Online Classification of Photo-Realistic Computer Graphics & Photographs – *Lessons Learned*

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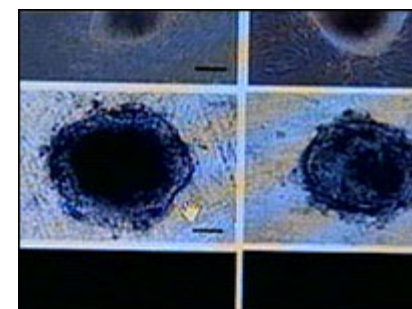# Image/Video Forensics

Seeing is Believing?

London Bombing 05'

Tsunami 05'

Bangkok Coup 06'

Hall of Fame of Image Forgery

Internet

News: LA Times

Scientific Journal

Images from www.camerairaq.com/faked_photos/ and www.worth1000.com

Related Problem: Image/Video Source Identification

- Are multiple videos of the same event captured by the same source?

- Are the visual imageries from real-world events or synthesized by advanced graphics tools?

From same camera?

Two video shots from a CNN new topic

Graphics Or Photo?

Alias 3D design

(Alias fake_or_foto site)

http://www.autodesk.com/eng/etc/fake_or_foto/quiz.html

Google

Fake or Foto?

Page ▾ Tools

Is it **Fake** OR **Foto**?

The Challenge

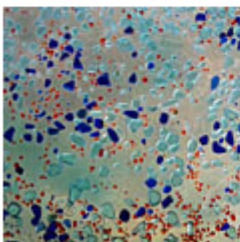Take a look at the ten images below. Some of them are photographs of real objects or scenes, others are created by computer graphics (CG) artists. Test your ability to tell which among the array of images are real, and which are CG. If you want a closer look, click the image to see a larger view of the picture. Once you've decided what's what, click either CG or REAL to begin the tally of your score. Work through each of the ten images. When you've finished, you'll be prompted to get your score.
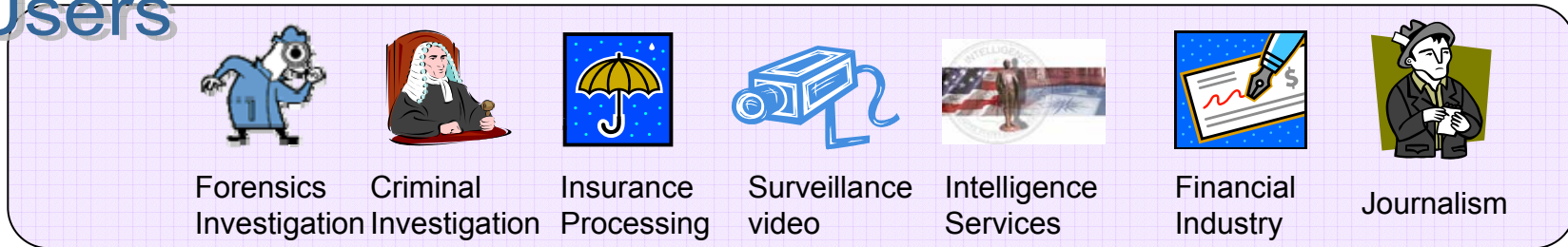
By the way, if you make the correct choice for all ten images, you can go to a bonus round or see the answers--in case it was just luck!

| CG | Real | CG | Real | CG | Real | CG | Real | CG | Real |

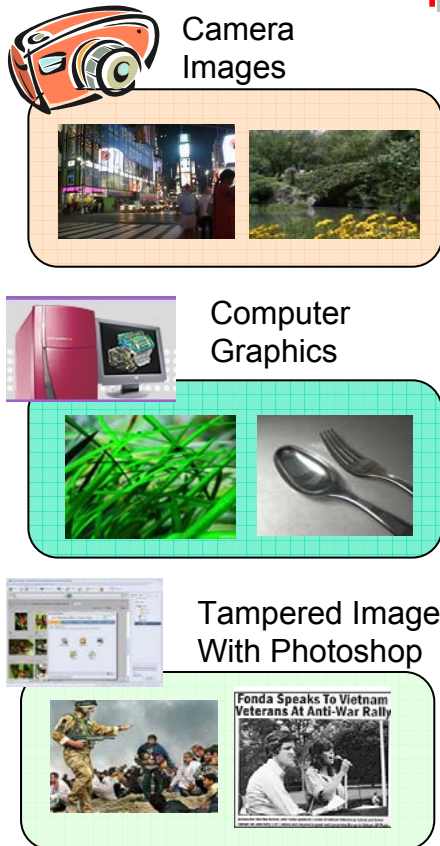| CG | Real | CG | Real | CG | Real | CG | Real | CG | Real |

Show me how many I have correct!

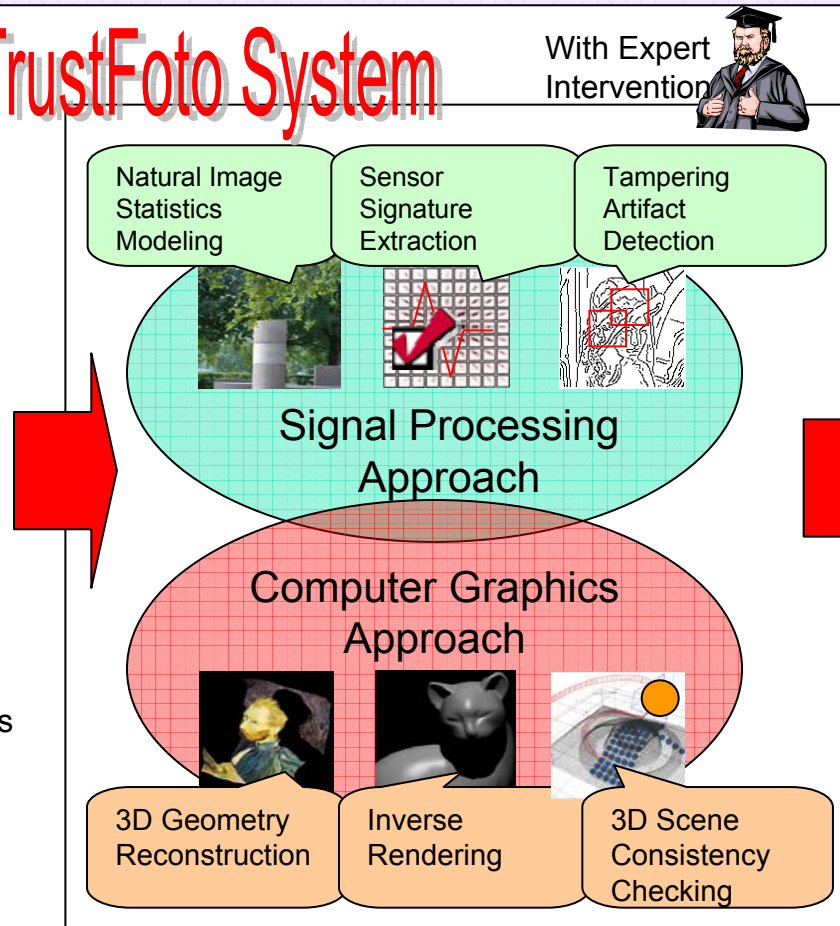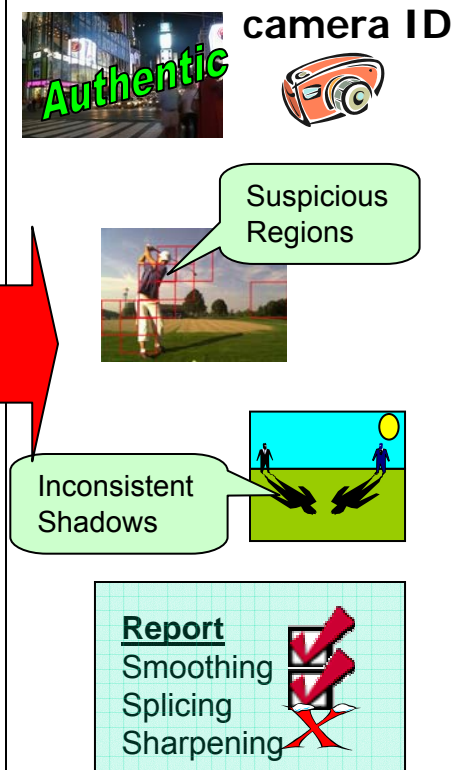# Columbia TrustFoto System (www.ee.columbia.edu/trustfoto)

Users

Forensics Investigation

Criminal Investigation

Insurance Processing

Surveillance video

Intelligence Services

Financial Industry

Journalism

Input Images

Camera Images

Computer Graphics

Tampered Images With Photoshop

TrustFoto System

With Expert Intervention

Natural Image Statistics Modeling

Sensor Signature Extraction

Tampering Artifact Detection

Signal Processing Approach

Computer Graphics Approach

3D Geometry Reconstruction

Inverse Rendering

3D Scene Consistency Checking

Diagnostic Output/ Decision Report

Authentic

camera ID

Suspicious Regions

Inconsistent Shadows

Report
Smoothing
Splicing
Sharpening

Principles:
Joint Physics and Statistics

Image/video Generation Process:

3D Scene

1. Use physics features derived from real-world scenes

Illuminant Source   Scene Object

Reflectance Property   Shadow

Scene Object

Camera Pipeline

Camera

2. Recover camera features from images

| Optical Lowpass | → | Sensor Noise | → | Demosaicing | White Balance | Enhance Operation | Gamma Correction |

Tampered Image

3. Find manipulation artifacts to detect splicing

Cut-and-Paste

Authentic Image

Joint Physics-based & Statistical Method:

Physics-based Approach

+

Statistical Approach

Typical Camera Response Function (CRF)?

