HASH FUNCTIONS

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01

WHAT IS CRYPTOGRAPHIC HASH FUNCTIONS?

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Hash functions are essential in cryptography because they allow you to **verify data without exposing the original content.**

They play a crucial role in ensuring **both data authenticity and integrity.**

02

BASIC RATIONALE AND DESIGN OF HASH FUNCTIONS

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There are many situations where **authentication and integrity verification need to be performed cheaply and without revealing private information** to the party performing the validation.

There are many situations where **authentication and integrity verification need to be performed cheaply and without revealing private information** to the party performing the validation.

EXAMPLES

Verifying that downloaded software hasn't been modified.

Windows 10 / 11

Download qBittorrent v5.0.4 (multiple installer choice)

▸ (Additional download options)

Download qBittorrent v5.1.0rc1 (multiple installer choice)

▸ (Additional download options)

▾ Checksums and library versions

Version	SHA2-256
5.0.4	61e516ba3be4ff0f3fd226d6271c5f7a505c2a5b080ab28c4964f741b569b1e4
5.0.4 (qt6 lt20)	e715ce2d484bd27073e0be6837fd72c97ab604b5848f529c9901eb02cc4a7245
5.1.0rc1	9388eb9e683ab209da9df8709b5d1cedf1154437e0787f74e0516e275d10185b
5.1.0rc1 (lt20 qt6)	08d494e793246a989b7110ea204f0da7ecefbec943624db2b2e1b782aae08a09

Library	Version
libtorrent-rasterbar	1.2.20+git2e537ee7af / 2.0.11+gitc31d90b59f
Qt	6.7.3 (v5.0.4) / 6.8.2 (v5.1.0rc1)
Boost	1.86.0

Download nightly builds

EXAMPLES

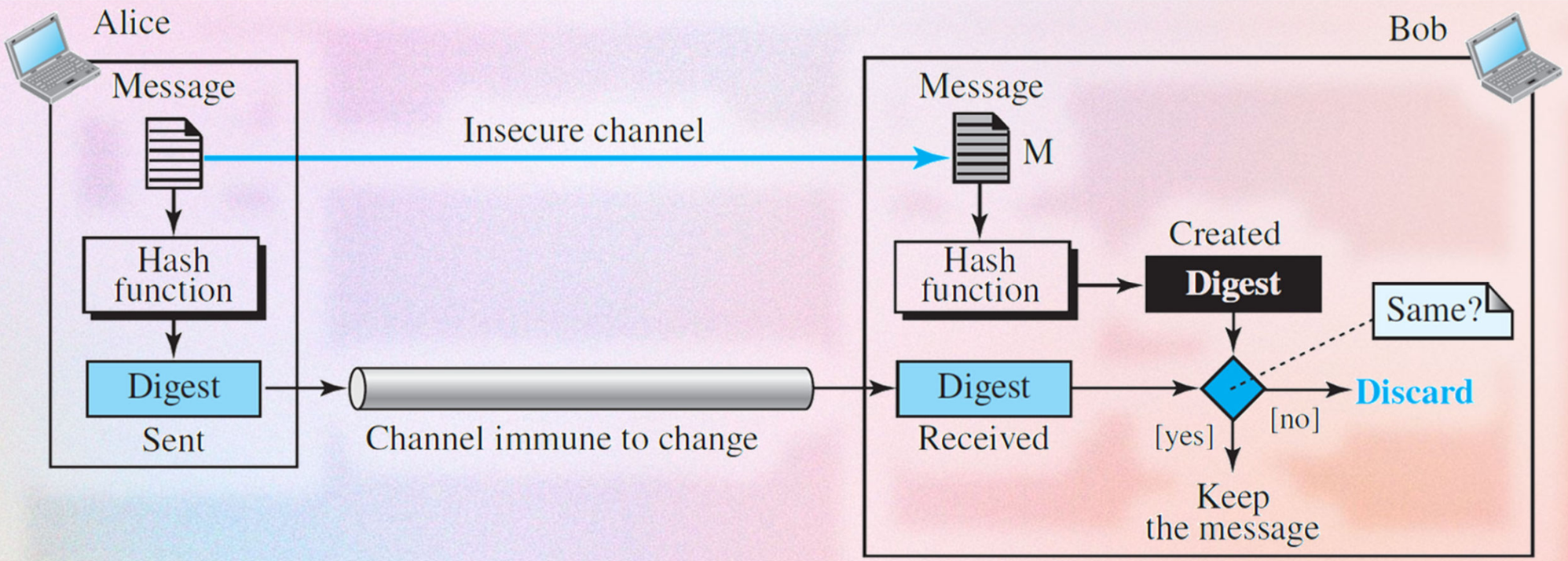
Authenticating web users without storing or transmitting actual passwords.


```
{
    "_id": 31498,
    "email": "rey.pollux@marsu.edu.ph",
    "password": "$2b$12$rkEH4wO5PyDqjJPJDUAO7eLQZ53u2LiGzfgf5LCci.XVe5tYrFdTO",
    "temporaryPassword": [redacted]
    "firstName": "Pollux",
    "middleName": "Murillo",
    "lastName": "Rey"
}
```

