Clonability of printable graphical codes

a machine learning approach

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Outline

State-of-the-art

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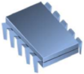

Electronics

Banknotes

Luxury objects

Art objects

Packaging

Risks of counterfeiting

- Danger for life
- Market loss
- Damage of brand reputation
- etc.

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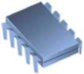
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  - \- increases the product cost
  - \+ expensive & difficult for copying

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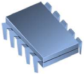
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  - \- verification often requires special equipment
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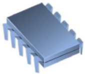
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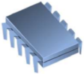

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- ▶ Anti-copying Pattern [Pic04, WB08]
  - \+ claimed to be **unclonable**

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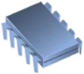

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- Anti-copying Pattern [Pic04, WB08]
  - ? is it really **unclonable**?

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Figure 1: Example of traditional 2D codes.

- Traditional codes are used to encode product info that is used for tracking and tracing

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- Traditional codes are used to encode product info that is used for tracking and tracing
- However they are clonable

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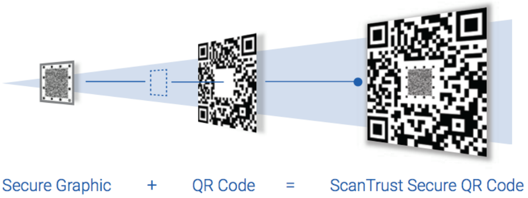

Figure 2: Example of ScanTrust QR code [https://www.scantrust.com].

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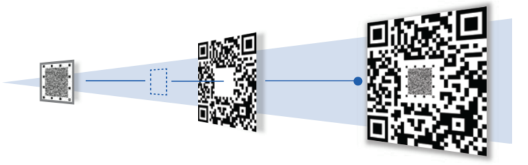

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- These codes referred to as Printable Graphical Codes (PGC) are used to distinguish authentic product from fakes and are claimed to be **unclonable** under **hand-crafted** attacks

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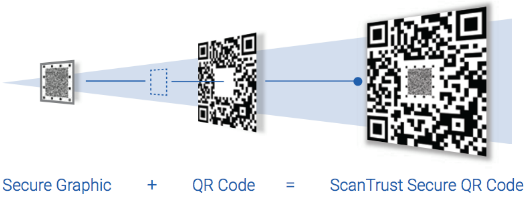

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- These codes referred to as Printable Graphical Codes (PGC) are used to distinguish authentic product from fakes and are claimed to be **unclonable** under **hand-crafted** attacks
- What about **machine learning based attacks**?

Machine learning based attacks

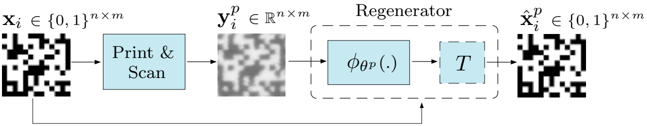
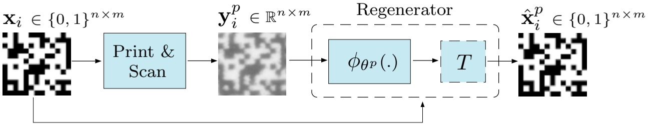


Figure 3: Training procedure based on training samples $\{\mathbf{x}_i, \mathbf{y}_i^p\}_{i=1}^M$ (p - printer type, M - number of training samples and T - thresholding).

Machine learning based attacks



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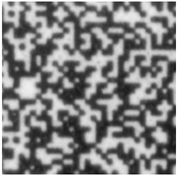
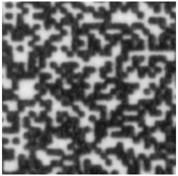
Training:

$$\hat{\theta}^p = \arg\min_{\theta^p} \sum_{i=1}^{M} \mathcal{L}\big(\mathbf{x}_i, T(\phi_{\theta^p}(\mathbf{y}_i^p))\big) + \lambda \Upsilon_{\theta^p}(\theta^p) \quad (1)$$

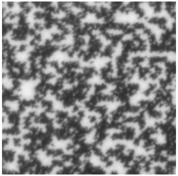
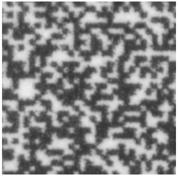
where $\mathcal{L}(.)$ is a loss function, ϕ_{θ^p} is a trained model, θ^p represents the parameters of the trained model for a printer p and $\Upsilon_{\theta^p}(.)$ is a regularizer for the model parameters.

