The Hitchhiker's Guide to the SHA-3 Competition

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Outline

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A(n Extremely) Short History of Hash Functions

1976 Diffie and Hellman suggest to use hash functions to make digital signatures shorter.

1979 Salted passwords for UNIX (Morris and Thompson).

1983/4 Davies/Meyer introduce Davies-Meyer.

1986 Fiat and Shamir use random oracles.

1989 Merkle and Damgård present the Merkle-Damgård hash function.

1990 MD4 is introduced by Rivest.

1990 N-Hash is almost broken by differential cryptanalysis.

1992 MD5 is introduced by Rivest.

1993 Preneel, Govaerts, Vandewalle study block-cipher based hashing.

1993 Bellare & Rogaway formally introduce random oracles.

A(n Extremely) Short History of Hash Functions

1993 SHA-0 is introduced.

1995 SHA-1 is introduced.

1997 SHA-0 is broken by Chabaud and Joux.

1999 Dean's long second preimage attack on Merkle-Damgård.

2001 SHA-2 is introduced.

2004 Joux's multicollision attack.

2004 Wang introduces attacks on MD4, MD5.

2005 Collision attacks on SHA-0 and SHA-1.

2006 Kelsey & Kohno's herding attack.

2007 Preimage attacks on reduced-round SHA-1.

2007 SHA-1 Collision BOINC project starts.

2008 The SHA-3 competition starts . . .

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- Apparently, most of the nonlinearity is introduced either in addition or locally (bitwise operations).
- An immediate consequence — easy to approximate the algorithm as a linear.
- Easy to define the conditions on when the approximation holds.
- Along with a simple message expansion, relatively slow diffusion, and many cool techniques* one can offer differentials with high probability that lead to collisions.

*multi-block collision, neutral bits, message modification, advance message modification, generalized differentials, amplified boomerang attack.

The Current State of Affairs

Hash	Collisions	Second Preimage	Preimage
MD4	By hand	2^{102}	2^{102}
MD5	2^{16}	$\approx 2^{124}$	$\approx 2^{124}$
SHA-0 (80 rounds)	2^{39}	up to 52 rounds	up to 52 rounds
SHA-1 (80 rounds)	$\approx 2^{60.3}$	up to 48 rounds	up to 48 rounds
SHA-256 (64 rounds)	up to 27 rounds	up to 43 rounds	up to 43 rounds
SHA-512 (80 rounds)	up to 24 rounds	up to 46 rounds	up to 46 rounds

Our Options

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The First Phase of the SHA-3 Competition

- January 2007: NIST announces that a SHA-3 competition will be held. Asks the public for comments.
- November 2007: NIST publishes the official rules of the competition.
- August 2008: First submission deadline.
- October 2008: The *real* deadline.

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Let the games begin!

Welcome to the Wild West

Candidate	Candidate	Candidate	Candidate	Candidate
Abacus	ARIRANG	AURORA	Blake	Blender
BMW	Boole	Cheeta	CHI	CRUNCH
CubeHash	DCH	Dynamic SHA	Dynamic SHA2	ECHO
ECOH	EDON-R	Enrupt	ESSENCE	FSB
Fugue	Grøstl	Hamsi	JH	KECCAK
Khichidi-1	Lane	Luffa	LUX	MCSSHA-3
MD6	MeshHash	NaSHA	NKS2D	SANDstorm
Sarmal	Sgáil	Shabal	SHAMATA	SIMD
Skein	SHAvite-3	Spectral Hash	StreamHash	SWIFFTX
Tangle	TIB3	Twister	Vortex	WaMM
		Waterfall		

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  1. Practical.
  2. Close to Practical.
  3. (Time, Memory) is better then for generic attacks (e.g., time-memory tradeoff attacks, birthday attack).
  4. Time $\times$ Memory is less than required in generic attacks.
  5. Money for finding {collision, second preimage, preimage} in a given time frame is less than for generic attacks.

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- To further reduce the list of candidates to about 15, they decided to *not select candidates* which "has no real chance to be selected as SHA-3".
- NIST allowed tweaks (small changes which do not invalidate previous analysis).
- And in July 2009 announced the second round candidates.

