Physics-Motivated Features for Distinguishing Photographic Images and Computer Graphics

Tian-Tsong Ng, Shih-Fu Chang
Jessie Hsu, Lexing Xie
Department of Electrical Engineering
Columbia University, New York, USA

Mao-Pei Tsui
Department of Mathematics
University of Toledo, Ohio, USA

Columbia University in the City of New York

dvmm DIGITAL VIDEO • MULTIMEDIA LAB

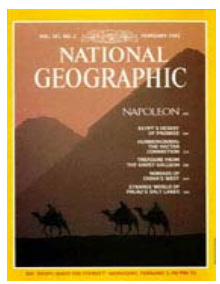
Background
Passive-blind Image Forensics

- Finding out the condition of an image without any prior information.
- Two main functions:
  - Image Forgery Detection
    - [Ng et al. 04] Photomontage Detection.
  - Image Source Identification
    - Photo vs. CG

Image Forgery Hall of Fame

LA Times ‘03

Internet ‘04



Nat. Geo. ‘92

Times ‘96

CG Or Photo?

Prior Work
Photo vs. CG

- [Ianeva et al. 03] Classifying photo and general CG (including drawing and cartoon).
  - For the purpose of improving video key-frame retrieval.
- [Lyu & Farid 05] Classifying photo and photorealistic CG.
  - Using wavelet statistics.
  - 67% detection rate (1% false alarm).
  - provides little insight into the physical differences between photo and CG.

Our Contributions

- A geometry-based image description framework
  - Motivated by the physical differences between Photo and CG.
- A two-level definition of image authenticity
  - Provides a systematic formulation and evaluation of an image forensics method.
- An effective classification model
  - Outperforms the methods in prior work.
- An open dataset
  - Avoids repeated data collection effort.
  - As a benchmark dataset.
- An online evaluation system.
  - Allows users to test the system.

Main Idea I
Definition of Image Authenticity

- Camera authenticity
  - Based on the characteristics of the camera.
  - **Local effect**: optical low-pass, color filter array interpolation, CCD sensor noise, white-balancing and non-linear gamma correction.
  - **Global effect**: lens distortion
- Scene authenticity
  - Based on the physics of light transport in the natural scenes.
  - **Global effect**: the orientation of a shadow is related to the lighting direction.
  - **Local effect**: real-world objects have complex reflectance model.

Computer Graphics

May be scene-authentic but not camera-authentic

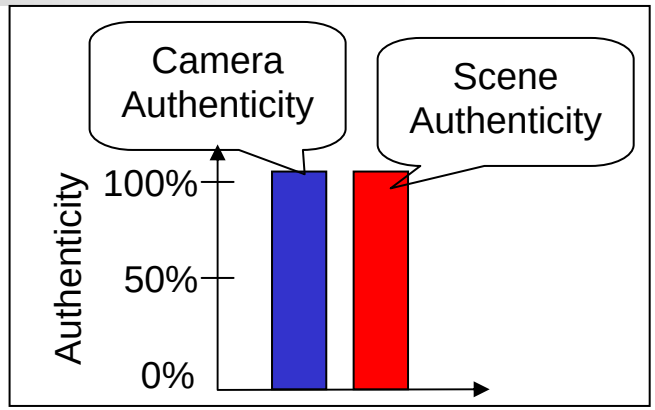
Photomontage

May be camera-authentic but not scene-authentic

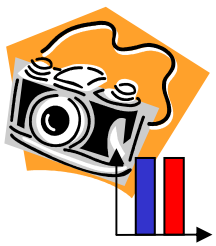
Main Idea I

Image Authenticity Life Cycle

KEY



Photo



Photomontage

Image-based Rendering

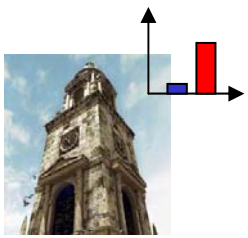
Excessive Post-processing

Normal Post-processing

Transmission

Reconstruction

Combination



CG

Post-processing

Transmission

Reconstruction

Recapturing

Main Idea II
Image Generative Process

- Photographic Images

Light source

(1) Complex surface model

- Subsurface scattering of human skin.
- Color dependency.

(2) Complex object geometry

- Human skin texture follows biological system.
- Building surface formed by air erosion.

(3) Non-linear camera Transfer function

- Not an arbitrary transform.

