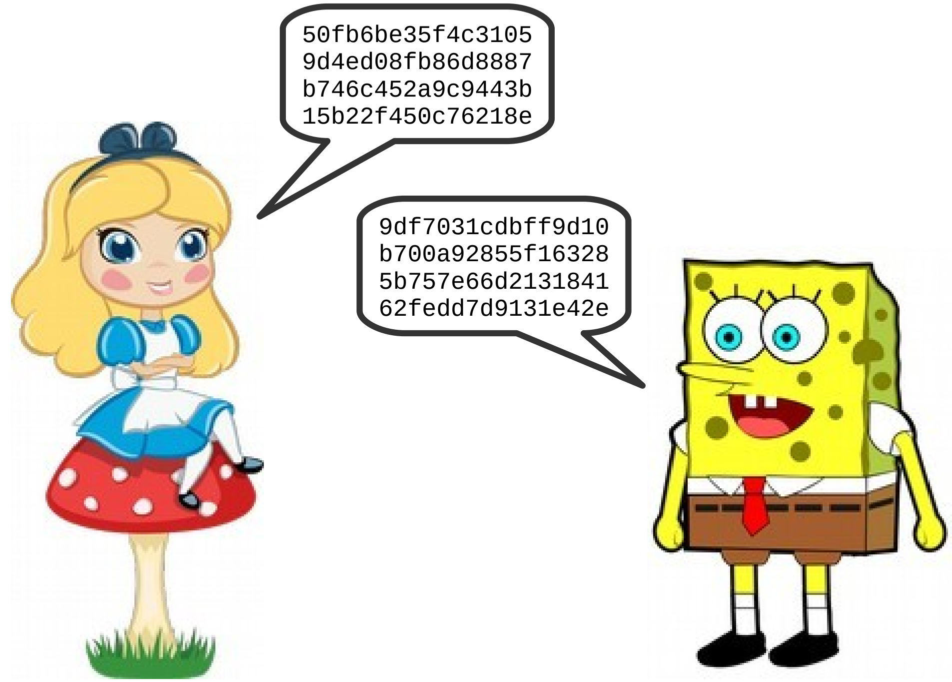
CS 470
Spring 2019

Mike Lam, Professor



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

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

Distributed security

- **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 “man-in-the-middle” (MITM) attacks
- **Fabrication**: can an attacker create legitimate-looking data?
  - Does not require existing communication

Security Solutions

- 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

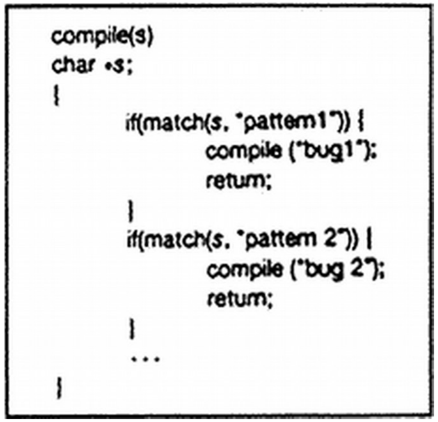
Distributed security

- **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
  - Tradeoff vs. convenience

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)

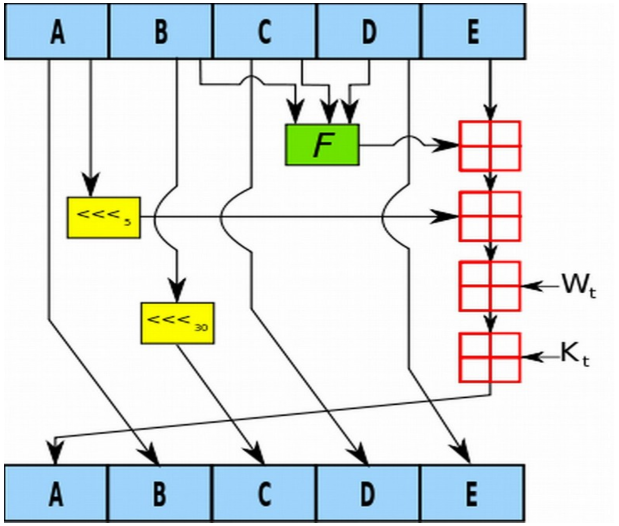
    `https://www.ece.cmu.edu/~ganger/712.fall02/papers/p761-thompson.pdf`
- Trusted Computing Base (TCB)
  - Minimal component of a system trusted to enforce security policies
  - Sometimes a physically-separate ROM-based processor
  - Hidden encryption key inaccessible to the rest of the system
  - Trusted 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: Data Encryption Standard (DES)
  - XOR-based operations with different 48-bit keys
  - Fast to encrypt/decrypt, relies on robust secret keys
- Asymmetric: 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

