SIGGRAPH2008

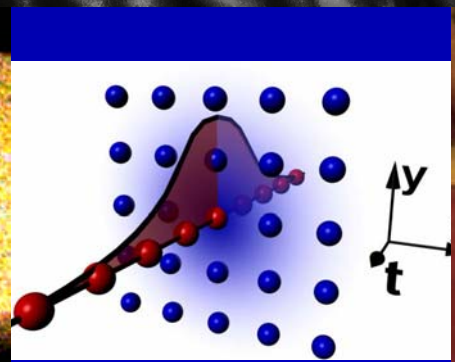
A Gentle Introduction to Bilateral Filtering and its Applications

SIGGRAPH2008

08/10: Applications: Advanced uses of Bilateral Filters

Jack Tumblin – EECS, Northwestern University

Advanced Uses of Bilateral Filters



Advanced Uses for Bilateral

A few clever, exemplary applications…

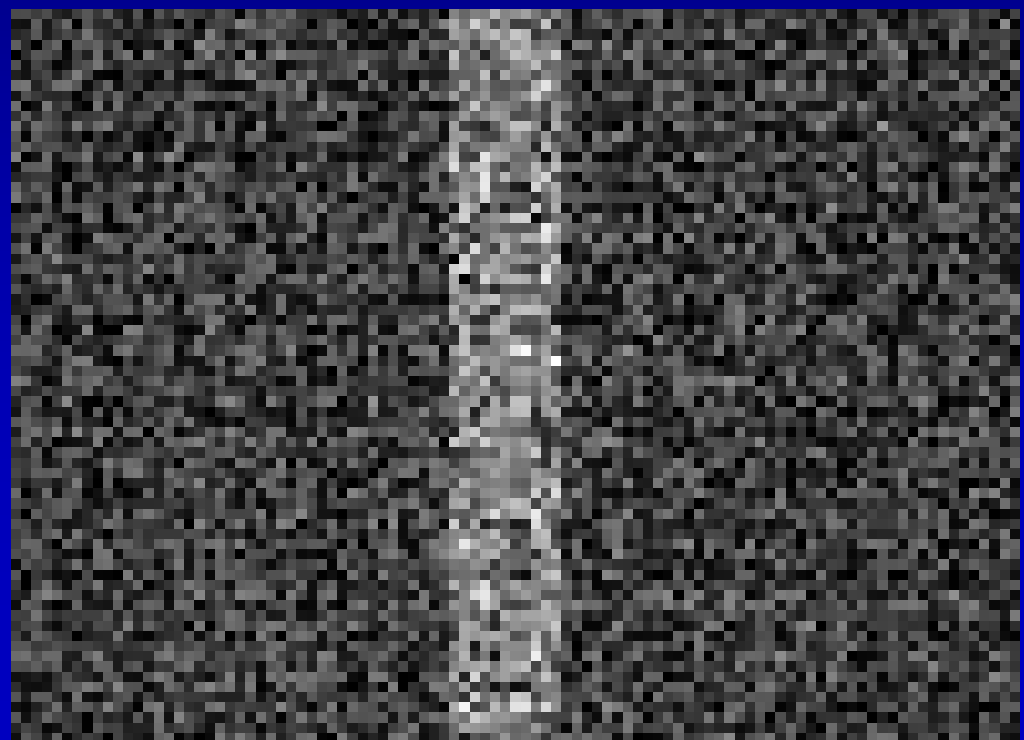
- Improved Stereo Depth Estimators (Ansar 2004,5)
- Flash/No Flash Image Merge (Petschnigg2004, Eisenman2004)
- Retinex (Elad 2006)
- Tone Management (Bae 2006)
- Exposure Correction (Bennett2006)
- Feature Fusion (Bennett 2007, Wang2008)
- Image Merging

Many more, many new ones…

– Broad interest…SIGGRAPH,EG,CVPR,ICIP, etc.

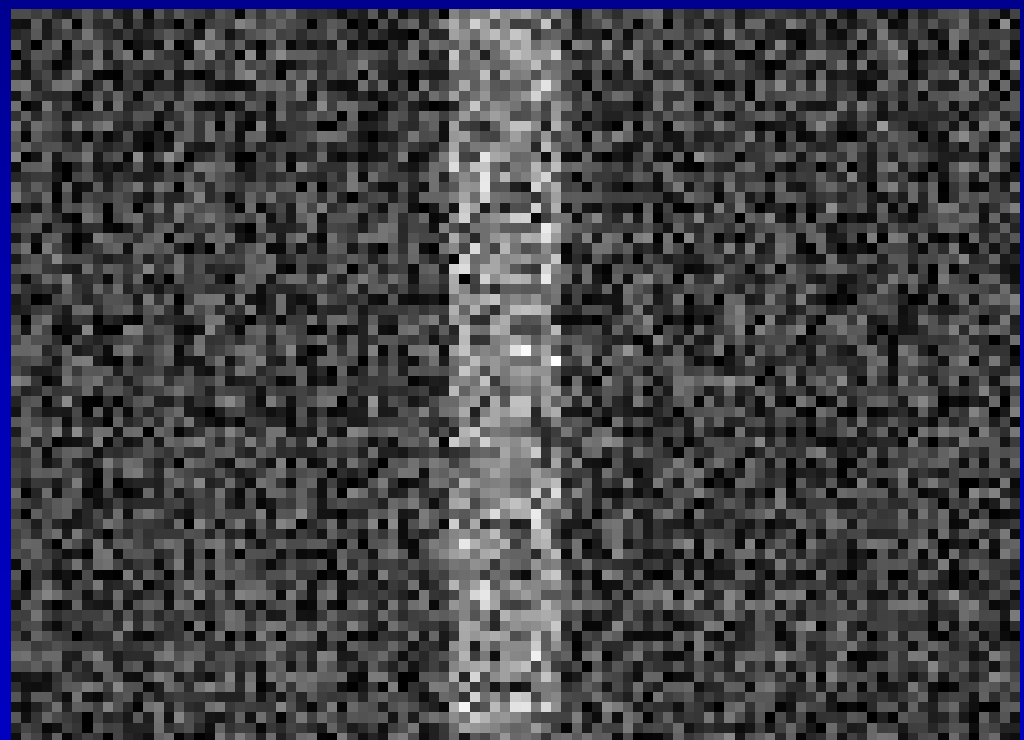
Enhanced Real-Time Stereo (Adnan 2004,…)

- Silhouettes → Strong depth edges
- Corresp. Errors → Noisy depth textures
- Bilateral: preserve edges, remove noise:



