H.264 Video Watermarking: Applications, Principles, Deadlocks, and Future

Marc Chaumont

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Outline

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LIRMM

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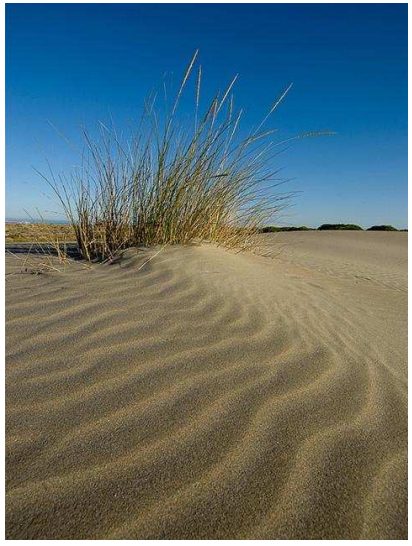


Where video compression is hidden in every days life?

A word of video compression

- Camera (Video surveillance, Smart Phone, ...),
- Streaming (YouTube, Television, ...),
- Storing (DVD, Blue-Ray, Hard-Disk, ...),
- Editing (Cinema, advertisement, entertainment).

$\longrightarrow$ Lots of people use videos.

There is a need for good compression algorithms

There is more and more video contents but:

- network bandwitch is limited,
- storing devices memories are limited.

Example:

SDTV (images 720x576, 25 fps, 90 min. of movie):

- Rate without compression: 237 Mbits/s,
- ADSL in France $\approx$ 30€/month for 20 Mbits/s.

- Storing capacity without compression: 1,22 Tera-bits,
- Storing capacity for a DVD: 4,7 GB.

Standardization - codecs evolution

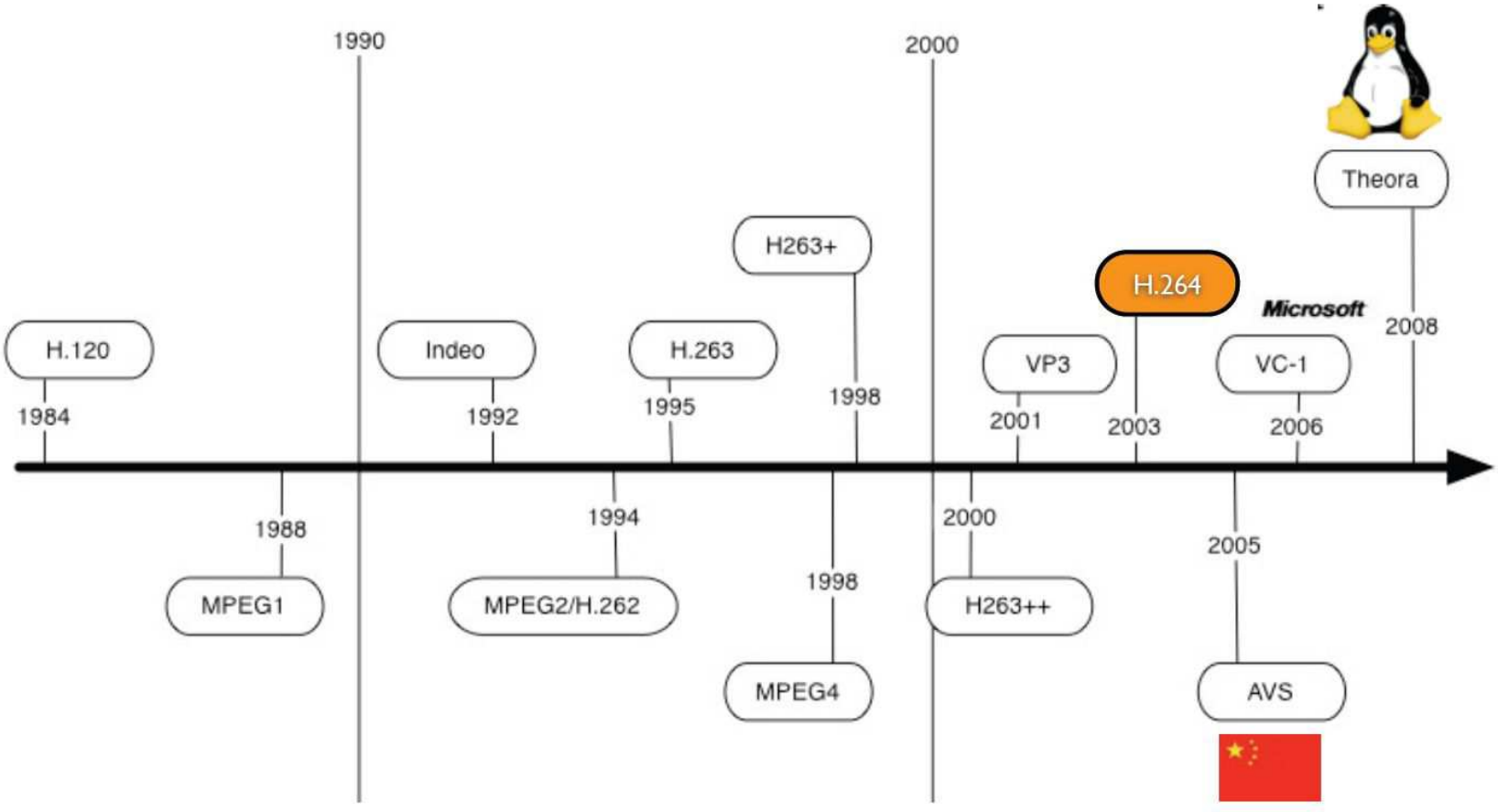


Figure: 25 years of video compression standards

And where is the money?

People making money with video contents :

- Producers,
- Distributors (Hollywood...),
- Cinema operators,
- Technology providers (Internet providers, Reading and Recording devices constructors).

Those lobbys are dynamic in standardization committees and/or watermarking.

A part of this money is used for protection

The problem for **right owners** is the pirates...

Scientists should find solutions in order to dissuade users from pirating

Many solutions for security

Possible solutions:

- **cryptography**
  $\longrightarrow$ flaws due to reverse engineering.
- **securize all the channel** from reader to displayer
  Example : Blue-Ray reader + HD TV + HDMI wire
  $\longrightarrow$ Blue-Ray DVDs have already been pirated.
- **spy the network and collect pirate IPs**
  $\longrightarrow$ it may dissuade casual user.
- **propose cheap movies renting**
  $\longrightarrow$ it may dissuade casual user.
- ...
- **watermarking**
  $\longrightarrow$ ...

What about watermarking?

Applications using watermarking:

Related to security	Related to media enhancement
copyright identification traitor tracing (active fingerprinting) authentication copy control	broadcast monitoring device control enrichment (functionalities and/or meta-datas) with forward compatibility improve compression performances improve error recovery & correction

In most of these applications, the watermarking should be robust.

Outline

What is H.264/AVC?

H.264 or MPEG-4 Part 10:

- **State-of-the-art** video coding standard,
- First version approved in **2003**,
- Normalized by ITU-T and ISO/IEC organizations,
- **Up to 50% in bit rate savings** compared to MPEG-2 and MPEG4 Part 2 simple profile.

"Draft ITU-T Recommendation and Final Draft International Standard of Joint Video Specification (ITU-T Rec. H.264 ISO/IEC 14496-10 AVC)," Tech. Rep., Joint Video Team (JVT), Doc. JVT-G050, March 2003.