Security policy enforcement

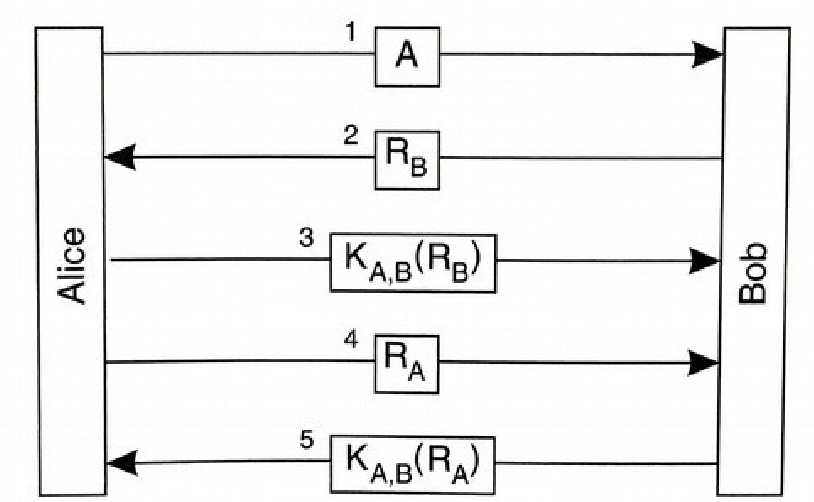
Authentication

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)

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

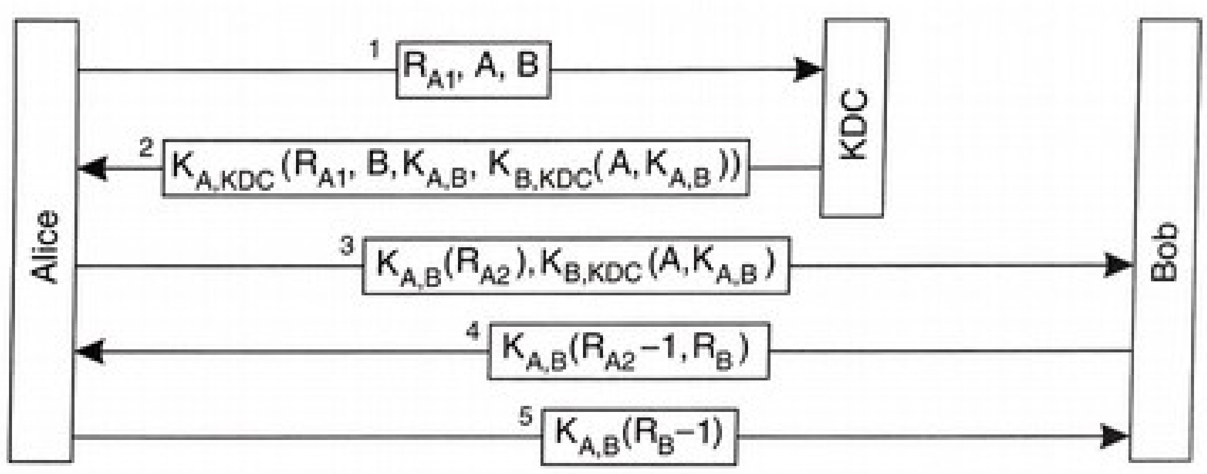


Figure 9-17. The Needham-Schroeder authentication protocol.

from Tanenbaum and Van Steen (Ch. 9)

