Cryptanalysis, Reverse-Engineering and Design of Symmetric Cryptographic Algorithms

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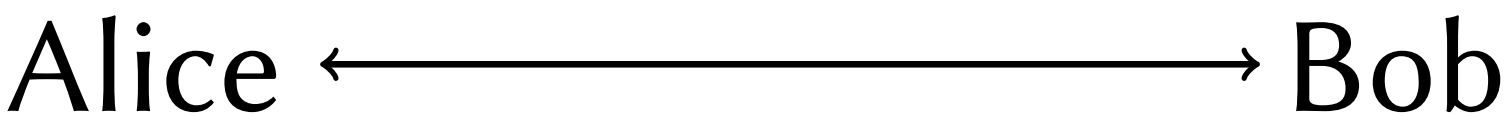
CryptoLUX Team ; supervised by Alex Biryukov

July 5th 2018

Cryptography? (1/3)



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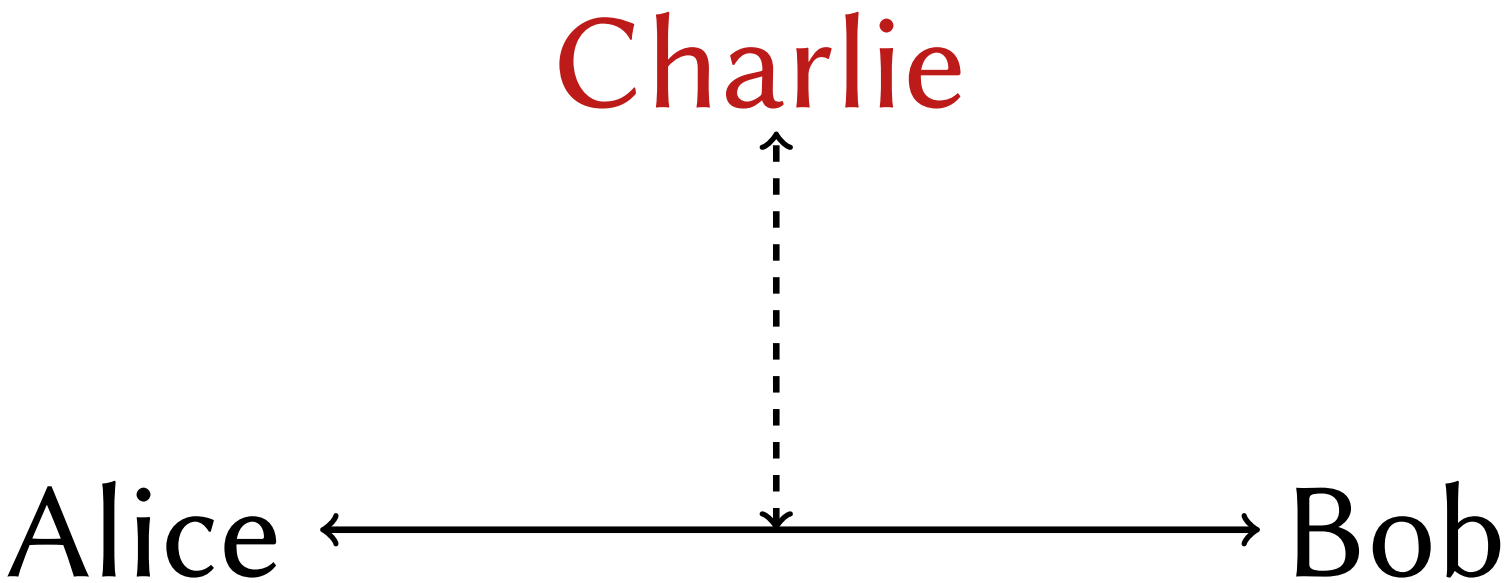
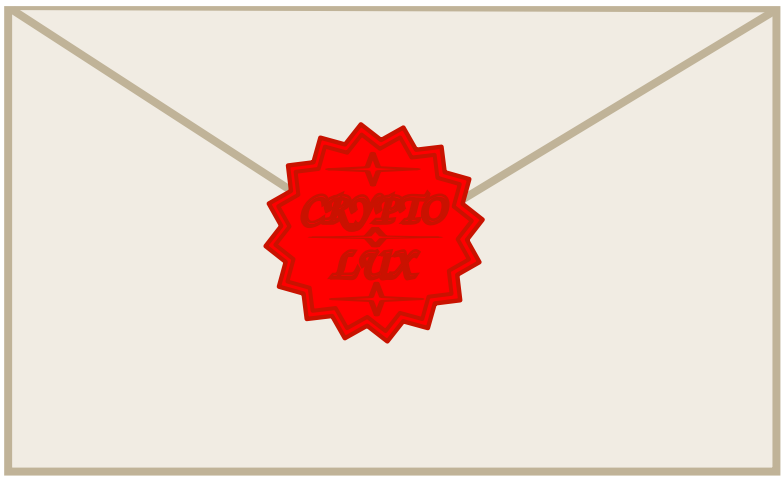


Cryptography? (1/3)

Cryptography? (2/3)

Cryptography is everywhere!

Cryptography? (3/3)



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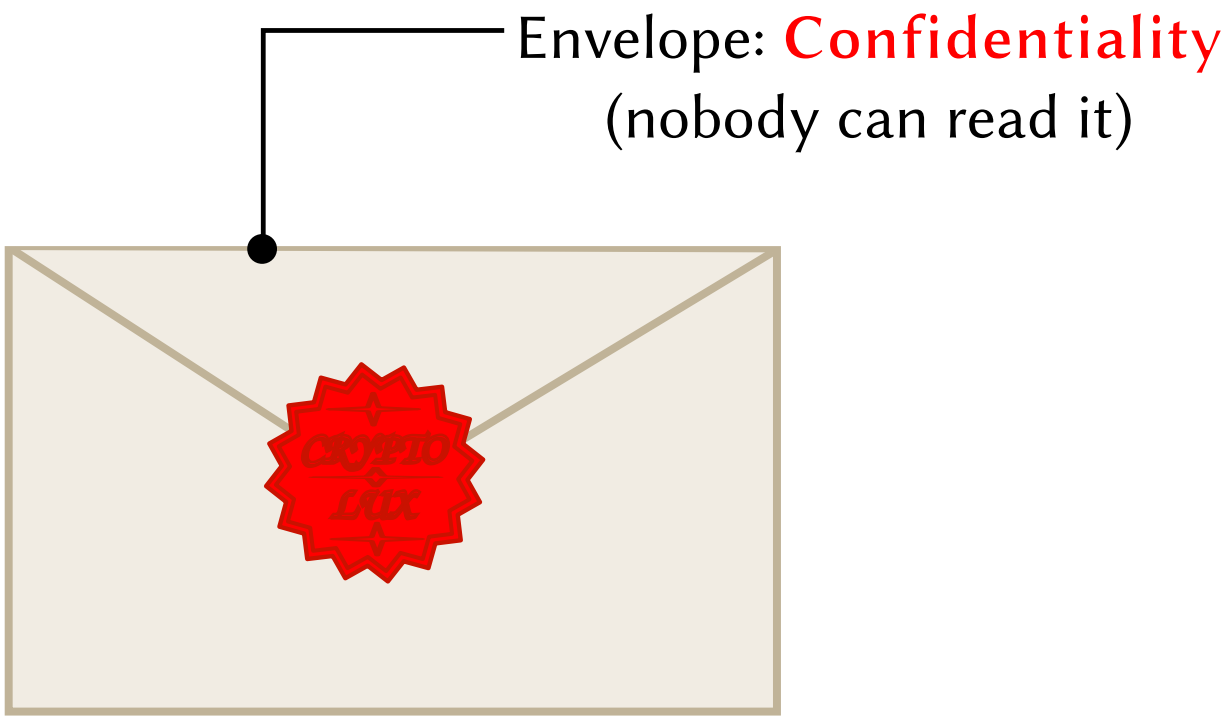

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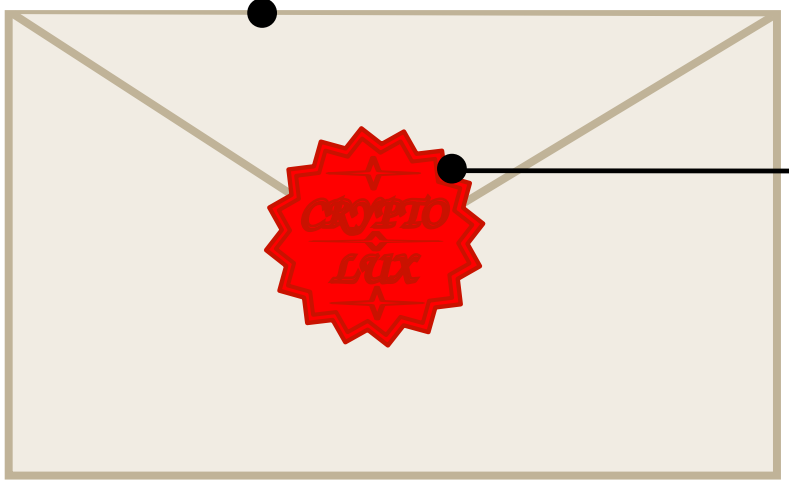

