Context

Why protect ?

- Privacy, property, forgery
- Avoid leaks (or trace them)
  - Medical data
    (Greenbone Networks Study, september 2019)

Greenbone Networks Study, (september 2019)

Monde/France

- 399 M/2.94 M medical images
- 24 M/54.000 patient records
- 500 faulty servers
- DICOM (Protocol)

3D Protection

3D Data Hiding

- Watermarking
- High-Capacity Data Hiding
- Steganography

Selective Encryption

- Confidential Protection
- Sufficient Protection
- Transparent Protection

V. Favier, N. Zemiti, O. Caravaca Mora, G. Subsol, G. Captier, R. Lebrun, L. Crampette, M. Mondain, B. Gilles
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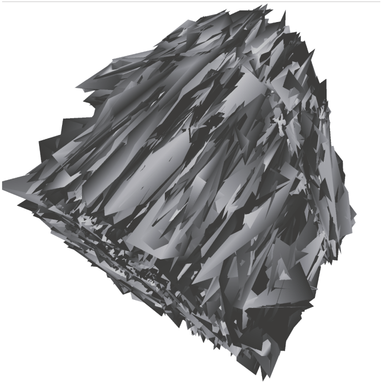

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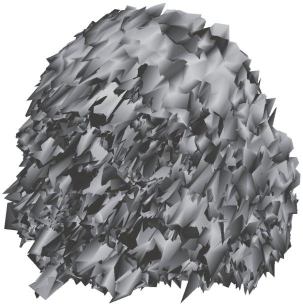

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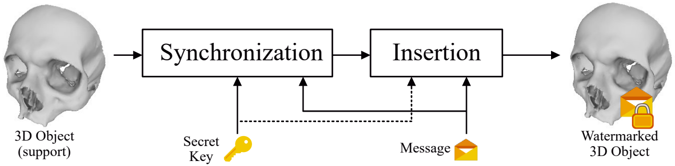
3D Data Hiding

Definition

The art to insert hidden message in data:

- Confidentiality: Statistical invisibility
- Robustness: Transformation resistance
- Capacity: Embedded message size



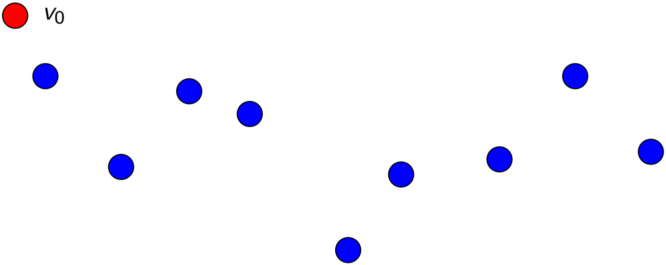
Interests

- Content Enrichment (Metadata)
- DRM (Trace, history logs)
- Integrity (Modification, forgery)

High-Capacity 3D Data Hiding

Hamiltonian Path Quantization (HPQ)

- Synchronization: Nearest Neighbour Halmitonian Path (NNHP)
- Insertion: Spherical coordinates (r, θ, ϕ)



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Multimedia Tools Applications, Springer, 2017

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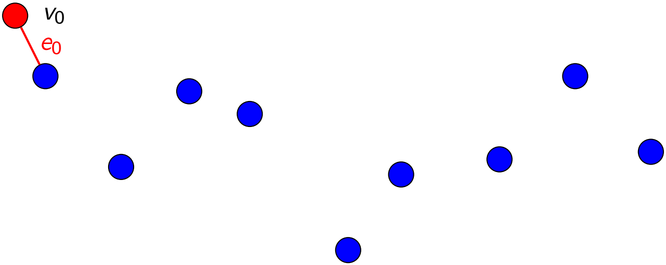

