and Support Manager	X	X	X		X	X		X	X	X		X	
End User		X	X	X			X	X	X			X	X
Data Entry	X		X	X			X	X	X	X	X	X	
Computer Operator	X	X	X		X	X		X	X	X	X	X	
Database Administrator	X		X	X	X	X	X		X	X		X	
Network Administrator	X		X	X	X	X	X	X					
System Administrator	X		X	X		X	X	X				X	
Security Administrator		X	X			X	X					X	
Systems Programmer	X		X	X	X	X	X	X		X	X		X
Quality Assurance		X	X		X							X	

X—Combination of these functions may create a potential control weakness.

X marks an incompatibility

Segregation of duties:

Declaração de Práticas de Certificação da EC do Cartão de Cidadão



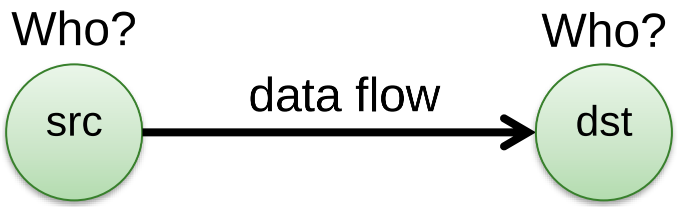
	Administração de Sistemas	Operação de Sistemas	Administração de Segurança	Auditoria de Sistemas	Custódia	Manutenção Sistemas de Suporte	Gestão
Administração de Sistemas	▨		X	X	X	X	X
Operação de Sistemas		▨	X	X	X	X	X
Administração de Segurança	X	X	▨	X	X	X	X
Auditoria de Sistemas	X	X	X	▨	X	X	X
Custódia	X	X	X	X	▨	X	X
Manutenção Sistemas de Suporte	X	X	X	X	X	▨	X
Gestão	X	X	X	X	X	X	▨

X marks an incompatibility

https://pki.cartaodecidadao.pt/publico/politicas/POL27.CPS_CC.pdf

Information flow models

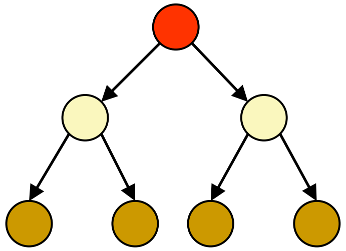
- Authorization is applied to data flows
  - Considering the data flow source and destination
  - Goal: avoid unwanted/dangerous information flows



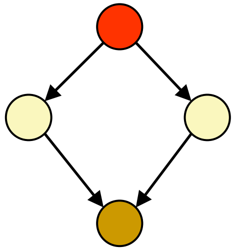
- Src and Dst security-level attributes
  - Information flows should occur only between entities with given security-level (SL) attributes
  - Authorization is given based on the SL attributes

Multilevel security

- Subjects (or roles) act on different security levels
  - Levels do not intersect themselves
  - Levels have some partial order
    - Hierarchy
    - Lattice



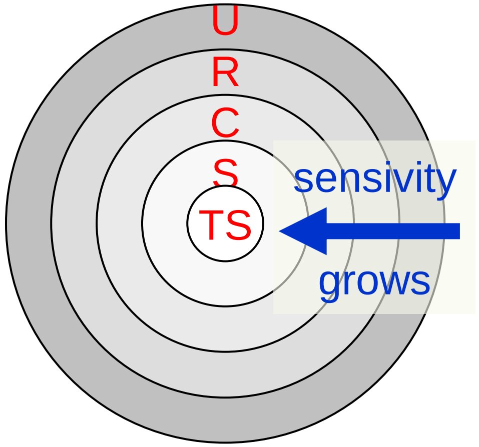
- Levels are used as attributes of subjects and objects
  - Subjects: security level clearance
  - Objects: security classification



- Information flows & security levels
  - Same security level → authorized
  - Different security levels → controlled
    - Authorized or denied on a "need to know" basis

Multilevel security levels:
Military / Intelligence organizations

- Typical levels
  - Top secret
  - Secret
  - Confidential
  - Restricted
  - Unclassified



- Portugal (NTE01, NTE04)
  - Muito Secreto
  - Secreto
  - Confidencial
  - Reservado

- EU example
  - EU TOP SECRET
  - EU SECRET
  - EU CONFIDENTIAL
  - EU RESTRICTED
  - EU COUNCIL / COMMISSION

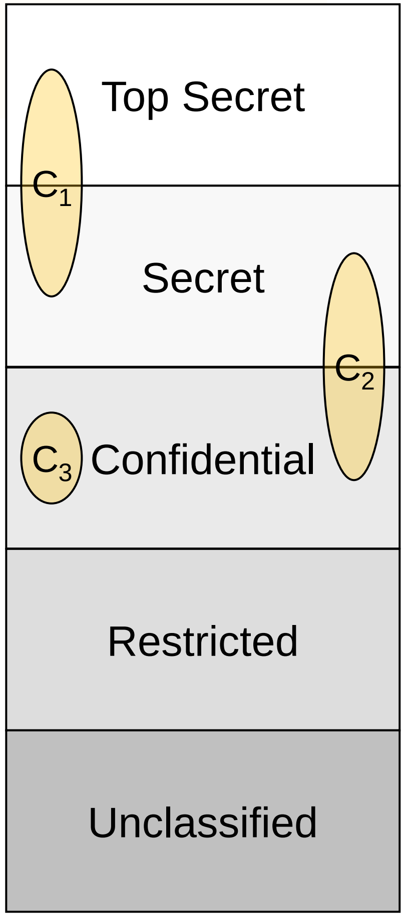
- NATO example:
  - COSMIC TOP SECRET (CTS)
  - NATO SECRET (NS)
  - NATO CONFIDENTIAL (NC)
  - NATO RESTRICTED (NR)

Multilevel security levels: Civil organizations

- Typical levels
  - Restricted
  - Proprietary
  - Sensitive
  - Public

Security categories (or compartments)

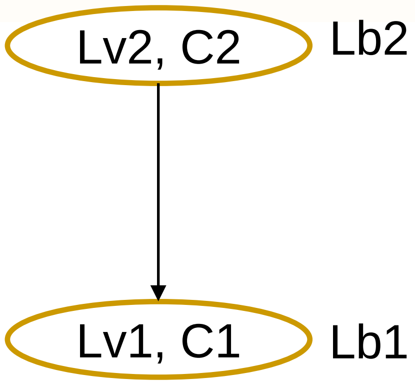
- Self-contained information environments
  - May span several security levels
- Military environments
  - Military branches, military units
- Civil environments
  - Departments, organizational units
- An object can belong to different compartments and have a different security classification in each of them
  - (top-secret, crypto), (secret, weapon)



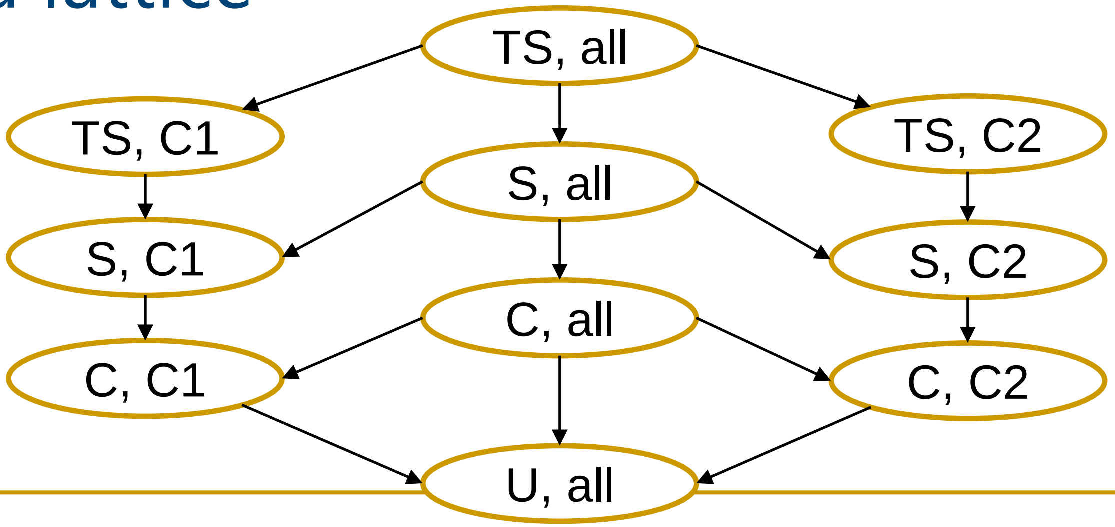
Security labels

- ▷ Label = Category + Level
- ▷ Relative order between labels

  Lb1 ≤ Lb2 ⇒ C1 ⊆ C2 ∧ Lv1 ≤ Lv2



- ▷ Labels form a lattice



Bell-La Padula MLS Model

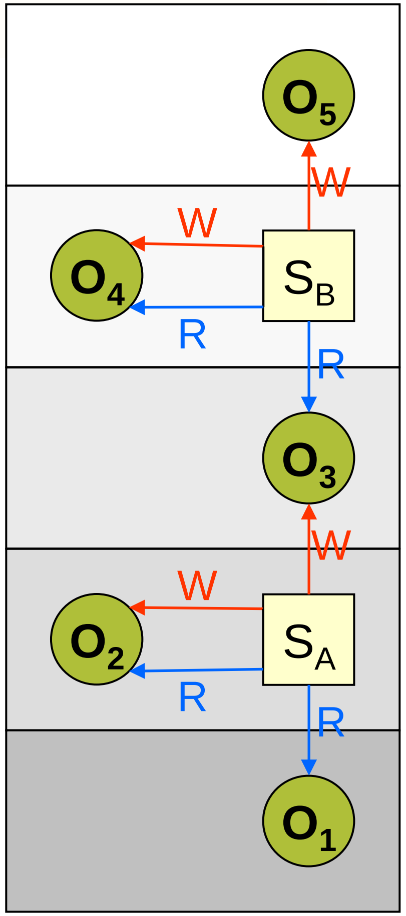
D. Elliott Bell, Leonard J. La Padula, "Secure Computer Systems: Mathematical Foundations”, MITRE Technical Report 2547, Volume I, 1973

- Access control policy for controlling information flows
  - Addresses data confidentiality and access to classified information
  - Addresses disclosure of classified information
    - Object access control is not enough
    - One needs to restrict the flow of information from a source to authorized destinations

- Uses a state-transition model
  - In each state there are subjects, objects, an access matrix and the current access information
  - State transition rules
  - Security levels and clearances
    - Objects have a security labels
    - Subjects have security clearances
    - Both refer to security levels (e.g. CONFIDENTIAL)

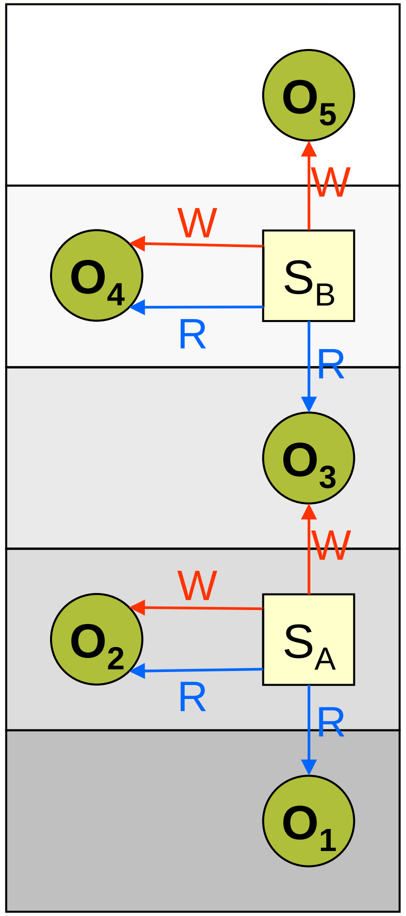
Bell-La Padula MLS Model: Secure state-transition model

- Simple security condition (no read up)
  - S can read O iff L(S) ≥ L(O)
- *-property (no write down)
  - S can write O iff L(S) ≤ L(O)
  - aka confinement property
- Discretionary Security Property
  - DAC-based access control



Bell-La Padula MLS Model: Secure state-transition model

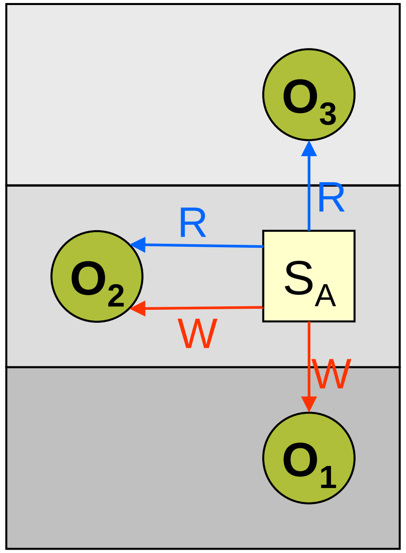
- Strong Star Property
  - S can read O iff L(S) = L(O)
- Tranquility Principle
  - Strong tranquility: S/O levels are static for the entire S/O lifetime
  - Weak tranquility: S/O levels may change if the security *spirit* of the system is not compromised
- Trusted Subjects
  - S can write to lower levels



Biba Integrity Model

K. J. Biba, "Integrity Considerations for Secure Computer Systems", MITRE Technical Report 3153, The Mitre Corporation, April 1977

- Access control policy for controlling information flows
  - For enforcing data integrity control
  - Uses integrity levels, not security levels



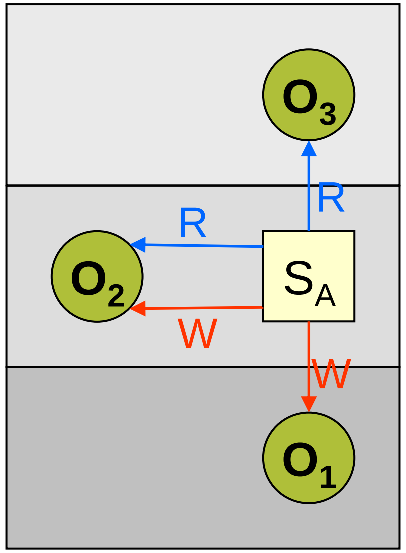
- Similar to Bell-La Padula, with inverse rules
  - Simple Integrity Property (no read down)
    - S can read O iff $I(S) \leq I(O)$
  - Integrity *-Property (no write up)
    - S can write O iff $I(S) \geq I(O)$

Biba Integrity Model

K. J. Biba, "Integrity Considerations for Secure Computer Systems", MITRE Technical Report 3153, The Mitre Corporation, April 1977

- Access control policy for controlling information flows
  - For enforcing data integrity control
  - Uses integrity levels, not security levels
  - Subjects cannot corrupt objects at higher levels

- Similar to Bell-La Padula, with inverse rules
  - Simple Integrity Property (no read down)
    - S can read O iff I(S) ≤ I(O)
  - Integrity *-Property (no write up)
    - S can write O iff I(S) ≥ I(O)



- Invocation Property
  - S cannot request higher access

Windows mandatory integrity control

- ▷ Allows mandatory (priority and critical) access control enforcement prior to evaluate DACLs
  - If access is denied, DACLs are not evaluated
  - If access is allowed, DACLs are evaluated

- ▷ Integrity labels
  - Untrusted
  - Low (or AppContainer)
  - Medium (default)
  - Medium Plus
  - High
  - System
  - Protected Process

DACL: discretionary access control list

https://learn.microsoft.com/en-us/windows/win32/secauthz/mandatory-integrity-control

Windows mandatory integrity control

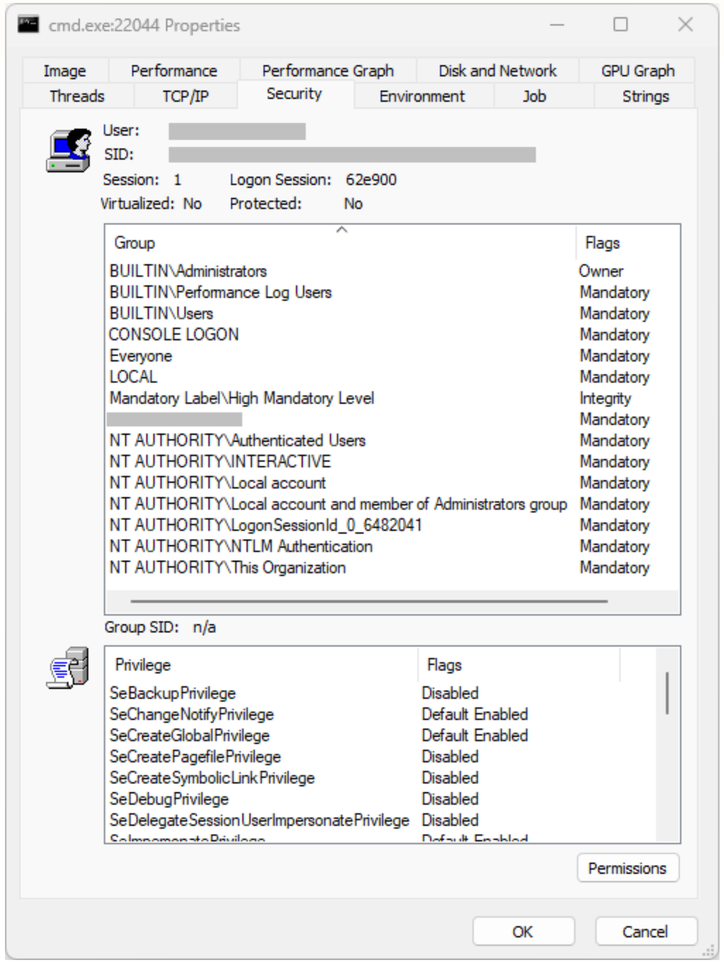
- Users
  - Medium: standard users
  - High: elevated users

- Process integrity level
  - The minimum associated to the owner and the executable file
  - User processes usually are Medium or High
    - Except if executing Low-labeled executables
  - Service processes: High

Windows mandatory integrity control

- Securable objects mandatory label
  - NO_WRITE_UP (default)
  - NO_READ_UP
  - NO_EXECUTE_UP

Windows mandatory integrity control

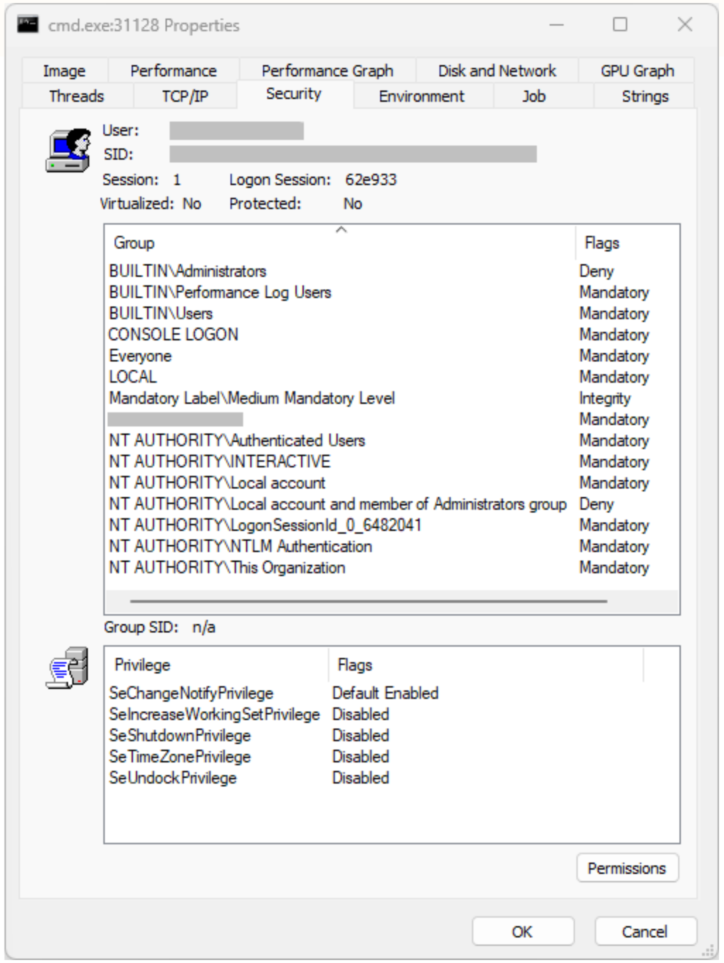


User: [redacted]
SID: [redacted]
Session: 1 Logon Session: 62e900
Virtualized: No Protected: No

Group	Flags
BUILTIN\Administrators	Owner
BUILTIN\Performance Log Users	Mandatory
BUILTIN\Users	Mandatory
CONSOLE LOGON	Mandatory
Everyone	Mandatory
LOCAL	Mandatory
Mandatory Label\High Mandatory Level	Integrity
[redacted]	Mandatory
NT AUTHORITY\Authenticated Users	Mandatory
NT AUTHORITY\INTERACTIVE	Mandatory
NT AUTHORITY\Local account	Mandatory
NT AUTHORITY\Local account and member of Administrators group	Mandatory
NT AUTHORITY\LogonSessionId_0_6482041	Mandatory
NT AUTHORITY\NTLM Authentication	Mandatory
NT AUTHORITY\This Organization	Mandatory

Group SID: n/a

Privilege	Flags
SeBackupPrivilege	Disabled
SeChangeNotifyPrivilege	Default Enabled
SeCreateGlobalPrivilege	Default Enabled
SeCreatePagefilePrivilege	Disabled
SeCreateSymbolicLinkPrivilege	Disabled
SeDebugPrivilege	Disabled
SeDelegateSessionUserImpersonatePrivilege	Disabled
SeImpersonatePrivilege	Default Enabled



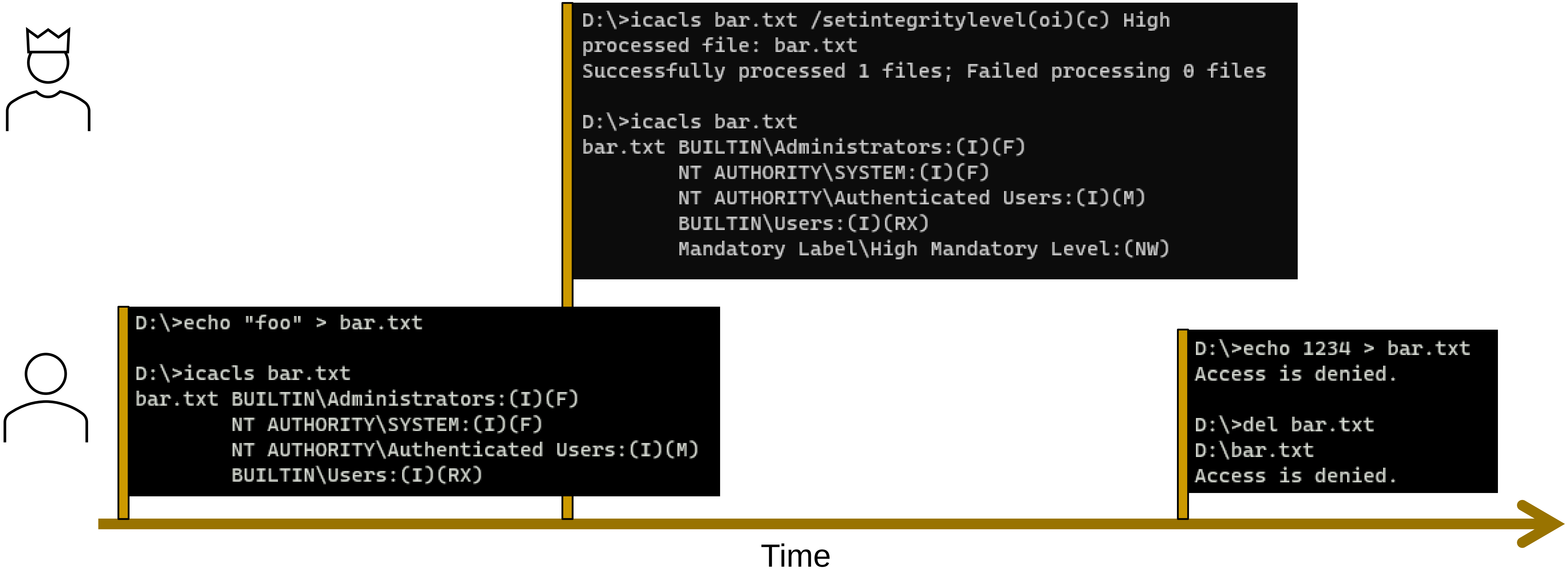
User: [redacted]
SID: [redacted]
Session: 1 Logon Session: 62e933
Virtualized: No Protected: No

Group	Flags
BUILTIN\Administrators	Deny
BUILTIN\Performance Log Users	Mandatory
BUILTIN\Users	Mandatory
CONSOLE LOGON	Mandatory
Everyone	Mandatory
LOCAL	Mandatory
Mandatory Label\Medium Mandatory Level	Integrity
[redacted]	Mandatory
NT AUTHORITY\Authenticated Users	Mandatory
NT AUTHORITY\INTERACTIVE	Mandatory
NT AUTHORITY\Local account	Mandatory
NT AUTHORITY\Local account and member of Administrators group	Deny
NT AUTHORITY\LogonSessionId_0_6482041	Mandatory
NT AUTHORITY\NTLM Authentication	Mandatory
NT AUTHORITY\This Organization	Mandatory

Group SID: n/a

Privilege	Flags
SeChangeNotifyPrivilege	Default Enabled
SeIncreaseWorkingSetPrivilege	Disabled
SeShutdownPrivilege	Disabled
SeTimeZonePrivilege	Disabled
SeUndockPrivilege	Disabled

Windows mandatory integrity control



```
D:\>echo "foo" > bar.txt

D:\>icacls bar.txt
bar.txt BUILTIN\Administrators:(I)(F)
        NT AUTHORITY\SYSTEM:(I)(F)
        NT AUTHORITY\Authenticated Users:(I)(M)
        BUILTIN\Users:(I)(RX)
```

```
D:\>icacls bar.txt /setintegritylevel(oi)(c) High
processed file: bar.txt
Successfully processed 1 files; Failed processing 0 files

D:\>icacls bar.txt
bar.txt BUILTIN\Administrators:(I)(F)
        NT AUTHORITY\SYSTEM:(I)(F)
        NT AUTHORITY\Authenticated Users:(I)(M)
        BUILTIN\Users:(I)(RX)
        Mandatory Label\High Mandatory Level:(NW)
```

```
D:\>echo 1234 > bar.txt
Access is denied.

D:\>del bar.txt
D:\bar.txt
Access is denied.
```

Clark-Wilson Integrity Model

D. D. Clark, D. R. Wilson, “A Comparison of Commercial and Military Computer Security Policies”, IEEE Symposium on Security and Privacy, 1987

- ▷ Addresses information integrity control
  - Uses the notion of transactional data transformations
  - Separation of duty: transaction certifiers ≠ implementers

- ▷ Terminology
  - Data items
    - Constrained Data Item (**CDI**)
      - Can only be manipulated by TPs
    - Unconstrained Data Item (**UDI**)

  - Integrity policy procedures
    - Integrity Verification Procedure (**IVP**)
      - Ensures that all CDIs conform with the integrity specification
    - Transformation Procedure (**TP**)
      - Well-formed transaction
        - Take as input a CDI or a UDI and produce a CDI
      - Must guarantee (via certification) that transforms all possible UDI values to “safe” CDI values

Clark-Wilson Integrity Model: Certification & Enforcement

- Integrity assurance
  - Certification
    - Relatively to the integrity policy
  - Enforcement
- Two sets of rules
  - Certification Rules (C)
  - Enforcement Rules (E)

Clark-Wilson Integrity Model: Certification & Enforcement rules

- Basic rules

  C1: when an IVP is executed, it must ensure that all CDIs are valid

  C2: for some associated set of CDIs, a TP must transform those CDIs from one valid state to another

  E1: the system must maintain a list of certified relations and ensure only TPs certified to run on a CDI change that CDI

- Separation of duty (external consistency)

  E2: the system must associate a user with each TP and set of CDIs. The TP may access CDIs on behalf of the user if authorized

  C3: allowed user-TP-CDI relations must meet “separation of duty” requirements

- Identification gathering

  E3: the system must authenticate every user attempting a TP (on each attempt)

- Audit trail

  C4: all TPs must append to a log enough information to reconstruct operations

- UDI processing

  C5: a TP taking a UDI as input may only perform valid transactions for all possible values of the UDI. The TP will either accept (convert to CDI) or reject the UDI

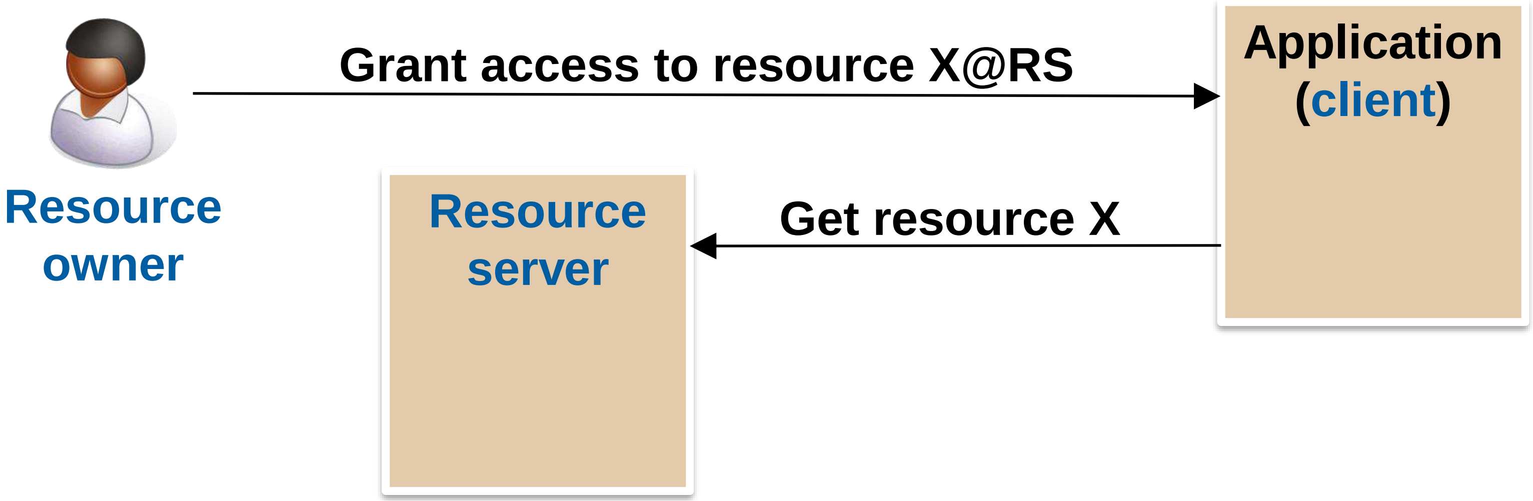
- Certification constraints

  E4: only the certifier of a TP may change the associated list of entities

OAuth 2.0
authorization framework

Goal

- Allow an application to access user resources maintained by a service/server



- Full reference at https://oauth.net/2/

Roles (RFC 6749)

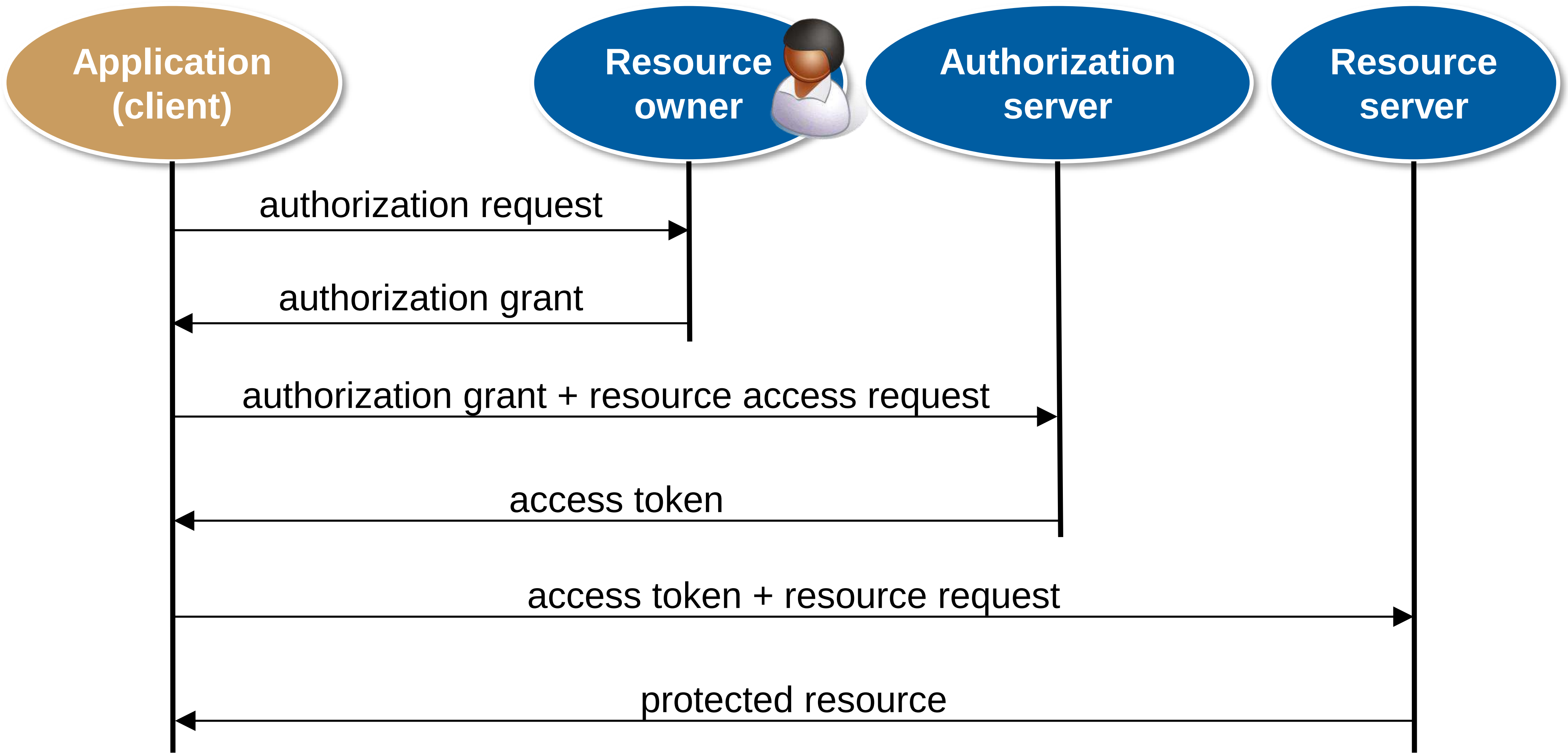
- Resource owner
  - An entity capable of **granting access** to a **protected resource**
  - **End-user**: a resource owner that is a person
- Resource server
  - The server hosting protected resources
  - Capable of accepting and responding to protected resource requests using **access tokens**

Roles (RFC 6749)

