QUARK
a lightweight hash

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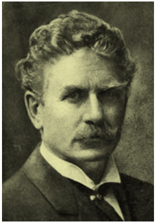
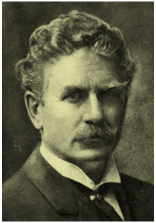


HASH, x. There is no definition for this word—nobody knows what hash is.

A. Bierce, The Devil's Dictionary



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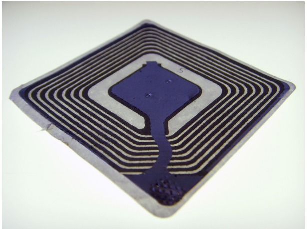
Arbitrary long string $\xrightarrow{HASH}$ Short random-looking string

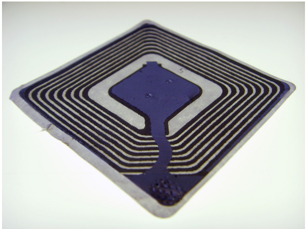
Most common hashes: MD5 (128 bits), SHA-1 (160 bits)

Hashing in dedicated IC's (as RFID tags' chips)



- Identification protocols
- Message authentication

Hashing in dedicated IC's (as RFID tags' chips)



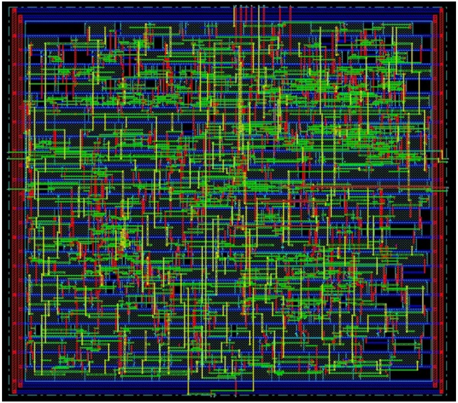
- Identification protocols
- Message authentication

MD5 and SHA-1 generally too big (6000+ GE)

Smallest known proposal: PRESENT-based hashes by Bogdanov et al. (CHES 2008)

- 64-bit hash: 1600 GE
- 128-bit hash: 2330 GE

QUARK



- 128-bit hash: 1379 GE
- 160-bit hash: 1702 GE
- 224-bit hash: 2296 GE

Let the design define security, not the hash length

Folklore: security defined by the hash length
$\Rightarrow$ restricts the diversity of designs

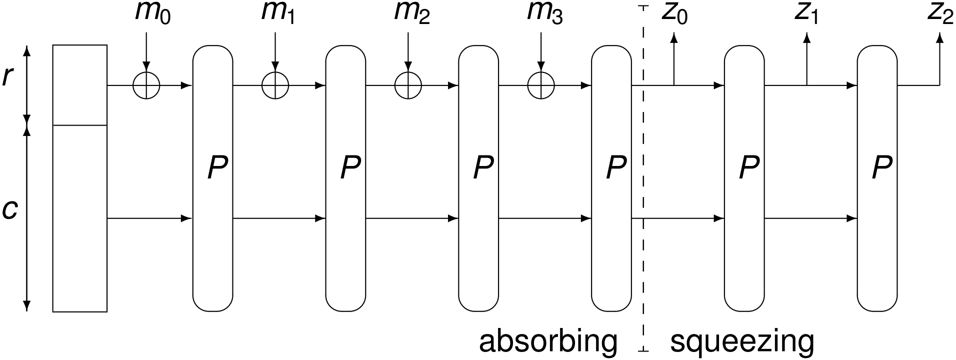
Let the design define security, not the hash length

Folklore: security defined by the hash length
⇒ restricts the diversity of designs

Proposal by Bertoni/Daemen/Peeters/Van Assche:
security defined by a parameter (the capacity)

Sponge functions

1. "Absorb" chunks of message $m_0, m_1, \ldots$
2. "Squeeze" to extract hash value $z_0, z_1, \ldots$



Sponge reduce memory requirements, if one tolerates suboptimal 2nd preimage resistance

Example:

- hash length $n = 128$
- capacity $c = 128$
- block size $r = 8$

If P is secure, guaranteed security of

- 128 bits against preimages (cf. next talk at 9h50)
- 64 bits against 2nd preimages
- 64 bits against collisions

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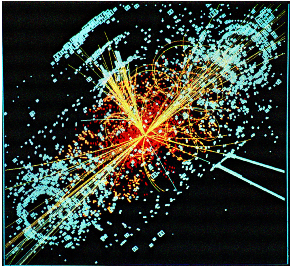
⇒ storage of 136 bits, instead of 256 with traditional constructions (save ≈1000 GE)

