An Overview of Common Adversary Models

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Requirements of Software Systems

1. Functional
   - Correctness: partial, termination, liveness, safety, . . .
2. Nonfunctional
   - Performance: time/memory/message complexity, . . .
   - **Security**: . . .
3. Architectural
4. . . .

Security Requirements: Some Questions

- Why do we need security?
  - Assuming a nonadversarial world, do we need security at all?
  - What are we protecting?
  - Who are we protecting it from?
- How do we describe security?
  - What assumptions must be made?
  - What are the capabilities of the adversary?

On Encryption

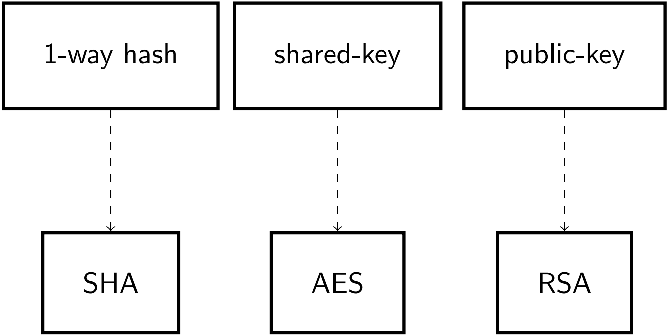
“Encryption is not synonymous with security.”

— Martín Abadi

Examples of Assumptions About the World

Type	**Assumption**
Fundamental	$\mathcal{P} \neq \mathcal{NP}$
Fundamental	exists 1-way functions
Problem-Specific	Decision Diffie-Hellman
Problem-Specific	Computational Diffie-Hellman
Problem-Specific	Discrete Logarithms
Situation-Specific	exists trusted party

Building Blocks of Cryptography



Examples of Properties of the Adversary

Computational Power
unlimited/bounded/structurally limited

Intent
curious/hostile

Capabilities of the Adversary

> *"We assume that an intruder can interpose a computer in all communication paths, and thus can alter or copy parts of messages, replay messages, or emit false material."*
>
> — Needham/Schroeder (1978)

Current Standard Capabilities of the Adversary

- Participate in some protocol runs
- Know certain data in advance
- Intercept message on some or all communication paths
- Inject any messages that it can produce

Unconditional Security: “trust nothing”

- Adversary has unbounded computational resources
- Must not obtain information from observing ciphertext

Definition

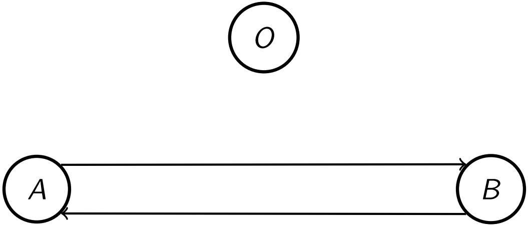
A cryptosystem has *perfect secrecy* if the *a posteriori* probability that the plaintext is x, given that the ciphertext y is observed, is identical to the *a priori* probability that the plaintext is x.

The Formal Model: "trust your primitives"

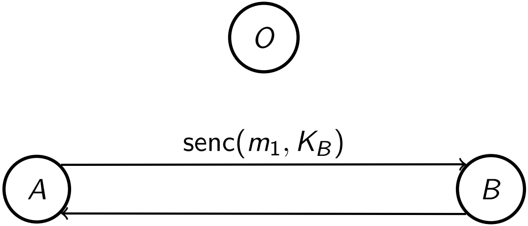
- Assume perfect cryptographic primitives ("black boxes")
- Messages exchanged are terms on cryptographic primitives
- Adversary is restricted to only reason on terms, e.g.
  - substitute terms for variables in equations
  - use equation terms in other equations
- Example equations for symmetric cryptography:

$$\forall x \forall y \; \mathsf{sdec}(\mathsf{senc}(x, y), y) = x$$
$$\forall x \forall y \; \mathsf{scheck}(\mathsf{senc}(x, y), y) = \mathsf{ok}$$