Cryptographic hash functions (CHFs) address such needs **efficiently and securely.**

CRYPTOGRAPHIC HASH FUNCTIONS

A cryptographic hash function ***converts any message into a fixed-length n-bit string*** *called a* ***digest.***



Data Communications And Networking, Behrouz A Forouzan

https://learning.quantum.ibm.com/course/practical-introduction-to-quantum-safe-cryptography

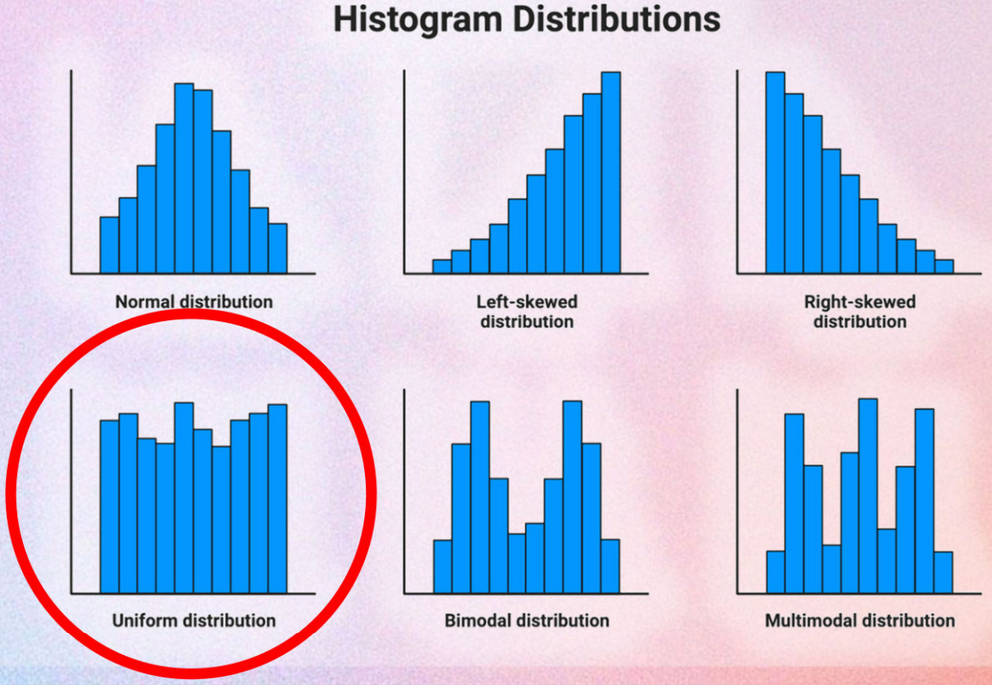
PROPERTIES OF CHFs

A useful CHF should satisfy several key properties:

1. Uniformity
2. Determinism
3. Irreversibility
4. Approximate Injectivity

UNIFORMITY

*The **output** of a CHF should be **distributed uniformly** and **appear random**, ensuring that **no clues about the input are revealed.***



