Better know your limits and adversaries

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Better know your limits and adversaries

A practical view on various template protection and key binding schemes

This talk is based on several joint works with various co-authors, in particular Hervé Chabanne and Constance Morel from Morpho, and that have been partially funded by European FP7 projects FIDELITY and BEAT.

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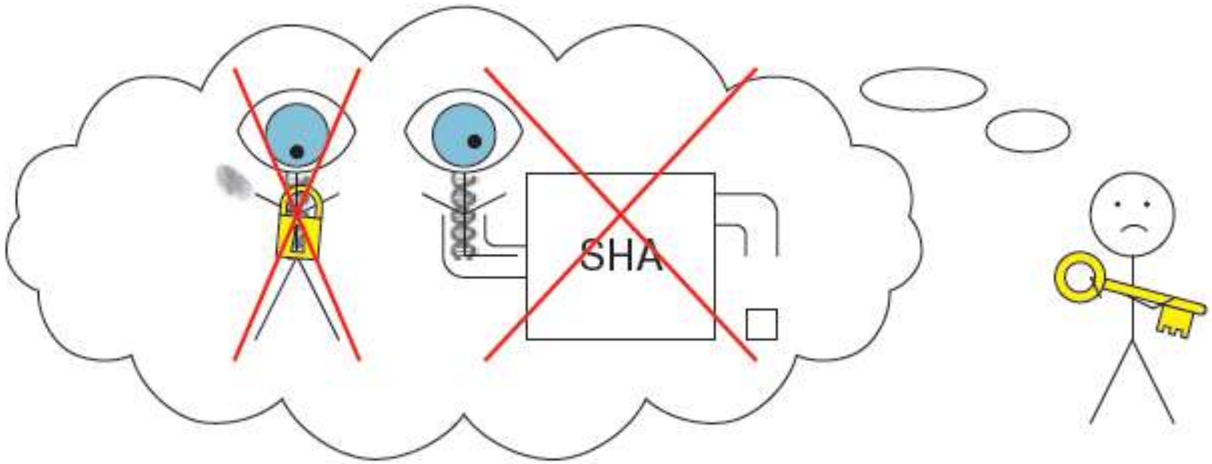
➔ This talk is NOT about

- Classical *on-the-shelf* crypto
- Homomorphic encryption
- Cryptographic protocols (e.g. SMC, private retrieval)
- PET (eg. *k*-anonymity, *l*-diversity, privacy protection of the link between ID & bio)
- HW-based solution
- Formal Models for PbD
- …

➔ It is about

- Template Protection Schemes (TPS) or TPS-like

➔ TPS principles come from both crypto and biometrics community

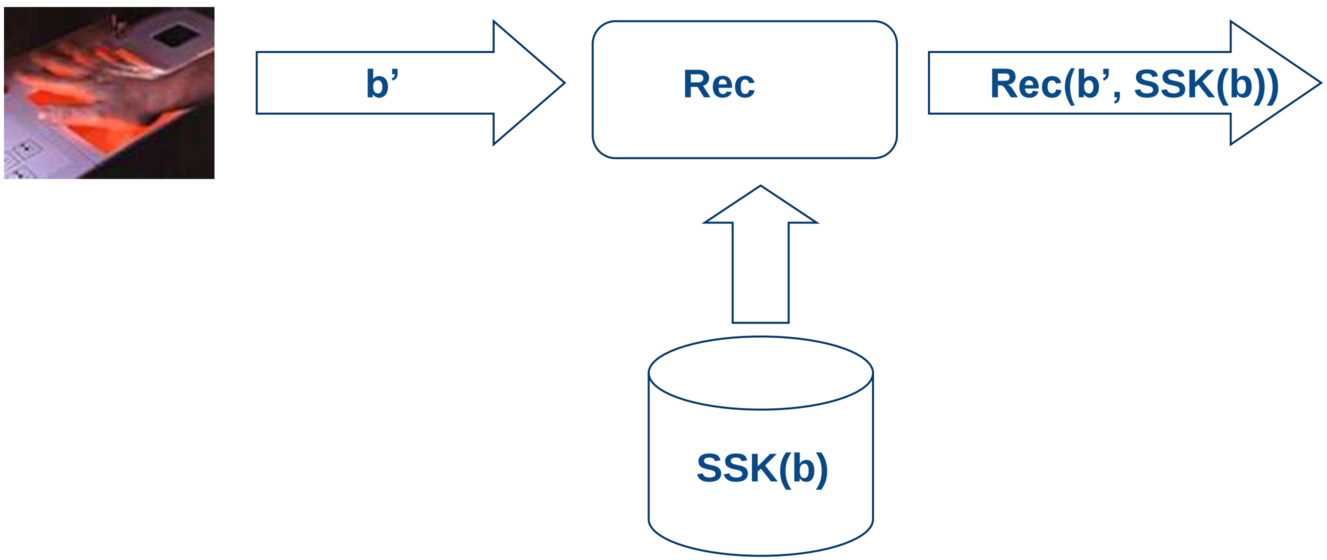


- Helper data, cancelable biometrics, biometric key, …
- FCS, FV, Code offset, SSK, FE …

Image courtesy of M. Favre

SECURE SKETCHES (DODIS, REYZIN & SMITH – 2004)

- **SSK: secure sketch function**
- **Rec: correction function**
- **Rec(b',SSK(b))=b if d(b,b') $\leq$ t**



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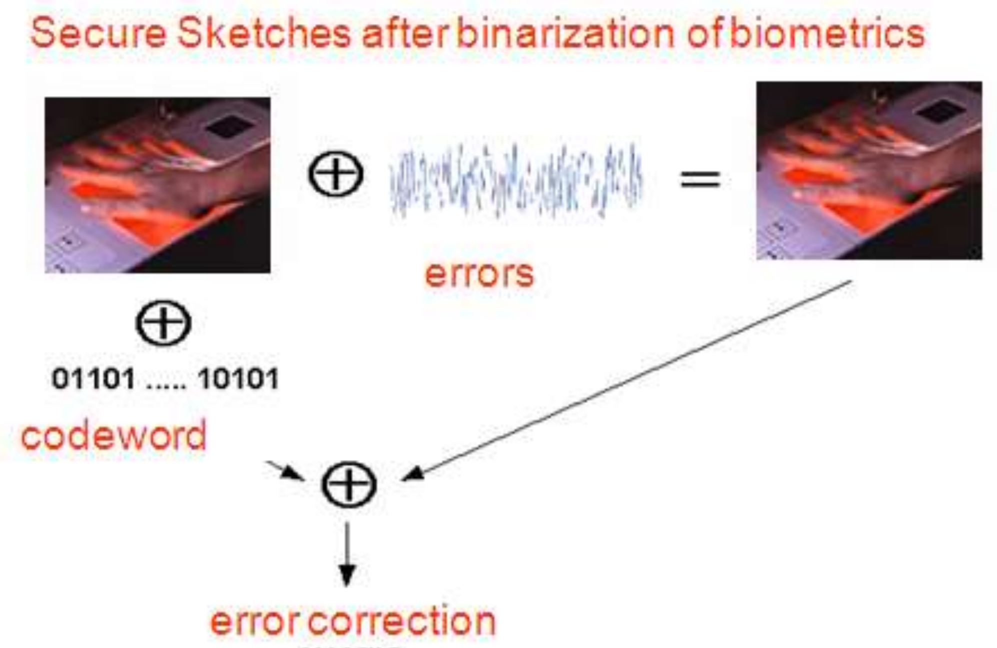
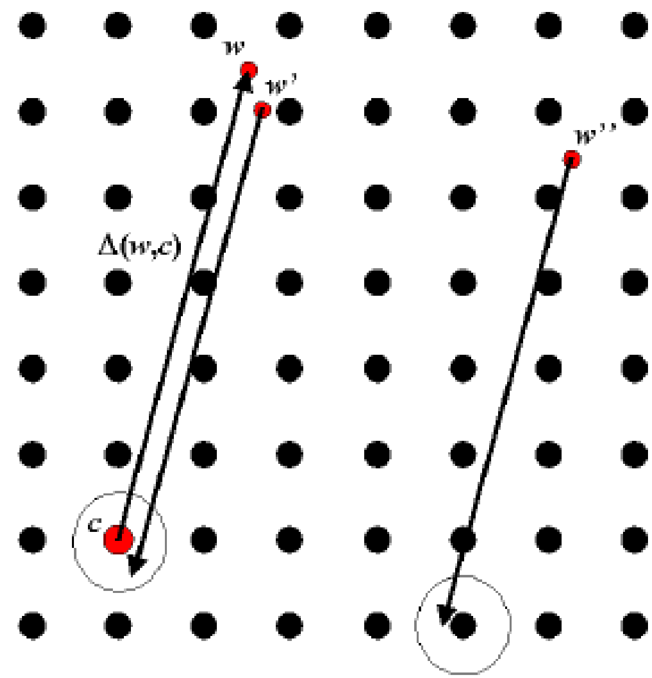
CODE-OFFSET CONSTRUCTION



