SIGGRAPH ASIA 2018 TOKYO
CONFERENCE 4 – 7 December 2018
EXHIBITION 5 – 7 December 2018
Tokyo International Forum, Japan
SA2018.SIGGRAPH.ORG



# GPU-Based Large-Scale Scientific Visualization

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Course Website:
http://johanna-b.github.io/LargeSciVis2018/index.html

# Part 4 -
# Display-Aware Visualization and Processing

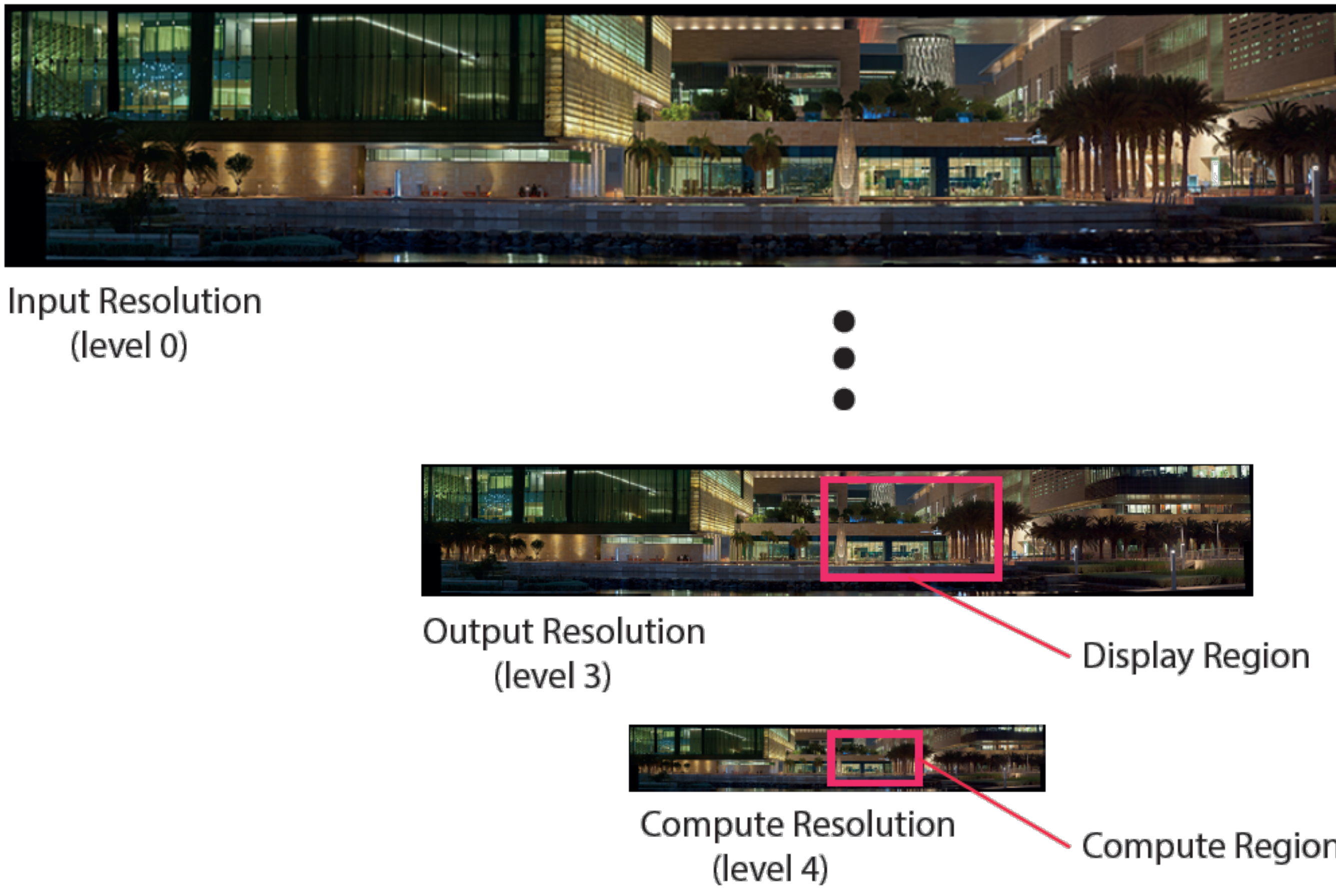
# MOTIVATION


goal:
perform computations
at output resolution
250 megapixels
<1 megapixel visible


resolution level 0


resolution level 3

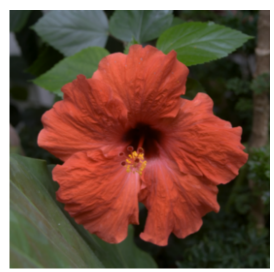
# DISPLAY-AWARE IMAGE OPERATIONS



# IMAGE PYRAMIDS

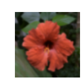
- Dyadic image pyramids
  - Mipmaps [Williams 1983]: texture mapping (standard on GPUs)
  - Gaussian/Laplacian pyramids [Burt and Adelson 1983]: image processing/compression

level 0



level 1

level 2



level 3

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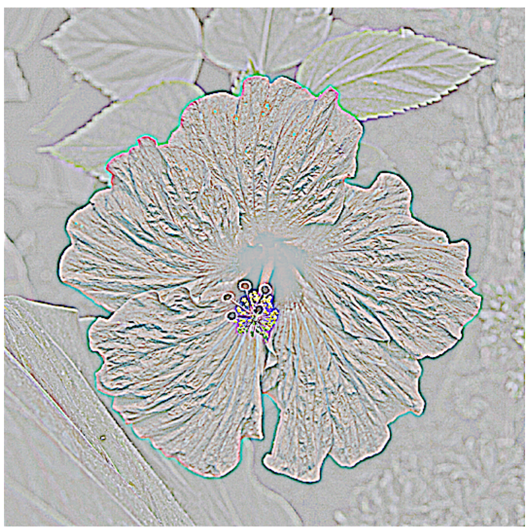
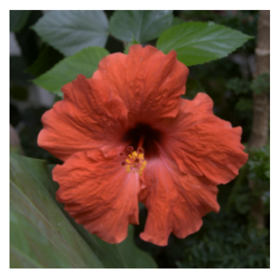
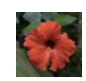

level 0


level 1


level 2


level 3

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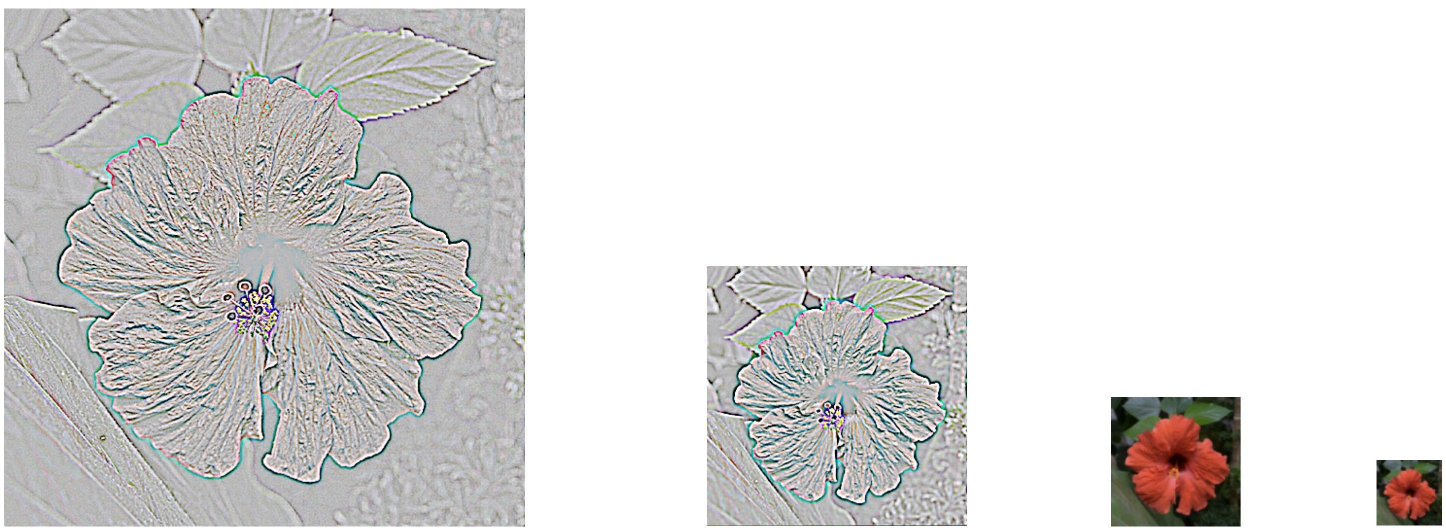

level 0 level 1 level 2 level 3

# IMAGE PYRAMIDS

- Dyadic image pyramids
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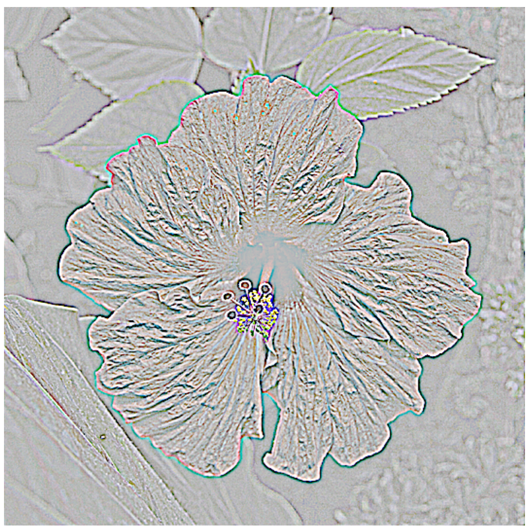
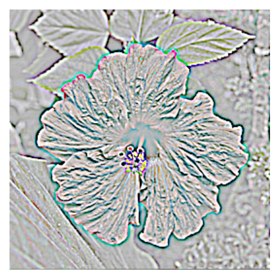
  - Gaussian/Laplacian pyramids [Burt and Adelson 1983]: image processing/compression
  - Sparse pdf maps [Hadwiger et al. 2012]

Laplacian pyramid

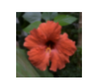


level 0



level 1

level 2



level 3

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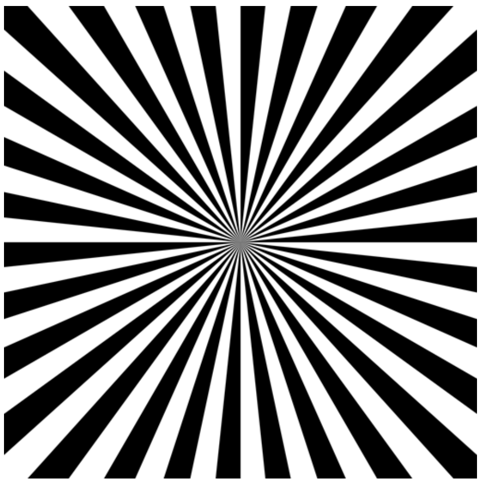
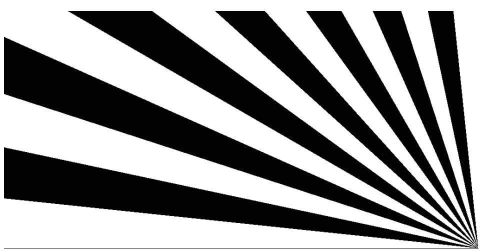
level 0 level 1 level 2 level 3