Dataset of *DataMatrix* codes

- Printers:
  - *Laser:* Samsung Xpress 430 (*SA*) 600 dpi
  - *Laser:* Lexmark CS310 (*LX*) 1200 dpi
  - *Inkjet:* Canon PIXMA iP7200 (*CA*) 600 dpi
  - *Inkjet:* HP OfficeJet Pro 8210 (*HP*) 1200 dpi

SA	LX

CA	HP

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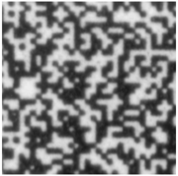
- Scanners:
  - Epson V850 Pro at 1200 ppi
- 384 codes of size 384×384 per printer
  - training 100 images:
    25600 sub-images of size 24×24
  - validation 50 images:
    12800 sub-images of size 24×24
  - test 224 images:
    59904 sub-images of size 24×24



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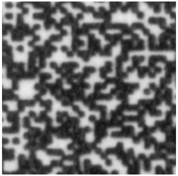
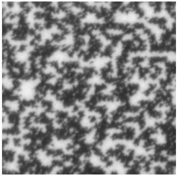


LX



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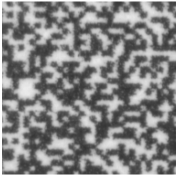

HP

Deep FC regenrator

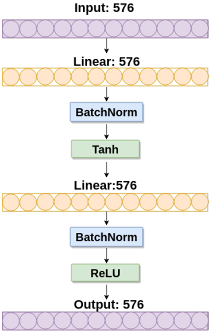

Figure 4: FC 2 layers.

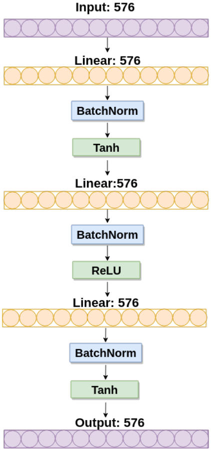

Figure 5: FC 3 layers.

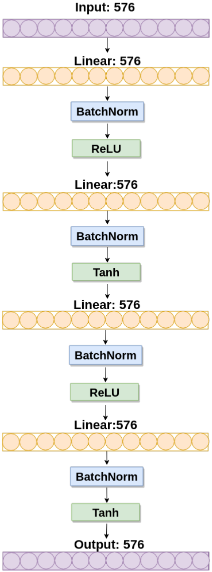

Figure 6: FC 4 layers.

Deep BN regenrator

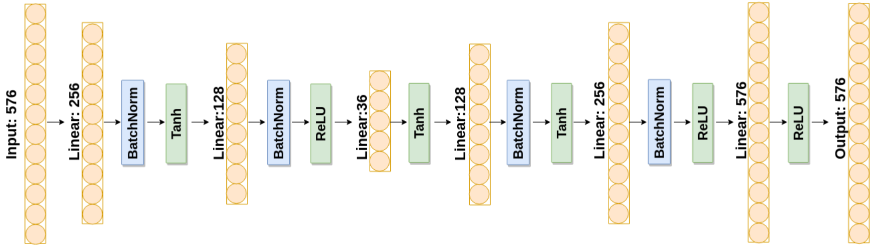

Figure 7: Deep BN regenrator architecture.

