

SipHash: a fast short-input PRF

Jean-Philippe Aumasson, Daniel J. Bernstein

SipHash: a fast short-input MAC

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UMAC

(Black, Halevi, Krawczyk, Krovetz, Rogaway; 2000)

| | 43 bytes | 256 bytes | 1500 bytes | 256 kbytes |
|---------------|-------------|------------|------------|------------|
| UMAC32 | 16.3 | 3.8 | 2.1 | 1.9 |
| UMAC-STD | 52.9 | 12.3 | 3.8 | 1.9 |
| UMAC16 | 14.0 | 2.7 | 1.2 | 1.0 |
| UMAC-MMX | 35.9 | 4.5 | 1.7 | 1.0 |

<http://fastcrypto.org/umac/update.pdf>

1 cycle/byte on a Pentium III !

$$\text{UMAC}(m) = H(k_1, m) \oplus \text{AES}(k_2, n)$$

UMAC's universal hash

Polynomial-evaluation using 64-bit multipliers with Horner's rule

$$\left(\sum_{i=1}^{\ell/2} ((m_{2i-1} + k_{2i-1}) \bmod 2^w) \cdot ((m_{2i} + k_{2i}) \bmod 2^w) \right) \bmod 2^{2w}$$

UMAC fast C implementation

2000+ LoC
(without AES)

Not portable

```
1798 int uhash(uhash_ctx_t ahc, char *msg, long len, char *res)
1799 /* assumes that msg is in a writable buffer of length divisible by */
1800 /* L1_PAD_BOUNDARY. Bytes beyond msg[len] may be zeroed. */
1801 {
1802     UINT8 nh_result[STREAMS*sizeof(UINT64)];
1803     UINT32 nh_len;
1804     int extra_zeroes_needed;
1805
1806     /* If the message to be hashed is no longer than L1_HASH_LEN, we skip
1807      * the polyhash.
1808      */
1809     if (len <= L1_KEY_LEN) {
1810         if (len == 0) /* If zero length messages will not */
1811             nh_len = L1_PAD_BOUNDARY; /* be seen, comment out this case */
1812         else
1813             nh_len = ((len + (L1_PAD_BOUNDARY - 1)) & ~(L1_PAD_BOUNDARY - 1));
1814         extra_zeroes_needed = nh_len - len;
1815         zero_pad((UINT8 *)msg + len, extra_zeroes_needed);
1816         nh(&ahc->hash, (UINT8 *)msg, nh_len, len, nh_result);
1817         ip_short(ahc,nh_result, res);
1818     } else {
1819         /* Otherwise, we hash each L1_KEY_LEN chunk with NH, passing the NH
1820          * output to poly_hash().
1821          */
1822         do {
1823             nh(&ahc->hash, (UINT8 *)msg, L1_KEY_LEN, L1_KEY_LEN, nh_result);
1824             poly_hash(ahc,(UINT32 *)nh_result);
1825             len -= L1_KEY_LEN;
1826             msg += L1_KEY_LEN;
1827         } while (len >= L1_KEY_LEN);
    }
```

* ----- */

/* ////////////////////////////////// IMPORTANT NOTES ////////////////////////////////// */

- * 1) This version does not work properly on messages larger than 16MB
- * 2) If you set the switch to use SSE2, then all data must be 16-byte aligned
- * 3) When calling the function umac(), it is assumed that msg is in a writable buffer of length divisible by 32 bytes. The message itself does not have to fill the entire buffer, but bytes beyond msg may be zeroed.

<http://fastcrypto.org/umac/2004/src/umac.c>

**UMAC uses a PRG to expand
the key to 33280 bits**

Using a PRG, map Key to $K = K_1K_2 \cdots K_{1024}$, with each K_i a 32-bit word,
and to A , where $|A| = 512$.

RFC4418 replaces UMAC's PRG with an AES-based KDF...

3.2.1. KDF Algorithm

Input:

`K`, string of length `KEYLEN` bytes.
`index`, a non-negative integer less than 2^{64} .
`numbytes`, a non-negative integer less than 2^{64} .

Output:

`Y`, string of length `numbytes` bytes.

Compute `Y` using the following algorithm.

```
//  
// Calculate number of block cipher iterations  
//  
n = ceil(numbytes / BLOCKLEN)  
Y = <empty string>  
  
//  
// Build Y using block cipher in a counter mode  
//  
for i = 1 to n do  
    T = uint2str(index, BLOCKLEN-8) || uint2str(i, 8)  
    T = ENCIPHER(K, T)  
    Y = Y || T  
end for  
  
Y = Y[1...numbytes]  
  
Return Y
```

... and uses AES and this KDF in a “Pad-Derivation Function”

3.3.1. PDF Algorithm

Input:

K, string of length KEYLEN bytes.
Nonce, string of length 1 to BLOCKLEN bytes.
taglen, the integer 4, 8, 12 or 16.

Output:

Y, string of length taglen bytes.