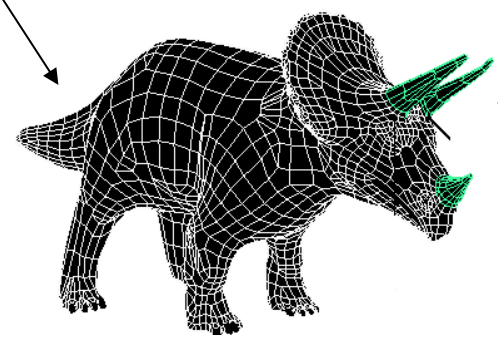
Main Idea II
Image Generative Process

- Computer Graphics

3 Differences for Photo and CG
(1) Surface Model Difference.
(2) Object Model Difference.
(3) Acquisition Difference.

Light source

(1) Simplified surface model
- Assume color independence.



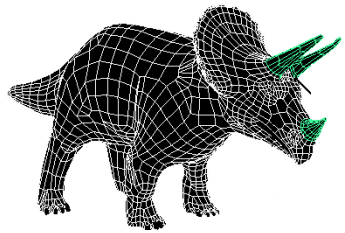
(3) Non-standard Post-processing
- Subject to the artist's taste.
- May different from camera transform.

Post-processing

(2) Polygonal object geometry
- Reduced mesh resolution for computational efficiency.
- Without care, it introduces sharp structures in rendered images.

Main Idea III

Feature Correspondences



Acquisition Difference

Object Model Difference

Surface Model Difference

Differential Geometry	Image Gradient	Quadratic Form	Surface Laplacian
Fractal Geometry		Distribution of the Local Fractal Dimension	
Local Patch Statistics	Distribution of the 3x3-pixels Local patches		

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!

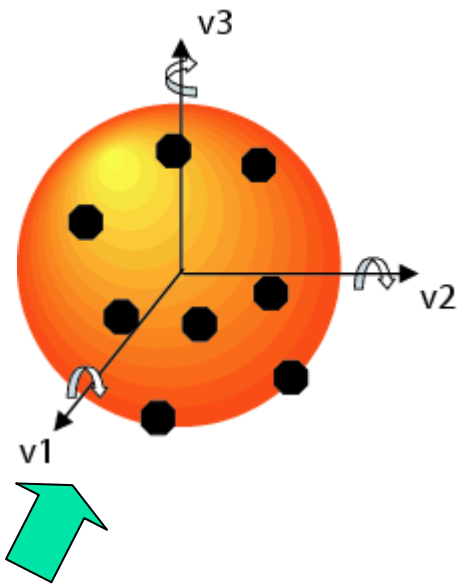
Local Patch Statistics

- We sample 4 types of patches.

Extract 4 types of patches

High Contrast Low Contrast	X	Grayscale Color

Patches projected to a 7-sphere In R^8



Extract the rotational moment features from the distribution, as if the data points are the point masses of a rigid body.

