High Dynamic Range Reconstruction: A Patch-based Approach

CVFX 2015

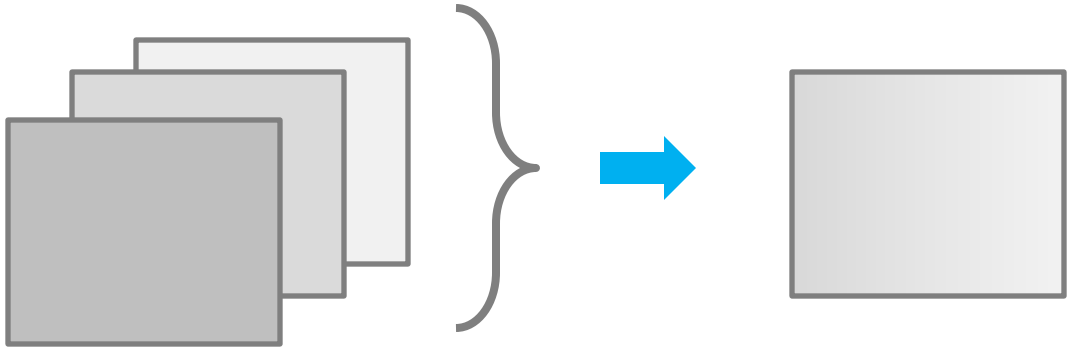
How to capture HDR images

[Sen et al.]

How to capture HDR images

Taking multiple images with different exposures

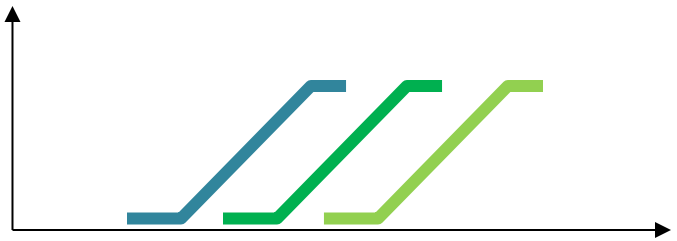
Multiple LDR images → an HDR image



Issues

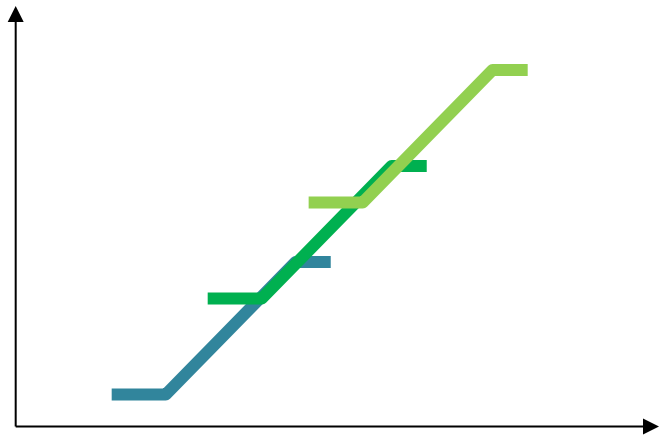
- **Camera response curves**
- **Linear format, raw data, de-mosaic**
- **Well exposed, over-saturated, under-exposed**