Scene radiance

$$R = f(r)$$

Image Irradiance $r(x; y)$

Camera sensor

Typical CRF $f(\cdot)$

Image Intensity $R(x; y)$
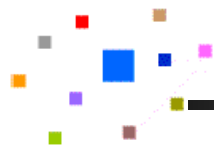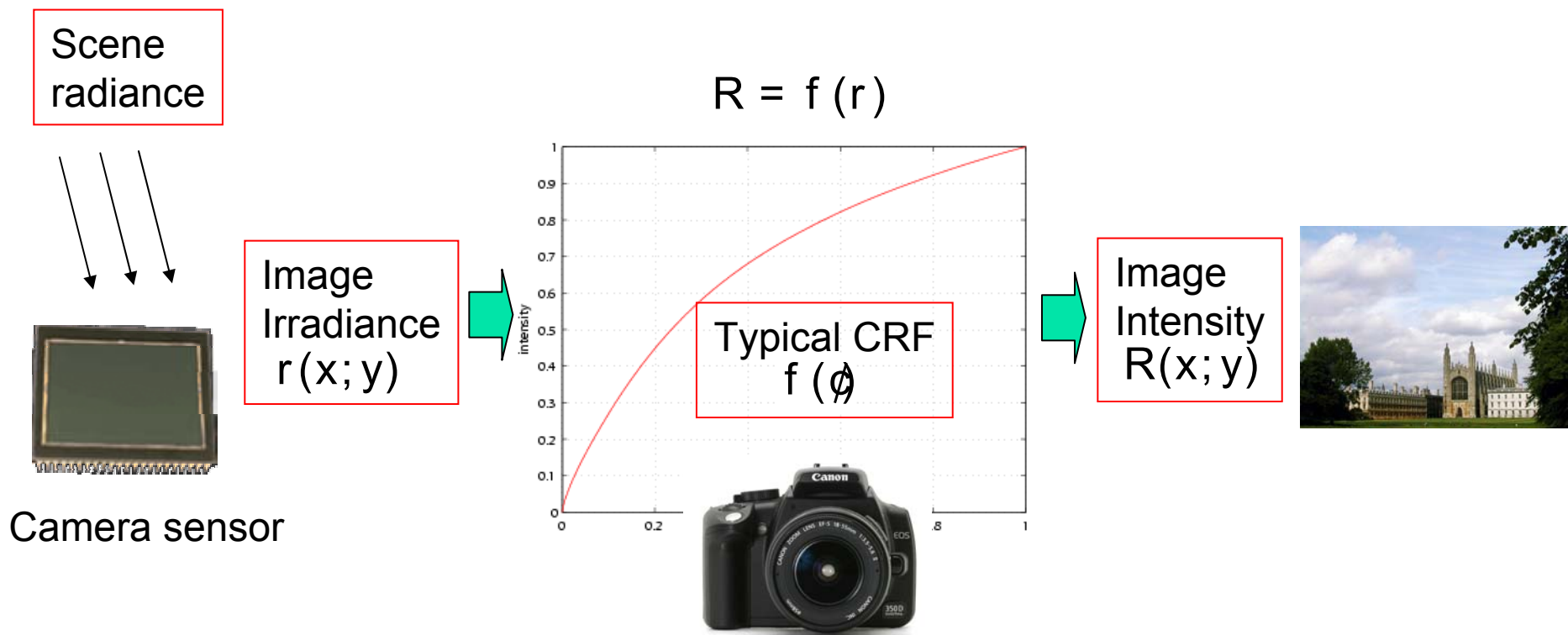
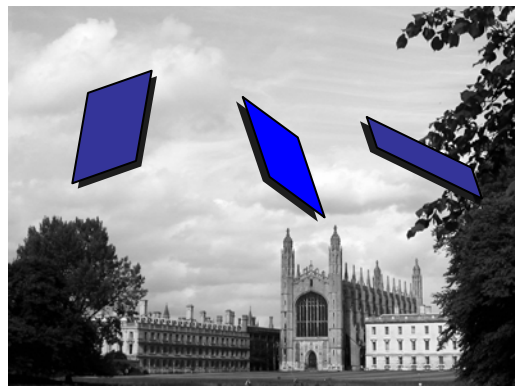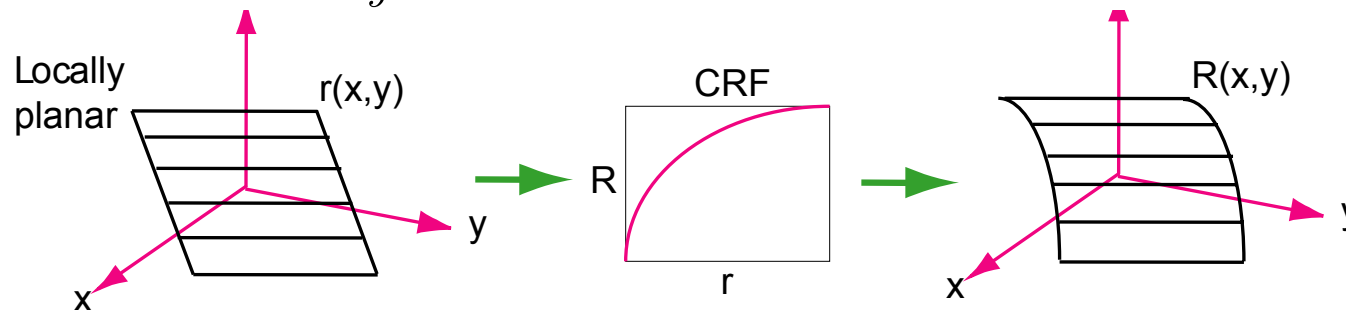# Estimate Camera Response Function (CRF) from a Single Image

- From locally planar regions, derivative ratios contains unique camera (CRF) information
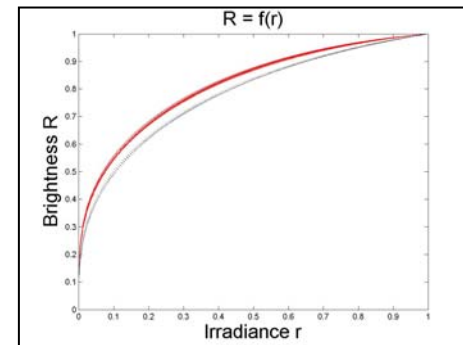
$$\frac{R_{xx}}{R_x^2} = \frac{R_{yy}}{R_y^2} = \frac{R_{xy}}{R_x R_y} = \frac{f''(r)}{f'(r)^2} = \frac{f''(f^{-1}(R))}{(f'(f^{-1}(R)))^2}$$
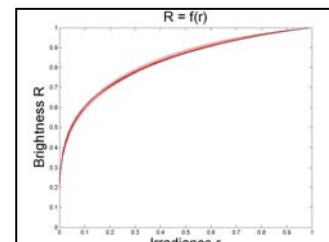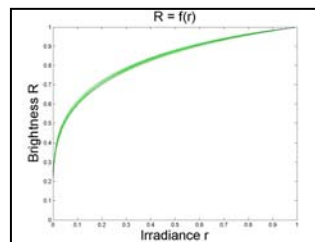

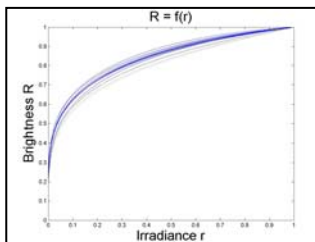Locally planar   r(x,y)   CRF   R(x,y)

R

r

Find the best curve to fit the measured invariant features

Camera Signature (CRF) consistency

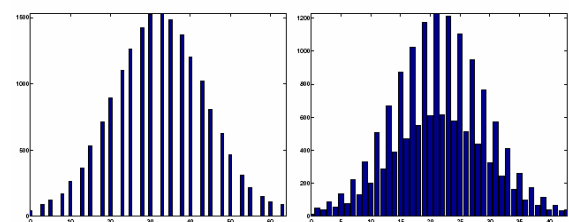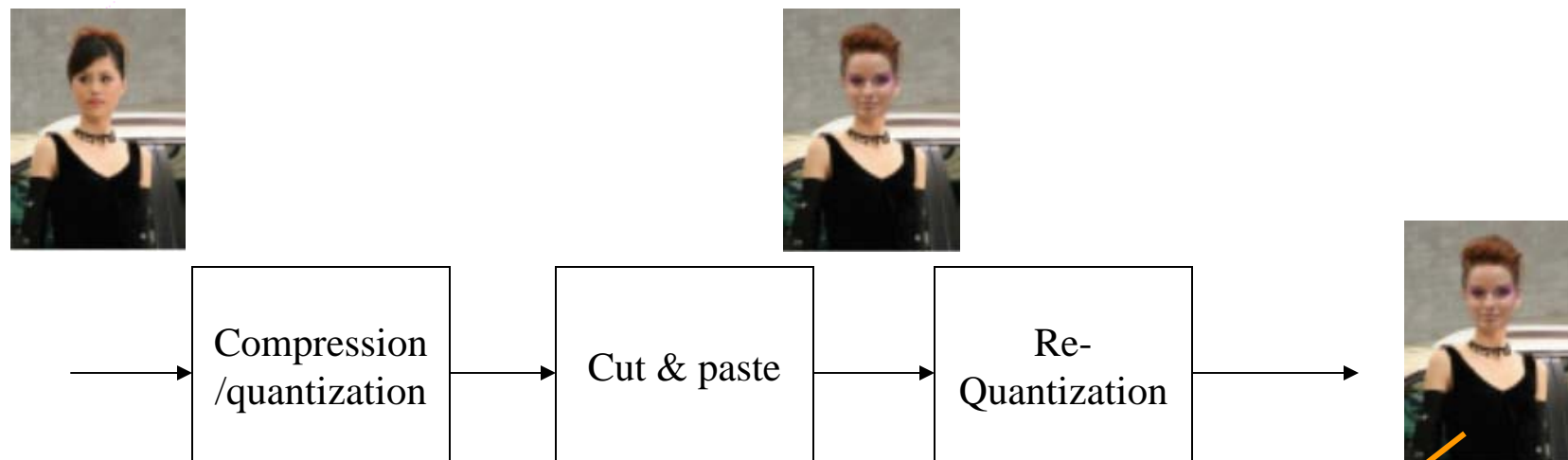- CRF checking in real broadcast videos

Different CRFs

u   ABC

85.9% accuracy over Columbia dataset

Consistent CRFs in all color channels confirms same source

Images from TRECVID data set

Double quantization artifacts from splicing

He, Lin, et al ECCV 06

| Compression /quantization | → | Cut & paste | → | Re-Quantization | → | |

Unique coeff. pattern after double quantization

(c) q1=5, q2=2   (d) q1=2, q2=3

Detecting spliced regions by detecting the unique artifacts

Example results

A Physics-based Approach to Classify Photo vs. CG

[Ng, Chang, Tsui '05]

- Analyze the physical differences between Photo and CG, in terms of the image generative process.

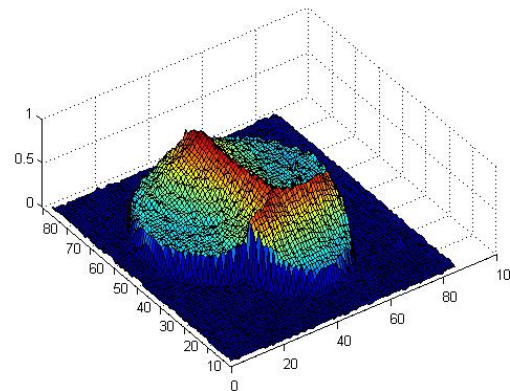- Propose a geometry-based image description framework

Image Surface Geometry

Image Generative Process

- Photographic Images

Light source

(1) Complex surface model
- Subsurface scattering of human skin.
- Color dependency.

(3) Non-linear camera response function
- Not an arbitrary transform.

(2) Complex object geometry
- Human skin texture follows biological system.
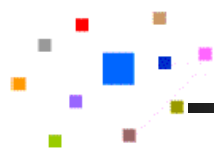- Building surface formed by natural erosion.

