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A Perceptual Framework for Contrast Processing of HDR Images

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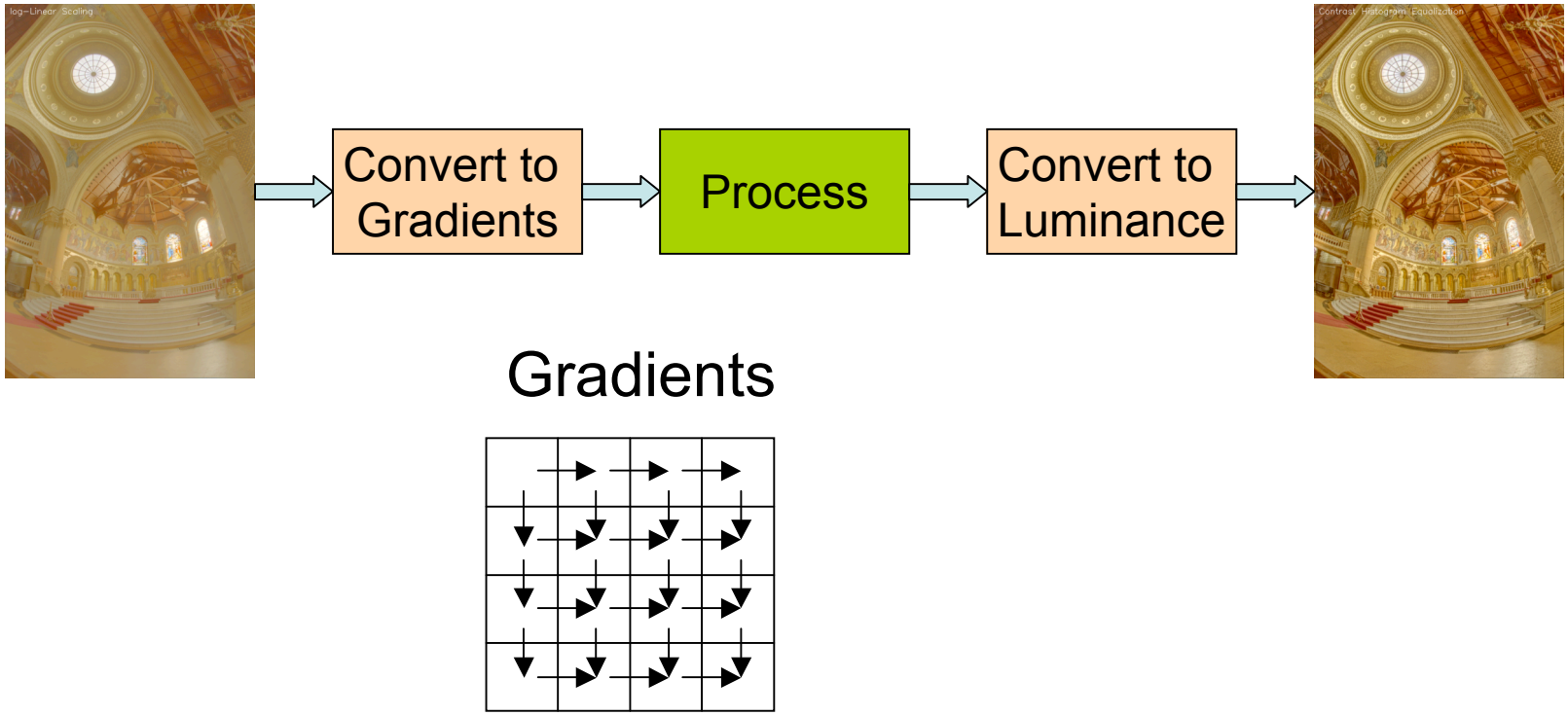
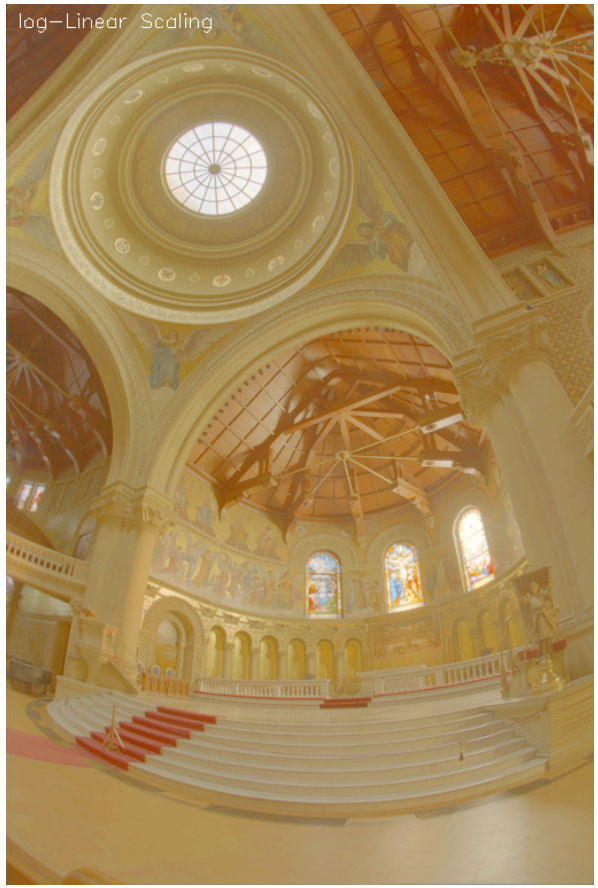
Motivation

