CS 470
Spring 2024

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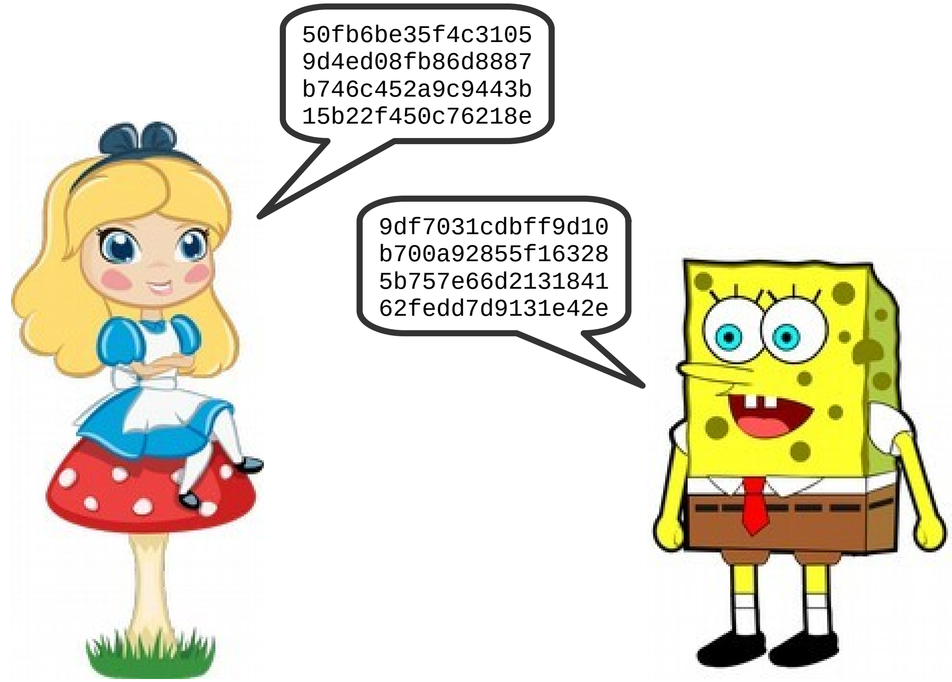


Security

a.k.a. “Why on earth do Alice and Bob need to share so many secrets?!?”

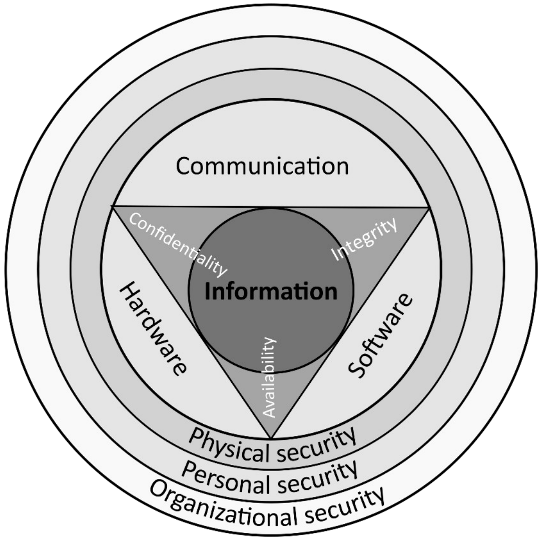
Content taken from the following:

"Distributed Systems: Principles and Paradigms" by Andrew S. Tanenbaum and Maarten Van Steen (Chapter 9)

Various online sources

Security Issues ("CIA Triad")

- Confidentiality: data is only disclosed to authorized users
- Integrity: changes can only be made by authorized users
- Availability: data is consistently accessible to authorized users
- Security threats
  - Interception
  - Interruption
  - Modification
  - Fabrication



https://en.wikipedia.org/wiki/Information_security

Threat models

- **Interception**: has data been received by an attacker?
  - Usually reserved for receipt of *unencrypted* data
- **Interruption**: can a service be disrupted by an attacker?
  - Sometimes via multiple sources
- **Modification**: can an attacker change data during transmission?
  - Enables “person-in-the-middle” attacks
- **Fabrication**: can an attacker create legitimate-looking data?
  - Does not require existing communication

Threat models

- An attacker manages to overwhelm a popular social media website by sending millions of messages via a botnet. What threat model does this correspond to?
  - A. Interception
  - B. Interruption
  - C. Modification
  - D. Fabrication
  - E. None of the above

