Secure Hash Algorithm 3

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Senior Seminar

Why should you care?

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Almost everything you do online uses a hash function

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- Passwords

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- Passwords
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- Message authentication

Hash Algorithms

"Any function that can be used to map data of arbitrary size to data of a fixed size"

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SHA-256[My] ->

8ed6791bdf3d61a1e6edcbb253979b0a6bef7f3d99dda0fb49cffe96923514b6

SHA-256[My name is Courtney] ->

543ab313f11d6316f84438e074964058613ffa595f1494f81eeafad23364b7cb

SHA-256, www.movable-type.co.uk

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SHA-256[My name is Courtnet] ->

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SHA-256[My name is Courtnet] ->

602e1fad697d322020a89b03339458cdcfabfef70a6173ae1daf4feafebe4a76

HASH[Pay me $30] = HASH[You owe me $50] $\leftarrow$ collision!

SHA-256, www.movable-type.co.uk

Outline

1. Background
   - History
   - Operators
   - Notation
   - Liner Feedback Shift Registers
   - Padding
2. Base Construction
3. Inner Workings
4. Conclusion

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SHA3 - 2015, chosen via competition.

Bitwise Operators

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XOR ($\oplus$) : Adding bits modulo 2

$$
\begin{array}{r}
0011 \\
\oplus 0101 \\
= 0110
\end{array}
$$

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AND ($\wedge$) : Multiplying bits modulo 2

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NOT ($\neg$) : Bit flipping

$$\begin{array}{r} \neg(0011) \\ = 1100 \end{array}$$

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($\varepsilon, 0, 1, 0010101, 100001,$ *etc*)

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A series of n 0s or 1s will be written 0^n or 1^n
So 111100 can be written $1^4 0^2$
If the number of bits is unknown, we'll use 0^* or 1^*

LFSRs

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LFSR	Output
100	-

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111	0

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LFSR	Output
100	-
110	0
111	0
011	1

Padding

Hash functions work with a specific block size

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Protect against extension attacks

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0110011 with a block size of 4 becomes

0110|011

0110|0111|0001

Outline

Sponge Construction

Transformation f, padding, and the bitrate r (and capacity c)
r+c=length of state s

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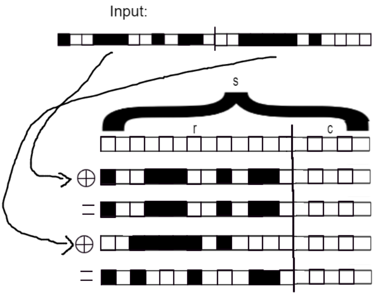

Sponge Construction

Transformation f, padding, and the bitrate r (and capacity c)
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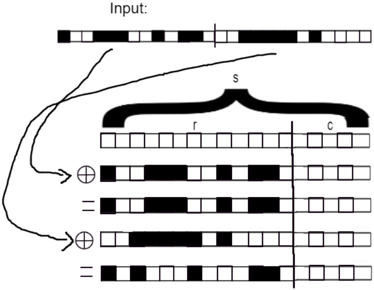
Variable input and output length, but fixed-length transformation

Absorbing: XOR r-length blocks into s, interleaved with the transformation

Squeezing: output r-length blocks, interleaving with transformation f



Example

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Input: 10010100
$f(x)$: Circular Left Shift by 1 (Shift left by 1 bit)
Block length: 4
Capacity: 2
Output length: 12

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Padding:

1001|0100|1001

Example

1001|0100|1001

Absorb:

$$
\begin{aligned}
s_0^a &= 000000 \\
s_1^a &= s_0^a \oplus 1001||00
\end{aligned}
$$

$$
\begin{aligned}
& 000000 \\
\oplus & 100100 \\
= & 100100
\end{aligned}
$$

$$
\begin{aligned}
s_2^a &= f(s_1^a) \\
&= f(100100) \\
&= 001001
\end{aligned}
$$

Example

1001|<u>0100</u>|1001

Absorb:

$$
\begin{aligned}
s_2^a =& 001001 \\
s_3^a =& s_2^a \oplus 0100||00 \\
\\
& \ 001001 \\
& \oplus 010000 \\
& = 011001 \\
s_4^a =& f(s_3^a) \\
=& f(011001) \\
=& 110010
\end{aligned}
$$

Example

1001|0100|<u>1001</u>

Absorb:

$$\begin{aligned}
s_4^a =& 110010 \\
s_5^a =& s_4^a \oplus 1001||00 \\
\\
& \;110010 \\
\oplus& 100100 \\
=& 010110 \\
s_6^a =& f(s_5^a) \\
=& f(010110) \\
=& 101100
\end{aligned}$$

Example

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Z &= \varepsilon \\
s_0^s &= 101100
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$$\begin{aligned} Z &= Z||\lfloor s_1^s \rfloor_4 \\ &= 1011|0110 \\ s_2^s &= f(s_1^s) \\ &= f(011001) \\ &= 110010 \end{aligned}$$