UNIFORMITY

*The **output** of a CHF should be **distributed uniformly** and **appear random**, ensuring that **no clues about the input are revealed.***

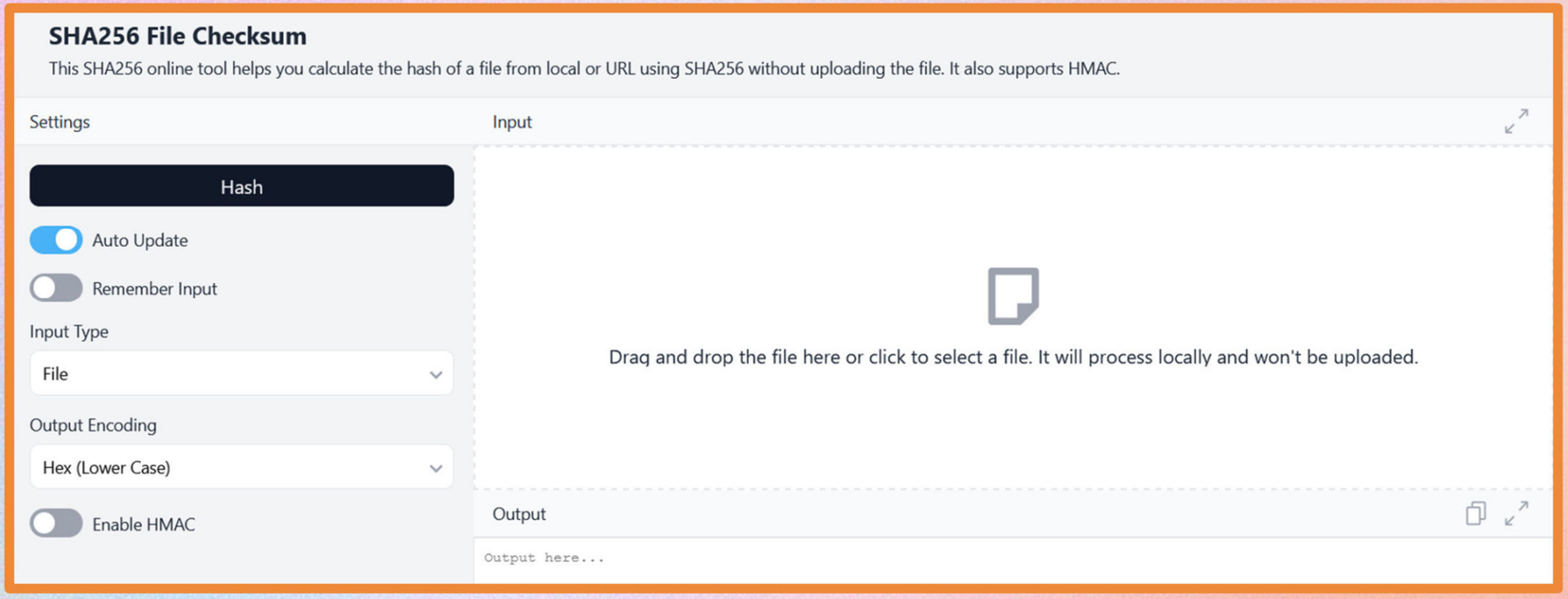
Example:

If the **MD5 hash 8b1a9953c4611296a827abf8c47804d7** (which corresponds to **"Hello"**) **can be generated from 1,000,000 different messages**, then **other hashes should also be generated from about 1,000,000 different messages.**

DETERMINISM

The same input must always produce the same digest.

