Computational Photography and Video:

Time-Lapse Video Analysis & Editing

Prof. Marc Pollefeys

Dr. Gabriel Brostow

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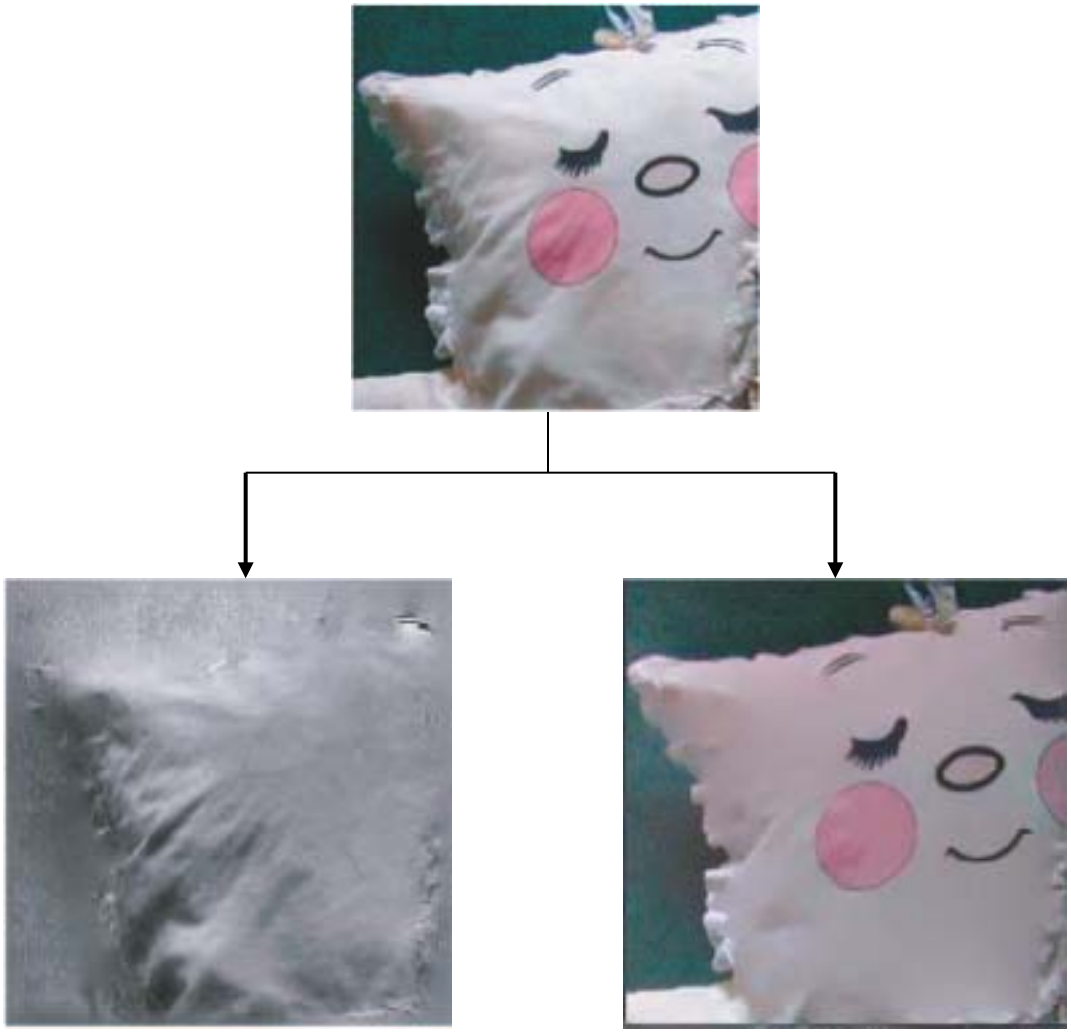
Last Time



Schedule	Computational Photography and Video	
24 Feb	Introduction to Computational Photography	
3 Mar	More on Camera,Sensors and Color	Assignment 1
10 Mar	Warping, Mosaics and Morphing	Assignment 2
17 Mar	Blending and compositing	Assignment 3
24 Mar	High-dynamic range	Assignment 4
31 Mar	Video Synthesis	Project proposals
7 Apr	*Easter holiday – no classes*	
14 Apr	Intrinsic Images	Papers
21 Apr	**Time-Lapse Video**	Papers
28 Apr	*TBD*	Papers
5 May	Project update	Project update
12 May	*TBD*	Papers
19 May	Papers	Papers
26 May	Papers	Papers
2 June	Final project presentation	Final project presentation

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Today's schedule

- Factored Time-Lapse Video
  - Sunkavalli, Matusik, Pfister, Rusinkiewicz, **Siggraph 2007**
- Computational Time-Lapse Video
  - Bennett & McMillan, **Siggraph 2007**
- Video Synopsis & Indexing,
  - Pritch, Rav-Acha, Peleg, **ICCV 2007**

Time-lapse Photography

- Definition: when frames are captured at a lower rate than the rate at which they will ultimately be played back.

- Compare to
  - Slow-motion
  - Bullet-time

Examples

Time-lapse Filmmaker's Challenges

Time-lapse Filmmaker's Challenges

- Lighting changes (strobing)
- High frequency motion (missed action)
  - Saturation & exposure
- Camera motion: intentional or not
- Triggering / data storage / camera safety

- Useful? Editable?

Factored Time-Lapse Video

Sunkavalli, Matusik, Pfister, Rusinkiewicz

SIGGRAPH 2007

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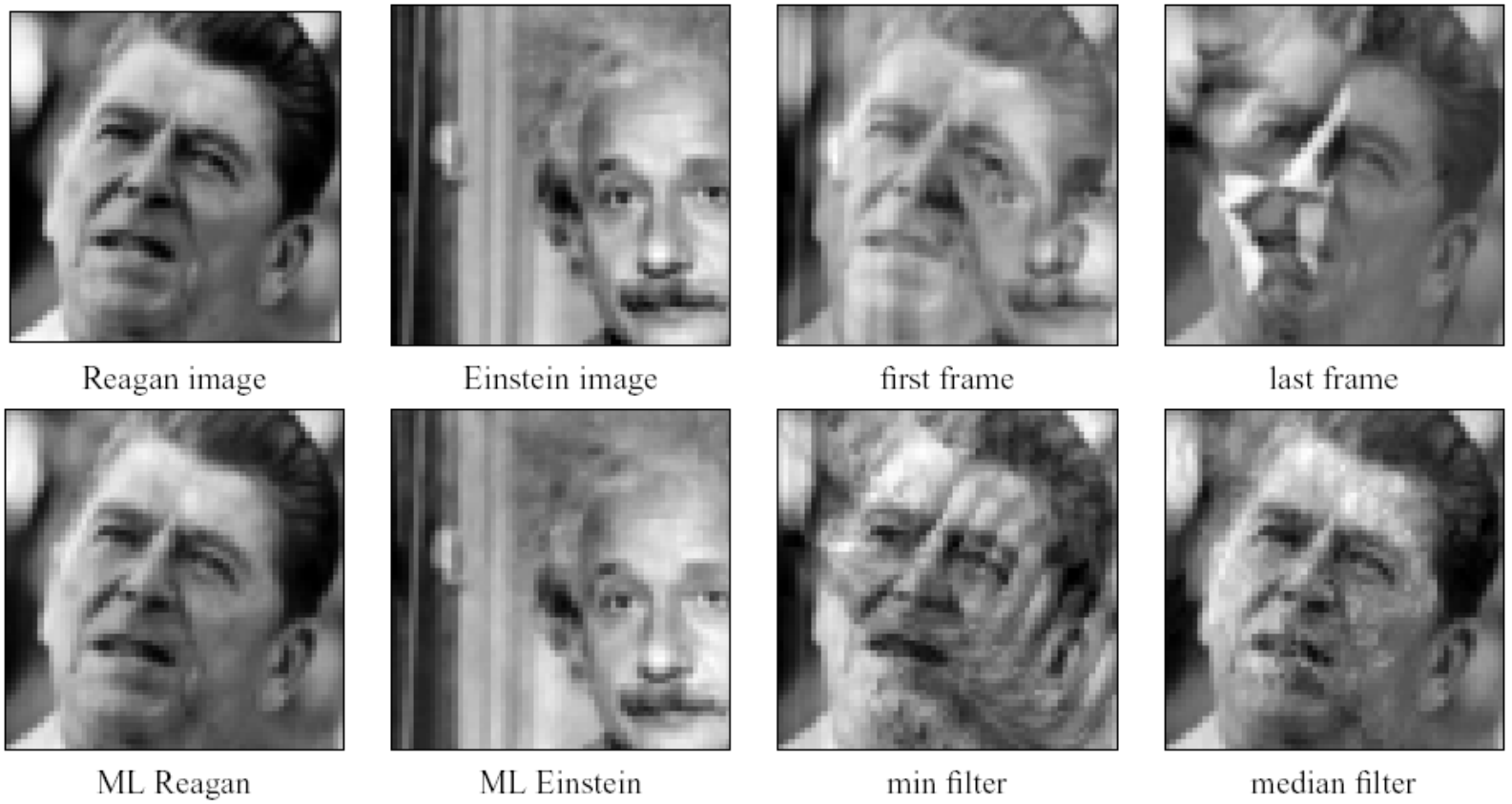
Project web page

Remember Intrinsic Images from Video?



Weiss ICCV'01

Outdoors: More Than Just Color vs Illumination?

Original

No Shadows

Given:

Daytime, under clear-sky conditions

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Outdoors: More Than Just Color vs Illumination?

Wishlist

Remove shadows
Render new shadows
Change albedo
Change global illumination

Original

No Shadows

Given:
Daytime, under clear-sky conditions

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Outdoors: More Than Just Color vs Illumination?

Original

No Shadows

Lighting due to sun? sky?
Surface Normals?

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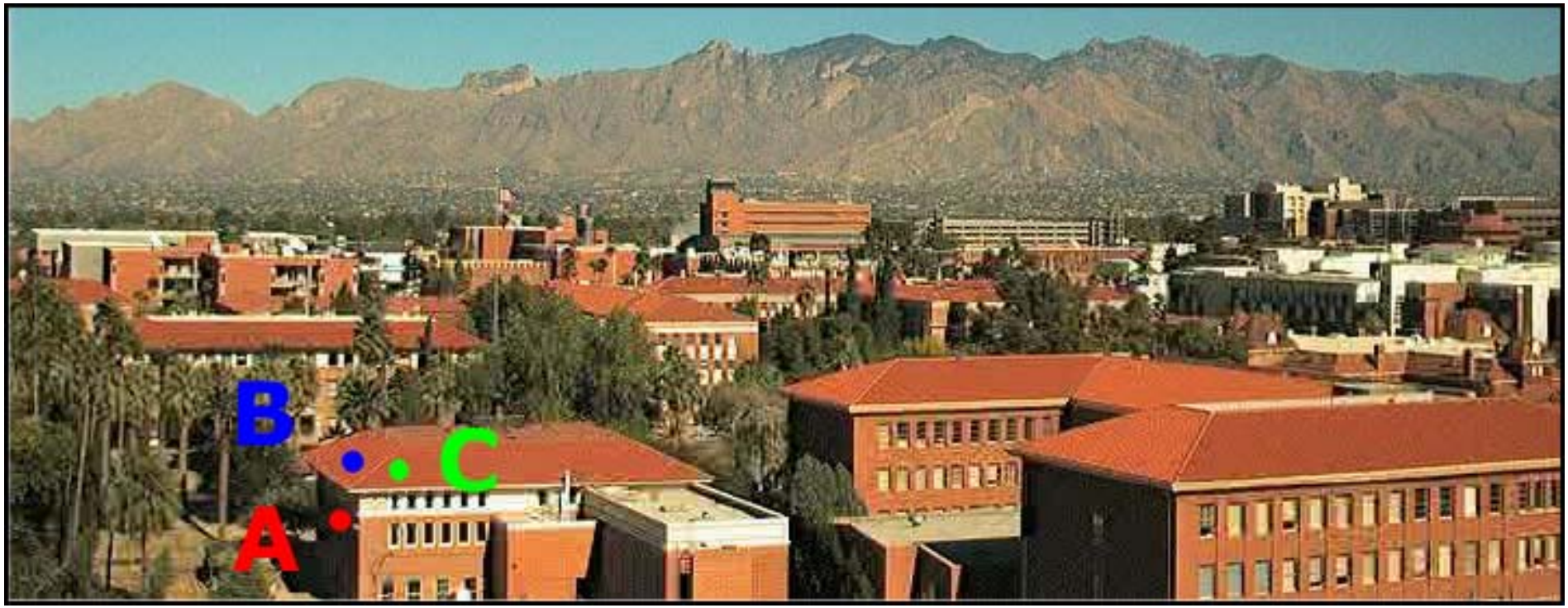
Formulation

$$\mathbf{F}(t) = \mathbf{I}_{sky}(t) + \mathbf{S}_{sun}(t) * \mathbf{I}_{sun}(t)$$