- Gradient Domain Methods
  - Operate on pixel gradients instead of pixel values



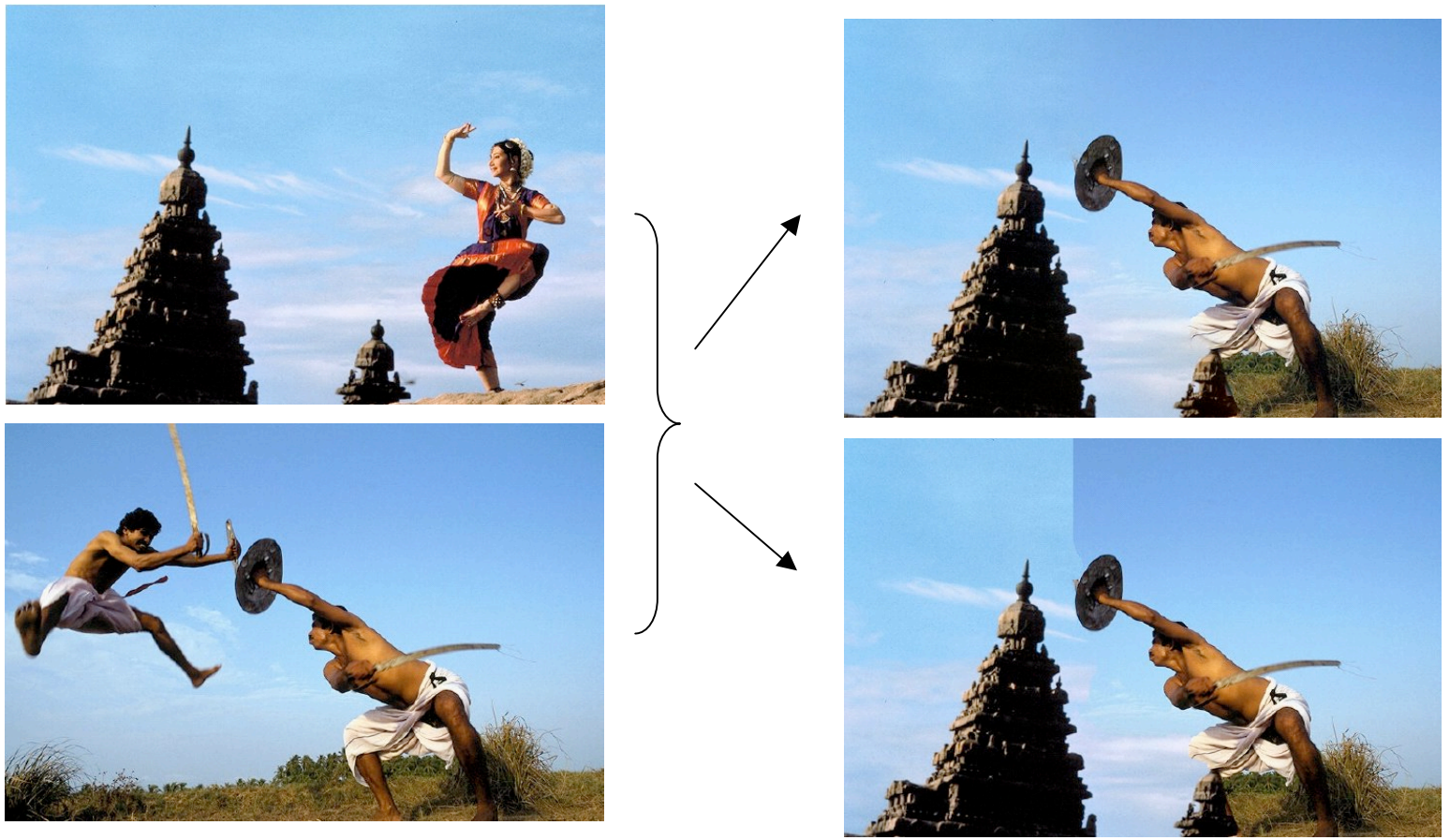
Gradient Domain: applications

- Tone Mapping



Gradient Domain: applications

- Compositing [Wang et al. 2004]



images from [Drori at al. 2004]

Gradient Domain: applications

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- More applications:
  - Lightness perception (Retinex) [Horn 1974]
  - Matting [Sun et al. 2004]
  - Color to gray mapping [Gooch et al. 2005]