# ANTI-ALIASING IN IMAGE PYRAMIDS



level 0



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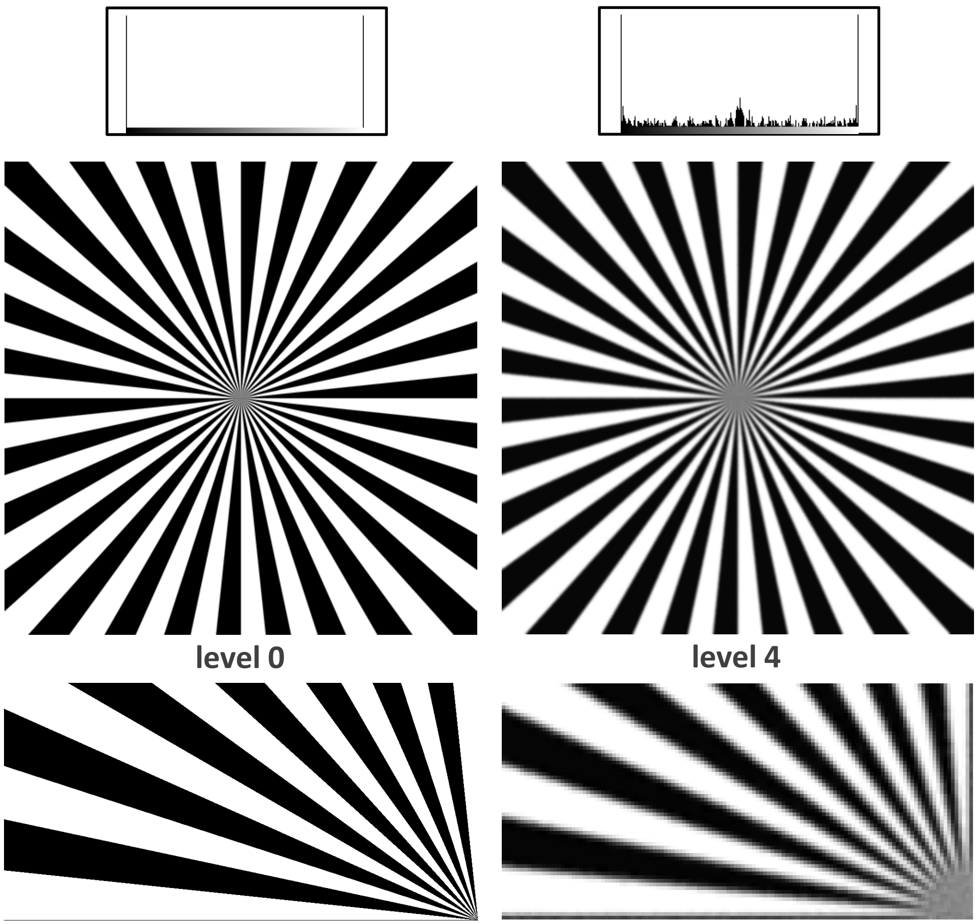

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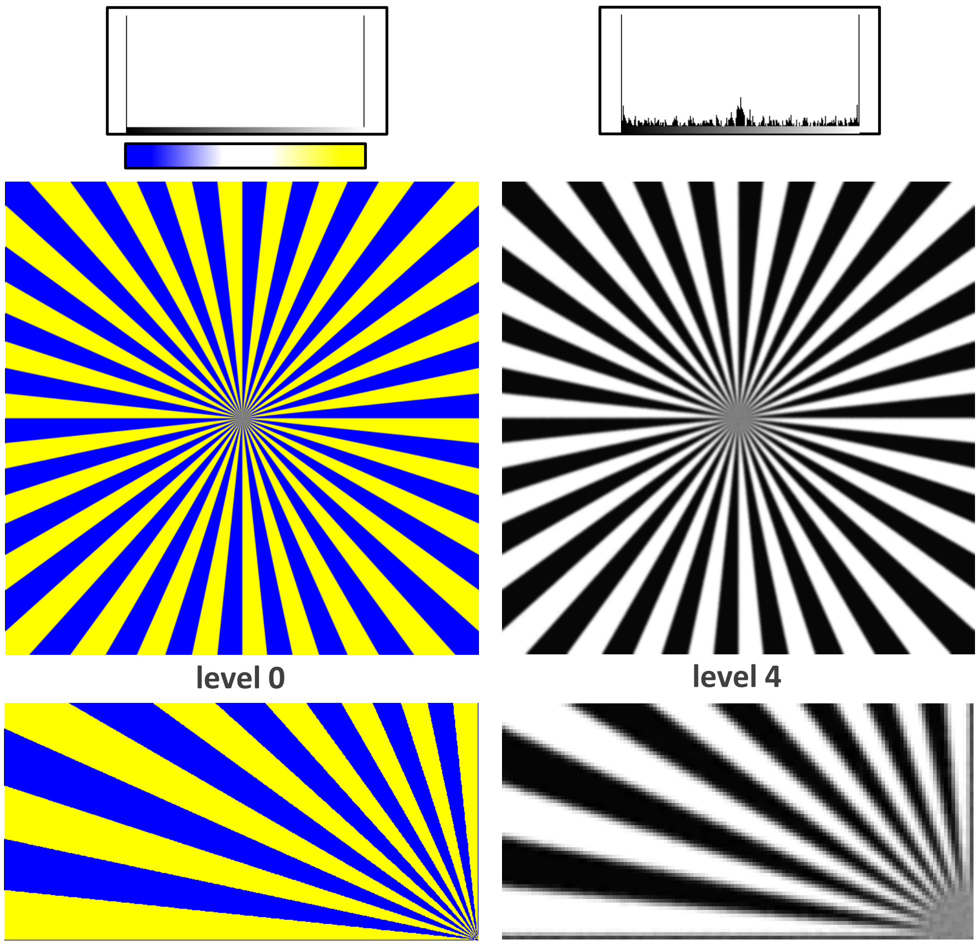

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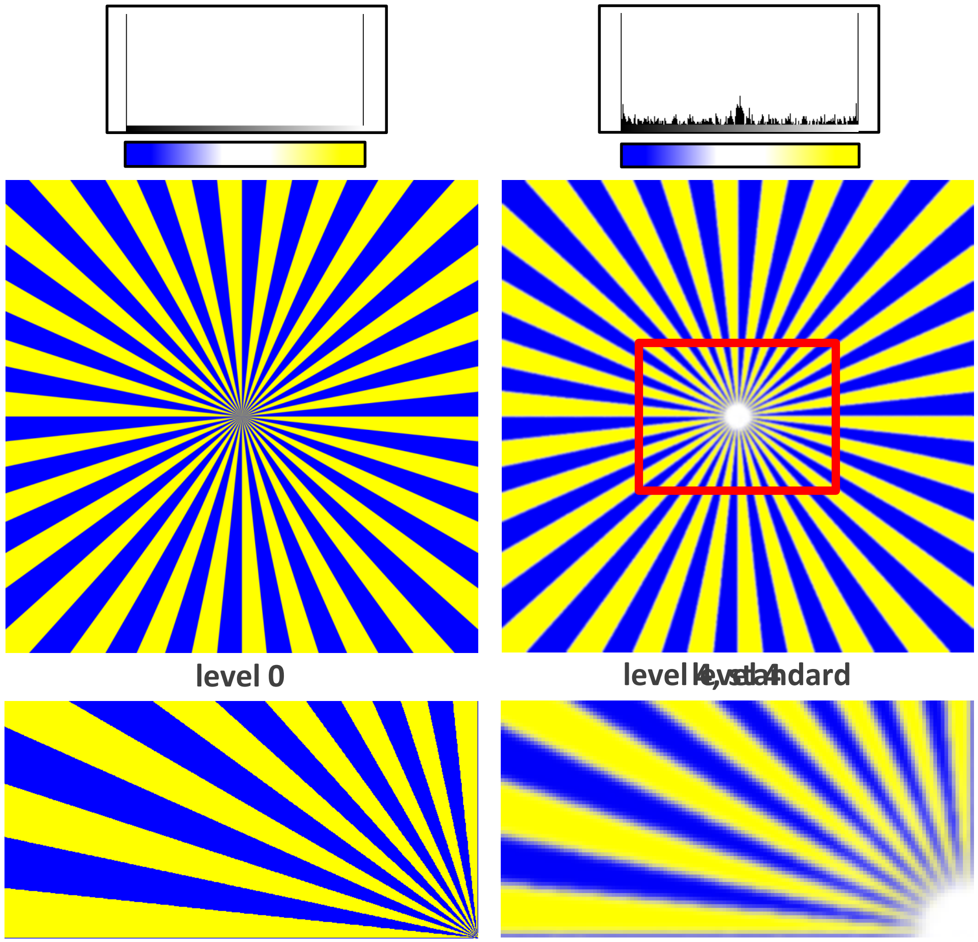

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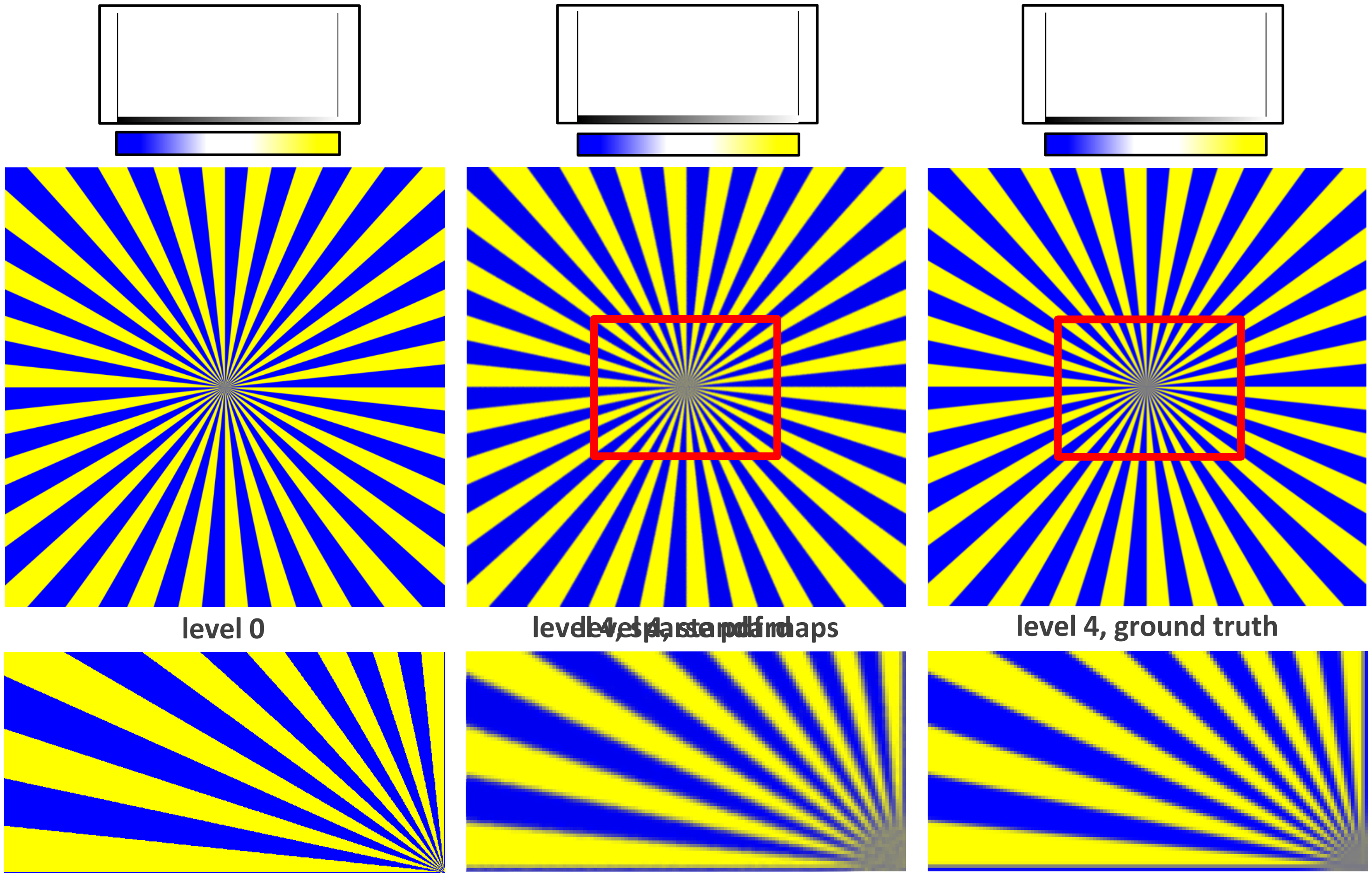
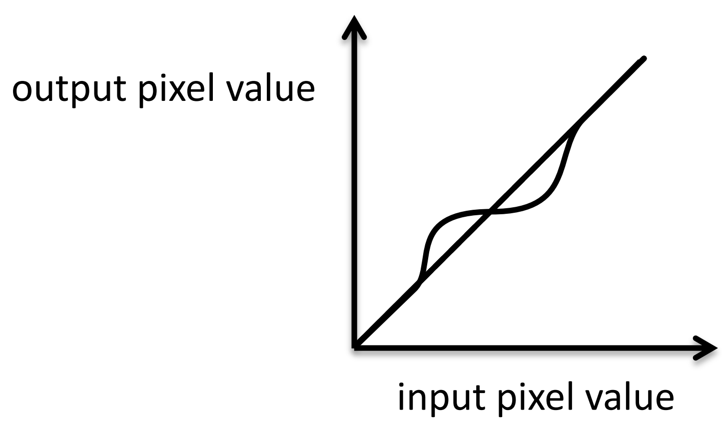