Compute Y using the following algorithm.

```
//  
// Extract and zero low bit(s) of Nonce if needed  
//  
if (taglen = 4 or taglen = 8)  
    index = str2uint(Nonce) mod (BLOCKLEN/taglen)  
    Nonce = Nonce xor uint2str(index, bytelength(Nonce))  
end if  
  
//  
// Make Nonce BLOCKLEN bytes by appending zeroes if needed  
//  
Nonce = Nonce || zeroes(BLOCKLEN - bytelength(Nonce))  
  
//  
// Generate subkey, encipher and extract indexed substring  
//  
K' = KDF(K, 0, KEYLEN)  
T = ENCIIPHER(K', Nonce)  
if (taglen = 4 or taglen = 8)  
    Y = T[1 + (index*taglen) ... taglen + (index*taglen)]  
else  
    Y = T[1...taglen]  
end if  
  
Return Y
```

Not so simple

SipHash

Simple ARX round function

Simple JH-like message injection

No key expansion

No external primitive

No state between messages

SipHash initialization

256-bit state v_0 v_1 v_2 v_3

128-bit key k_0 k_1

$$v_0 = k_0 \oplus 736f6d6570736575$$

$$v_1 = k_1 \oplus 646f72616e646f6d$$

$$v_2 = k_0 \oplus 6c7967656e657261$$

$$v_3 = k_1 \oplus 7465646279746573$$

SipHash initialization

256-bit state v_0 v_1 v_2 v_3

128-bit key k_0 k_1

$$v_0 = k_0 \oplus \text{"somepseu"}$$

$$v_1 = k_1 \oplus \text{"dorandom"}$$

$$v_2 = k_0 \oplus \text{"lygenera"}$$

$$v_3 = k_1 \oplus \text{"tedbytes"}$$

SipHash compression

Message parsed as 64-bit words **m0**, **m1**, ...

$$v3 \oplus = m0$$

c iterations of SipRound

$$v0 \oplus = m0$$

SipHash compression

Message parsed as 64-bit words **m0**, **m1**, ...

$$v3 \oplus = \mathbf{m1}$$

c iterations of SipRound

$$v0 \oplus = \mathbf{m1}$$

SipHash compression

Message parsed as 64-bit words **m0**, **m1**, ...

$$v3 \oplus = m2$$

c iterations of SipRound

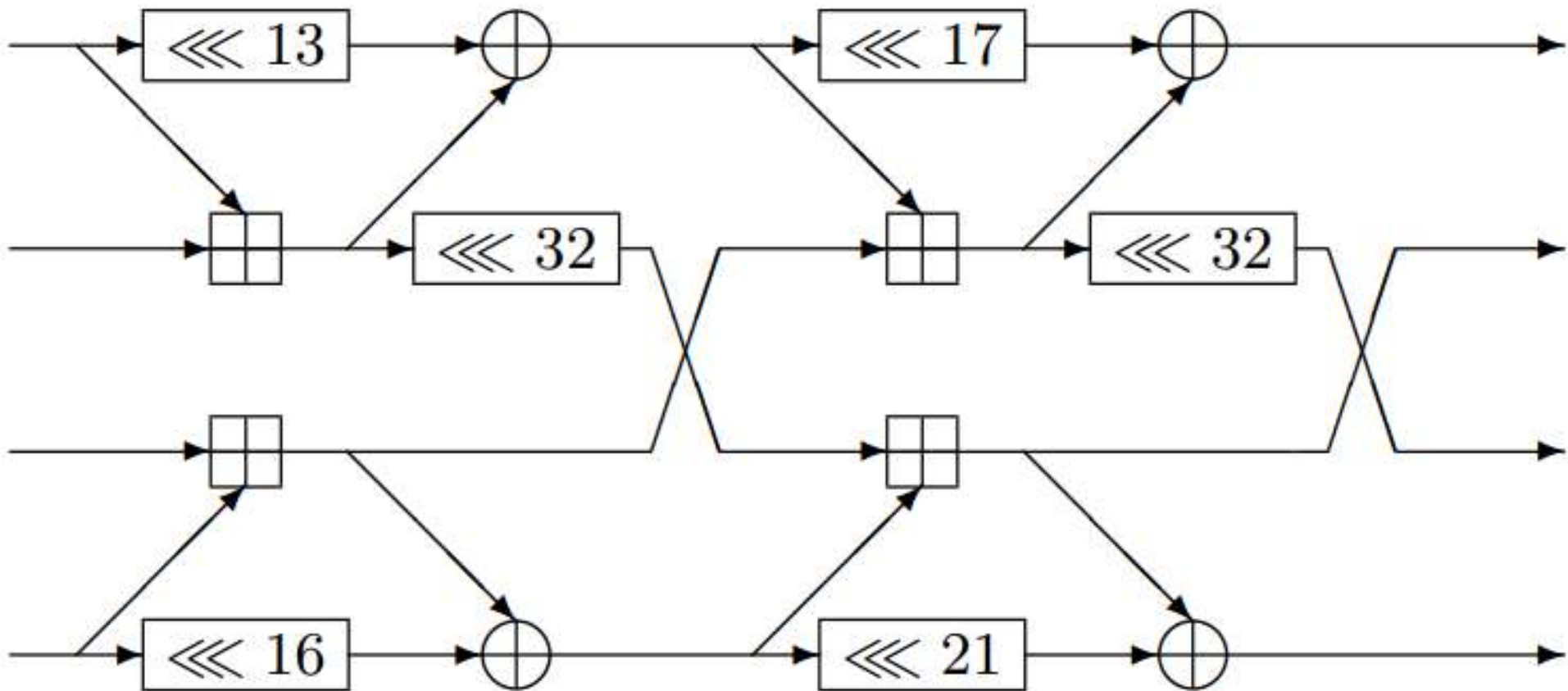
$$v0 \oplus = m2$$

SipHash compression

Message parsed as 64-bit words **m0**, **m1**, ...