  - Video Editing [Perez at al. 2003, Agarwala et al. 2004]
  - Photoshop's Healing Brush [Georgiev 2005]

Drawbacks of gradient methods

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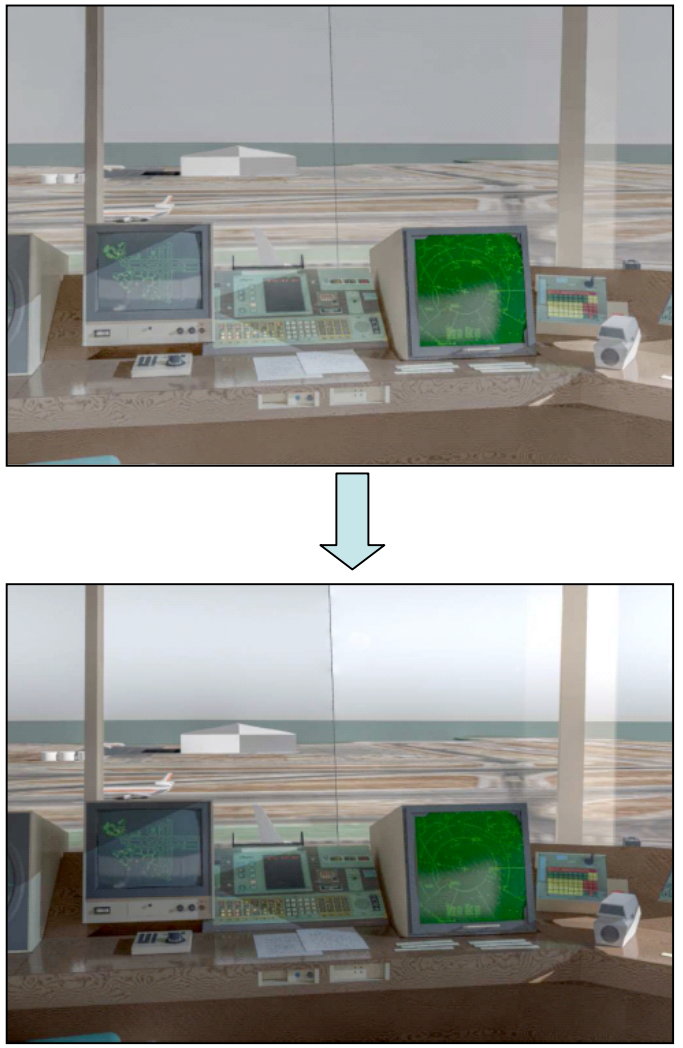
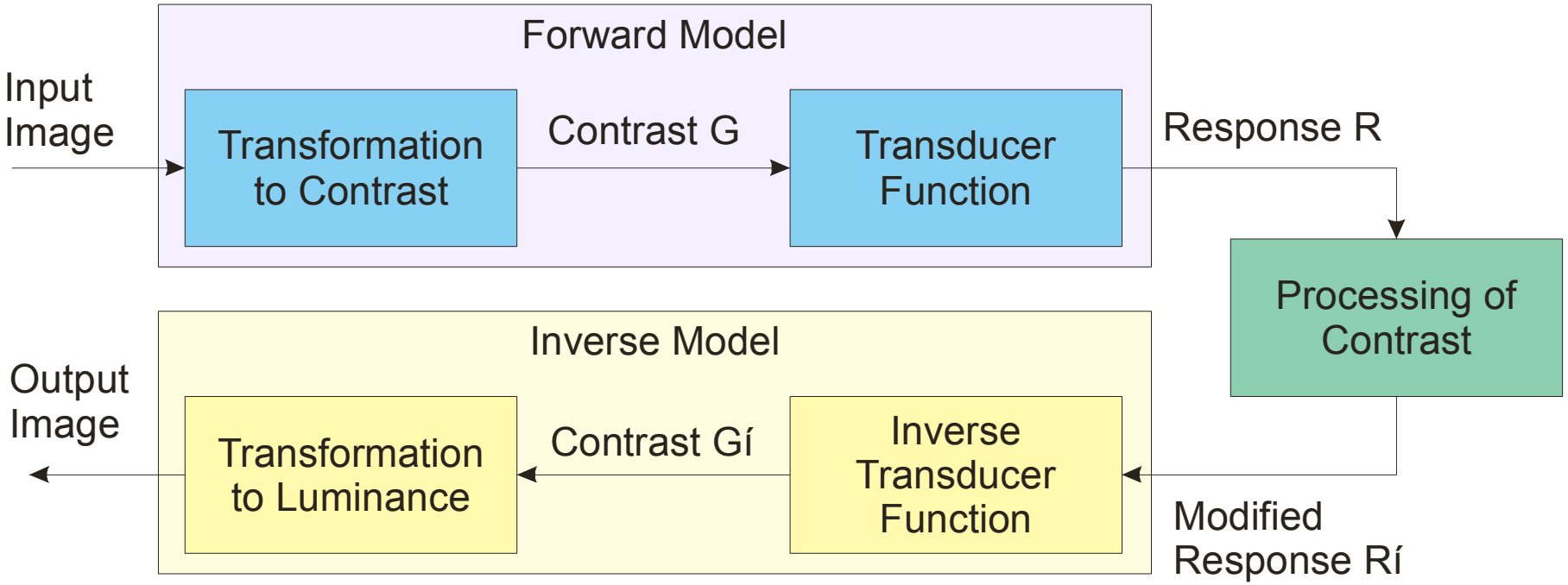
- Only local
  - Consider only differences between neighboring pixels
  - Low spatial frequencies can be distorted
  - Artifacts in the resulting images
- Perceptually implausible
  - Are there any perceptual basis for gradients?