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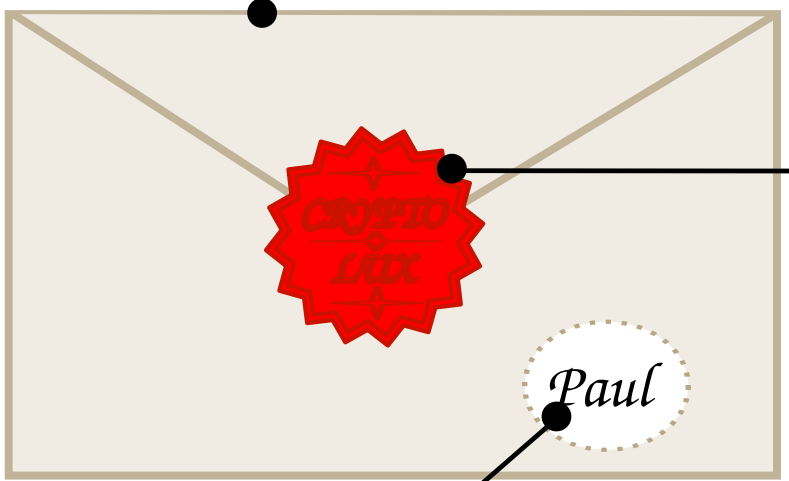


Envelope: **Confidentiality**
(nobody can read it)

Seal: **Integrity**
(nobody can modify it)

Signature: **Authentication**
(it was written by the right person)

Modern Cryptography

	Before
Data encrypted	Letters/Digits
Method	By hand/ machine
Cryptographers	Linguists inventors
Example	

Modern Cryptography

	Before	Now
Data encrypted	Letters/Digits	0,1 (bits)
Method	By hand/ machine	Computer program
Cryptographers	Linguists inventors	Mathematicians Computer scientists
Example		

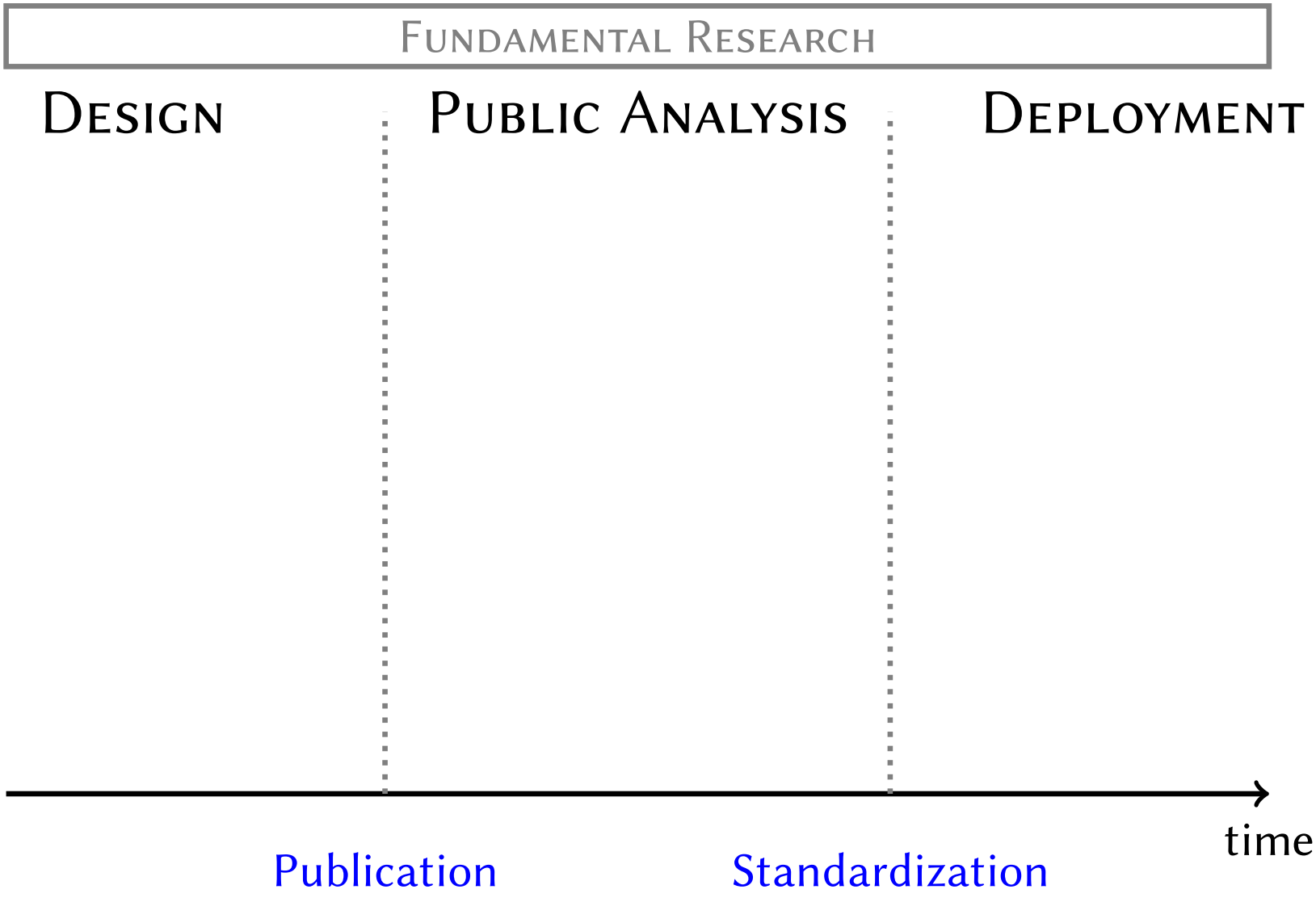
```
void sparx_encrypt(uint16_t * x, uint16_t k[][2*R_S]) {
    unsigned int s, r, b;
    for (s=0 ; s<N_S ; s++) {
        for (b=0 ; b<N_B ; b++)
            for (r=0 ; r<R_S ; r++) {
                x[2*b  ] ^= k[N_B*s + b][2*r    ];
                x[2*b+1] ^= k[N_B*s + b][2*r + 1];
                A(x[2*b], x[2*b+1]);
            }
        L(x);
    }
    for (b=0 ; b<N_B ; b++) {
        x[2*b  ] ^= k[N_B*N_S][2*b  ];
        x[2*b+1] ^= k[N_B*N_S][2*b+1];
    }
}
```

How do we design such algorithms?

"Cryptographic Pipeline"

Fundamental Research

"Cryptographic Pipeline"



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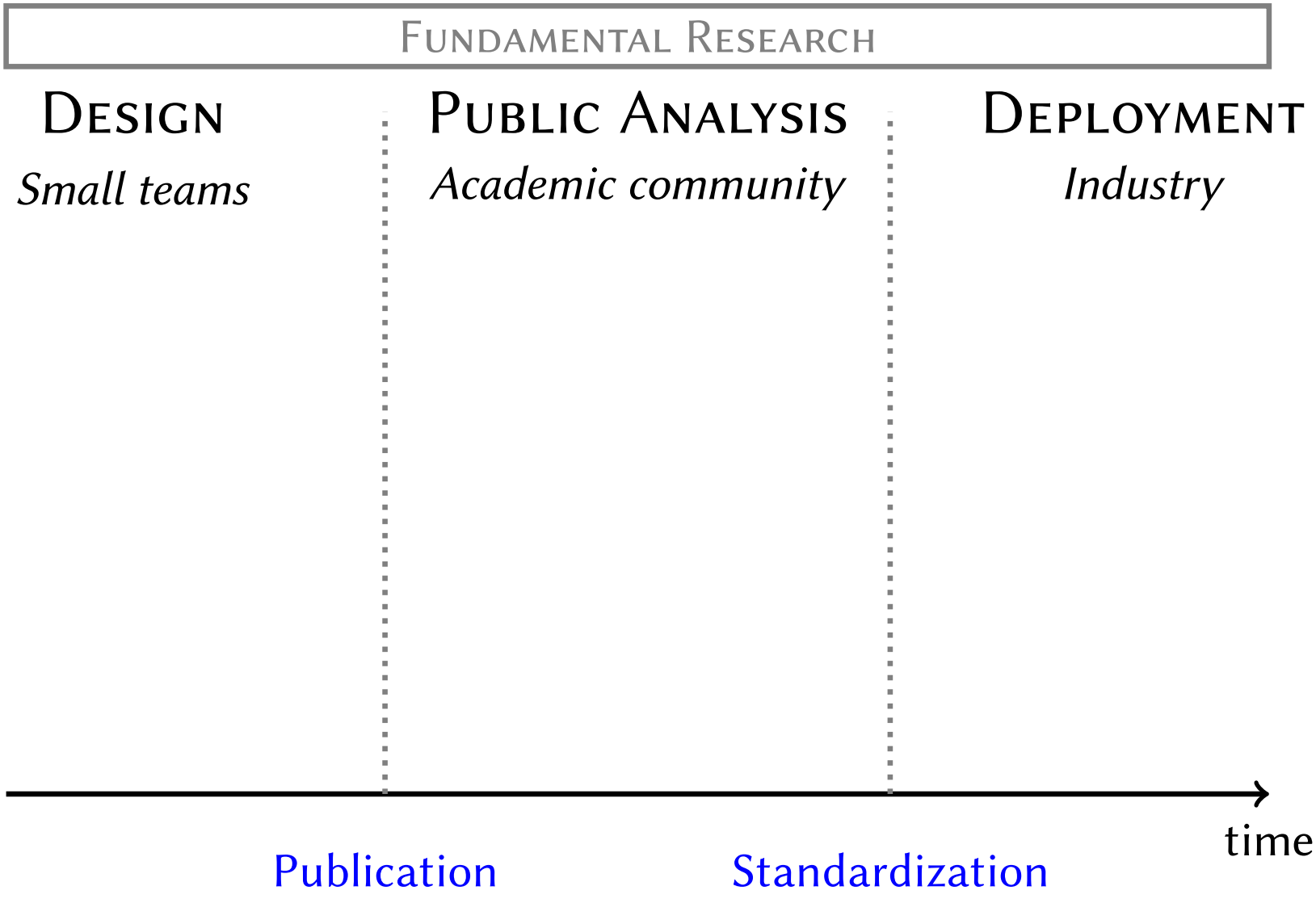