Etc.

SipRound



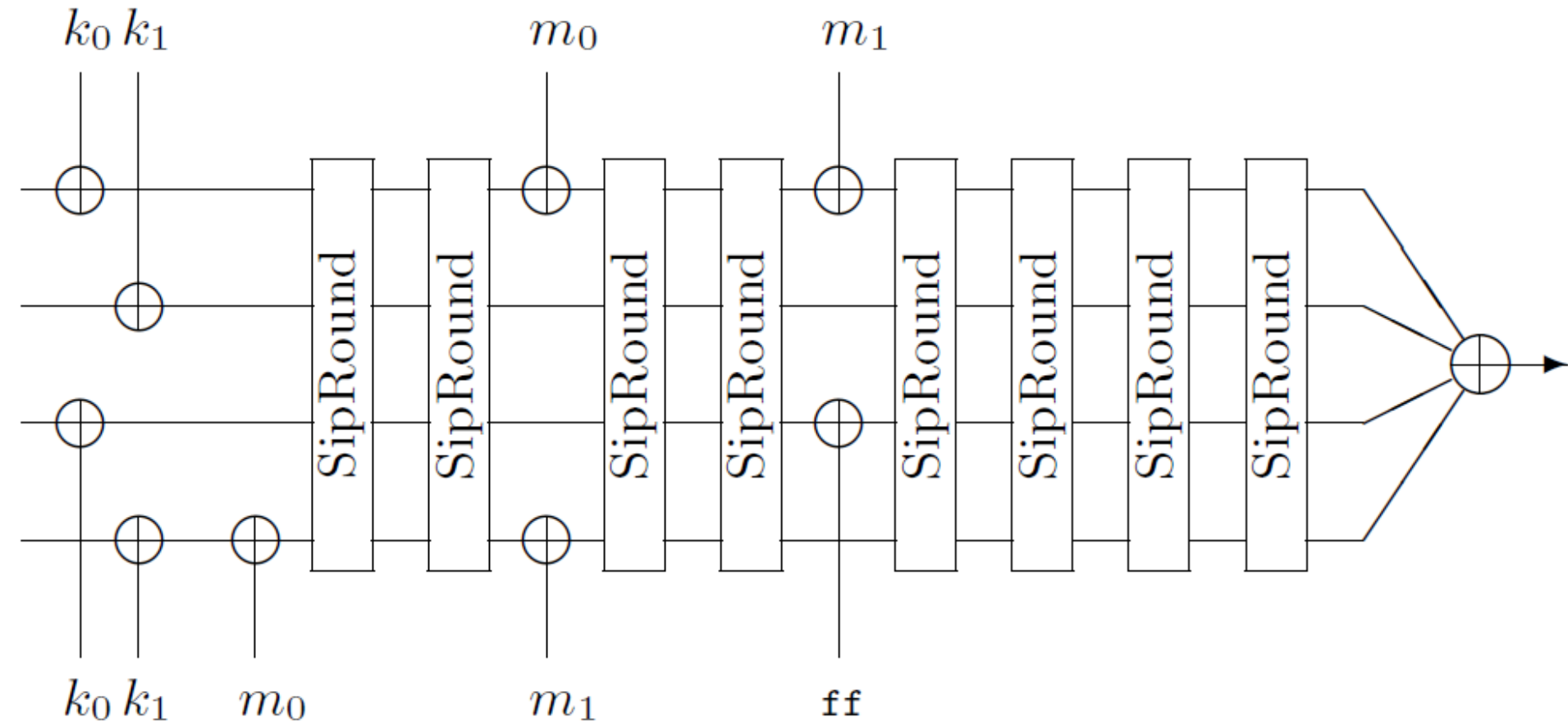
SipHash finalization

$v2 \oplus = 255$

d iterations of SipRound

Return $v0 \oplus v1 \oplus v2 \oplus v3$

SipHash-2-4 hashing 15 bytes



Family SipHash-**c-d**

Fast proposal: SipHash-**2-4**

Conservative proposal: SipHash-**4-8**

Weaker versions for cryptanalysis:

SipHash-1-0, SipHash-2-0, etc.

SipHash-1-1, SipHash-2-1, etc.

Etc.

(Many) short inputs?



