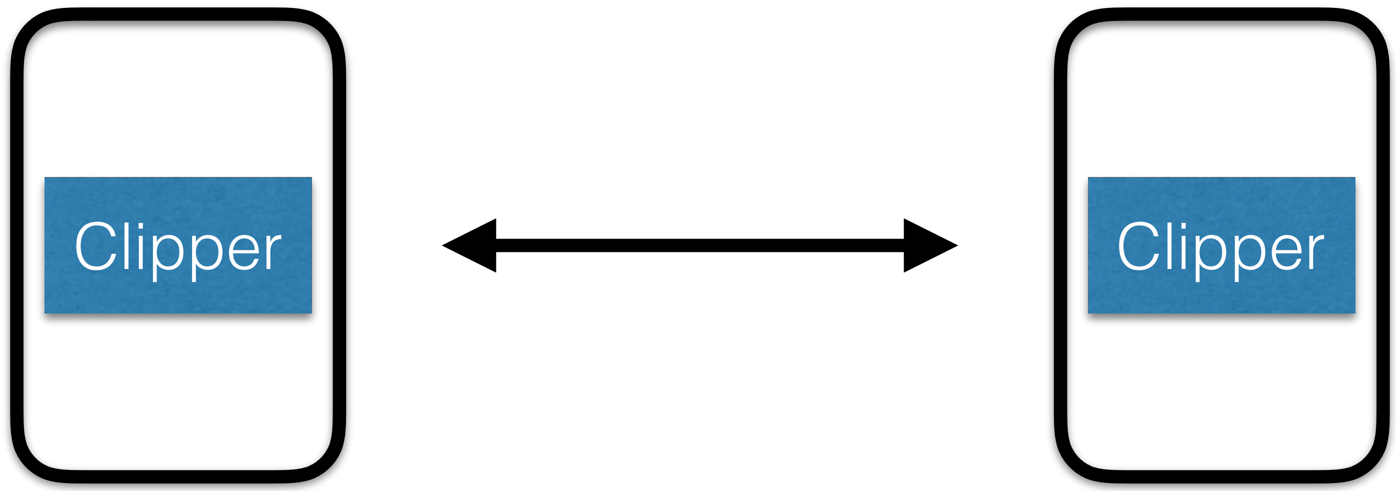
Midterm Recap

Misuse of Crypto

and Future Work

Clipper chip

A lesson in poorly designed protocols



Goal: Confidentiality — Support encrypted communication between devices

Goal: Key escrow — Permit law enforcement to obtain “session keys” with a warrant

Clipper chip: Design

Tamper-proof hardware

Hardware that is difficult to introspect (e.g., extract keys), alter (change the algorithms), or impersonate

Skipjack
encryption algorithm

Skipjack Keys
Unit key
Global family key

Diffie-Hellman
key exchange

LEAF generation
& validation

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Block cipher designed by the NSA, originally classified SECRET.

(Violates Kirchhoff's principle)

Broken within *one day* of declassification.

80-bit key; similar algorithm to DES (also broken)

Clipper chip: Design

Tamper-proof hardware

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Assigned when the hardware is manufactured.

Unit key is unique to this unit in particular (each Clipper chip also has a *unit ID*).

Global family key is the same across many units.

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Used for establishing a (symmetric) ***session key***

Session keys are ephemeral (e.g., last only for a given connection, transaction, etc.)

General properties about session keys:

- Compromising one session key does not compromise others
- Compromising a long-term key should not compromise past session keys (**forward secrecy**)

Clipper chip: Design

Tamper-proof hardware

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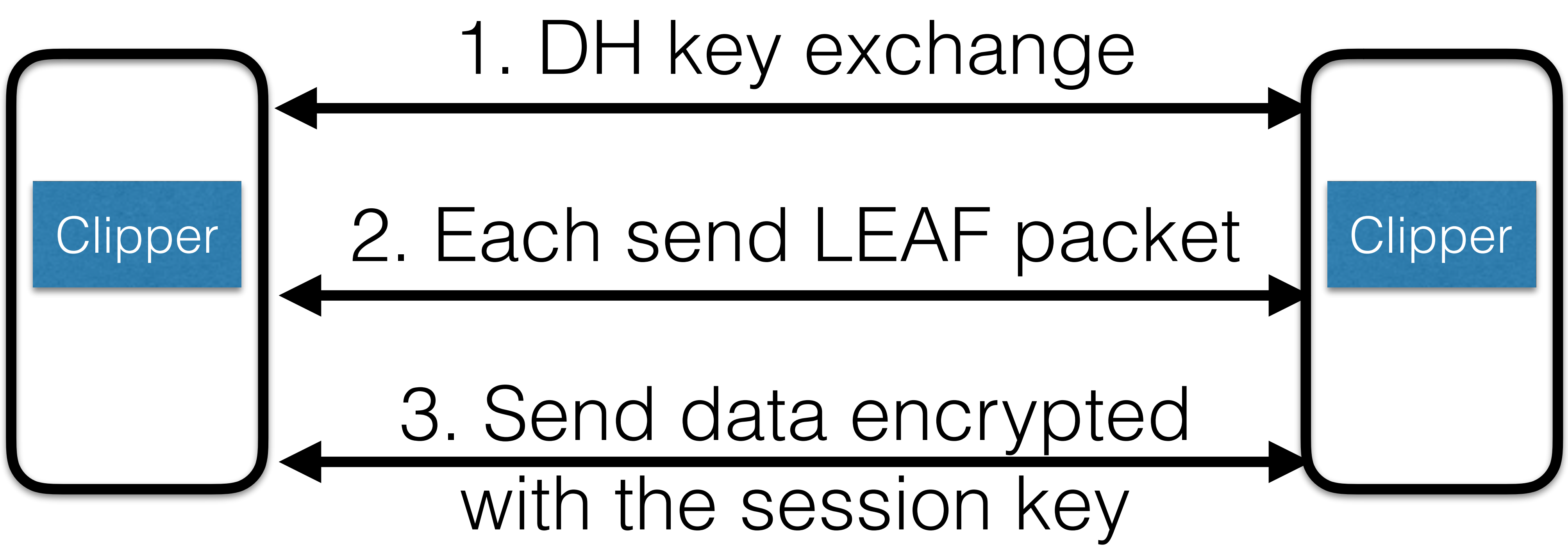
LEAF
(Law Enforcement Access Field)

To permit wiretapping, law enforcement needs to be able to extract session keys, but only has access to what is sent during communication

Idea: send data that has enough info to allow law enforcement to extract keys (but not any other eavesdropper).

