# Part I

# Steganography and Watermarking

# WISDOM

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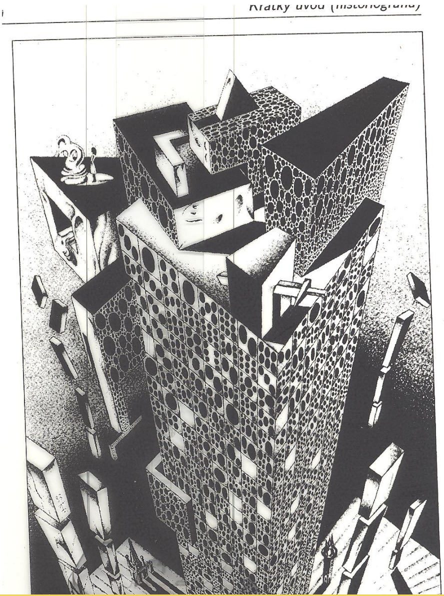
**Steganography/watermarking** goals is to make some transmitted messages **invisible** by the third party.

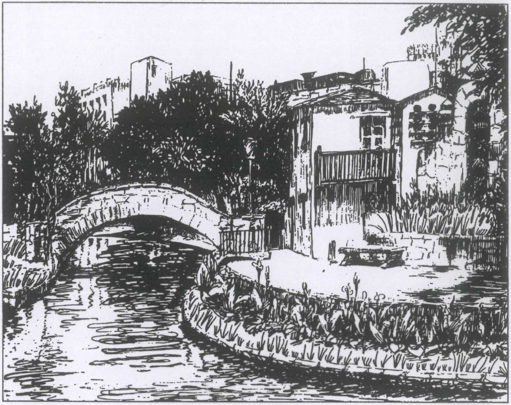
# EXAMPLE - FIND NUMBERS

Find two well-known numbers in the following picture



# EXAMPLE - ANALYSIS of a SCENE - I.

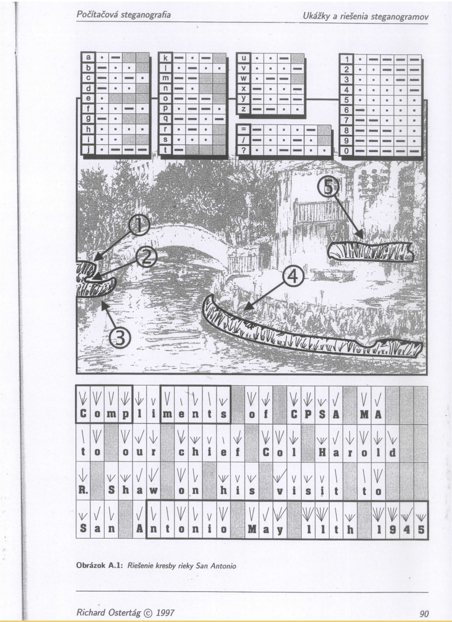




**Obrázok 0.4:** *Kresba rieky San Antonio*

rývajú tajnú správu. Každá cenzorská stanica mala svoju banku známok. Cenzori známky, ktoré mohli niesť nejakú tajnú infor-

# EXAMPLE - ANALYSIS of a SCENE - II.






**Obrázok A.1:** *Riešenie kresby rieky San Antonio*

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We will also discuss several **anonymity problems** and methods to solve them.

Preservation of the anonymity of communicating parties is in many cases also of large importance.

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Steganography and (digital) watermarking are main parts of the fast developing area of **information hiding.**

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**Steganography** – covered writing – from Greek $\sigma\tau\varepsilon\gamma\alpha\nu$–$\xi$ $\gamma\rho\alpha\phi$–$\varepsilon\iota\nu$

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**Watermarking** – is the **art and science of embedding watermarks** in **carriers in undetectable or unremovable way**.

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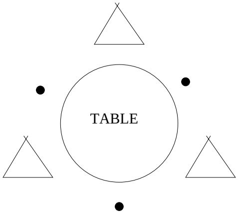
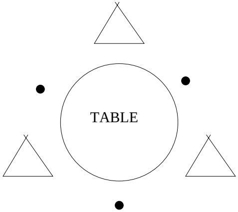
There are various techniques to deal with this problem.