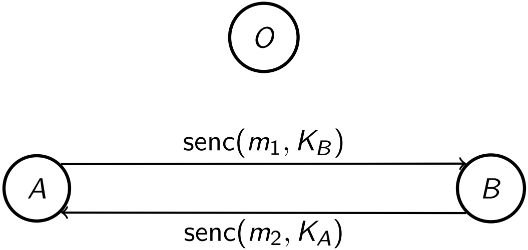
The Formal Model Illustrated



The Formal Model Illustrated



The Formal Model Illustrated



Example Properties in the Formal Model

Secrecy
: Adversary cannot obtain the secret

Correspondance
: Authentication

Strong Secrecy
: Adversary does not see the difference when the value of the secret changes

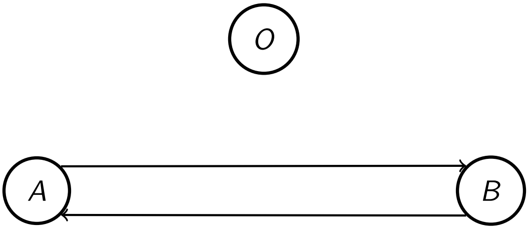
Pros and Cons of the Formal Model

+ simple
+ tool support
+ necessary for security
- insufficient for security
- unrealistic?

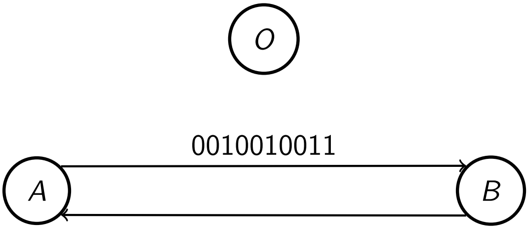
The Computational Model: "limit trust in your primitives"

- Messages are bitstrings
- Adversary is a polynomial-time probabilistic Turing machine
- Adversary can do low-level bit operations on messages
- Assumes Computational Diffie-Hellman

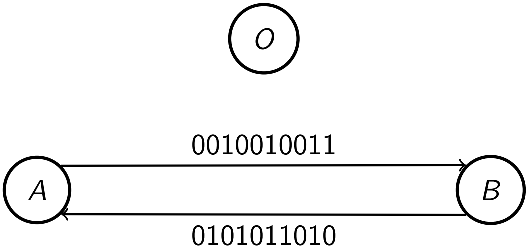
The Computational Model Illustrated



The Computational Model Illustrated



The Computational Model Illustrated



Example Properties in the Computational Model

Secrecy
: Adversary cannot obtain the secret

Correspondences
: Authentication

Resilience
: Probability of success of an attack against the protocol as a function of the probability of breaking each cryptographic primitive and of the number of sessions

Pros and Cons of the Computational Model

+ sufficient for probabilistic security
+ reduction-based
+ realistic?
- complicated
- tool support

Byzantine Fault Tolerance

- Distributed system with n nodes connected in a network
- $m < n$ nodes behave erratically (can omit or falsify messages)

Lemma

Suppose we have a network with nodes n_1, n_2 and n_3, where n_3 behaves erratically. Then n_1 and n_2 cannot become in agreement on a value by network communication.

Theorem

Reaching agreement by network communication (without using cryptographic assumptions) is only possible when $n \geq 3m + 1$.

Multiparty Computation

- n parties communicating through a network
- Each party has private input and knows function to compute
- $t < n$ parties are passively or actively corrupted

Example Properties in Multiparty Computation

Secrecy
: Players' inputs remain secret

Correctness
: Results of the computation are correct

Resilience
: Above holds despite corruption

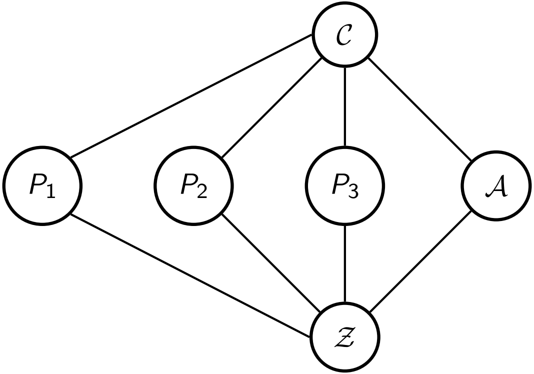
Universal Composability Framework

- Adversary is any interactive probabilistic polynomial time Turing machine
- Exists “operating system” that takes care of subprotocols
- Asynchronous network in *ideal* or *real* communication model