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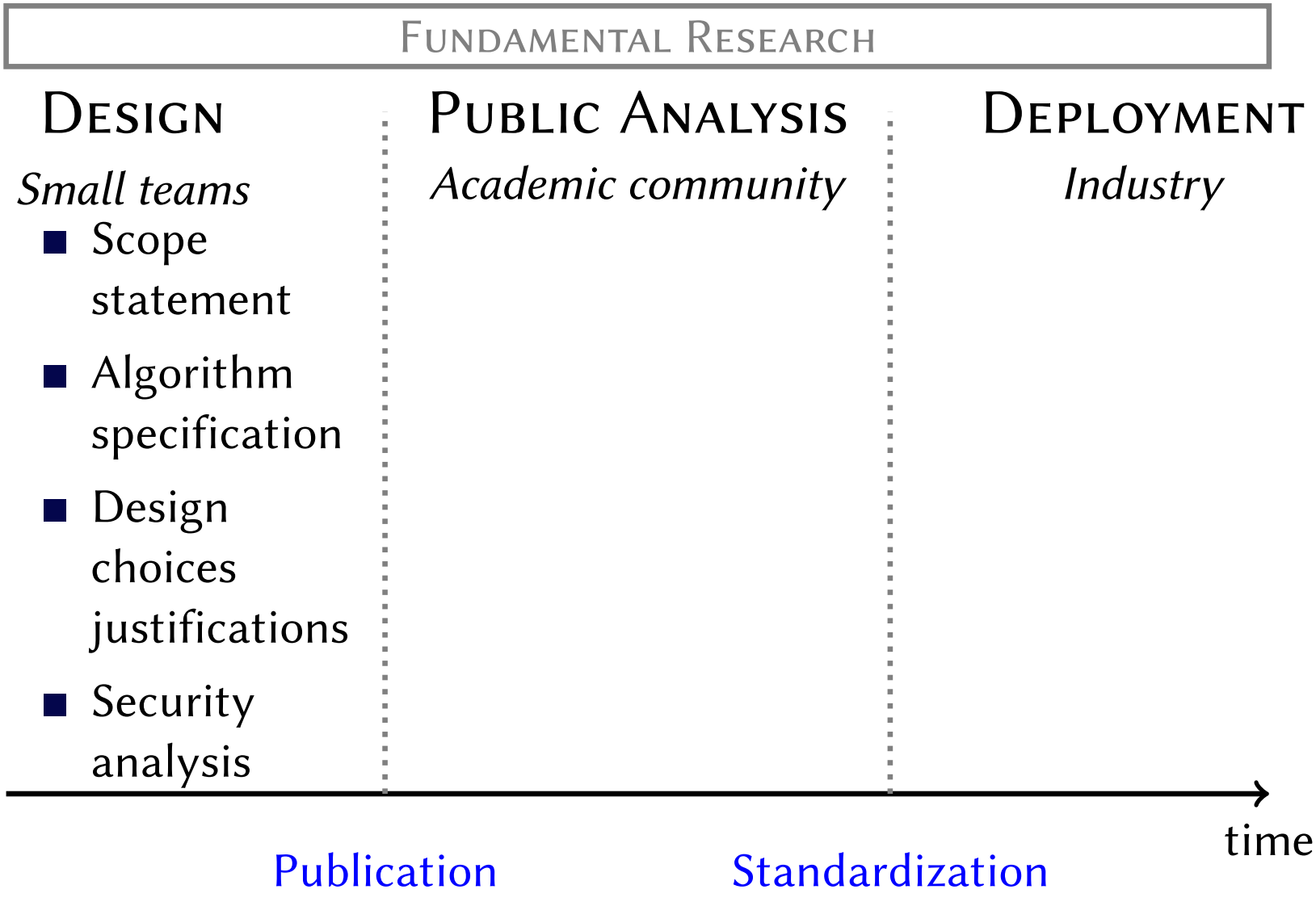

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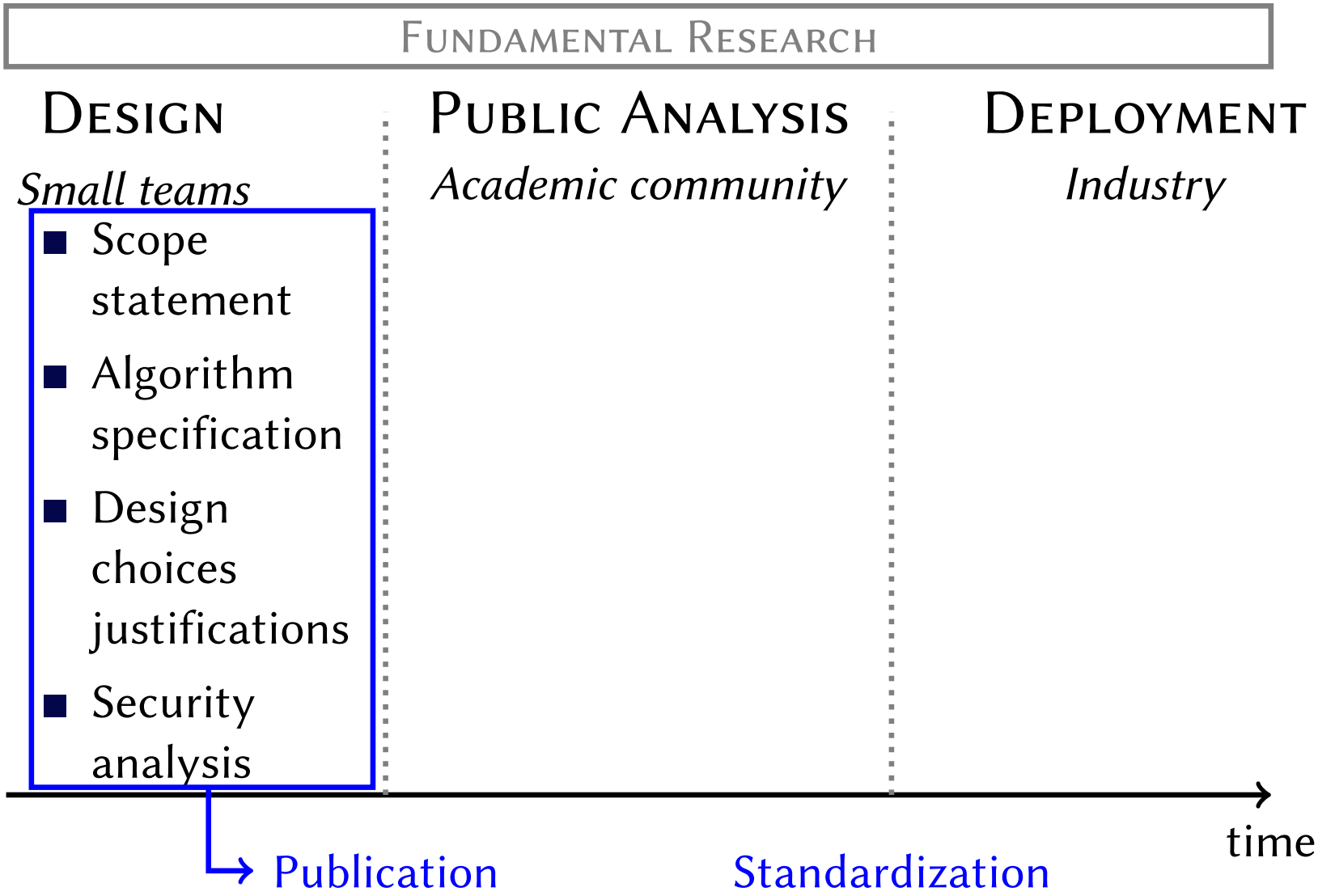

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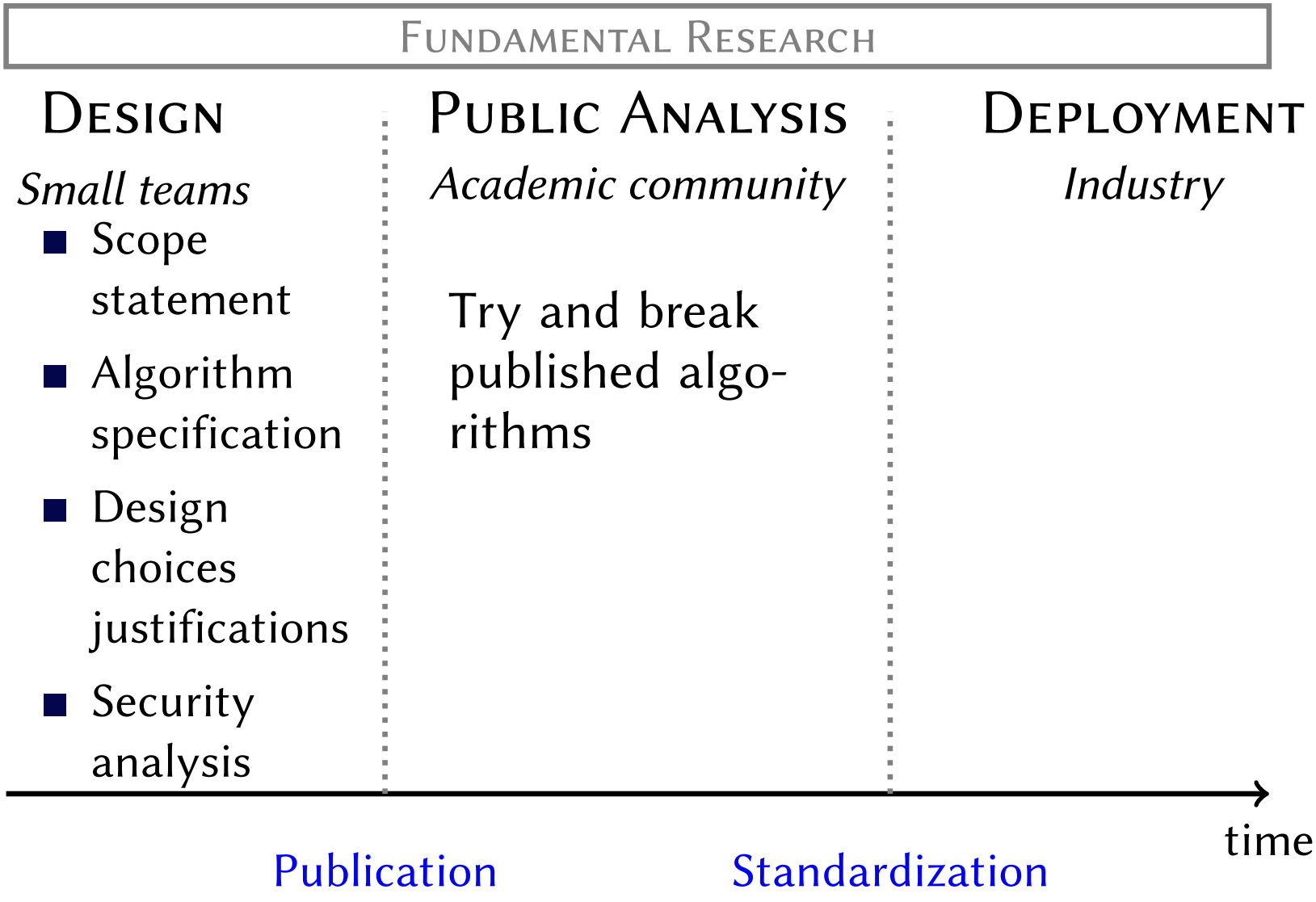