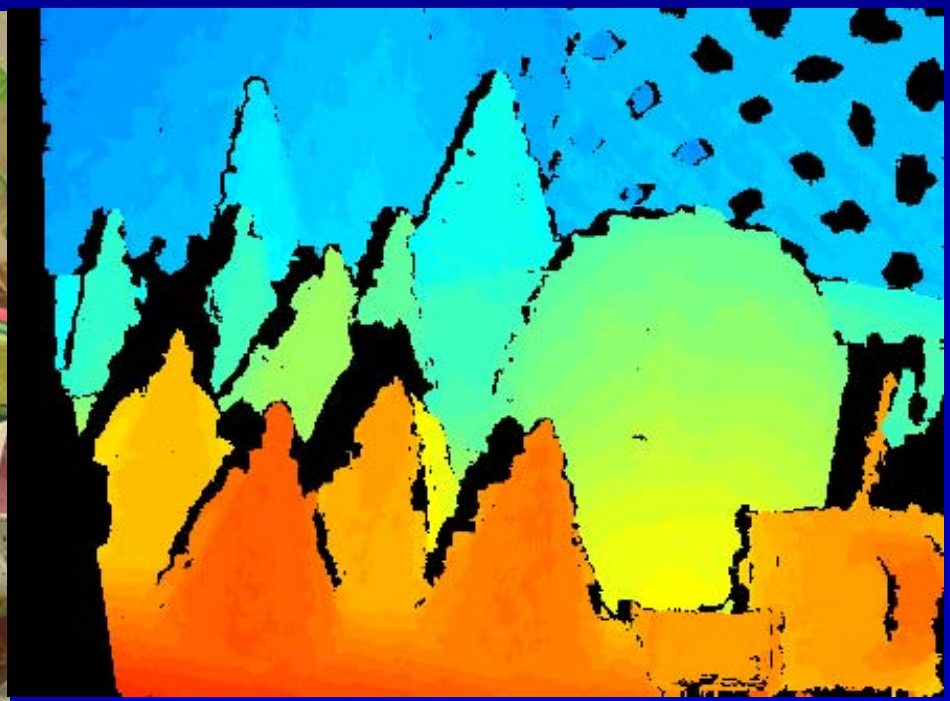
Enhanced Real-Time Stereo (Adnan 2004, …)

- Silhouettes → Strong depth edges
- Corresp. Errors → Noisy depth textures
- Bilateral: preserve edges, remove noise:



Enhanced Real-Time Stereo (Adnan 2004, …)

- Silhouettes → Strong depth edges
- Corresp. Errors → Noisy depth values
- Bilateral: preserve edges, remove noise:

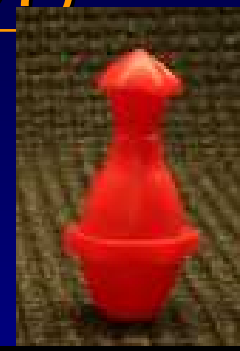


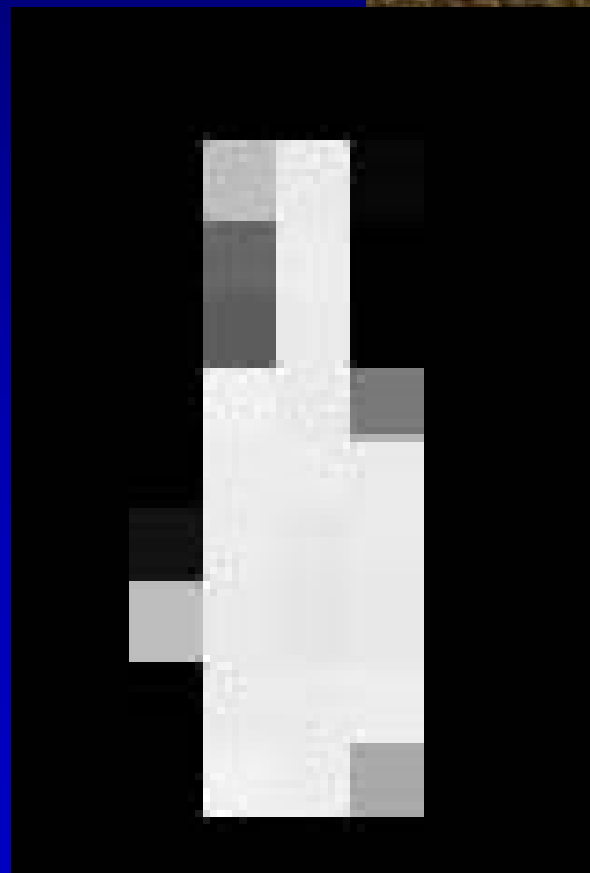
Spatial-Depth Super Resolution for Range Images (Yang et al. 2007)

- Edges from 2 registered high-res photos
- Depth from low-res, sparse, noisy
- Iterative bilateral refinement…

Spatial-Depth Super Resolution for Range Images (Yang et al. 2007)

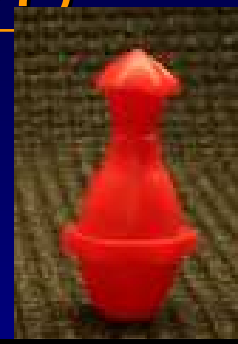
- Edges from 2 registered high-res photos
- Depth from low-res, sparse, noisy
- Iterative bilateral refinement…

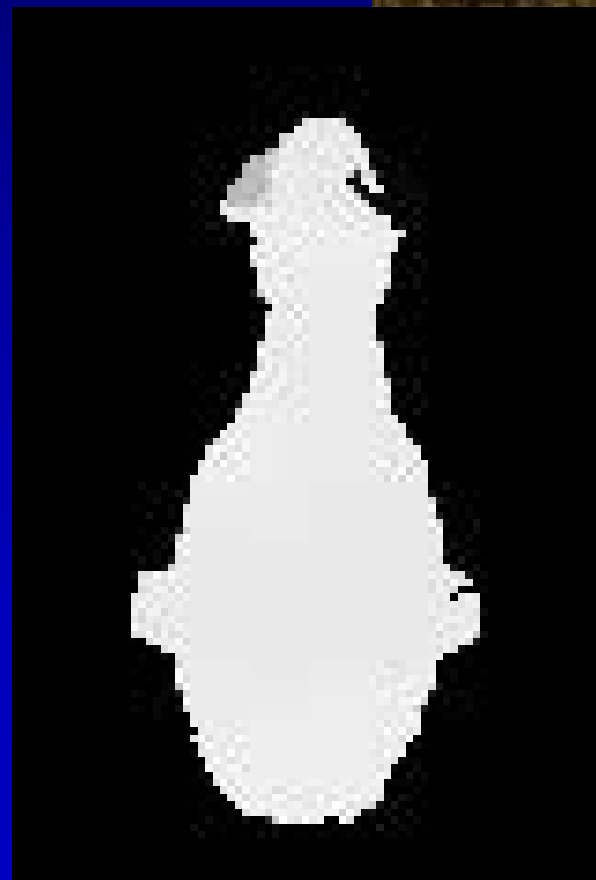




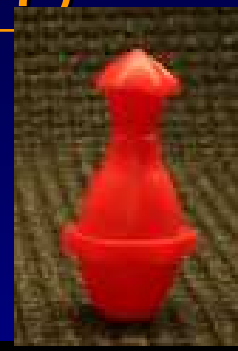
Spatial-Depth Super Resolution for Range Images (Yang et al. 2007)

- Edges from 2 registered high-res photos
- Depth from low-res, sparse, noisy
- Iterative bilateral refinement…

