Dedicated Collision Search

Christian Rechberger

Special-purpose Hardware for Attacking Cryptographic Systems
SHARCS 2007

SHA-1 Collision Search: http://boinc.iaik.tugraz.at

Institute for Applied Information Processing and Communications (IAIK) - Krypto Group

Faculty of Computer Science
Graz University of Technology

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Motivation

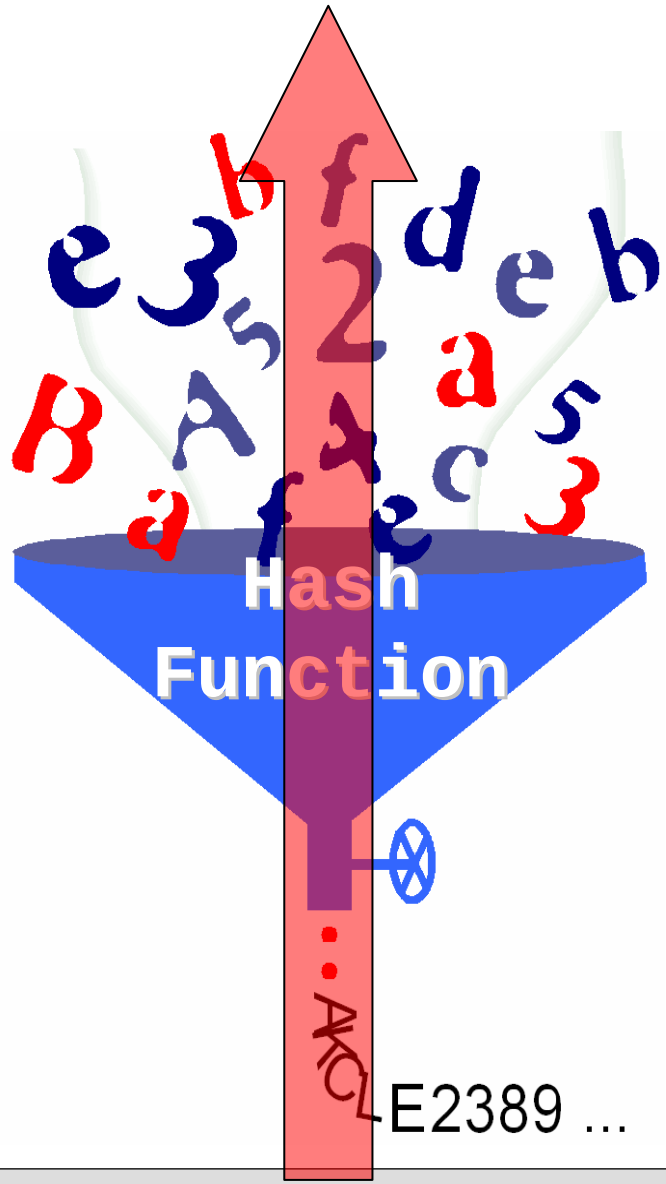
- Browse SSL-secured websites
- Administer your server via ssh
- Console login
- Digitally sign something
- Integrity checks of p2p traffic
- ...

- What do they have in common?

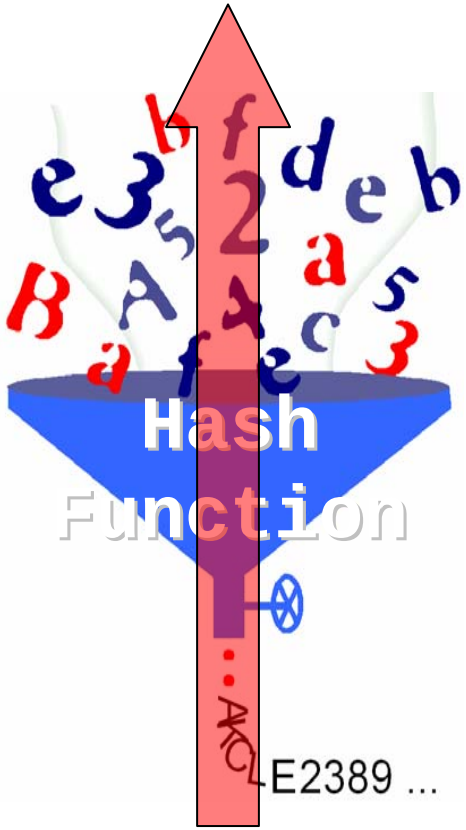
Some properties of hash functions

- Efficient to compute
- One-wayness
- Collision resistance

One-wayness



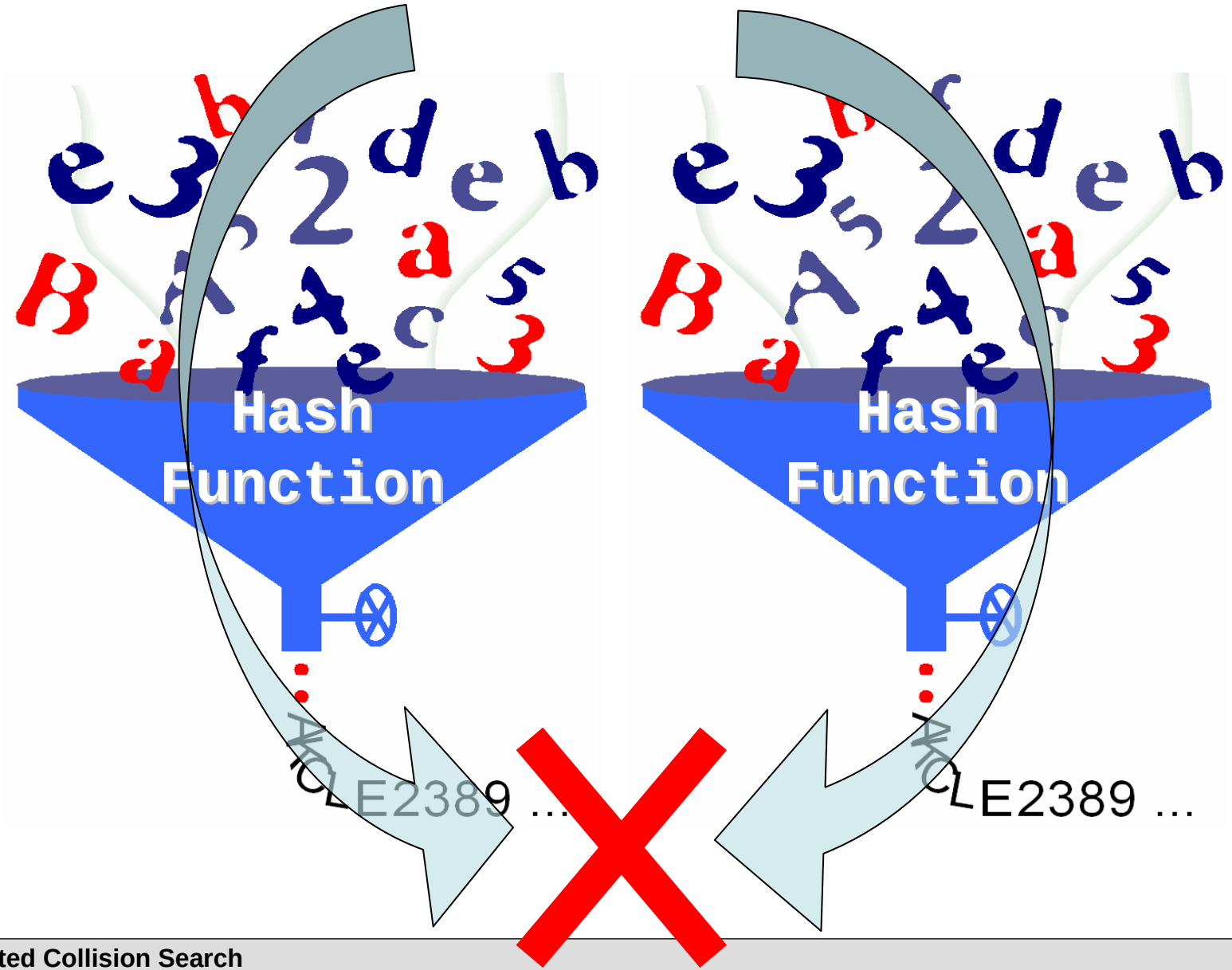
One-wayness



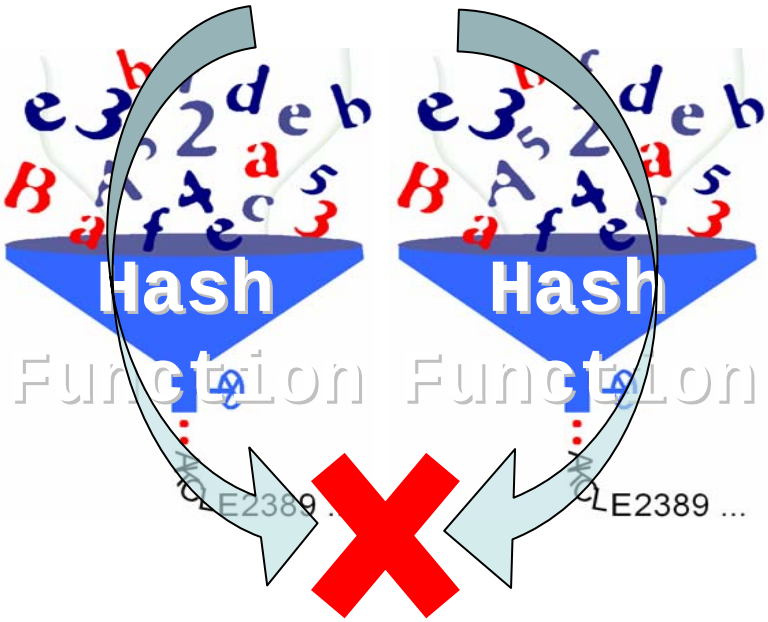
Applications:

- Storing a password
- Payment schemes (e.g. Hashcash)
- Key derivation
- Commitment schemes
- Random number generation
- …

Collision resistance



Collision resistance



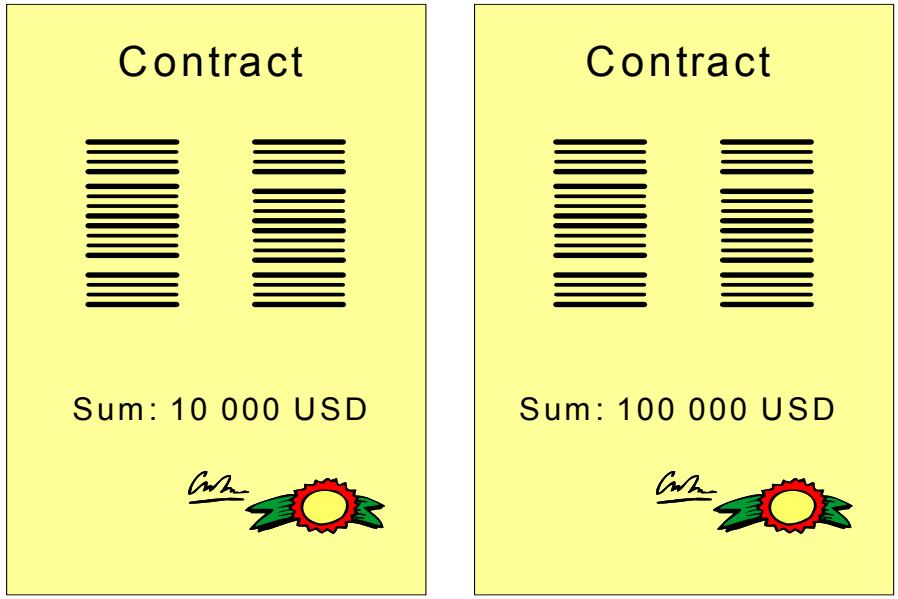
Applications:

Integrity checks

Authentication
(Digital signatures,
MAC, …)

Often required by law

Application requiring collision resistance

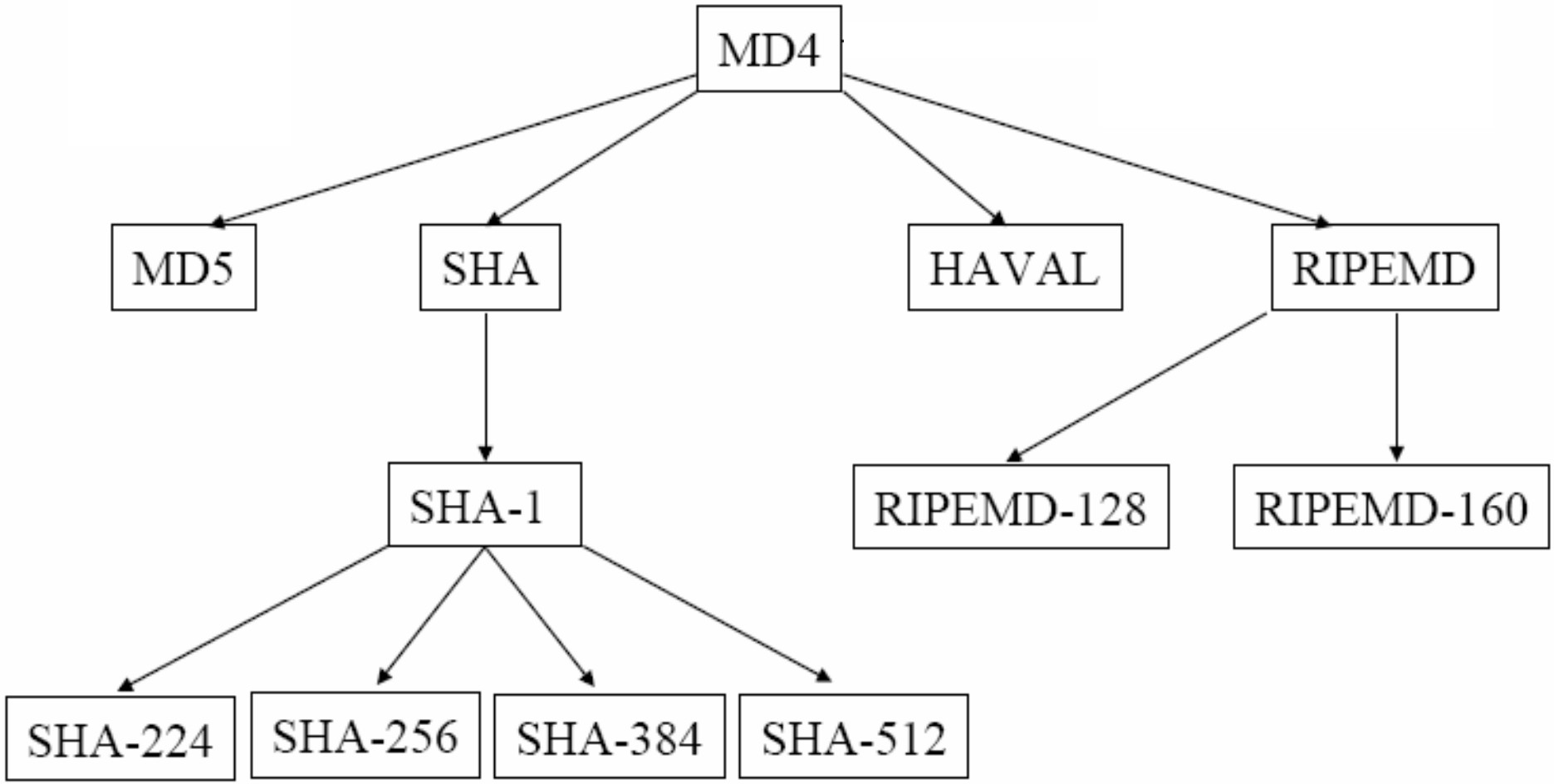


Two documents producing the same fingerprint.

Same fingerprints ⇒ same signatures.

Signature verifier can not detect replacing of document

What happened so far?