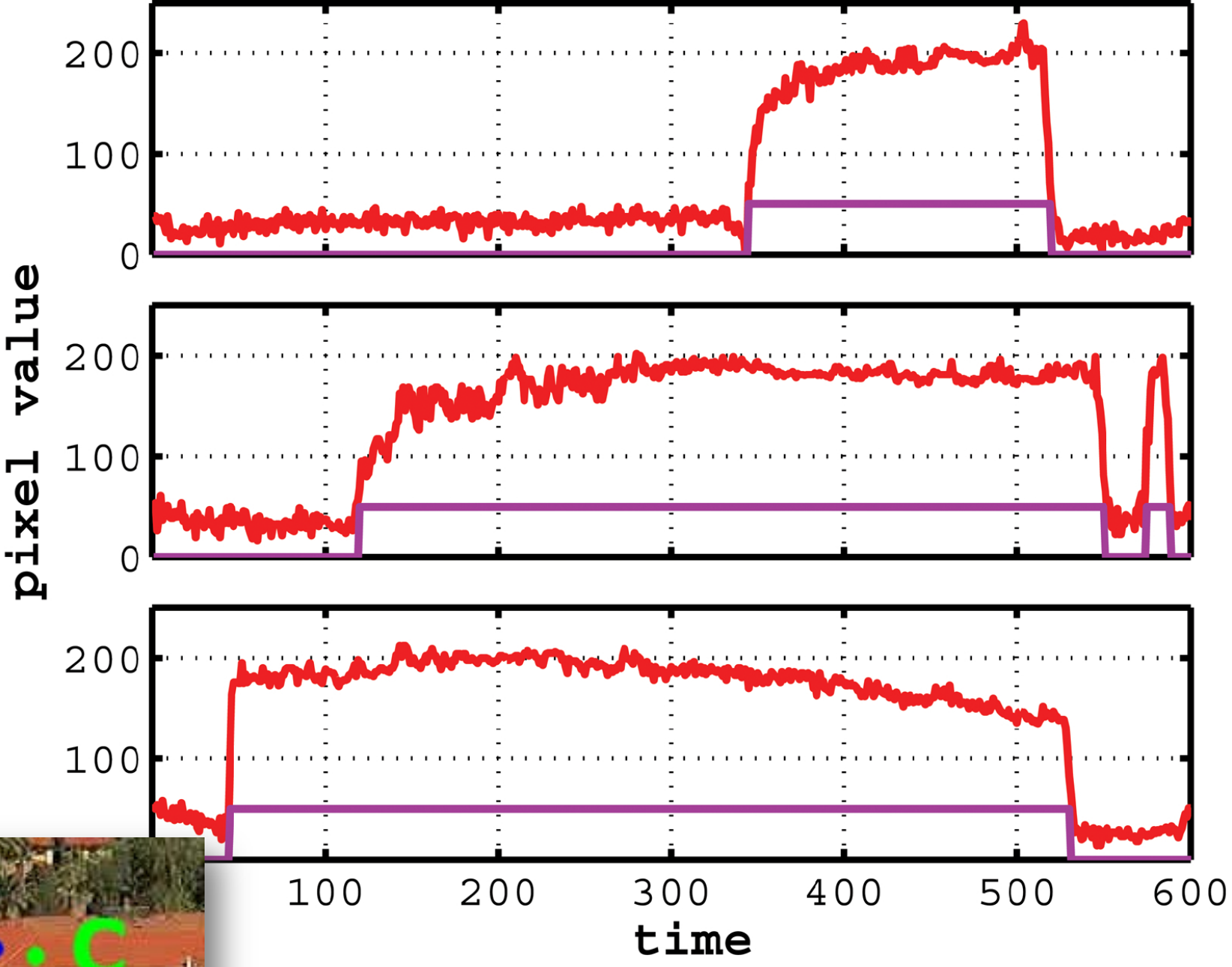
- size: *width* x *height* x *time*
- $\mathbf{F}$: xyt volume of frames over time

- $\mathbf{I}_{sky}$: Accumulated intensity due to sky-light
- $\mathbf{I}_{sun}$: Accumulated intensity due to sun-light
- $\mathbf{S}_{sun}$: Binary; is a pixel in shadow

Intuition



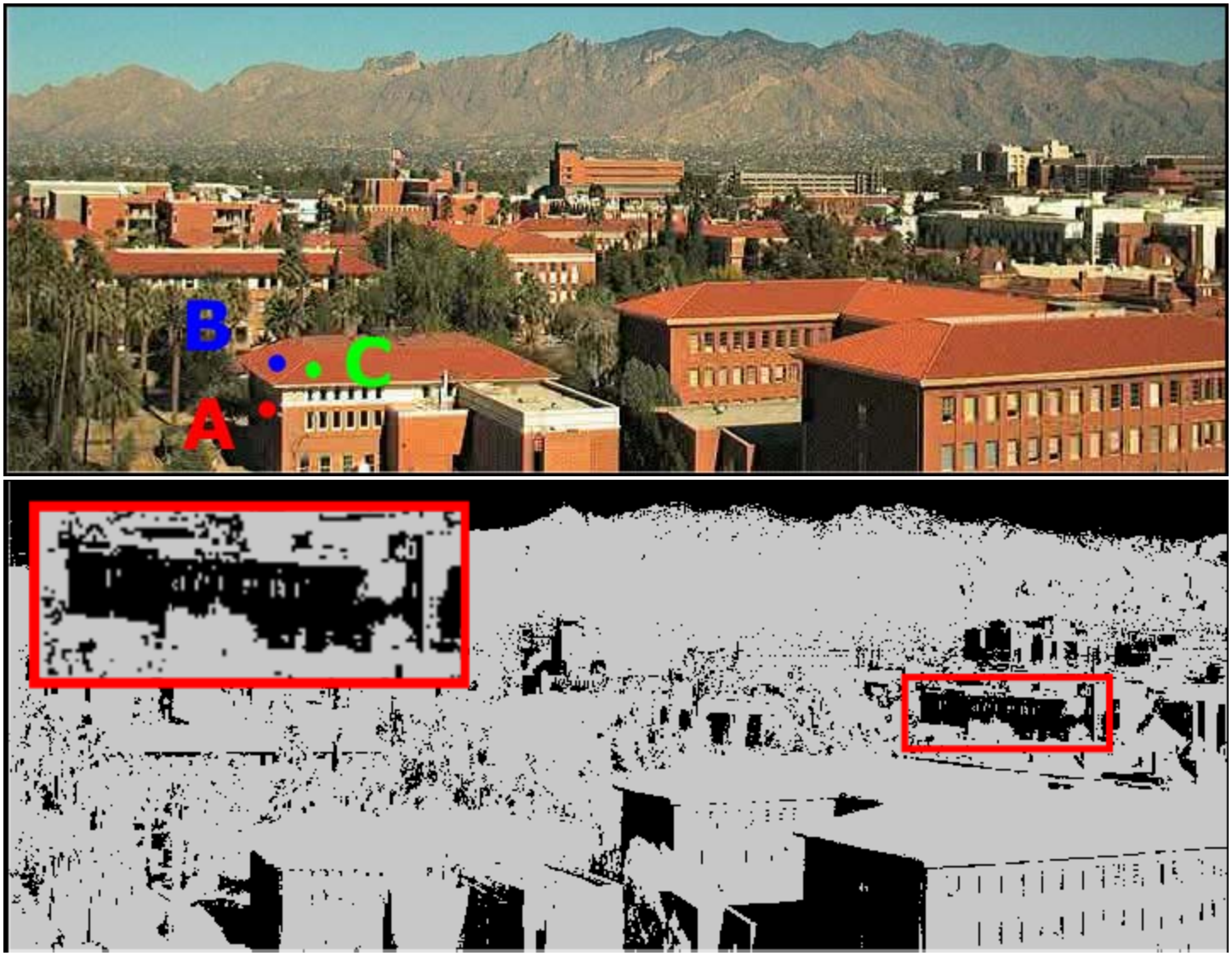

B
C
A


pixel value
200
100
0
200
100
0
200
100
100
200
300
400
500
600
time

Separate Sky first

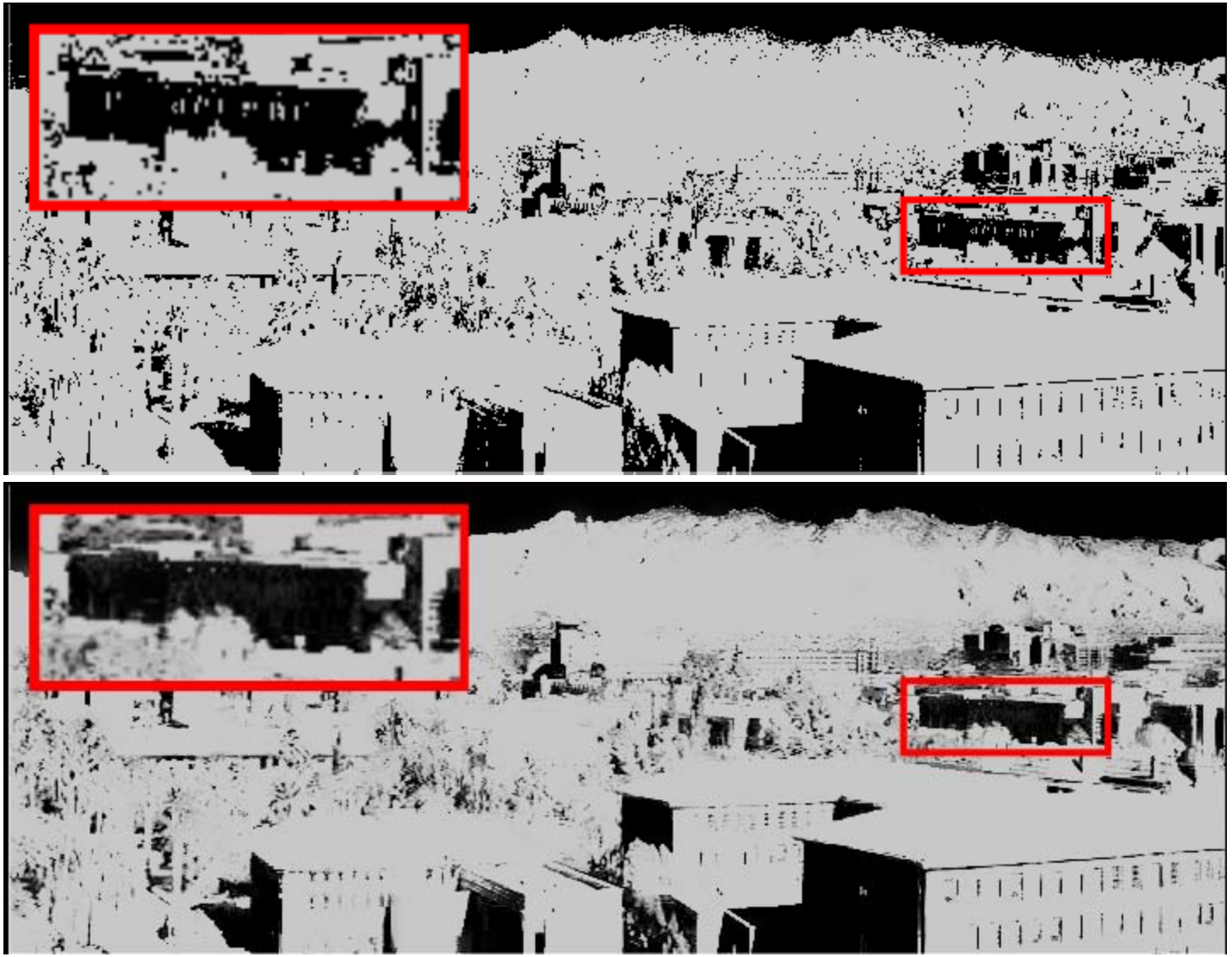
$$\mathbf{F}(t) = \mathbf{I}_{sky}(t) + \mathbf{S}_{sun}(t) * \mathbf{I}_{sun}(t)$$

- Photoshop!
  - Just to pick “non-surfaces”
- When is sun’s contribution == 0?
  - Leaving just sky’s contribution