Threat models

- An attacker manages to steal your email password using a packet sniffer at a coffee shop. What threat model does this correspond to?
  - A. Interception
  - B. Interruption
  - C. Modification
  - D. Fabrication
  - E. None of the above

Threat models

- An attacker tricks a web server into revealing sensitive information by forging a packet that looks like a normal request. Which threat model does this correspond to?
  - A. Interception
  - B. Interruption
  - C. Modification
  - D. Fabrication
  - E. None of the above

Security policies

- Security policy: description of actions allowed in a system
  - E.g., "*users in group 'students' may read files located in* `/shared` *but cannot write to them*"
- Policy enforcement mechanisms
  - Encryption
  - Authentication
  - Authorization
  - Auditing

Security policies

- **Encryption**: are messages secure against eavesdroppers?
  - Variation on end-to-end principle
- **Authentication**: are you connecting to the real recipient?
  - Issue of identity verification
- **Authorization**: do you have permission to perform this action?
  - Intersects with business/policy concerns
- **Auditing**: has the system been compromised?
  - Often bound by legal requirements

Least privilege

- Principle Of "Least Privilege" (POLP)
  - Every process or user should only be able to access resources or perform actions that are *strictly necessary*
  - Systems should be designed to *minimize privilege*
  - Limits vulnerability of the system to compromised components
  - Minimizes the need for full trust in participants
    - Social engineering can compromise even well-meaning participants

Least privilege

- The principle of "least privilege" often reveals a tension between security and
  - A. scalability
  - B. consistency
  - C. partition tolerance
  - D. convenience
  - E. availability

Trust

```
compile(s)
char *s;
{
        if(match(s, "pattern1")) {
                compile ("bug1");
                return;
        }
        if(match(s, "pattern 2")) {
                compile ("bug 2");
                return;
        }
        ...
}
```

- How much of your computer do you *trust*?
  - (and what does that even mean?)
- *"Reflections on Trusting Trust"*
  - A compiler virus that inserts a backdoor into `login()`
  - It also re-inserts itself to any further compilers
  - Ken Thompson Turing Award lecture (1984)

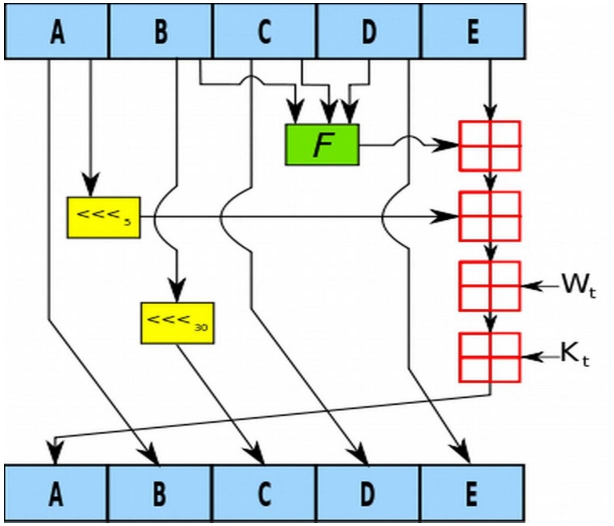
    https://www.ece.cmu.edu/~ganger/712.fall02/papers/p761-thompson.pdf
- Trusted Computing Base (TCB)
  - Minimal component of a system trusted to enforce security policies
  - Sometimes a physically-separate ROM-based processor
  - Hidden encryption key inaccessible to the rest of the system
  - Trusted Computing Group's Trusted Platform Module (TPM)

Security policy enforcement

Encryption

Hash functions

- One-way hash functions w/ collision resistance
  - Computationally infeasible to reverse
  - MD5: 128-bit fixed-length message digest
  - SHA-1 / SHA-2 / SHA-256 / SHA-512



One iteration of SHA-1

SHA1("The quick brown fox jumps over the lazy dog")
 = `2fd4e1c67a2d28fced849ee1bb76e7391b93eb12`

SHA1("The quick brown fox jumps over the lazy cog")
 = `de9f2c7fd25e1b3afad3e85a0bd17d9b100db4b3`