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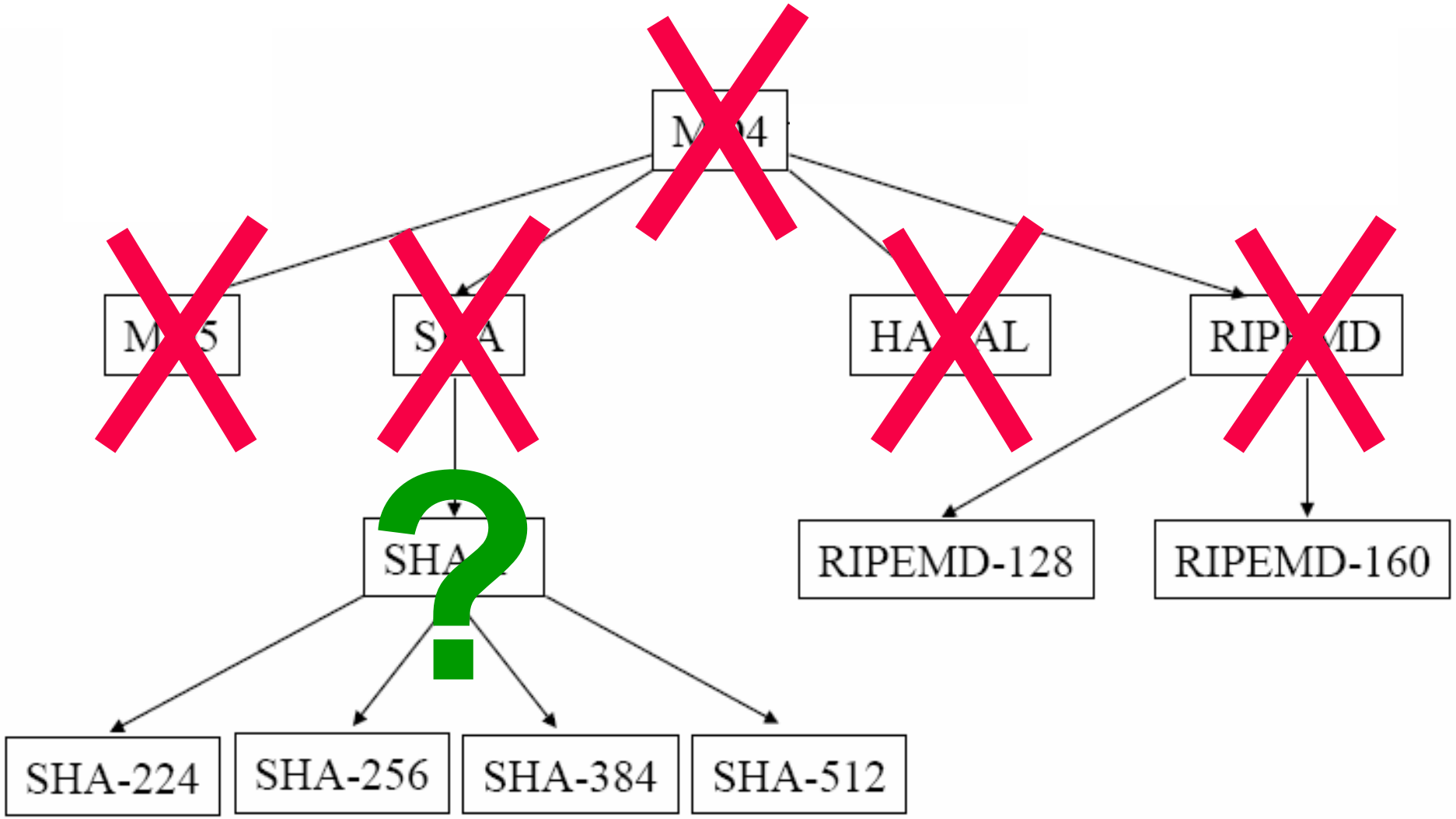
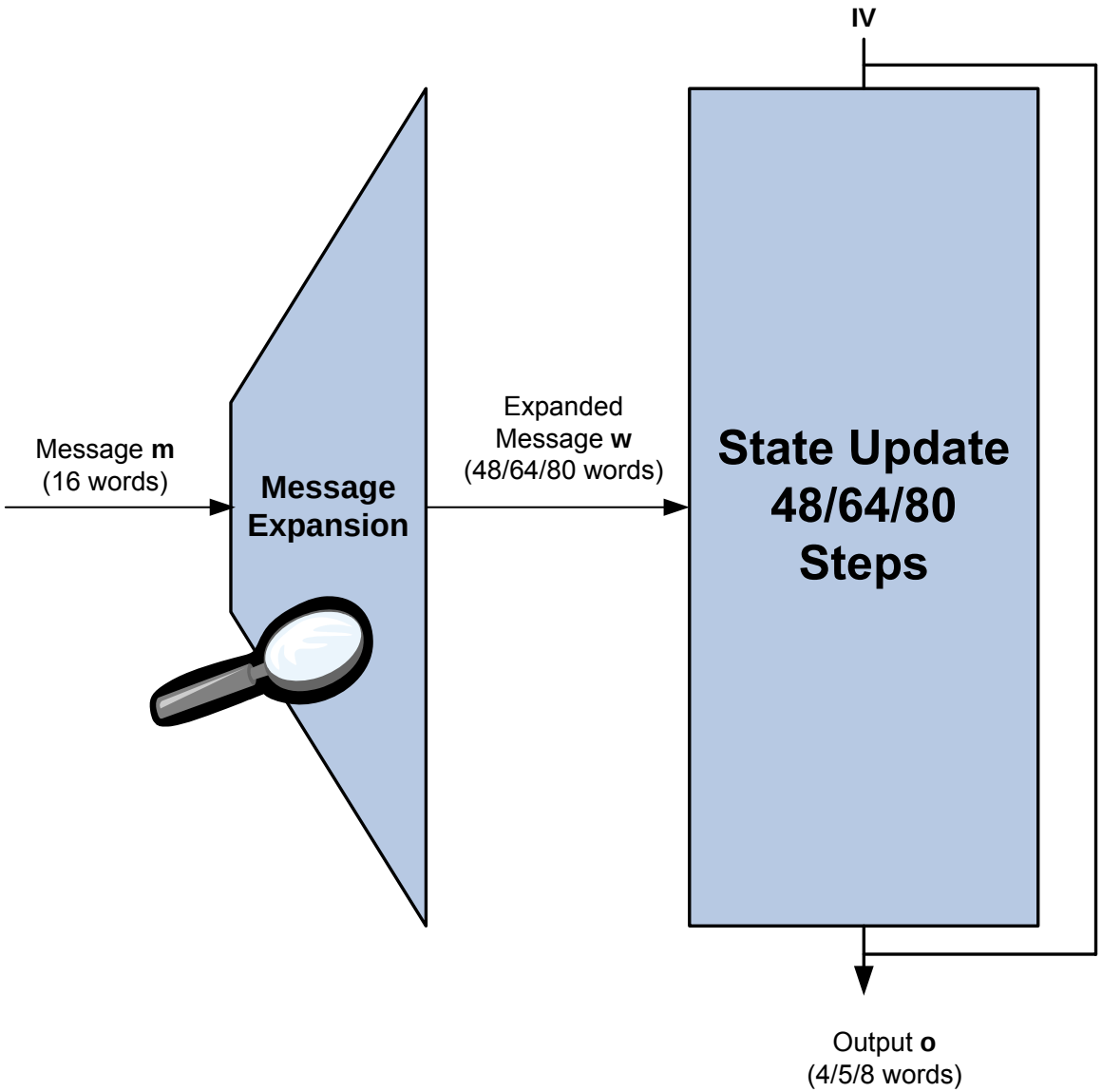
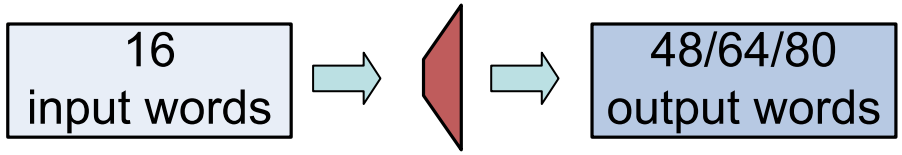