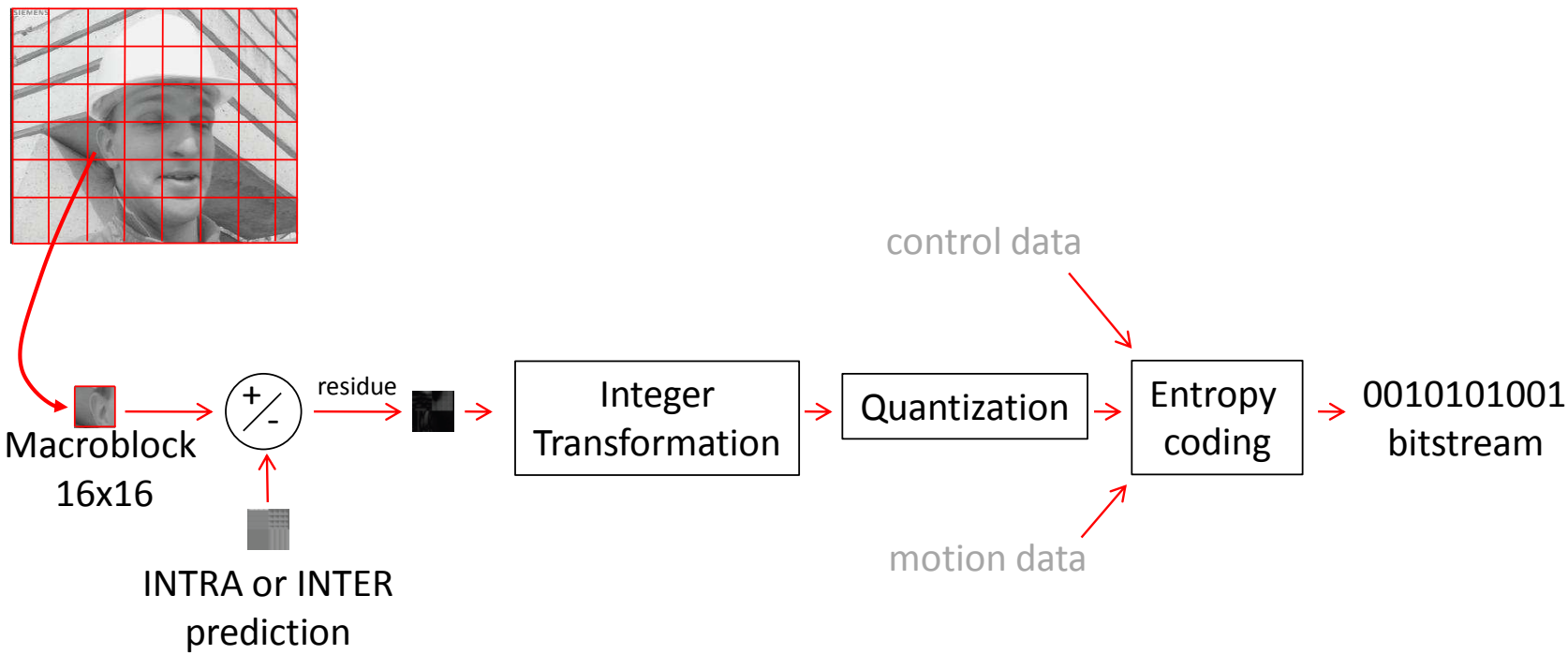

I. Richardson, "H.264 and MPEG-4 Video Compression: Video Coding for Next-Generation Multimedia", 2003.

Visual example...