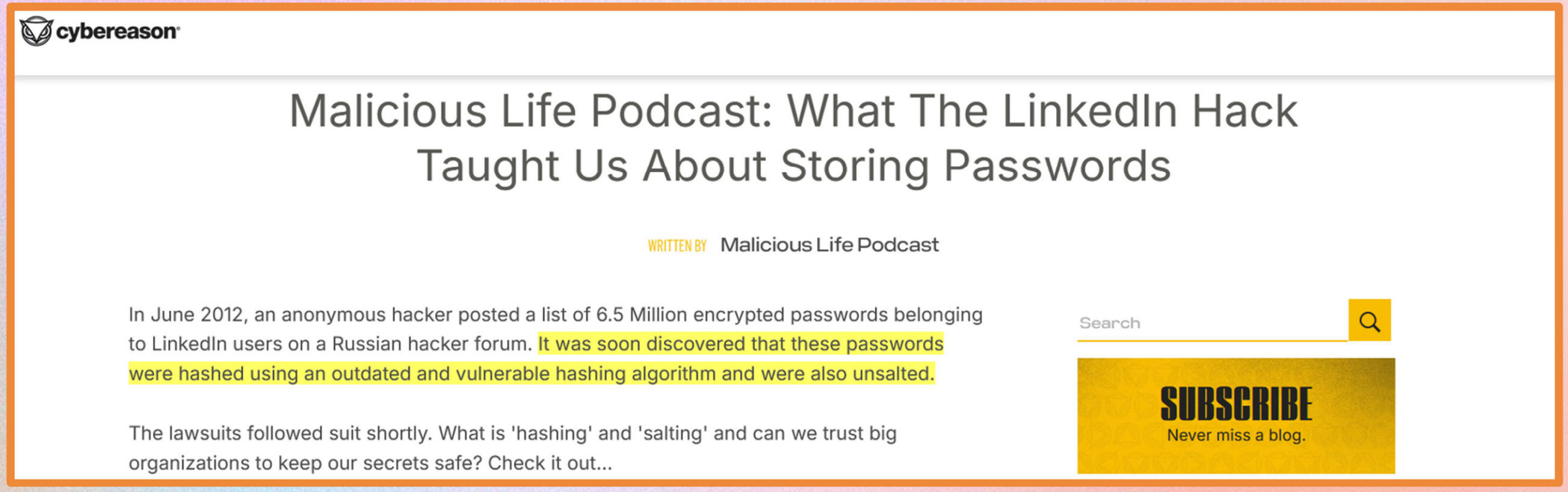
Example:



IRREVERSIBILITY

*It should be **nearly impossible to reverse the process and retrieve the original input** from the output.*

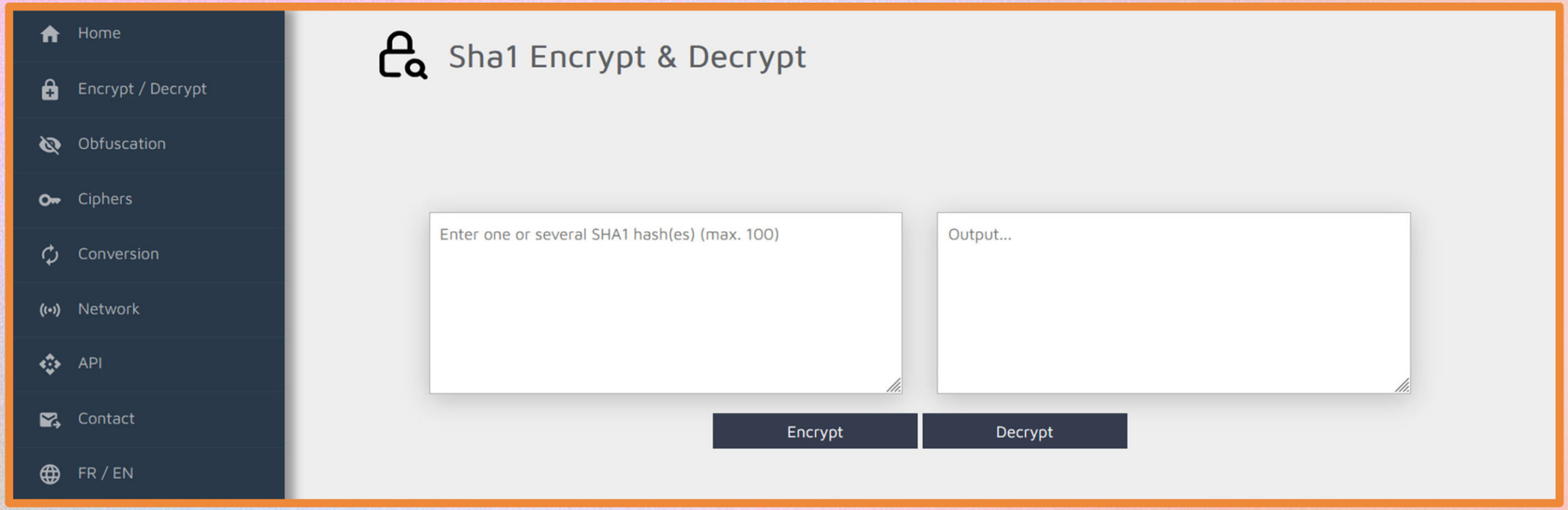
Counterexample:



https://learning.quantum-ibm.com/course/practical-introduction-to-quantum-safe-cryptography

https://www.cybereason.com/blog/malicious-life-podcast-what-the-linkedin-hack-taught-us-about-storing-passwords

IRREVERSIBILITY



https://md5decrypt.net/en/Sha1/

https://learning.quantum.ibm.com/course/practical-introduction-to-quantum-safe-cryptography

APPROXIMATE INJECTIVITY

*While CHFs are **many-to-one functions**, they should **appear to behave like one-to-one functions.***

Small input changes should produce vastly different digests.

APPROXIMATE INJECTIVITY

Example:

Input:

I LOVE CICS

SHA-256 Digest:

7255aca5ea60dece819eb67de70539bb
b0c51d43b825841a51da315bddc0bd8a

https://emn178.github.io/online-tools/sha256.html

https://learning.quantum.ibm.com/course/practical-introduction-to-quantum-safe-cryptography

APPROXIMATE INJECTIVITY

Example:

Input:

I LOVE SICS

SHA-256 Digest:

ed12a878e5c9f97a3da0c6bd9c07c252
59c0cafbcce897ac653747666ebe4057

https://emn178.github.io/online-tools/sha256.html

https://learning.quantum.ibm.com/course/practical-introduction-to-quantum-safe-cryptography

APPROXIMATE INJECTIVITY

Example:

7255aca5ea60dece819eb67de70539bb
B0c51d43b825841a51da315bddc0bd8a

Ed12a878e5c9f97a3da0c6bd9c07c252
59c0cafbcce897ac653747666ebe4057

Character difference: 59

https://emn178.github.io/online-tools/sha256.html

https://learning.quantum.ibm.com/course/practical-introduction-to-quantum-safe-cryptography

Given this, it's possible to validate a piece of data against the original instance by comparing a digest of the data to a digest of the original.

CRYPTOGRAPHIC HASH FUNCTIONS

1. If the **two digests match**, we can be **confident with high probability** that the **data is identical to the original.**
2. If the **digests differ**, we can be sure that the **data was tampered with or is otherwise inauthentic.**

Since the CHF digests themselves **do not reveal the actual contents of the data or the original**, they **enable validation while preserving privacy.**