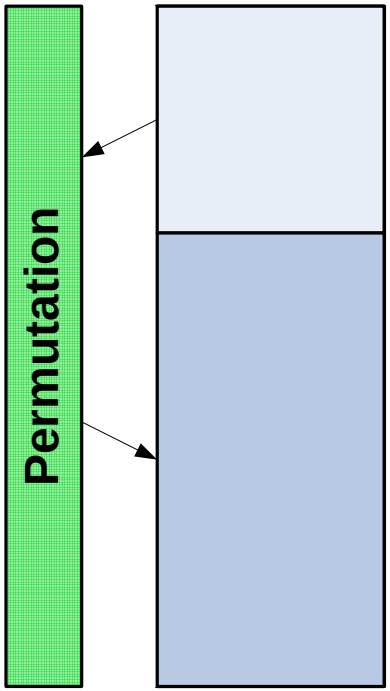
Outline of MD4-style Hash Functions



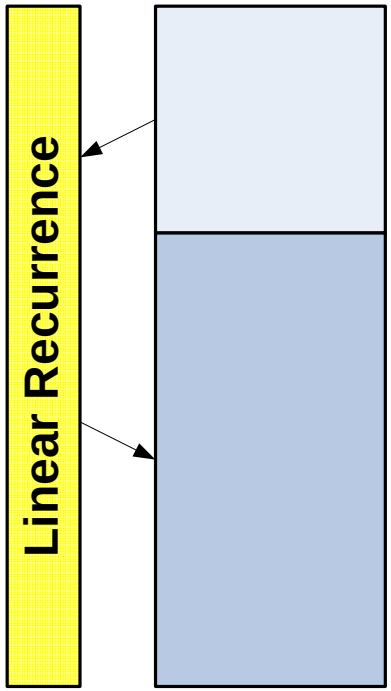
Message Expansions in the MD4 family



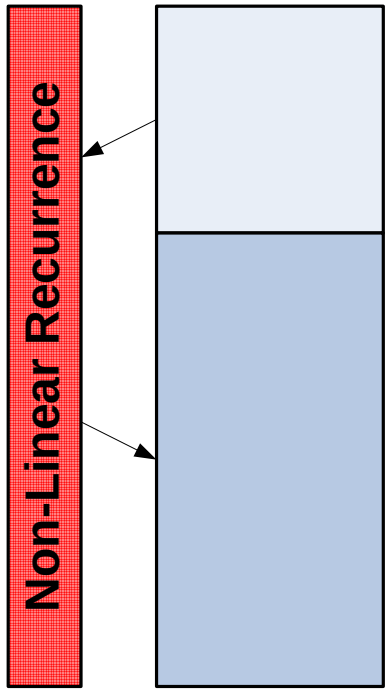
MD4/5, RIPEMD



SHA / SHA-1



SHA-2 members



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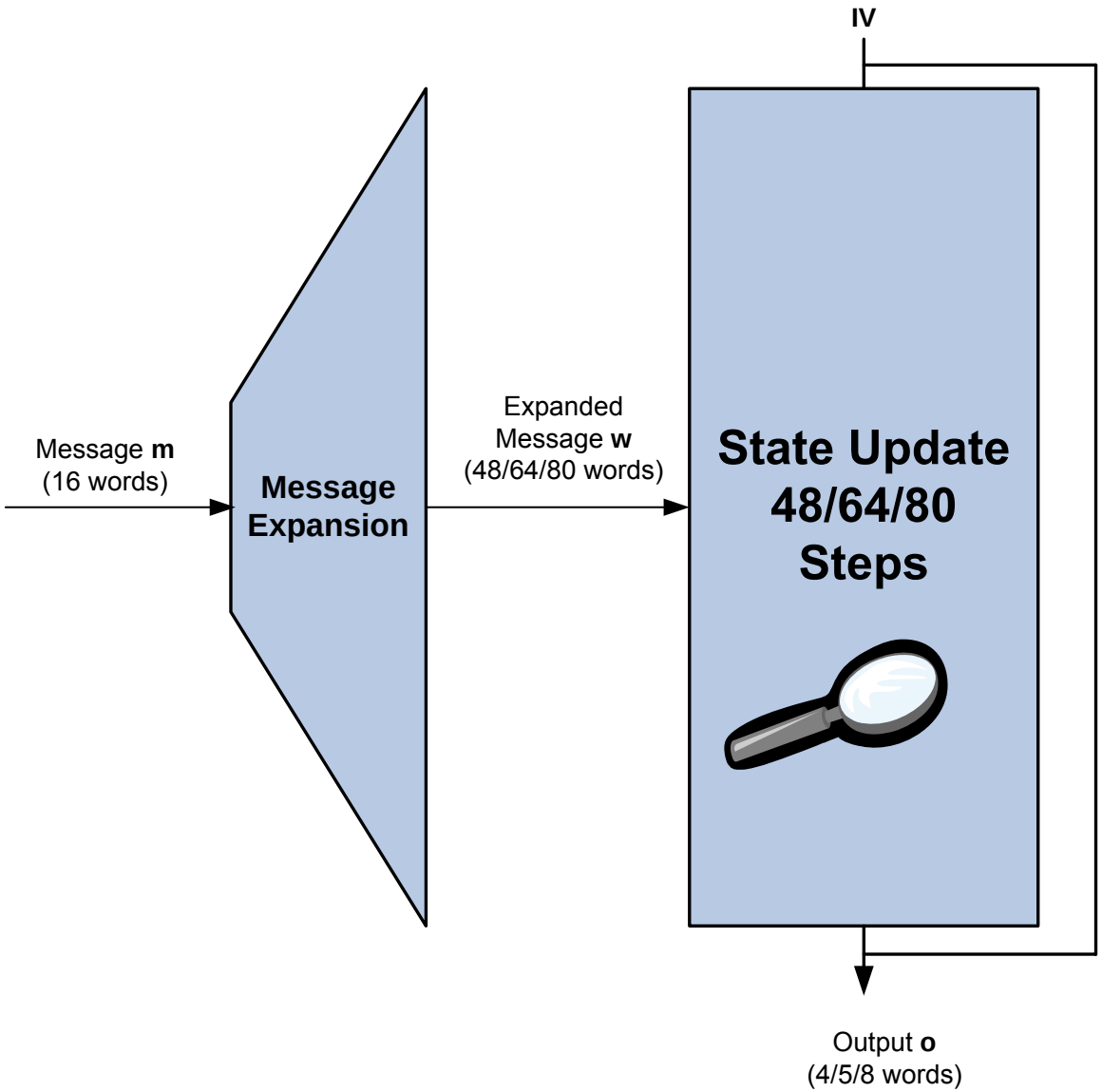
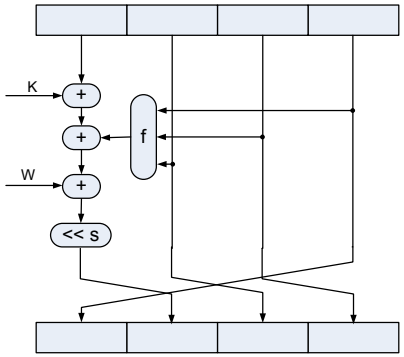
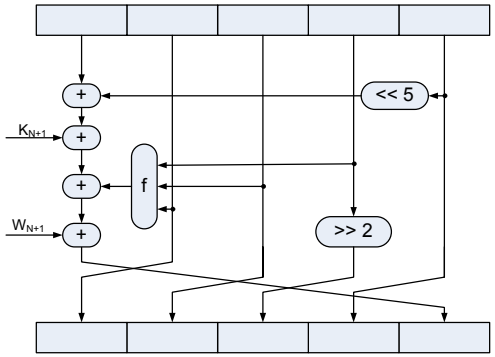


