YHQL YLGL YLFL — J. Caesar

Cryptography

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The Menu

- Symmetric Crypto

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- Asymmetric Crypto (aka Public-Key)

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- Asymmetric Crypto (aka Public-Key)
- Hashes, MICs, and MACs

Cryptography

Eveの盗聴でAliceとBobのビットが異なる確率は？

Aliceの偏光に比べて		Eveの基底 正しい	間違い
Bobの基底	正しい	正しいビット	違うビット列が1/2で出る
	間違い	ビットは作らない	

Eveが間違った基底を選ぶ確率は $\frac{1}{2}$

さらに、BobがAliceと違う偏光を測定する確率が $\frac{1}{2}$

よってEveの盗聴が感知される確率は $\frac{1}{4}$

Nビット照合して、盗聴が感知されない確率は $\left(\frac{3}{4}\right)^N$

10ビット照合する場合、盗聴がばれない確率は $\left(\frac{3}{4}\right)^{10}=5.6\times10^{-2}$

100ビット照合する場合には

1000ビット照合する場合には

<u>*ビーム遮断では盗聴がばれる*</u>

3000ビット照合する場合には

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Avoid subscript k; easily confused with subscript K.

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- Examples: RSA, Elgamal, ECC

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With AES, you can choose m and n independently from $\{128, 160, 192, 224, 256\}$.

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That’s a bit difficult to attain in practice, because we can’t see into the future!

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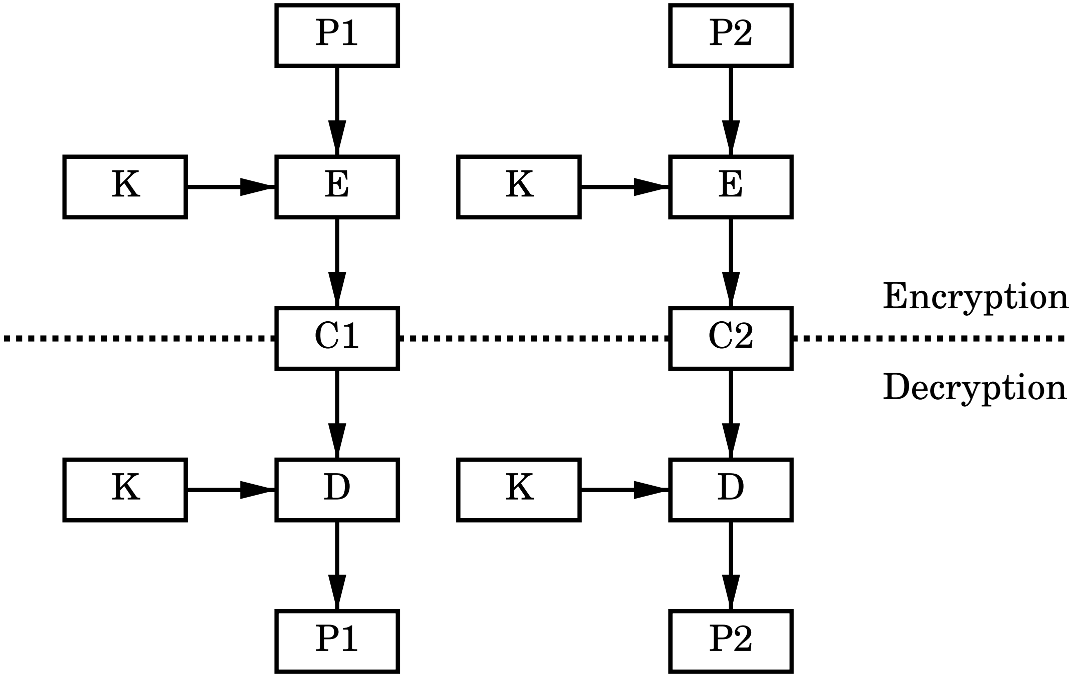
Electronic Codebook Mode (ECB)