A, B, C, D and E are 32-bit words of the state;
F is a nonlinear function that varies;
$<<<_n$ denotes a left bit rotation by n places;
n varies for each operation;
W_t is the expanded message word of round t;
K_t is the round constant of round t;
+ denotes addition modulo 2^{32}

from `https://en.wikipedia.org/wiki/SHA-1`

Cryptography

- Terminology
  - Plaintext: original message
  - Ciphertext: encrypted plaintext
  - Nonce: random number that is only used once
  - Encrypt: turn plaintext into ciphertext
    - $C = E_K(P)$
    - Usually based on a one-way hash function
  - Decrypt: turn ciphertext into plaintext
    - $P = D_K(C)$
    - Alternatively: $P = D_K(E_K(P))$
  - Cryptographic system: pair of $D()$ and $E()$ functions

Cryptography

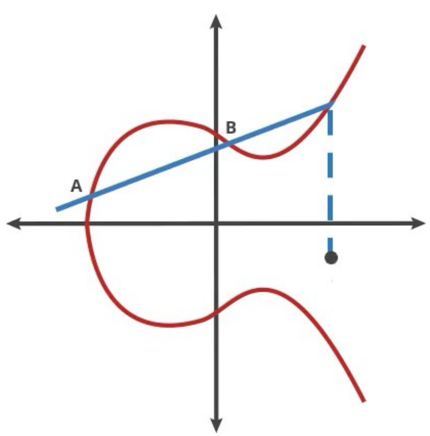
- Symmetric ($P = D_K(E_K(P))$) vs. asymmetric ($P = D_{KD}(E_{KE}(P))$)
  - Same key vs. key pair
  - Private key vs. public/private keys
- Symmetric (e.g., Advanced Encryption Standard (AES))
  - Various bitwise operations with different key values
  - Fast to encrypt/decrypt, relies on robust secret keys
  - Relatively secure against quantum computing attacks
- Asymmetric (e.g., Rivest, Shamir, Adleman (RSA))
  - Multiplication and modulus operations with large prime keys
  - Signing (encrypt w/ private) and secure messaging (encrypt w/ public)
  - Slow to encrypt/decrypt
  - Relies on difficulty of prime factorization or elliptic curve discrete logarithms

Cryptography

- Why are one-way hash functions used for cryptography?
  - A. They don’t require floating-point operations
  - B. They are computationally expensive to compute
  - C. They are computationally expensive to reverse
  - D. They generate true random numbers
  - E. They generate pseudo-random numbers

Elliptic curve cryptography

- Elliptic curves (e.g., $y^2 = x^3 + ax + b$)
  - Horizontal symmetry, and any non-vertical line will intersect the curve in at most three places
  - "Dot" operation: given two points, find third and then reflect
    - Very difficult to undo! (essentially a one-way hash)
  - ECDSA is a variant of DSA that uses elliptic curves



https://blog.cloudflare.com/a-relatively-easy-to-understand-primer-on-elliptic-curve-cryptography/

Cryptography

- Suppose you already have a shared secret with a friend. Which technology is best for transferring a very large (multi-GB) file with that friend?
  - A. AES
  - B. RSA
  - C. MD5
  - D. SHA-1
  - E. SHA-256

Security policy enforcement

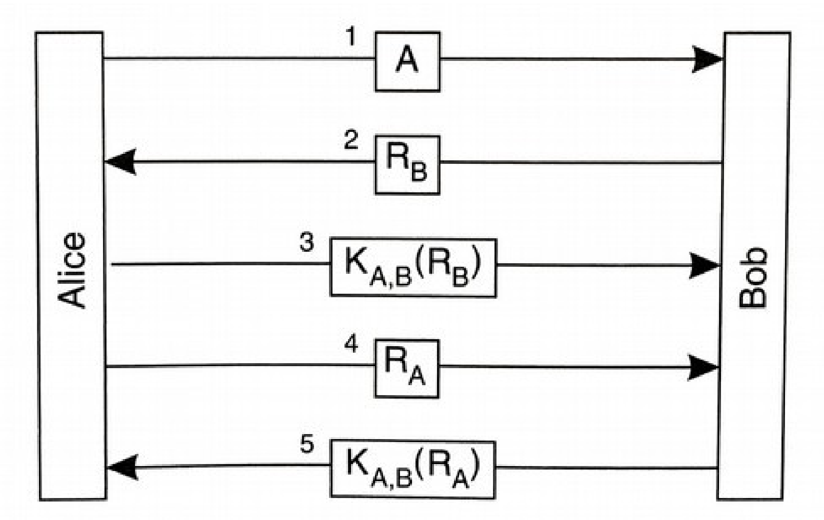
Authentication

Authentication

- A secure channel provides security on an unsecured network
  - Requires some kind of setup first
  - Protects against interception, modification, and fabrication
    - Cannot prevent interruption (recall CAP theorem)
  - Issue: authentication (verifying the identity of the recipient)
  - Issue: establishing shared secrets (after verifying identity)
- Security protocols
  - Shared-key authentication (requires pairwise secrets)
  - Needham-Schroeder authentication (uses central server)
  - Key signing parties (physical exchange of keys)
  - Diffie-Helman key exchange (uses public messaging)