Evolution of the State Updates in the MD4 Family

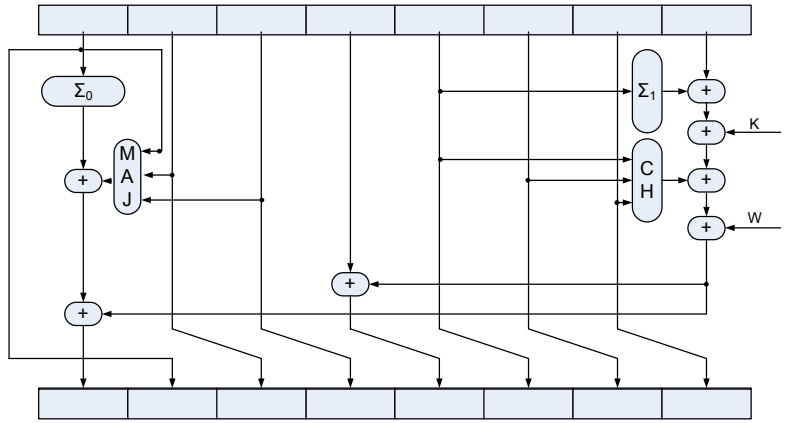
MD4



SHA/SHA-1

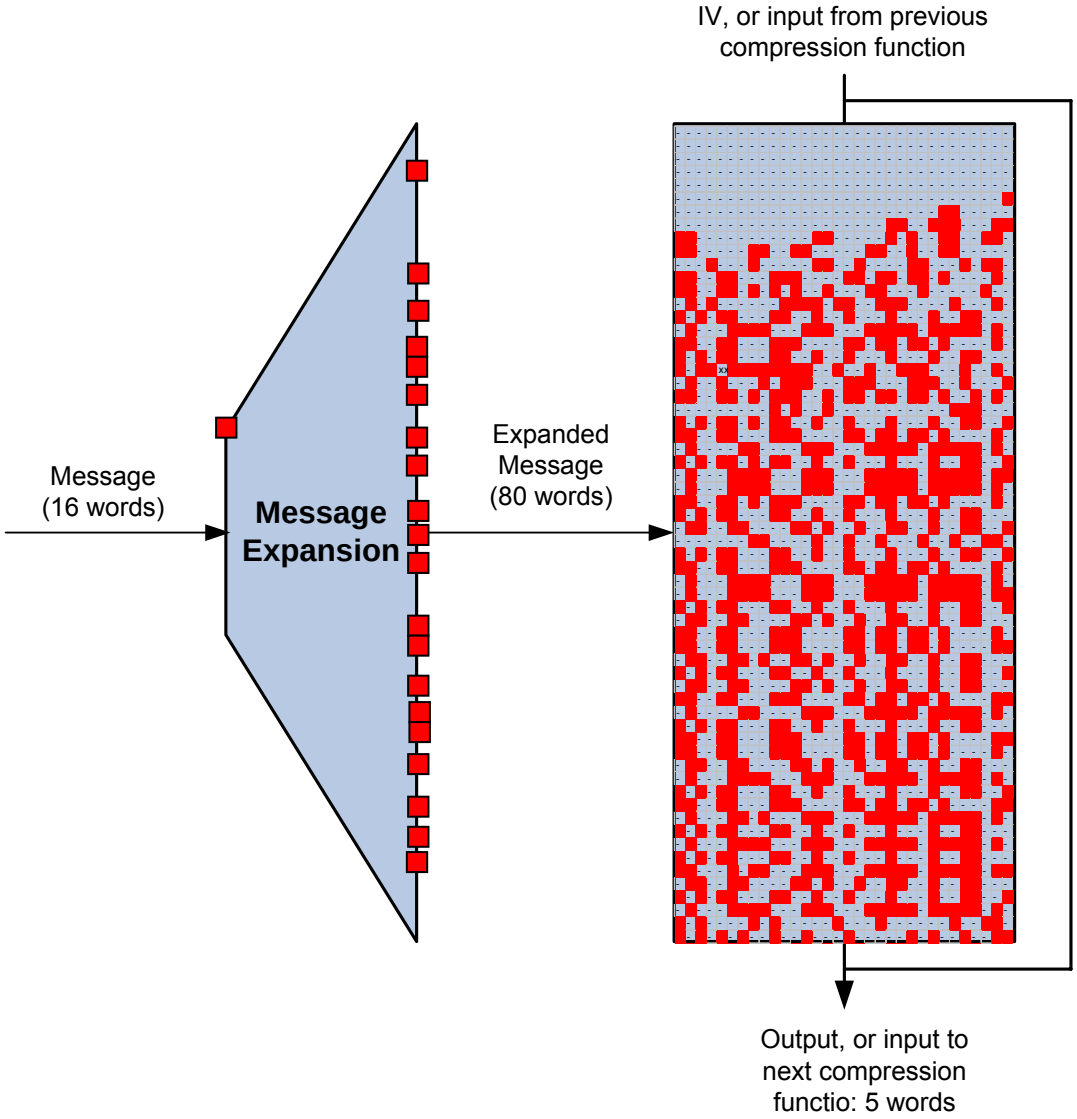


SHA-2 members

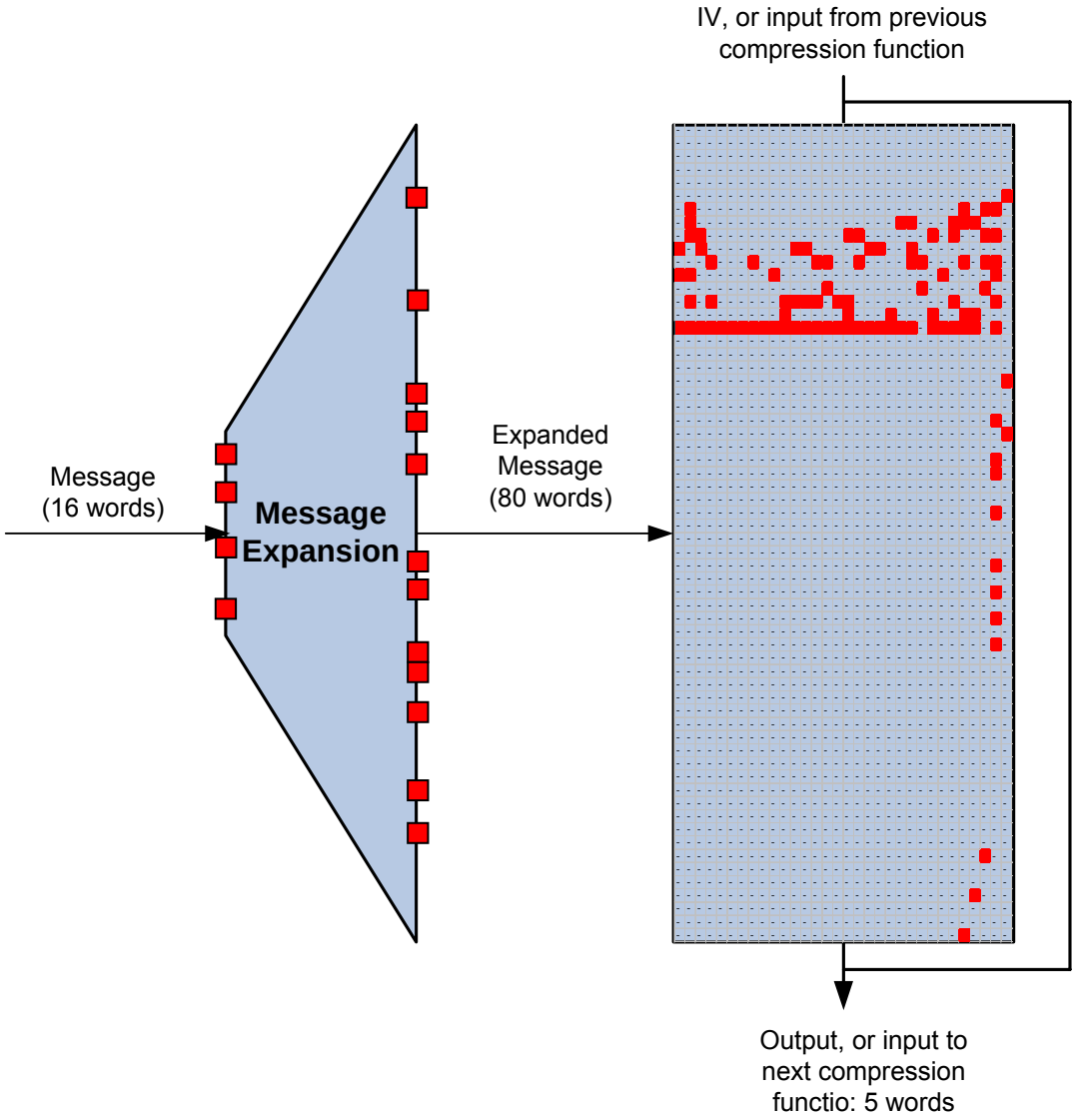


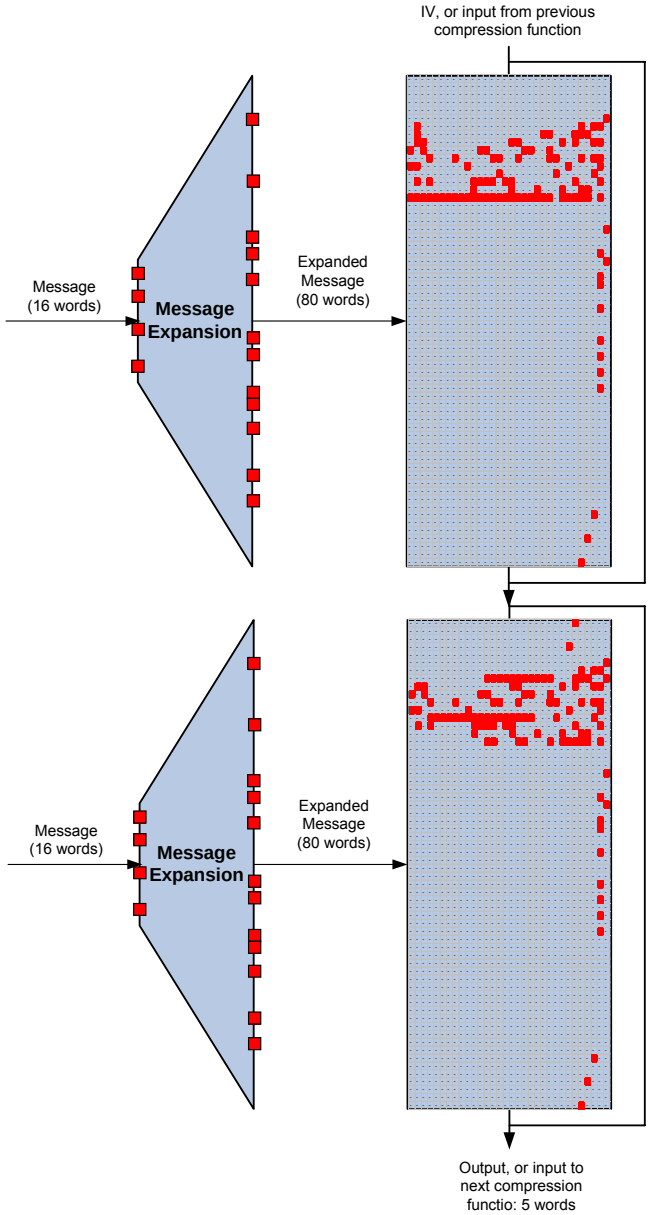
Design Complexity

Effect of a single bit flip



Differential Attack on SHA-1





Attack on SHA-1

1st block:

- Near collision

2nd block:

- Same message difference
- Same near collision

2xnear collision cancels out → **Collision**

Anatomy of a collision search attack on SHA-1

- Message difference
- Sequence of differences with high probability
- Speed-up methods
- Actual search (search space large enough?)

Anatomy of a collision search attack on SHA-1

- **Message difference**
- Sequence of differences with high probability
- Speed-up methods
- Actual search (search space large enough?)

XOR-Approx→ Search for candidate characteristic

Several proposals: [RO05], [WYY05], [PRR05]

Precise evaluation of candidates: [DR06]

(no counting of Hamming weight, no ad-hoc rules)

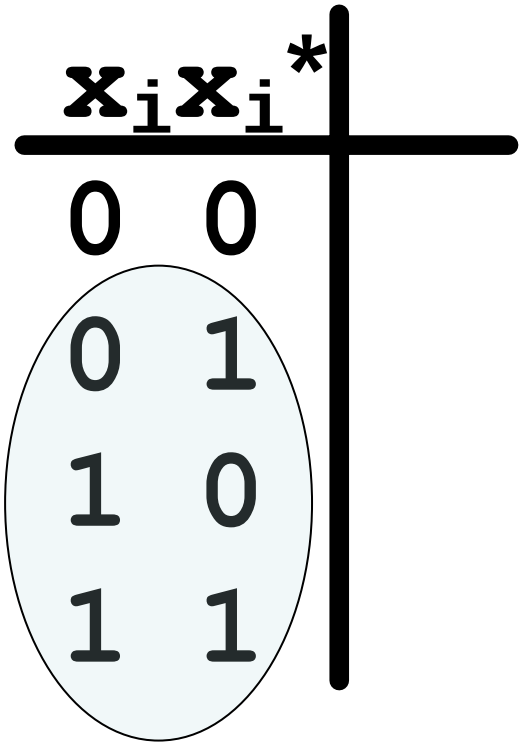
Anatomy of a collision search attack on SHA-1

- Message difference
- **Sequence of differences with high probability**
- Speed-up methods
- Actual search (search space large enough?)