The 3 QUARK flavors



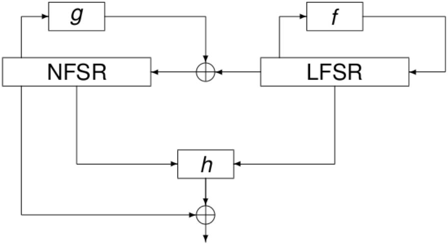
	capacity	block	state
	$n = c$	r	$c + r$
U-QUARK	128	8	136
D-QUARK	160	16	176
T-QUARK	224	32	256

Don't reinvent the wheel: borrow from the best lightweight algorithms

Grain (stream cipher)
Hell/Johansson/Meier, ECRYPT eSTREAM portfolio

KATAN (block cipher)
De Cannière/Dunkelman/Knežević, CHES 2009

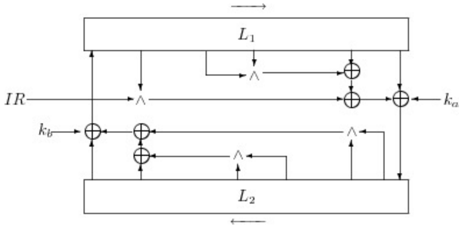
Grain



What we borrow

- Update mechanism with 3 boolean functions
- High-degree boolean functions for rapid growth of internal nonlinearity
- Internal parallelism to allow space/time implementation trade-offs

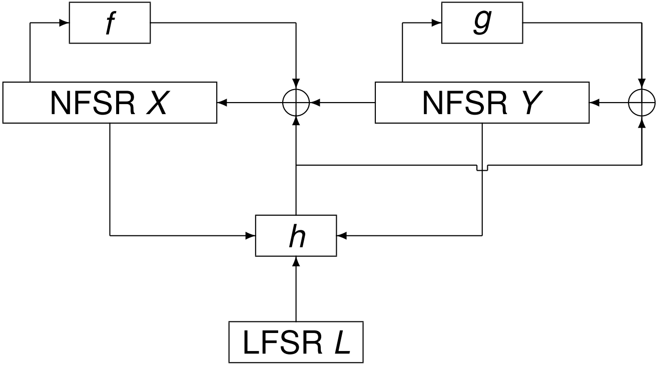
KATAN



What we borrow

- 2 NFSR’s rather than 1 NFSR and 1 LFSR for better nonlinearity, and to avoid too much dissymmetry
- Auxiliary LFSR as a counter and breaking round self-similarity

QUARK's *P* permutation



- Load input in (X, Y) and a constant in L
- Clock $4 \times (|X| + |Y|)$ times
- Return final value of (X, Y)

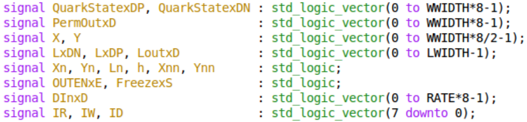
Confidence in security based on

- Well-chosen boolean functions and taps
- High number of rounds (4× that of Grain)
- Benchmarks with basic cube and differential attacks $\Rightarrow$ 22% of the rounds broken (nonrandom), consistent for all 3 flavors of QUARK

	Total	Rounds attacked		
	rounds	in 2^8	in 2^{16}	in 2^{24}
U-QUARK	544	109	111	114
D-QUARK	704	144	144	148
T-QUARK	1024	213	220	222

Sponge proof $\Rightarrow$ any attack must exploit a flaw in P

VHDL implementation



```
signal QuarkStatexDP, QuarkStatexDN : std_logic_vector(0 to WWIDTH*8-1);
signal PermOutxD                    : std_logic_vector(0 to WWIDTH*8-1);
signal X, Y                         : std_logic_vector(0 to WWIDTH*8/2-1);
signal LxDN, LxDP, LoutxD           : std_logic_vector(0 to LWIDTH-1);
signal Xn, Yn, Ln, h, Xnn, Ynn      : std_logic;
signal OUTENxE, FreezexS            : std_logic;
signal DInxD                        : std_logic_vector(0 to RATE*8-1);
signal IR, IW, ID                   : std_logic_vector(7 downto 0);
```