Perhaps the most modern one, that is being explored currently, is to write down watermarks into materials using tools of nanotechnology.

# ANONYMITY

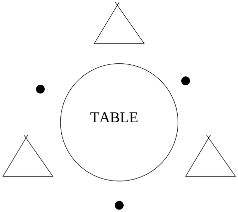
- Three cryptographers have dinner at a round table of a 5-star restaurant.





TABLE

# THE DINING CRYPTOGRAPHERS PROBLEM - II.

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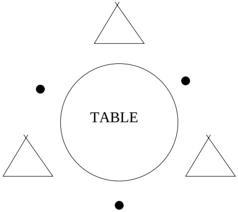


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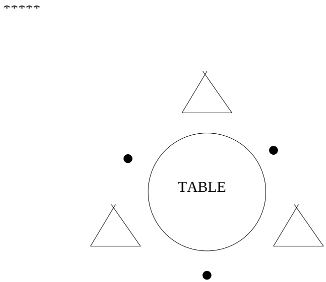


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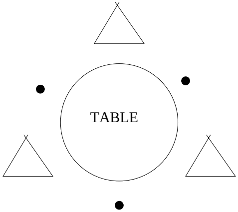


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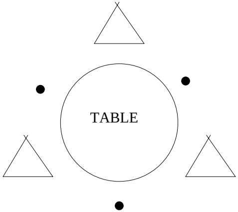
- How should cryptographers proceed that all could learn whether one of them payed the bill without learning (for other two) which one did that? - In case NASA did not pay dinner?




- Protocol
  - Each cryptographer flips a perfect coin between him and the cryptographer on his right, so that only two of them can see the outcome.

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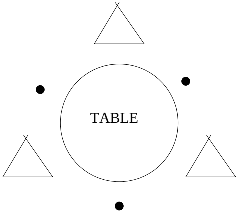


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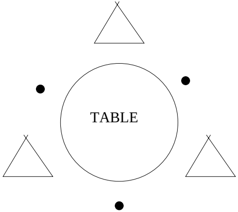


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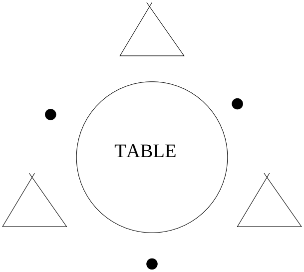
  - Each cryptographer who did not pay dinner says aloud whether the two coins he see - the one he flipped and the one his right-hand neighbour flipped - fell on the same side or on different sides.
  - The cryptographer who paid the dinner says aloud the opposite what he sees.

# SOLUTION

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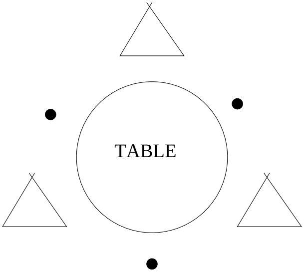


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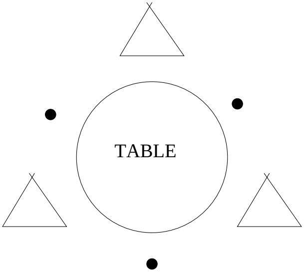
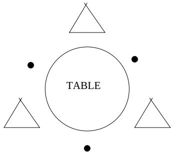



- Correctness
  - An odd number of differences uttered at the table will imply that a cryptographer paid the dinner.
  - An even number of differences uttered at the table will imply that NSA paid the dinner.
  - **Observation:** In a case a cryptographer paid the dinner the other two cryptographers would have no idea he did that.

# TECHNICALITIES of SOLUTION

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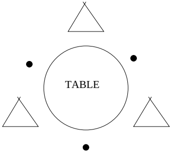


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In case none of cryptographers payed dinner, they announce the values

$$b_1 \oplus b_2, b_2 \oplus b_3, b_3 \oplus b_1,$$

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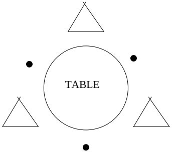


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In case one of them payed dinner, say Cryptographer 2, they announce:

$$b_1 \oplus b_2, \overline{b_2 \oplus b_3}, b_3 \oplus b_1$$

and the parity of outcomes is

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# MAIN TYPES of ANONYMOUS COMMUNICATIONS

- **Anonymous one-to-many or broadcast communication**: there is one anonymous sender and all parties receive the message that has been sent.
- **Anonymous many-to-one communication**: all parties send messages and there is only one receiver.