Introduction of “Signed-bit differences”,
First solution by [WYY05], manual

Introduction of “Generalized characteristics”,
Automated Method: [DR06]

Generalized conditions



Type	Possibilities
XOR	2
Signed-bit	4-6
Generalized:	**16**

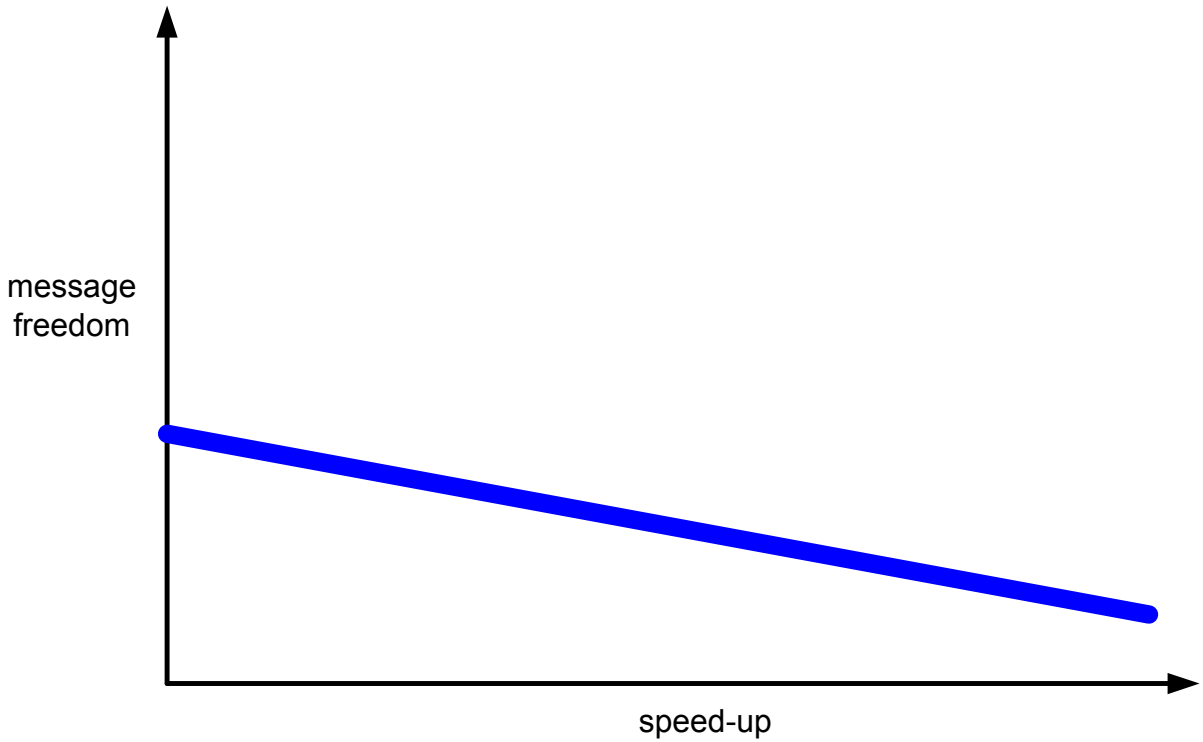
Anatomy of a collision search attack on SHA-1

- Message difference
- Sequence of differences with high probability
- **Speed-up methods**
- Actual search (search space large enough?)

- **New method:** (Almost) deterministically toggle single bits up to more than 30 steps
  - Efficient in terms of computations needed
  - Efficient use of degrees of freedom

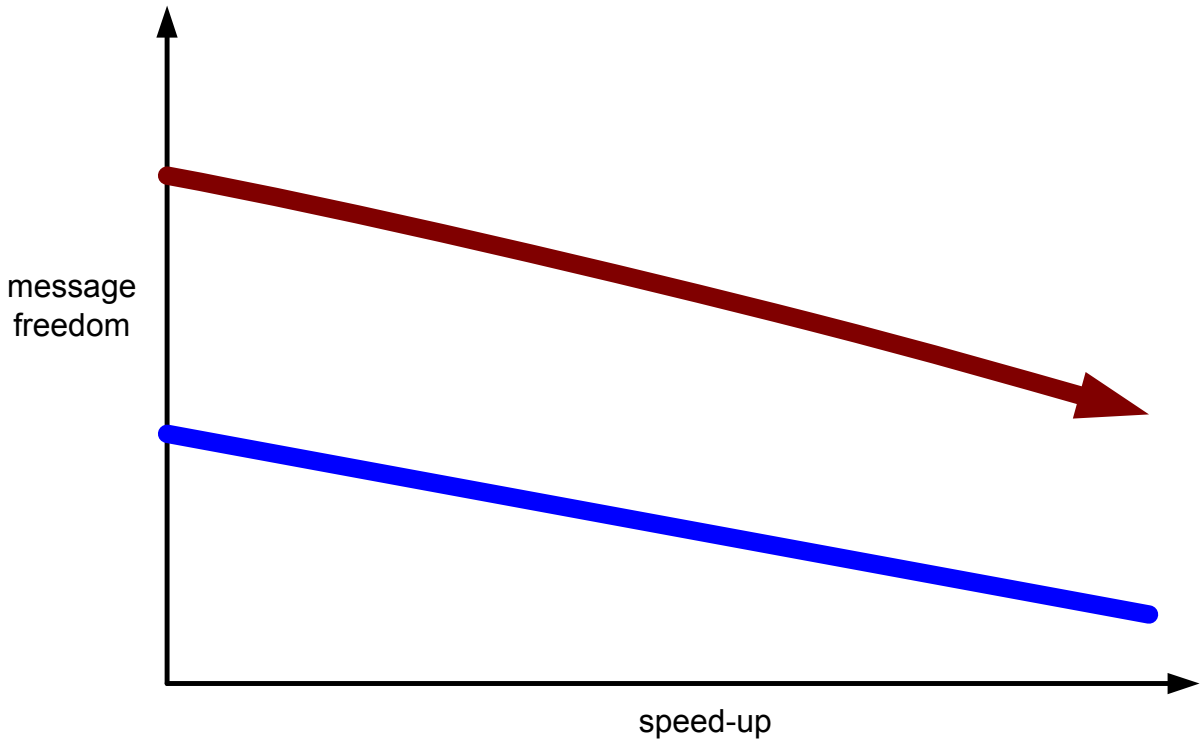
Cost of speed-up

2) Loss of degrees of freedom



Cost of speed-up

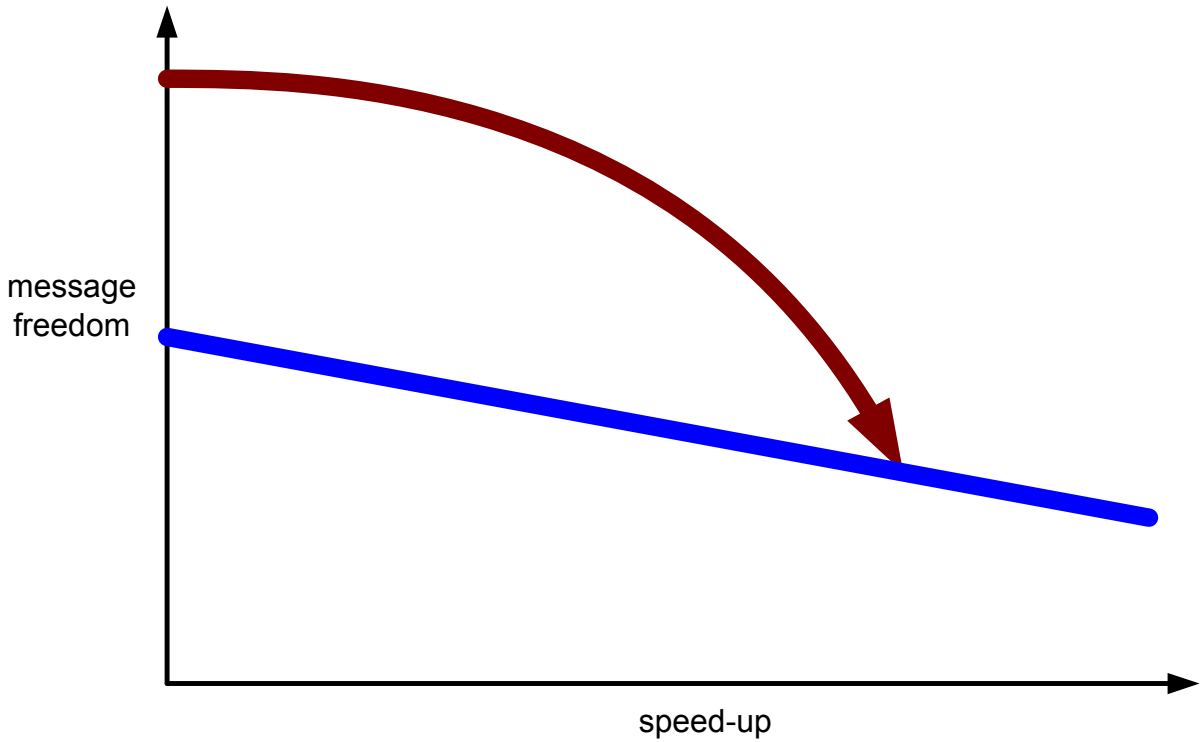
2) Loss of degrees of freedom case MD4/MD5/SHA