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

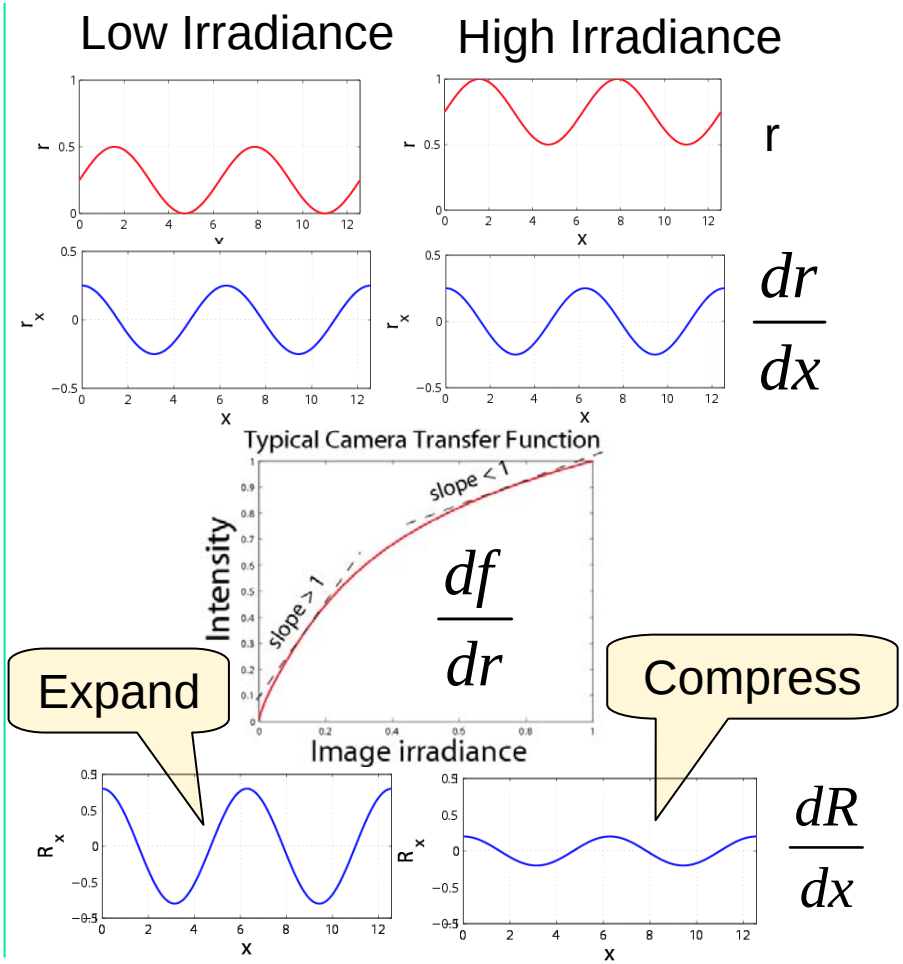
R
image Intensity

Chain Rule

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

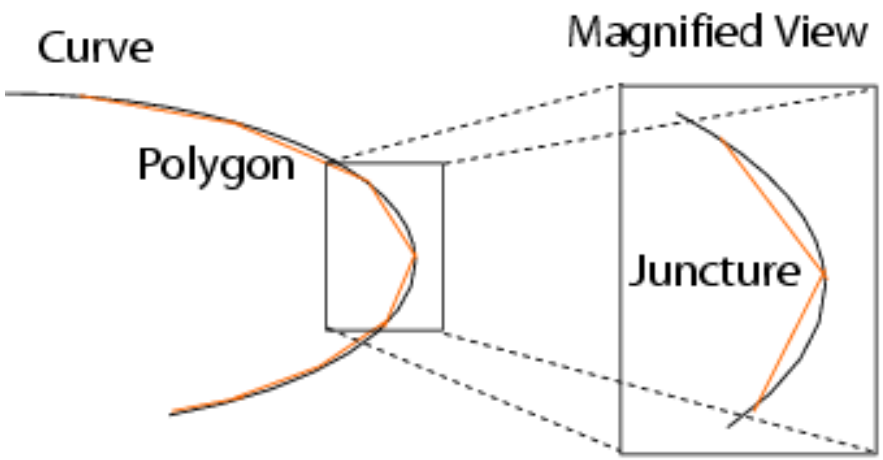
$$\frac{df}{dr}$$
Slope of the curve

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



Differential Geometry II
Quadratic Form

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



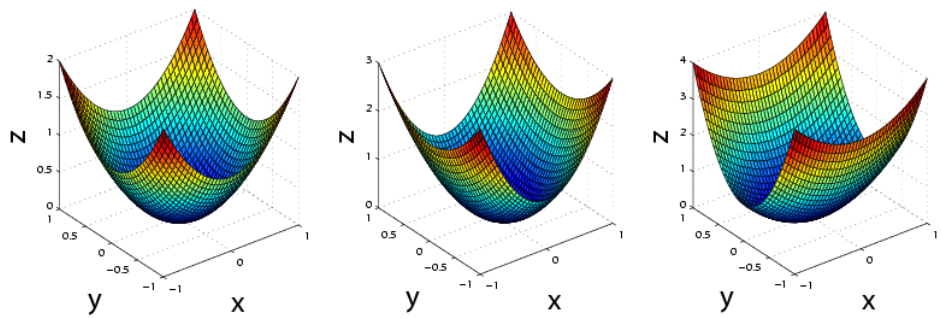
A smooth is approximated by a polygon

Unusually sharp transition

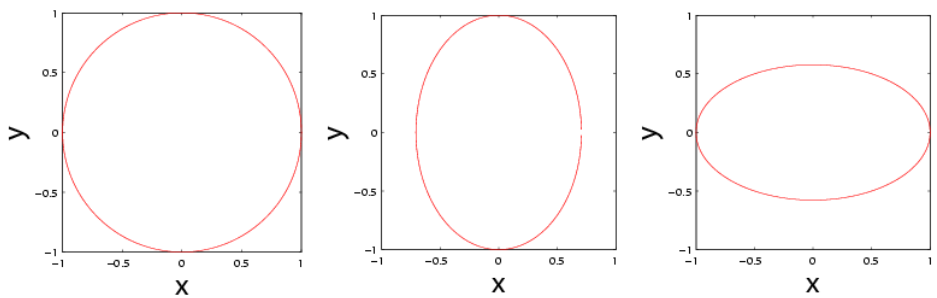
Differential Geometry II
Quadratic Form