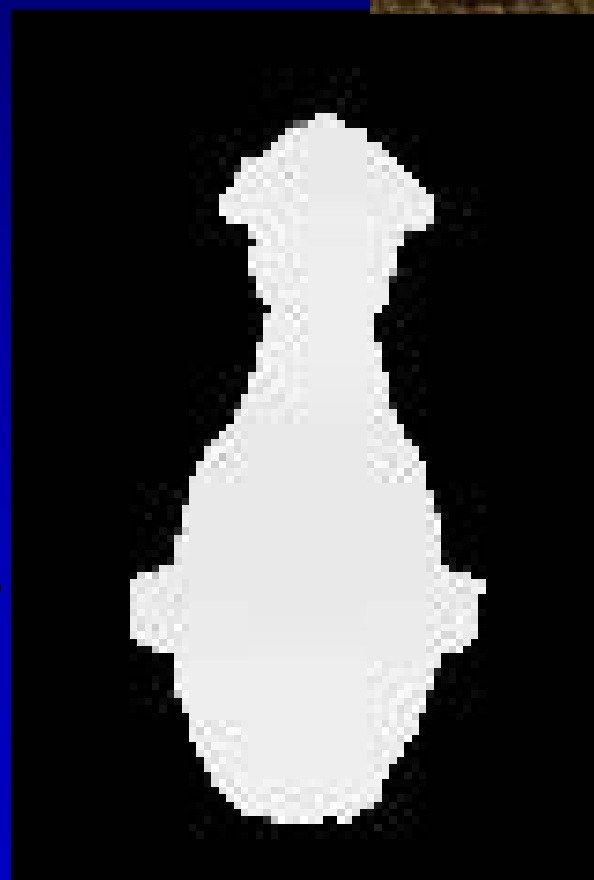




Spatial-Depth Super Resolution for Range Images (Yang et al. 2007)



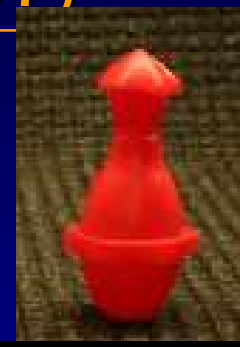
- Edges from 2 registered high-res photos
- Depth from low-res, sparse, noisy
- Iterative bilateral refinement

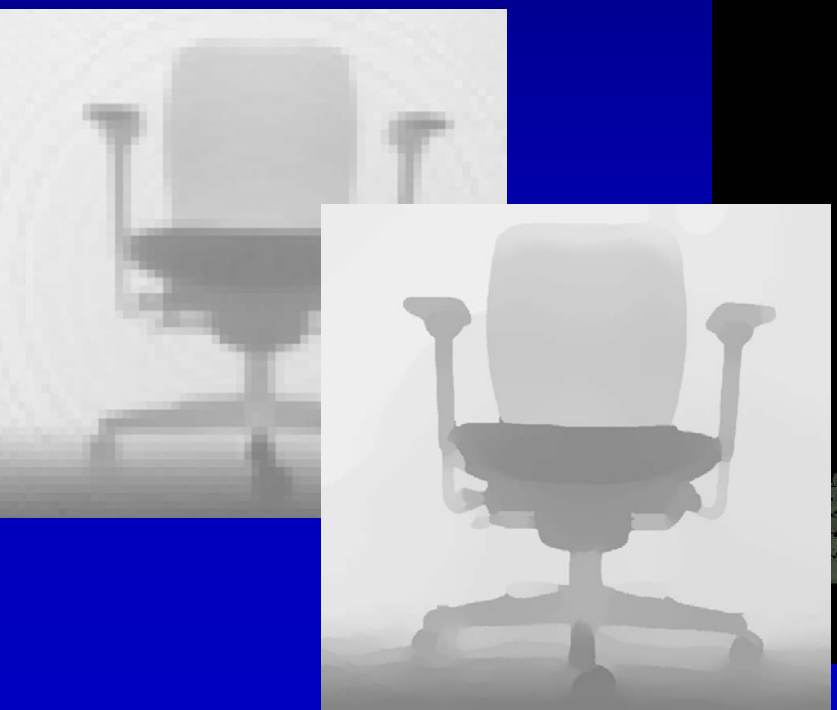


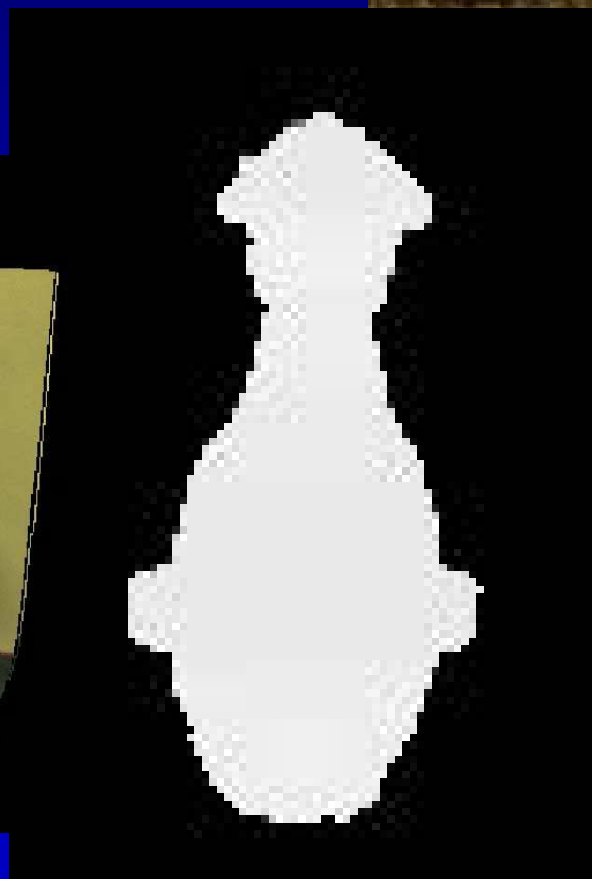
- RESULTS
  - Exceptionally accurate on entire Middlebury Data set:
  - Subpixel accuracy, → 100X resol.

Spatial-Depth Super Resolution for Range Images (Yang et al. 2007)

- Edges from 2 registered high-res photos
- Depth from low-res, sparse, noisy
- Iterative bilateral refinement…







Retinex from 2 Bilateral Filters [Elad05]

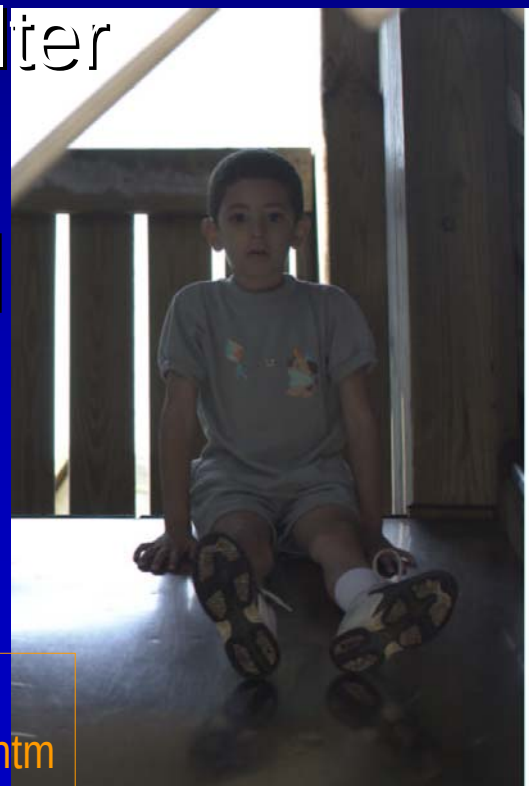
M. Elad, "Retinex by Two Bilateral Filters", Scale-Space 2005, Hofgeismar, Germany, 7-10 April 2005

