Batteries Included

Features and Modes for Next Generation Hash Functions

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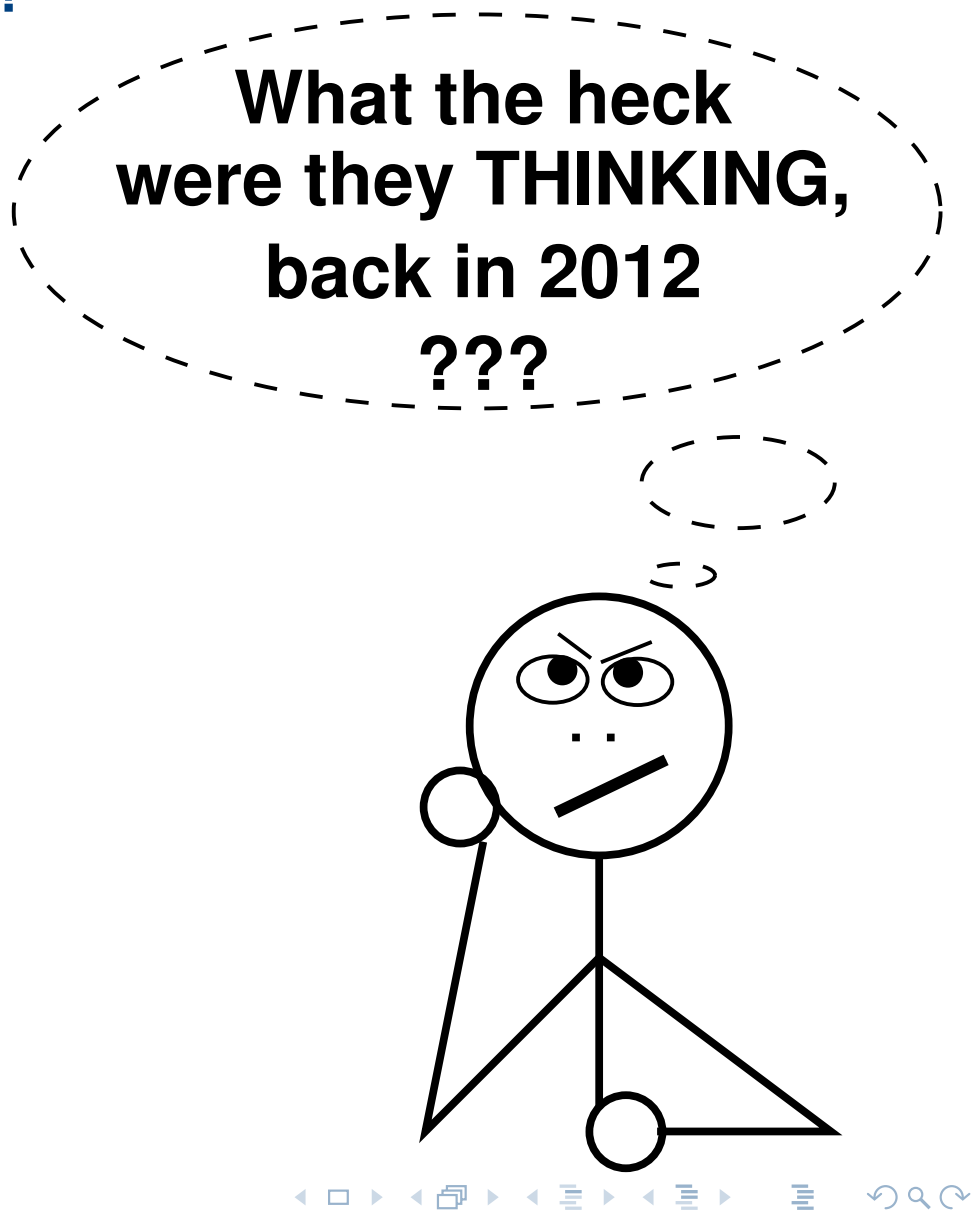
Skipping Forward to 2022

Why could a SHA-3 user be unhappy?

The fool doth think he is wise, but the wise man knows himself to be a fool.