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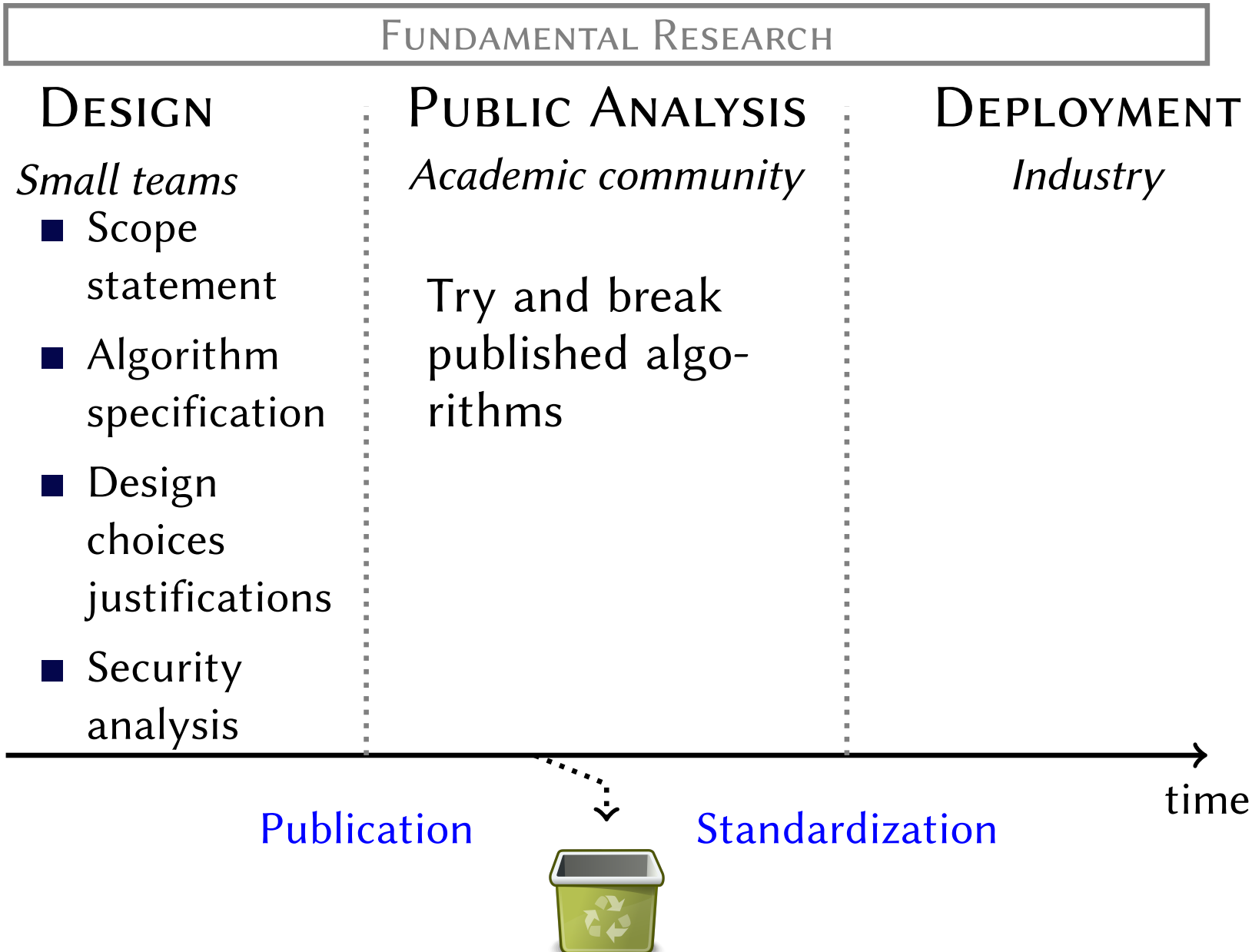

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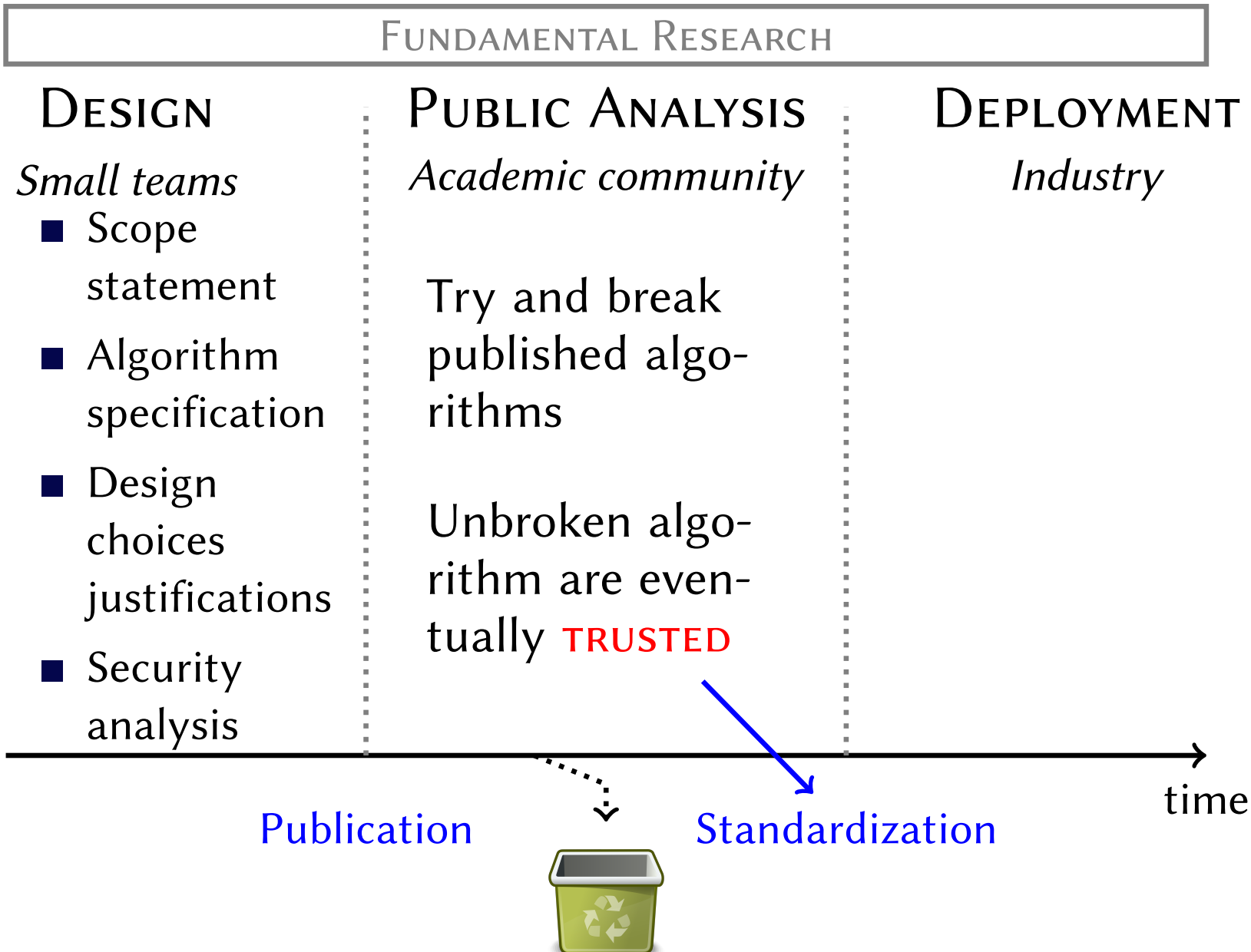