- A graph submanifold can be locally approximated by a quadratic form.
  - Quadratic form can be characterized by 2 eigenvalues
  - The large eigenvalue implies sharp structures

3D plot of elliptic Quadratic form.



Cross-section of the quadratic form at z=1.



eigenvalues

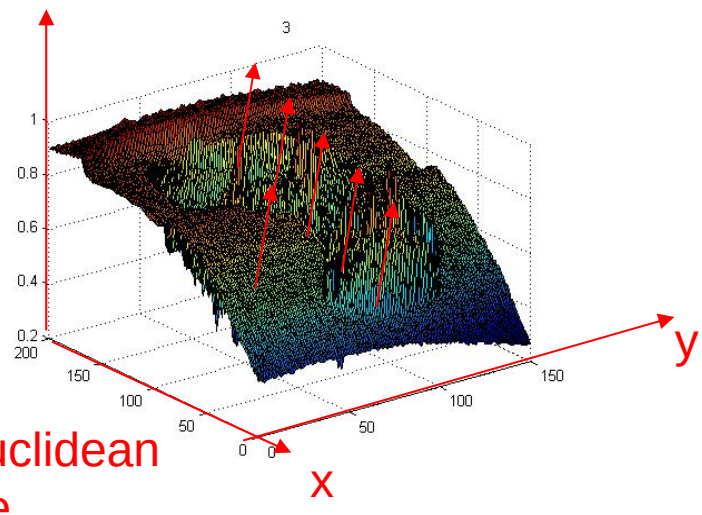
(1,1) (2,1) (3,1)

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

(R,G,B)

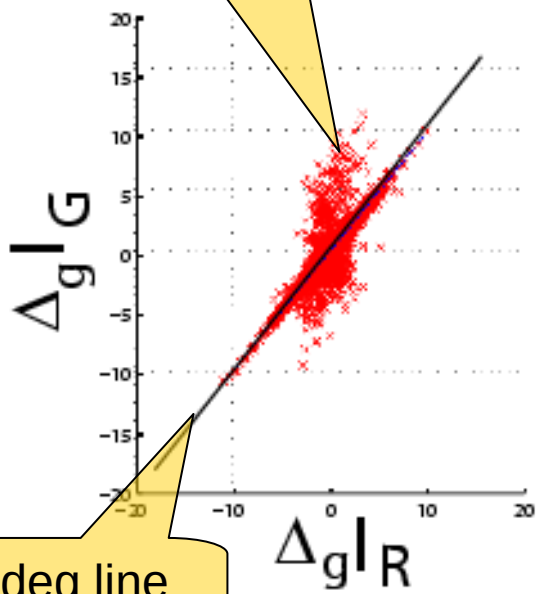
$(\Delta_g I) = (\Delta_g I_R, \Delta_g I_G, \Delta_g I_B)$



5D Euclidean Space

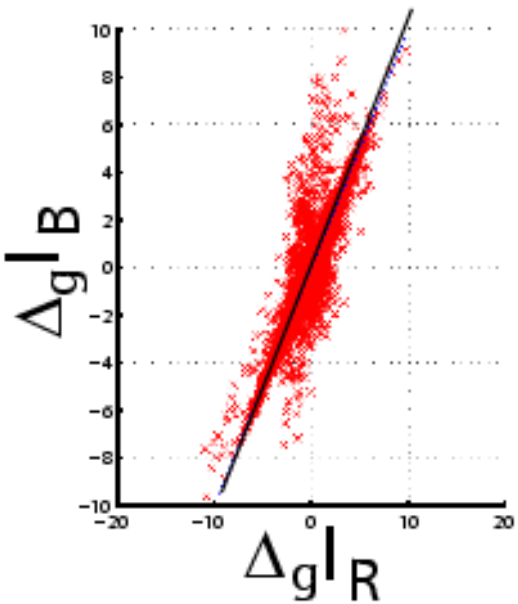
Differential Geometry III
Surface Laplacian