File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: tcp.dstport eq 80 or tcp.dstport eq 443 Expression... Clear Apply

| No. | Time | Source | Destination | Protocol | Length | Info |
|------|------------|--------|-------------|----------|--------|------------------------------------------------------------------------------------|
| 2519 | 149.923984 | | | TCP | 66 | 53518 > http [ACK] Seq=2 Ack=2 Win=255 Len=0 TSval=76674761 TSecr=1806619891 |
| 2542 | 151.325449 | | | HTTP | 831 | Continuation or non-HTTP traffic |
| 2543 | 151.325475 | | | HTTP | 1333 | Continuation or non-HTTP traffic |
| 2549 | 151.504048 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=40432 Win=65535 Len=0 |
| 2551 | 151.504058 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=41120 Win=65535 Len=0 |
| 2553 | 151.509701 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=42480 Win=65535 Len=0 |
| 2555 | 151.509713 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=43168 Win=65535 Len=0 |
| 2557 | 151.517987 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=44528 Win=65535 Len=0 |
| 2559 | 151.517999 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=45216 Win=65535 Len=0 |
| 2561 | 151.524712 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=46576 Win=65535 Len=0 |
| 2563 | 151.524725 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=47264 Win=65535 Len=0 |
| 2565 | 151.527101 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=48624 Win=65535 Len=0 |
| 2567 | 151.527112 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=49312 Win=65535 Len=0 |
| 2569 | 151.532604 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=50672 Win=65535 Len=0 |
| 2571 | 151.532612 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=51360 Win=65535 Len=0 |
| 2573 | 151.535491 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=52720 Win=65535 Len=0 |
| 2575 | 151.535503 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=53408 Win=65535 Len=0 |
| 2577 | 151.537818 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=54768 Win=65535 Len=0 |
| 2579 | 151.537828 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=55456 Win=65535 Len=0 |
| 2583 | 151.543724 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=57504 Win=65535 Len=0 |
| 2585 | 151.548877 | | | TCP | 54 | 45886 > http [ACK] Seq=8269 Ack=58501 Win=65535 Len=0 |
| 2645 | 155.535986 | | | TCP | 66 | 53517 > http [ACK] Seq=2 Ack=2 Win=1104 Len=0 TSval=76676164 TSecr=1806625501 |
| 2682 | 158.265727 | | | TCP | 66 | 53517 > http [FIN, ACK] Seq=2 Ack=2 Win=1104 Len=0 TSval=76676846 TSecr=1806625501 |
| 2684 | 158.265970 | | | TCP | 66 | 53518 > http [FIN, ACK] Seq=2 Ack=2 Win=255 Len=0 TSval=76676846 TSecr=1806619891 |
| 3306 | 196.607981 | | | TCP | 54 | [TCP Keep-Alive] 45886 > http [ACK] Seq=8268 Ack=58501 Win=65535 Len=0 |

Type: IP (0x0000)

Internet Protocol Version 4, Src: , Dst:

Transmission Control Protocol, Src Port: 53518 (53518), Dst Port: http (80), Seq: 2, Ack: 2, Len: 0

Source port: 53518 (53518)

Destination port: http (80)

[Stream index: 0]

Sequence number: 2 (relative sequence number)

Hash tables

```
h = {}           # empty table
h['foo'] = 'bar' # insert 'bar'
Print h['foo']   # lookup
```

Non-crypto functions to produce 'foo':

```
for (; nKeyLength > 0; nKeyLength -=1) {
hash = ((hash << 5) + hash) + *arKey++;
}
```

Hash flooding attacks

Multicollisions forcing worst-case complexity of $\Theta(n^2)$, instead of $\Theta(n)$

[when table implemented as linked lists]

djbdns/cache.c, 1999

```
nextpos = prevpos ^ get4(pos);
prevpos = pos;
pos = nextpos;
if (++loop > 100) return 0; /* to protect against hash flooding */
}

return 0;
}
```

USENIX 2003

Denial of Service via Algorithmic Complexity Attacks

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Abstract

We present a new class of low-bandwidth denial of service attacks that exploit algorithmic deficiencies

some $O(n)$ time to insert n elements. However, if each element hashes to the same bucket, the hash table will also degenerate to a linked list, and it will take $O(n^2)$ time to insert n elements.

Vulnerabilities in Perl, web proxy, IDS

CCC 2011

Effective Denial of Service attacks against web application platforms

We are the 99% (CPU usage)

This talk will show how a common flaw in the implementation of most of the popular web programming languages and platforms (including PHP, ASP.NET, Java, etc.) can be (ab)used to force web application servers to use 99% of CPU for several minutes to hours for a single HTTP request.



SPEAKERS



Alexander 'alech' Klink



[Julian | zeri](#)

SCHEDULE

Day [Day 2 - 2011-12-28](#)

Room [Saal 1](#)

Start time [14:00](#)

Duration [01:00](#)

INFO

ID [4680](#)

Event type [Lecture](#)

Track [Hacking](#)

Language [English](#)
used for presentation.

Affected: PHP, ASP.net, Python, etc.

n.runs AG

<http://www.nruns.com/>

n.runs-SA-2011.004

security(at)nruns.com

28-Dec-2011

Vendors: PHP, <http://www.php.net>

Oracle, <http://www.oracle.com>

Microsoft, <http://www.microsoft.com>

Python, <http://www.python.org>

Ruby, <http://www.ruby.org>

Google, <http://www.google.com> Affected Products: PHP 4 and 5

Java

Apache Tomcat

Apache Geronimo

Jetty

Oracle Glassfish

ASP.NET

Python

Plone

CRuby 1.8, JRuby, Rubinius

v8

Vulnerability: Denial of Service through hash table
multi-collisions

How short?