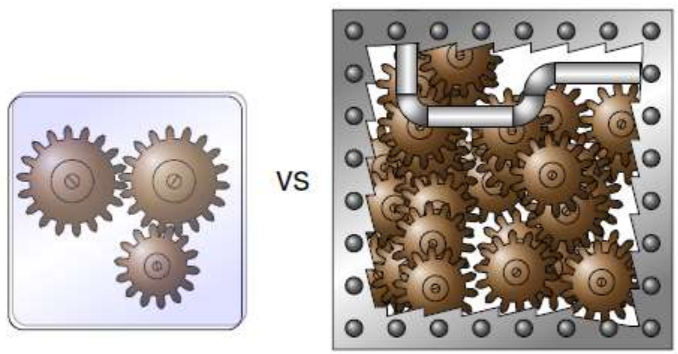
Concept introduced in late 90's



PROBLEM SOLVED?

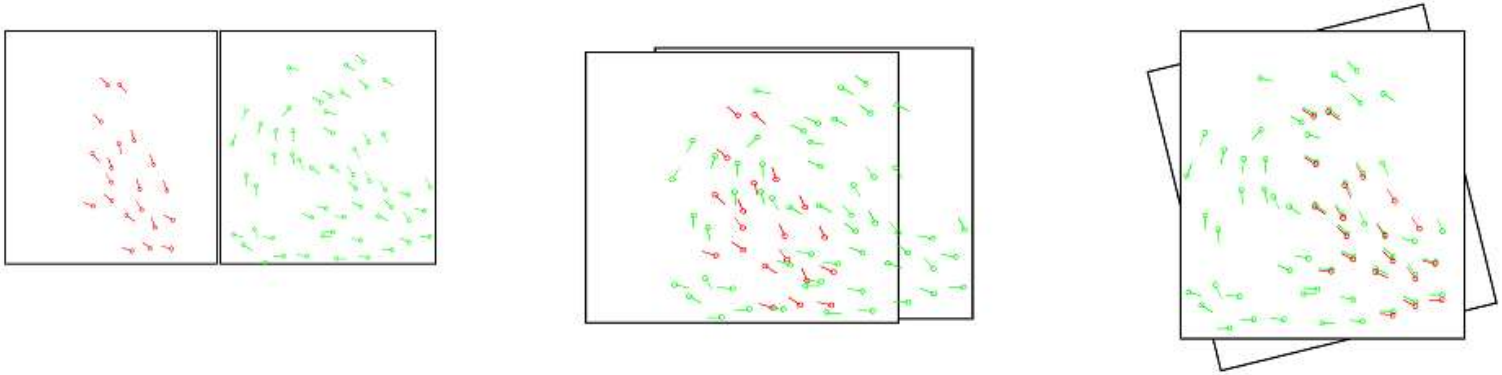
➔ …

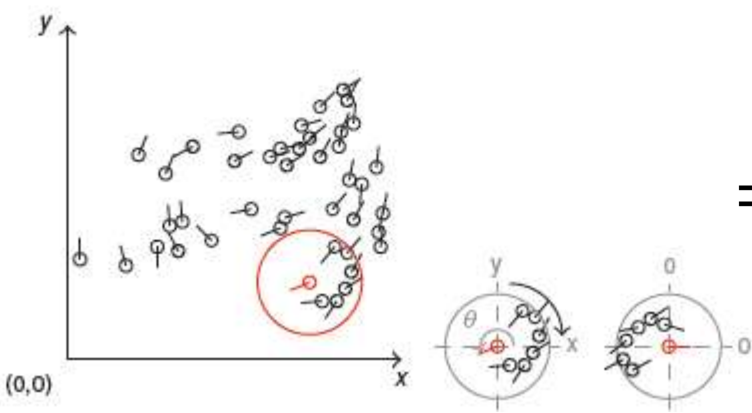
- Need to find a representation compatible with TPS algorithm
  - Usually binary & fixed-length vector
- Correcting large amount of errors
- finding nice trade-off between accuracy and security
- Impact of storage & computational cost on operational constraints



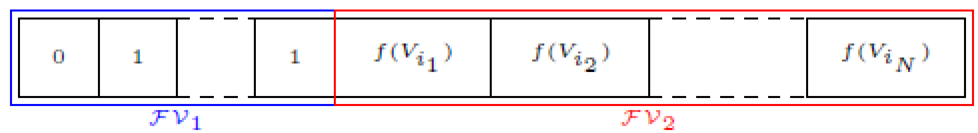
➔ **To date, still very important challenges: security vs performances vs use cases (functionality & cost)**

FINGERPRINT EXAMPLE





=>



one of the most accurate published solution but…

Related to papers @ BTAS 2010, SPIE 2011 with V. Despiegel & M. Favre

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FINGERPRINT EXAMPLE

	FRR@10^{-3} FA FVC 2002 DB2	FRR@10^{-3} FA FVC 2000 DB2
one COTS	1.25 %	0,81 %
FV(Feature-Vector)-based	14.1 %	15 %