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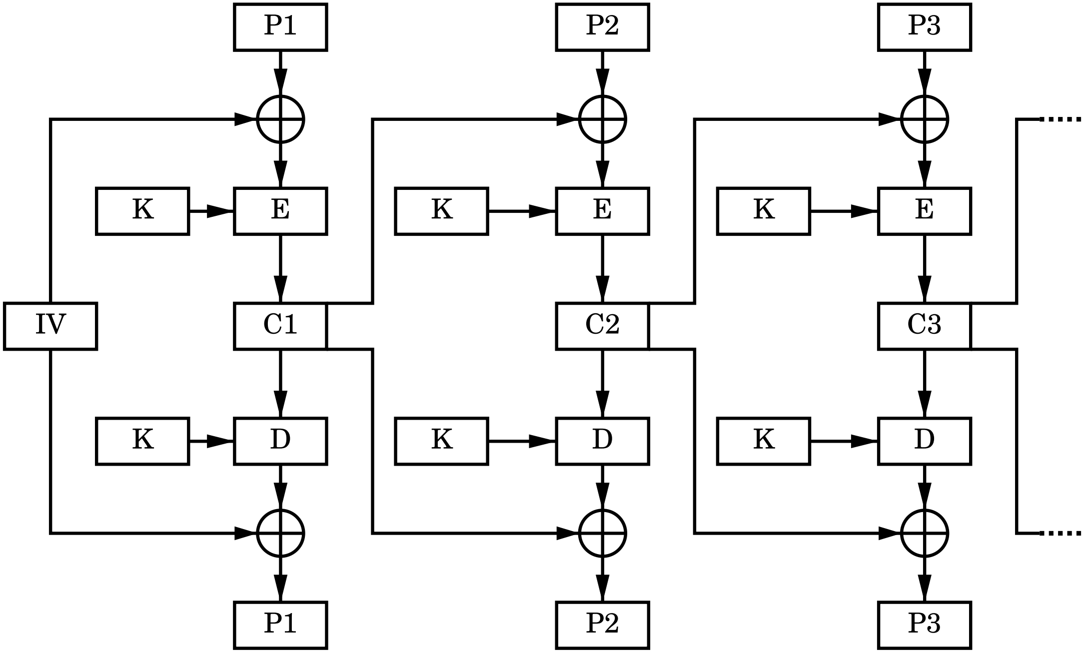
...without breaking the encryption scheme.

Cipher Block Chaining (CBC)



The “IV” is a random initialization vector that is sent unencrypted with the message.

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In most cases, security is not weakened by choosing a constant IV for each message, but there are exceptions (see exercises).

Problems With CBC (1)

Assume the plaintext is “Trudy␣␣␣R&D␣␣␣$20000␣␣␣”

The character 2 has the bit representation 00110010. 3 is 00110011. Can Trudy force this single bit to change?

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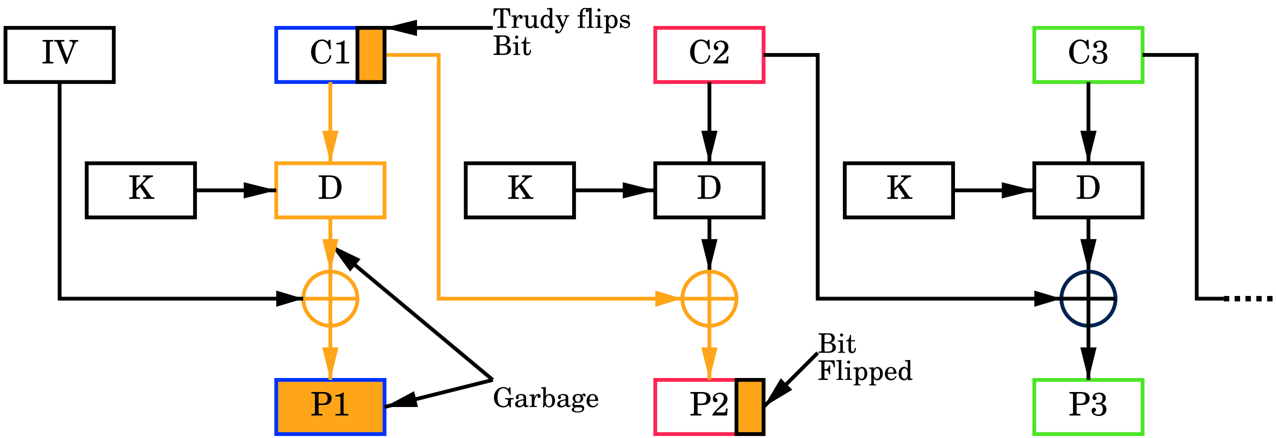