# NON-LINEAR IMAGE OPERATORS

Apply non-linear operation to each pixel

- Color map or non-linear contrast adjustment
- Bilateral filtering: range weight
- Smoothed local histogram filtering [Kass and Solomon 2010]
- Local Laplacian filtering [Paris et al. 2011]: point-wise, non-linear re-mapping

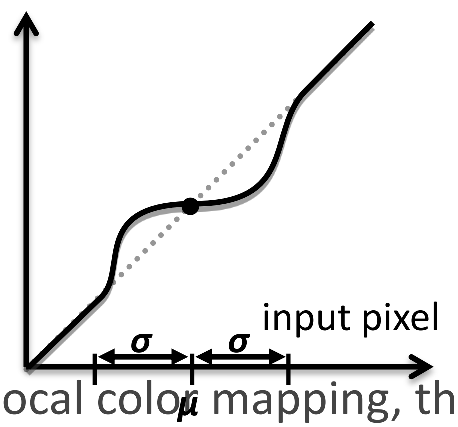


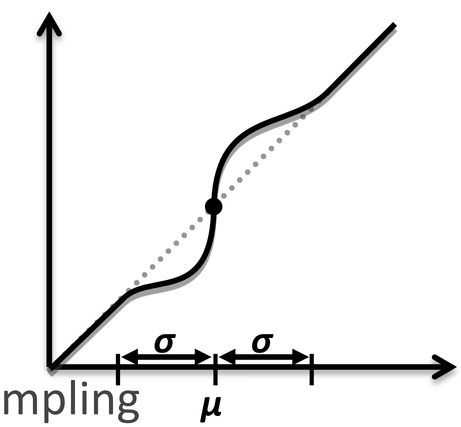
# LOCAL LAPLACIAN FILTERING [PARIS ET AL. 2011]

Compute Laplacian pyramid coefficient

- Adjust local contrast via point-wise non-linearity; then downsample

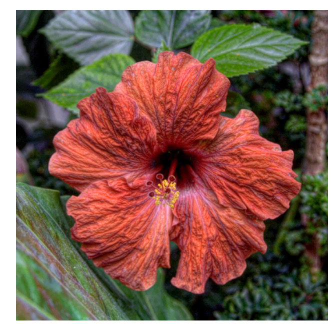
output pixel



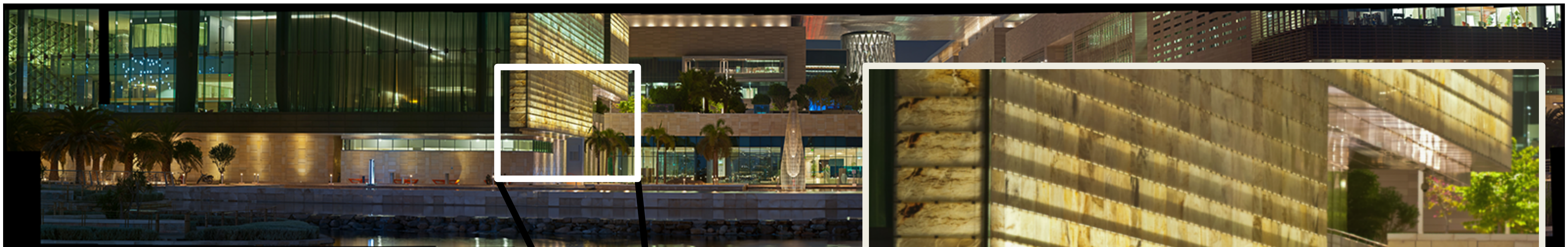

Same as local color mapping, then downsampling

- Cannot apply the re-mapping function to the downsampled image!
- Need to compute ground truth (pyramid!) or proper “anti-aliasing”

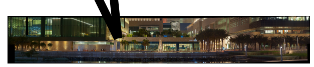


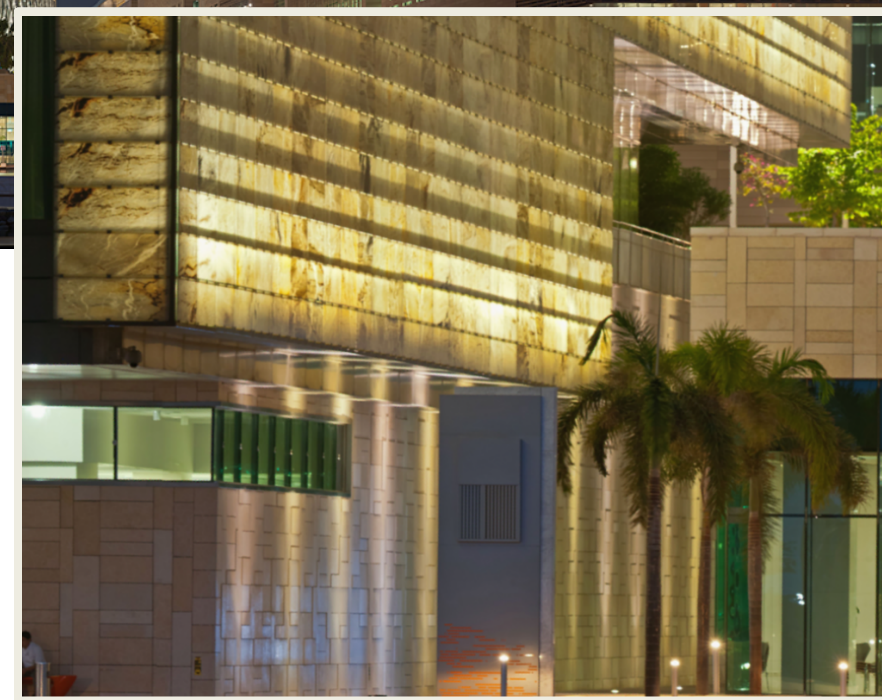
# LOCAL LAPLACIAN FILTERING: SCALABILITY

- Night Scene Panorama: 47,908 x 7,531 pixels (361 Mpixels)



- Every downsampled pixel results from the entire pyramid above it
- Sparse PDF maps allow direct computation!

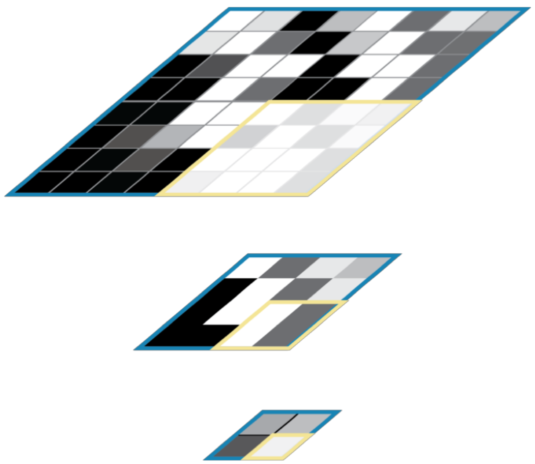




# Sparse PDF Maps: Concept

# SPARSE PDF MAPS

Represent distribution of pixel values in footprint in original image



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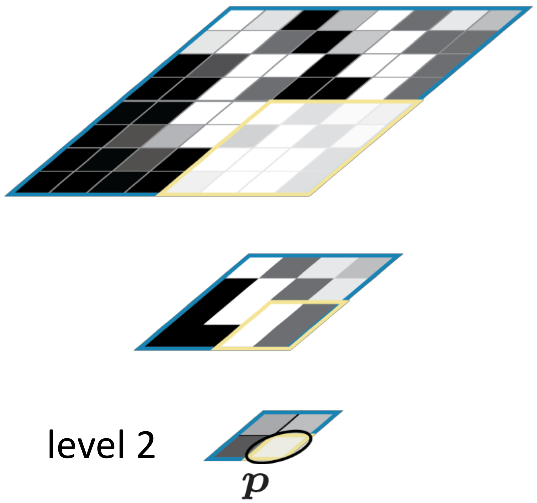

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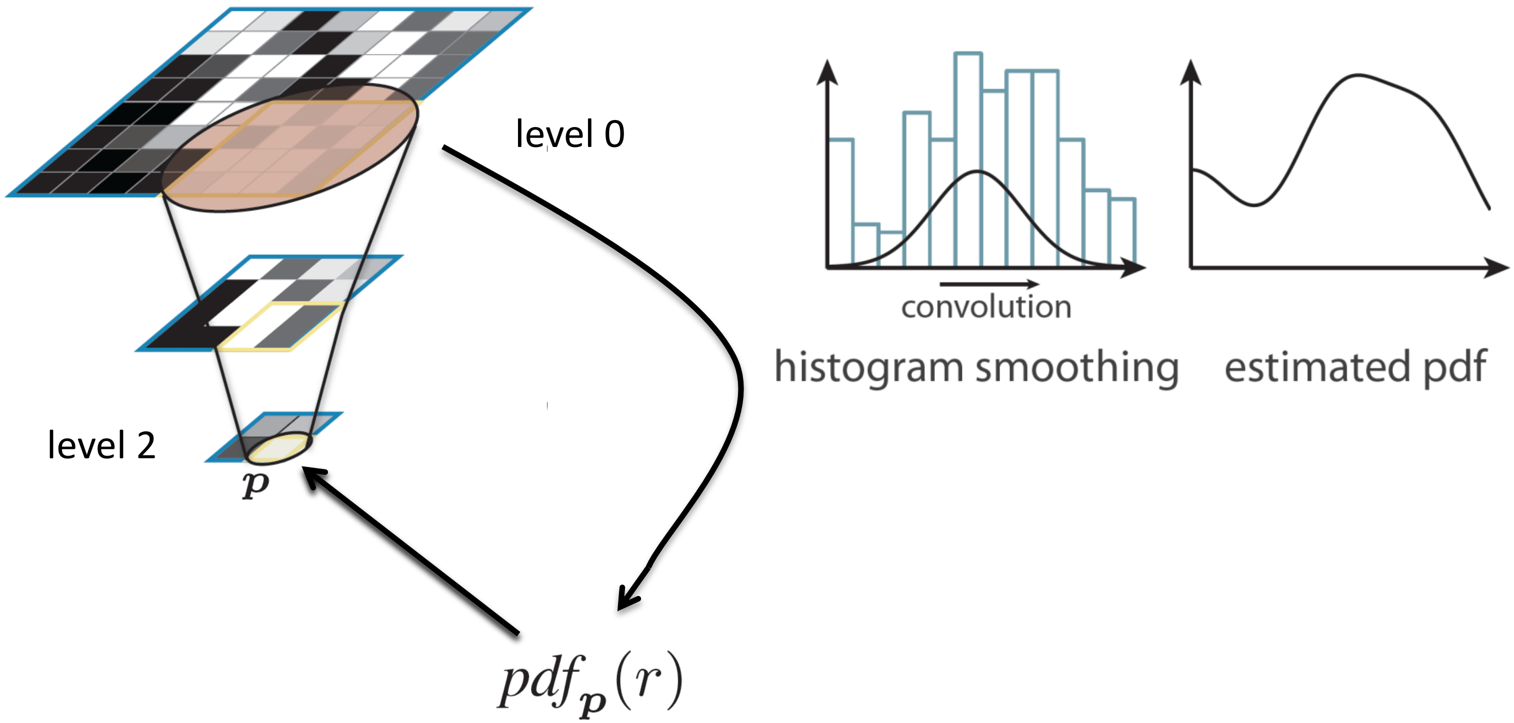