Outline

Welcome to the Second Round

Candidate	Candidate	Candidate	Candidate	Candidate
Blake	BMW	CubeHash	ECHO	Fugue
Grøstl	Hamsi	JH	KECCAK	Luffa
Shabal	SHAvite-3	SIMD	Skein	

The Second Round Process

- During the second round, all 14 candidates were analyzed.
- Hamsi was the only one that was (marginally) broken.
- Distinguishing properties were reported for the full compression functions of BMW, CubeHash, Grøstl, KECCAK, Luffa, Shabal, SHAvite-3, and SIMD.
- These attacks do not scale to the full hash function (at the moment).
- Attacks on almost the full compression functions of ECHO, Fugue, and Skein were also reported.
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- JH and Blake were also analyzed.
- Some primitives received less cryptanalytic attention.

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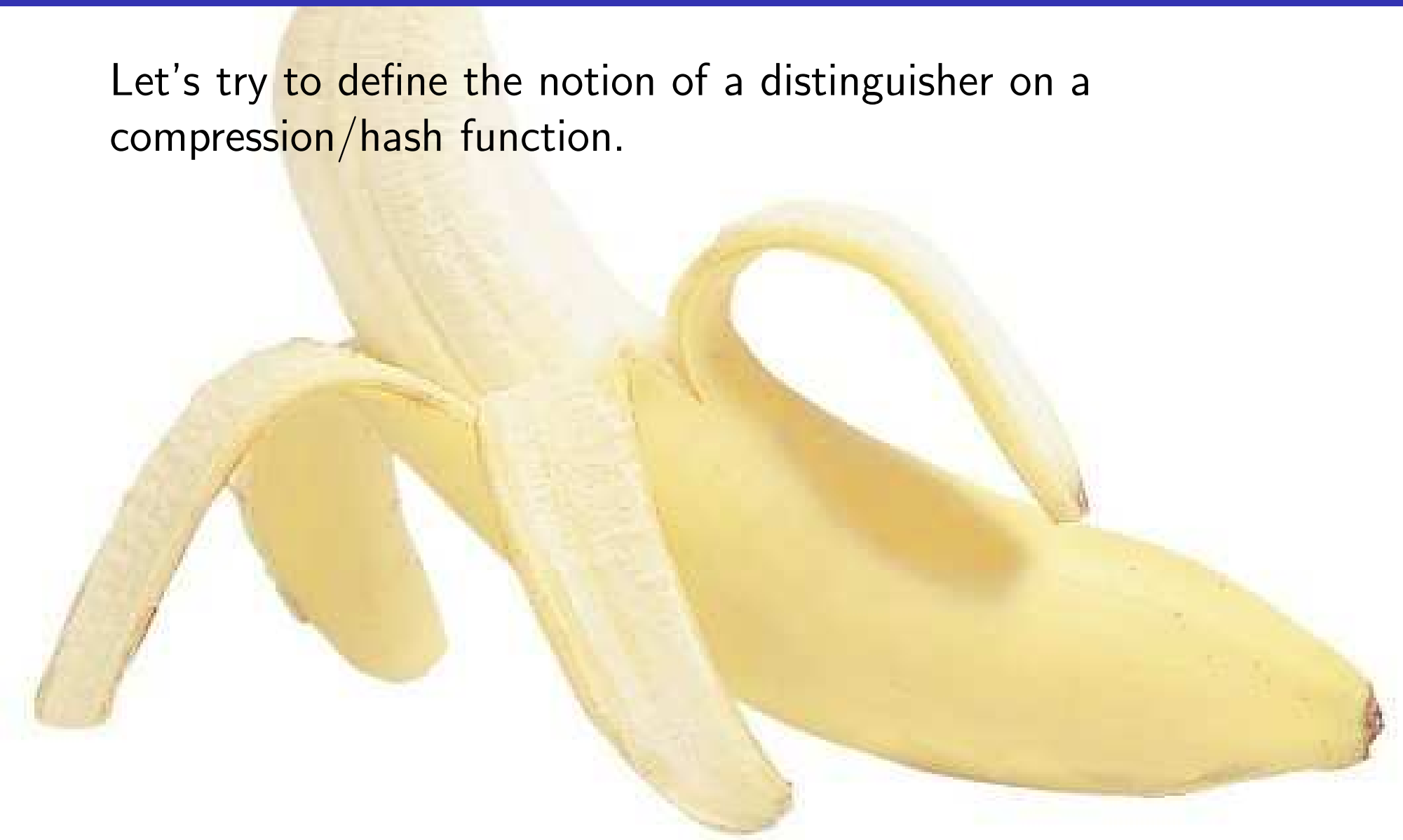
- Luckily for Shabal — not so easy to get to Shabal*.

To Distinguish or Not to Distinguish

Let's try to define the notion of a distinguisher on a compression/hash function.