- Retinex Theory (Edwin Land, 1972):
  - Eyes “discount the illuminant”. Computable?
  - Color: set by spectral AND spatial relationships
  - Done in retina? In visual cortex? →→ ‘Retinex’

Retinex from 2 Bilateral Filters [Elad05]

M. Elad, "Retinex by Two Bilateral Filters", Scale-Space 2005, Hofgeismar, Germany, 7-10 April 2005

- Estimate Illumination & Reflectance Bilaterally
  - Smooth between object edges
  - Illum. Sets image upper bounds (0 < Refl. < 1)
- Tailored Bilateral Filter
- Further Justifies [Durand&Dorsey02] speedup approx.



Good Retinex Summary: http://scien.stanford.edu/class/psych221/projects/00/mjahr/ppframe.htm

Flash / No-Flash Photo Improvement (Eisemann04) (Petschnigg04)

Merge best features: warm, cozy candle light (no-flash)
low-noise, detailed flash image

‘Joint Bilateral’ or ‘Cross Bilateral’ (2004)

Bilateral → *two kinds* of weights, so…

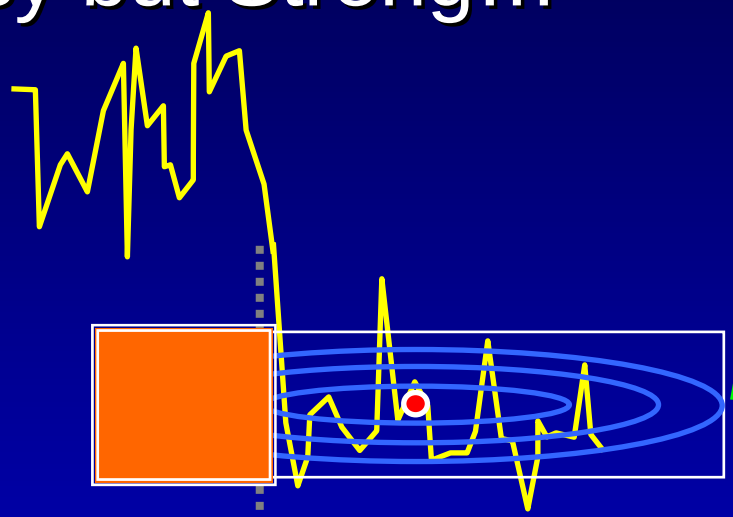
Cross Bilateral Filter (CBF):

→ get them from *two kinds* of images.

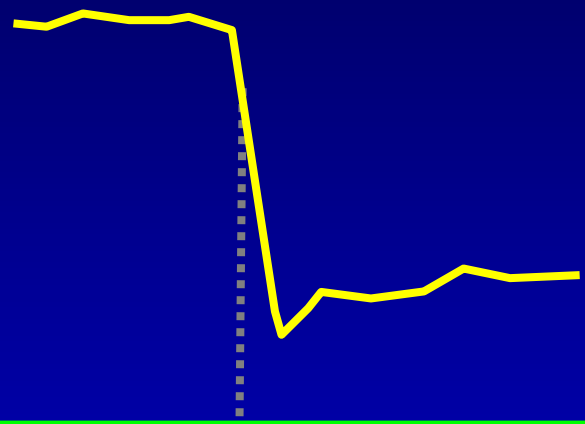
- Spatial smoothing of pixels in image A, with
- WEIGHTED by intensity similarities in image B:

Recall: ‘Cross’ or ‘Joint’ Bilateral Idea

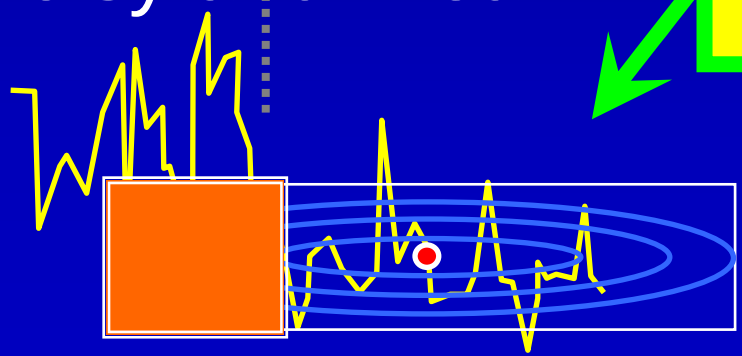
Noisy but Strong…



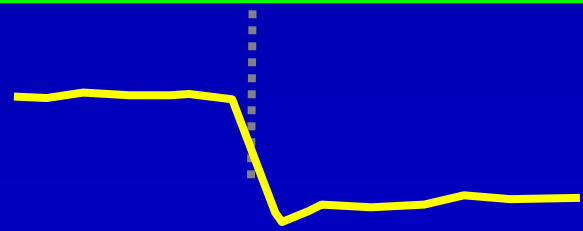
Range filter preserves signal



Noisy and Weak…



Use stronger signal’s range within weaker signal’s noise…



Overview

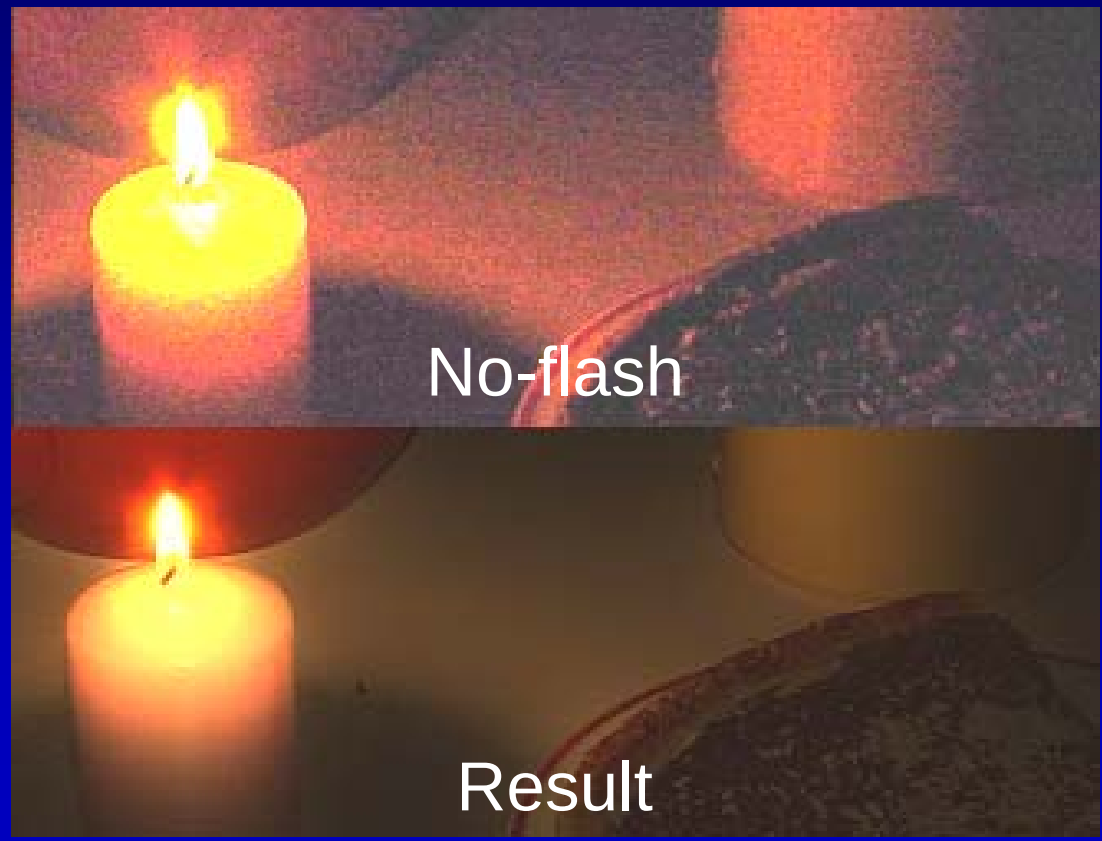
Basic approach of both flash/noflash papers