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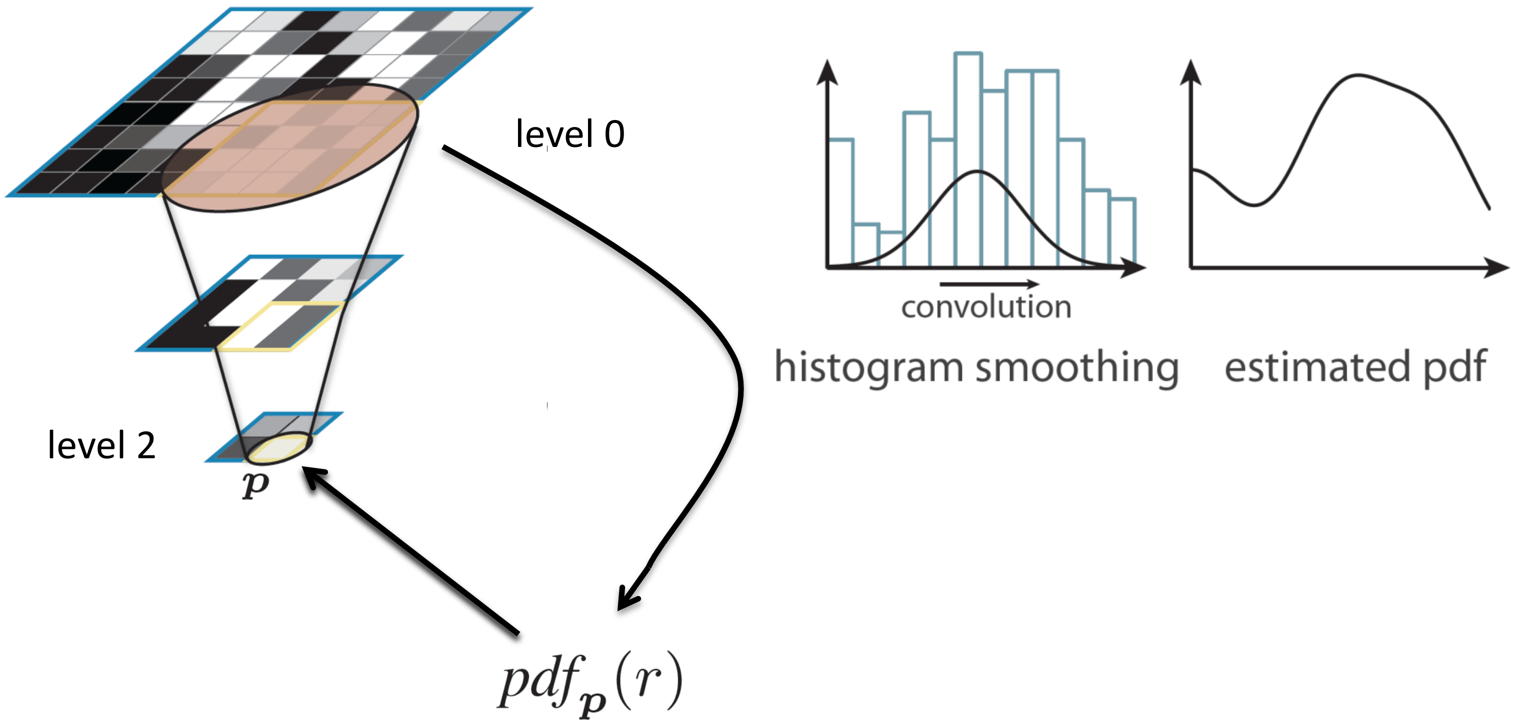
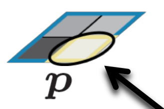


# SPARSE PDF MAPS

Represent distribution of pixel values in footprint in original image

Apply non-linear operation

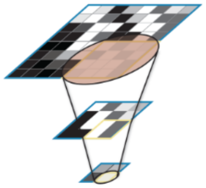
level 2




$$E\boxed{\left[t_{\boldsymbol{p}}\left(X_{\boldsymbol{p}}\right)\right]} = \frac{1}{w_{\boldsymbol{p}}} \int_0^1 \boxed{t_{\boldsymbol{p}}(r)}\,\boxed{pdf_{\boldsymbol{p}}(r)}\, dr$$

# EXAMPLE 1: DOWNSAMPLED IMAGE

$$E\left[t_{\boldsymbol{p}}\left(X_{\boldsymbol{p}}\right)\right] = \frac{1}{w_{\boldsymbol{p}}} \int_0^1 t_{\boldsymbol{p}}(r) pdf_{\boldsymbol{p}}(r)\, dr$$

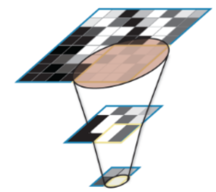



$$t_{\boldsymbol{p}}(r) = r$$

$$w_{\boldsymbol{p}} = 1$$

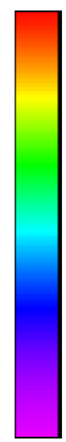
# EXAMPLE 2: COLOR MAPPING

$$E\left[t_{\boldsymbol{p}}\left(X_{\boldsymbol{p}}\right)\right] = \frac{1}{w_{\boldsymbol{p}}} \int_0^1 t_{\boldsymbol{p}}(r) pdf_{\boldsymbol{p}}(r)\; dr$$




$$t_{\boldsymbol{p}}(r) = \text{color map}$$

$$w_{\boldsymbol{p}} = 1$$



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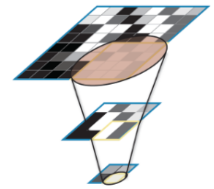
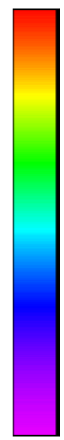
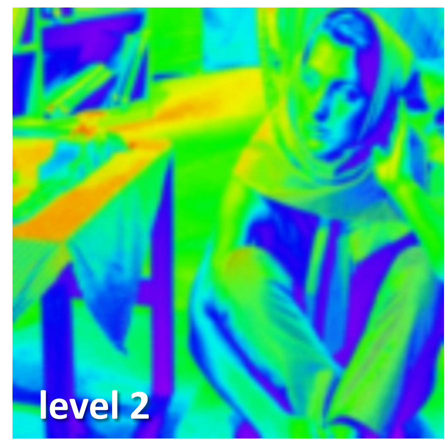



$t_{\boldsymbol{p}}(r) =$ color map

$w_{\boldsymbol{p}} = 1$



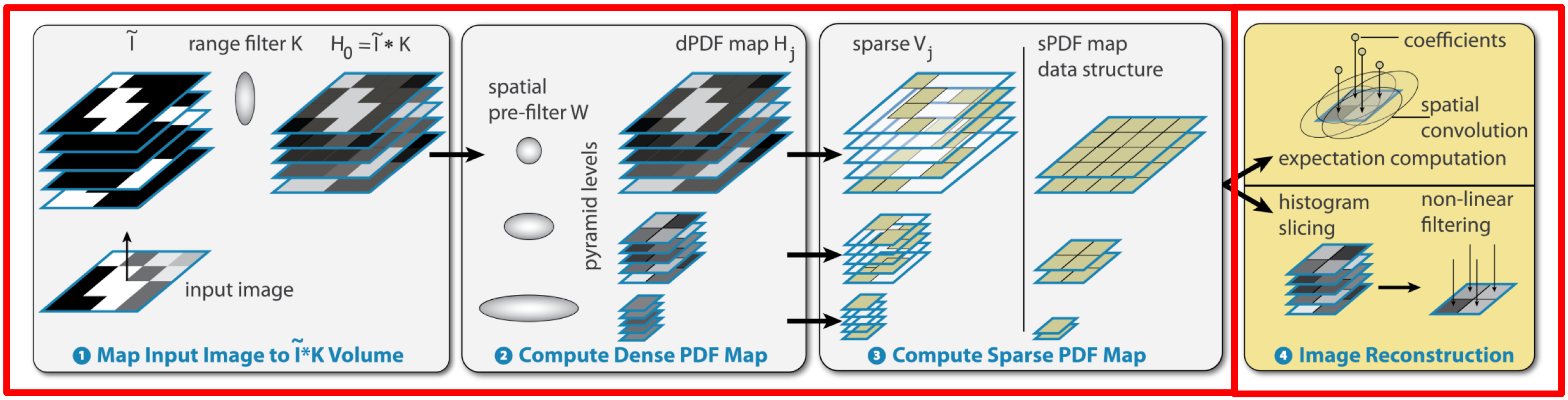



plus: bilateral filtering, local Laplacian filtering in linear time, …

# INTERACTIVE GIGAPIXEL FILTERING

# Sparse PDF Map Computation

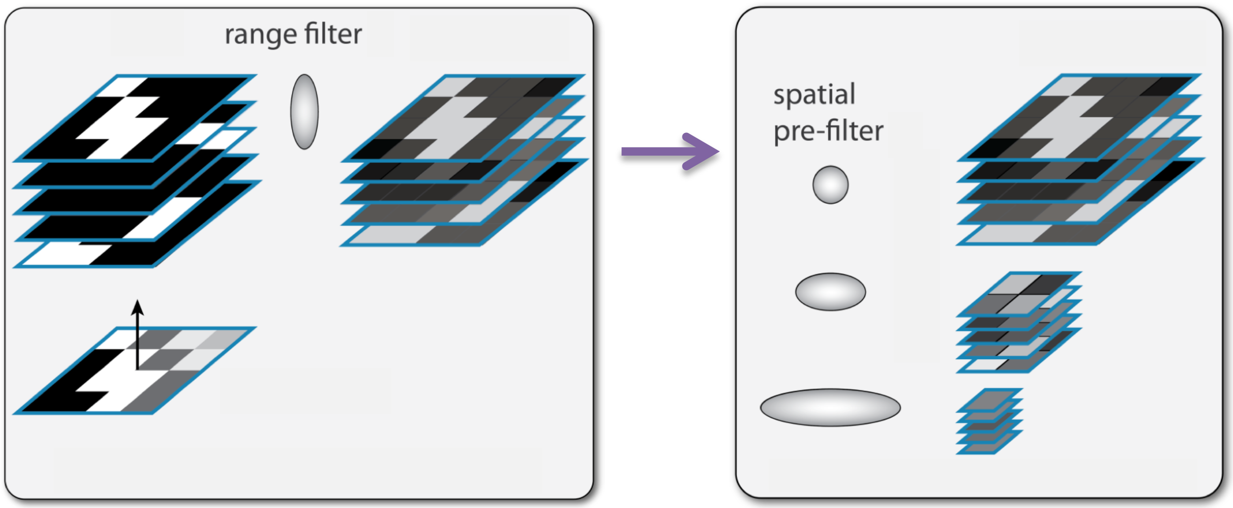
# PIPELINE



Ĩ
range filter K
$H_0 = \tilde{I} * K$
input image
1 Map Input Image to Ĩ*K Volume
dPDF map $H_j$
spatial pre-filter W
pyramid levels
2 Compute Dense PDF Map
sparse $V_j$
sPDF map data structure
3 Compute Sparse PDF Map
coefficients
spatial convolution
expectation computation
histogram slicing
non-linear filtering
4 Image Reconstruction

# STEP 1: DENSE PDF MAP

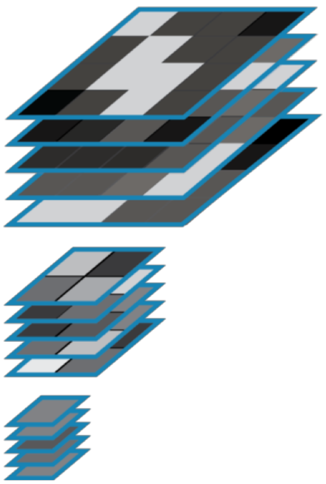
# DENSE PDF MAP COMPUTATION




$H$ is similar to a pyramid of bilateral grids [Chen et al. 2007]

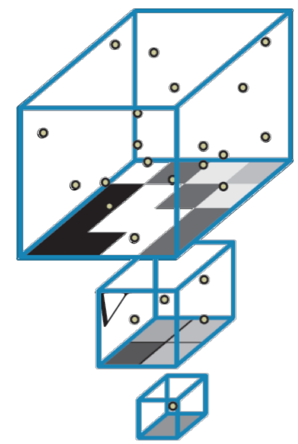
# STEP 2: SPARSE PDF MAP

# SPARSE REPRESENTATION



$$\boxed{H} \approx \boxed{V} \boxed{* \, (W \otimes K)}$$

$$G_{\boldsymbol{\sigma}_s} \otimes G_{\sigma_r}$$



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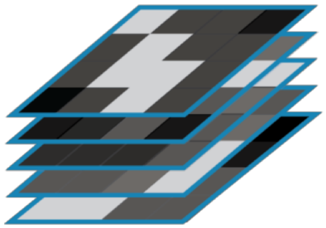
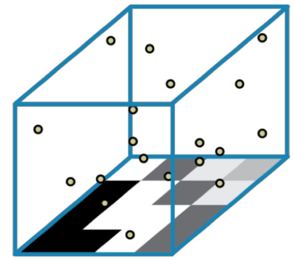


$$H \approx V * (W \otimes K)$$

$$G_{\boldsymbol{\sigma}_s} \otimes G_{\sigma_r}$$



Compute via Matching Pursuit [Mallat and Zhang 1993]