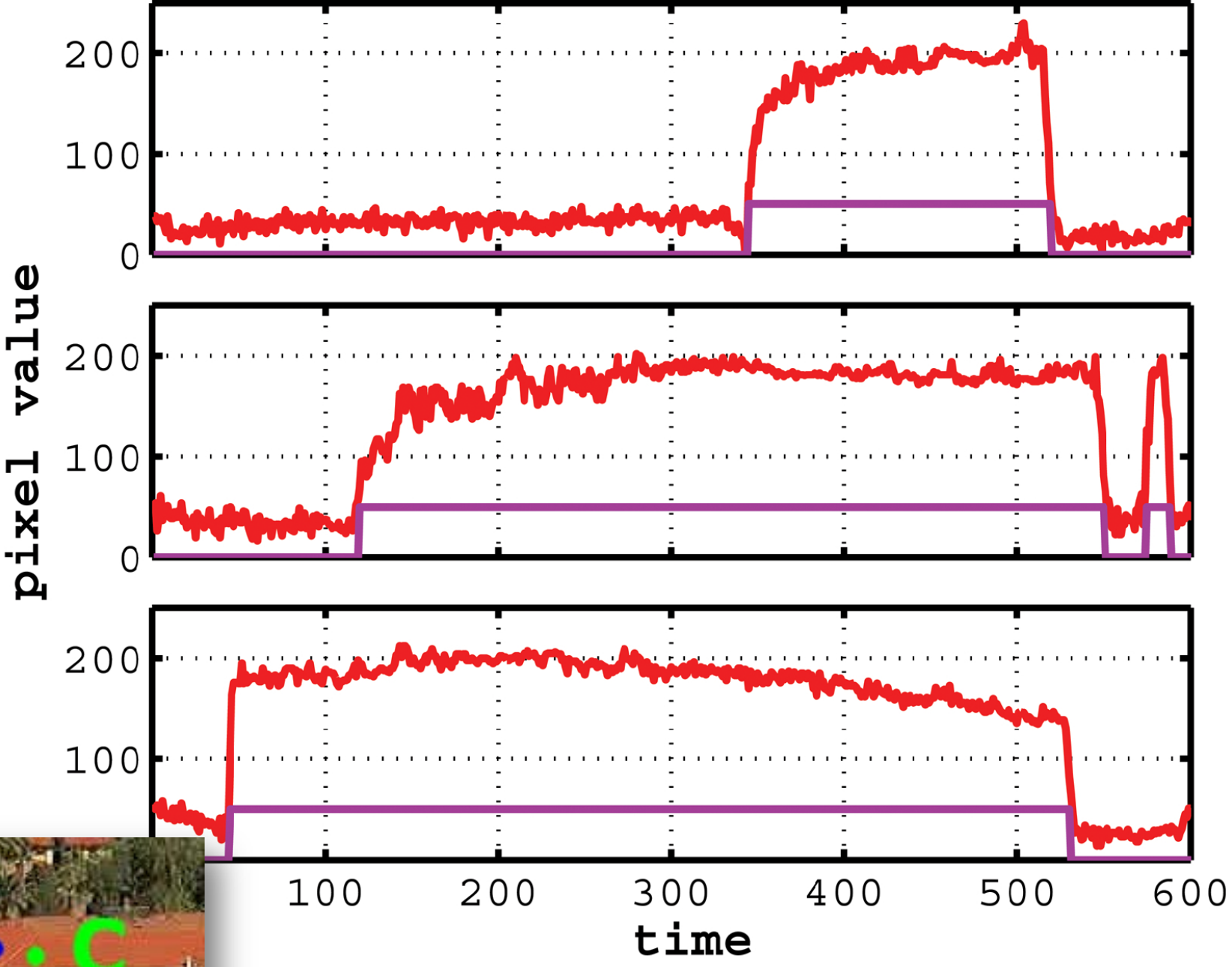


- “Definitely” shadow: median of darkest 20%, then threshold at 1.5x

Bilateral Filter “Definitely” Shadow




B
C
A

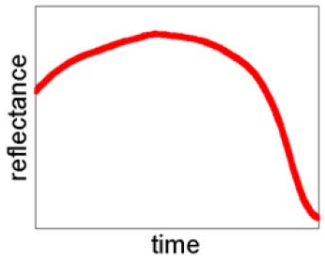

200
100
0
200
100
0
200
100
pixel value
100
200
300
400
500
600
time

How Did Skylight Change?

$$\mathbf{F}(t) = \mathbf{I}_{sky}(t) + \mathbf{S}_{sun}(t) * \mathbf{I}_{sun}(t)$$

$$\mathbf{I}_{sky,i}(t) \approx \mathbf{W}_{sky,i}\,\mathbf{H}_{sky}(t)$$

- $\mathbf{I}_{sky}$: Accumulated intensity due to sky-light
- $\mathbf{W}_{sky}$: Sky-light image
- $\mathbf{H}_{sky}$: Sky-light basis curve (1D function!!)
  - Whole scene got brighter/darker together



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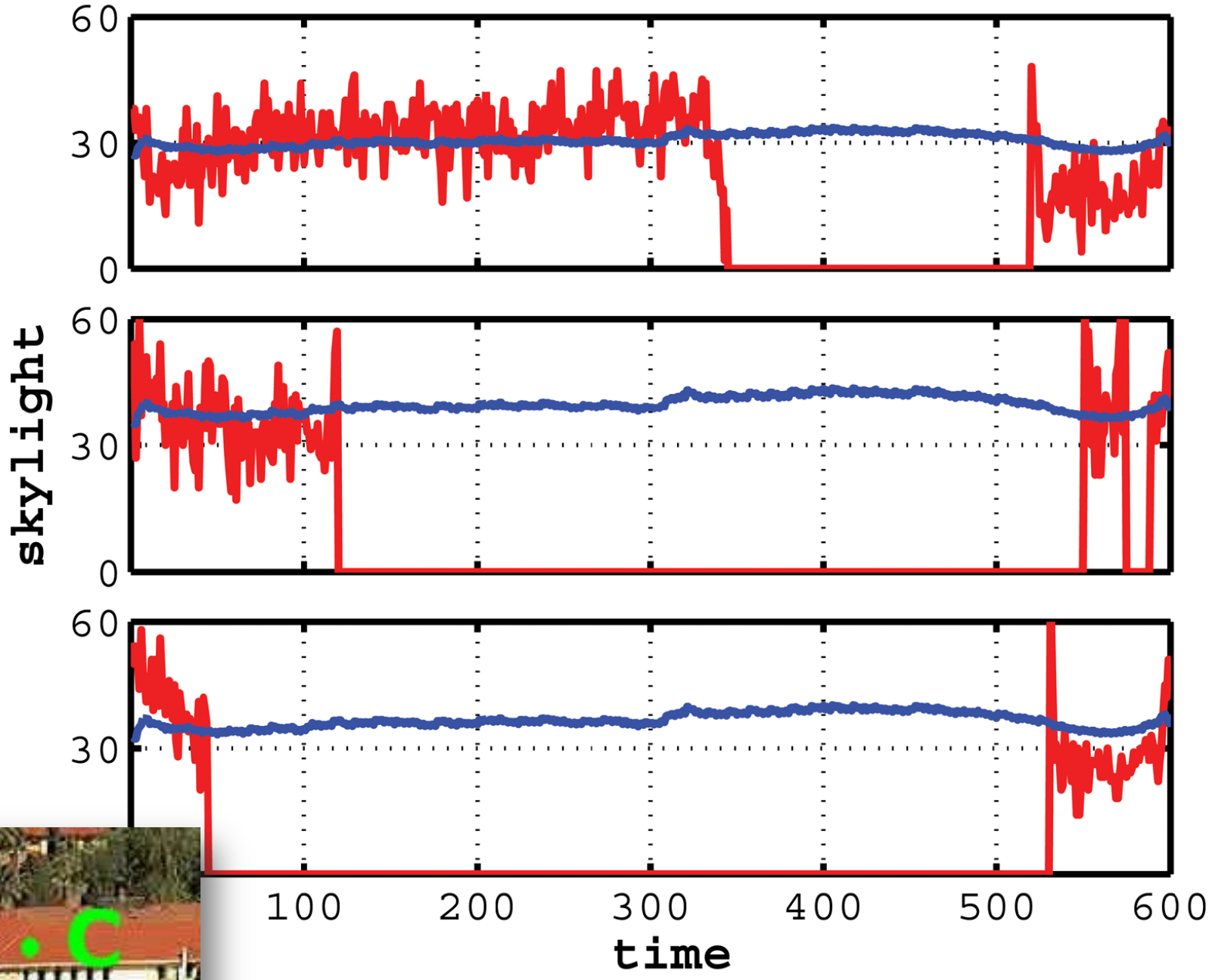
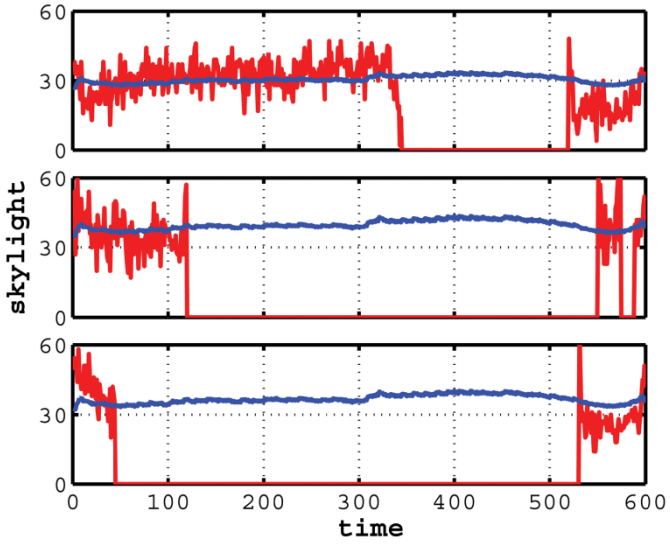


- Blue: skylight curve (same one)

Factorization

$$\mathbf{I}_{sky,i}(t) \approx \mathbf{W}_{sky,i}\,\mathbf{H}_{sky}(t)$$

- Decompose appearance into
  - per-pixel $\mathbf{W}$
  - $\mathbf{H}$ curve
- Alternating Constrained Least Squares (ACLS):
  - $\mathbf{H}(t)$ is held fixed while $\mathbf{W}$ is optimized using least squares, then vice versa



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ACLS: Alternating Constrained Least Squares

- Inverse shade trees for non-parametric material representation and editing,
  - Lawrence et al., Siggraph 2006, code online

Algorithm Groups	Properties:		
	Linear	Positive	Sparse
SVD / ICA	Yes	No	No
Homomorphic	No	Yes	No
Clustering	No	Yes	Yes
NMF / pLSI	Yes	Yes	No
Our Method: ACLS	Yes	Yes	Yes

Table 1: *Comparison of matrix factorization algorithms. Existing methods do not satisfy the three properties of linearity, positivity, and control over sparsity, which are critical for a meaningful editable decomposition.*

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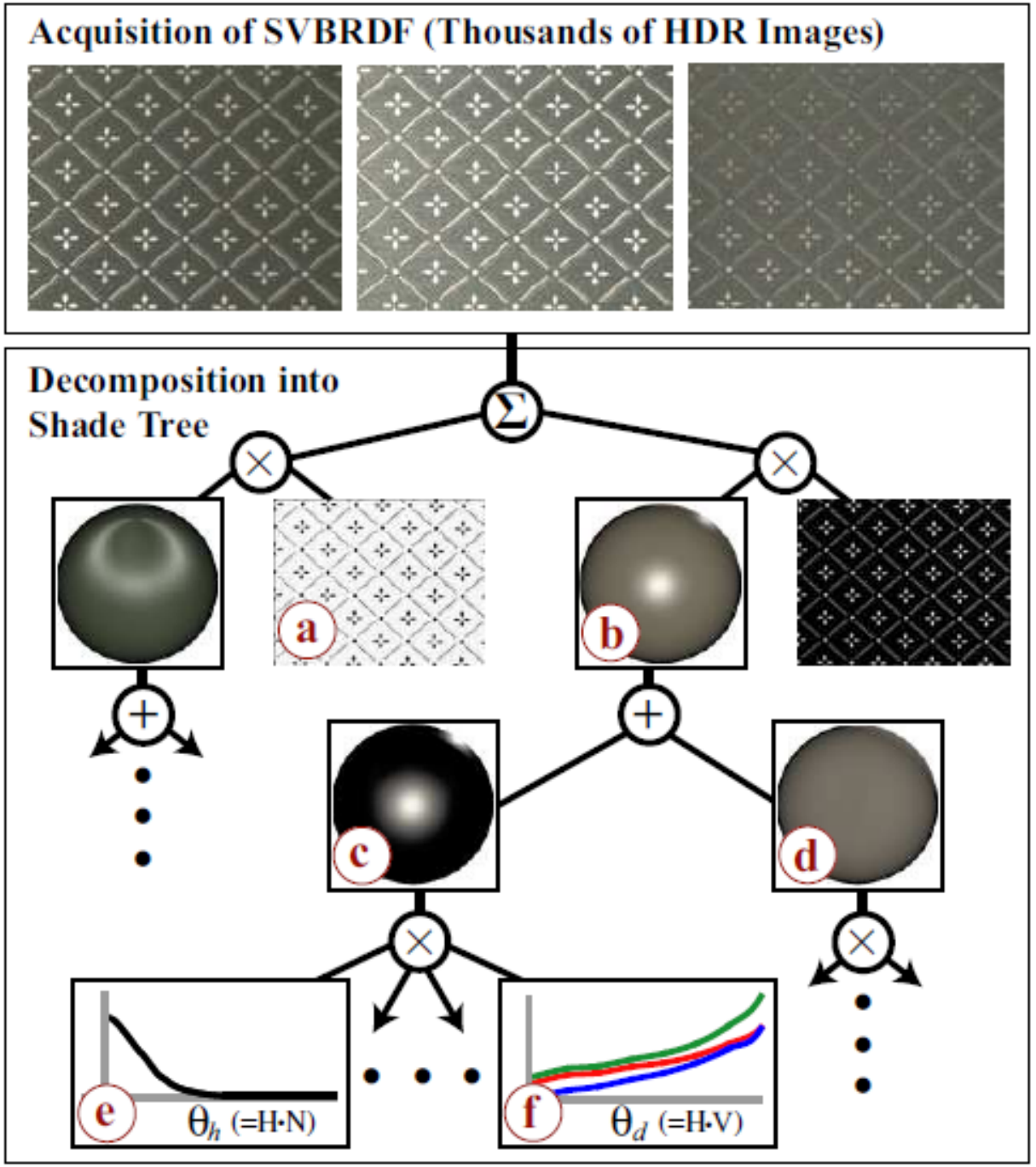
Acquisition of SVBRDF (Thousands of HDR Images)
Decomposition into
Shade Tree
Σ
a
b
c
d
e
f
θ_h (=H·N)
θ_d (=H·V)