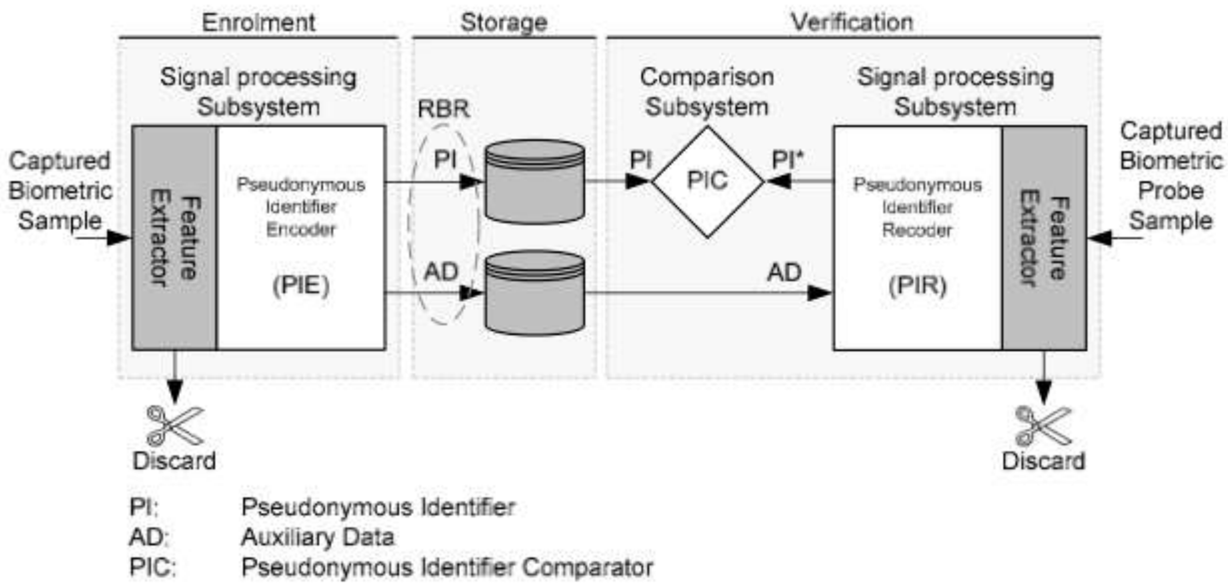
➔ **Accuracy drop of 1 order of magnitude**

➔ **Usual size**

- of a template w/o TPS: 100-200B
- w/ the FV representation: ~29kB

STANDARDS

➔ **Issued ISO/IEC 24745:2011, Information technology — Security techniques — Biometric information protection**



➔ **On-going ISO CD 30136, Information Technology — Performance Testing of Template Protection Schemes**