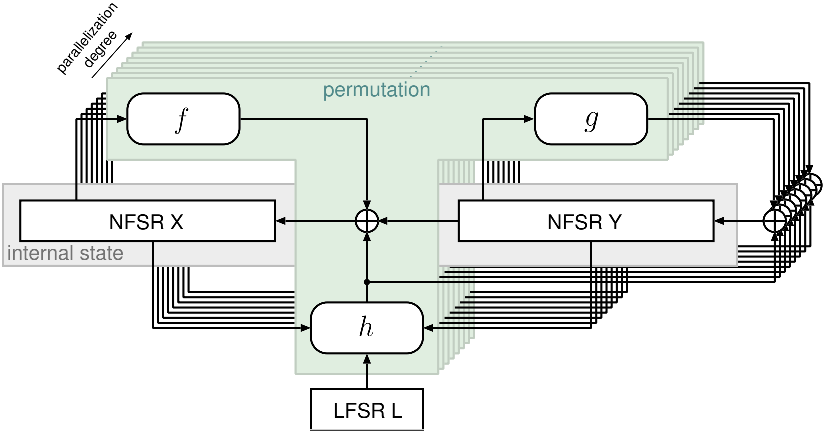
2 architectures of each flavor

- Serial (1 instance of each boolean function)
- Parallel (8 or 16 instances of each function)

Tech: UMC 0.18 µm 1P6M CMOS

Place-and-route, and simulations at 100 kHz

Goal: minimize area and power consumption

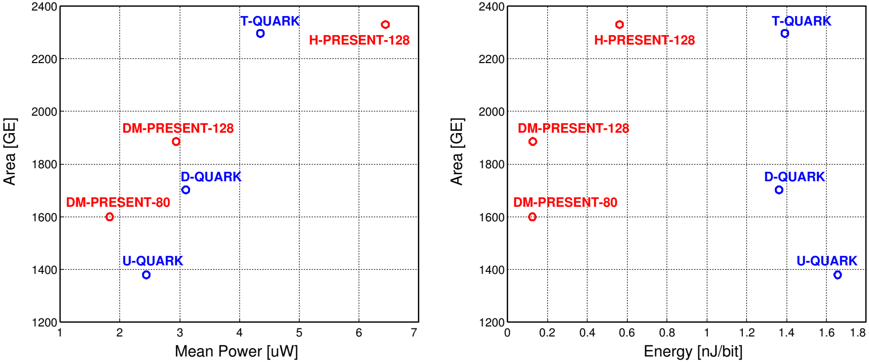

parallelization degree
permutation
f
g
NFSR X
NFSR Y
internal state
h
LFSR L

QUARK vs. PRESENT-based hashes (serial)

	Security			Area	Thr.	Power [µW]	
	Pre	2nd	Col	[GE]	[kbps]	Mean	Peak
DM-PRESENT-80	64	64	32	1600	14.63	1.83	-
DM-PRESENT-128	64	64	32	1886	22.90	2.94	-
H-PRESENT-128	128	128	64	2330	11.45	6.44	-
U-QUARK	128	64	64	1379	1.47	2.44	2.96
D-QUARK	160	80	80	1702	2.27	3.10	3.95
T-QUARK	224	112	112	2296	3.13	4.35	5.53

QUARK vs. PRESENT-based hashes (parallel)

	Security			Area	Thr.	Power [µW]	
	Pre	2nd	Col	[GE]	[kbps]	Mean	Peak
DM-PRESENT-80	64	64	32	2213	242.42	6.28	-
DM-PRESENT-128	64	64	32	2530	387.88	7.49	-
H-PRESENT-128	128	128	64	4256	200.00	8.09	-
U-QUARK×8	128	64	64	2392	11.76	4.07	4.84
D-QUARK×8	160	80	80	2819	18.18	4.76	5.80
T-QUARK×16	224	112	112	4640	50.00	8.39	9.79


2400
2200
2000
1800
1600
1400
1200
Area [GE]
1
2
3
4
5
6
7
Mean Power [uW]
T-QUARK
H-PRESENT-128
DM-PRESENT-128
D-QUARK
DM-PRESENT-80
U-QUARK
2400
2200
2000
1800
1600
1400
1200
Area [GE]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Energy [nJ/bit]
H-PRESENT-128
T-QUARK
DM-PRESENT-128
D-QUARK
DM-PRESENT-80
U-QUARK

QUARK is indeed lightweight!

- 128-bit preimage resistance with only 1379 GE
- 224-bit preimage resistance with only 2296 GE
- Low power consumption ($<$5 µW)

Compared to PRESENT-based hashes

- Better security/area ratio
- Lower throughput (and thus more energy/bit)
- Better security margin
  ($\approx$80% of PRESENT's rounds attacked)

A multi-purpose primitive!

Like most hash functions, QUARK can be used as

- PRF
- MAC
- PRNG
- stream cipher
- entropy extractor
- parallel tree-hash
- key derivation function

etc.

A hash is always secure, until it's broken.
(adapted from) Y. Berra

Please cryptanalyze QUARK!

Full version of the paper, VHDL and C code available at

http://131002.net/quark/

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