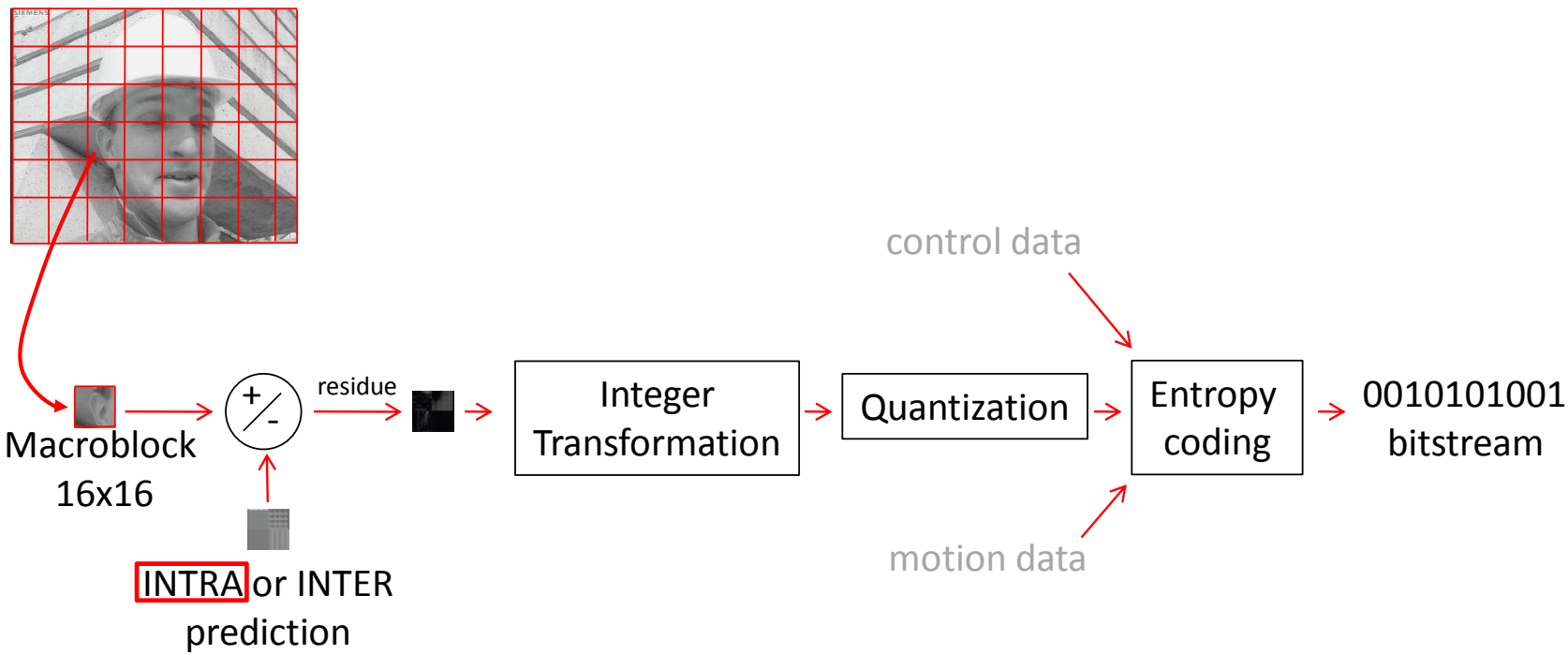
H.264 100Kbs

MPEG2 100Kbs

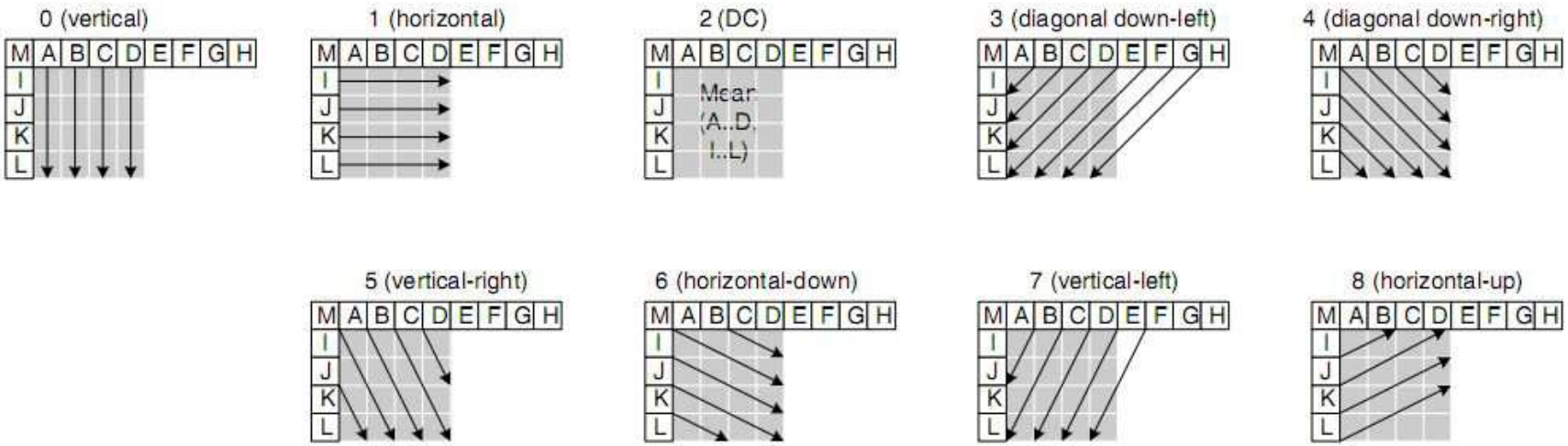
General coding scheme



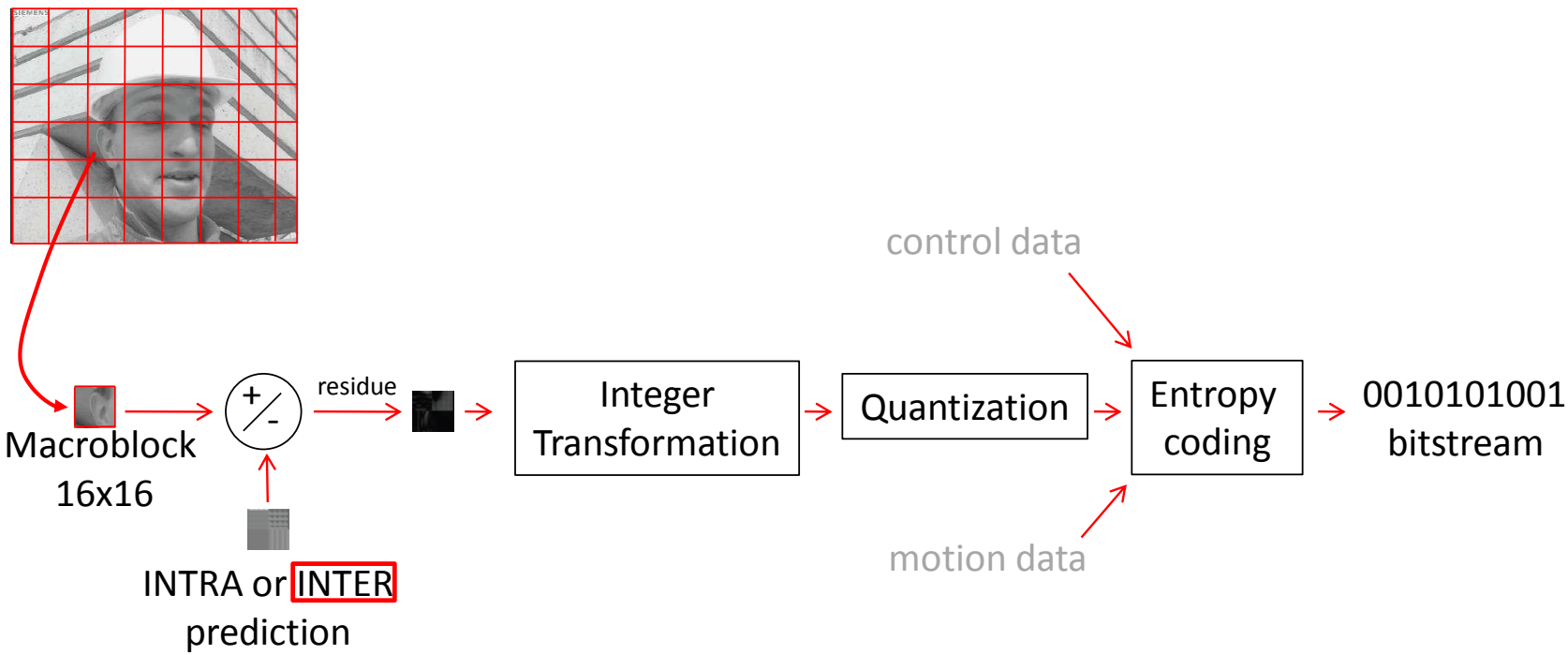
General coding scheme



Intra prediction modes



General coding scheme



Inter prediction - Motion Estimation

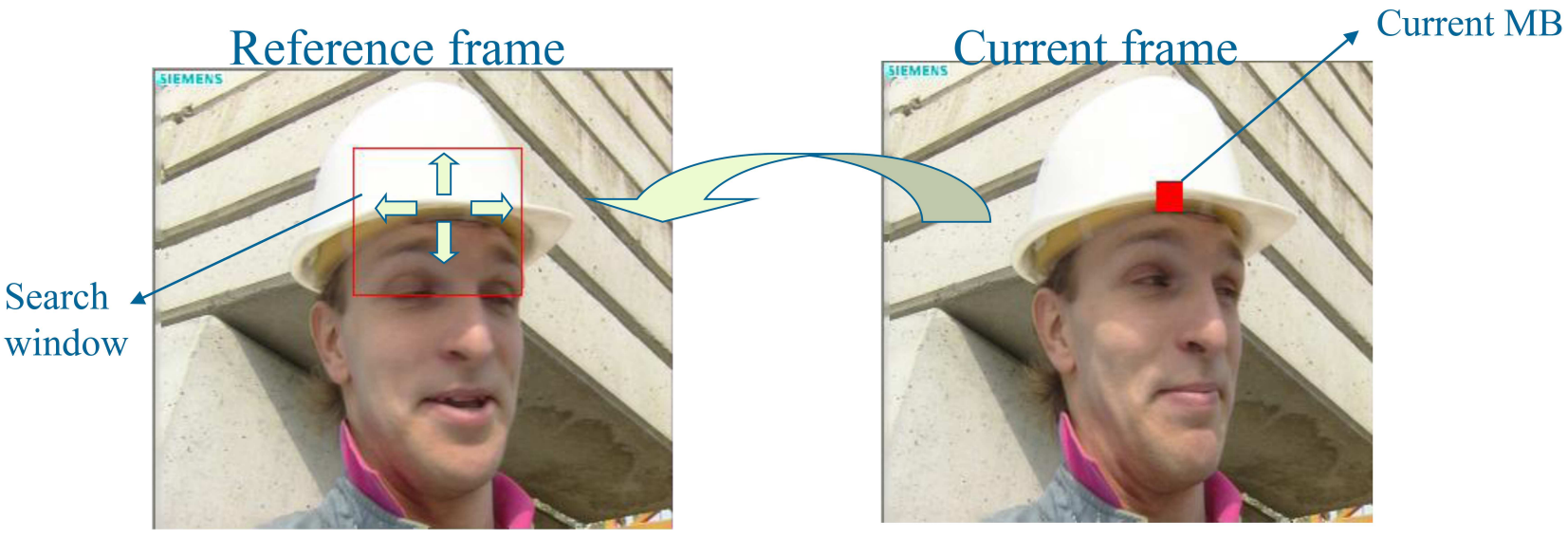
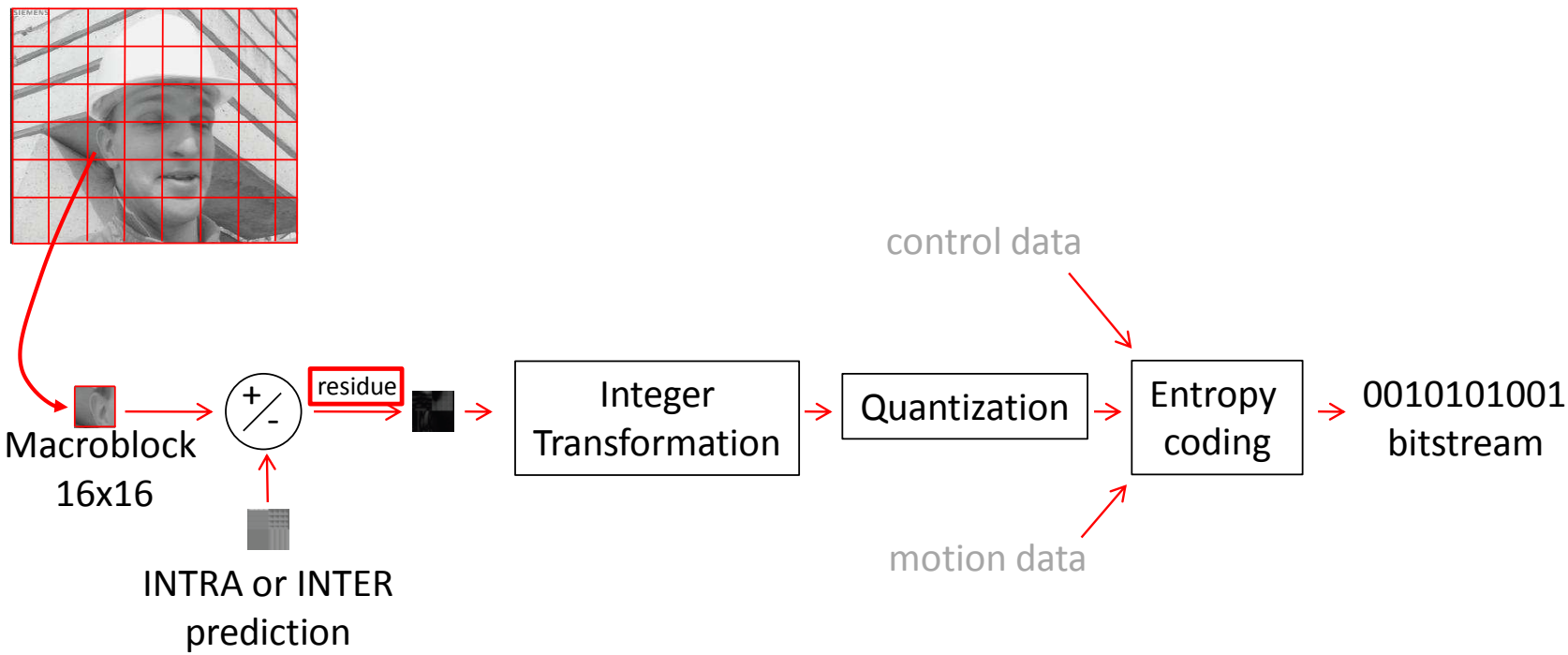


Figure: Motion estimation in temporal direction.

Inter prediction - Motion Vectors

Figure: Motion vectors.