Image Generative Process

- Computer Graphics

Differences between Photo and CG

Light source

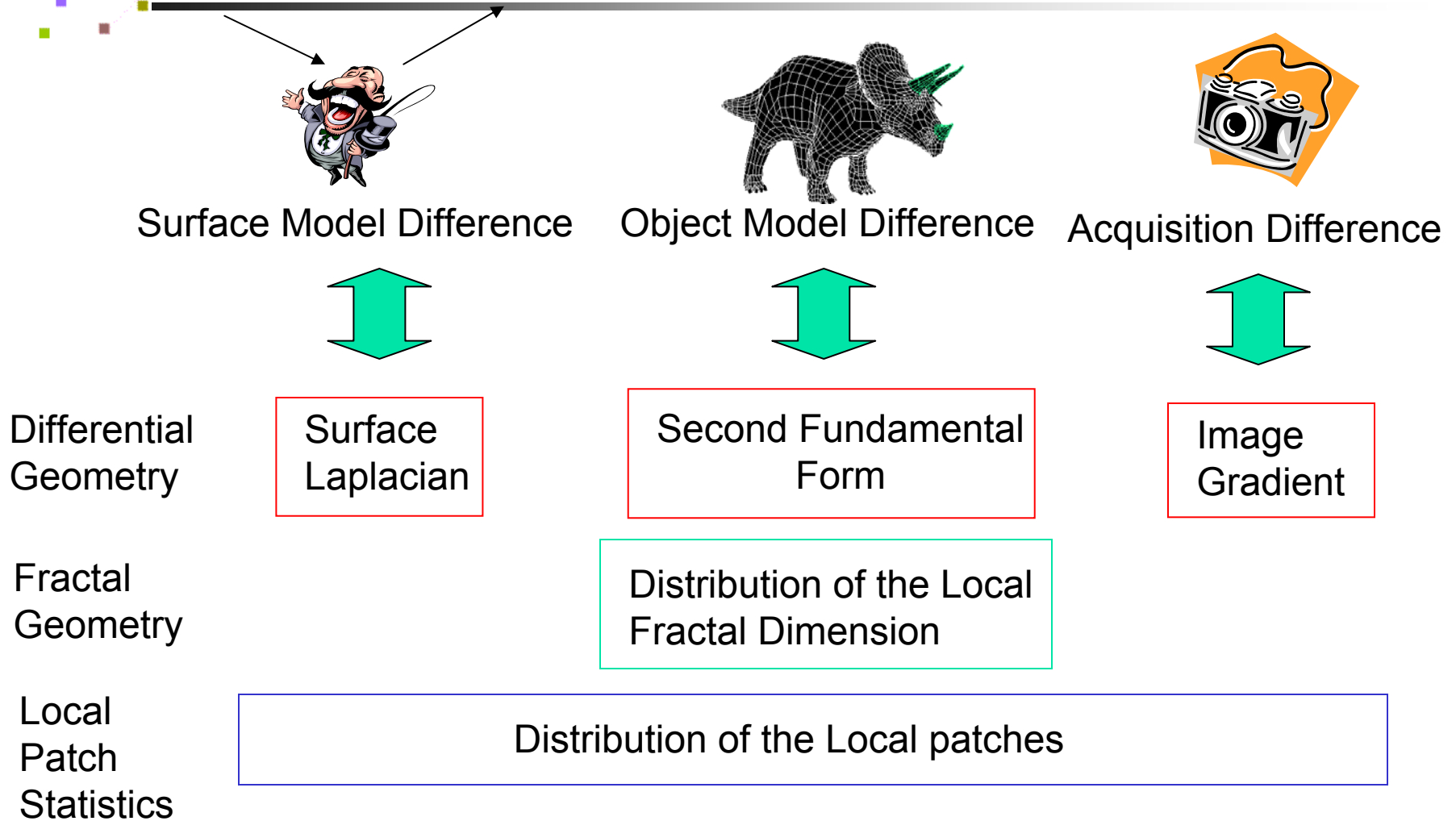**(1) Simplified surface model**
- Assume color independence.
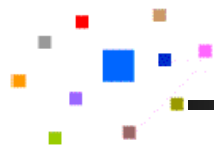
(2) Polygonal object geometry
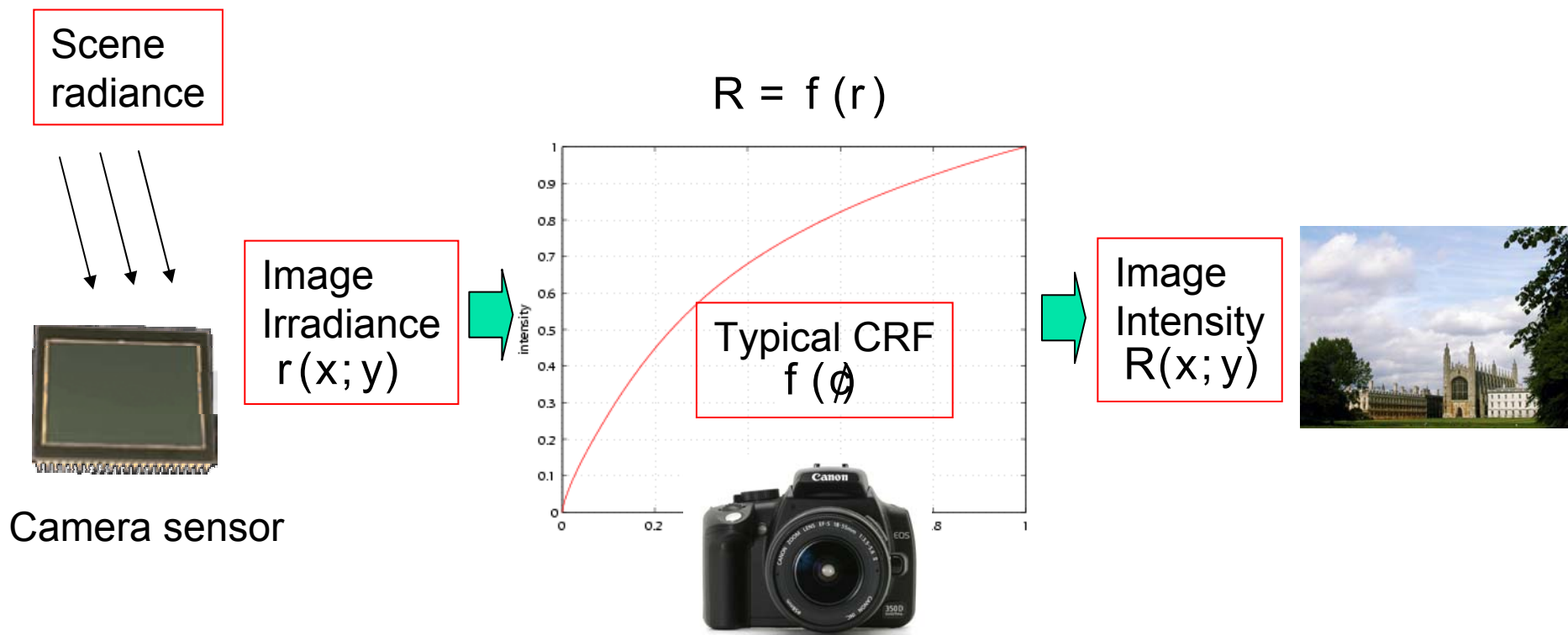- Reduced mesh resolution for computational efficiency.
- Without care, it introduces unnatural structures in rendered images.
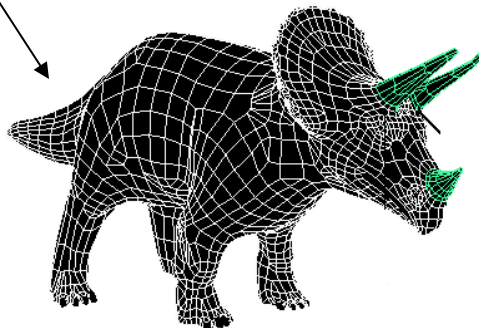
(3) Non-standard Post-processing
- Subject to the artist's taste.
- Different from camera transform.

Post-processing

Feature Correspondences

Surface Model Difference   Object Model Difference   Acquisition Difference

Differential Geometry	Surface Laplacian	Second Fundamental Form	Image Gradient
Fractal Geometry		Distribution of the Local Fractal Dimension	
Local Patch Statistics	Distribution of the Local patches		

Typical Camera Response Function (CRF)?

Scene radiance

$$R = f(r)$$

Camera sensor

Image Irradiance $r(x;y)$

Typical CRF $f(\ )$

Image Intensity $R(x;y)$

Differential Geometry I
Image Gradient

- Non-linear camera transform has effects on image Gradient!

Camera Model

| r |
| image irradiance |

↓

| R=f(r) |
| Camera Transfer Function |

↓

| R |
| image Intensity |
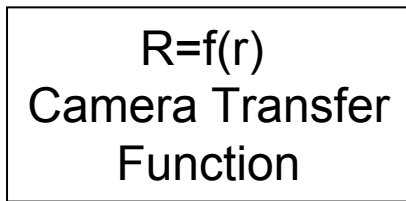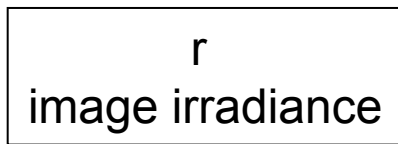
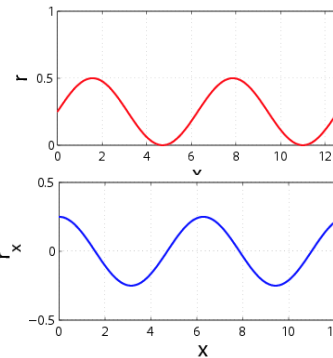**Chain Rule**

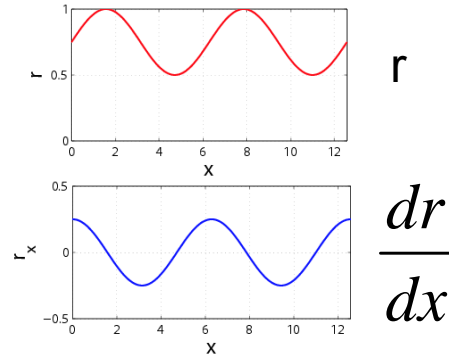$$\frac{dr}{dx}$$

↓

$$\frac{df}{dr}$$
Slope of the curve
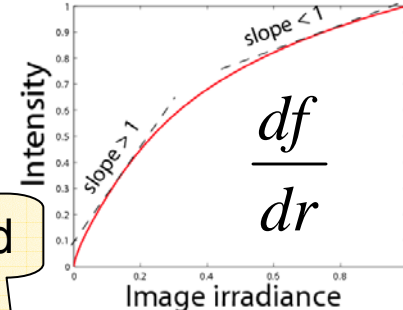
↓

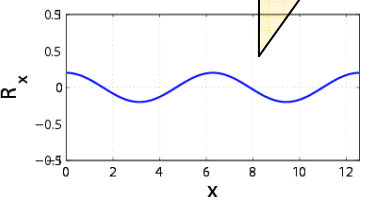$$\frac{dR}{dx} = \frac{df}{dr}\frac{dr}{dx}$$

