A Novel Permutation-based Hash Mode of Operation FP
and
The Hash Function SAMOSA

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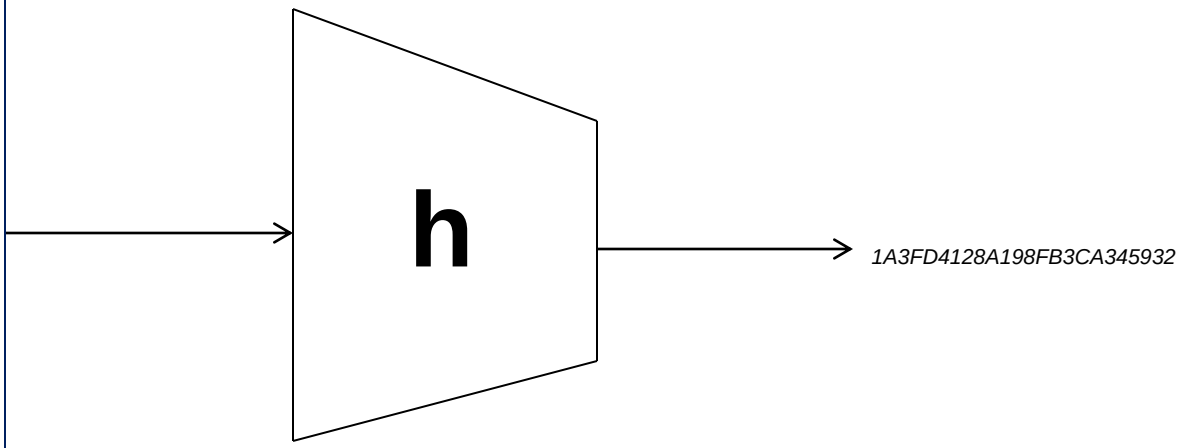
What is a hash function?

- $h:\{0,1\}^* \rightarrow \{0,1\}^n$

The UK-based bank was alleged to have helped launder money belonging to drug cartels and states under US sanctions.
Earlier this year HSBC admitted having poor money laundering controls following a US Senate investigation.
Last month announced it had set aside $1.5bn to cover the costs of any settlement or fines.
The deal could be announced as early as Tuesday, the Wall Street Journal reports.
It follows the announcement of a similar but much smaller settlement with UK-based Standard Chartered bank, which will pay $300m in fines for violating US sanction rules.



Uses of Hash Function

- digital signatures
- data authentication
- password-protection
- micro-payments
- Commitment protocol
- pseudo-random string generation/key derivation
- entropy extraction
- MACs, enciphering schemes
- 2005: 800 uses of MD5 in Microsoft Windows

Properties of a Hash Function

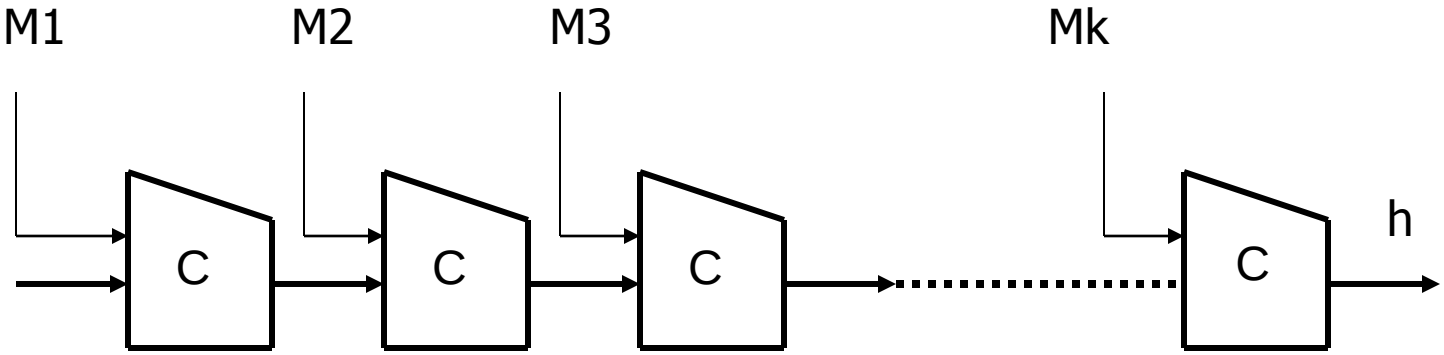
- Pre-image resistance
- 2nd Pre-image resistance
- Collision resistance
- Length extension attack resistance
- Indifferentiability attack resistance

Basic Recipe to Design an Iterative Hash Function

- Mode of Operation
- An iterative Function/Compression function
- Padding Rule
- Constants if any in the above three

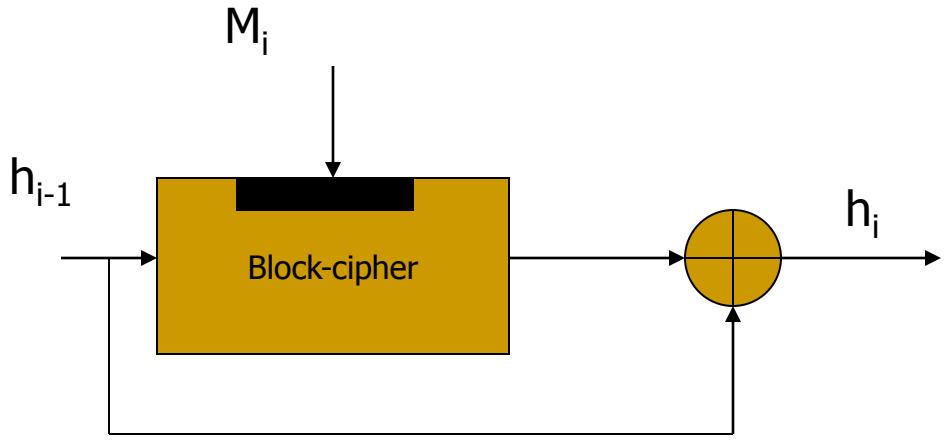
Example: Merkle-Damgard Mode

Pad(M)=$M_1M_2M_3$----M_K



Compression Function using a block cipher

- Davis-Meyer Construction



- More: Matyas-Meyer-Oseas, Miyaguchi-Preneel, etc.