General coding scheme



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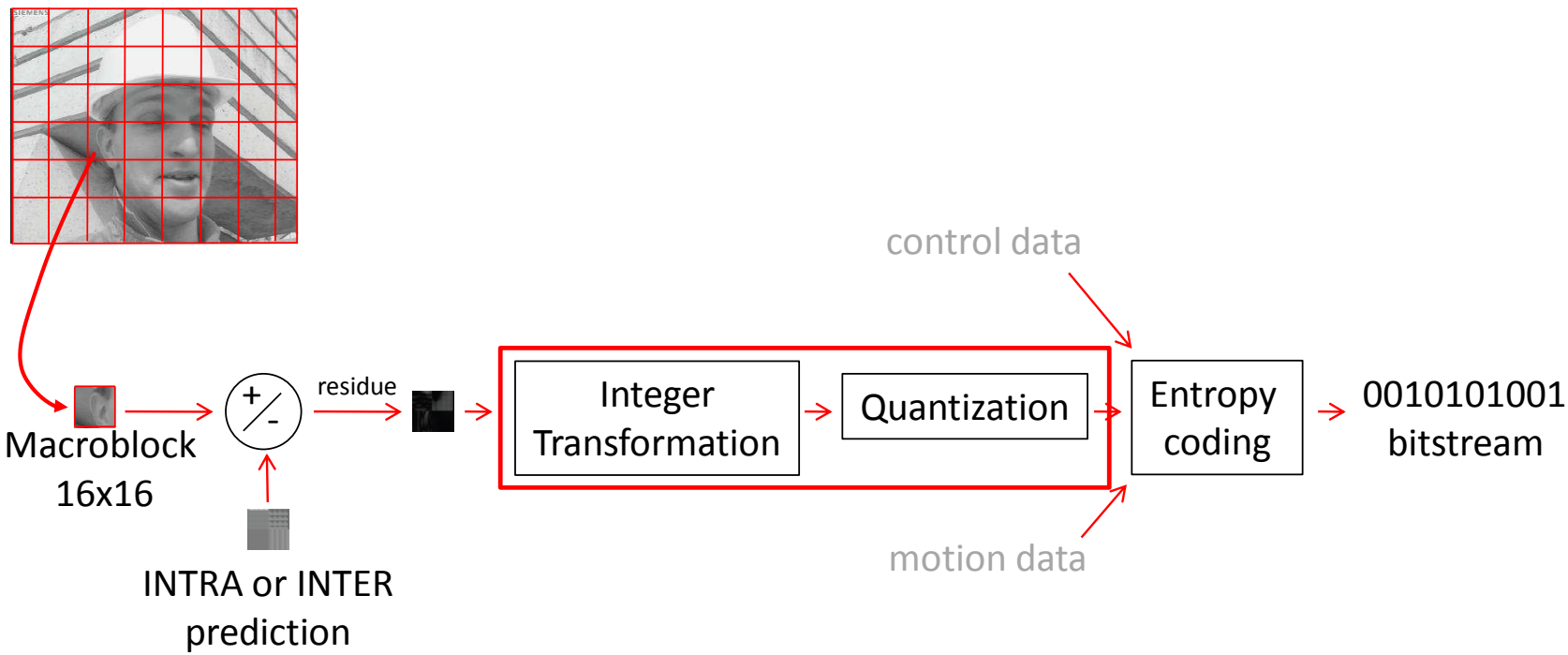

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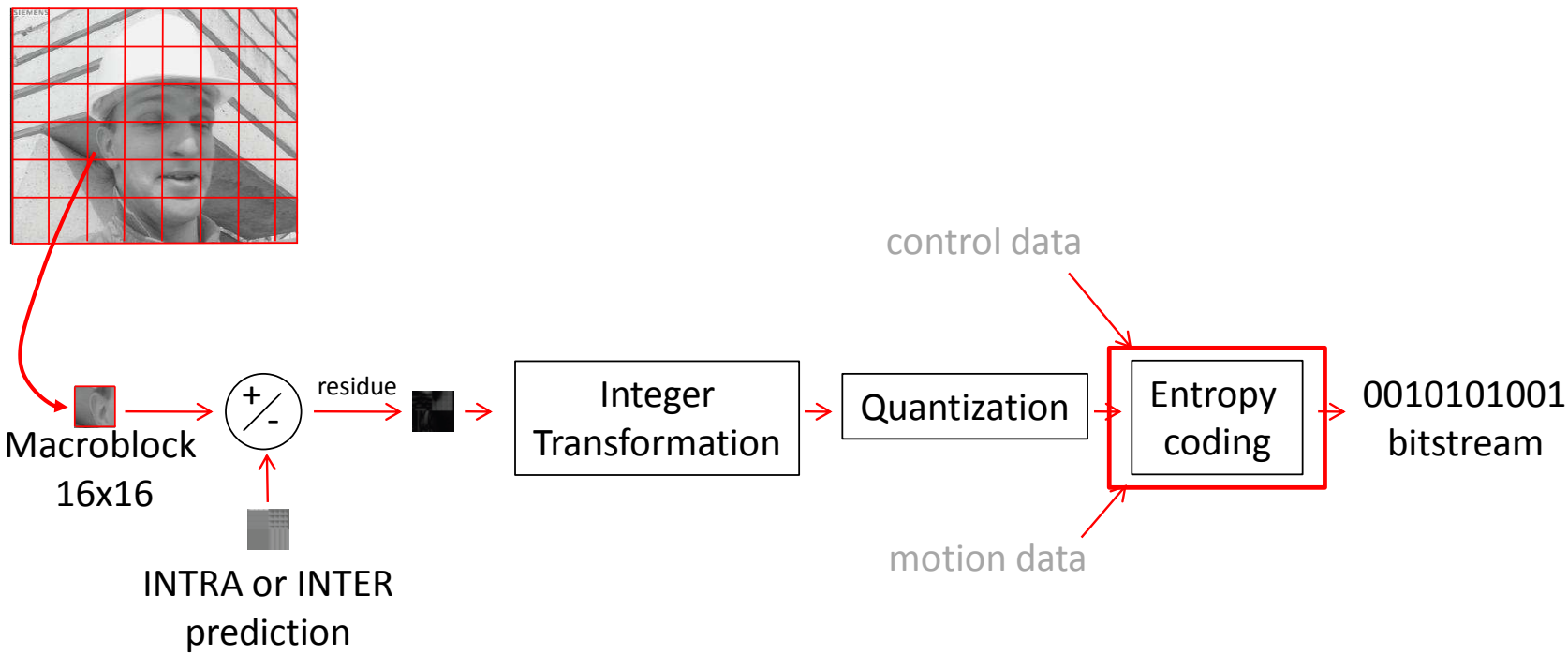

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Recall: applications

Applications using watermarking:

Related to security	Related to media enhancement
copyright identification traitor tracing (active fingerprinting) authentication copy control	broadcast monitoring device control enrichment (functionalities and/or meta-datas) with forward compatibility improve compression performances imrove error recovery & correction

In most of these applications, the watermarking should be robust.

What is robust watermarking?

The robust watermarking is the art of modifying a media (image, sound, video, ...) such that:

- it contains a **message** most of the time in relation with the media,
- degradation is most of the time **imperceptible**,
- the hidden **message is not lost** when media degradation occurs (attacks).

Robustness illustration

original

watermarked

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Robustness illustration(1): detection = Ok

watermarked

additive noise

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Robustness illustration(2): detection = Ok

watermarked

blur

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Robustness illustration(3): detection = Ok

watermarked

luminosity upscaling

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Robustness illustration(4): detection = Ok

watermarked

luminosity downscaling

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Robustness illustration(5): detection = Ok

watermarked

sharp amplification

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Desynchronization attack detection = NOT Ok

watermarked

rotated, cropped, and resized

"Broken Arrows", Teddy Furon and Patrick Bas, EURASIP Journal on Information Security, 2008.

Few non-malicious attacks for a video

Non-malicious attacks:

Photometric	Noise addition, DA/AD conversion Gamma correction Transcoding and video format conversion Intra and inter-frames filtering Chrominance resampling (4:4:4, 4:2:2, 4:2:0)
Spatial Desynchronization	Changes display formats (4/3, 16/9, 2.11/1) Changes resolution (NTSC, PAL, SECAM) Positional jitter Hand-held camera recording (curved-bilinear transform)
Temporal Desynchronization	Changes of frame rate Frame dropping / insertion Frame decimation / duplication
Video editing	Cut-and-splice and cut-insert-splice Fade-and-dissolve and wipe-and-matte Graphic overlay (subtitles, logo)

"Security issue and collusion attacks in video watermarking", PhD Thesis, G. Doërr, Supervised by J.-L. Dugelay, University of Nice-Sophia Antipolis, France, june 2005.

Robust watermarking families

The three major families (multi-bits):

Not informed	:	Spread Spectrum (DM-SS),
Informed	:	Quantized-based (QIM, SCS, P-QIM),
Informed	:	Trellis-based (DPTC).