Low Irradiance   High Irradiance

r

$$\frac{dr}{dx}$$

Typical Camera Transfer Function

slope < 1

slope > 1

Intensity

Image irradiance

$$\frac{df}{dr}$$
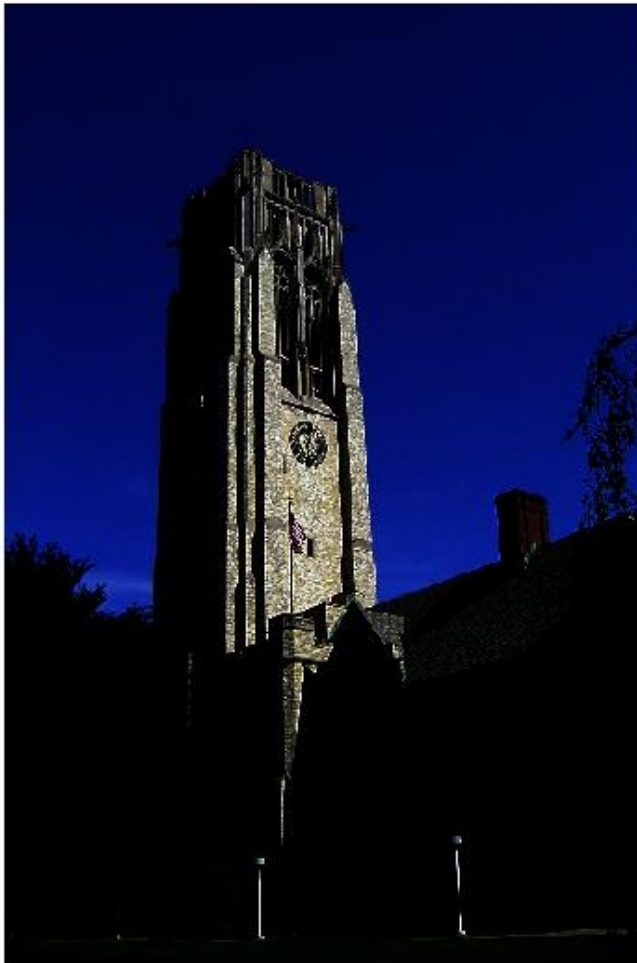
Expand

Compress
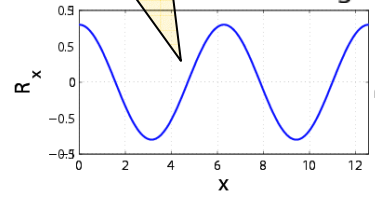
$$\frac{dR}{dx}$$

The Visual Effect of CRF Transform
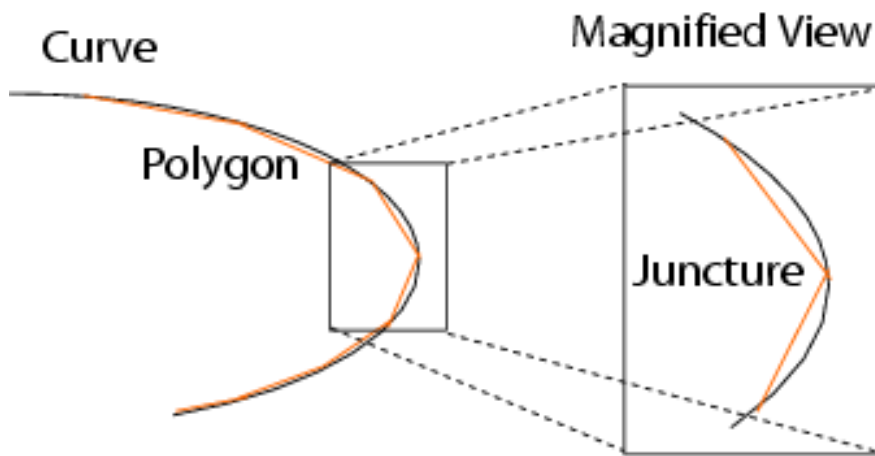
Before CRF Transform

After CRF Transform

Differential Geometry II
Second Fundamental Form

- Polygonal Model leads to unsmooth structures
  - At the junctures, the polygon is always sharper than the smooth curve.

A smooth curve is approximated by a polygon


Unusually sharp transition

Differential Geometry II
Second Fundamental Form

- Locally, any surface can be written as a graph of a differentiable function over the tangent plane.
- The local graph can be approximated by a quadratic function.
  - The Hessian of the quadratic function is the second fundamental form.
  - The Hessian can be characterized by 2 eigenvalues
  - Large eigenvalues implies sharp structures

$$\frac{1}{\sqrt{1+I_x^2+I_y^2}} \begin{pmatrix} I_{xx} & I_{xy} \\ I_{xy} & I_{yy} \end{pmatrix}$$

3D plot of elliptic Quadratic function.
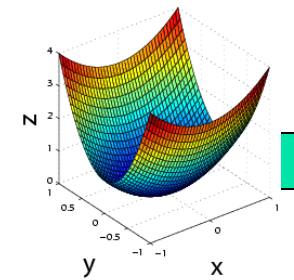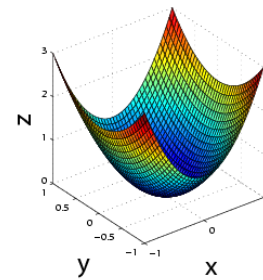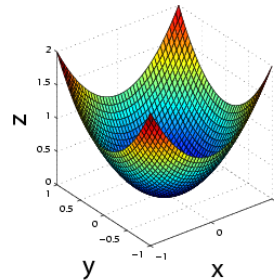
Cross-section of the quadratic function at z=1.
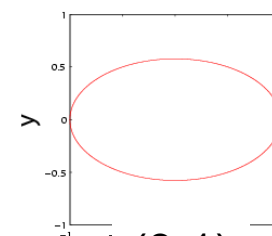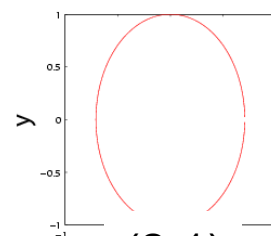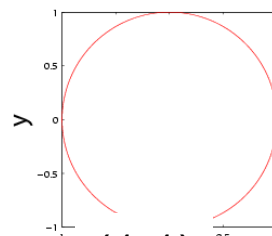
eigenvalues

(1,1)   (2,1)   (3,1)

Differential Geometry III
Surface Laplacian

- Rendering of CG often assumes color independence in the object surface model (generally, not true for real-world object):

  - We capture the difference in the RGB correlation for Photo and CG using the surface Laplacian.

- Laplacian operator (Δ_g) on a graph surface

  - A vector pointing to the direction which decreases the surface area.

  - For a submanifold in the 5D space, it measures the correlation between R, G and B.

(R,G,B)

$(\Delta_g I) = (\Delta_g I_R, \Delta_g I_G, \Delta_g I_B)$

5D Euclidean Space

y

x

Differential Geometry III
Surface Laplacian

Misalignment with 45 deg line

45 deg line

CG
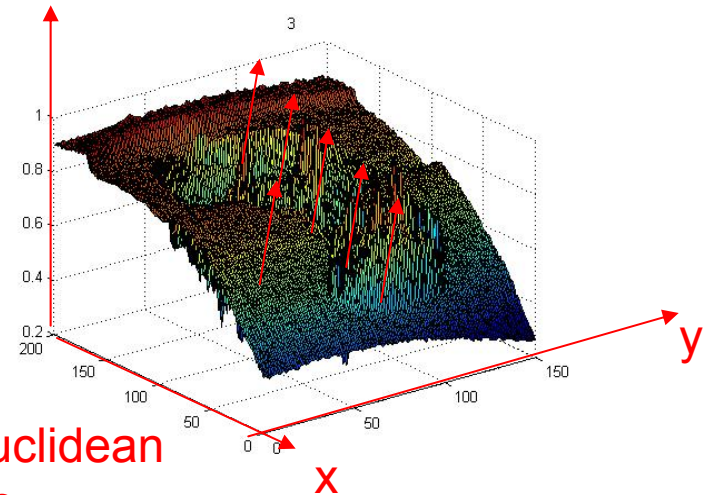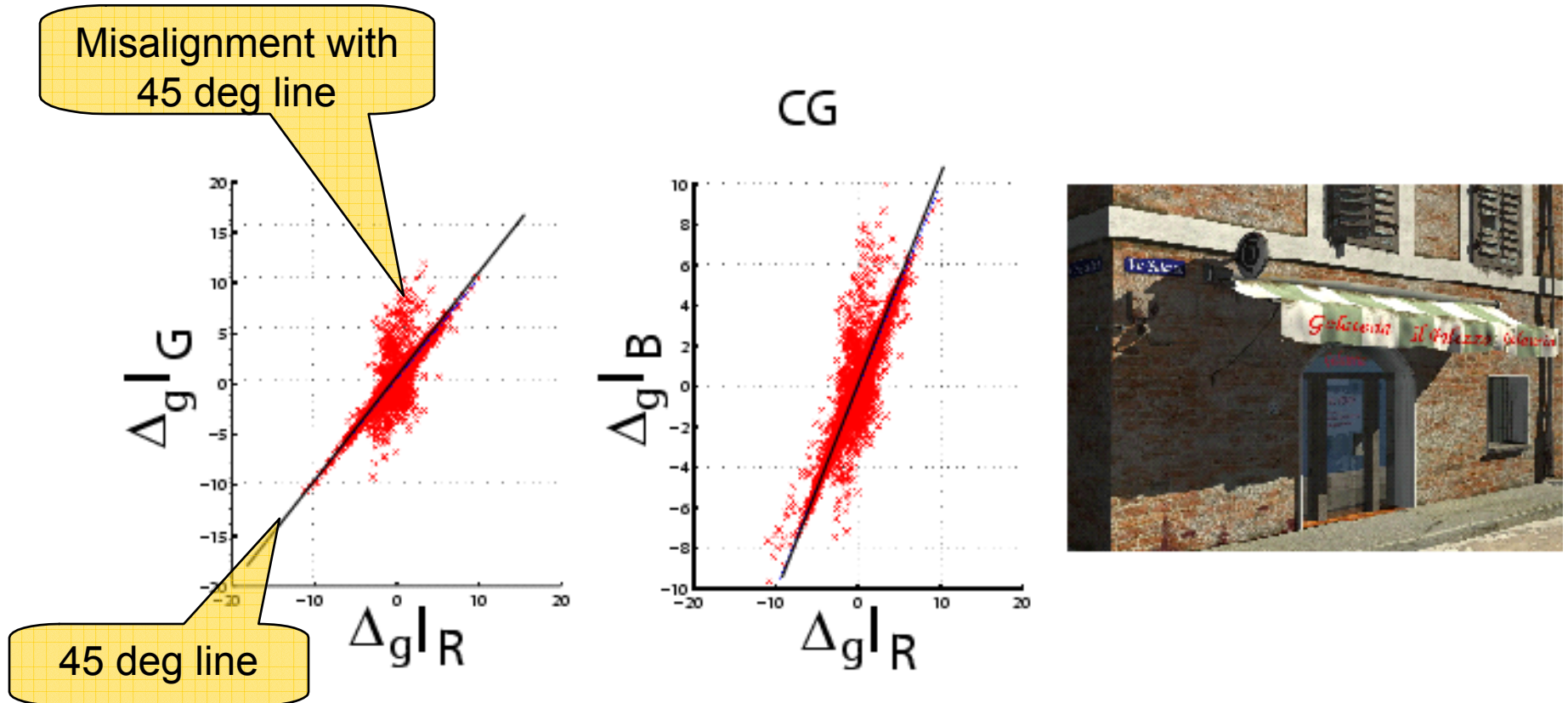
20% of CG has this misalignment, compared to only 5% of Photo.