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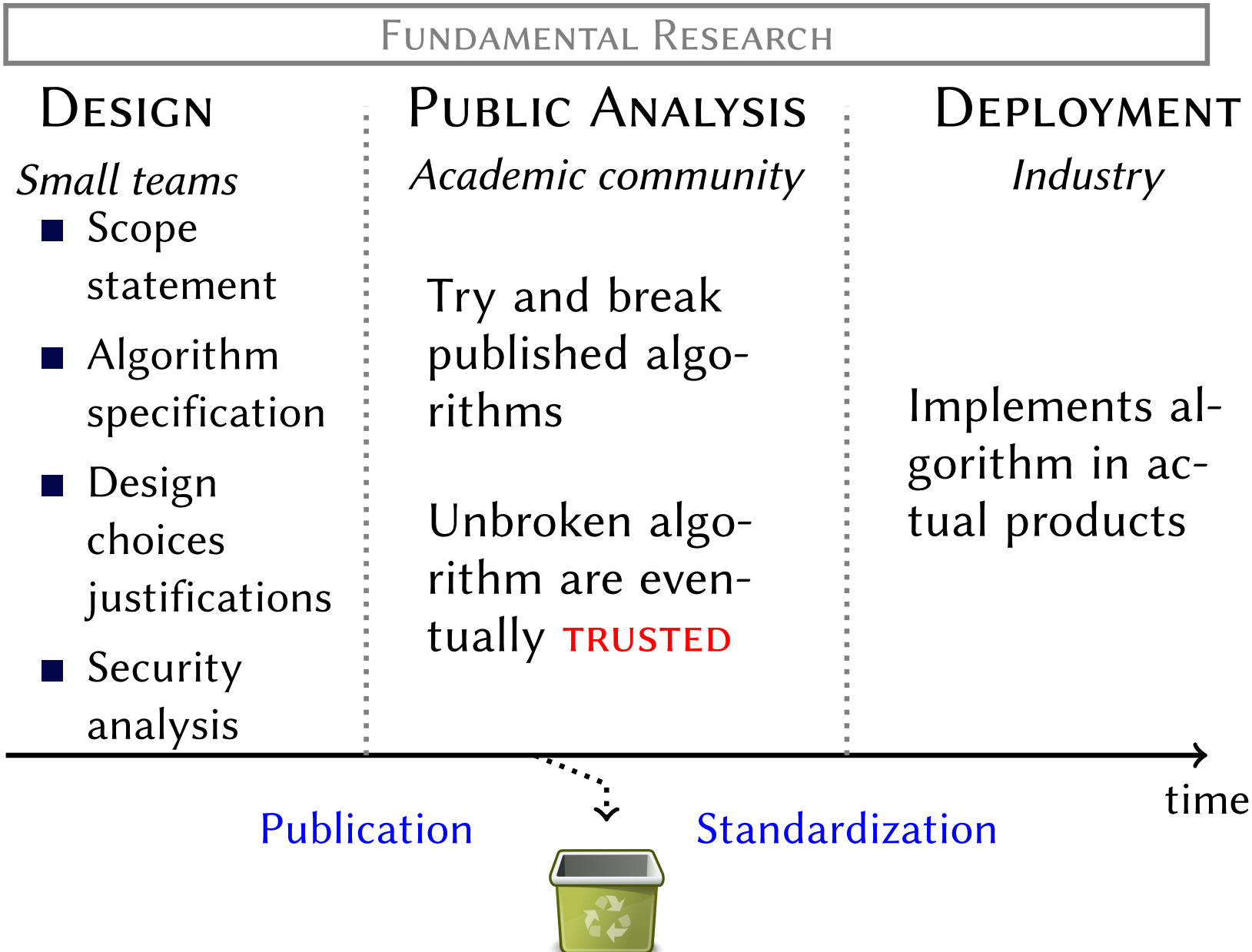

What about my thesis?

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Funded by the FNR (ACRYPT Project)

3 Different Directions

Lightweight Cryptography

- 5 papers (FSE, ASIACRYPT, JoCEn), 2 invited talks
- 1 new block cipher

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- Discussions with ISO

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Purposefully Hard Cryptography

- 1 paper (ASIACRYPT)
- 1 patent (+1 paper under submission)

Outline

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Internet of Things

Everything is being connected to the internet.

Internet of Things

Everything

Internet of Things

Everything

Internet of Things

Everything

Security

"In IoT, the S is for Security."

- Internet-enabled devices have security flaws.
- Security is an afterthought (at best).

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- Internet-enabled devices have security flaws.
- Security is an afterthought (at best).
- Security has a cost in terms of engineering...
- ... and computationnal resources!

Lightweight Cryptography

Lightweight cryptography uses little resources.

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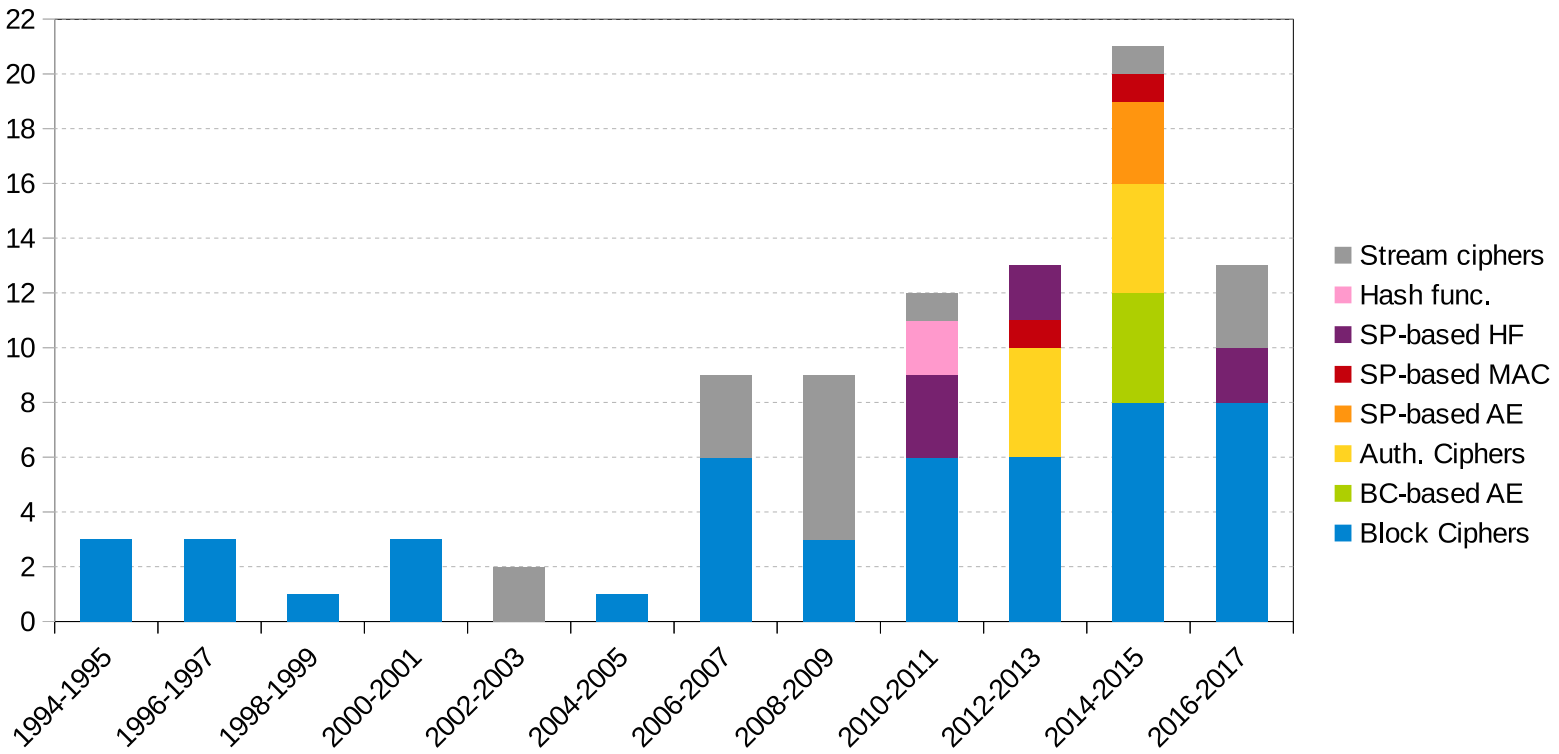


LWC is a very active research area!