Hash functions using Merkle-Damgard and Block Cipher

- SHA-0/1/2 (NIST/NSA)
- MD-4/5 (Rivest)
- RIPEMD (Dobbertin, Bosselaers and Preneel)
- WHIRLPOOL (Barreto and Rijmen)
- TIGER (Anderson and Biham)
- ..
- ..

Merkle-Damgard Mode is Damaged

- Length-extension attacks
- Joux multi-collision attacks
- Kelsey-Schneier 2^{nd} preimage attack
- Kelsey-Kohno Herding attack
- …

NIST SHA-3 Hash Function Competition

None of the 64 submitted algorithms was based on Merkle-Damgard Mode!!!

Block cipher may not be the best alternative

- Key schedule often turns out to be weak
- Implementing a wide block cipher requires relatively larger memory
- Ideal cipher assumption is a stronger assumption

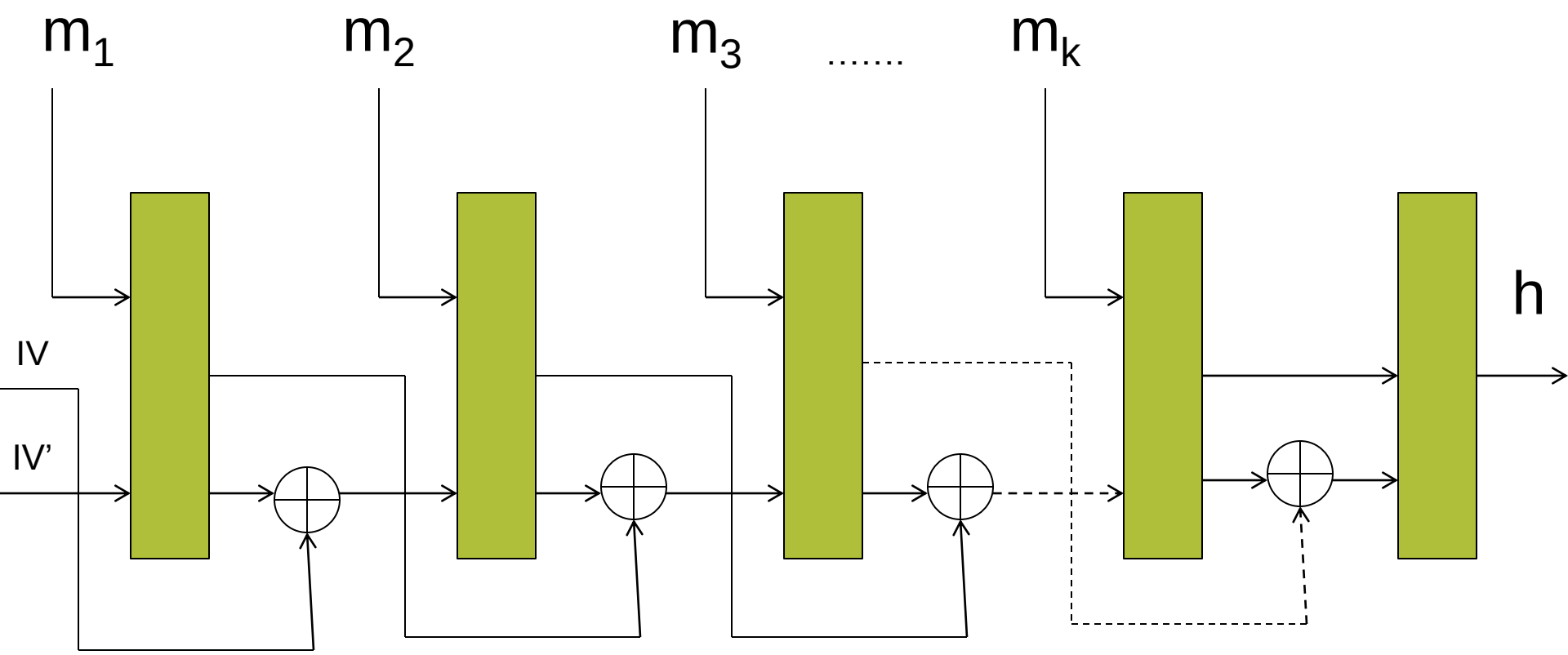
Block-cipher-based Hash Functions On the Decline

- Most of the hash functions in the recently concluded NIST SHA 3 hash function competition were not block-cipher-based
- 9 out 14 semi-finalists are permutation-based
- 3 out of 5 finalists are permutation-based
- The SHA-3 winner is permutation-based

