Lecture 11: Authentication Protocols (cont'd)

CS 181S

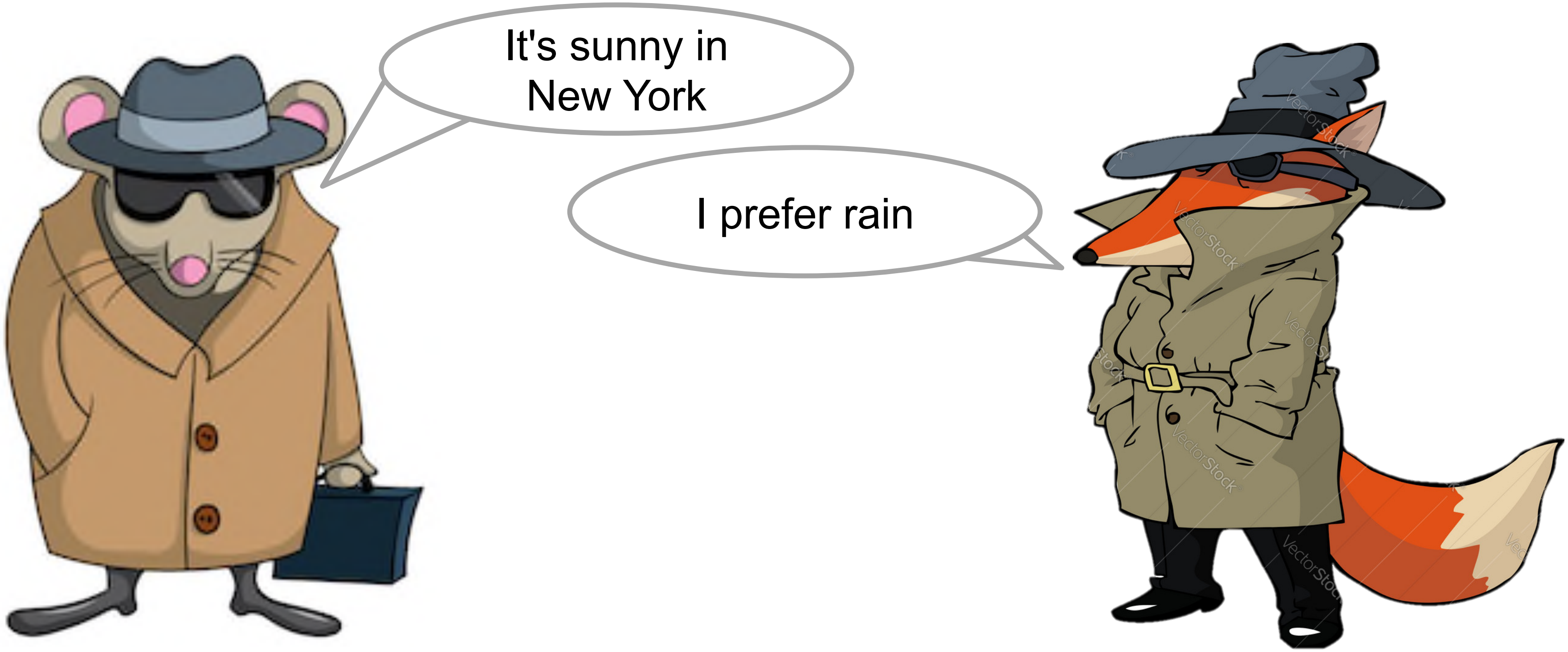
Fall 2020

Review: Authentication

- **Threat:** attacker who controls the network
  - Dolev-Yao model: attacker can read, modify, delete messages
- **Vulnerability:** communication channel between sender and receiver can be controlled by other principals
- **Harm:** attacker can pretend to be someone else (violating security goals)
- **Countermeasure:** authentication protocols

