# Shabal

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initiated by the Saphir project

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# Main characteristics of Shabal

## Parameters.

- Internal state: 44 words (1408 bits).
- Message blocks: 16 words (512 bits).

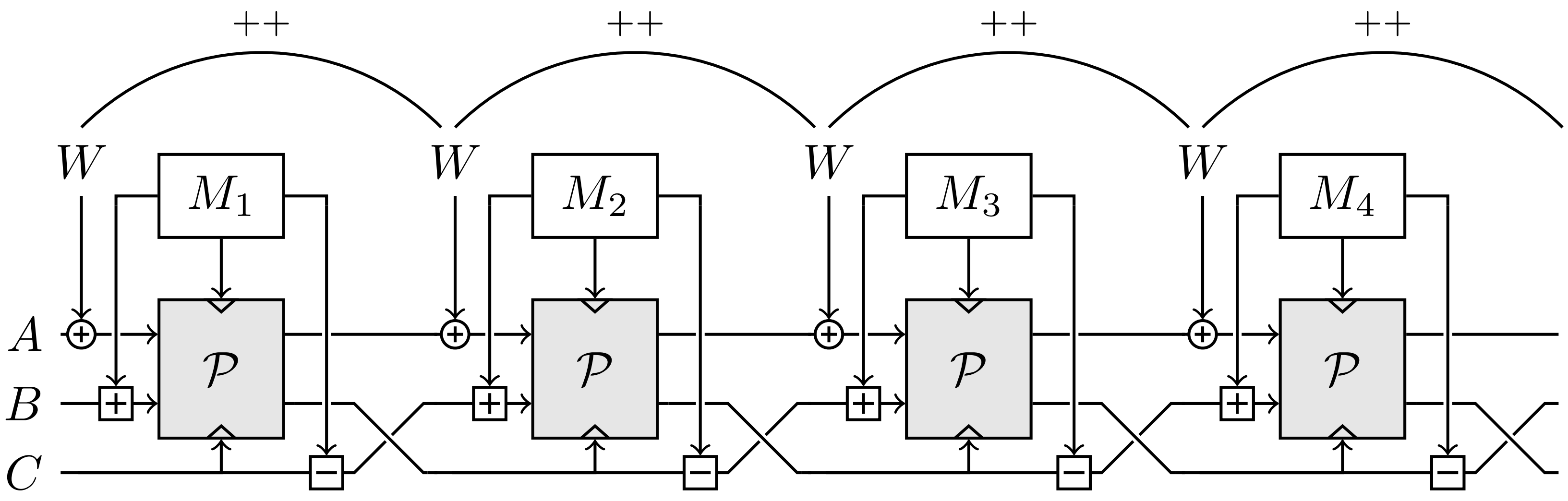
## Generic construction.

- Message rounds: iterate a keyed permutation with respect to a provably secure mode of operation;
- Final rounds: 3 slightly different additional rounds;
- Output: $\ell_h$ bits from the internal state;
- Keyed permutation: operates on a $28$-word input, parameterized by two $16$-word values.