Permutation-based Hash Functions

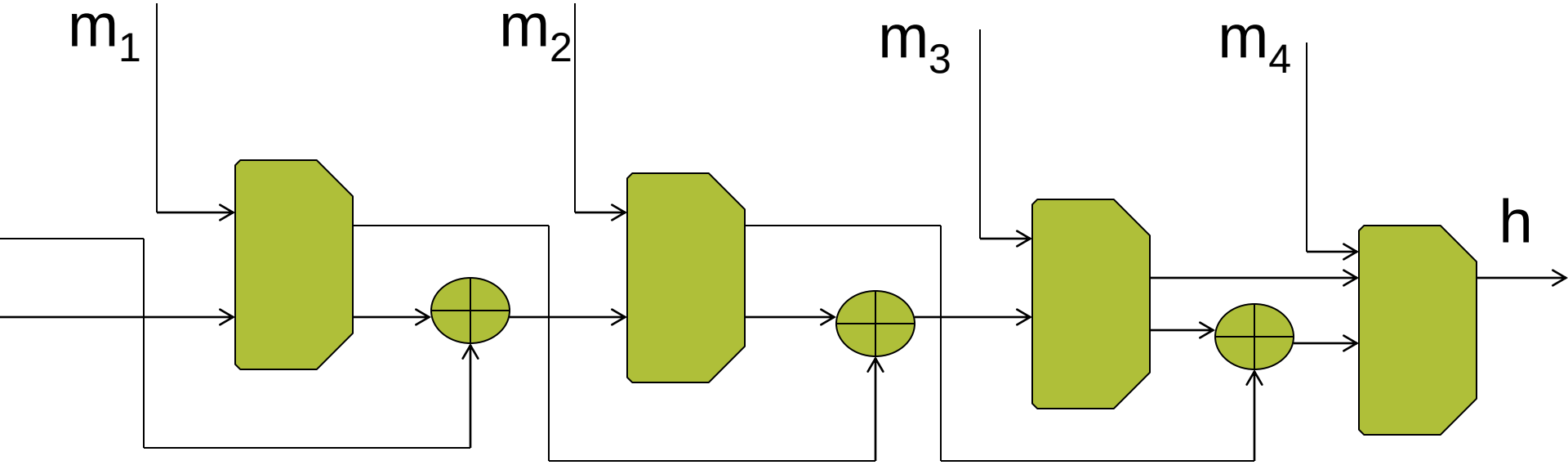
- Grøstl
- JH
- Sponge
- MD6
- Luffa
- HAMSI
- Parazoa
- ..

A Novel Permutation-based Mode: FP



All wires are n bits each

Origin of FP: The FWP Mode (2010)



FWP: rate=0.5; presently holds the record of achieving the best indifferentiability bound of 2n/3 bits (up to an additive constant)

How FP Mode compares With Other Permutation-based Modes

Mode of operation	Msg-blk (ℓ)	Size of π (a)	Rate (ℓ/a)	Indiff. bound		# of independent permutations
				lower	upper	
Hamsi [24]	$n/8$	$2n$	0.07	$n/2$	n	1
Luffa [5]	$n/3$	n	0.33	$n/4$	n	3
Sponge [4]	n	$3n$	0.33	n	n	1
Sponge [4]	n	$2n$	0.5	$n/2$	$n/2$	1
JH [29]	n	$2n$	0.5	$n/2$	$n(1-\epsilon)$	1
Grøstl [17]	n	$2n$	0.5	$n/2$	n	2
FP	$\boldsymbol{n}$	$\boldsymbol{2n}$	**0.5**	$\boldsymbol{n/2}$	$\boldsymbol{n}$	**1**
MD6 [14]	$6n$	$8n$	0.75	n	n	1
$\mathbf{FP}^{\mathrm{Ext1}}$	$\boldsymbol{6n}$	$\boldsymbol{7n}$	**0.85**	$\boldsymbol{n/2}$	$\boldsymbol{n}$	**1**

Proof of Indifferentiability

- We proved indifferentiability of FP up to n/2 bits. Full proof in eprint archive
- We conjecture that the bound could be improved up to 2n/3 bits

(We do not explain the proof here. But ….)

Small Cash Rewards

- Indifferentiability attack on FP mode with work n/2-bit or less (US$ 100)
- Indifferentiability attack on FP mode with work between n/2 and 2n/3-bit (US$ 50)
- Improvement of bound to 3n/4-bit or more (US$ 100)
- (Serious)Bug in the proof (US$99)

SAMOSA From Grøstl

Grøstl

SAMOSA

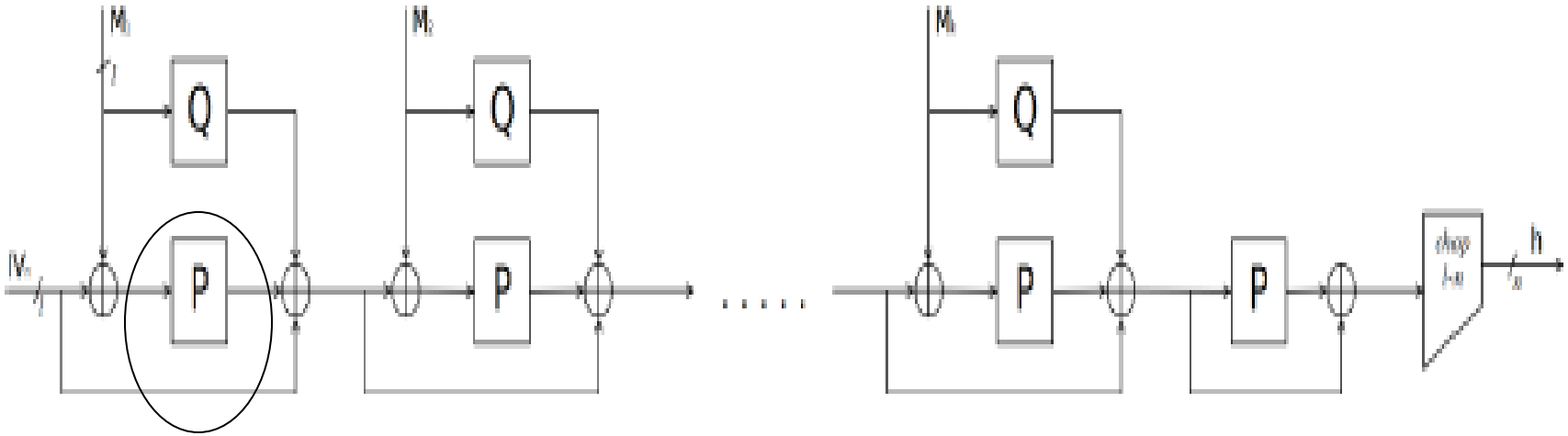
SAMOSA: A Hash Function Based on FP Mode