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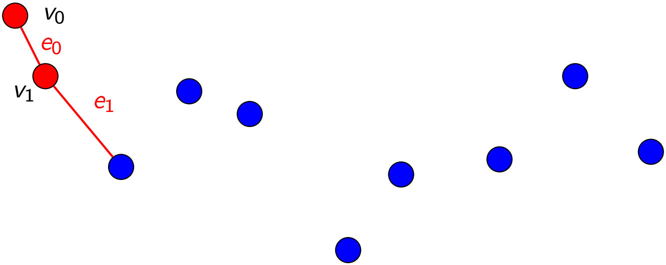

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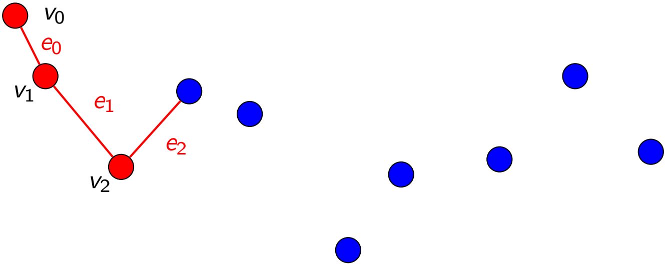

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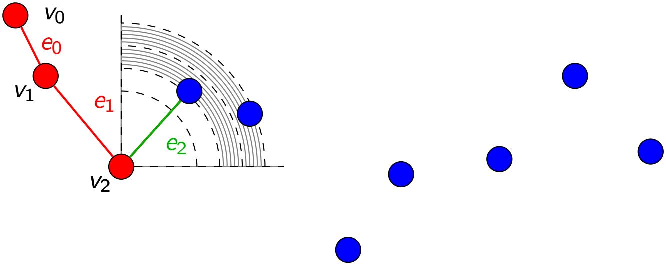

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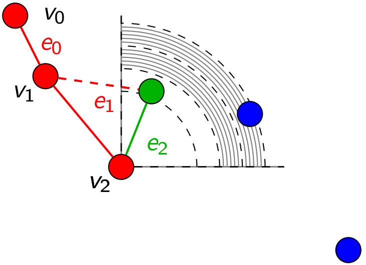

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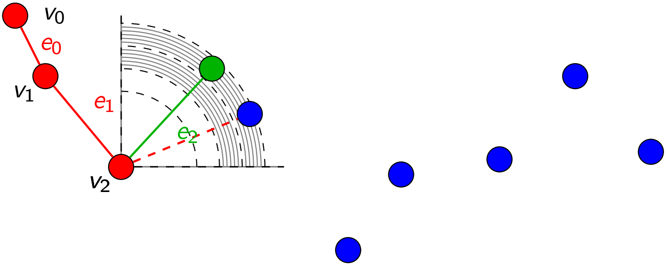

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Multimedia Tools Applications, Springer, 2017

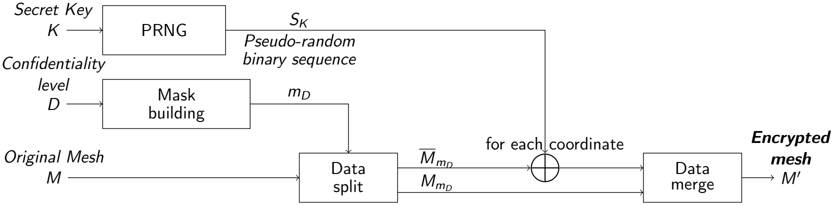
3D Selective Encryption - Method overview

Selective encryption

- Reversible
- Controlled visual confidentiality level

Format-compliant

- Viewable encrypted mesh
- Size preservation

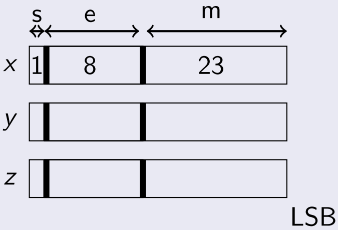


3D Selective Encryption - Data representation

Mesh

- Geometry (Vertices)
- Connectivity (Faces)