Regeneration metrics

- Hamming distance: $\mathbf{x} \in \{0,1\}^{n \times m}$, $\mathbf{y}^p \in \mathbb{R}^{n \times m}$, $T_{t^p}(.)$ - binarization function: ("hard" coding)

$$d(\mathbf{x}, \mathbf{y}^p) = \frac{1}{n \cdot m} \sum_{j=1}^{n \cdot m} \mathbf{x}(j) \oplus T_{t^p}(\mathbf{y}^p(j)) \tag{2}$$

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- Pearson correlation [PHMHSB13]: $\mathbf{x} \in \{0,1\}^{n \times m}$, $\mathbf{y}^p \in \mathbb{R}^{n \times m}$: ("soft" coding)

$$\rho(\mathbf{x}, \mathbf{y}^p) = \frac{cov(\mathbf{x}, \mathbf{y}^p)}{\sigma_{\mathbf{x}} \sigma_{\mathbf{y}^p}} \tag{3}$$

Regeneration results

Method	*SA*	*LX*	*HP*	*CA*
		Pearson correlation		
Thr	0.774	0.766	0.742	0.704
FC 2	0.995	0.994	0.982	0.981
FC 3	0.994	0.994	0.982	0.983
FC 4	0.994	0.995	0.981	0.982
BN	**0.996**	**0.996**	**0.986**	**0.984**
		normalized Hamming distance		
Thr	11	12	13	15
FC 2	0.22	0.24	0.93	0.98
FC 3	0.23	0.24	0.90	0.85
FC 4	0.24	0.23	0.95	0.90
BN	**0.21**	**0.22**	**0.69**	**0.76**

Table 1: Regeneration results with respect to original codes.

Results visualisation

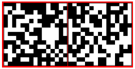
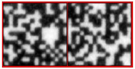
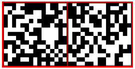
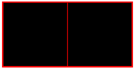
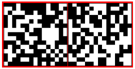
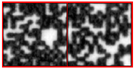
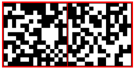
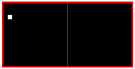
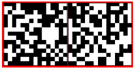
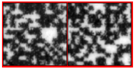
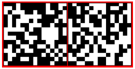
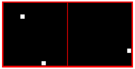
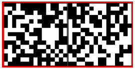
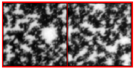
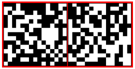
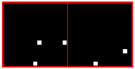
	Printer	Original	Scanned original	Reconstructed (*BN*)	Difference
Laser printers	SA				
	LX				
Inkjet printers	HP				
	CA				

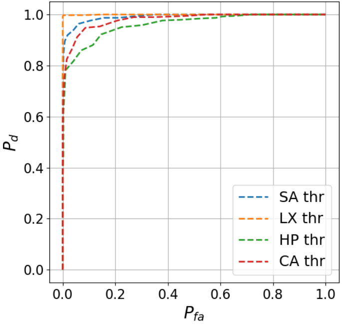
Table 2: Examples of attacks against PGC: two samples of scanned codes, the estimates produced by *BN* model and the difference between the original and attacked codes.

Authentication metrics

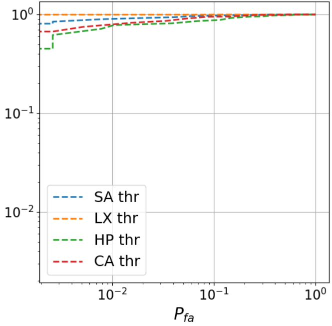
$$\begin{aligned} P_d &= \Pr\{\alpha \cdot d(\mathbf{x}_i, \mathbf{y}_i^p) \leq \gamma | \mathcal{H}_0\} \\ P_{fa} &= \Pr\{\alpha \cdot d(\mathbf{x}_i, \mathbf{y}_i^p) < \gamma | \mathcal{H}_1\}, \end{aligned} \tag{4}$$

where γ is the threshold, $d(.)$ is a similarity measure between the original and printed codes, $\mathcal{H}_0$ corresponds to the hypothesis that $\mathbf{y}_i^p$ is an authentic code and $\mathcal{H}_1$ is the hypothesis that $\mathbf{y}_i^p$ is a fake (cloned) code, α equals to -1 for the *Pearson correlation* and to 1 for *Hamming distance*.

