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We use the following steps.

$(\mathsf{s}_1 \wedge \mathsf{s}_2) \longrightarrow \mathsf{s}_1$	by (1)
Alice says $((\mathsf{s}_1 \wedge \mathsf{s}_2) \longrightarrow \mathsf{s}_1)$	by (4)
Alice says s_1	by (3)

Axioms about principals

5 $(P \wedge Q)$ says s $\equiv$ $(P$ says s$) \wedge (Q$ says s$)$

6 $(P \mid Q)$ says s $\equiv$ P says $(Q$ says s$)$

7 $(P = Q) \rightarrow (P$ says s $\equiv$ Q says s$)$

$=$ is equality on principals.

8 $(P_1 \mid (P_2 \mid P_3)) = ((P_1 \mid P_2) \mid P_3)$

Quoting is associative.

9 $(P_1 \mid (P_2 \wedge P_3)) = (P_1 \mid P_2) \wedge (P_1 \mid P_3)$

Quoting distributes over conjunction

10 $(P \Rightarrow Q) \equiv (P = P \wedge Q)$

11 $(P \text{ says } (Q \Rightarrow P)) \rightarrow (Q \Rightarrow P)$

A principal is free to choose a representative.

Example We want to conclude s from the three statements:

– $(Alice \wedge Bob)$ says $(Charlie \Rightarrow (Alice \wedge Bob))$

– $Charlie \mid Alice$ says s

– $(Alice$ says $\mathsf{s}) \rightarrow \mathsf{s}$

$(Alice \wedge Bob)$ says $(Charlie \Rightarrow (Alice \wedge Bob))$	
$\quad \rightarrow (Charlie \Rightarrow (Alice \wedge Bob))$	by (11)
$(Charlie \Rightarrow (Alice \wedge Bob))$	by (2)
$Charlie = (Charlie \wedge Alice \wedge Bob)$	by (10)
$Charlie$ says $(Alice$ says $\mathsf{s})$	by (6)
$(Charlie \wedge Alice \wedge Bob)$ says $(Alice$ says $\mathsf{s})$	by (7,2)

$Alice$ says ($Alice$ says s) by (5,1,2)

$Alice$ says (($Alice$ says s)$\rightarrow$s) by (4)

$Alice$ says s by (3)

s by (2)

Modeling Java stack inspection using ABLP

Wallach, Felten, 1998

Code can be digitally signed by a signer. We treat code, public keys and signers as principals. Stack frames created during execution of code are also treated as principals. Targets (resources to be protected) are also treated as principals.

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If K is a public key of S then we have the statement

$$K \Rightarrow S \tag{S1}$$

If some code C was signed and K is the corresponding public key then we have the statement

$$K \text{ says } (C \Rightarrow K) \tag{S2}$$

If F is the stack frame generated for executing code C then we have the statement

$$F \Rightarrow C \tag{S3}$$

Frame credentials Φ = set of all valid statements of the form S1,S2 and S3.

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Note that from K says $(C \Rightarrow K)$ using (11) we can conclude $C \Rightarrow K$.

Further we can show transitivity of $\Rightarrow$: given $A \Rightarrow B$ and $B \Rightarrow C$ we have:
$A = A \wedge B$ by (10)
$B = B \wedge C$ by (10)
Hence $A = A \wedge B \wedge C = A \wedge C$
Hence we have $A \Rightarrow C$

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Hence from S1, S2 and S3 we can conclude $F \Rightarrow S$.

For each target T we treat $\mathsf{Ok}(T)$ as an atomic statement.

It means that access to T is permitted.

We consider the axiom

$$(T \;\mathsf{says}\; \mathsf{Ok}(T)) \rightarrow \mathsf{Ok}(T) \tag{S4}$$

A target is always free to grant permission to itself.

Targets are dummy principals. They never speak, but other (non-dummy) principals representing them may speak for them.

Target credentials $\mathcal{T}$ is the set of such axioms for all targets T.

Policy for a virtual machine M is defined by a set

access credentials $\mathcal{A}_{\mathsf{M}}$ of statements of the form $P \Rightarrow T$ where P is a principal and T is a target.

This rule means that the local policy of virtual machine M allows P to access T.

Stacks

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Enabling privileges

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Function calls

Function call from stack frame F creates a new stack frame G.

$\mathcal{B}_G = \{F \ \mathsf{says}\ \mathsf{s} \mid \mathsf{s} \in \mathcal{B}_F\}$.