Remove noise + details from image A,

Keep as image A Lighting

Obtain noise-free details from image B,

Discard Image B Lighting



Petschnigg:

- Flash:

+ Strong, sharp edges

- Stark, ugly light / shadow

Petschnigg:

- No Flash:

- Weak, noisy edges

+ Warm, cozy light / shadow

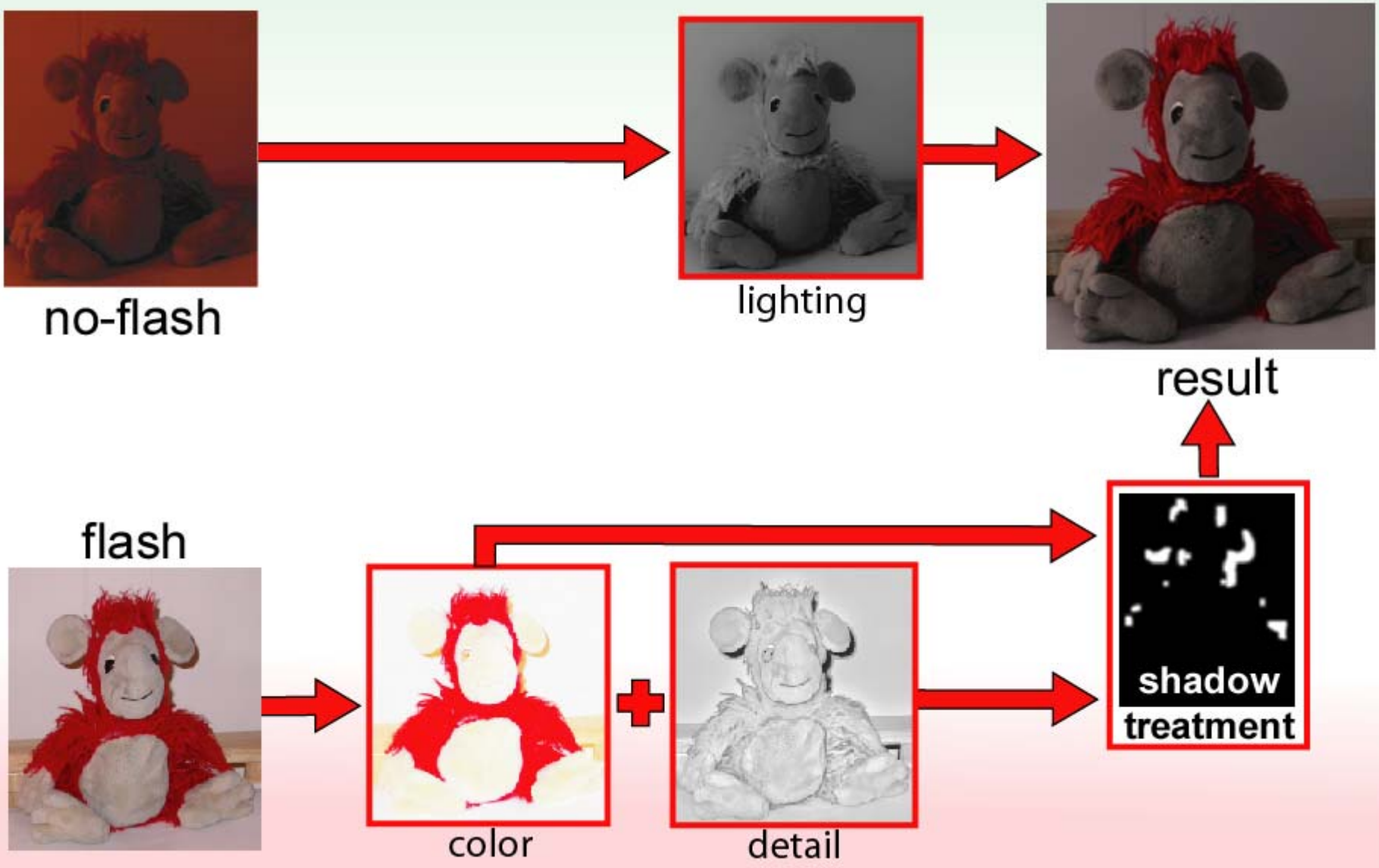
Petschnigg:

- Result

+ Strong, sharp edges

+ Warm, cozy light / shadow

Approaches - Main Idea



‘Joint’ or ‘Cross’ Bilateral Filter (CBF)

- Enhanced ability to find weak details in noise
  (B’s weights preserve similar edges in A)

- Useful Residues for ‘Detail Transfer’
  - CBF(A,B) to remove A’s noisy details
  - CBF(B,A) to remove B’s less-noisy details;
  - add to CBF(A,B) for clean, detailed, sharp image

  (See the papers for details)

‘Joint’ or ‘Cross’ Bilateral Filter (CBF)

- Enhanced ability to find weak details in noise (B’s weights preserve similar edges in A)

Petschnigg: Detail Transfer Results

- Lamp made of hay:

No Flash

Flash

Detail Transfer

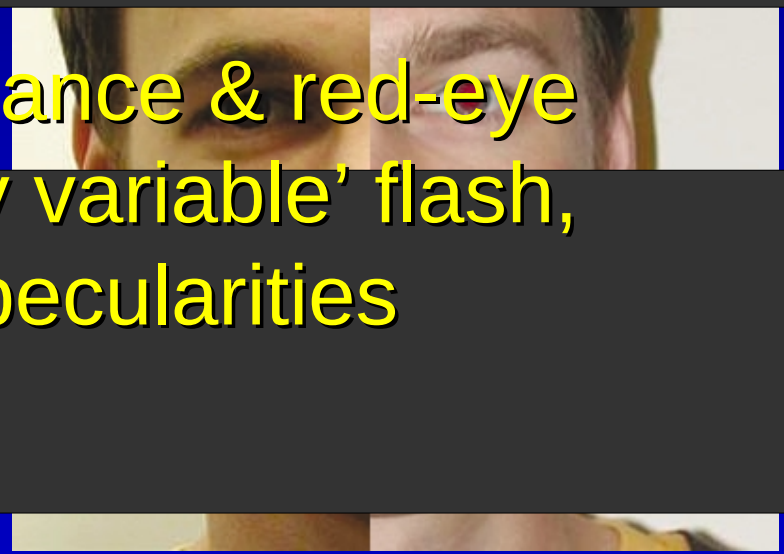
Petschnigg04, Eisemann04 Features

Eisemann 2004:

--included image registration,
--used lower-noise flash image for color, and
--compensates for flash shadows

Petschnigg 2004:

--included explicit color-balance & red-eye
--interpolated ‘continuously variable’ flash,
--Compensates for flash specularities



Tonal Management (Bae et al., SIGGRAPH 2006)

Cross bilateral, residues →
visually compelling
image decompositions.

- Explore: adjust each component's contrast,
  find visually pleasing transfer functions,etc.
- Stylize: finds transfer functions that
  match histograms of preferred artists,
- 'Textureness'; local measure of textural richness;
  to guide local mods, to match artist's

Tone Mgmt Examples:

Original

Tone Mgmt Examples:

‘Bright and Sharp’

Tone Mgmt Examples:

Gray and detailed

Tone Mgmt Examples:

Smooth and grainy

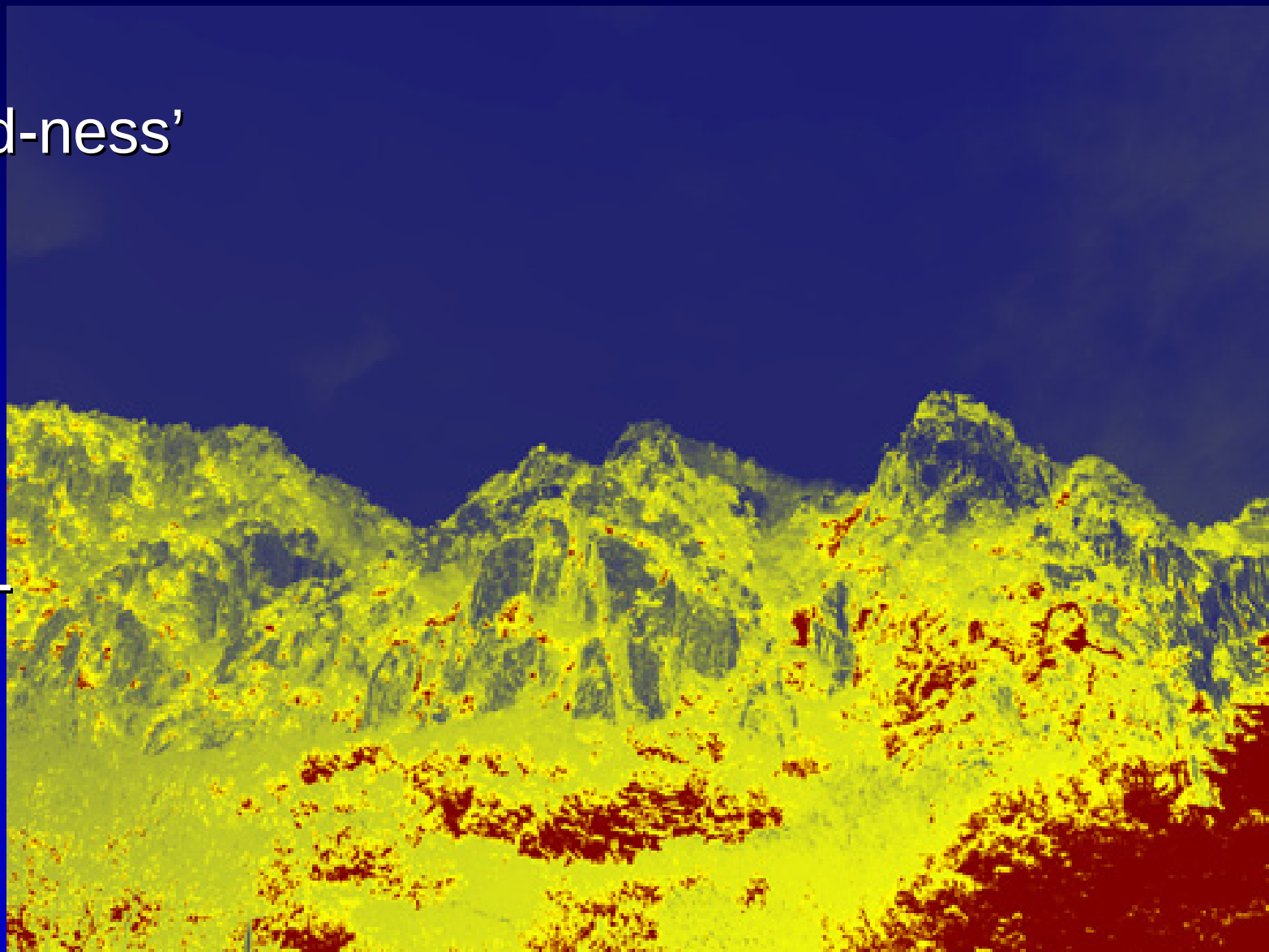
Tone Management Examples

Source

Tone Management (Bae06)

‘Textured-ness’ Metric:

(shows highest Contrast-adjusted texture)



Reference Model

Model: Ansel Adams

Input with auto-levels

Results

Results

- Direct Histogram Transfer (dull)

Results

- Best…

Multi-Light Detail Transfer

SIGG2007 Fattal et al., Multiscale Shape and Detail Enhancement from Multi-light Image Collections

- Different light → Different visible details
- Extract, Control/Enhance, Merge details

Multi-Light Detail Transfer

SIGG2007 Fattal et al., Multiscale Shape and Detail Enhancement from Multi-light Image Collections

- Different light → Different visible details
- Extract, Control/Enhance, Merge details

Light 1

Multi-Light Detail Transfer

SIGG2007 Fattal et al., Multiscale Shape and Detail Enhancement from Multi-light Image Collections

- Different light → Different visible details
- Extract, Control/Enhance, Merge details

Light 2

Multi-Light Detail Transfer

SIGG2007 Fattal et al., Multiscale Shape and Detail Enhancement from Multi-light Image Collections

- Different light → Different visible details
- Extract, Control/Enhance, Merge details

Multi-Light Detail Transfer

SIGG2007 Fattal et al., Multiscale Shape and Detail Enhancement from Multi-light Image Collections

- Different light → Different visible details
- Extract, Control/Enhance, Merge details

- Bilateral filters
- User-set weights
- Adjust to suit… flat, detailed or with shadows

Multi-Light Detail Transfer

SIGG2007 Fattal et al., Multiscale Shape and Detail Enhancement from Multi-light Image Collections