pixel value

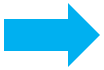


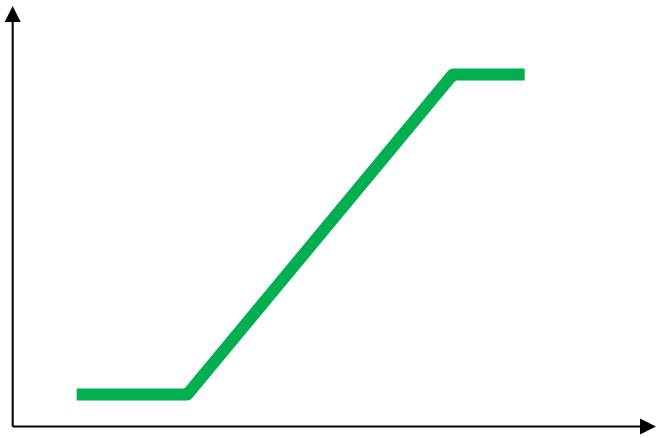
scene radiance

irradiance



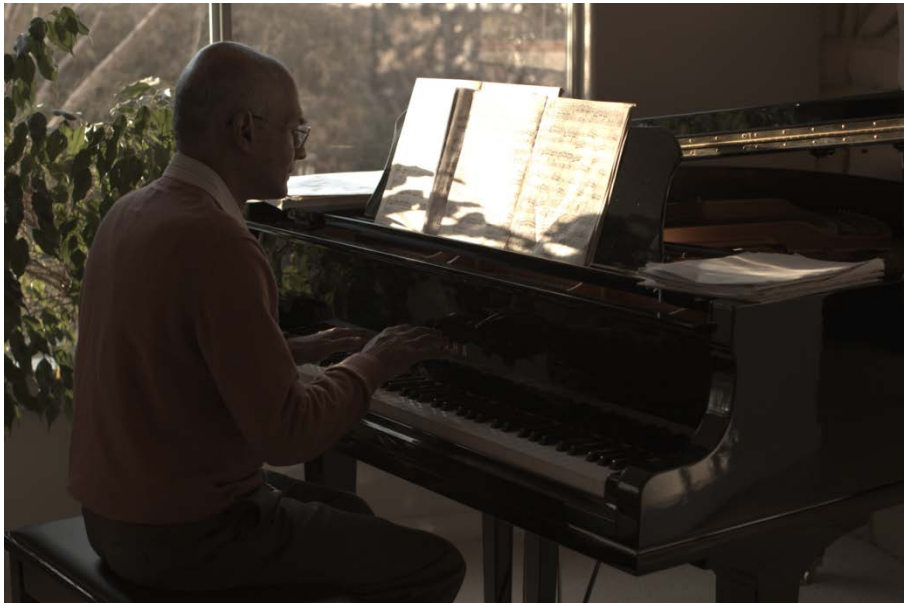
scene radiance





So, what is the problem?

The scene is not static



non-rigid motion

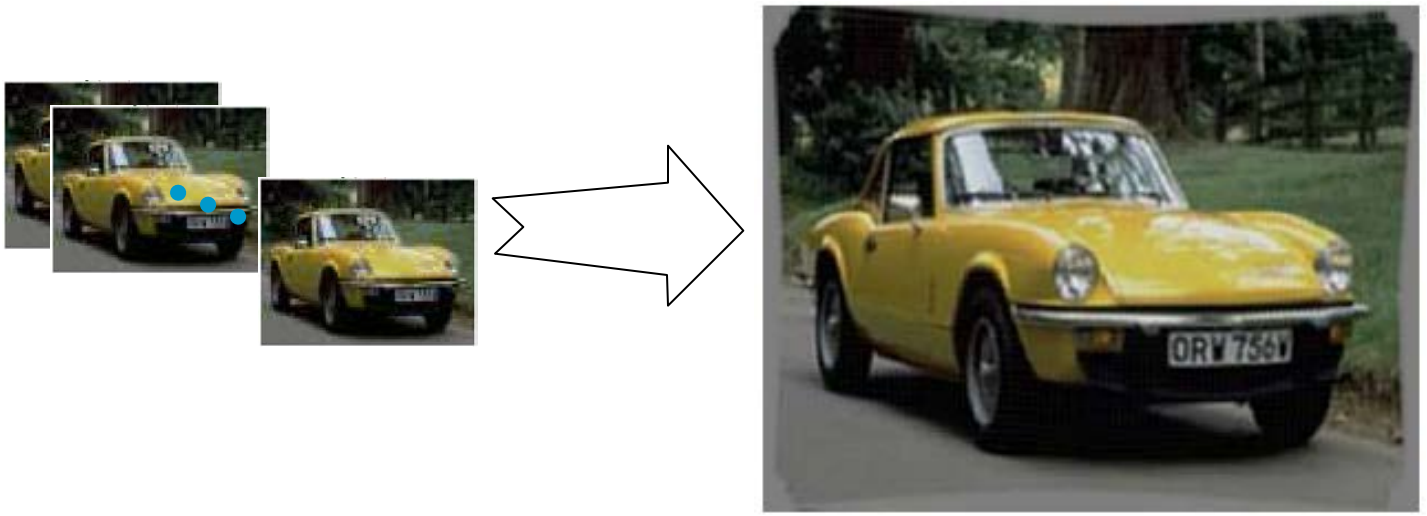
Taking multiple images is very useful.

The key is image alignment, in particular dense correspondence.

Super-resolution
De-noising
Panorama stitching
Stereo matching
Depth, refocusing
…