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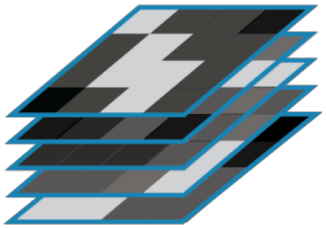
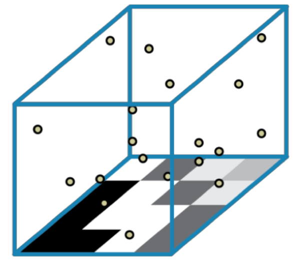
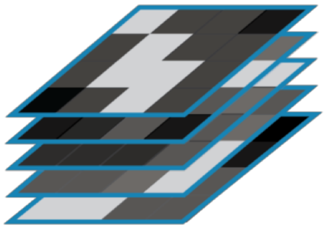


$$H \approx V * (W \otimes K)$$

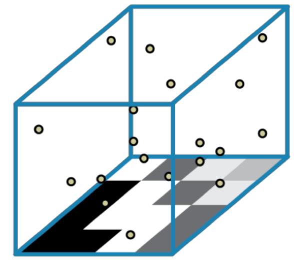


$$V(\boxed{\boldsymbol{p}_n}, \boxed{r_n}) = \boxed{c_n} \qquad c_n \neq 0$$

# SPARSE REPRESENTATION



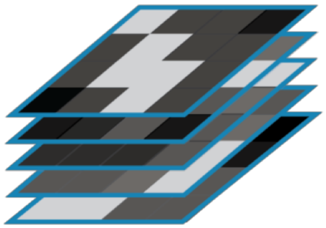
$$H \approx V * (W \otimes K)$$



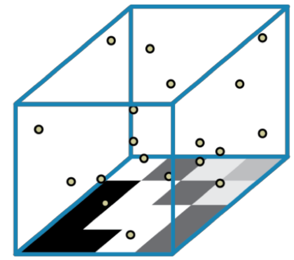
$$V(\boldsymbol{p}_n, r_n) = c_n \qquad c_n \neq 0$$

$$(\boldsymbol{p}_n, r_n, c_n)$$

# SPARSE REPRESENTATION



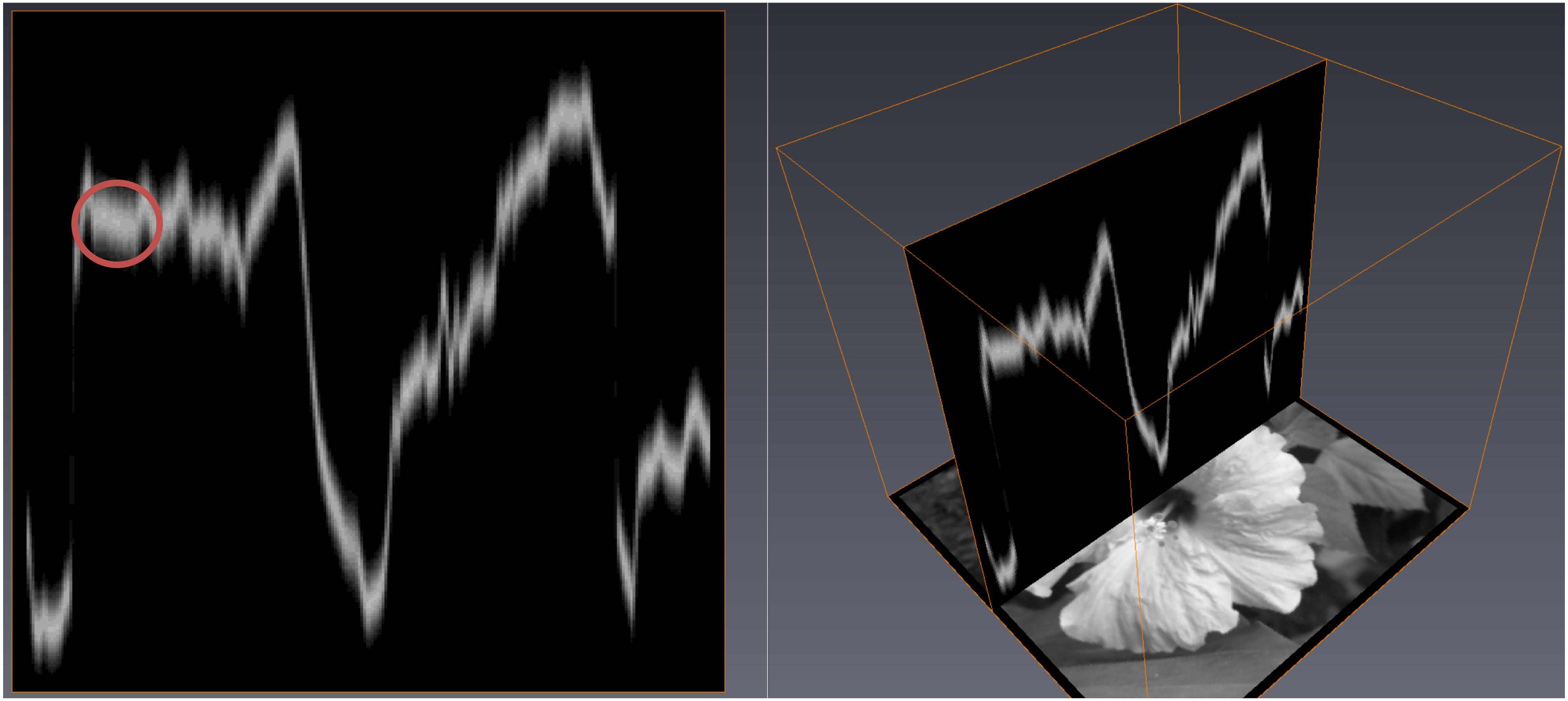
$$H \approx V * (W \otimes K)$$



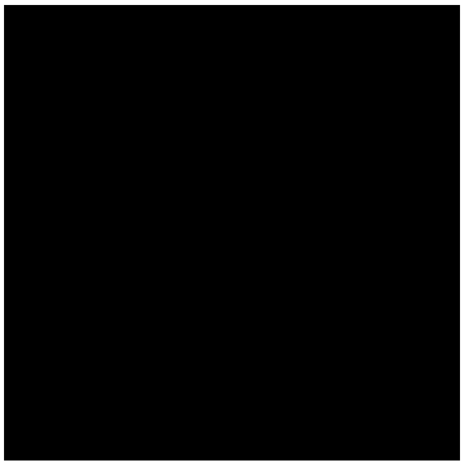
$$V(\boldsymbol{p}_n, r_n) = c_n \qquad c_n \neq 0$$

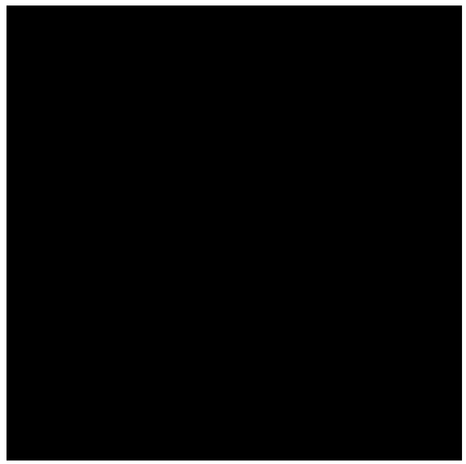
$$(\boldsymbol{p}_n, r_n, c_n)$$

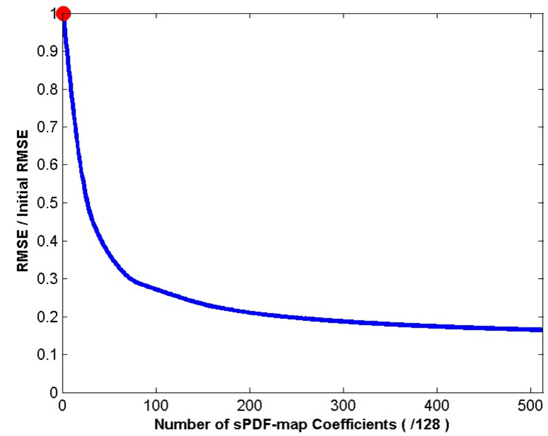
# SPATIAL AND RANGE COHERENCE

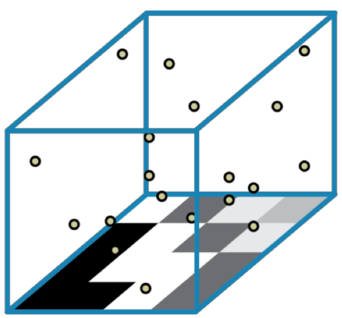


# GREEDY APPROXIMATION







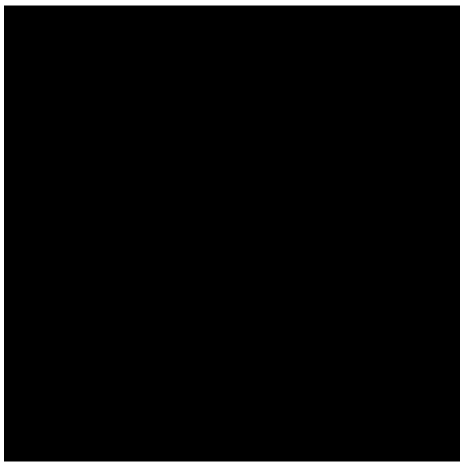



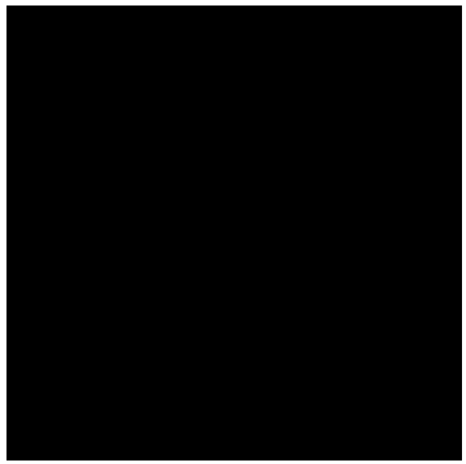
Spatial filter $W$ : 5 x 5

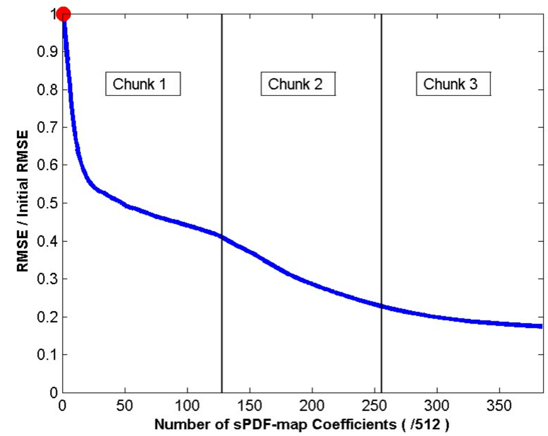
1 coefficient chunk

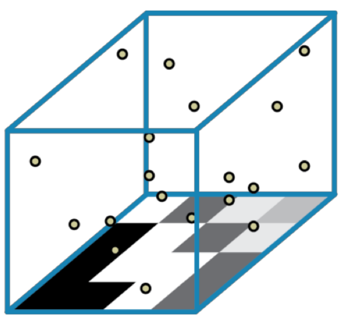
(# coefficients == 1 * # pixels)

# GREEDY APPROXIMATION







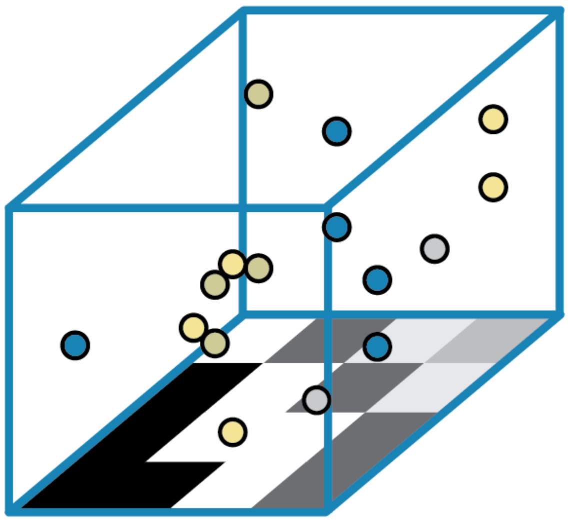
Spatial filter $W$ : 3 x 3

1-3 coefficient chunks

(# coefficients == 1-3 * # pixels)