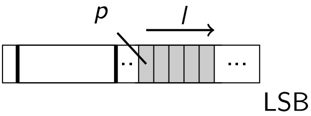
Vertex



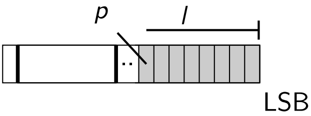
3D Selective Encryption - Mask construction

Confidentiality level $D =< p, l >$

- p, position of first bit to encrypt $p \in [\![0\ ;\ 22]\!]$
- l, number of bits to encrypt $l \in [\![1\ ;\ p+1]\!]$

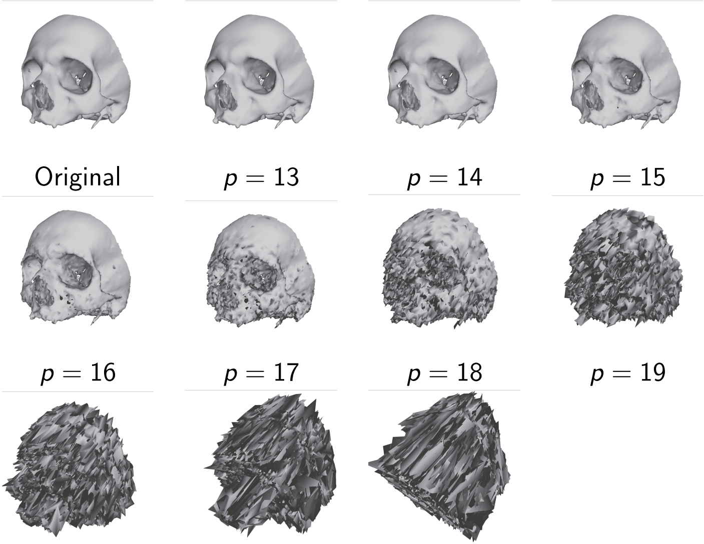


D-SW mask ($D =< p, l >$)



D-LSB mask
($D =< p, l = p + 1 >$)

3D Selective Encryption - Experimental results



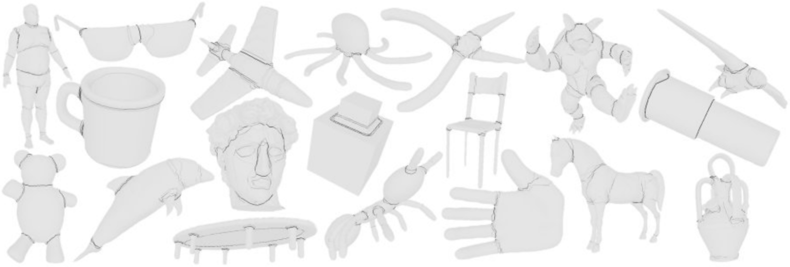
Original | $p = 13$ | $p = 14$ | $p = 15$

$p = 16$ | $p = 17$ | $p = 18$ | $p = 19$

$p = 20$ | $p = 21$ | $p = 22$

3D Selective Encryption as a function of Confidentiality level $D =< p, p + 1 >$

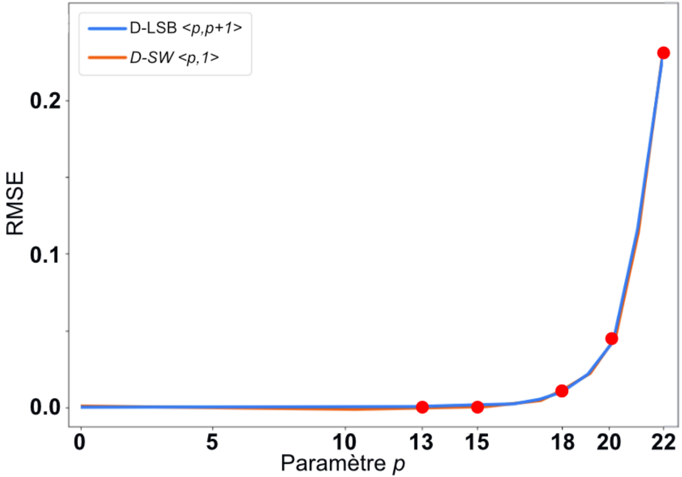
3D Selective Encryption - Experimental results