Example: image super-resolution

- **Extracting a single high-quality image from a set of low-resolution images**

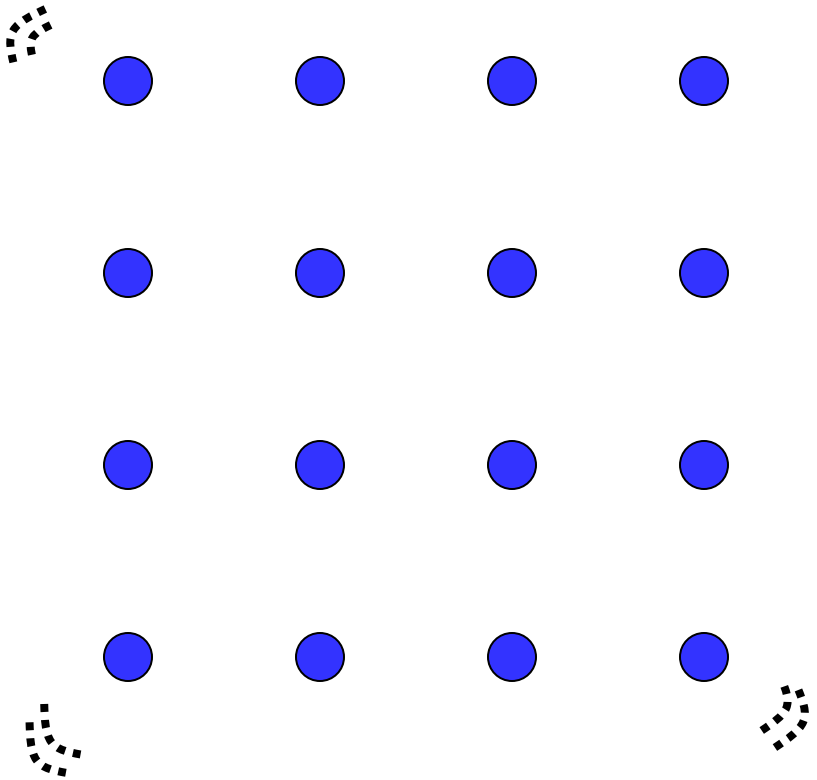


How to take a 72-megapixel image with an 18-megapixel camera?