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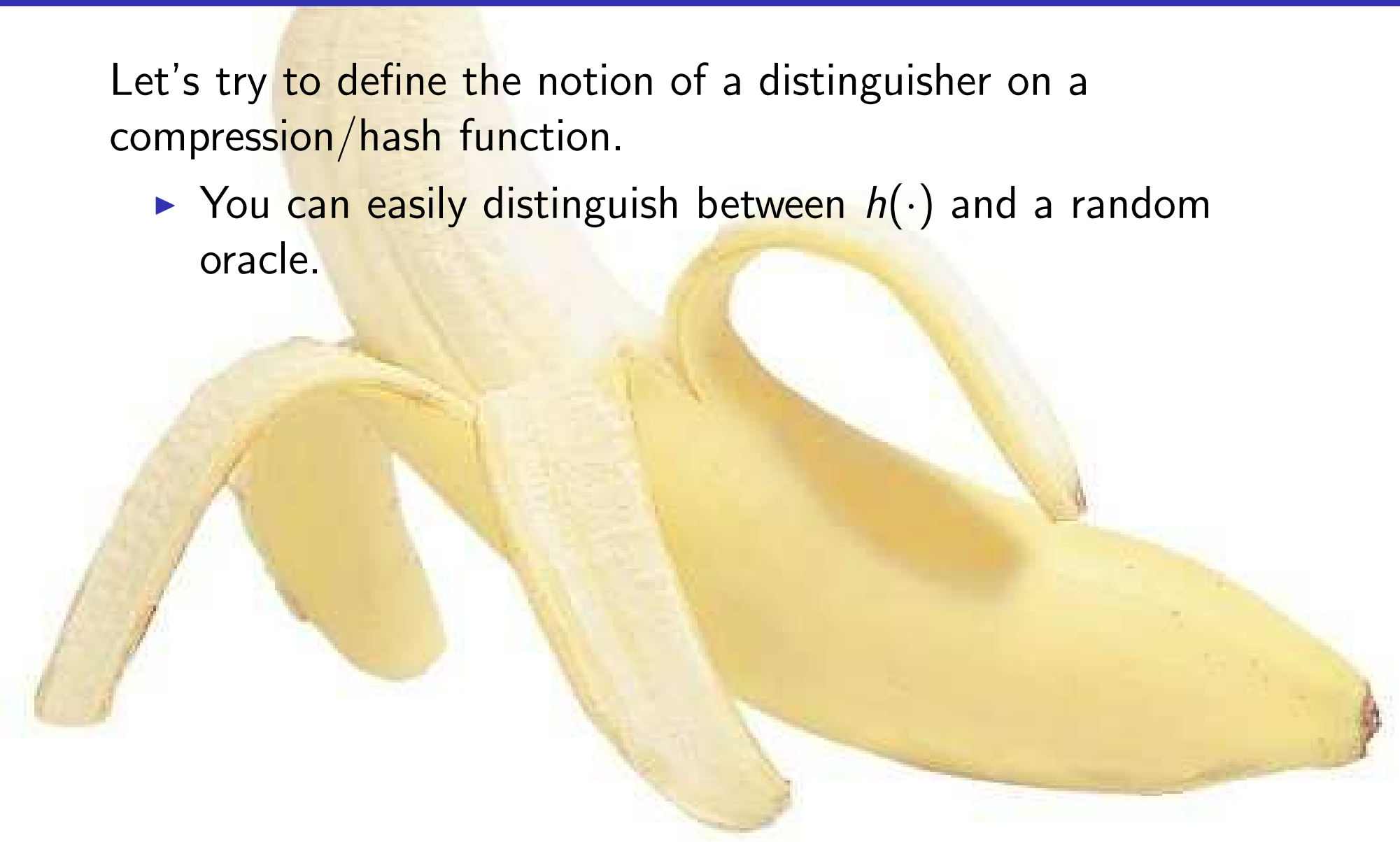