If Trudy flips the last bit of C_1, block 1 will decrypt as garbage, but C_2 will decrypt as R&D␣␣␣$2 $\oplus 1 =$ R&D␣␣␣$3, a 50% increase in Trudy's salary!

Problems With CBC (2)

In CBC, $p_i = c_{i-1} \oplus D_K(c_i)$ where c_0 is the IV. Hence, $D(c_i) = c_{i-1} \oplus p_i$.

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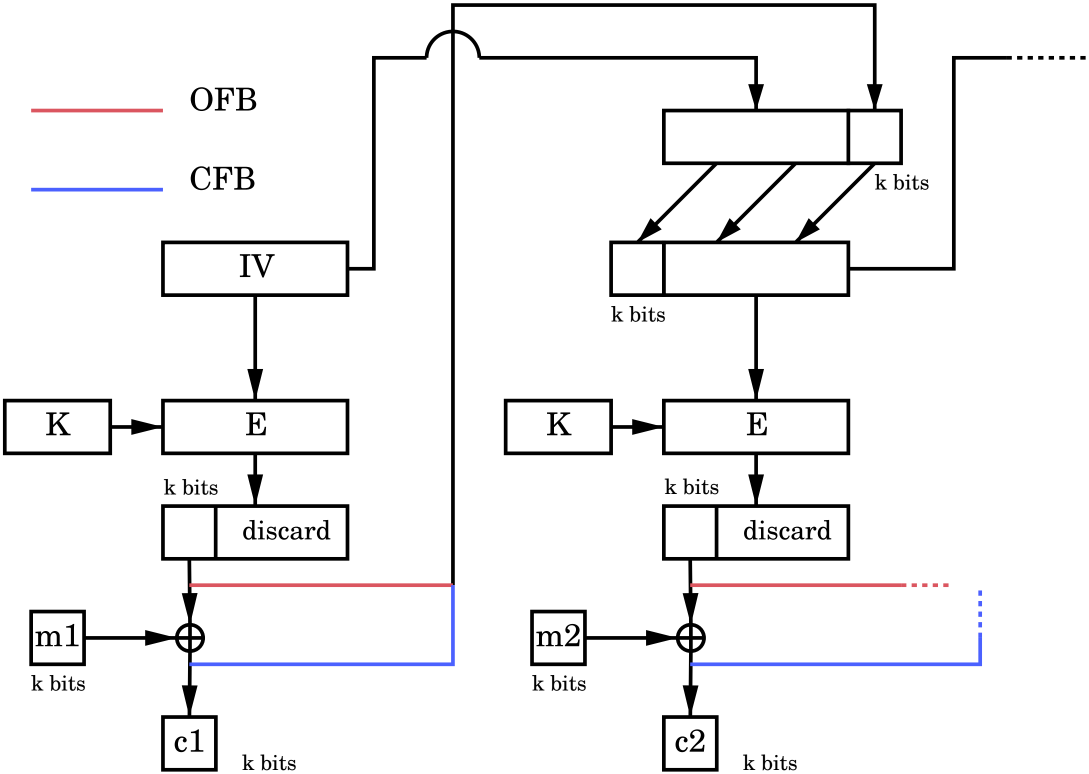
Arrangement	Decryption
$c_0 \vert c_1 \vert c_2 \vert c_3$	$p_1 \vert p_2 \vert p_3$
$c_1 \vert c_0 \vert c_2 \vert c_3$	$c_1 \oplus D(c_0) \vert c_0 \oplus D(c_1) \vert p_3$
$c_0 \vert c_1 \vert c_2 \vert c_2$	$p_1 \vert p_2 \vert c_2 \oplus D(c_2) = p_3 \oplus D(c_3) \oplus D(c_2)$

It is improbable that rearranged messages will decrypt to something useful, but it's still a threat.