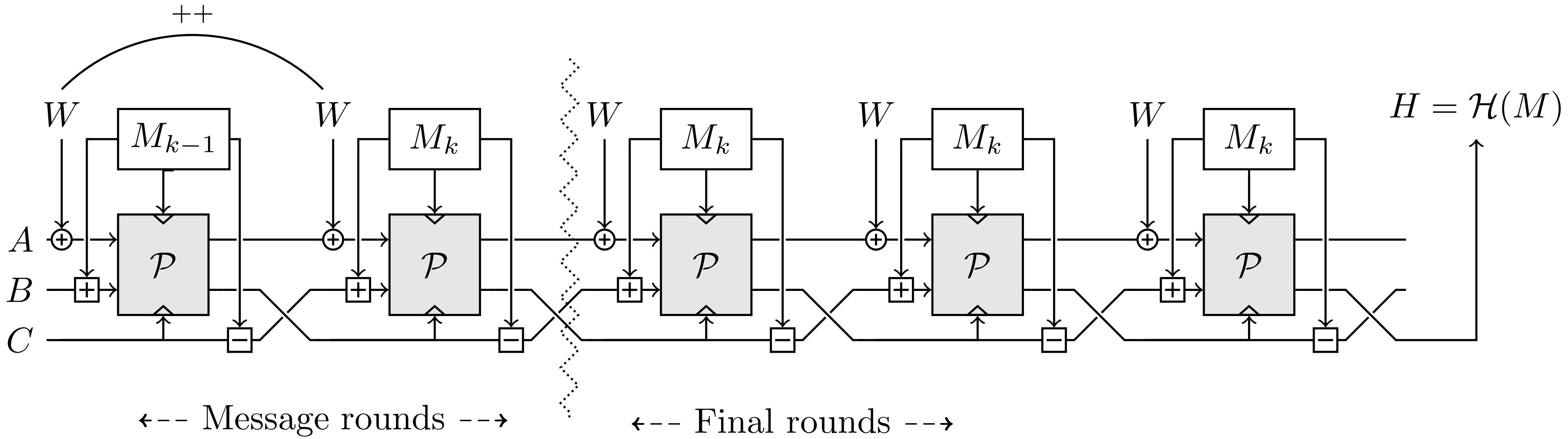
# Message rounds

$|\boldsymbol{A}| = \mathbf{12}$ words and $|\boldsymbol{B}| = |\boldsymbol{C}| = \mathbf{16}$ words.

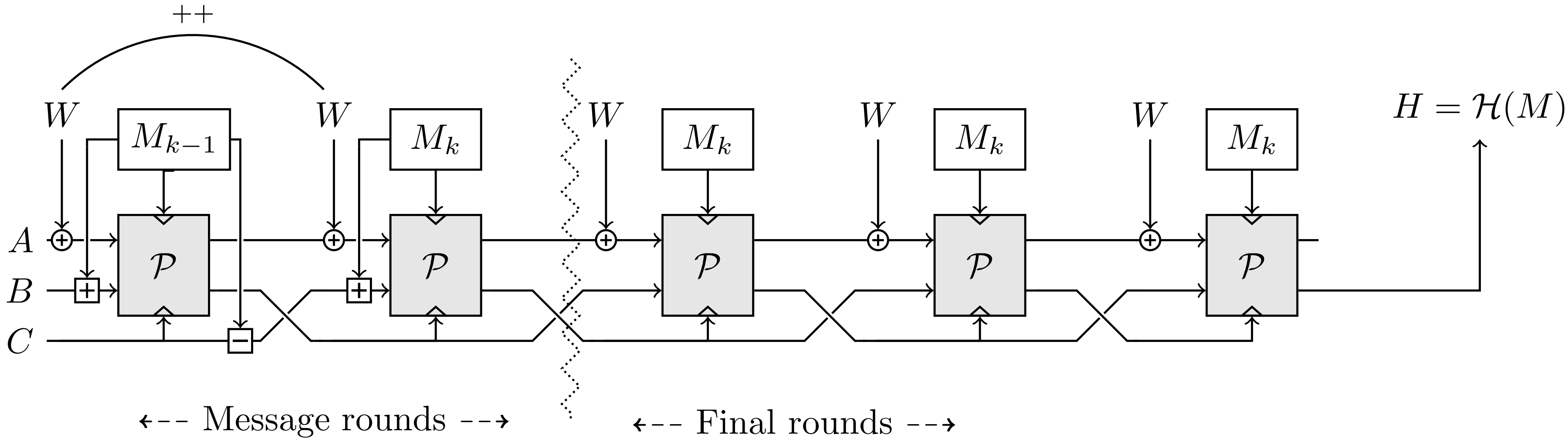
$\boldsymbol{W}$: $\mathbf{2}$-word counter.