Local Patch Statistics

- [Lee et al. 2003] 3x3 local patch forms a 2D sub-manifold in the normalized 8D Euclidean space.
- [Rosales et al. 2003] Use local patches to characterize image styles (e.g., Van Gogh Style).

Patch dictionary from a Van Gogh Image.

Input Photo

translation

Van Gogh style Image
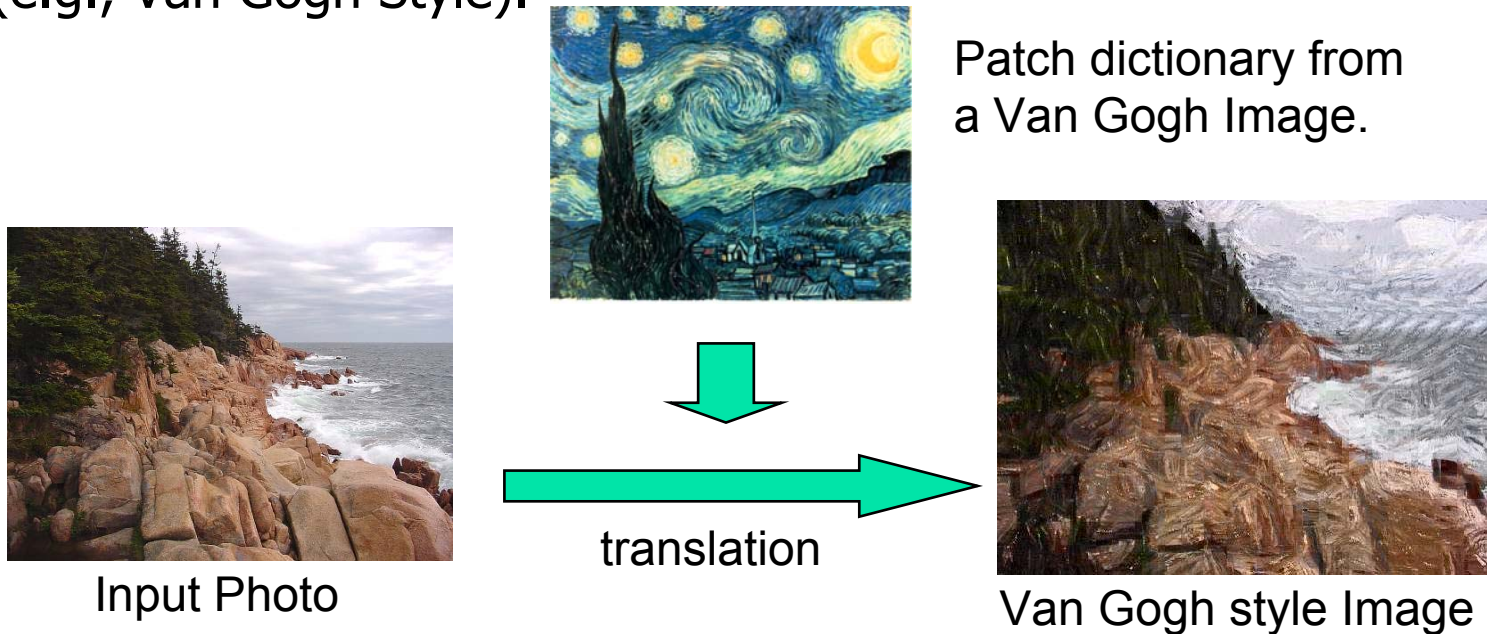
- Photo and CG are just images of different styles!

Fractal Geometry

- Surface property of the real-world objects may be modeled by the fractal geometry.
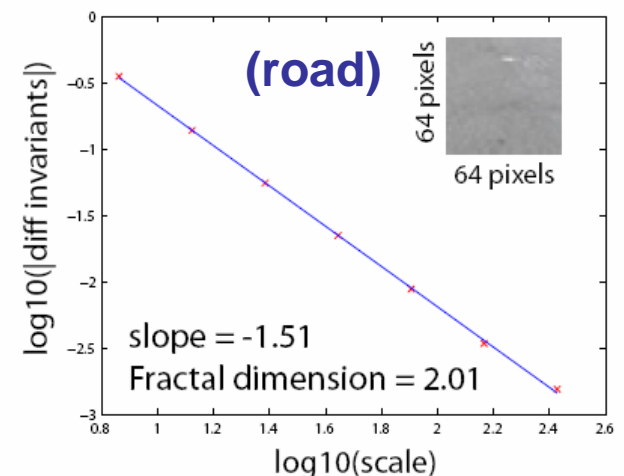
- Fractal dimension measures the factor of self-similarity across scales

- Fractional Brownian Motion model for images:

$$\|I^{(2)}(t)\| = \sum_{\text{all } (x,y)} |I^{(2)}(x,y;t)| \quad \text{where } I^{(2)} = L_{xx}^2 + 2L_{xy}^2 + L_{yy}^2$$

t: scale

Fractal Dim. = 0.5 - slope

The faster the 2nd-order differential decreases, the higher fractal dim is.

(tree)
64 pixels
64 pixels
slope = -1.83
Fractal dimension = 2.33
log10(|diff invariants|)
log10(scale)

(road)
64 pixels
64 pixels
slope = -1.51
Fractal dimension = 2.01
log10(|diff invariants|)
log10(scale)
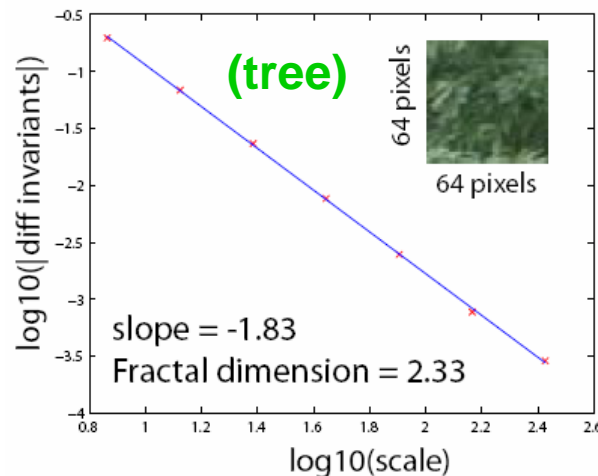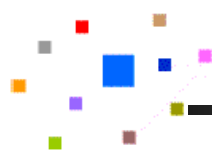
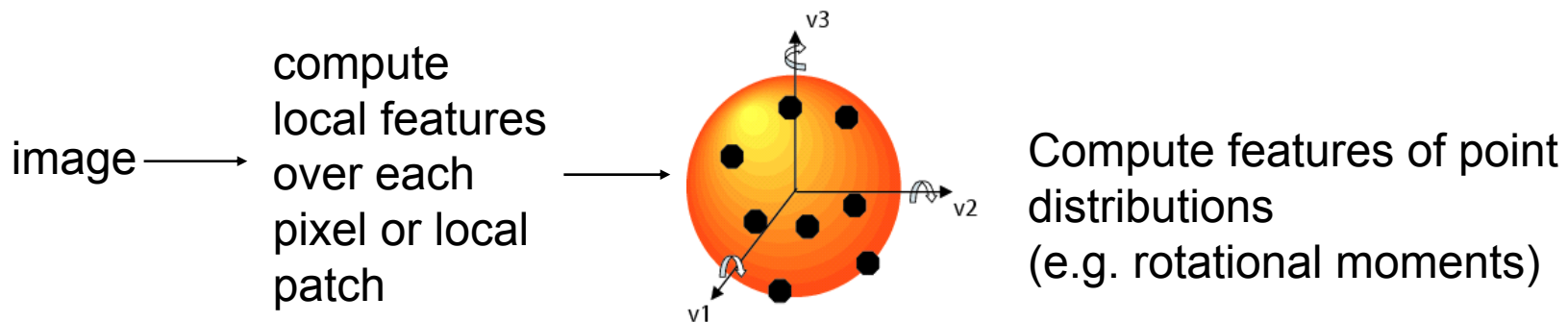# Recap: Physics-based feature pool

Original Image

Scale-space

Fine Scale

Intermediate Scale

- Local Fractal Dimension (13D) **(f)**
- Local Patches Statistics (72D) **(p)**

Differential Geometry
- Surface Gradient (31D) **(g)**
- 2nd Fundamental Form (58D) **(s)**
- Beltrami Flow Vectors (31D) **(b)**

image → compute local features over each pixel or local patch → Compute features of point distributions (e.g. rotational moments)

v3

v2

v1
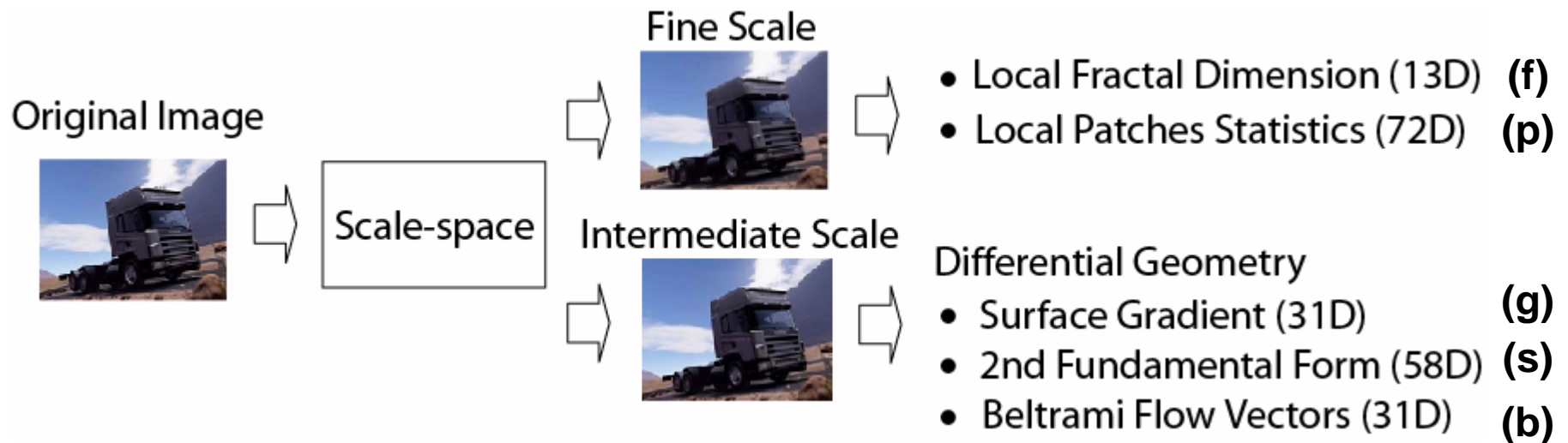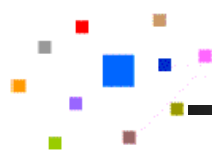
Effectiveness of the features

- Gaussian plots in 2D projection space
- Confirms discriminativeness of the proposed features