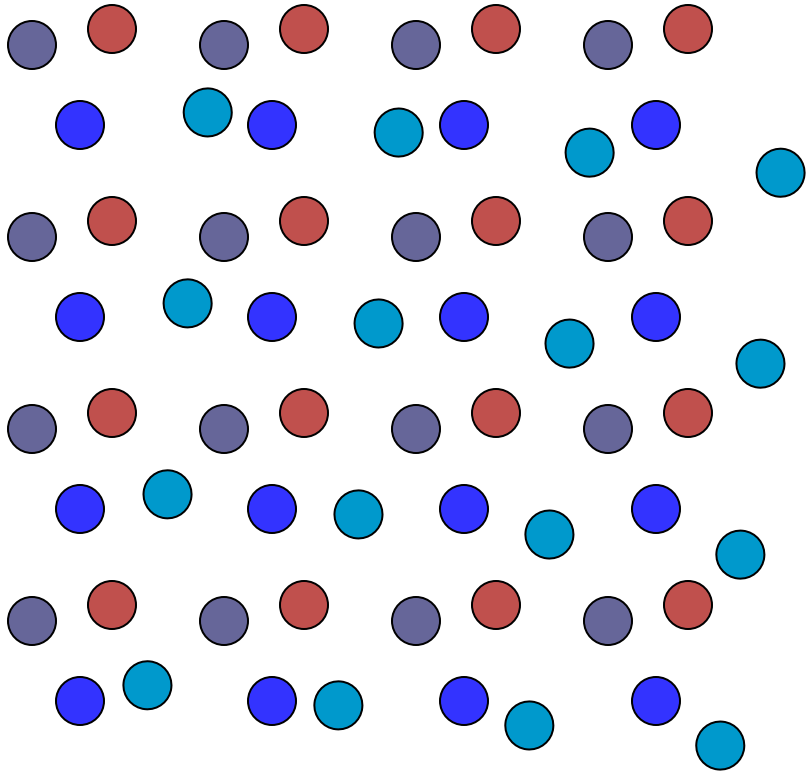
If you have a tripod

Image Stitching

A different way of sampling



A different way of sampling



Super-resolution

De-noising

Panorama stitching

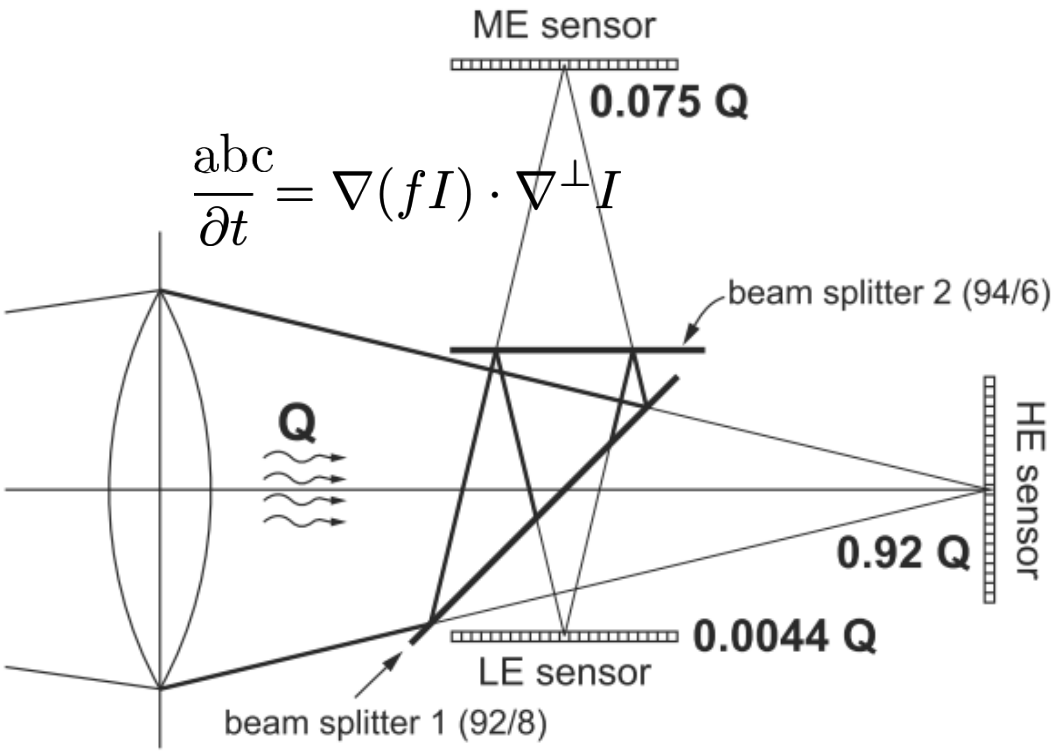
Stereo matching

Depth, refocusing

…

High dynamic range reconstruction

Beam splitter



Robust Patch-Based HDR Reconstruction of Dynamic Scenes

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Dan B Goldman[3] Eli Shechtman[3]

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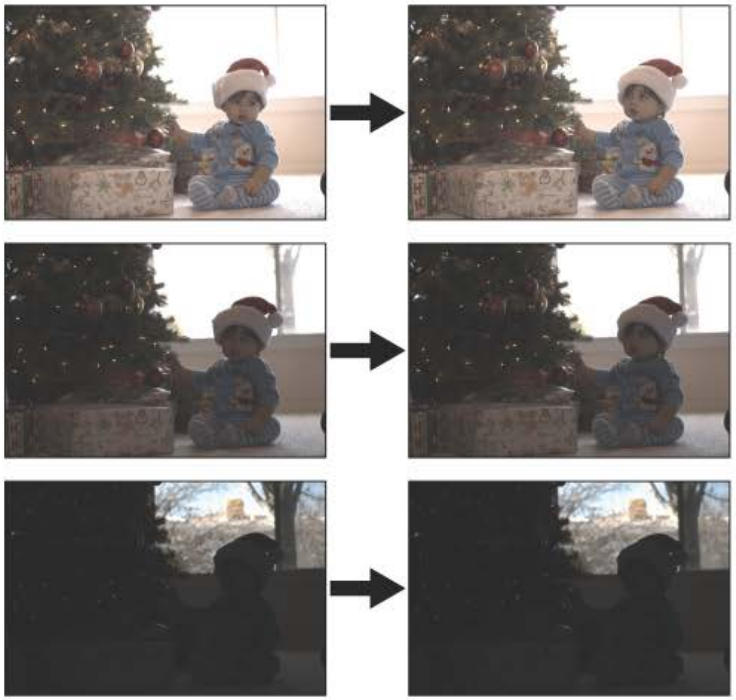


Input LDR sources Reconstructed LDR images

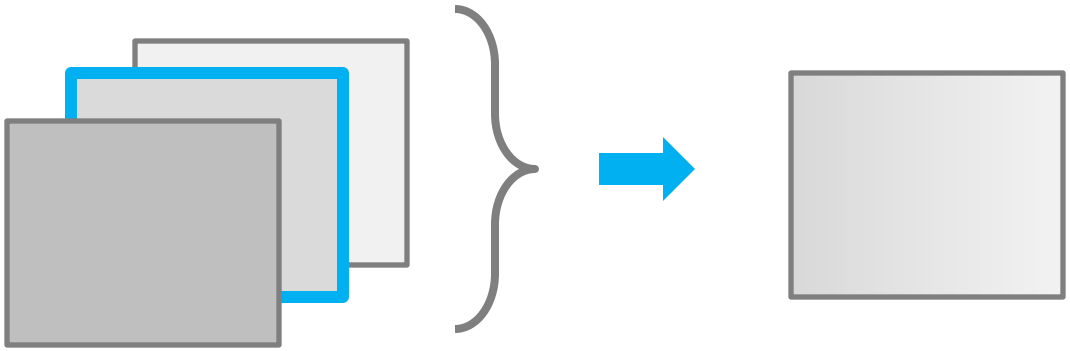
Final tonemapped HDR result

Patch-based optimization for HDR reconstruction

Input: LDR images $L_1, \ldots, L_N$

LDR reference L_{ref}

Output: HDR image H



Patch-based optimization for HDR reconstruction

Input: LDR images $L_1, \ldots, L_N$

LDR reference L_{ref}

Output: HDR image H

Desired properties of H?