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Output: 101101101100

Outline

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There are 7 different versions of Keccak, labelled 0-6 (ℓ)

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Consists of n_r rounds of R, where R = $\iota \circ \chi \circ \rho \circ \pi \circ \theta$.

n_r = 12+2ℓ

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$$s[w(5y + x) + z] = \alpha[x][y][z]$$

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$s[w(5y + x) + z] = \alpha[x][y][z]$
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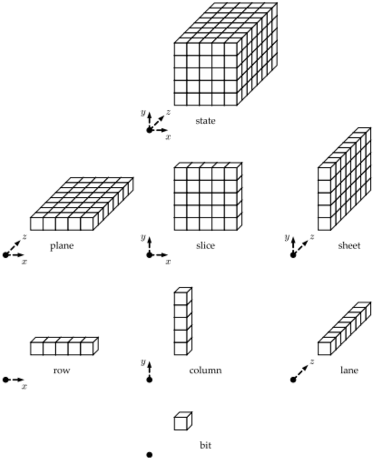

The state of Keccak [Keccak Reference]

R $= \iota \circ \chi \circ \rho \circ \pi \circ \underline{\theta}$.

Theta

```
FOR x = 0 to 4
    C[x][z] := α[x][0][z]
    FOR y = 1 to 4
        C[x][z] := C[x][z] ⊕ α[x][y][z]
    END FOR
END FOR
FOR x = 0 to 4
    D[x][z] := C[x-1][z] ⊕ C[x+1][z-1]
    FOR y = 0 to 4
        α[x][y][z] := α[x][y][z] ⊕ D[x][z]
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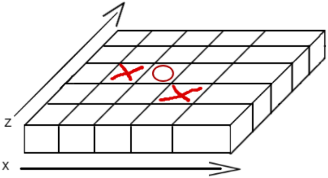

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For massive diffusion

R = $\iota \circ \chi \circ \rho \circ \underline{\pi} \circ \theta$.

Pi

FOR x = 0 to 4

FOR y = 0 to 4

$$\begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 2 & 3 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

α[a][b][z] := α[x][y][z]

END FOR

END FOR

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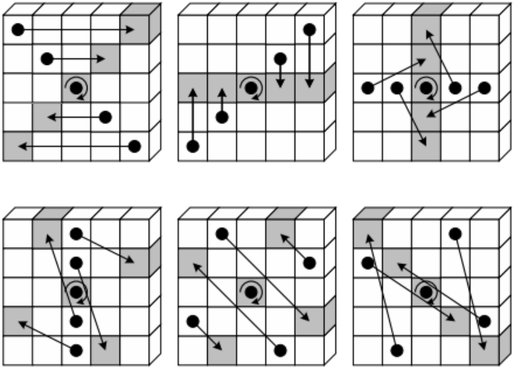
Lanes shifted



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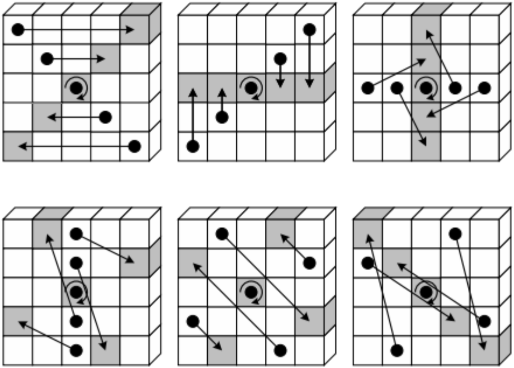

Pi [Keccak Reference]

For long-term diffusion

$\mathrm{R} = \iota \circ \chi \circ \underline{\rho} \circ \pi \circ \theta.$

Rho

$$\begin{bmatrix} x \\ y \end{bmatrix} := \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

FOR t = 0 to 23

α[x][y]: = ROT(α[x][y],(t+1)(t+2)/2)

$$\begin{bmatrix} x \\ y \end{bmatrix} := \begin{bmatrix} 0 & 1 \\ 2 & 3 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

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So when t = 2, rotate lane at α[2][3] by 6

For inter-slice dispersion

$R = \iota \circ \underline{\chi} \circ \pi \circ \rho \circ \theta.$

Chi

FOR x = 0 to 4
FOR y = 0 to 4
α[x][y] := α[x][y]
$\oplus$ ($\neg\alpha$[x+1][y] $\wedge$ α[x+2][y])
END FOR
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Non-linear

$\mathrm{R} = \underline{\iota} \circ \chi \circ \pi \circ \rho \circ \theta.$

Iota

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LFSR output is XORed with lane at α[0][0]

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To disrupt symmetry

Outline

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Collisions found for SHA1, can be applied to SHA2.

Thank You

Elena Machkasova, advisor

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Questions?