TPS PROPERTIES: 101

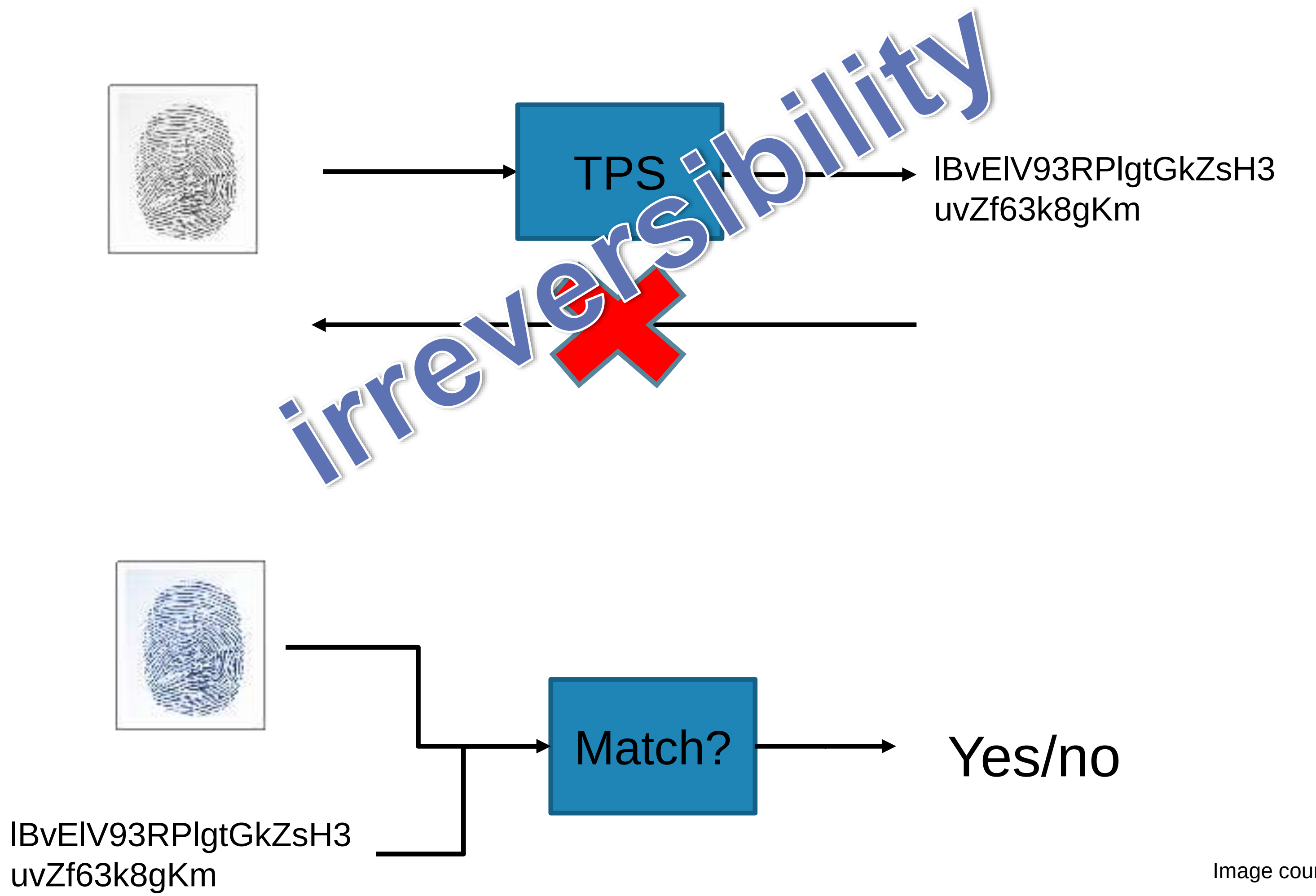


Image courtesy of Jens Hermans

TPS PROPERTIES: 101

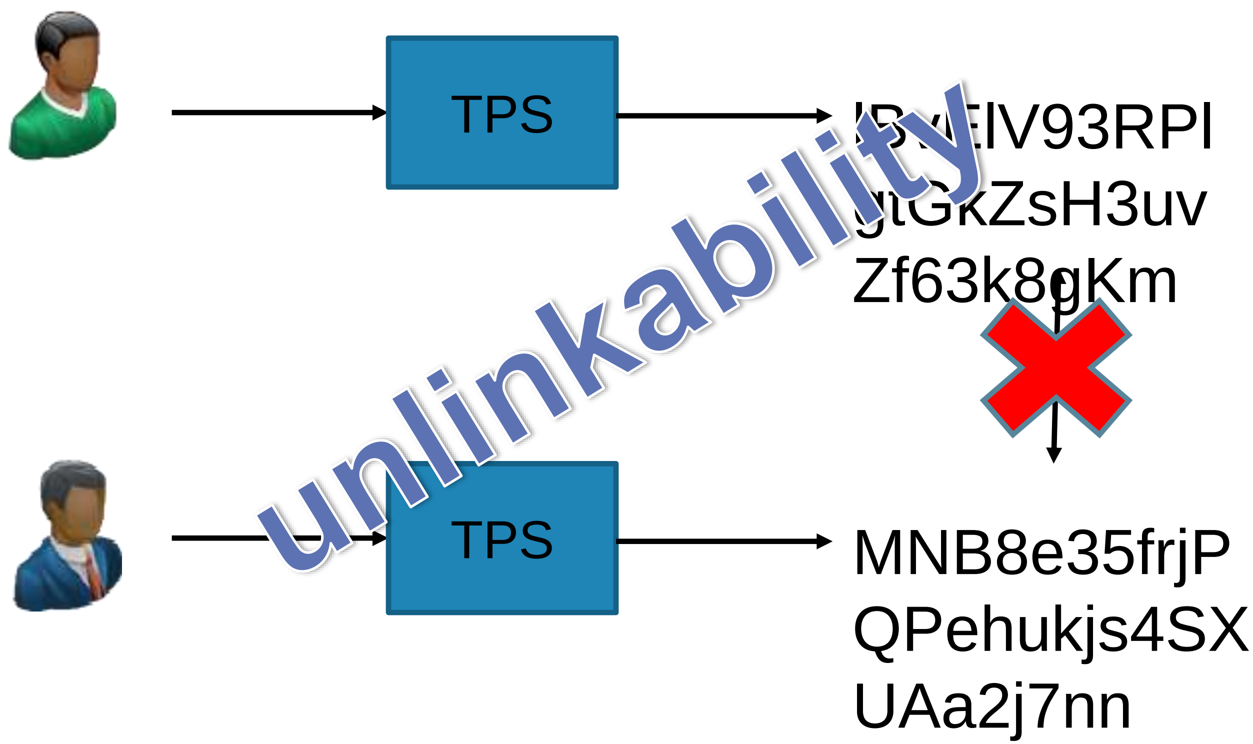


Image courtesy of Jens Hermans

TPS PROPERTIES: 101

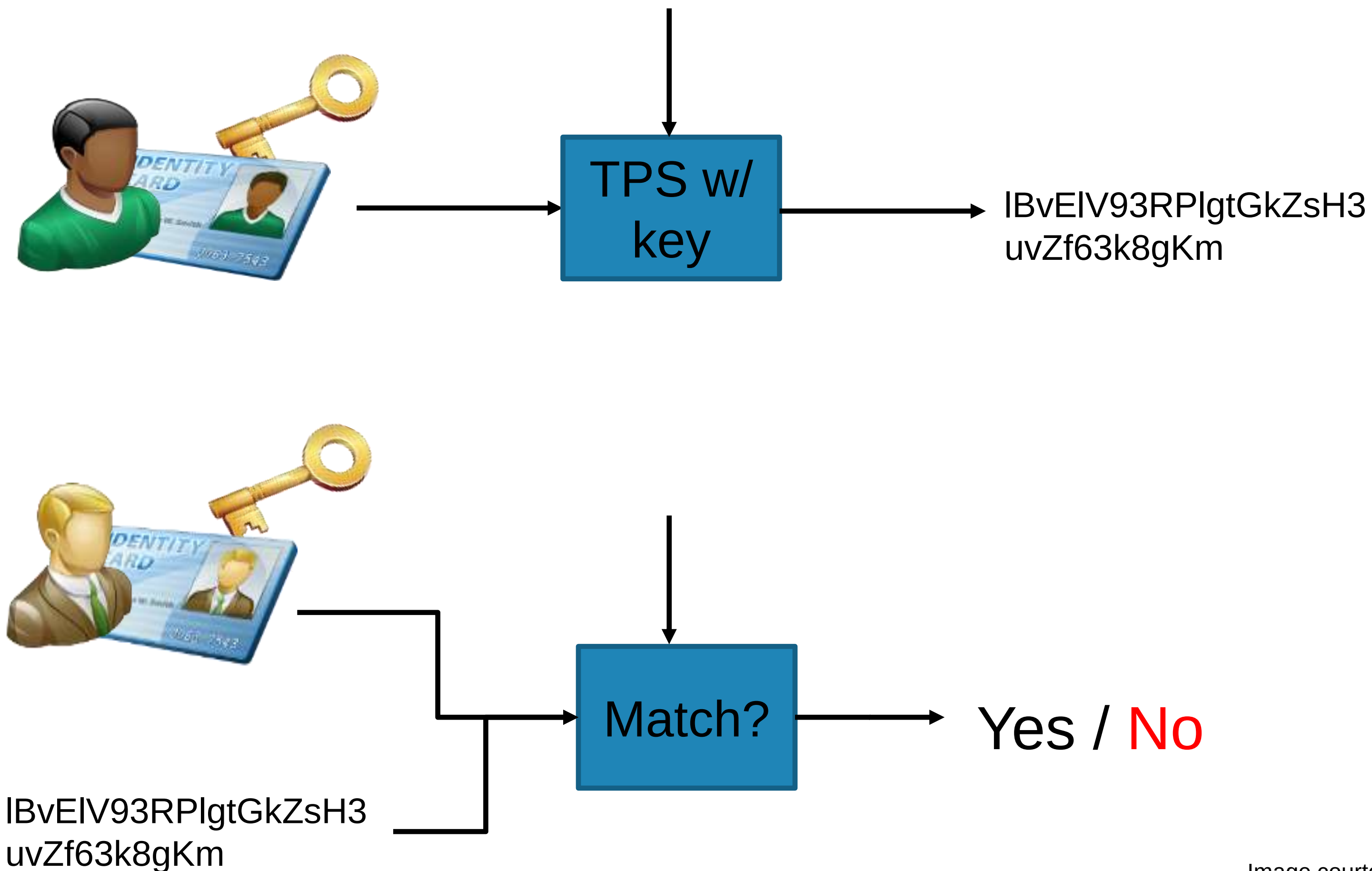


Image courtesy of Jens Hermans

TPS PROPERTIES: 101

Also

- **False Match Rate (FMR) / False Accept Rate (FAR)**
- **False Non-Match Rate (FNMR) / False Reject Rate (FRR)**
- Failure-To-Enroll (FTE) Rate
- Failure-To-Acquire (FTA) Rate
- **Successful Attack Rate (SAR)**
- Accuracy Variation
- Template Diversity
- Storage Requirement per Registered User, speed…

THREAT MODELS (ISO 30136)

➔ Naive Model

- No information, black box, no access to any biometric data.

➔ Collision Model

- adversary possesses a large amount of biometric data.

FA attack issue

➔ General Models

- Full knowledge of the underlying TPS
- Standard Model
  - none of the secrets.
  - related to known-ciphertext attack.
- Advanced Model
  - augmented with the capability of the adversary to execute part of or all submodules that make use of the secrets.
  - related to chosen-plaintext attack and chosen-ciphertext attack
- Full Disclosure Model
  - augmented by disclosing the secrets to the adversary (e.g. malicious insider)

SOME PRACTICAL CONCERNS

➔ With ECC based construction

- Use of non-perfect codes => if one decodes, it is most probably that d(b,b')<t

⇒ *unlinkability attacks (Simoens et al. 2009)*

➔ FAR attack

- Linkability issue
- Pseudo-reversibility issue
  - With SSK construction, enables to retrieve b

➔ Biometric data and errors between data may NOT be uniformly distributed

- Can we do more?
- Statistical attacks possible

Shuffling is not sufficient

Related to IJCB 2014 Security Analysis of Cancelable Iriscodes based on a Secret Permutation with H. Chabanne & C. Morel

USE OF APPLICATION-SPECIFIC TRANSFORM

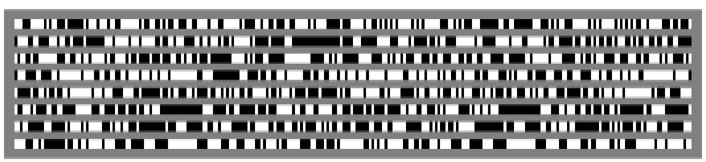
- **Cancelable biometrics / Ratha et al., 2001**
- **Application-specific bio / Cambier et al. 2002**
- **Also as user-specific secret, e.g. biohashing / Goh et al. 2004**
- **Also combined with other techniques, e.g. with fuzzy commitment scheme (Bringer et al. 2007, Kelkboom et al. 2011)**