# Final rounds



# Final rounds: equivalent view



# Padding and initialization

## Padding.

The message is post-padded with a 1 followed by as many 0 as required so that the length is a multiple of 512 bits.

## Initialization.

- Prefix approach: the message is prefixed with two 512-bit blocks

$$(\ell_h, \ldots, \ell_h + 15), (\ell_h + 16, \ldots, \ell_h + 31)$$

where $\ell_h$ is the output length.

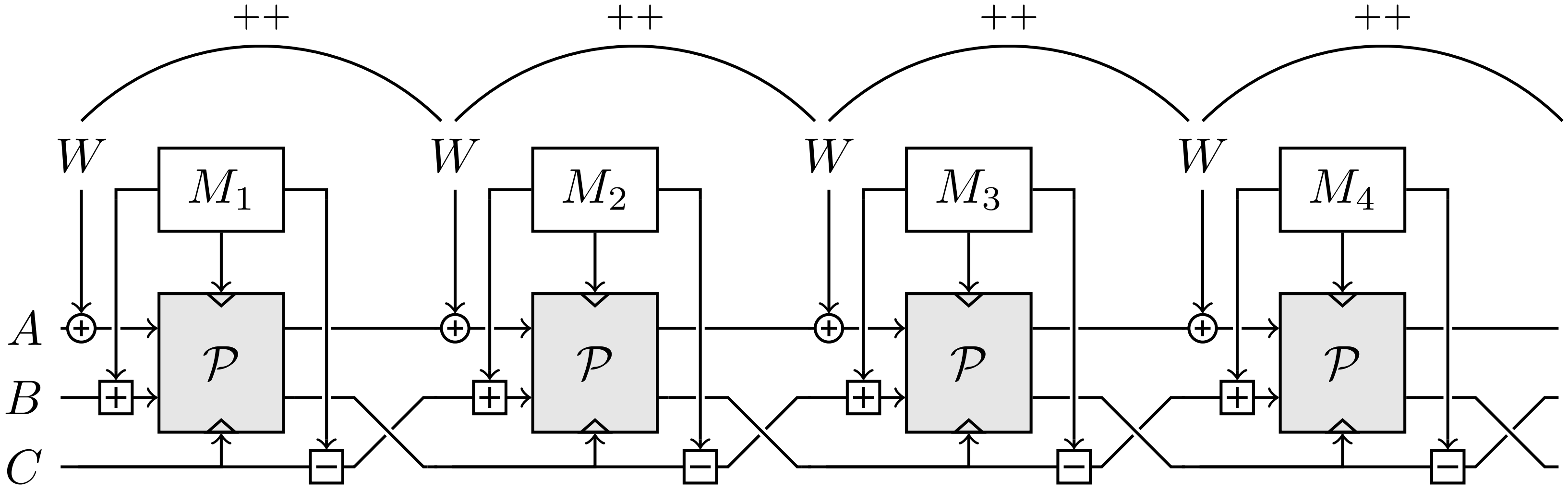
$$\text{internal state } \leftarrow \mathbf{0}, \text{ counter } \leftarrow -1.$$

- IV approach:

$$\text{internal state } \leftarrow IV_{\ell_h}, \text{ counter } \leftarrow 1.$$

# Shabal generic operating mode

$|\boldsymbol{A}| = \boldsymbol{\ell_a}$ bits and $|\boldsymbol{B}| = |\boldsymbol{C}| = |\boldsymbol{M_i}| = \boldsymbol{\ell_m}$ bits.



## A provably secure operating mode

If the keyed permutation $\mathcal{P}$ is viewed as a random keyed permutation, we can prove:

**Indifferentiability from a random oracle.**

- Shabal behaves like a random oracle up to

$$\mathbf{2}^{\frac{\ell_a+\ell_m}{2}} = \mathbf{2}^{448}$$

  evaluations of $\mathcal{P}$ or $\mathcal{P}^{-1}$.