Shared-key authentication

- Basic challenge-response protocol
  - Alice contacts Bob (“A”)
  - Bob issues a challenge (“R_B”) and receives a response (R_B encrypted using shared key "$K_{A,B}$")
  - Alice also issues a challenge (“R_A”) and receives a similar response
  - Issue: requires shared key



from Tanenbaum and Van Steen (Ch. 9)

Shared-key authentication

- What is the minimum number of steps for a challenge-response protocol, assuming that neither entity has contacted the other yet (but assuming that they do have a shared key)?
  - A. 2
  - B. 3
  - C. 4
  - D. 5
  - E. 6

Needham-Schroeder authentication

- Uses a central Key Distribution Center (KDC)
  - Alice sends a nonce to the KDC to request communication with Bob
    - The nonce prevents a replay attack using an old (compromised) $K_{B,KDC}$
  - Alice receives a new shared key ($K_{A,B}$) as well as an encrypted copy to send to Bob
  - Bob and Alice then exchange challenges and responses using this shared key

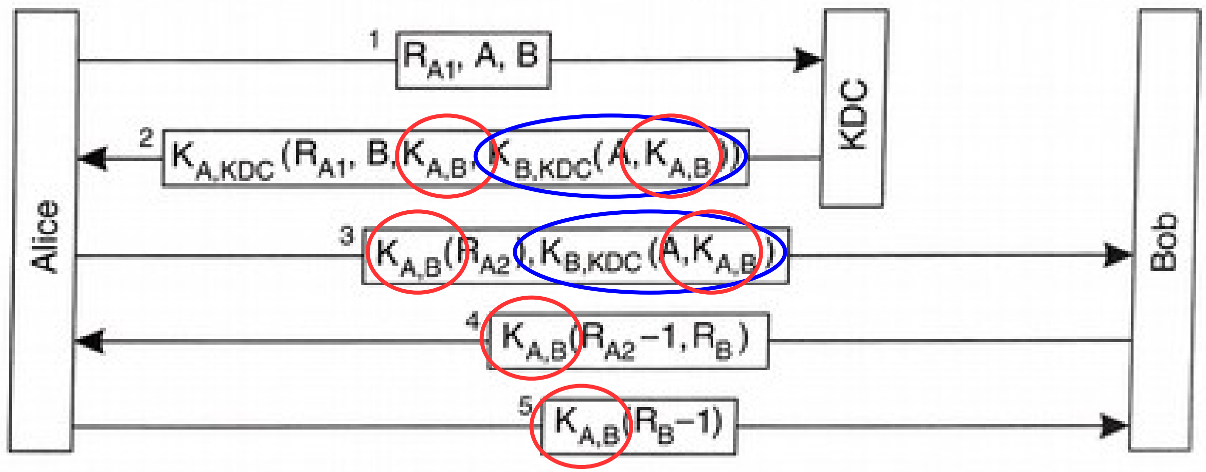


Figure 9-17. The Needham-Schroeder authentication protocol.

shared secret

Bob's copy of shared secret

from Tanenbaum and Van Steen (Ch. 9)

Needham-Schroeder authentication

- Kerberos is similar, but uses two servers:
  - Authentication Server (AS) to establish identity (authentication)
  - Ticket Granting Server (TGS) to verify permissions (authorization) and set up shared key

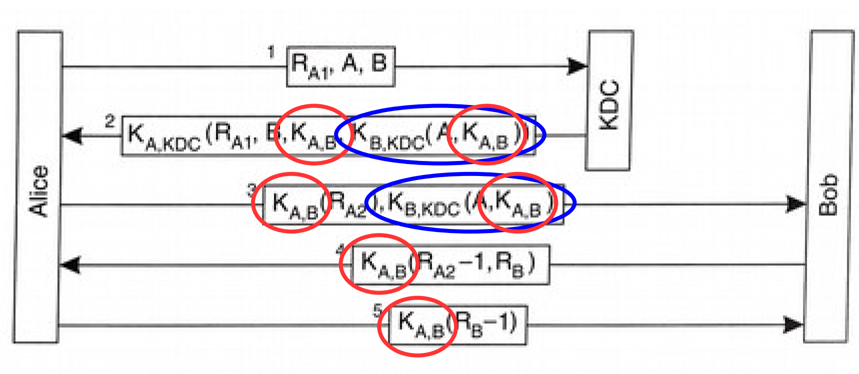


Figure 9-17. The Needham-Schroeder authentication protocol.