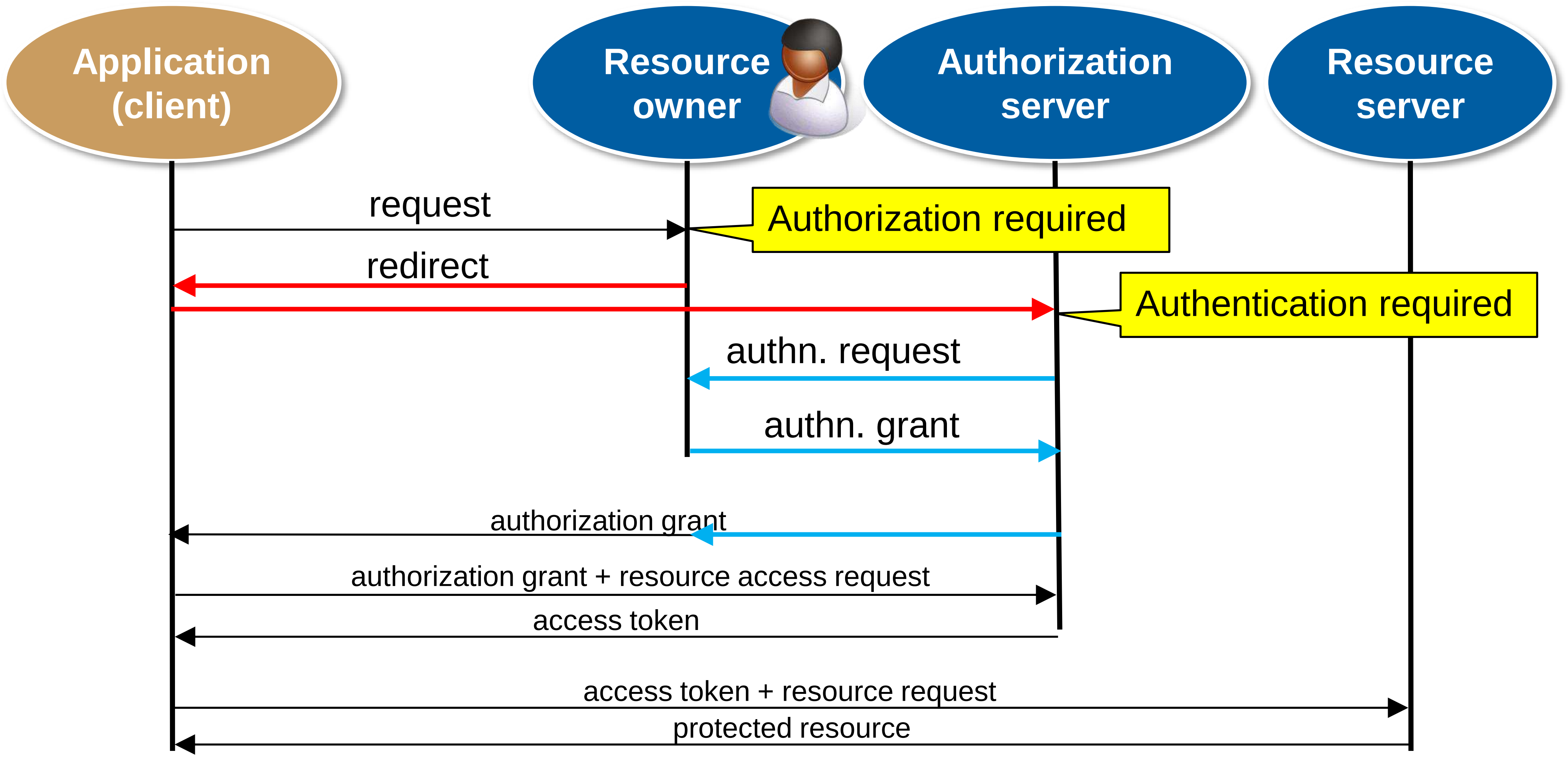
- Client
  - An **application** making requests for protected resources on behalf of the resource owner and with its authorization

- Authorization server (aka OAuth server or provider)
  - The server issuing **access tokens** to the client after successfully **authenticating** the resource owner and obtaining its **authorization** for the client to access one of its resources

Abstract protocol flow (RFC 6749)



Common protocol flow



Communication endpoints: Authorization endpoint

- Service provided by the **OAuth server**
  - Authenticates the resource owner (the user)
  - Asks for the delegation of access rights to its protected resources to the client
  - Send an authorization grant to the **redirection endpoint**

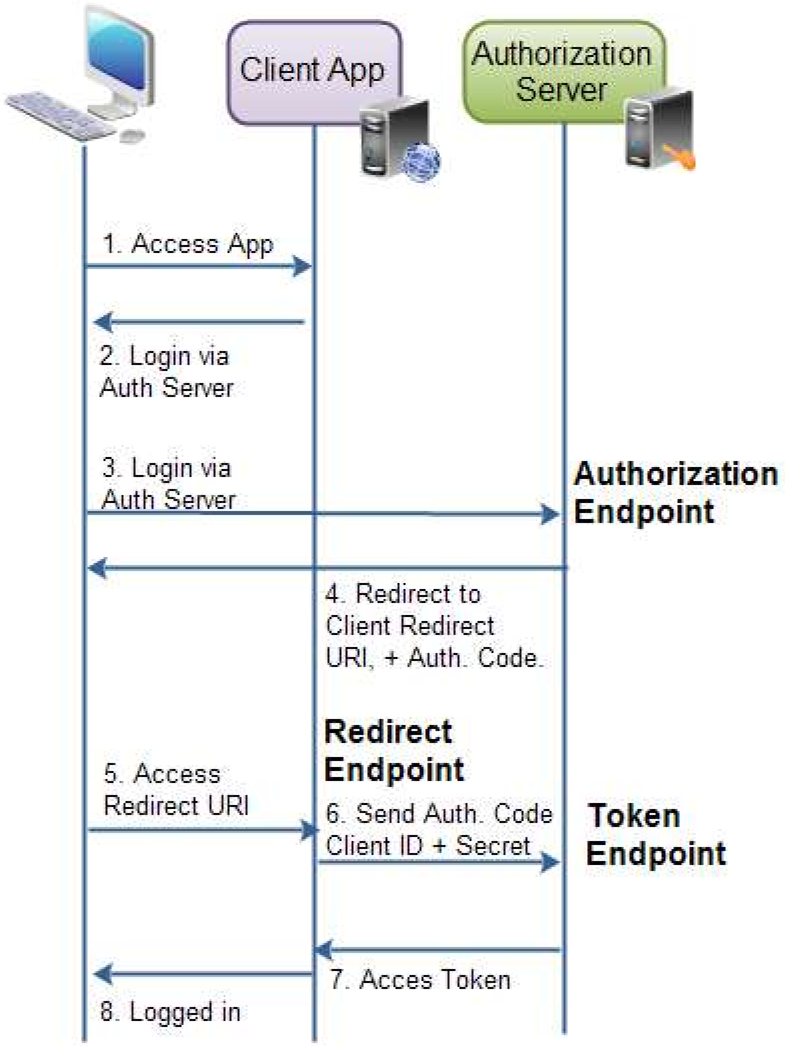
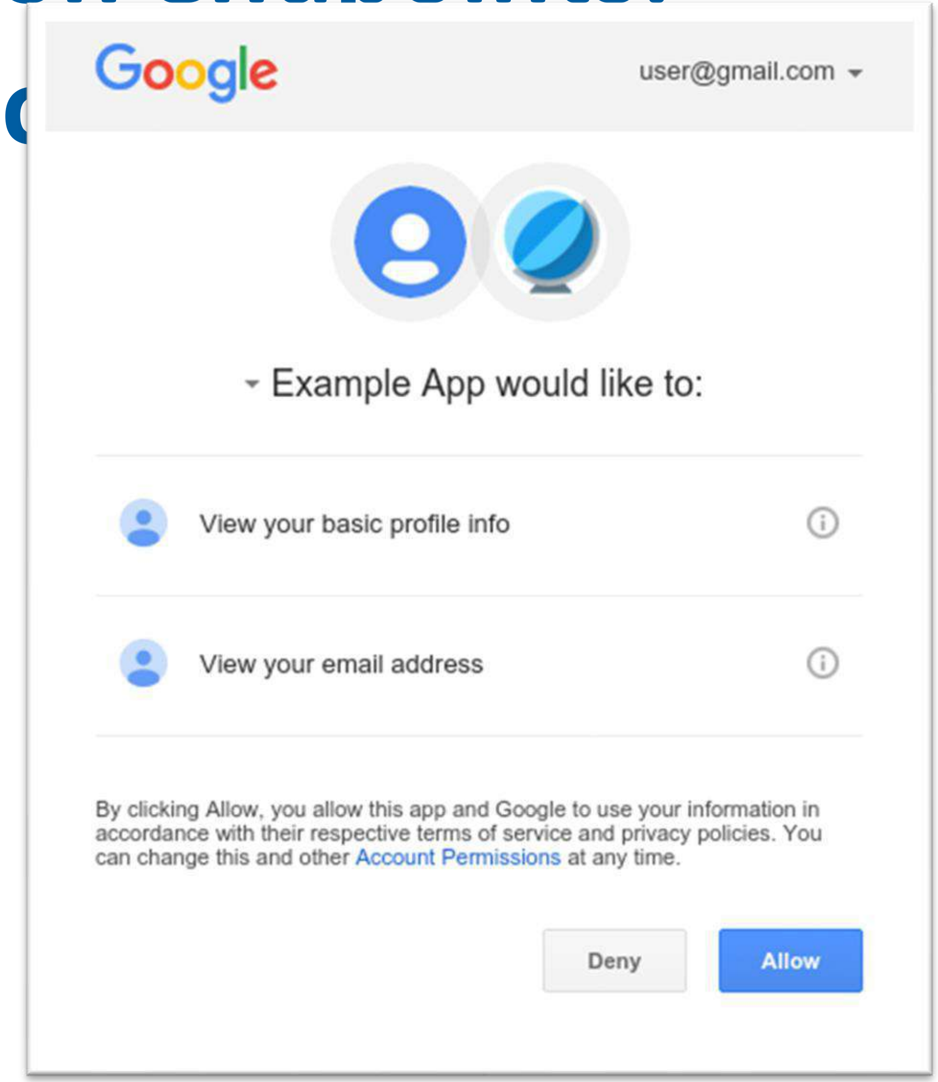


Image: https://jenkov.com/tutorials/oauth2/endpoints.html

Communication endpoints: Authorizatic



Google user@gmail.com

Example App would like to:

View your basic profile info

View your email address

By clicking Allow, you allow this app and Google to use your information in accordance with their respective terms of service and privacy policies. You can change this and other Account Permissions at any time.

Communication endpoints: Token endpoint

- Service provided by the **OAuth server**
  - Produces access tokens given an authorization grant
  - It can also produce refresh tokens
  - Refresh tokens can be used to get new tokens
    - With an authorization grant

- Client authentication
  - ClientID + ClientSecret + HTTP basic authentication

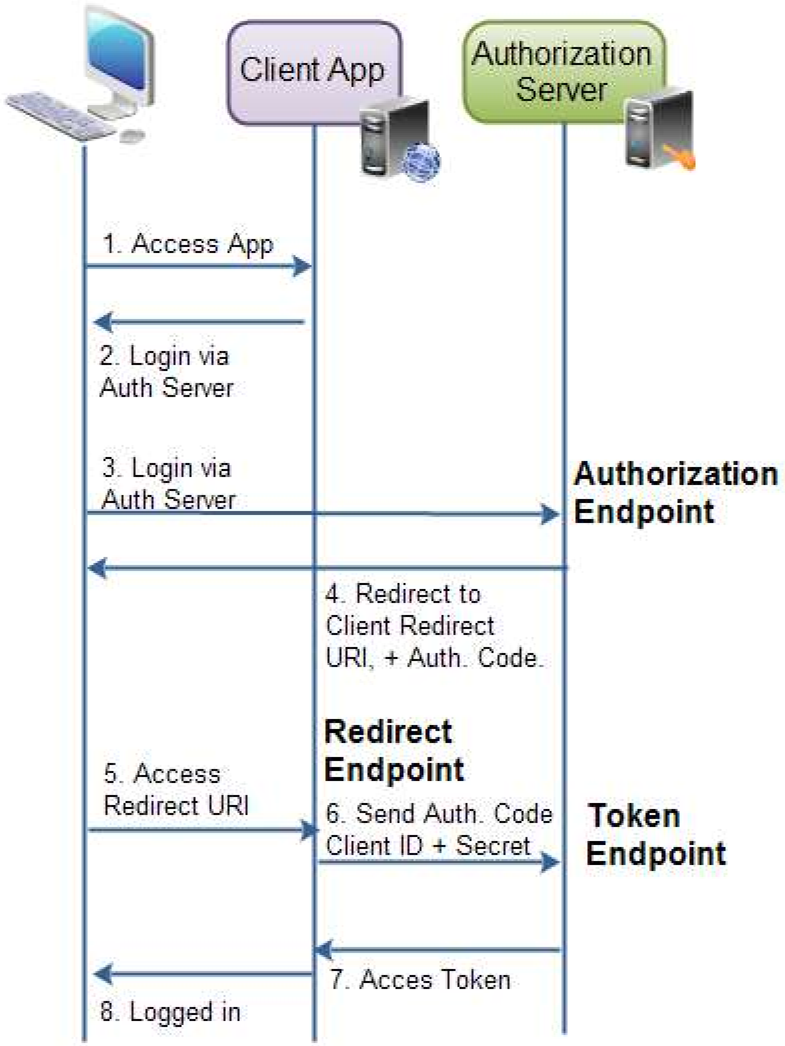


Image: https://jenkov.com/tutorials/oauth2/endpoints.html

Communication endpoints: Redirect endpoint

- ▷ Service provided by the client
  - It collects the authorization grant provided by the OAuth server
  - It should be called by the OAuth server using an HTTP redirect

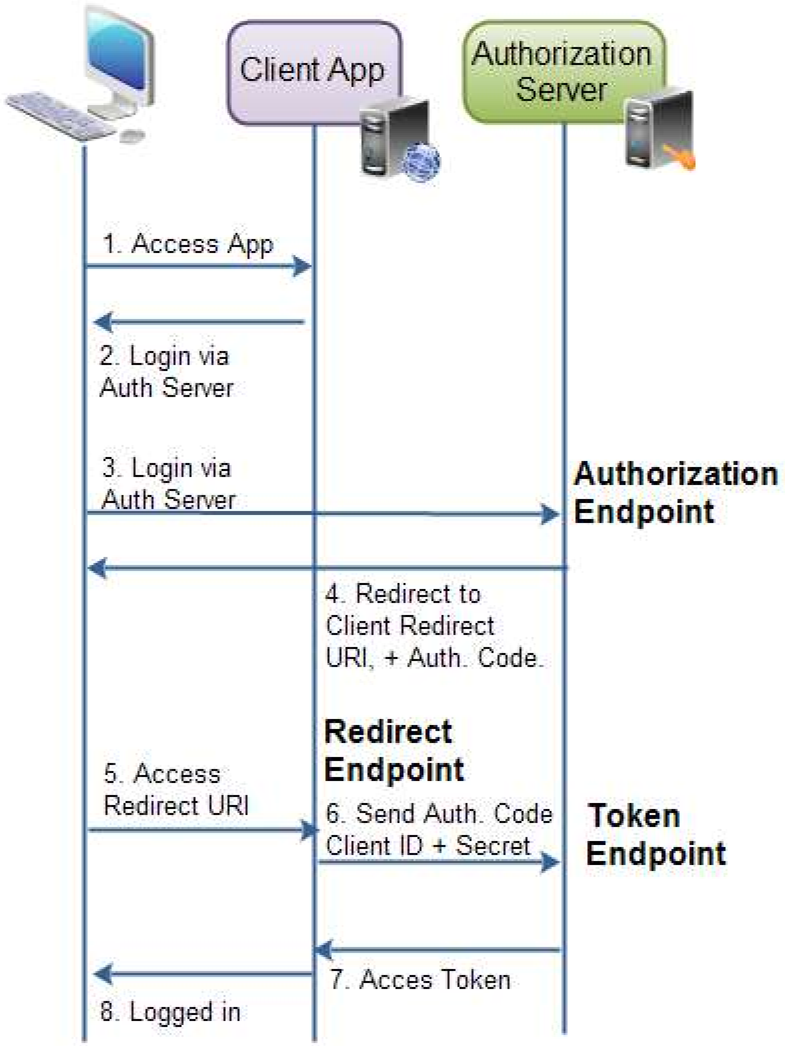


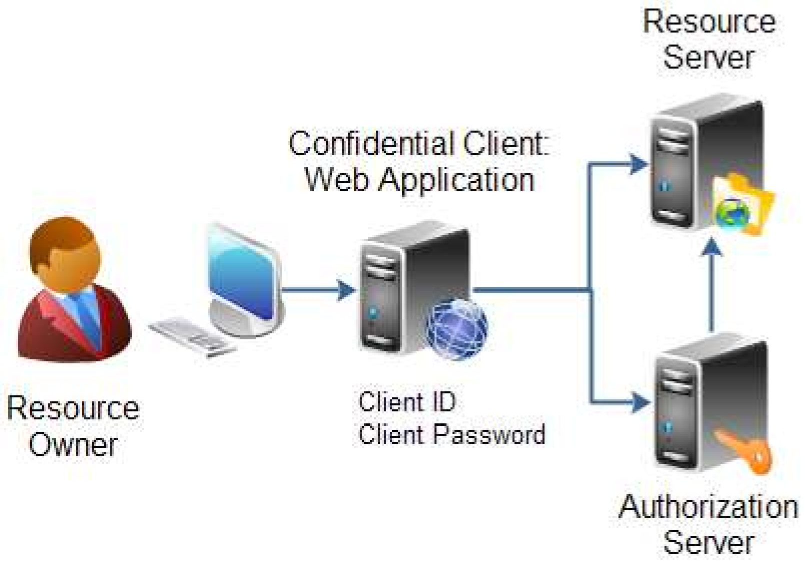
Image: https://jenkov.com/tutorials/oauth2/endpoints.html

Application (client) types

- Type is related with the ability to maintain the confidentiality of client credentials
  - Even from the resource owner
- Confidential
  - Capable
  - e.g. a secure server
- Public
  - Incapable
  - e.g. a web browser-based application, a mobile App
- Different application types will be allowed to execute different flows

Application (client) profiles

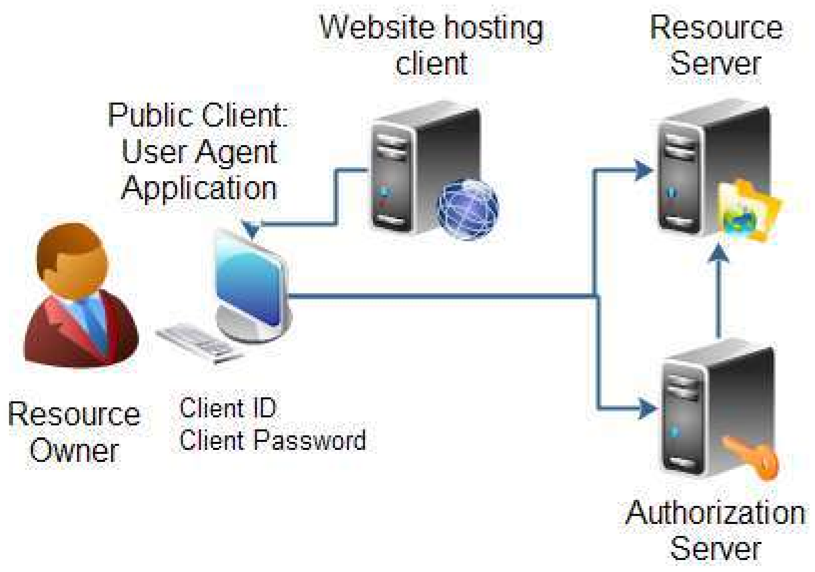
- Web application
  - Confidential client running on a web server



https://jenkov.com/tutorials/oauth2/client-types.html

Application (client) profiles

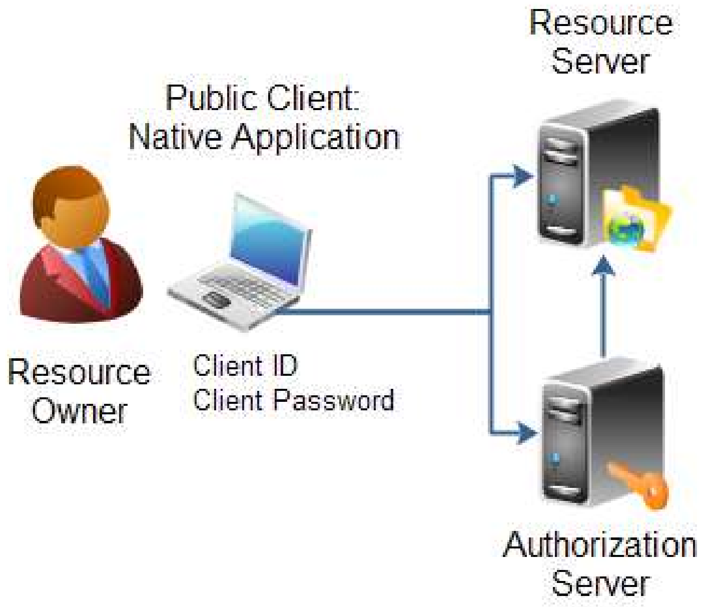
- User-agent based application
  - Public client where the client code runs on a user-agent application
    - e.g. a browser



https://jenkov.com/tutorials/oauth2/client-types.html

Application (client) profiles

- Native application
  - Public client installed and executed on the device used by the resource owner



https://jenkov.com/tutorials/oauth2/client-types.html

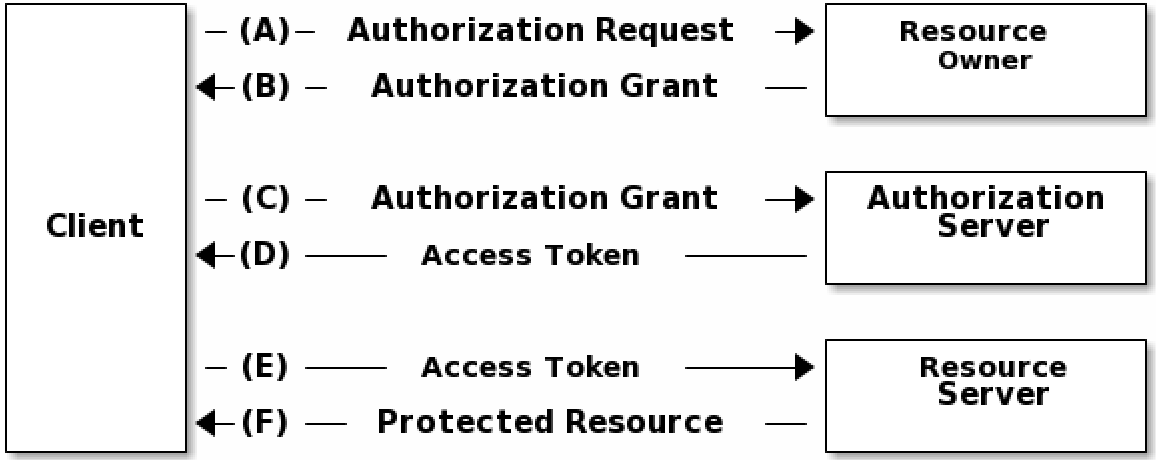
Application (client) registration (in an OAuth server)

- Clients accessing OAuth servers must be previously registered
  - Nevertheless, the standard does not exclude unregistered clients
  - A registered client is given a unique identifier
    - ClientID

- Registration includes both informational, legal and operational information
  - Redirection URLs
  - Acceptance of legal terms
  - Application (client) name, logo, web site, description
  - Client type
  - Client authentication method (for confidential clients)

OAuth tokens: Authorization grant

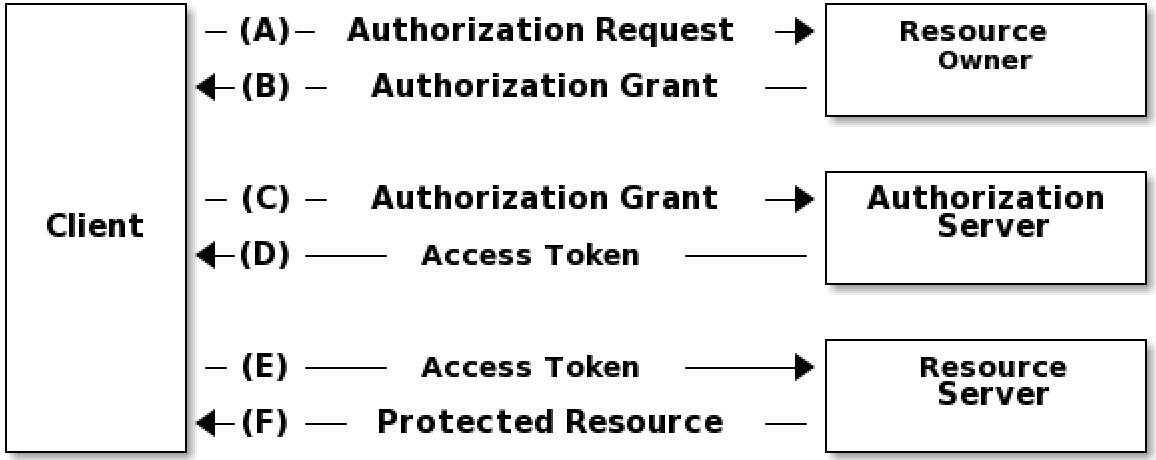
- Created by an OAuth server
  - Upon authenticating a resource owner and getting its consent to grant access to a protected resource
  - An opaque byte blob that makes sense only to its issuer
- Short validity time
  - Just enough to get an access token



OAuth tokens:
Access token

- Created by an OAuth server
  - Upon authenticating a client and receiving an authorization grant
  - An opaque byte blob that makes sense to its issuer and to the resource owner
    - An access capability

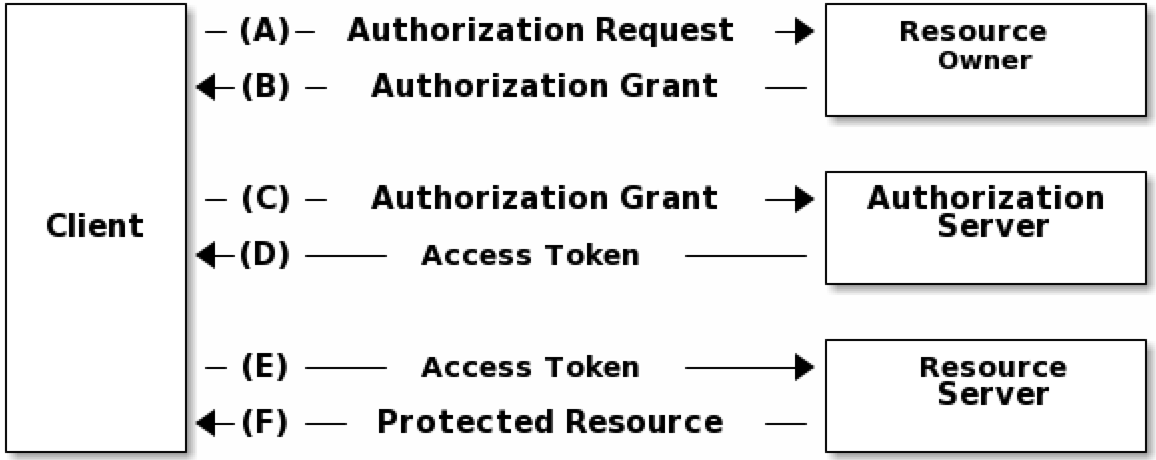
- Bearer tokens
  - Clients need to protect their use with HTTPS
  - Clients can handover tokens to others



OAuth tokens:
Refresh token

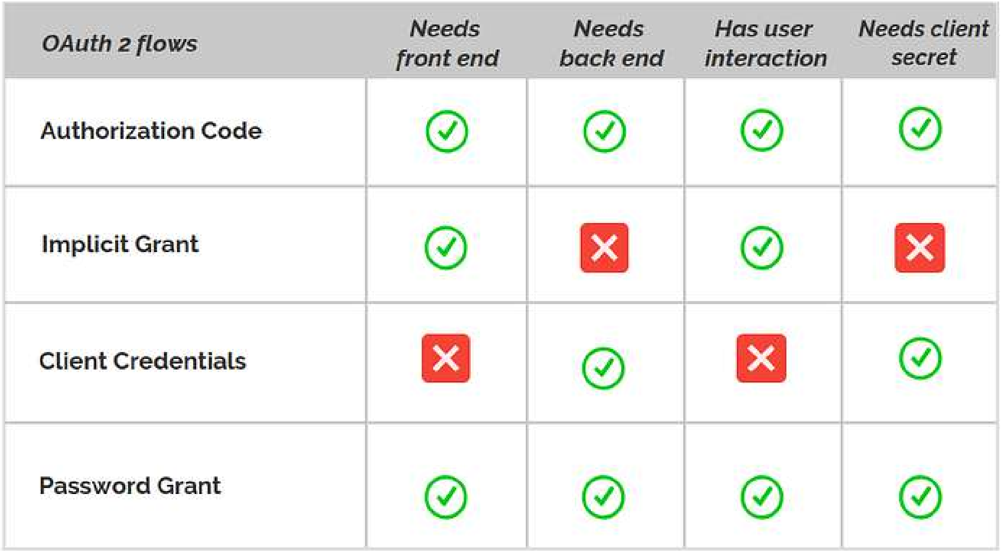
- Created by an OAuth server
  - When creating an access token
  - An opaque byte blob that makes sense only to its issuer
  - It can be used to collect a new access token
    - Still requiring the client authentication

- Bearer tokens
  - Clients need to protect their use with HTTPS
  - Clients can handover tokens to others



OAuth flows

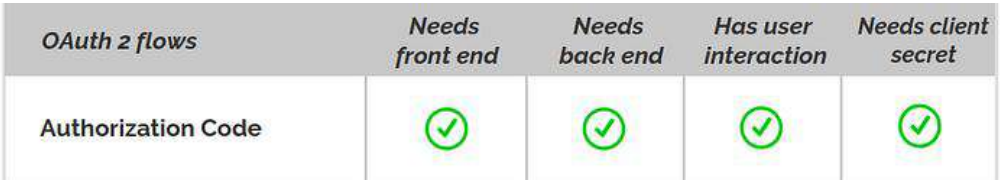
- ▷ Authorization code flow
  - 3-legged OAuth
  - Default OAuth flow
  - The most secure
- ▷ Implicit flow (grant)
- ▷ Resource owner password credentials flow
- ▷ Client credentials flow
  - 2-legged flow



OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Authorization Code	✓	✓	✓	✓
Implicit Grant	✓	✗	✓	✗
Client Credentials	✗	✓	✗	✓
Password Grant	✓	✓	✓	✓

Authorization code flow

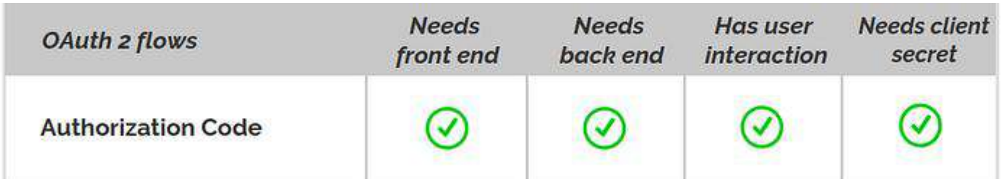
- 3-legged OAuth
  - Enables checking the identity of the 3 involved actors
- OAuth server authenticates the resource owner
  - Username + password or other means
- OAuth server authenticates the client
  - ClientID + ClientSecret + HTTP basic authorization
- Client authenticates the OAuth server
  - Certificate + URL



OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Authorization Code	✓	✓	✓	✓

Authorization code flow

- Requirements
  - Confidential application types
  - Secure storage for tokens, ClientID and ClientSecret
- Setup
  - Client registration in the OAuth server
    - Client receives ClientID and ClientSecret
    - Not regulated by OAuth



OAuth 2 flows	Needs front end	Needs back end	Has user interaction	Needs client secret
Authorization Code	✓	✓	✓	✓

Authorization code flow

- Resource owner uses a server-based Web App
  - The client

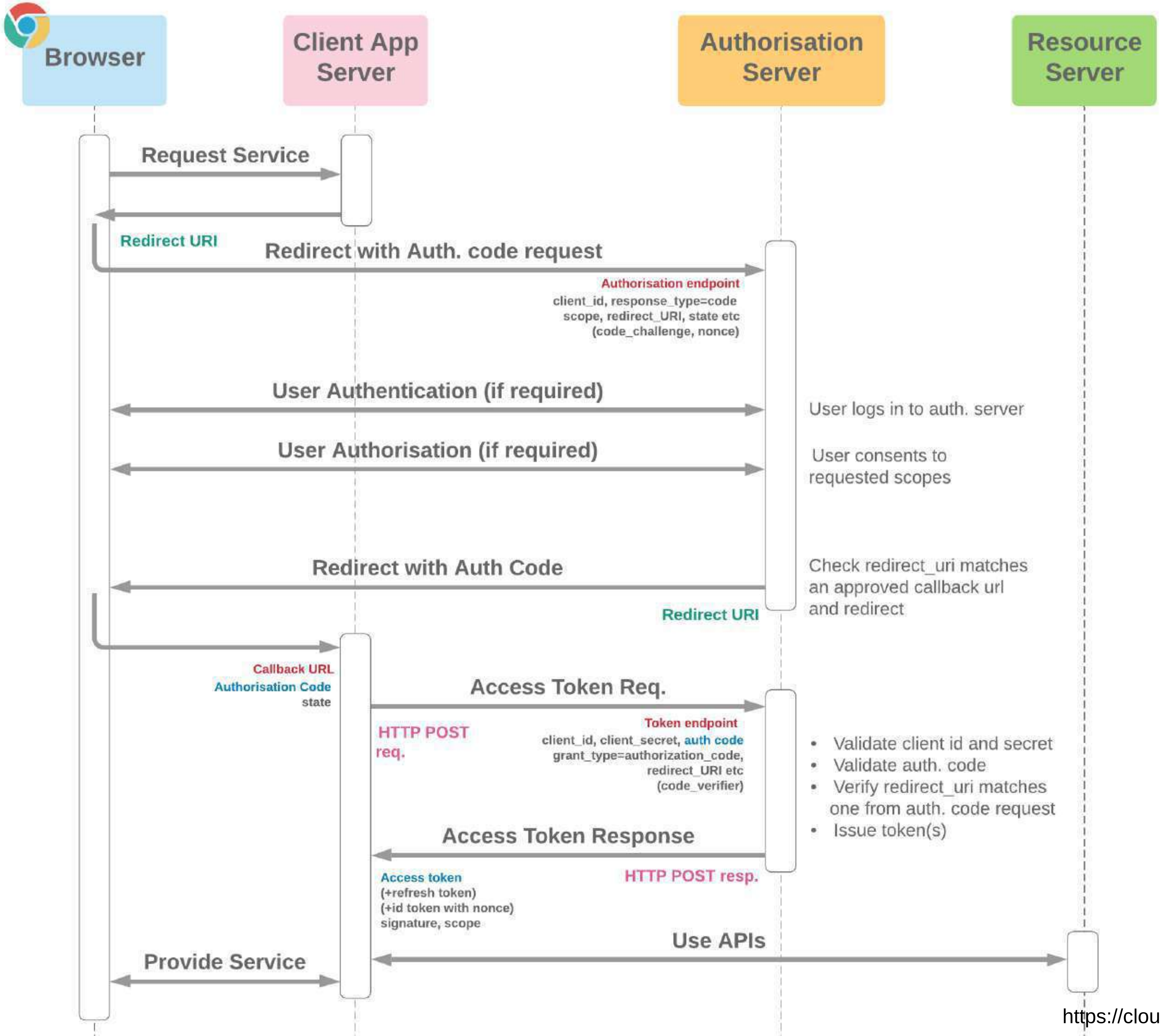
- The client uses the resource server API to get a resource
  - The resource server redirects the client to the OAuth server

- The OAuth server authenticates the resource owner
  - And sends an authorization grant to the client

- The client gets an access token from the OAuth server
  - Using its credentials (to have access permission)
  - Using its authorization grant

- The client uses again the resource server API to get a resource
  - This time providing an access token

Aut



Browser

Client App Server

Authorisation Server

Resource Server

Request Service

Redirect URI

Redirect with Auth. code request

Authorisation endpoint

client_id, response_type=code
scope, redirect_URI, state etc
(code_challenge, nonce)

User Authentication (if required)

User logs in to auth. server

User Authorisation (if required)

User consents to requested scopes

Redirect with Auth Code

Redirect URI

Check redirect_uri matches an approved callback url and redirect

Callback URL
Authorisation Code
state

Access Token Req.

HTTP POST req.

Token endpoint

client_id, client_secret, auth code
grant_type=authorization_code,
redirect_URI etc
(code_verifier)

- Validate client id and secret
- Validate auth. code
- Verify redirect_uri matches one from auth. code request
- Issue token(s)

Access Token Response

HTTP POST resp.