Feedback Modes (CFB, OFB)



Feedback Modes Explained

OFB and CFB generate a *one-time pad* consisting of pseudo-random numbers from an IV and a key: $c_i = p_i \oplus k_i$, where k_i is the key stream generated by the IV and K.

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OFB	CFB
Uses only key and IV to generate key stream	Also uses message
Encryption pad can be computed beforehand	Must wait for plaintext
Can generate ciphertext as fast as the plaintext appears	Can generate ciphertext as fast as plaintext appears if block sizes match

Effect of Transmission Errors and Attacks

Error	OFB Decryption	CFB Decryption
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Added ciphertext	Garbles rest of message	Will re-synchronize

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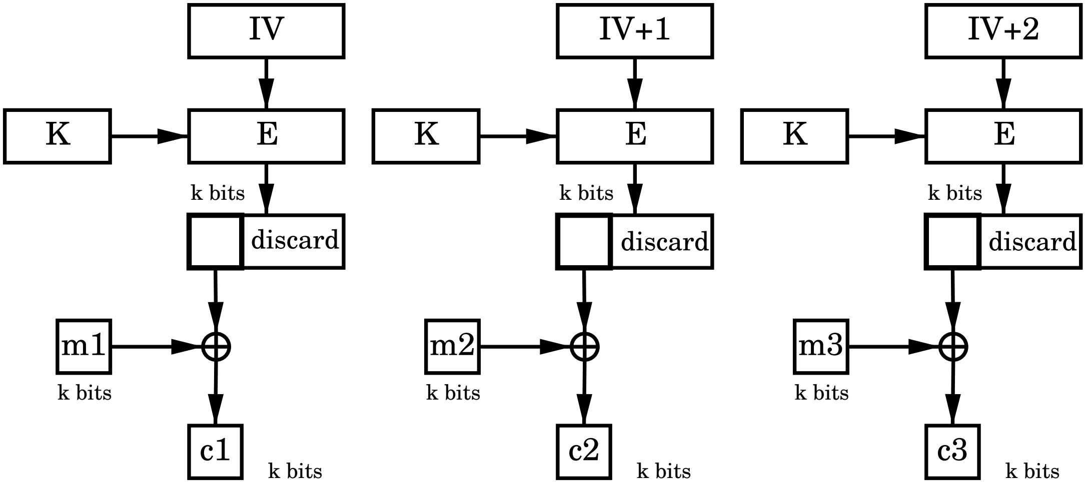
Since $p_i = c_i \oplus k_i$, we must substitute $p'_i \oplus k_i$ for c_i if we want the i-th ciphertext character to decrypt to p'_i.

Counter Mode (CTR)



Key stream can again be precomputed (like OFB) and decryption can start at any point (not just at the beginning).

Advice

Encrypt What	Recommendation
Files	CBC with a random IV (especially if you want to access the file non-sequentially). Also use a good Message Integrity Code (MIC) in order to detect modification of the ciphertext.
Net Sessions	CFB or OFB with a random IV or native stream cipher like RC4. Protect each packet with a MIC.
Short Database Fields	CBC with random IV and MIC.
Encryption Keys	ECB with MIC.

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Do not deploy any algorithm without checking whether it has been broken in the meantime. It happens.

More Advice on Algorithms

Do not use these ciphers; they are broken: GDES, DESX, (and most other DES variants), Bass-O-Matic, Khufu, Khafre, FEAL, Akelarre, SPEED, Enigma 2000, JEL, StreamBuddy, and many *many* more.

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N.B.: DES is an excellent cipher; it has withstood about 30 years of cryptanalysis. The best way of attacking DES is brute force. The problem with DES is that brute force is too easy.

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Example: I've seen an application that fed the plaintext back instead of the ciphertext, turning CFB into "PFB", which exposes patterns in the input. (Code change: one identifier.)