Authentication results



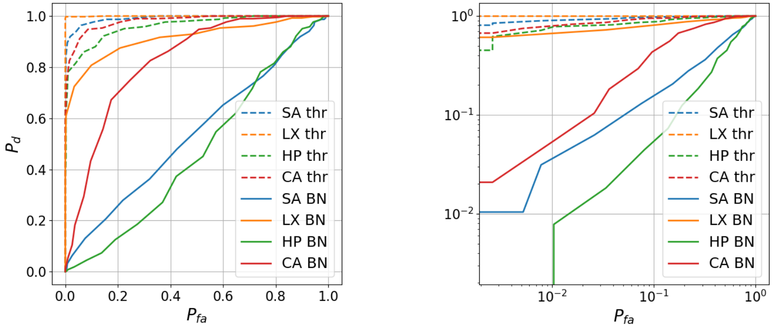
(a) Hamming distance



(b) Hamming distance: log scale

Figure 8: The ROC curves for*Hamming distance* between the original and fake printed codes estimated via $\mathcal{Thr}$ methods. P_d denotes the probability of the correct detection and P_{fa} is the probability of false acceptance.

Authentication results

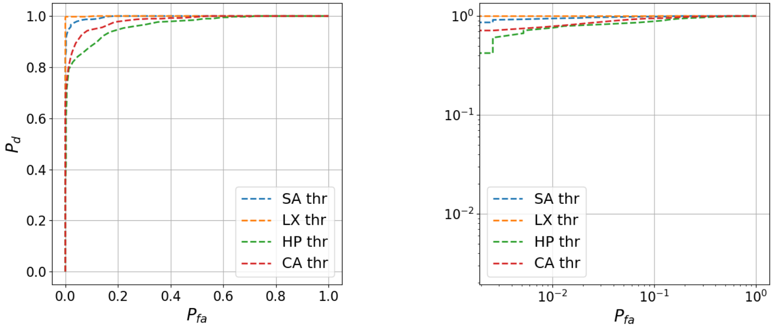


(a) Hamming distance

(b) Hamming distance: log scale

Figure 9: The ROC curves for *Hamming distance* between the original and fake printed codes estimated via BN and Thr methods. P_d denotes the probability of the correct detection and P_{fa} is the probability of false acceptance.

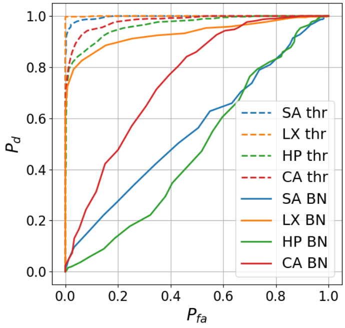
Authentication results



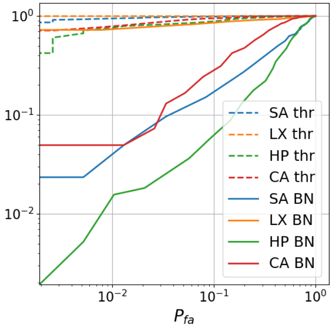
(a) Pearson correlation (b) Pearson correlation: log scale

Figure 10: The ROC curves for *Pearson correlation* between the original and fake printed codes estimated via $\mathcal{T}hr$ methods. P_d denotes the probability of the correct detection and P_{fa} is the probability of false acceptance.

Authentication results



(a) Pearson correlation



(b) Pearson correlation: log scale

Figure 11: The ROC curves for *Pearson correlation* between the original and fake printed codes estimated via BN and Thr methods. P_d denotes the probability of the correct detection and P_{fa} is the probability of false acceptance.

Conclusions

- we investigated the clonability of generic printable graphical codes using machine learning based attacks
- we examined the proposed framework on real printed codes reproduced with 4 printers
- we demonstrated a possibility of sufficiently accurate cloning of the PGC from their printed counterparts
- this should serve as a warning that more research are needed on the colonability of PGC

web-page:

http://sip.unige.ch/projects/snf-it-dis/publications/icassp-2019

GitHub:

https://github.com/taran0/clonability-of-printable-graphical-codes

Dataset:

http://sip.unige.ch/projects/snf-it-dis/datasets/dp0e/

References I

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