Energy minimization

fidelity in well exposed regions

$$E(H) = \sum_{p \in \text{pixels}} \Big[\alpha_{\text{ref}_{(p)}} \cdot \left(h(L_{\text{ref}})_{(p)} - H_{(p)} \right)^2 + \left(1 - \alpha_{\text{ref}_{(p)}}\right) \cdot E_{\text{MBDS}}(H \mid L_1, \ldots, L_N) \Big]$$

information from poorly exposed pixels
patch-based similarity

(Patch-based) Multisource Bi-Directional Similarity measure

$$E_{\mathrm{MBDS}}(H \mid L_1, \ldots, L_N) = \sum_{k=1}^{N} \mathrm{MBDS}\left(l^k(H) \mid g^k(L_1), \ldots, g^k(L_N)\right)$$

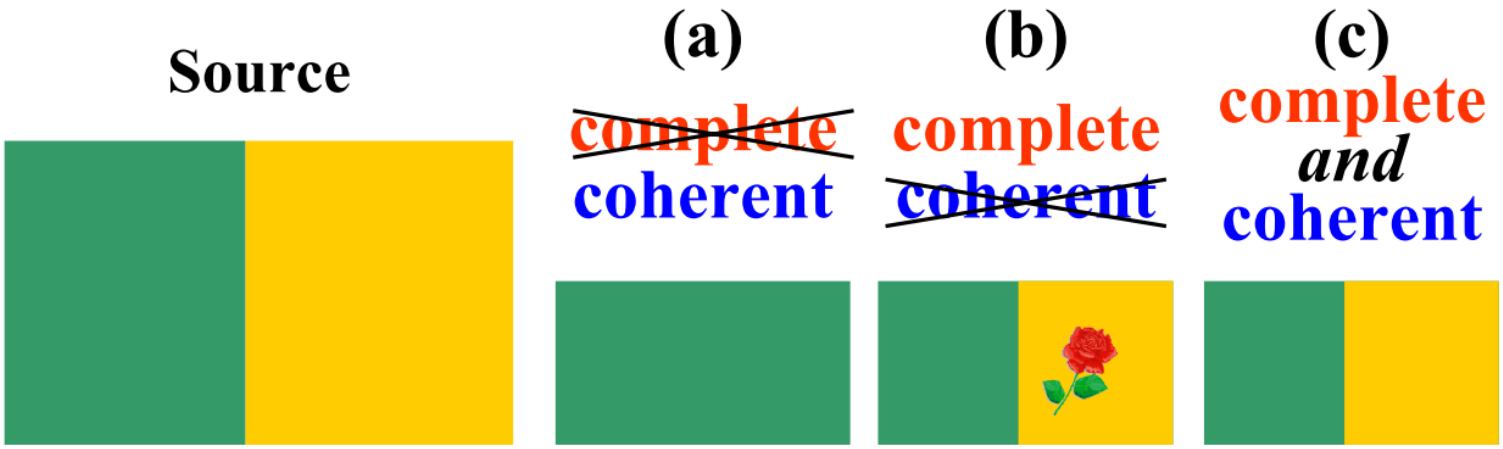
sourceMaskPyramid

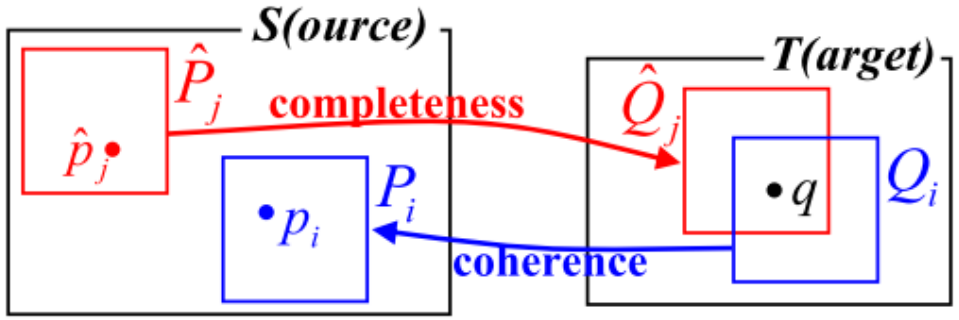
$$\mathrm{MBDS}(T \mid S_1, \ldots, S_N) = \frac{1}{N} \sum_{k=1}^{N} \sum_{P \in S_1, \ldots, S_N} w_k(P) \min_{Q \in T} d(P, Q) +$$

