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Research Center for
Information & Communication Technologies

Grissom in Awe. The CSI Effect and Media Forensics

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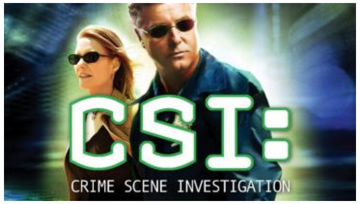
Signal Theory and Communications Department

Universidad de Vigo - SPAIN

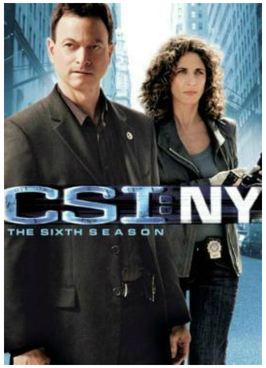
Who is Gil Grissom, PhD?

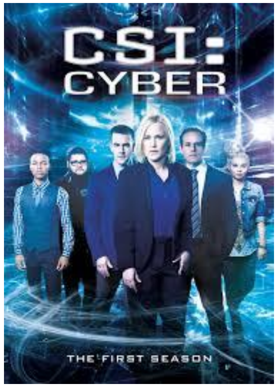
The CSI franchise

CSI (2000-2015)



- CSI Miami (2002-2013)
- CSI New York (2004-2013)
- CSI Cyber (2014-2016)





The CSI Franchise

- Created by Anthony Zuicker in 2000.
- 3 spin-offs.
- + novels, comic books, toys, and video and board games.
- More than 800 episodes combined.
- By 2009 it had reached a global audience of 73 M viewers.
- Huge influence in many other TV shows and movies.

The CSI Effect

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The CSI Effect

- Belief that jurors should/can demand more forensic evidence, thus raising the burden of proof for prosecutors.
- Consequence of unrealistic expectations for forensic technologies from shows like CSI.
- CSI vs reality:
  - Evidence takes less to obtain and process (e.g., DNA).
  - Accuracy is always 100% (e.g., fingerprints are ‘matched’)
  - Many techniques (40%, by one estimate) don’t/can’t exist.
  - Only 2% of the death cases they analyze are actual homicides.
- CSI has also made prosecutors to change their opening statements and closing arguments to explain that jurors should adhere to court standards, not CSI’s.

The CSI Effect

- CSI has created an inflation on ‘unrealistic forensic technology’ that has hit most other crime TV shows.
- And CSI might have been instructing criminals to better destroy evidence.

Comparative Ballistic Lead Analysis (CBLA)

- Chemical analysis of the traces in crime-scene bullets and comparison with ammunition in possession of suspect.
- Used by FBI for more tan 40 years when standard ballistics were not possible.
- Challenged by a retired FBI examiner, William Tobin, the NAS was asked to review the technique.
- NAS Report 2004: “The available data do not support any statement that a crime bullet came from a particular box of ammunition. In particular, references to 'boxes' of ammunition in any form should be avoided as misleading.”
- One year later, FBI discontinued the use of CBLA, but didn’t request to revise the convictions were CBLA had played a significant role.


19
12
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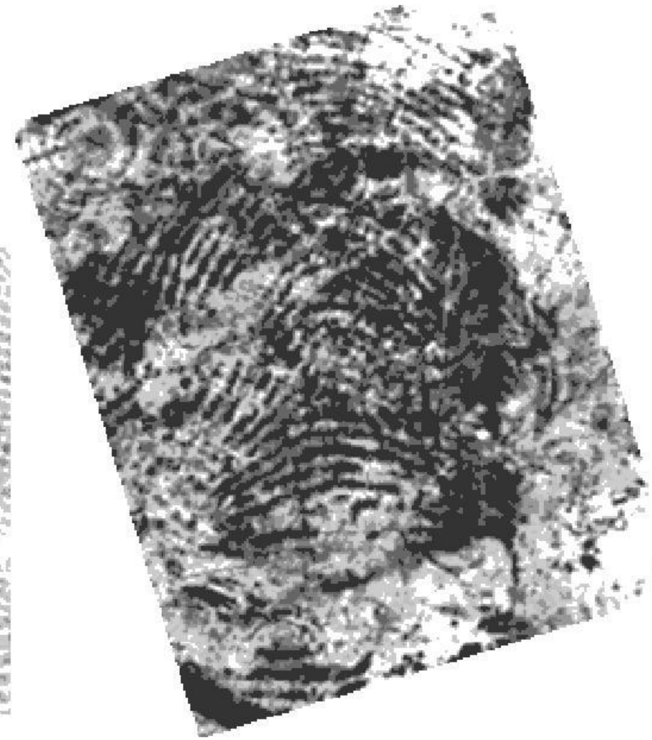
60
MINUTES

Are fingerprints really unique?

- US lawyer, Brandon Mayfield, mistakenly detained by FBI in connection with Madrid bombings.
- An FBI supercomputer positively identified one of the Madrid fingerprints on a bag of detonators as Mayfield's.
- FBI maintained its certainty despite Spanish authorities denied the match.
- Actually, the fingerprints corresponded to an Algerian man.

In November 2006, the federal government agreed to pay Mayfield $2 million for his wrongful jailing.

Compare The Prints



Brandon Mayfield's left index fingerprint from his arrest when he was 17 years old.

Note: Mayfield's fingerprint and the Madrid fingerprint were published in The Seattle Times, June 7, 2004.

This is a copy of the latent print found on the plastic bag in a van near where three of the bombed trains in Madrid, Spain departed on March 11, 2004. The print is rotated 17 degrees to match the orientation of the other fingerprint.

Are bite marks accurate?

- There is no scientific support for the reliability or the accuracy of bite marks.
- Ray Krone was put in the death-row in 1992 after being accused of murdering a waitress. Krone had a ‘snaggle tooth’ which resembled the bite pattern found in the victim.
- There was no other physical evidence relating Krone to the murder.
- He spent 10 years in prison and was discharged after DNA analysis of some blood found on the victim’s pants.


"SNAGGLETOOTH KILLER"
CONVICTED

NAS Report on Forensic Sciences (2009)

- "Forensic Sciences have never been exposed to stringent scientific scrutiny".
- "Do not meet the fu
- They questioned no
  - Analyzing blood sp
  - Matching hair and
  - Ballistic analysis.
  - Analyzing shoeprin

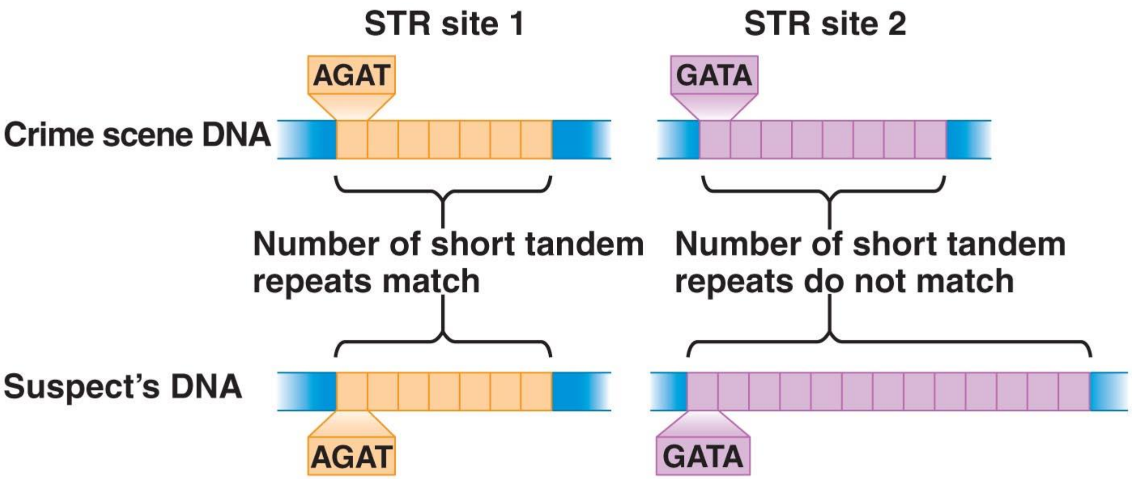
PETER NEUFELD, Innocence Project: "Lawyers are scientifically illiterate. Judges are scientifically illiterate. And certainly juries are. So there has to be a fix upstream to make sure that before any evidence gets to a court of law, that it has been validated, that it is reliable, that it does meet national standards, and that we can all have confidence in the result."

NAS Report on Forensic Sciences (2009)

- Indeed, DNA testing has been used to exonerate persons who were convicted as a result of the misapplication of other forensic science evidence. [343 persons by the Innocence Project]
- "This history stands in sharp contrast to the history of research involving most other forensic science disciplines, which have not benefitted from extensive basic research, clinical applications, federal oversight, vast financial support from the private sector for applied research, and national standards for quality assurance and quality control."

What's right with DNA forensics?

- Appeared in mid 80's.
- Initially refused by courts because of perceived flaws.
- It was sometimes called "DNA fingerprinting" to suggest that it was as reliable as fingerprinting.
- Currently uses short tandem repeat loci (13 of them).



What's right with DNA forensics?

- Scientific groundwork for DNA analysis had been laid outside the context of law enforcement.
- Serious studies on DNA analysis preceded the establishment and implementation of "individualization" criteria.
- There exists a vast literature assessing the reliability of "DNA individualization" which has taken a statistical approach.
- No unquestioned hypotheses; they can be revised any time.

Why NAS liked DNA forensics so much?

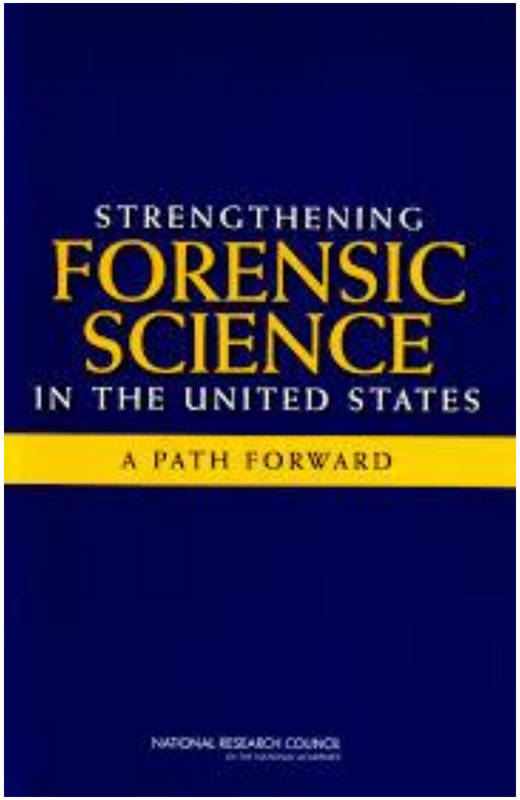
(1) There are biological explanations for individual-specific findings;

(2) The 13 STR loci used to compare DNA samples were selected so that the chance of two different people matching on all of them would be extremely small;

(3) The probabilities of false positives have been explored and quantified in some settings (even if only approximately);

(4) The laboratory procedures are well specified and subject to validation and proficiency testing; and

(5) There are clear and repeatable standards for analysis, interpretation, and reporting.



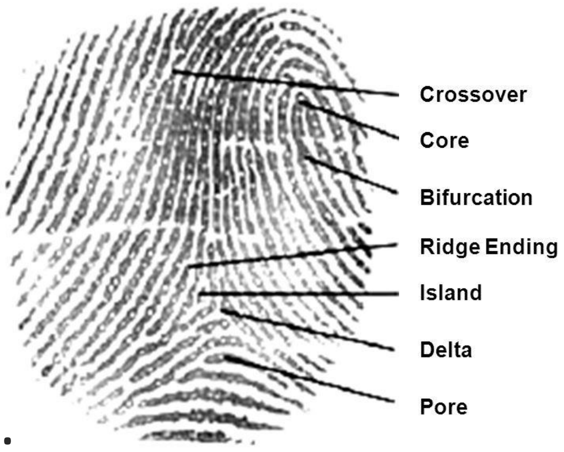
So what's wrong with 'friction ridge' forensics?

- More than 100 years in use.
- ACE-V protocol.
- Analysis subject to many sources of error for latent fingerprints:
  - Condition of the skin.
  - Type of residue.
  - Mechanics of touch.
  - Nature of the surface touched.
  - Development technique.
  - Capture technique.
  - Percentage of latent print available.

So what's wrong with 'friction ridge' forensics?

- Visual comparison by expert.
- Evaluation: number of agreements

and sufficiency of the detail, based on experience.



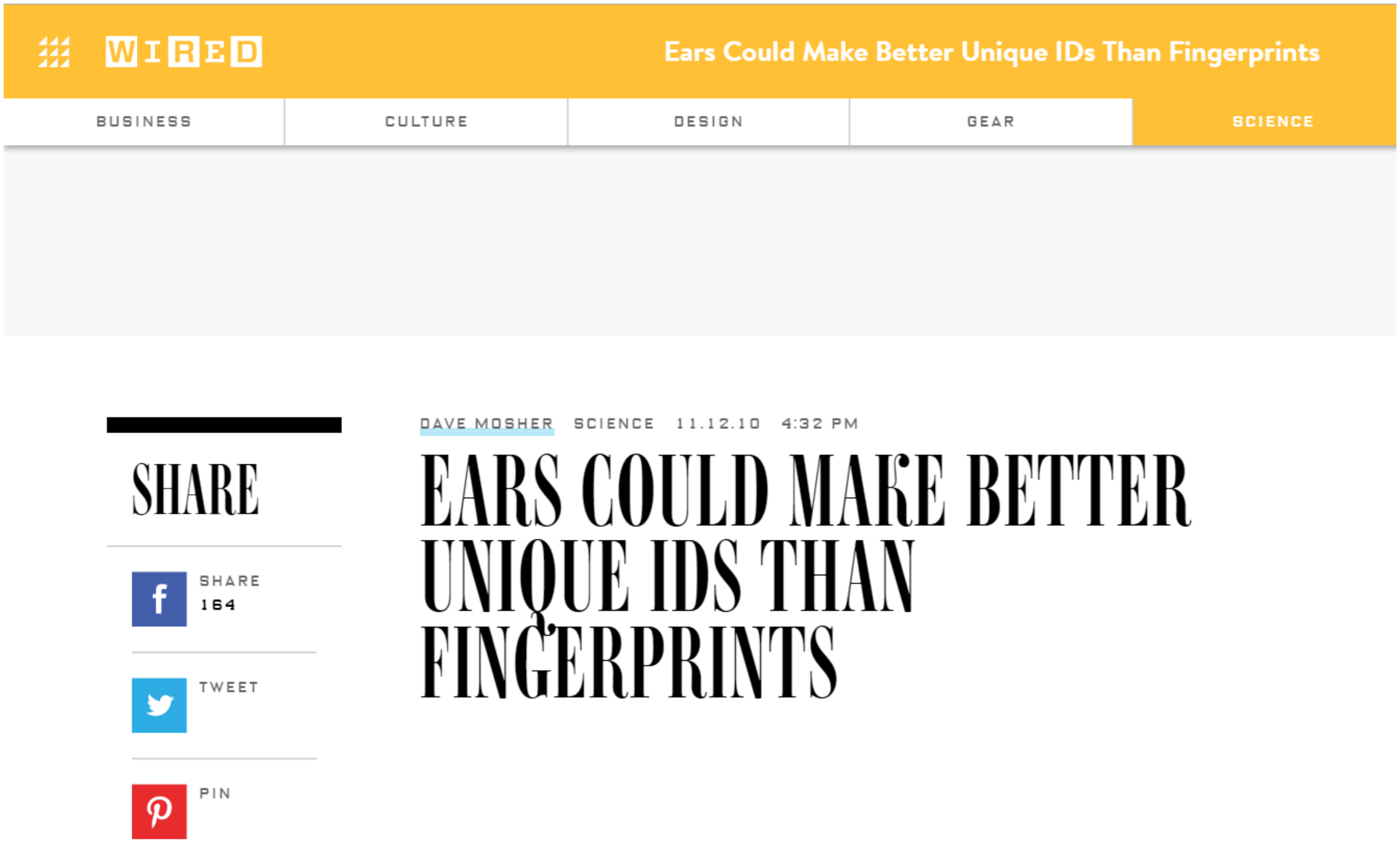
- Verification by another qualified expert.
- Large degree of subjectivity.
- No statistical assessment (although much progress done after the NAS report).
- No population statistics.
- No standard set of characteristics; difficult repeatability.

So what's wrong with 'friction ridge' forensics?

Matthew 10:30, "But even the hairs of your head are all numbered".

- Above all, relies … sis.
- NAS Report: "The fingerprint community continues to assert that the ability to see latent print detail is an acquired skill attained only through repeated exposure to friction ridge impressions."
- "Thresholds based on counting the number of features that correspond, lauded by some as being more "objective," are still based on primarily subjective criteria."
- "The friction ridge community actively discourages its members from testifying in terms of the probability of a match."
- Haber&Haber, 2008: "We have reviewed available scientific evidence of the validity of the ACE-V method and found none."

…and yet the mistake is repeated…


WIRED

Ears Could Make Better Unique IDs Than Fingerprints

BUSINESS | CULTURE | DESIGN | GEAR | SCIENCE

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DAVE MOSHER SCIENCE 11.12.10 4:32 PM

EARS COULD MAKE BETTER UNIQUE IDS THAN FINGERPRINTS

…over and over

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Home * Clinical * New oral features can be considered unique as a fingerpri

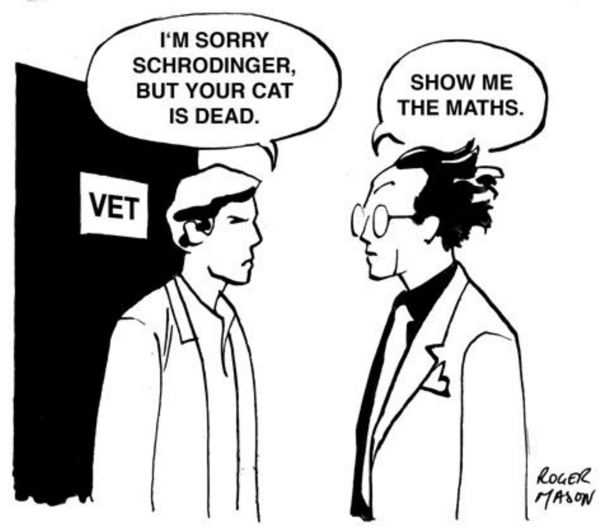
New oral features can be co fingerprint

Posted by DentistryIQ Editors

SOURCE: ASNANPORTAL.com

> NAS report: "Although one might argue that those who perform the work in laboratories that conduct hundreds or thousands of evaluations of impression evidence develop useful experience and judgment, it is difficult to assert that the field has enough collective judgment about the variabilities in lip prints and ear prints based on tens of examinations."