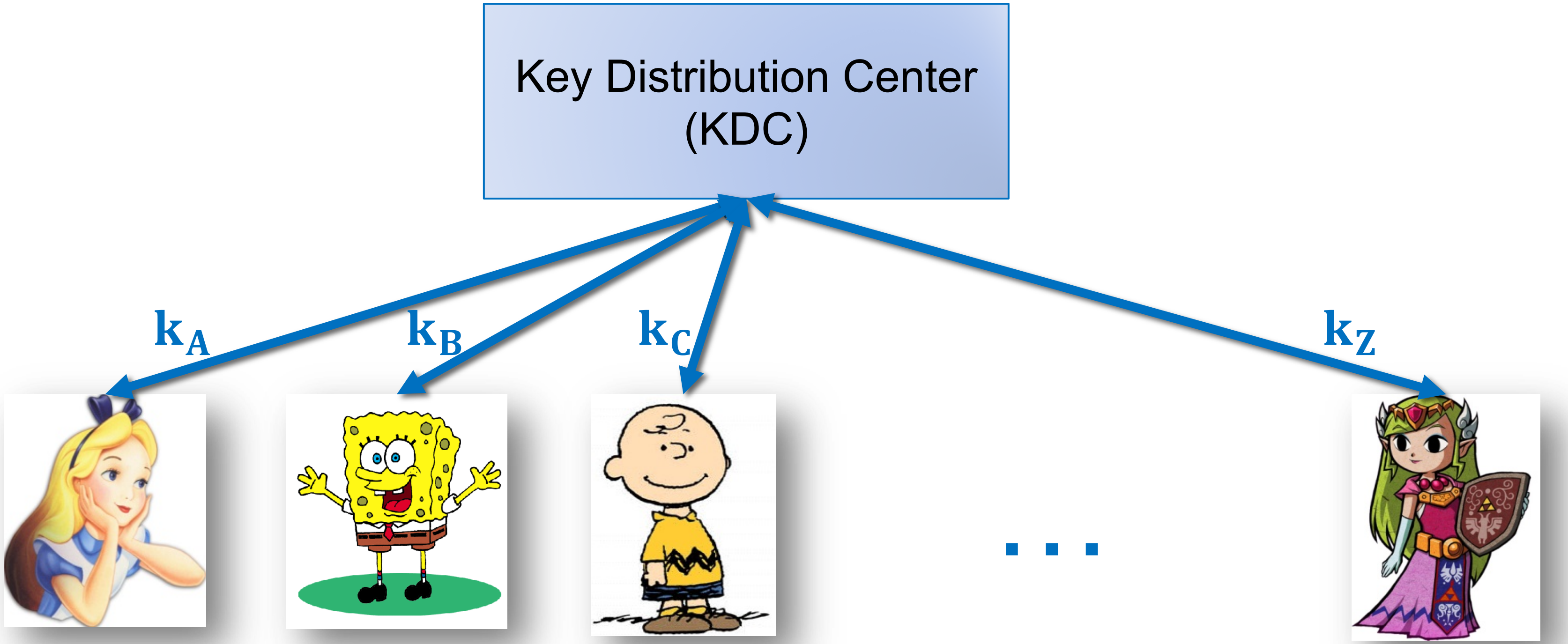
Review: Authentication Protocols

- An **authentication protocol** allows a principal receiving a message to verify the identity of the principal that sent that message



Assumptions

- ~~Assume Alice and Bob have a shared secret key k~~
- Assume that symmetric-key crypto works
- Assume there is a trusted **Key Distribution Center (KDC)** and that all principals have a shared key with the KDC



Goals

- Alice and Bob should acquire a shared key that they can use to securely communicate
- Alice should be convinced that she is talking to Bob
- Bob should be convinced that he is talking to Alice

Protocol 1

1. A -> KDC: A, B
2. KDC -> A: A, B, Enc(k; k_A)
3. KDC -> B: A, B, Enc(k; k_B)

Protocol 2

1. A -> KDC: A, B
2. KDC -> A: A, B, Enc(k; k_A), Enc(k; k_B)
3. A -> B: A, B, Enc(k; k_B)

Threat Model

- Dolev-Yao attacker
  - controls the network, can read, modify, create packets

- A **replay attack** occurs when an adversary repeats fragments of a previous protocol run
- ~~A **reflection attack** occurs when an adversary sends messages from an ongoing protocol back to the originator~~
- A **man-in-the-middle attack** occurs when an adversary secretly relays (and potentially changes) communications between two principals who believe they are communicating directly with eachother

Exercise 1: Replay Attacks

Is this protocol vulnerable to a replay attack?