LEAF protocol design

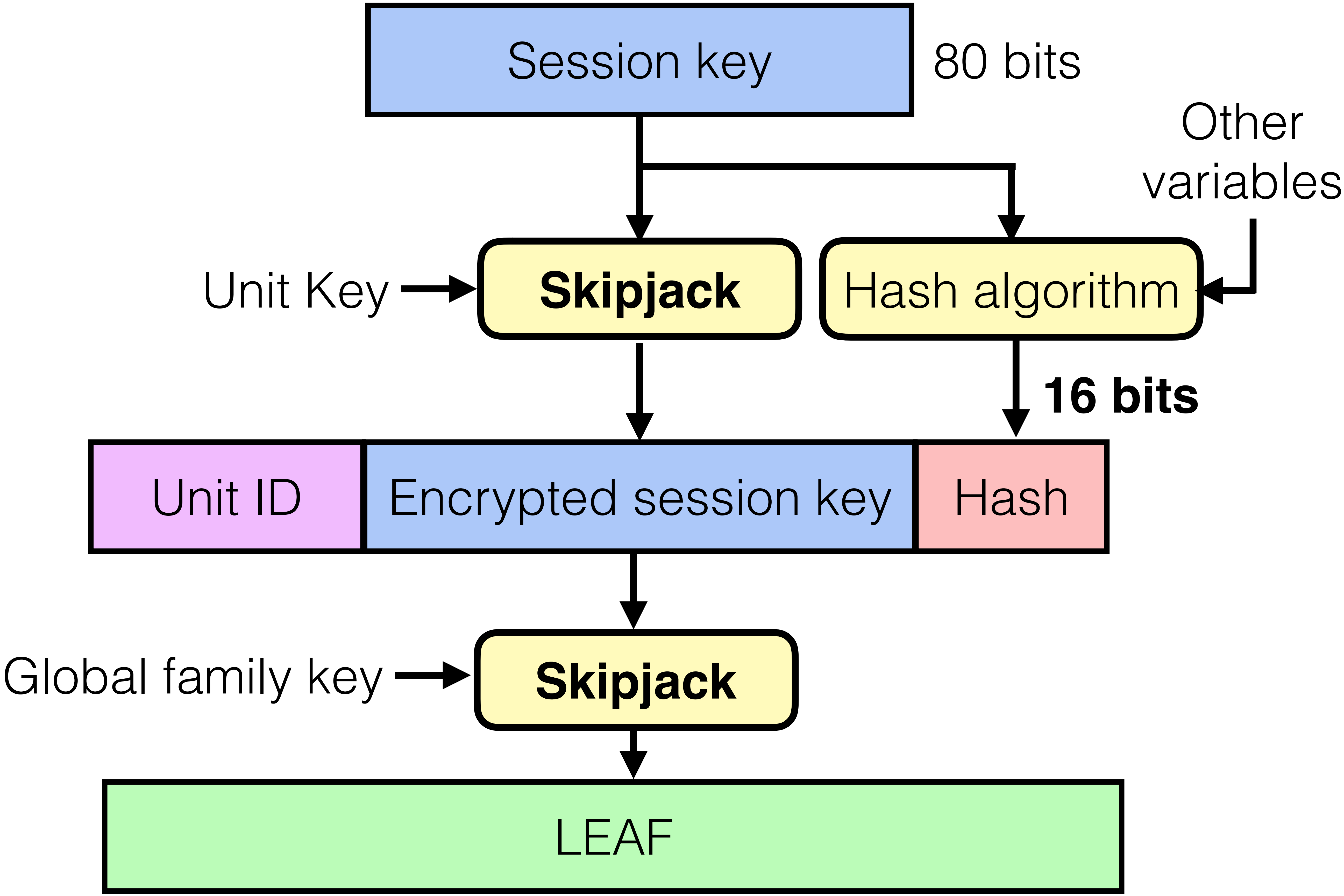


The Clipper chips will not decrypt until it has received a valid LEAF packet

Law enforcement sees all packets.