A thought experiment



- Matching based on 15 features $X_i, i = 1, \cdots, 15$, each taking 100 posible values.
- As not much is known about the joint pdf, i.i.d. uniform is assumed (i.i.d. uniform maximizes the entropy).
- Then, the probability that two given persons have the same 'profile' is 10^{-30}

A thought experiment

- But suppose that 10 of the 100 posible values take 90% of the probability and the observed profile is composed of those.
- The probability that another person shares this profile is now $\approx 2 \cdot 10^{-16}$
- Suppose alternartively that the 15 features are not independent, but correlated through a hidden variable Z

$$X_i = Z + N_i, \qquad Z \in \{0, 3, \ldots, 96\}, \qquad N_i \sim U\{1, 2, 3\}$$

- Now, the probability of a random match with a given suspect is $\approx 2 \cdot 10^{-9}$

A thought experiment

- What if the suspect has been found after searching a profiles database and there is no additional evidence?
- Then, the probability of a match linearly increases with the size of the database. Mayfield was picked out after the FBI searched the IAFIS database with about 500 M fingerprints.
- One should expect on average one false positive in the entire database.

- But the probability that such person is a random match is not $\approx 2 \cdot 10^{-9}$ (*prosecutor's fallacy #1)*.
- Likewise, the probability that the suspect is not guilty is not $\approx 2 \cdot 10^{-9}$ (*prosecutor's fallacy #2)*.

A thought experiment

NAS Report: "Not all fingerprint evidence is equally good, because the true value of the evidence is determined by the quality of the latent fingerprint image".

- What if the test profile has mea
- Suppose that every test feature has measurement noise

$$Y_i = X_i + W_i, \qquad W_i \sim U\{0,\ldots,2\}$$

- The distribution of Y_i is roughly the same as before, and so is the probability of false positives (recall: $\approx 2 \cdot 10^{-9}$).
- BUT now the true positive rate is only $\approx 7 \cdot 10^{-8}$.
- Actually, if we want to recover the TPR=1, the probability of false positives would be $\approx 1/33$(one is basically able to distinguish only values of Z).

How to adjust probabilities?

- Blackstone's formulation (1760s):

"All presumptive evidence of felony should be admitted cautiously; for the law holds it better that ten guilty persons escape, than that one innocent party suffer."

- Benjamin Franklin's version:

"It is better 100 guilty Persons should escape than that one innocent Person should suffer."

Conclusions

- Non-uniformity reduces entropy.
- Correlation reduces entropy.
- Overestimating entropy benefits the prosecution.
- **Randomness is no surrogate for lack of knowledge**.
- Measurement uncertainty leads to smaller detection rates.
- Probabilities are neither large or small in absolute terms. One needs to specify with respect to what (i.e., alternative hypothesis).
- Decision risks must be carefully assessed.

On top of this: human bias

- Ignoring base rate information: e.g., carpet fibers in crime scene matching the carpet in the suspect's home. Probative value depends on the rate at which the fibers are in other homes' carpets.
- Framing the question unproperly: e.g., police line-ups where the witness assumes that the suspect is present.
- Contextual bias: experts where asked to analyze fingerprints that they had, unkown to them, analyzed at some other time of their careers, but this time with contextual information. Their conclusions, biased by the context, differed in 25% of the cases.
- Imperfections in reasoning ability: e.g., sticking to the very first pieces of evidence found.

Enhance, enhance, enhance…

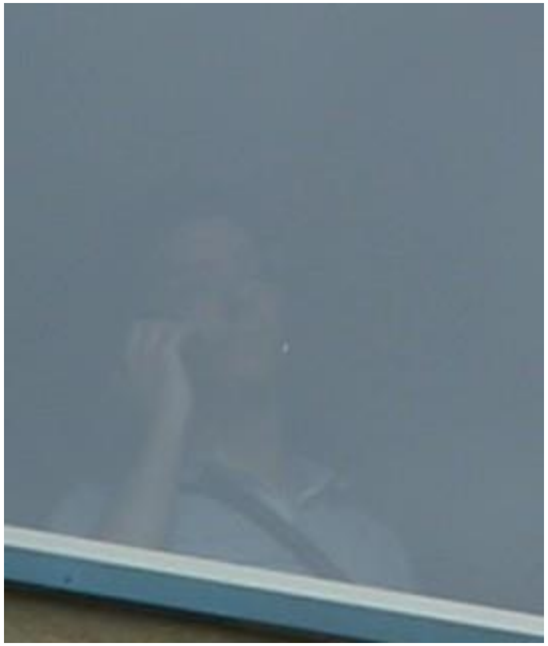

CSI:


SPECIAL AGENTS WOULD NEVER FIGURE OUT WHO THE VILLAIN IS.
WE RECONSTRUCTED THIS IMAGE FROM A 4-PIXEL PHOTO.
TURNS OUT, IT'S THEORETICALLY IMPOSSIBLE.
Before
After


CRIME LAB
okay zoom in on that
further
THERE
THAT'S OUR KILLER
AND SO:
HOW DID YOU FIND ME
SAME WAY WE FIND EVERYONE, BUDDY
SAME WAY WE FIND EVERYONE

So what is real-world enhancement?

Contrast enhancement



Sharpen

Motion-blur correction

AMPED SOFTWARE

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Noise removal

Optical distortion correction

Perspective correction

AMPED SOFTWARE

De-interlace video

AMPED SOFTWARE

Video enhancement via frame integration

AMPED SOFTWARE

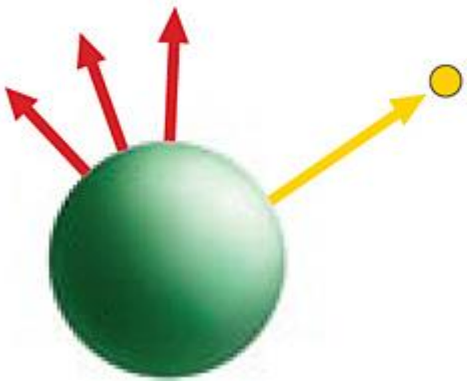
Plus

- Automatic reporting:
  - Tools that have been used.
  - Scientific papers backing those tools.

Semantic media forensics

Video Tampering in CSI Cyber

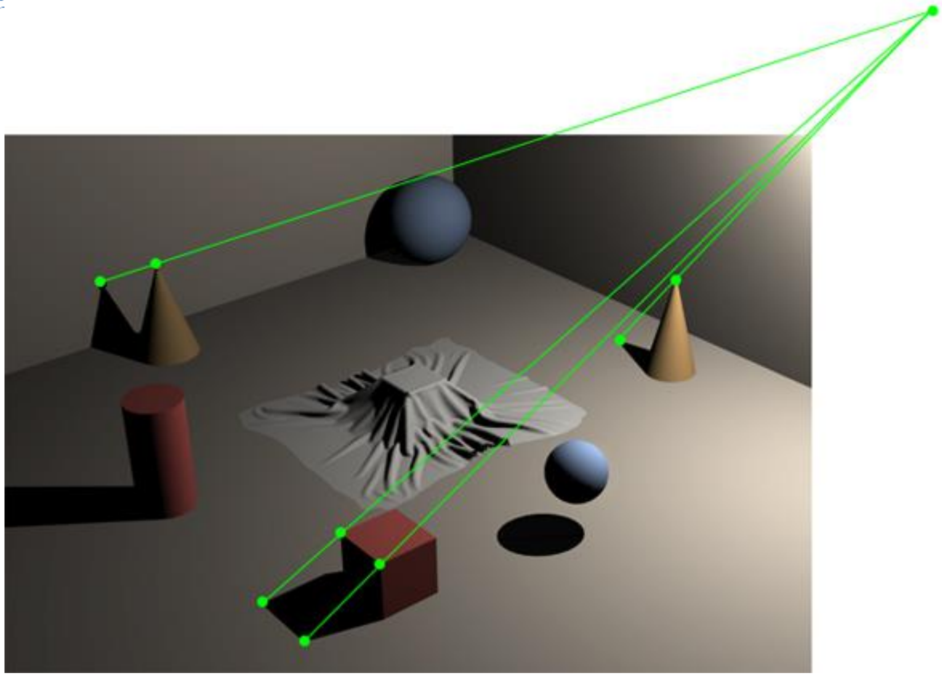
Lighting inconsistencies



Source: Farid08

The accidental tourist

Shadow inconsistencies

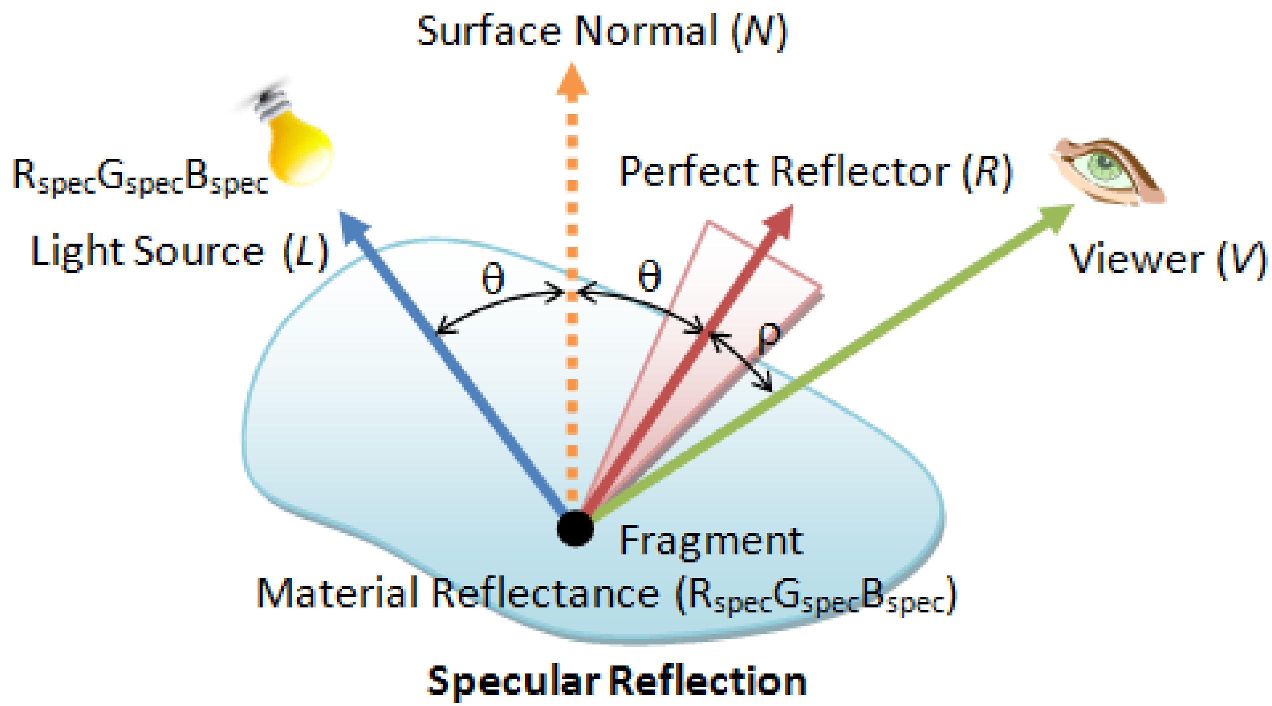


Source: fourandsix.com

Source: fourandsix.com

Was Kim Jong Il there? (2008)

Specular reflection inconsistencies



Source: Chua Hock-Chuan. Intro to OpenGL

National Geographic International Contest, 2008

Photo and caption by Shibnath Basu, India

Places Winner

These shallow waters are mainly famous for flamingos at Nal Sarovar near Ahmedabad, Gujarat, India. The picture shows the reflection of clouds on water.

2 x 30,000$

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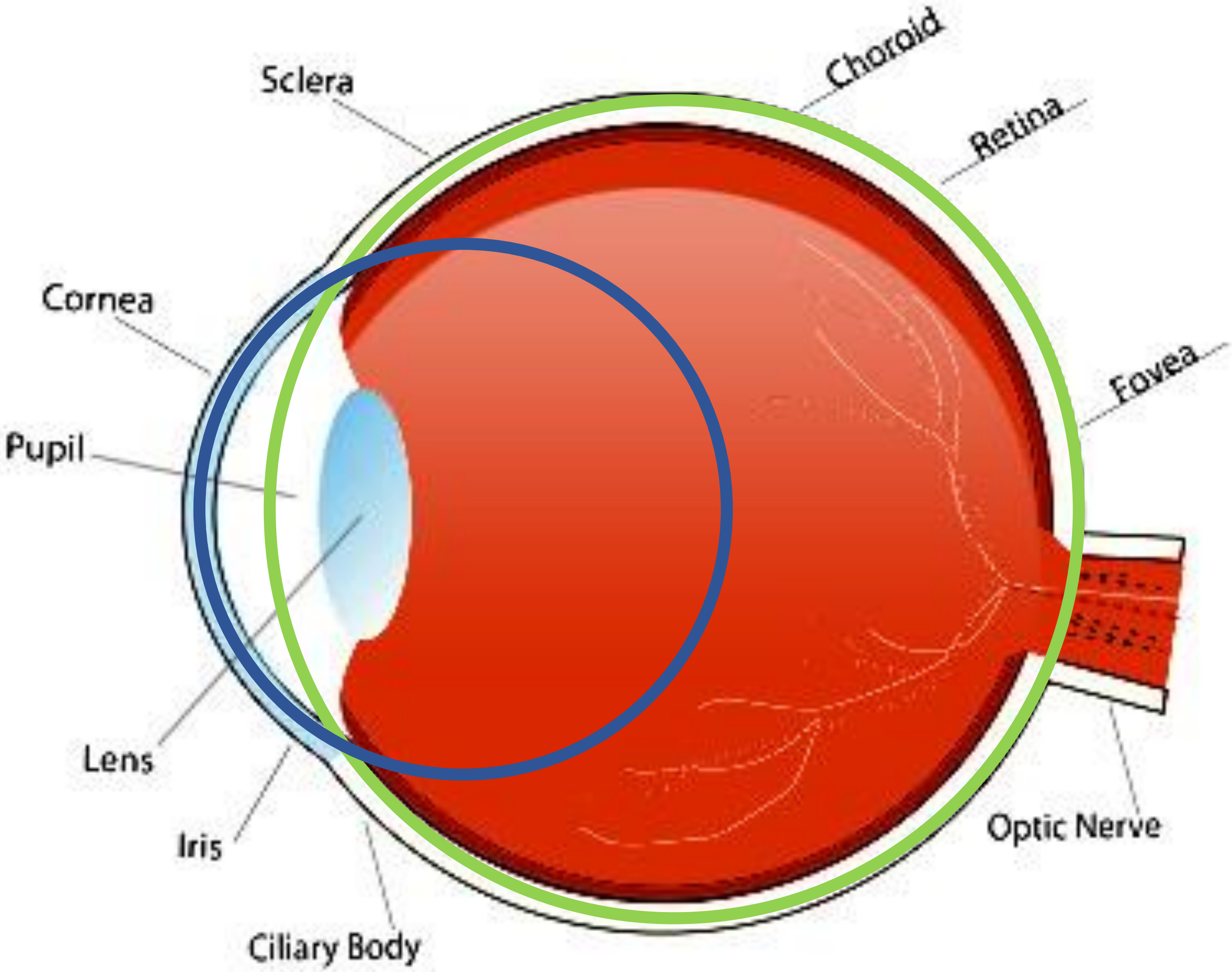
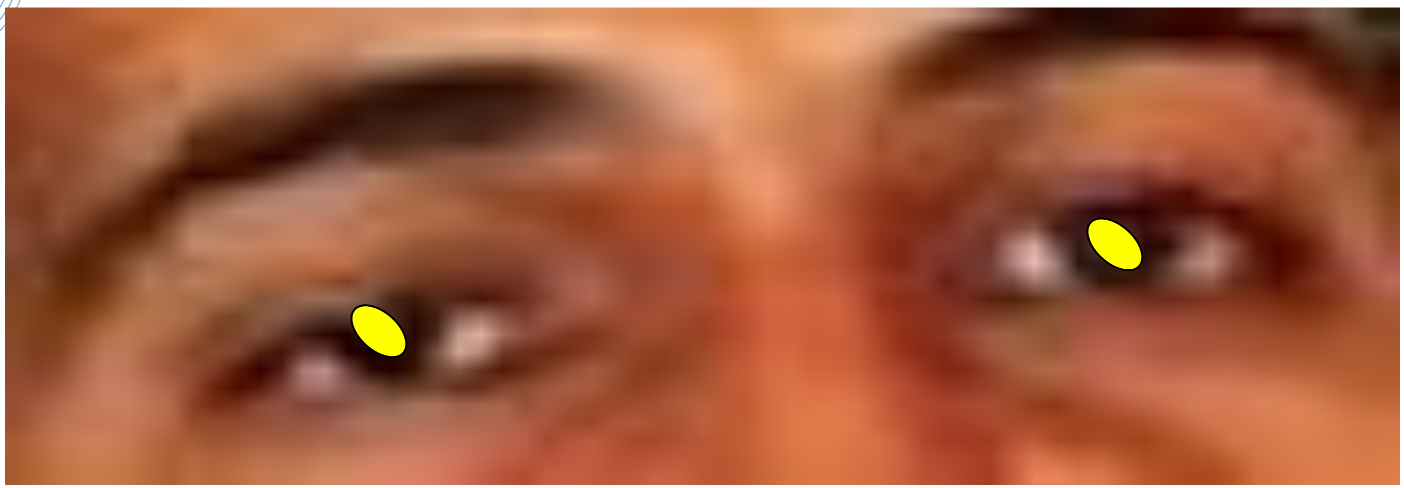
Shadows + reflection