- Internal collisions require no less than $\mathbf{2}^{448}$ evaluations of $(\mathcal{P}, \mathcal{P}^{-1})$;

- Shabal is collision resistant when the collision finder is bounded to $\mathbf{2}^{\ell_h/2}$ evaluations of $(\mathcal{P}, \mathcal{P}^{-1})$.

# A provably secure operating mode (2)

## (Second)-preimage resistance.

- Shabal is preimage resistant when the preimage finder is limited to

$$\min\left(2^{\ell_h}, 2^{\ell_a+\ell_m-\log(\ell_m+1)-2}\right) = \min\left(2^{\ell_h}, 2^{885}\right) = 2^{\ell_h}$$

  evaluations of $(\mathcal{P}, \mathcal{P}^{-1})$.

- Shabal is second preimage-resistant for $\kappa$-bit messages up to

$$\min\left(2^{\ell_h}, 2^{\ell_a+\ell_m-\log k^*}\right) = \min\left(2^{\ell_h}, 2^{903-\log \kappa}\right)$$

  evaluations of $(\mathcal{P}, \mathcal{P}^{-1})$ where $k^* = \lceil(\kappa+1)/\ell_m\rceil$.

# Sébastien Chabal

http://commons.wikimedia.org/wiki/File:Sebastien-Chabal_large.jpg

THE Sun

Tuesday, February 10, 2009



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## Chabal eats Gröstl for breakfast

## The keyed permutation

**Input:** $M, A, B, C$ **Output:** $A, B$

**for** $i$ from $0$ to $15$ **do**

$B[i] \leftarrow B[i] \lll 17$

**end for**

**for** $j$ from $0$ to $2$ **do**

**for** $i$ from $0$ to $15$ **do**

$$\begin{aligned} A[i + 16j \bmod 12] \leftarrow\ & \mathcal{U}\big(A[i + 16j \bmod 12] \oplus C[8 - i \bmod 16] \\ & \oplus \mathcal{V}(A[i - 1 + 16j \bmod 12] \lll 15)\big) \\ & \oplus M[i] \oplus B[i + 13 \bmod 16] \\ & \oplus (B[i + 9 \bmod 16] \wedge \overline{B[i + 6 \bmod 16]}) \end{aligned}$$