1: 完整性 2:一致性

$$\frac{1}{|T|} \sum_{Q \in T} \min_{P \in S_1, \ldots, S_N} d(Q, P),$$

Bidirectional Similarity Measure





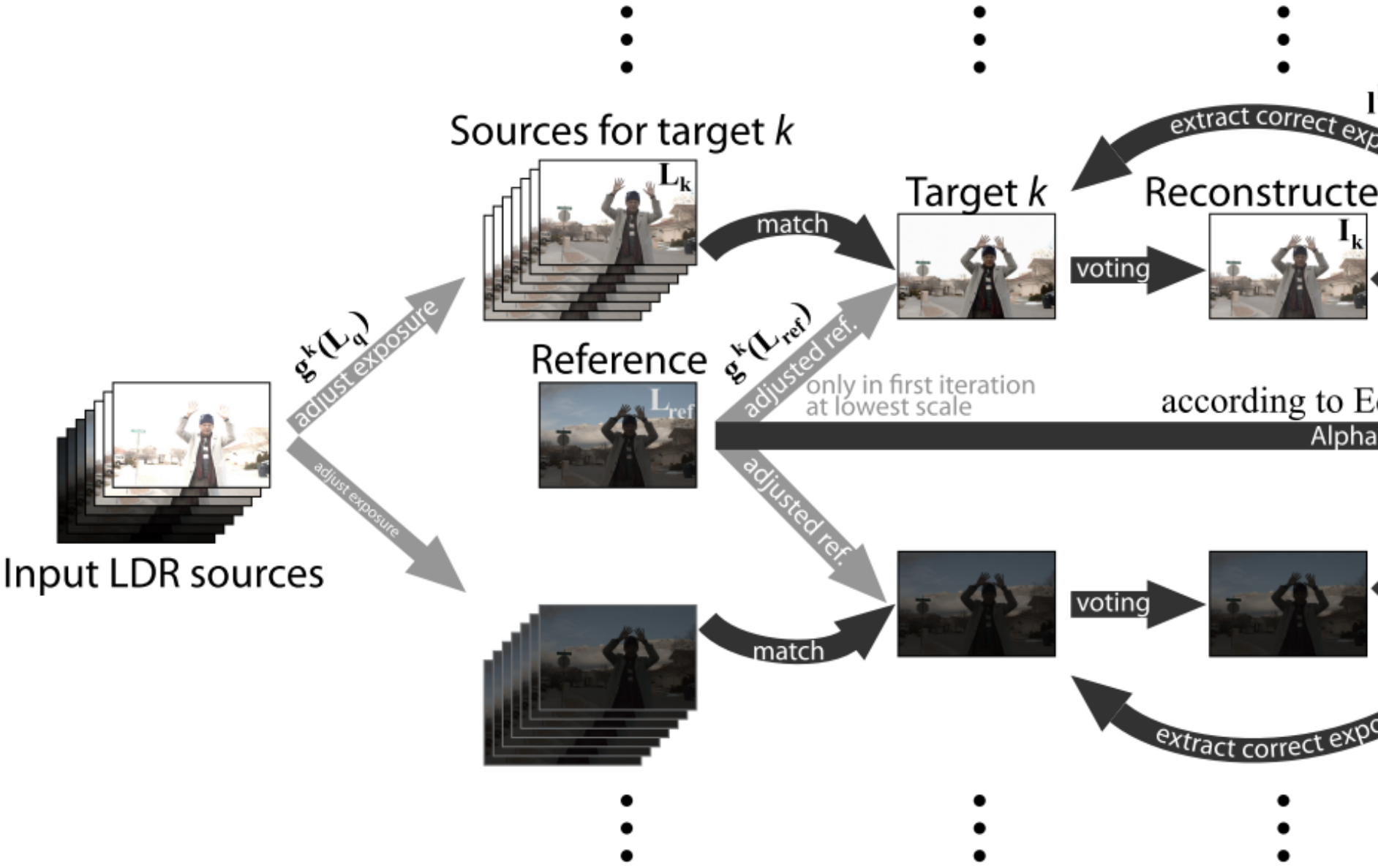
HDR image synthesis equation

fidelity in well exposed regions

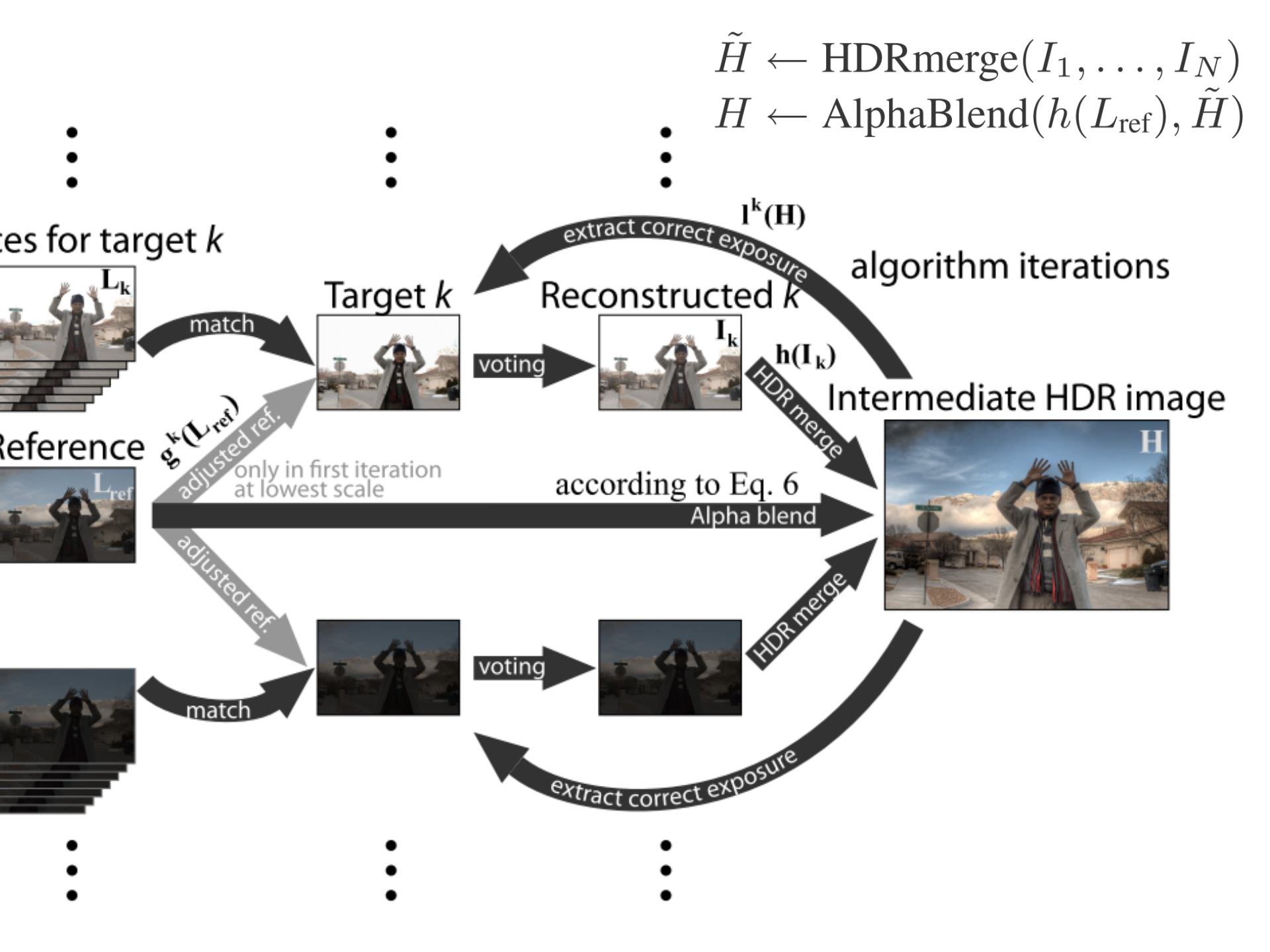
$$E(H) = \sum_{p \in \text{pixels}} \Big[\alpha_{\text{ref}_{(p)}} \cdot \left(h(L_{\text{ref}})_{(p)} - H_{(p)} \right)^2 + \left(1 - \alpha_{\text{ref}_{(p)}}\right) \cdot E_{\text{MBDS}}(H \mid L_1, \ldots, L_N) \Big]$$

information from poorly exposed pixels