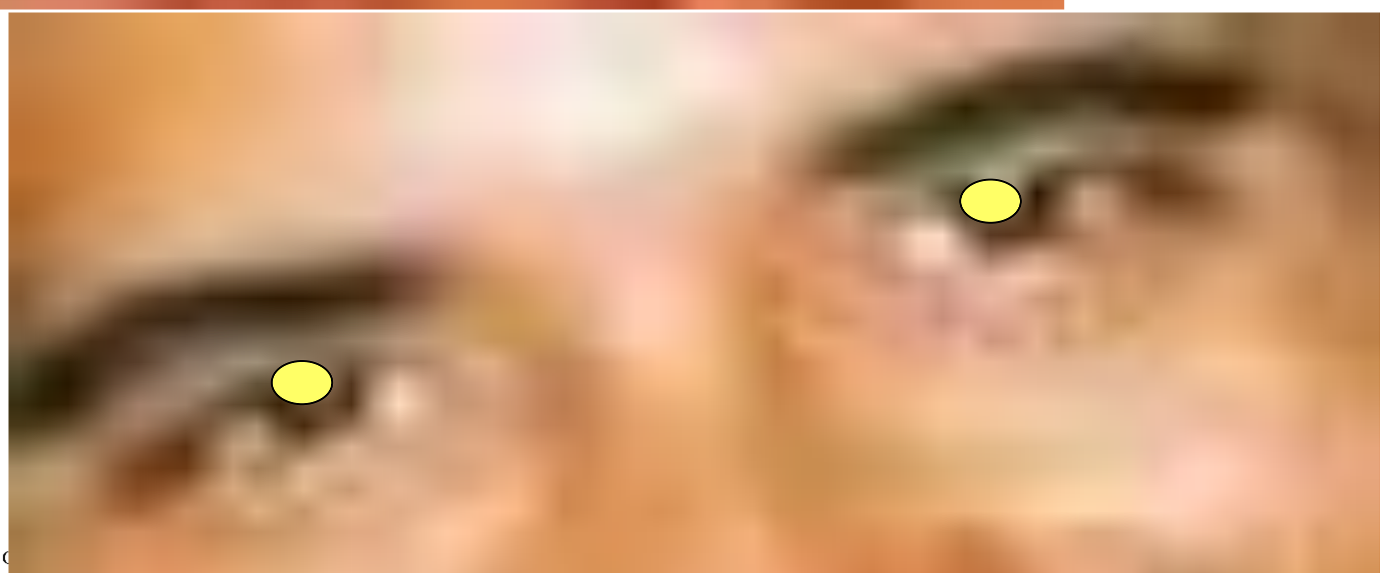
Catch-light inconsistencies

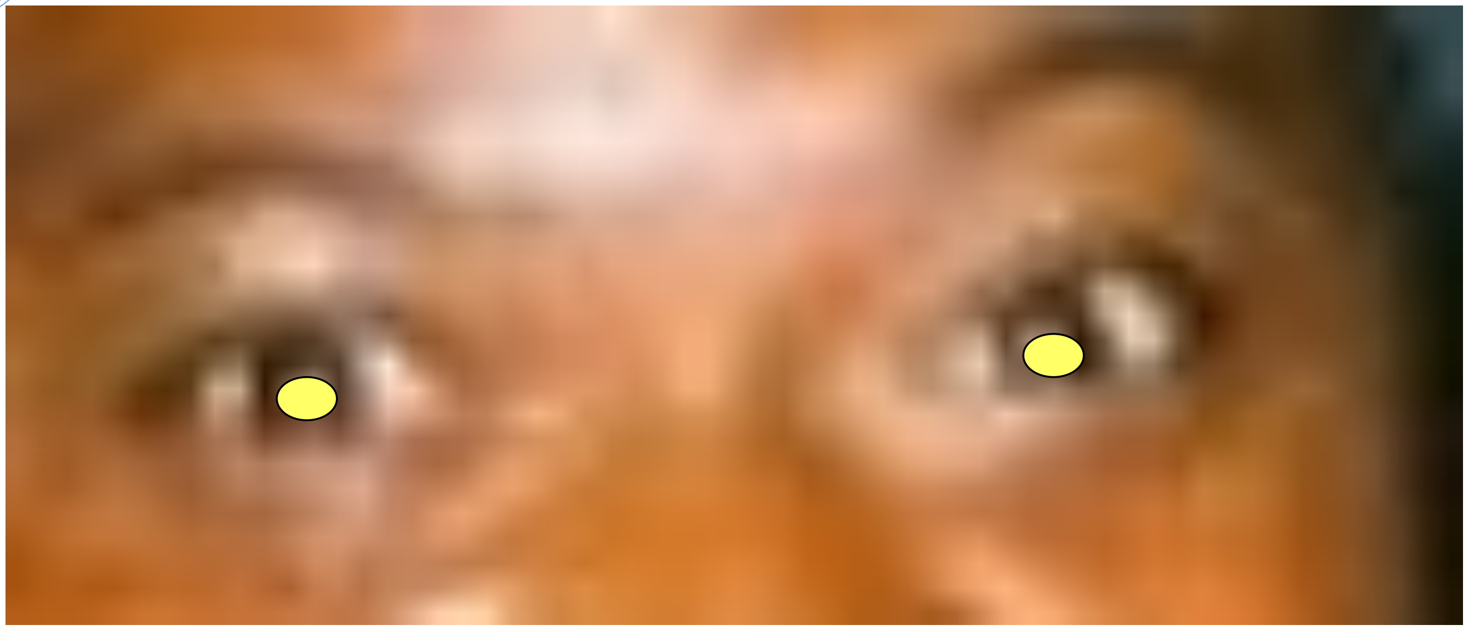


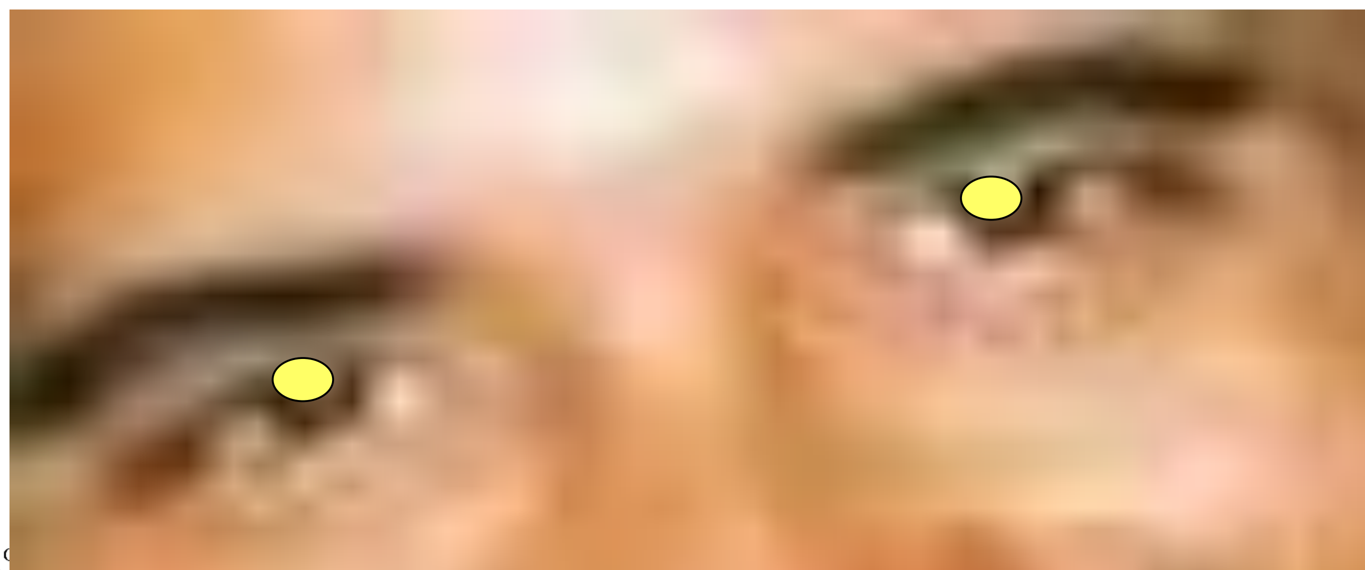
Catch-light inconsistencies

The odd couple









Perspective inconsistencies

“Jesus Before the Caif”, Giotto, 1305.

Source: cristophertyler.org

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ESSENTIEL
le tapis
p. 342
Une envie D'éco

Sometimes, you must look to the ground

Cropping traces

King of Ghana

King of Ghana

El Mundo, January 4, 2015

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+ Lighting

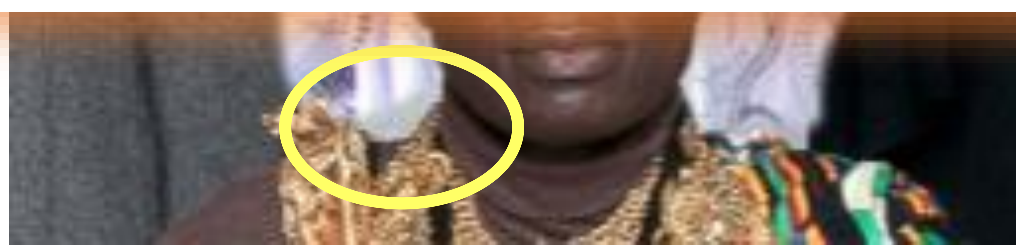
Move to Inbox | More | 28 of many

RE: Foto errónea Inbox x

Community Manager El Mundo <communitymanager@elmundo.es> — Jan 4

to me

Gracias a usted de nuevo. No había ninguna intención de manipular la imagen porque de hecho en la edición impresa, editada por quienes conocen el reportaje, ha salido la buena. Estamos intentando precisamente averiguar a qué se debe la presencia de la foto falsa en la carpeta de imágenes. La selección de fotos semanal incluye material de distintas secciones. Se pensó, con buen criterio, que la imagen de este 'rey de Ghana' respondía a un tema propio y que merecía aparecer … y al buscar saltó esa foto que nunca debió llegar a esa carpeta. Un saludo.



Other semantic inconsistencies


NOVO
aqua LIGHT
PANTENE PRO-V
Olga Kurylenko
SNAŽNA KOSA?* DA!
TEŠKA KOSA? NE VIŠE!
Isprobala sam različite balzame koji su moju kosu činili težom nego što jest. Pantene Aqua Light je potpuno drukčiji: izuzetno je lagan, baš kao da je napravljen za moju kosu. Čini je snažnom* dajući joj pritom i lepršavost i volumen, kao da je puna mjehurića zraka koji je podižu.
Pantene Aqua Light 100% snage*, 0 težine."
PANTENE


Shopping Mega P
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Fone: 11 2886.63
Show Room de P
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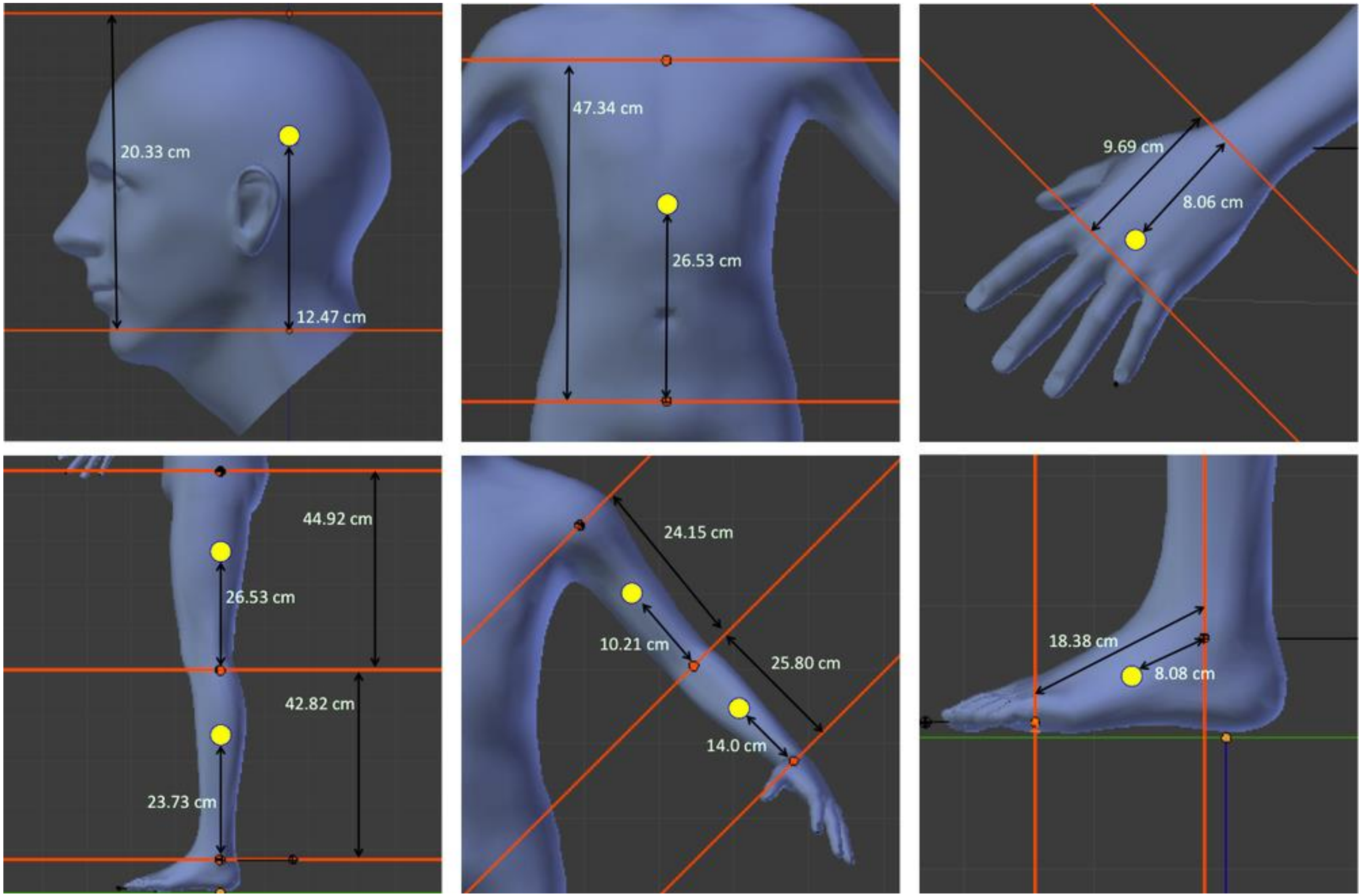
Physical stability

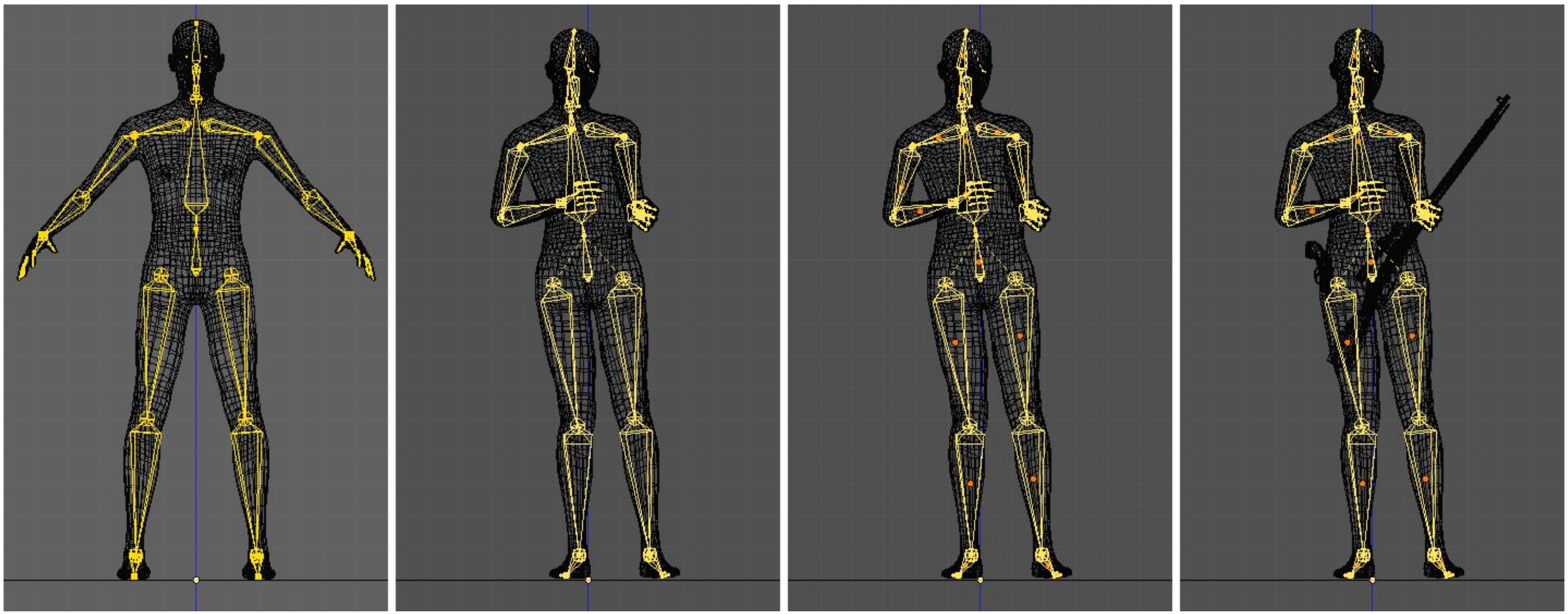
Source: Pittala15

Physical stability



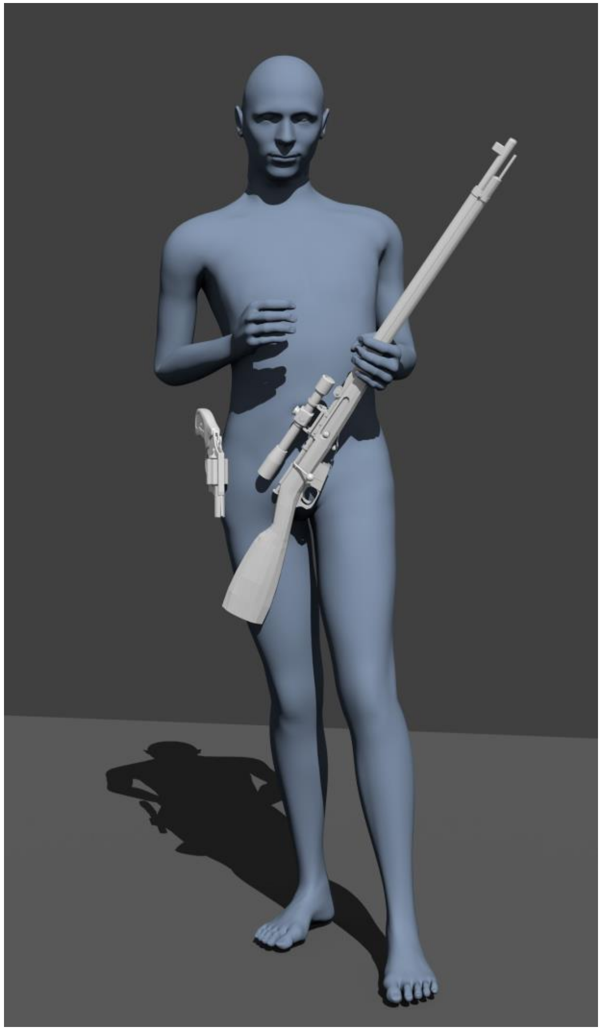
Source: Pittala15

Physical stability



Source: Pittala15

Physical stability



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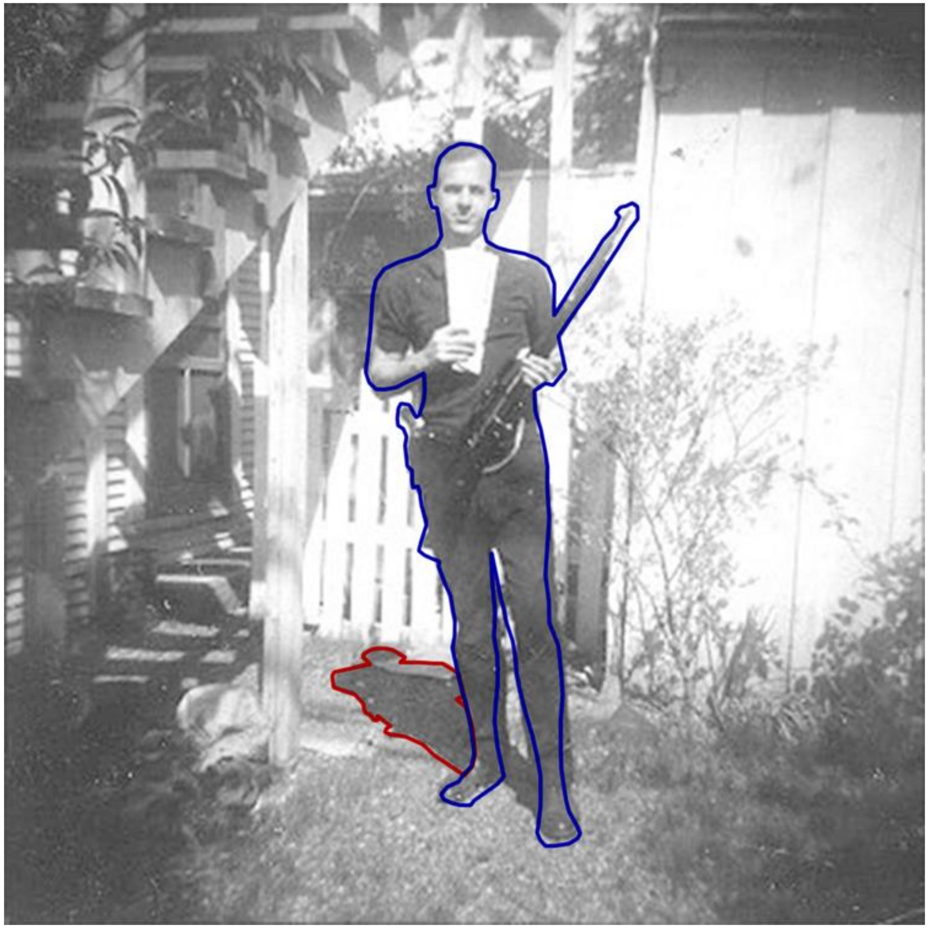
Physical stability