Cost of speed-up

2) Loss of degrees of freedom

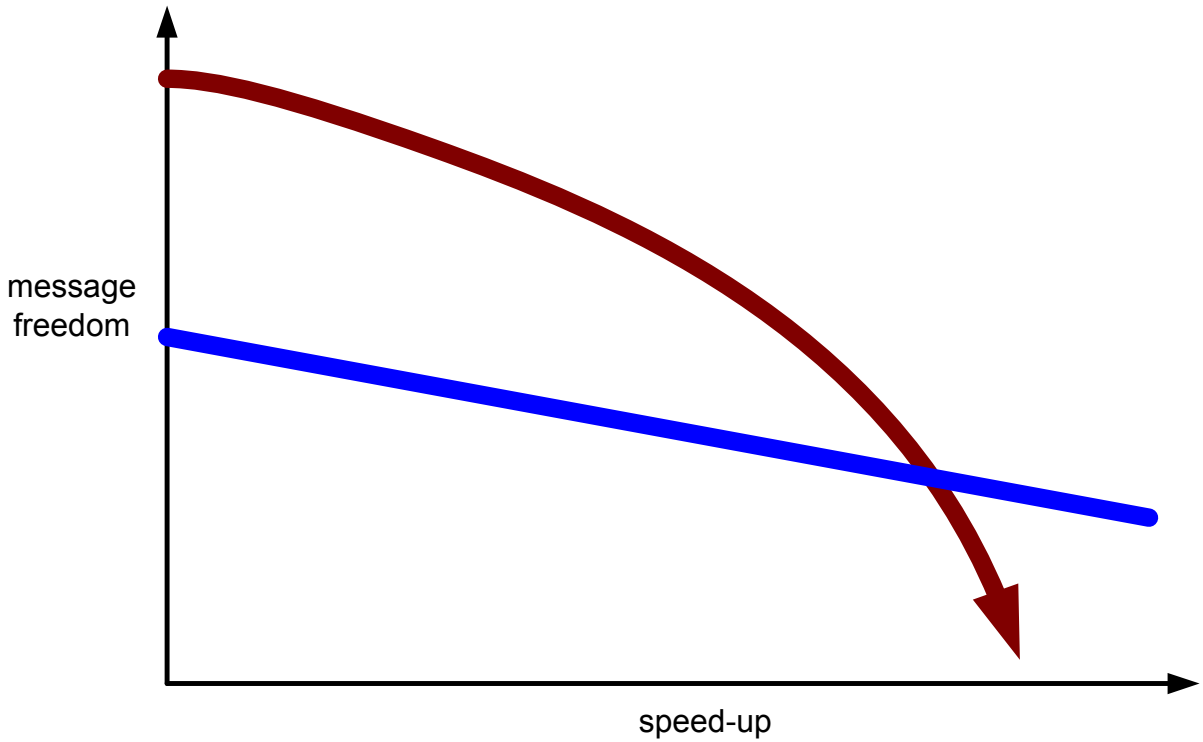
case SHA-1



Cost of speed-up

2) Loss of degrees of freedom

case SHA-1

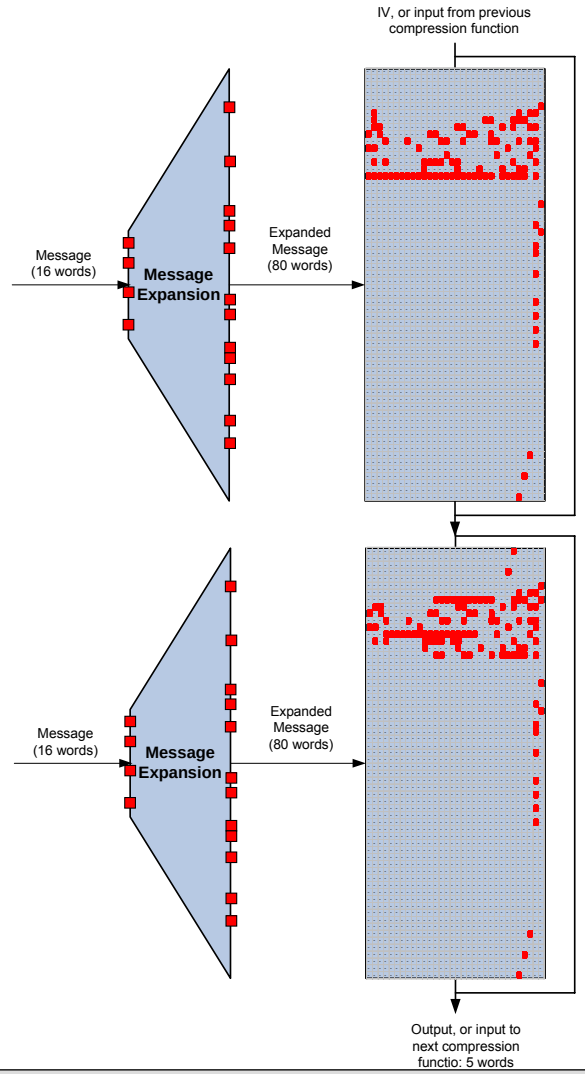


Source of degrees of freedom

160

512

512



Summary of new techniques

- **Distribute workload**

  3 blocks (instead of 2 blocks)

- **Efficiently control bits in state**

  up to step 31 (best before was 25)

- **Number of distinct attacks**

  millions of attacks (instead of a single one)

- **Fine grained optimization model**

  #steps (instead of #trials)

Effort for dedicated collision search

- $2^x * c$
- Constant c depends on
  - details of actual collision-search algorithm
  - the used platform / architecture