$B[i] \leftarrow (B[i] \lll 1) \oplus \overline{A[i + 16j \bmod 12]}$

**end for**

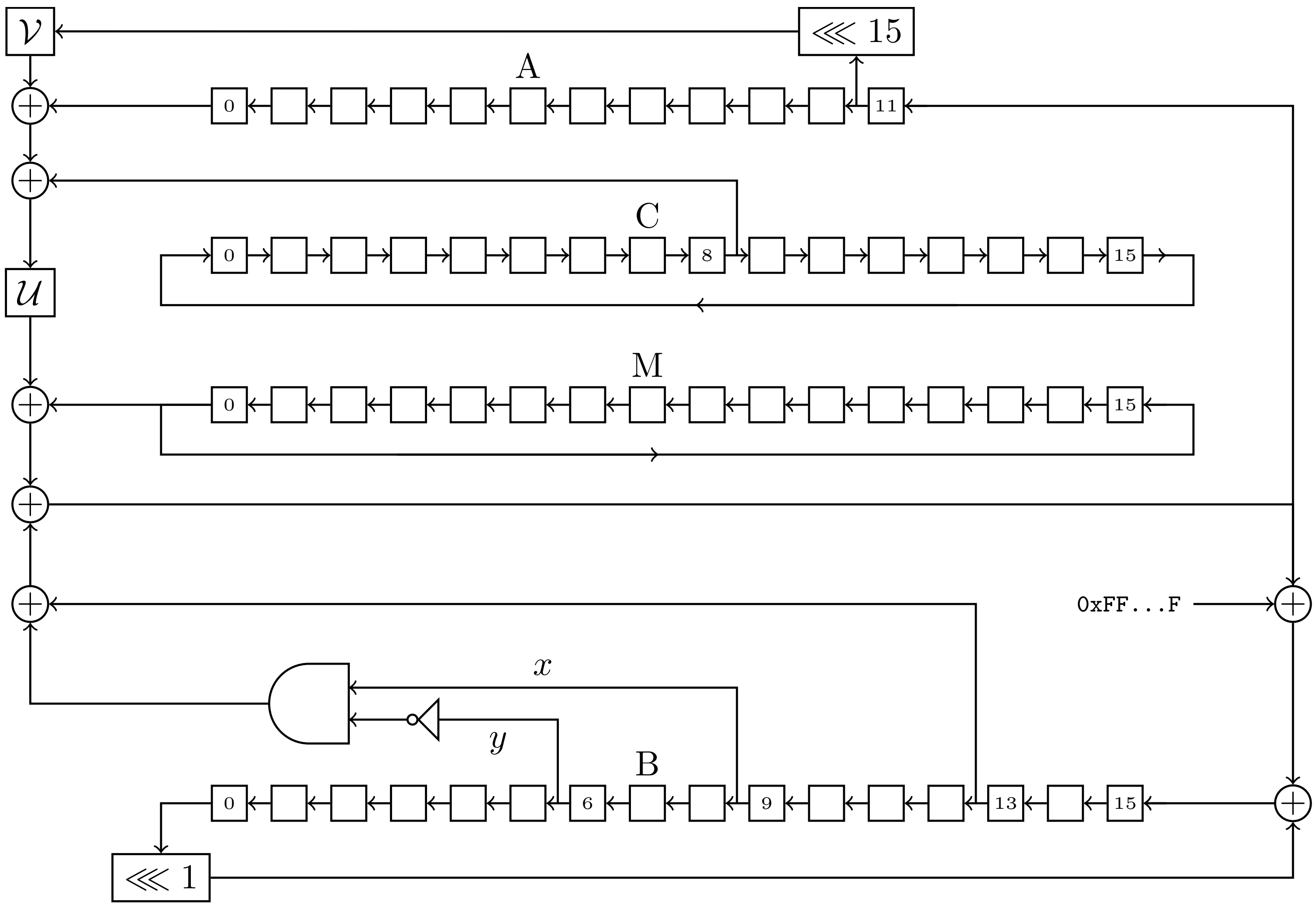
**end for**

**for** $j$ from $0$ to $35$ **do**

$A[j \bmod 12] \leftarrow A[j \bmod 12] + C[j + 3 \bmod 16]$

**end for**

# The keyed permutation (without the final update of $A$)

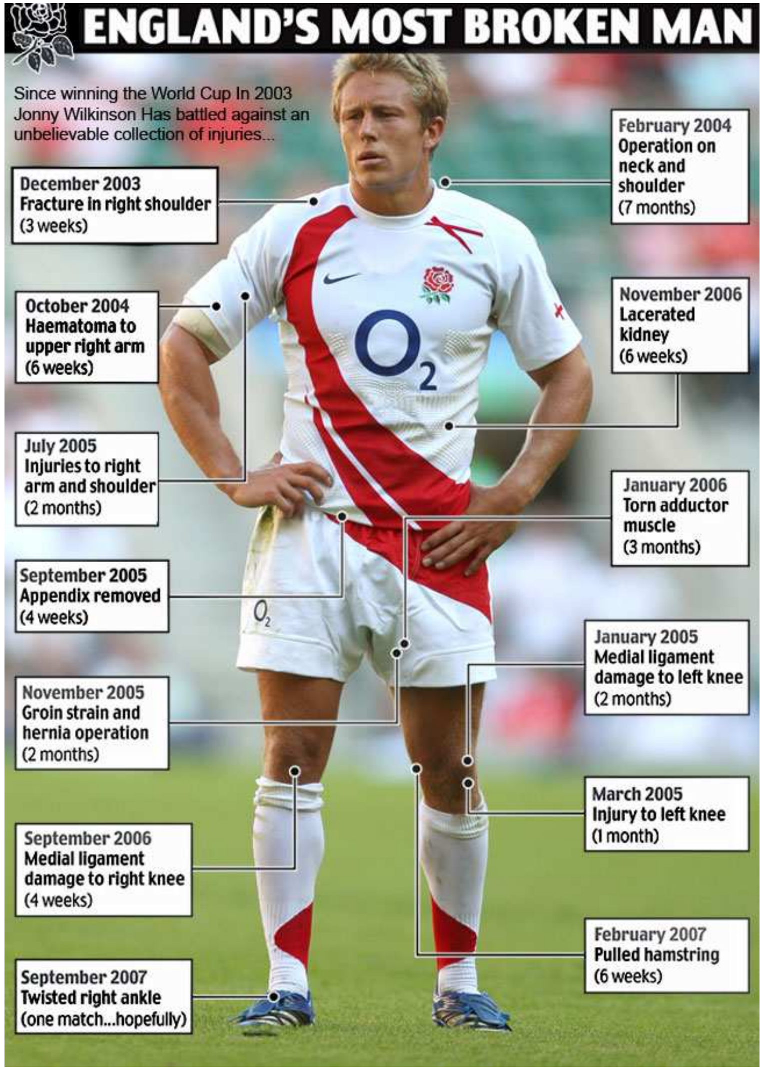


## Choice of the nonlinear permutations

$$\mathcal{U} : x \mapsto 3 \times x \bmod 2^{32}$$
$$\mathcal{V} : x \mapsto 5 \times x \bmod 2^{32}$$

- they avoid the use of look-up tables;
- they can be easily hard-coded (one bit shift and one addition);
- they cannot transform a symmetric difference (the all-one word) into a symmetric difference;
- one difference in the message block causes at least one difference between the inputs of $\mathcal{U}$ or of $\mathcal{V}$ after two rounds.

## Weakened versions of Shabal: Weakinson-xxx




http://www.dailymail.co.uk/sport/rugbyunion/article-480057/