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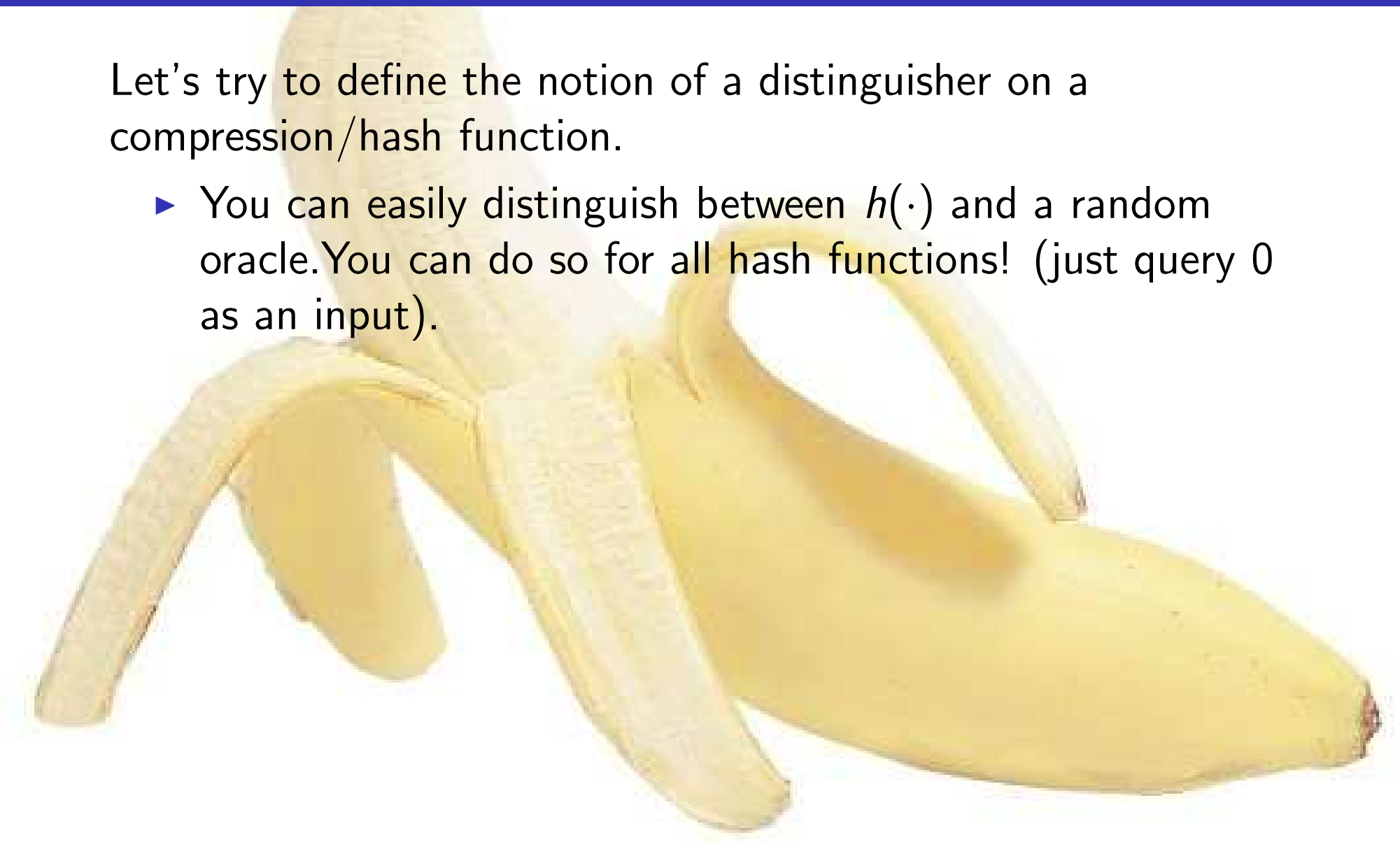