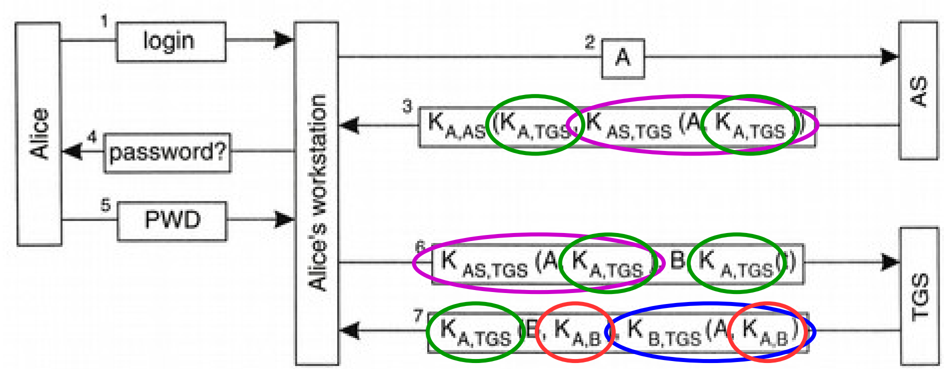


Figure 9-23. Authentication in Kerberos.

shared secret | Bob's copy of shared secret | session key | ticket

from Tanenbaum and Van Steen (Ch. 9)

