Practical and Tightly-Secure Digital Signatures and Authenticated Key Exchange

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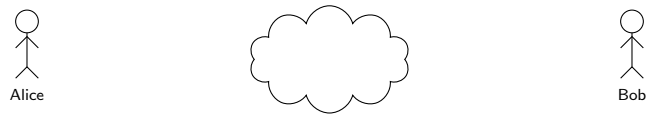
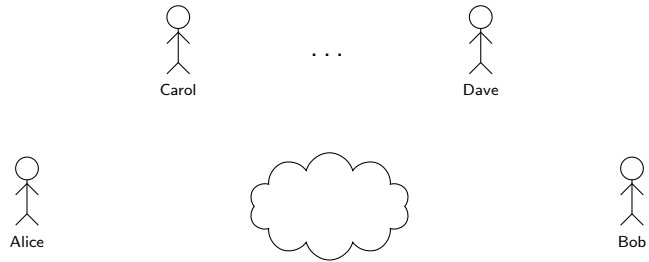
Authenticated Key Exchange



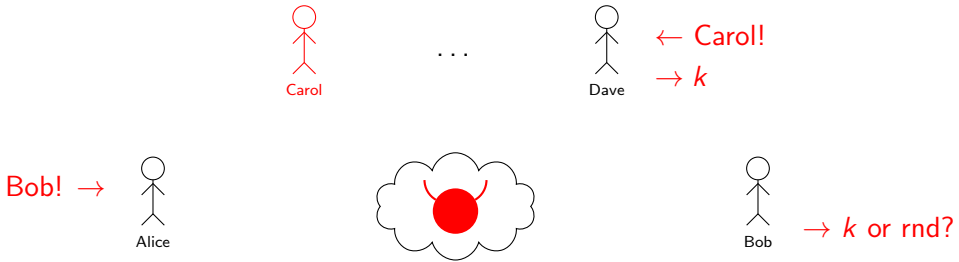
Alice and Bob want to exchange a key.

Authenticated Key Exchange



Alice and Bob and Carol and . . . want to exchange keys.

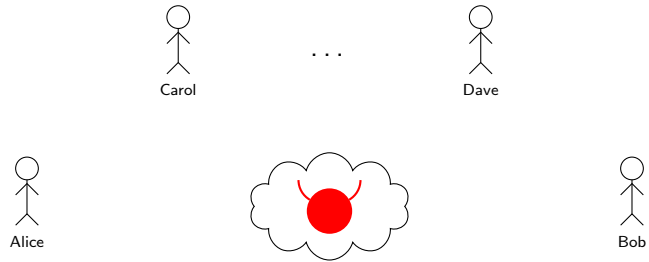
Authenticated Key Exchange



The adversary

- directs honest users' key exchanges;
- can inspect keys or test keys (real-or-random);
- controls the network;
- and can adaptively corrupt users.

Authenticated Key Exchange



Our goal: If

- Alice believes she has exchanged a key with Bob,

it must be true that

- Bob exchanged exactly the same key exactly once with Alice; and
- it looks random.

Why Security Proofs?

A typical security proof is a reduction from some problem to attacking our crypto:

> *A poly-time crypto adversary with non-negligible advantage*
> *gives us*
> *a poly-time problem solver with non-negligible advantage.*

The scheme is secure if we believe no such solver exists.

Why do we want them?

- Why not?
- Ensure that our system is not trivially breakable.
- Help us choose security parameters.

Why Security Proofs?

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> *A crypto adversary using time T_1 with advantage ϵ_1*
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Why Tight Security Proofs?

A typical security proof is a reduction from some problem to attacking our crypto:

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The scheme is secure if we believe no such solver exists.

- A reduction is tight if $T_1 \approx T_2$ and $\epsilon_1 \approx \epsilon_2$.

Why do we want them?