- Cannot infer key from DH key exchange
- *Can* infer it from the LEAF packet

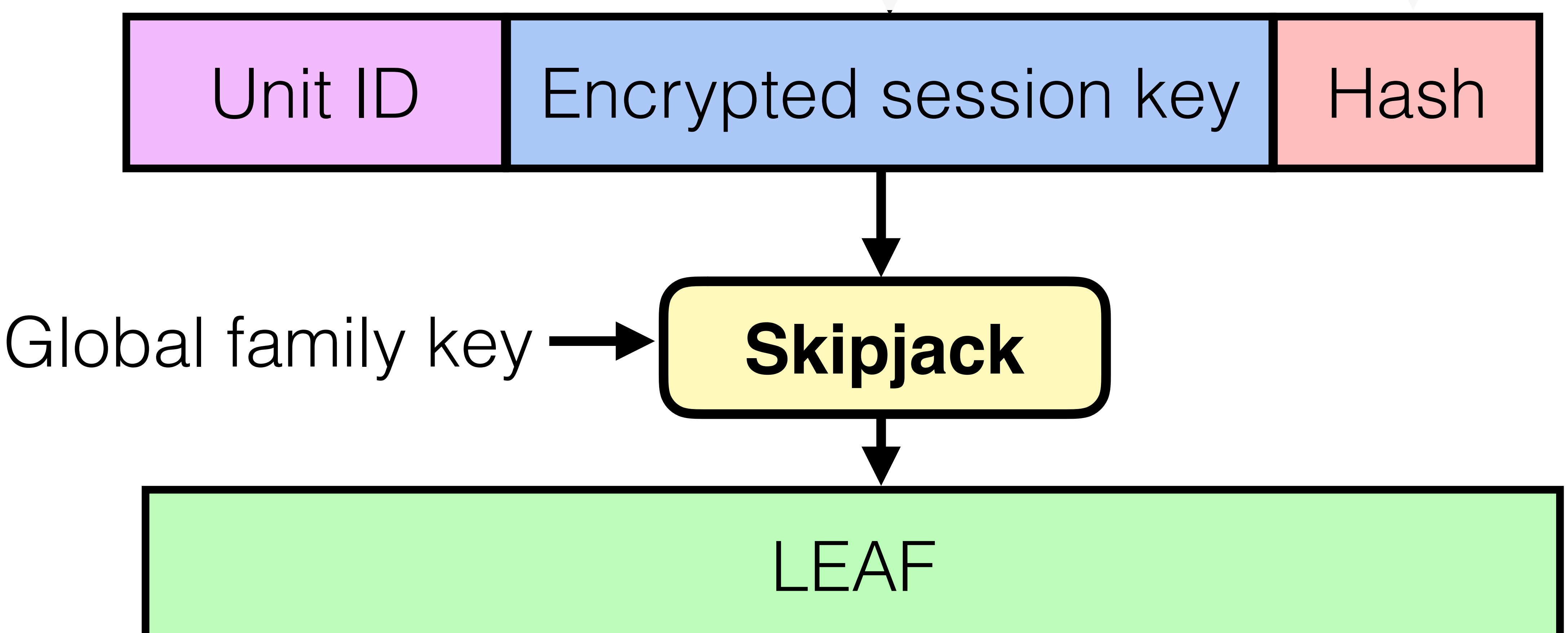
LEAF message structure



LEAF message structure

The other Clipper chip also has the Global Family key

=> Can decrypt the LEAF to obtain this triple



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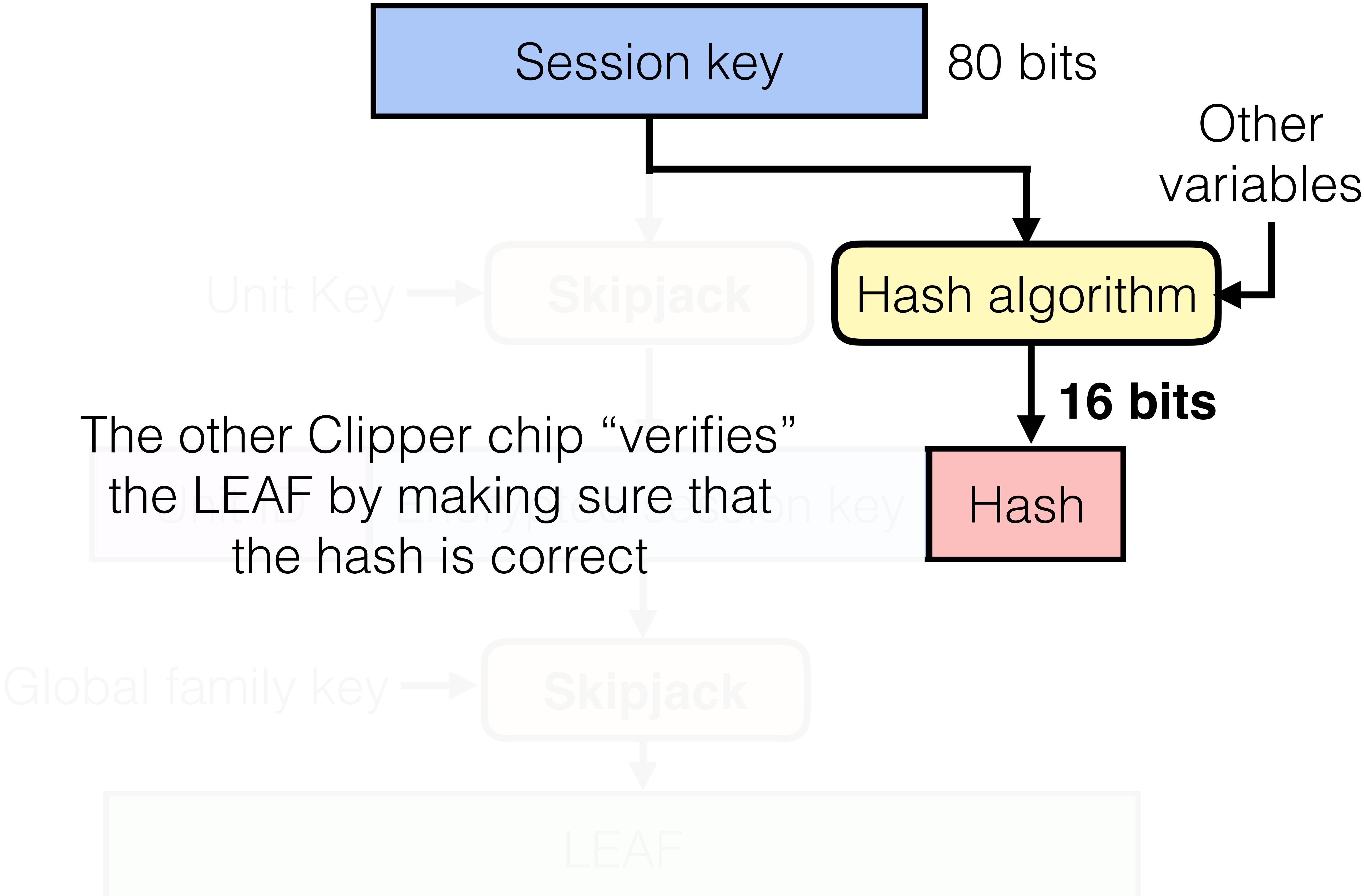
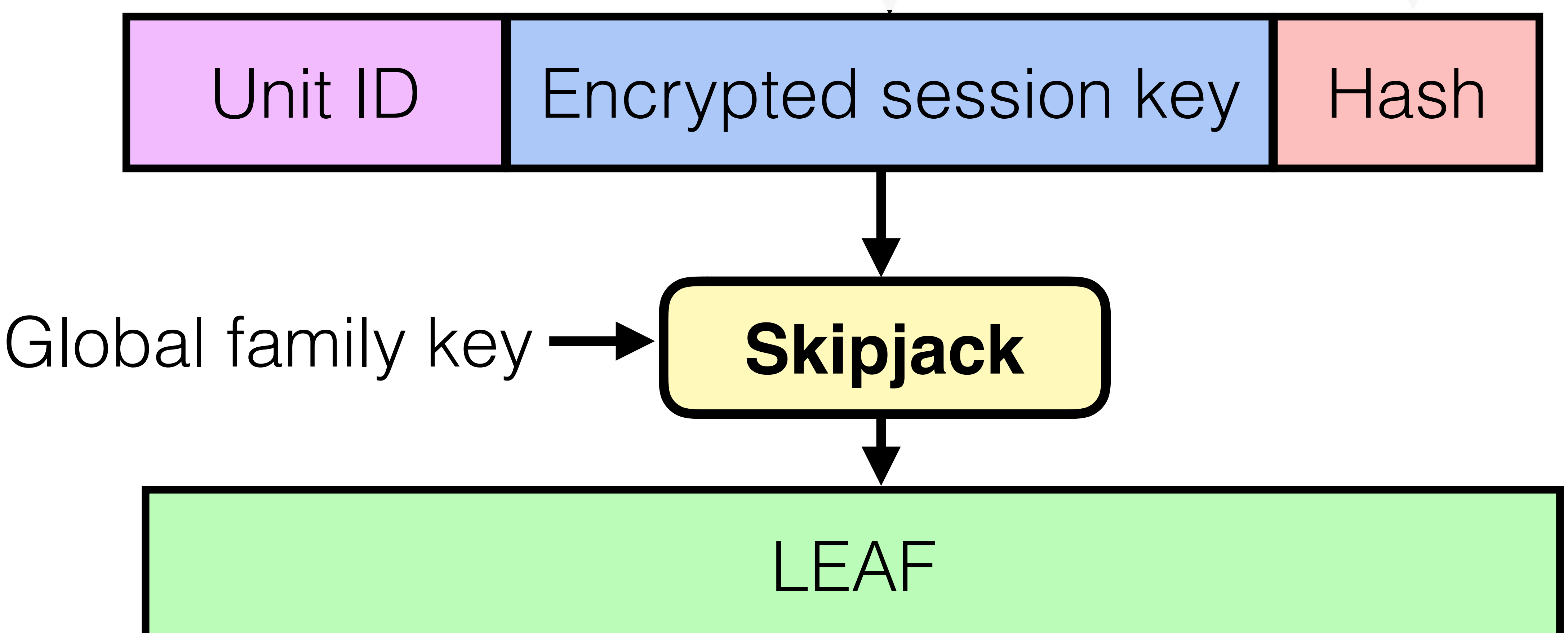


The other Clipper chip “verifies” the LEAF by making sure that the hash is correct

LEAF message structure

Law enforcement also has the Global Family Key

=> Can decrypt the LEAF to obtain this triple



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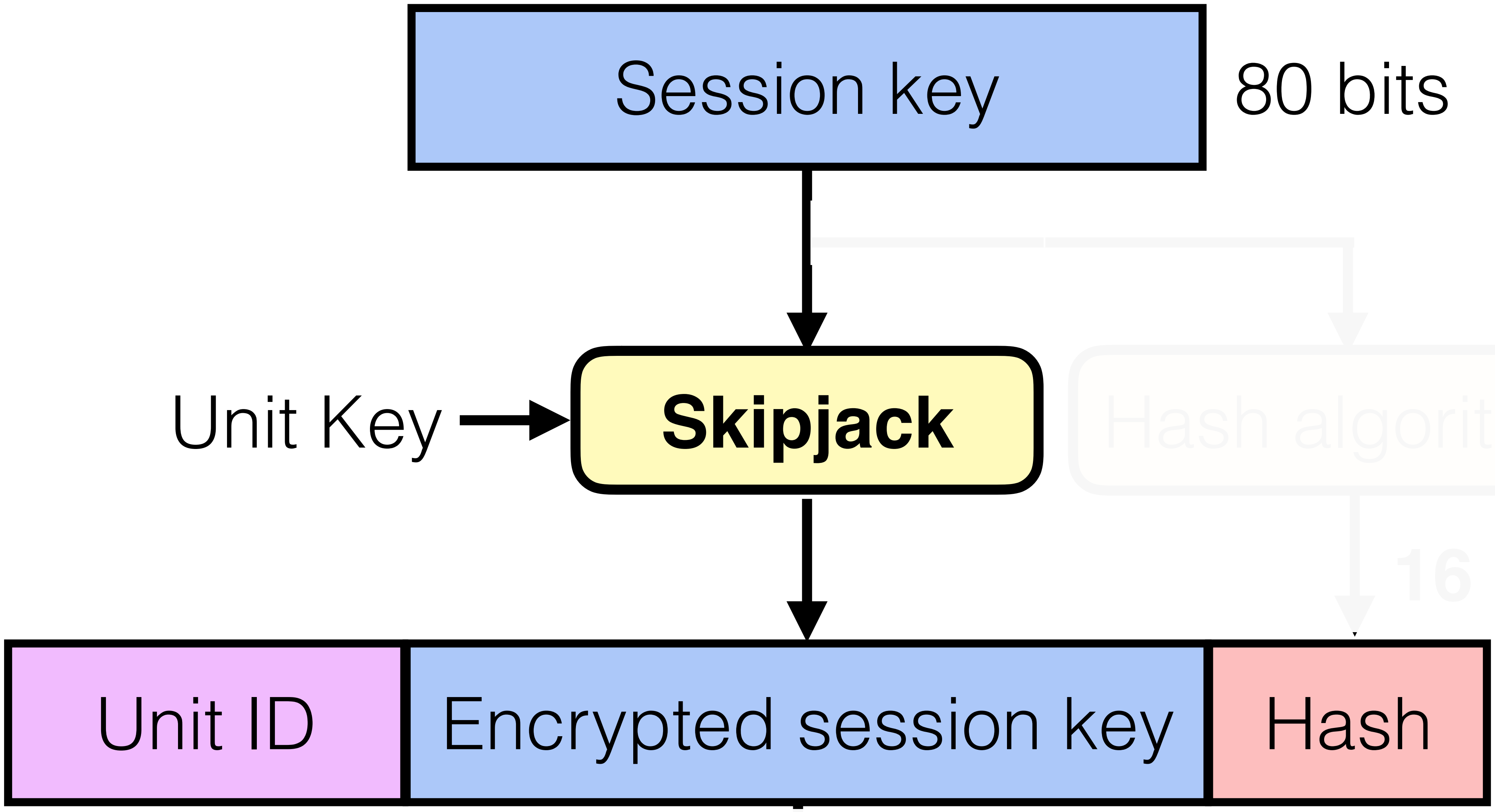
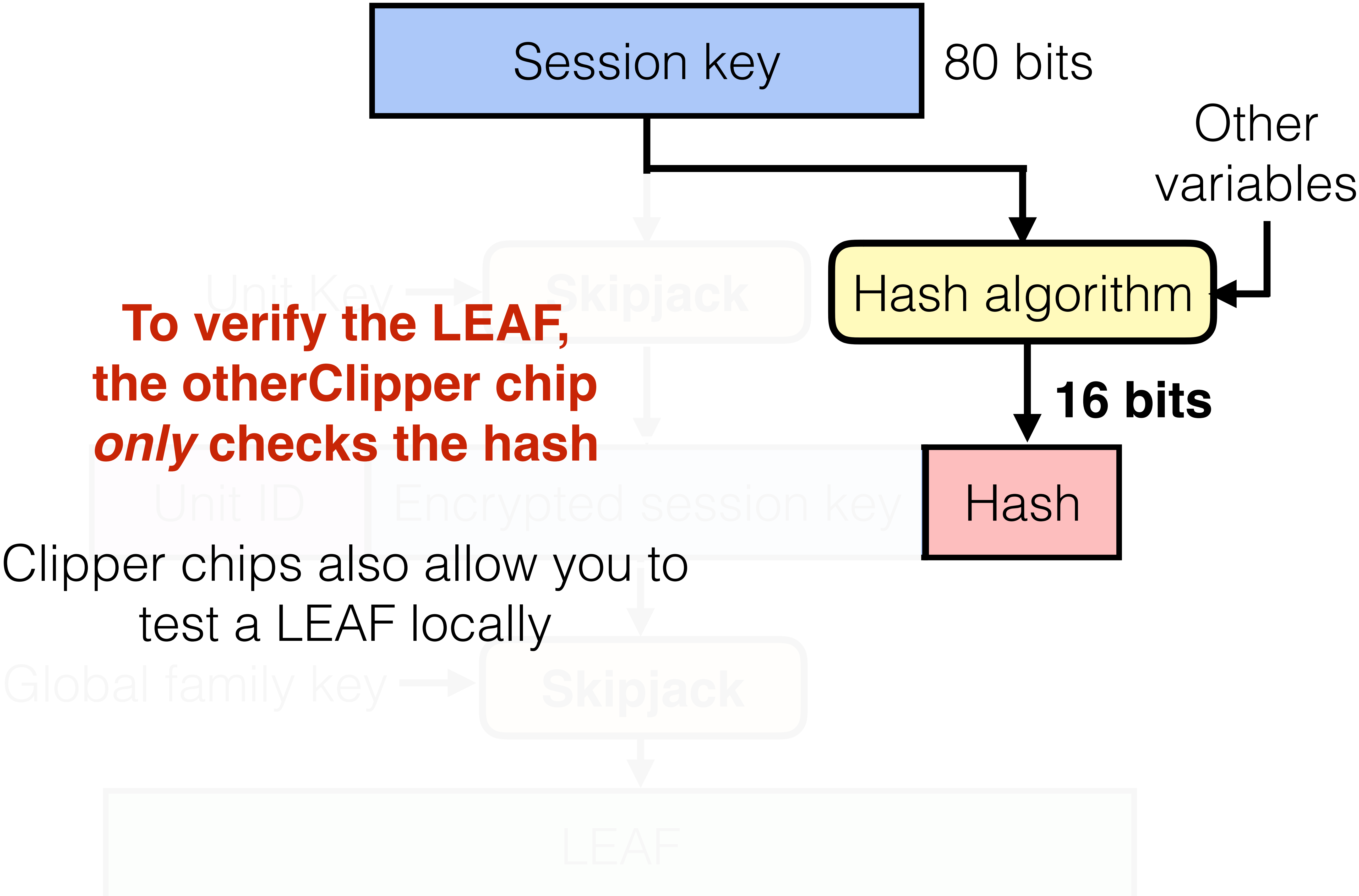