Informed embedding scheme

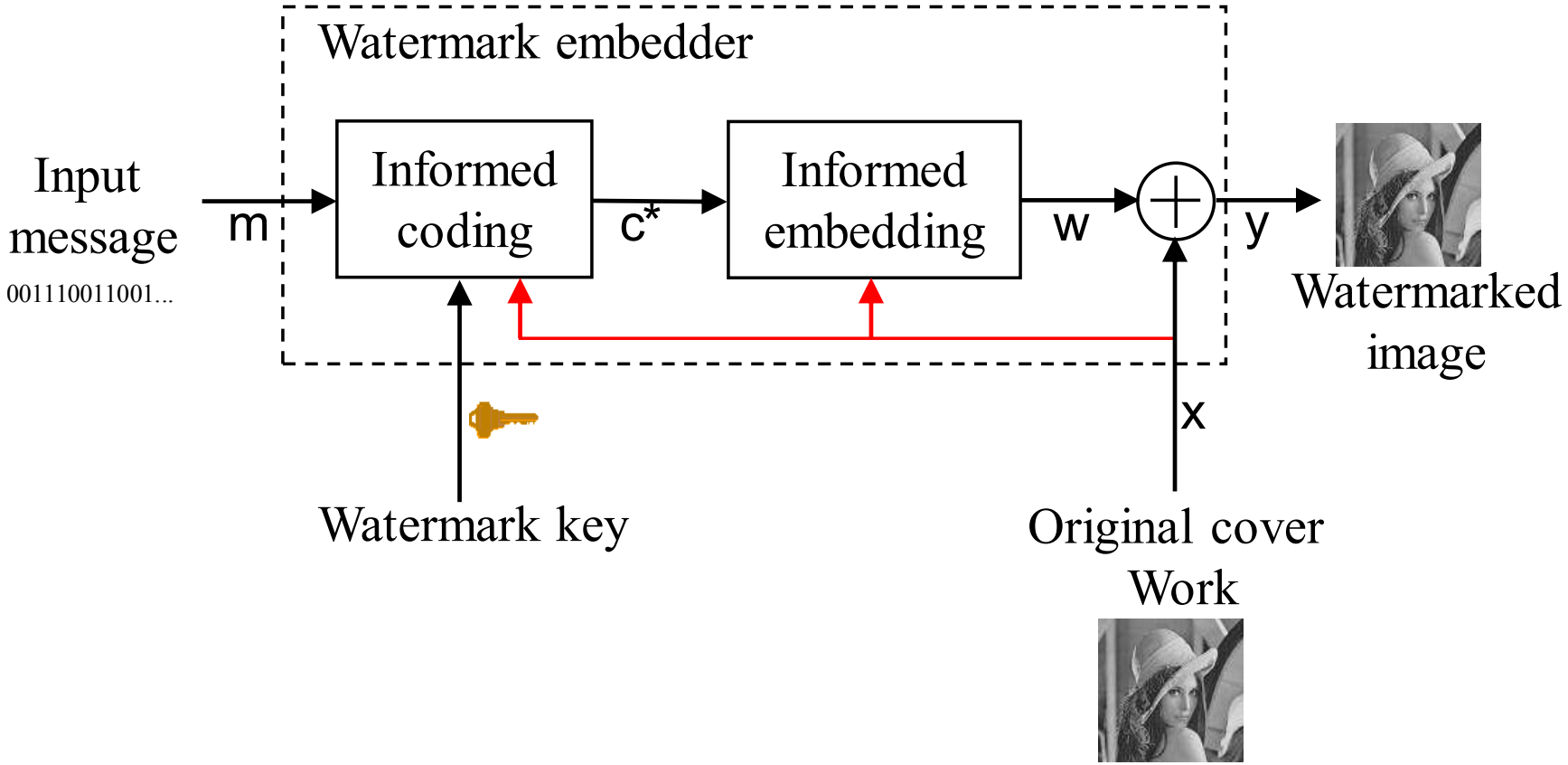

Figure: Informed embedding.

Informed extracting scheme

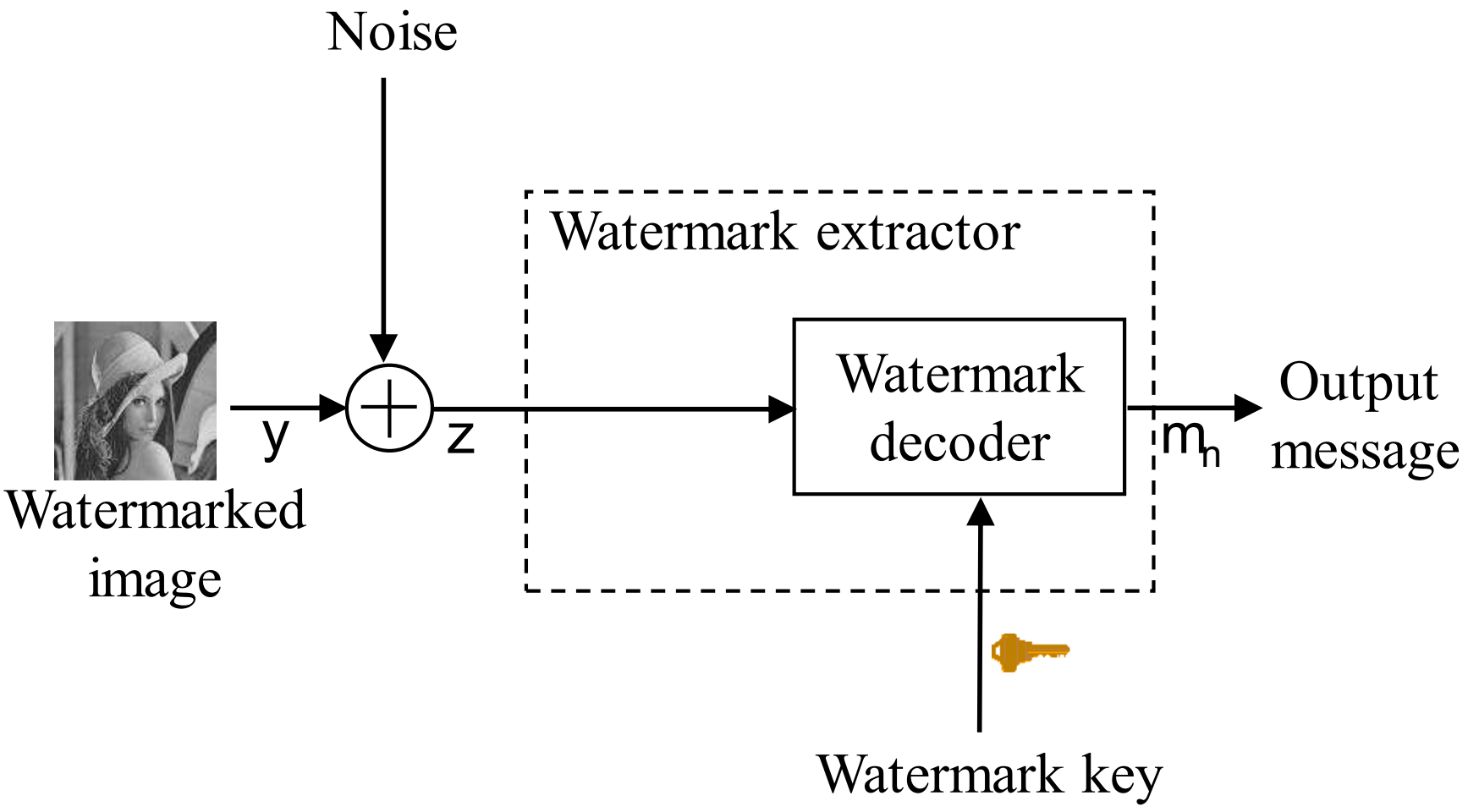

Figure: Blind extraction.

Outline

Major approaches

Before compression

images

SS [Cox et al., TIP'1997]
DPTC [Miller et al., TIP'2004]
P-QIM [Li and Cox, TIFS'2007]
...

sequence of images

Temporal watermarking
[Haitsma and Kalker,ICIP'2001]
[Chen et al., IWDW'2009]

3D DFT
[Deguillaume et al., SPIE'1999]

On-off keying (Extended BA)
[Xie et al., MM&Sec2008]

...

Inside H.264 structure

Before quantization

Luma modification:
[Golikeri et al., JEI'2008]

Motion vectors modification:
[Zhang et al., SCGIP'2001]

GOP structure modification:
[Linnartz and Talstra, ESRCS'1998]

...