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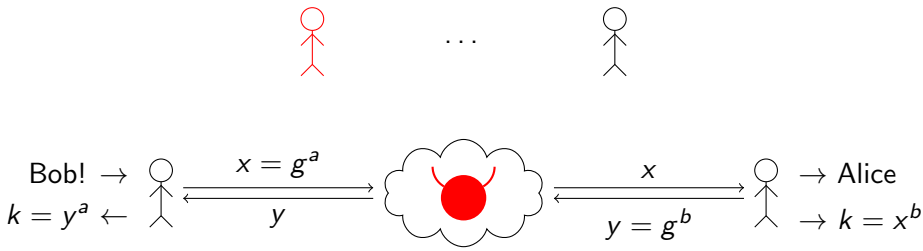
Plain Diffie-Hellman

No Tampering + Static Corruption = No Problem



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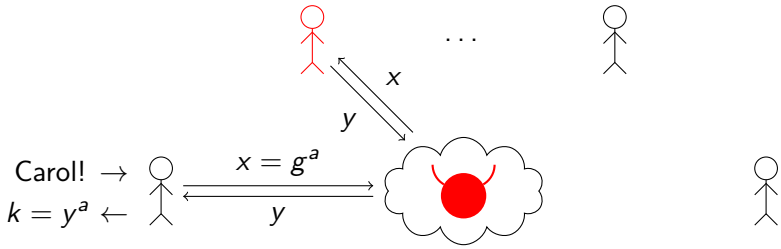

When Alice talks to a corrupted Carol, we run Diffie-Hellman as usual.

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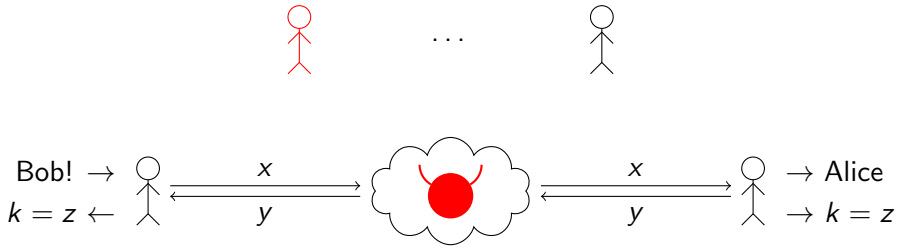
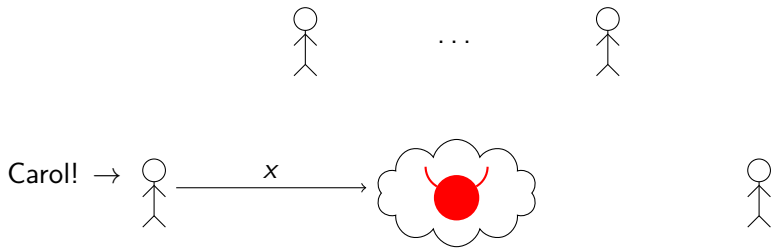


When Alice talks to an honest Bob, we simulate the conversation using a Diffie-Hellman tuple (g, x, y, z).

Rerandomization gives us many tuples and a tight proof.

Plain Diffie-Hellman

No Tampering + Adaptive Corruption = Commitment Problem



The commitment problem: the adversary may corrupt the responder after we have committed by sending the first message.

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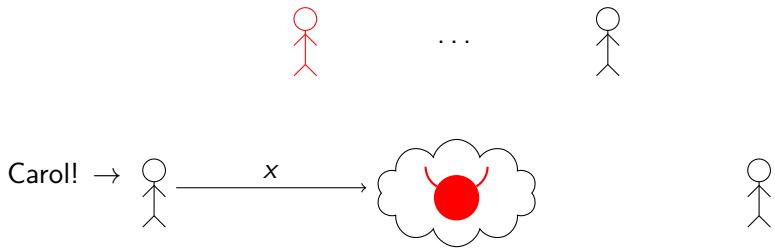

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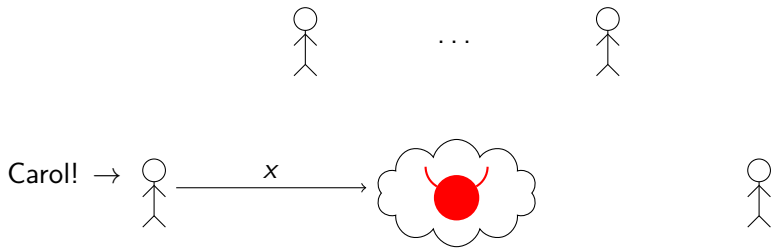

The commitment problem: the adversary may corrupt the responder after we have committed by sending the first message.