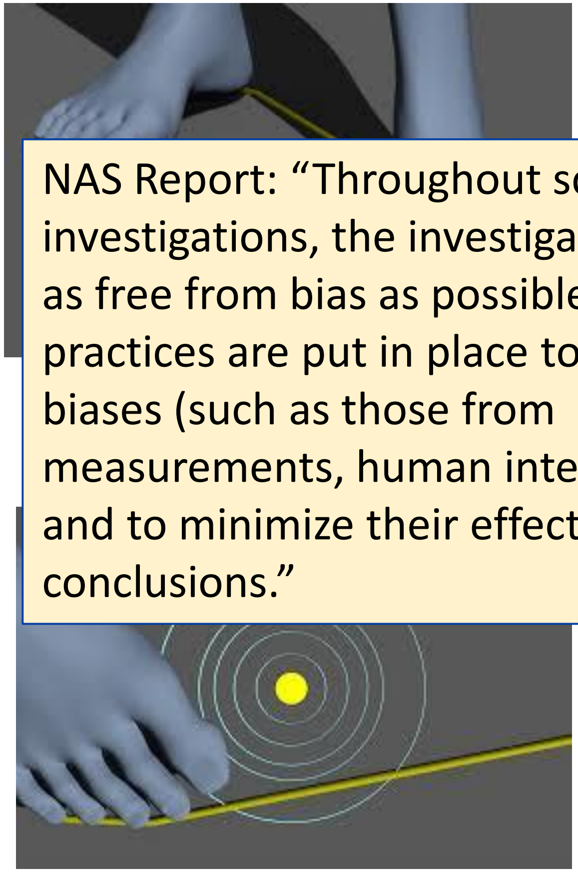


Source: Pittala15

Physical stability

Source: Pittala15

Physical stability

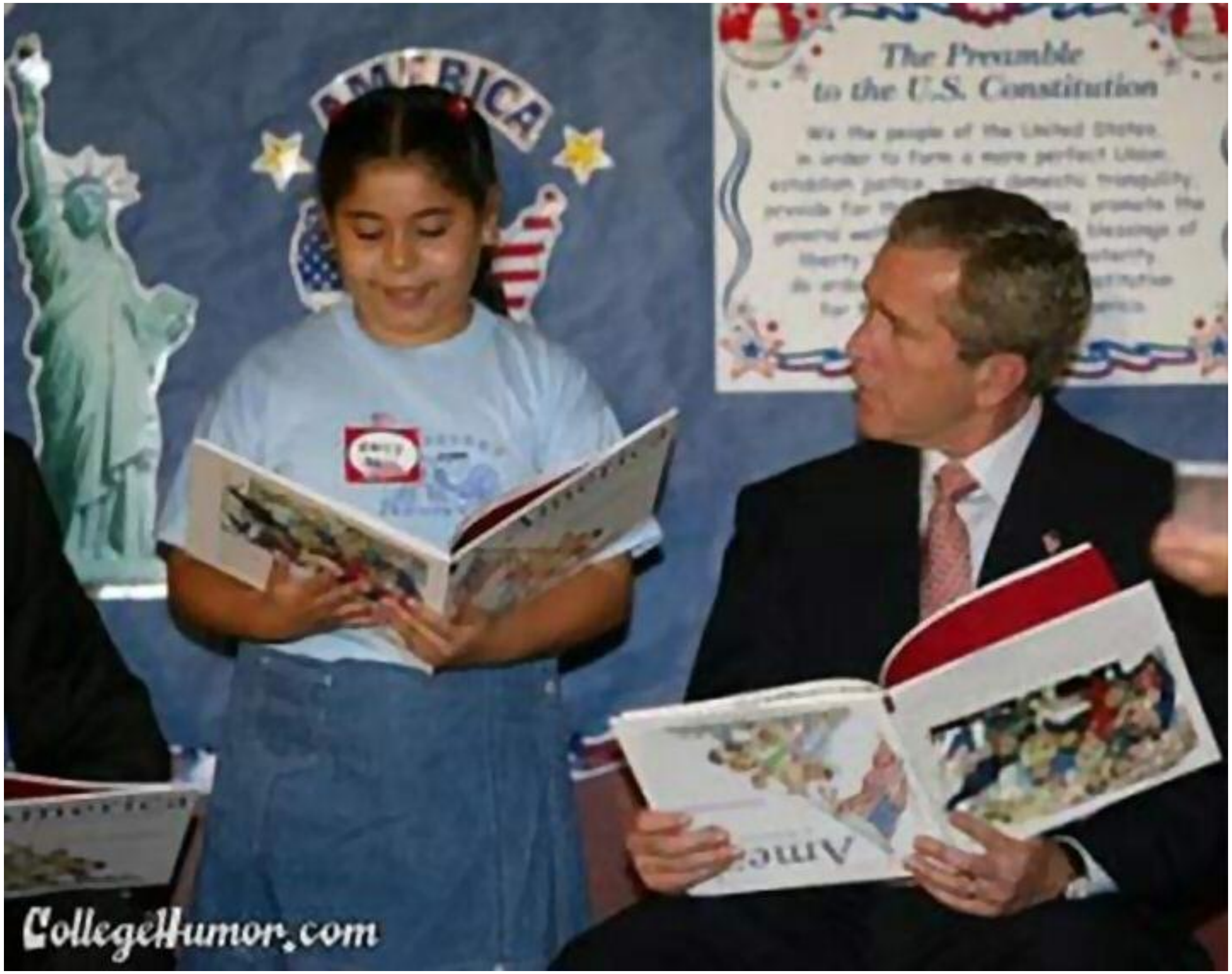


NAS Report: “Throughout scientific investigations, the investigator must be as free from bias as possible, and practices are put in place to detect biases (such as those from measurements, human interpretation) and to minimize their effects on conclusions.”

Source: Pittala15

What’s wrong with this one?

How about this one?



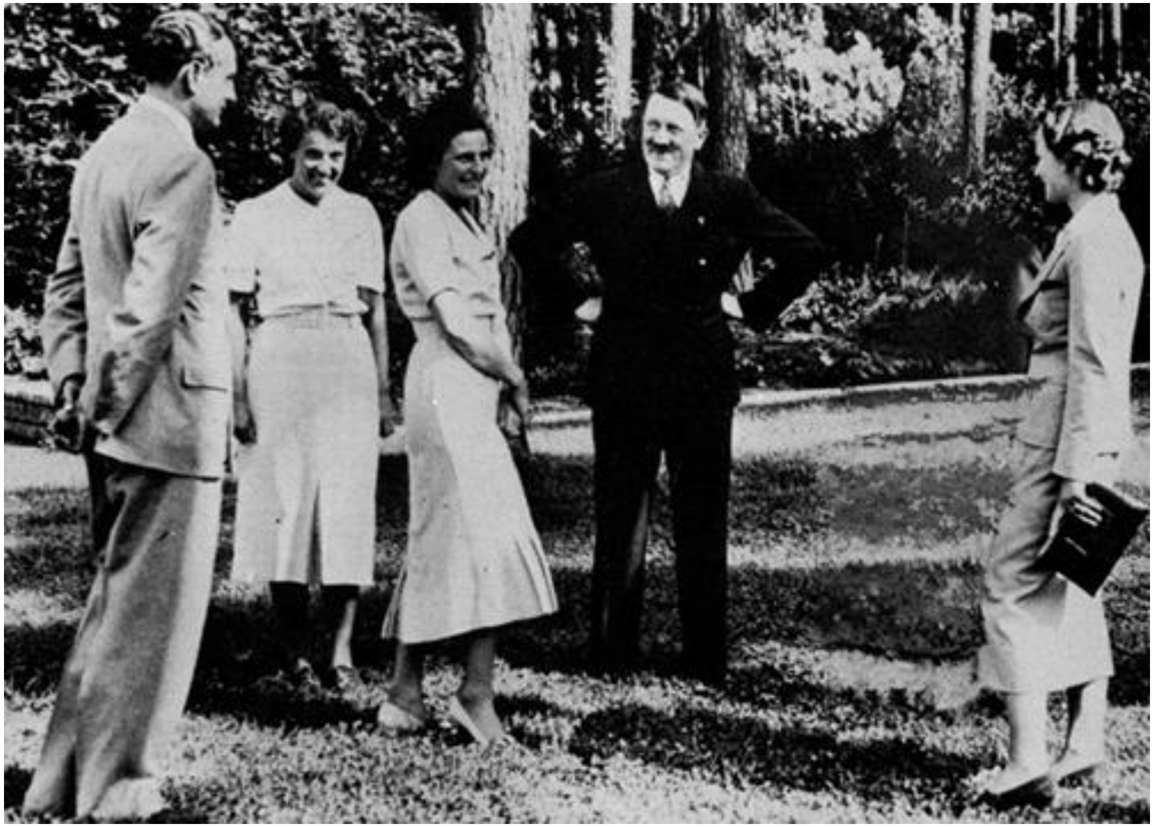
Physical media forensics

Los Angeles Times / Brian Walski (2003)

LA Times: “What Brian did is totally unacceptable and he violated our trust with our readers […] We do not for a moment underestimate what he has witnessed and experienced. We don't feel good about doing this, but the integrity of our organization is essential**. If our readers can't count on honesty from us, I don't know what we have left**.”

Lenin, Trotsky, Lev Kamenev y Khalatov (1919)

Hitler & Goebbels (1937)



Hitler & Franco (1940)

"Capo del Governo e Duce del Fascismo"

“Capo del Governo e Duce del Fascismo”

Berlusconi (2008?)

Diario As (2007)

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Iranian missile affair (2008)

Mubarak (2010)

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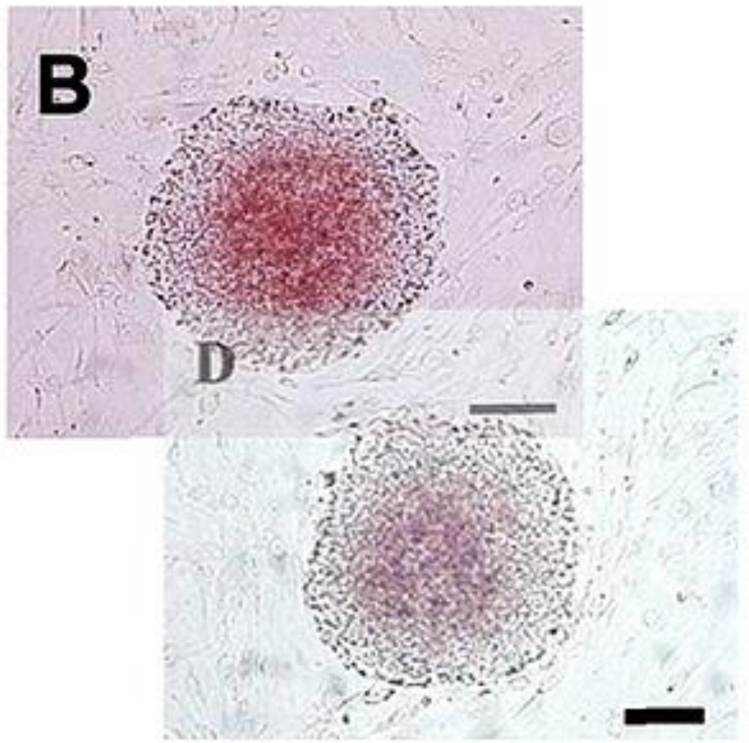
Jacques Setinberg (2008)

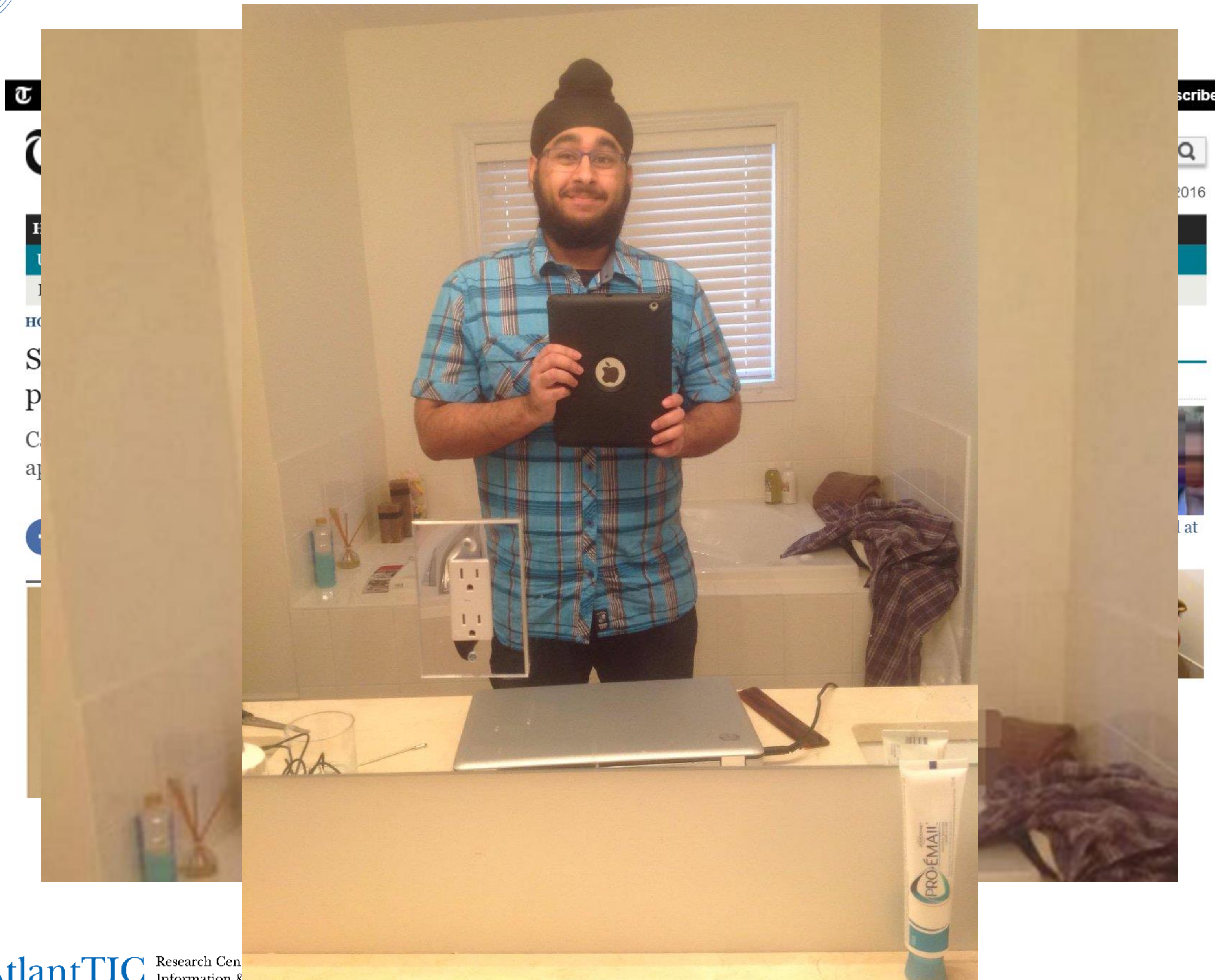
Sarkozy (2007)

Rachida Dati (2008)

Christine Lagarde (2010)

Hwang Woo Suk, supreme scientist (2005)





The Indian who went up a hill but came down a mountain (2016)

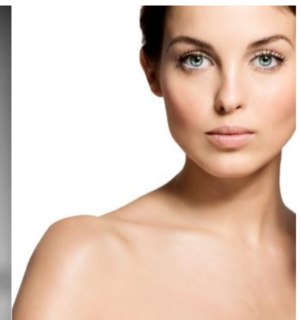
Steve McCurry, National Geographic (1985)

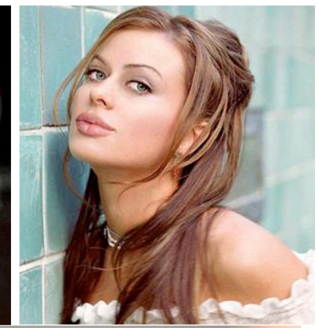
Steve McCurry, Havana

Steve McCurry, Delhi

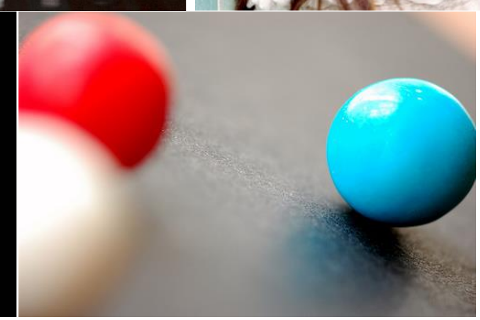
Real or CG?

CG Real Real CG







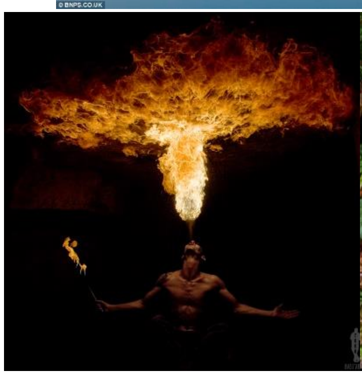
CG CG Real Real

Photoshopped or not?