SHUFFLING ON IRIS

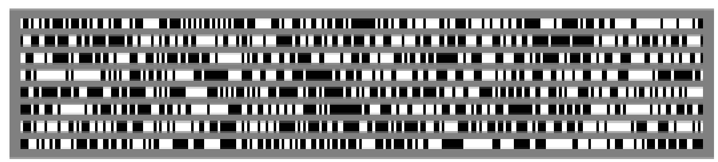
Images from Rathgeb & Uhl, A survey on biometric cryptosystems and cancelable biometrics. EURASIP J. of. Inf. Sec. 2011

➔ Iriscode : 256-byte iris + 256-byte mask

- Mask indicates (in)exploitable data: eyelids, eyelashes, blurred pixels…



VS



$$score((I1,M1),(I2,M2)) = \frac{\|(I1 \oplus I2) \cap M1 \cap M2\|}{\|M1 \cap M2\|}$$

Threshold : ~0.3

John Daugman: How iris recognition works. IEEE Trans. Circuits Syst. Video Techn. (TCSV) 14(1):21-30 (2004)

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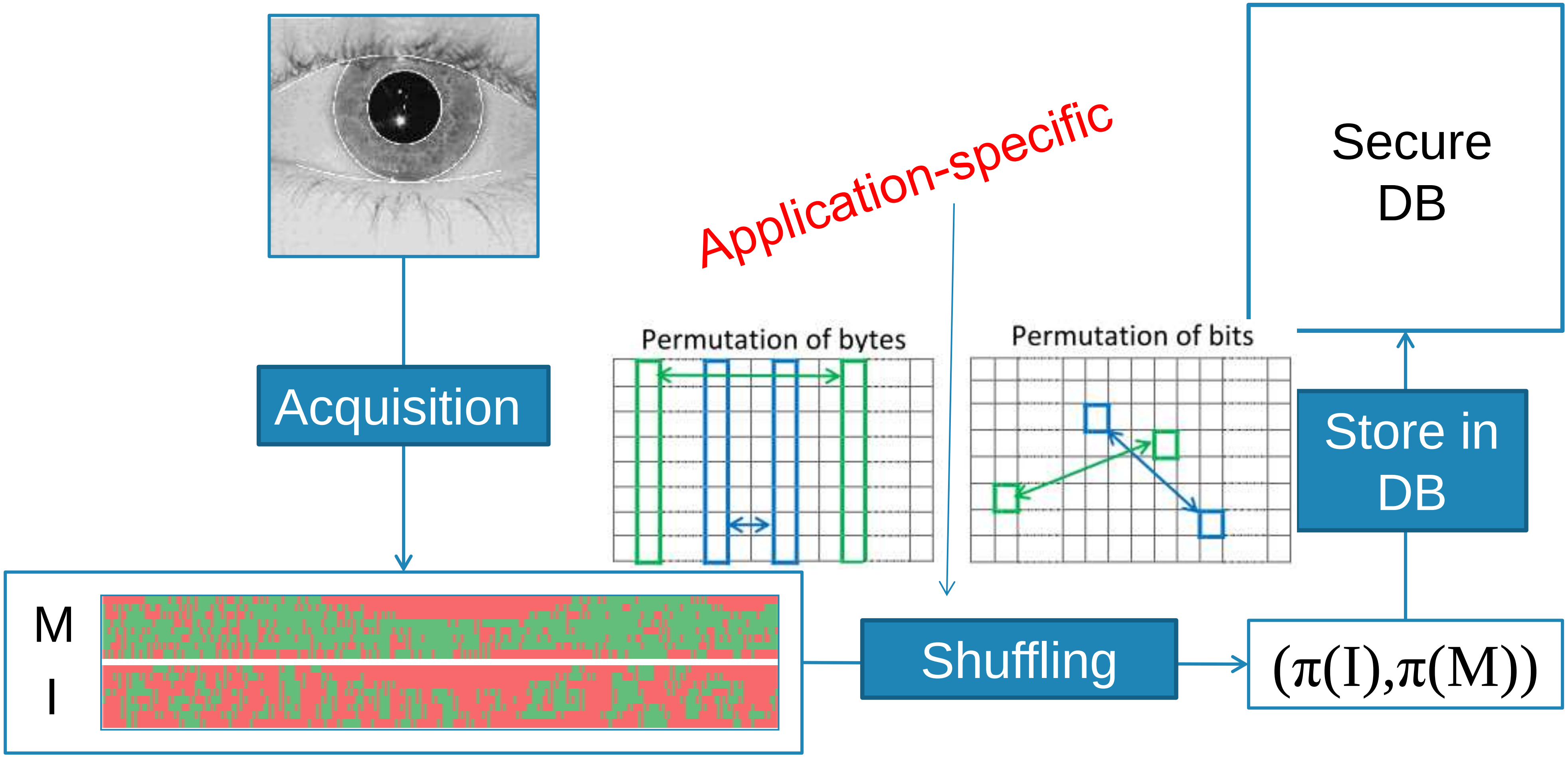
SHUFFLING ON IRIS



SHUFFLING

➔ Naive Model, Collision Model

- ok …

➔ Full Disclosure Model

- NOK

➔ Advanced Model (execution)

- FAR attacks
- Statistics with know (plaintext or matching-plaintext, ciphertext) couples
  => good appromixate of permutation

➔ Standard Model

- ?

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SHUFFLING IS NOT SUFFICIENT

- **Same transformation applied to the whole reference DB**

- **Biometric data are not uniformly random**
  - Correlated bits
    - cf. e.g. *A. Vetro, S. Draper, S. Rane, and J. Yedidia. Securing biometric data. In P. Dragotti and M. Gastpar, editors, Distributed Source Coding. Elsevier, Jan. 2009*
    - For instance, on iris information part
      - Transition 0 → 0 proba > 0.40
      - Transition 1 → 1 proba > 0.20
  - Non-random masks

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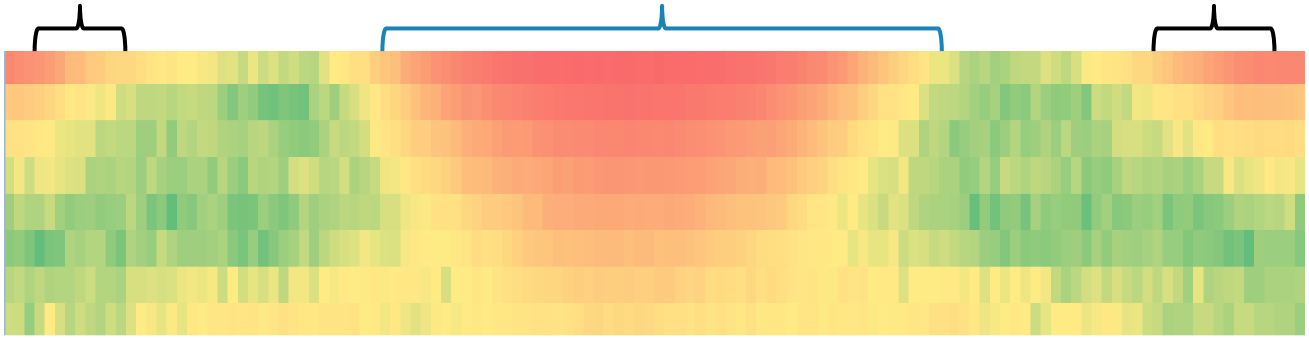
ATTACK WITH STOLEN DB)
(ON BYTE PERMUTATION)