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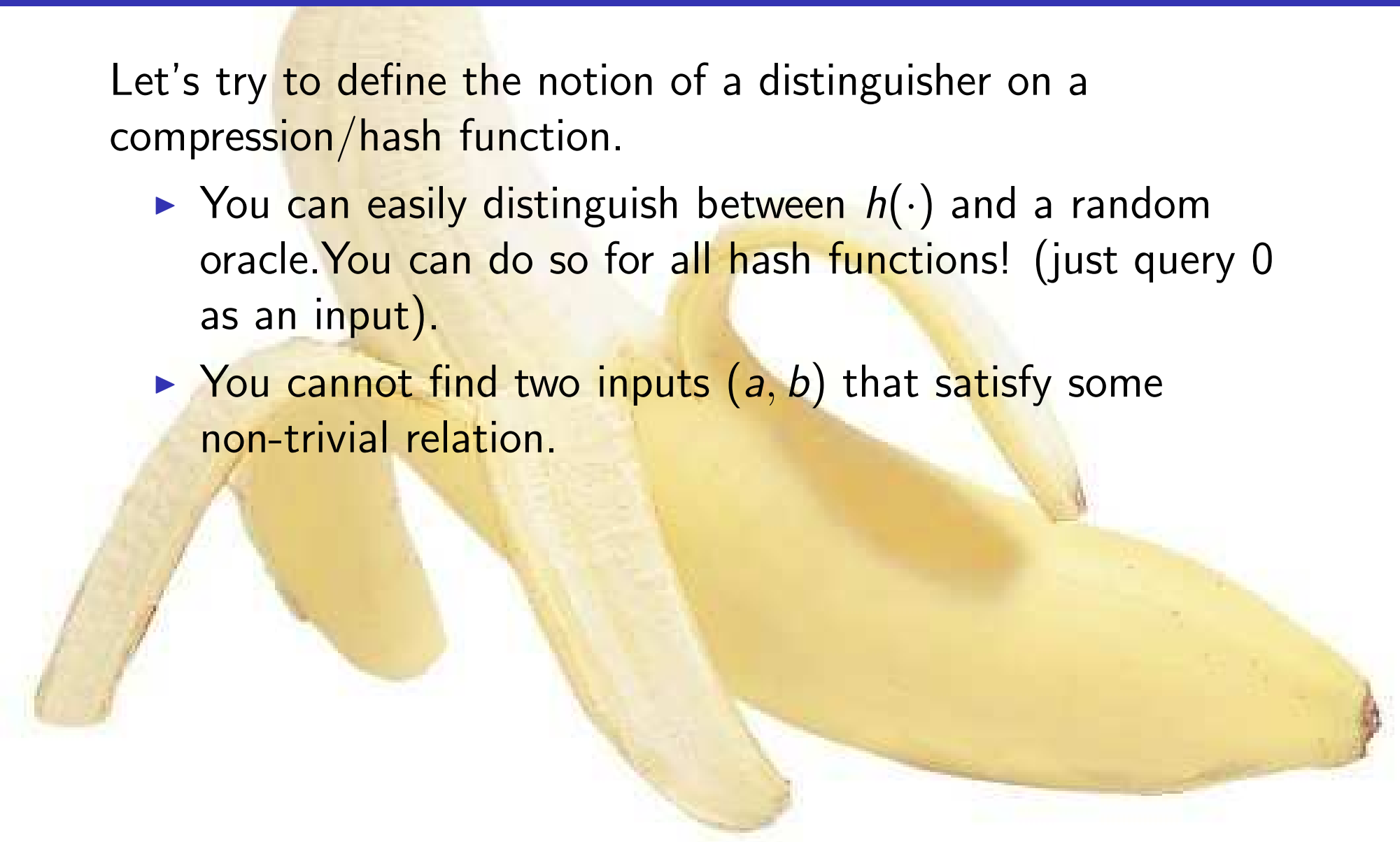