Misalignment with 45 deg line



45 deg line

CG



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

Dataset
Columbia Open Dataset

- First publicly available Photo/CG dataset.
- 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

Experimental Results I
SVM Classification

- SVM classification with radial basis function (RBF) kernel.
- Cartoon feature is the conventional feature for modeling the general computer graphics (includes cartoon or drawing)

Features	Geometry	Wavelets	Cartoon
Accuracy	83.5%	80.3%	71.0%

Receiver operating characteristic (ROC) curve

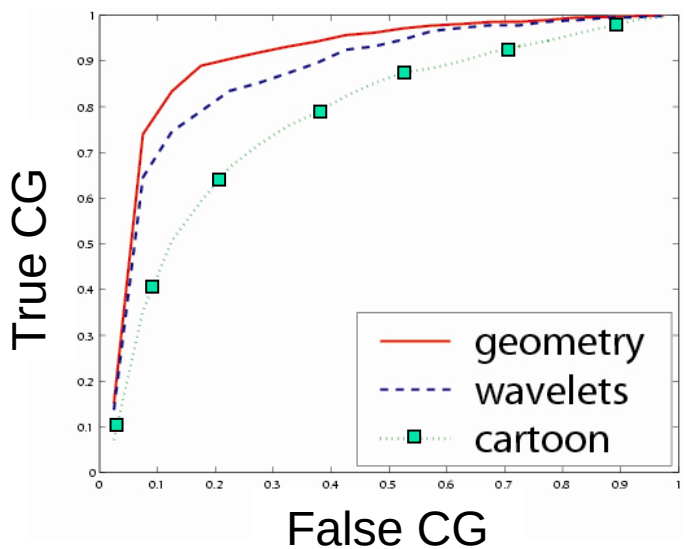


Photo
Vs
Internet CG

Experimental Results II
Recapturing Attack

- Testing with the recaptured CG (recapturing of a real scene)

Features	Geometry	Wavelets
Classified as Photo	97.2%	96.6%

- Counter-attack measure: Let the classifier learns the characteristics of the recaptured CG.