# CHAUM's PROTOCOL for ANONYMOUS BROADCASTING

Let communicating scheme be modeled by an unoriented graph $G = (V, E)$ with $V = \{1, 2, \ldots, n\}$ representing nodes (parties) and $E$ edges (communication links). Let $n$ be a large integer.

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- **For each** $j \in \{1, 2, \ldots, n\}$ **it sets** $k_{ij} \leftarrow 0$**;**
- **If** $(i, j) \in E$**,** $i < j$**,** $P_i$ **randomly chooses a key** $k_{ij}$ **and sends it securely to** $P_j$**;**
- **If** $(i, j) \in E$**,** $j < i$**, after receiving** $k_{ji}$ $P_i$ **sets** $k_{ij} \leftarrow -k_{ji} \bmod n$**;**
- $P_i$ **broadcasts** $O_i = m_i + \sum_{j=1}^{n} k_{ij} \bmod n$**, where** $m_i \in \{0, \ldots, n-1\}$ **is the message being sent by** $P_i$**;**

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- **$P_i$ broadcasts $O_i = m_i + \sum_{j=1}^{n} k_{ij} \bmod n$, where $m_i \in \{0, \ldots, n-1\}$ is the message being sent by $P_i$;**
- **$P_i$ computes the global sum $\Sigma = \sum_{j=1}^{n} O_j \bmod n$.**

# CHAUM's PROTOCOL for ANONYMOUS BROADCASTING

Let communicating scheme be modeled by an unoriented graph $G = (V, E)$ with $V = \{1, 2, \ldots, n\}$ representing nodes (parties) and $E$ edges (communication links). Let $n$ be a large integer.

**Protocol**: Each party $P_i$ performs the following actions (all parties in parallel).

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**Observation** One can show that to preserve anonymity of a correctly behaving sender $P_i$ it is sufficient that one another participants $P_j$ such that $(i, j) \in E$ behaves correctly.

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**Data hiding dilemma:** to find the best trade-off between three quantities of embeddings: **robustness, capacity and security.**

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**Steganography methods usually do not need to provide strong security against removing or modification of the hidden message. Watermarking methods need to to be very robust to attempts to remove or modify watermarks.**

# STEGANOGRAPHY versus CRYPTOGRAPHY

- **Cryptography is art, science and technology of presenting information through secret codes.**
- **Steganography is art, science and technology of hiding information.**

- **The goal of cryptography is to make the data unreadable by a third party.**
- **The goal of steganography is to hide the data from a third party.**

Steganography is often used with cryptography to crate a double protection. Data are first encrypted using a cryptography system and then hidden using a steganography tool.

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- Various secret religious groups and terrorist groups have been reported to use steganography to communicated in public.
- Methods and tools of steganography are consider of increasing importance for national security of world-powers and their developments and study is seen as being of increasing importance.

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All kind of data can be watermarked: audio, images, video, formatted text, 3D models, . . .

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The advantage of steganography over cryptography is that messages do not attract attention by themselves.

# CRYPTOGRAPHY and STEGANOGRAPHY

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Indeed, when steganography is used to hide the encrypted communication, an enemy is not only faced with a difficult decryption problem, but also with the problem of finding the communicated data.

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- During the Second World War a technique was developed to shrink photographically a page of text into a dot less than one millimeter in diameter, and then hide this microdot in an apparently innocent letter. (The first microdot has been spotted by FBI in 1941.)

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- During the First World War messages to and from spies were reduced to microdots, by several stages of photographic reductions, and then stuck on top of printed periods or commas (in innocuous cover materials, such as magazines).

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In 1518 Trithemius printed 6 books, 540 pages, on cryptography and steganography called **Polygraphiae.**

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In 1665 Gaspari Schotti published the book "Steganographica", 400pages. (New presentation of Trithemius.)