Access token
(+refresh token)
(+id token with nonce)
signature, scope

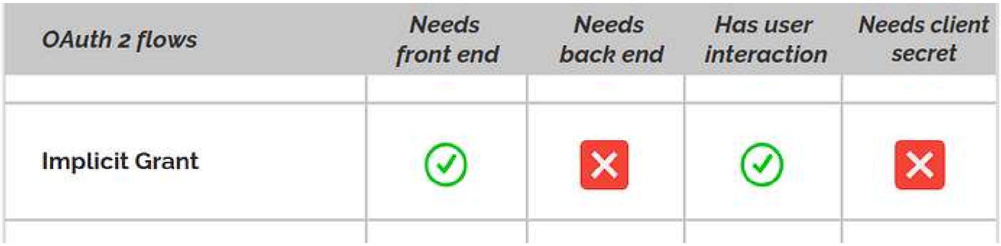
Use APIs

Provide Service

https://cloudsundial.com/salesforce-oauth-flows

Implicit flow

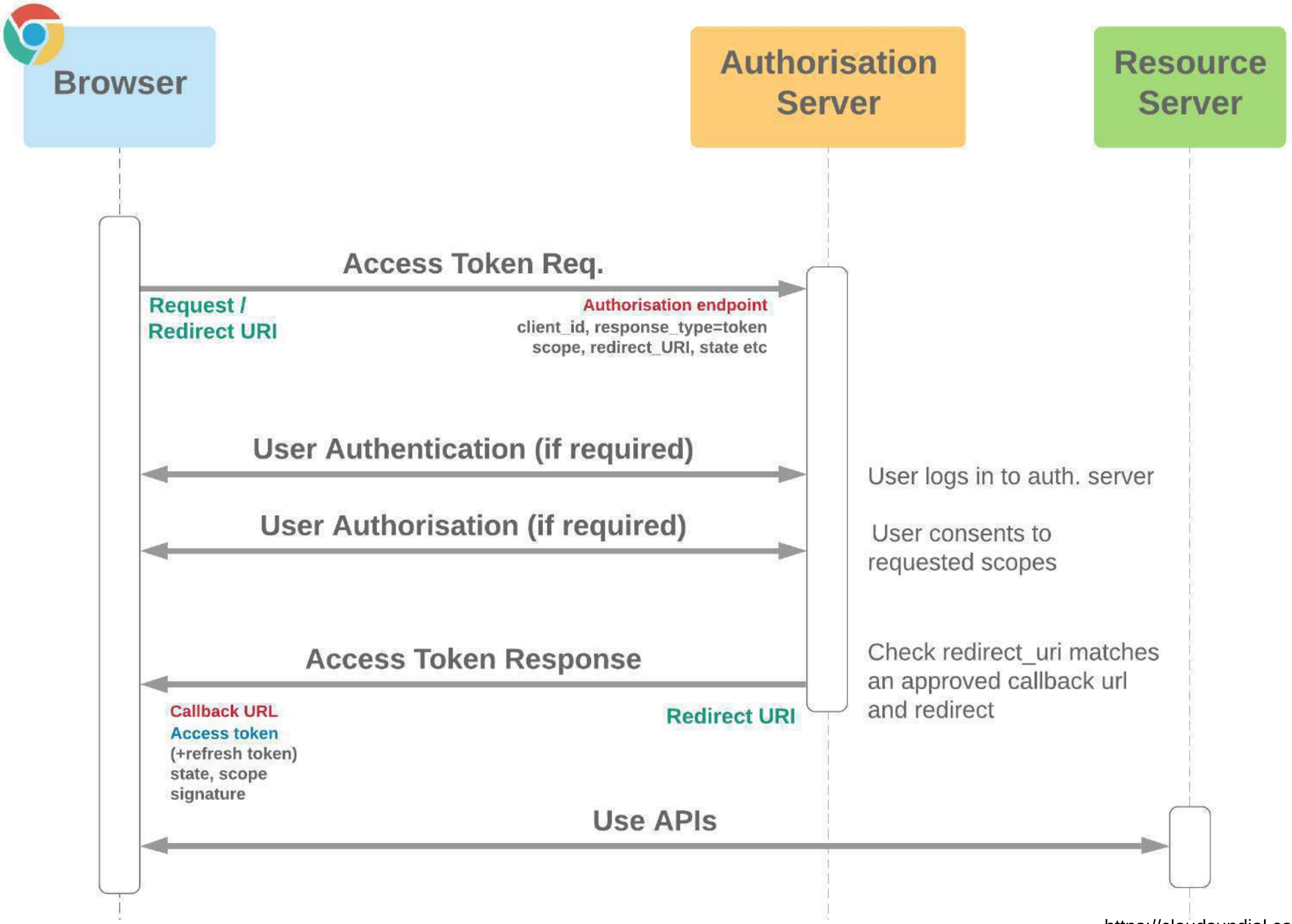
- ▷ Requirements
  - Public application types
- ▷ Setup
  - Client registration in the OAuth server
    - Client receives ClientID
    - Not regulated by OAuth
- ▷ Limitations
  - No client authentication
  - No refresh tokens



OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Implicit Grant	✓	✗	✓	✗

Implicit flow

- Resource owner uses a mobile or client-based Web App
  - The client
- The client uses the resource server API to get a resource
  - The resource server redirects the client to the OAuth server
- The OAuth server authenticates the resource owner
  - And sends an access token to the client
- The client uses again the resource server API to get a resource
  - This time providing an access token



Browser

Authorisation Server

Resource Server

Access Token Req.

Request / Redirect URI

Authorisation endpoint
client_id, response_type=token
scope, redirect_URI, state etc

User Authentication (if required)

User logs in to auth. server

User Authorisation (if required)

User consents to requested scopes

Access Token Response

Check redirect_uri matches an approved callback url and redirect

Callback URL
Access token
(+refresh token)
state, scope
signature

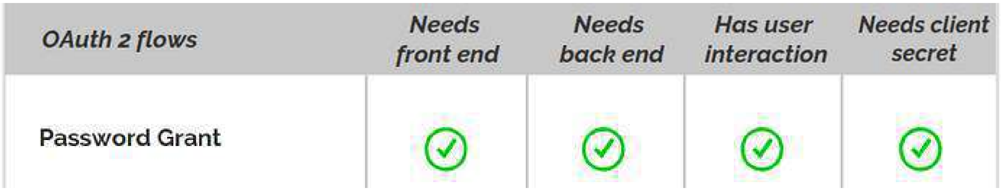
Redirect URI

Use APIs

https://cloudsundial.com/salesforce-oauth-flows

Resource owner password flow

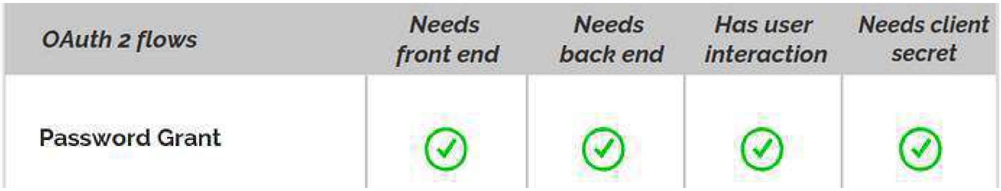
- Requirements
  - Confidential application types
  - Sharing of resource owner credentials with client applications
  - Secure storage for tokens, ClientID and ClientSecret
- Setup
  - Client registration in the OAuth server
    - Client receives ClientID and ClientSecret
    - Not regulated by OAuth
- Limitations
  - Resource owners need to trust on client applications



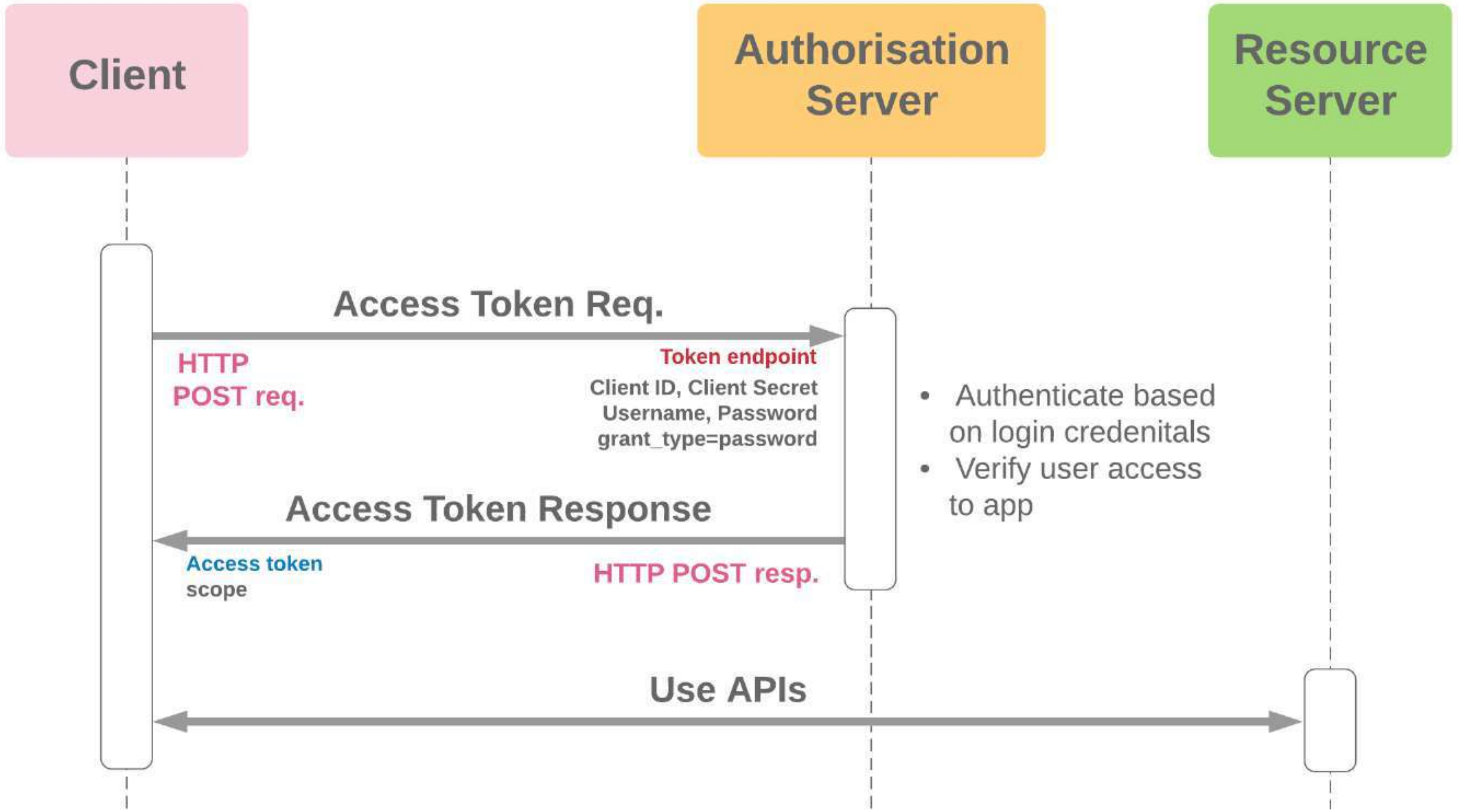
OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Password Grant	✓	✓	✓	✓

Resource owner password flow

- Resource owner uses a server-based Web App
  - The client
- The client uses the resource server API to get a resource
  - The resource server requests a token
- The client asks the resource owner for authentication credentials
- The client gets an access token from the OAuth server
  - Using its credentials (to have access permission)
  - Using the resource owner's credentials
  - These should be immediately discarded
- The client uses again the resource server API to get a resource
  - This time providing an access token



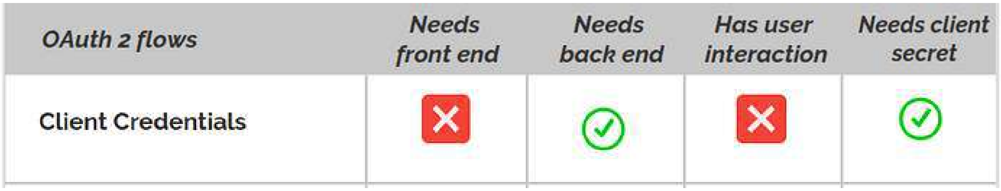
OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Password Grant	✓	✓	✓	✓



- Authenticate based on login credenitals
- Verify user access to app

Client credentials flow

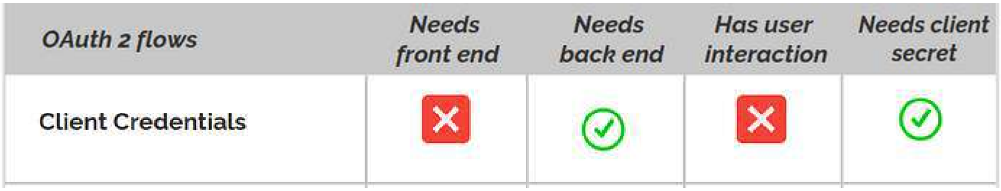
- Requirements
  - Confidential application types
  - Secure storage for tokens, ClientID and ClientSecret
- Setup
  - Client registration in the OAuth server
    - Client receives ClientID and ClientSecret
    - Not regulated by OAuth
- Limitations
  - No resource owner authentications or authorizations



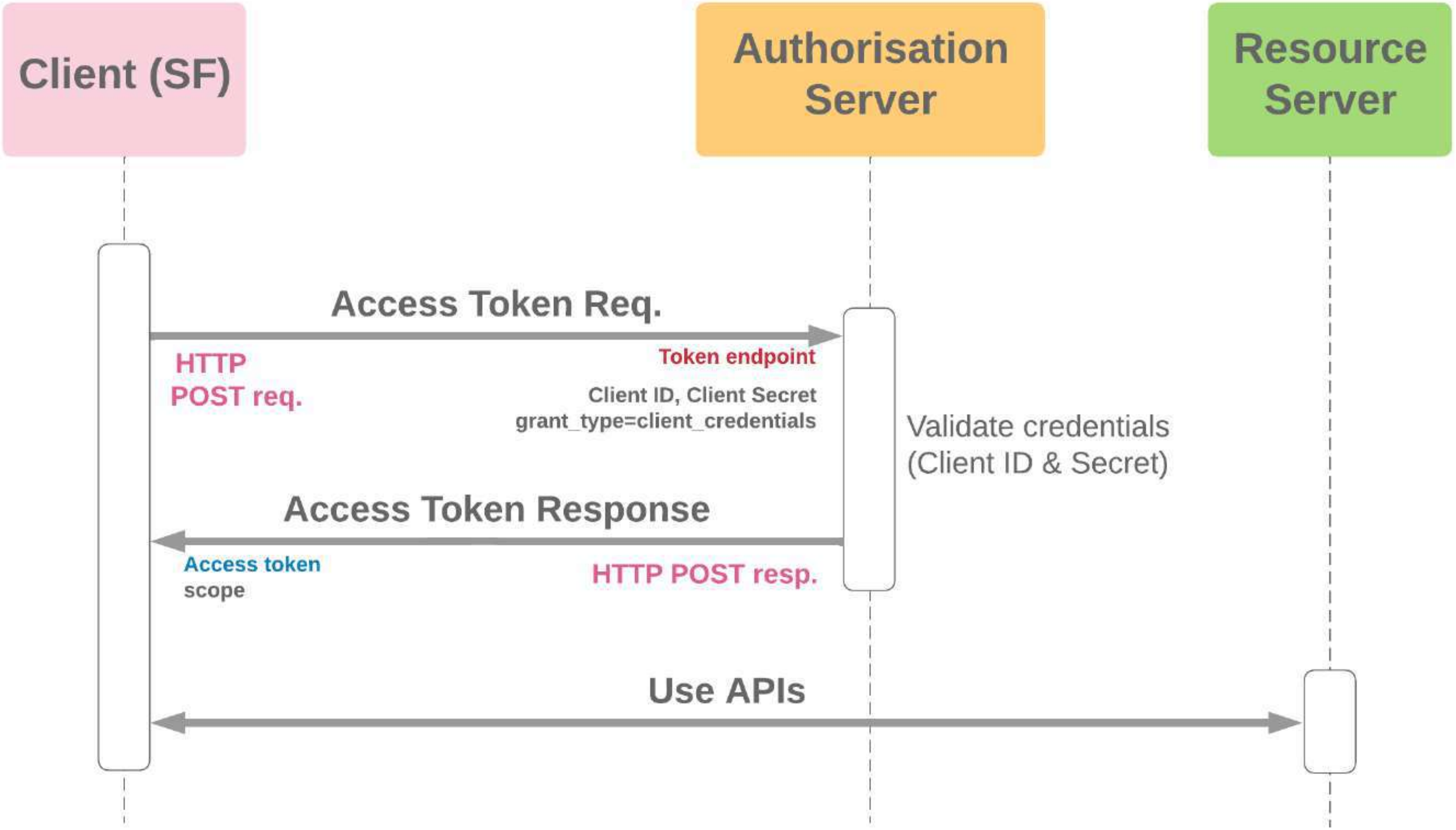
OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Client Credentials	✗	✓	✗	✓

Client credentials flow

- ▷ Resource owner uses a server-based Web App
  - The client
- ▷ The client uses the resource server API to get a resource
  - The resource server requests a token
- ▷ The client gets an access token from the OAuth server
  - Using its credentials (to have access permission)
- ▷ The client uses again the resource server API to get a resource
  - This time providing an access token



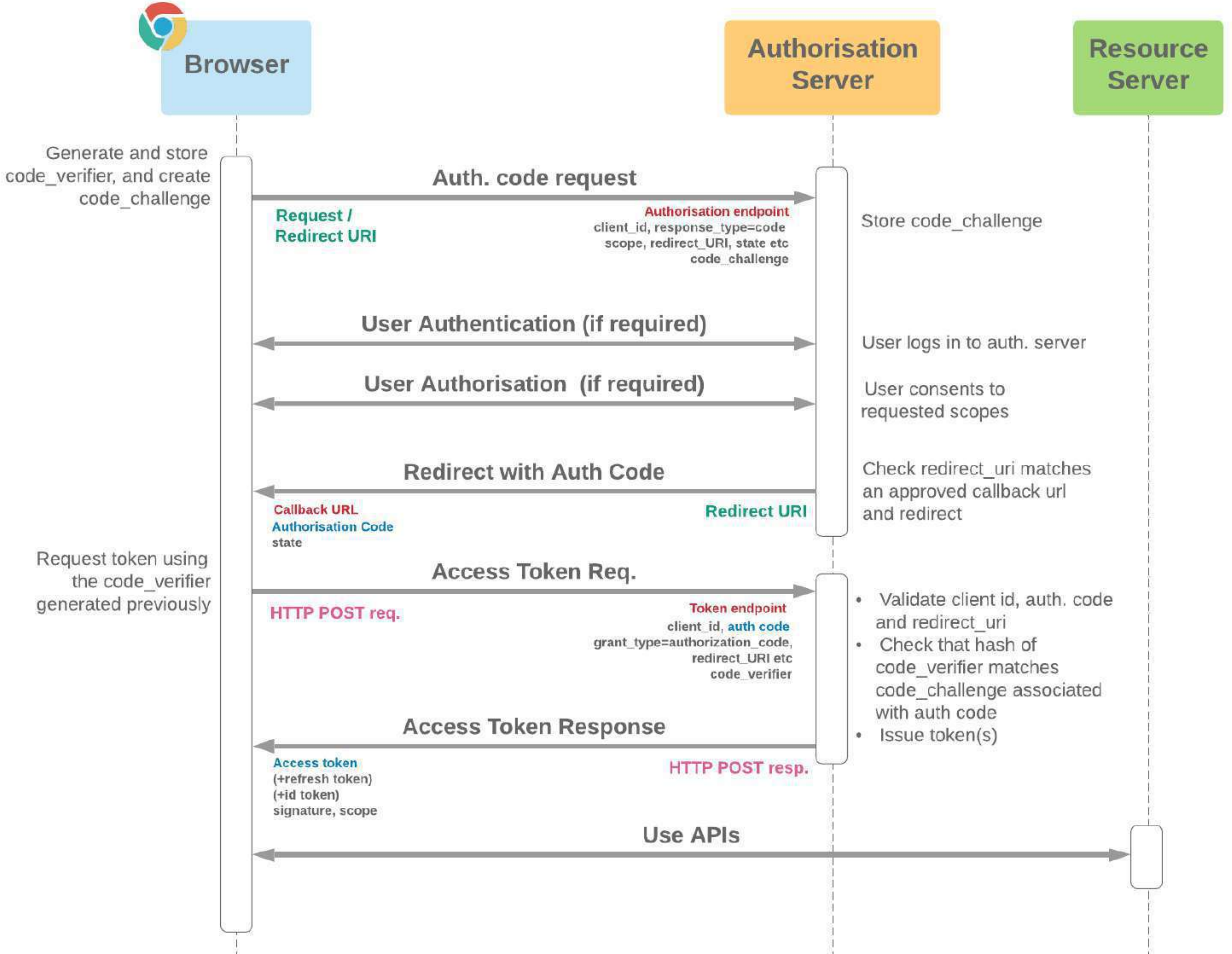
OAuth 2 flows	*Needs front end*	*Needs back end*	*Has user interaction*	*Needs client secret*
Client Credentials	✗	✓	✗	✓


Client (SF)
Authorisation Server
Resource Server
Access Token Req.
HTTP POST req.
Token endpoint
Client ID, Client Secret
grant_type=client_credentials
Validate credentials (Client ID & Secret)
Access Token Response
Access token
scope
HTTP POST resp.
Use APIs

Proof Key for Code Exchange (PKCE, RFC 7636)

- Binds authorization grants to their requesters
  - Using a Code Challenge
    - A digest of a Code Verifier
    - A bit commitment
  - Cannot the used by eavesdroppers

- The requester is required to demonstrate the ownership of the authorization grant when fetching the access token
  - Providing the Code Verifier



Browser

Authorisation Server

Resource Server

Generate and store code_verifier, and create code_challenge

Auth. code request

Request / Redirect URI

Authorisation endpoint
client_id, response_type=code
scope, redirect_URI, state etc
code_challenge

Store code_challenge

User Authentication (if required)

User logs in to auth. server

User Authorisation (if required)

User consents to requested scopes

Redirect with Auth Code

Callback URL
Authorisation Code
state

Redirect URI

Check redirect_uri matches an approved callback url and redirect

Request token using the code_verifier generated previously

Access Token Req.

HTTP POST req.

Token endpoint
client_id, auth code
grant_type=authorization_code,
redirect_URI etc
code_verifier

- Validate client id, auth. code and redirect_uri
- Check that hash of code_verifier matches code_challenge associated with auth code
- Issue token(s)

Access Token Response

Access token
(+refresh token)
(+id token)
signature, scope

HTTP POST resp.

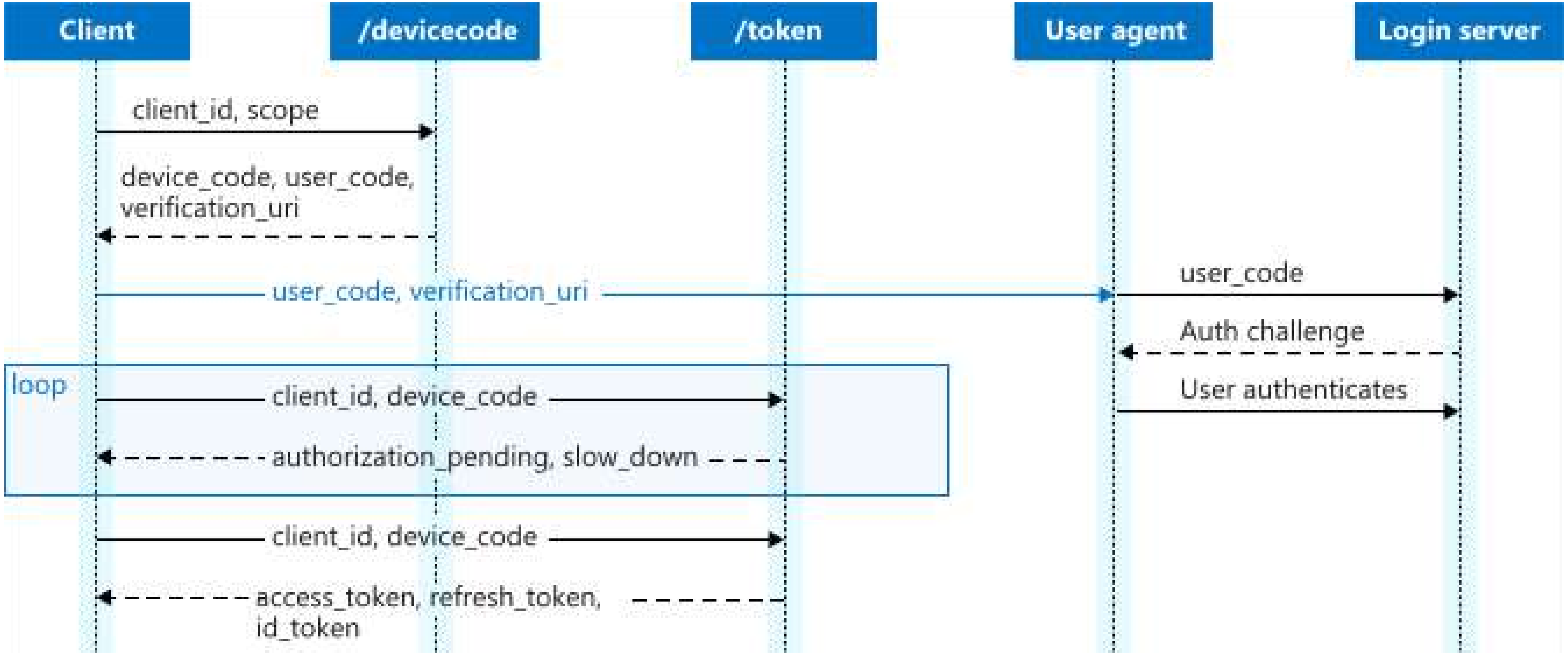
Use APIs

Device authorization grant (RFC 8628)

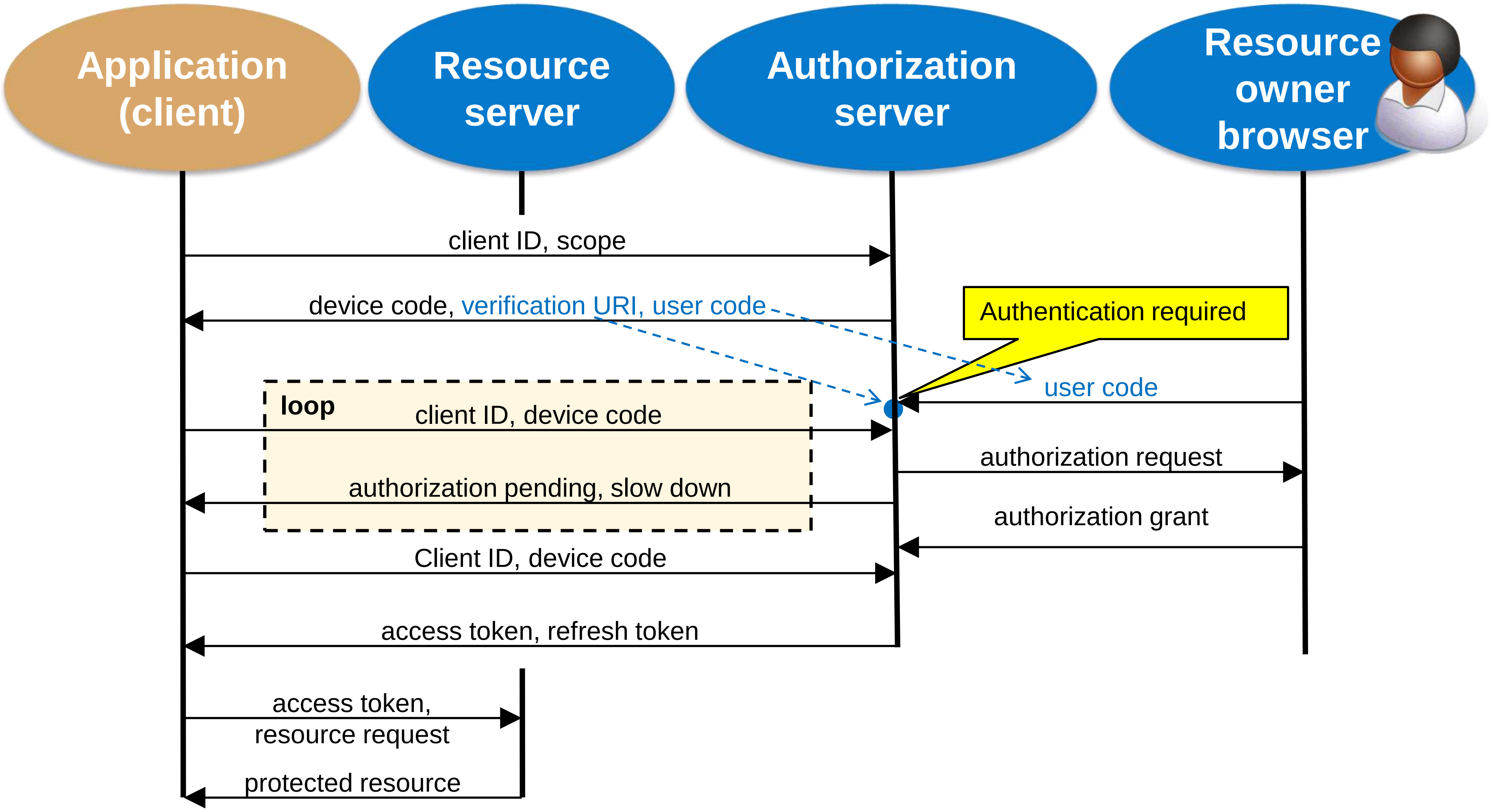
- In some cases the user is using a device with no browser to interact with a OAuth client
  - No HTTP redirections to Authorization server and back to client
  - No user interface
    - To authenticate the user
    - To review and authorize request

- Solution
  - Use a second device to perform the user authentication and to grant the authorization
    - e.g. mobile phone, tablet, etc.
  - Client fetches the access token from the Authorization server
    - Possibly with a refresh token

Device authorization grant (RFC 8628)



Actual protocol flow



Linux
security mechanisms

Mechanisms

- Capabilities

- cgroups (control groups)

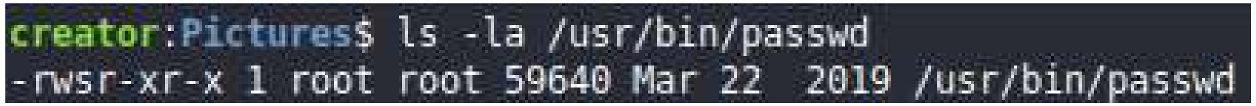
- LSM (Linux Security Modules)

Linux management privileges

- ▷ Initial UNIX philosophy
  - ◆ Privileged processes (UID = 0)
    - Bypass all kernel permission checks
  - ◆ Unprivileged processes (UID ≠ 0)
    - Subject to permission checking based on their credentials
    - Effective UID, effective GID, secondary group list

Unix file protection ACLs:
Special protection bits

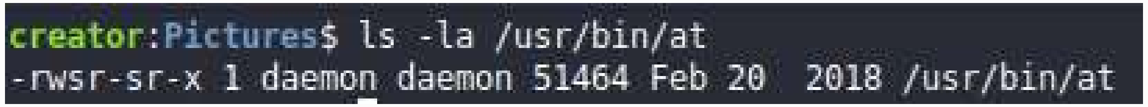
- Set-UID bit



```
creator:Pictures$ ls -la /usr/bin/passwd
-rwsr-xr-x 1 root root 59640 Mar 22  2019 /usr/bin/passwd
```

  - Is used to change the UID of processes executing the file

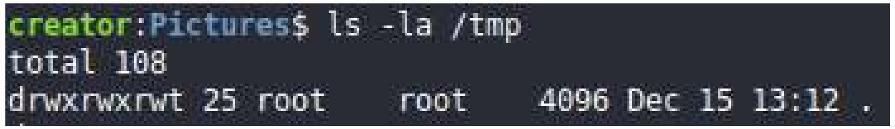
- Set-GID bit



```
creator:Pictures$ ls -la /usr/bin/at
-rwsr-sr-x 1 daemon daemon 51464 Feb 20  2018 /usr/bin/at
```

  - Is used to change the UID of processes executing the file

- Sticky bit



```
creator:Pictures$ ls -la /tmp
total 108
drwxrwxrwt 25 root    root    4096 Dec 15 13:12 .
```

  - Hint to keep the file/directory as much as possible in memory cache

Privilege elevation: Set-UID mechanism

- Change the effective UID of a process running a program stored on a Set-UID file
  - If a program file is owned by UID X and the set-UID bit of its ACL is set, then it will be executed in a process with UID X
    - Independently of the UID of the subject that executed the program

- Allows normal users to execute privileged tasks encapsulated in administration programs
  - Change the user’s password (passwd)
  - Change to super-user mode (su, sudo)
  - Mount devices (mount)

Privilege elevation: Set-UID mechanism (cont.)