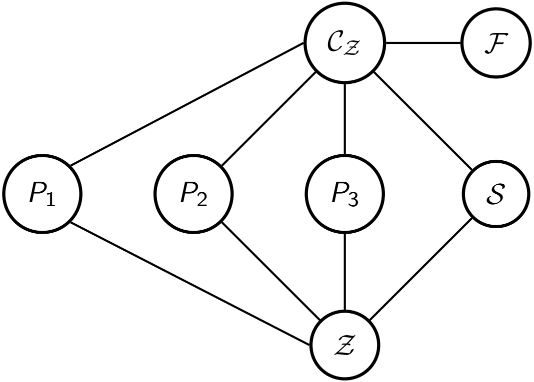
  Ideal
  : “Dummy” parties, but has trusted party performing ideal functionality

  Real
  : “Real” parties, adversary and environment

Universal Composability Real Model Illustrated



Universal Composability Ideal Model Illustrated



Some Properties of Universal Composability

- A protocol π in the real model *securely realizes* an ideal functionality $\mathcal{F}$ if for any real adversary $\mathcal{A}$, there exists ideal adversary $\mathcal{S}$ such that no environment $\mathcal{Z}$ can tell[1] whether it is interacting with real or ideal model
- If the protocol π securely realizes some functionality $\mathcal{F}$, π can be used instead of the functionality regardless of how $\mathcal{F}$ is employed
- Protocols remain secure even if arbitrarily composed with other instances of the same or other protocols

[1] with non-negligable probability

Information Flow

- Assume variables in a program P are divided into levels, e.g.:
  - L (low) for publicly visible variables
  - H (high) for private, or secret, variables
- Assume adversary:
  - Knows the syntax and semantics of P
  - Can observe L-variables before and after executing P

Example Properties of Information Flow

- Information about secret s can be exposed by:

  explicit flow: a variable in L being assigned s

  implicit flow: branching on s and assigning to variable in L

- Define *noninterference* for program P:

$$\forall \sigma_1, \sigma_2.\ \sigma_1 \approx_L \sigma_2 \Rightarrow P(\sigma_1) \approx_L P(\sigma_2)$$

- Can be generalized to distributed systems
  - use logics of knowledge

Applicability

- Adversary model as part of designing a software system
- Explicit assumptions about
  - Cryptographic primitives
  - Resources of adversary
  - Intent of adversary
  - Authenticity requirements
  - Secrecy requirements
- Tradeoff between correctness, resource usage, security and performance

The Ideal System

Functional Requirements
: Certificate of adherence to specification

Performance Requirements
: Certificate of adherence for performance model to performance requirements and evidence that it represents real system

Security Requirements
: Certificate of security against specified adversary model

Questions to Ponder

- What is the adversary model for a simple web service?
- How do XSS attacks fit into this model?

Further Reading

[1] M. Abadi. Security protocols: Principles and calculi. In *Tutorial Lectures, FOSAD 2006/2007*, 2007.

[2] R. Carnetti. Universally composable security: a new paradigm for cryptographic protocols. In *42nd IEEE Symposium on Foundations of Computer Science*, pages 136–145, 2001.

[3] R. Impagliazzo. A personal view of average-case complexity. In *10th IEEE Conference on Structure in Complexity Theory*, pages 134–147, 1995.

[4] U. Maurer. Secure multi-party computation made simple. In *Lecture Notes in Computer Science 2576*, pages 14–28. Springer, 2003.

[5] M. Pease, R. Shostak, and L. Lamport. Reaching agreement in the presence of faults. *Journal of the ACM*, 27(2):228–234, 1980.

[6] K. Wiegers. *Software Requirements*. Microsoft Press, second edition, 2003.