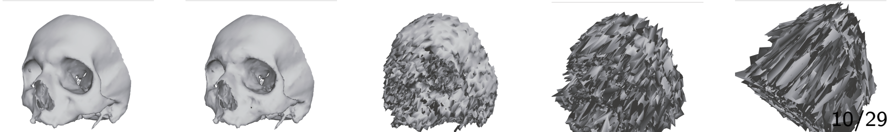


Experimental setup

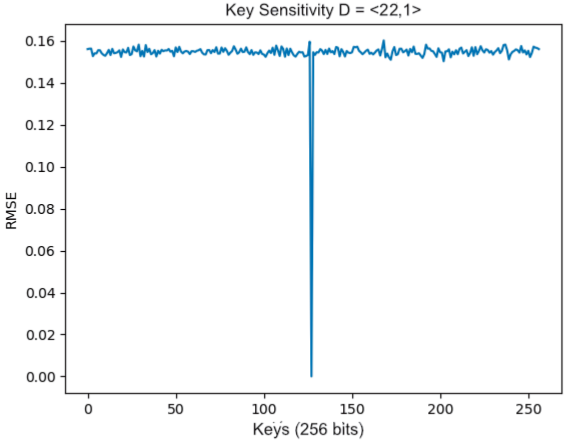
- 380 3D Objects from Princeton Mesh Segmentation Database
- Metric : Root Mean Square Error (*RMSE*)
- Parameters : $D =< p, l = 1$ bit $>$ and $D =< p, l = p + 1$ bits $>$

3D Selective Encryption - Statistical Analysis



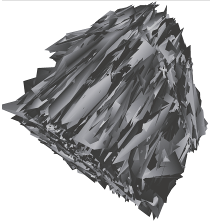


3D Selective Encryption - Secret key sensitivity

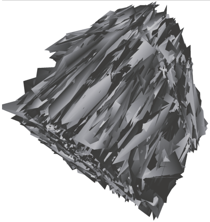


RMSE between M and M_{K_w} as a function of the secret key K and keyset $\mathbb{K} = \{K_w | d_{Hamming}(K, K_w) = 1\}$.

M'



M_{K_0}



3D Selective Encryption - Robustness analysis

Selective data encryption

- Encrypted bit quantity lower than full encryption
- Weak against attacks guessing content rather than attacks guessing secret key

Example

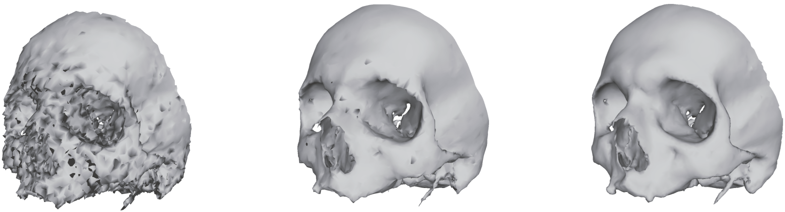
- $D =< p, 1 >$ (D-SW mask)
- N vertices
- 3 bits per vertex (3.125% of geometry)

Guessing probability for 3 bits fo all N vertices

$$P = \frac{1}{2^{3\times N}}$$

3D Selective Encryption - Mesh processing attacks

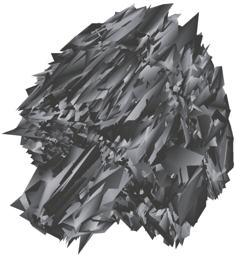
- Laplacian smoothing ($\lambda = 0.3$ and 100 iterations)
- $D =< 17, 18 >$ (Transparent protection)



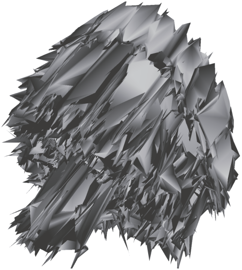
Encrypted Smoothed Original

3D Selective Encryption - Mesh processing attacks

- Laplacian smoothing ($\lambda = 0.3$ and 100 iterations)
- $D =< 21, 22 >$ (Sufficient protection)