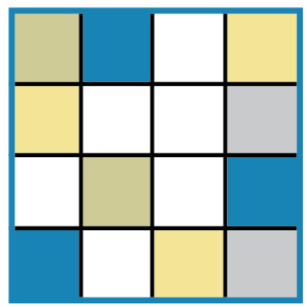
# sPDF-Maps Data Structure

# SPDF-MAPS DATA STRUCTURE



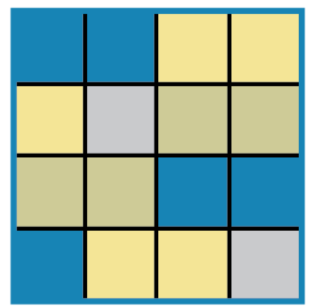
conceptual

$$V(\boldsymbol{p}_n, r_n) = c_n$$



index image

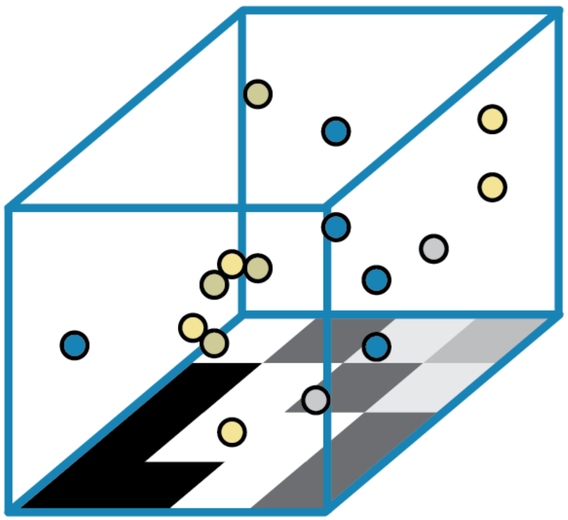
$$(index, count)_{\boldsymbol{p}}$$



coefficient image

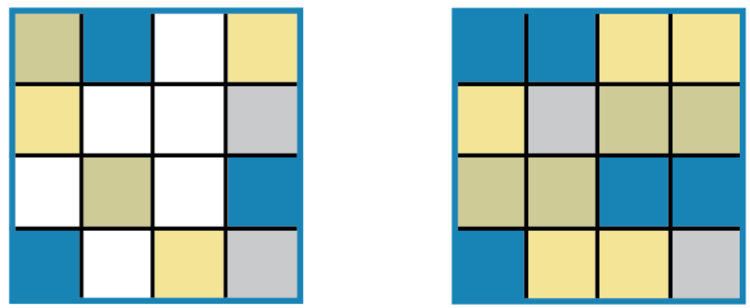
$$(r_n, c_n)$$

# SPDF-MAPS DATA STRUCTURE



conceptual

$V(\boldsymbol{p}_n, r_n) = c_n$



index image

coefficient image

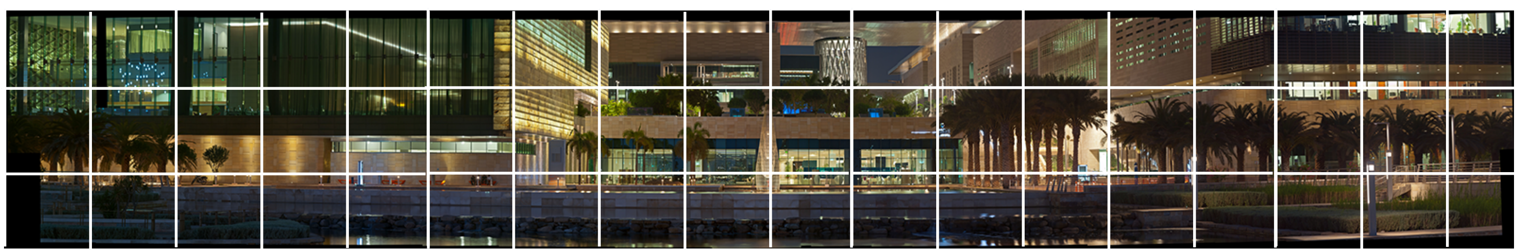
$(index, count)_{\boldsymbol{p}}$

$(r_n, c_n)$

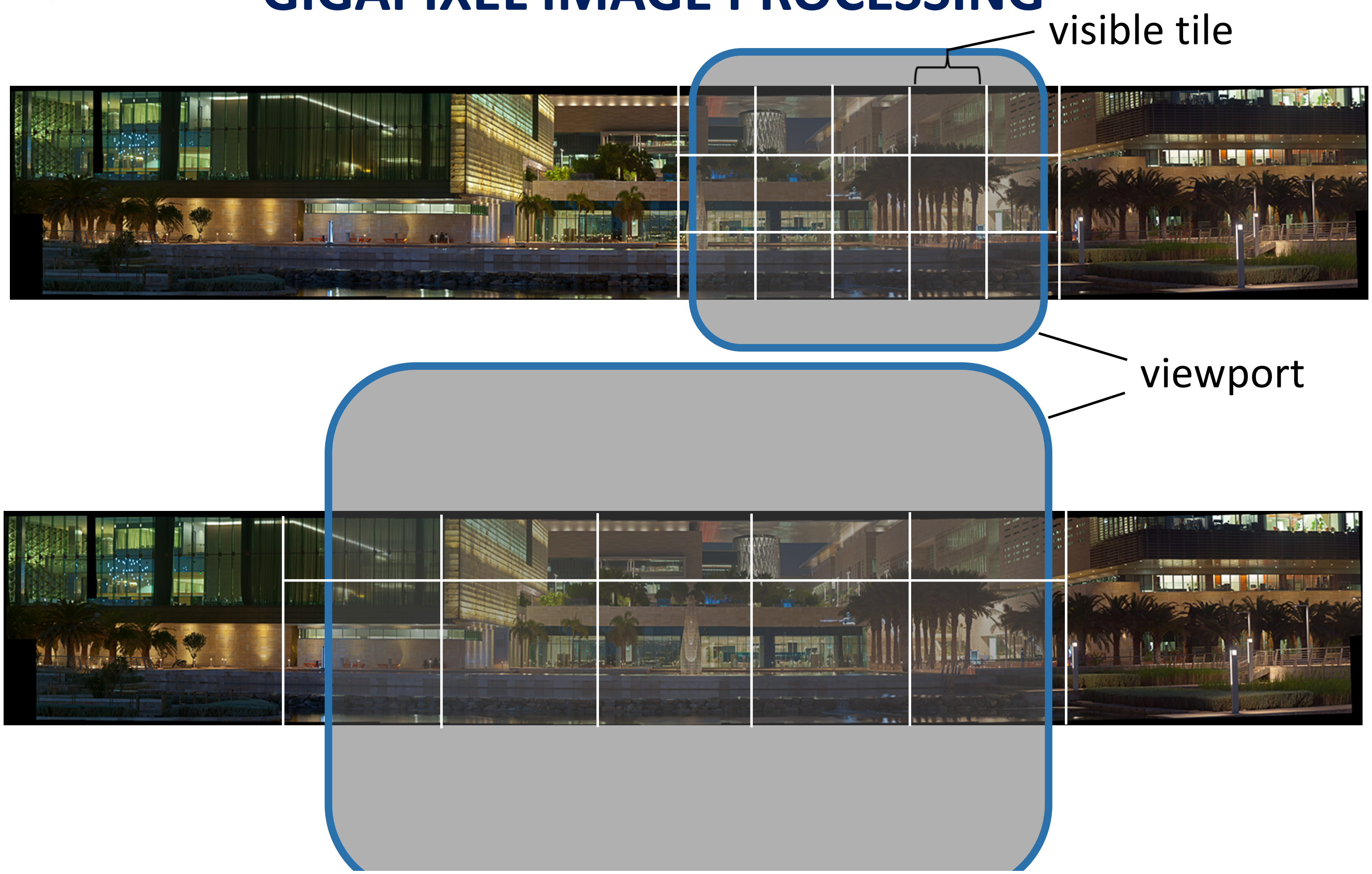
# Display-Aware Gigapixel Image Processing

# GIGAPIXEL IMAGE PROCESSING

- Out-of-Core Processing
  - Divide data into smaller tiles, process each tile independently (e.g., 256x256)
  - Image operations are performed only on requested sub-tiles (display-aware)
  - Rendering based on tiled data, using GPU-based virtual memory approach

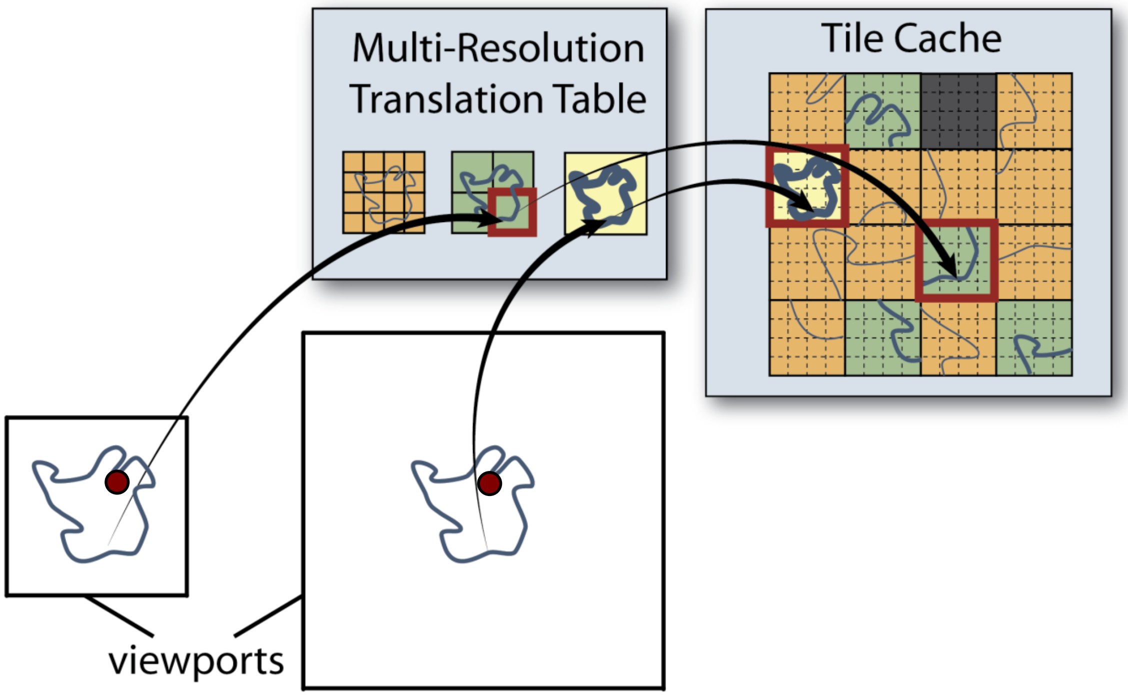


# GIGAPIXEL IMAGE PROCESSING

- 

# GIGAPIXEL IMAGE PROCESSING

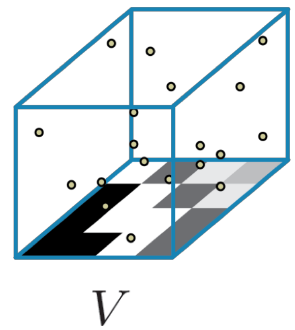
- GPU-based virtual memory architecture [Hadwiger et al. 2012]



# Image Reconstruction

## IMAGE RECONSTRUCTION

$$E\left[t_{\boldsymbol{p}}\left(X_{\boldsymbol{p}}\right)\right] = \frac{1}{w_{\boldsymbol{p}}} \int_0^1 t_{\boldsymbol{p}}(r) pdf_{\boldsymbol{p}}(r)\, dr$$