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

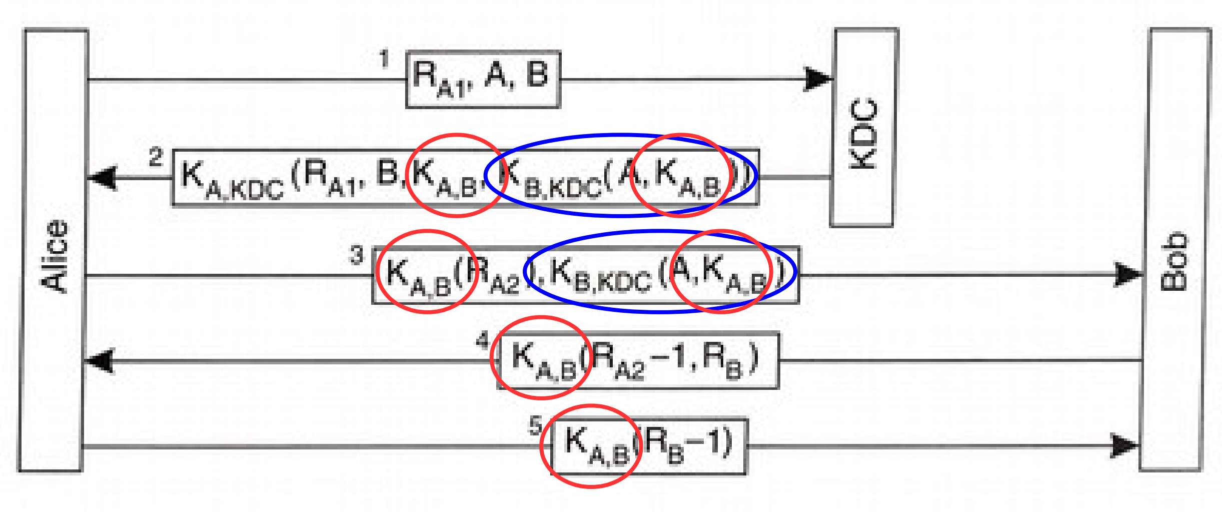
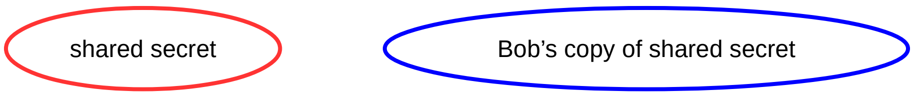


Figure 9-17. The Needham-Schroeder authentication protocol.



from Tanenbaum and Van Steen (Ch. 9)

Needham-Schroeder authentication

- Kerberos is similar, but uses an Authentication Server (AS) to establish identity and a Ticket Granting Server (TGS) to set up shared keys

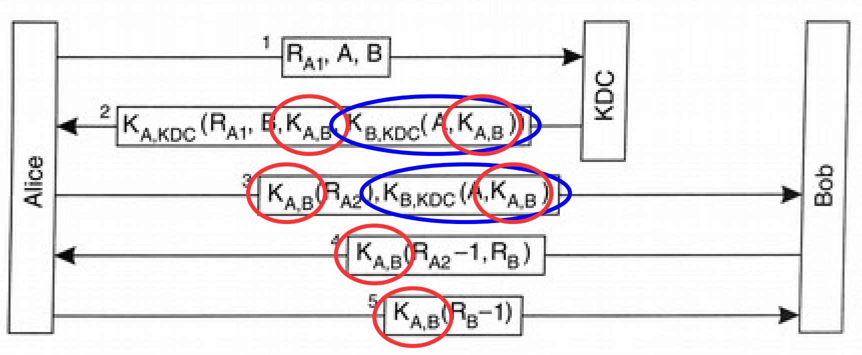


Figure 9-17. The Needham-Schroeder authentication protocol.

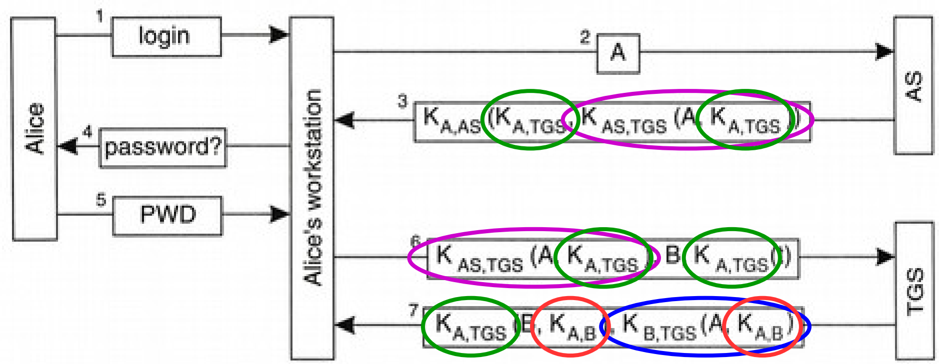


Figure 9-23. Authentication in Kerberos.