Fast, efficient, with good statistics, but often broken.

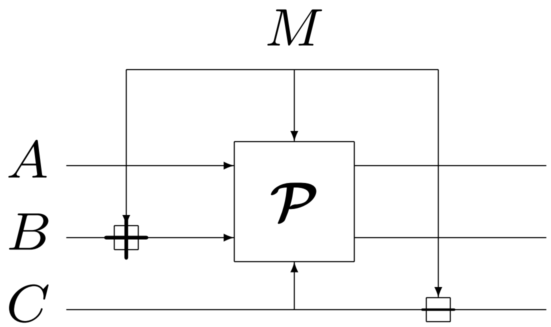
## Security analysis of Weakinson

### Distinguishers for the keyed permutation? [Aumasson09].

Distinguish $\mathcal{P}$ from some queries $\mathcal{P}_{M,C}(A,B)$ for fixed unknown values of $A, B, C$ and for different chosen values of $M$.

- distinguisher for $\mathcal{P}$ from $2^{12}$ queries [Aumasson09];
- distinguisher for $\mathcal{P}^{-1}$ from $2$ queries [Shabal, Section 11.6].

### Can such distinguishers be used?




- For Shabal: **no**;
- For Weakinson with $2$ loops instead of $3$ and without the final update of $A$ in $\mathcal{P}$: preimage attack with $2^{512}$ calls to $\mathcal{P}$ [Shabal, Section 11.6].

## Security claims

For any $\ell_h \in \{192, 224, 256, 384, 512\}$.

### Collision resistance.

Finding a collision for Shabal-$\ell_h$ requires at least $2^{\ell_h/2}$ calls to the message round function.