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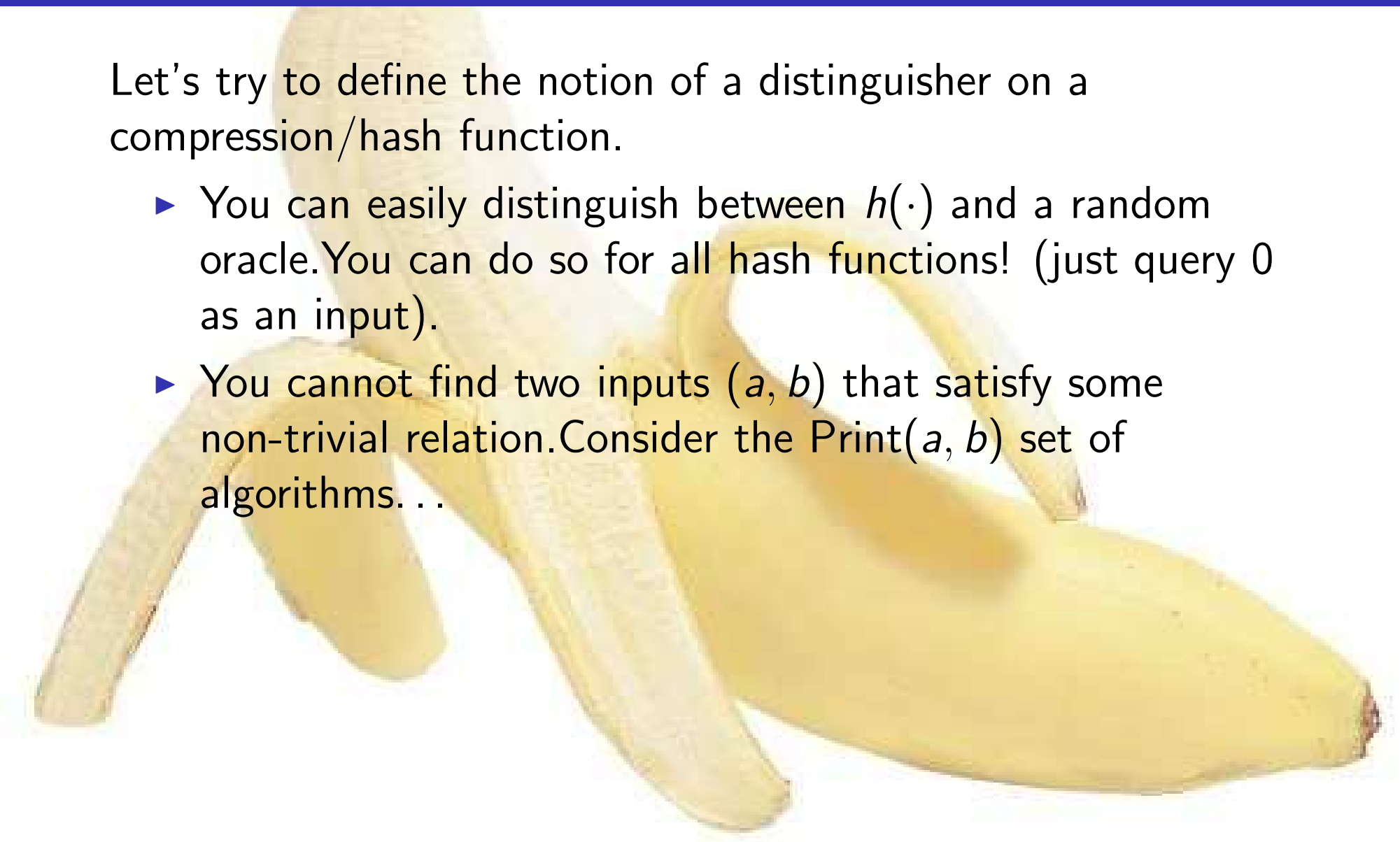

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- Known-key distinguisher approach: It is possible to find a set of inputs that satisfy some relation in the output, faster than for a random oracle.
- ...and if you do not like this name, feel free to use: pseudo-distinguisher or ...bananas.

Performance Evaluation — Software

- Some teams had many people on them. Some not.
- All teams submitted C code, but not all submitted assembler code, or optimized per-platform code.
- Some teams supply measurements using method A, some by using method B, ...
- Some teams supply measurements on a machine type A, some machine type B, ...
- Some teams used compiler X, some Y, ...
- Some teams had ...

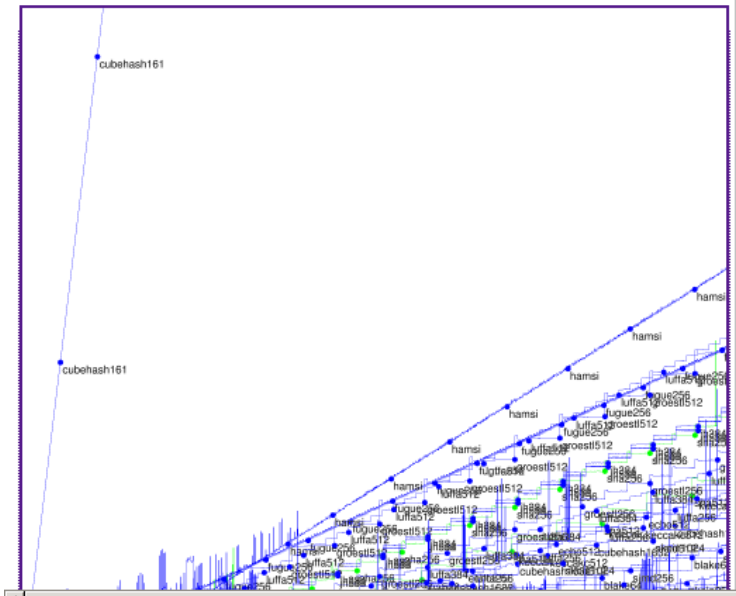
So how can you compare the speed?!?!?

Performance Evaluation — Software (cont.)