➔ Method

- Assign a probability of being neighbors for each couple of bytes



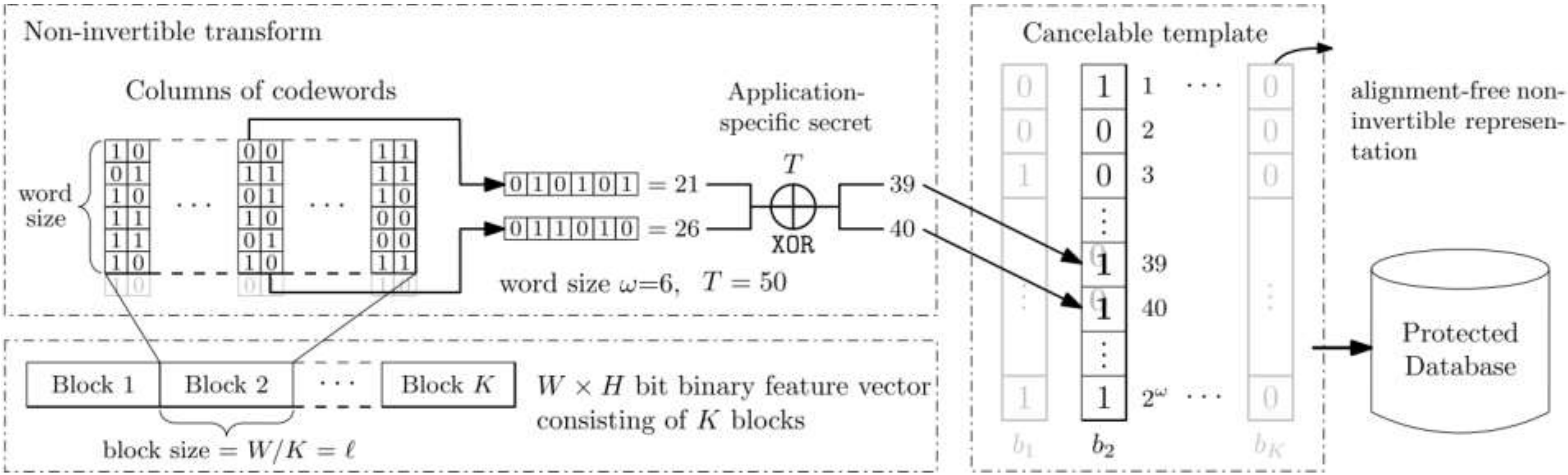
➔ Results :

- Blue - Percentage of the permutation retrieved : 39% and Matching : 0.33
- Blue+Black - Percentage of the permutation retrieved : 58% and Matching : 0.20

Compression is neither sufficient

*Related to ICB 2015 Security analysis of Bloom Filter-based Iris Biometric Template Protection w/ C. Morel & C. Rathgeb

HASHING TABLE-BASED TPS



From Rathgeb et al.'s ICB 2013

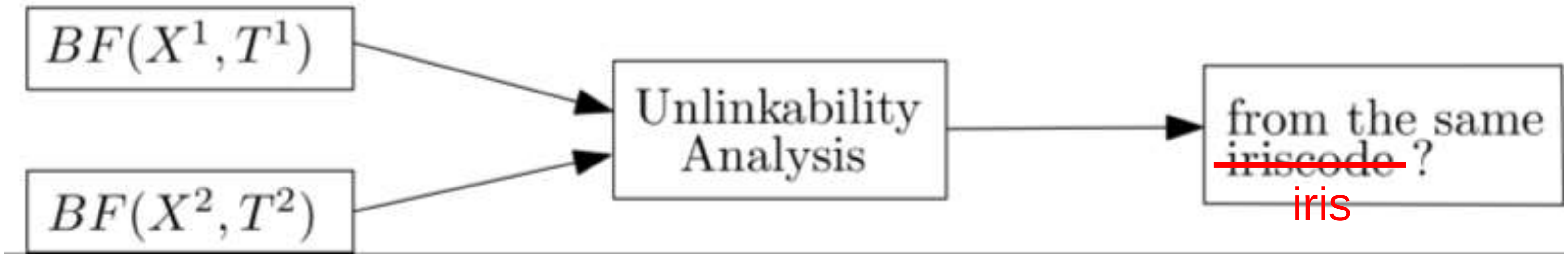
➔ **Claimed properties (even with T public): unlinkability & irreversibility**

➔ **Full Disclosure Model = Advanced Model = Standard Model**

- FAR attacks => linkability & pseudo-reversibility
- Can we do more?

BIOSIG 2014 ANALYSIS

➔ Unlinkability analysis



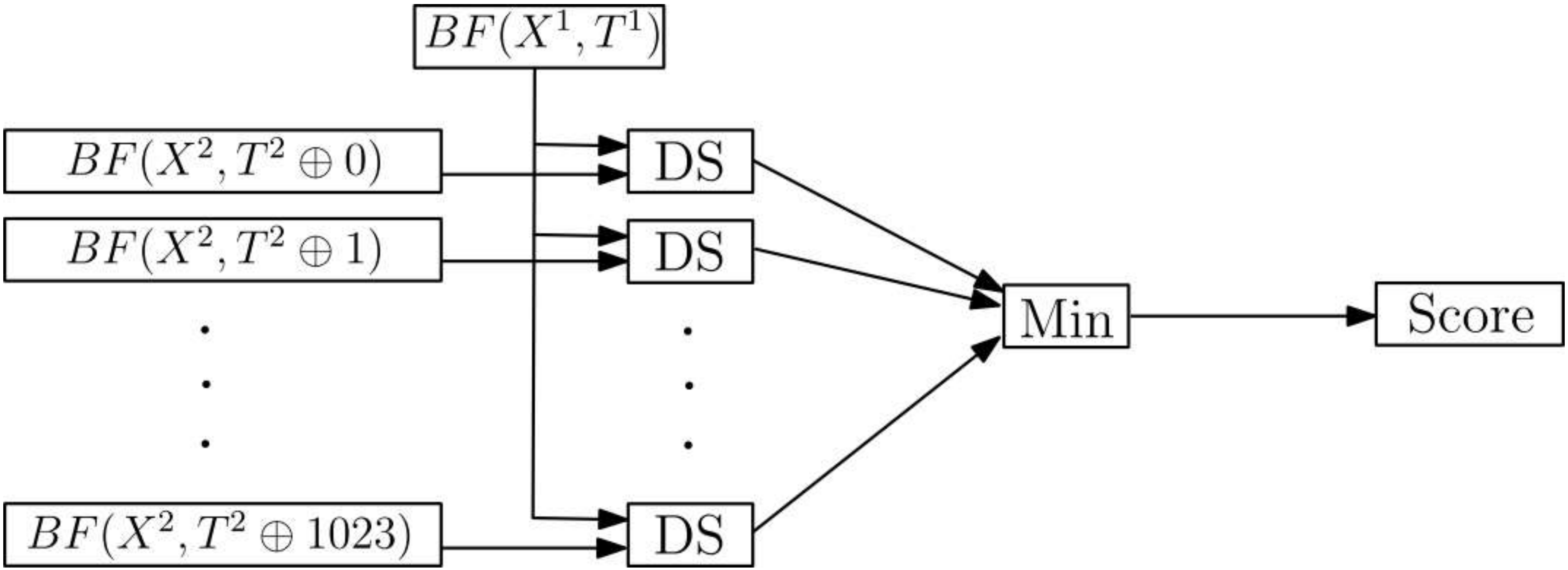
- Methods: $|BF(X,T^1)| = |BF(X,T^2)|$
- Results: 96% of success

➔ Irreversibility analysis

- Methods: analysis based on ~~uniformly random data~~ real biometric data
- Results: reconfirm Rathgeb et *al.*'s irreversibility security analysis

J. Hermans, B. Mennink, and R. Peeters. When a bloom filter is a doom filter: Security assessment of a novel iris biometric template protection system. In BIOSIG 2014 .