Kerberos

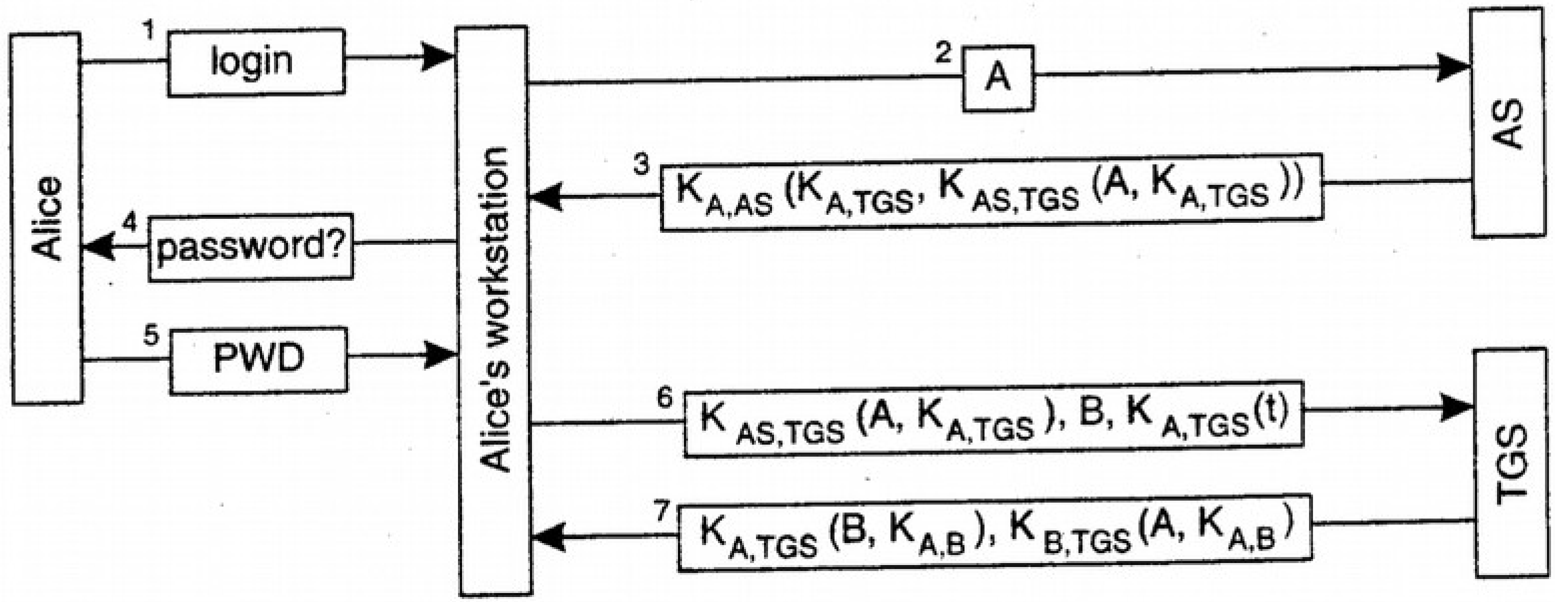


Figure 9-23. Authentication in Kerberos.

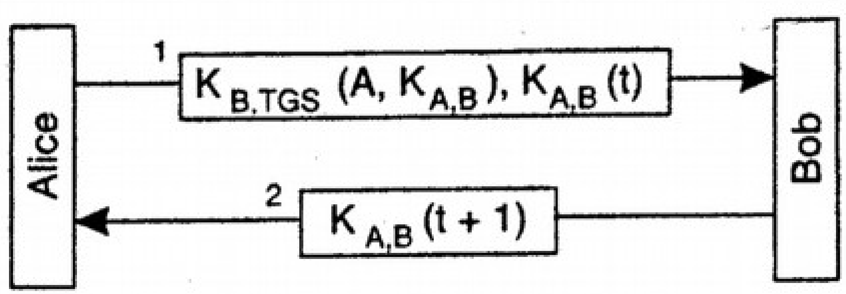


Figure 9-24. Setting up a secure channel in Kerberos.

from Tanenbaum and Van Steen (Ch. 9)

Public keys

- Private keys are used to sign documents by encrypting them
  - Public key can also be used to encrypt a document for a single recipient (the one who holds the private key)
- A certificate is a signed document claiming to own a public key
  - Only the public key can decrypt the document, proving it was encrypted using the corresponding private key
- At a key signing party, participants exchange public keys
  - This allows others to later sign a certificate containing a known public key (thus vouching for its authenticity)
  - Purely peer-to-peer; no central server required

Public keys

- Issues: scaling and certificate revocation
  - Revocation lists and certificate lifetime limits
- In a large distributed system, a Public-Key Infrastructure (PKI) provides scalable certificate management
  - Usually implemented using trusted third-party certificate authorities (CAs)
  - CAs issue certifications, handle authorization requests, and revoke certificates when necessary
  - Domain validation (DV) vs. organization/extended validation (OV/EV)

Let's Encrypt

- Open source and free certificate authority
  - Goal: make HTTPS (encrypted HTTP) ubiquitous
  - Automated Certificate Management Environment (ACME) protocol for certificate issuing

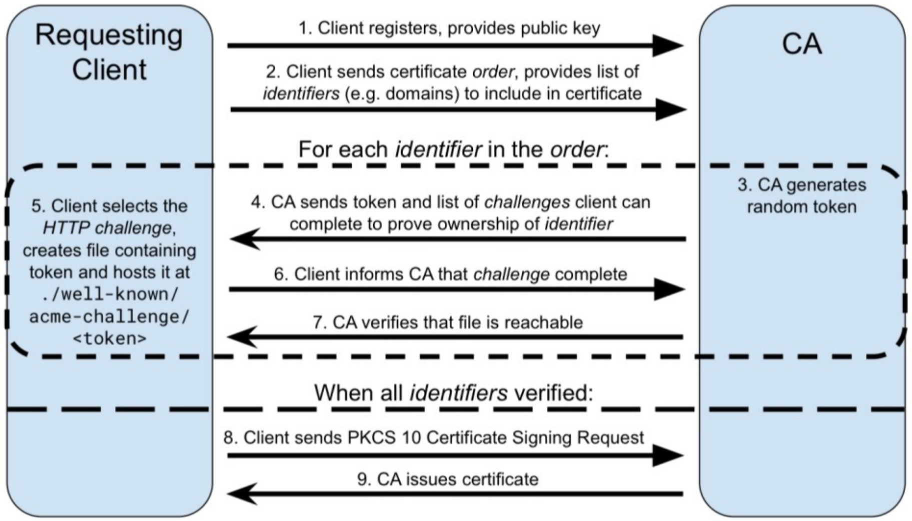


Figure 2: ACME protocol. This diagram illustrates how an ACME client can obtain a certificate without human interaction. In the dashed region, the client proves ownership of the domain using an HTTP-based challenge.