Contrast Processing Framework



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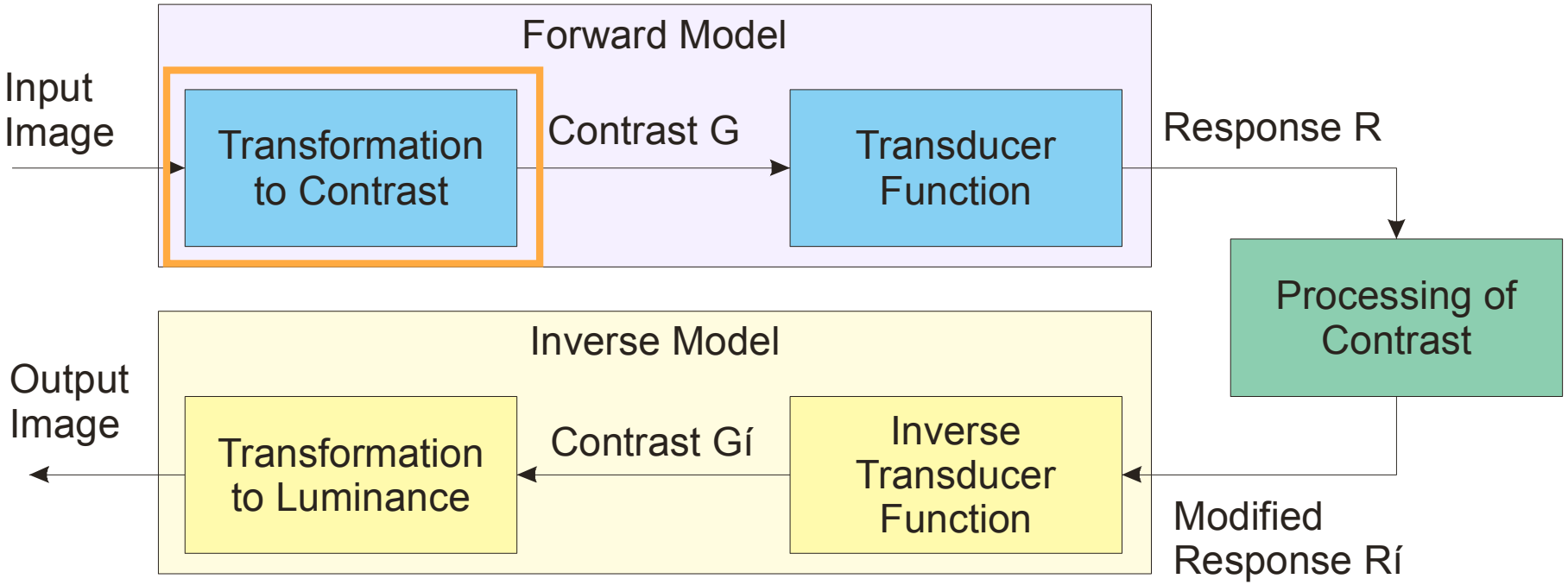