Law enforcement *does not* have direct access to all unit keys; needs a **warrant** to get them

Unit keys are split across two locations (one location gets a OTP, the other gets the XOR)

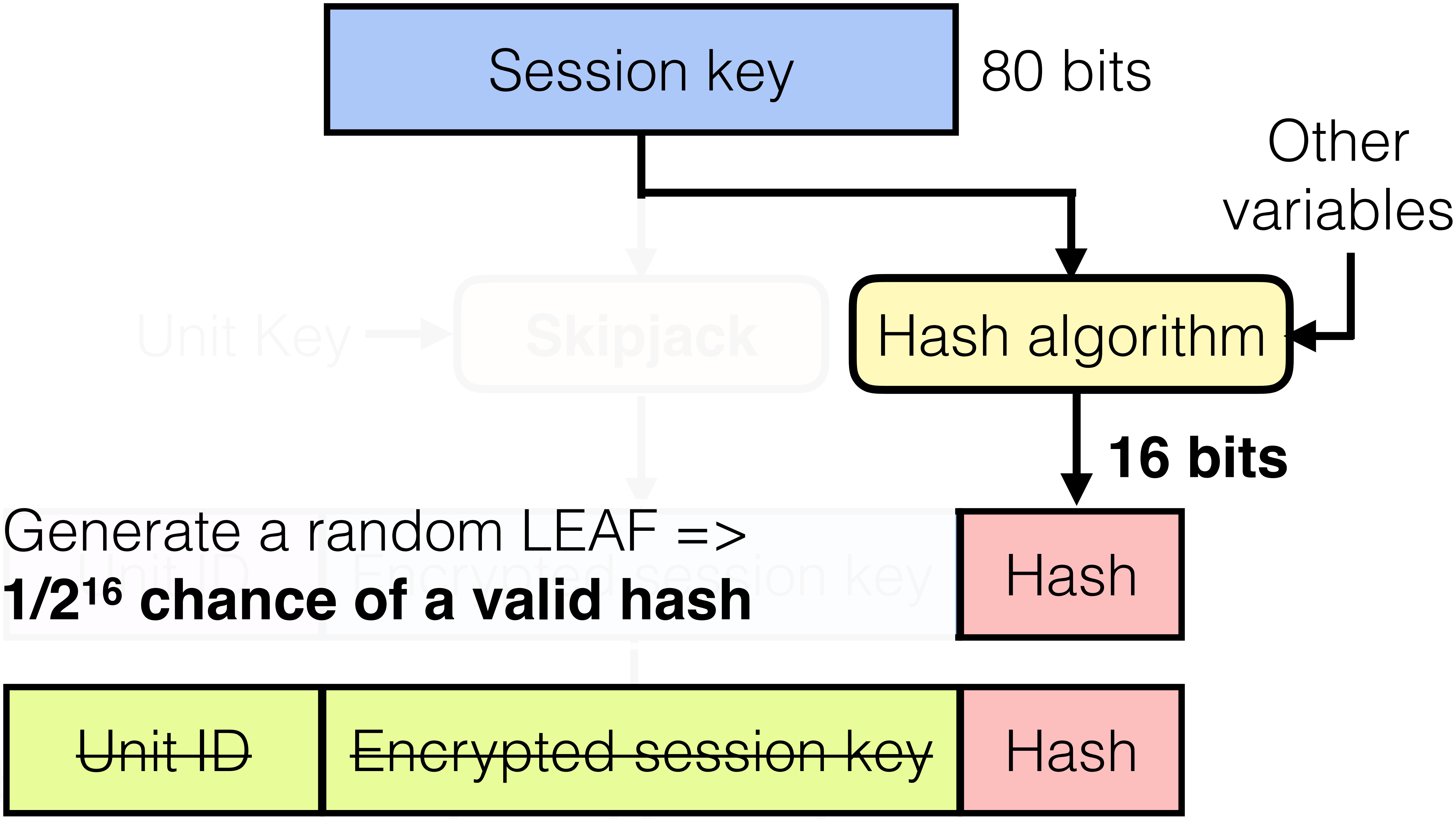
LEAF: failure



To verify the LEAF, the otherClipper chip *only* checks the hash

Clipper chips also allow you to test a LEAF locally

LEAF: failure



Generate a random LEAF =>
$1/2^{16}$ chance of a valid hash

But law enforcement will just see random ID & key

Validates at the other Clipper chip (so it will decrypt messages)

Misusing crypto

Avoid shooting yourself in the foot:

- Do not **roll your own** cryptographic mechanisms
  - Takes peer review
  - Apply Kerkhoff's principle
- Do not ***misuse*** existing crypto
- Do not even ***implement*** the underlying crypto

An Empirical Study of Cryptographic Misuse in Android Applications

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6. Do not use **static seeds** to seed `SecureRandom(.)`

Crypto misuse in Android apps

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Analyzed **11,748** of them

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	# apps	violated rule
48%	5,656	Uses ECB (BouncyCastle default) (R1)
31%	3,644	Uses constant symmetric key (R3)
17%	2,000	Uses ECB (Explicit use) (R1)
16%	1,932	Uses constant IV (R2)
	1,636	Used iteration count < 1,000 for PBE(R5)
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BouncyCastle defaults

- BouncyCastle is a library that conforms to Java's `Cipher` interface:

```
Cipher c =
   Cipher.getInstance("AES/CBC/PKCS5Padding");

// Ultimately end up wrapping a ByteArrayOutputStream
// in a CipherOutputStream
```

- Java documentation specifies:

> If no mode or padding is specified, provider-specific default values for the mode and padding scheme are used. For example, the `SunJCE` provider uses `ECB` as the default mode, and `PKCS5Padding` as the default padding scheme for `DES`, `DES-EDE` and `Blowfish` ciphers.