03

APPLICATIONS OF CRYPTOGRAPHIC HASHING

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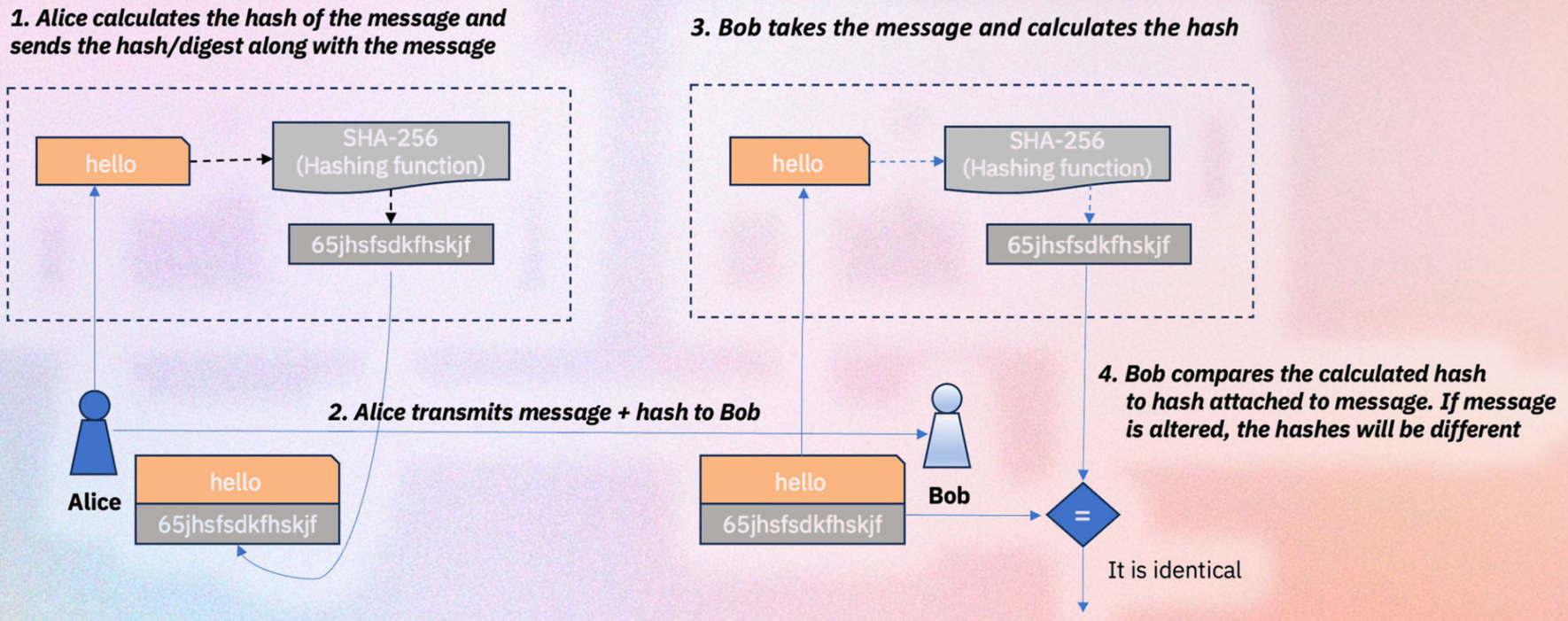
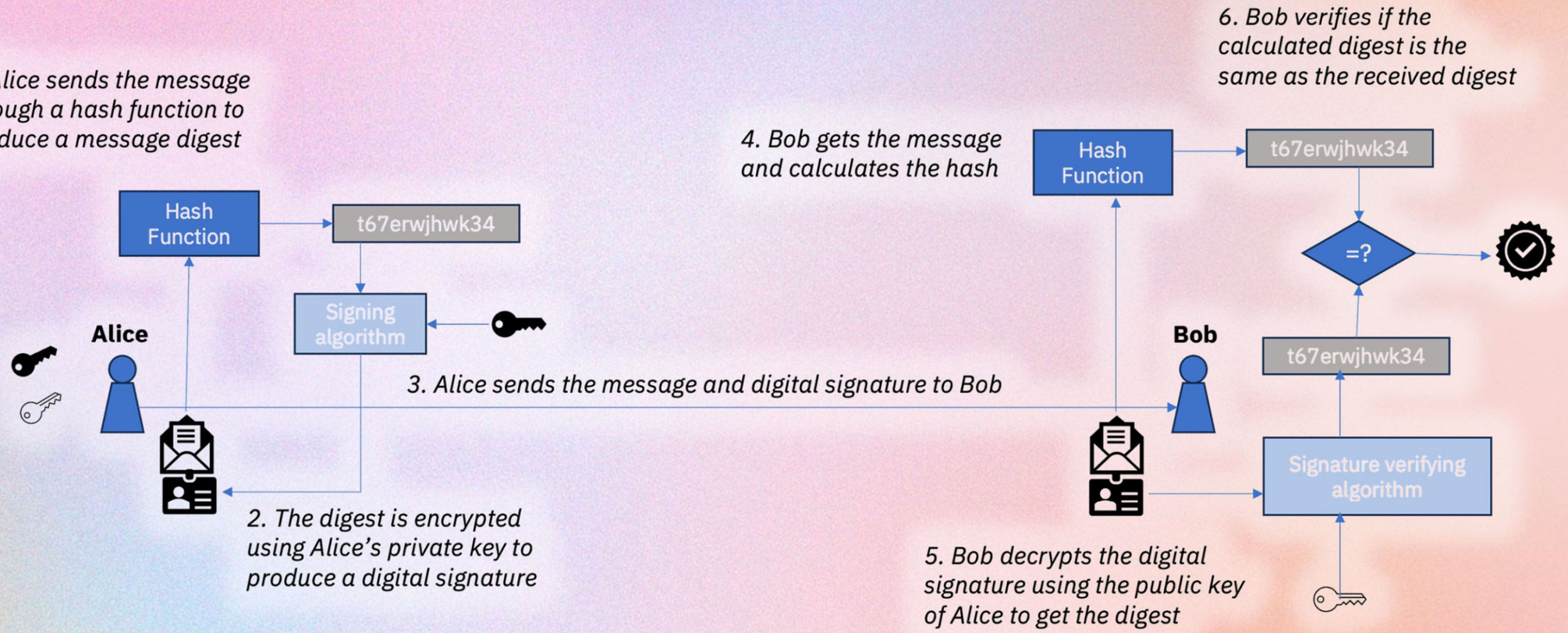
The unique properties of CHFs make them suitable for a wide array of applications.