– Wiliam Shakespare,
(As You Like It)



First Generation Hash Functions

MD5, SHA-1, SHA-2, . . . share

1. a design principle (Merkle-Damgård)
2. a set of structural weaknesses (length extension)
3. a usage model
   - message of arbitrary size is read sequentially;
   - eventually an **n**-bit hash value is emitted,
   - where **n** is the single output size supported
4. a simple security definition, depending on **n**:
   - no collisions at $\ll \mathbf{2^{n/2}}$ units of time
   - no preimages at $\ll \mathbf{2^{n}}$ units of time

First Generation Hash Functions Were Extremely Successful

Used in many applications not foreseen by the original hash function designers:

- keyed hashing (i.e., turn the hash functions into a MAC)
- processing the plaintext in public-key encryption schemes, (e.g., OAEP)
- key derivation,
- entropy extraction from non-uniform random sources,
- etc.

As of 2012, we can forsee these and some more applications for SHA-3. We should be prepared!

Hash Function Based MACs

keyed hashing is the second most common cryptographic algorithm cited in Internet standards

HMAC outnumbers AES by 2:1

First generation:

$MAC_K(M) = H(K||M)$ is insecure, due to M-D principle
Remedy:

$$\text{HMAC}(K, M) = H((K \oplus \text{opad})||H((K \oplus \text{ipad})||M))$$

provably secure (under reasonable assumptions)
but inefficient for short messages

SHA-3 should support more efficient message authentication (=keyed hashing) than HMAC-SHA-3!

Different Output Sizes

Sometimes, the user of a **n**-bit hash function just happens to need **s** bits of output.

Any choice is possible: $\mathbf{s} < \mathbf{n}$, $\mathbf{s} = \mathbf{n}$ and $\mathbf{s} > \mathbf{n}$.

First generation:

- ad-hoc methods to truncate or extend the hash
- not always in a compatible way

SHA-2: SHA-256 and SHA-224, SHA-512 and SHA-384, recently SHA-512/*t*

SHA-3 should provide a single hash function supporting any output size you want!

Smaller Output Sizes ($\mathbf{s} < \mathbf{n}$)

easy to realize, e.g.

$$H_{\mathbf{s}}(M) = \text{truncate}_{\mathbf{s}} H(H(\mathbf{s})||M)$$

"for free" if one uses the same **s** all the time

people will use this anyway – but without standardization probably in incompatible ways

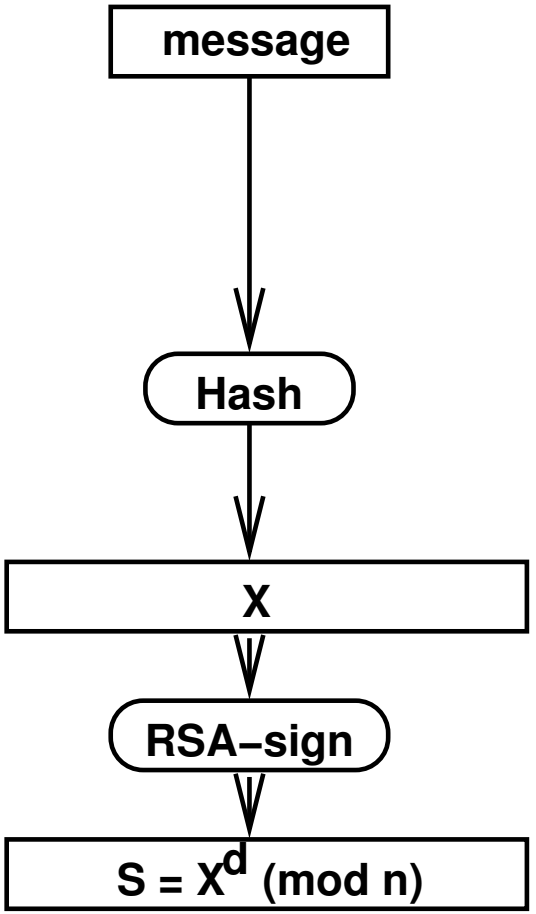
take care about trivial near-collisions between $H_{\mathbf{s}}$ and H, and trivial collisions between $H_{\mathbf{n}}$ and H

If H doesn't natively support different output lengths: **better make $H_{\mathbf{s}}$ the standard, rather than H!**