SAMOSA Hash Function

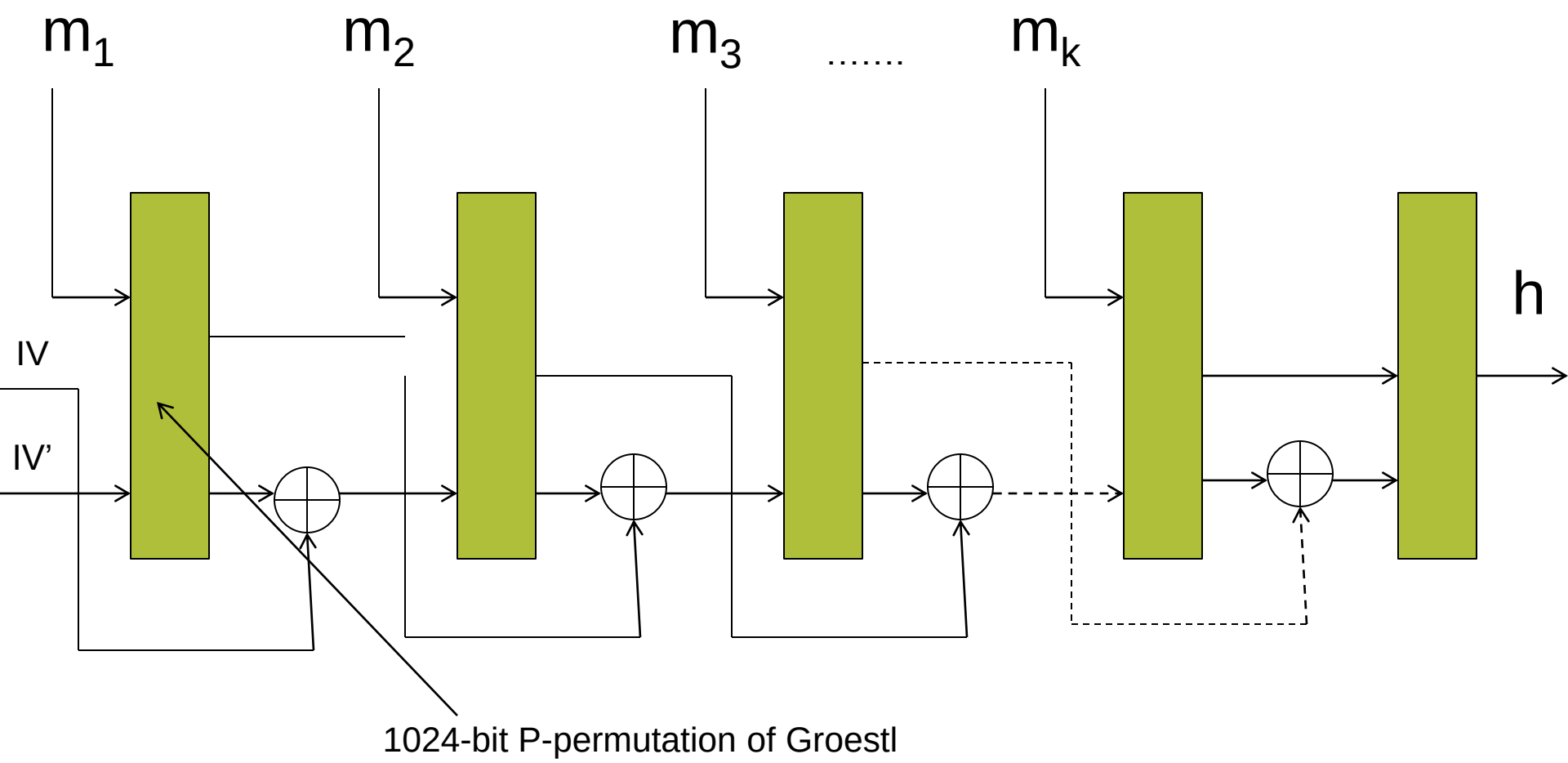
=

FP Mode + P-permutation of Grøstl

Grøstl Hash Function



SAMOSA Hash Function



Security of SAMOSA Hash Function

- Security of the FP Mode
  - Conjectured to be indifferentiable secure up to n bits
- Security of the 1024-bit P-permutation of Grøstl
  - Grøstl is one of the most heavily analyzed hash functions

SAMOSA: Hardware Implementation Motivation

- Performance in software and hardware decides whether an algorithm can be adopted as a standard when security levels of competing algorithms are comparable

- Grøstl is used as a reference point as it shares a very significant building block, permutation P, with SAMOSA

Grøstl: Hardware Implementation Previous Work

Grøstl-256, without padding unit, in Xilinx Virtex 5 FPGA

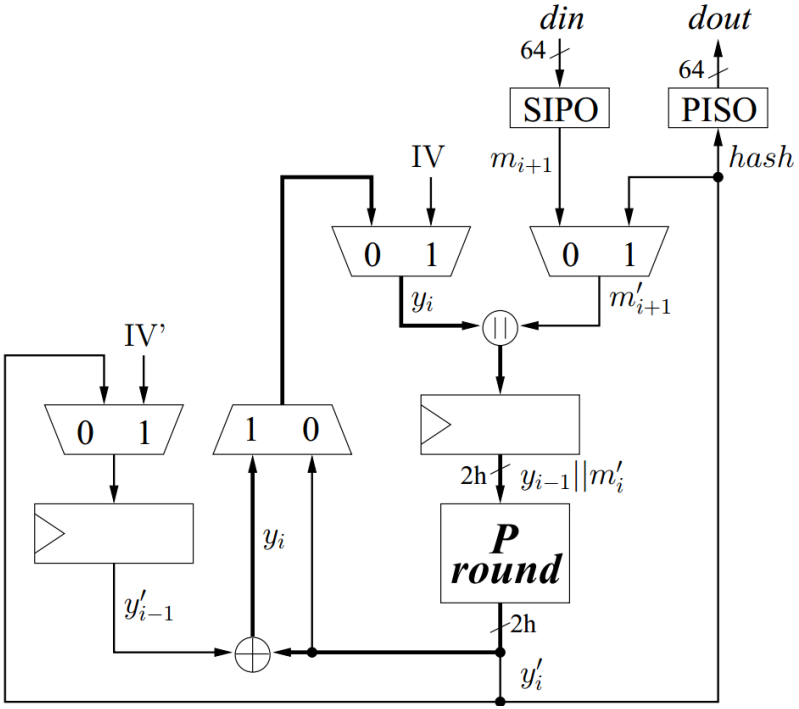
Source	Architecture Variant	Throughput [Mbit/s]	Area [CLB slices]	Thr/Area [(Mbit/s)/ CLB_slices]
Latif et al.	x1 (P/Q)	6200	1419	4.37
Gaj et al.*	**x1 (P/Q)**	**6117**	**1795**	**3.41**
Homsirikamol et al.	x1 (P/Q)	6072	1912	3.18
Gaj et al.	/2(v) (P/Q)	3721	1195	3.11
Homsirikamol et al.	/2(v) (P+Q)	4014	1598	2.51
Gaj et al.	x1 (P+Q)	7213	2906	2.48
Baldwin et al.	x1 (P+Q)	7709	3137	2.46
Guo et al.	x1 (P+Q)	5027	3798	1.32