- Key idea # 1

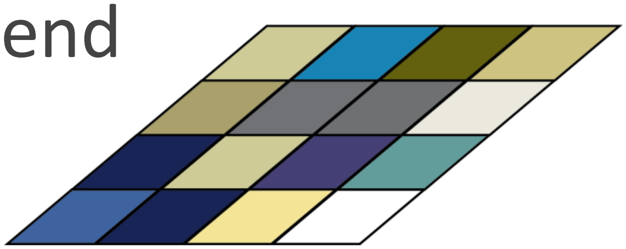
  Use $V * (W \otimes K)$ instead of $pdf_{\boldsymbol{p}}(r)$

- Key idea # 2

  Pre-convolve $t_{\boldsymbol{p}}(r)$ with $K$: $\tilde{t}_{\boldsymbol{p}} = t_{\boldsymbol{p}} * K$

## COLOR MAPPING

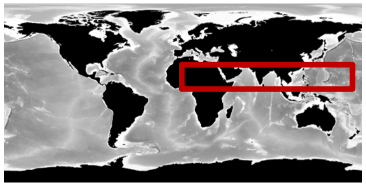
- Pre-convolve color map (with range kernel)
- For each pixel go over its coefficients
  - Apply color map to coefficient and sum up (not spatially convolved yet!)
- One spatial convolution in the end

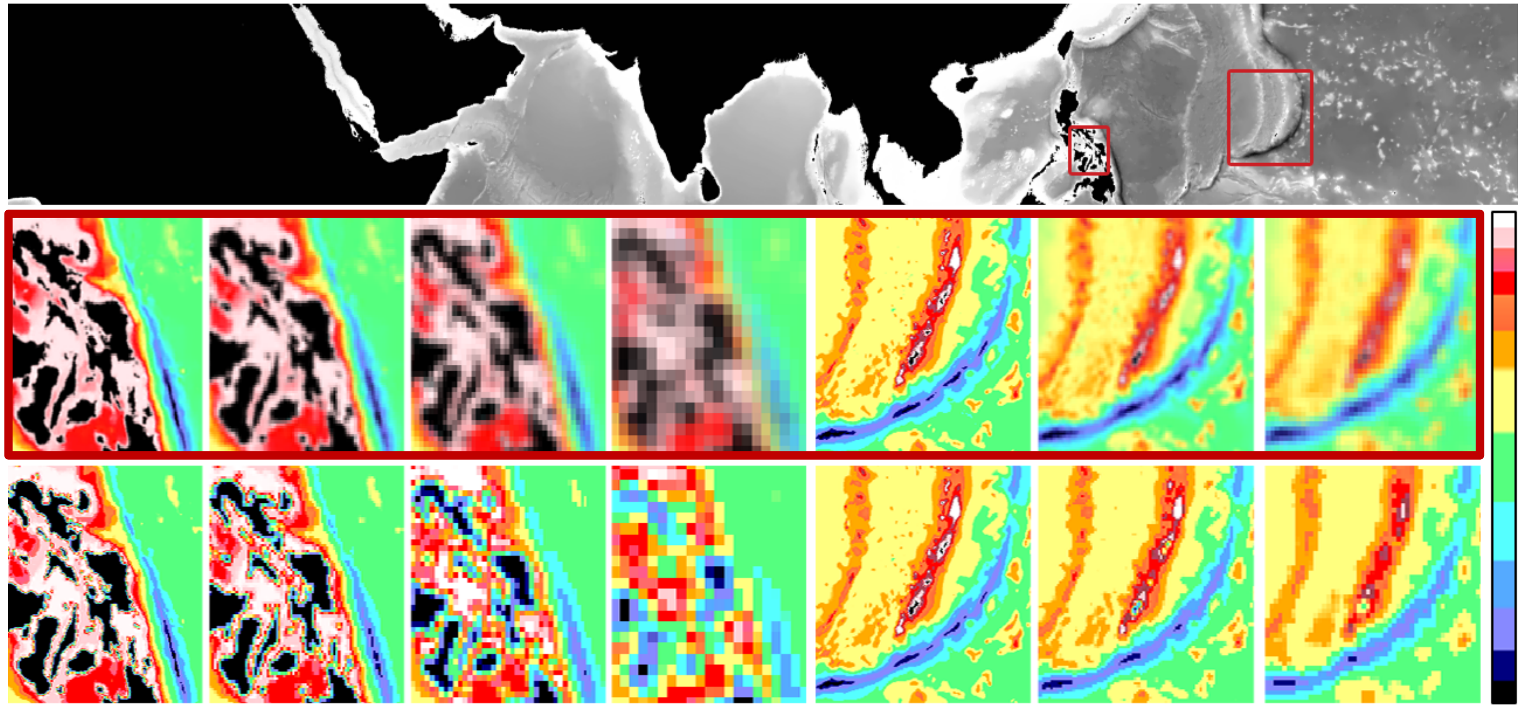


# Results

# COLOR MAPPING GIGAPIXEL IMAGES

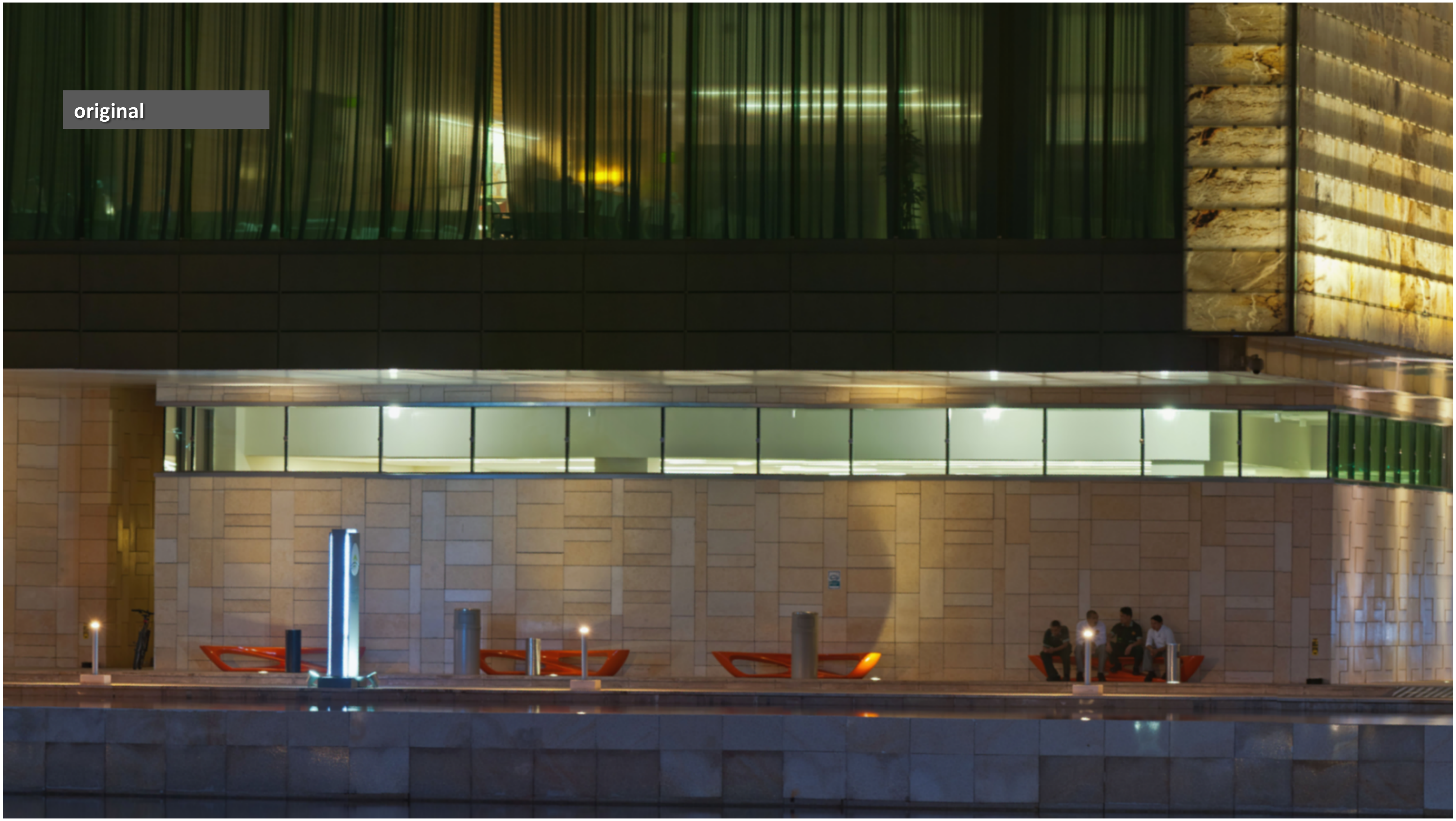
NASA Blue Marble bathymetry: 21,601 x 10,801 pixels (233 Mpixels)