Diffie-Hellman key exchange

- Allows distributed entities to establish a shared secret via unsecured channels
- Can be extended to more than two entities
- Resists person-in-the-middle attacks
  - Third party pretends to be other conversant

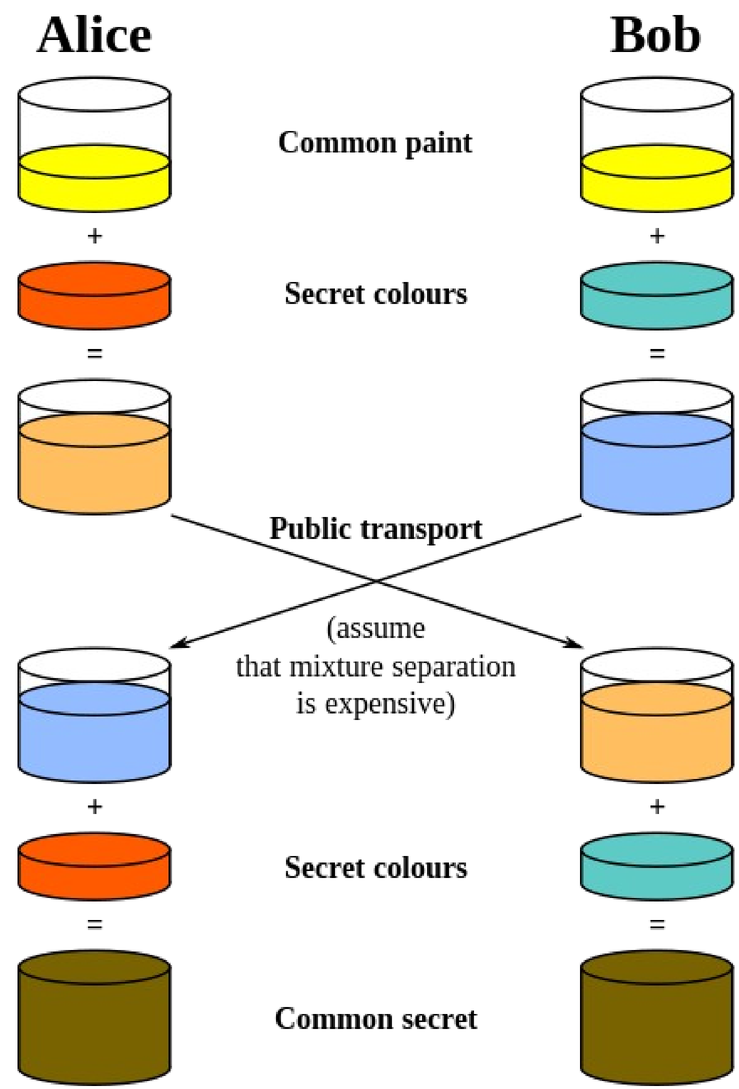
1. Alice and Bob agree to use a modulus $p = 23$ and base $g = 5$
2. Alice chooses a secret integer $a = 6$, then sends Bob $A = g^a \bmod p$
   - $A = 5^6 \bmod 23 = 8$
3. Bob chooses a secret integer $b = 15$, then sends Alice $B = g^b \bmod p$
   - $B = 5^{15} \bmod 23 = 19$
4. Alice computes $s = B^a \bmod p$
   - $s = 19^6 \bmod 23 = 2$
5. Bob computes $s = A^b \bmod p$
   - $s = 8^{15} \bmod 23 = 2$
6. Alice and Bob now share a secret (the number 2).

Both Alice and Bob have arrived at the same value s, because, under mod p,

$A^b \bmod p = g^{ab} \bmod p = g^{ba} \bmod p = B^a \bmod p$[9]

More specifically,

$(g^a \bmod p)^b \bmod p = (g^b \bmod p)^a \bmod p$



from `https://en.wikipedia.org/wiki/Diffie-Hellman_key_exchange`

Security policy enforcement

Authorization

Authorization

- Access control mechanisms enforce authorization constraints
  - Internal vs. external access control
  - Firewalls prevent external access to a host or internal network
    - Defends against Denial-of-Service (DoS) or distributed DoS (DDoS) attacks
  - Access control lists/matrices track user permissions

$$\texttt{-}\overbrace{\texttt{rw-}}^{\text{user}}\overbrace{\texttt{r--}}^{\text{group}}\overbrace{\texttt{r--}}^{\text{other}}$$

directory?