Real | Photoshop | Real | Real



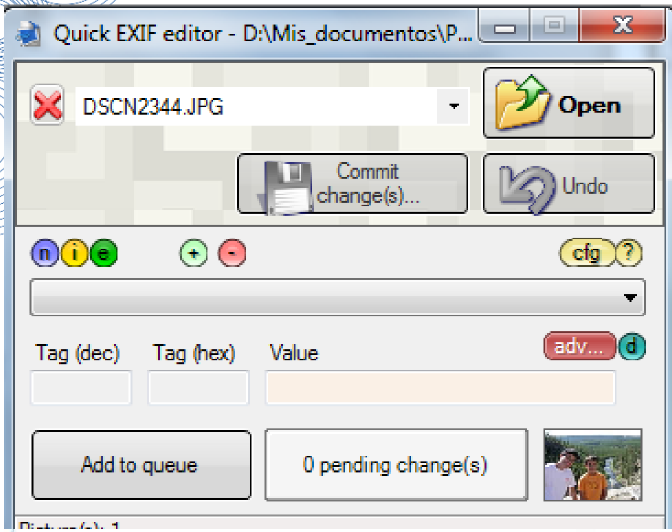


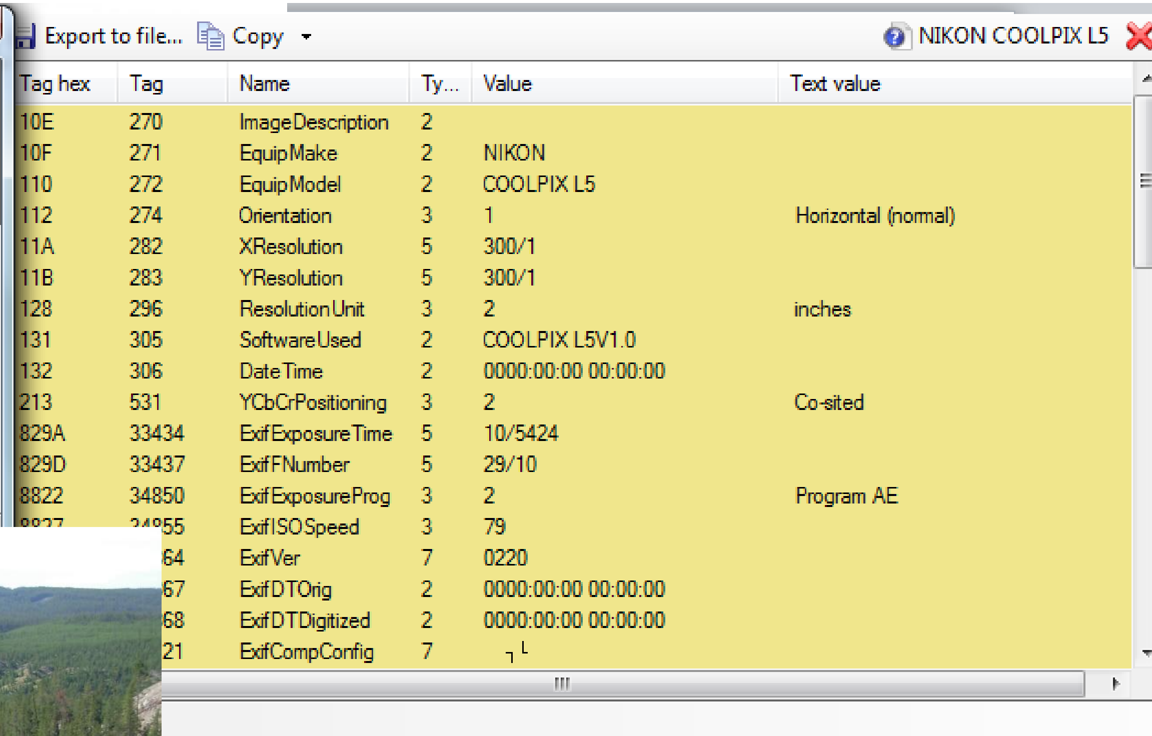



Real | Photoshop | Real | Photoshop

EXIF metadata format

- EXIF: Exchangeable Image Format.
- Some metadata are embedded by the camera, others by the photographer, and others by the editing software.
- Date and time.
- Camera parameters: orientation, aperture, focal distance, etc.
- Thumbnail.
- Processing software.





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10F	271	EquipMake	2	NIKON	
110	272	EquipModel	2	COOLPIX L5	
112	274	Orientation	3	1	Horizontal (normal)
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11B	283	YResolution	5	300/1	
128	296	ResolutionUnit	3	2	inches
131	305	SoftwareUsed	2	COOLPIX L5V1.0	
132	306	DateTime	2	0000:00:00 00:00:00	
213	531	YCbCrPositioning	3	2	Co-sited
829A	33434	ExifExposureTime	5	10/5424	
829D	33437	ExifFNumber	5	29/10	
8822	34850	ExifExposureProg	3	2	Program AE
8827	34855	ExifISOSpeed	3	79	
64		ExifVer	7	0220	
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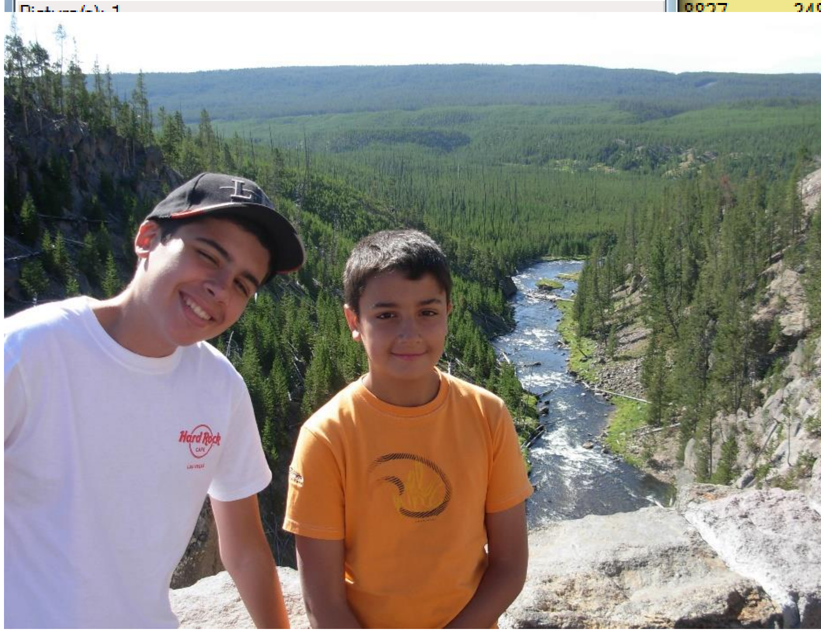

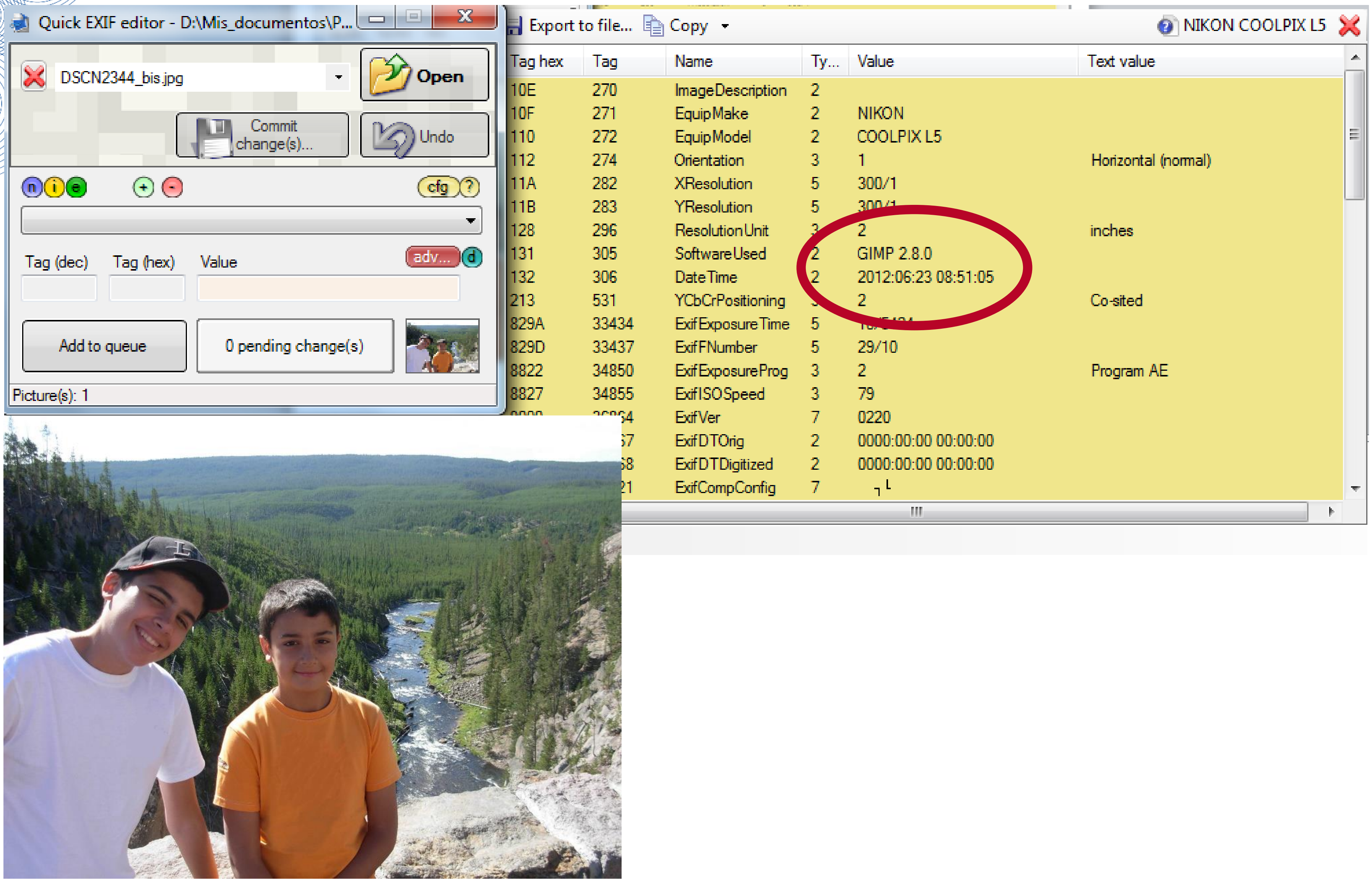
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Commit change(s)...
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Export to file...
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110 272 EquipModel 2 COOLPIX L5
112 274 Orientation 3 1 Horizontal (normal)
11A 282 XResolution 5 300/1
11B 283 YResolution 5 300/1
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ExifDTDigitized 2 0000:00:00 00:00:00
ExifCompConfig 7

So…why Grissom is in awe?

Physical media forensics

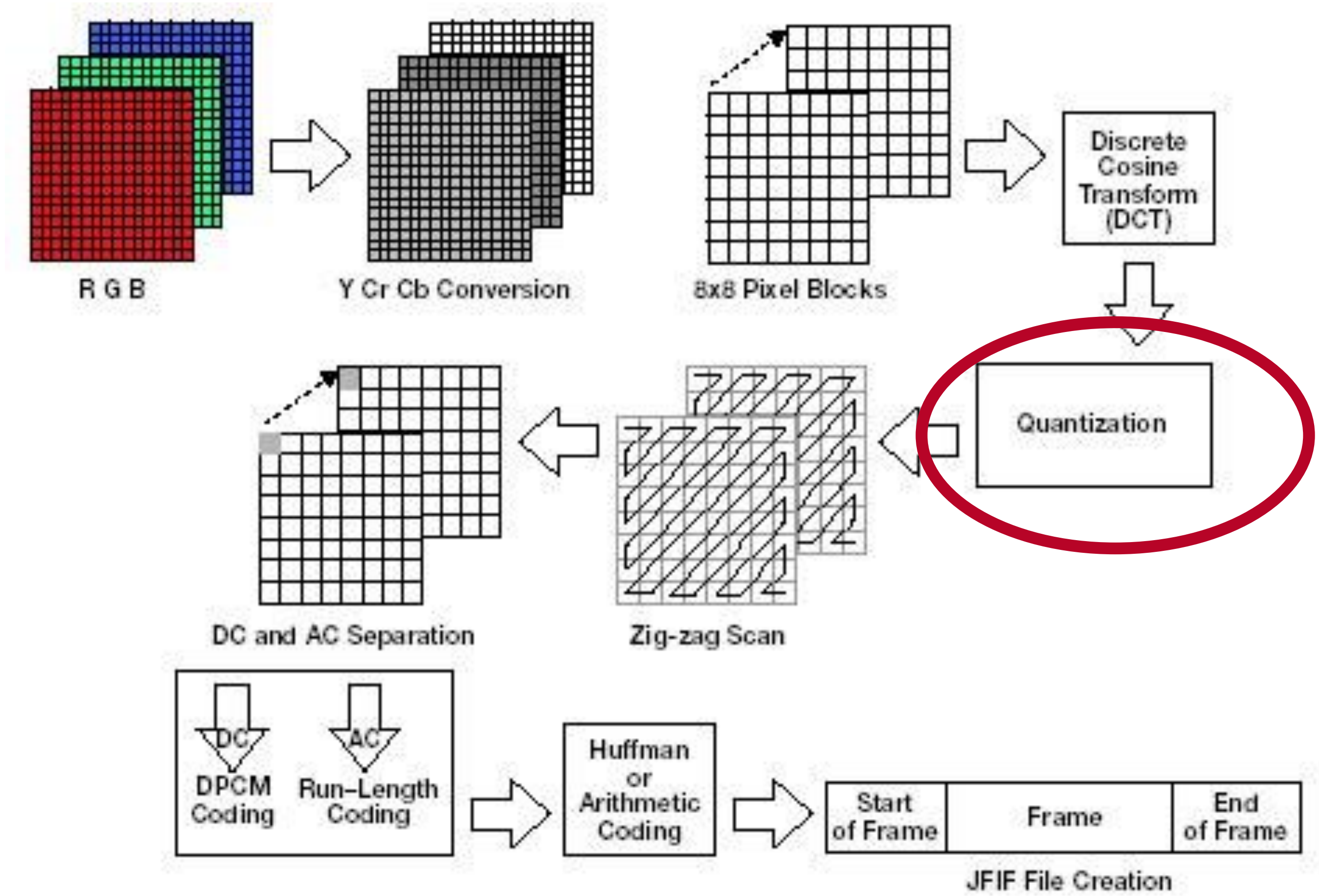
- Use mathematical properties of media to detect manipulations.
- Applicable to images, video, audio. We'll cover images here.
- Most methods statistical in natu... hypotheses tests; but a few determi...
- It is possible to deter... tions, but traces tend to get... ssing.
- Methods can be often co... n.
- The dangers of machine learning in forensic...

Physical image forensics

- Single/Double compression traces.
  - Histogram periodicities.
  - Benford's law.
  - Blocking artifacts.
- Filtering (including some non-linear) traces.
  - Fourier analysis.
  - Set membership (feasibility).
- Resampling traces.
  - Fourier analysis / cyclostationarity.
  - SVD / eigenspace analysis.
- Clone and splicing detection.
  - SIFT.
  - Spectral discontinuities.

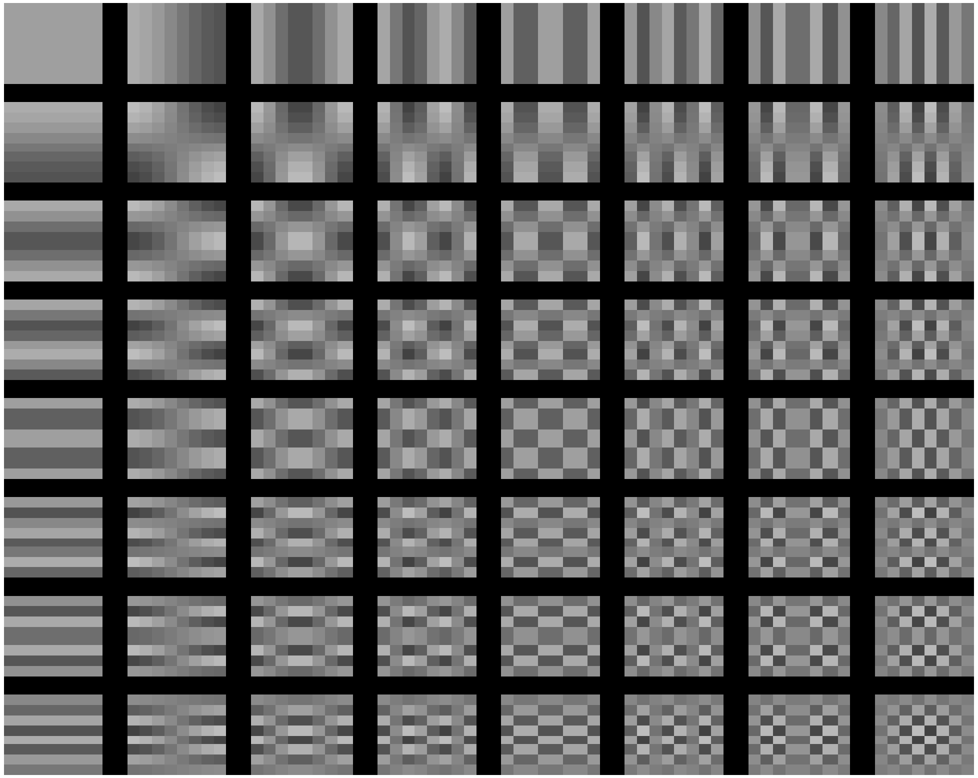
Detecting double compression

The DCT



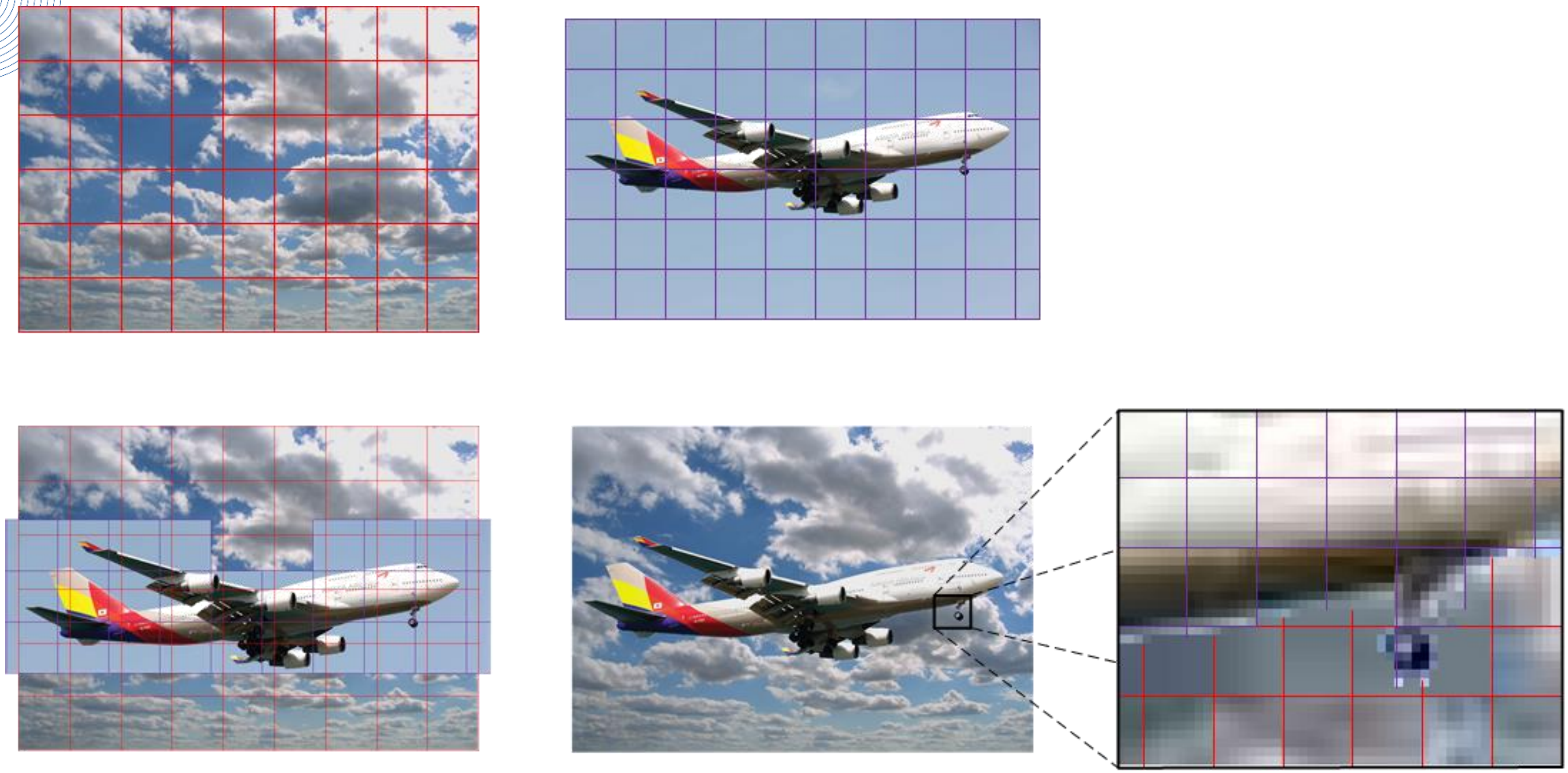
Source: Katz&Gentile, EE Times 2003.