**Implementation by Latif et al. is not portable among FPGA families, and its source code has not been published.*

Therefore, the implementation by Gaj et al. is used for comparison.

SAMOSA: Hardware Implementation Top-Level Comparison

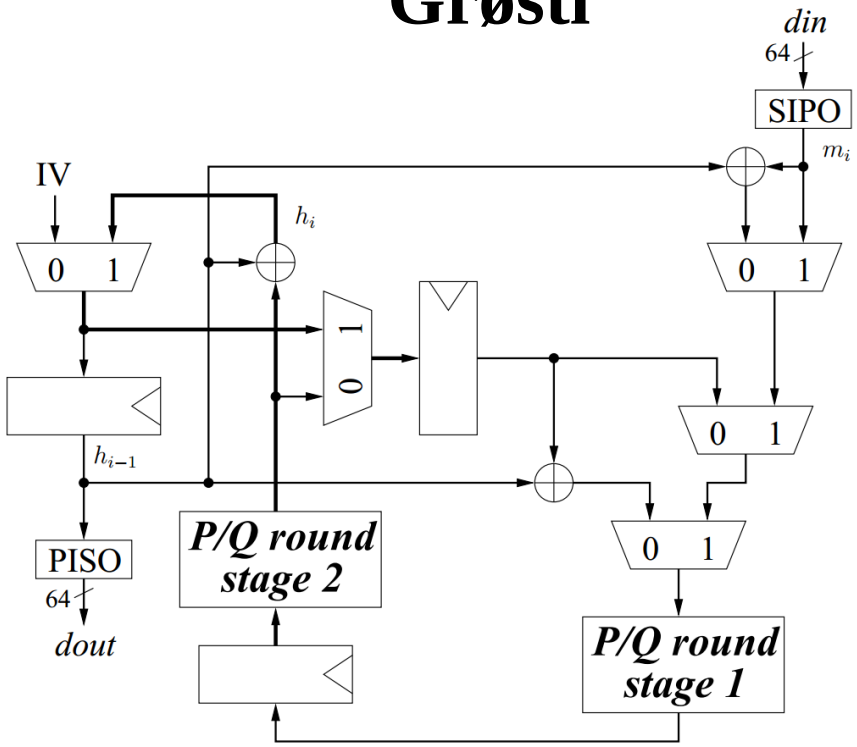
SAMOSA



SAMOSA-256: h=256
SAMOSA-512: h=512

Note: **All buses** are **h-bit wide**, unless specified otherwise

Grøstl



Grøstl-256: b=512
Grøstl-512: b=1024

Note: **All buses** are **b-bit wide**, unless specified otherwise

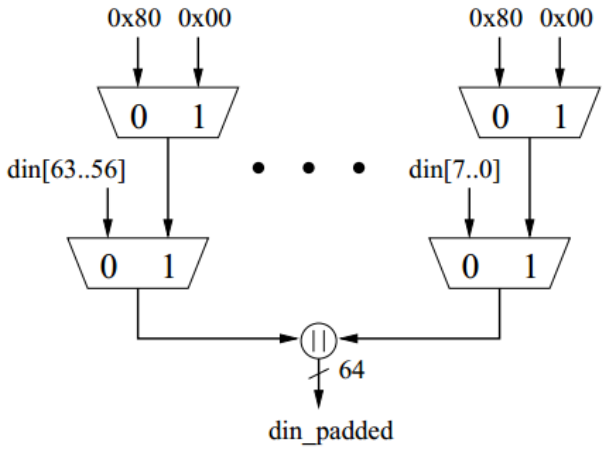
SAMOSA: Hardware Implementation Major Differences

	SAMOSA	**Grøstl**
Clock cycles per round	r	2r+1
Input block size	h	2h
Logic outside of the main round (P or P/Q)		
Number of 1-bit registers	3h	4h
Number of 2-to-1 multiplexers	4h	10h
Number of 2-input XOR gates	h	6h
Number of bits in SIPOs	h	2h