- eBASH — An effort to run everything everywhere.
  1. Strong points: lots of machines, easy to submit a new implementation.
  2. Weak points: still someone needs to implement, takes time for new implementations to be measured, some measurements are inconsistent.
  3. Measurement method can be "attacked": submit a hash function with a message block size of 16,000 bytes.
- sphlib — An effort to implement everything by one guy (without using per-CPU optimization) in C.
  1. Strong point: portable code is sometimes important.
  2. Weak points: based on a one-man show (who is actually a submitter of Shabal), why not to use per-CPU optimizations? why only C?

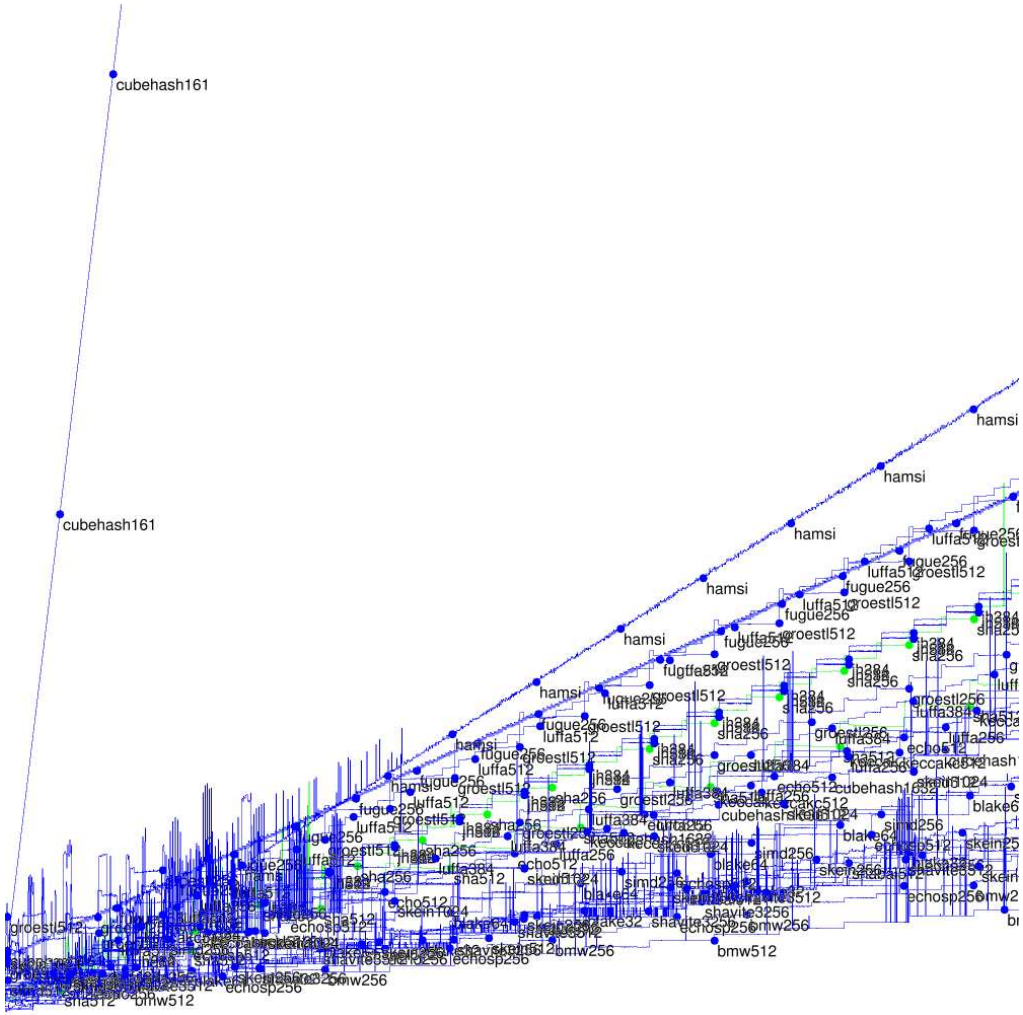
eBASH — A Glimpse

amd64, 2401MHz, Intel Xeon E5620 (206c2), giant4, supercop-20100821



Cycles/byte for long messages				Cycles/byte for 4096 bytes				Cycles/byte	
quartile	median	quartile	hash	quartile	median	quartile	hash	quartile	median
3.81	3.83	3.84	bmw512	4.11	4.11	4.12	bmw512	4.59?	4.59?
5.19	5.21	5.23	bmw256	5.40	5.40	5.41	bmw256	5.71	5.71
4.82?	5.46?	6.61?	echosp256	5.87	5.88	6.45	echosp256	5.98	5.99
4.79?	5.47?	5.52?	shavite3512	6.07	6.07	6.08	skein512	6.32	6.32
5.22?	5.83?	5.84?	shavite3256	5.81	6.12	6.13	shavite3512	6.69?	6.71?
2.88?	5.93?	5.94?	skein512	5.85	6.15	6.16	shavite3256	7.17	7.18
6.31	6.32	6.33	shabal512	6.73	6.73	6.73	shabal512	7.41	7.42
3.32?	6.61?	6.63?	echo256	6.74	6.75	6.75	echo256	7.55?	7.56?
5.40?	7.20?	7.22?	blake32	7.35	7.36	7.37	blake32	7.59	7.59
7.54?	7.59?	16.98?	skein256	7.65?	7.67?	12.35?	skein256	7.77	7.80
8.19	8.21	8.21	echosp512	8.38	8.38	8.39	echosp512	9.32	9.35
8.65	8.67	8.75	simd256	8.93	8.94	8.97	simd256	9.41?	9.42?
8.75?	9.04?	16.56?	blake64	9.36?	9.37?	13.12?	blake64	9.92	9.93
9.62	9.62	9.63	cubehash1632	10.30	10.31	10.34	simd512	10.97	10.98
9.88	9.91	9.97	simd512	9.85	10.36	10.37	skein1024	11.00?	11.00?
8.95?	9.98?	9.99?	skein1024	10.49	10.49	10.49	cubehash1632	11.93	11.93
11.58	11.59	11.60	keccakc512	12.08	12.09	12.09	keccakc512	12.62	12.63
11.90	11.94	11.96	echo512	12.25	12.25	12.25	luffa256	12.64?	12.65?
-0.62?	12.02?	12.03?	luffa256	12.49	12.50	12.50	echo512	13.39	13.41
12.40	12.43	12.46	keccak	12.89	12.90	12.90	keccak	13.64	13.69
12.50	12.52	13.34	sha512	13.08	13.08	13.49	sha512	14.01	14.01
13.31	13.33	13.34	luffa384	13.68	13.69	13.69	luffa384	14.28	14.28

eBASH — A Glimpse (cont.)



Performance Evaluation — Hardware