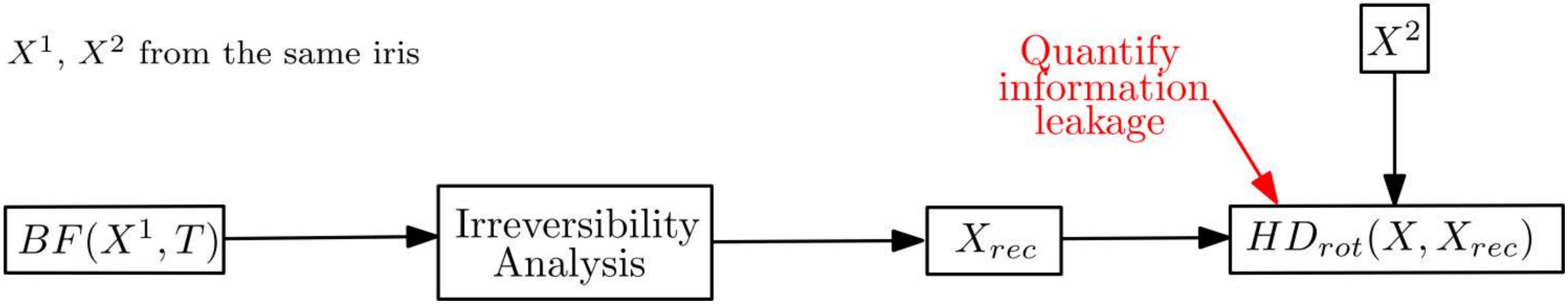
UNLINKABILITY ANALYSIS



IRREVERSIBILITY ANALYSIS

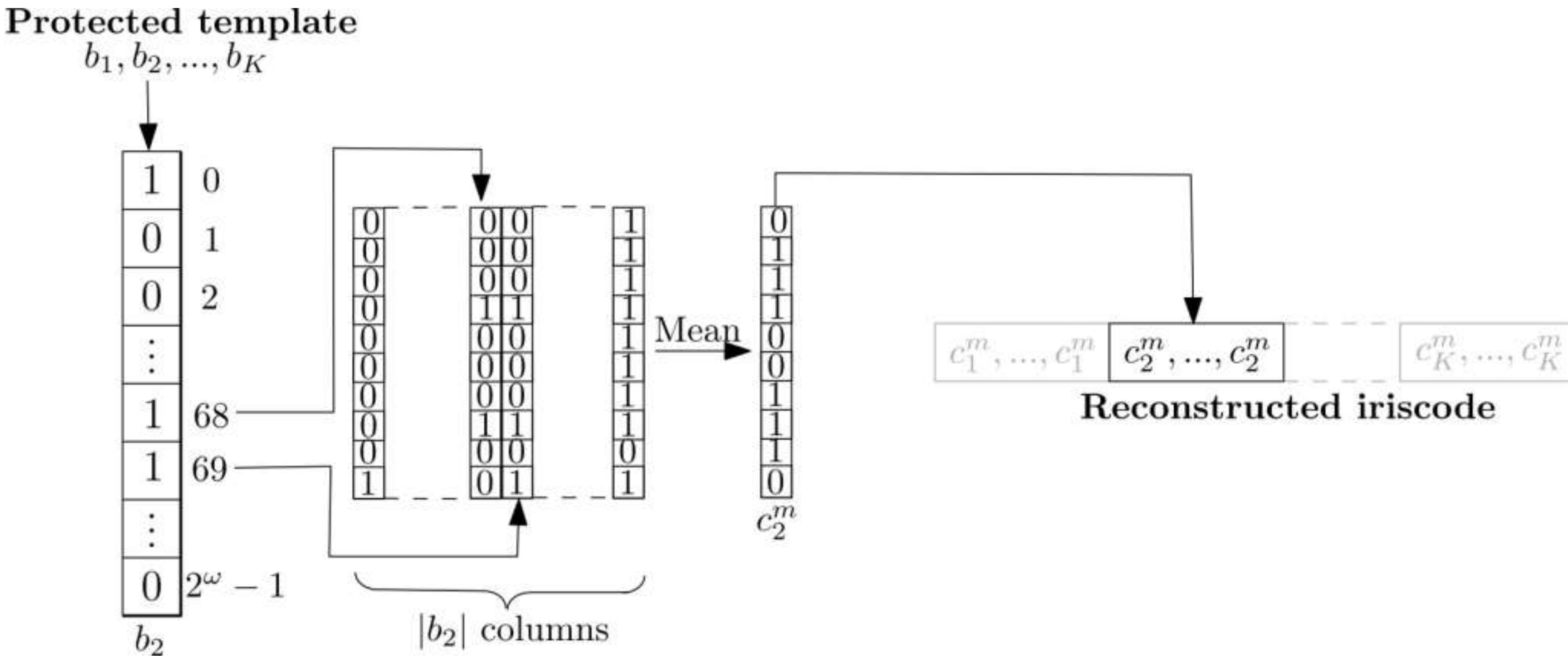
➔ General irreversibility attack

➔ Our irreversibility attack



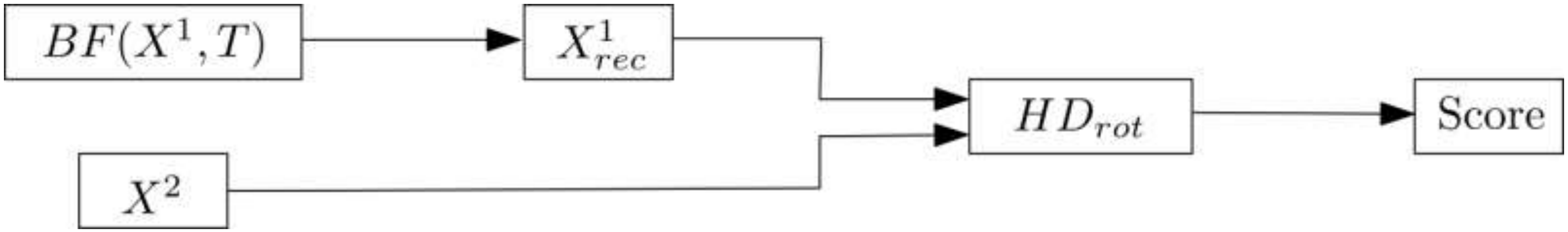
MEAN COLUMN OF EACH BLOCK

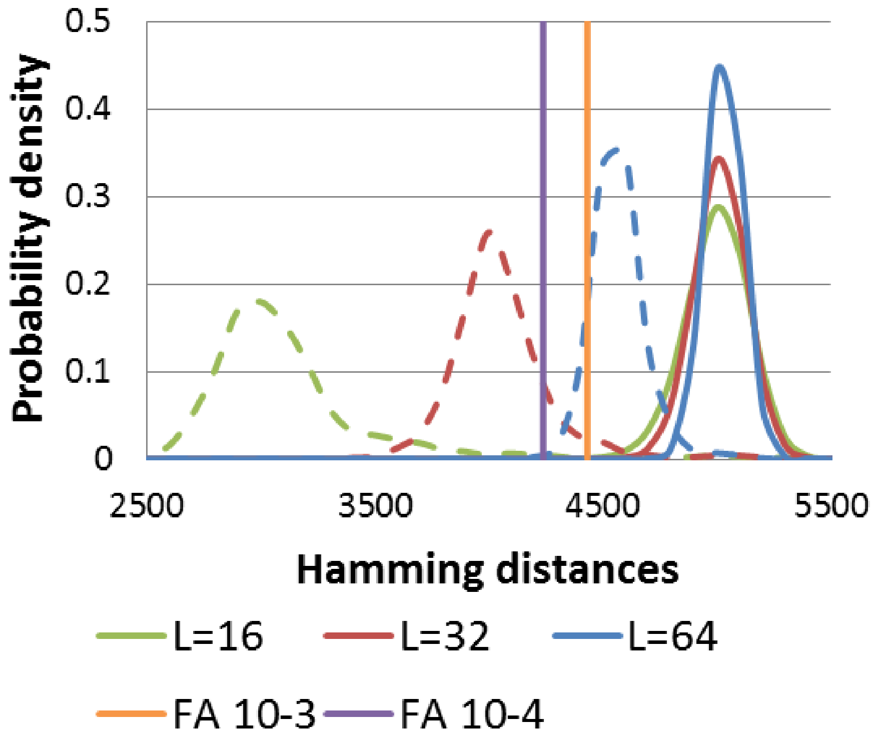
T=0



IRREVERSIBILITY ATTACK - EXPERIMENTATIONS

T=0





Optimal security?

OPTIMAL SECURITY…?

- **Goal: ensuring FAR attack = worst case situation**
- **Seems realistic for error-correcting code (ECC) based TPS**
- **One of our solutions**
  - Product codes
  - +randomly permuted biometric binary vector (interleaving)
  - +iterative soft decoding algorithm

Underlying idea: to tend toward the worst-possible FAR

- Use near-optimal decoding algorithm (vs Shannon)
- And use i.i.d. bits for messages or break correlations

Related to IEEE TIFS 2008 Theoretical and Practical Boundaries of Binary Secure Sketches w/ H. Chabanne, G. Cohen, B. Kindarji & G. Zémor

APPLICATION TO DIFFERENT MODALITIES

- **Preliminary step:**
  - embedding into a Hamming space
  - constraints: amount of errors, low FAR with usable FRR

- **Almost direct for iris** (cf. IEEE TIFS 08, BTAS 2007 w/ Chabanne, Cohen, Kindarji & Zémor)

- **Works well for vein recognition**
  - (with specific dedicated alignment-based techniques) (cf. ICISP 2015 w/ Chabanne & Favre & Picard)