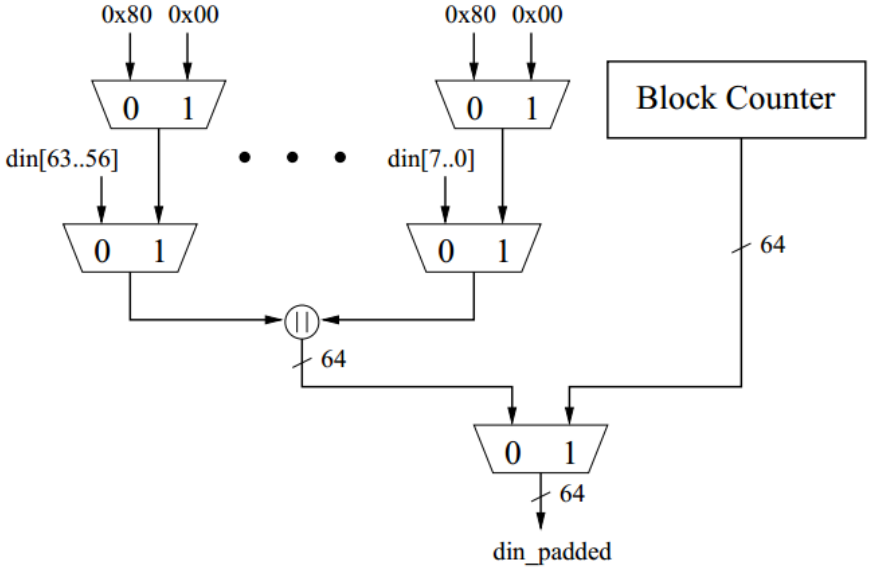
Notation:
r = number of rounds
h = hash size