OpenDNS cache: **27 bytes** on average

Ruby on Rails web application: **<20 bytes**

Why SipHash?

Minimizes hash flooding

→ impact limited to $\sqrt{\text{communication}}$

Well-defined security goal (PRF)

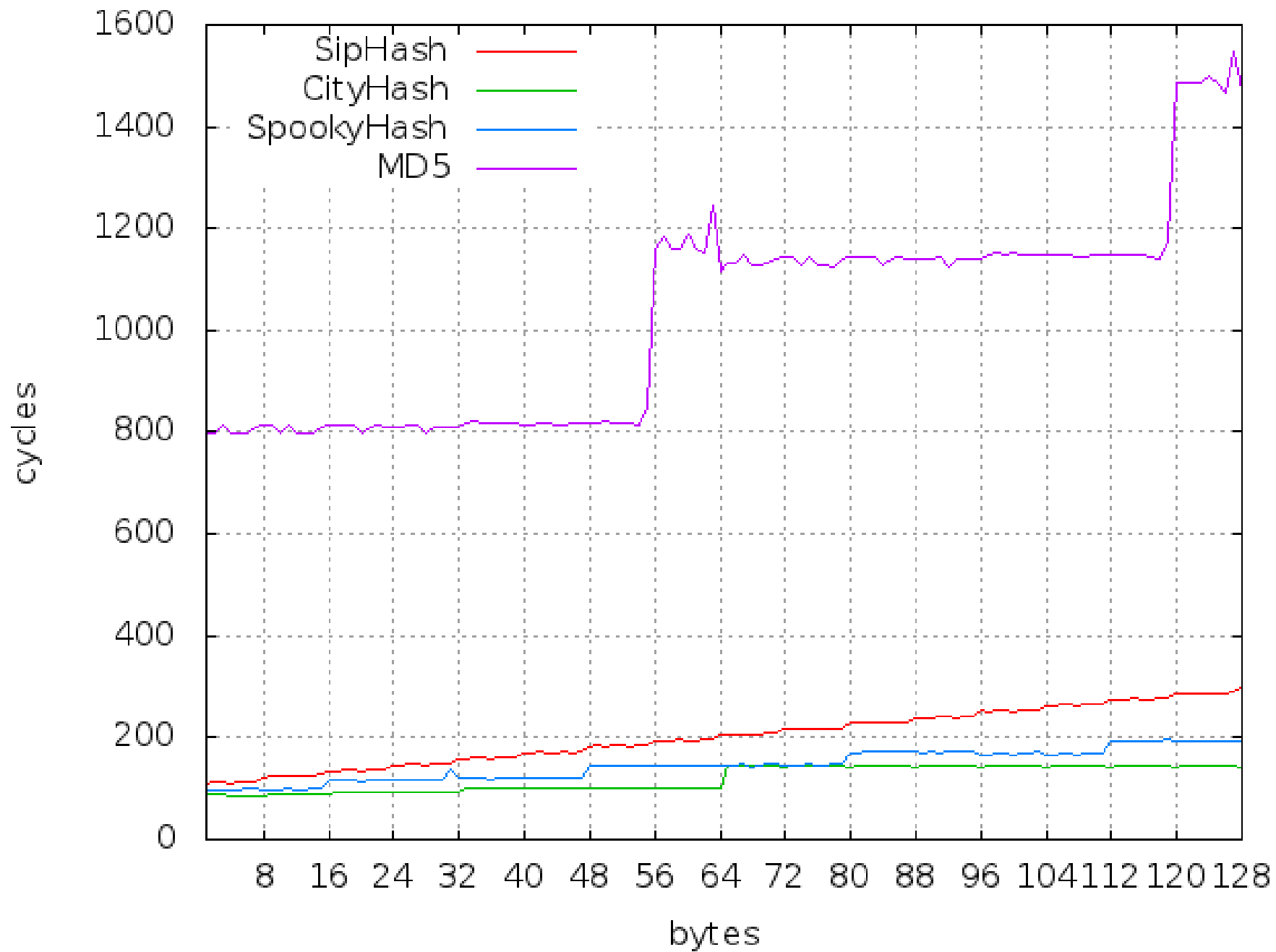
Competitive in speed with non-crypto hashes