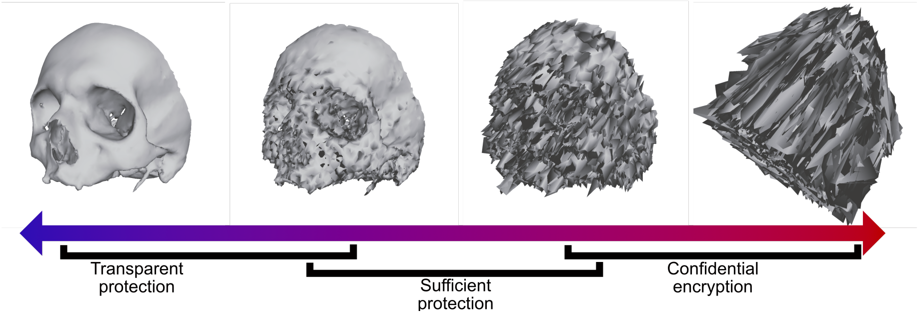
Encrypted



Smoothed

Original

3D Selective Encryption - Conclusion

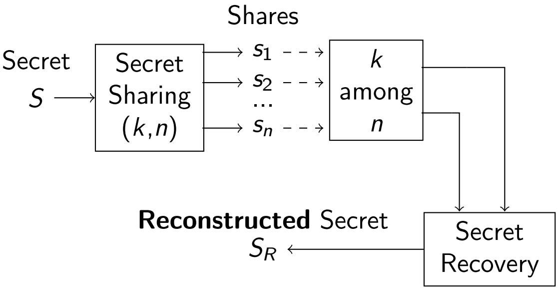


[beugnon2019icme] Sébastien Beugnon, William Puech and Jean-Pierre Pedeboy
From Visual Confidentiality To Transparent Format-Compliant Selective Encryption Of 3D Objects.
IEEE International Conference on Multimedia & Expo, 2018

Secret Sharing

Secret Sharing

- Threshold cryptography method (k, n)
- Distribution of n shares
- Secret recovery when at least k participants



Secret Sharing

Secret Sharing

- Threshold cryptography method (k, n)
- Distribution of n shares
- Secret recovery when at least k participants

Interests

- Critical data storage
- Confidentiality
- Reliability

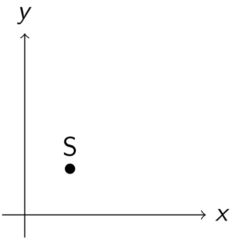
Approaches

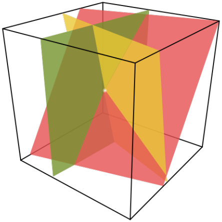
- G.R. Blakley (1979)
- A. Shamir (1979)

Secret Sharing - Blakley

Blakley's scheme (1979)

- Secret S is a k-D point
- *Shares* $s_i | i \in \{1, n\}$ are k-D hyperplanes





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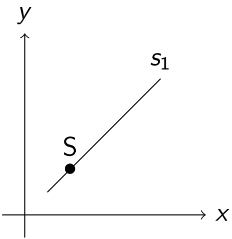

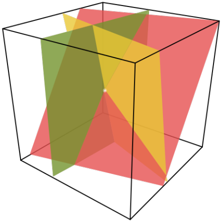

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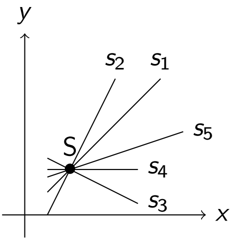

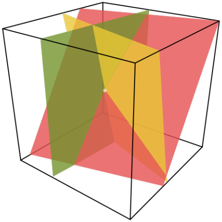

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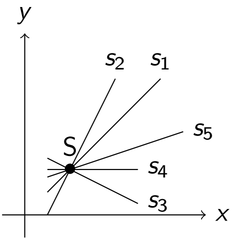