SAMOSA: Hardware Implementation Padding Unit Comparison

SAMOSA



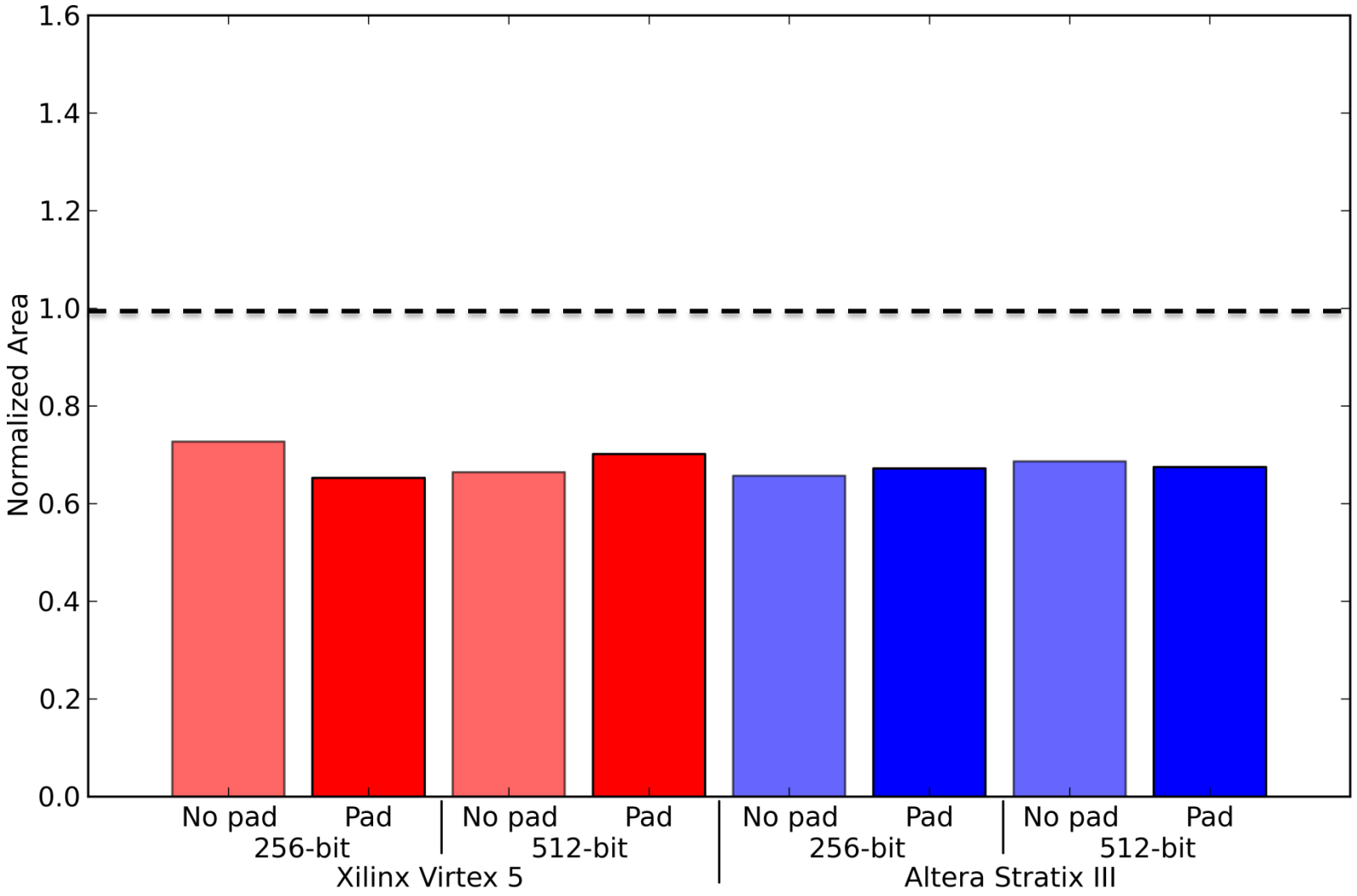
Grøstl



Block counter is not needed any longer in SAMOSA

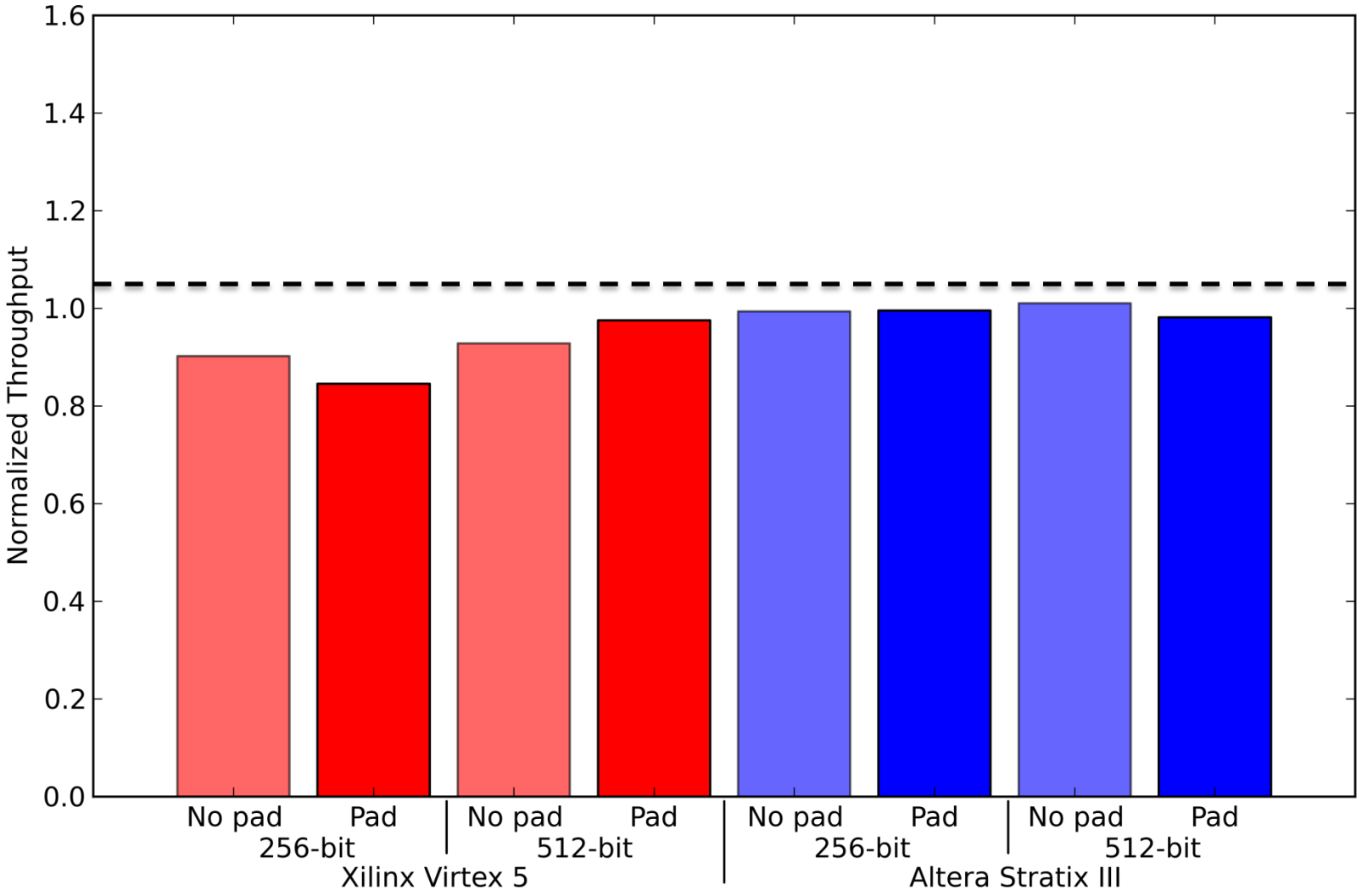
SAMOSA: Hardware Implementation Normalized Area

Normalized to Grøstl with the same padding mode, hash size, and FPGA family



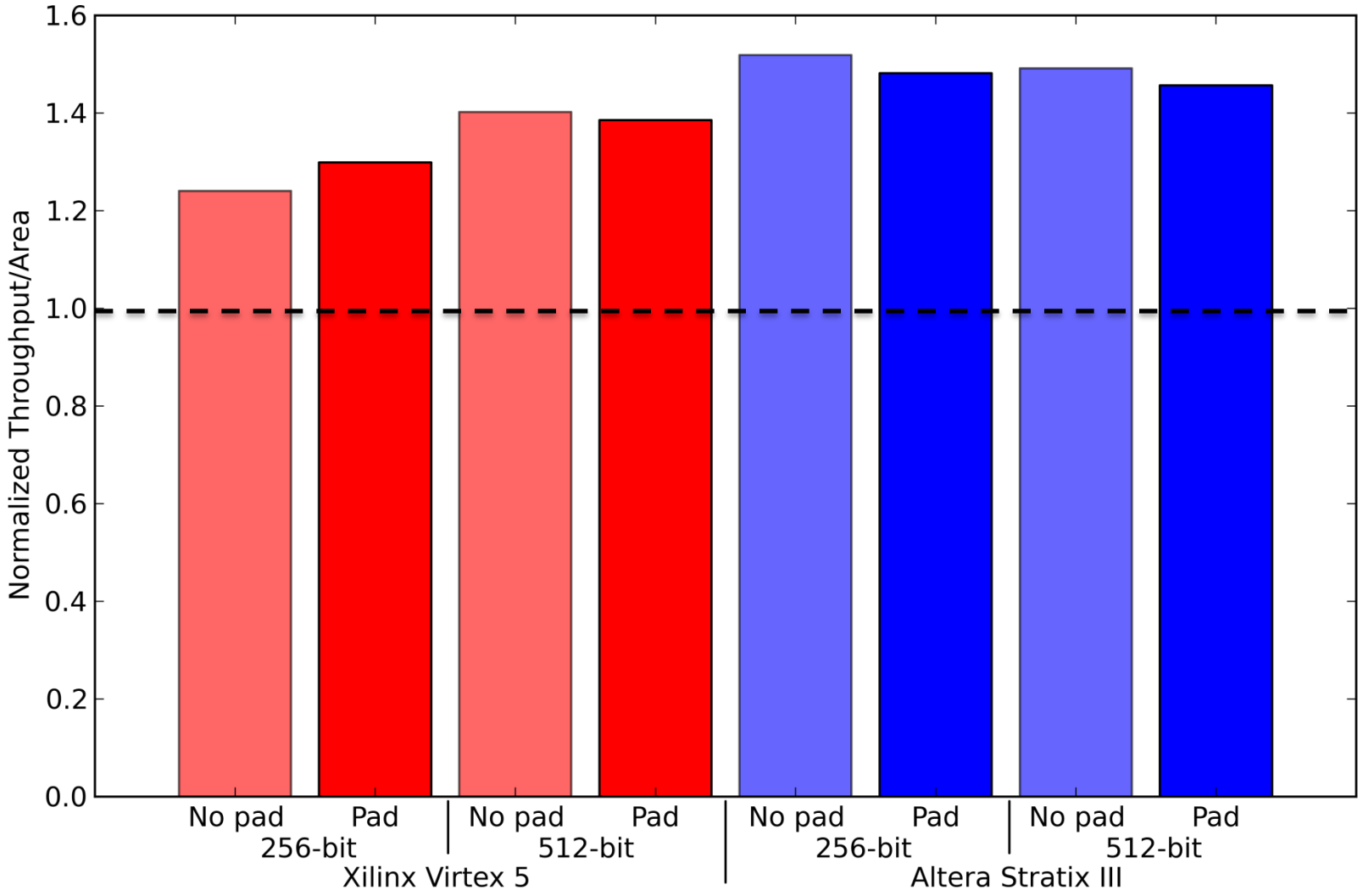
SAMOSA: Hardware Implementation Normalized Throughput