### Preimage resistance.

Any preimage attack against Shabal-$\ell_h$ requires at least $2^{\ell_h}$ calls to the message round function.

### Second-preimage resistance.

Any second-preimage attack against Shabal-$\ell_h$ for messages shorter than $2^k$ bits requires at least $2^{\ell_h - k}$ calls to the message round function.

### Resistance to length-extension attacks.

Any length-extension attack against Shabal-$\ell_h$ requires at least $2^{256}$ calls to the message round function.

## Cycles/byte: AMD 64 Intel Core 2 Quad [eBASH]

| | long | 4096 bytes | 576 bytes |
|---|---|---|---|
| Edon-R-512 | 3.06 | 3.20 | 3.75 |
| Blue Midnight Wish-512 | 5.26 | 5.45 | 6.28 |
| Skein-512 | 6.71 | 6.89 | 8.00 |
| SHA-1 | 7.50 | 7.89 | 10.22 |
| **Shabal-512** | **8.03** | **8.56** | **11.72** |
| BLAKE-64 | 10.06 | 10.53 | 12.08 |
| Keccak[r=1024,c=576] | 10.45 | 10.90 | 12.39 |
| SIMD-256 | 11.50 | 11.79 | 13.47 |
| CubeHash 8/16 | 13.46 | 14.65 | 21.84 |
| SHA-512 | 14.17 | 14.83 | 17.36 |
| Grøstl-512 | 30.09 | 31.63 | 37.83 |
| MD6-512 | 52.60 | 40.61 | 102.14 |
| SHAvite-3-512 | 111.50 | 115.03 | 124.78 |
| LANE-512 | 139.97 | 148.46 | 219.31 |
| CubeHash 8/1 | 213.01 | 214.19 | 221.39 |

## Cycles/byte: x86 Intel Core 2 Duo [eBASH]

| | long | 4096 bytes | 576 bytes |
|---|---|---|---|
| Edon-R-256 | 8.10 | 8.30 | 9.50 |
| Blue Midnight Wish-256 | 9.86 | 10.11 | 11.50 |
| **Shabal-512** | **10.22** | **10.90** | **15.04** |
| CubeHash 8/16 | 12.70 | 13.92 | 21.32 |
| SIMD-256 | 13.46 | 13.80 | 15.93 |
| BLAKE-32 | 20.15 | 20.59 | 23.18 |
| Grøstl-256 | 22.73 | 23.38 | 27.33 |
| SHA-256 | 22.98 | 23.47 | 26.43 |
| LANE-256 | 26.27 | 27.17 | 32.62 |
| SHAvite-3-256 | 29.38 | 30.04 | 33.76 |
| Keccak[r=1024,c=576] | 31.52 | 32.67 | 35.40 |
| Skein-512 | 38.89 | 39.79 | 45.01 |
| MD6-224 | 84.95 | 79.20 | 157.10 |
| SHA-512 | 115.27 | 119.30 | 131.15 |
| CubeHash 8/1 | 202.52 | 204.02 | 213.18 |

# Smartcard platforms

**32-bit processor.**

code size: 2 kBytes

RAM: 300 bytes

for 256-byte messages: 195 cycles/byte (IV approach)

($2\times$ slower than SHA-1)

**8-bit 8051 smartcard.**

code size: 1.2 kBytes

RAM: 192 bytes

for 256-byte messages: 2930 cycles/byte (IV approach)

($2.5\times$ slower than SHA-1)

**8-bit smartcard with arithmetic coprocessor.**

code size: 1.2 kBytes

RAM: 256 bytes

for 256-byte messages: 625 cycles/byte (IV approach)

($3\times$ slower than SHA-1)

# Conclusions

http://www.flickr.com/photos/sam_herd/2620280308/

- fast, simple and efficient;
- based on a provably secure operating mode;
- important security margins;
- very few instructions requested;
- no S-box;
- fast on many different platforms.