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

from Tanenbaum and Van Steen (Ch. 9)

Kerberos

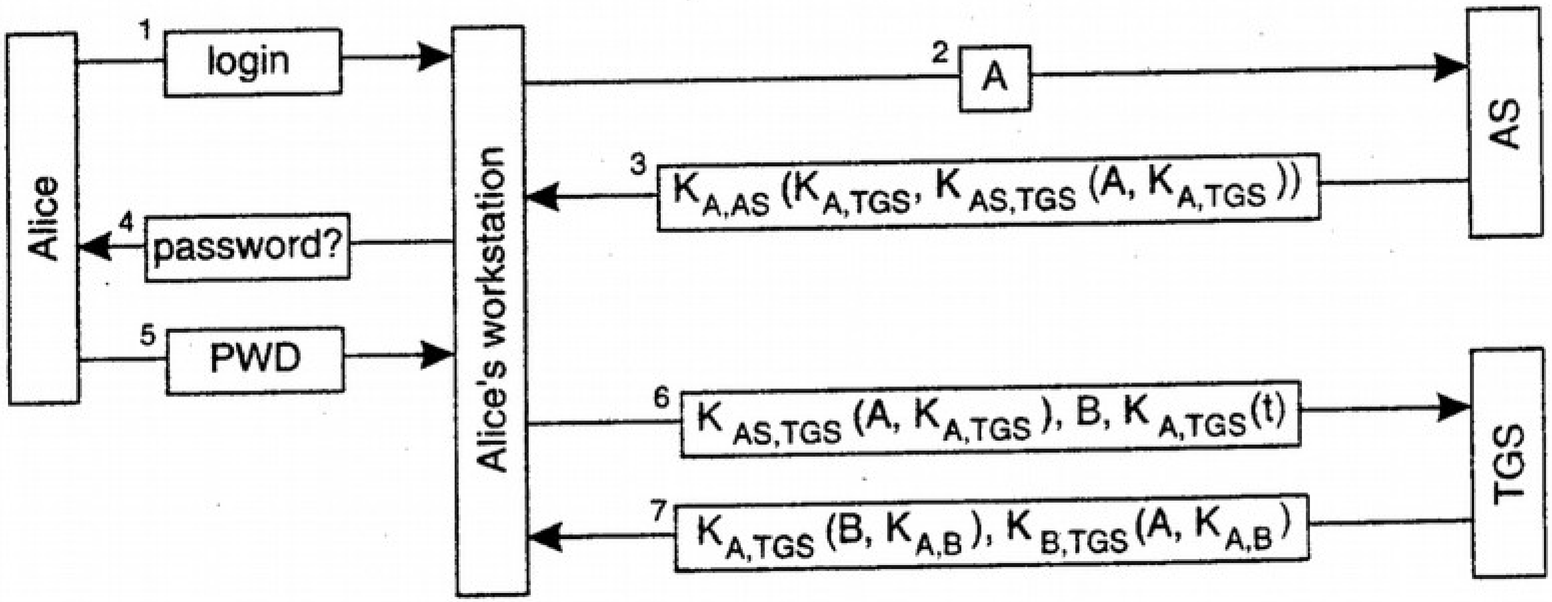


Figure 9-23. Authentication in Kerberos.

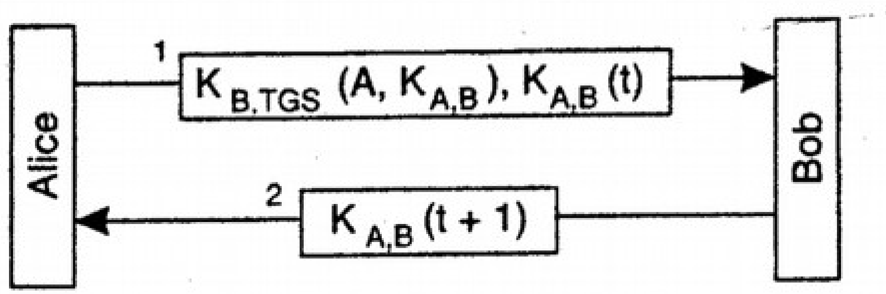


Figure 9-24. Setting up a secure channel in Kerberos.