Contrast in Complex Images

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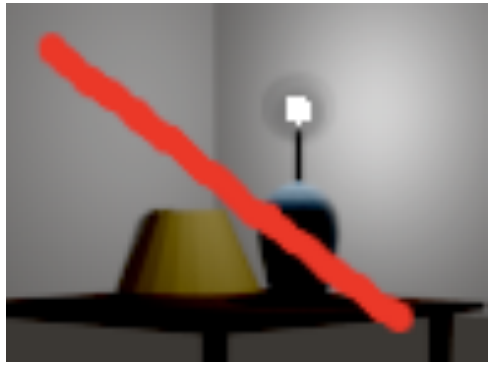
- Contrast in psychophysics:
  - Michaelson's contrast, Weber fraction, Westheimer's contrast, … and many more
  - Applicable only to simple stimuli
- Contrast in Complex Images [Peli 1990]
  - Center-surround structures in retina
  - Can introduce halos since contrast measure is band-pass limited
- Wavelets
  - Efficient to compute
  - May introduce halos



Low-pass Contrast in Images

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- Logarithmic domain
  - A ratio becomes a difference:
    $y_1/y_2 = \log_{10} y_1 - \log_{10} y_2$

Low-pass Contrast in Images

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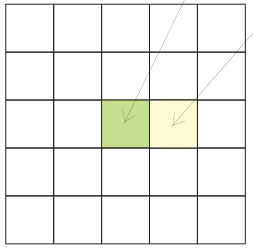
$G_{ij} = x_i - x_j$



- Logarithmic domain
  - A ratio becomes a difference: $y_1/y_2 = \log_{10} y_1 - \log_{10} y_2$
- Difference between a pixel and its neighbors

Low-pass Contrast in Images

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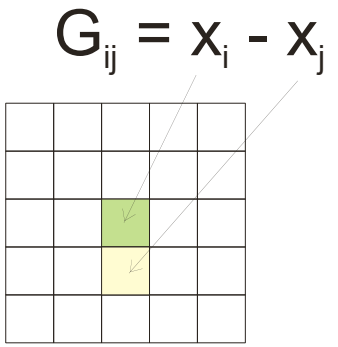

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Low-pass Contrast in Images

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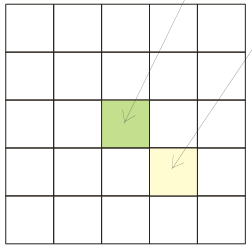

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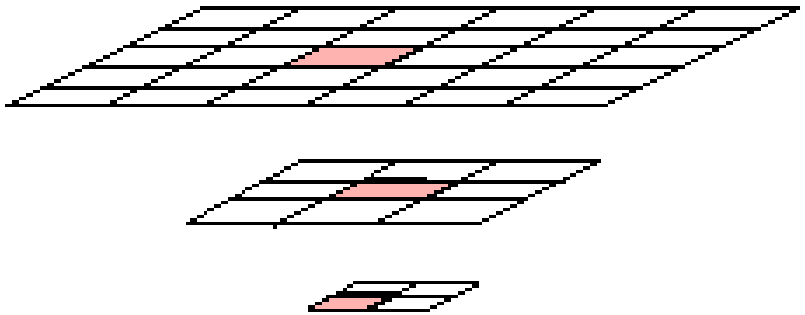

- Logarithmic domain
  - A ratio becomes a difference: $y_1/y_2 = \log_{10} y_1 - \log_{10} y_2$
- Difference between a pixel and its neighbors
- For each level of Gaussian pyramid