DCT: Frequency Distribution



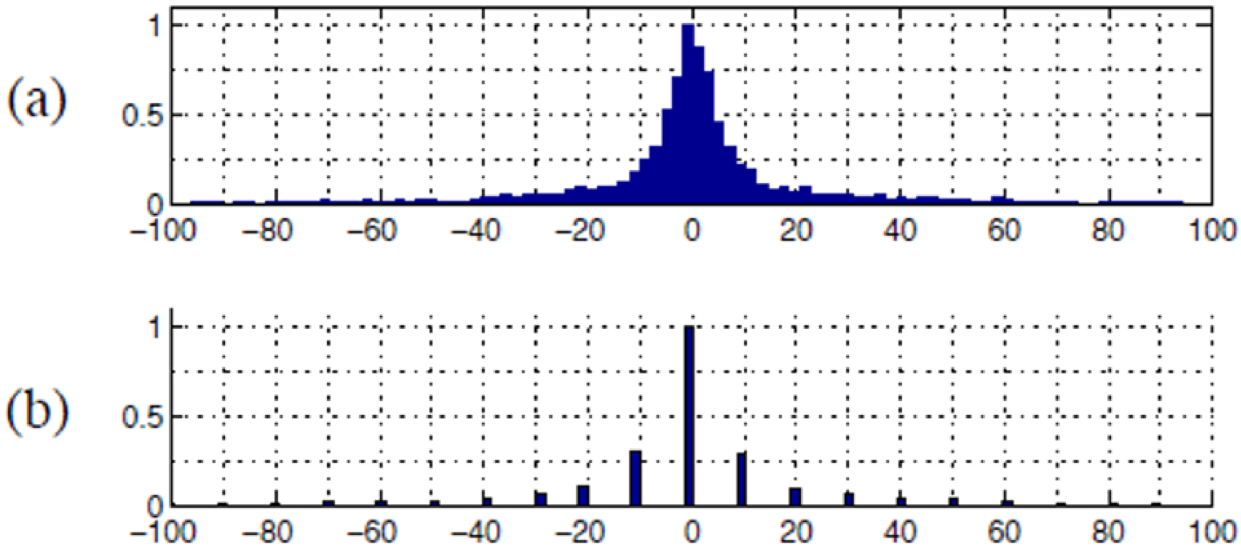
Source: Richard Kelley: the DCT

Double compression detection



Compression effects on histogram

- (2,2) DCT coefficient
- Step size = 10



Bianchi's double JPEG compression detector

- I_1 is JPEG-compressed with a QF_2 and then decompressed, the resulting image I_2 can be modeled as

$$I_2 = D_{00}^{-1} \circ Q_2 \circ D_{00} I_1 + E_2 = I_1 + R_2$$

- D_{00}: 8x8-block DCT, D^{-1}_{00}: inverse block DCT, Q_2: quantization with quality factor QF_2. E_2 : rounding error (to 8 bits), $R_2 = E_2$+DCT quantization error.
- Suppose I_1 corresponds to a I_0 JPEG-compressed with QF_1 with a grid shifted by $(x, y) \neq (0,0)$

$$I_1 = D_{xy}^{-1} \circ Q_1 \circ D_{xy} I_0 + E_1$$

- Then, I_2, which would be non-aligned double compressed (NA-DC), is

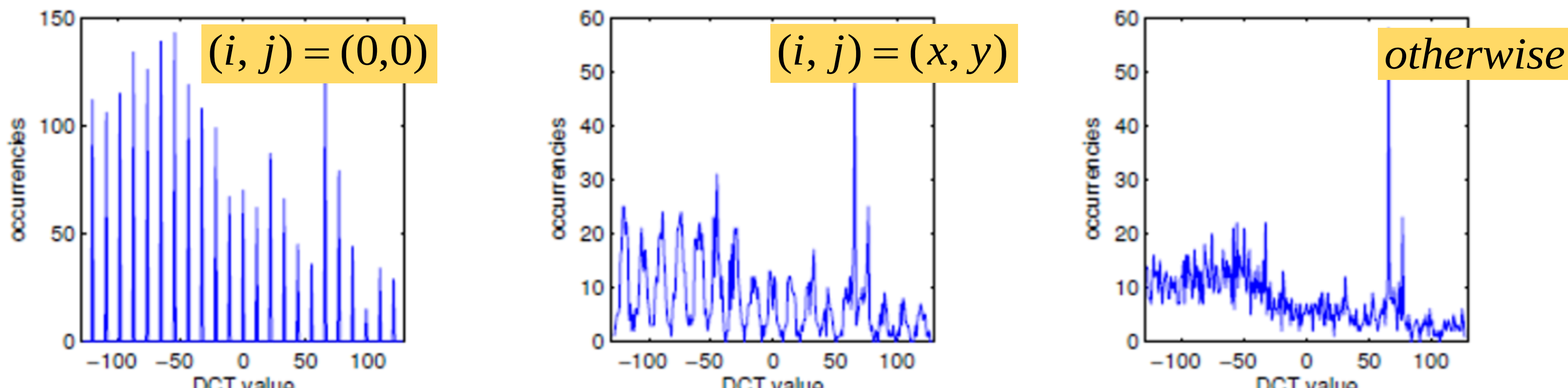
$$I_2 = D_{xy}^{-1} \circ Q_1 \circ D_{xy} I_0 + E_1 + R_2$$

Bianchi's double JPEG compression detector

- Take the block DCT of I_2 with shift *(i,j)*. There are 3 cases depending on *(i,j)*:

$$D_{ij} I_2 = \begin{cases} Q_2 \circ D_{00} I_1 + D_{00} E_2, & \text{if } (i,j) = (0,0) \\ Q_1 \circ D_{xy} I_0 + D_{xy}(E_1 + R_2), & \text{if } (i,j) = (x,y) \\ D_{ij} \circ D_{00}^{-1} \circ Q_2 \circ D_{00} I_1 + D_{ij} E_2, & \text{otherwise} \end{cases}$$

- Then, the values after the DCT of I_2 will be clustered around the respective quantization points with some error. If *(i,j)* is not aligned with *(0,0)* or *(x,y)* there will no such clustering



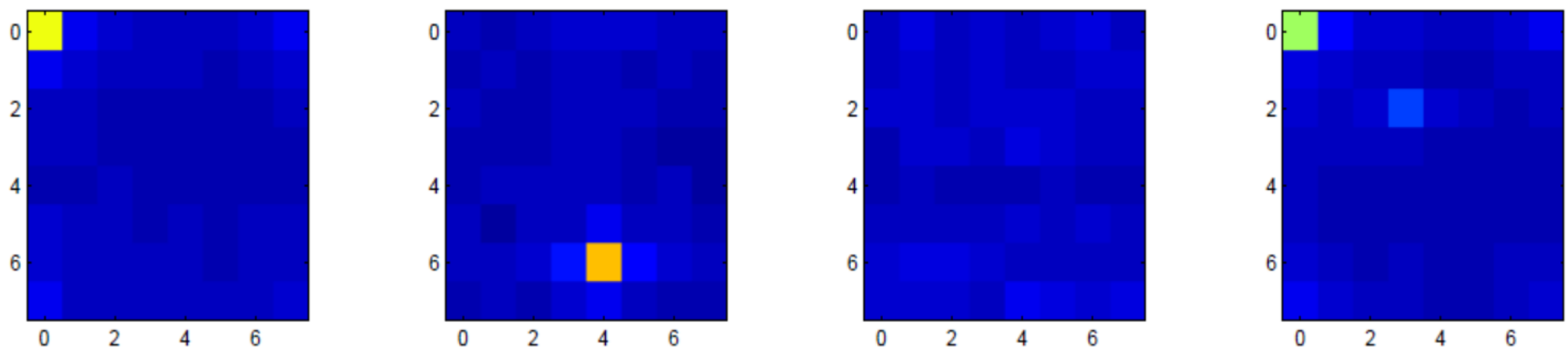
Bianchi's double JPEG compression detector

- E_2: uniformly distributed in [-1/2,1/2]; D_{00} unitary, then $D_{00}E_2$ approx. Gaussian with variance 1/12.
- $D_{xy}(E_1 + R_2)$ is approx. Gaussian with variance $(q_2^2 + 1)/12$, where q_2 is the quantization step of the 2nd compression.
- Clustering will be only evident if the std is $< q_1 / 2$
- Bianchi's method focuses on the DC coeffs where clustering is more evident.
- To detect the presence of the lattice, Bianchi proposes to take the Fourier Transform of the histogram: there should be peaks at $2\pi / q_1$ when *(i,j)=(0,0)* and at $2\pi / q_2$ when *(i,j)=(x,y)*.

Bianchi's double JPEG compression detector

- For each *q*, $f_{ij}(q)$ is the FT of the histogram evaluated at $2\pi / q$
- The Integer Periodic Map (IPM) is then defined as

$$M_{ij}(q) = \frac{f_{ij}(q)}{\sum_{i',j'} |f_{i',j'}(q)|}$$



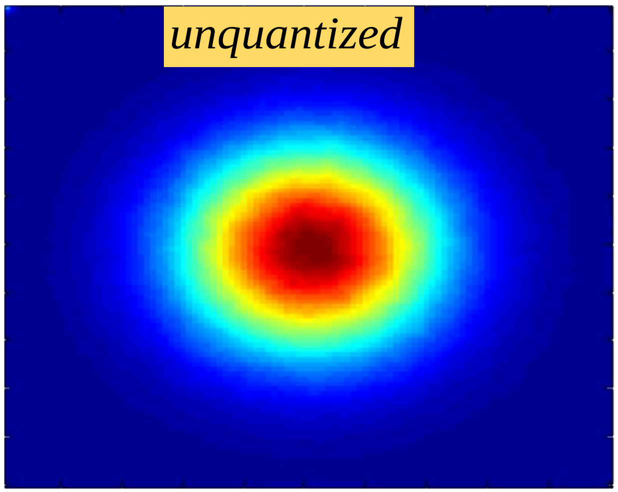
$M_{ij}(q_2)$

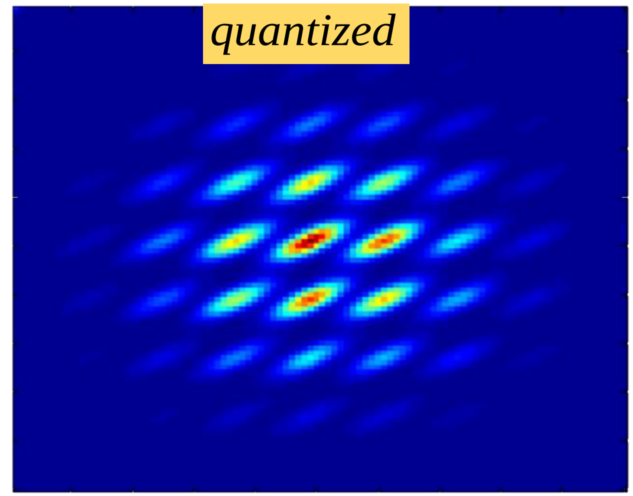
$M_{ij}(q_1), (x,y) = (6,4)$

$M_{ij}(q), q \neq q_2, q_1$

$M_{ij}(q), q_2 = q_1,$
$(x,y) = (2,3)$

A statistical approach





$$f_{\mathbf{X}}(\mathbf{x}) = \sum_{\mathbf{k}^* \in \mathbb{Z}^N} w(\mathbf{k}^*) g(\mathbf{x} - \Theta\mathbf{k}; \mathbf{C})$$

- $w(\mathbf{k}^*)$: prob that image block is quantized to bin indexed by $\mathbf{k}^*$
- $g(\mathbf{x};\mathbf{C})$: 64-D Gaussian with covariance matrix $\mathbf{C}$
- Θ: Matrix that generates quantization lattice in DCT domain

A statistical approach

- If the signal has a large variance compared to the size of the quantization bins:

$$\sum_{\mathbf{k}^* \in Z^N} w(\mathbf{k}^*) g(\mathbf{x} - \Theta \mathbf{k}^*) \propto \sum_{\mathbf{k}^* \in Z^N} g(\mathbf{x} - \Theta \mathbf{k}^*)$$

- This is a periodic (in 64-D) function that can be expanded in Fourier series using the dual lattice.
- With a large variance, the unquantized signal can be approximated by a constant pdf. Then, the likelihood ratio test is

$$\sum_{\mathbf{k}^* \in Z^N} g(\mathbf{x} - \Theta \mathbf{k}^*) \gtrless \eta$$

A statistical approach

- If the quantization noise is small compared to the size of the bins:

$$\sum_{\mathbf{k}^* \in Z} g(\mathbf{x} - \Theta \mathbf{k}^*) \cong g(\mathbf{x} - \Theta \mathbf{k}_0^*)$$

where $\mathbf{x}$ is quantized to $\Theta \mathbf{k}_0^*$

- Since *g* is Gaussian, this leads to the LLRT

$$(\mathbf{x} - \Theta \mathbf{k}_x^*)^T \mathbf{C}^{-1} (\mathbf{x} - \Theta \mathbf{k}_x^*) \gtrless \tau$$

A statistical approach

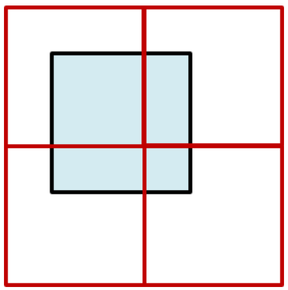
- Recall that for the NA-DC:

$$D_{ij} I_2 = Q_1 \circ D_{xy} I_0 + D_{xy}(E_1 + R_2), \ \text{if} \ (i,j) = (x,y)$$

- If D is the DCT matrix then the noise covariance is

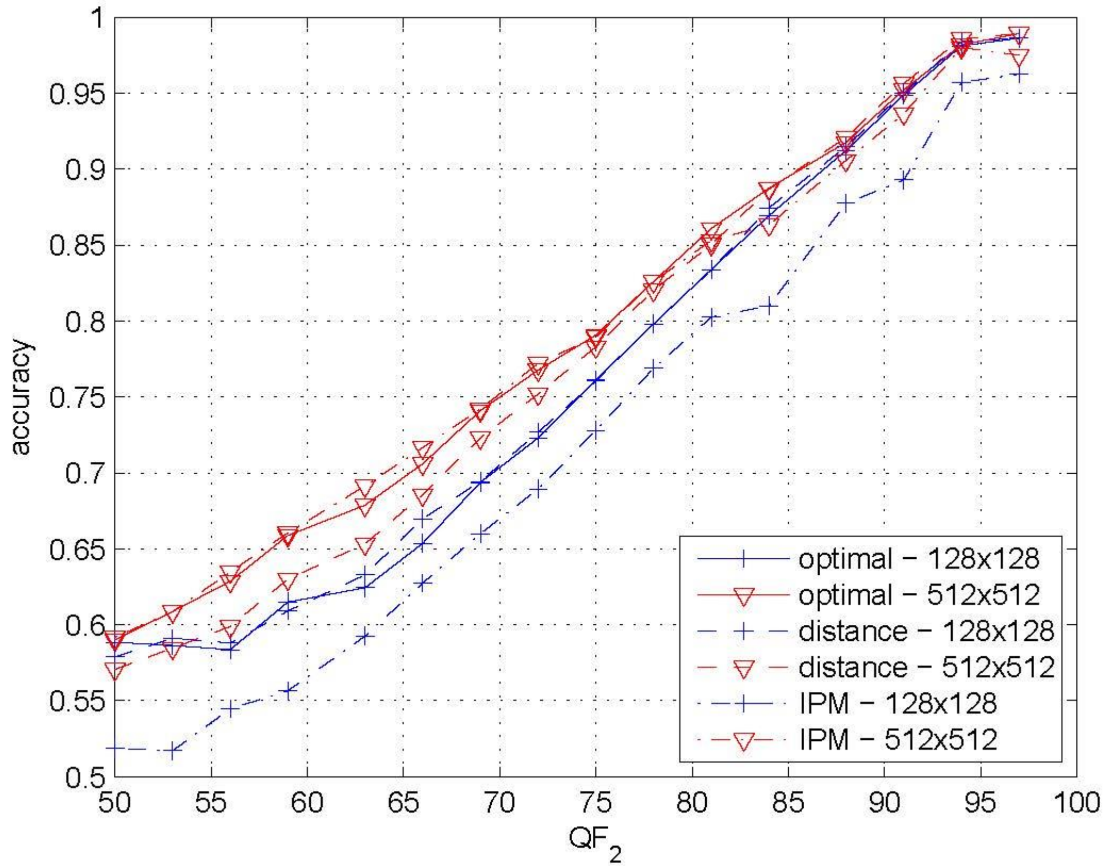
$$\mathbf{C} = \mathbf{D}(\mathbf{C}_E + \mathbf{C}_R)\mathbf{D}^T$$