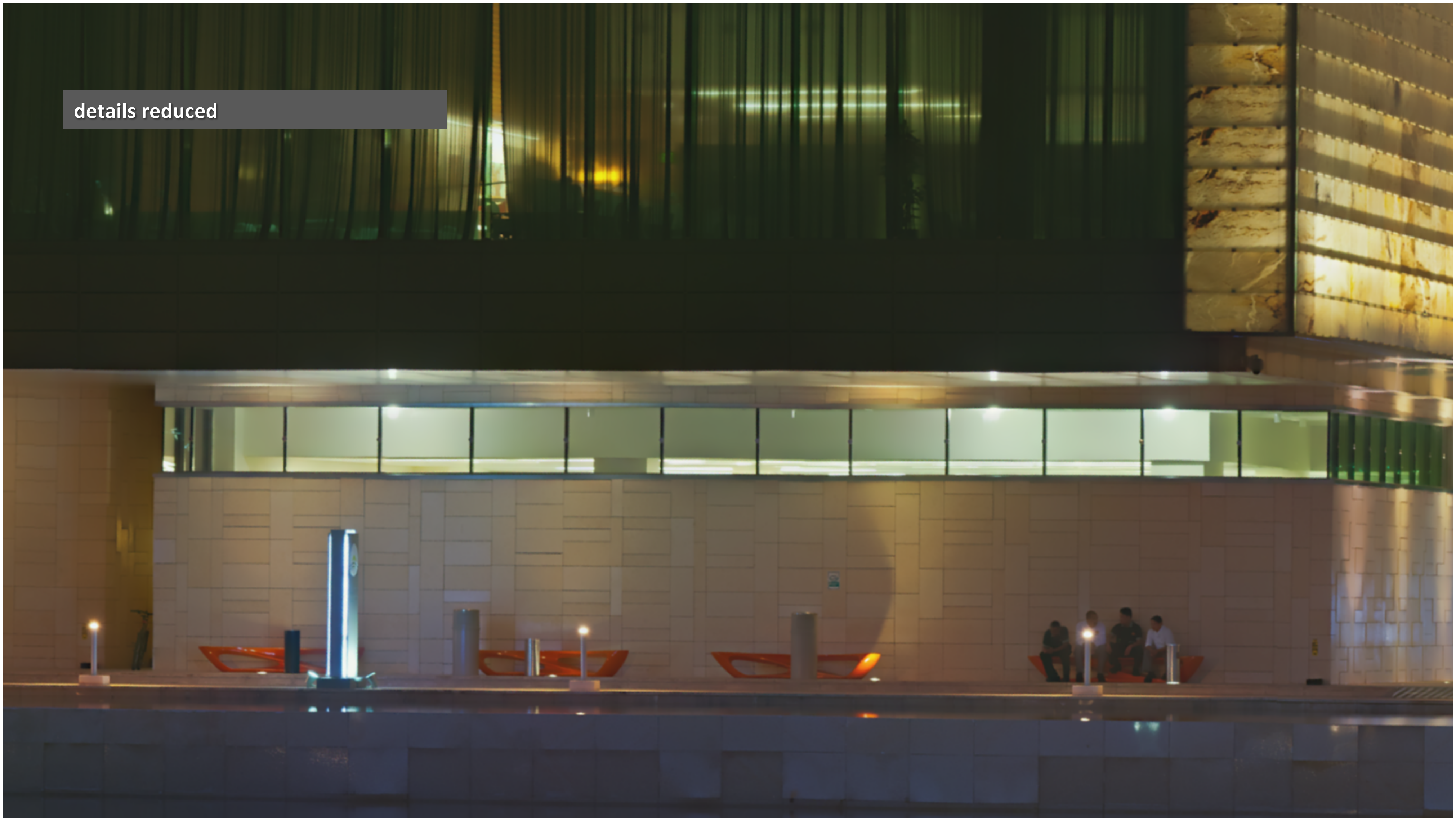


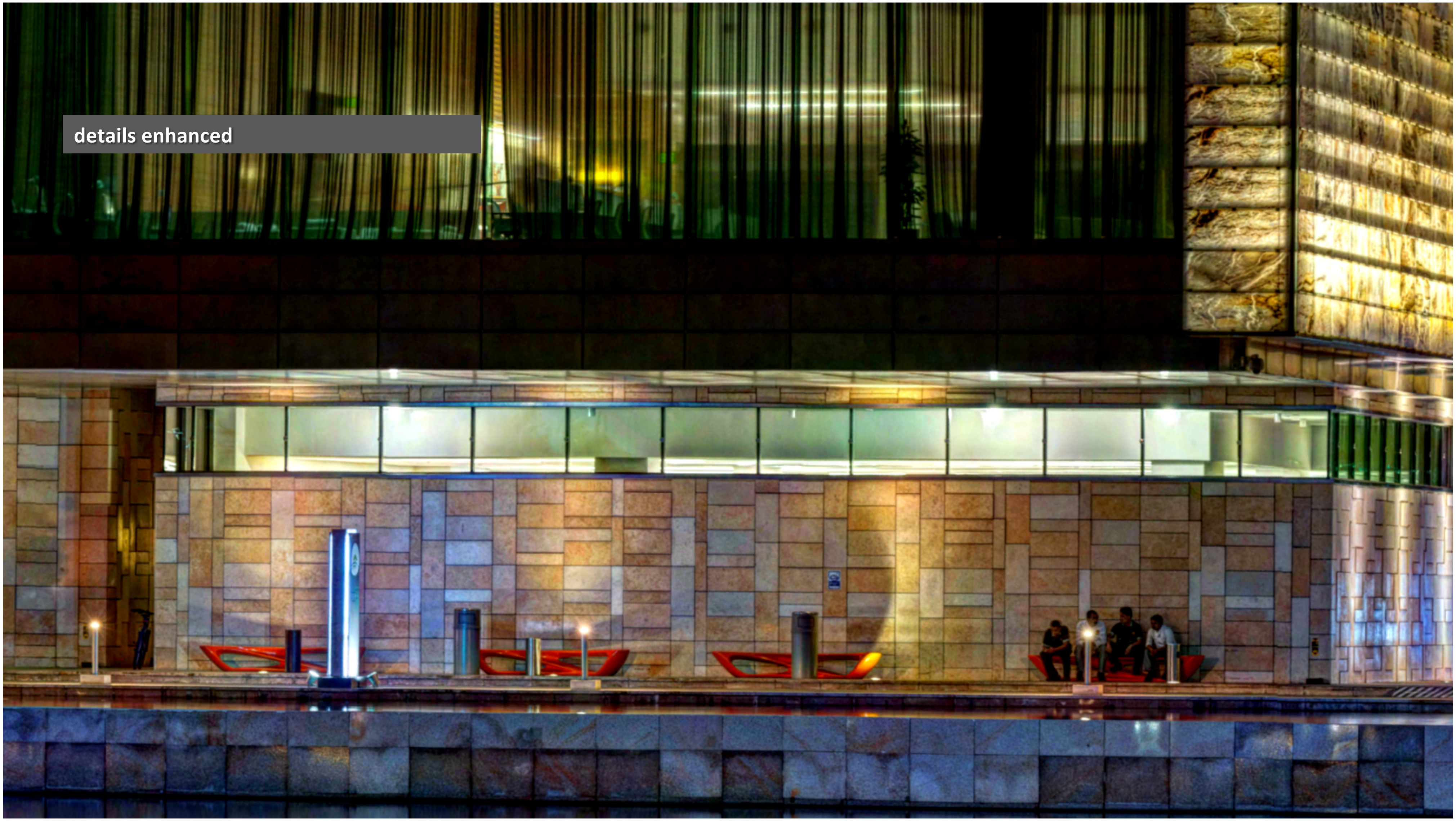



details enhanced
original
details reduced
details enhanced
original
details reduced

# GIGAPIXEL LOCAL LAPLACIAN FILTERING


original


details reduced


details enhanced

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## SUMMARY

Display-aware processing with flexible new image pyramid (spdf map)

- Consistent, sparse representation of pixel footprint pdfs

Unified evaluation of many important non-linear image operations

- Local Laplacian filtering for gigapixel images

Efficient CUDA implementation

Pre-computation costly, but only performed once

Run time storage and computation similar to standard pyramids

Hadwiger, Sicat, Beyer, Krüger, Möller,
Sparse PDF Maps for Non-Linear Multi-Resolution Image Operations,
Siggraph Asia 2012

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# GPU-Based Large-Scale Scientific Visualization

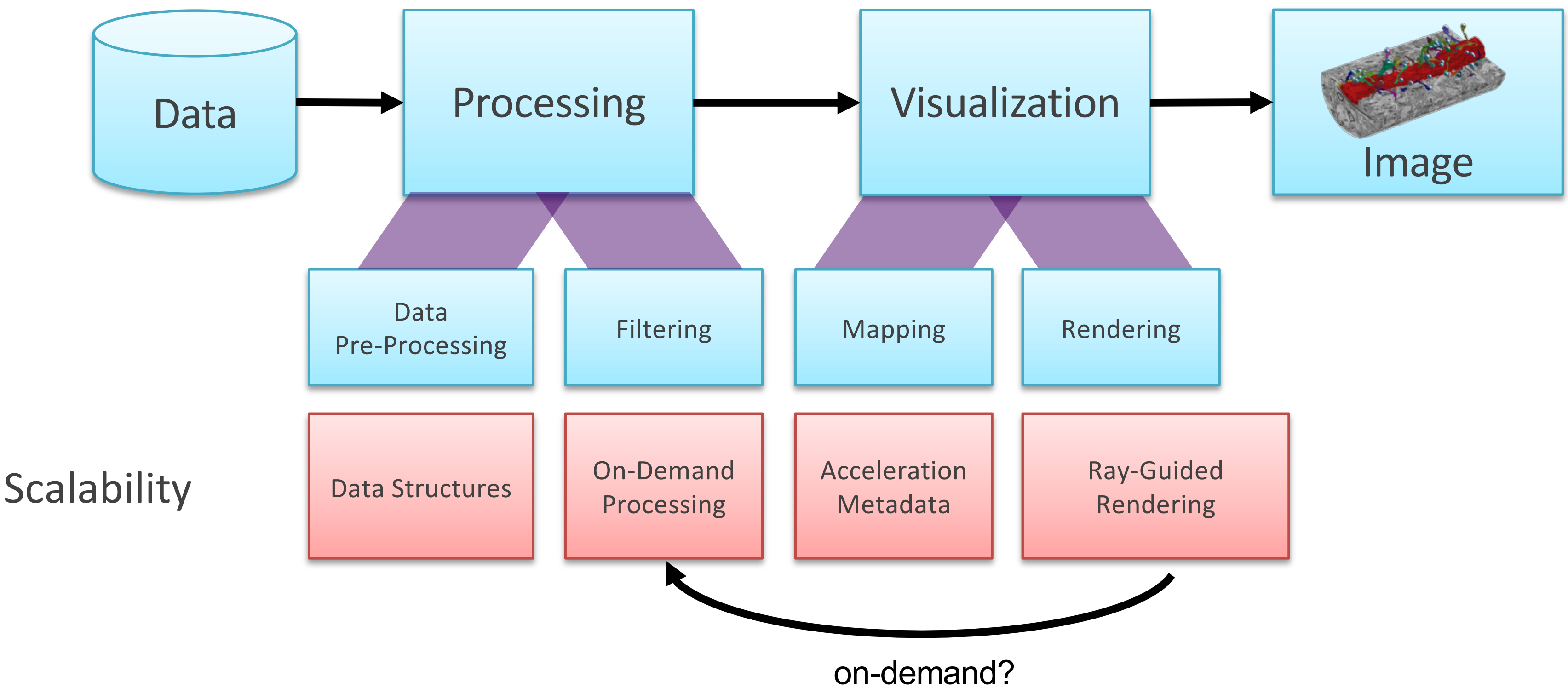

**Johanna Beyer, Harvard University**

**Markus Hadwiger, KAUST**


Course Website:
http://johanna-b.github.io/LargeSciVis2018/index.html

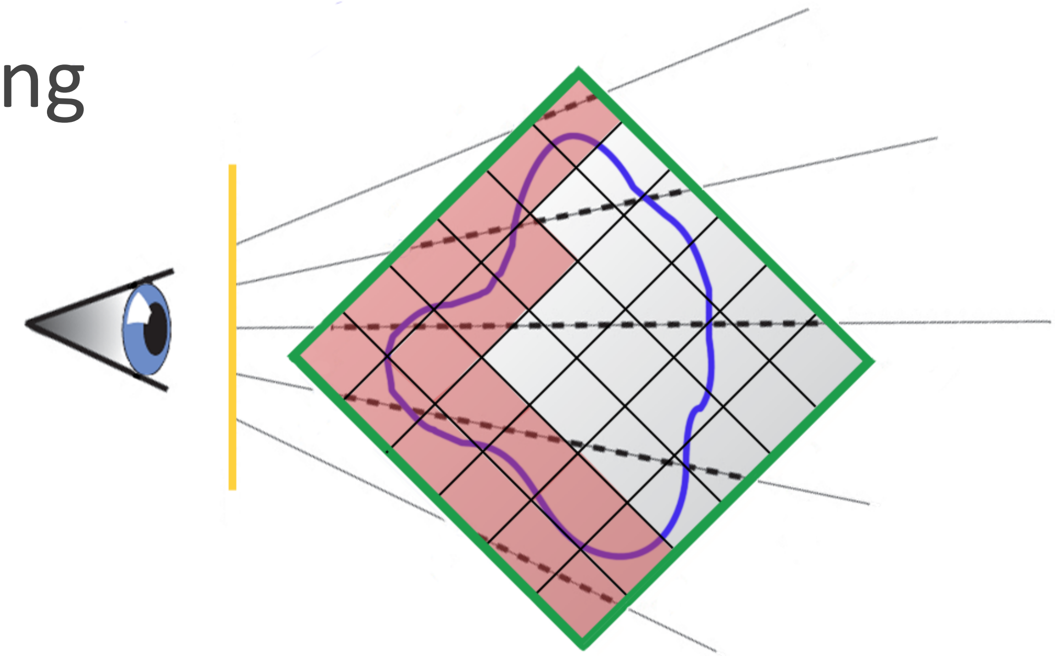
# Summary & Outlook

# LARGE-SCALE VISUALIZATION PIPELINE



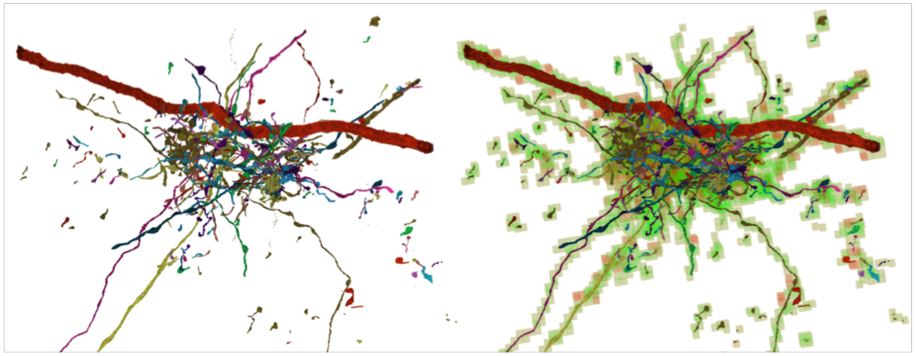
## RAY-GUIDED VOLUME RENDERING

- Working set determination on GPU
- Single-pass rendering
- Traversal on GPU
- Virtual texturing



# VOLUME RENDERING FOR SEGMENTED DATA

- Empty space skipping essential
- Efficient culling is basis for empty space skipping
  - Compact and scalable data structure (to millions of objects)
  - Hierarchical culling algorithm
- Hybrid approaches
  - Image-order vs. object-order
  - Deterministic vs. probabilistic

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# THANK YOU!

Johanna Beyer, Harvard University
Markus Hadwiger, KAUST

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