Overview

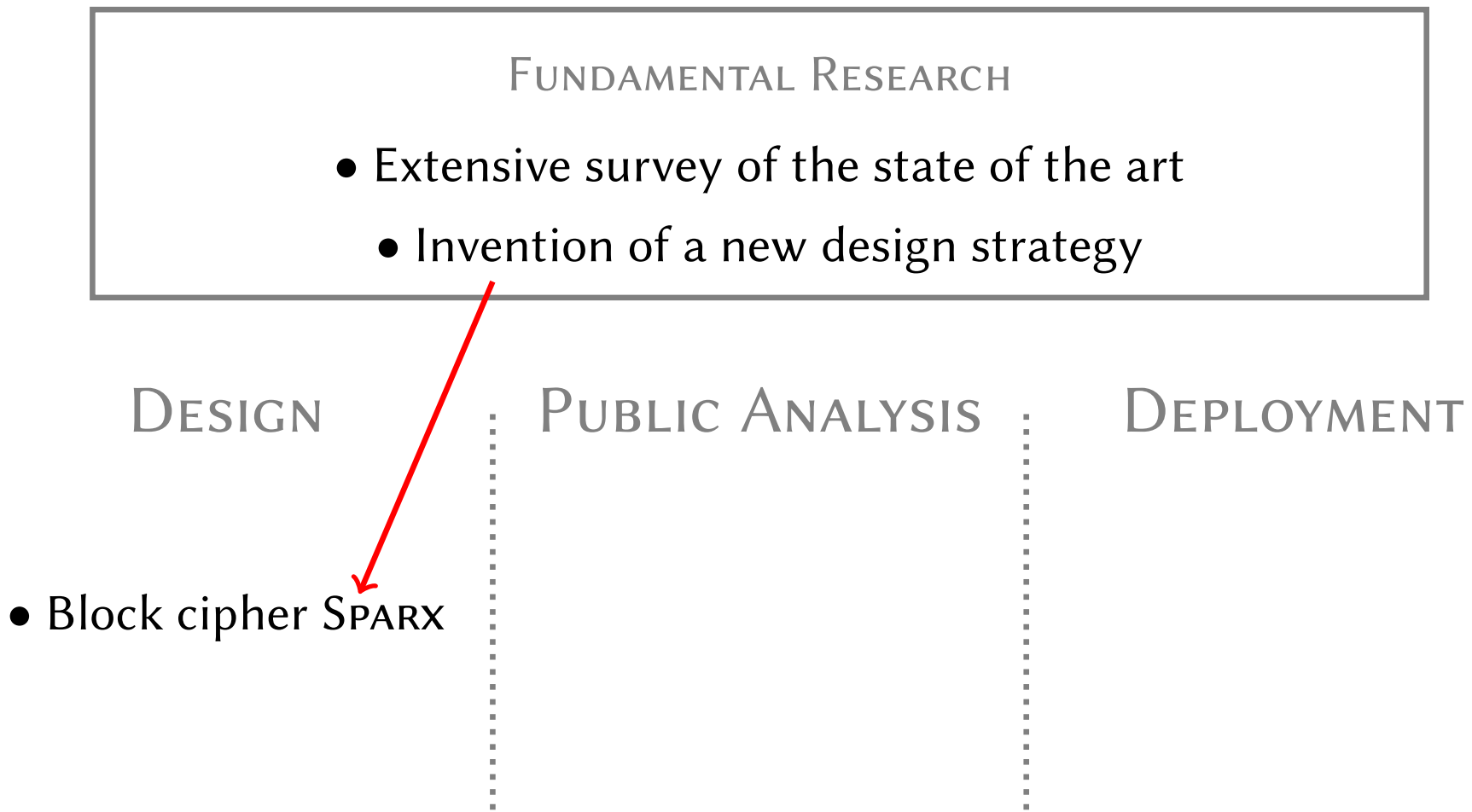
Overview

Fundamental Research

- Extensive survey of the state of the art

Design | Public Analysis | Deployment

Overview


Fundamental Research
• Extensive survey of the state of the art
• Invention of a new design strategy
Design
Public Analysis
Deployment
• Block cipher Sparx

Overview

Fundamental Research

- Extensive survey of the state of the art
- Invention of a new design strategy

Design

- Block cipher Sparx

Public Analysis

- Attacks on Gluon
- Results on Prince
- Results on Twine

Deployment

Highlights

Attacks on PRINCE

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- Design strategy re-used by third parties from Waterloo (Canada) to build *sLiSCP*

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NIST

- Survey greatly appreciated (and cited) by NIST in their ongoing standardization effort
- I presented SPARX at a NIST workshop

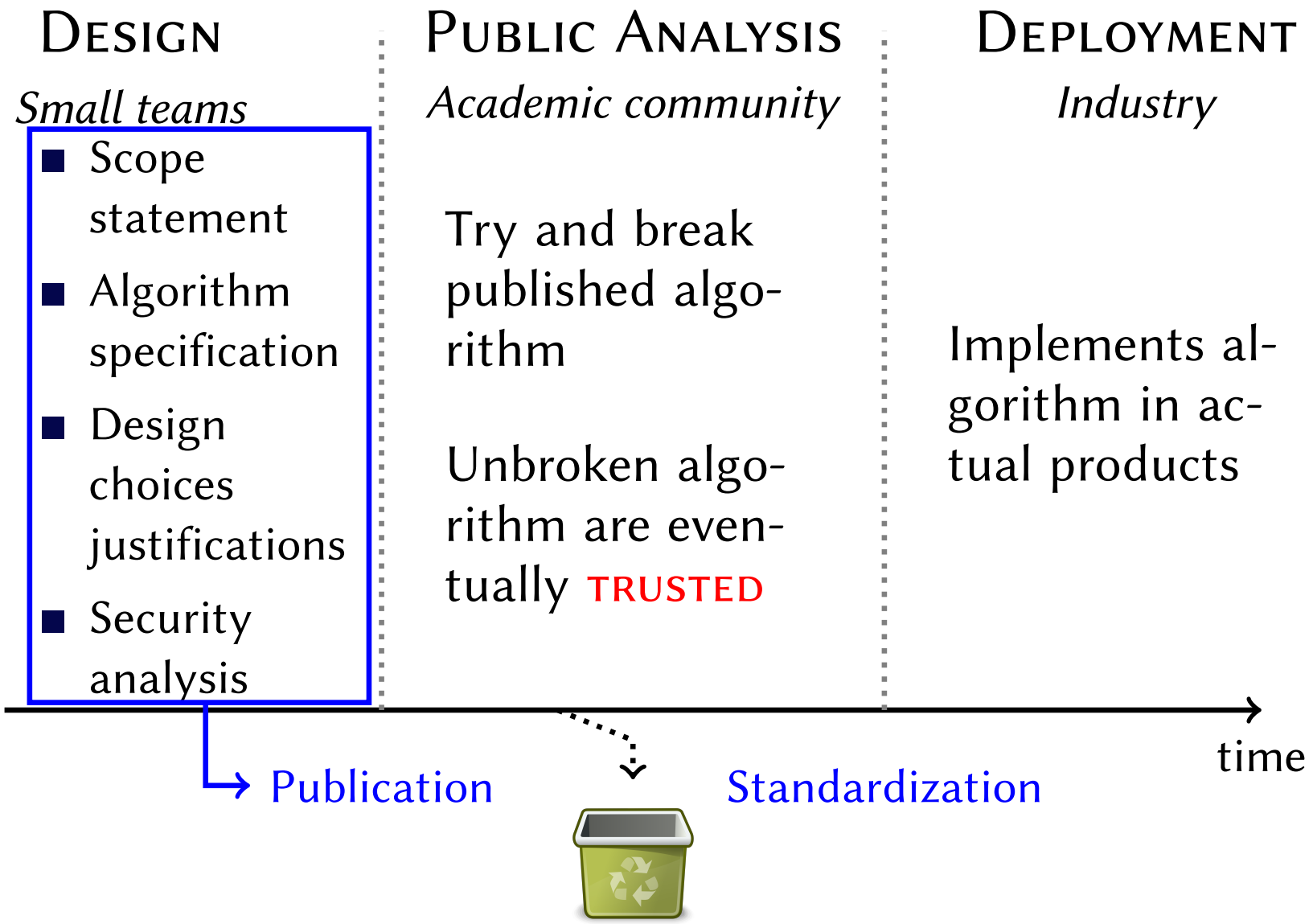
Outline

What is an S-Box?

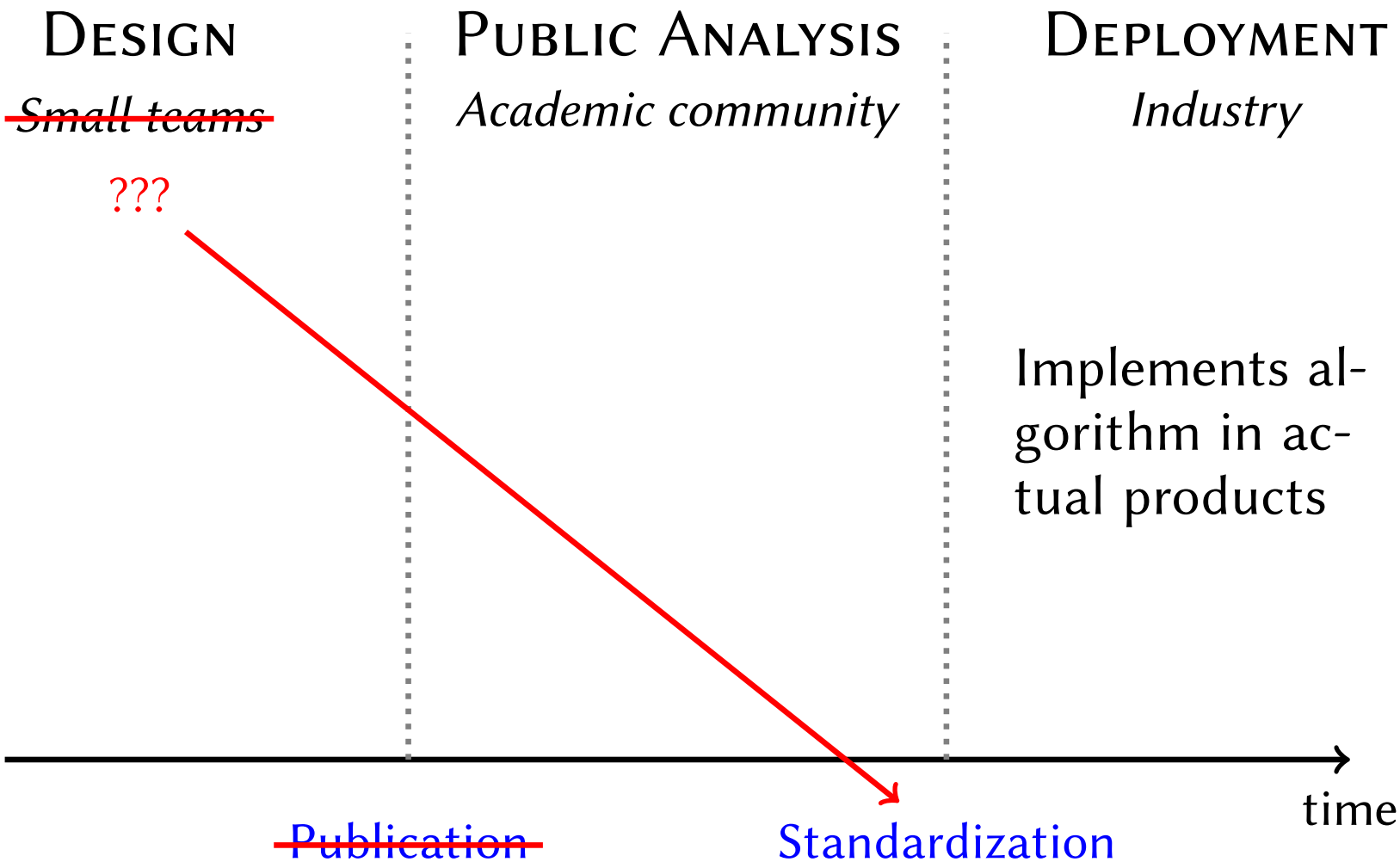
π' = (252, 238, 221, 17, 207, 110, 49, 22, 251, 196, 250, 218, 35, 197, 4, 77, 233, 119, 240, 219, 147, 46, 153, 186, 23, 54, 241. 187, 20, 205, 95, 193, 249, 24, 101, 90, 226, 92, 239, 33, 129, 28, 60, 66, 139, 1, 142, 79, 5, 132, 2, 174, 227, 106, 143, 160, 6, 11, 237, 152, 127, 212, 211, 31, 235, 52, 44, 81, 234, 200, 72, 171, 242, 42, 104, 162, 253, 58, 206, 204, 181, 112, 14, 86, 8, 12, 118, 18, 191, 114, 19, 71, 156, 183, 93, 135, 21, 161, 150, 41, 16, 123, 154, 199, 243, 145, 120, 111, 157, 158, 178, 177, 50, 117, 25, 61, 255, 53, 138, 126, 109, 84, 198, 128, 195, 189, 13, 87, 223, 245, 36, 169, 62, 168, 67, 201, 215, 121, 214, 246, 124, 34, 185, 3, 224, 15, 236, 222, 122, 148, 176, 188, 220, 232, 40, 80, 78, 51, 10, 74, 167, 151, 96, 115, 30, 0, 98, 68, 26, 184, 56, 130, 100, 159, 38, 65, 173, 69, 70, 146, 39, 94, 85, 47, 140, 163, 165, 125, 105, 213, 149, 59, 7, 88, 179, 64, 134, 172, 29, 247, 48, 55, 107, 228, 136, 217, 231, 137, 225, 27, 131, 73, 76, 63, 248, 254, 141, 83, 170, 144, 202, 216, 133, 97, 32, 113, 103, 164, 45, 43, 9, 91, 203, 155, 37, 208, 190, 229, 108, 82, 89, 166, 116, 210, 230, 244, 180, 192, 209, 102, 175, 194, 57, 75, 99, 182).