#Occurences	Symmetric encryption scheme
5878	AES/CBC/PKCS5Padding
4803	AES *
1151	DES/ECB/NoPadding
741	DES *
501	DESede *
473	DESede/ECB/PKCS5Padding
468	AES/CBC/NoPadding
443	AES/ECB/PKCS5Padding
235	AES/CBC/PKCS7Padding
221	DES/ECB/PKCS5Padding
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Table 4: Distribution of frequently used symmetric encryption schemes. Schemes marked with * are used in ECB mode by default.

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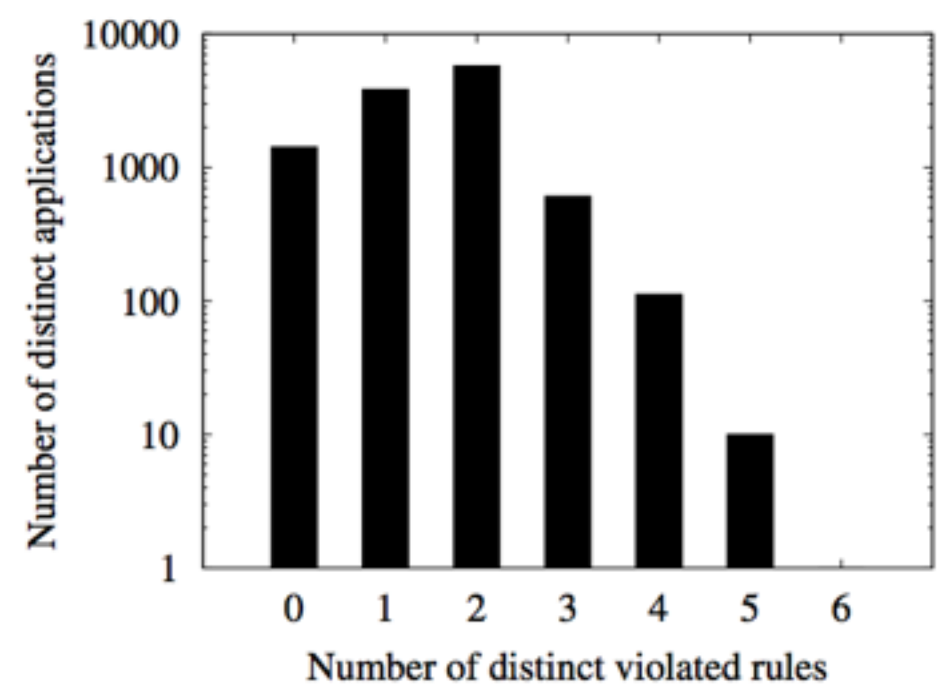

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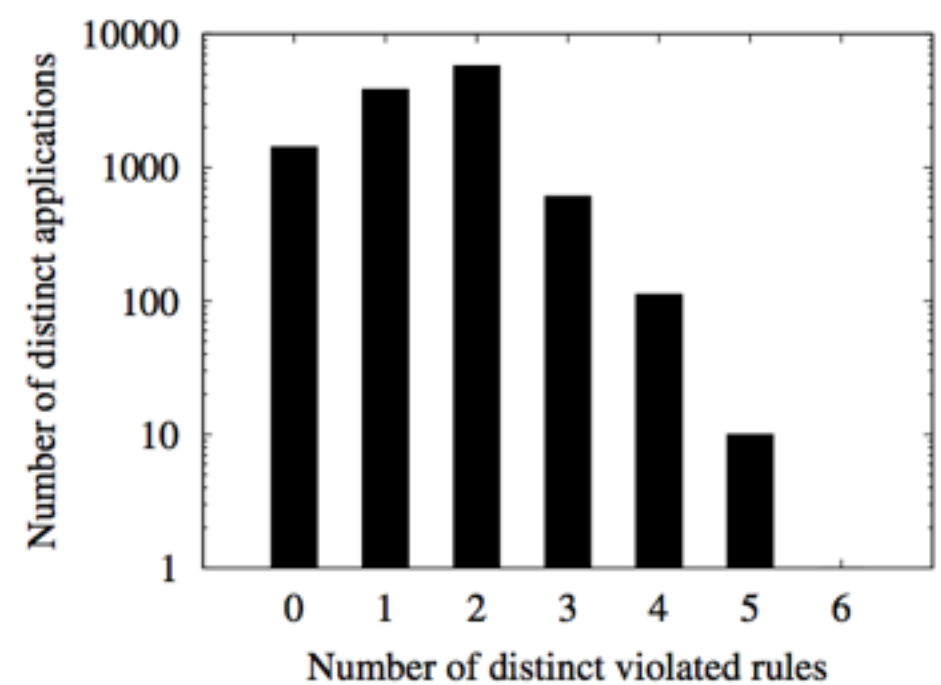

A failure of the programmers to **know the tools** they use

A failure of library writers to **provide safe defaults**

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Why not implement AES/RSA/etc. yourself?

- Not talking about creating a brand new crypto scheme, just implementing one that's already widely accepted and used.

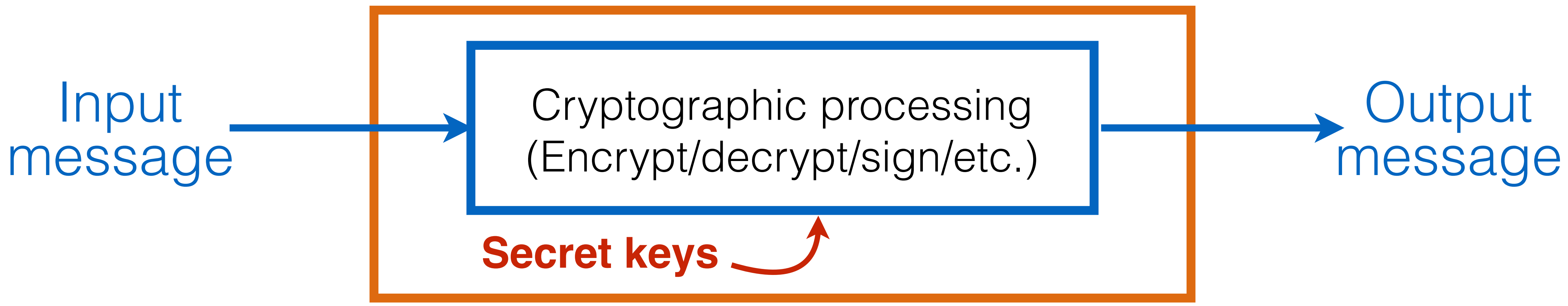
- Kerkhoff's principle: these are all open standards; should be implementable.

- Potentially buggy/incorrect code, but so might be others' implementations (viz. OpenSSL bugs, poor defaults in Bouncy castles, etc.)

- So why not implement it yourself?