- Assuming the quantization errors E_1 i.i.d. uniform in [-1/2, 1/2], $\mathbf{C}_E = \mathbf{I}/12$
- $\mathbf{C}_R$ is modeled considering the 4 quantization errors of the neighboring blocks



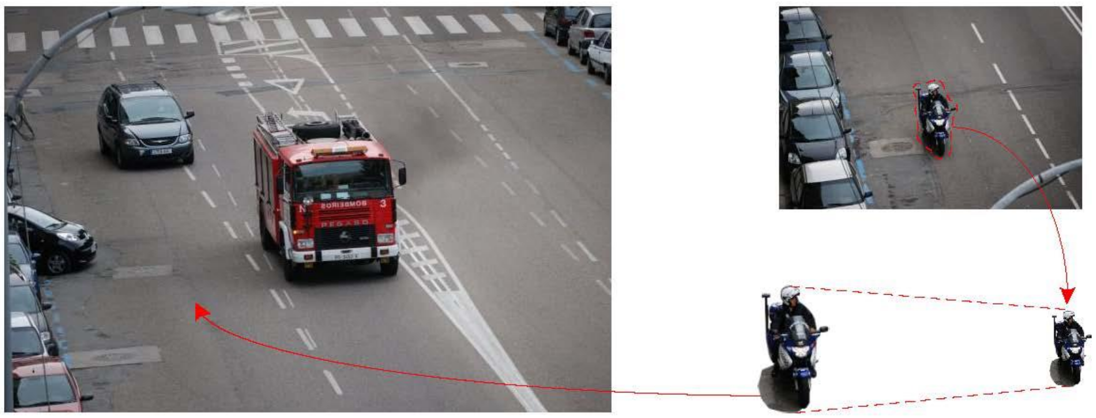
A statistical approach

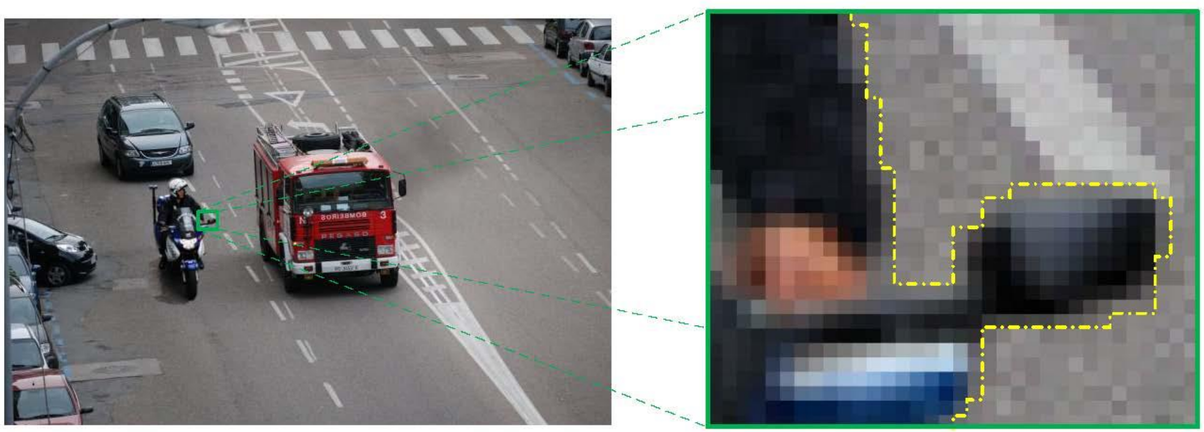
- Maximum accuracy. Results averaged over QF_1, and for $QF_1 \neq QF_2$



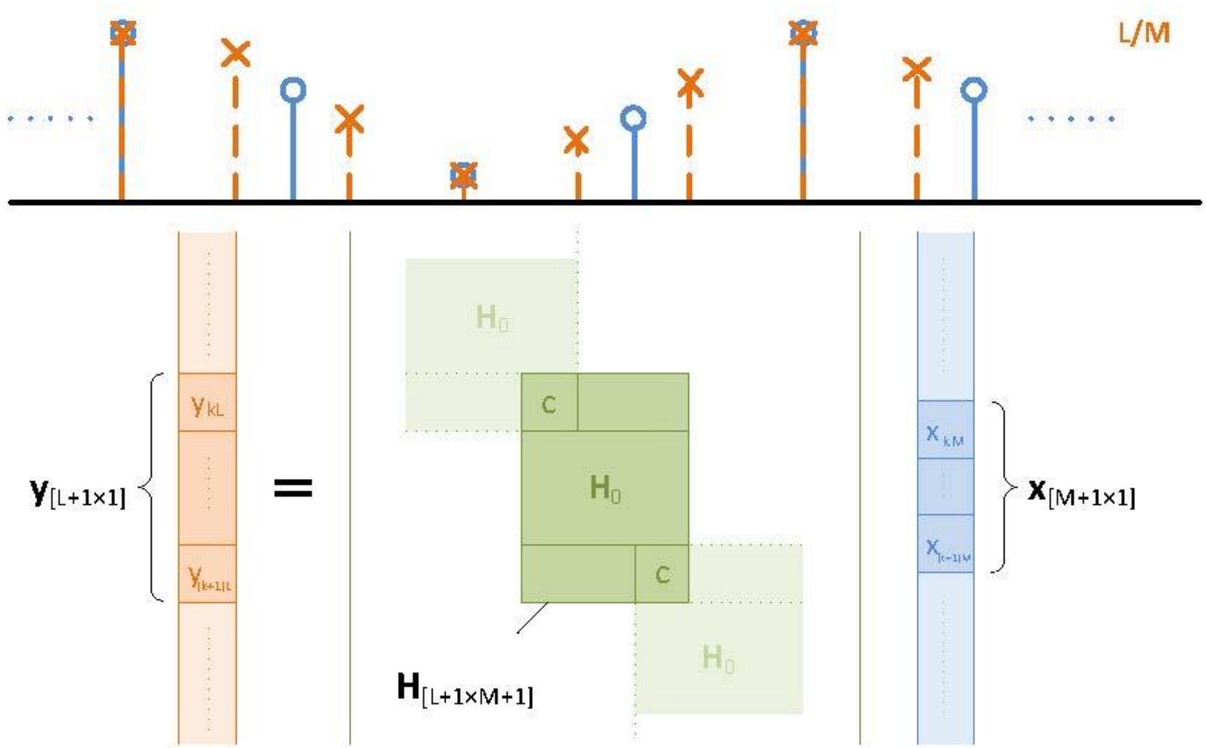
Detecting traces of resampling

Resampling traces





Resampling by *L*/ *M*



Popescu and Farid's resampling factor estimator

- Writing the observed samples as a linear combination of the original samples

$$\mathbf{y} = \mathbf{H} \cdot \mathbf{x}$$

- The matrix for L/M=4/3 has the form

Popescu & Farid, IEEE TSP, 2005.

$$\mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & \\ 0.25 & 0.75 & 0 & 0 & \\ 0 & 0.50 & 0.50 & 0 & \\ 0 & 0 & 0.75 & 0.25 & \\ 0 & 0 & 0 & 1 & \\ & & & & \ddots \end{bmatrix}$$

- For L/M=2

$$\mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & \\ 0.50 & 0.50 & 0 & \\ 0 & 1 & 0 & \\ 0 & 0.50 & 0.50 & \\ 0 & 0 & 1 & \\ & & & \ddots \end{bmatrix}$$

Popescu and Farid's resampling factor estimator

- If the length of **x** is *N*, then the length of **y** is approximately *NL*/*M*, so the size of **H** is approximately (*NL*/*M*)x*N*. Then, for large *N*, there must be linearly dependent rows in **H**.
- Consider the matrix for *L*/*M* = 4/3. The second row $\mathbf{h}_2$ can be written as a linear combination of $\mathbf{h}_1$, $\mathbf{h}_3$, $\mathbf{h}_4$ and $\mathbf{h}_5$:

$$\mathbf{h}_2 = 0.25\mathbf{h}_1 + 1.5\mathbf{h}_3 - \mathbf{h}_4 + 0.25\mathbf{h}_5$$

- This implies that

$$y_2 = 0.25 y_1 + 1.5 y_3 - y_4 + 0.25 y_5$$

- This relationship repeats periodically, i.e.,

$$y_{kL+2} = 0.25 y_{kL+1} + 1.5 y_{kL+3} - y_{kL+4} + 0.25 y_{kL+5}$$

Similar relations hold for the other samples

Popescu and Farid's resampling factor estimator

- Assuming there is Gaussian noise in **y**

$$f_{Y_i|\mathbf{b}_p}(y_i|\mathbf{b}_p) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{|y_i - \sum_{k=-P}^{P} y_{i-k} b_{p,k}|^2}{2\sigma^2}\right)$$

with $\mathbf{b}_p$,$p=i$ mod L, the vector describing the linear combination.

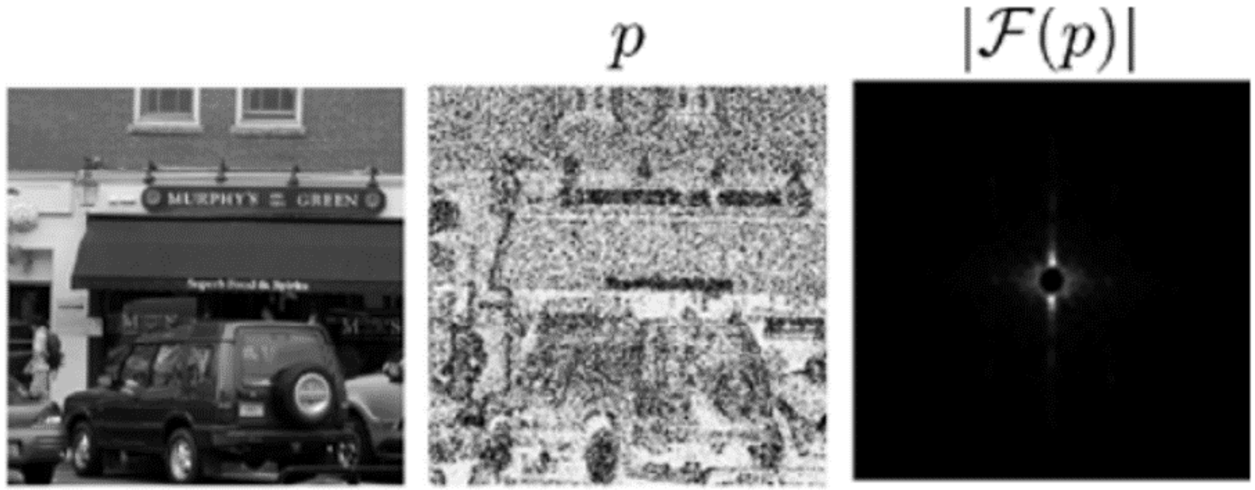
- In the case of no interpolation Y_i is assumed to be uniform over its domain.
- Since neither $\mathbf{b}_p$ nor σ^2 are known they can be estimated using the EM algorithm. E-step: Prob of Y_i given $\mathbf{b}_p$ and σ^2
- M-step: estimate $\mathbf{b}_p$ as the minimizer (e.g. via Least Squares) of

$$\sum_i f_{Y_{iL+p}}(y_{iL+p}) \left(y_{iL+p} - \sum_{k=-P}^{P} y_{iL+p-k} b_{p,k}\right)^2$$

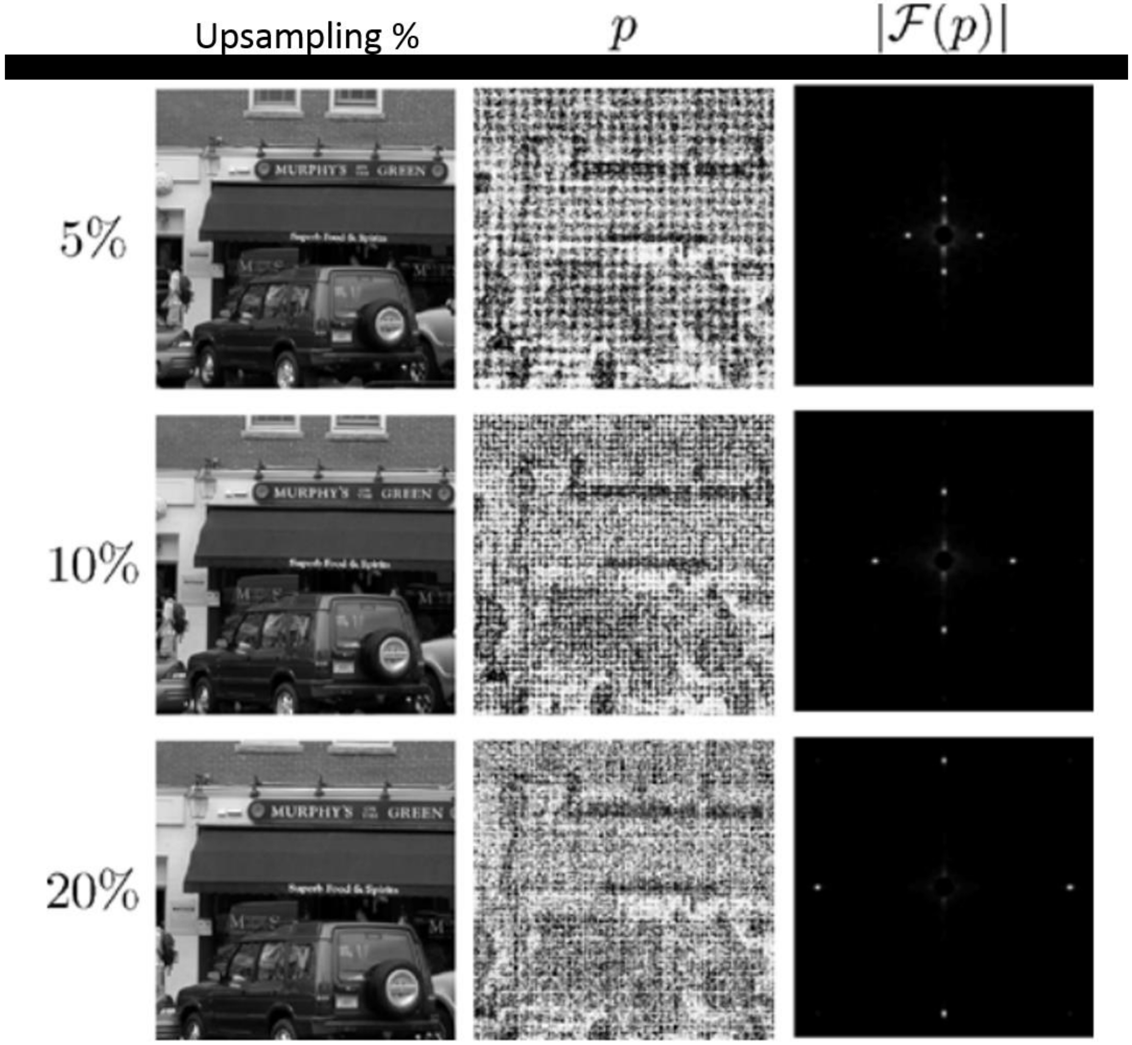
and σ^2 is the minimum cost.

Popescu and Farid's resampling factor estimator

- The probs for each y_i can be represented in a prob map.
- These probs are periodic and show in the Fourier Transform as peaks.
- No interpolation

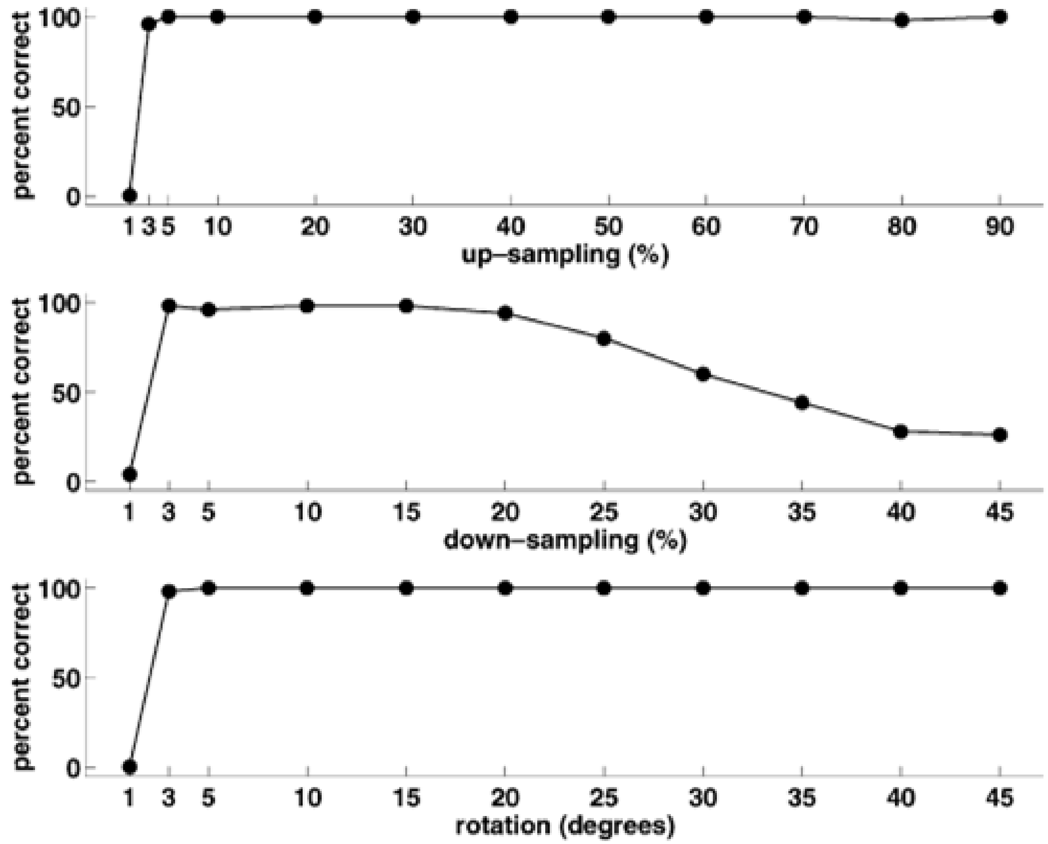


Popescu and Farid's resampling factor estimator



Popescu and Farid's resampling factor estimator

- Average detection accuracy for 50 images

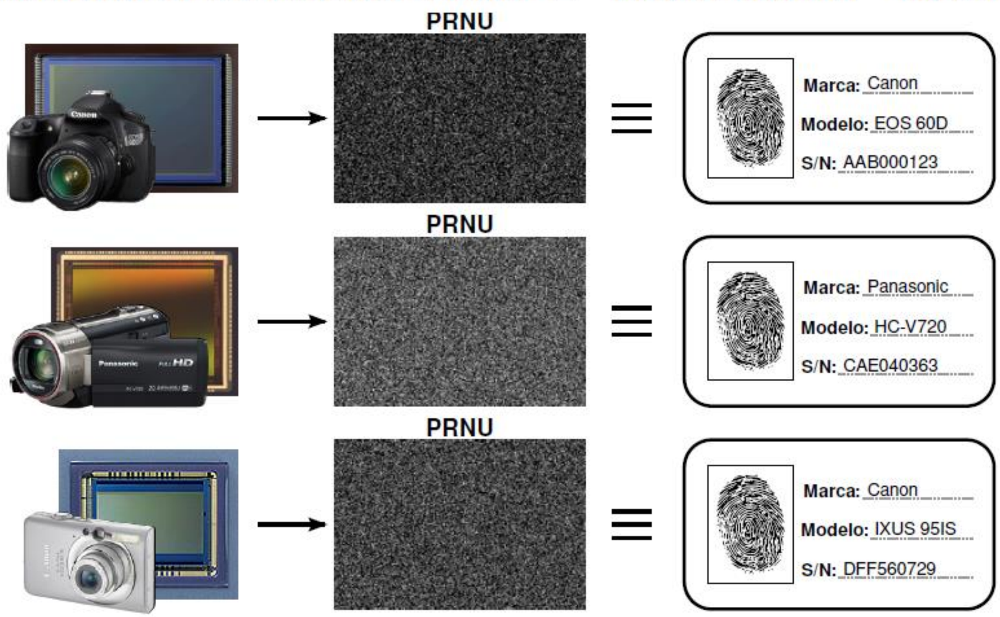


Camera identification

Image source identification

Practically all (CMOS, CCD, etc.) have an intrinsic noise pattern: **PRNU (Photo Response Non Uniformity)**