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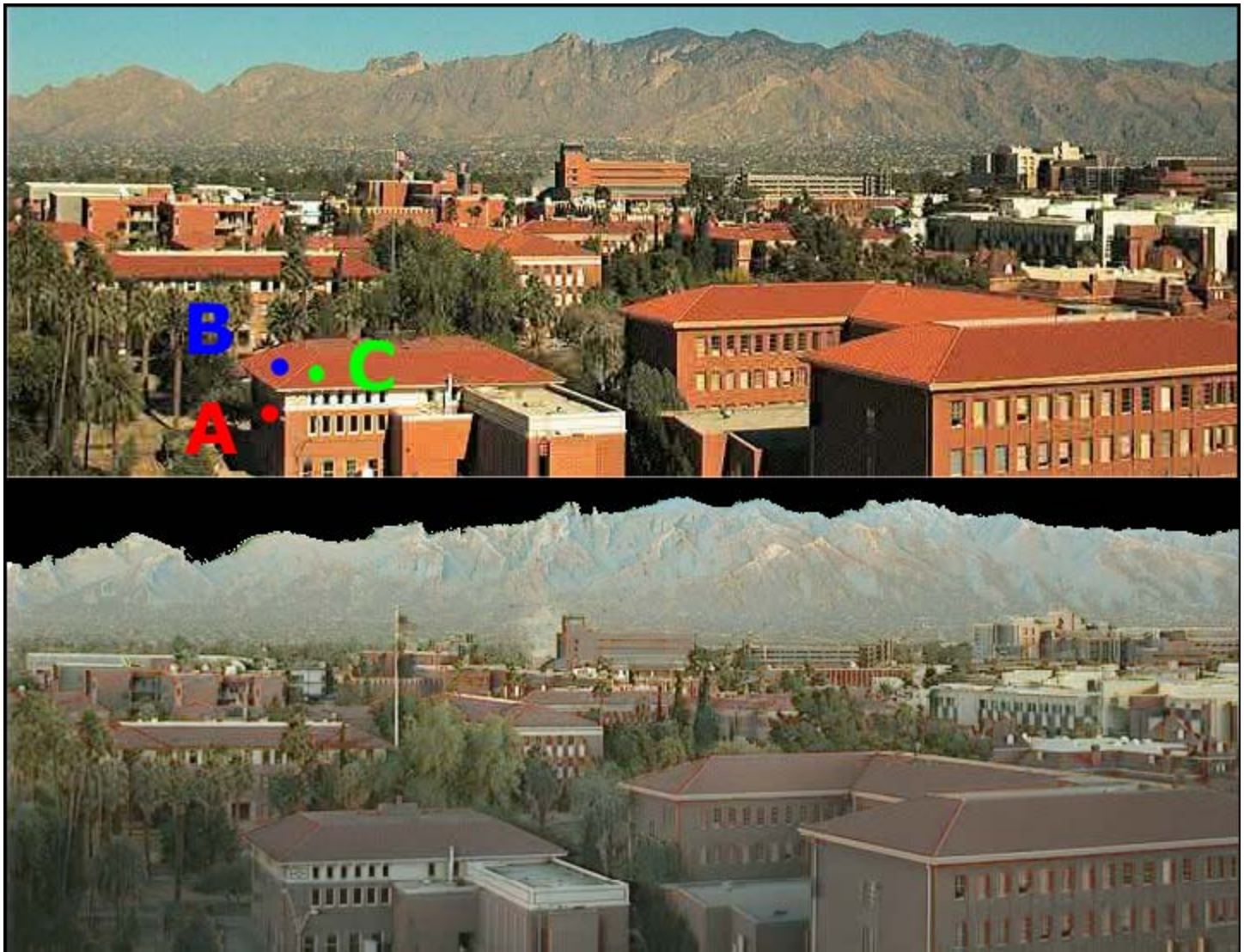
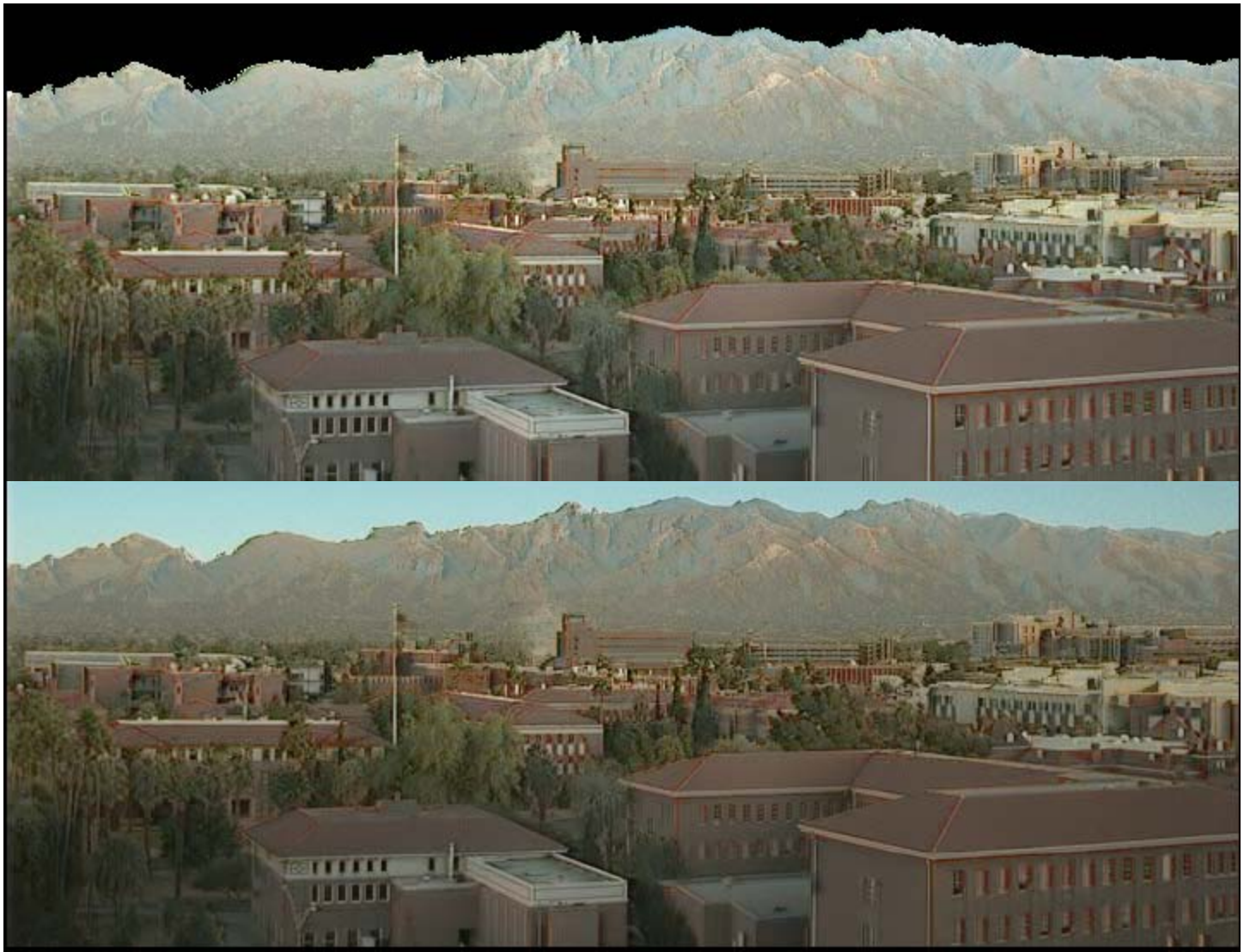
Original and I_{sky}



I_{sky} and Reconstruction



Explained Sky…

$$\mathbf{F}(t) = \mathbf{I}_{sky}(t) + \mathbf{S}_{sun}(t) * \mathbf{I}_{sun}(t)$$

$$\mathbf{I}_{sky,i}(t) \approx \mathbf{W}_{sky,i}\,\mathbf{H}_{sky}(t)$$

Now Decompose Sun's Contributions

$$\mathbf{F}(t) = \mathbf{I}_{sky}(t) + \mathbf{S}_{sun}(t) * \mathbf{I}_{sun}(t)$$

$$\mathbf{I}_{sun,i}(t) \approx \mathbf{W}_{sun,i}\, \mathbf{H}_{sun}(t + \Phi_i)$$

- $\mathbf{I}_{sun}$: Accumulated intensity due to sun-light
- $\mathbf{W}_{sun}$: Sun-light image, per-pixel weights
- $\mathbf{H}_{sun}$: Sun-light basis curve
- Φ_i : Shift-map; per pixel offset in time