We can guess a communicating pair, but then tightness is lost.

Our Modified Diffie-Hellman

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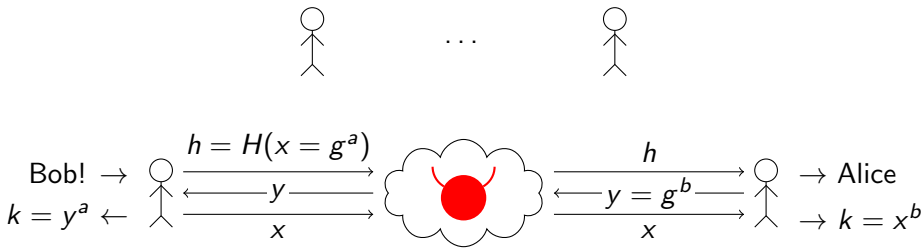

- We hash the first message, and send x only after receiving the response.

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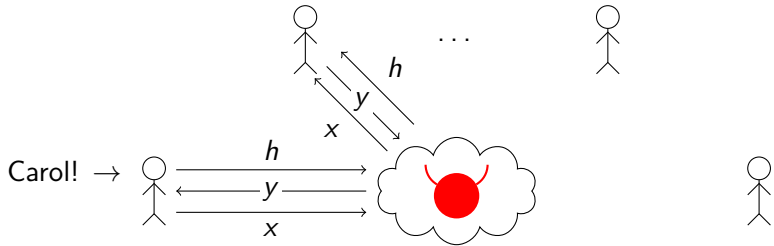

- We hash the first message, and send x only after receiving the response.
- In the random oracle model, our reduction does not have to commit to x until we know if the response was honest or not. We get a tight reduction.

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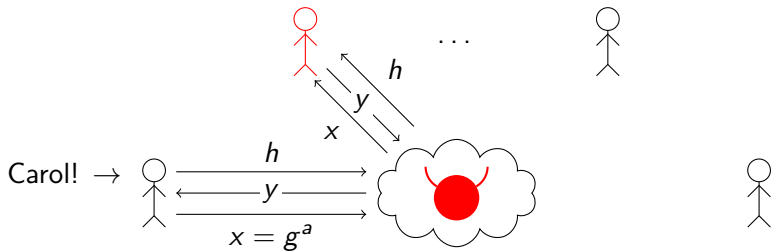

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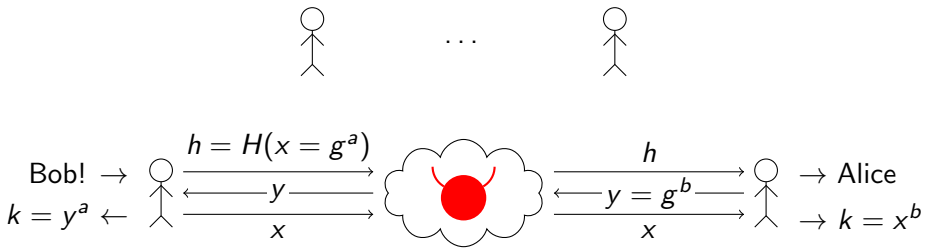

- We hash the first message, and send x only after receiving the response.
- Note that there is an additional message flow compared to plain Diffie-Hellman. The responder also learns the key later. This is often not a problem.

Security Parameters and Performance

We compare our protocol with plain Diffie-Hellman.

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For plain Diffie-Hellman:

- Small-scale: 2^{16} users, 2^{16} sessions and quadratic loss 2^{64}: NIST P-384.
- Large-scale: 2^{32} users, 2^{32} sessions and quadratic loss 2^{128}: NIST P-521.