patch-based similarity

$$I_k \leftarrow \text{SearchVote}(I_k \mid g^k(L_1), \ldots, g^k(L_N))$$
$$I_k \leftarrow \text{Blend}(I_k, l^k(H))$$



$$\tilde{H} \leftarrow \text{HDRmerge}(I_1, \ldots, I_N)$$
$$H \leftarrow \text{AlphaBlend}(h(L_{\text{ref}}), \tilde{H})$$

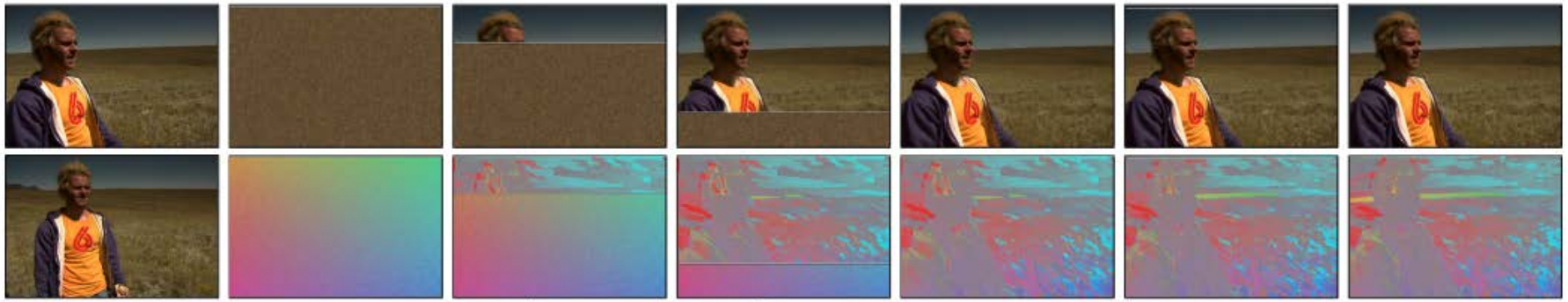


PatchMatch

PatchMatch: A Randomized Correspondence Algorithm for Structural Image Editing

Connelly Barnes[1] Eli Shechtman[2,3] Adam Finkelstein[1] Dan B Goldman[2]
[1]Princeton University [2]Adobe Systems [3]University of Washington