- Effective UID / Real UID
  - Real UID (rUID) is the UID of the process creator
    - App launcher
  - Effective UID (eUID) is the UID of the process
    - The one that really matters for defining the rights of the process
    - eUID may differ from rUID

- UID change
  - Ordinary application
    - eUID = rUID = UID of process that executed **exec**
    - eUID cannot be changed (unless = 0)
  - Set-UID application
    - eUID = UID of **exec**'d application file, rUID = initial process UID
    - eUID can revert to rUID
  - rUID cannot change

Privilege elevation:
Set-UID/Set-GID decision flowchart

- exec (path, …)
  - File referred by path has Set-UID?
  - Yes
    - ID = path owner
    - Change the process effective UID to ID of path owner
  - No
    - Do nothing
  - File referred by path has Set-GID?
  - Yes
    - ID = path GID
    - Change the process GIDs to ID only
  - No
    - Do nothing

Capabilities

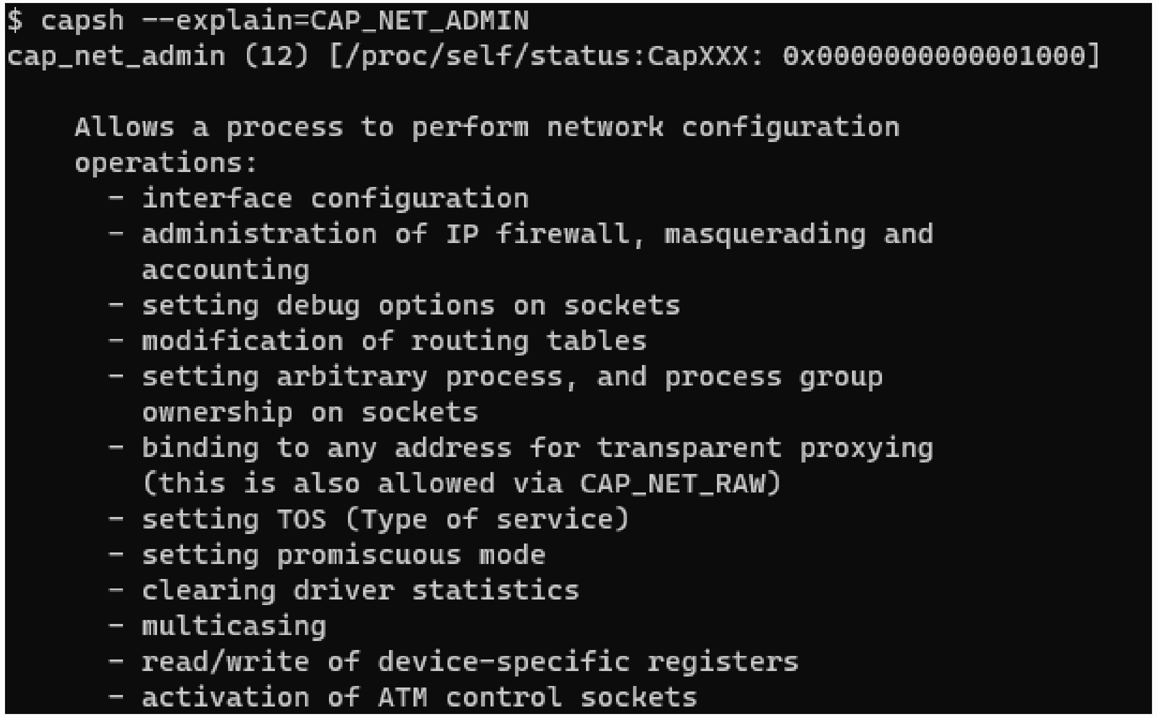
- Protection mechanism introduced in Kernel 2.2

- Allow to divide the traditional super-user privileges into distinct units
  - That can be independently enabled and disabled

- Capabilities are a per-thread attribute
  - Propagated through forks
  - Changed explicitly of by execs

List of capabilities:
Examples (small sample …)

- ▷ CAP_CHOWN
  - Make arbitrary changes to file UIDs and GIDs
- ▷ CAP_DAC_OVERRIDE / CAP_DAC_READ_SEARCH
  - Bypass file permission / directory transversal checks
- ▷ CAP_KILL
  - Bypass permission checks for sending signals
- ▷ CAP_NET_ADMIN
  - Perform various network-related operations
- ▷ CAP_SYS_ADMIN
  - Overloaded general-purpose administration capability



```
$ capsh --explain=CAP_NET_ADMIN
cap_net_admin (12) [/proc/self/status:CapXXX: 0x0000000000001000]

    Allows a process to perform network configuration
    operations:
      - interface configuration
      - administration of IP firewall, masquerading and
        accounting
      - setting debug options on sockets
      - modification of routing tables
      - setting arbitrary process, and process group
        ownership on sockets
      - binding to any address for transparent proxying
        (this is also allowed via CAP_NET_RAW)
      - setting TOS (Type of service)
      - setting promiscuous mode
      - clearing driver statistics
      - multicasting
      - read/write of device-specific registers
      - activation of ATM control sockets
```

Capability management

- Per-thread capabilities
  - They define the privileges of the thread
  - Divided in **sets**

- Sets
  - Effective
  - Inheritable
  - Permitted
  - Bounding
  - Ambient

Thread capability sets:
Effective

- Set of capabilities used by the kernel to perform permission checks for the thread

- That is: these are the effective capabilities being used

Thread capability sets:
Inheritable

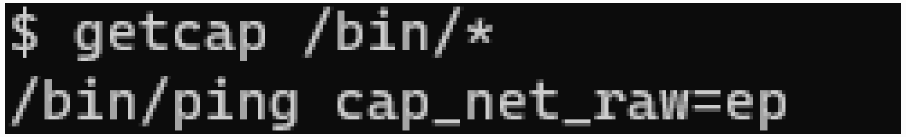
- Set of capabilities preserved across an exec
  - Remain inheritable for any program

- Are added to the permitted set when executing a program that has the corresponding bits set in the file inheritable set

Thread capability sets: Permitted

- ▷ Limiting superset
  - For the effective capabilities that the thread may assume
  - For the capabilities that may be added to the inheritable set
    - Except for threads w/ CAP_SETPCAP in their effective set

- ▷ Once dropped, it can never be reacquired
  - Except upon executing a file with special capabilities



```
$ getcap /bin/*
/bin/ping cap_net_raw=ep
```

Thread capability sets: Bounding

- Set used to limit the capabilities that are gained during an exec
  - From a file with capabilities set
- Was previously a system-wide attribute
  - Now is a per-thread attribute

Thread capability sets: Ambient

- Set of capabilities that are preserved across an exec of an unprivileged program
  - No set-UID or set-GID
  - No capabilities set
- Executing a privileged program will clear the ambient set

Thread capability sets:
Ambient

- Ambient capabilities must be both permitted and inheritable
  - One cannot preserve something one cannot have
  - One cannot preserve something one cannot inherit
  - Automatically lowered if either of the corresponding permitted or inheritable capabilities is lowered

- Ambient capabilities are added to the permitted set and assigned to the effective set upon an exec

Files extended attributes (xattr)

- Files' metadata in UNIX-like systems
  - Some not interpreted by kernels
- Linux: key-value pairs
  - Keys can be defined or undefined
  - If defined, their value can be empty or not
  - Key's namespaces
    - `namespace.attr_name[.attr_name]`

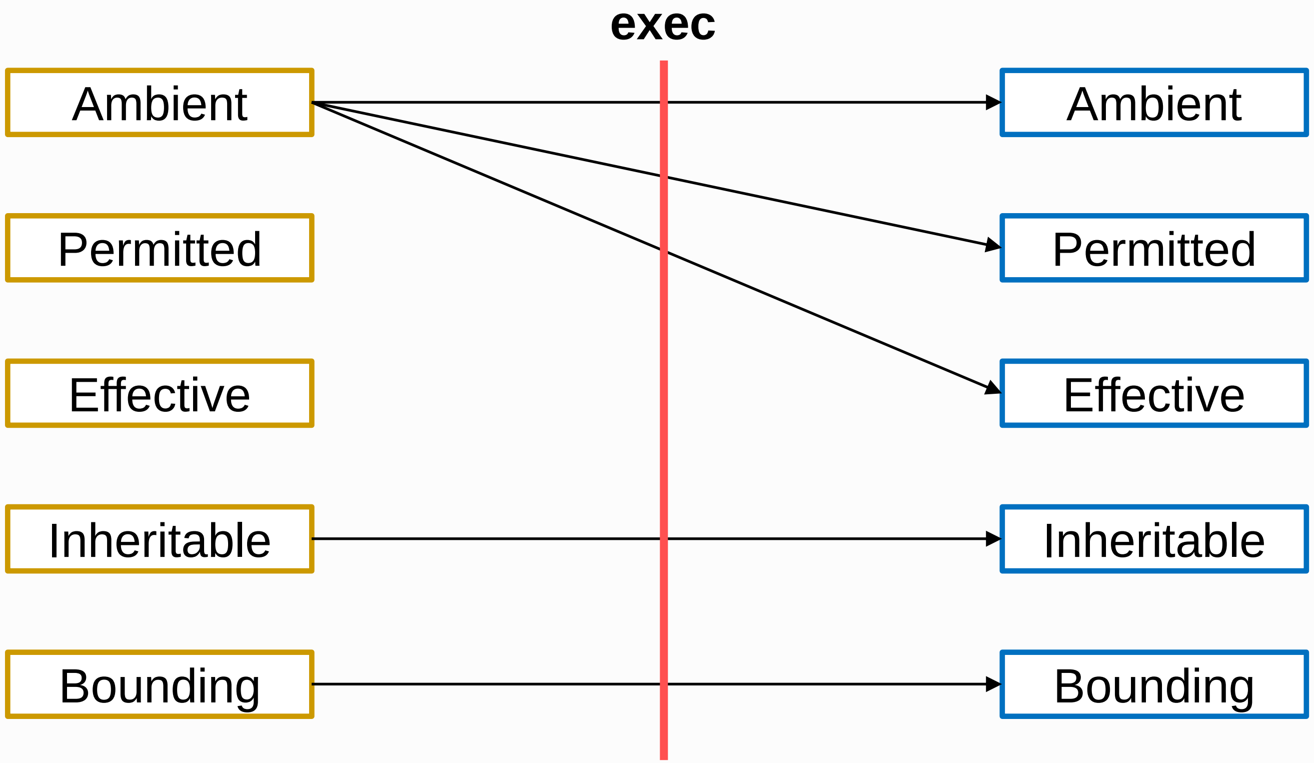
- Namespaces
  - security
    - For files' capabilities
    - setcap / getcap
  - system
    - ACL
  - trusted
    - Protected metadata
  - user
    - setfattr / lsattr / getfattr

File capabilities

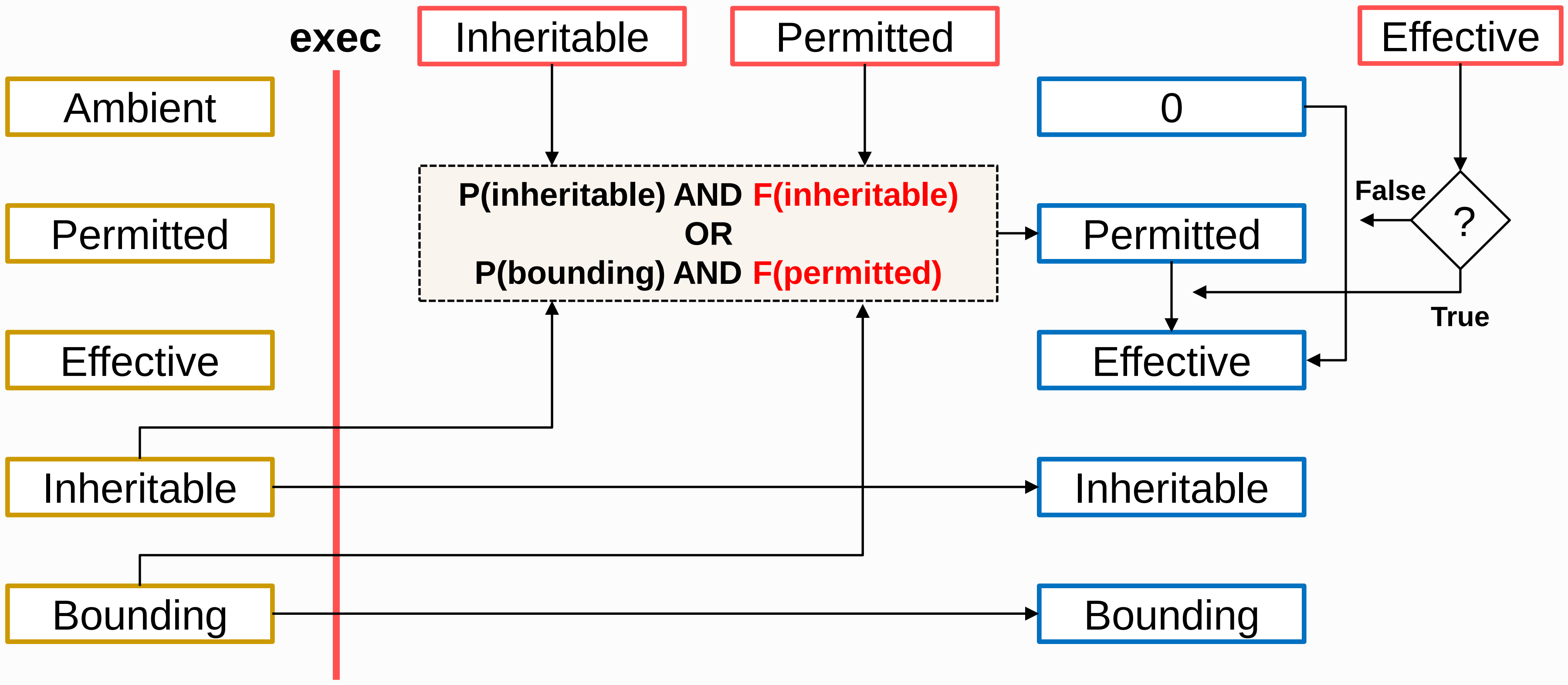
- Stored in the security.capability attribute

- Specify capabilities for threads that exec a file
  - Permitted set
    - Immediately forced into the permitted set
    - Previous AND with the thread's bounding set
  - Inheritable set
    - To AND with the threads' inheritable set
    - Can be used to reduce the effective set upon the exec
  - Effective bit
    - Enforce all new capabilities into the thread's effective set

Capability transfer across exec: No privileged files



Capability transfer across exec (non-root) Privileged files



Capability transfer across exec (root)

- EUID = 0 or RUID = 0
  - Capability sets are considered to be all 1’s

- EUID = 0
  - File effective bit considered 1

- Exception: EUID = 0, RUID ≠ 0
  - Set-UID file was executed
  - File capabilities are honored if present

Control groups (cgroups)

- Collection of processes bound by the same criteria and associated with a set of parameters or limits

- cgroups are organized hierarchically
  - cgroup file system
  - Limits can be defined at each hierarchical level
    - Affecting the sub-hierarchy underneath

- Subsystems
  - Kernel component that modifies the behavior of cgroup processes
  - Resource controllers (or simply controllers)

cgroups v1 and v2

- Currently two versions coexist
  - But controllers can only be used in on of them

cgroups file system

- This file system is created by mounting several controllers as cgroup-type file system entities
  - Usually /sys/fs/cgroup
  - In V2 all controllers are part of a single cgroup2

- Each controller defines a tree of cgroups below the mount point
  - e.g. memory controller → /sys/fs/cgroup/…/memory.[…]

cgroup V2 (and V1) controllers

- cpu (cpu & cpuacct in V1)
  - CPU usage & accounting
- cpuset
  - CPU bounding
- memory
  - Memory usage & accounting
- devices
  - Device creation & usage
- freezer
  - Suspend/resume groups of processes
- Io (blkio in V1)
  - Block I/O management
- perf_event
  - Performance monitoring
- hugelb
  - Huge pages management
- pids
  - # of processes in cgroup
- rdma
  - RDMA / IB resources' management
- Deprecated from V1
  - net_cls
    - Outbound packet classification
  - net_prio
    - Network interfaces priorities

cgroup V2 definition

- Directory under /sys/fs/cgroup
  - With a set of controllers defined by cgroup.controllers
  - With hierarchy limits defined by cgroup.depth and cgroup.descendants
  - With files to send KILL signals (cgroup.kill) and freeze/unfreeze orders (cgroup.freeze) to all cgroup processes
    - Including descendants
  - The processes using the cgroup are given by cgroup.procs and their status reported by cgroups.events
    - We can add a process to a cgroup just by writing its PID on the first file

- For each active controller, specific files will exist

- Processes can only belong to leaf cgroups
  - "No internal processes" rule

cgroups of a process

- A process can be controlled by an arbitrary number of cgroups

- The list of a process' cgroups is given by the /proc file system
  - /proc/[PID]/cgroup

Linux Security Modules (LSM)

- Framework to add new Mandatory Access Control (MAC) extensions to the kernel

- Those extensions are not kernel modules
  - They are embedded in the kernel code
  - They can be activated or not at boot time
  - List of extensions given by /sys/kernel/security/lsm

LSM extensions

- Capabilities (default)
- AppArmor
  - MAC for applications
- LoadPin
  - Kernel-loaded files origin enforcement
- SELinux
- Smack
  - Simplified Mandatory Access Control Kernel
- TOMOYO
  - Name-based MAC extension
- Yama
  - System-wide DAC security protections that are not handled by the core kernel itself
- SafeSetID
  - Restricts UID/GID transitions

Source: https://www.kernel.org/doc/html/next/admin-guide/LSM/index.html

AppArmor

- Enables the definition of per-application MAC policies
  - Profiles
  - Applications are identified by their path
    - Instead of i-node
- Profiles restrict applications' actions to the required set
  - All other actions will be denied
- Profiles define
  - Actions white-listed
  - Logging actions

AppArmor: profiles

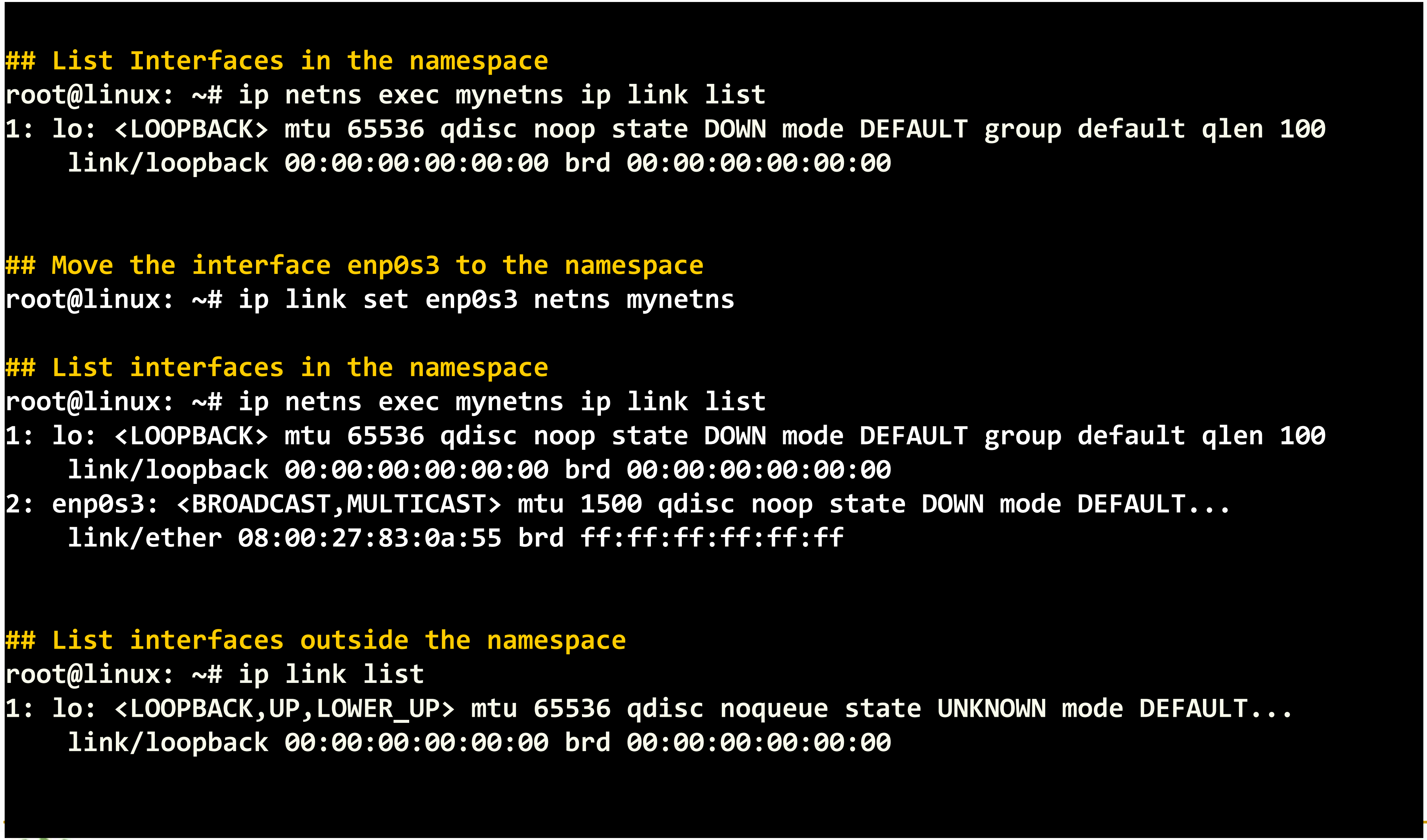
- Profiles are loaded into the kernel
  - Upon compilation from textual files
  - apparmor_parser

- Profiles can be used on a voluntary basis
  - aa-exec

Confinement: Namespaces

- Allows partitioning of resources in views (namespaces)
  - Processes in a namespace have a restricted view of the system
  - Activated through syscalls by a simple process:
    - clone: Defines a namespace to migrate the process to
    - unshare: disassociates the process from its current context
    - setns: puts the process in a Namespace
- Types of Namespaces
  - **Mount**: Applied to mount points
  - **process id**: first process has id 1
  - **network**: "independent" network stack (routes, interfaces…)
  - **IPC**: methods of communication between processes
  - **uts**: name independence (DNS)
  - **user id**: segregation of permissions
  - **cgroup**: limitation of resources used (memory, cpu…)

```
## Create netns named mynetns
root@vm: ~# ip netns add mynetns

## Change iptables INPUT policy for the netns
root@linux: ~# ip netns exec mynetns iptables -P INPUT DROP


## List iptables rules outside the namespace
root@linux: ~# iptables -L INPUT
Chain INPUT (policy ACCEPT)
target     prot opt source               destination


## List iptables rules inside the namespace
root@linux: ~# ip netns exec mynetns iptables -L INPUT
Chain INPUT (policy DROP)
target     prot opt source               destination
```



```
## List Interfaces in the namespace
root@linux: ~# ip netns exec mynetns ip link list
1: lo: <LOOPBACK> mtu 65536 qdisc noop state DOWN mode DEFAULT group default qlen 100
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00


## Move the interface enp0s3 to the namespace
root@linux: ~# ip link set enp0s3 netns mynetns

## List interfaces in the namespace
root@linux: ~# ip netns exec mynetns ip link list
1: lo: <LOOPBACK> mtu 65536 qdisc noop state DOWN mode DEFAULT group default qlen 100
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
2: enp0s3: <BROADCAST,MULTICAST> mtu 1500 qdisc noop state DOWN mode DEFAULT...
    link/ether 08:00:27:83:0a:55 brd ff:ff:ff:ff:ff:ff


## List interfaces outside the namespace
root@linux: ~# ip link list
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN mode DEFAULT...
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
```

Confinement: Containers

- Explores namespaces to provide a virtual view of the system
  - Network isolation, cgroups, user ids, mounts, etc...
- Processes are executed under a container
  - Container is an applicational construction and not of the core
  - Consists of an environment by composition of namespaces
  - Requires building bridges with the real system network interfaces, proxy processes
- Relevant approaches
  - **LinuX Containers**: focus on a complete virtualized environment
    - evolution of OpenVZ
  - **Docker**: focus on running isolated applications based on a portable packet between systems
    - uses LXC

Authentication protocols

Identity attributes

- Set of attributes for setting apart individuals
  - Name
  - Numerical identifiers
    - Fixed for life
    - Variable with context
  - Address
  - Photo
  - Identity of relatives
    - Usually parents
  - …

Authentication: Definition

- Proof that an entity has a claimed identity attribute

  - Hi, I’m Joe
  - Prove it!
  - Here are my Joe’s credentials
  - Credentials accepted/not accepted

  - Hi, I’m over 18
  - Prove it!
  - Here is the proof
  - Proof accepted/not accepted

Authentication: proof types

- Something we know
  - A secret memorized (or written down…) by Joe
- Something we have
  - An object/token solely held by Joe
- Something we are
  - Joe's Biometry
- Multi-factor authentication
  - Join or consecutive use of different proof types

Multi-factor verification jokes

Authentication: goals

- Authenticate interactors
  - People, services, servers, hosts, networks, etc.
- Enable the enforcement of authorization policies and mechanisms
  - Authorization ⇒ authentication
- Facilitate the exploitation of other security-related protocols
  - e.g. key distribution for secure communication

Authentication: requirements

- Trustworthiness
  - How good is it in proving the identity of an entity?
  - How difficult is it to be deceived?
  - Level of Assurance (LoA) (NIST, eIDAS, ISO 29115)

    LoA 1 - Little or no confidence in the asserted identity

    LoA 2 - Some confidence in the asserted identity

    LoA 3 - High confidence in the asserted identity

    LoA 4 - Very high confidence in the asserted identity
- Secrecy
  - No disclosure of secrets used by legitimate entities

Authentication: requirements

- Robustness
  - Prevent attacks to the protocol data exchanges
  - Prevent on-line DoS attack scenarios
  - Prevent off-line dictionary attacks
- Simplicity
  - It should be as simple as possible to prevent entities from choosing dangerous shortcuts
- Deal with vulnerabilities introduced by people
  - They have a natural tendency to facilitate or to take shortcuts

Authentication: Entities and deployment model

- Entities
  - People
  - Hosts
  - Networks
  - Services / servers

- Deployment model
  - Along the time
    - Only when interaction starts
    - Continuously along the interaction
  - Directionality
    - Unidirectional
    - Bidirectional (or mutual)

Authentication interactions: Basic approaches

- Direct approach
  - Provide credentials
  - Wait for verdict
  - Authenticator checks credentials against what it knows
- Challenge-response approach
  - Get challenge
  - Provide a response computed from the challenge and the credentials
  - Wait for verdict
  - Authenticator checks response for the challenge provided and the credentials it knows

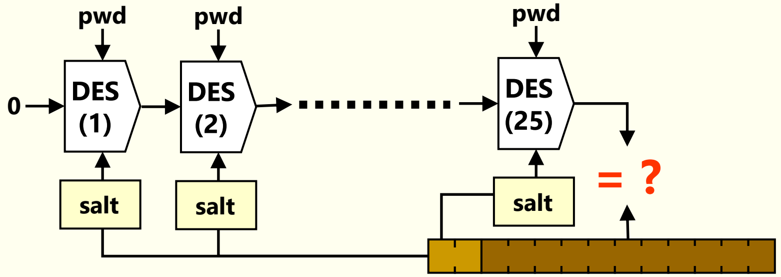
Authentication of people: Direct approach w/ known password

- A password is matched with a stored value
  - For a claimed identity (username)
- Personal stored value:
  - Transformed by a unidirectional function
    - Key Derivation Function (KDF)
    - Preferably slow!
    - Bcrypt, scrypt, Argon2, PBKDF2
  - UNIX: DES hash + salt
  - Linux: KDF + salt
  - Windows: digest function

DES hash = $\text{DES}_{pwd}^{25}(0)$

$\text{DES}_k^n(x) = \text{DES}_k(\text{DES}_k^{n-1}(x))$

Permutation of 12 subkeys´bit pairs with salt (12 bits)



Authentication of people: Direct approach w/ known password

- Advantage
  - Simplicity!
  - Sharing!
- Problems
  - Usage of predictable passwords
    - They enable dictionary attacks
  - Different passwords for different systems
    - To prevent impersonation by malicious admins
    - But our memory has limits!
  - Exchange along insecure communication channels
    - Eavesdroppers can easily learn the password
    - e.g. Unix remote services, PAP

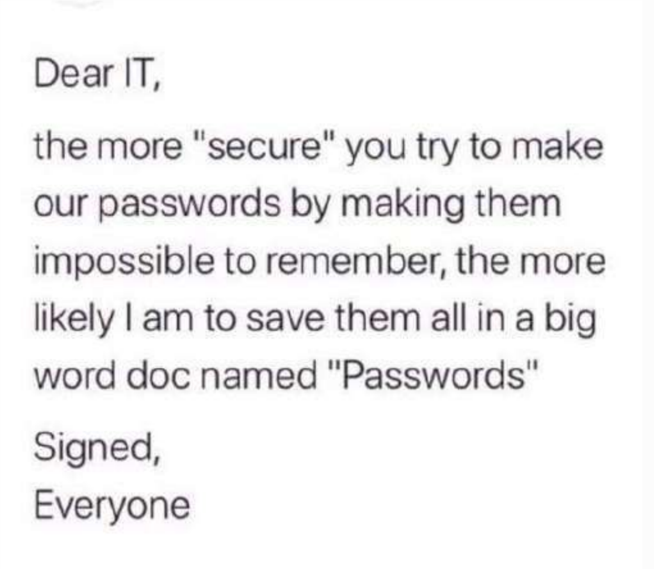
PUZZLES? TRYING TO REMEMBER MY PASSWORDS IS ALL THE MENTAL STIMULATION I NEED.
STAHLER 9/30
©2015 Jeff Stahler/Dist. by Universal UClick for UFS

Top 10 2023 at Portugal by NordPass

1 - 123456
2 - 12345
3 - 123456789
4 – 12345678
5 - benfica
6 - portugal
7 - sporting
8 - 1234567890
9 - password
10 - 1234567

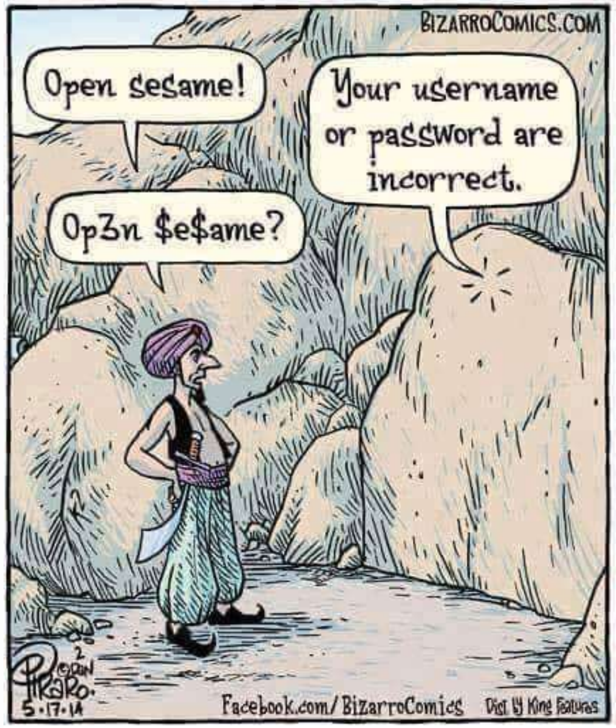
source: https://nordpass.com/most-common-passwords-list/
Image https://www.pinterest.com/networkboxusa/it-humor

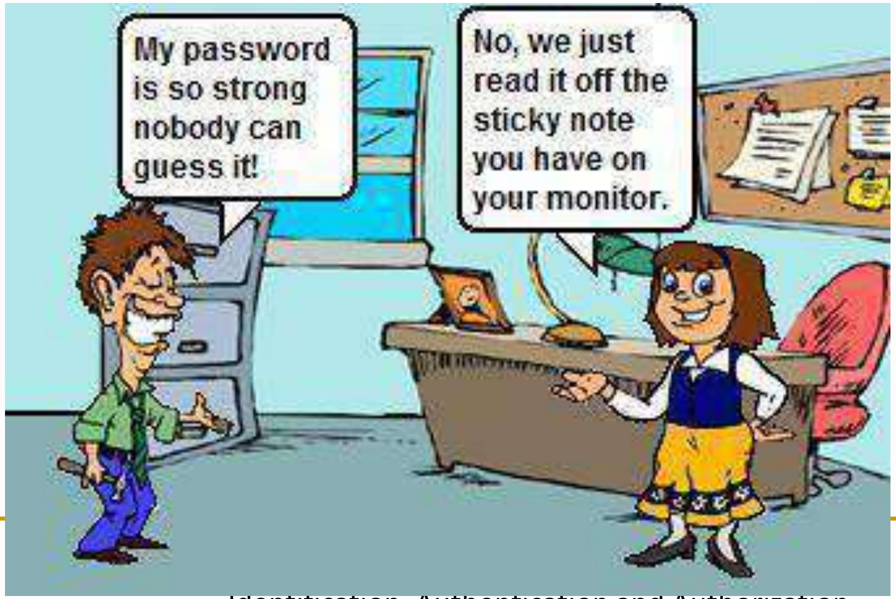
Password selection jokes

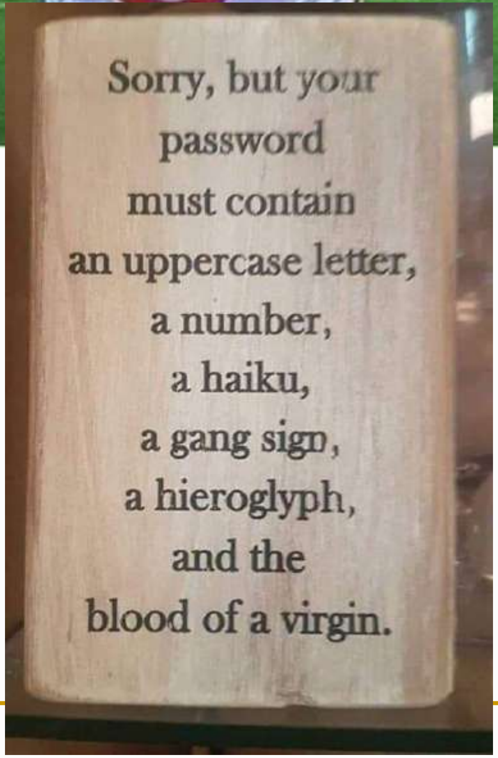

Dear IT,

the more "secure" you try to make our passwords by making them impossible to remember, the more likely I am to save them all in a big word doc named "Passwords"

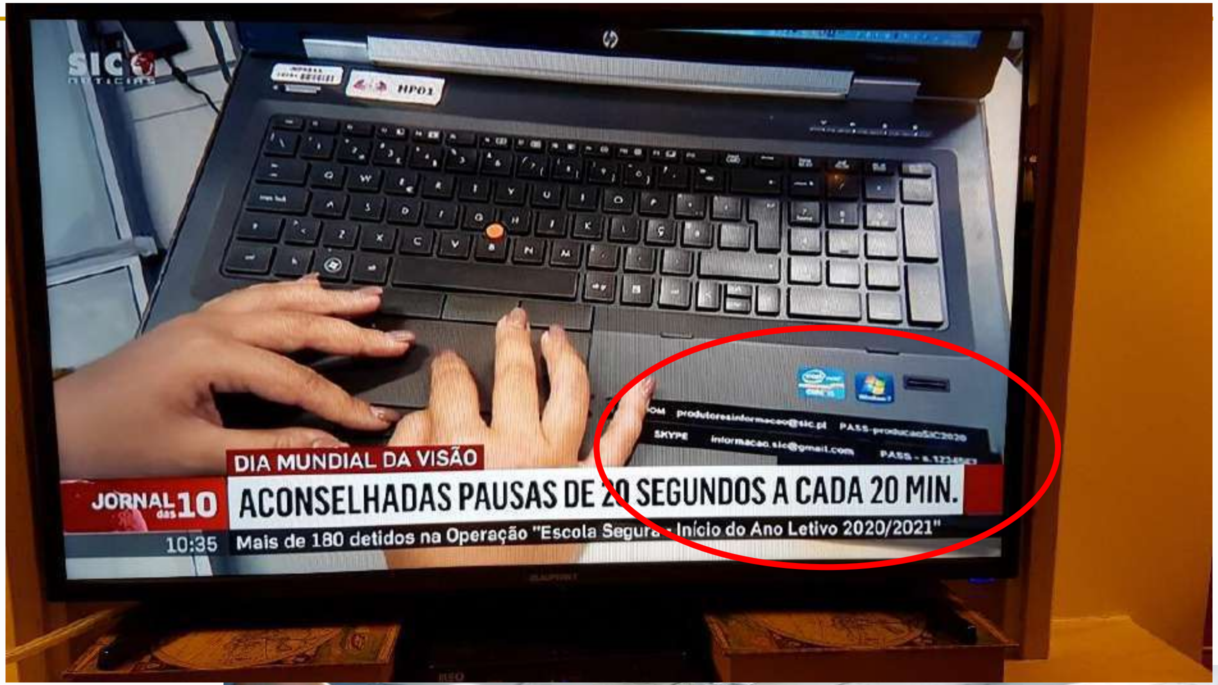
Signed,
Everyone

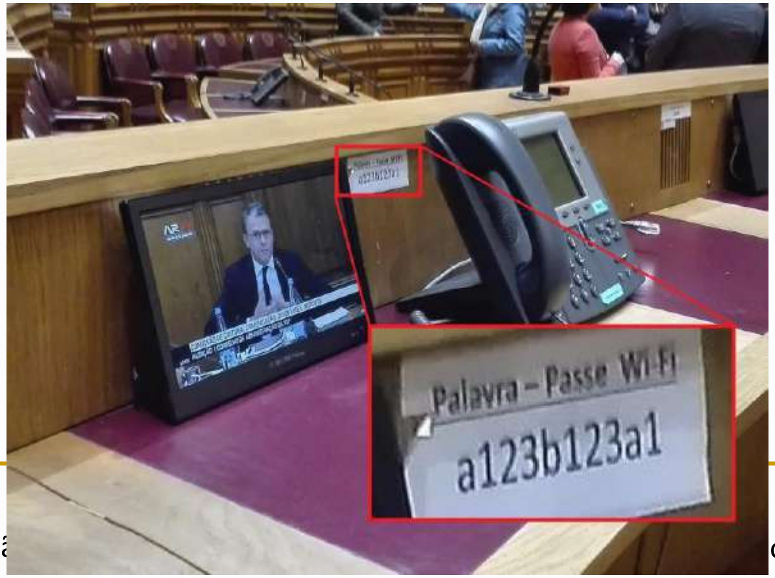

BIZARROCOMICS.COM
Open sesame!
Your username or password are incorrect.
Op3n $e$ame?
Facebook.com/BizarroComics
Dist. by King Features


My password is so strong nobody can guess it!
No, we just read it off the sticky note you have on your monitor.


Sorry, but your password must contain an uppercase letter, a number, a haiku, a gang sign, a hieroglyph, and the blood of a virgin.