Side-channel attacks

- Cryptography concerns the *theoretical* difficulty in breaking a cipher



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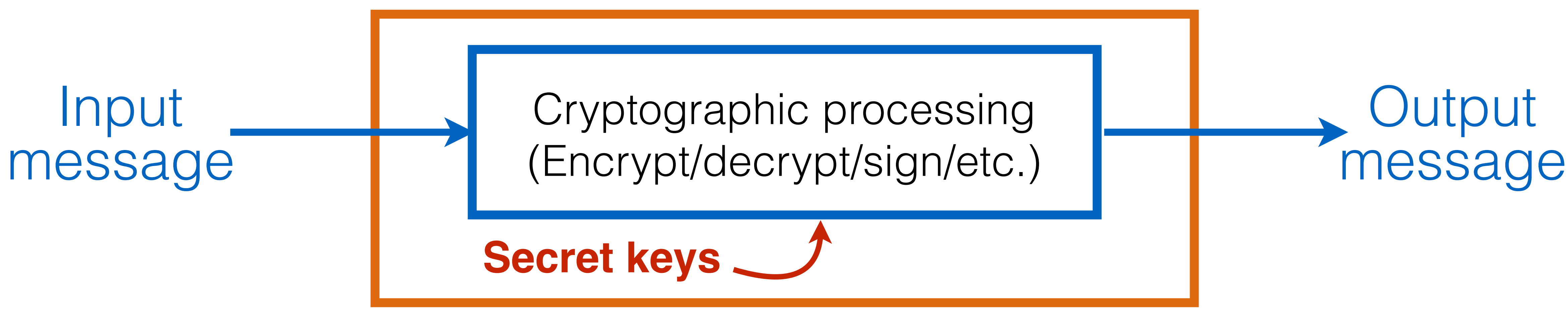

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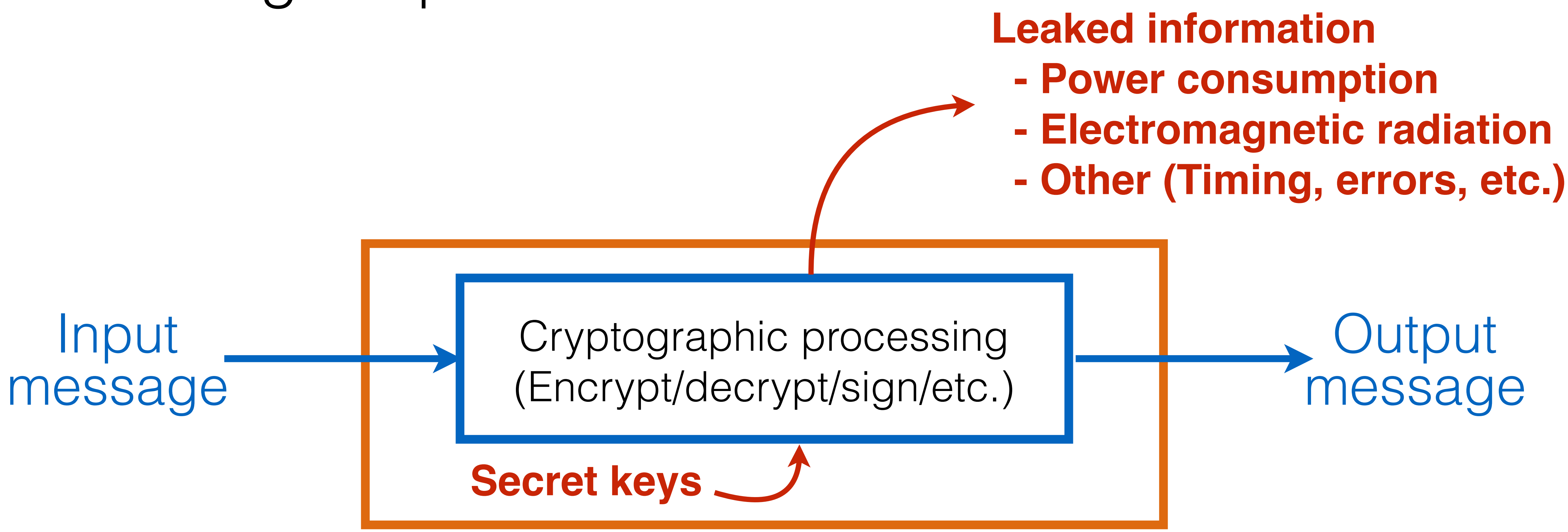

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Simple Power Analysis (SPA)

- Interpret *power traces* taken during a cryptographic operation

- Simple power analysis can reveal the sequence of instructions executed

SPA on DES

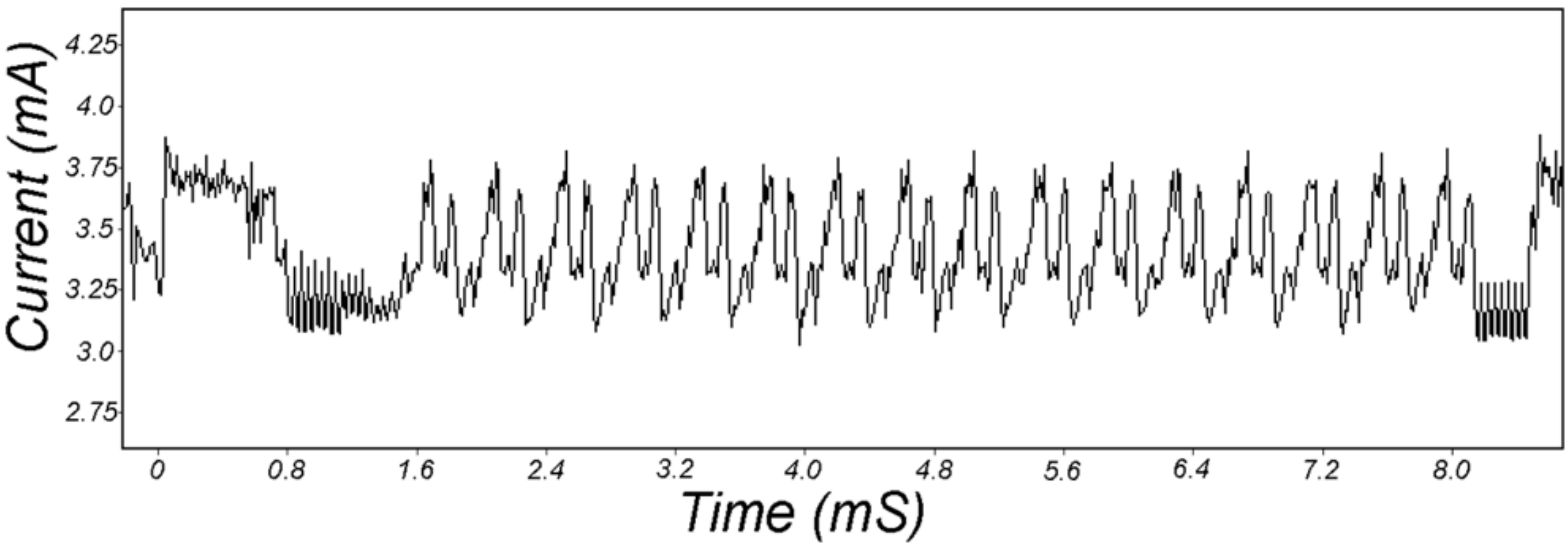
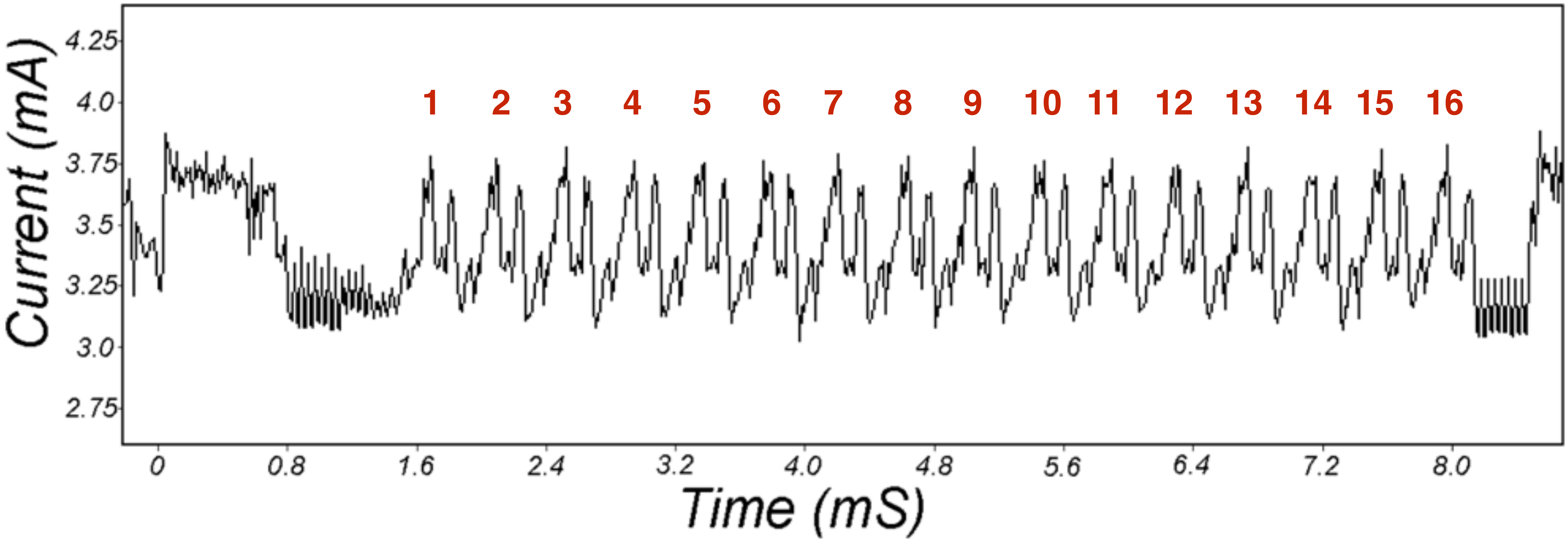


Figure 1: SPA trace showing an entire DES operation.