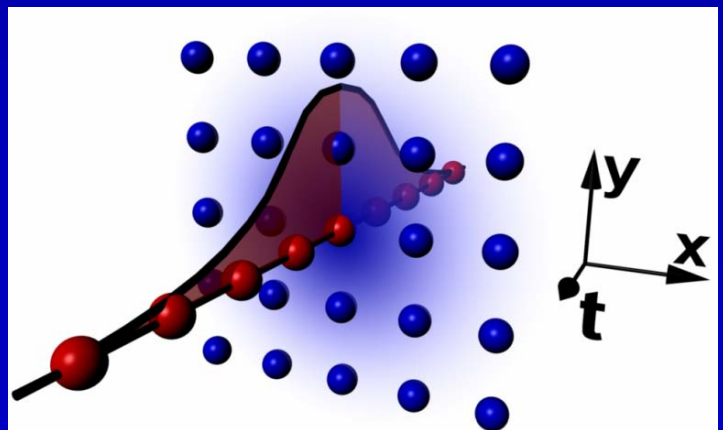
- Different light → Different visible details
- Extract, Control/Enhance, Merge details

- Bilateral filters
- User-set weights
- Adjust to suit… flat, detailed or with shadows

Video Enhancement Using Per Pixel Exposures (Bennett, 06)

From this video:

ASTA: ***A*daptive**
***S*patio-**
***T*emporal**
***A*ccumulation** Filter



VIDEO

The Process for One Frame

- Raw Video Frame: (from FIFO center)
- Histogram stretching; (estimate gain for each pixel)
- *'Mostly Temporal'* Bilateral Filter:
  - Average recent similar values,
  - Reject outliers (avoids 'ghosting'), spatial avg as needed
  - Tone Mapping

The Process for One Frame

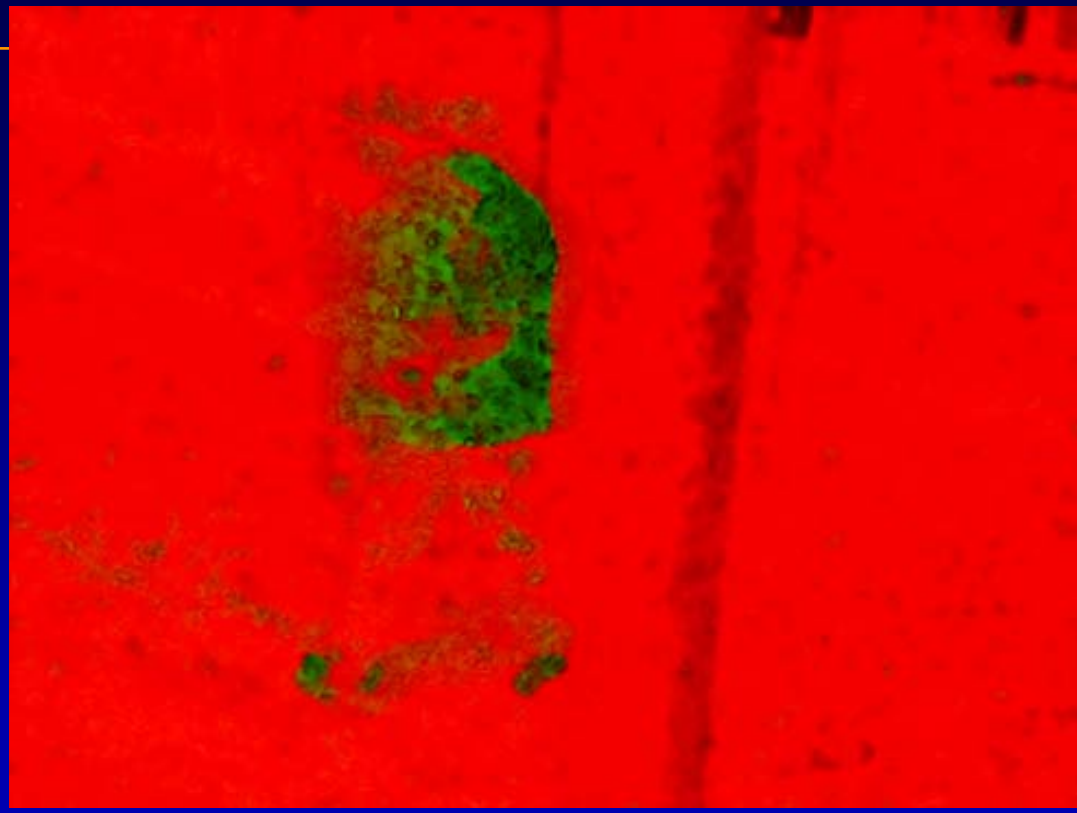
- Raw Video Frame: (from FIFO center)

- Histogram stretching; (estimate gain for each pixel)
- *'Mostly Temporal'* Bilateral Filter:
  - Average recent similar values,
  - Reject outliers (avoids 'ghosting'), spatial avg as needed
  - Tone Mapping

The Process for One Frame

- Raw Video Frame:
  (from FIFO center)

- Histogram stretching;
  (estimate gain for
  each pixel)



- *'Mostly Temporal'* 3D Bilateral Filter:
  - Average recent similar values,
  - Reject outliers (avoids 'ghosting'), spatial avg as needed
  - Tone Mapping

(color: # avg' pixels)

The Process for One Frame

- Raw Video Frame:
  (from FIFO center)

- Histogram stretching;
  (estimate gain for
  each pixel)

- *'Mostly Temporal'* 3D Bilateral Filter:
  - Average recent similar values,
  - Reject outliers (avoids 'ghosting'), spatial avg as needed
  - Tone Mapping

Bilateral Filter Variant: Mostly Temporal

- FIFO for Histogram-stretched video
  - Carry gain estimate for each pixel;
  - Use *future* as well as previous values;
- Expanded Bilateral Filter Methods:
  - Static scene? Temporal-only avg. works well
  - Motion? Bilateral rejects outliers: no ghosts!

- Generalize: 'Dissimilarity' (not just $|| I_p - I_q ||^2$)

- Voting: spatial filter de-noises motion

Bennett2007: Multispectral Video Fusion

Dual-Bilateral filter:

fuses best of visible + IR

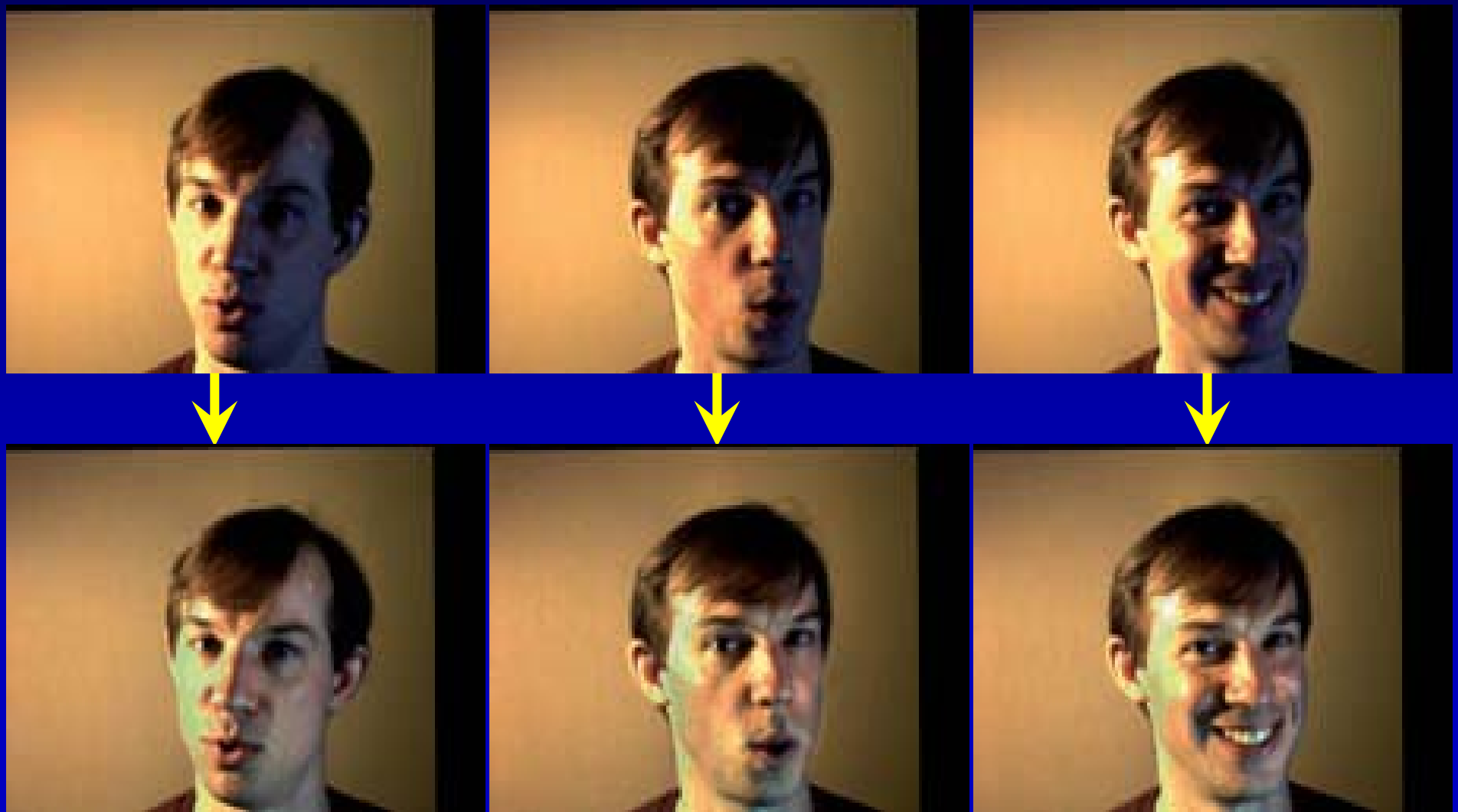
Original IR

Histogram-Stretched RGB

Fusion Result

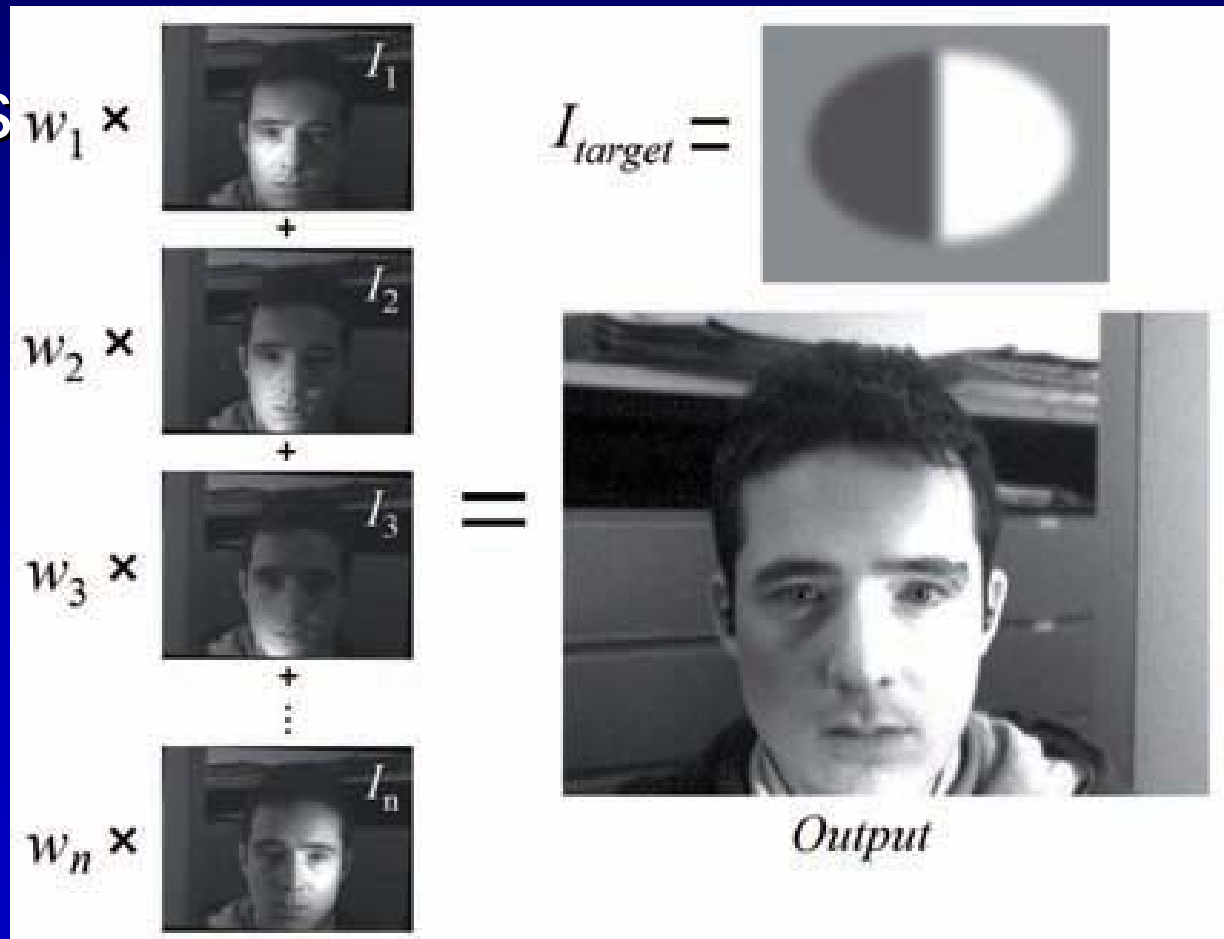
Video Relighting from IR illumination

EG2008, Wang,Davis et al.” Video Relighting Using Infrared Illumination”



Video Relighting from IR Illumination

- Switched IR illuminators, 8 photos per frame
- Ratio Images
- Hue Corrections



Conclusions

- Bilateral Filter easily adapted, customized to broad class of problems
- One tool among many for complex problems
- Useful in for any task that needs Robust, reliable smoothing with outlier rejection

SIGGRAPH2008

Applications

- 30 Minutes
- <40 slides