Red = Photo
Blue = CG

Gradient

Second Fundamental Form

Surface Laplacian (Beltrami)
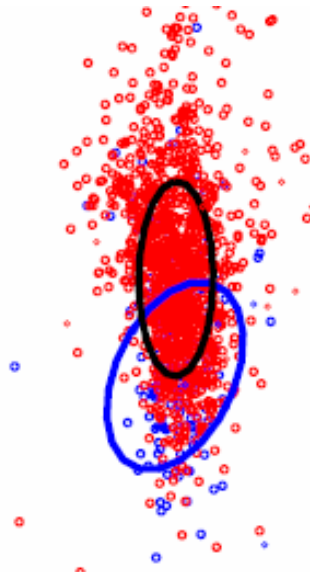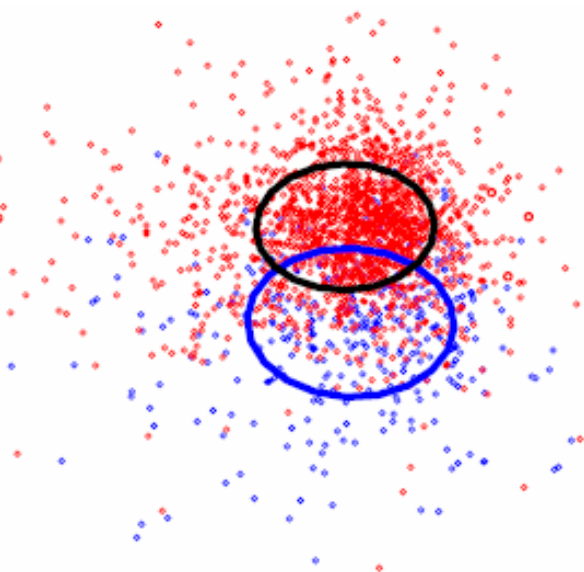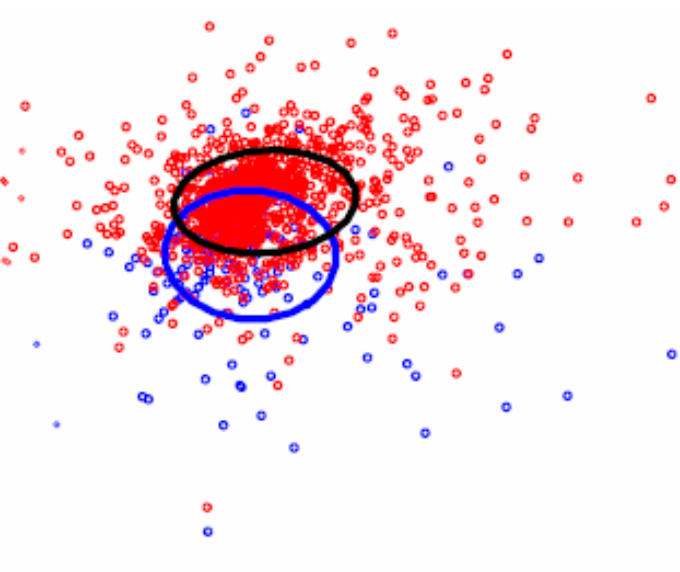
Dataset

Columbia Open Dataset

- First publicly available Photo/CG dataset, downloaded 20+ groups
- Consists of 4 subsets, 800 images for each subset.

From a few personal collections of photo

Personal Photo

Google Photo

Internet CG

Recaptured CG

Downloaded from Google Image Search

Downloaded from the 3D artist websites

Recaptured from a LCD screen by a Canon G3 camera

Available at http://www.ee.columbia.edu/trustfoto

Test Set Covers Diverse Conditions

Architecture (295) Game (41) Nature (181)

Object (220) Life (50) Hybrid (13)

(a) Computer Graphics

Indoor-light (40) Indoor-dark (38) Outdoor-rain (63) Outdoor-night (26)
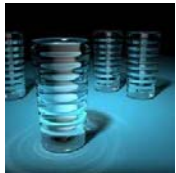
Outdoor-day (76) Outdoor-dusk (29) Natural-obj (62) Artificial-obj (66)

(b) Author's Personal

# Comparison with Other Work in Photo vs. Photorealistic CG Classification

- [Ianeva et al. 03] Classifying **photo and general CG** (including drawing and cartoon).
  - Use simple color distributions, intensity, edge features.

- [Lyu & Farid 05] Classifying **photo and photorealistic CG**.
  - Use image statistics from wavelet coefficients.
  - 67% detection rate (1% false alarm).
  - Lack strong insight into the physical differences between photo and CG.

- [Wang & Moulin 06] Classifying **photo and photorealistic CG**.
  - Based on the marginal distributions of the wavelet coefficients.
  - Capture the difference using characteristic functions of distributions.
  - On a different dataset: 100% detection rate (1% false alarm).
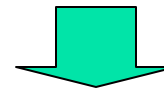
Wavelet Higher-order Statistics Features
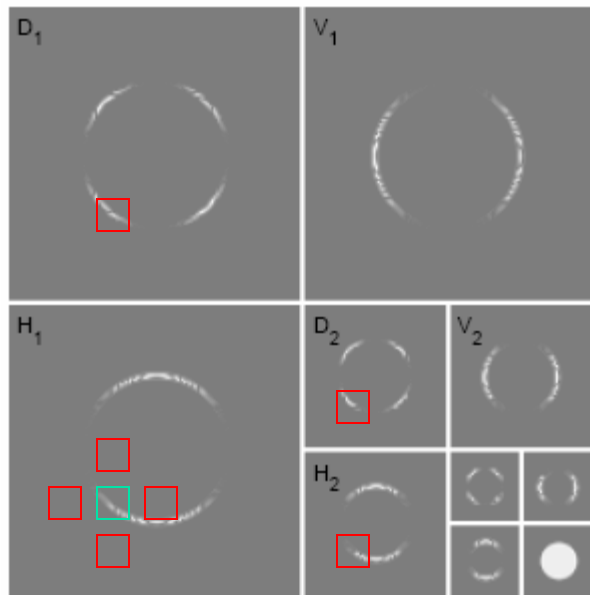
Compute the ***mean, variance, skewness and kurtosis*** of the coefficients for each subband

72 dims

Predict the Green coefficient from Red coefficients, and compute the prediction error.

Compute the ***mean, variance, skewness and kurtosis*** of the prediction errors.

72 dims

Experimental Results I
Support Vector Machine Classification

■ SVM classification with radial basis function (RBF) kernel.

Features	Geometry	Wavelets	Cartoon
Accuracy	83.5%	80.3%	71.0%

Receiver operating characteristic (ROC) curve
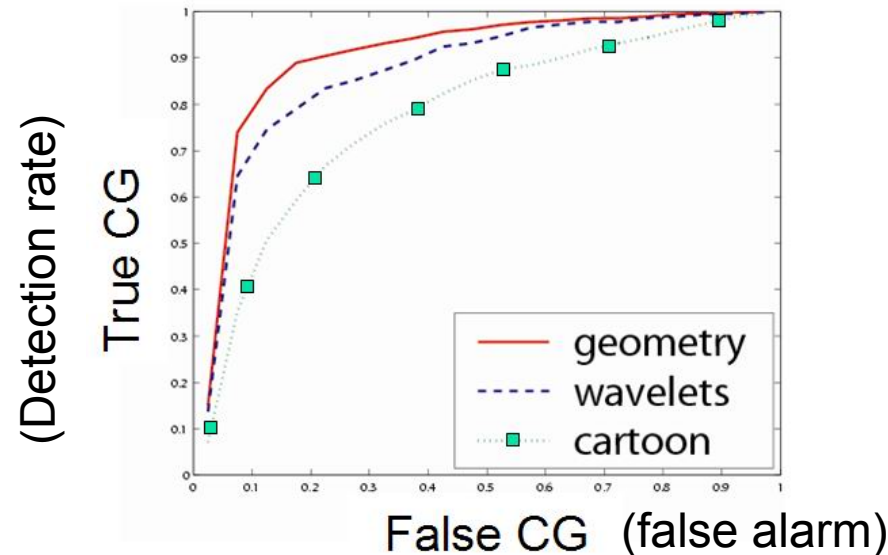
Photo
Vs
Internet CG

The First Online CG-Photo Classification System

URL: http://www.ee.columbia.edu/trustfoto/demo-photovscg.htm

The Results Page

Natural Images vs. Computer Graphics Detection Results - Microsoft Internet Explorer

File   Edit   View   Favorites   Tools   Help

Address   http://apollo.ee.columbia.edu/trustfoto/trustfotoV4/process.cgi   Go   Links

Photographic Image vs. Computer Graphics Detection Results

Format = JPEG
Geometry = 586 x 419
Colorspace = RGB
Type = TrueColor
Depth = 8

Image Information

Detection Results

| Geometry Feature	Computation time = **4.88** seconds Detection Results = **Computer Graphics** It has **0.01** chance to be a photograph
Wavelet Feature	Computation time = **1.71** seconds Detection Results = **Computer Graphics** It has **0.17** chance to be a photograph
Cartoon Feature	Computation time = **0.62** seconds Detection Results = **Computer Graphics** It has **0.01** chance to be a photograph
Wavelet+Geometry+Cartoon Fusion	Computation time = **0.14** seconds Detection Results = **Computer Graphics** It has **0.08** chance to be a photograph

Combined Classifier

Return to the test page

This page is based on a perl-script from PerlScriptsJavaScripts.com

demo
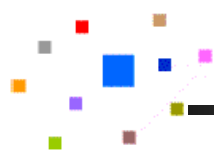
Lessons from Online System

- System launched since Oct 2005
- ~1700 submissions
- Questions
  - User behaviors
  - Types of images submitted
  - Agreement between classifier output and user labels
  - Classifier performance on online images
  - Speed

User Submitted Images are Interesting!

G=cg, W=cg, C=cg, F=cg
http://www.latimes.com/media/
alternatethumbnails/
photo/2006-06/24010006.jpg

G=photo, W=cg, C=cg, F=photo
http://www.iht.com/images/2006/06/
25/web.0626city9ss4.jpg

G=photo, W=photo, C=photo, F=photo
http://www.spiegel.de/img/
0,1020,681928,00.jpg

G=photo, W=photo, C=photo, F=photo
http://www.spiegel.de/img/
0,1020,681938,00.jpg

Interesting cases

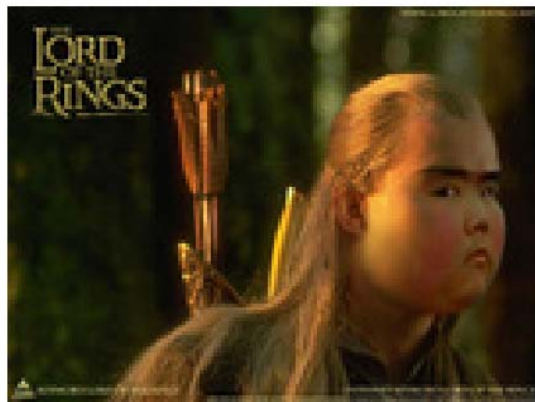

G=cg, W=cg, C=cg, F=cg
http://www.aromatherapycandlesandgifts.com/
gift-baskets/gift-basket-illume-pillar-400.jpg

G=photo, W=photo, C=photo, F=photo
submitted from a local machine

G=cg, W=cg, C=cg, F=cg
http://news.tom.com/img/assets/200311/
031111135215gg111120.jpg
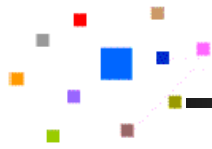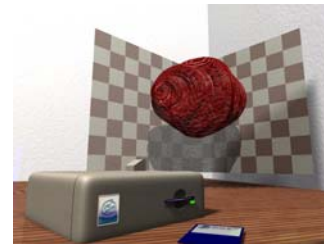
G=photo, W=photo, C=photo, F=photo
submitted from a local machine

Comparisons between Machine & Human Judgments

Human Judgments

CG
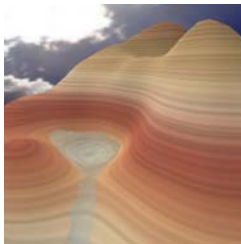
Machine Classification

✓ ✓ ✓ ✓ ✗

Photo

✓ ✓ ✗ ✓ ✓

As one of the application scenarios, the cases with disagreement may be handed to experts for further analysis.