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- It is not necessary that $\{M\}_{\mathrm{Alice}}$ be in the domain of $[\cdot]_{\mathrm{Alice}}$. (Signature without encryption.)

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There are crypto libraries out there that are so orthogonal that they allow you to specify RSA with CBC, *but that's nonsense!*

It's even more important than in the case with symmetric crypto *not to write your own RSA package*, because there are even more things that can go wrong when you don't do it right.

RSA Key Generation

The number of positive integers that are relatively prime to some positive integer x (and less than it) is written $\phi(x)$, aka Euler's Totient Function.

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Let p and q be two different odd primes. Let $n = pq$. We have $\phi(n) = (p-1)(q-1)$. Choose e such that $\gcd(e, p-1) = 1$ and $\gcd(e, q-1) = 1$. Note that this means that $\gcd\left(e, \phi(n)\right) = 1$.

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Some choices of p and q are better than others! Beware!

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To encrypt a message $0 < P < n$, compute $C = P^e \bmod n$. To decrypt a message, compute $P' = C^d \bmod n$.

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When P is a multiple of p or q, things also work out. (Having $P = kp$ would expose p, because $\gcd(P^e \bmod n, n) = p$, but that is just as likely as correctly guessing p or q.)

RSA Pitfalls: Small Encryption Exponent

You want to send a message P to three participants with public keys $(3, n_1)$, $(3, n_2)$, and $(3, n_3)$. Encryption is:

$$C_j = P^3 \bmod n_j \qquad \text{for } 1 \le j \le 3.$$

By the Chinese Remainder Theorem, we can compute some x with $C_j = x \bmod n_j$ $(1 \le j \le 3)$, if the n_j are pairwise relatively prime (very likely).

This x is unique modulo $n_1 n_2 n_3$. We compute the smallest nonnegative such x.

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Solution: Choose $e = 65537$.

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If $e = 3$ (many still are!), and if the message P is so small that $P^3 < n$, then you can simply take the e-th root of the ciphertext to get P back.

Most messages are indeed small (112-bit or 128-bit encryption keys, for example), where there's a chance that this will happen.

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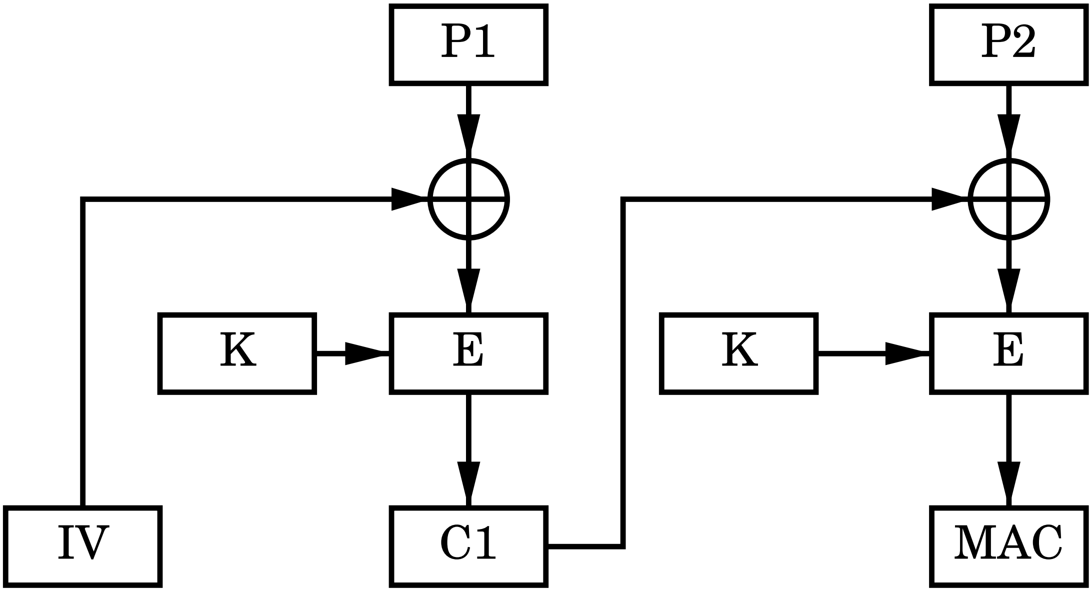
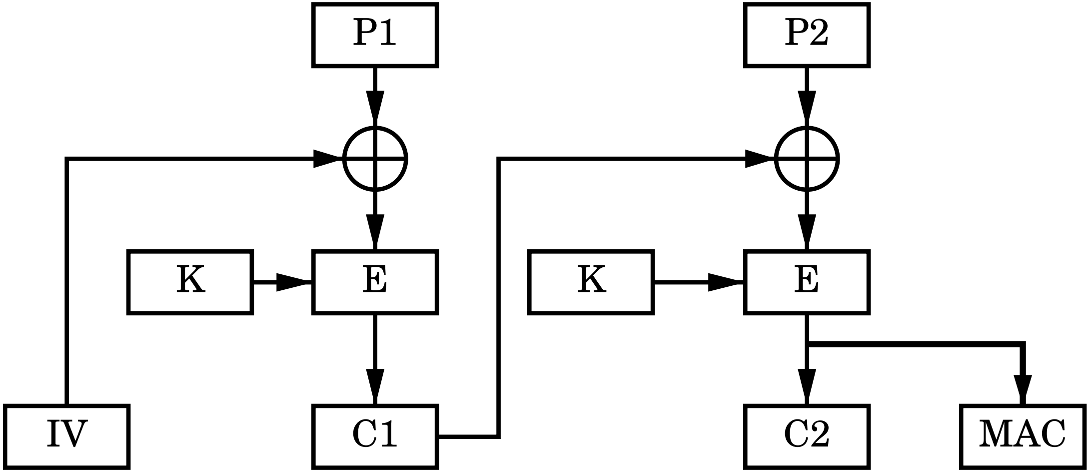
All but the last requirements are also required of hash functions.