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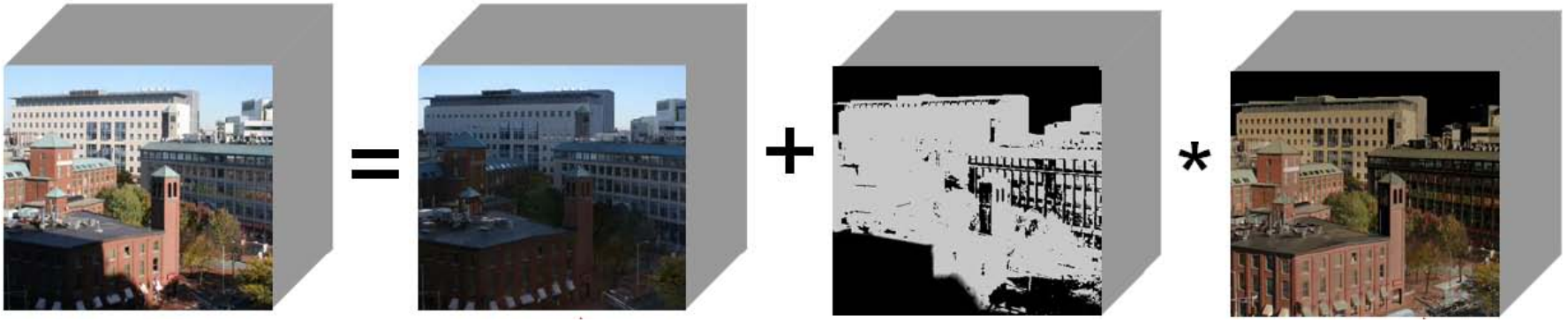
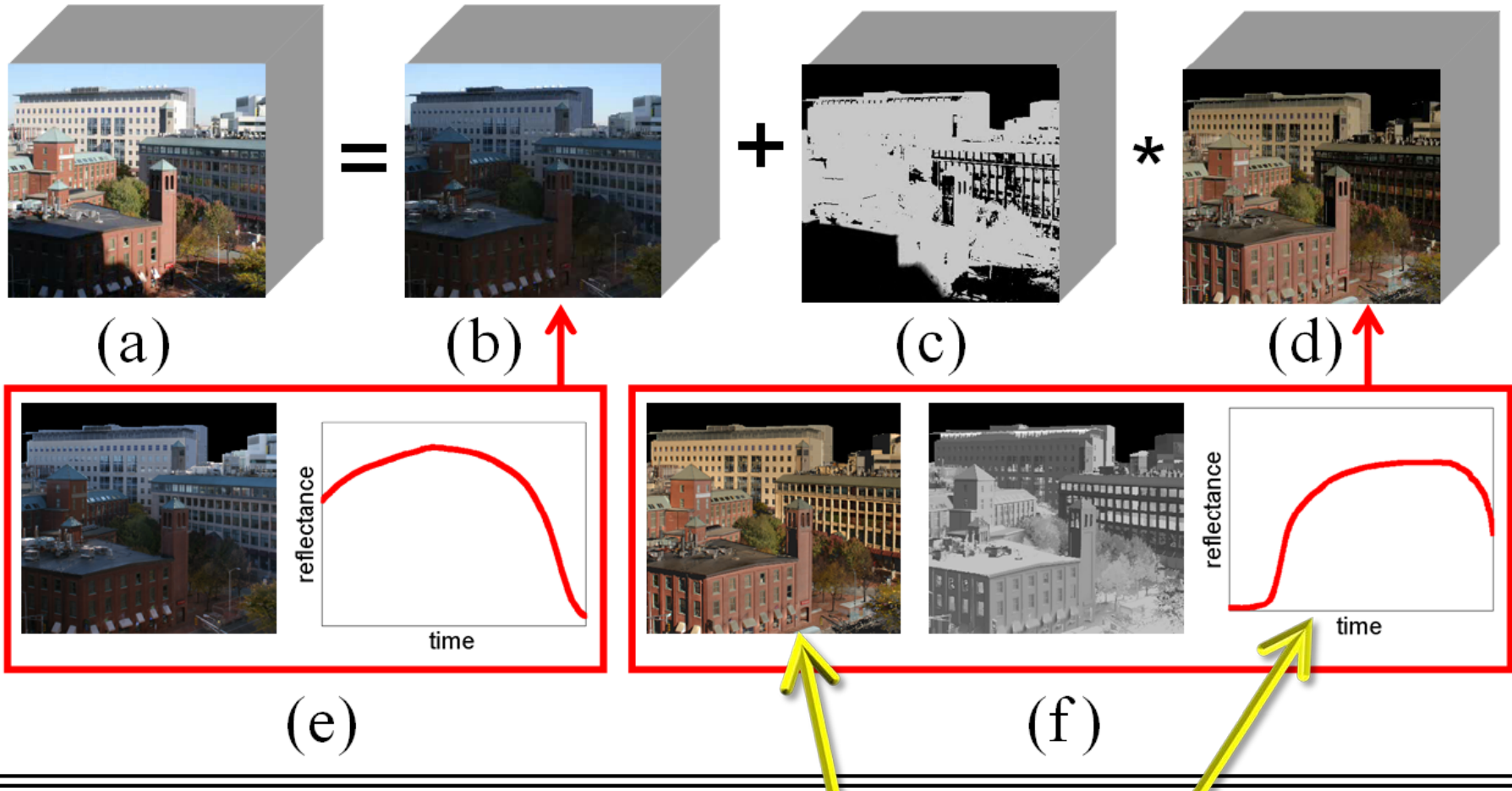
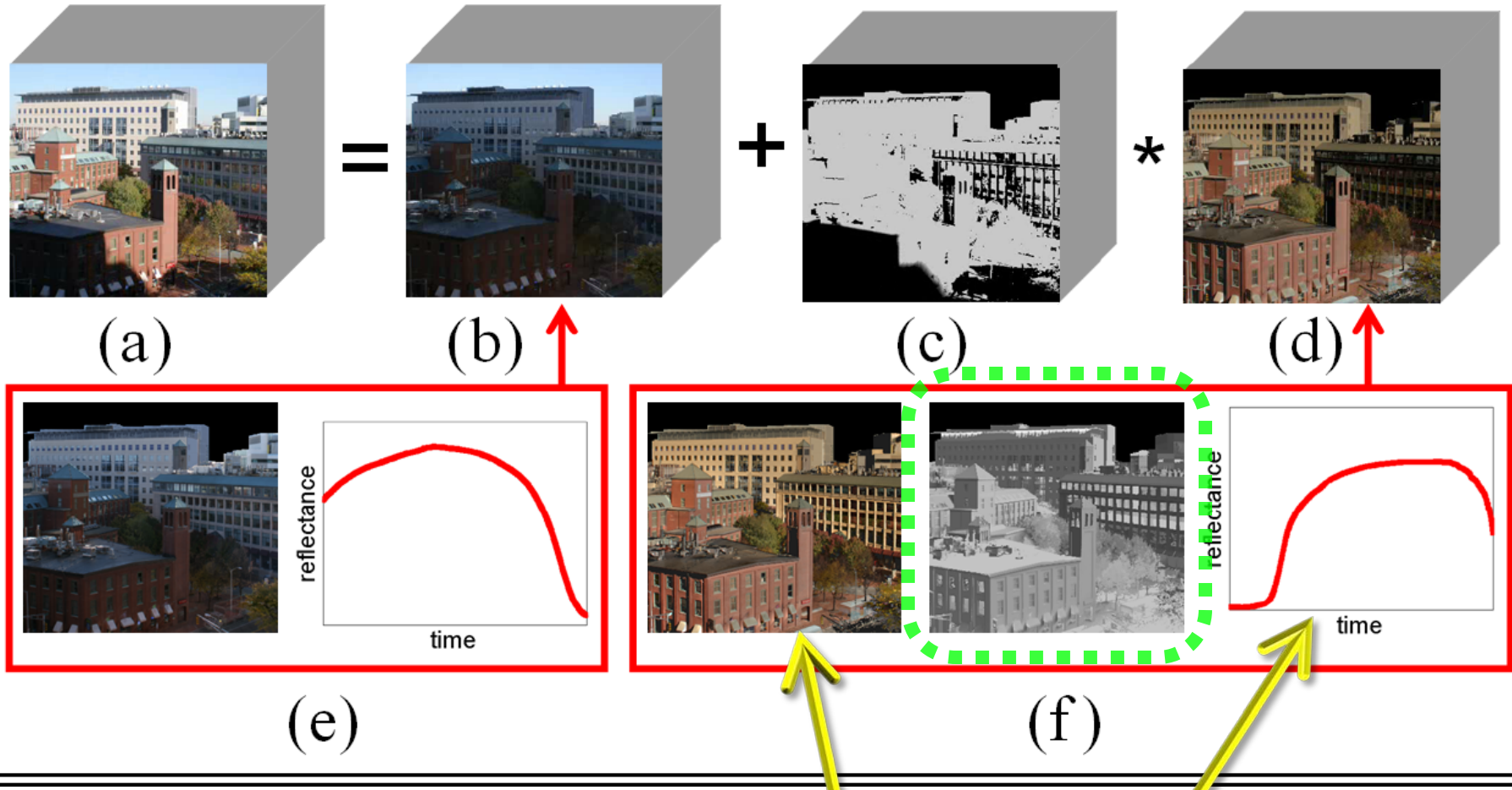


$$\mathbf{F}(t) = \mathbf{I}_{sky}(t) + \mathbf{S}_{sun}(t) * \mathbf{I}_{sun}(t)$$



$$\mathbf{I}_{sun,i}(t) \approx \mathbf{W}_{sun,i}\,\mathbf{H}_{sun}(t + \Phi_i)$$

- $\mathbf{I}_{sun}$: Accumulated intensity due to sun-light
- $\mathbf{W}_{sun}$: Sun-light image, per-pixel weights
- $\mathbf{H}_{sun}$: Sun-light basis curve
- Φ_i : Shift-map; per pixel offset in time



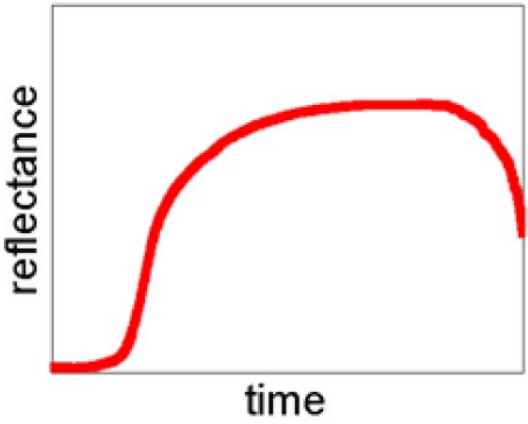
$$\mathbf{I}_{sun,i}(t) \approx \mathbf{W}_{sun,i}\,\mathbf{H}_{sun}(t + \Phi_i)$$

- $\mathbf{I}_{sun}$: Accumulated intensity due to sun-light
- $\mathbf{W}_{sun}$: Sun-light image, per-pixel weights
- $\mathbf{H}_{sun}$: Sun-light basis curve
- Φ_i : Shift-map; per pixel offset in time

Total sunlight contribution

Sunlight image
(like on moon)

Shift map



Sunlight

Factorize Again!

- For each image, subtract off $\mathbf{I}_{sky}(\mathrm{t})$
- $\mathbf{S}_{sun}$: Sky-light mask, serves as $\boldsymbol{C}$, confidence map

- ACLS again
  - But add 3rd update phase, searching for Φ_i that minimizes reconstruction error of scaled + offset $\mathbf{H}(t)$ vs. $\mathbf{F}(t)$

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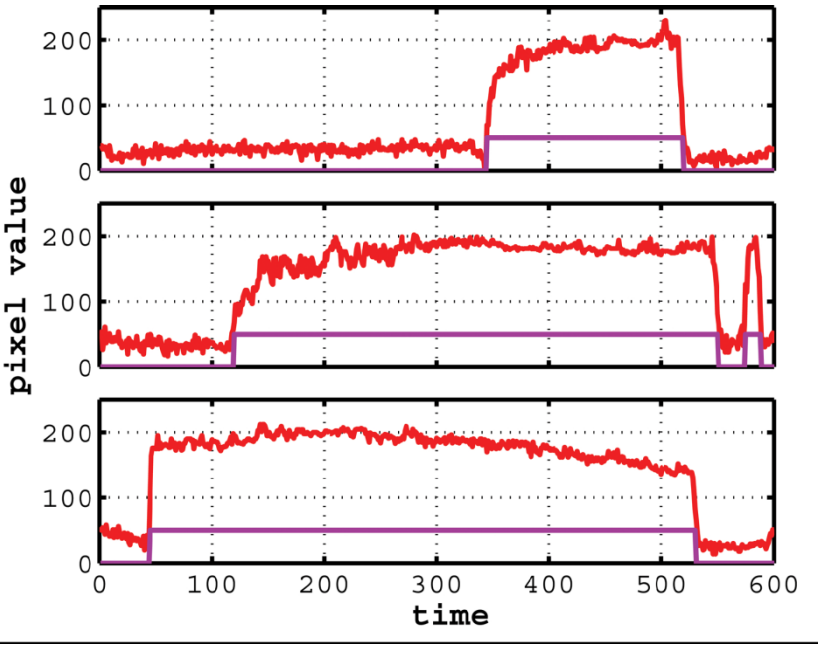
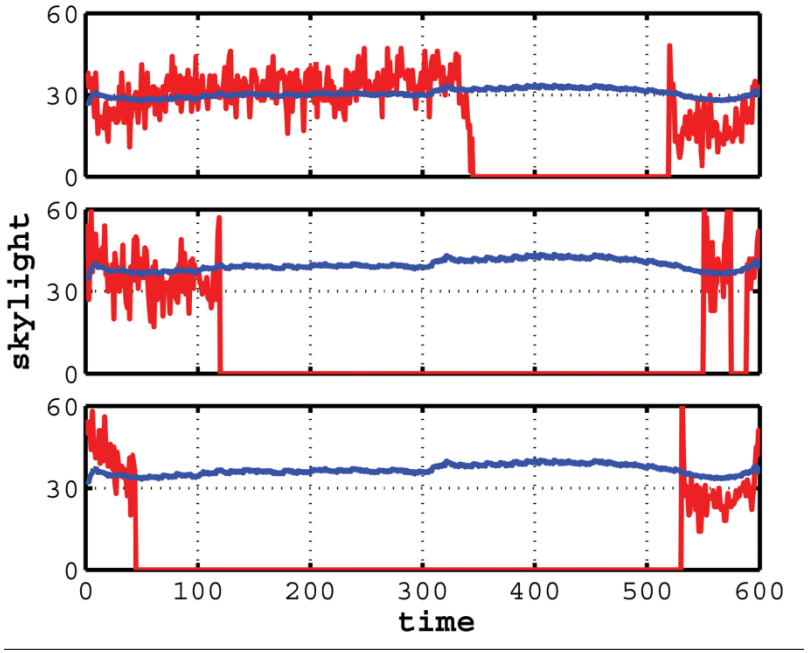
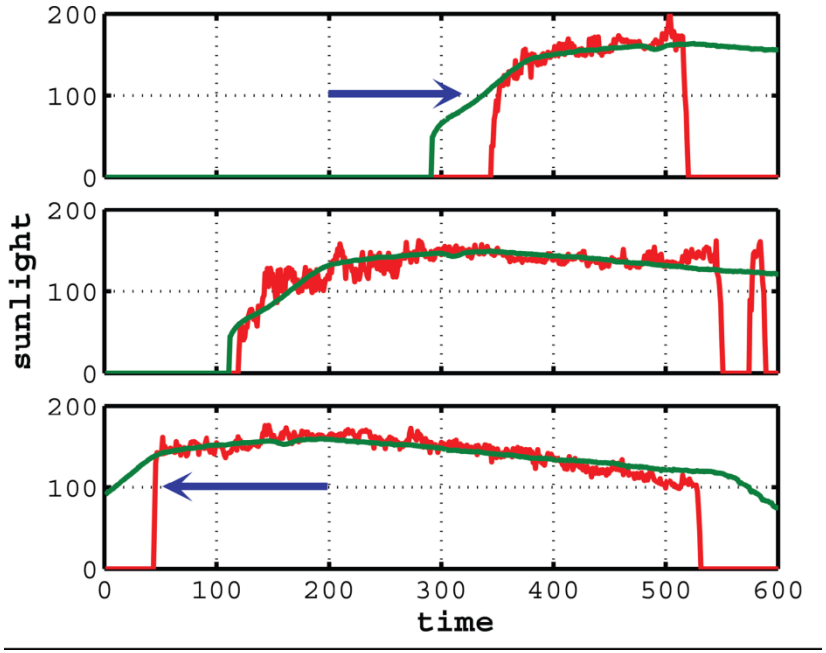
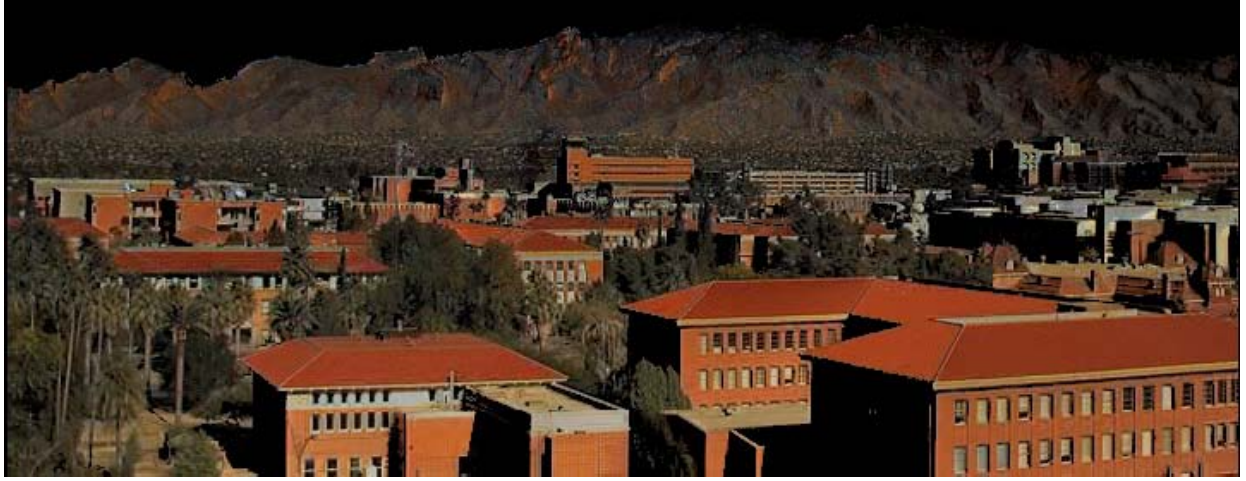