Categorizing User Submitted Images

(a) Photograph (Photo)

(b) Photorealistic CG (PRCG)

(c) Non-photorealistic CG (NPRCG)

(d) Painting or Drawing (Painting)

(e) Hybrid (Hybrid)

(f) Others (Others)

The system also invites users to indicate type of the image submitted.
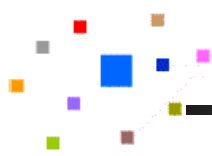
Analysis of user-submitted images(1)

- Majority of image types are unknown!
  - Users are unenthusiastic about labeling -- or
  - Distinguishing high-quality CG images is HARD!

(a) User–specified Image Label Distribution

Label	Percentage
Unknown	79.3%
Other	0.5%
Hybrid	0.9%
Painting	0.7%
NPRCG	0.8%
PRCG	2.6%
Photo	15.3%

Image count
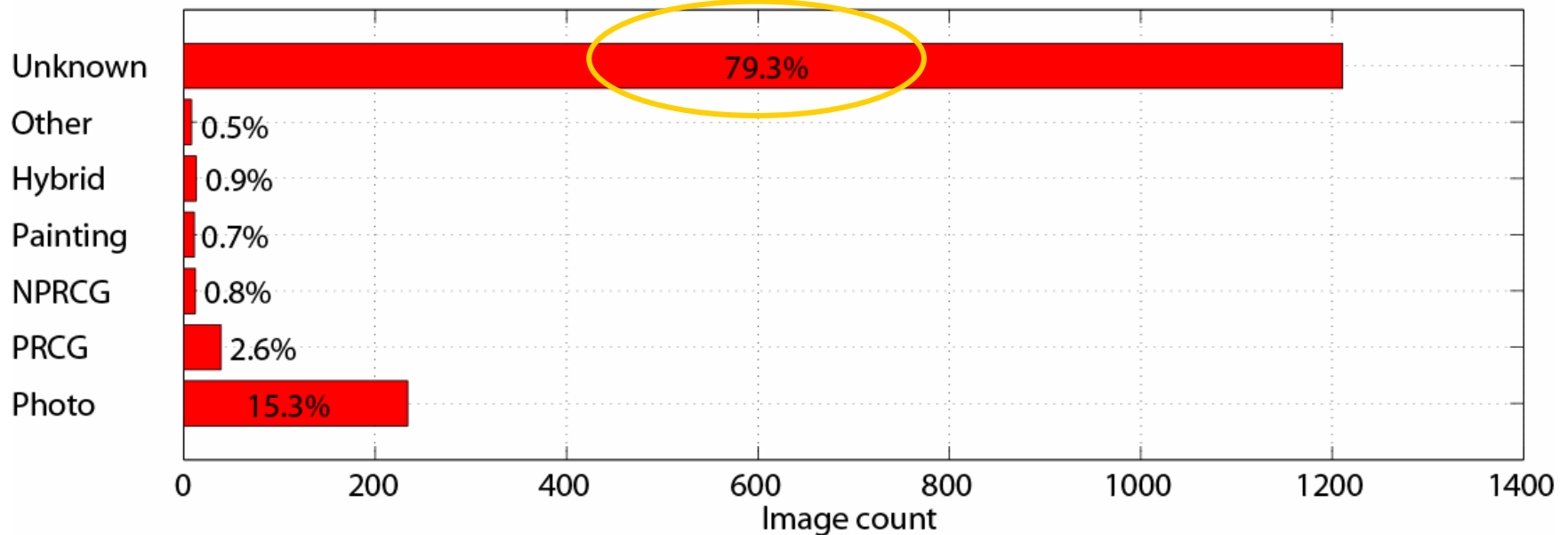
Analysis of user-submitted images(2)

- Users are more "confident" about their own images than those from the Web
  - They provide more labels for their own images
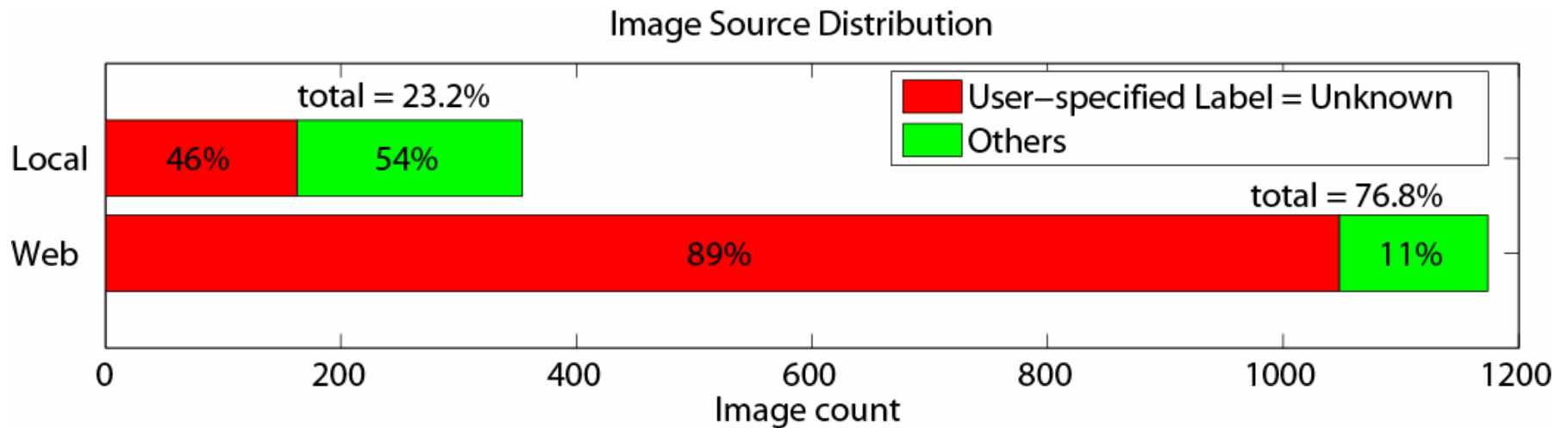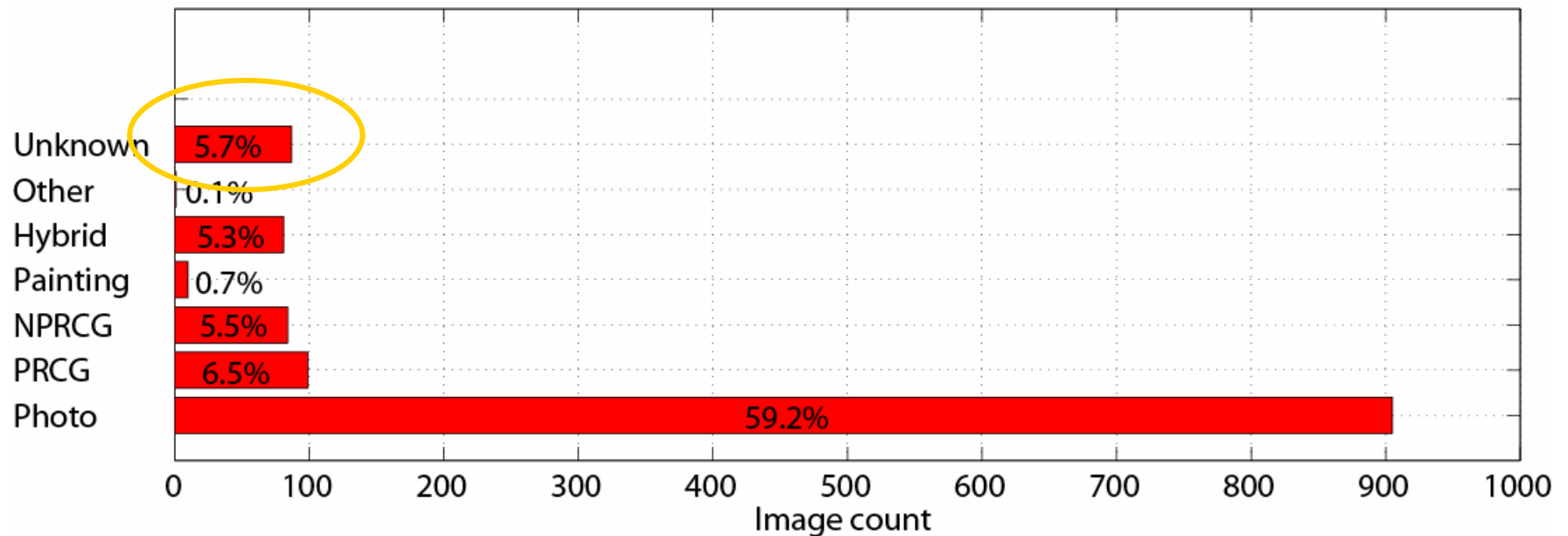
Image Source Distribution

Legend:
- User–specified Label = Unknown (red)
- Others (green)

Local: total = 23.2%, 46% | 54%
Web: total = 76.8%, 89% | 11%

X-axis: Image count (0, 200, 400, 600, 800, 1000, 1200)
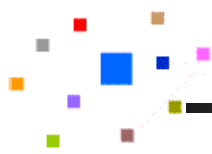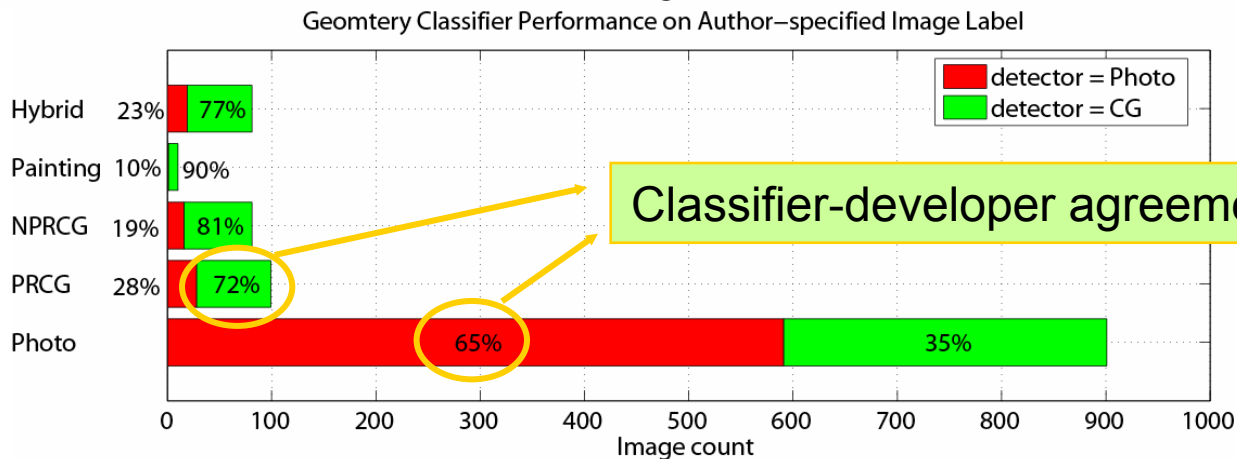
An Attempt of Resolution

- We attempted to resolve the ambiguity…
- Developers of the system may be more familiar with the techniques and definition

(b) Author-specified Image Label Distribution

Label	Percentage
Unknown	5.7%
Other	0.1%
Hybrid	5.3%
Painting	0.7%
NPRCG	5.5%
PRCG	6.5%
Photo	59.2%

Image count

Agreement between classifier-user-developer

- Higher agreement between classifier and developer
  - Familiar with definition and techniques?