Computing a MAC: CBC Residue

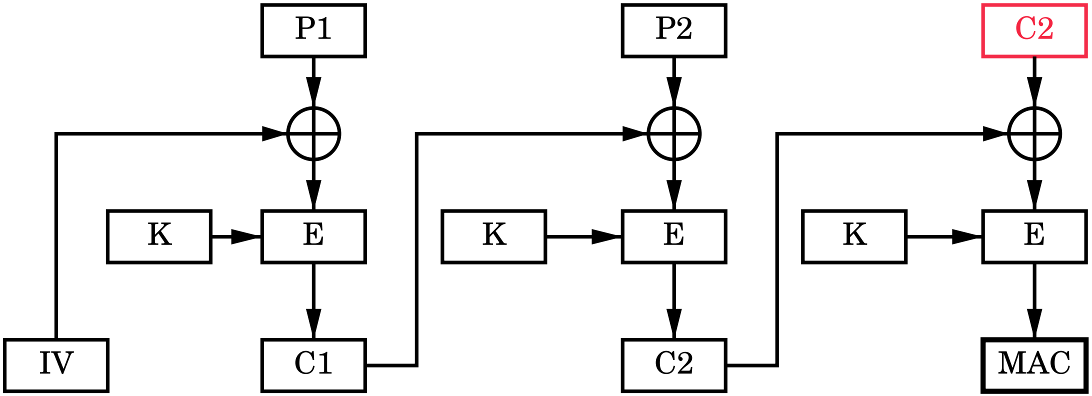


Privacy And Integrity (1)

Can we get encryption *and* integrity protection at the same time?



Privacy And Integrity (2)