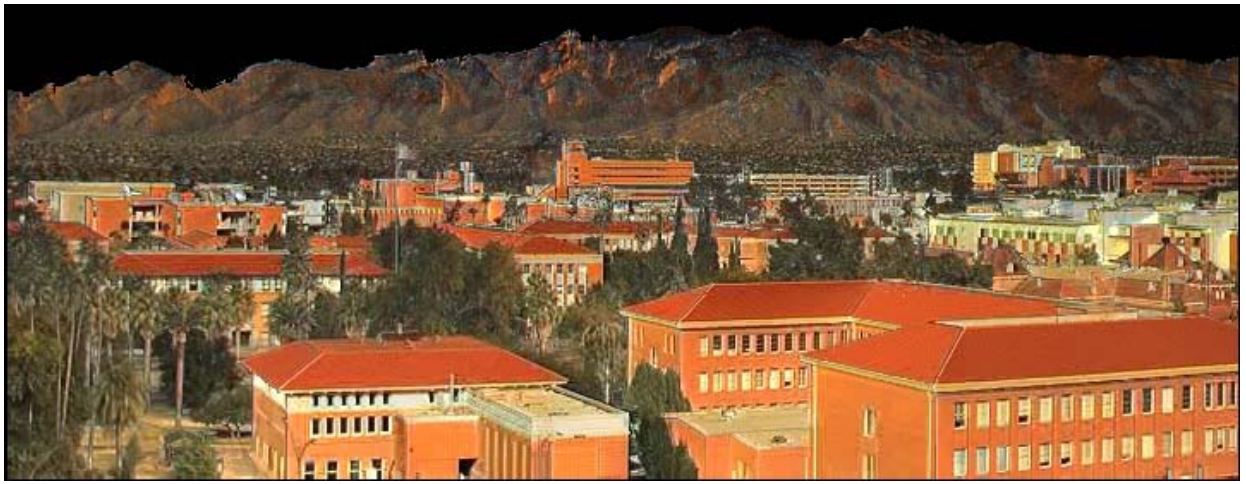
Green: sunlight curve

(same one, but time-shifted)

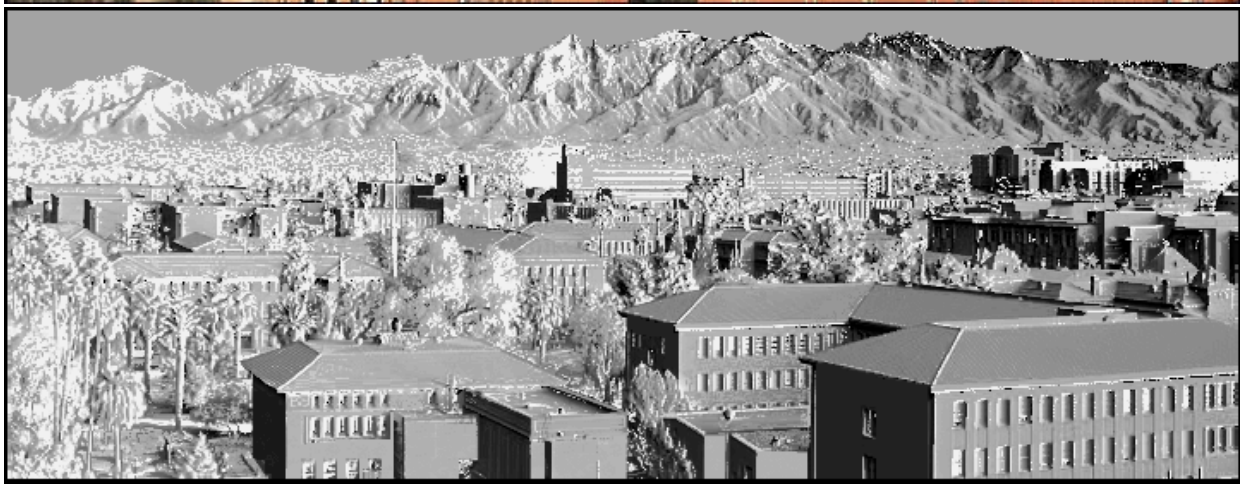




$\mathbf{I}_{sun}(t)$

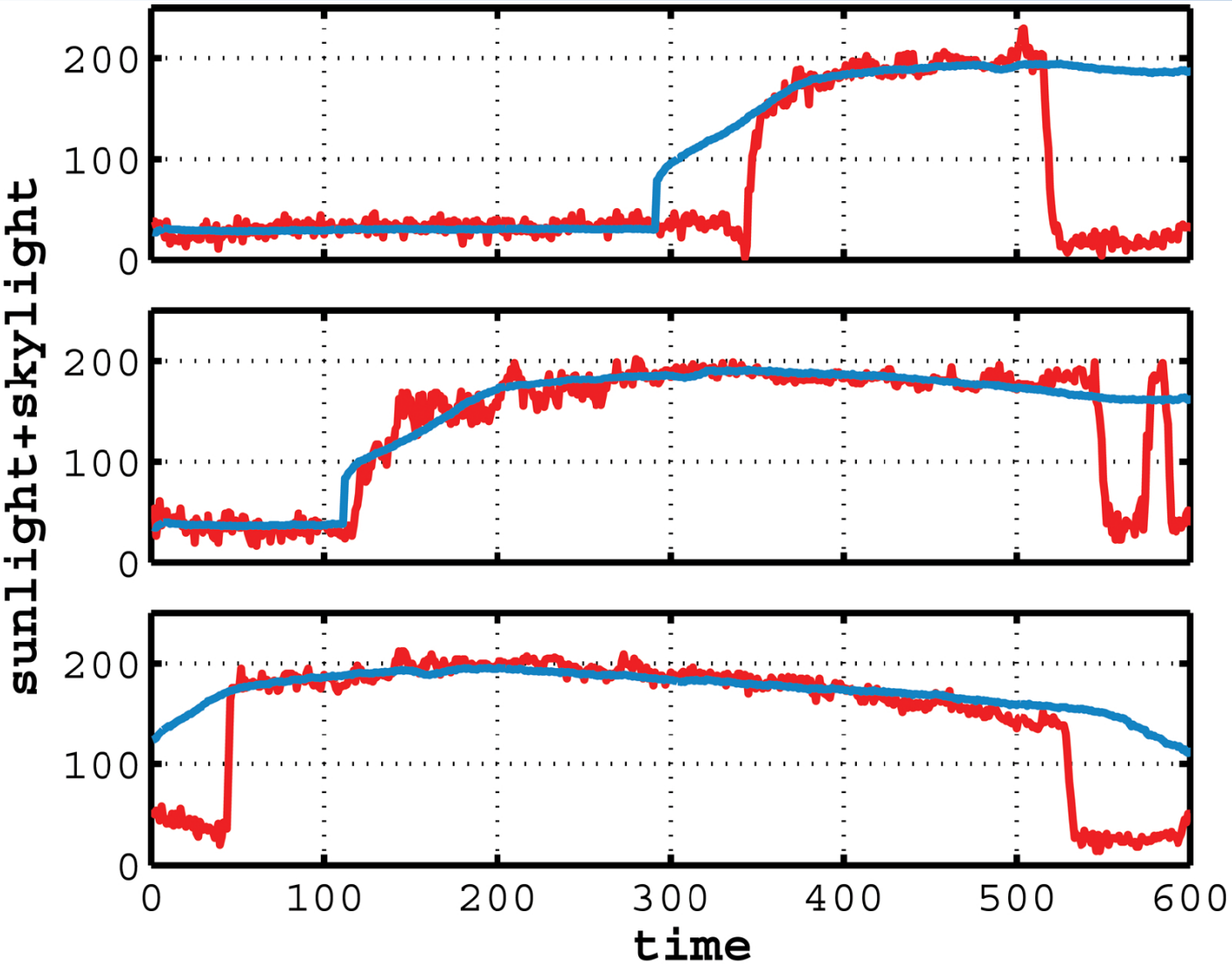


$\mathbf{W}_{sun}$



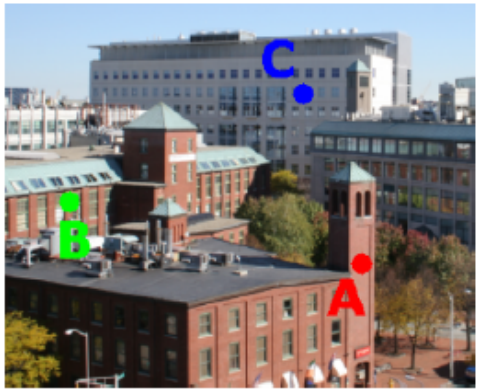
Φ_i

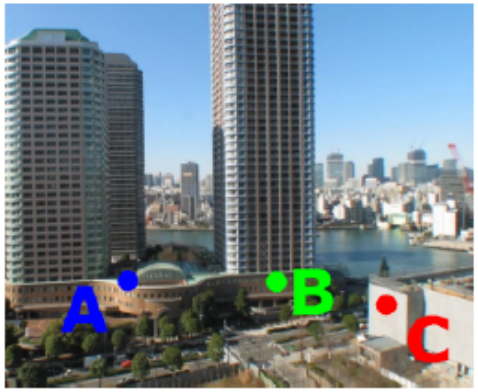
Reconstruction



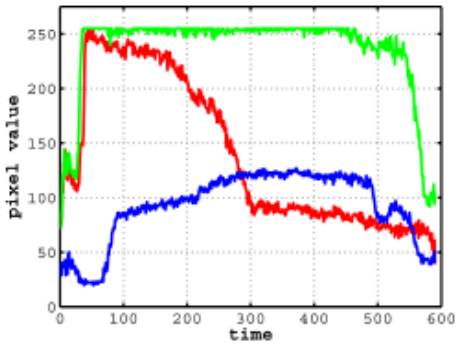
Does It Work?