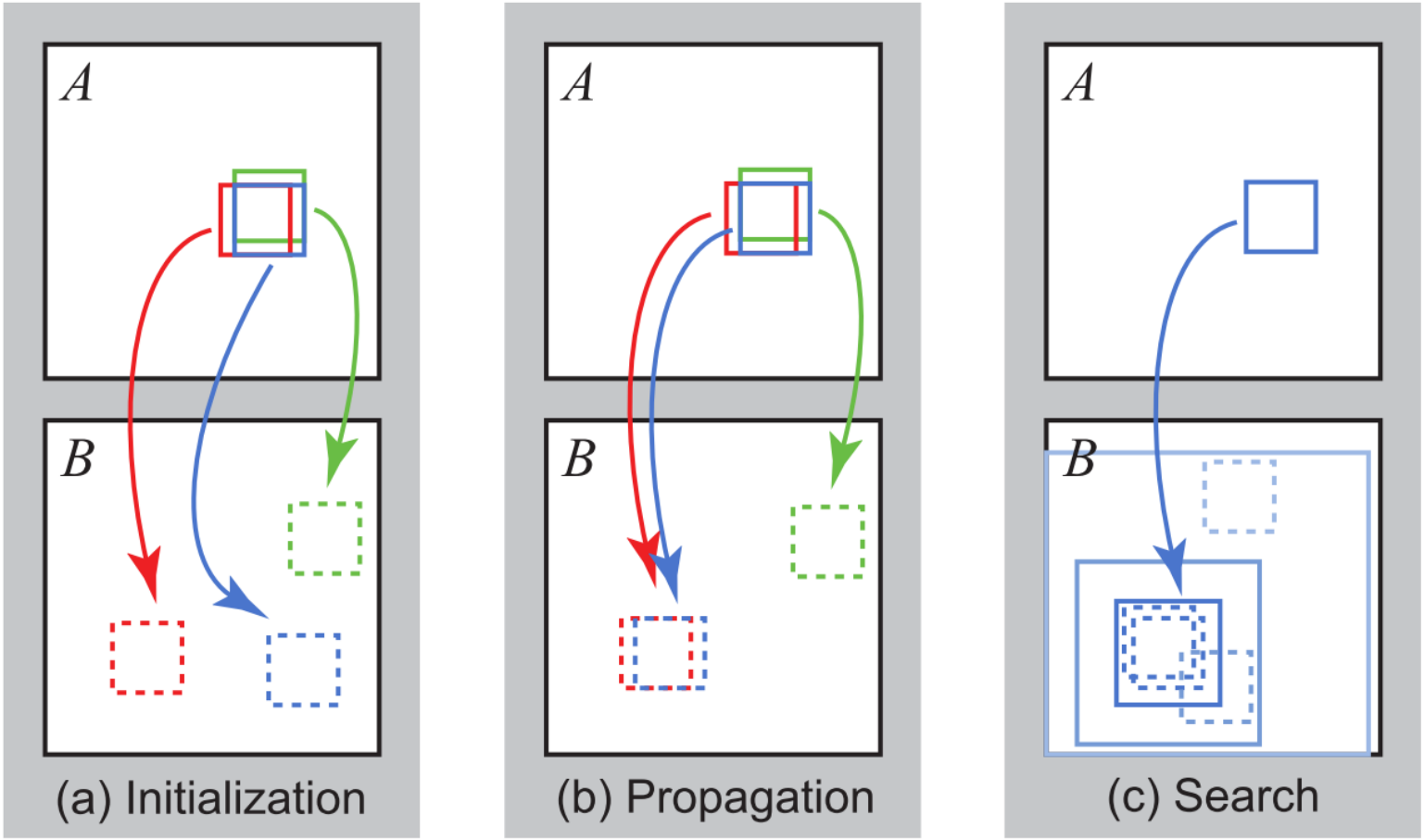
(a) original (b) hole+constraints (c) hole filled (d) constraints (e) constrained retarget (f) reshuffle



(a) originals (b) random (c) $\frac{1}{4}$ iteration (d) $\frac{3}{4}$ iteration (e) 1 iteration (f) 2 iterations (g) 5 iterations

Nearest Neighbor Field (NNF)

Randomized nearest neighbor search



$$\{D(f(x,y)), D(f(x-1,y)), D(f(x,y-1))\}$$

Using NNF to solve for BDS

- **Search and vote**

$$d_{BDS}(S,T) = \overbrace{\frac{1}{N_S}\sum_{s\subset S}\min_{t\subset T} D(s,t)}^{d_{complete}(S,T)} + \overbrace{\frac{1}{N_T}\sum_{t\subset T}\min_{s\subset S} D(t,s)}^{d_{cohere}(S,T)}$$

So far so good, some discussions

- **Bracketed exposures**
  - **Changing shutter speed**
  - **Varying apertures** ☺
    - **Super-resolution**

- **Propagate noise in the reference**

Conclusion

- **Developing fast nearest neighbor search algorithms**
  - **Very useful in every aspect of image processing**
  - **Optical flow and dense correspondence**