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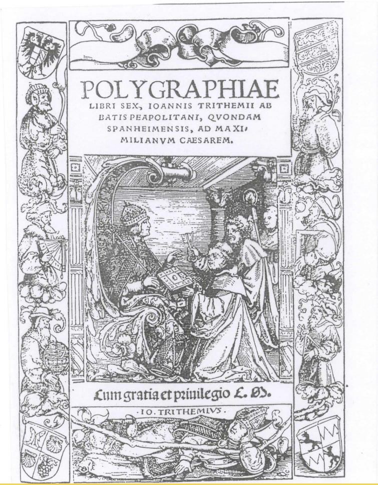
# FRONT PAGE of the TRITHEMIOUS BOOK



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Steganography using enormous potential of digitalization and of modern computers is usually called **digital steganography**.

# MODERN DIGITAL STEGANOGRAPHY

# THEORY and METHODS

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Some examples:

- Network steganography
- Echo steganography

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- With the advancement of steganalytic techniques, steganographic methods became more and more sophisticated, which in turn initiated another wave of research in steganalysis.
- One can therefore say: **Steganography is advanced through steganalysis**.

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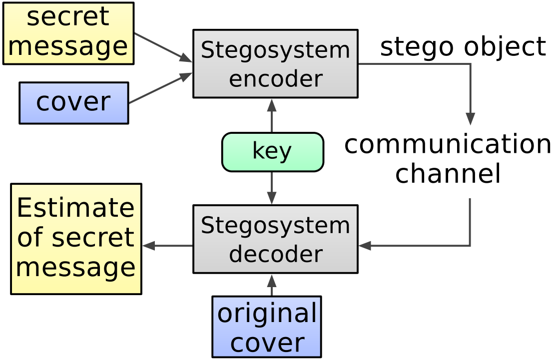
**Messages extracting algorithm**: depending on shared secret keys.

For formal analysis and security considerations it is usually expected that covers, keys and messages are assumed by random variables.

# GENERAL STEGANOGRAPHIC MODEL

A general model of a steganographic system:

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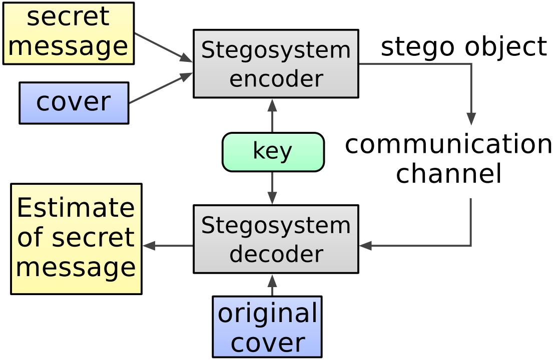


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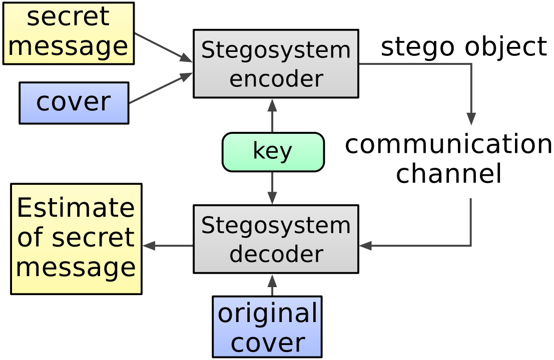


Figure 1: Model of steganographic systems

**Steganographic algorithms are in general based on replacing noise component of a digital object with a to-be-hidden message.**

**Kerckhoffs's principle holds also for steganography. Security of the system should not be based on hiding the embedding algorithm, but on hiding the key.**

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- **Security requirement** is that a third person watching such a communication should not be able to find out whether the sender has been active, and when, in the sense that he really embedded a message in the covertext. **In other words, stegotexts should be indistinguishable from covertexts.**

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If the set of covers is the set of all $512 \times 512$ grayscale images and one bit of to-be-message is embedded by a pixel, then $2^{12 \times 512}$ messages can be embedded in all covers.

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**Definition:** **Secret-key (asymmetric) stegosystem** $S = \langle C, M, K, E_K, D_K \rangle$, where C is the set of possible covertexts, M is the set of secret messages with $|C| \geq |M|, K$ is the set of secret keys, $E_K : C \times M \times K \rightarrow C$, $D_K : C \times K \rightarrow M$ with the property that $D_K(E_K(c, m, k), k) = m$ for all $m \in M$, $c \in C$ and $k \in K$.