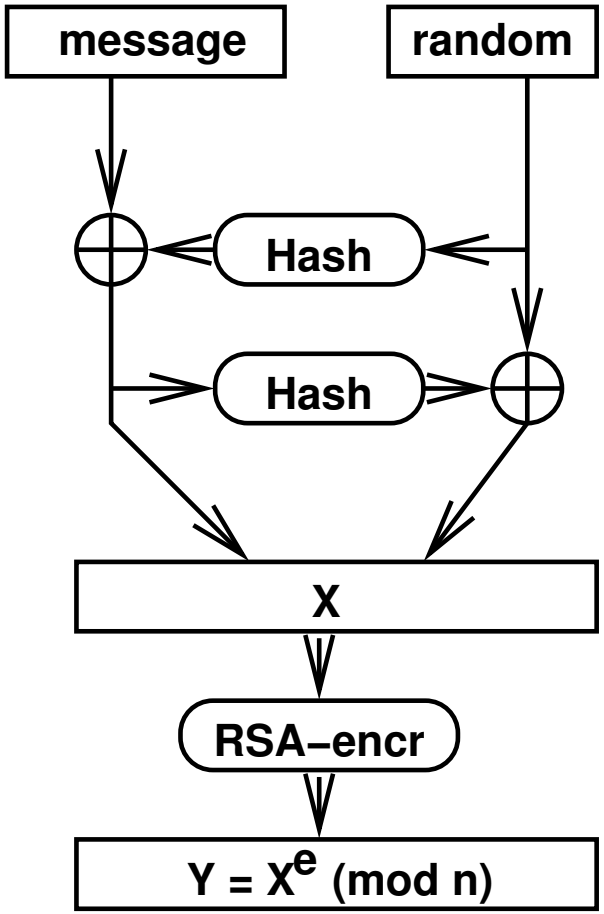
Two Example Applications with s > n

Currently using ad-hoc techniques to generate s output bits

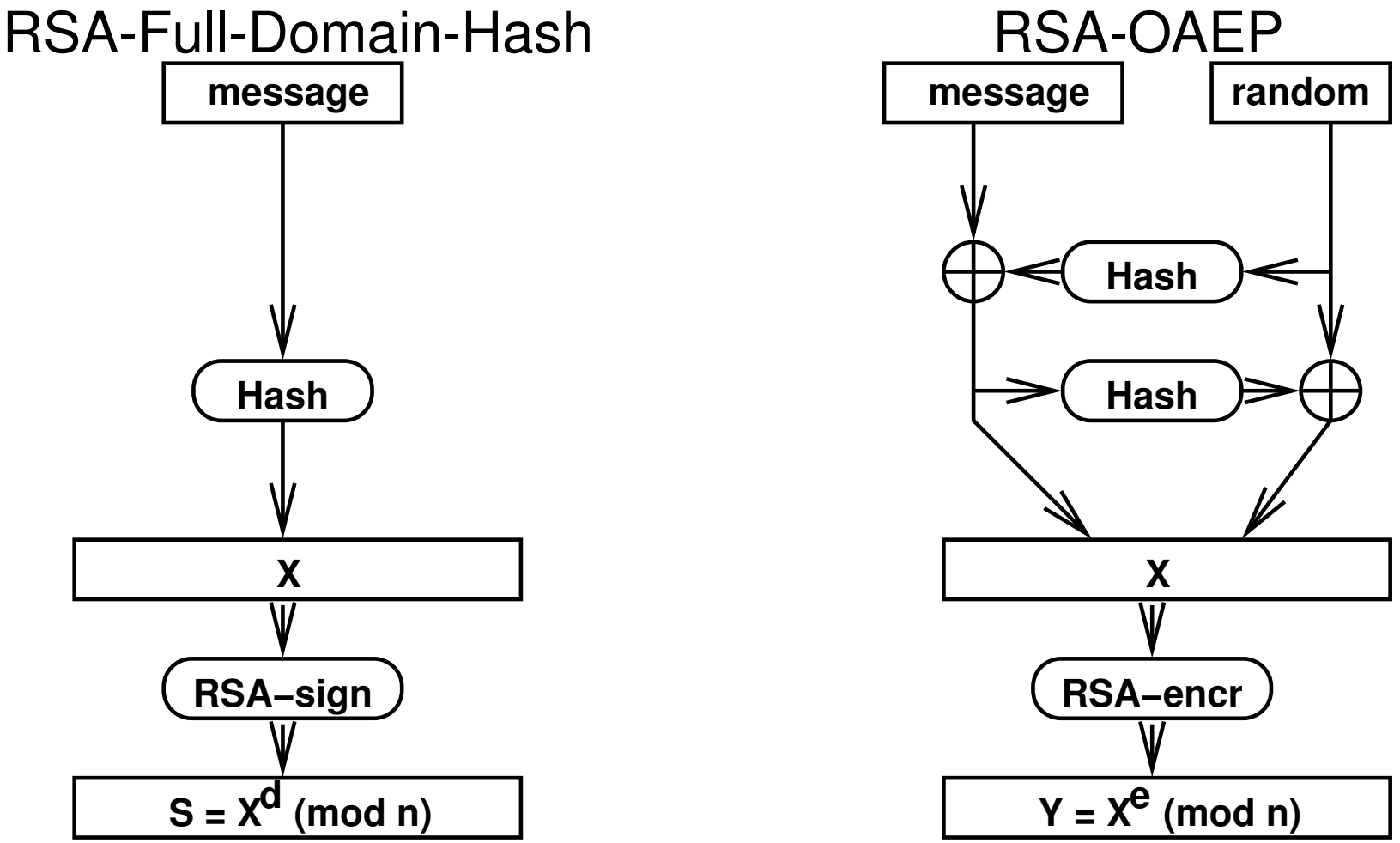
RSA-Full-Domain-Hash



RSA-OAEP



SHA-3 should not require ad-hoc methods to extend the hash size for applications such as OAEP.



Tree Hashing

first proposed to support hash-based digital signatures to handle many one-time signatures

but can also used to support an arbitrary level of parallelism for hashing large messages

following the current trend in computer architecture, parellelized tree hashing may become important

easy to implement for any secure hash function (cf. Bertoni et al, 2009)

but take care about the possibility of generating trivial collisions between the sequential and the tree hash:

$$M \neq M^t \quad \text{with} \quad H^t(M) = H(M^t)$$

and take care to maintain compatibility between different tree hashing applications

Anticipate a demand for (SHA-3-based) tree-hashing.

Hash-Based Signatures

long history (Lamport, Diffie, Winternitz, Merkle, . . .)

extremely compact implementations

no unproven security conjecture, beyond the hash function's own security (no factorization or discrete log assumption)

number one candidate for post-quantum secure signatures

well suited for

- applications requiring tamper resistance, such as protection against hardware trojans,
  and for low-end systems with short messages, e.g., a single measured value in a sensor network

Implementations of Hash-Based Signatures would benefit from

a *keyed hashing mode* for key derivation.

a *shortened hash* (**s** $<$ **n**) in the one-time signature component, to save signature size without reducing security, and

a *tree signature scheme* for the tree hash component.

A SHA-3 standard that incorporated these modes would encourage and support hash-based signatures.

Other Modes that would be nice to have