Feature selection and speed

Original Image → Scale-space

Fine Scale

Intermediate Scale
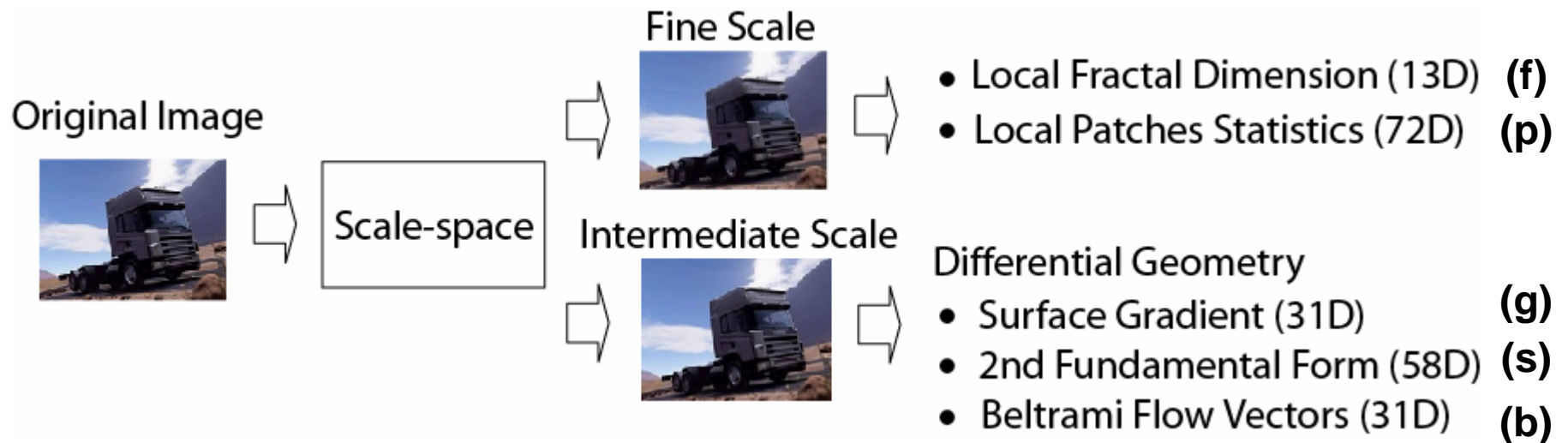
- Local Fractal Dimension (13D) **(f)**
- Local Patches Statistics (72D) **(p)**

Differential Geometry
- Surface Gradient (31D) **(g)**
- 2nd Fundamental Form (58D) **(s)**
- Beltrami Flow Vectors (31D) **(b)**
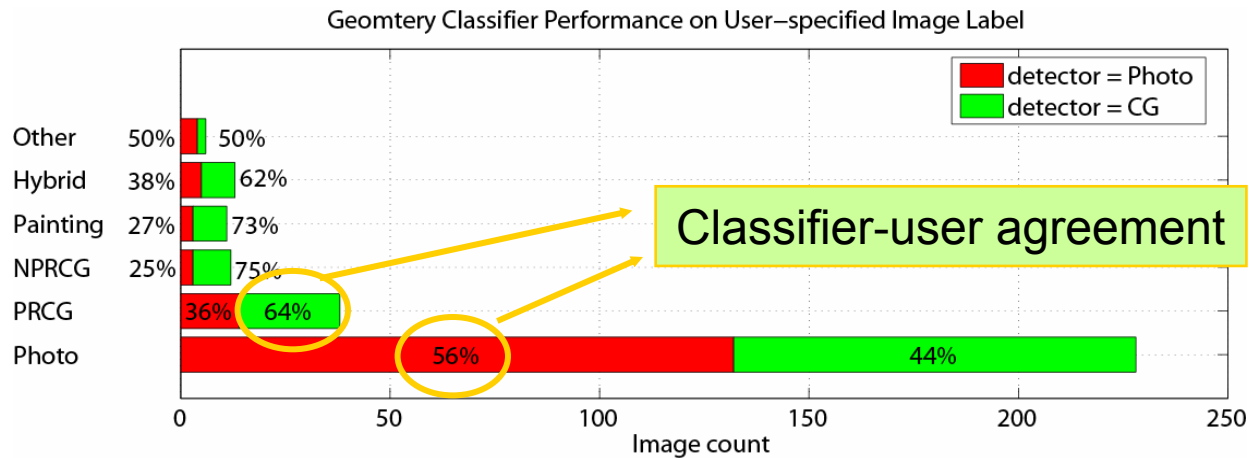
- Feature Contribution to Classification performance
  - 2nd fundamental form > local patch > gradient > Beltrami > fractal
- > 80% feature extraction time is used for fractal dimension
- Feature trimming→ 6+ times speedup without hurting accuracy
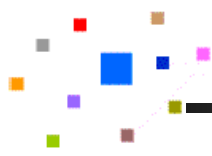
Feature selection and speedup

- Classification performance
  - 2nd fundamental form > local patch > gradient > Beltrami > fractal

(a) Without Local Fractal Demension Feature

(b) With Local Fractal Demension Feature
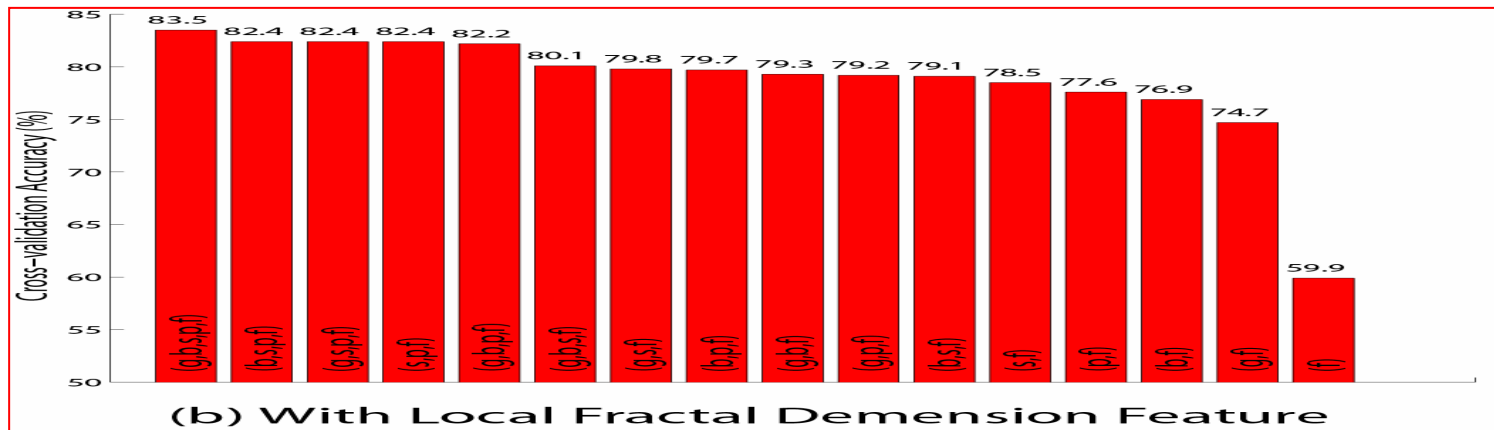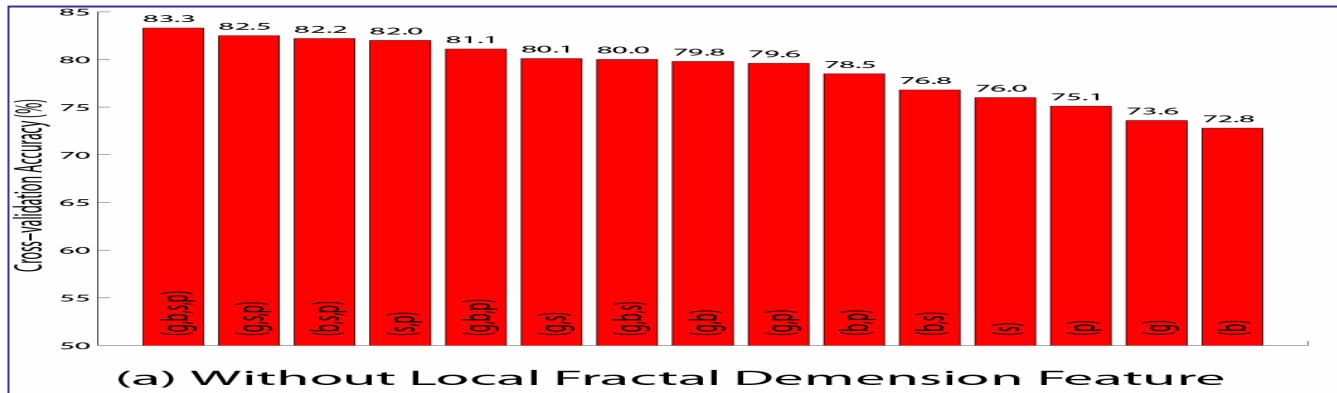
Next Step

- Online Incremental Learning
  - Improve system performance based on user input
- Conduct tests with real forensics domain scenarios and experts
- Extend to videos and temporal dimension

Remaining Issues

- Distinguishing Photo and CG at the level of the local region.
  - Hybrid content of photo and CG
  - Synthesized content from texture mapping, image based rendering etc
- Designing counter-measure for the Oracle attack.
  - When the attackers have access to the detector, they can modify an image until they obtains the desired output from the detector!
- Future Photography – what's real?
  - More challenging by new generations of cameras
  - Computational photography

More Information

- Columbia TrustFoto project
- http://www.ee.columbia.edu/trustfoto