Disabling privileges

If stack frame F calls $\mathsf{disablePrivilege}(T)$ then we update

$\mathcal{B}_F := \mathcal{B}_F \setminus \{\mathsf{s} \mid \mathsf{Ok}(T) \text{ occurs in } \mathsf{s}\}$

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Reverting privileges

If stack frame F calls $\mathsf{revertPrivilege}(T)$ then we update $\mathcal{B}_F := \mathcal{B}_F \setminus \{\mathsf{Ok}(T)\}$

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Reverting privileges

If stack frame F calls $\mathsf{revertPrivilege}(T)$ then we update $\mathcal{B}_F := \mathcal{B}_F \setminus \{\mathsf{Ok}(T)\}$

Checking privileges

When F calls $\mathsf{checkPrivilege}(T)$ then we check that $\mathsf{Ok}(T)$ can be concluded from the set

$\Phi \cup \mathcal{T} \cup \mathcal{A}_{\mathsf{M}} \cup \{F \ \mathsf{says}\ \mathsf{s} \mid \mathsf{s} \in \mathcal{B}_F\}$.

Example Assume at the beginning that $\mathcal{B}_{F_1} = \{\}$.

Now F_1 calls $\mathsf{enablePrivilege}(T_1)$. We have $\mathcal{B}_{F_1} = \{\mathsf{Ok}(T_1)\}$.

F_1 calls $\mathsf{checkPrivilege}(T_1)$.

Hence we take the statement F_1 says $\mathsf{Ok}(T_1)$.

Let S_1 be the signer of the code which produced the frame F_1.

Then we conclude $F_1 \Rightarrow S_1$ from the frame credentials Φ.

If the access credentials set $\mathcal{A}_{\mathsf{M}}$ has a statement $S_1 \Rightarrow T_1$

then using the statement $(T_1 \;\mathsf{says}\; \mathsf{Ok}(T_1)) \rightarrow \mathsf{Ok}(T_1)$ from T

we conclude $\mathsf{Ok}(T_1)$.

Now F_1 makes a function call and the new frame F_2 calls $\mathsf{enablePrivilege}(T_2)$.

We have $\mathcal{B}_{F_2} = \{F_1 \text{ says } \mathsf{Ok}(T_1), \mathsf{Ok}(T_2)\}$

F_2 makes function call and the new frame F_3 calls $\mathsf{disablePrivilege}(T_1)$.

We have $\mathcal{B}_{F_3} = \{F_2 \text{ says } \mathsf{Ok}(T_2)\}$.

F_3 makes function call and the new frame F_4 calls $\mathsf{enablePrivilege}(T_2)$.

We have $\mathcal{B}_{F_4} = \{(F_3 \mid F_2) \text{ says } \mathsf{Ok}(T_2), \mathsf{Ok}(T_2)\}$.

F_4 calls $\mathsf{revertPrivilege}(T_2)$.

We have $\mathcal{B}_{F_4} = \{(F_3 \mid F_2) \text{ says } \mathsf{Ok}(T_2)\}$.

Now F_4 calls $\mathsf{checkPrivilege} T_2$.

We take the statement $(F_4 \mid F_3 \mid F_2)$ says $\mathsf{Ok}(T_2)$ i.e.

F_4 says $(F_3$ says $(F_2$ says $\mathsf{Ok}(T_2)))$.

Suppose from the frame credentials Φ imply that

$F_4 \Rightarrow S_4 \quad F_3 \Rightarrow S_3 \quad F_2 \Rightarrow S_2$

Suppose that $\mathcal{A}_{\mathsf{M}}$ further has statements

$S_4 \Rightarrow T_2 \quad S_3 \Rightarrow T_2 \quad S_2 \Rightarrow T_2$

Then we conclude:

T_2 says $(F_3$ says $(F_2$ says $\mathsf{Ok}(T_2)))$
T_2 says $(T_2$ says $(F_2$ says $\mathsf{Ok}(T_2)))$

T_2 says (T_2 says (T_2 says Ok(T_2)))

Further (T_2 says Ok(T_2))→Ok(T_2) is in $\mathcal{T}$.

Hence T_2 says (T_2 says ((T_2 says Ok(T_2))→Ok(T_2))).

Hence T_2 says (T_2 says Ok(T_2)).

Similarly T_2 says Ok(T_2).

Hence Ok(T_2).

Security protocols

For secure communication over an insecure network.

- Adversary can spy on messages,
- delete messages,
- modify messages,
- impersonate as Alice to Bob,
- deny having sent or received a message
- ...