After quantization

During encoding process

[Shahid et al., EUSIPCO'2009]
[Noorkami and Mersereau, TIFS'2008]
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In an already H.264 encoded bitstream

[Hartung and Girod, Signal Processing 1998]
[Gong and Lu, ISM'2008]
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During Entropy coding

[Mobasseri and Raikar, SPIE'2007]
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Chosen schemes

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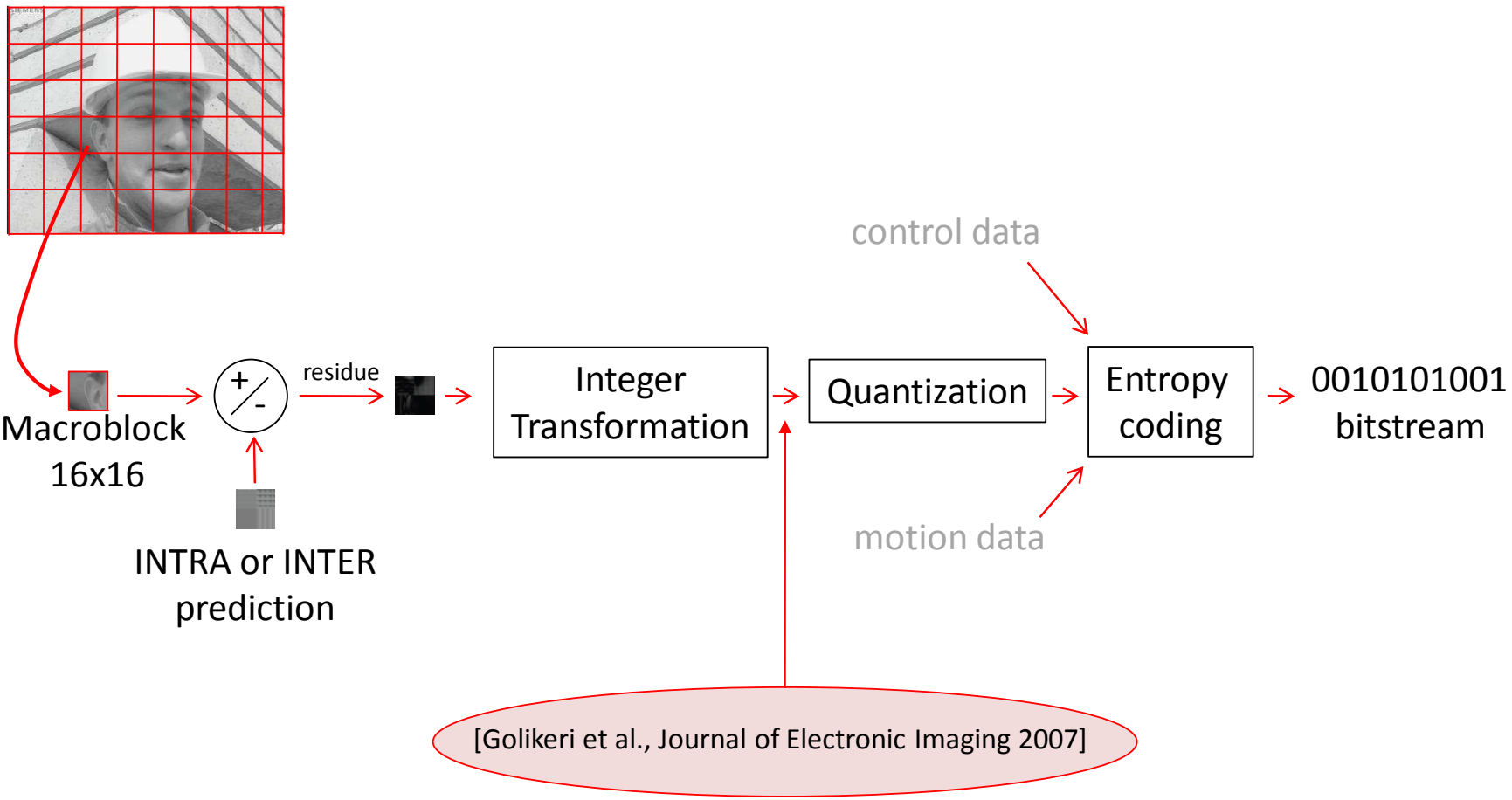


A. Golikeri, P. Nasiopoulos, and Z. Wang, "Robust Digital Video Watermarking Scheme for H.264 Advanced Video Coding Standard," Journal of Electronic Imaging 16(4), 2007.

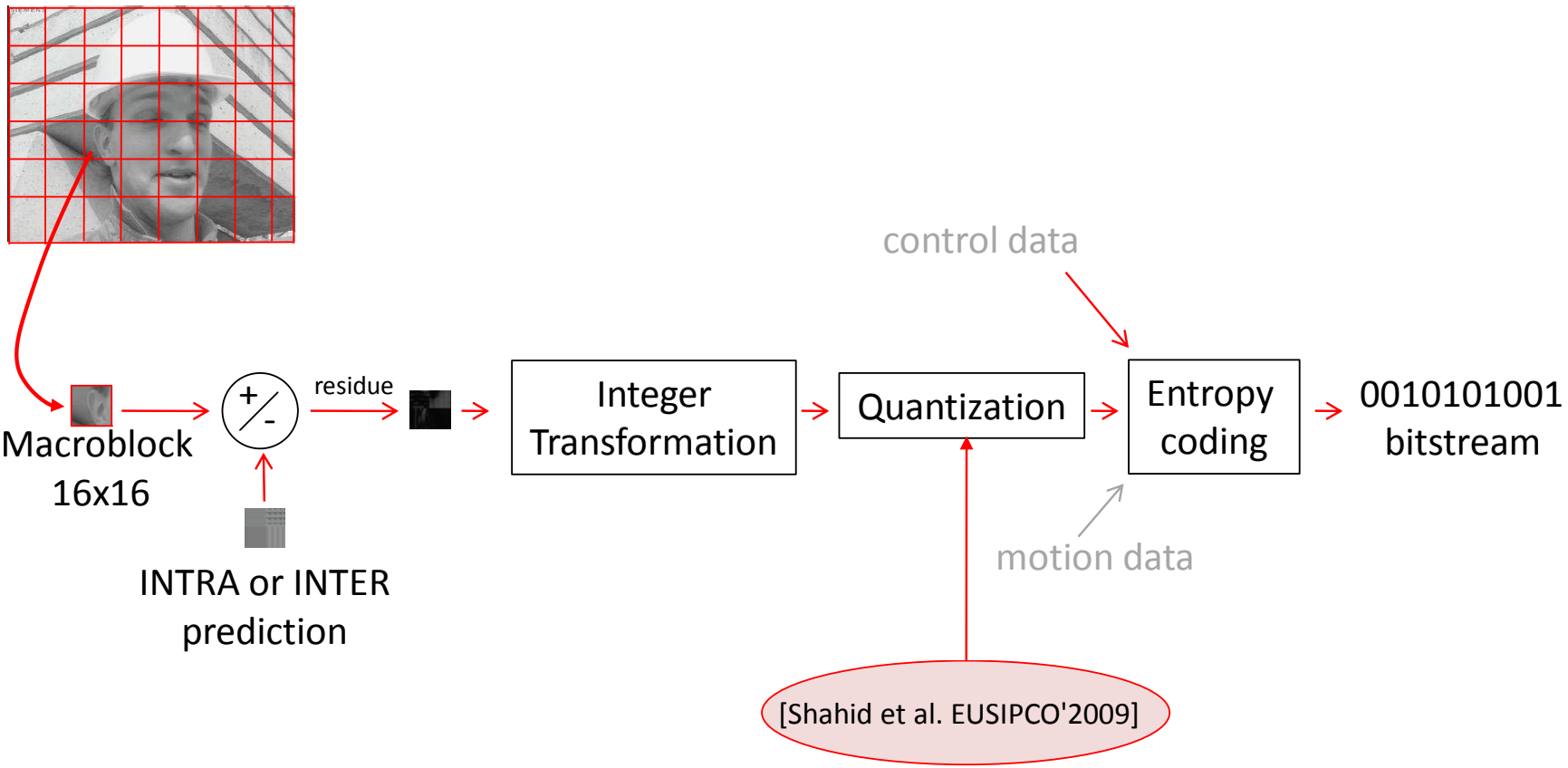
Golikeri et al. scheme

- Embed 1 bit in 1 macro-block,
- Use of a perceptual mask,
- Quantization-based watermarking (ST-SCS),
- Step size Δ and strength α parameters tune depending on the H.264 quantization.

Imperceptible	$\surd$
Photometric robustness	$\surd$ (should reduce payload)
Video bitrate weakly modified	$\surd$ respect 'quiet well' RD constraints
No Drift	$\surd$
Real-time	$\surd$

Not robust to desynchronisation or temporal attacks.