1. A -> KDC: A, B
2. KDC -> A: A, B, Enc(k; k_A), Enc(k; k_B)
3. A -> B: A, B, Enc(k; k_B)

Exercise 1: Replay Attacks

Is this protocol vulnerable to a replay attack?

```
1. A -> KDC: A, B
2. KDC -> A: A, B, Enc(k; k_A), Enc(k; k_B)
3. A -> B: A, B, Enc(k; k_B)
   1) A -> T: A, B
   2) T -> A: A, B, Enc(k; k_A), Enc(k; k_B)
   3) A -> B: A, B, Enc(k; k_B)
```

Protocol 3

1. `A -> KDC: A, B, r`
2. `KDC -> A: A, B, Enc(k,r;k_A), Enc(k;k_B)`
3. `A -> B: A, B, Enc(k; k_B)`

MITM Attack

```
1. A -> T: A, B, r
   1) T -> KDC: A, T, r
   2) KDC -> T: A, T, Enc(k, r; k_A), Enc(k; k_T)
   1) T -> KDC: T, B, r
   2) KDC -> T: A, T, Enc(k2, r; k_T), Enc(k2; k_B)
2. T -> A: A, B, Enc(k, r; k_A), Enc(k2; k_B)
3. A -> B: A, B, Enc(k2; k_B)
```

Protocol 5

1. A -> KDC: A, B, r
2. KDC -> A: A, B, Enc(k, r, Enc(k; k_B);k_A)
3. A -> B: A, B, Enc(k; k_B)

Attack on Protocol 5

1. T -> KDC: T, B, r
2. KDC -> T: T, B, Enc(k, r, Enc(k; k_B);k_T)
3. T -> B: A, B, Enc(k; k_B)

Protocol 6

1. A -> KDC: A, B, r
2. KDC -> A: A, B, Enc(k,r,Enc(A,B,k; k_B);k_A)
3. A -> B: A, B, Enc(A,B,k; k_B)

Attack on Protocol 6

1. A -> T: A, B, r
    1. T -> KDC: A, T, r
    2. KDC -> T: A, T, Enc(k, r, Enc(A,T,k; k_T);k_A)
2. T -> A: A, B, Enc(k, r, Enc(A,T,k; k_T);k_A)
3. A -> T: A, B, Enc(A,T,k; k_T)

Protocol 7

1. A -> KDC: A, B, r
2. KDC -> A: Enc(A,B,k,r,Enc(A,B,k; k_B);k_A)
3. A -> B: A, B, Enc(A,B,k; k_B)

Protocol 8: Needham-Schroeder

1. `A -> KDC: A, B, r`
2. `KDC -> A: Enc(A,B,k,r,Enc(A,B,k; k_B);k_A)`
3. `A -> B: A, B, Enc(A,B,k; k_B)`
4. `B -> A: A, B, Enc(r2; k)`
5. `A -> B: A, B, Enc(r2+1; k)`

Exercise 2: MITM Attacks

Consider the following variant of Needham-Schroeder. Is this protocol vulnerable to a MITM attack?

```
1. A -> KDC: A, B, r
2. KDC -> A: Enc(A,B,r;k_A),Enc(r,k; k_A)
3. KDC -> B: Enc(A,B,r;k_B),Enc(r,k; k_B)
4. B -> A: A, B, Enc(r2; k)
5. A -> B: A, B, Enc(r2+1; k)
```