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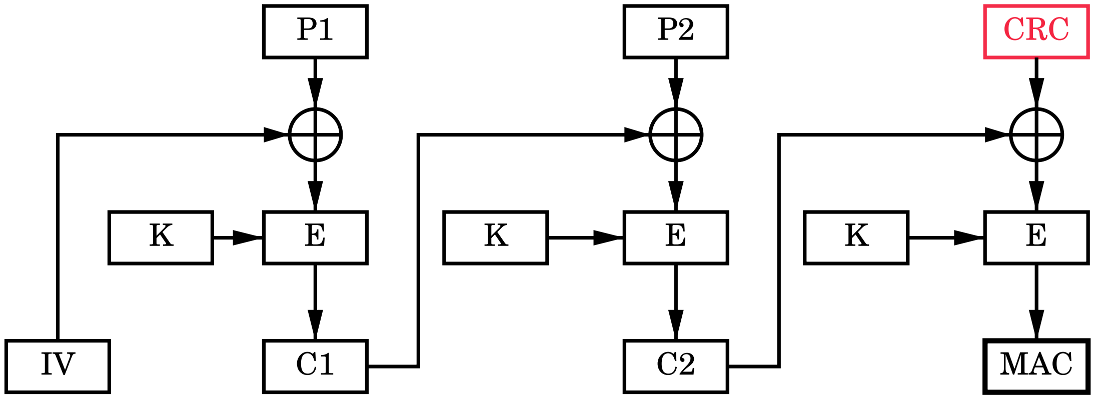

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Do not try to take shortcuts in crypto!

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Note that it cannot be *impossible* to find collisions, because of the pigeonhole principle: If you have infinitely many messages, but only finitely many hashes, some messages must hash to the same value.

How Infeasible is Finding a Collision?

Let's say the hash function is cryptographically strong, but I still want to crack it. I follow the following algorithm:

1. Set $S \leftarrow \varnothing$.
2. Generate a new, random message m and its hash $h(m)$.
3. If $(m, h(m)) \in S$, terminate the algorithm. Otherwise, set $S \leftarrow S \cup (m, h(m))$ and repeat step 2.

How often will step 2 have to be executed before the algorithm terminates? (We may assume that the messages that are generated contain no duplicates.)

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$$P(k) = \frac{N}{N} \cdot \frac{N-1}{N} \cdots \frac{N-k+1}{N} = \prod_{j=0}^{k-1} \left(1 - \frac{j}{N}\right)$$

Now we want to know the first k for which $P(k) < 0.5$.

Collision Probability (2)

$$
\begin{aligned}
\prod_{j=0}^{k-1}\left(1-\frac{j}{N}\right) &< \left(\frac{1}{k}\sum_{j=0}^{k-1}\left(1-\frac{j}{N}\right)\right)^k \\
&= \left(1-\frac{k-1}{2N}\right)^k \\
&\approx \left(1-\frac{k}{2N}\right)^k \\
&< \exp(-k^2/2N).
\end{aligned}
$$

To find k for which $P(k) < 0.5$, we solve $\exp(-k^2/2N) < 0.5$ for k to yield $k > \lambda\sqrt{N}$ where $\lambda = \sqrt{2\ln 2} \approx 1.18$.

If $N = 2^n$, and if n is even, $\sqrt{N} = 2^{n/2}$. We'll leave out the factor of λ (since it's so close to 1).

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Any hash function that has less than 128 bits of hash should be considered insecure and weak *and should not be used*.

Well-Known Hash Functions

For some reason, it seems to be easier to create good hash functions than to create good encryption schemes. Some good hash functions are:

Name	Bits	Comment
MD5	128	Less fast than predecessor MD4 (*)
SHA-1	160	Standard (*)
RIPEMD-160	160	

(*) Length limited to be less than 2^{64} bits; but "If you can't say something in 2^{64} bits, you probably shouldn't say it at all".

If we could hash one Terabyte per second (which we can't), hashing the entire 2^{64} bits would take about 550,000 years to compute.

Computing MACs With Hashes

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How can we add a key to the message digest algorithm?

MACs With Hashes And Keys (1)

Alice and Bob agree on a shared secret K_{AB}. If Alice sends a message m to Bob, she concatenates K_{AB} and m and sends $\mathrm{hash}(K_{AB}|m)$ as the MAC.