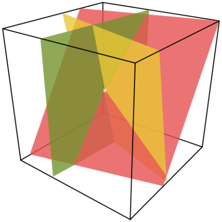

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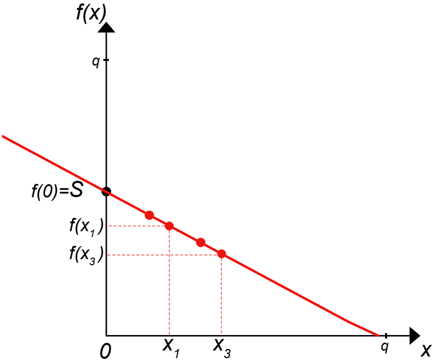
Secret Sharing - Shamir

Secret Sharing $(k,\ n)$ (Shamir, 1979)

Polynomial Interpolation:

$$f(x) = \sum_{i=0}^{k-1} a_i \times x^i$$

- Finite field $\mathbb{F}_q$ where q is prime
- $S = a_0 = f(0)$
- *Share* $s_j = (x_j, f(x_j))$ where $j \in [\![0\ ;\ n[\![$ and $x_j \in \mathbb{F}_q^*$



A. Shamir
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Communications of the ACM, 1979

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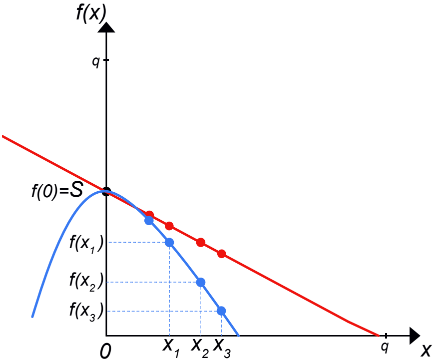

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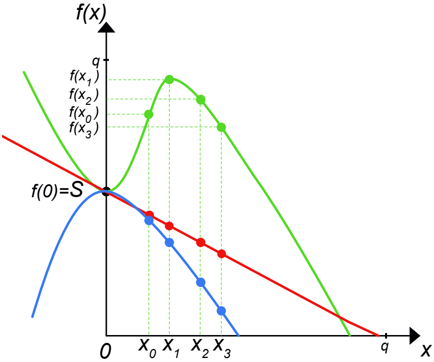

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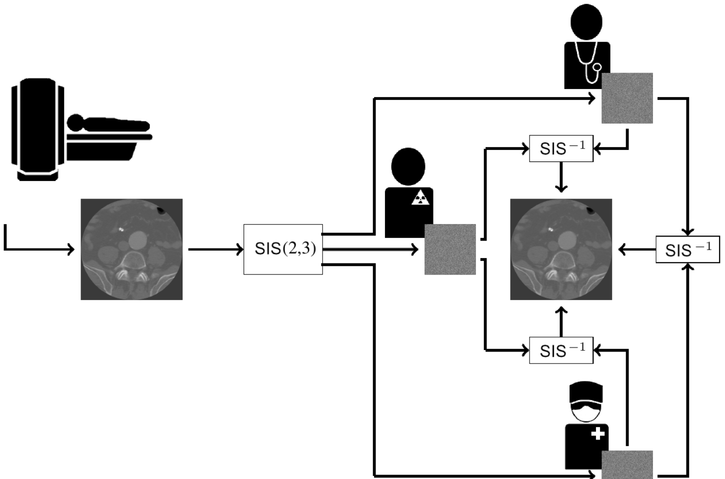
Secret Image Sharing

Secret Image Sharing

- *shares* = images



Secret Image Sharing

Secret Image Sharing

- *shares* = images

Constraints

- Image size preservation
- Shared pixel are independant
- Lossless
- No secret key

Secret Image Sharing

Approaches

- Polynomial-based Secret Image Sharing (PSIS)
- Visual Cryptography (VC)

Methods (VC)

- Visual cryptography (M. Naor et A. Shamir, 1994)
- Application of Visual Cryptography to Biometric Authentication (N. Askari *et al.*, 2015)