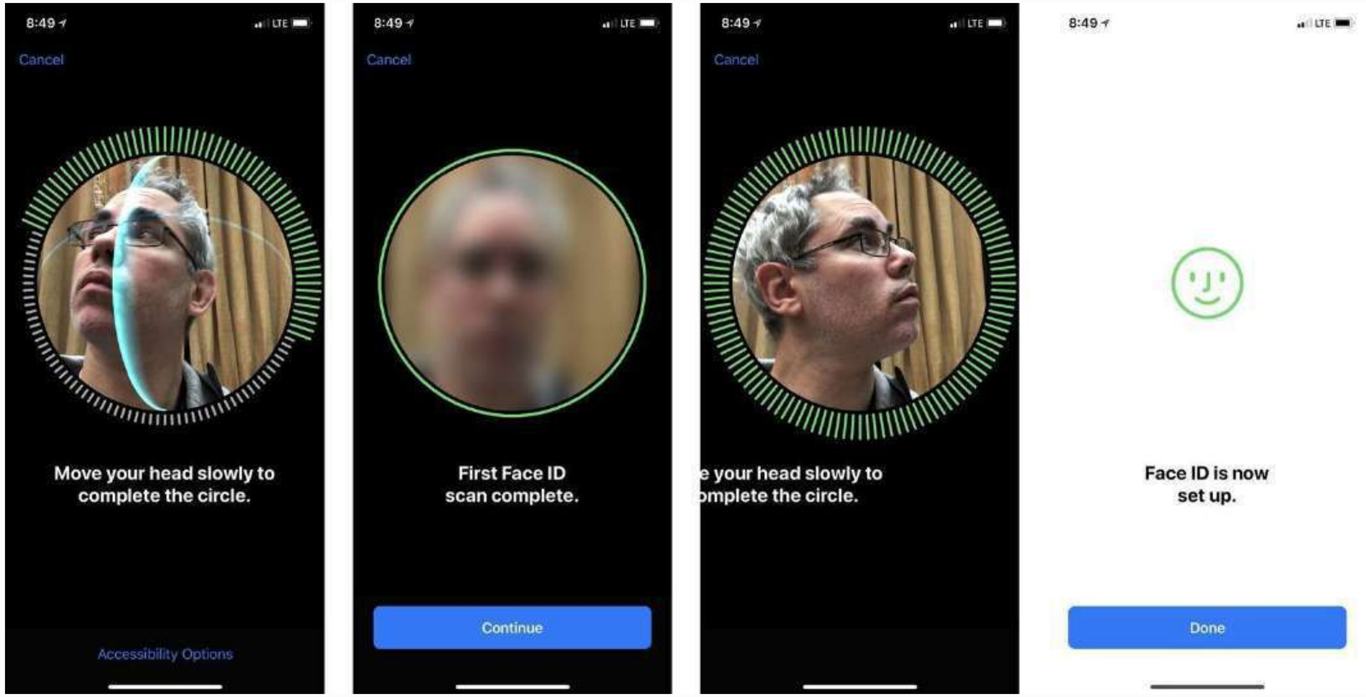
Password bloopers


SIC Notícias
produtoresinformacao@sic.pt PASS-producaoSIC2020
SKYPE informacao.sic@gmail.com PASS - a.123456
DIA MUNDIAL DA VISÃO
JORNAL das 10
ACONSELHADAS PAUSAS DE 20 SEGUNDOS A CADA 20 MIN.
10:35
Mais de 180 detidos na Operação "Escola Segura - Início do Ano Letivo 2020/2021"



Authentication of people:
Direct approach with biometrics

- People get authenticated using body measurements
  - Biometric samples or features
  - Common modalities
    - Fingerprint
    - Facial recognition
    - Palm print
    - Iris scan
    - Voice recognition
    - DNA
- Measures are compared with personal records
  - Biometric references (or template)
  - Registered in the system with a previous enrolment procedure

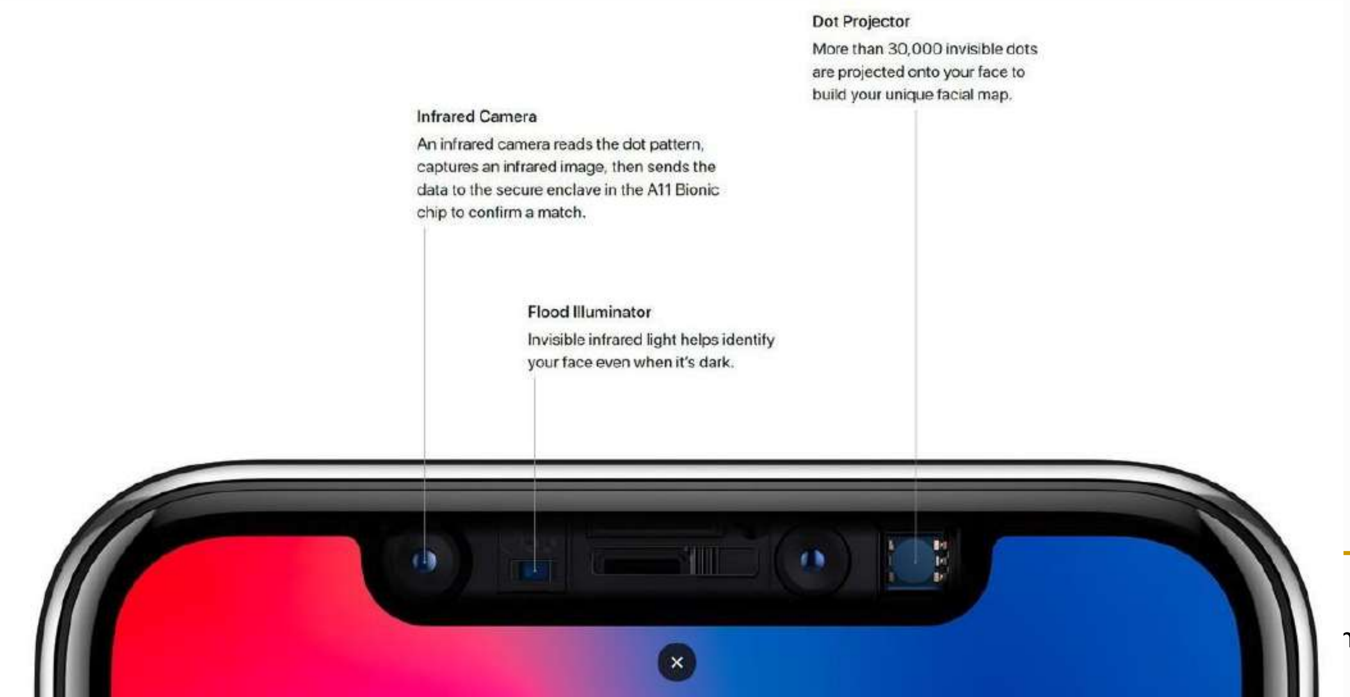


Move your head slowly to complete the circle.

First Face ID scan complete.

e your head slowly to omplete the circle.

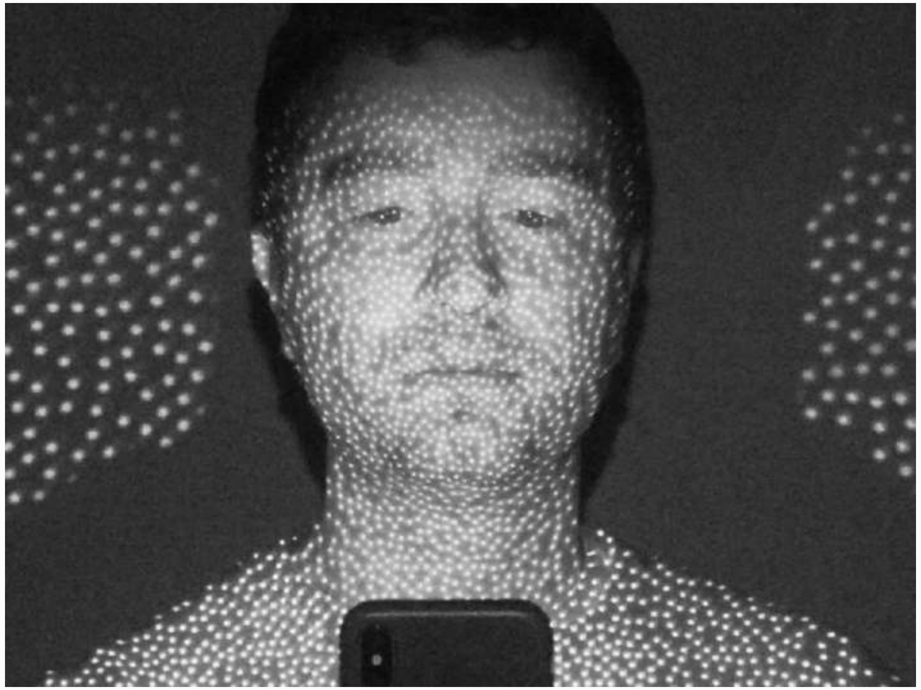
Face ID is now set up.



Dot Projector
More than 30,000 invisible dots are projected onto your face to build your unique facial map.

Infrared Camera
An infrared camera reads the dot pattern, captures an infrared image, then sends the data to the secure enclave in the A11 Bionic chip to confirm a match.

Flood Illuminator
Invisible infrared light helps identify your face even when it's dark.



Fingerprint sensor

An optical sensor.

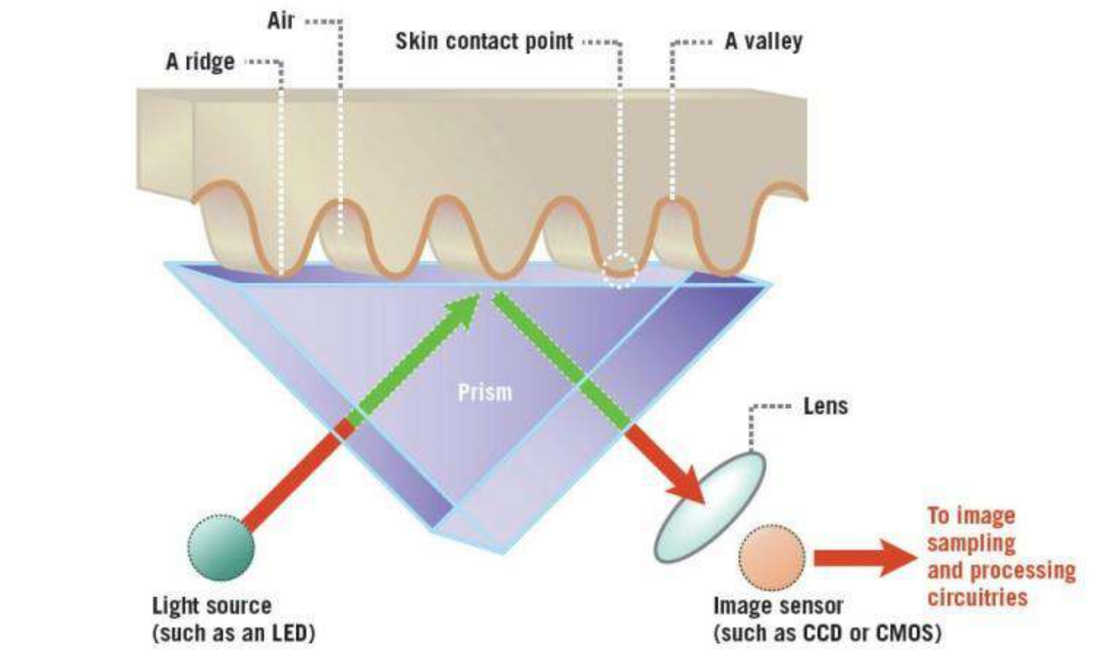
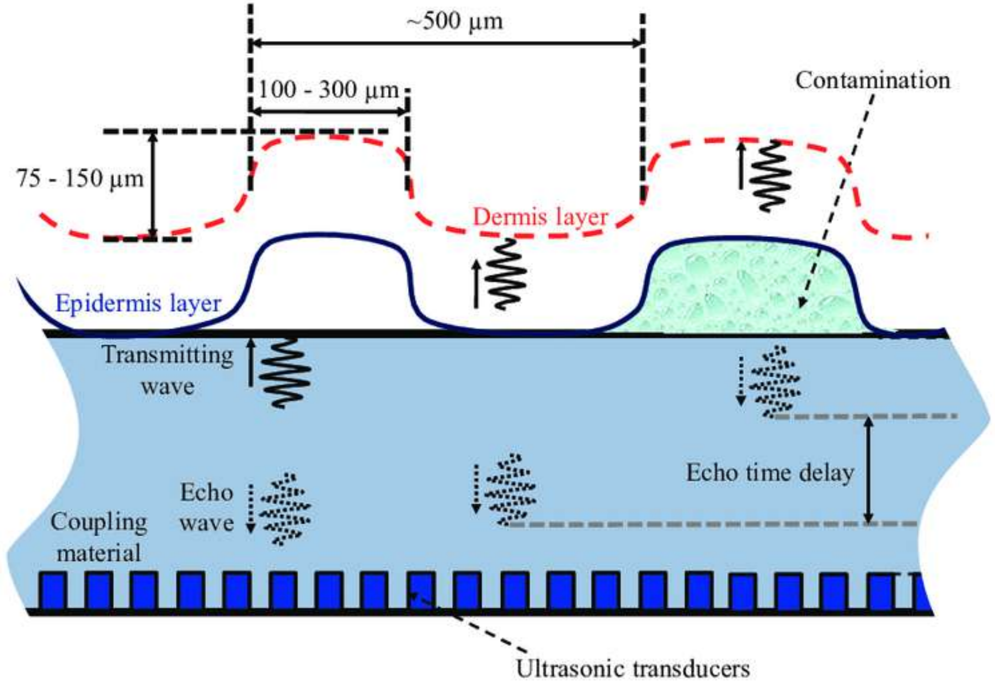


Figure 2



- ▷ Easy to bypass: youtube/watch?v=hJ35ApLKpN4

Biometrics: advantages

- Convenient: people do not need to use memory
  - Just be their self
- People cannot choose weak passwords
  - In fact, they don’t choose anything
- Credentials cannot be transferred to others
  - One cannot delegate their own authentication
- Stealth identification
  - Interesting for security surveillance

Biometrics: problems

- Usability
  - Comfort of people, ergonomic
  - Exploitation scenario
- Biometrics are still being improved
  - In many cases they can be easily cheated
  - Liveness detection
- People cannot change their credentials
  - Upon their robbery
- It can be risky for people
  - Removal of body parts for impersonation of the victim

Image source: https://biometrics.mainguet.org/types/tongue.htm

Biometrics: problems

- Sensitivity tuning
  - Reduction of FRR (annoying)
  - Reduction of FAR (dangerous)
  - Tuning is mainly performed with the target population
    - Not with attackers!
- Not easy to deploy remotely
  - Requires trusting the remote sample acquisition system
- Can reveal personal sensitive information
  - Diseases
- Credentials cannot be (easily) copied to others
  - In case of need in exceptional circumstances

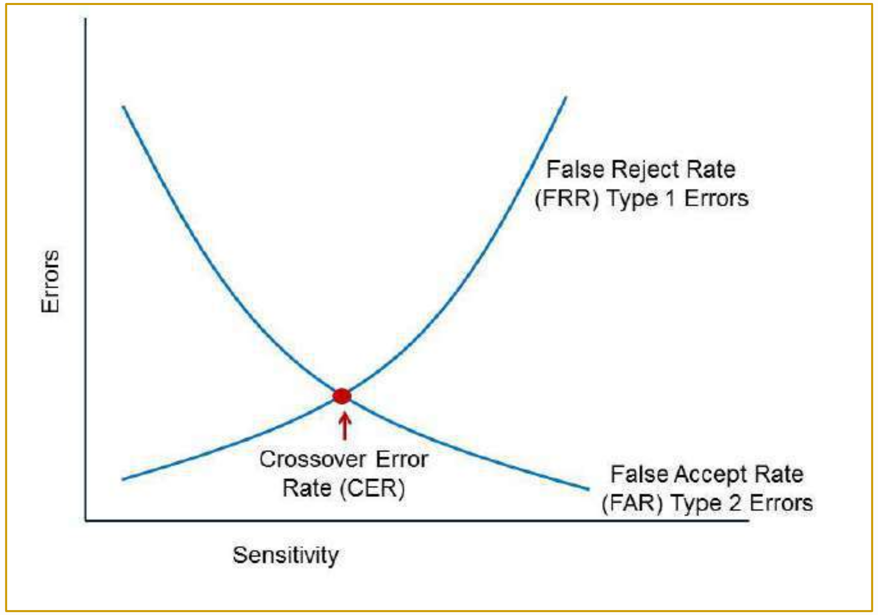


Image source: http://www.pearsonitcertification.com/articles/article.aspx?p=1718488

Authentication of people: Direct approach with OTPs

- One-time password (OTP)
  - Credential that can be used only once

- Advantage
  - OTPs can be eavesdropped
  - Eavesdroppers cannot impersonate the OTP owner
    - True for passive eavesdroppers
    - False for active attackers!

Authentication of people: Direct approach with OTPs

- Problems
  - Interactors need to know which password they should use at different occasions
    - Requires some form of synchronization
  - People may need to use extra resources to maintain or generate one-time passwords
    - Paper sheets
    - Computer programs
    - Special devices, etc.

Authentication of people: OTPs and secondary channels

- OTPs are codes sent through secondary channels
  - A secondary channel is a channel that is not the one were the code is going to be used
    - SMS, email, Twitter, Firebase, QR codes, NFC, etc.
  - The secondary channel provides the synchronization
    - Just-in-time provision of OTP

- Two authentications are possible
  - Confirm a secondary channel provided by a profile owner
    - In order to trust that that channel belongs to the profile owner
  - Authenticate the owner of a profile
    - Which is bound to a secondary channel

Authentication of people: OTPs produced from a shared key

- HOTP (Hash-based One Time Password, RFC 4226)
  - OTP generated from a counter and a shared key
  - Counters are updated independently

- TOTP (Time-based One Time Password, RFC 6238)
  - OTP generated from a timestamp and a shared password
  - TOTP is HOTP with timestamps instead of counters
  - Clocks need a rough synchronization

HOTP (HMAC-based one-time password, RFC 4226)

- Numeric OTP computed from shared key K and synchronized counter C
  - Hash key and counter
    - And increase counter
  - From hash, get a (floating) portion of 31 contiguous bits
    - Dynamic Binary Code (DBC)
  - Compute a *d*-long decimal number
    - $d \geq 6$

- Issues
  - Counter synchronization upon a failure
    - If the authenticator keeps it after a failure, exhaustive search attacks are viable
    - If the authenticator always increments it, DoS attacks are possible
  - Acceptance windows
    - Mitigates minor desynchronizations, but decreases security

TOPT (Time-based one-time password, RFC 6238)

- HOTP with a counter derived from time

- $C_T = \left\lfloor \frac{T - T_0}{T_x} \right\rfloor$
  - T – initial time
  - T_0– initial time
  - T_x– time interval (default: 30 seconds)

- $\mathrm{TOTP}(K) = \mathrm{HOTP}(K, C_T)$

Token-based OTP generators: RSA SecurID

- Personal authentication token
  - Or software modules for handhelds (PDAs, smartphones, etc.)

- It generates a unique number at a fixed rate
  - Usually one per minute (or 30 seconds)
  - Bound to a person (User ID)
  - Unique number computed with:
    - A 64-bit key stored in the token
    - The actual timestamp
    - A proprietary digest algorithm (SecurID hash)
    - An extra PIN (only for some tokens)

RSA SecurID

- OTP-based authentication
  - A user combines their User ID with the current token number

    OTP = User ID, Token Number

- An RSA ACE Server does the same and checks for match
  - It also knows the person’s key stored in the token
  - There must be a synchronization to tackle clock drifts
    - RSA Security Time Synchronization

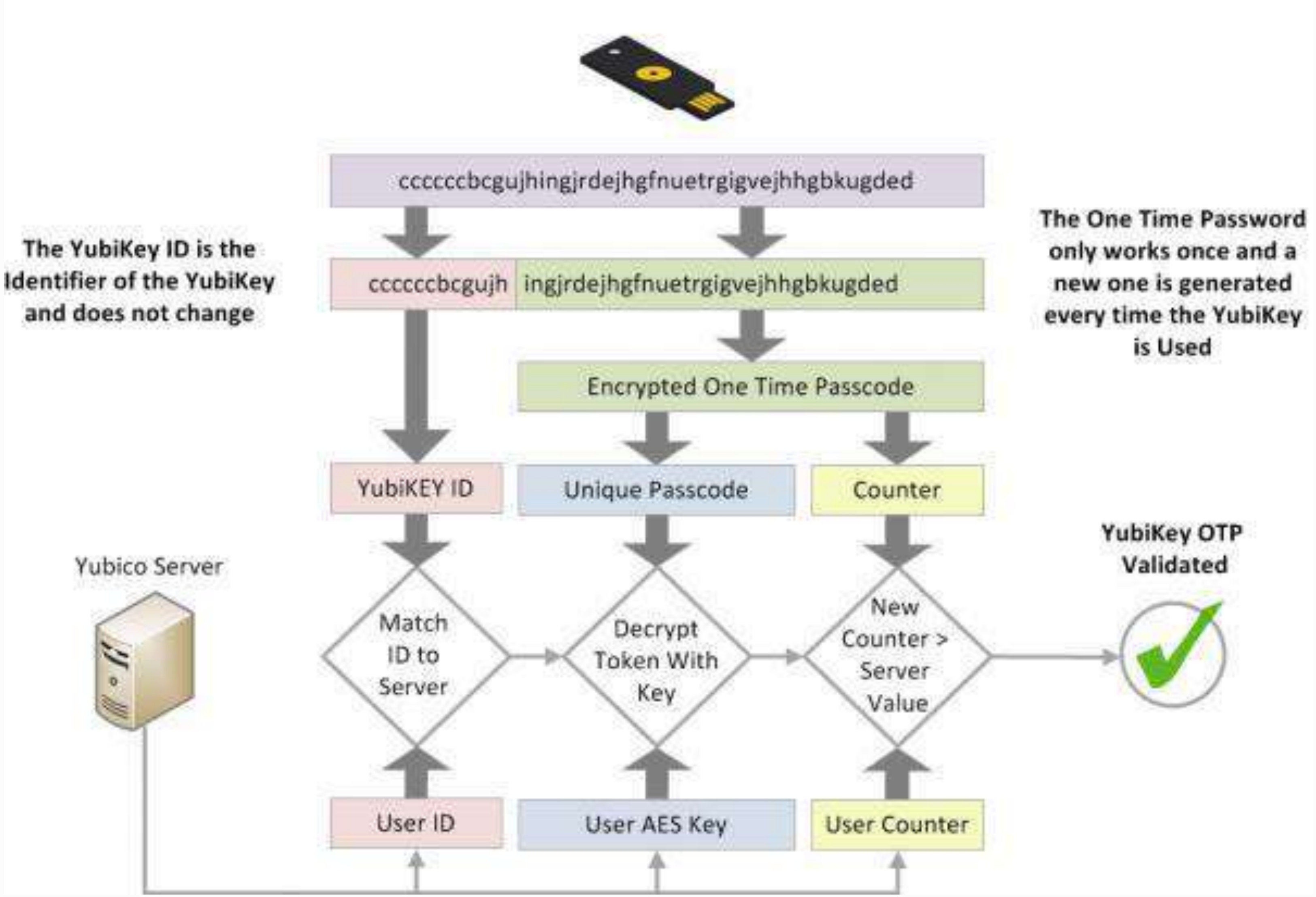
- Robust against dictionary attacks
  - Keys are not selected by people

Yubikey

- Personal Authentication Device
  - USB and/or NFC

- Activation generates a 44 characters key
  - Emulates a USB keyboard (besides an own API)
  - Supports HOTP (events) or TOPT (Temporal)
  - If a challenges is provided, user most touch the button to obtain a result
  - Several algos, including AES 256

cccjgjgkhcbbirdrfdnlnghhfgrtnnlgedjlftrbdeut



cccccbcgujhingjrdejhgfnuetrgigvejhhgbkugded
cccccbcgujh
ingjrdejhgfnuetrgigvejhhgbkugded
The YubiKey ID is the Identifier of the YubiKey and does not change
The One Time Password only works once and a new one is generated every time the YubiKey is Used
Encrypted One Time Passcode
YubiKEY ID
Unique Passcode
Counter
Yubico Server
Match ID to Server
Decrypt Token With Key
New Counter > Server Value
YubiKey OTP Validated
User ID
User AES Key
User Counter

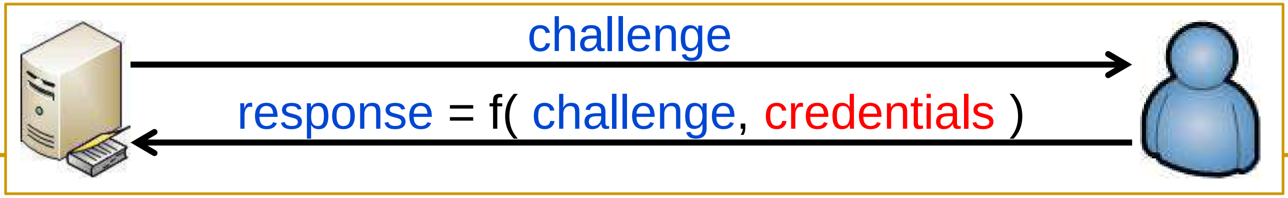
Challenge-response approach: Generic description

- The authenticator provides a challenge

- The entity being authenticated transforms the challenge
  - With its authentication credentials

- The result (response) is sent to the authenticator

- The authenticator checks the response
  - Produces a similar result and checks if they match
  - Transforms the result and checks if it matches the challenge or a related value



Challenge-response approach: Generic description

- Advantage
  - Authentication credentials are not exposed
- Problems
  - People may require means to compute responses
    - Hardware or software
  - The authenticator may have to have access to shared secrets
    - How can we prevent them from using the secrets elsewhere?
  - Offline dictionary attacks
    - Against recorded challenge-response dialogs
    - Can reveal secret credentials (passwords, keys)

Challenge-response protocols: selection of challenges

- Challenges cannot be repeated for the same entity
  - Same challenge → same response
  - An active attacker can impersonate a user using a previously recorded protocol run

- Challenges should be nonces
  - Nonce: number used only once
  - Stateful services can use counters
  - Stateless services can use (large) random numbers
  - Time can be used, but with caution
    - Because one cannot repeat a timestamp

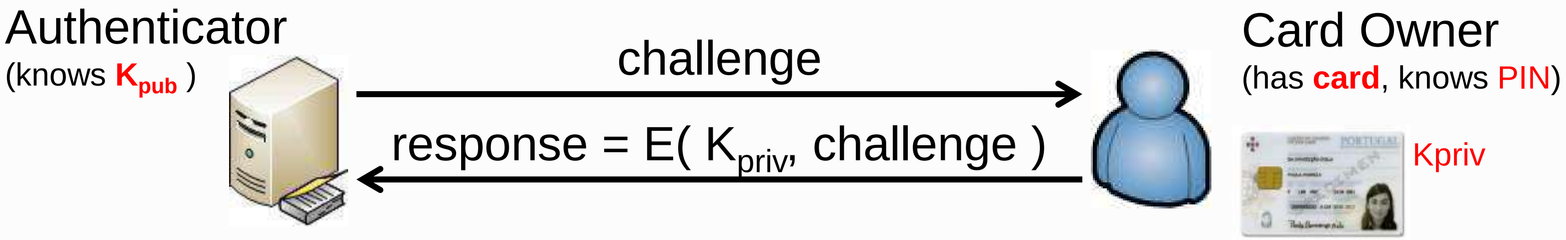
Authentication of people: Challenge-response with smartcards

- ▷ Authentication credentials
  - The smartcard
    - e.g. Citizen Card
  - The private key stored in the smartcard
  - The PIN to unlock the private key

- ▷ The authenticator knows
  - The corresponding public key
  - Or some personal identifier
    - Which can be related with a public key through a (verifiable) certificate

PORTUGAL
DA CONCEIÇÃO ÁVILA
PAULA ANDREIA
SPECIMEN
PORTUGAL
RAFAEL DA CRUZ ÁVILA * MARGARIDA RIBEIRO DA CONCEIÇÃO ÁVILA
I<PRT000000000<<0<ZZ4<<<<<<<<<<2
8108108F1201158PRT<<<<<<<<<<<1
AVILA<<PAULA<ANDREIA<CONCEICAO

Authentication of people: Challenge-response with smartcards



Authenticator

(knows K_{pub})

challenge

response = E(K_{priv}, challenge)

Card Owner

(has **card**, knows PIN)

Kpriv

- Signature-based protocol
  - The authenticator generates a random challenge
    - Or a value not used before
  - The card owner ciphers the challenge with their private key
    - PIN-protected
  - The authenticator decrypts the result with the public key
    - If the output matches the challenge, the authentication succeeds

- Encryption-based protocol
  - Possible when private key decryption is available

Authentication of people:

Challenge-response with memorized password

- Authentication credentials
  - Passwords selected by people

- The authenticator knows
  - All the registered passwords; or
  - A transformation of each password
    - Preferable option
    - Preferably combined with some local value (salt)
    - Preferable using a tunable function (e.g. iterations)

Authentication of people:

Challenge-response with memorized password

- ▷ The authenticator generates a random challenge

- ▷ The person computes a function of the challenge and password
  - e.g. a joint digest: response = digest (challenge, password)
  - e.g. an encryption response = $E_{password}$ (challenge)

- ▷ The authenticator does the same (or the inverse)
  - If the output matches the response (or the challenge), the authentication succeeds

- ▷ Examples
  - CHAP, MS-CHAP v1/v2, S/Key

PAP & CHAP (RFC 1334, 1992, RFC 1994, 1996)

- Protocols used in PPP (Point-to-Point Protocol)
  - Unidirectional authentication
    - Authenticator is not authenticated
- PPP developed in 1992
  - Mostly used for dial-up connections
- PPP protocols are used by PPTP VPNs
  - e.g. vpn.ua.pt

PAP & CHAP (RFC 1334, 1992, RFC 1994, 1996)

- PAP (PPP Authentication Protocol)
  - Simple UID/password presentation
  - Insecure cleartext password transmission

- CHAP (CHallenge-response Authentication Protocol)

  Aut → U: authID, challenge
  U → Aut: authID, MD5(authID, pwd, challenge), identity
  Aut → U: authID, OK/not OK

  - The authenticator may require a reauthentication anytime

MS-CHAP (Microsoft CHAP) (RFC 2433, 1998, RFC 2759, 2000)

- Version 1

  A → U: authID, **C**
  U → A: **R1**, **R2**
  A →U: OK/not OK

  R1 = DES_{LMPH}(C)
  R2 = DES_{NTPH}(C)

  LMPH = DEShash(pwd')
  NTPH = MD4(pwd)

  pwd' = capitalized(pwd)

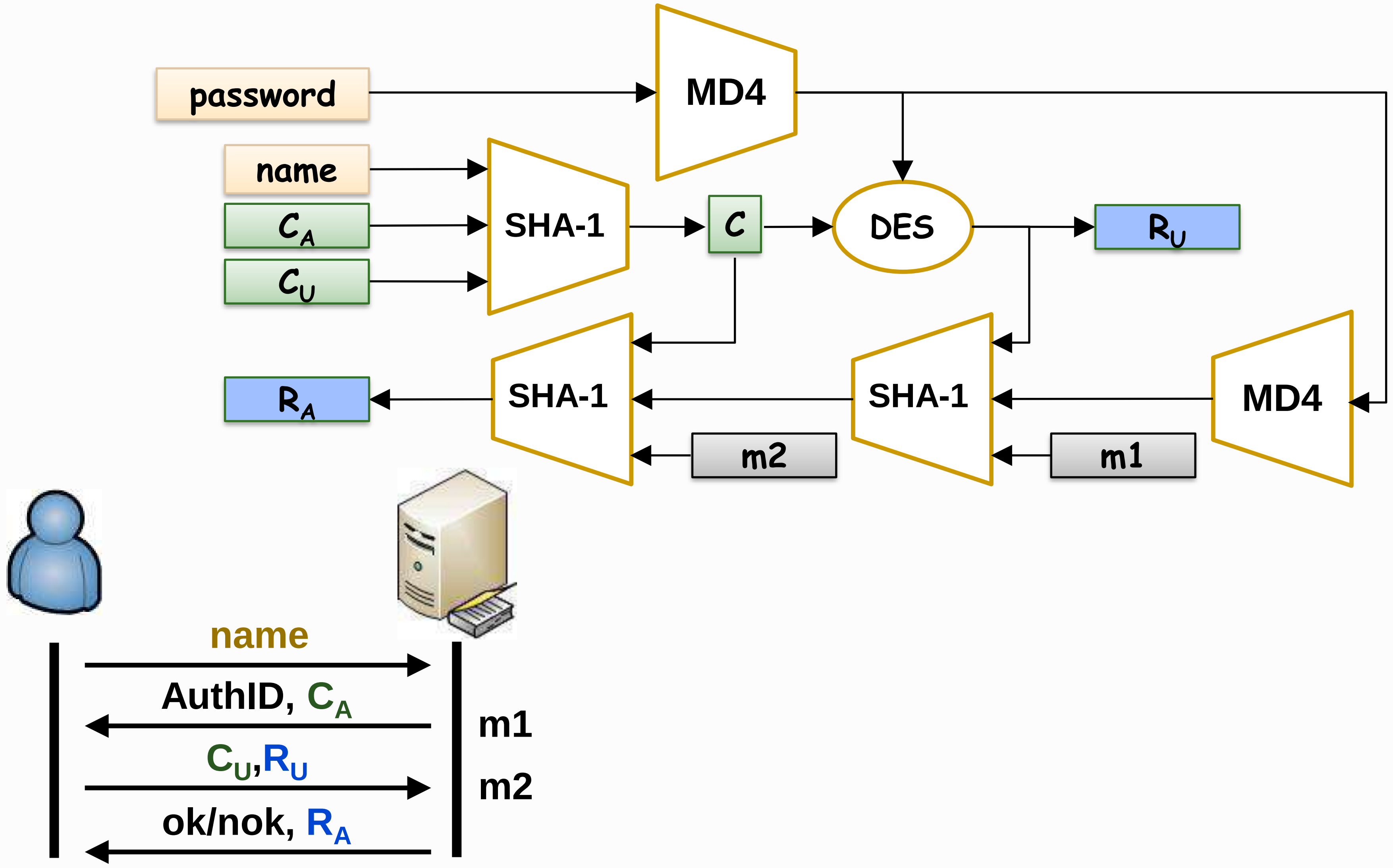
- Version 2

  A → U: authID, $\mathbf{C_A}$ ← m1
  U → A: $\mathbf{C_U}$, **R1** ← m2
  A → U: OK/not OK, **R2**

  R1 = DES_{PH} (C)
  C = SHA(C_U, C_A, username)
  PH = MD4(password)
  R2 = SHA(SHA(MD4(PH), R1, m1), C, m2)

- Mutual authentication
- Passwords can be updated

MS-CHAP v2



name

AuthID, C_A

C_U,R_U

ok/nok, R_A

m1

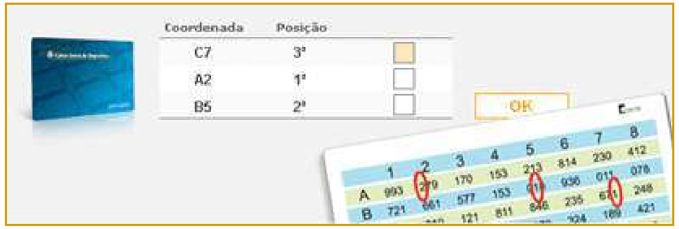
m2

Authentication of people:
Generation of OTPs with challenges

- ▷ OTPs can be produced from a challenge received
  - The fundamental protocol is password-based
    - But passwords are OTPs
  - OTPs are produced from a challenge
  - One can use several algorithms to handle OTPs

Authentication of people: OTPs selected from shared data

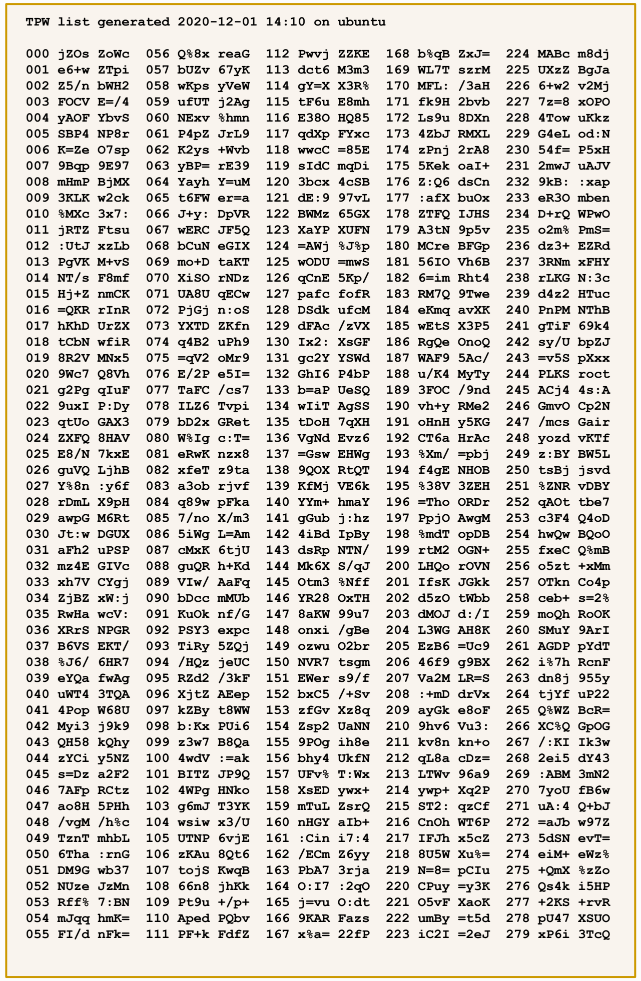
- ▷ Advantage:
  - Shared data can be random
  - No long-term short secrets to protect
- ▷ OTPs build from printed data
  - Example: online bank codes