DATA INTEGRITY CHECKS

***Any modifications to the data**, intentional or not, will **result in a different checksum**, alerting systems or users to the change.*



DIGITAL SIGNATURES



BLOCKCHAIN AND CRYPTOCURRENCIES

Cryptocurrencies like Bitcoin ***rely heavily on CHFs****,*
particularly in ***creating transaction integrity***
and ***enabling consensus mechanisms like proof of work.***

BLOCKCHAIN AND CRYPTOCURRENCIES

Content Curated by Pollux M. Rey

https://www.youtube.com/watch?v=_160oMzblY8

04

SECURITY OF CRYPTOGRAPHIC HASHING

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The **security of a CHF** is typically assessed **based on resistance to two types of attacks:** and **pre-image** and **collision.**

PRE-IMAGE RESISTANCE

Pre-image resistance means that given a digest, it should be **infeasible to find the input**.

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PRE-IMAGE RESISTANCE

A good CHF is designed in such a way that a party wishing to conduct a **pre-image attack** has **no better option than a brute force approach**, which has time complexity 2^n.

COLLISION RESISTANCE

Collision resistance means that it is **difficult to find two different inputs that hash to the same digest.**

COLLISION RESISTANCE

Collision resistance is crucial for applications like **digital signatures and certificates**, where it could be disastrous if a **malicious party were able to create a forgery that hashes to the same value.**

COLLISION RESISTANCE

Collision resistance is a harder requirement than pre-image resistance and necessitates output lengths **twice as long as that needed for pre-image resistance.**

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COLLISION RESISTANCE

This is because a brute force attack known as the **birthday attack**, which can be used to identify hash collisions, has time complexity $2^{n/2}$.

05

COMMONLY USED CRYPTOGRAPHIC HASH FUNCTIONS

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COMMONLY USED CHFs

Hash Function	Output Length (bits)	Common Applications
MD5	128	File integrity checking, older systems, non-crypto uses
SHA-1	160	Legacy systems, Git for version control
SHA-256	256	Cryptocurrency (Bitcoin), digital signatures, certificates
SHA-3	Variable (up to 512)	Various cryptographic applications, successor to SHA-2
Blake2	Variable (up to 512)	Cryptography, replacing MD5/SHA-1 in some systems
Blake3	Variable (up to 256)	Cryptography, file hashing, data integrity

THANK YOU!

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