Methods (PSIS)

- Secret Image Sharing (C. Thien and J. Lin, 2002)
- Secret image sharing with user-friendly shadow images (C. Thien and J.Lin, 2003)
- Sharing and hiding secret images with size constraint (Y. Wu, C. Thien and J. Lin, 2004)

Secret 3D Object Sharing

Secret 3D Object Sharing

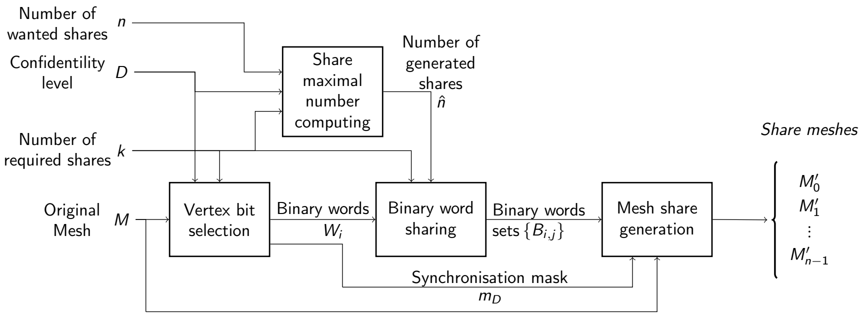
- *shares* = meshes

Constraints

- Visualisable encrypted meshes
- Controlled visual confidentiality level
- Size preservation and same number of vertices

Sébastien Beugnon, William Puech and Jean-Pierre Pedeboy
Format-Compliant Selective Secret 3D Object Sharing Scheme.
IEEE Transactions on Multimedia, 2019

Selective Secret 3D Object Sharing - Method overview



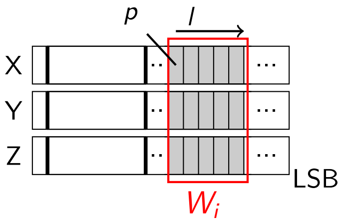
Method

- Sharing independently each vertex $v_i | i \in [\![1 \; ; \; N_v]\!]$
- Selection of sharing data space

Selective Secret 3D Object Sharing - Vertex bit selection

Confidentiality level $D =< p, l >$

- p, position of first bit to share $p \in [\![0\ ;\ 22]\!]$
- l, number of bits to share $l \in [\![1\ ;\ p+1]\!]$



Selective Secret 3D Object Sharing - Binary word sharing

Sharing parameters

- $2 <= k <= n_{max}$

Using Shamir's Scheme

- Secret is W_i
- Defined on Galois field GF($2^{(3*l)}$)
- $B_{i,j} = f(x_j) = W_i + ... + a_{k-1} \times x_j^{k-1}$

Maximum number of shares

$$n_{max} = |GF(2^m)| - 1 = |GF(2^{3\times l})| - 1 = 2^{(3\times l)} - 1$$

Secret 3D Object Sharing - Binary word sharing

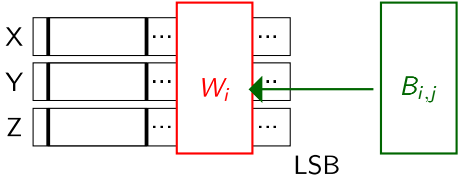
Using Blakley's scheme

- W_i is fragmented into small blocks as coordinate of secret point S
- Transform share hyperplane coefficients into a binary word $B_{i,j}$

Maximum number of shares

$$n_{max} = \prod_{j=0}^{k-2} C_1^{2^{|a_j|}} = \prod_{j=0}^{k-2} 2^{|a_j|}$$

Secret 3D Object Sharing - Shared 3D object generation



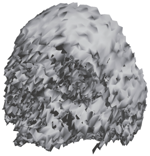
- Substitute selected vertex data by binary word from sharing process