Exponentiation relative time cost: P-256 $= 1$, P-384 $= 2.7$, P-521 $= 7.7$.

Security Parameters and Performance

We compare our protocol with signed Diffie-Hellman.

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For signed Diffie-Hellman:

- Small-scale: 2^{16} users, 2^{16} sessions and quadratic loss 2^{64}: NIST P-384.
- Large-scale: 2^{32} users, 2^{32} sessions and quadratic loss 2^{128}: NIST P-521.

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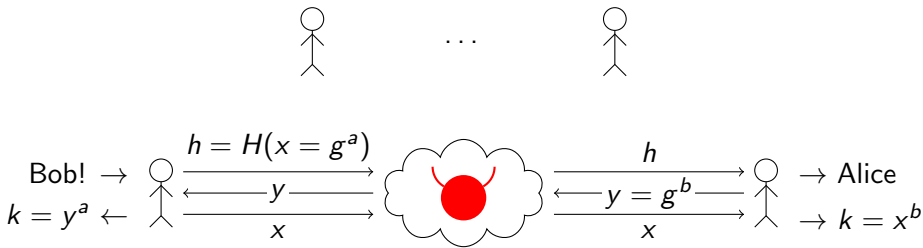
		small-scale		large-scale	
	# exps.	# bits	time	# bits	time
Our scheme	2	770	2	770	2
Plain DH	2	770	5.4	1044	15.4

Our Modified Diffie-Hellman

~~No~~ Tampering + Adaptive Corruption = A Need for Signatures



- If the adversary is allowed to tamper with messages, this protocol obviously fails.

Our Modified Diffie-Hellman

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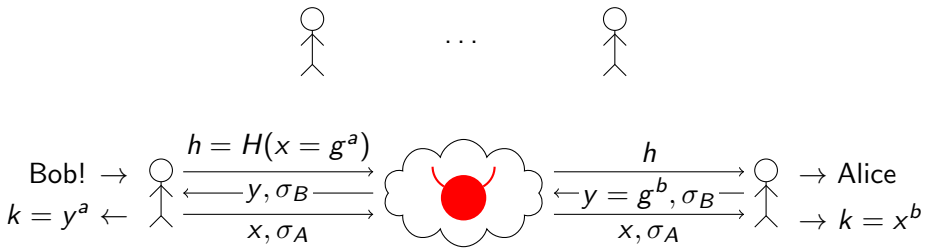

- If the adversary is allowed to tamper with messages, this protocol obviously fails.
- The natural answer is to add the usual signatures.
- But this requires a signature scheme with a tight reduction!

Signatures with Tight Reductions

The standard security notion for signatures considers only a single key pair.

- There is a standard reduction to many key pairs, but it is non-tight.
- In fact, the loss in the standard reduction is quadratic in the number of users, because of adaptive compromise.

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The main obstacle to a tight reduction:

- We need to know every secret key to respond to compromise.
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Tight reductions are impossible for schemes with unique signatures or signing keys.

“Double-signature” idea

The “double-signature” idea from Bader et al. (TCC 15).

- The user has “real” and a “fake” verification key.
- A signature consists of a real signature for the “real” verification key, and a fake signature for the “fake” verification key.
- We embed our hard problem in the “fake” verification key.
- If “real” and “fake” keys and signatures are indistinguishable, the adversary will produce a forgery that applies to the “fake” verification key with probability $1/2$.

This “double-signature” idea does not work for most signature schemes. The only previous construction is impractical.

Our Signature Scheme

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The usual AKE security models require strongly unforgeable signatures. This scheme is not strongly unforgeable, so we need to use a slightly different security model.

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Our scheme II	17	4358	17	4358	17
DH+ECDSA	5	2306	13.5	3128	38.5

Summary

- First practical tightly-secure signature scheme with adaptive corruptions.
- First practical tightly-secure AKE.
- More efficient than ordinary signed Diffie-Hellman for large-scale deployment settings

Questions?