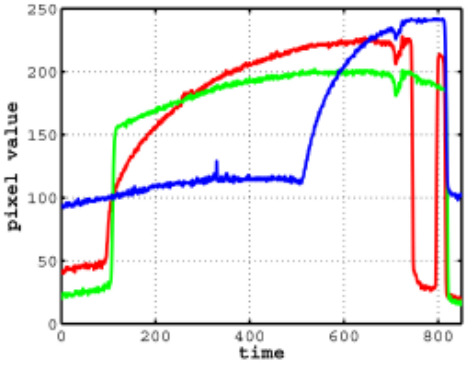

B
A
C

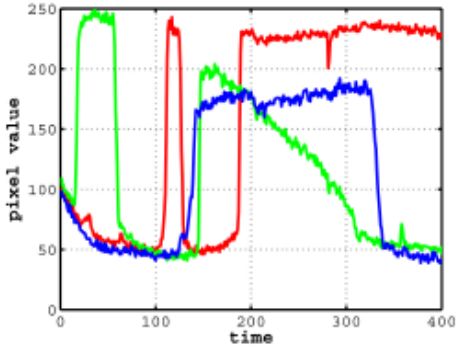

C
B
A

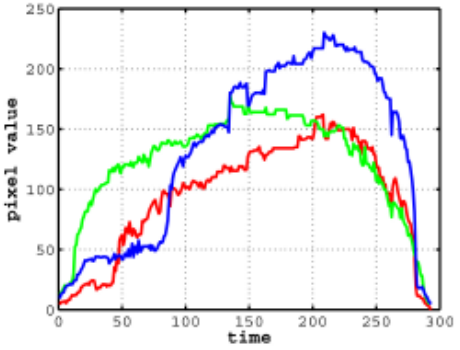

A
B
C

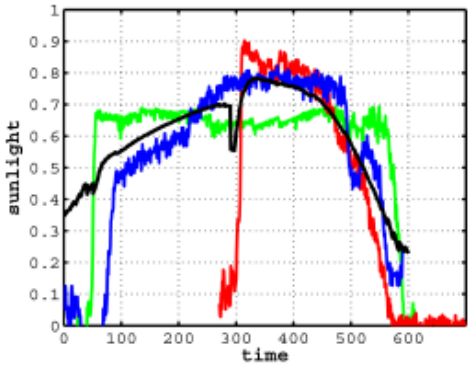

A
C
B

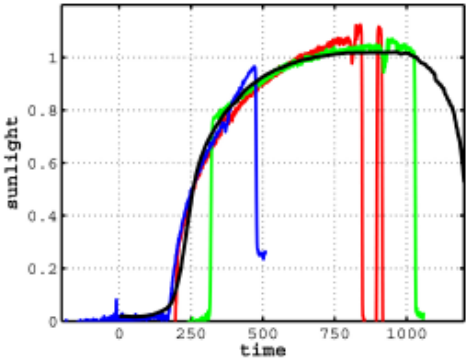

pixel value
time

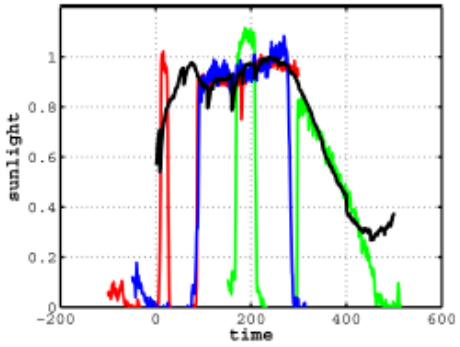

pixel value
time

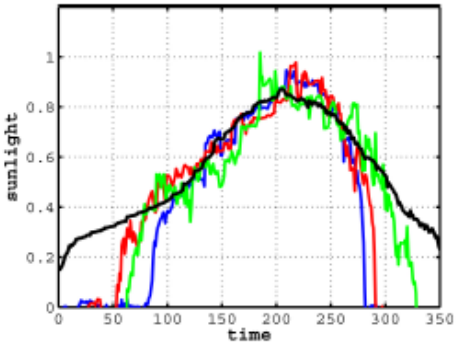

pixel value
time


pixel value
time

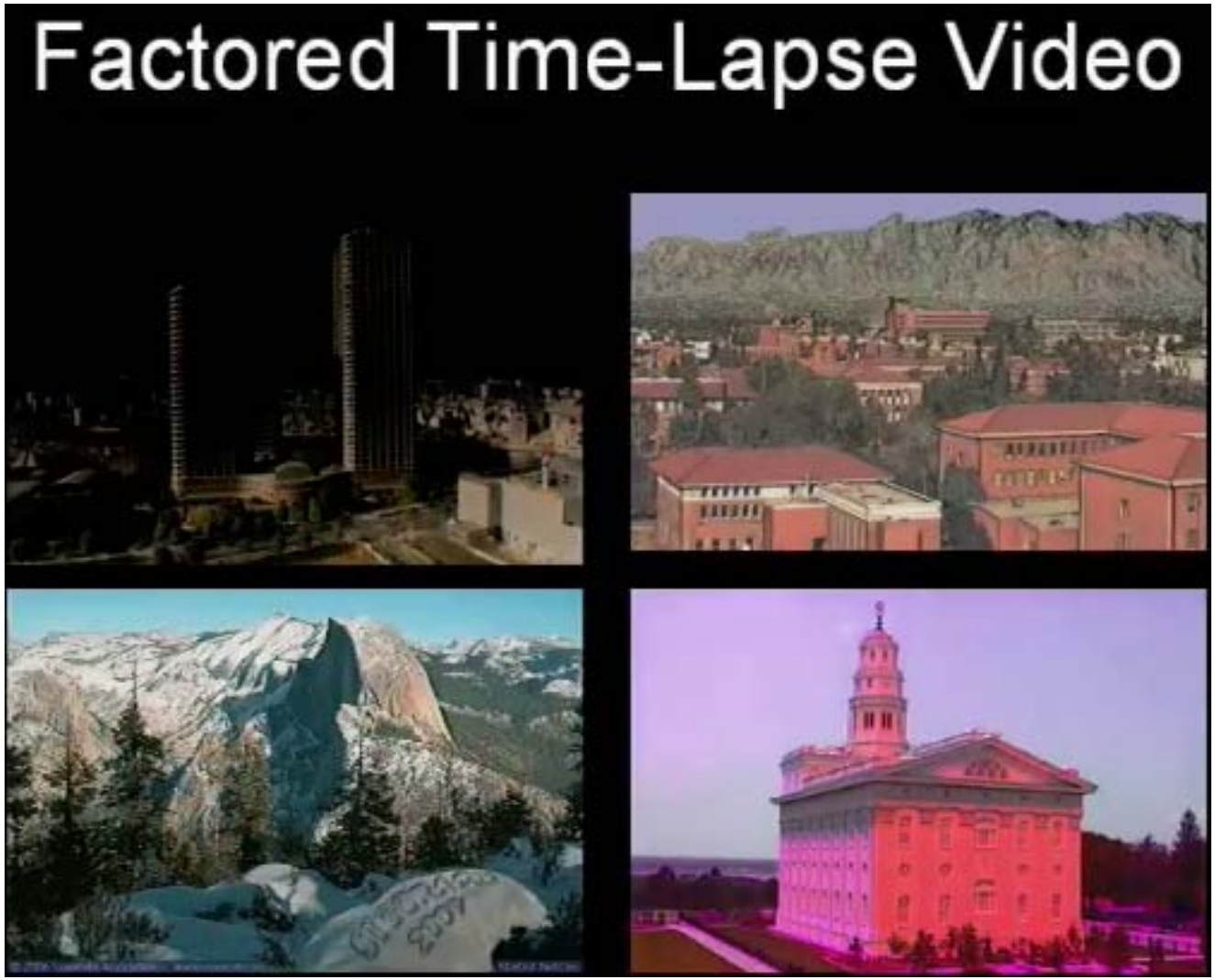

sunlight
time


sunlight
time


sunlight
time


sunlight
time

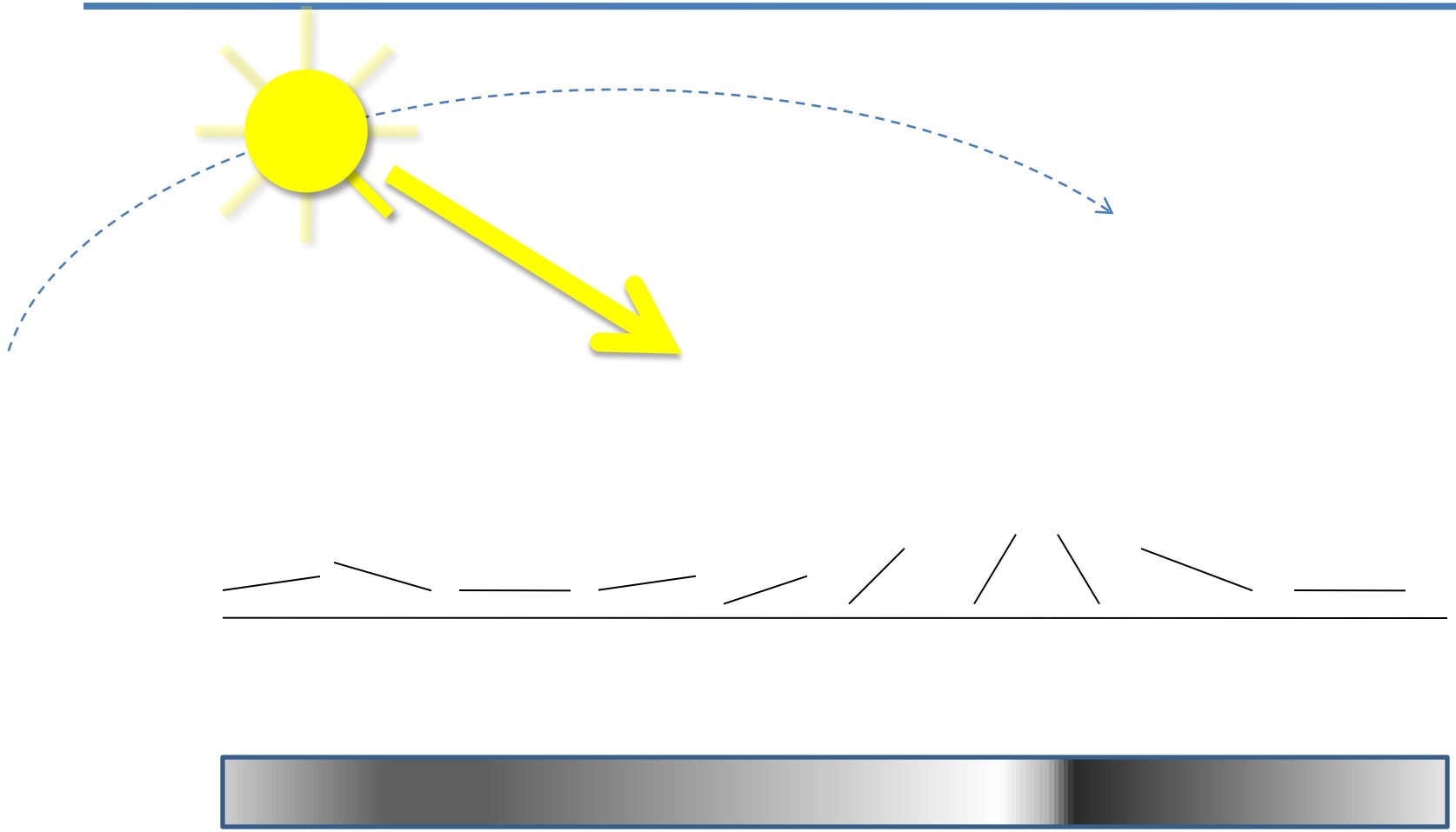
Video: FactoredTimeLapseV



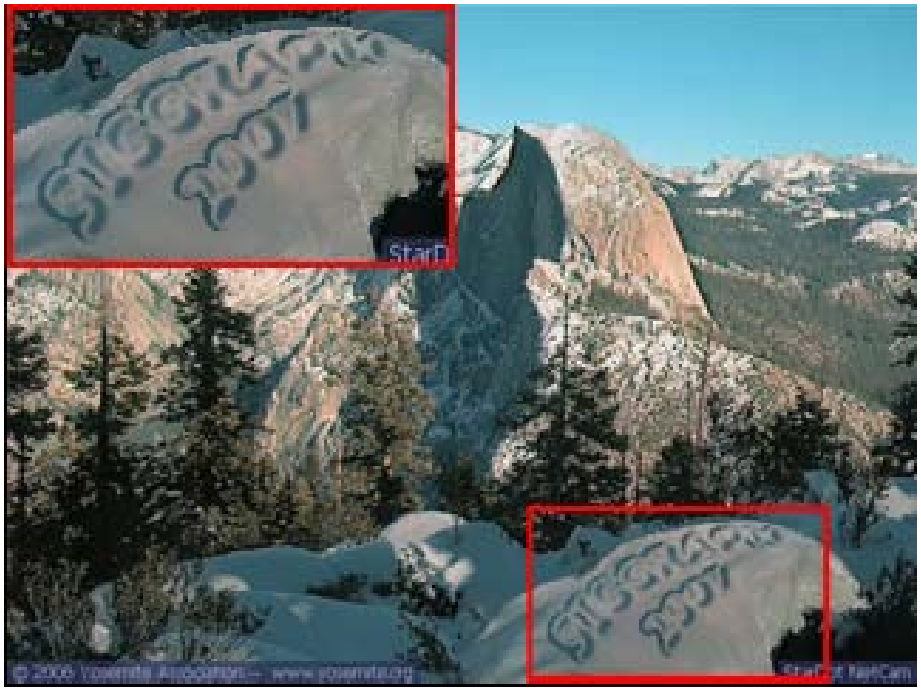
What have we gained?