Public keys

- Private keys are used to sign documents by encrypting them
- 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

Diffie-Helman key exchange

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

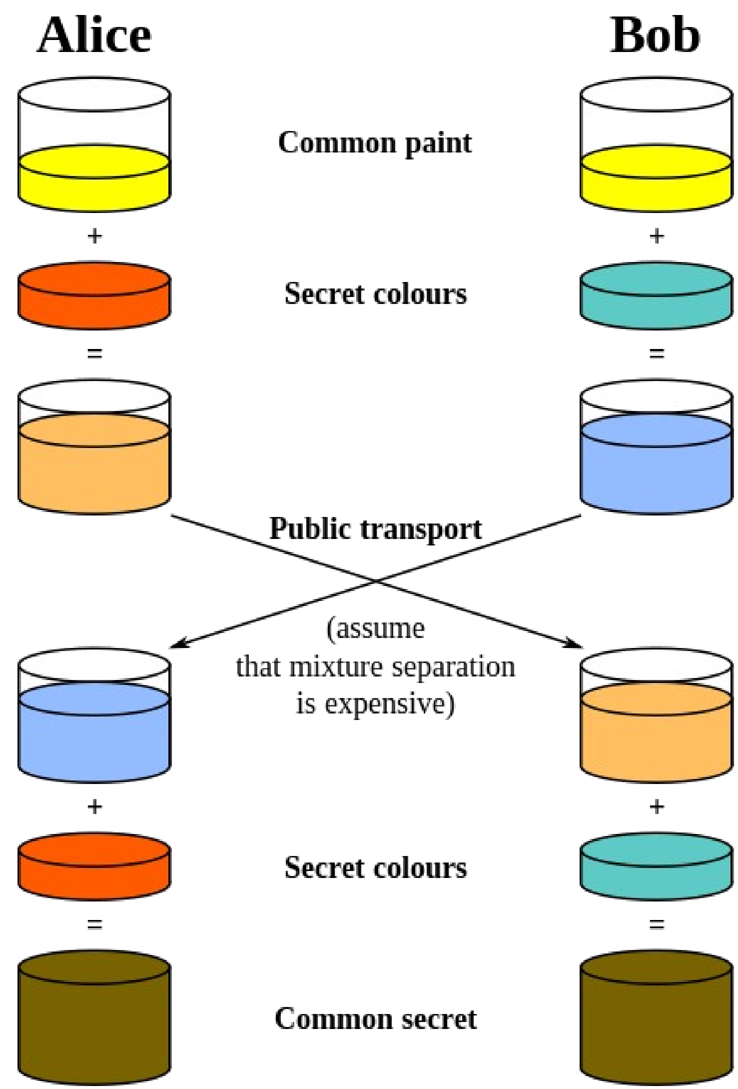
1. Alice and Bob agree to use a modulus $p = 23$ and base $g = 5$
2. Alice chooses a secret integer $a = 6$, then sends Bob $A = g^a \bmod p$
   - $A = 5^6 \bmod 23 = 8$
3. Bob chooses a secret integer $b = 15$, then sends Alice $B = g^b \bmod p$
   - $B = 5^{15} \bmod 23 = 19$
4. Alice computes $s =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

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



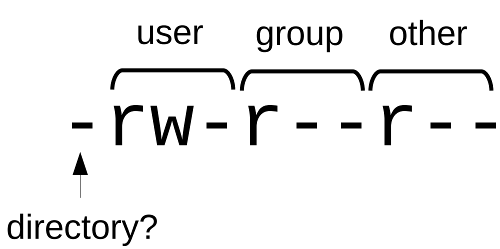
from `https://en.wikipedia.org/wiki/Diffie-Hellman_key_exchange`

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



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/permissions 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 LDAP and/or Kerberos
  - 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://anders.com/blockchain/blockchain.html`