- **PRNU properties:** robustness, stability, universality
- Dark current noise has been also proposed but performs much worse



Camera identification

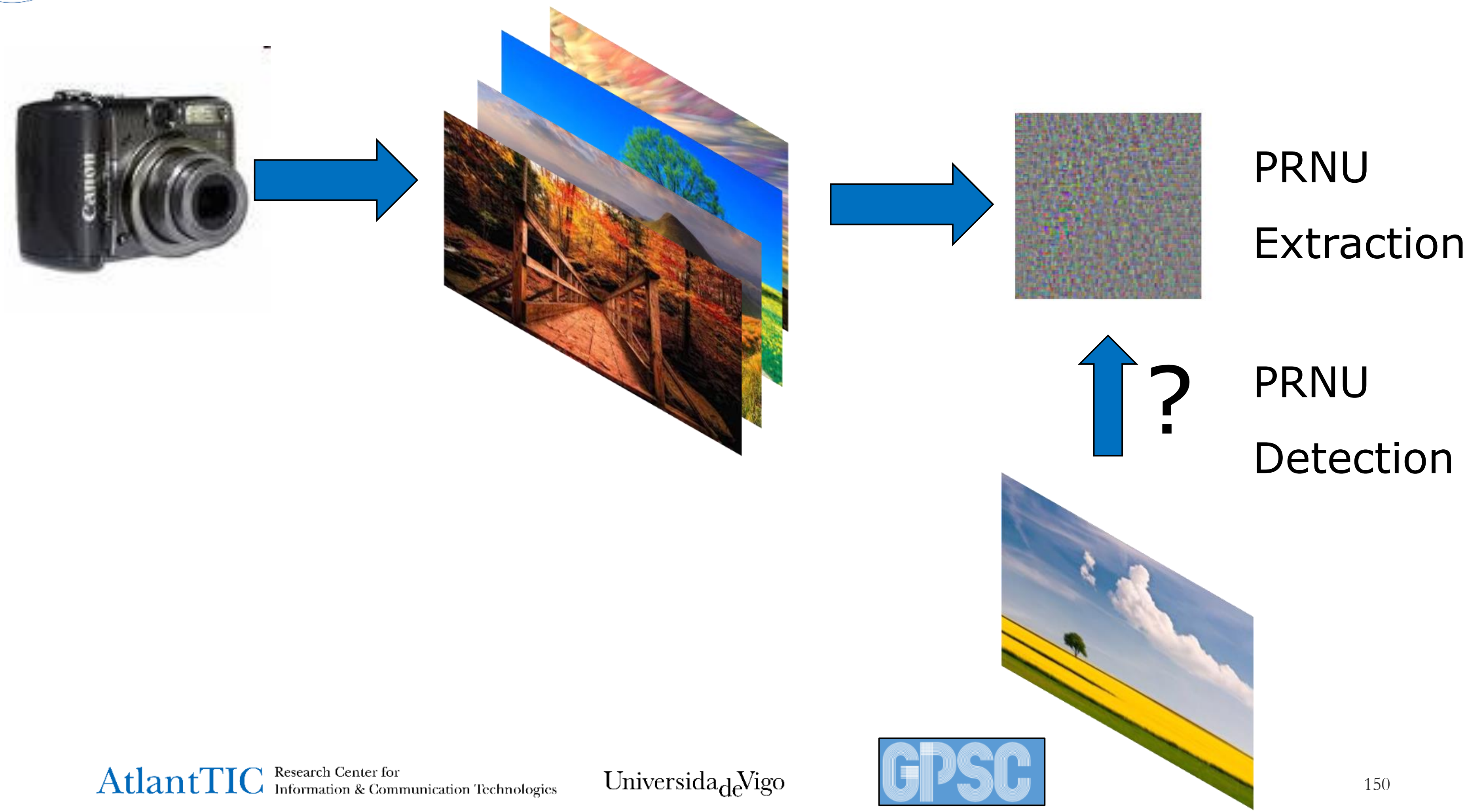
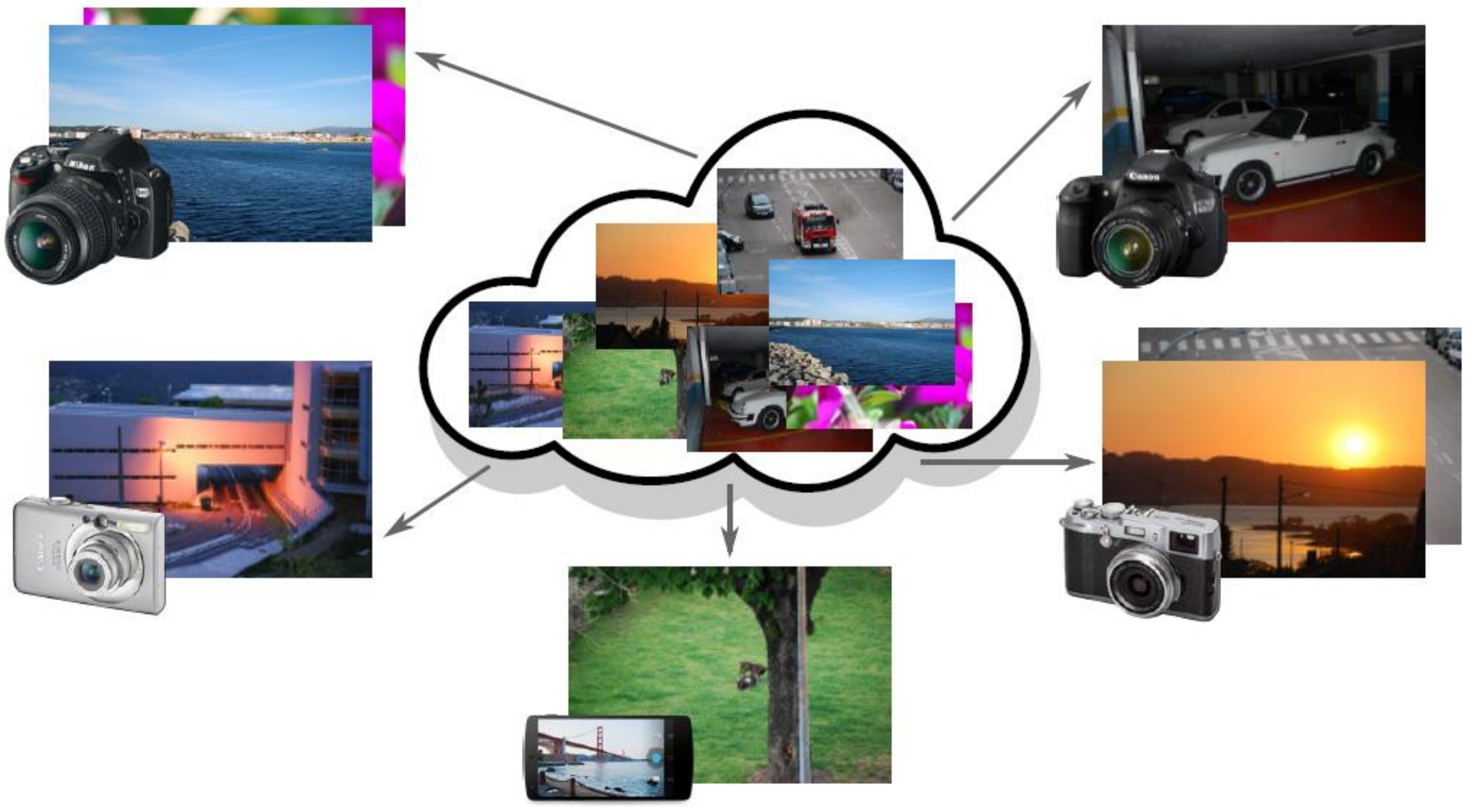


Image clustering according to the PRNU

Using the PRNU, images can be clustered by their source



Statistical approach to camera identification

- Chen et al.'s model

$$\mathbf{y} = g^{\gamma}[(1 + \mathbf{K}') \circ \mathbf{x} + \mathbf{n}']^{\gamma} + \mathbf{q}$$

$\mathbf{y}$: image pixels captured by the camera

g : gain on RGB values to obtain the right white balance

$\mathbf{K}'$: zero-mean PRNU

$\mathbf{n}'$: combination of noise sources, including dark current, shot-noise and read-out

$\mathbf{q}$: quantization noise

$\mathbf{x}$: scene light intensity

γ : gamma correction factor

Statistical approach to camera identification

- After a Taylor series expansion using $(1+x)^{\gamma} = 1+\gamma \cdot x + O(x^2)$

$$\mathbf{y} = \mathbf{x}_0 \circ (1+\mathbf{K}) + \mathbf{n}'$$

$\mathbf{x}_0 = (g\mathbf{x})^{\gamma}$: sensor output in the absence of noise

$\mathbf{K} = \gamma \cdot \mathbf{K}'$

$\mathbf{n}'$: all the noise terms (except PRNU)

- A first step to PRNU extraction is to remove $\mathbf{x}_0$. This is done with some denoising algorithm to obtain $\hat{\mathbf{x}}_0$

$$\mathbf{w} = \mathbf{y} - \hat{\mathbf{x}}_0 = \mathbf{x}_0 \circ \mathbf{K} + (\mathbf{x}_0 - \hat{\mathbf{x}}_0) + \mathbf{n}' = \mathbf{x}_0 \circ \mathbf{K} + \mathbf{n}$$

PRNU estimation

- If we have N images $\mathbf{y}_1, \cdots, \mathbf{y}_N$ known to be taken by a given camera and for every image the samples of the noise are i.i.d. Gaussian and independent of **y**, for every pixel of the ith image

$$\frac{w_i}{x_{0,i}} = K + \frac{n_i}{x_{0,i}}$$

- The log-likelihood can be written as

$$\ell(K) \propto \sum_{i=1}^{N} \frac{(w_i/x_{0,i} - K)^2}{2\sigma_n^2/x_{0,i}^2}$$

- The ML estimate of the PRNU is then

$$\hat{K} = \frac{\sum_{i=1}^{N} w_i x_{0,i}}{\sum_{i=1}^{N} x_{0,i}^2}$$

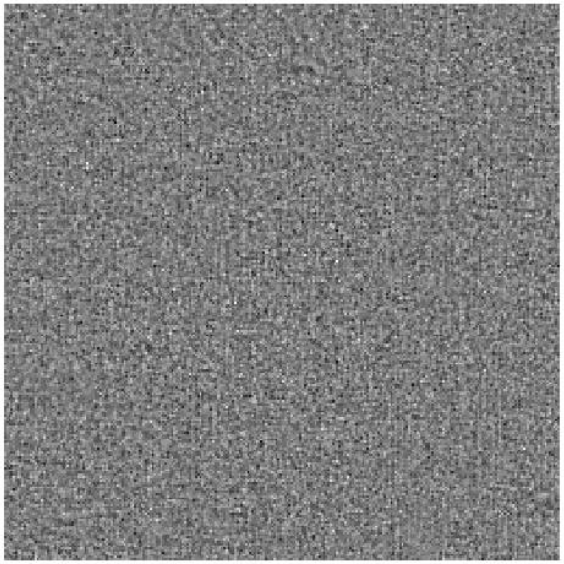
PRNU estimation

- The variance of this estimator is

$$\mathrm{Var}(\hat{K}) = \frac{\sigma_n^2}{\sum_{i=1}^{N} x_{0,i}^2}$$

- The variance decreases roughly as 1/*N* and is smaller when the scene light intensity is higher (but does not saturate).
- Since σ_n^2 contains a contribution from the denoising residue, this will be smaller for flatter images.

PRNU estimation



- Extracted PRNU from 50 images of a Canon D60 camera.

256 x 256 block. Contrast maximized for display purposes.

PRNU-based verification

- Detection problem: given a denoised image $\mathbf{x}_t$, we want to test whether it contains the PRNU $\mathbf{K}_0$ of a given suspicious camera.
- Notice that we don't have $\mathbf{K}_0$ but $\hat{\mathbf{K}}_0$ from the extraction stage.
- Hypothesis test:

$$H_0 : \mathbf{w}_t = \mathbf{K}' \circ \mathbf{x}_t + \mathbf{n}_0$$

$$H_1 : \mathbf{w}_t = \mathbf{K}_0 \circ \mathbf{x}_t + \mathbf{n}_1$$

with $\mathbf{K}'$ the PRNU from another camera. We assume $\mathbf{n}_0$ and $\mathbf{n}_1$ to be i.i.d. Gaussian with variance σ_n^2 .

- The LLRT is then $\|\mathbf{w}_t\|^2 - \|\mathbf{w}_t - \mathbf{K}_0 \circ \mathbf{x}_t\|^2 \underset{H_0}{\overset{H_1}{\gtrless}} \eta \sigma_n^2$

or

$$\langle \mathbf{w}_t, \mathbf{K}_0 \circ \mathbf{x}_t \rangle - \frac{1}{2}\|\mathbf{K}_0 \circ \mathbf{x}_t\|^2 \underset{H_0}{\overset{H_1}{\gtrless}} \eta'$$

Replacing $\mathbf{K}_0$ by its estimate leads to very bad performance because the 2nd term is very sensitive to estimation noise.

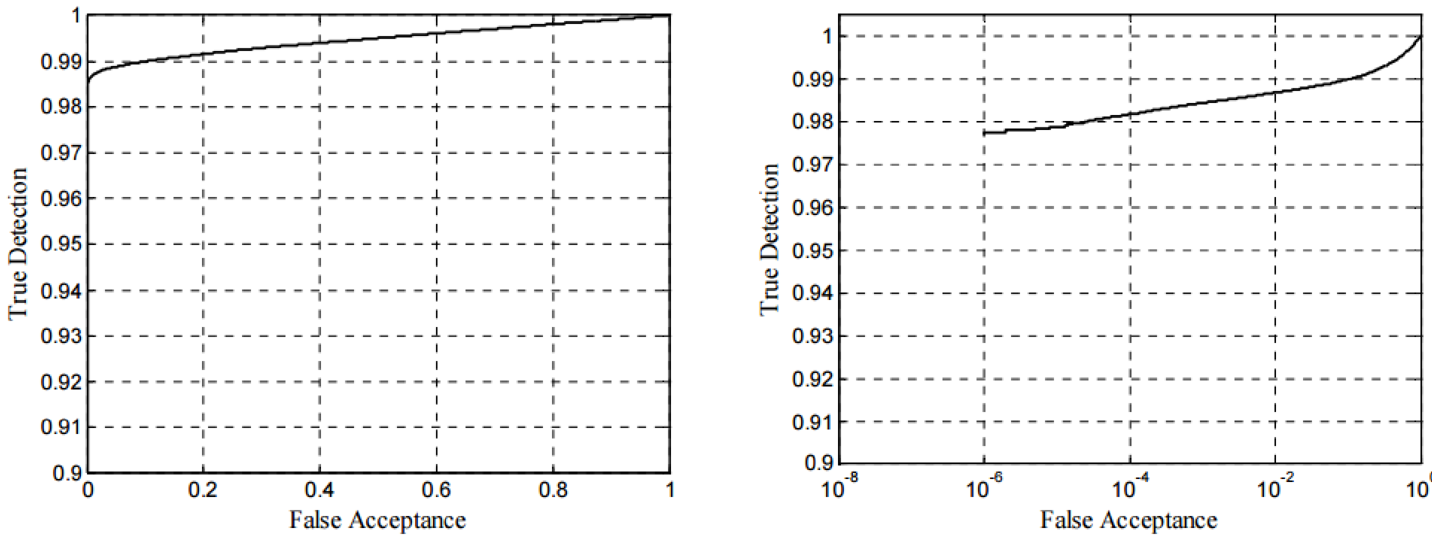
PRNU-based verification

- One can construct a (suboptimal) test using $\langle \mathbf{w}_t, \mathbf{K}_0 \circ \mathbf{x}_t \rangle$
- Under H_0 this statistic has zero mean; under H_1 is $\|\mathbf{K}_0 \circ \mathbf{x}_t\|^2$
- The variance σ_u^2 in both cases can be computed using $\langle \Delta\mathbf{w}_t, \mathbf{K}_0 \circ \mathbf{x}_t \rangle$, with $\Delta\mathbf{w}_t$ a "sufficiently shifted" version of $\mathbf{w}_t$
- Since the mean under H_1 is not accurately computable, we assume that it is unknown but positive. Application of the Karlin-Rubin theorem shows that the optimal detector is

$$\frac{\langle \mathbf{w}_t, \hat{\mathbf{K}}_0 \circ \mathbf{x}_t \rangle}{\hat{\sigma}_u} \gtrless \eta_2$$

- Even though we can compute P_F, we can't estimate P_D because $\|\mathbf{K}_0 \circ \mathbf{x}_t\|^2$ is unknown.

PRNU-based verification



Results from Goljan et al. 2008 on flickr images

- PRNUs estimated from 50 images each. Images are JPEG compressed and with native resolution.
- About 6800 cameras.
- On tests on camera matching with 100,000 images, only 8 could not be matched to the camera.

Concluding reflections

AtlantTIC Research Center for Information & Communication Technologies

Universidade Vigo

GPSC

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Information & Communication Technologies

GPSC

Grupo Procesado de
Señal en Comunicaciones

Thanks!

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