Coordenada	Posição	
C7	3ª	□
A2	1ª	□
B5	2ª	□

OK

- ▷ Selection of an OTP from a printed / saved list



```
TPW list generated 2020-12-01 14:10 on ubuntu

000 jZOs ZoWc  056 Q%8x reaG  112 Pwvj ZZKE  168 b%qB ZxJ=  224 MABc m8dj
001 e6+w ZTpi  057 bUZv 67yK  113 dct6 M3m3  169 WL7T szrM  225 UXzZ BgJa
002 Z5/n bWH2  058 wKps yVeW  114 gY=X X3R%  170 MFL: /3aH  226 6+w2 v2Mj
003 FOCV E=/4  059 ufUT j2Ag  115 tF6u E8mh  171 fk9H 2bvb  227 7z=8 xOPO
004 yAOF YbvS  060 NExv %hmn  116 E38O HQ85  172 Ls9u 8DXn  228 4Tow uKkz
005 SBP4 NP8r  061 P4pZ JrL9  117 qdXp FYxc  173 4ZbJ RMXL  229 G4eL od:N
006 K=Ze O7sp  062 K2ys +Wvb  118 wwcC =85E  174 zPnj 2rA8  230 54f= P5xH
007 9Bqp 9E97  063 yBP= rE39  119 sIdC mqDi  175 5Kek oaI+  231 2mwJ uAJV
008 mHmP BjMX  064 Yayh Y=uM  120 3bcx 4cSB  176 Z:Q6 dsCn  232 9kB: :xap
009 3KLK w2ck  065 t6FW er=a  121 dE:9 97vL  177 :afX buOx  233 eR3O mben
010 %MXc 3x7:  066 J+y: DpVR  122 BWMz 65GX  178 ZTFQ IJHS  234 D+rQ WPwO
011 jRTZ Ftsu  067 wERC JF5Q  123 XaYP XUFN  179 A3tN 9p5v  235 o2m% PmS=
012 :UtJ xzLb  068 bCuN eGIX  124 =AWj %J%p  180 MCre BFGp  236 dz3+ EZRd
013 PgVK M+vS  069 mo+D taKT  125 wODU =mwS  181 56IO Vh6B  237 3RNm xFHY
014 NT/s F8mf  070 XiSO rNDz  126 qCnE 5Kp/  182 6=im Rht4  238 rLKG N:3c
015 Hj+Z nmCK  071 UA8U qECw  127 pafc fofR  183 RM7Q 9Twe  239 d4z2 HTuc
016 =QKR rInR  072 PjGj n:oS  128 DSdk ufcM  184 eKmq avXK  240 PnPM NThB
017 hKhD UrZX  073 YXTD ZKfn  129 dFAc /zVX  185 wEtS X3P5  241 gTiF 69k4
018 tCbN wfiR  074 q4B2 uPh9  130 Ix2: XsGF  186 RgQe OnoQ  242 sy/U bpZJ
019 8R2V MNx5  075 =qV2 oMr9  131 gc2Y YSWd  187 WAF9 5Ac/  243 =v5S pXxx
020 9Wc7 Q8Vh  076 E/2P e5I=  132 GhI6 P4bP  188 u/K4 MyTy  244 PLKS roct
021 g2Pg qIuF  077 TaFC /cs7  133 b=aP UeSQ  189 3FOC /9nd  245 ACj4 4s:A
022 9uxI P:Dy  078 ILZ6 Tvpi  134 wIiT AgSS  190 vh+y RMe2  246 GmvO Cp2N
023 qtUo GAX3  079 bD2x GRet  135 tDoH 7qXH  191 oHnH y5KG  247 /mcs Gair
024 ZXFQ 8HAV  080 W%Ig c:T=  136 VgNd Evz6  192 CT6a HrAc  248 yozd vKTf
025 E8/N 7kxE  081 eRwK nzx8  137 =Gsw EHWg  193 %Xm/ =pbj  249 z:BY BW5L
026 guVQ LjhB  082 xfeT z9ta  138 9QOX RtQT  194 f4gE NHOB  250 tsBj jsvd
027 Y%8n :y6f  083 a3ob rjvf  139 KfMj VE6k  195 %38V 3ZEH  251 %ZNR vDBY
028 rDmL X9pH  084 q89w pFka  140 YYm+ hmaY  196 =Tho ORDr  252 qAOt tbe7
029 awpG M6Rt  085 7/no X/m3  141 gGub j:hz  197 PpjO AwgM  253 c3F4 Q4oD
030 Jt:w DGUX  086 5iWg L=Am  142 4iBd IpBy  198 %mdT opDB  254 hwQw BQoO
031 aFh2 uPSP  087 cMxK 6tjU  143 dsRp NTN/  199 rtM2 OGN+  255 fxeC Q%mB
032 mz4E GIVc  088 guQR h+Kd  144 Mk6X S/qJ  200 LHQo rOVN  256 o5zt +xMm
033 xh7V CYgj  089 VIw/ AaFq  145 Otm3 %Nff  201 IfsK JGkk  257 OTkn Co4p
034 ZjBZ xW:j  090 bDcc mMUb  146 YR28 OxTH  202 d5zO tWbb  258 ceb+ s=2%
035 RwHa wcV:  091 KuOk nf/G  147 8aKW 99u7  203 dMOJ d:/I  259 moQh RoOK
036 XRrS NPGR  092 PSY3 expc  148 onxi /gBe  204 L3WG AH8K  260 SMuY 9ArI
037 B6VS EKT/  093 TiRy 5ZQj  149 ozwu O2br  205 EzB6 =Uc9  261 AGDP pYdT
038 %J6/ 6HR7  094 /HQz jeUC  150 NVR7 tsgm  206 46f9 g9BX  262 i%7h RcnF
039 eYQa fwAg  095 RZd2 /3kF  151 EWer s9/f  207 Va2M LR=S  263 dn8j 955y
040 uWT4 3TQA  096 XjtZ AEep  152 bxC5 /+Sv  208 :+mD drVx  264 tjYf uP22
041 4Pop W68U  097 kZBy t8WW  153 zfGv Xz8q  209 ayGk e8oF  265 Q%WZ BcR=
042 Myi3 j9k9  098 b:Kx PUi6  154 Zsp2 UaNN  210 9hv6 Vu3:  266 XC%Q GpOG
043 QH58 kQhy  099 z3w7 B8Qa  155 9POg ih8e  211 kv8n kn+o  267 /:KI Ik3w
044 zYCi y5NZ  100 4wdV :=ak  156 bhy4 UkfN  212 qL8a cDz=  268 2ei5 dY43
045 s=Dz a2F2  101 BITZ JP9Q  157 UFv% T:Wx  213 LTWv 96a9  269 :ABM 3mN2
046 7AFp RCtz  102 4WPg HNko  158 XsED ywx+  214 ywp+ Xq2P  270 7yoU fB6w
047 ao8H 5PHh  103 g6mJ T3YK  159 mTuL ZsrQ  215 ST2: qzCf  271 uA:4 Q+bJ
048 /vgM /h%c  104 wsiw x3/U  160 nHGY aIb+  216 CnOh WT6P  272 =aJb w97Z
049 TznT mhbL  105 UTNP 6vjE  161 :Cin i7:4  217 IFJh x5cZ  273 5dSN evT=
050 6Tha :rnG  106 zKAu 8Qt6  162 /ECm Z6yy  218 8U5W Xu%=  274 eiM+ eWz%
051 DM9G wb37  107 tojS KwqB  163 PbA7 3rja  219 N=8= pCIu  275 +QmX %zZo
052 NUze JzMn  108 66n8 jhKk  164 O:I7 :2qO  220 CPuy =y3K  276 Qs4k i5HP
053 Rff% 7:BN  109 Pt9u +/p+  165 j=vu O:dt  221 O5vF XaoK  277 +2KS +rvR
054 mJqq hmK=  110 Aped PQbv  166 9KAR Fazs  222 umBy =t5d  278 pU47 XSUO
055 FI/d nFk=  111 PF+k FdfZ  167 x%a= 22fP  223 iC2I =2eJ  279 xP6i 3TcQ
```

S/Key (RFC 2289, 1998)

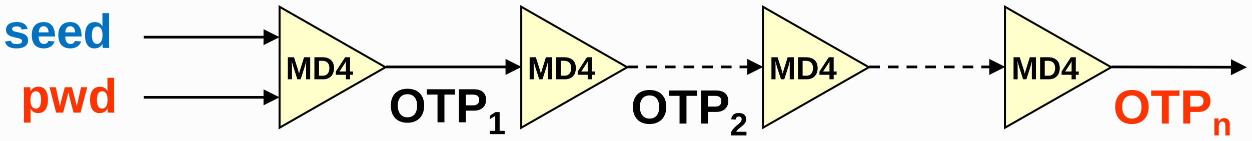
- Authentication credentials
  - A password (pwd)
- The authenticator knows
  - The last used one-time password (OTP)
  - The last used OTP index
    - Defines an order among consecutive OTPs
  - A seed value for each person’s OTPs
    - The seed is similar to a UNIX salt

S/Key setup

- The authenticator defines a random seed
- The person generates an initial OTP as:

  $OTP_n = h^n$ (seed, pwd), where h = MD4

  - Some S/Key versions also use MD5 or SHA-1
- The authenticator stores seed, n and OTP_n as authentication credentials



S/Key authentication protocol

- Authenticator sends seed & index of the person
  - They act as a challenge
- The person generates index-1 OTPs in a row
  - And selects the last one as result
  - result = $OPT_{index-1}$
- The authenticator computes h (result) and compares the result with the stored OPT_{index}
  - If they match, the authentication succeeds
  - Upon success, stores the recently used index & OTP
    - index-1 and $OPT_{index-1}$

S/Key

- Advantages
  - Users passwords are unknown to authenticators
  - OTPs can be used as ordinary passwords

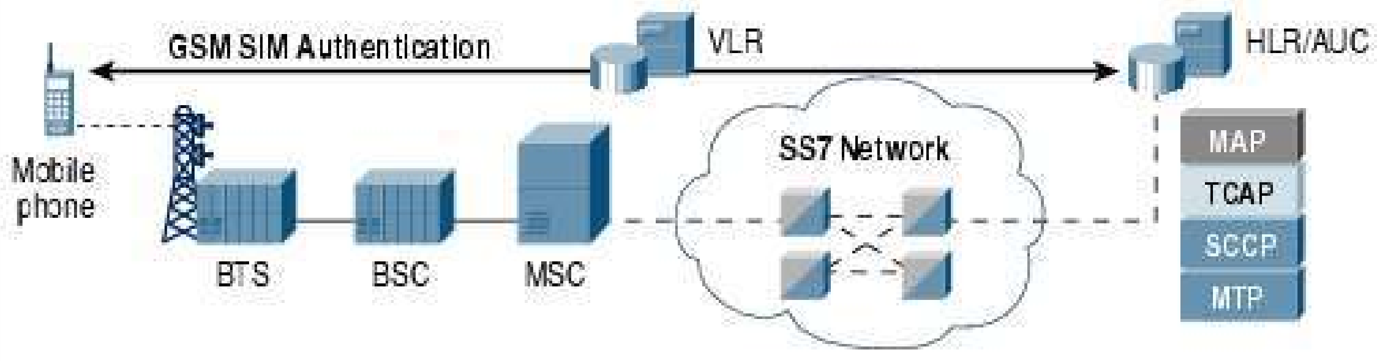
- Disadvantages
  - People need an application to compute OTPs
  - Passwords can be derived using dictionary attacks
    - From data stored in authenticators
    - From captured protocol runs

Authentication of people:
Challenge-response with shared key

- Uses a shared key instead of a password
  - Robust against dictionary attacks
  - Requires some token to store the key

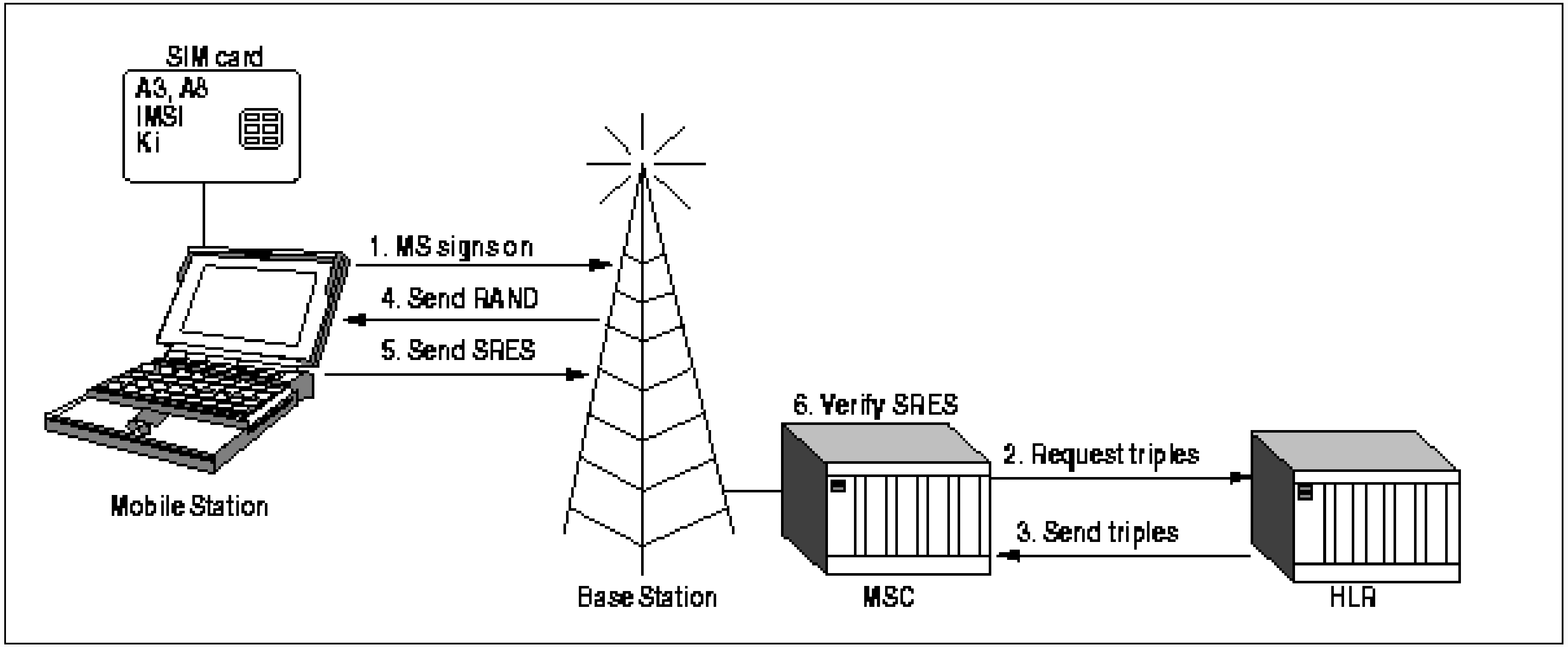
- Example:
  - GSM

GSM: authentication architecture



- Based on a secret key shared between the HLR and the station
  - 128 Ki, stored in the station's SIM card
  - Can only be used after entering a PIN
- Algorithms (initially not public):
  - A3 for authentication
  - A8 for generating a session key
  - A5 for encrypting the communication
- A3 and A8 implemented by SIM card
  - Can be freely selected by the operator

GSM: mobile station authentication



GSM: mobile station authentication

- MSC fetches trio from HLR
  - RAND, SRES, Kc
  - In fact more than one are requested

- HLR generates RAND and corresponding trio using subscriber’s Ki
  - RAND, random value (128 bits)
  - SRES = A3 (Ki, RAND) (32 bits)
  - Kc = A8 (Ki, RAND) (64 bits)

- Usually operators use COMP128 for A3/A8
  - Recommended by the GSM Consortium
  - [SRES, Kc] = COMP128 (Ki, RAND)

Host authentication

- By name or address
  - DNS name, IP address, MAC address, other
  - Extremely weak, no cryptographic proofs
    - Nevertheless, used by many services
    - e.g. NFS, TCP *wrappers*

- With cryptographic keys
  - Keys shared among peers
    - With an history of usual interaction
  - Per-host asymmetric key pair
    - Pre-shared public keys with usual peers
    - Certified public keys with any peer

Service / server authentication

- Host authentication
  - All co-located services/servers are indirectly authenticated
- Per-service/server credentials
  - Shared keys
    - When related with the authentication of people
    - The key shared with each person can be used to authenticate the service to that person
  - Per-service/server asymmetric key pair
    - Certified or not

TLS (Transport Layer Security, RFC 8446)

- Secure communication protocol over TCP/IP
  - Created upon SSL V3 (Secure Sockets Layer)
  - Manages per-application secure sessions over TCP/IP
    - Initially conceived for HTTP traffic
    - Actually used for other traffic types
- There is a similar version for UDP (DTLS, RFC 6347)
- Security mechanisms
  - Communication confidentiality and integrity
    - Key distribution
  - Authentication of communication endpoints
    - Servers (or, more frequently, services)
    - Client users
    - Both with asymmetric key pairs, typically with certified public keys

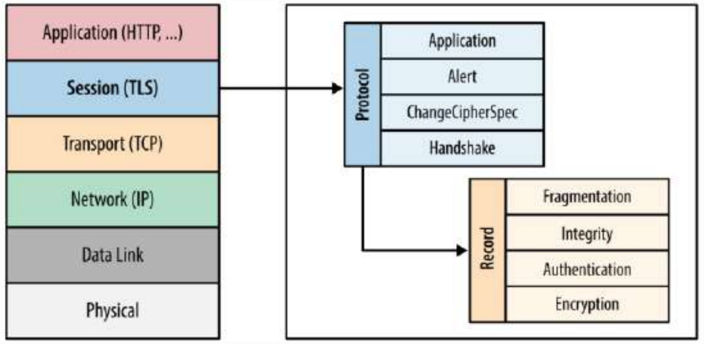
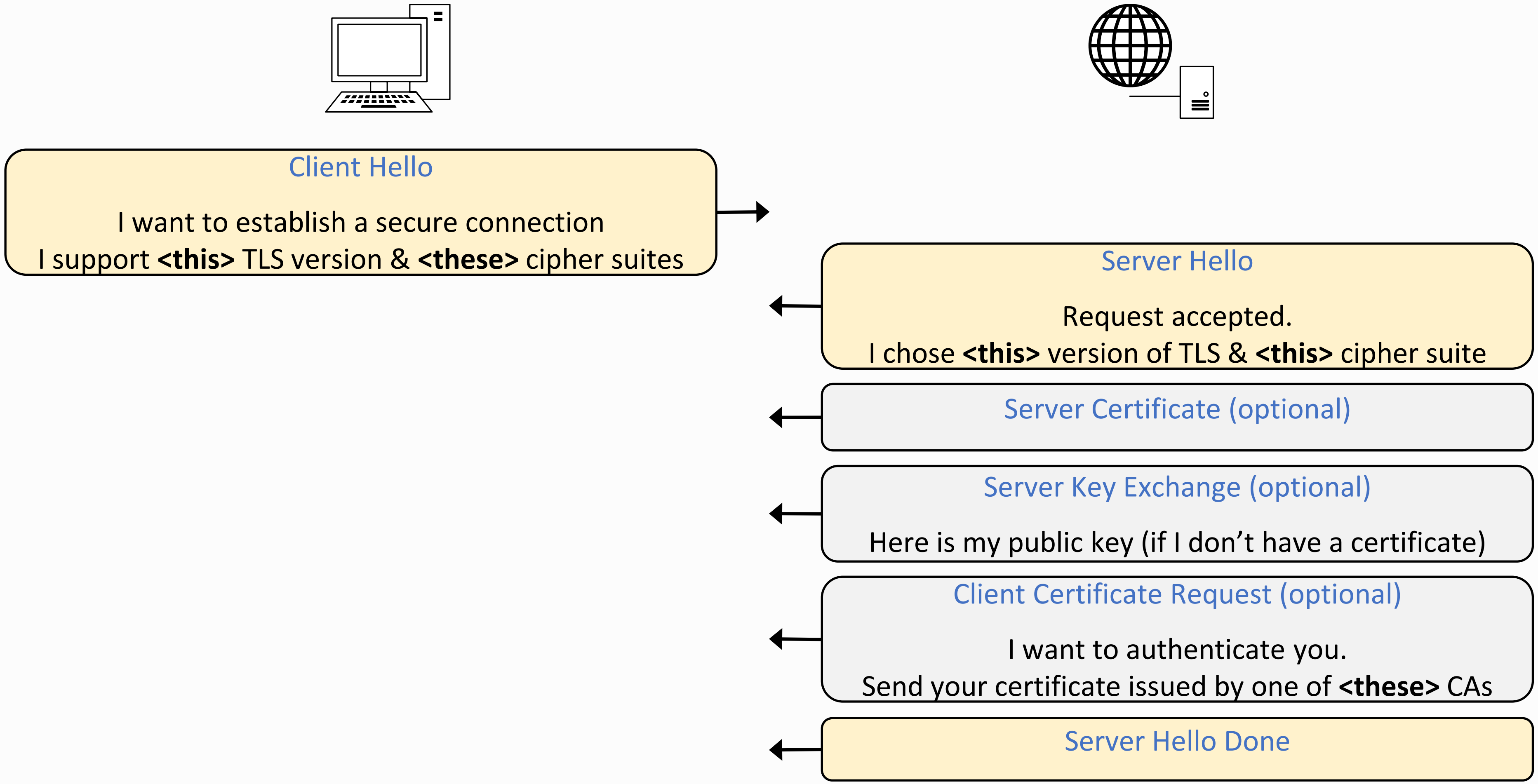


Image source: https://hpbn.co/transport-layer-security-tls/

TLS interaction diagrams (1st part)



Client Hello

I want to establish a secure connection
I support **<this>** TLS version & **<these>** cipher suites

Server Hello

Request accepted.
I chose **<this>** version of TLS & **<this>** cipher suite

Server Certificate (optional)

Server Key Exchange (optional)

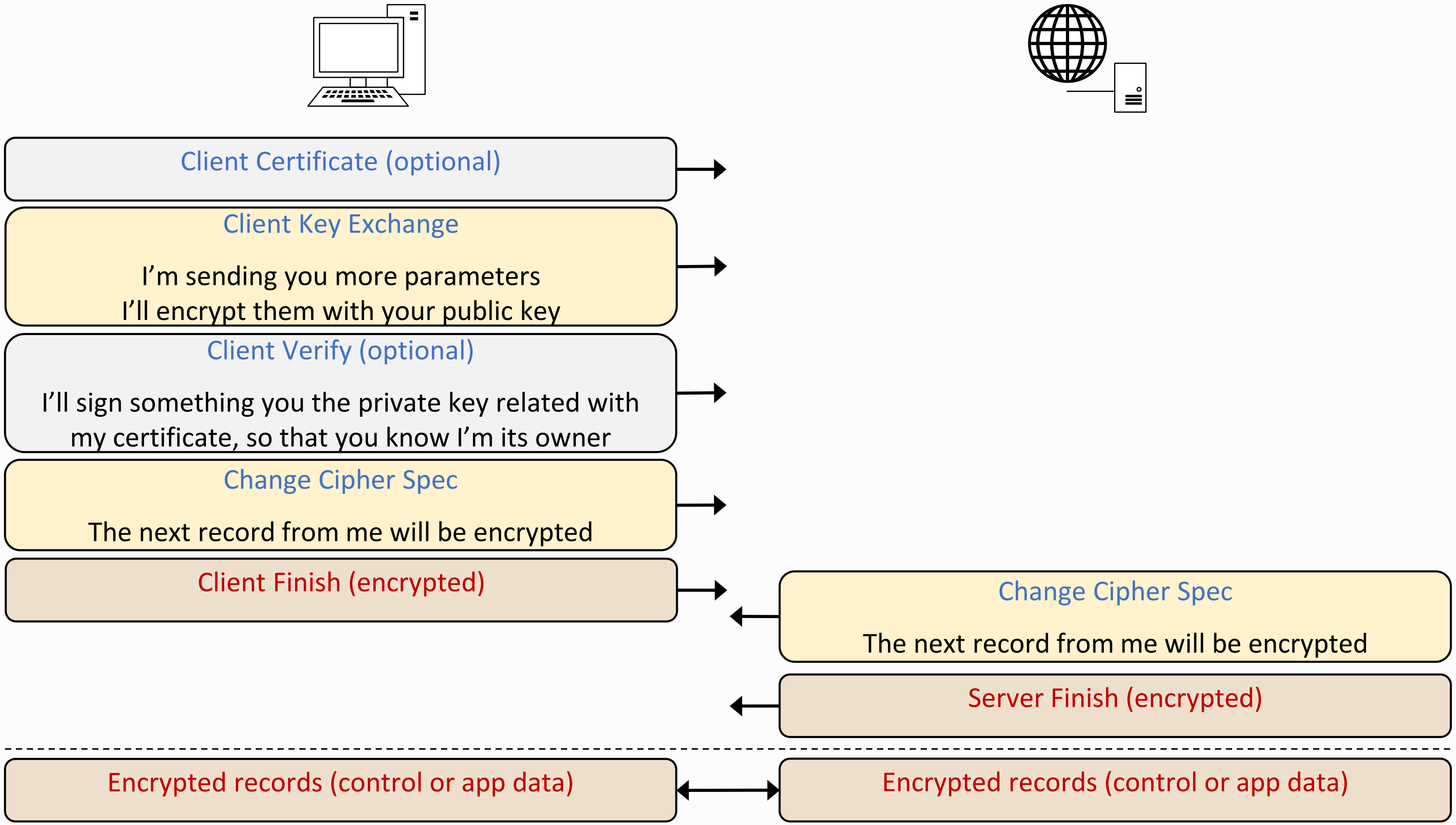
Here is my public key (if I don’t have a certificate)

Client Certificate Request (optional)

I want to authenticate you.
Send your certificate issued by one of **<these>** CAs

Server Hello Done

TLS interaction diagrams (2nd part)



Client Certificate (optional)

Client Key Exchange

I’m sending you more parameters
I’ll encrypt them with your public key

Client Verify (optional)

I’ll sign something you the private key related with my certificate, so that you know I’m its owner

Change Cipher Spec

The next record from me will be encrypted

Client Finish (encrypted)

Change Cipher Spec

The next record from me will be encrypted

Server Finish (encrypted)

Encrypted records (control or app data)

Encrypted records (control or app data)

TLS Ciphersuites

- If a server supports a single algorithm, it not expected for all clients to also support it
  - More powerful/limited, older/newer

- The Ciphersuite concept allows the negotiation of mechanisms between client and server
  - Both send their supported ciphersuites, and select one they both share
  - TLS v1.3: O servido escolhe

- Example: ECDHE-RSA-AES128-GCM-SHA256

- Format:
  - Key negotiation algorithm: ECDHE
  - Authentication algorithm: RSA
  - Cifra algorithm, and cipher mode: AES-128 GCM
  - Integrity control algorithm: SHA256

SSH (Secure Shell, RFC 4251)

- Alternative to telnet/rlogin protocols/applications
  - Manages secure consoles over TCP/IP
  - Initially conceived to replace telnet
  - Actually used for other applications
    - Secure execution of remote commands (rsh/rexec)
    - Secure copy of contents between machines (rcp)
    - Secure FTP (sftp)
    - Creation of arbitrary secure tunnels (inbound/outbound/dynamic)

- Security mechanisms
  - Communication confidentiality and integrity
    - Key distribution
  - Authentication of communication endpoints
    - Servers / machines
    - Client users
    - Both with different techniques

SSH authentication mechanisms

- Server: with asymmetric keys pair
  - Inline public key distribution
    - Not certified!
  - Clients cache previously used public keys
    - Caching should occur in a trustworthy environment
    - Update of a server’s key raises a problem to its usual clients
- Client users: configurable
  - Username + password
    - By default
  - Username + private key
    - Upload of public key in advance to the server

Single Sign-On (SSO)

- Unique, centralized authentication for a set of federated services
  - The identity of a client, upon authentication, is given to all federated services
  - The identity attributes given to each service may vary
  - The authenticator is called Identity Provider (IdP)

- Examples
  - SSO authentication @ UA
    - Performed by a central IdP (idp.ua.pt)
    - The identity attributes are securely conveyed to the service accessed by the user

Authentication metaprotocols

- Generic authentication protocols that encapsulate other authentication protocols

- Examples
  - EAP (Extensible Authentication Protocol)
    - Used in 802.1X (WiFi, enterprise mode)
    - e.g. PEAP (Protected EAP) and EAP-TLS run over EAP
  - ISAKMP(Internet Security Association and Key Management Protocol)
    - Formerly used in IPSec
    - e.g. IKE v1 (Internet Key Exchange) runs over ISAKMP

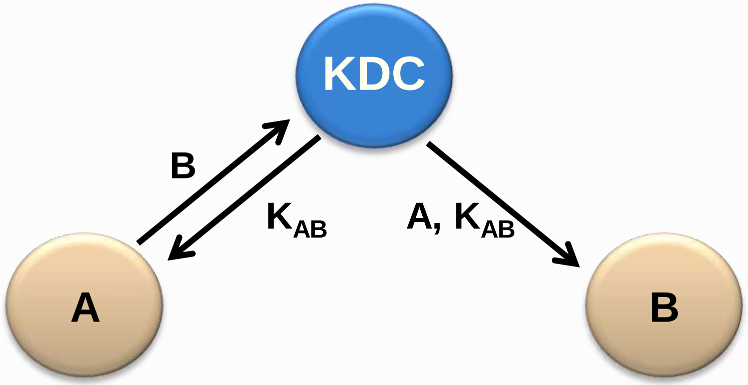
Authentication services

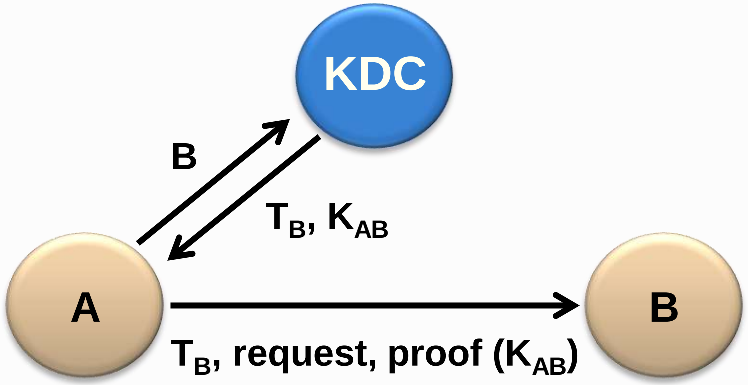
- Trusted third parties (TTP) used for authentication
  - But often combined with other related functionalities

- AAA services
  - Authentication, Authorization and Accounting
  - e.g. RADIUS

Key distribution services

- Services that distribute a shared key for authenticated entities
  - That key can then be used by those entities to protect their communication and ensure source authentication
- Examples
  - 802.1X (Wi-Fi, enterprise mode)
  - Kerberos





PAM

(Pluggable Authentication Modules)

Motivation

- Users
  - Unification of authentication mechanisms for different applications
- Manufacturers
  - Authenticated access to services independent of authentication mechanisms
- Administrators
  - Easy orchestration of authentication mechanisms different services requiring client authentication
  - Flexibility to configure specific authentication mechanisms for each host
- Manufacturers and Administrators
  - Flexible and modular approach for integrating novel authentication mechanisms

PAM: features

- Independent authentication protocols / mechanisms
  - Linux password, S/Key, smartcards, biometrics, etc.
  - One module per protocol / mechanism

- Orchestration of protocols / mechanisms
  - Alone or combined
  - AND and OR combinations
  - Application-independent

- Several interface approaches
  - Input from text consoles of graphical windows
  - Access to special devices (smart-cards, biometric readers, etc.)

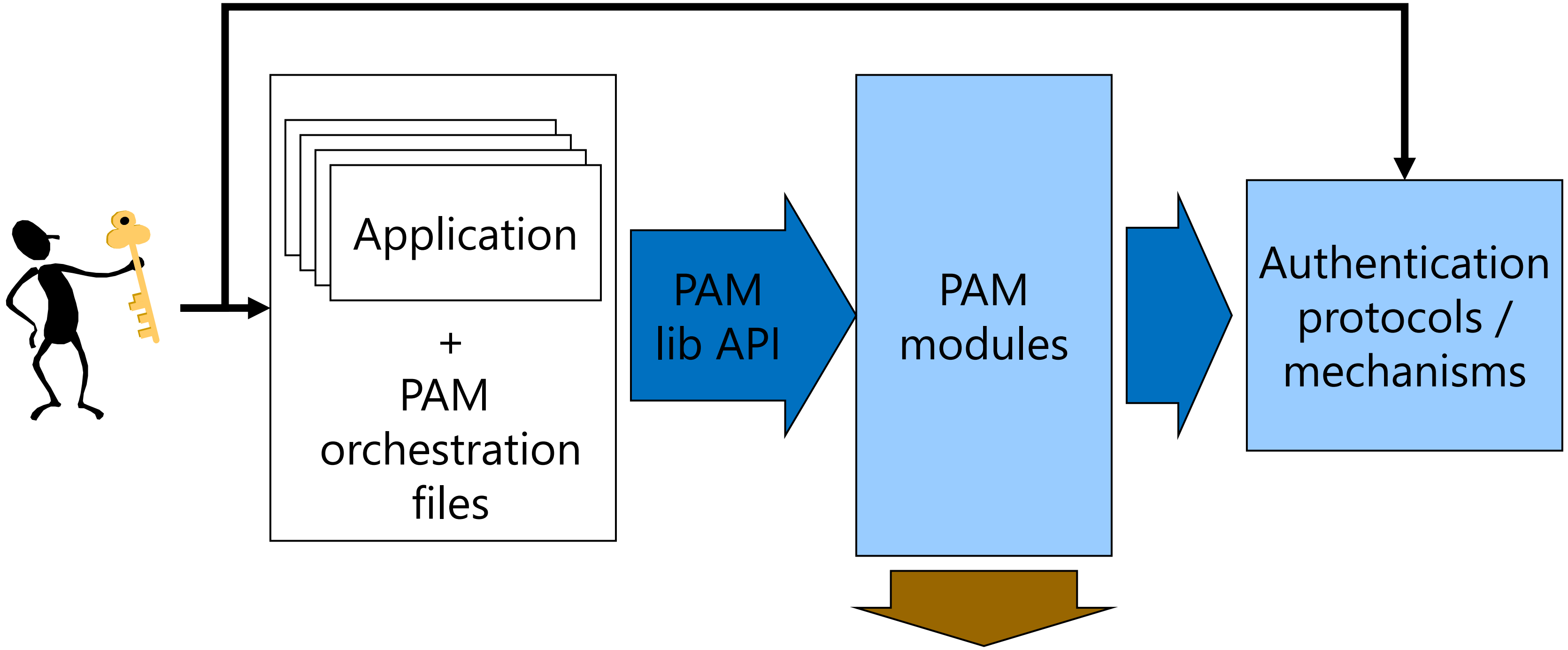
PAM: features

- Modular and extensible architecture
  - Dynamic loading of required modules
  - Handling of several actions besides authentication
    - Password management
    - Accounting management
    - Session management
- Default orchestration per host
  - Defined by the administrator
    - Username/password, biometrics, smart-cards, etc.
- Application-specific orchestrations
  - Each application can use a unique orchestration

Classic Unix authentication

- Requested input: username + password
- Validation
  - Active account for username
    - Entry with the username in the /etc/passwd file
  - Transformed password for that username
    - Entry with the username in the /etc/shadow file
  - Transformation of the provided password with the function and the salt used for that username
  - Comparison with the stored transformation
- Obtained credentials
  - UID + GID [+ list of secondary GIDs]
  - New process descriptor (login shell)

PAM: Architecture



Setup of identification, authentication and authorization information

PAM: Actions

- Authentication (auth)
  - Identity verification
- Account Management (account)
  - Enforcement of access policies based on account properties
- Password Management (password)
  - Management of authentication credentials
- Session Management (session)
  - Verification of operational parameters
  - Setup of session parameters
    - max memory, max file descriptions, graphical interface configuration, …

PAM: Modules

- Dynamically loaded (*shared libraries*)
  - /lib/security/pam_*.so
  - /lib/x86_64-linux-gnu/security/pam_*.so

- Standard API
  - Functions provided by the modules that are used
    - C interfaces
    - Python wrapper exists
  - Decision provided on returned code
    - PAM_SUCCESS
    - PAM_AUTH_ERR, PAM_AUTHINFO_UNAVAIL, etc...
  - Not all functions need to be implemented
    - A module does not need to implement all 4 actions

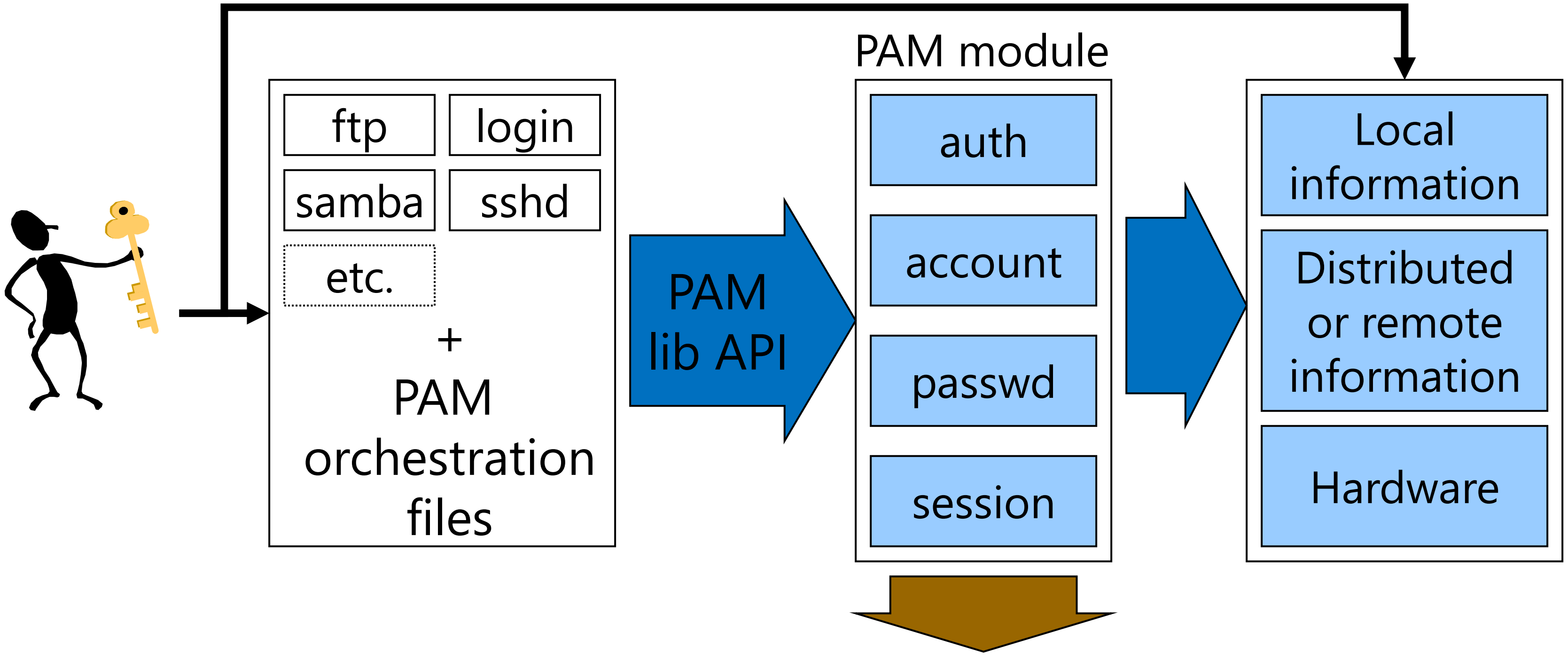
PAM: orchestration files

- Typically, one per PAM client application
  - e.g. /etc/pam.d/ftp or /etc/pam.d/ssh
  - Can use shared files: /etc/pam.d/common-auth

- Specify how the actions should be applied
  - Their mechanisms (modules)
  - Their parameters
  - Their termination, with or without success

- Each module uses a particular set of resources
  - Local files
    - /etc/passwd, /etc/shadow, /etc/groups, etc.
  - Distributed information or located in remote servers
    - NIS, Kerberos, LDAP, etc.