Overall operation clearly visible:
Can identify the **16 rounds of DES**

SPA on DES



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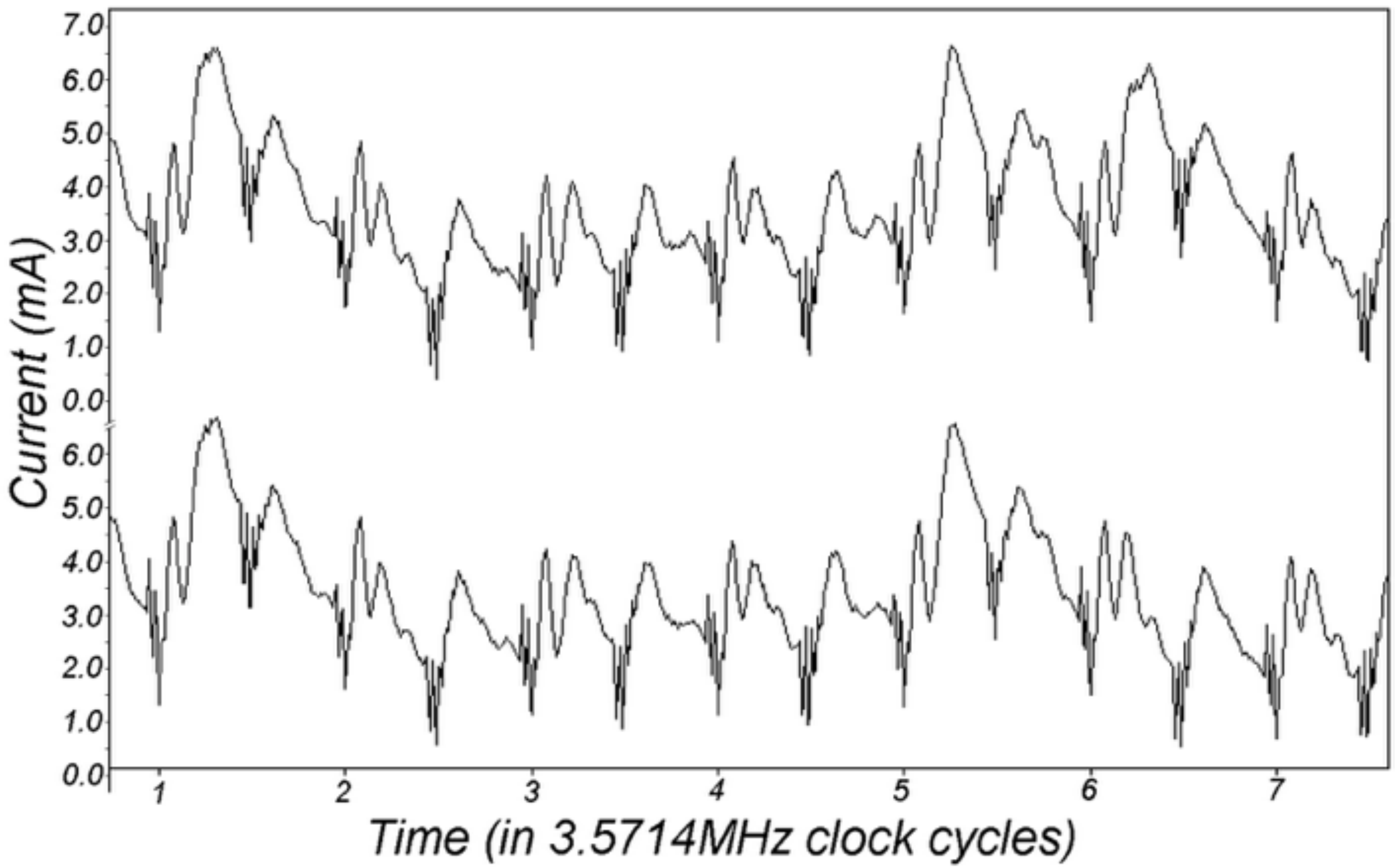

Figure 3: SPA trace showing individual clock cycles.

Specific **instructions** are also discernible

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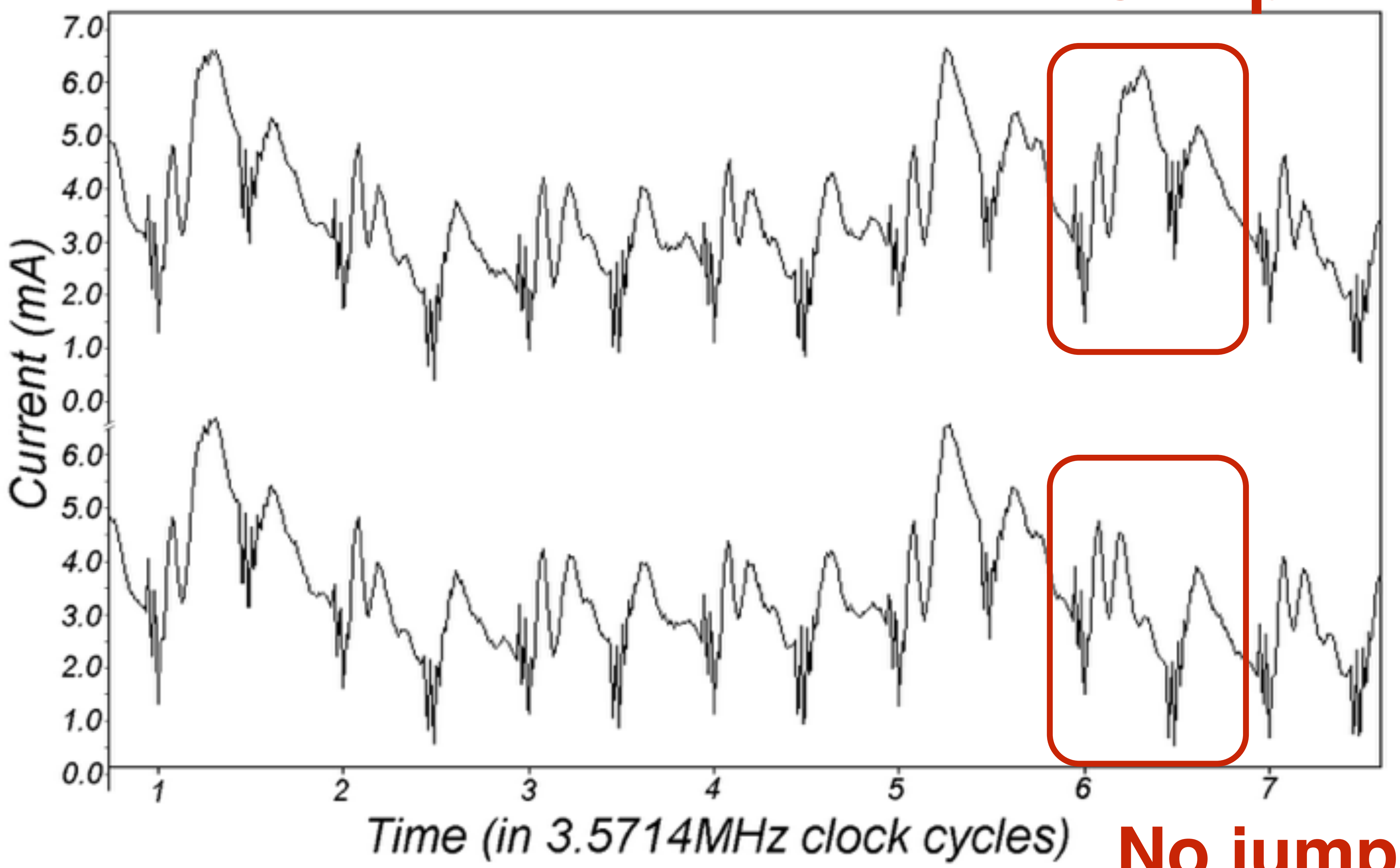

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```
HypotheticalEncrypt(msg, key) {
  for(int i=0; i < key.len(); i++) {
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- made more noise?
- ...