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For example, in case Alice wants to send a message m to Bob, she encrypts first m using Bob's public key $e_B$, then embeds of $e_B(m)$ using process E into a cover and then sends the resulting stegotext to Bob, who recovers $e_B(m)$ using D and then decrypts it, using his decryption function $d_B$.

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- An improvement of the previous method is to distribute plaintext letters randomly in the cover-text and then use a mask to read it.
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**Text steganography (a really good one) is considered to be very difficult kind of steganography due to the lack of redundancy in texts comparing to images or audio.**

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with the translation

Brother Francesco Colonna passionately loves Polia

CZ

# Akrostichy 27/3/2003

## Akrostichy na jména a přezdívky

### Akrostichy (a jiné verše) na dívčí jména

### "Kryptogram" na opomenuté jméno

*Věnováno Z. Š. a K. Krylovi s díky za inspiraci.*
*9/10/2000*

**Z**atmění slunce. Zatmění smyslů. Zatmění rozumu.
**O**hnivá bouře naruby převrací vše.
**R**ozťala život na části "před Ní" a "po Ní"
**A** krátkou extázi, jež je od sebe dělí.

### Lenka

*Lenek je na Písmákovi hodně, ale ta, kterou jsem měl při psaní na mysli, bude vědět, o které to je. No a pro ty ostatní to také trošku je, protože je to moc hezké jméno.*
*13/12/2000*

**L**áskyplná
**E**roticky přitažlivá
**N**ěžná
**K**amarádská
**A** moc hezká...

### Akrostichy na další ženská jména

*18/1/2001*

**M**užské srdce -
**A** nejenom srdce -
**R**ádo pookřeje,
**K**dyž se nablízku vynoří
**É**terická bytost s
**T**ak starobylým a přitom
**A**traktivním jménem.

### Když na tebe pomyslím…

*23/2/2001*

**K**rychle je kulatá
**L**ednička hraje tango
**Á**bel je bratrovrah
**R**ozum se choulí v koutku
**A** srdci neporučí

### Akrostichy pro Lucii

*4/5/2001*
*Bridžový:*

**L**icituji slam
**U**klouznutí bude drahé
**C**ity netolerují ztrátové zdvihy
**I**mpas na srdcovou dámu
**E**fektní, ale riskantní

*Geriatrický:*

**L**odyhy lučních květin

# PERFECT SECRECY of STEGOSYSTEMS

In order to define secrecy of a stegosystem we need to consider

- probability distribution $P_C$ on the set C of covertexts;
- probability distribution $P_M$ on the set M of secret messages;
- probability distribution $P_K$ on the set K of keys;
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The basic related concept is that of the relative entropy, or **KL-distance**, $D(P_1 \| P_2)$ of two probability distributions $P_1$ and $P_2$ defined on a set Q by

$$D(P_1 \| P_2) = \sum_{q \in Q} P_1(q) lg \frac{P_1(q)}{P_2(q)},$$

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**Definition** Let S be a stegosystem, $P_C$ the probability distribution on covertexts C and $P_S$ the probability distribution of the stegotexts and $\varepsilon > 0$. Stegosystem **S** is called – $\varepsilon$-secure against passive attackers, if

$$D(P_C \| P_S) \leq \varepsilon$$

and **perfectly secure** if $\varepsilon = 0$.

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In the extraction process, the message m can be extracted from s by the computation

$$m = s \oplus c.$$

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If the embedding method does not depend on a key shared by the sender and receiver, then an attacker can forge messages, since the recipient is not able to verify sender's identity.

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- It is computationally unfeasible to detect hidden messages.

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**Cover generation techniques:** do not embed the message in randomly chosen cover-objects, but create covers that fit a message that needs to be hidden.

# DIGITAL COVER DATA

A **cover-object** or, shortly, a **cover c** is a sequence of numbers $c_i, i = 1, 2, \ldots, |c|$.

Such a sequence can represent digital sounds in different time moments, or a linear (vectorized) version of an image.