PAM: Detailed Architecture



Setup of identification, authentication and authorization information

PAM APIs:
PAM lib (used by applications)

- Start/end of the PAM lib

  pam_start(service, user name, callback, &pam_handle)

  pam_end(pam_handle, status)

- Module specific data

  pam_get_data()
  pam_set_data()

  pam_get_item()
  pam_set_item()

- "auth" action

  pam_authenticate(pam_handle, flags)
  pam_setcred(pam_handle, flags)

- "account" action

  pam_acct_mgmt(pam_handle, flags)

- "passwd" action

  pam_chauthtok(pam_handle, flags)

- "session" action

  pam_open_session(pam_handle, flags)
  pam_close_session(pam_handle, flags)

Orchestration of PAM actions

- Sequence of module invocations per action
  - By default, modules are executed sequentially
  - Each module has its own parameters and calling semantic
    - Required, requisite, sufficient, optional
    - […]
  - Execution proceeds until the end, or failure
    - To better hide the source of a failure, module execution can either abort immediately or delay the failure upon executing the entire sequence
  - Applications can recover from failures

PAM APIs:
PAM modules’ API

- “auth” action
  pam_sm_authenticate(pam_handle, flags)
  pam_sm_setcred(pam_handle, flags)
- “account” action
  pam_sm_acct_mgmt(pam_handle, flags)
- “passwd” action
  pam_sm_chauthtok(pam_handle, flags)
- “session” action
  pam_sm_open_session(pam_handle, flags)
  pam_sm_close_session(pam_handle, flags)

PAM: Module invocation

- Syntax: action control module [parameters]

- Control is specified for each action and module

  requisite
  required
  sufficient
  optional

  [success=ok/number default=ignore/die/bad ...]

PAM: Module invocation

- required: The module result must be successful for authentication to continue.
  - If the test fails at this point, the user is not notified until the results of all module tests that reference that interface are complete.
- requisite: The module result must be successful for authentication to continue.
  - However, if a test fails at this point, the user is notified immediately with a message reflecting the first failed required or requisite module test.
- sufficient: The module result is ignored if it fails.
  - If the result of a module flagged sufficient is successful and no previous modules flagged required have failed, then no other results are required and the user is authenticated

PAM: Module invocation

- optional: The module result is ignored.
  - A module flagged as optional only becomes necessary for successful authentication when no other modules reference the interface.

- include: Unlike the other controls, this does not relate to how the module result is handled.
  - This flag pulls in all lines in the configuration file which match the given parameter and appends them as an argument to the module.

Configuration files: /etc/pam.d/login

```
auth optional pam_faildelay.so delay=3000000
auth [success=ok new_authtok_reqd=ok ignore=ignore user_unknown=bad default=die] pam_securetty.so
auth requisite pam_nologin.so

session [success=ok ignore=ignore module_unknown=ignore default=bad] pam_selinux.so close
session required pam_loginuid.so
session [success=ok ignore=ignore module_unknown=ignore default=bad] pam_selinux.so open
session required pam_env.so readenv=1
session required pam_env.so readenv=1 envfile=/etc/default/locale

@include common-auth
auth optional pam_group.so

session required pam_limits.so
session optional pam_lastlog.so
session optional pam_motd.so motd=/run/motd.dynamic
session optional pam_motd.so noupdate
session optional pam_mail.so standard
session optional pam_keyinit.so force revoke

@include common-account
@include common-session
@include common-password
```

PAM orchestration files: Advanced decision syntax

- [value=action value=action …]
- Actions:
  - ignore: take no decision
  - bad: continue, but the final decision will be a failure
  - die: terminate immediately with failure
  - ok: continue, so far the decision is success
  - done: terminate immediately with success
  - reset: clear the entire state and continue
  - N (unsigned integer): same as ok + jump over N lines

PAM orchestration files: Advanced decision syntax

- Values (return codes)
  - *success*
  - *open_err*
  - *symbol_err*
  - *service_err*
  - *system_err*
  - *buf_err*
  - *perm_denied*
  - *auth_err*
  - *cred_insufficient*
  - *authinfo_unavail*
  - *user_unknown*
  - *maxtries*
  - *new_authtok_reqd*
  - *acct_expired*
  - *session_err*
  - *cred_unavail*
  - *cred_expired*
  - *cred_err*
  - *no_module_data*
  - *conv_err*
  - *authtok_err*
  - *authtok_recover_err*
  - *authtok_lock_busy*
  - *authtok_disable_aging*
  - *try_again*
  - *ignore*
  - *abort*
  - *authtok_expired*
  - *module_unknown*
  - *bad_item*
  - *conv_again*
  - *incomplete*
  - *default*
    - *Any not specified*

PAM orchestration files: Simplified decision syntax

- High-level decisions definitions
  - requisite
    - [success=ok new_authtok_reqd=ok ignore=ignore default=die]
  - required
    - [success=ok new_authtok_reqd=ok ignore=ignore default=bad]
  - sufficient
    - [success=done new_authtok_reqd=ok default=ignore]
  - optional
    - [success=ok new_authtok_reqd=ok default=ignore]

Scenario 2 – LDAP auth with local backoff

```
auth     required    /lib/security/pam_env.so
auth     sufficient  /lib/security/pam_unix.so likeauth nullok
auth     sufficient  /lib/security/pam_ldap.so use_first_pass
auth     required    /lib/security/pam_deny.so

account  required    /lib/security/pam_unix.so
account  [default=bad success=ok user_unknown=ignore] pam_ldap.so


password required    /lib/security/pam_cracklib.so retry=3
password sufficient  /lib/security/pam_unix.so nullok use_authtok md5 shadow
password sufficient  /lib/security/pam_ldap.so
password required    /lib/security/pam_deny.so

session  required    /lib/security/pam_limits.so
session  required    /lib/security/pam_unix.so
session  optional    /lib/security/pam_ldap.so
```

Try local accounts (for offline admin) and then LDAP

Allow changing the password of both local and remote accounts

Scenario 1 – Local authentication

```
auth     required    /lib/security/pam_env.so
auth     sufficient  /lib/security/pam_unix.so likeauth nullok
auth     required    /lib/security/pam_deny.so

account  required    /lib/security/pam_unix.so

password required    /lib/security/pam_cracklib.so retry=3
password sufficient  /lib/security/pam_unix.so nullok use_authtok md5 shadow
password required    /lib/security/pam_deny.so

session  required    /lib/security/pam_limits.so
session  required    /lib/security/pam_unix.so
```

Use system files

Prevent using weak passwords

Use md5 to store passwords in shadow

Scenario 2 – LDAP auth with local backoff

- LDAP server provides directory with users
  - Identifiers, shell, email, name
  - Group membership

- saslauthd: provides interface with remote directory
  - User identifiers and atributes
  - Group membership

Scenario 2 – LDAP auth with local backoff

```
ldap_servers: ldaps://dc1.DOMAIN.TLD
ldap_search_base: dc=DOMAIN,dc=TLD
ldap_bind_dn: cn=admin,ou=host,dc=DOMAIN,dc=TLD
ldap_bind_pw: Sup3rS3cr3TP4ssw0Rd
ldap_filter: (uid=%U)
ldap_scope: sub
#ldap_group_attr: memberUid
#ldap_group_match_method: filter
#ldap_group_filter: (memberUid=%u)
#ldap_group_search_base: ou=group,dc=DOMAIN,dc=TLD
#ldap_size_limit: 0
ldap_tls_check_peer: yes
ldap_tls_cacert_file: /etc/ldap/certs.txt
ldap_tls_cacert_dir: /etc/ssl/certs/
ldap_time_limit: 15
ldap_timeout: 15
ldap_version: 3
```

Specificies where server can be found

bind_dn is a system account to query the LDAP

Group membership mapping can be set

Scenario 2 – LDAP auth with local backoff

```
auth     required    /lib/security/pam_env.so
auth     sufficient  /lib/security/pam_unix.so likeauth nullok
auth     sufficient  /lib/security/pam_ldap.so use_first_pass
auth     required    /lib/security/pam_deny.so

account  required    /lib/security/pam_unix.so
account  [default=bad success=ok user_unknown=ignore] pam_ldap.so


password required    /lib/security/pam_cracklib.so retry=3
password sufficient  /lib/security/pam_unix.so nullok use_authtok md5 shadow
password sufficient  /lib/security/pam_ldap.so
password required    /lib/security/pam_deny.so

session  required    /lib/security/pam_limits.so
session  required    /lib/security/pam_unix.so
session  optional    /lib/security/pam_ldap.so
```

Try local accounts (for offline admin) and then LDAP

Allow changing the password of both local and remote accounts

Scenario 3 – MS AD auth with local backoff

- MS AD server provides directory with users
  - Identifiers, shell, email, name
  - Group membership
- Machine must be enrolled into domain
  - Requires login using admin credentials
- sssd: System Security Services Daemon
  - Provides and caches information from remote AD system

Scenario 3 – MS AD auth with local backoff

```
[sssd]
domains = DOMAIN.TLD
config_file_version = 2
services = nss, pam
default_domain_suffix = DOMAIN.TLD

[domain/DOMAIN.TLD]
default_shell = /bin/bash
krb5_store_password_if_offline = True
cache_credentials = True
krb5_realm = DOMAIN.TLD
realmd_tags = manages-system joined-with-adcli
id_provider = ad
fallback_homedir = /home/%u@%d
ad_domain = DOMAIN.TLD
use_fully_qualified_names = True
ldap_id_mapping = True
access_provider = simple
simple_allow_groups = group-admins
```

Typical SSSD configuration at /etc/sssd/sssd.conf

Specified Domain and Kerberos5 configurations

Kerberos is the effective authentication protocol issuing authnz tickets

Supports MFA and HSM

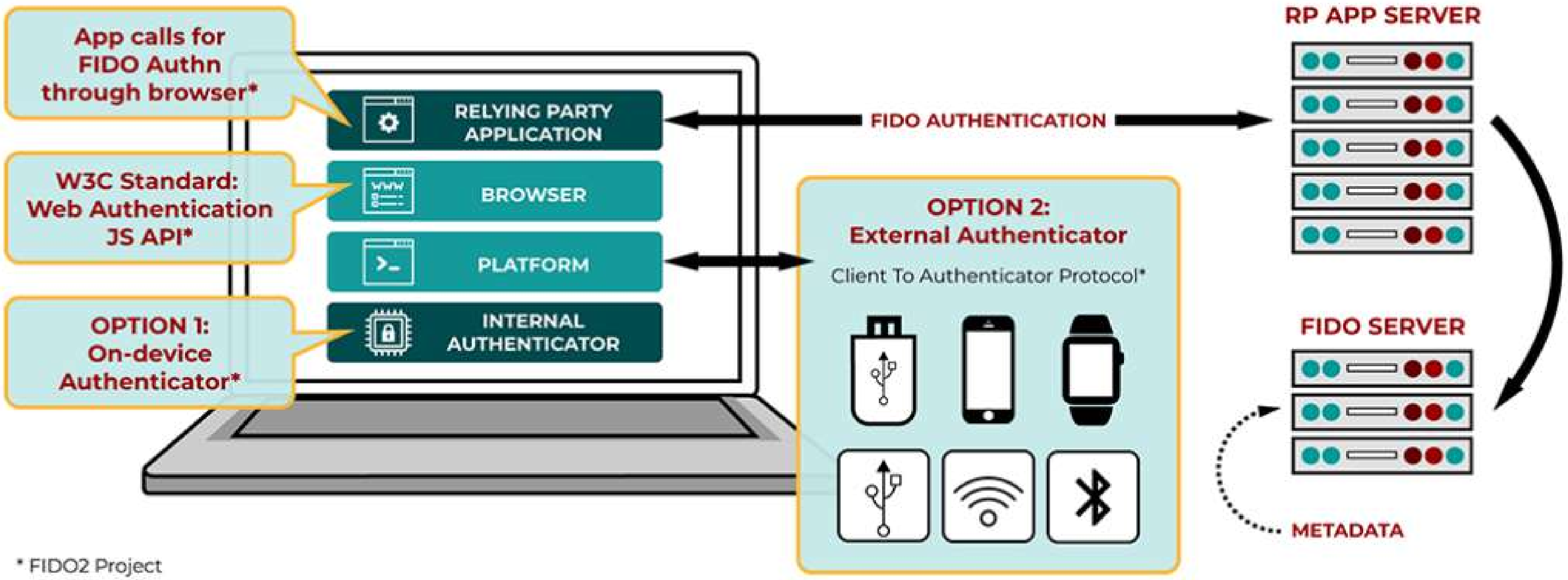
Scenario 3 – MS AD auth with local backoff

```
auth            [success=2 default=ignore]     pam_unix.so nullok
auth            [success=1 default=ignore]     pam_sss.so use_first_pass
auth            requisite                      pam_deny.so
auth            required                       pam_permit.so
auth            optional                       pam_cap.so

account [success=1 default=ignore]                     pam_unix.so
account [default=bad success=ok user_unknown=ignore]   pam_sss.so
account required                                       pam_permit.so

password        requisite                      pam_pwquality.so retry=3
password        [success=2 default=ignore]     pam_unix.so obscure use_authtok try_first_pass yescrypt
password        sufficient                     pam_sss.so use_authtok
password        requisite                      pam_deny.so
password        required                       pam_permit.so

session         required                      pam_unix.so
session         optional                      pam_sss.so
session         optional                      pam_systemd.so
session         optional                      pam_mkhomedir.so
session         required                      pam_permit.so
```

Try local accounts (for offline admin) and then AD
Deny the rest
Clear errors
Set inheritable capabilities

Set Session Settings from local conf, AD
Register session in systemd
Create home directory

FIDO and FIDO2 framework


App calls for FIDO Authn through browser*
W3C Standard: Web Authentication JS API*
OPTION 1: On-device Authenticator*
RELYING PARTY APPLICATION
BROWSER
PLATFORM
INTERNAL AUTHENTICATOR
FIDO AUTHENTICATION
OPTION 2: External Authenticator
Client To Authenticator Protocol*
RP APP SERVER
FIDO SERVER
METADATA
* FIDO2 Project

FIDO (Fast Identity Online) Alliance

- Open industry association

- Mission
  - Develop open authentication standards and promote their adoption to reduce the use of passwords

- Approach
  - Strong authentication based on public keys
  - Phishing resistance
  - Good usability

FIDO token-based authentication

- Authentication key pairs are stored in tokens
  - Thus we need protocol to interact with them
- Authentication is based on signatures
  - But these are too long to be copied by people
- Enrolment of devices in users' profiles is left to the authenticators
  - Plus the recovery procedure upon loosing a token

FIDO certification

- Validation of the quality of FIDO products
- Certification programs
  - Functional
    - Compliance and interoperability
  - Authenticator
    - Protection of secrets (L1 up to L3+)
  - Biometric
    - FAR, FRR
    - IAPMR (Impostor Attack Presentation Match Rate)

Universal 2nd Factor (U2F) protocol

- The user has a U2F device
  - The device creates a unique key pair per service
    - URL based
  - The service registers the public key on the user account
    - Different services get different keys
    - No user tracking
  - The service requests a user's device signature for their authentication

- Interface with a U2F device
  - JavaScript API (within browsers)
  - Native OS APIs

U2F devices

- USB devices
  - With a distinctive, recognizable HID interface
- NFC devices
- Bluetooth LE devices
- Software applications
  - Possibly backed up by hardware security devices
- Devices must have a “test of user presence”
  - To prevent accessible devices to be used without user consent
  - Devices cannot provide responses without such consent
  - Consent usually involves touching a button (may involve fingerprint or pin code)

U2F protocols

- Upper layer
  - Core cryptographic protocol
  - Defines the semantics and contents of the data items exchanged and produced
  - Defines the cryptographic operations involved in the processing of those data items

- Lower layer
  - Host-device transport protocol
  - CTAP (Client To Authenticator Protocol)

U2F upper layer protocol: User registration

- The U2F device is asked to generate a service-specific key pair
  - Service is identified with a hash of the service identity
    - protocol, hostname, port

- The U2F device generates a key pair
  - And returns a Key Handle and the public key
  - These elements are provided to the service
  - The Key Handle encodes the service identity

U2F upper layer protocol: User authentication (1)

- The user provides their identifier within the service
  - e.g. a user name
  - The service returns the user Key Handle and a random challenge

- The user's client application contacts a locally accessible device to perform a signature, providing
  - The Key Handle
  - A hash of the service identity
  - A hash of client data, which include
    - The random challenge
    - The service hostname
    - And an optional TLS ChannelID extension

U2F upper layer protocol: User authentication (2)

- The device checks if the service identity hash is valid for the Key Handle
  - On success looks up for the corresponding private key
  - And uses it to sign the hashed client data

- The signature is returned to the caller
  - That forwards it to the service for validation
  - Together with the client data

- The service validates the client data
  - And if valid, validates its signature with the user's public key

Certification of U2F devices

- Service providers need to be sure about the quality of U2F devices
  - They need a certification

- U2F have an attestation key pair
  - With a public key certificate issued by the manufacturer
  - And manufacturers need to be FIFO certified

- Public key produced by the device are signed with the attestation private key
  - To prove they were produced by a certified device

Anonymity of attestation key pairs

- U2F devices cannot have unique attestation key pairs
  - They would not be anonymous any more
  - Different services could track a user by their attestation public key
- Attestation key pairs are shared by batches of attestation key pairs
  - And thus, users' U2F devices cannot be tracked

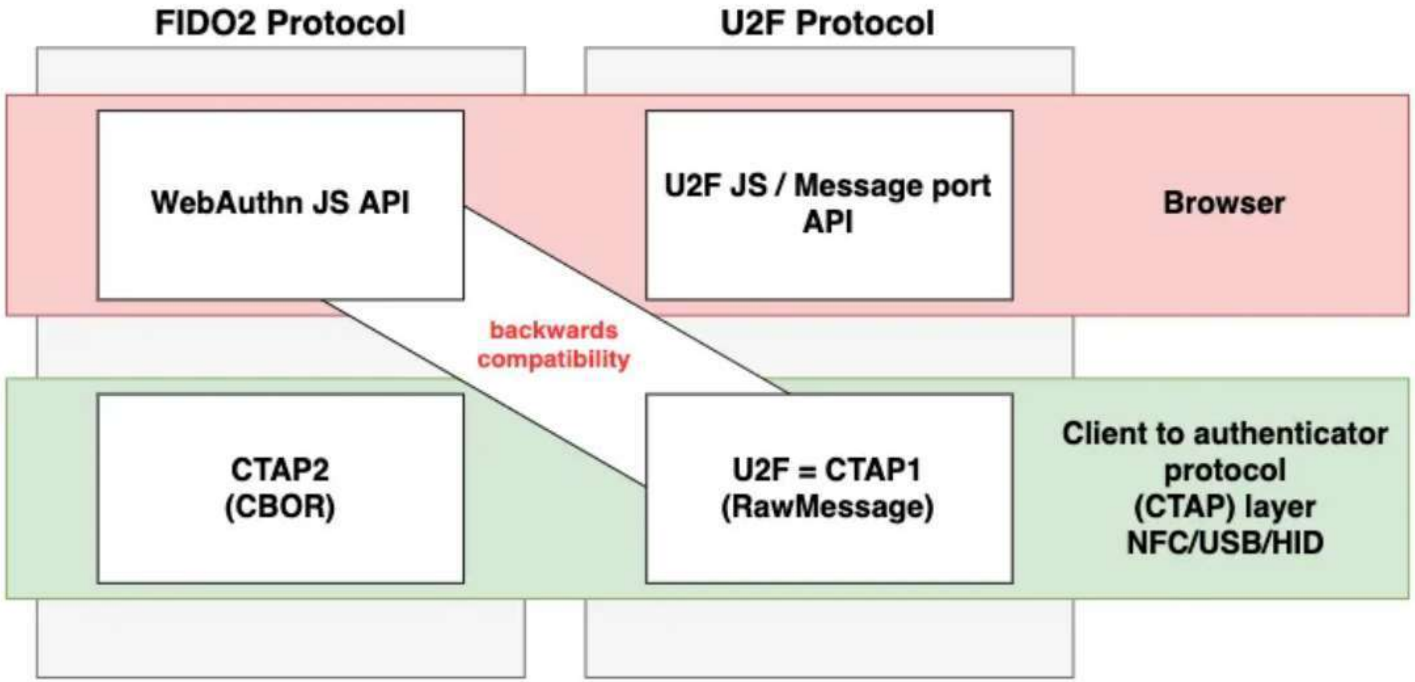
Uncertified U2F devices

- They can exist and still being used
  - It all depends on the service

- But in this case, services have to have their own trust chain for those devices

FIDO2 and U2F

- ▷ FIDO2 is backward compatible with U2F devices



Source: https://medium.com/webauthnworks/sorting-fido-ctap-webauthn-terminology-7d32067c0b01

U2F JS / MessagePort API

- JavaScript interface used by services Web pages to interact with U2F devices
  - Using a MessagePort API
  - https://fidoalliance.org/specs/u2f-specs-master/fido-u2f-javascript-api.html

WebAuthn

- Part of the FIDO2 framework
  - Web Authentication API
    - An evolution of the U2F API
  - Specification written by the W3C and FIDO
    - With the participation of Google, Mozilla, Microsoft, Yubico, and others
- Web API
  - Service API for dealing with the registration and authentication of U2F devices
- JavaScript API
  - Used by Web pages to interact with local U2F devices
  - Implemented by browsers

Client to Authenticator Protocol (CTAP)

- Standard interoperation between a user platform (e.g. a laptop) and a user-controlled cryptographic authenticator
  - ITU-T Recommendation X.1278

- Based in the Universal 2nd Factor (U2F) authentication standard

CTAP variants

- CTAP1/U2F
  - Aka FIDO U2F
  - Raw message format

- CTAP2
  - For FIDO2 authenticators (aka WebAuthn authenticators)
  - CBOR (Concise Binary Object Representation) data serialization format
    - Loosely based on JSON but in a binary format

Use case: Passkeys

- Passkeys appeared as a way to avoid common auth issues
  - Weak passwords
  - Phishing
  - Password/cookie theft
  - Lack of a second factor
  - MITM or Leak
  - Cost with 2nd factor

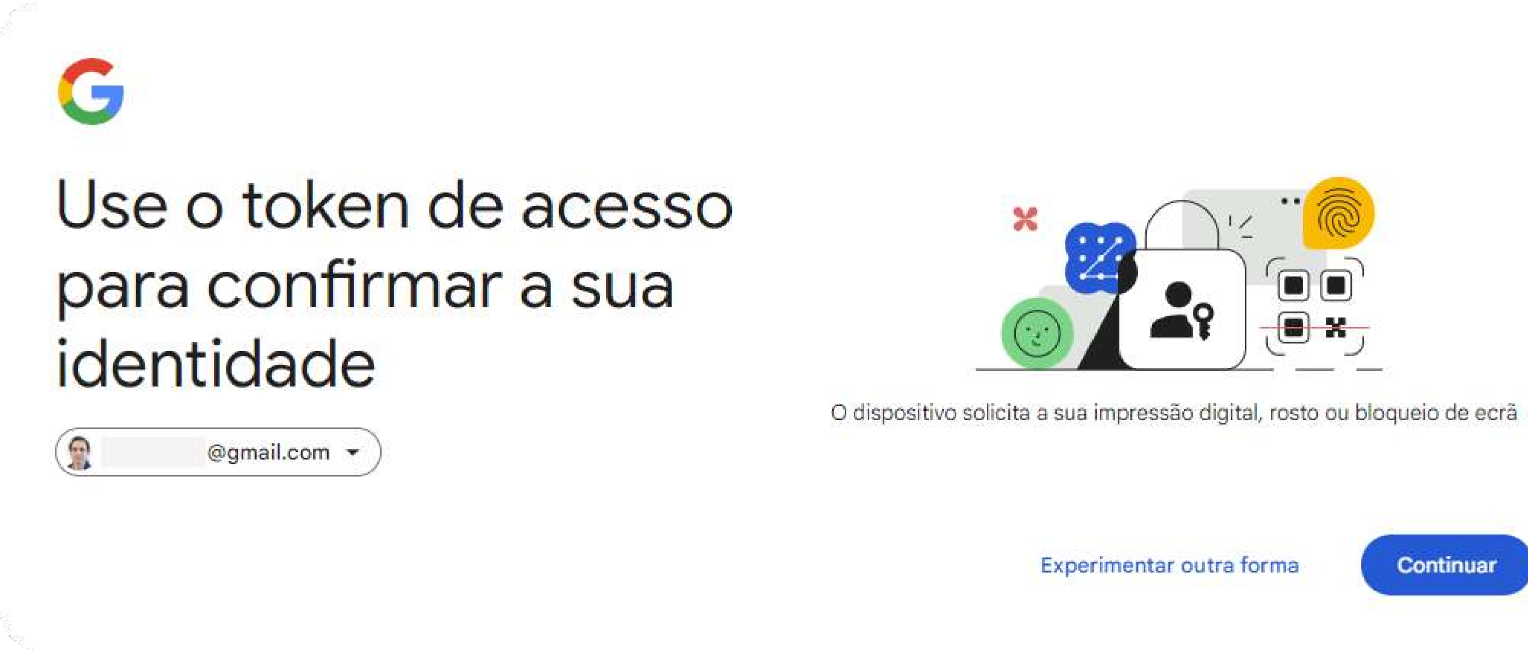
- They promote better usability
  - No need to generate/memorize/manage hundreds of passwords

Use case: Passkeys

- How:
  - Using auth material from the user directly in the device
    - This will never be exposed to others
    - Face, Fingerprint, PIN code (PIN can be alphanumeric)
    - Auth material enables the process but it is not sent
  - Generating a keypair, whose public key is stored at the servisse
    - Compromise of the service will only allow access to the **public** key
  - Authentication considers the service, device, keys and user
    - Implicit use of 2FA and external HSM may be used

- Why: No secret is exposed to third parties
  - Also: domain is matched by browser, blocking phishing and typos

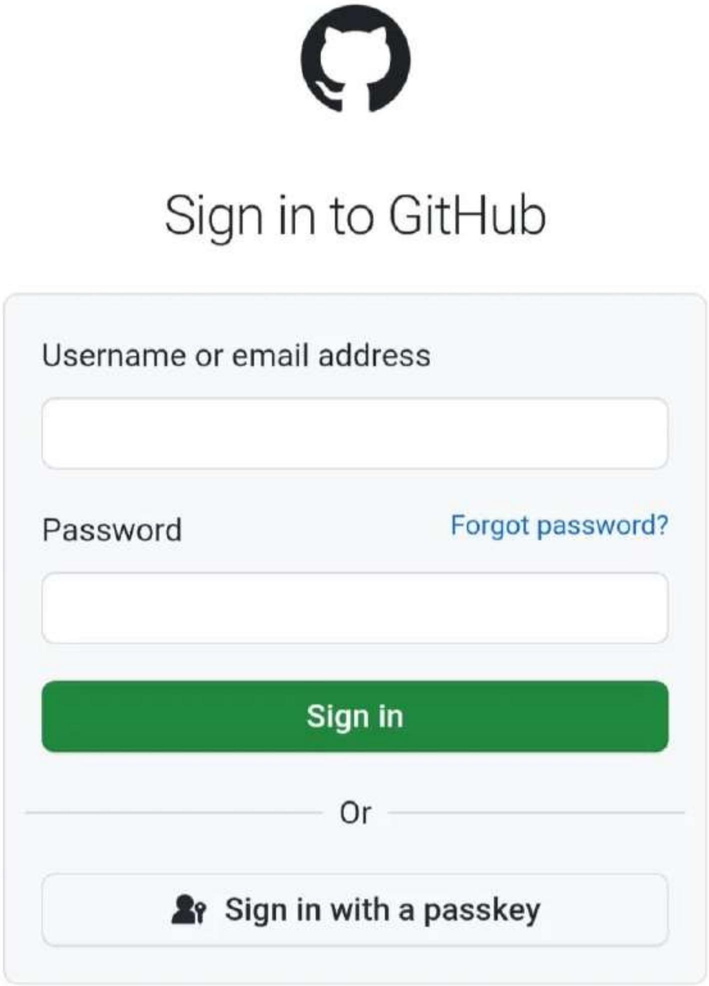
Use case: Passkeys



Use o token de acesso para confirmar a sua identidade

@gmail.com

O dispositivo solicita a sua impressão digital, rosto ou bloqueio de ecrã



Sign in to GitHub

Username or email address

Password

Use case: Passkeys
Functionality

- Device Bound Passkeys: device specific keys that may never leave it
  - Such as typical FIDO 2 keys

- Attestation: capability to ensure the provenance of the authenticator
  - Ensures that the authenticator is actually providing the auth data
    - Public key is packed into na attestation object, signed by a private key
    - Very flexible, as long as relying party can verify the attestation

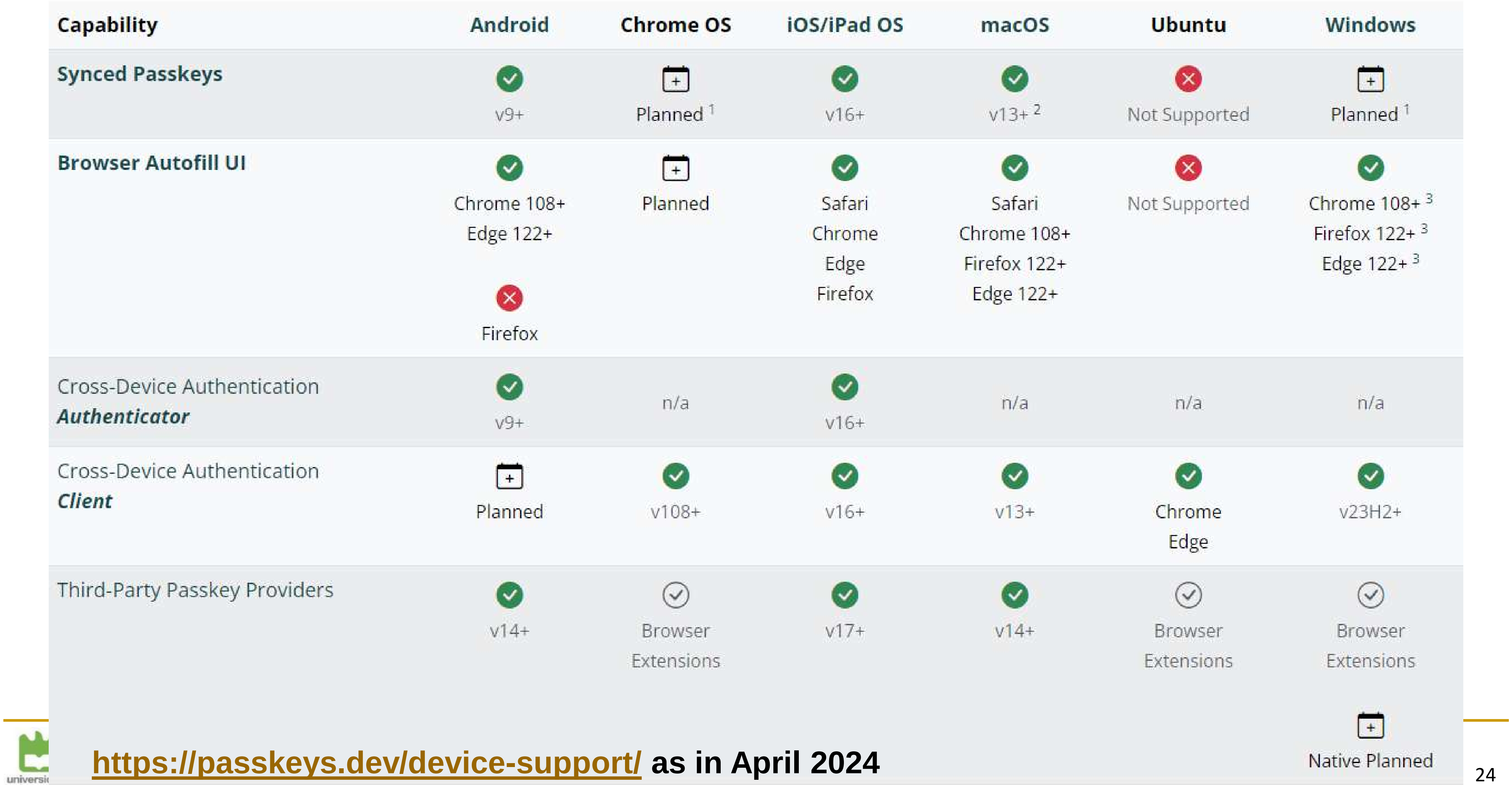
- Synced Passkeys: capability to keep passkeys available
  - Passkeys are backed up and used when required