The “S-Box” of the last Russian standards

Breaking the Pipeline



Breaking the Pipeline



The Need for Reverse-Engineering

A malicious designer can easily hide a structure in an S-Box.

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To keep an advantage in implementation...

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A malicious designer can easily hide a structure in an S-Box.

To keep an advantage in implementation...
... or an advantage in cryptanalysis (backdoor).

Kuznyechik/Stribog

Stribog

Type Hash function

Publication 2012

Kuznyechik

Type Block cipher

Publication 2015

Kuznyechik/Stribog

Stribog

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Publication 2012

Kuznyechik

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Publication 2015

Common ground

- Both are standard symmetric primitives in Russia.
- Both were designed by the FSB (TC26).
- Both use the same 8×8 S-Box, π.

How?

Given an S-Box... Where do we even start?

Fourier to the Rescue

Linear Approximations Table (LAT)

The LAT of $S : \{0,1\}^n \to \{0,1\}^n$ is a $2^n \times 2^n$ matrix such that

$$\mathrm{LAT}_S[a,b] = \sum_{x \in \mathbb{F}_2^n} (-1)^{a \cdot x \oplus b \cdot S(x)} .$$

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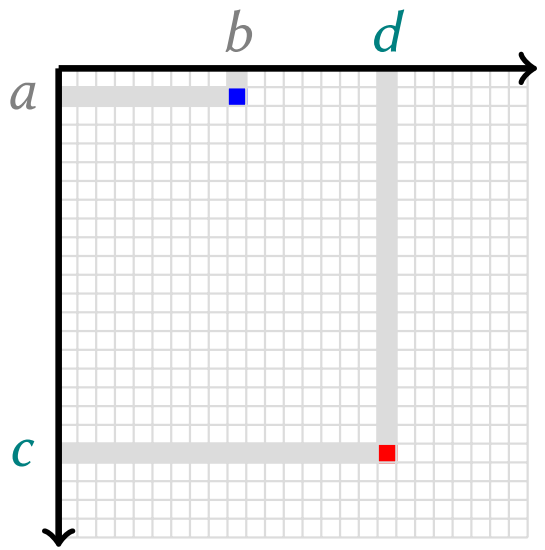
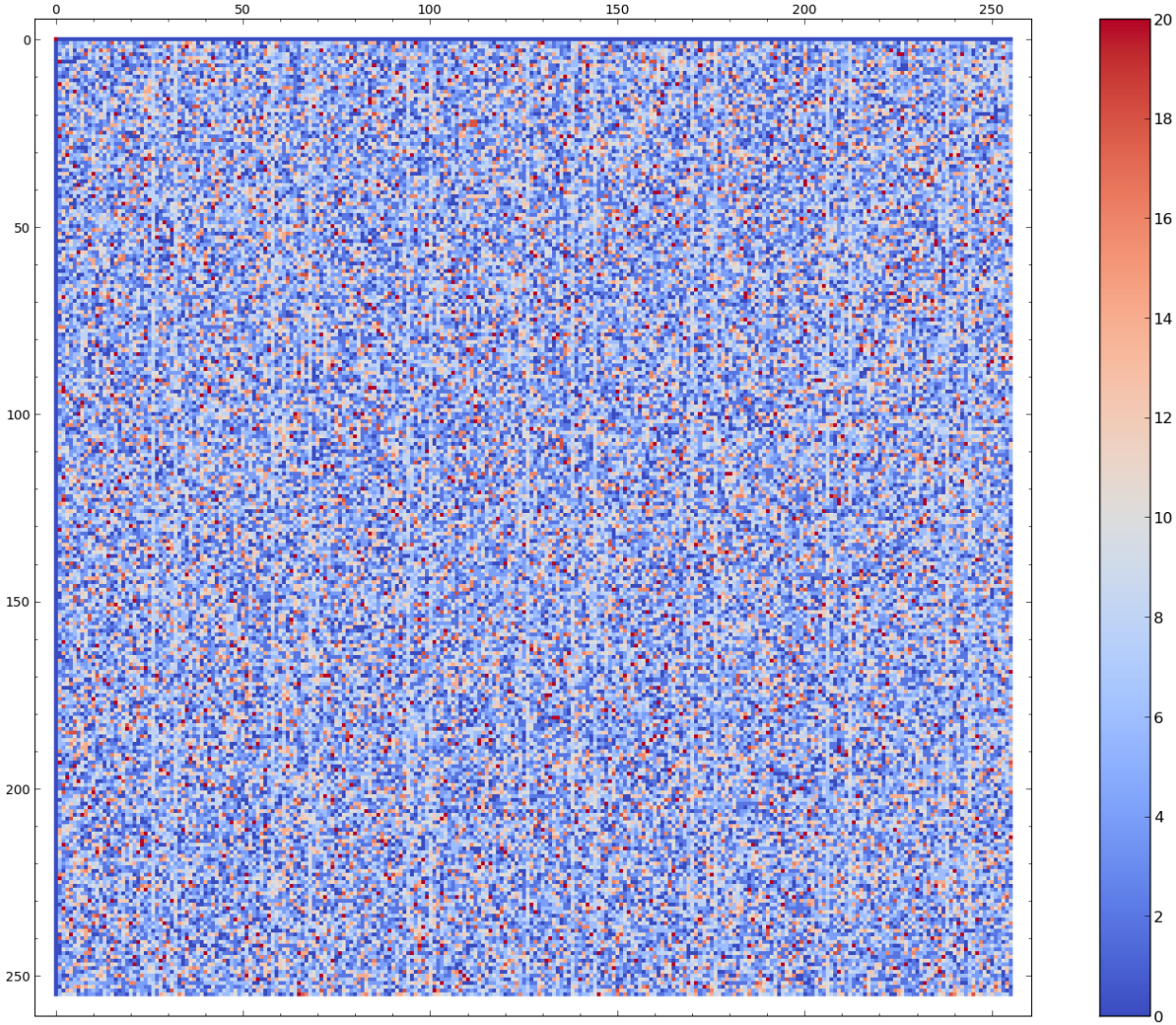