Personalized Hashing:

- hash functions H_P, depending on "personalization information" P
- useful to define "independent" hash functions, e.g., for OAEP
- useful to hinder *key substitution attacks* and *domain parameter substitution attacks*
- ...

Support for Encryption and Authenticated Encryption:

- a constrained device can perform both hashing and encryption using one single primitive
- a common motivation to study block cipher based hashing

Remark

Two of us are members of the Skein team, and Skein actually adresses the issues we raised here.

Still, this talk is not about advertising Skein!

Any finalist can be made to address these issues.
But some would need to be tweaked/patched!

Which of the following choices would you prefer?

1. Address the issues now, before SHA-3 has been fixed.
2. Fix SHA-3 now, and later “patch” these issues by filing additional standards.
3. Don’t address these issues. Allow the proliferation of different incompatible and sometimes insecure ad-hoc solutions.

Summary

For the next generation of hash functions, the raw hash function isn't enough. It is important that the next generation of hash functions supports

- hash function based MACs,
- hashing for different output sizes **s**, both **s** $<$ **n** and **s** $>$ **n**,
- and parallelized tree hashing.

Among other benefits, the support for these features would aid the usage of hash-based signatures.

Further useful options would be a way to personalize SHA-3, and to use SHA-3 for encryption purposes. It should be possible to combine these features, and to formally prove them secure.

Skipping Forward to 2022 (2)

Can we make this guy happy?

We **cannot** forsee all future usage patterns for SHA-3.

But we **can** forsee some.

And SHA-3, the first one of a new generation of hash function, **can** support these usage patterns, where SHA-1 and SHA-2 had failed.