- Can
  - Remove shadows
  - Change albedo
  - Change amount of global illumination
- Compression
- Render new shadows:
  - We have 1 component of the per-pixel Normals, $\mathbf{N}$

Estimated Normals (1D)



Recap: Manipulating Normals



Does the old definition of time-lapse still hold?

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Today's schedule

- Factored Time-Lapse Video
  - Sunkavalli, Matusik, Pfister, Rusinkiewicz, **Siggraph 2007**

- Computational Time-Lapse Video
  - Bennett & McMillan, **Siggraph 2007**
- Video Synopsis & Indexing,
  - Pritch, Rav-Acha, Peleg, **ICCV 2007**

Still 1 frame at a time

Examine parts of frames

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(Quick Overview of) Computational Time-Lapse Video

Bennett & McMillan

Siggraph 2007

(Project web page)

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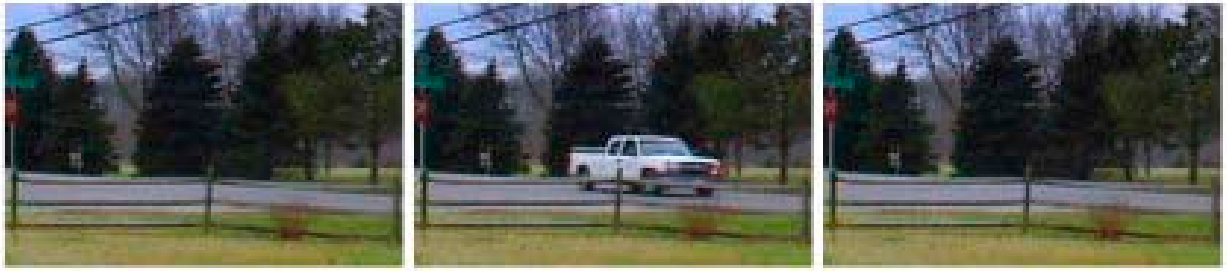
Uniform Sampling



Uniform Sampling With Motion Tails

Non-Uniform Sampling

Non-Uniform Sampling With Motion Tails

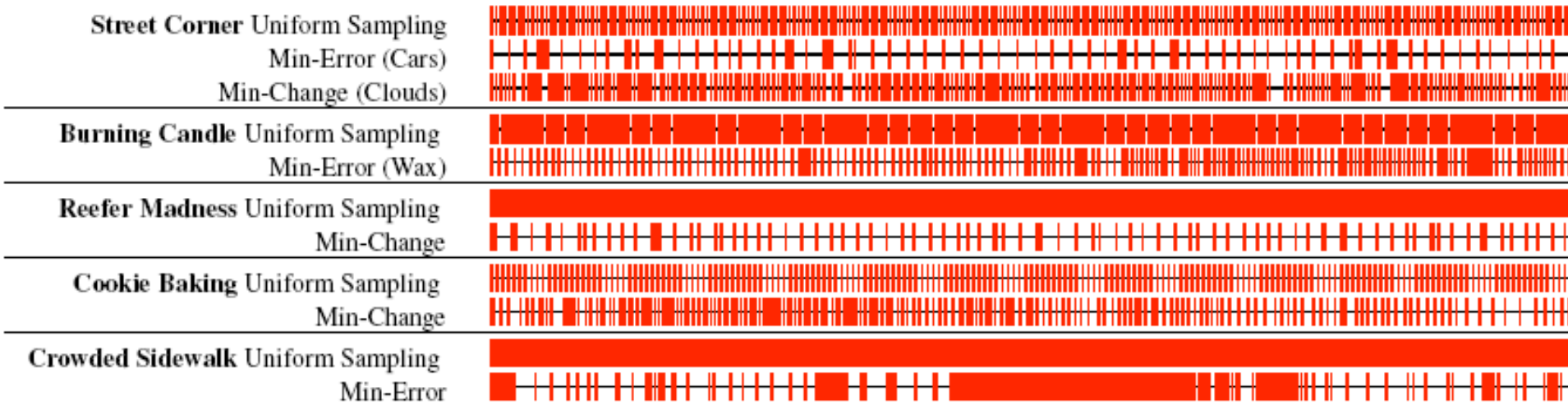
Frame $n-1$ Frame n Frame $n+1$

Sampling in 1D

- Uniform
- Interpolate linearly+ piece-wise

- Same # of samples, but where needed!
- Optimum polygonal approximation of digitized curves, Perez & Vidal, PRL'94
  - Use dynamic programming to find global min.

Completely User-controllable: Min-Change, Min-Error, Median, etc



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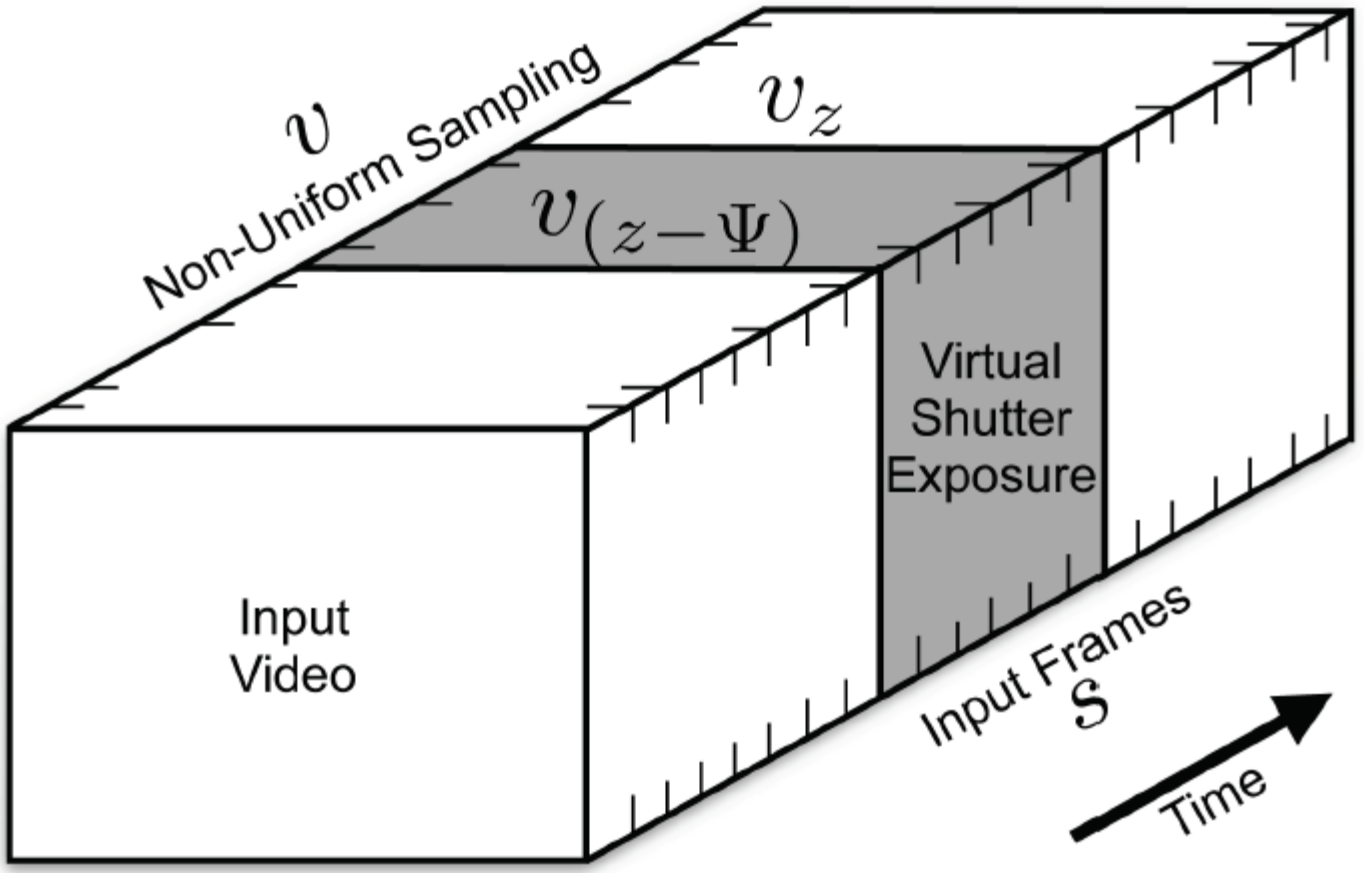
Video

Virtual Shutter



(View Results of)
Video Synopsis & Indexing

Pritch, Rav-Acha, Peleg

ICCV 2007, PAMI 2008

(Project web page)

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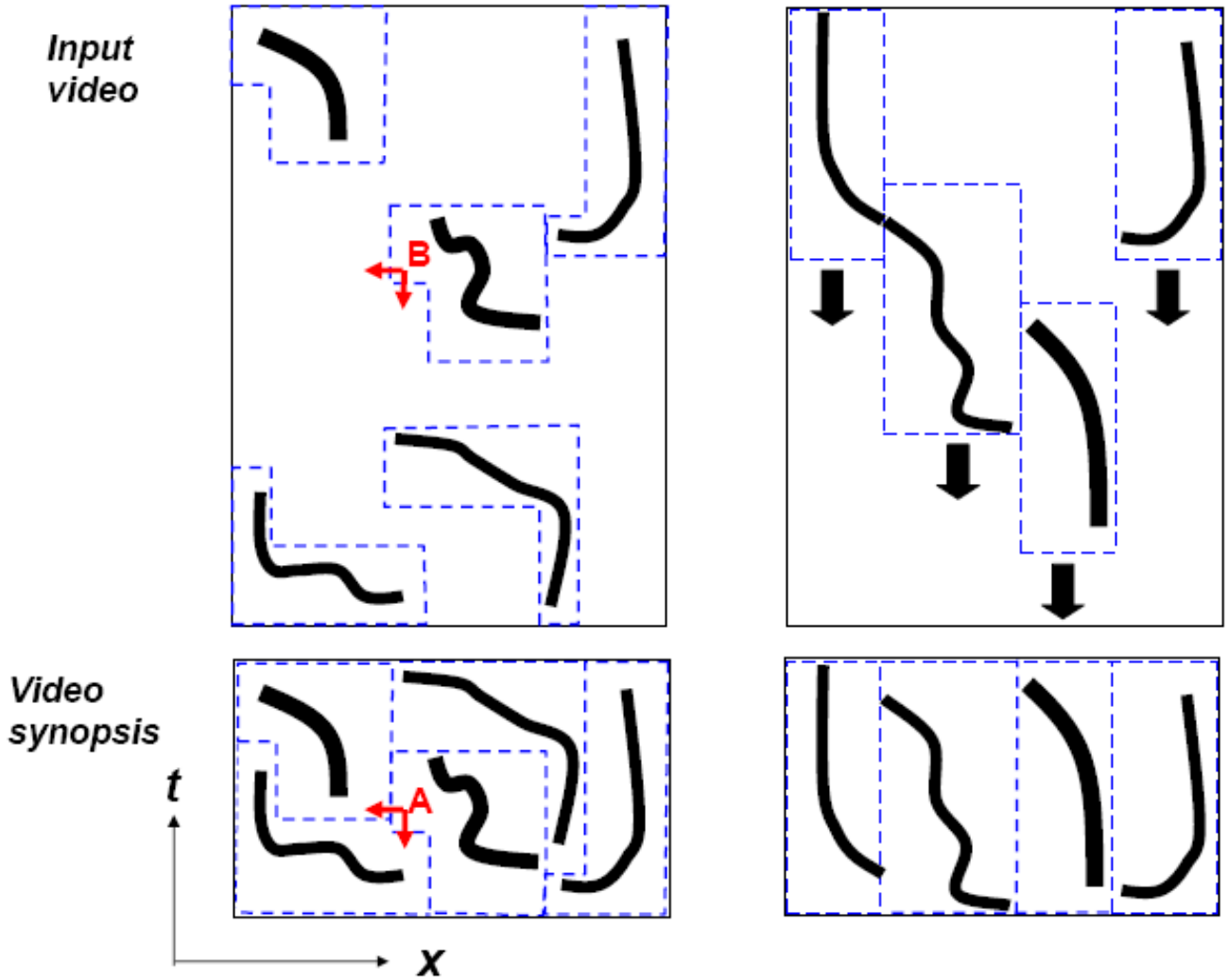
What to do with blob-tracks?



[(Project web page)]

HDR Time-Lapse

- Essentially started in 2006 (manually at first)
- More are popping up online

Discussion