- Less people working on hardware implementation.
- More optimization targets (throughput vs. size vs. energy consumption)
- More technologies (ASIC vs. FPGA).
- Less common to share the “code”.

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SHA-3 Finalists

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1. BLAKE
2. Grøstl
3. JH
4. KECCAK
5. Skein

The SHA-3 Finalists

- Each of the five finalists has different design methodology:
  - Narrow pipe (Haifa/UBI): BLAKE and Skein,
  - Double pipe: Grøstl and JH,
  - Sponge: KECCAK
- Each of them also rely on different "security" mechanism:
  - ARX: BLAKE, KECCAK, and Skein,
  - S-boxes: Grøstl and JH

Software Performance — Recent 64-bit Platforms

1. Skein: 4–8 cpb,
2. Blake: 5–10 cpb,
3. KECCAK: 14–16 cpb,
4. Grøstl: 15–35 cpb,
5. JH: 16–45 cpb.

For comparison: SHA-512 is about 15 cpb.

Software Performance — Recent 8-bit Platforms

1. Depending on the exact architecture, Blake, Skein, and KECCAK, tend to be the most optimal.
2. We note that in these systems, usually low memory consumption is more important than speed.
3. For more details — visit the XBX: eXtenral Benchmarking eXtension project website (`http://xbx.das-labor.org/trac`)

SHA-3 — My Guesses

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- Selecting something which offers less security than "optimal".
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In other words, NIST will pick the fastest secure-enough SHA-3 finalist.

SHA-3 — My Guess (Mode of Iteration)

- Merkle-Damgård— Not the best security achievable.
- Sponges — too new, not such a good track-record, not suitable for small devices.
- Widepipe — twice the state, but good security.
- HAIFA — re-using the bit-counter with some extra functionality.

My guess: Widepipe or HAIFA. Depending on what NIST would like to obtain.

SHA-3 — My Guess (Compression Functions)

- Performance not much worse than SHA-256/-512.
- Implementable on 8-bit platforms.
- ASIC speeds that can reach 5 Gbps.
- Possible to implement with "restricted" memory.
- RFID **will not** play any role.
- Good differential and linear properties.
- Known and well-understood components (e.g., XOR vs. addition).

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- Hence, little time to work on SHA-1/SHA-2 . . .
- What if this is all a scheme to make cryptanalysts work hard to extend SHA-1/2's lifetime?

Questions?

Thank you for your Attention!