Bridging two Approaches

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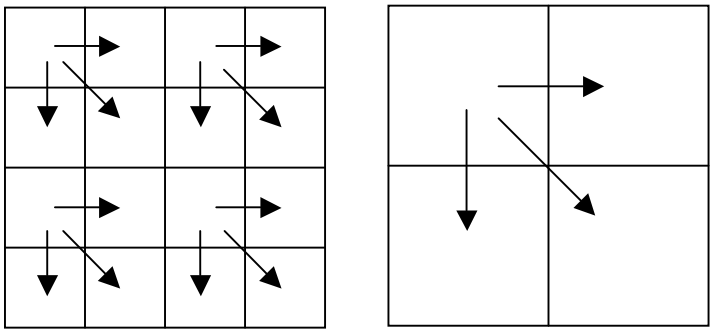
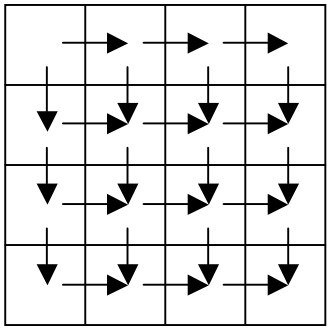
Wavelets

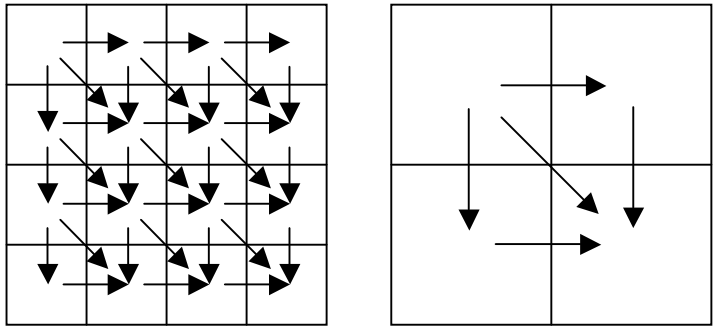


1st level 2nd level

Gradients



Low-pass Contrast



1st level 2nd level

Contrast in Images – Summary

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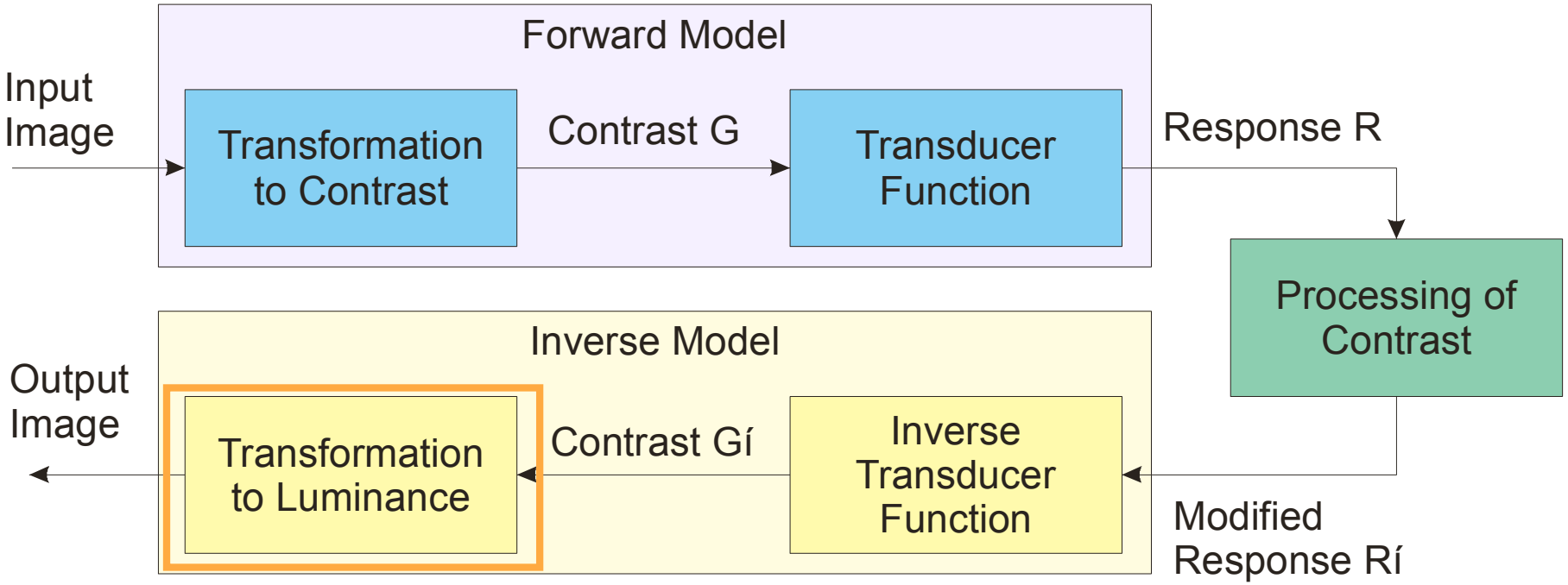
- Properties
  - Low-pass contrast
  - Multiple pyramids
  - Over-determined
  - Analogy to receptive fields
  - Not an accurate model of retina – intended for image processing
  - Halo artifacts can be easily avoided