Normalized to Grøstl with the same padding mode, hash size, and FPGA family

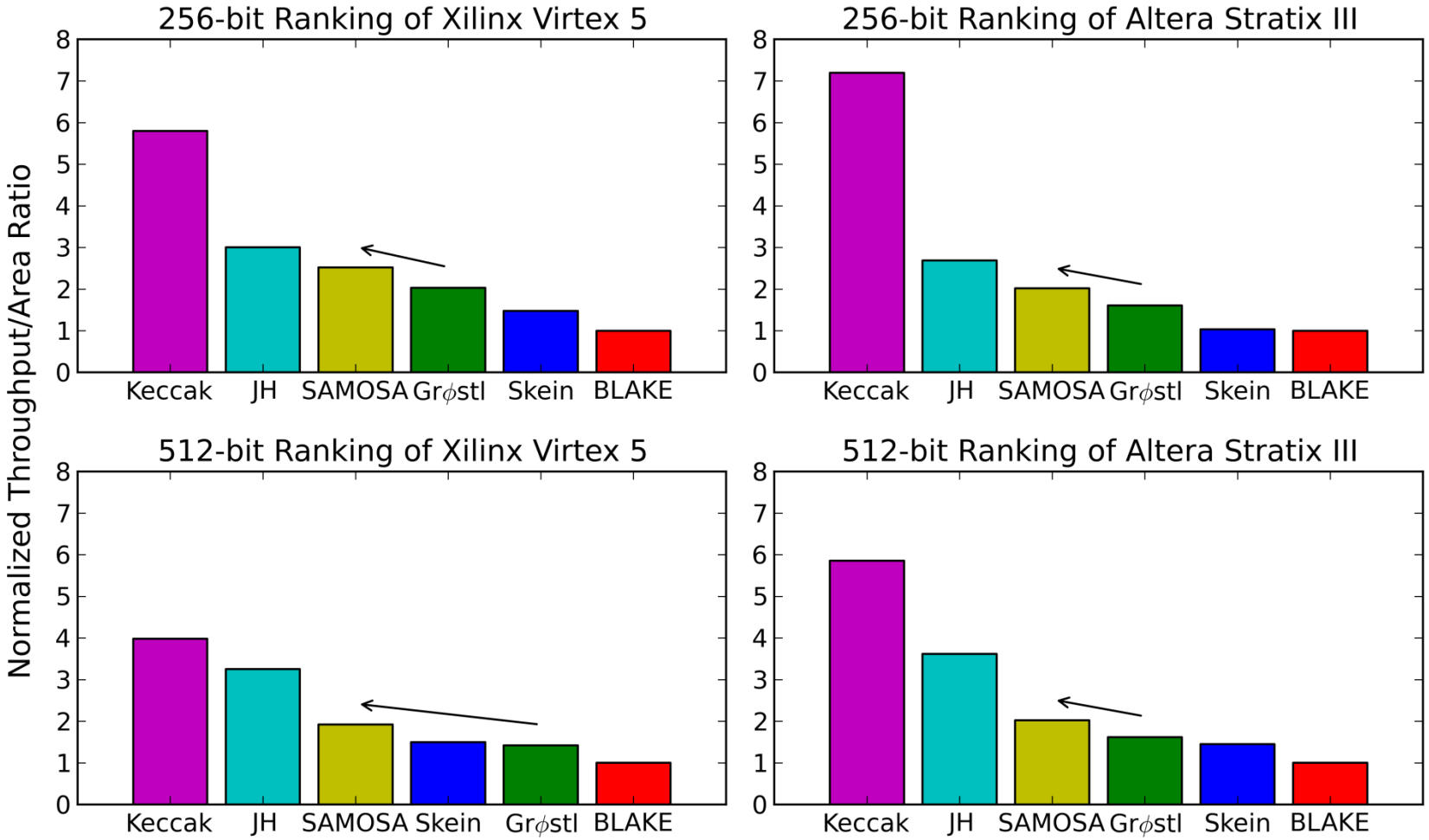


SAMOSA: Hardware Implementation Normalized Throughput/Area ratio

Normalized to Grøstl with the same padding mode, hash size, and FPGA family



SAMOSA: Hardware Implementation Best Single Message Ranking



All values normalized to the lowest throughput/area ratio (i.e., to the results for BLAKE)

Conclusions

- We propose a new permutation-based hash mode of operation FP and the hash function SAMOSA based on that.

- SAMOSA performs consistently better than BLAKE, Grøstl and Skein, and loses only to Keccak and JH

- The performance of SAMOSA may be improved by changing the underlying permutation

Thanks

Questions?