Receiver operating characteristic (ROC) curve

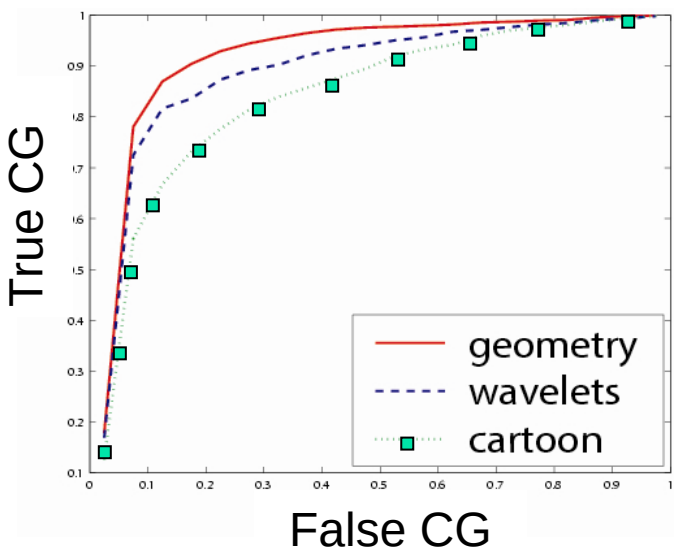
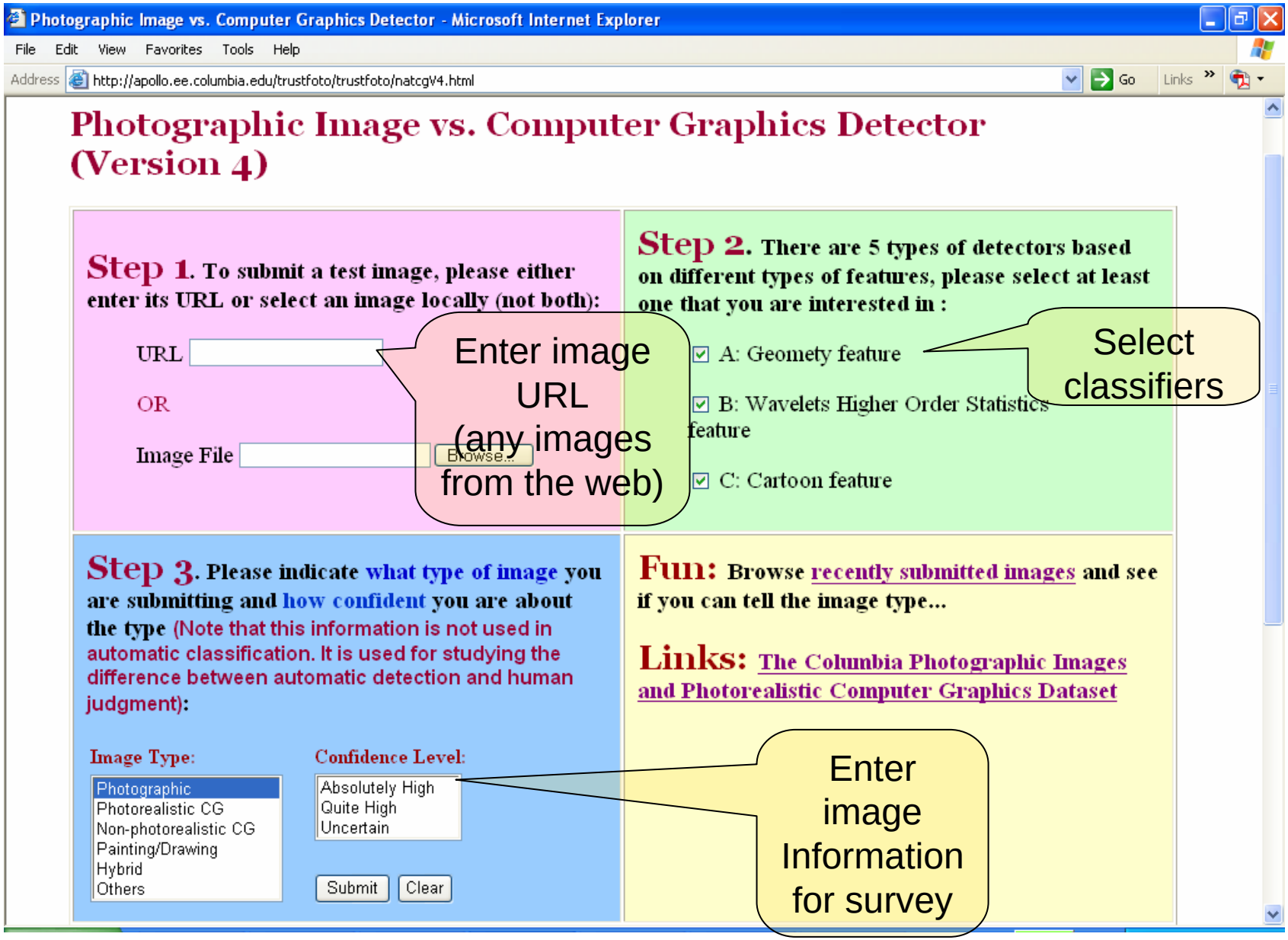


Photo
Vs
Internet CG + recaptured CG

Good classification accuracy, counter-attack is successful!

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

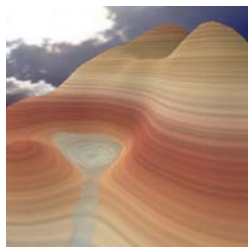
Return to the test page

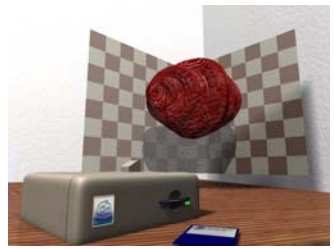
This page is based on a perl-script from PerlScriptsJavaScripts.com

Online Demo III
Consistency with Human Judgments

Human Judgments

CG




Photo





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

Conclusions and Future Work

- Conclusions
  - We propose a novel physics-based features.
  - We provide the first publicly available Photo/CG dataset.
  - We deploy the first online Photo Vs. CG classifier.
- Future and Ongoing Work
  - Camera transfer function estimation from a single image.
  - Detecting Photo Vs. CG at the local regions.
  - Designing counter-measure for the Oracle attack.
  - Capturing global scene authenticity (e.g., consistency between lightings and shadows).

Thank you!

Dataset and Project Website: http://www.ee.columbia.edu/trustfoto
Online Demo: http://www.ee.columbia.edu/trustfoto/demo-photovscg.htm