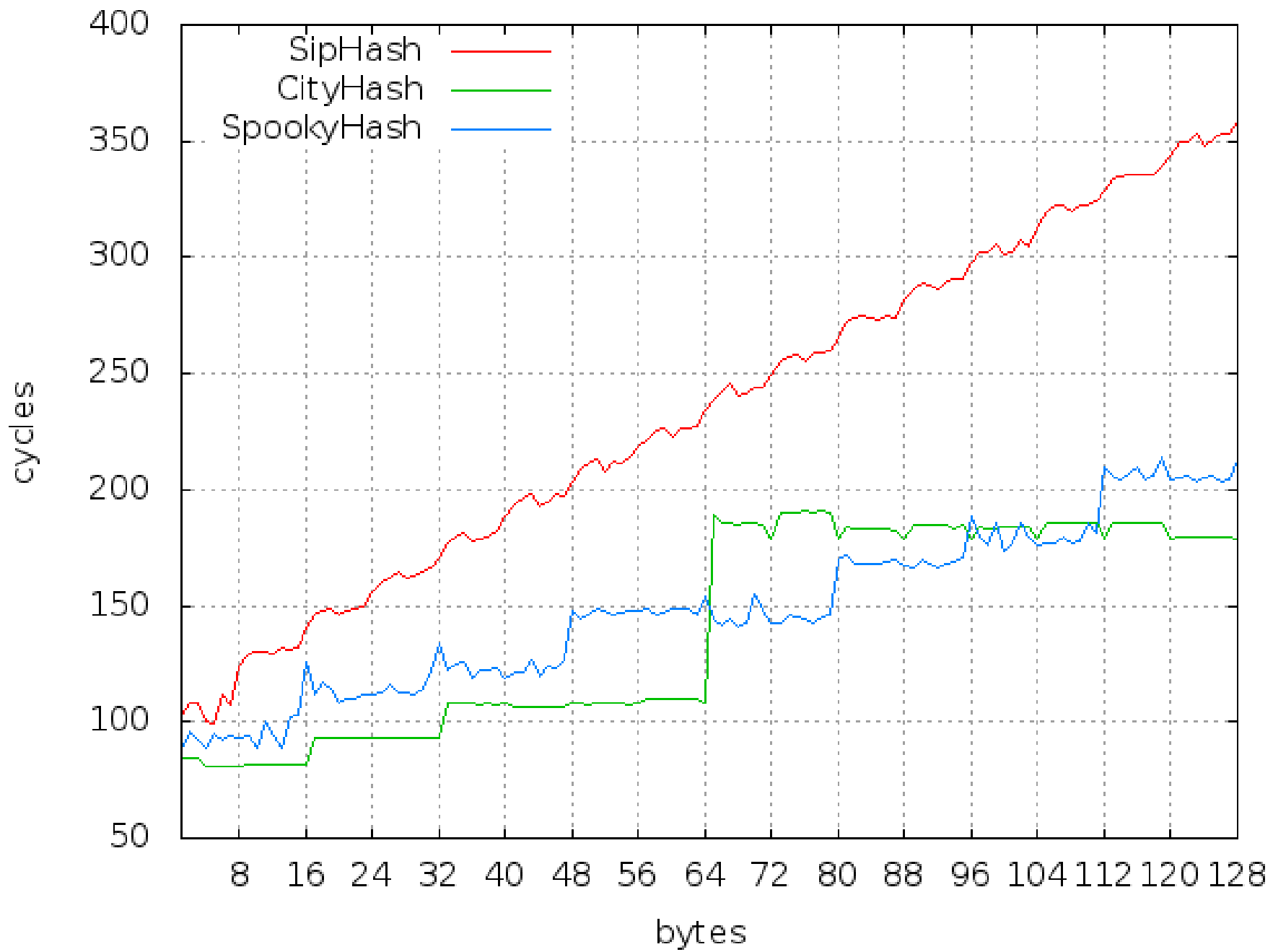
How fast?