Exercise 2: MITM Attacks

Consider the following variant of Needham-Schroeder. Is this protocol vulnerable to a MITM attack?

```
1.  A -> T: A, B, r
    1)  T -> KDC: A, B, r
    2)  KDC -> T: Enc(A,B,r;k_A), Enc(r,k;k_A)
    3)  KDC -> T: Enc(A,B,r;k_B), Enc(r,k;k_B)
    1)  T -> KDC: A, T, r
    2)  KDC -> T: Enc(A,T,r;k_A), Enc(r,k2;k_A)
    3)  KDC -> T: Enc(A,T,r;k_T), Enc(r,k2;k_T)
    1)  T -> KDC: T, B, r
    2)  KDC -> T: Enc(T,B,r;k_T), Enc(r,k3;k_T)
    3)  KDC -> T: Enc(T,B,r;k_B), Enc(r,k3;k_B)
2.  T -> A: Enc(A,B,r;k_A),Enc(r,k2; k_A)
3.  T -> B: Enc(A,B,r;k_B),Enc(r,k3; k_B)
4.  B -> T: A, B, Enc(r2; k3)
5.  T -> B: A, B, Enc(r2+1; k3)
    1.  T -> A: A, B, Enc(r2; k2)
    2.  A -> T: A, B, Enc(r2+1; k2)
```

Protocol 8: Needham-Schroeder

1. `A -> KDC: A, B, r`
2. `KDC -> A: Enc(A,B,k,r,Enc(A,B,k; k_B);k_A)`
3. `A -> B: A, B, Enc(A,B,k; k_B)`
4. `B -> A: A, B, Enc(r2; k)`
5. `A -> B: A, B, Enc(r2+1; k)`

Solution #1: More nonces

1. `A -> B: A, B`
2. `B -> A: A, B, r3`
3. `A -> KDC: A, B, r, r3`
4. `KDC -> A: Enc(A,B,k,r,Enc(A,B,k,r3; k_B);k_A)`
5. `A -> B: A, B, Enc(A,B,k,r3; k_B)`
6. `B -> A: A, B, Enc(r2; k)`
7. `A -> B: A, B, Enc(r2+1; k)`

Solution #2: Timestamps

1. A -> KDC: A, B, r,
2. KDC -> A: Enc(A,B,k,r,Enc(A,B,k,t; k_B);k_A)
3. A -> B: A, B, Enc(A,B,k,t; k_B)
4. B -> A: A, B, Enc(r2; k)
5. A -> B: A, B, Enc(r2+1; k)

Solution #3: Otway-Rees

```
1. A -> B: n, A, B, Enc(r1,n,A,B;k_A)
2. B -> KDC: n, A, B, Enc(r1,n,A,B;k_A),
                      Enc(r2,n,A,B;k_B)
3. KDC -> B: n, Enc(r1,k;k_A),
                      Enc(r2,k;k_B)
4. B -> A: n, Enc(r1,k;k_A)
```

Type Attack

```
1. A -> B: n, A, B, Enc(r1,n,A,B;k_A)
2. B -> KDC: n, A, B, Enc(r1,n,A,B;k_A),
                      Enc(r2,n,A,B;k_B)
3. T -> B: n, Enc(r1,n,A,B;k_A),
                      Enc(r2,n,A,B;k_B)
4. B -> A: n, Enc(r1,n,A,B;k_A)
```

Exercise 3: Type Attacks

Consider the following variant of Otway-Rees

```
1. A -> B: n, A, B, Enc(r1,n,A,B;k_A)
2. B -> KDC: n, A, B, Enc(r1,n,A,B;k_A),
                     Enc(r2,n,A,B;k_B)
3. KDC -> B: n, Enc(r1+1,k;k_A),
                     Enc(r2+1, k;k_B)
4. B -> A: n, Enc(r1+1,k;k_A)
```

Would this protocol be vulnerable to a type attack?

Authentication in Practice

Exercise 4: Feedback

1. Rate how well you think this recorded lecture worked
    1. Better than an in-person class
    2. About as well as an in-person class
    3. Less well than an in-person class, but you still learned something
    4. Total waste of time, you didn't learn anything

2. How much time did you spend on this video lecture (including time spent on exercises)?

3. Do you have particular questions you would like me to address in this week's problem session?

4. Do you have any other comments or feedback?