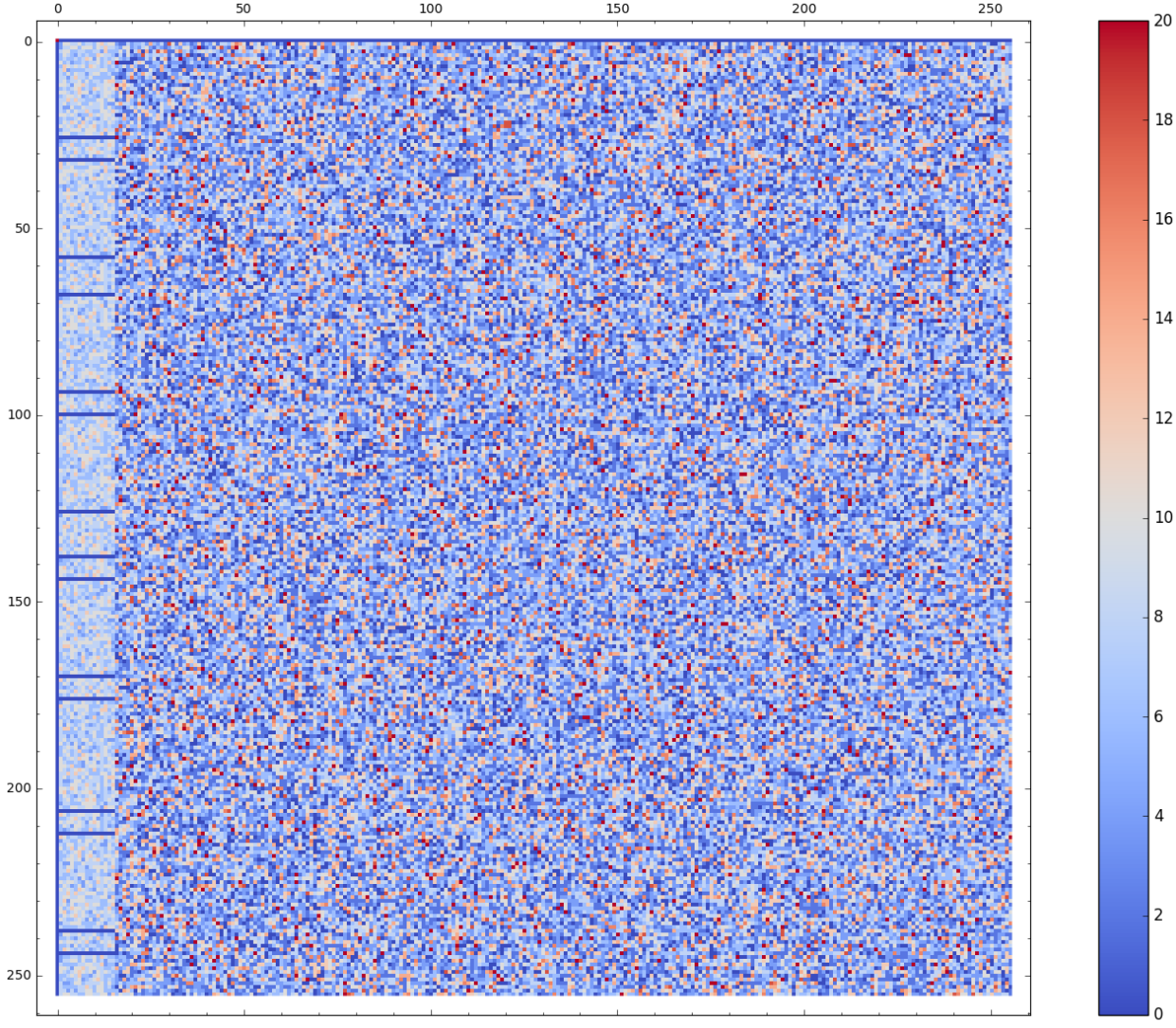
$$|\mathrm{LAT}_S[a,b]| = 0$$

$$|\mathrm{LAT}_S[c,d]| \geq 20$$

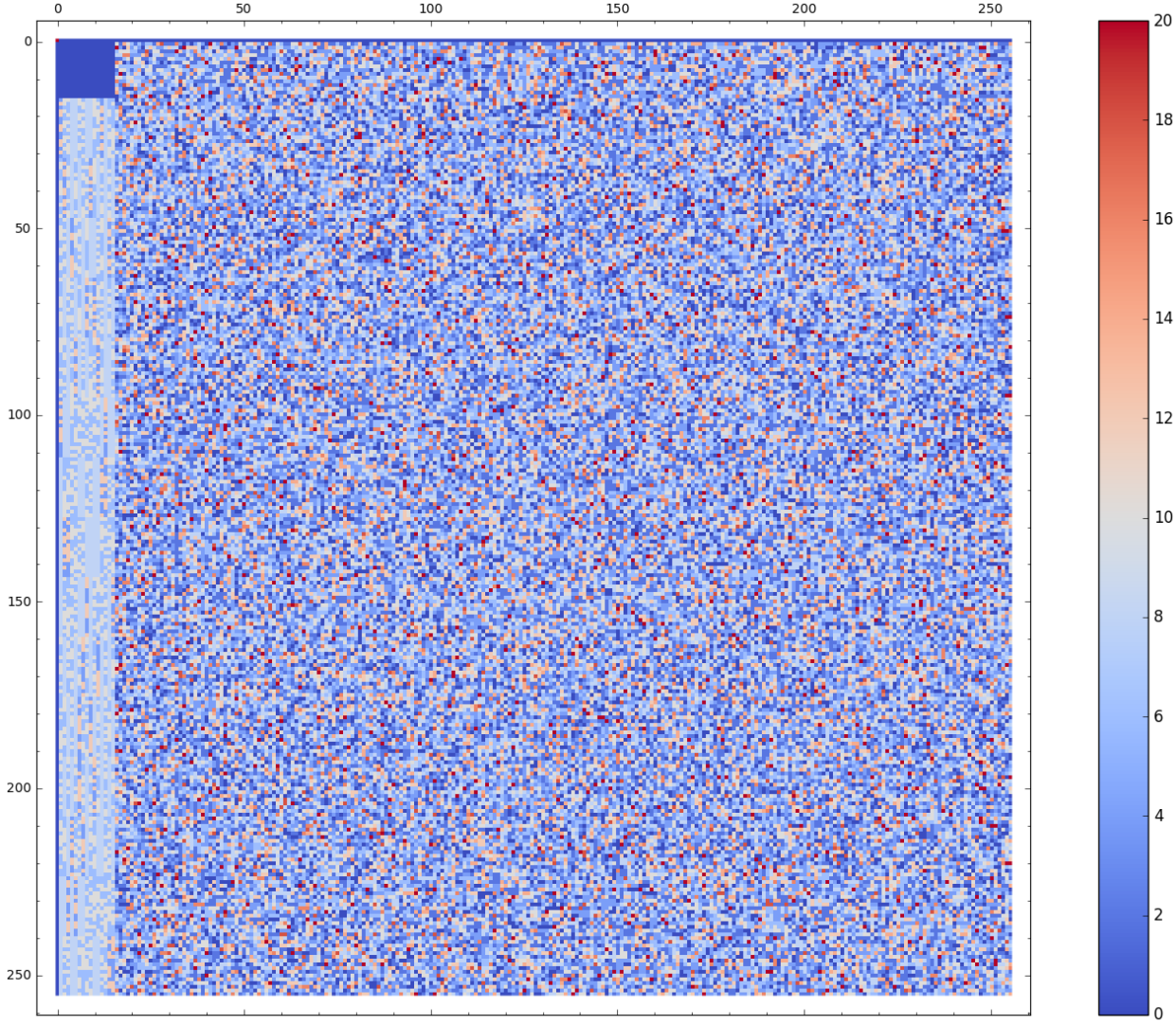
The LAT of π



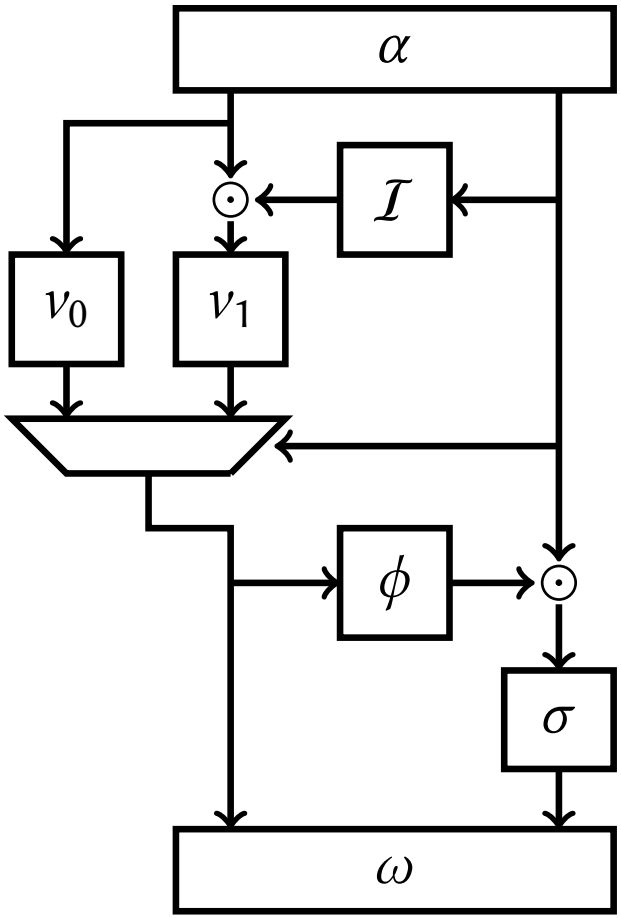
The LAT of π (reordered columns)



The LAT of $\eta \circ \pi \circ \mu$



Final Decomposition Number 1



- $\odot$ Multiplication in $\mathbb{F}_{2^4}$
- α Linear permutation
- $\mathcal{I}$ Inversion in $\mathbb{F}_{2^4}$
- ν_0, ν_1, σ 4×4 permutations
- ϕ 4×4 function
- ω Linear permutation

S-Box Reverse-Engineering: Summary

- Set up a process and tools to recover hidden structures and/or design criteria for S-Boxes.
- Successful applications to Streebog/Kuznyechik (FSB), Skipjack (NSA)... and a theorem!
- Found new cryptographic attacks.

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- Found new cryptographic attacks.
- Hopefully, deterred publications of unjustified algorithms.
- Caught the attention of the community: I gave many invited talks on this topic.

Outline

Conclusion

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- the *Amis de l'Université* and their sponsors...

... and to you for listening!