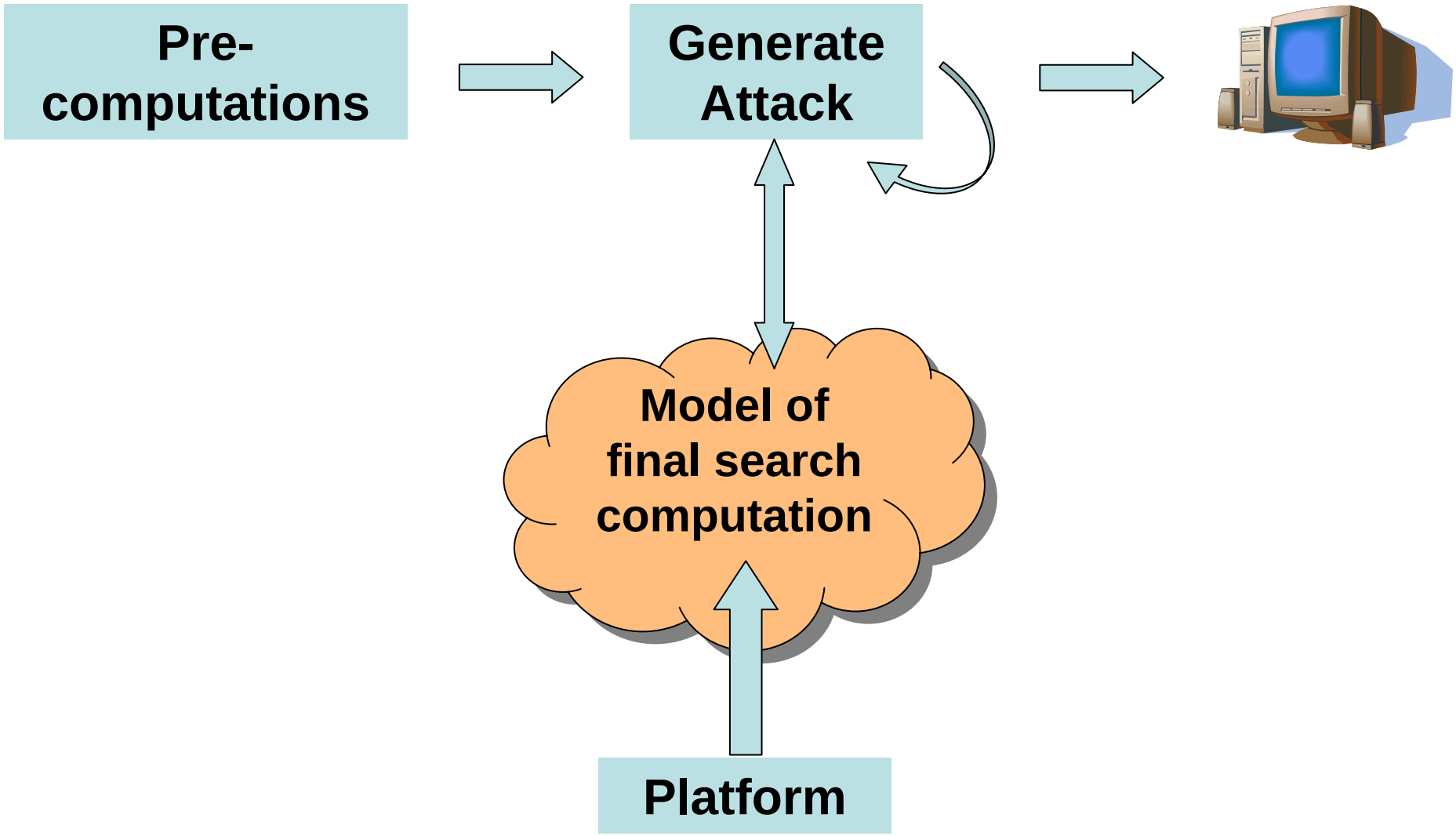
First attempt on full SHA-1

Current rough estimate: ~$2^{60.x}$ compress

We recently started a distributed computing effort:

URL: http://boinc.iaik.tugraz.at

Workflow


Pre-computations
Generate Attack
Model of final search computation
Platform

Candidate Platforms

- Standard PCs
- GPUs
- New platforms: Cell / PS3, …
- FPGA
- ASIC

Good architecture for clients

- Little memory / communication needed

- Fully pipelined vs. massively parallel architecture

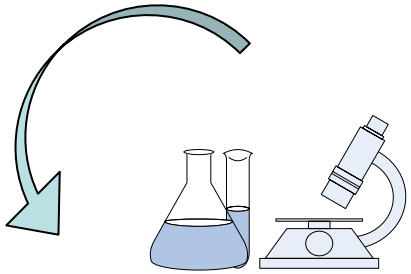
Open Problems

"we are in particular interested in exploring the interaction between cryptanalytical algorithms and computer hardware"

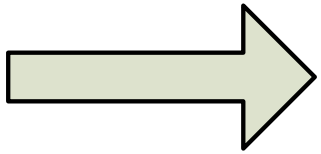
www.sharcs.org

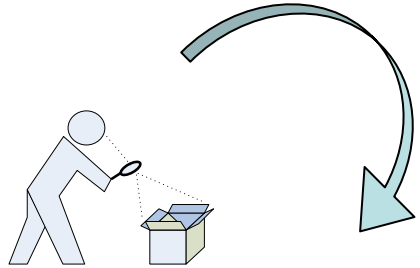
Explore design space spanned by
* different/custom architectures and their
* interaction between different cryptanalytic methods

Typical workflow



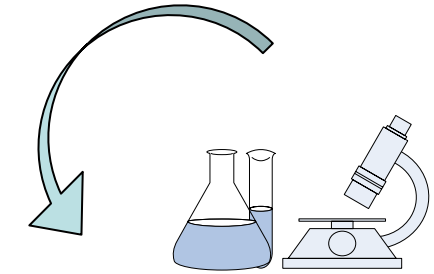
Cryptanalytical Work



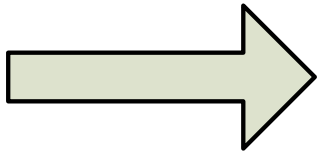


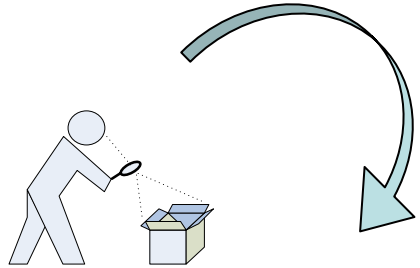
Efficient Implementation

Typical workflow



Cryptanalytical Work





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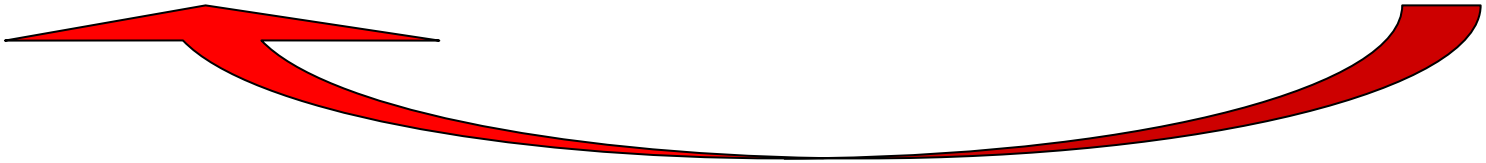

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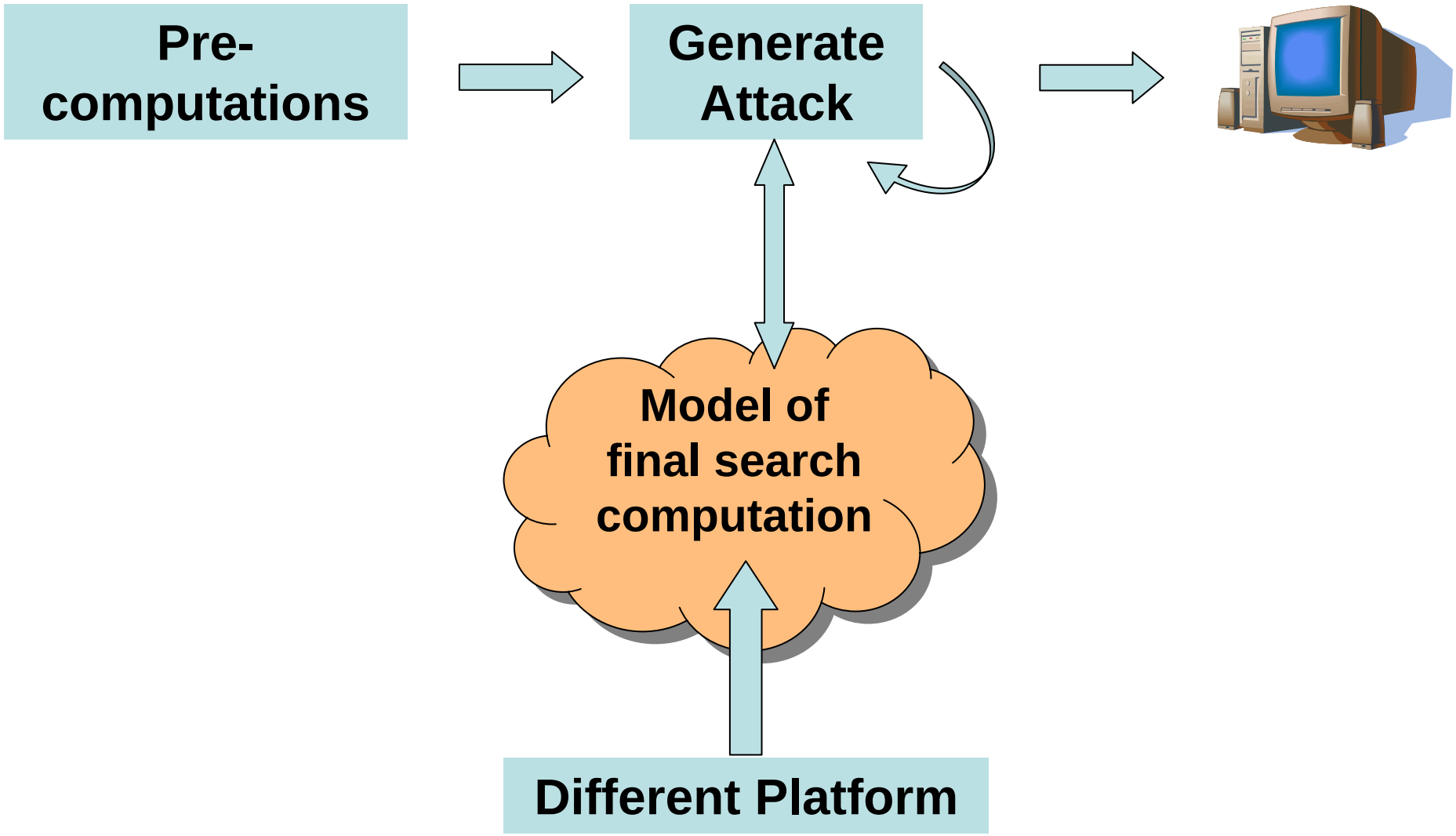
Pre-computations
Generate Attack
Model of final search computation
Different Platform

Wrap-up

- The challenge: finding the first SHA-1 collision
- New method
  - exploit more degrees of freedom
  - use them more efficiently
  - many different attacks are generated on demand
- Open Problem
  - Exploit interaction between client architecture and cryptanalytic method

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