After quantization



Z. Shahid, P. Meuel, M. Chaumont and W. Puech, "Considering the Reconstruction Loop for Watermarking of Intra and Inter Frames of H.264/AVC", EUSIPCO'2009, The 17th European Signal Processing Conference, Glasgow, Scotland, 24-28 August, 2009 (an extended version has been submitted to Journal of Electronic Imaging 2010).

Shahid et al. scheme

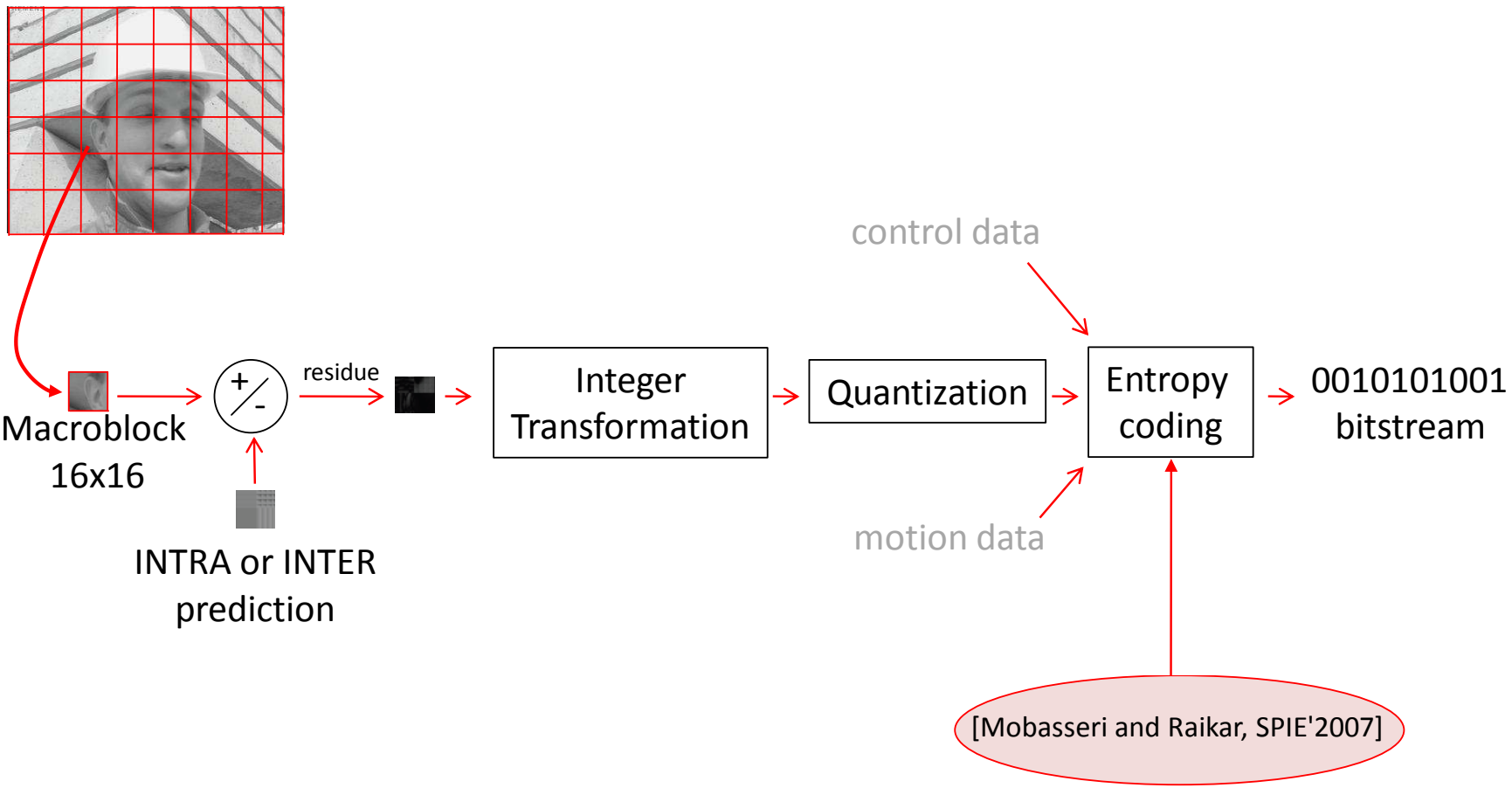
- Modify LSB (1, 2 or 1&2) of non-zero ACs quantized coefficients whose magnitude are greater or equals to 2,
- Inter and Intra,
- RD optimization mode selection achieved on all prediction modes.

Imperceptible	√
Photometric robustness	**NO**
Video bitrate weakly modified	√
No Drift	√
Real-time	√

Not robust to desynchronisation or temporal attacks.

Note: In [Noorkami and Mersereau, TIFS'2008], robust 0-bit watermarking, psychovisual masking, embedding in ACs coefficients and detection without knowing exact location of watermarked coefficients.

During entropy coding (codeword substitution)



B.G. Mobasseri and Y.N. Raikar. "Authentication of H.264 Streams by Direct Watermarking of CAVLC Blocks". In Security, Steganography, and Watermarking of Multimedia Contents IX, SPIE'2007.

Mobasseri and Raikar scheme

The algorithm creates "exceptions" in H.264 code space (portion of CAVLC) that only the decoder understands while keeping the bitstream syntax compliant.

Imperceptible	√
Photometric robustness	**NO**
Video bitrate weakly modified	√ (file size unchanged)
No Drift	√
Real-time	√

Watermark can be removed but cannot be forged or replaced.

Not robust to desynchronisation or temporal attacks.

Brief conclusion

Good news

There are good solutions robust to photometric attacks **INSIDE H.264** (or a similar codec).

Bad news

Most of the solutions (all?) **INSIDE H.264** (or a similar codec) are **not robust** (or not enough robust) to **temporal and spatial desynchronizations**.

Major approaches

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$\rightarrow$ What about security?

Outline

Definition

The classical framework of security:

Kerckhoffs's framework

The embedding and extracting algorithms are known by the attacker and the attacker owns observations. The only secret parameter is the key.

Security attack

A security attack is an attack for which secrets parameters or secret informations are obtained.

Security subject addresses those technical points:

- Analysis and creation of secure algorithm,
- Analysis and creation of security attack.

F. Cayre, C. Fontaine, T. Furon, "Watermarking Security: Theory and Practice", IEEE Transactions on Signal Processing, vol. 53, no. 10, pp. 3976-3987, 2005.

Security of few images schemes

Security addresses the problem of recovering secret parameters.

Images	Proposed attacks
Spread Spectrum	"Comparison of secure spread-spectrum modulations applied to still image watermarking" B. Mathon, P. Bas P, F. Cayre F, and B. Macq. Annals of Telecommunication, 2009.
Broken Arrows	"Two Key Estimation Techniques for the Broken-Arrows Watermarking Scheme", P. Bas and A. Westfeld, MM&Sec'2009. Counter Attack : "Better security levels for 'Broken Arrows' ", F. Xie, T. Furon, and C. Fontaine, SPIE'2010.
DPTC	"Evaluation of an Optimal Watermark Tampering Attack Against Dirty Paper Trellis Schemes".P Bas and G. Doërr, MM&Sec'2008.
Quantized based	"Exploiting security holes in lattice data hiding", L. Perez-Freire and F. Perez-Gonzalez. IH'07.

Collusion attack

Collusion type I occurs when:

The **same watermark** is embedded into **different copies** of different data.

Collusion = estimate watermark from each watermarked data (e.g. average individual estimations)

Hypothesis: The watermark is often considered as noise addition. A simple estimation consequently consists in computing the difference between the watermarked data and a low-pass filtered version of it.

G. Doërr, J.-L. Dugelay, "A guide tour of video watermarking", Signal Processing: Image Communication 18 (2003) 263-282.

Collusion attack

Collusion type II occurs when:

Different watermarks are embedded into **different copies** of the same data.

Collusion = suppress watermarks thanks to a linear combination of the different watermarked data
(e.g. average in order to produce unwatermarked data).

Hypothesis: Generally, averaging different watermarks converges toward zero.

G. Doërr, J.-L. Dugelay, "A guide tour of video watermarking", Signal Processing: Image Communication 18 (2003) 263-282.

Collusion attack

Inter video collusion (not specific to video):
Collusion with several videos

	Collusion type I	Collusion type II
Copyright application (same watermark in $\neq$ videos)	$\surd$	
Traitor tracing application ($\neq$ watermarks in the same videos)		$\surd$

Intra video collusion (specific to video):
collusion with just 1 video

	Collusion type I	Collusion type II
Same watermark in $\neq$ frames of the video	$\surd$	
$\neq$ watermarks in each frame of the video (and thus in static scenes)		$\surd$

$\longrightarrow$ main security "danger" is Intra video collusion.