- **Face: quite okay as fixed length feature vectors in Euclidean space**

- **Fingerprint still a challenge**

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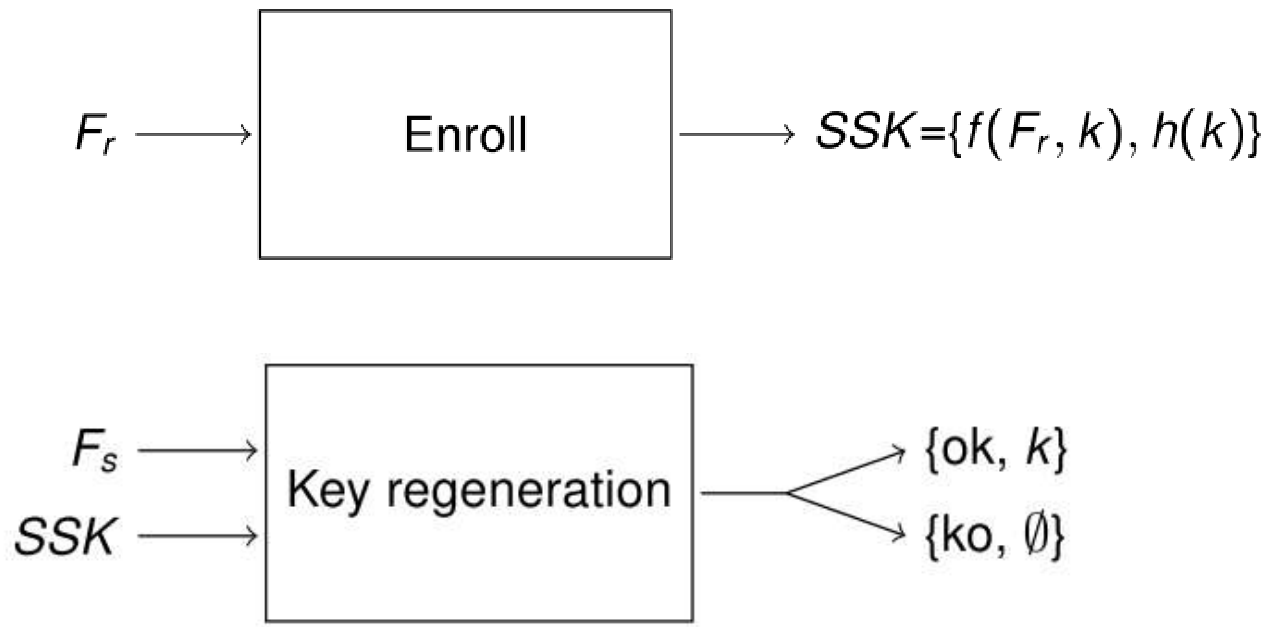
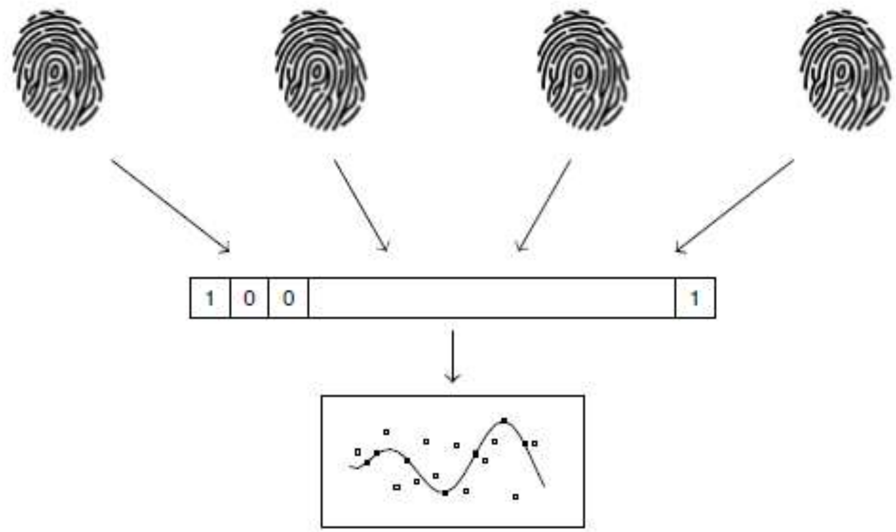
APPLICATION TO KEY BINDING



➔ **Goals: low FAR and « valuable » key length**

FUSION FOR DECREASING FAR

- Fusion of binary vectors and application to fuzzy vault



- Results on FVC2000 DB2

Number of fused templates	FRR (%) at 0.01% FAR	Computational Security (bits)
1	32.87	31
2	17,30	36
4	2.10	53
8	0.30	143

- Security
  - More costly FA attacks due to fusion
  - High computational security in fuzzy vault setting

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CONCLUSION

- **Design of TPS**
  - Need to take in account practical constraints
  - Security analysis is a critical task in the design
    - FAR and Intrinsic properties of data MUST be taken in account
  - Progresses in the last years on trade-offs between security vs accuracy/efficiency
    - Decreasing FAR for some modalities still desirable
  - Applications to key generation

- **1st layer of protection for “stand-alone” use case**

- **To be combined or replaced with more robust cryptographic techniques in a system-oriented approach**