Contrast Processing Framework



Transformation to Luminance

- Restoring the image, X, from contrast, G, values can be formulated as a minimization problem:

$$f(x_1, x_2, \ldots, x_N) = \sum_{k=1}^{K} \sum_{i=1}^{N} \sum_{j=1}^{M} (G_{i,j}^k - \hat{G}_{i,j}^k)^2$$

where:

$x_1, x_2, \ldots, x_N$ pixel values

$\hat{G}_{i,j}^k$ desired contrast

$G_{i,j}^k$ realized contrast

- If *only* one level of Gaussian pyramid ($k = 1$) and only four neighboring pixels are considered - the same problem as in Gradient methods, e.g. [Fattal et al. 2002].

Numerical Solution

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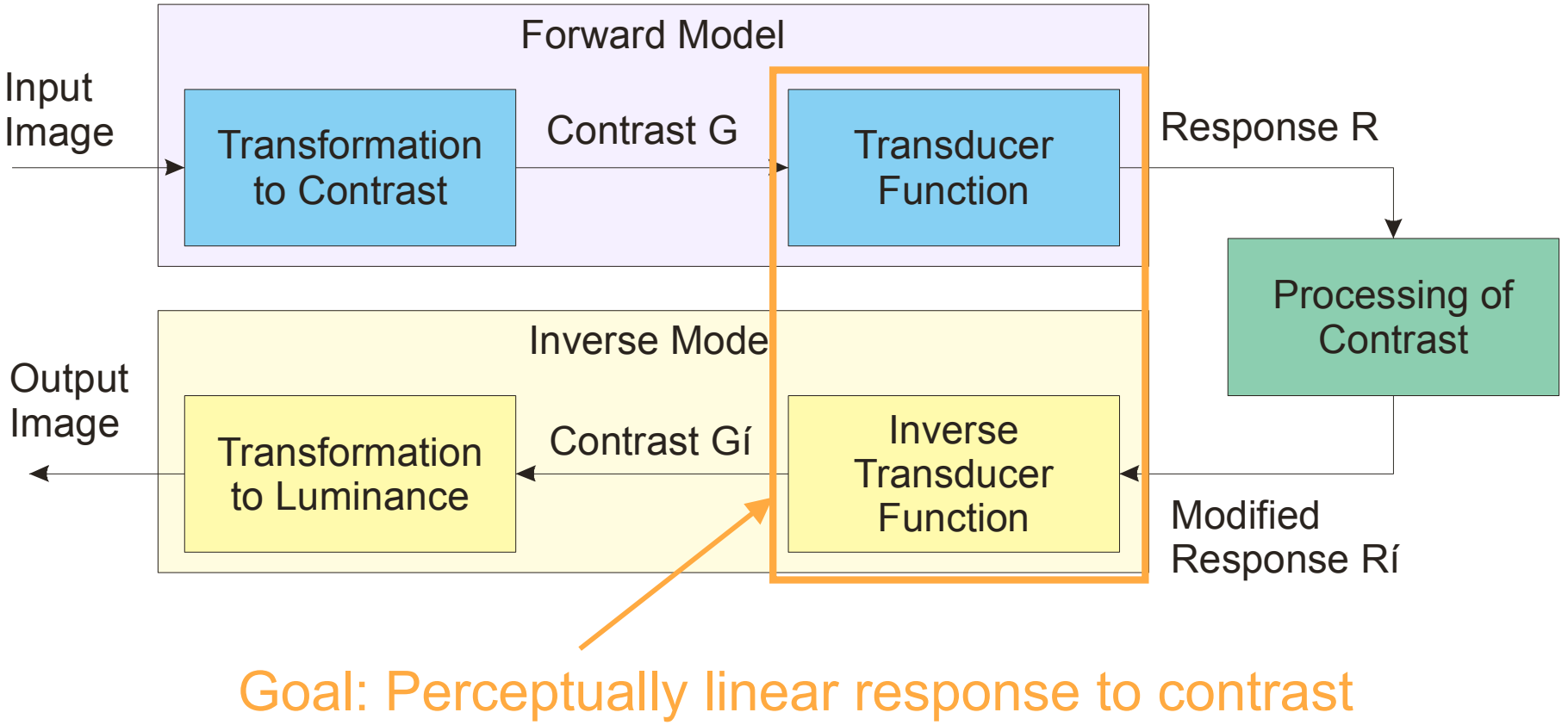
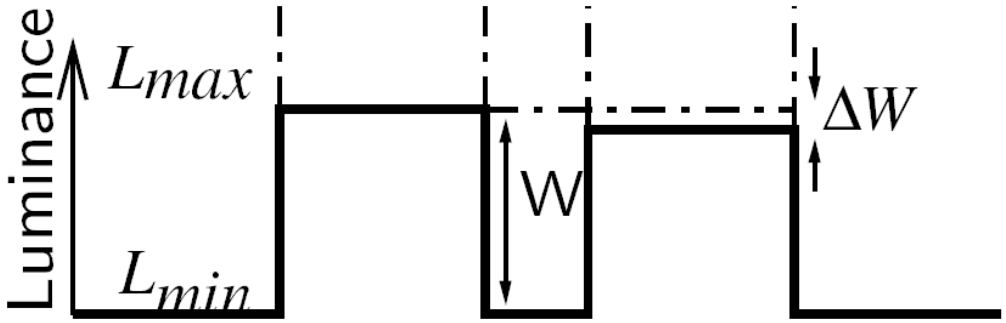
- Numerical solution of the minimization problem
  - Biconjugate Gradient Method
  - Very efficient multiplication of a semi-sparse matrix and a vector
- Performance
  - Converges fast
  - But computationally expensive
    - O(nlog(n)) with large coefficients
  - Suitable only for off-line processing
    - Below one minute for 1-5MPixel image
  - GPU implementation possible