Encrypting and decrypting messages

. . . the naive way:

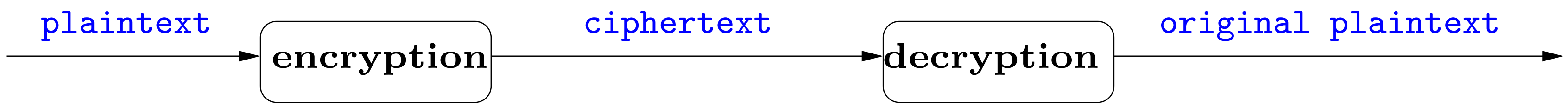
Instead of Alice ⟶ Bob:

`This is Alice.  My credit card number is 1234567890123456`

We have Alice ⟶ Bob:

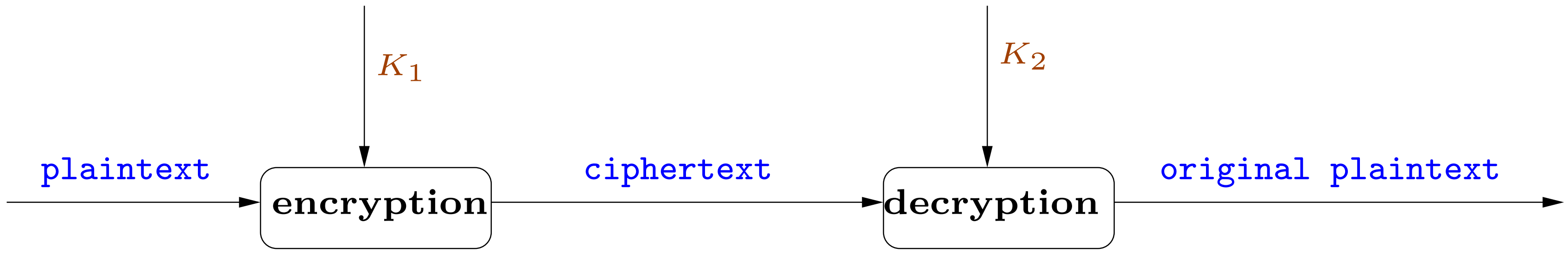
`6543210987654321 si rebmun drac tiderc yM .ecilA si sihT`

Alice and Bob agree on the method of encryption and decryption.



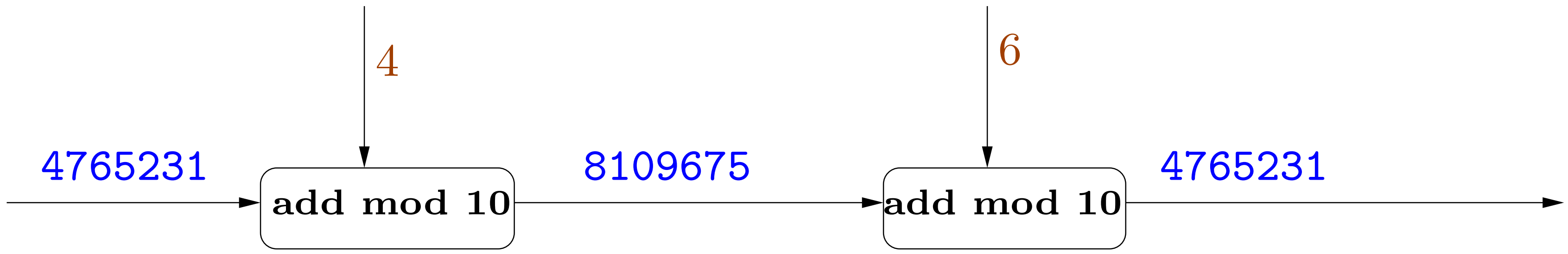
Cryptography with keys

Today we instead have the following picture:



The encryption and decryption algorithms are assumed to be publicly known.

The security lies in the (secret) keys.



Cryptography of the pre-computer age **Substitution ciphers**: each character is mapped to the another character. The famous Caesar cipher: A $\to$ D, B $\to$ E, ..., Z $\to$ C.

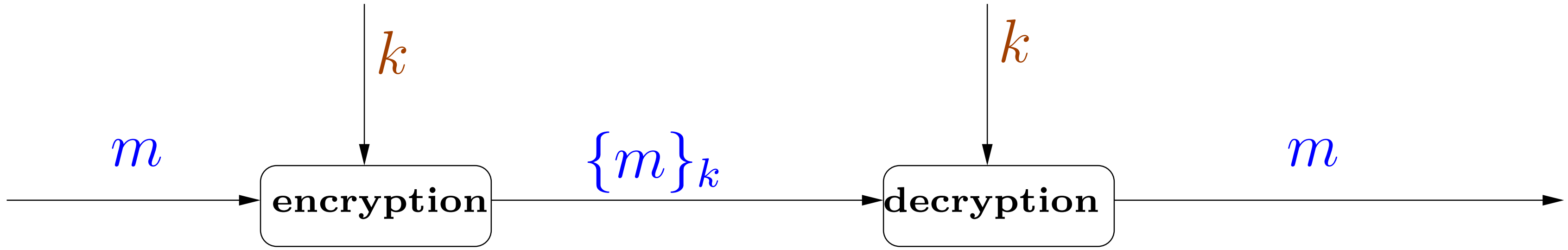
transposition cipher: shuffling around of characters.