SipHash-2-4 on an AMD Athlon II Neo

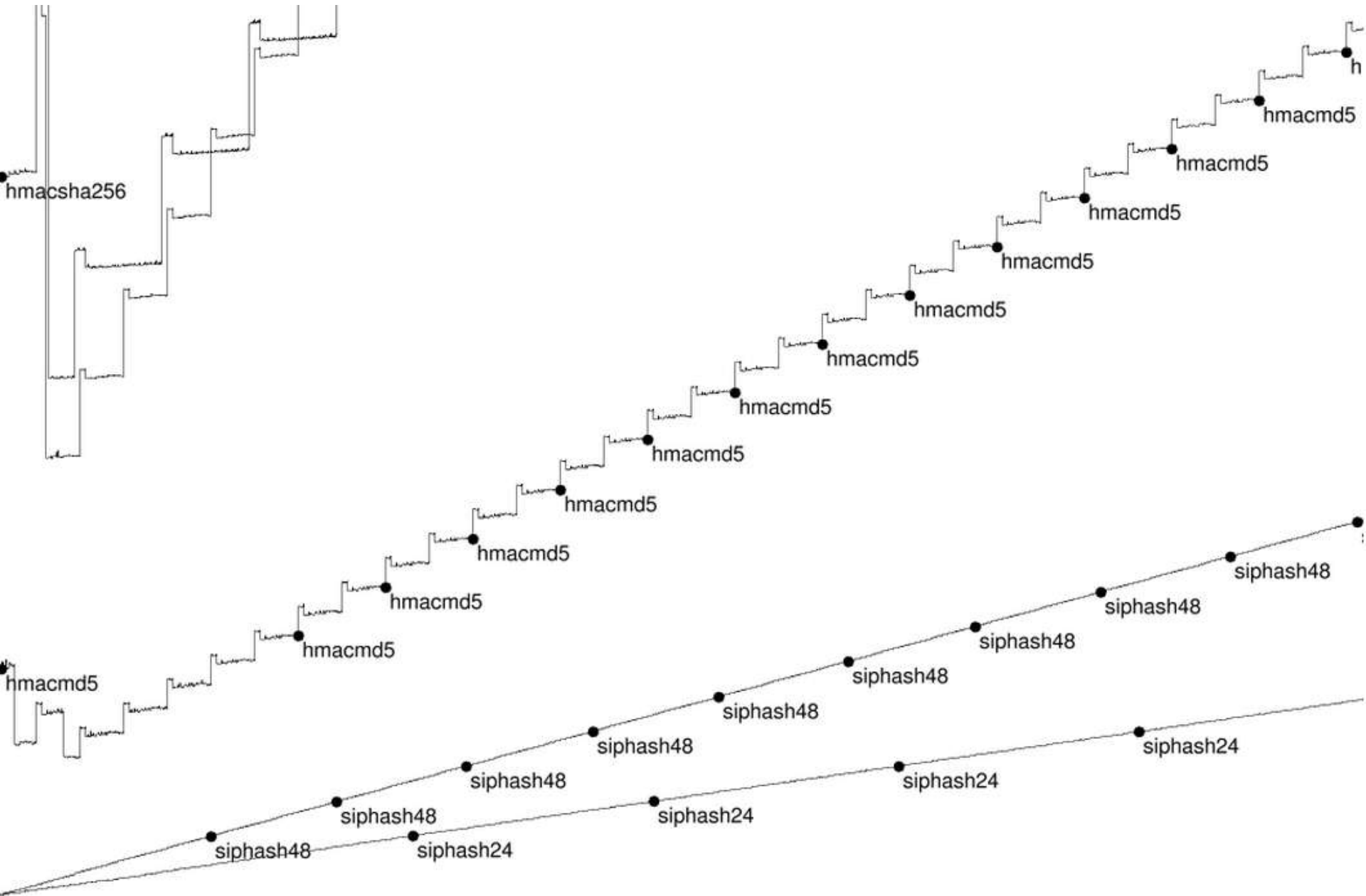
| Byte length | 8 | 16 | 32 | 64 |
|----------------------|----------------|---------------|---------------|---------------|
| Cycles (per byte) | 123 (15.38) | 134 (8.38) | 158 (4.25) | 204 (3.19) |