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Differential Power Analysis (DPA)

- SPA just visually inspects a single run
- DPA runs iteratively and reactively
  - Get multiple samples
  - Based on these, construct new plaintext messages as inputs, and repeat

Mitigating such attacks

- Hide information by making the execution paths depend on the inputs as little as possible
    - Have to *give up some optimizations* that depend on particular bit values in keys
        - Some Chinese Remainder Theorem (CRT) optimizations permitted remote timing attacks on SSL servers

- The crypto community should seek to design cryptosystems under the assumption that some information is going to leak

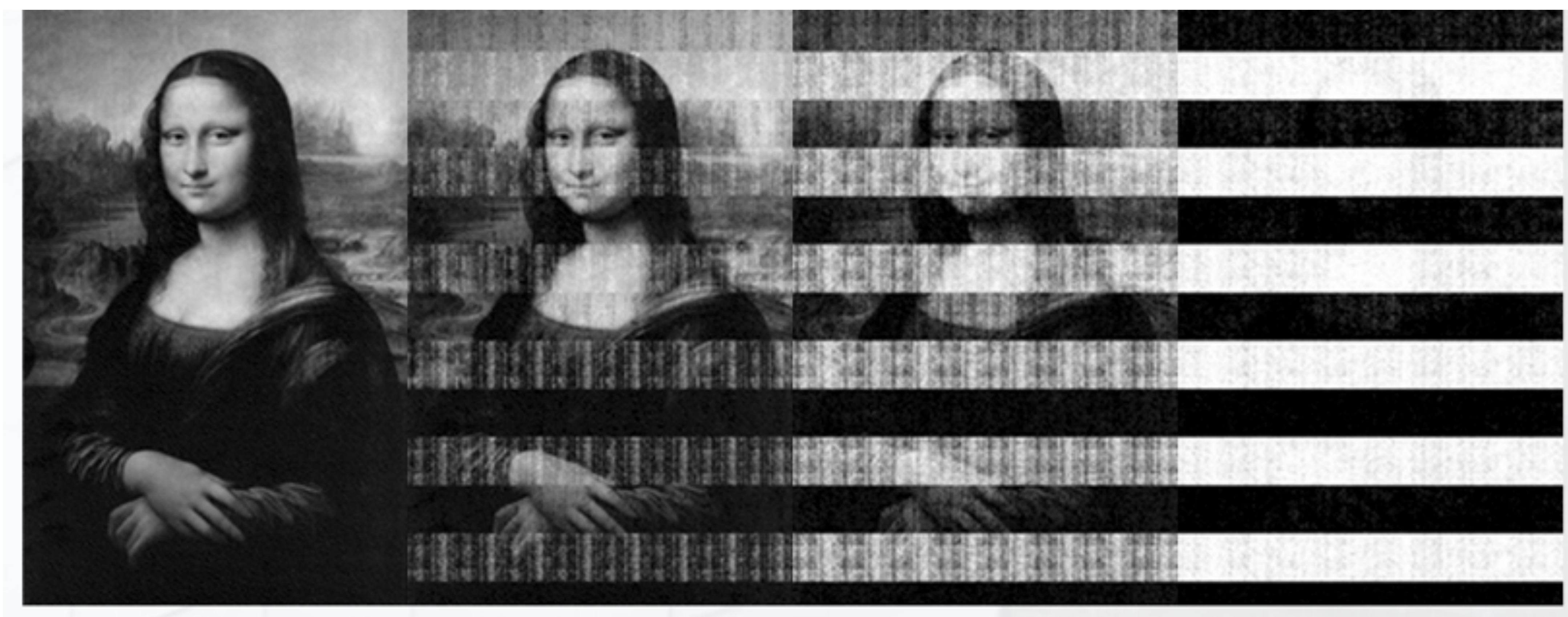
Other side-channel attacks

- Typical threat model: attacker doesn't have root access to a particular machine
  - So we safely store keys in memory
- But what if the attacker had physical access to the machine?

Attack

- Attacker's goal: reboot the machine into an OS that that he or she controls to look at memory contents

- Challenge: memory loses state without power



5 sec 30 sec 60 sec 5 min

Cold boot attack

Memory loses its state slower at really cold temperatures

	Seconds w/o power	Error % at operating temp.	Error % at $-50\,^{\circ}$C
A	60	41	(no errors)
	300	50	0.000095
B	360	50	(no errors)
	600	50	0.000036
C	120	41	0.00105
	360	42	0.00144
D	40	50	0.025
	80	50	0.18

Table 2: Effect of cooling on error rates

Cold boot attack

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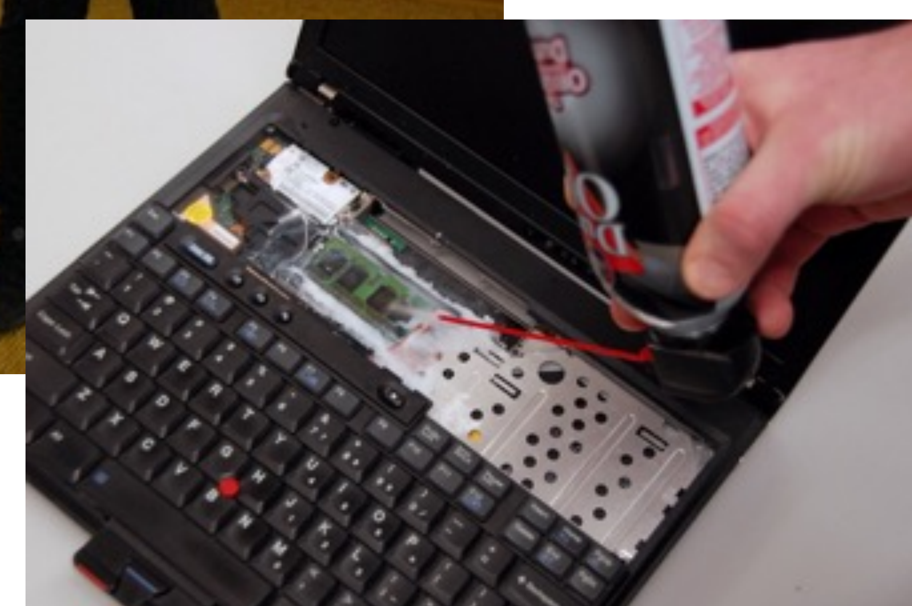

Cold boot attack

- **Launching** the attack:
  - Cool down the memory & then power off/take it out
  - Boot into your own OS
  - Scan the memory image for keys (non-trivial but doable, especially if the keys have a format that's easy to detect)

- Some **defenses** against the attack:
  - Encrypt all of memory (increased CPU support for this)
  - Use trusted hardware (Xbox does this)
    - TPM (Trusted Platform Module) stores keys in hardware that is very difficult to inspect (some self-destruct)
  - Limit the amount of time keys live in memory
    - E.g., remove keys from memory when you enter Sleep mode

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Ongoing work in crypto

- Constantly attacking/defending crypto schemes
  - Must stay on top of best practices
  - Ideally, write your code so you can change easily
- New mechanisms to permit new types of interactions
- A style of interaction that's been getting a lot of attention:
  - Alice has proprietary data
  - Bob has proprietary code (or computational resources)
  - Goal: Bob runs his code on Alice's data without learning her input *or* the output

Some things to look for

- Fully homomorphic encryption
  - Normal encryption: D(k, E(k, m)) = m
  - FHE: D(k, F(E(k, m))) = F(m)

- Secure multiparty computation
  - Alice and Bob both have data and want to know the output of a function over their *private data*, without having to reveal their data to each other
  - E.g., “which of us has more money” without having to reveal exactly how much either has