Unix file permissions

```
# file: .
# owner: studentid
# group: csmajor
user:instructorid:rwx
user:graderid:rwx
user:studentid:rwx
group:faculty:r-x
group:csmajor:---
```

Access control list on stu

Authorization

- A directory service provides internal distributed authorization and access control
  - Handles user management, group membership, and password storage
  - Often distributed and/or replicated among multiple servers
  - Lightweight Directory Access Protocol (LDAP) for communication
  - Authentication provided by protocols like Kerberos
  - Example: Active Directory

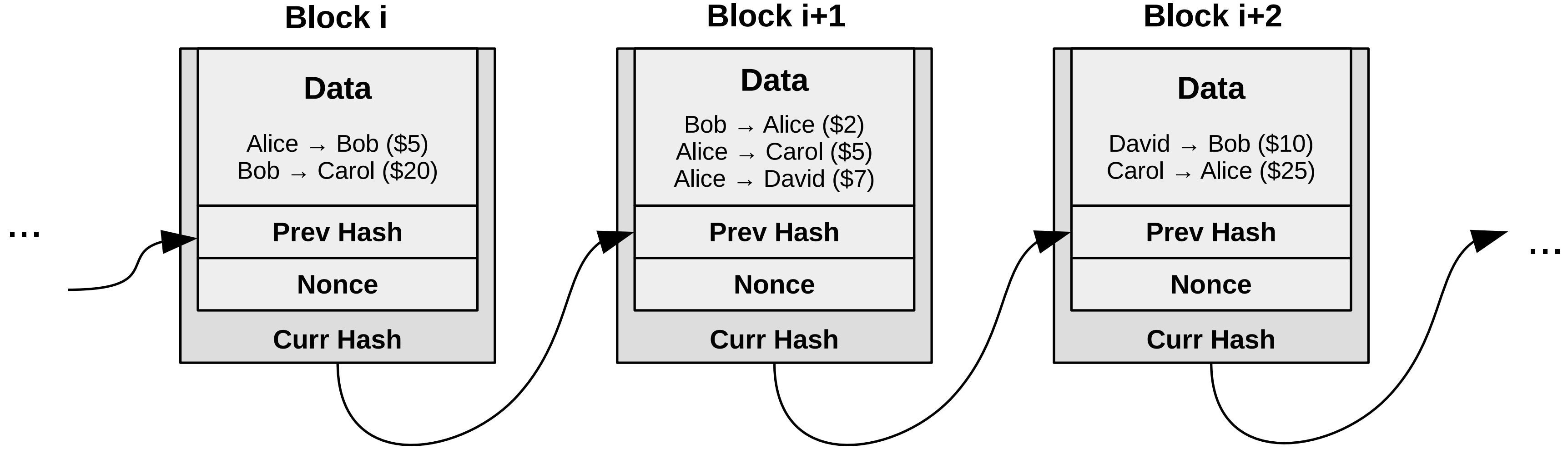
- A single sign-on service provides authorization for multiple applications or systems
  - Often provides seamless hand-off of an authentication ticket
  - May also use a directory service
  - Examples: Facebook Connect, OAuth, OpenID, Shibboleth

Security policy enforcement

Auditing

Auditing

- Access logs provide an audit trail for a system
  - Who can access the logs? Who can modify them?
    - Encryption is useful here
  - Append-only logs provide guarantees against tampering using checksums and/or cryptographic signing
  - Bitcoin (and other cryptocurrencies) uses an append-only blockchain of cryptographically-signed transactions to preserve financial integrity
    - Demo: `https://andersbrownworth.com/blockchain/blockchain`



Security

- What security concern does the Needham-Schroeder protocol primarily address?
  - A. Encryption
  - B. Authentication
  - C. Authorization
  - D. Auditing
  - E. None of the above

Security

- What security concern does blockchain technology primarily address?
  - A. Encryption
  - B. Authentication
  - C. Authorization
  - D. Auditing
  - E. None of the above

Security

- What security concern does the RSA algorithm primarily address?
  - A. Encryption
  - B. Authentication
  - C. Authorization
  - D. Auditing
  - E. None of the above