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That means that if Eve sees $\mathrm{hash}(K_{AB}|m)$, she can compute

$$\mathrm{hash}(K_{AB}|m|\texttt{Romeo must die})$$

MACs With Hashes And Keys (2)

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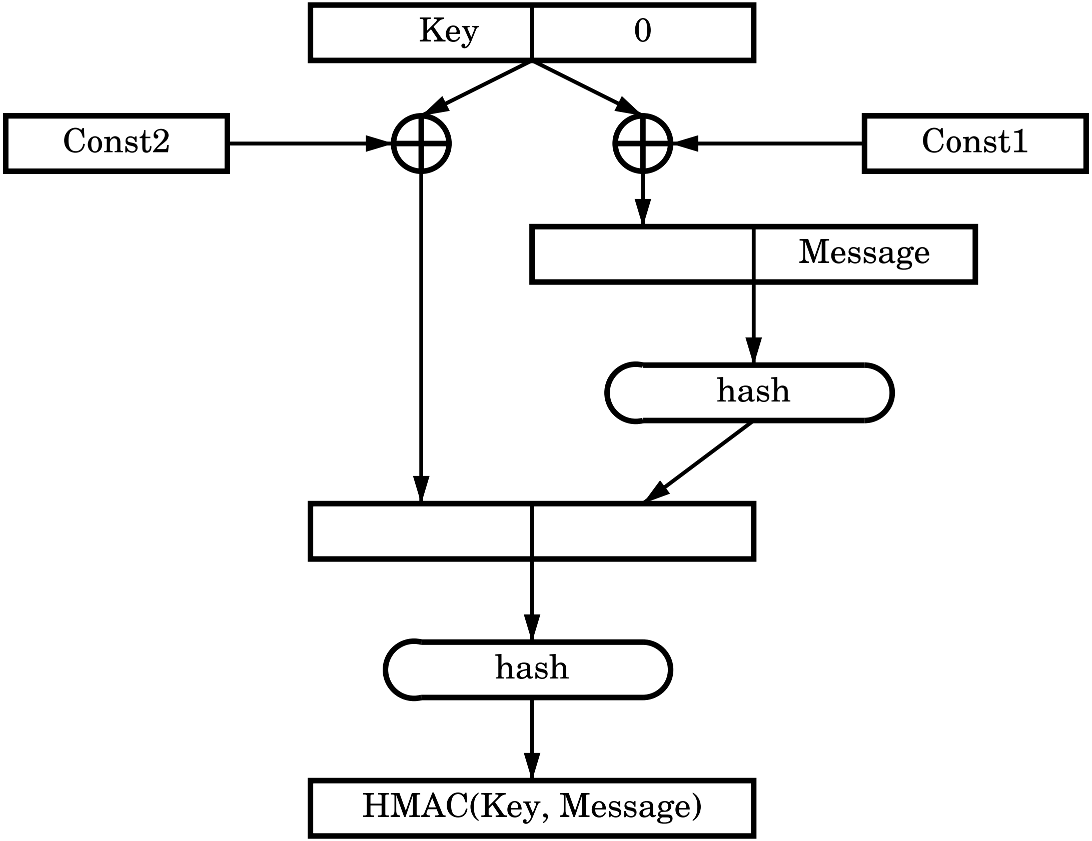
HMAC is provably "secure" if the underlying hash algorithm is "secure":

- It has collision resistance; and
- if the attacker doesn't know the key K, he cannot compute $\mathrm{MAC}(K, x)$ even if he sees arbitrarily many $\mathrm{MAC}(K, y)$ values.

HMAC



Libraries: OpenSSL and cryptlib (1)

	OpenSSL	cryptlib
Author	Eric Young, OpenSSL Project Team	Peter Gutmann
Since	1990's	1990's
Vuln's	several	none
Scope	wide, many OSS projects	wide, mostly non-OSS projects
Approach	bunch of functions	application support
Runs on	mostly Unix and Windows	tons of stuff: mainframes to embedded systems
License	OSS	OSS
Free?	all use	noncommercial use

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Once it’s set up, encrypting an email message is a matter of three lines, including S/MIME enveloping.

Summary

- Symmetric Crypto

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- Hashes, MICs, and MACs

References

- The OpenSSL Project, `http://www.openssl.org`.
- Cryptlib, `http://www.cryptlib.com`.
- Bruce Schneier, *Applied Cryptography*, John Wiley & Sons

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