Use case: Passkeys

Limitations

- Device support: It’s still a new technology
- Device dependency: Passkeys are rapidly device specific
  - Cross Device Authentication allows linking devices but authenticators must support it
  - Different ecossystems may still not be fully interoperable
- Biometrics are not that safe against local attacks
  - But most attacks are not local…
  - At it’s better than only passwords

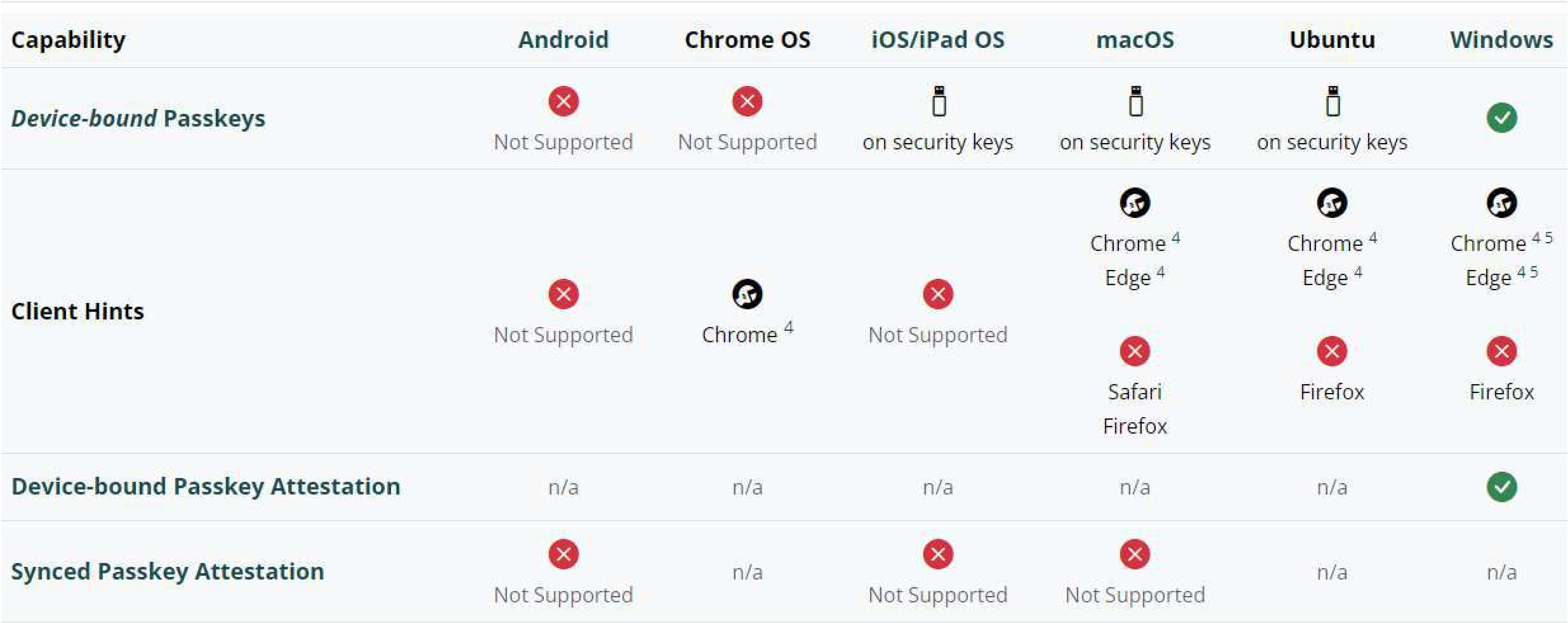
Use case: Passkeys



Capability	Android	Chrome OS	iOS/iPad OS	macOS	Ubuntu	Windows
Synced Passkeys	✅ v9+	📅 Planned [1]	✅ v16+	✅ v13+ [2]	❌ Not Supported	📅 Planned [1]
Browser Autofill UI	✅ Chrome 108+ Edge 122+ ❌ Firefox	📅 Planned	✅ Safari Chrome Edge Firefox	✅ Safari Chrome 108+ Firefox 122+ Edge 122+	❌ Not Supported	✅ Chrome 108+ [3] Firefox 122+ [3] Edge 122+ [3]
Cross-Device Authentication ***Authenticator***	✅ v9+	n/a	✅ v16+	n/a	n/a	n/a
Cross-Device Authentication ***Client***	📅 Planned	✅ v108+	✅ v16+	✅ v13+	✅ Chrome Edge	✅ v23H2+
Third-Party Passkey Providers	✅ v14+	✓ Browser Extensions	✅ v17+	✅ v14+	✓ Browser Extensions	✓ Browser Extensions 📅 Native Planned

https://passkeys.dev/device-support/ **as in April 2024**

Use case: Passkeys



Capability	Android	Chrome OS	iOS/iPad OS	macOS	Ubuntu	Windows
Device-bound Passkeys	✗ Not Supported	✗ Not Supported	on security keys	on security keys	on security keys	✓
Client Hints	✗ Not Supported	Chrome[4]	✗ Not Supported	Chrome[4] Edge[4] ✗ Safari Firefox	Chrome[4] Edge[4] ✗ Firefox	Chrome[4,5] Edge[4,5] ✗ Firefox
Device-bound Passkey Attestation	n/a	n/a	n/a	n/a	n/a	✓
Synced Passkey Attestation	✗ Not Supported	n/a	✗ Not Supported	✗ Not Supported	n/a	n/a

https://passkeys.dev/device-support/ **as in April 2024**

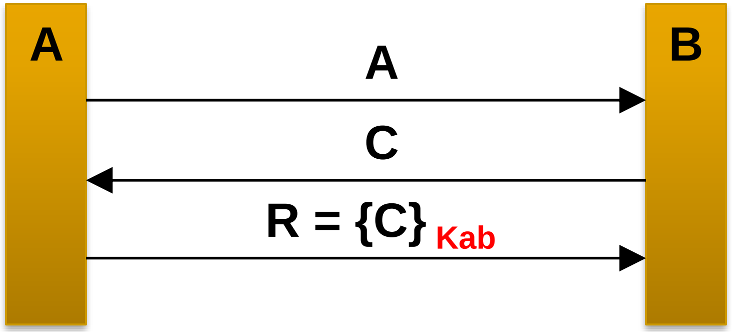
Authentication with Trusted Third Parties / KDCs

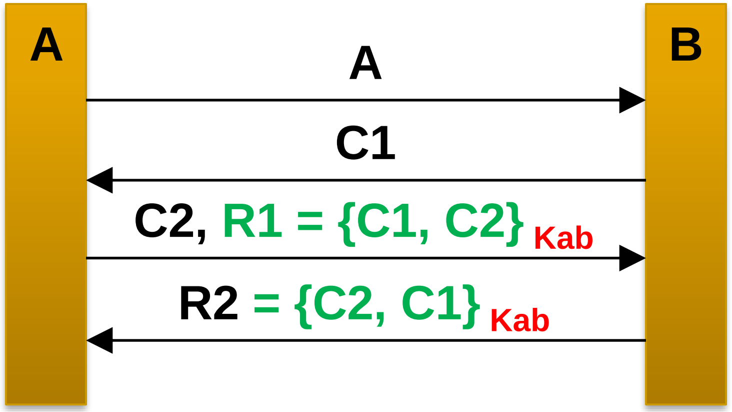
SAML Web Browser SSO Profile

Kerberos

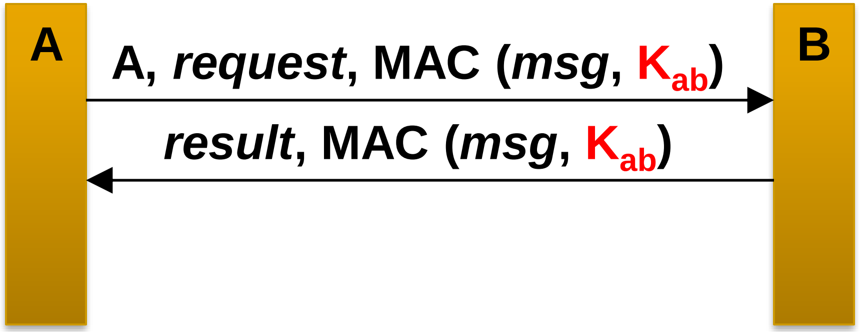
Shared-key authentication

- ▷ Connection-oriented





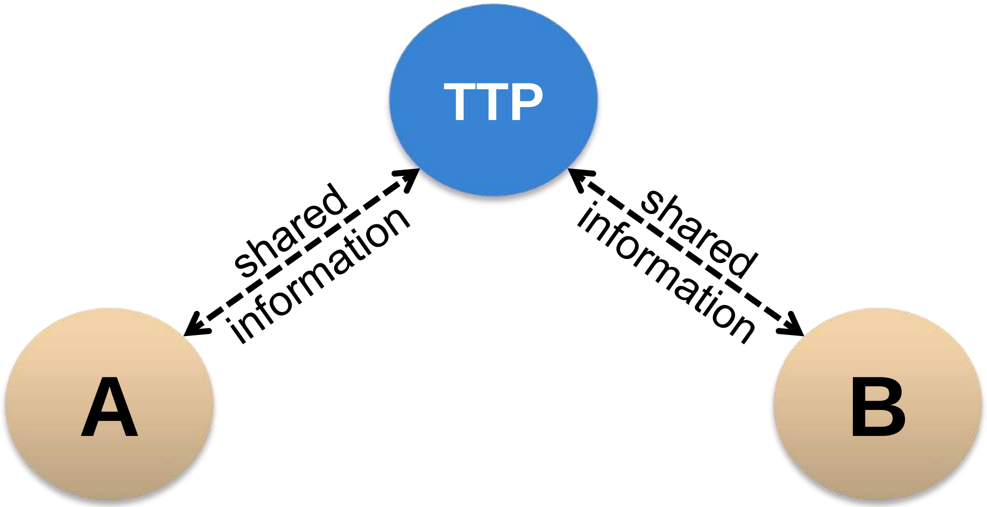
- ▷ Connection-less


A
B
A, *request*, MAC (*msg*, K_{ab})
result, MAC (*msg*, K_{ab})

- ▷ Issue
  - How to distribute K_{ab} to all possible A-B pairs?

Authentication with Trusted Third Party:
Key Distribution Center (KDC) concept

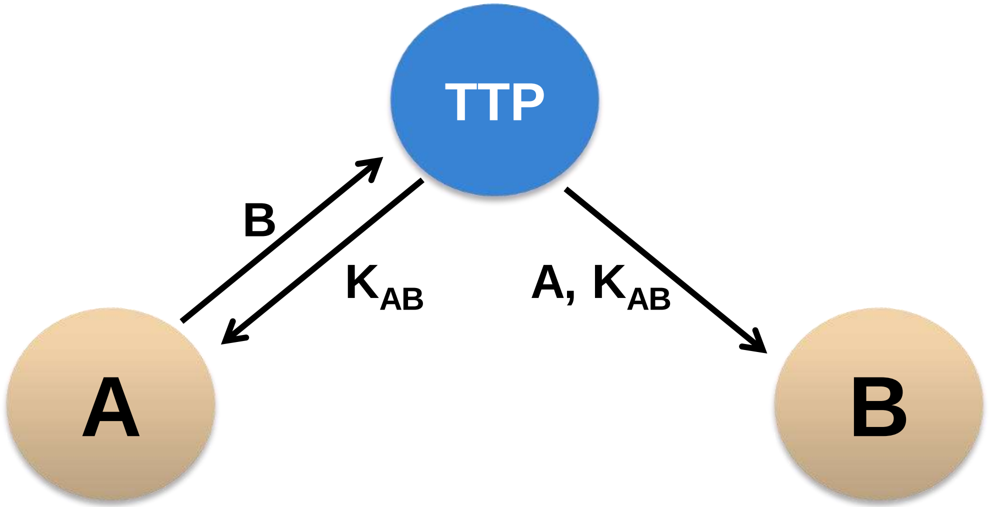
- TTP is responsible for bridging the gap between peers
  - A and B don’t have any shared information
  - A and B have shared information with TTP

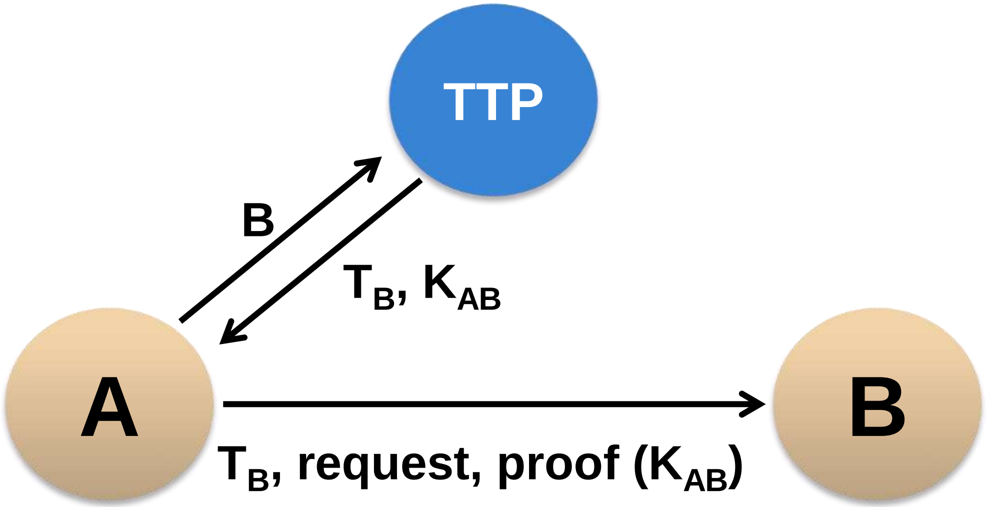


Why KDC?

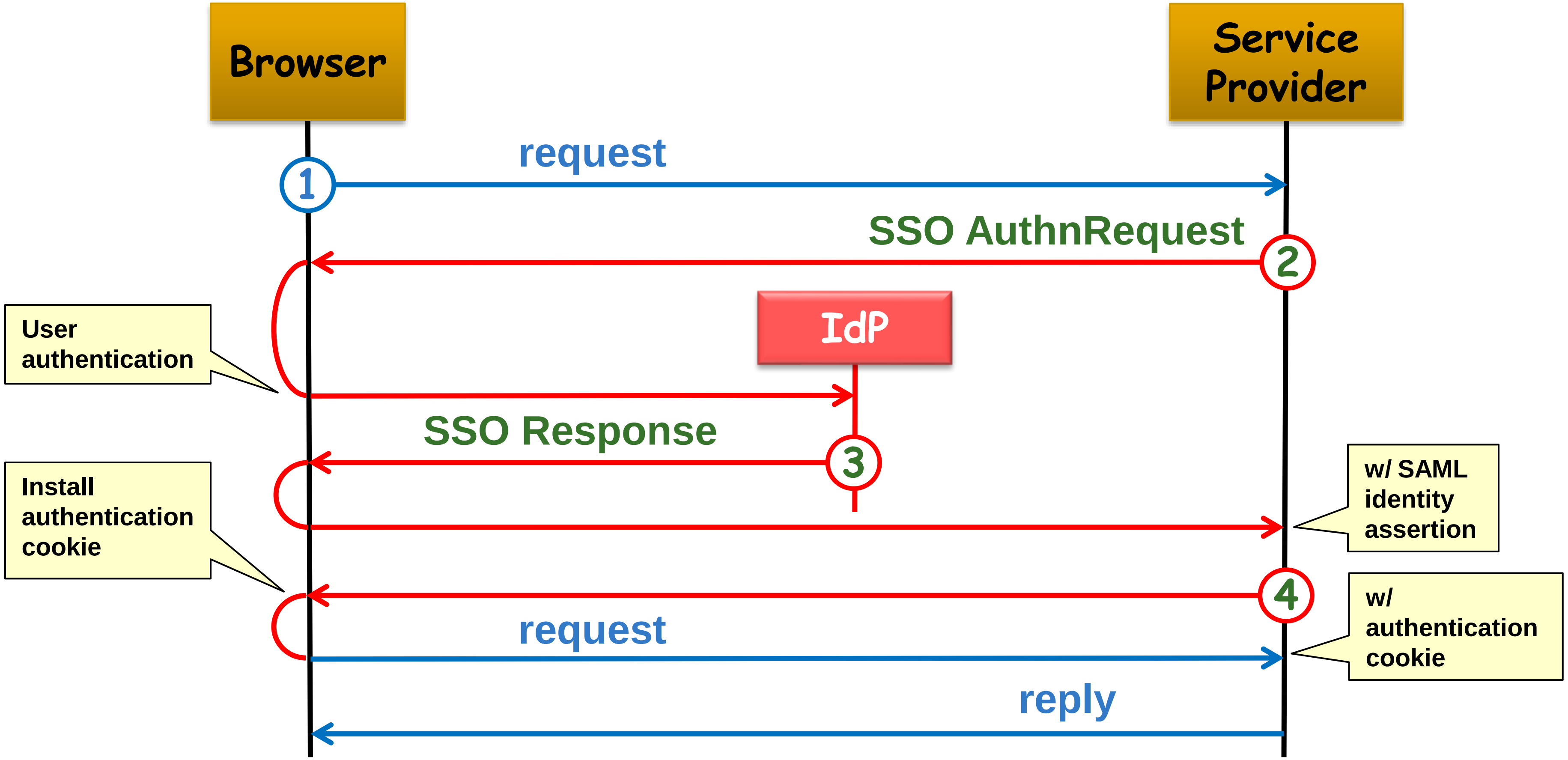
- Because a TTP can distribute a session key to A and B for proving each other their identity
  - Session key K_{AB}
    - It is temporary (only for one session)
  - A uses K_{AB} to prove its identity is B
  - B uses K_{AB} to prove its identity is A
- The proofs by A and B can be made in different ways
  - Only in the beginning of a session
  - On each interaction along a session

Session key distribution





Example:
SAML Web Browser SSO Profile



Kerberos:
Goals

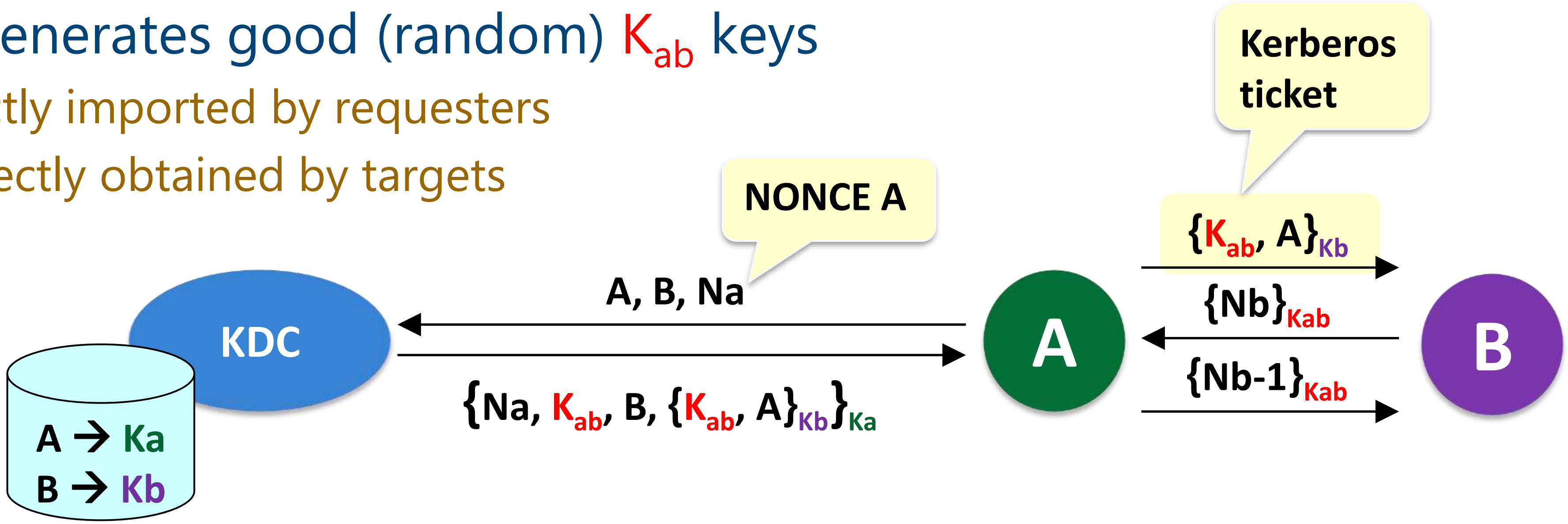
- Authenticate peers in a distributed environment
  - Targeted for Athena (at MIT)

- Distribute session keys for adding security to sessions between peers
  - Authentication (the initial goal)
  - Confidentiality (optional)

- Single Sign-On
  - Only one password to remember
  - Daily use (typically)

Kerberos background: Needham-Schroeder (1978)

- A and B trust on a common KDC
  - Key Distribution Center
- KDC shares a key with every A and B
  - Central authentication authority
- KDC generates good (random) K_{ab} keys
  - Directly imported by requesters
  - Indirectly obtained by targets



Kerberos:
Architecture and base concepts

- Architecture
  - Two Kerberos KDC services
    - Authentication Service (AS)
    - Ticket Granting Server (TGS)
  - Entities (principals)
    - All have a secret shared with Kerberos (AS or TGS)
    - People: a key derived from a password:
      K_U = hash(password)
    - Services/servers: key stored in some repository
  - Requisites
    - Clocks (very well) synchronized

- Authentication elements
  - Ticket: required to make a request of a service
  - Authenticator: proof of the identity of a requester

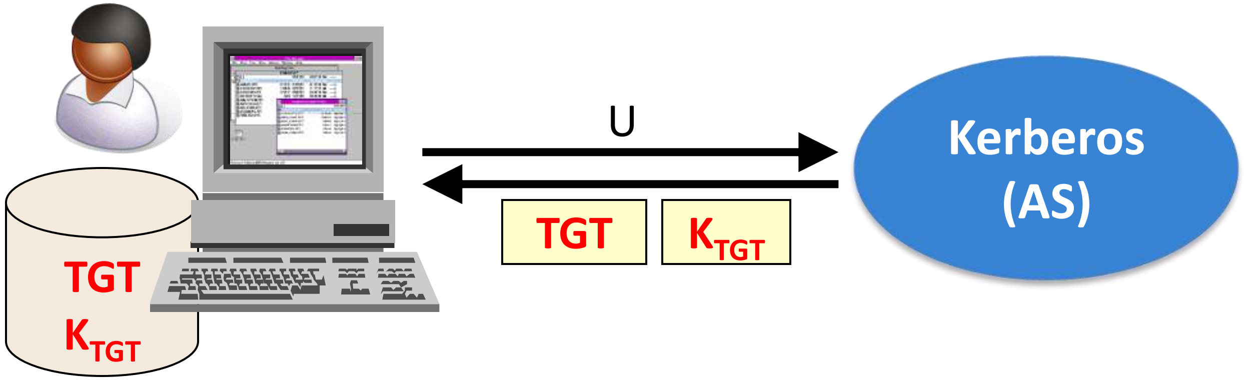
Kerberos:
Tickets and authenticators

- Ticket
  - Unforgeable piece of data
  - Can only be interpreted by the target service
  - Carries the identities of the client that can use it
  - Carries a session key
  - Carries a validity timestamp

- Authenticator
  - Carries a timestamp of the request
  - Carries the identity of the client
  - Proves that the client knows the session key

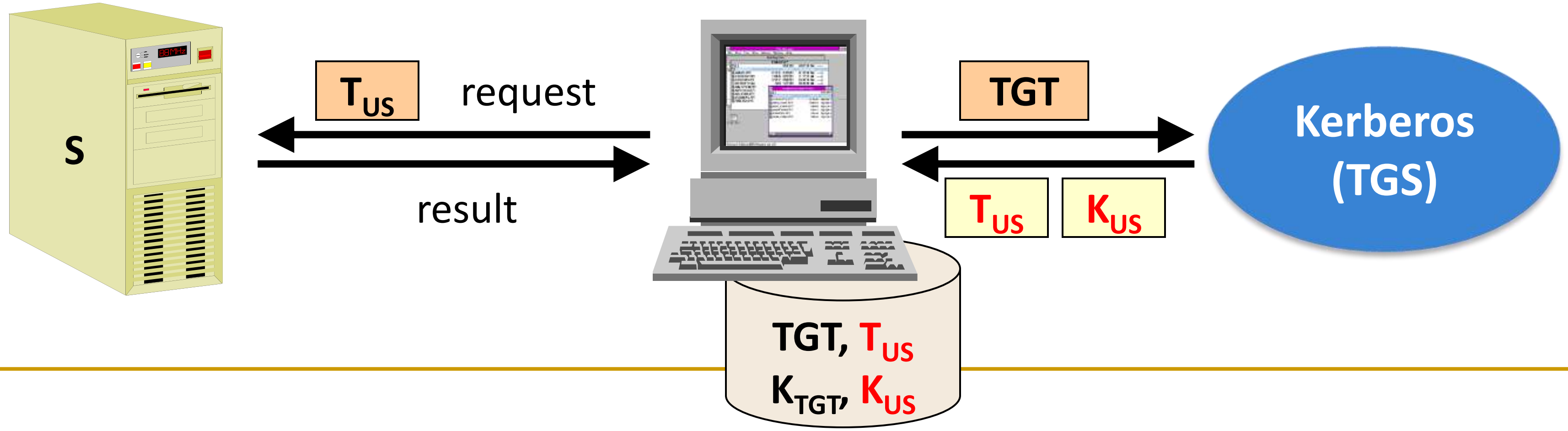
Overview of Kerberos SSO:
1^{st} step: Login

- Location of the Kerberos servers of the realm
- Authentication of user U by Kerberos (AS)
  - User gets a Ticket Granting Ticket (TGT) and a session key (K_{TGT}) for interacting with another Kerberos service (TGS)
  - The TGT can be used to request other tickets needed by the user U to access each and every service S



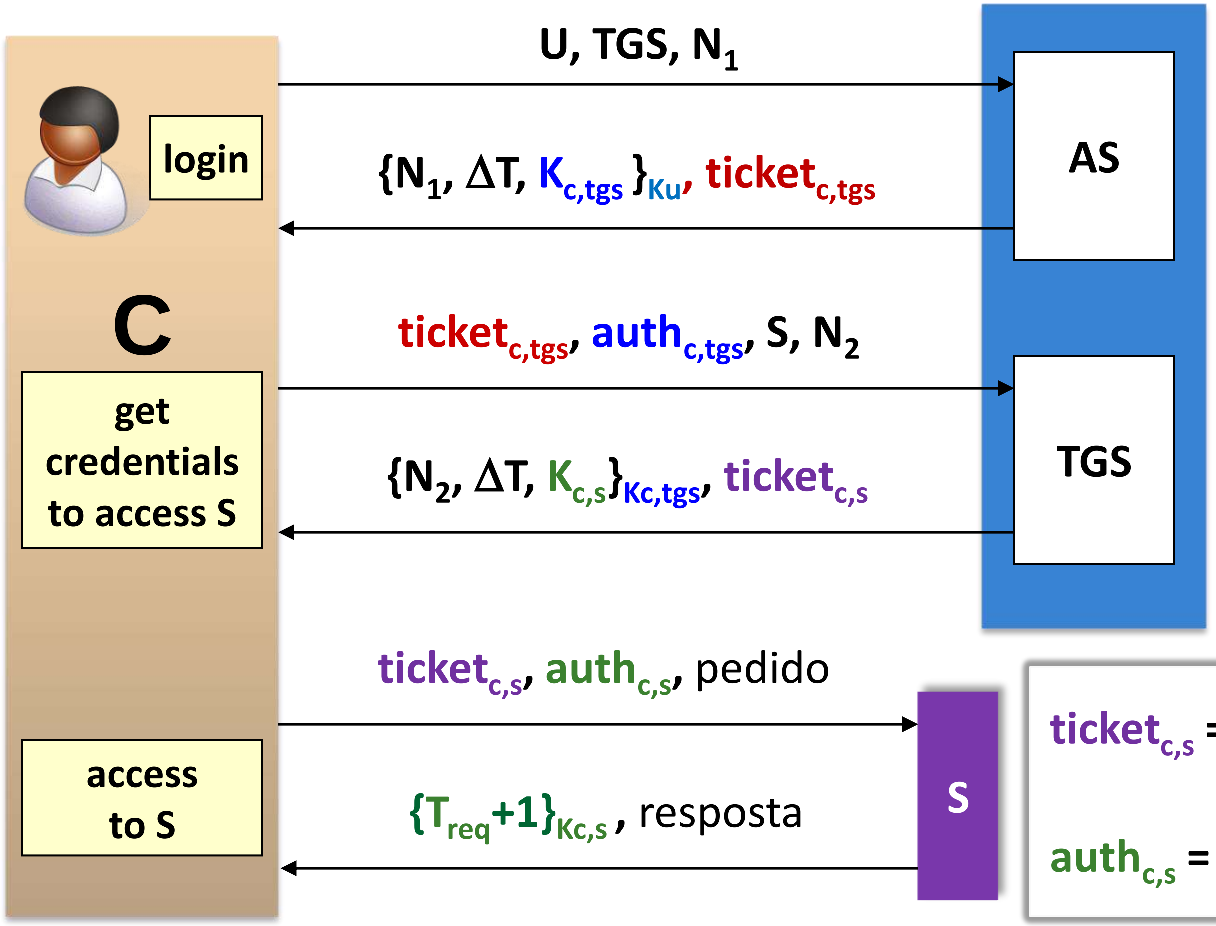
Overview of Kerberos SSO: 2nd step: Authenticated access to servers

- ▷ U requests Kerberos (TGS) a ticket for accessing S
  - U uses TGT in the request
  - U must prove that he is the owner of TGT
  - U gets a session key (K_{US}) and a ticket to S (T_{US})
- ▷ U uses T_{US} to make authenticated requests to S
  - Server S uses T_{US} to check the identity of U
  - U must prove that he is the owner of T_{US}



Kerberos:

Protocol (of version V5)



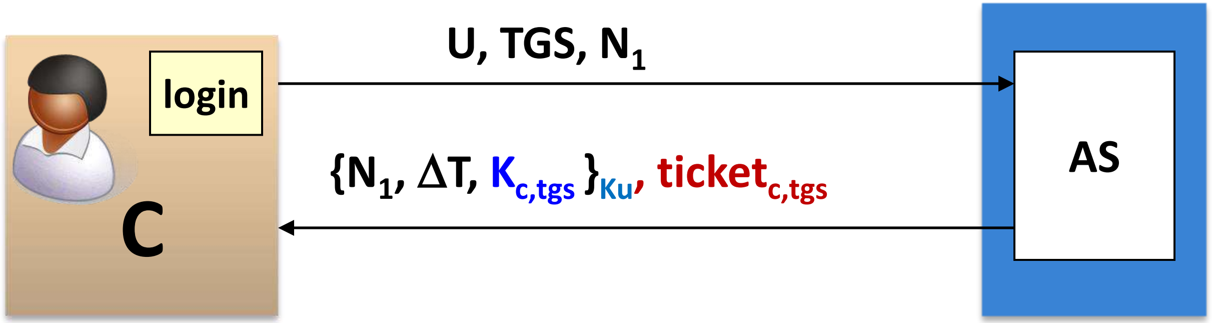
login
C
get credentials to access S
access to S
AS
TGS
S
U, TGS, N_1
$\{N_1, \Delta T, K_{c,tgs}\}_{Ku}, ticket_{c,tgs}$
$ticket_{c,tgs}, auth_{c,tgs}, S, N_2$
$\{N_2, \Delta T, K_{c,s}\}_{Kc,tgs}, ticket_{c,s}$
$ticket_{c,s}, auth_{c,s}$, pedido
$\{T_{req}+1\}_{Kc,s}$, resposta

	C (U)	TGS	S
AS	K_U	K_{tgs}	
TGS	$K_{c,tgs}$		K_s
S	$K_{c,s}$		

$ticket_{c,s} = S, \{U, addrs_c, \Delta T, K_{c,s}\}_{Ks}$

$auth_{c,s} = \{U, T_{req}, K', seq\}_{Kc,s}$

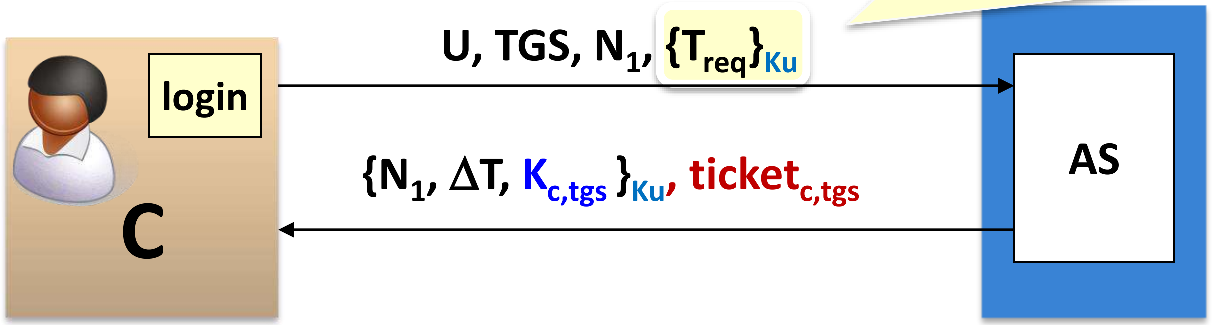
Kerberos:
Pre-authentication alternative


login
C
U, TGS, N_1
$\{N_1, \Delta T, K_{c,tgs}\}_{Ku}$, $\text{ticket}_{c,tgs}$
AS

	C (U)	TGS	S
AS	K_U	K_{tgs}	▨
TGS	$K_{c,tgs}$	▨	K_s
S	$K_{c,s}$	▨	▨

- Vulnerable to proactive dictionary attacks! (Kerberoasting)

for filtering out illegitimate requests (limiting kerberoasting)


login
C
U, TGS, N_1, $\{T_{req}\}_{Ku}$
$\{N_1, \Delta T, K_{c,tgs}\}_{Ku}$, $\text{ticket}_{c,tgs}$
AS

Kerberos:
Scalability

- Authentication scope
  - Realms
  - A kerberos server per realm
- Inter-realm cooperation
  - Fundamental to allow a client from a realm to access a server on another realm
  - Realms need to trust on authentication performed by other realms
- Protocol
  - Secret keys shared between TGS servers of different realms
    - Inter-realm key
    - Each inter-realm key is associated to a trust path
  - A client (user) needs to jump from TGS to TGS for getting a ticket
    - Not particularly user-friendly

Kerberos V5:
Security politics and mechanisms

- Entity authentication
  - Secret keys, names, networks addresses
  - name/instance@realm (user@ua.pt, ftp/ftp.ua.pt@ua.pt)
- Validity periods
  - Timestamps in tickets (hours)
  - Timestamps in authenticators (seconds, minutes)
- Replay protections
  - Nonces (in ticket distributions)
  - Timestamps / sequence numbers (in authenticators)
- Protection against an excessive use of session keys
  - Key distribution in authenticators
- Delegation (proxying)
  - Options and authorizations in tickets
- Inter-real authentication
  - Secret keys shared among TGS services, trust paths
  - Ticket issuing from a TGS to another TGS

Kerberos:
Security issues

- Kerberos KDC can impersonate anyone
  - Needs maximum security in its administration
- Kerberos KDC may be a single point of failure
  - Replication is an option, since stored keys are seldom updated
- A stolen user password allows others to impersonate the victim in every service of the realm
  - Stolen TGS credentials are less risky, as their validity is shortly limited (≈ one day, usually)

Kerberos V5:
Actual availability

- MIT releases
  - http://web.mit.edu/kerberos
  - Sources and binaries

- Windows versions
  - Windows 2000 adopted Kerberos for inter-domain authentication
  - Kerberos was modified to accommodate Windows credentials

- Components
  - Kerberos servers/daemons
  - Libraries for “kerberizing” applications
  - Support applications
    - klogin, kpasswd, kadmin
  - Kerberized applications (clients and servers)