Long data: **1.44** cycles/byte

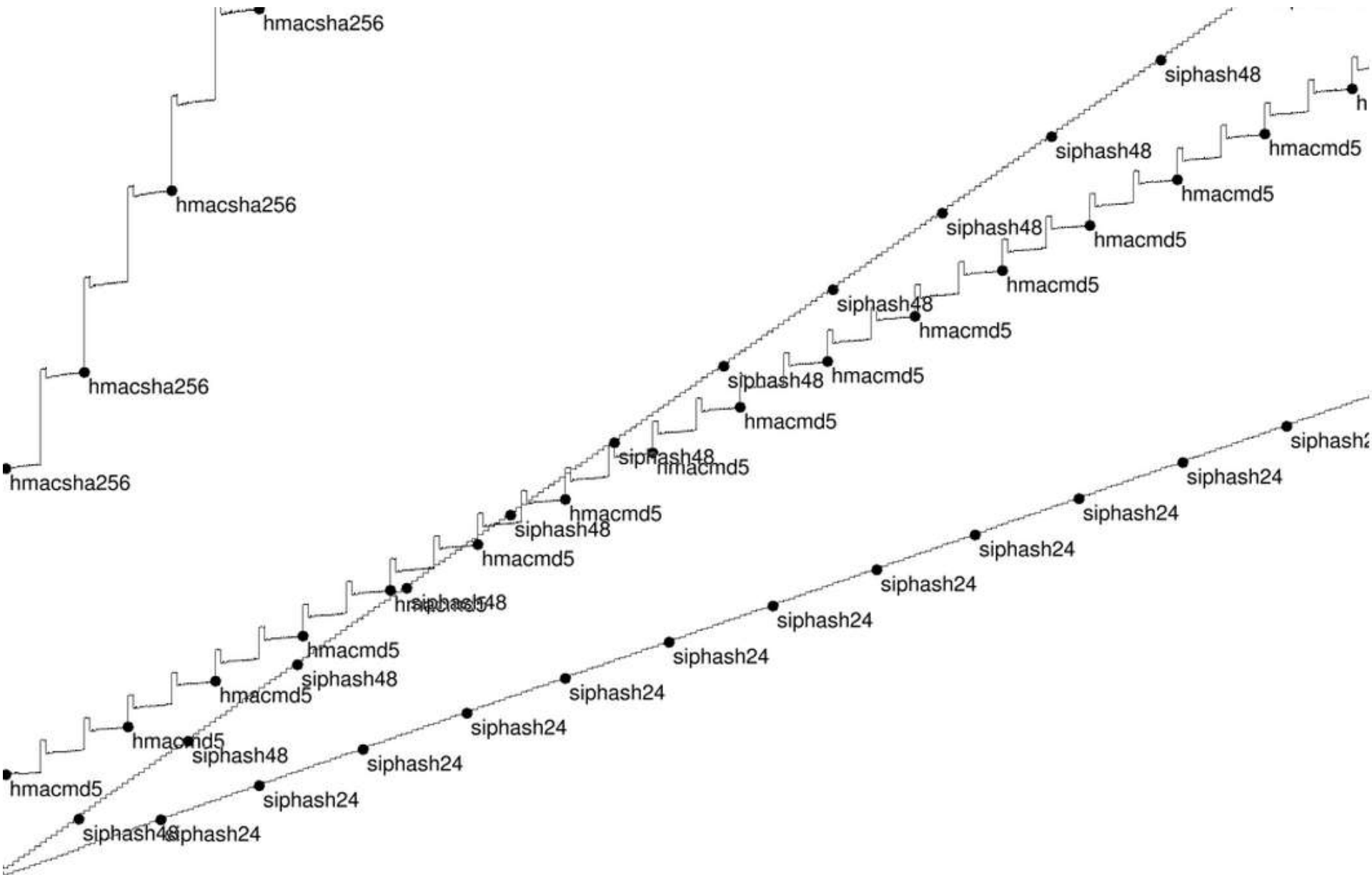




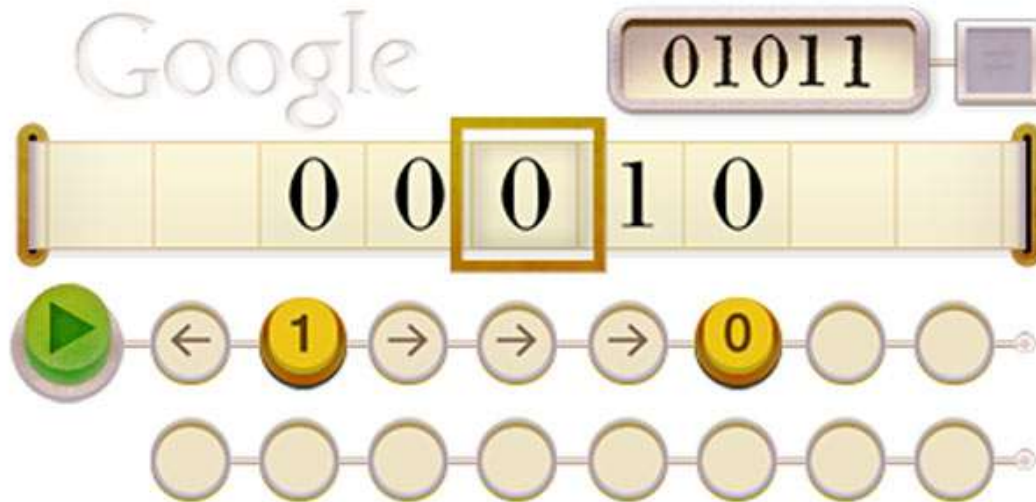
amd64; K10 45nm; 2010 AMD Phenom II X6 1090T



x86; K10 45nm; 2010 AMD Phenom II X6 1090T



Cryptanalysis



Generic attacks

$\approx 2^{128}$ key recovery

$\approx 2^{192}$ state recovery

$\approx 2^{128}$ internal-collision forgeries

$\approx 2^s$ forgery attack with
success probability 2^{s-64}

| Round | Differences | Prob. |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 1 |8.....8.....8... | 1 (1) |
| 2 | 8.....8... 8..... 8.....8..... 8.....1...1.8...8..... 9... 8.....1.8.1.8... 8.1.....1..... | 13 (14) |
| 3 | ..1.8.....1..... 8.....11a.1.1... 8.1.1...8.....1. 8.1.82.....2.. a...1...8.1.8.11 8.12b413a2.....92..8....21. 82..92..82..82.. | 42 (56) |
| 4 | 22..82...21..211 e835621322.1.235 22...21.8.122613 621.c21.42..42.3 2.11..24ca35e.13 66778453..57bd22 4.1.c...c212641. 82..82..8.11.6.. | 103 (159) |
| 5 | a21182244a24e613 2ec144fcb8.115dd c245d93226674453 e2.18..48a34a6.3 f225f3ce8cd.c6d8 a44f51d8d.9e5616 2.445936ac53e25. a.4.d3.2.a5...51 | 152 (311) |
| 6 | 52652.cc868.c689 27baa9d2d.e.fcd8 7ccdb44684.b.8ee 32246acc8cb4ce93 566.3a5175df891e 2.e5d3.249fb3ea6 4ee9de8a.8bfc67d 2425523ec62cf459 | 187 (498) |

Characteristic verified with ARXtools

<http://www.di.ens.fr/~leurent/arxtools.html>

Proof of insecurity

$$\text{SipRound}(0) = 0$$

That is, SipRound is not ideal

Therefore SipHash is insecure



Proof of simplicity

June 20: paper published online

June 28: **18** third-party implementations

C (Floodyberry, Boßlet, Neves); **C#** (Haynes)

Cryptol (Lazar); **Erlang**, **Javascript**, **PHP** (Denis)

Go (Chestnykh); **Haskell** (Hanquez);

Java, **Ruby** (Boßlet); **Lisp** (Brown);

More on SipHash:

<http://131002.net/siphash>

Thanks to all implementers!