Rules fighting against video **intra** collusion

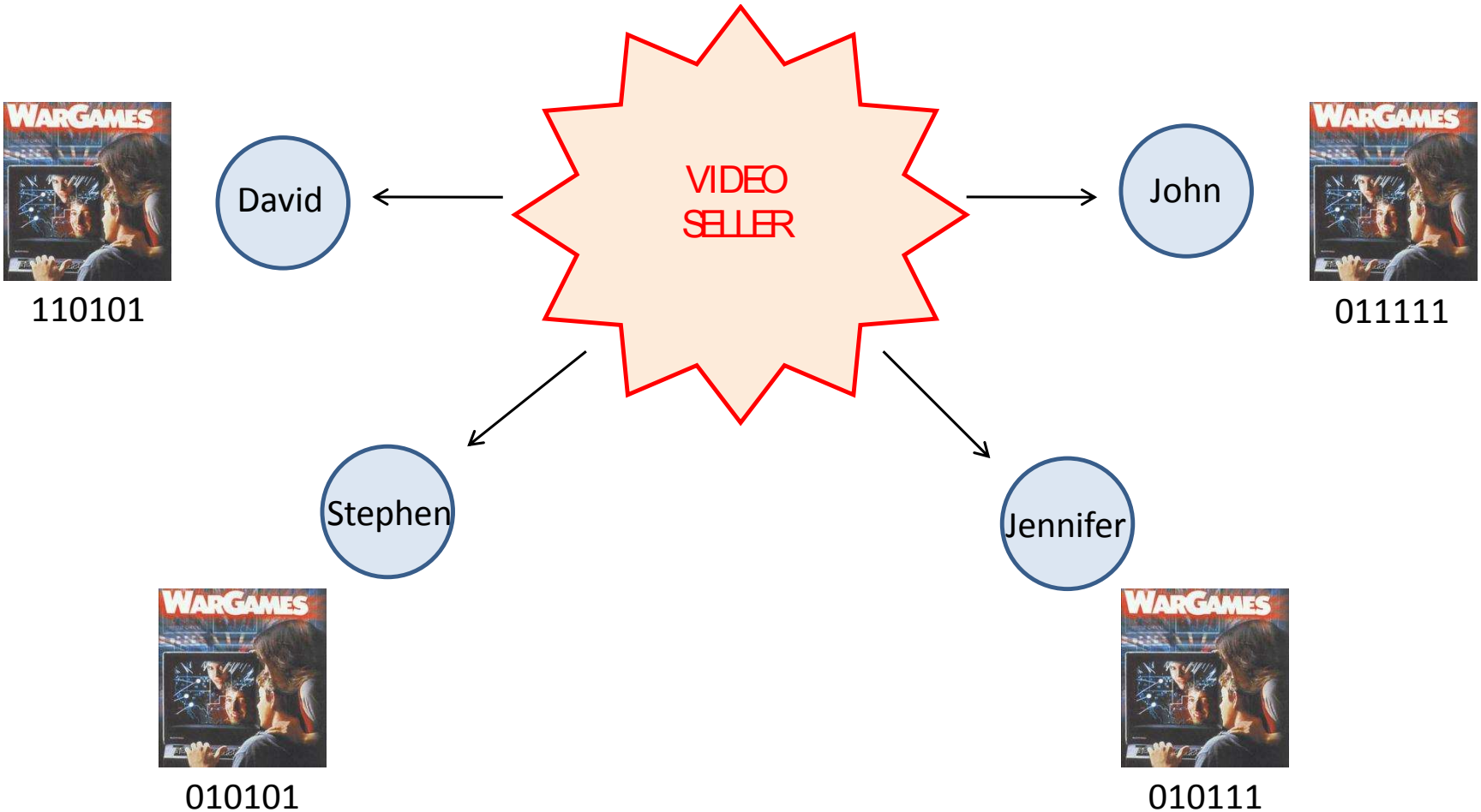
if two frames are quite the same,
then the embedded watermarks should be highly correlated.

if two frames are different,
the watermarks should be uncorrelated.

$\longrightarrow$ it is a form of informed watermarking.

Outline

Traitor tracing concept



Example of watermarking for security: traitor tracing application

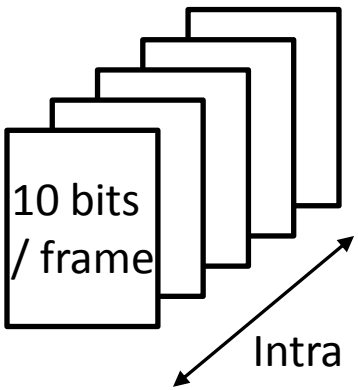
An investigation experiment:

Z. Shahid, M. Chaumont and W. Puech, "Spread Spectrum-Based Watermarking for Tardos Code-Based Fingerprinting of H.264/AVC Video", ICIP'2010, IEEE International Conference on Image Processing, Hong-Kong, China, 26-29 September, 2010, 4 pages.

- The best probabilistic code (coming from cryptography community): The Tardos code.
- A video watermarking technique inside H.264, before quantization, taking into account RD optimization, robust to photometric attacks, and real time.

Example of watermarking for security: Shahid, Chaumont and Puech, ICIP'2010

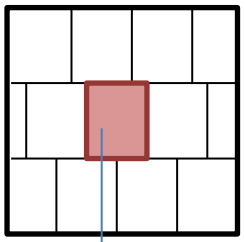
100 users maximum
20 colluders maximum
Probabilty accusing an innocent 10^{-3}
User ID (codeword) on 92 104 bits



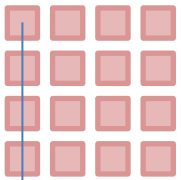
Intra
CIF 352x288
25 fps

92 104 bits
$\simeq$? minutes

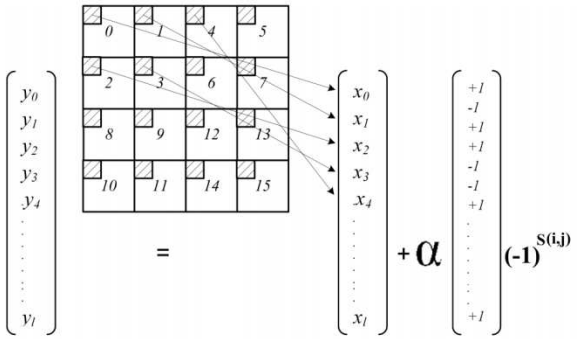
Frame



Macroblocs hiding the same bit



Spread Spectrum embedding
(DCs coefficients modification)



Collusion attacks

f_k: a video frame from a colluder k.
$\mathcal{C}$: the set of colluders.
K: the number of colluders.

$f_{min} = \min\{f_k\}_{k \in \mathcal{C}}$	$f_{max} = \max\{f_k\}_{k \in \mathcal{C}}$
$f_{avg} = \sum_{k \in C} \frac{f_k}{K}$	$f_{median} = median\{f_k\}_{k \in \mathcal{C}}$
$f_{minmax} = \frac{f_{min}+f_{max}}{2}$	$f_{modNeg} = f_{min} + f_{max} - f_{median}$

'bus', 'city', 'foreman', 'football', 'soccer', 'harbour', 'ice' and 'mobile', have been concatenated and repeated 4 times.

Detection of the colluders

K	No. of colluders detected for attacks					
	avg	min	max	median	minmax	modNeg
2	2	2	2	2	2	2
5	5	5	5	5	5	5
8	8	8	8	8	8	6
11	11	10	10	10	10	7
14	14	13	13	13	13	9
17	16	15	16	16	16	10
20	18	18	18	19	18	11

Visual evaluation

DEMO

Original video

Watermarked Video

Colluded video with 17 colluders (avg attack)

Colluded video with 8 colluders (modNeg attack)

Shahid, Chaumont and Puech, ICIP'2010; remarks

- An interesting practical scheme,
- but the watermarking scheme is not enough secure,
- and the algorithm is not robust to spatial and temporal desynchronizations.

Another interesting approach (outside H.264):

F. Xie, T. Furon, C. Fontaine, "On-Off Keying Modulation and Tardos Fingerprinting", MM & Sec'08, September 22-23, 2008, Oxford, United Kingdom.

There is still lots of work...

Outline

Conclusion and perspectives

- lots of possible ways to do watermarking inside H.264 (depends on application)
- If **desynchronization (spatial & temporal) robustness** is a requirement
  $\Rightarrow$ Very few algorithms; still an open problem.
- If **security** is a requirement (but not desynchronization (spatial & temporal) robustness)
  $\Rightarrow$ Very few algorithms; still an open problem
- If **desynchronization (spatial & temporal) robustness & security** are requirements
  $\Rightarrow$ The Graal quest !

End

Slides may be downloaded at: http://www.lirmm.fr/∼chaumont/Publications.html

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