Plaintext: `this is alice my credit card number is 1234567890123456`

```
thisisalic
emycreditc
ardnumberi
s123456789
0123456
```

Ciphertext: `teas0 hmr11 iyd22 scn33 iru44 sem55 adb66 lie7i tr8cc i9`

Private key cryptography



- The same key k is used for encryption and decryption
- Given message m and key k, we can compute the encrypted message $\{m\}_k$
- Given the encrypted message $\{m\}_k$ and the key k, we can compute the original message m

Private key cryptography

Suppose K_{ab} is a private key shared between A and B.

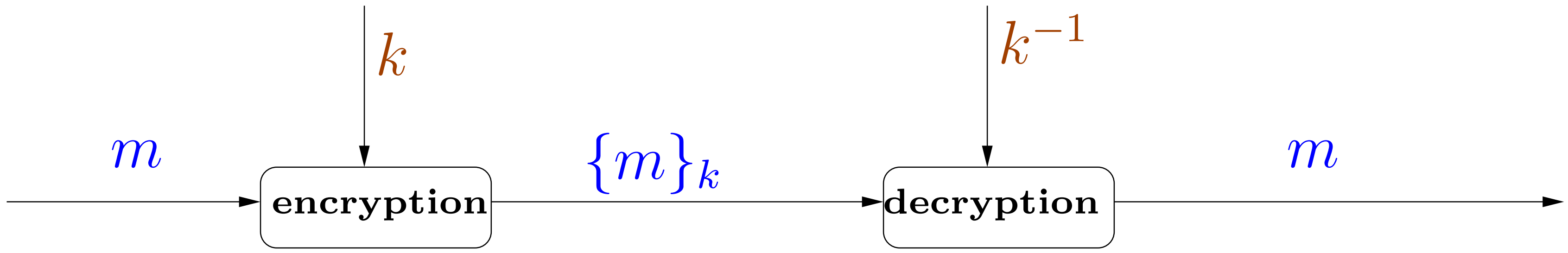
A can send a message m to B using private key cryptography:

$$A \longrightarrow B : \{m\}_{K_{ab}}$$

Only B can get back the message m.

A and B need to agree beforehand on a key K_{ab} which should not be disclosed to any one else

Public key cryptography



- A chooses pair (K_a, K_a^{-1}) of keys such that
  - messages encrypted with K_a can be decrypted with K_a^{-1}
  - K_a^{-1} cannot be calculated from K_a
- A makes K_a public: this is the public key of A
- A keeps K_a^{-1} secret: this is the private key of A

Public key cryptography

Then any B can send a message to A which only A can read:

$$B \longrightarrow A : \{m\}_{K_a}$$

Sometimes we have the additional property: messages encrypted with K_a^{-1} can be decrypted with K_a

Then A can send a message m to B

$$A \longrightarrow B : \{m\}_{K_a^{-1}}$$

and B is sure that the message m was encrypted by A. Hence we have authentication

One way hash functions

Properties of a one way hash function H:

– Given M, it is easy to compute $H(M)$ (called message digest).
– Given $H(M)$ is is difficult to find M' such that $H(M) = H(M')$.

A sends to B the message M together with the encrypted hash value $\{H(M)\}_{K_{ab}}$.

Efficient means of demonstrating authenticity, since $H(M)$ is of a fixed size.

Cryptography is not enough!

Intruder is more clever. He can attack even if the cryptographic algorithms are perfect.

Alice tells Bank to transfer £5000 to Charlie's (intruder) account:

$$A \longrightarrow B : \{A, B, \text{ transfer 5000 euros } \ldots\}_{K_{ab}}$$

- B believes that message comes from A
- Charlie has no way to decrypt the message

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- B believes that message comes from A
- Charlie has no way to decrypt the message
- But: Charlie can send the same message again to the bank

Intruder can replay known messages (freshness attack)

Solution: use session key

Generate fresh random value (nonce) for each new session and use it as a key for that session.

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And then uses it during that session.

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Doesn't work. What about

$$A \longrightarrow B : \{K_{ab}\}_{K_{long}}$$

Using a long term key to agree on a session key.

A more complex solution A and B both choose a nonce each.

1. $A \longrightarrow B : \{A, N_a\}_{K_b}$
2. $B \longrightarrow A : \{N_a, N_b\}_{K_a}$
3. $A \longrightarrow B : \{N_b\}_{K_b}$

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$$3. \quad A \longrightarrow B : \{N_b\}_{K_b}$$

The second message is to assure A that B is active and N_b is fresh.
The third message is to assure B that A is active and N_a is fresh.

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The third message is to assure B that A is active and N_a is fresh.

Expected security property: N_a and N_b are known only to A and B.
Expected authentication property: A and B are assured that they are talking to each other.

$$A \longrightarrow B : \{A, B, N_a, N_b \text{ transfer 5000 euros } \ldots\}_{K_b}$$

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How secure is this ? How to guarantee security ?