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**Note** An **RGB-vector** can be converted to YCbCr-vector as follows:

$$\mathrm{Y} = 0.299\ \mathrm{R} + 0.587\ \mathrm{G} + 0.114\ \mathrm{B}$$
$$Cb = 0.5 + \frac{(B - Y)}{2}$$
$$Cr = 0.5 + \frac{(R - Y)}{1.6}$$

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- **Substitution in binary images.** If image $c_i$ has more (less) black pixels than white pixels and $m_i = 1 (m_i = 0)$, then $c_i$ is not changed; otherwise the portion of black and white pixels is changed (by making changes at those pixels that are neighbors of pixels of the opposite color).

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  For example, $k_{i+1} = k_i + r_i$, where $r_i$ is a sequence of numbers generated by a specific pseudo-random generator.
- **Substitution into parity bits of blocks.** If the parity bit of block $c_{k_i}$ is $m_i$, then the block $c_{k_i}$ is not changed; otherwise one of its bits is changed.
- **Substitution in binary images.** If image $c_i$ has more (less) black pixels than white pixels and $m_i = 1 (m_i = 0)$, then $c_i$ is not changed; otherwise the portion of black and white pixels is changed (by making changes at those pixels that are neighbors of pixels of the opposite color).
- **Substitution in unused or reserved space in computer systems.**

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Observe that actually only 4 LSB have been changed – less than 50%

# CAT in a TREE

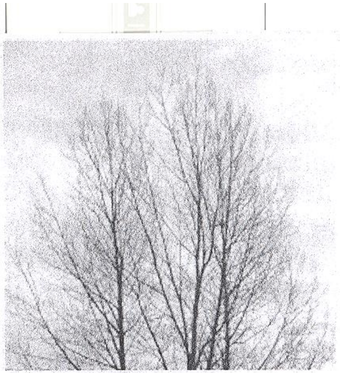

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Image of a cat extracted from the tree image above.

Cover figure and stego figure:

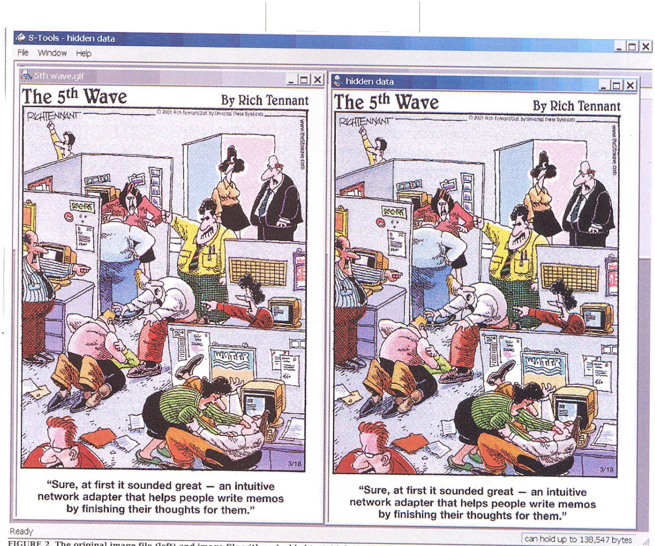


FIGURE 2. The original image file (left) and image file with embedded text (right), side by side.

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**Setting**: Let $m \in \{0,1\}^n$ be a message to be embedded in the cover $c \in C^n$, $C = \{0, 1, \ldots, 2^k - 1\}$ for some $k$ and $\pi$ be a pseeudorandom permutation of $\{1, , 2, \ldots, n\}$

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In general, sophisticates statistical tools are used in modern steganalysis attacks.

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- Into phase hiding. It embedds data into phase.

SHOW EXAMPLE: !!!!!!!!!!!!!!!!!!!!!!!

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  - Reversing operations that has been made by an active attacker.

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Let $S$ be a stegosystem which is $\varepsilon$-secure against passive attackers, $\beta$ the probability that the attacker does not detect a hidden message and $\alpha$ the probability that the attacker falsely detects a hidden message. Then

$$d(\alpha, \beta) \leq \varepsilon,$$

where $d(\alpha, \beta)$ is the binary relative entropy defined by

$$d(\alpha, \beta) = \alpha \lg \frac{\alpha}{1-\beta} + (1-\alpha) \lg \frac{1-\alpha}{\beta}.$$

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A use of network steganography is usually very hard to detect.

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**Solution:** Digital watermarking tries to solve the above problem using a variety of methods of informatics, cryptography, signal processing, ... and in order to achieve that tries to insert specific information (watermarks) into data/carrier/signal in such a way that watermarks cannot be extracted or even detected and if data with one or several watermarks are copied, watermarks should not change.