Secret 3D Object Sharing - Results

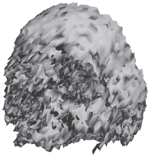
Application

- $(k = 3, n = 4)$
- $D =< 18, 19 >$

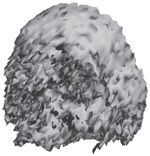
- Sharing



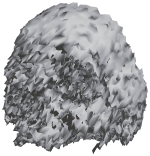
M'_0



M'_1



M'_2



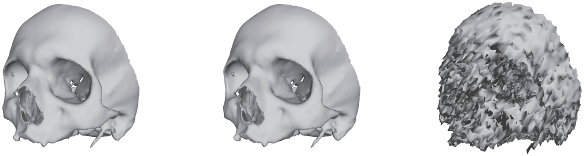
M'_3

Secret 3D Object Sharing - Results

Application

- $(k = 3, n = 4)$
- $D =< 18, 19 >$

- Reconstruction

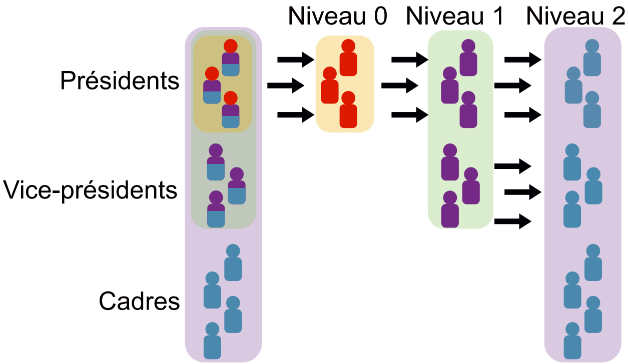


(M_0', M_1', M_2') (M_0', M_1', M_3') (M_0', M_1')

Hierarchical Secret Sharing

Multilevel hierarchy

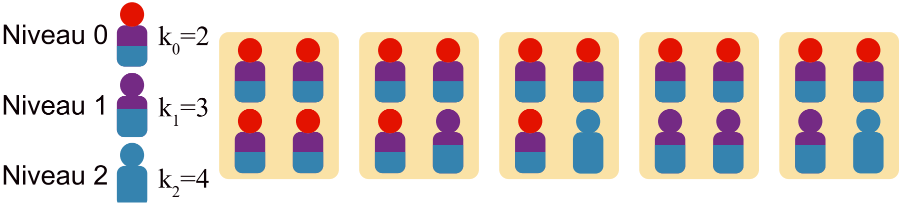
- L levels
- $\mathbf{k} = (k_0, \ldots, k_{L-1})$, with $k_i < k_j$ such as $\forall i, j \in [\![0\ ;\ L[\![, i < j$
- $\mathbf{n} = (n_0, \ldots, n_{L-1})$



Hierarchical Secret Sharing

Tassa's hierarchy (2007)

- Based on Shamir's scheme
- Using derived from the polynomial

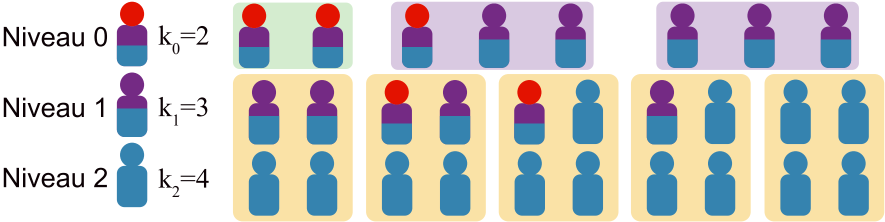


T. Tassa
Hierarchical threshold secret sharing.
Journal of cryptology, 2007

Hierarchical Secret Sharing

Belenkiyes hierarchy (2008)

- Same as Tassa
- The secret is hidden in the last coefficient



M. Belenkiy
Disjunctive Multi-Level Secret Sharing.
IACR Cryptology ePrint Archive, 2008

Priority Access Hierarchy (PAH)

Definition

- Hierarchy more realist of industrial usecase
- Using derived from the polynomial
- Distributing polynomials' coefficients