# BASIC APPLICATIONS

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- **Copyright protection - ownership assertion** For example, if a watermark is embedded into a music (or video) product, then each time music (video) is played in public information about author is extracted and tandem are established. Another example: annotation of digital photographs

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- **Source tracing.** Watermarks can be used to trace or verify the source of digital data.
- **Insertion of additional (sensitive) information** For example, personal data into röntgen photos r of keywords into multimedia products.

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The first publications that really focused on watermarking of digital images were from 1990 and then in 1993.

## in WATERMARKING SYSTEMS

Figure 2 shows the basic scheme of the watermarks embedding systems.

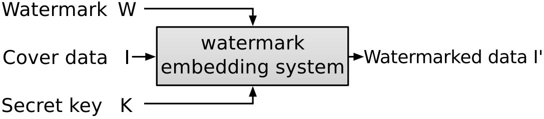


Figure 2: Watermark embedding scheme

**Inputs** to the scheme are the watermark, the cover data and an optional **public or secret** key. The output are watermarked data. The key is used to enforce security.

# EMBEDDING and RECOVERY SYSTEMS

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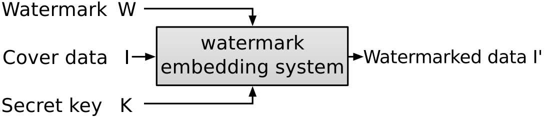


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Figure 3 shows the basic scheme for **watermark recovery schemes.**

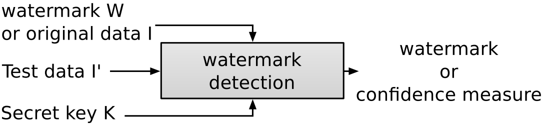


Figure 3: Watermark recovery scheme

**Inputs** to the scheme are the **watermarked data**, the **secret or public key** and, depending on the method, the **original data and/or the original watermark**. The **output** is the **recovered watermark W** or some kind of **confidence measure indicating how likely it is for the given watermark at the input to be present in the data.**

# TYPES of WATERMARKING SCHEMES

**Private (non-blind) watermarking** systems require for extraction/detection the original cover-data.

- Type I systems use the original cover-data to determine where a watermark is and how to extract the watermark from stego-data.
- Type II systems require a copy of the embedded watermark for extraction and just yield a yes/no answer to the question whether the stego-data contains a watermark.

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**Semi-private (semi-blind) watermarking** does not use the original cover-data for detection, but tries to answer the same question. (Potential application of blind and semi-blind watermarking is for evidence in court ownership,. . . )

**Public (blind) watermarking** – neither cover-data nor embedded watermarks are required for extraction – this is the most challenging problem.

# SECRET SHARING by SECRET HIDING

A simple technique has been developed, by Naor and Shamir, that allows for a given n and $t < n$ to hide any secret (image) message m in images on transparencies in such away that each of n parties receives one transparency and

- no t - 1 parties are able to obtain the message m from the transparencies they have.
- any t of the parties can easily get (read or see) the message m just by stacking their transparencies together and aligning them carefully.

# APPENDIX

# WATERMARKS

Historically, a watermark is a replication of an image, logo, or text on paper stock so that the source of the document can be, at least partially, determined.

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In case of images, systems gets as input an image and text to be hidden (and key) and provide stego-image hiding a given text.

The intended receiver who knows the key takes corresponding stegoanalysis tool and for a given stego-image and stego-key gets the hidden data/message.

# SIGNAL PROCESSING TERMINOLOGY

In some applications of steganography the following signal processing terminology is used.

- **Payload** - message to be secretly communicated;
- **Carrier** - data file or signal into which payload is embedded
- **Package - stego file - covert message** - the outcome of embedding of payload into carrier.
- **Encoding density** - the percentage of bytes or other signal elements into which the payload is embedded.

# TO REMEMBER !!!

There is no use in trying, she said: one cannot believe impossible things.

I dare to say that you have not had much practice, said the queen,

When I was your age, I always did it for half-an-hour a day and sometimes I have believed as many as six impossible things before breakfast.

Lewis Carroll: Through the Looking-glass, 1872