Contrast Processing Framework

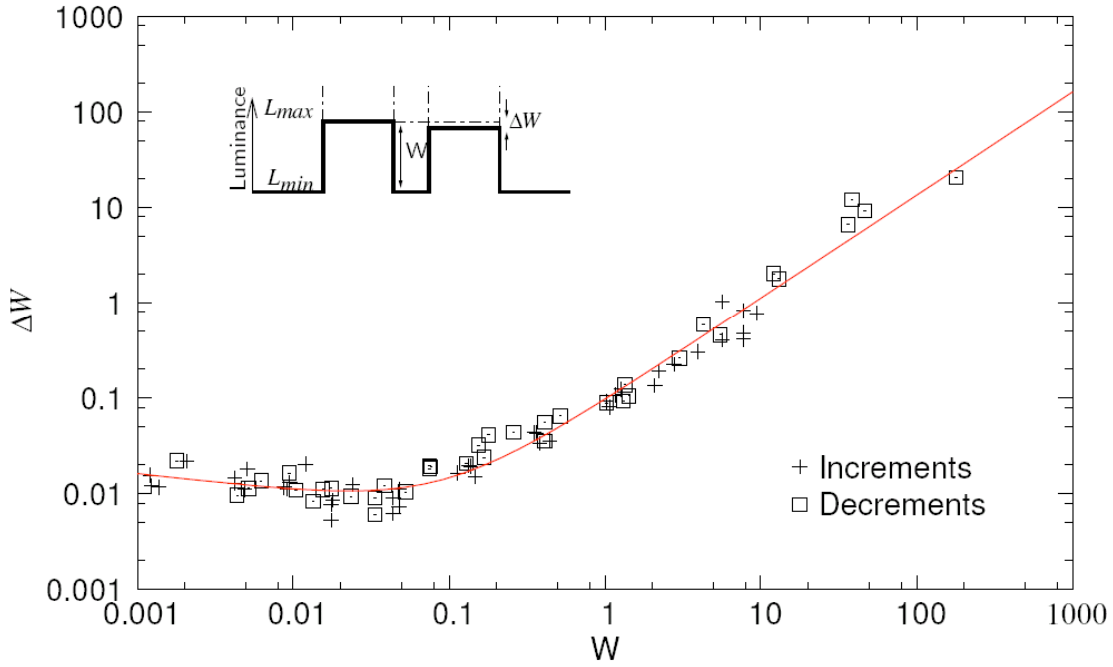


Contrast Discrimination

- Contrast Discrimination Threshold ΔW - The smallest visible difference between two nearly identical signals



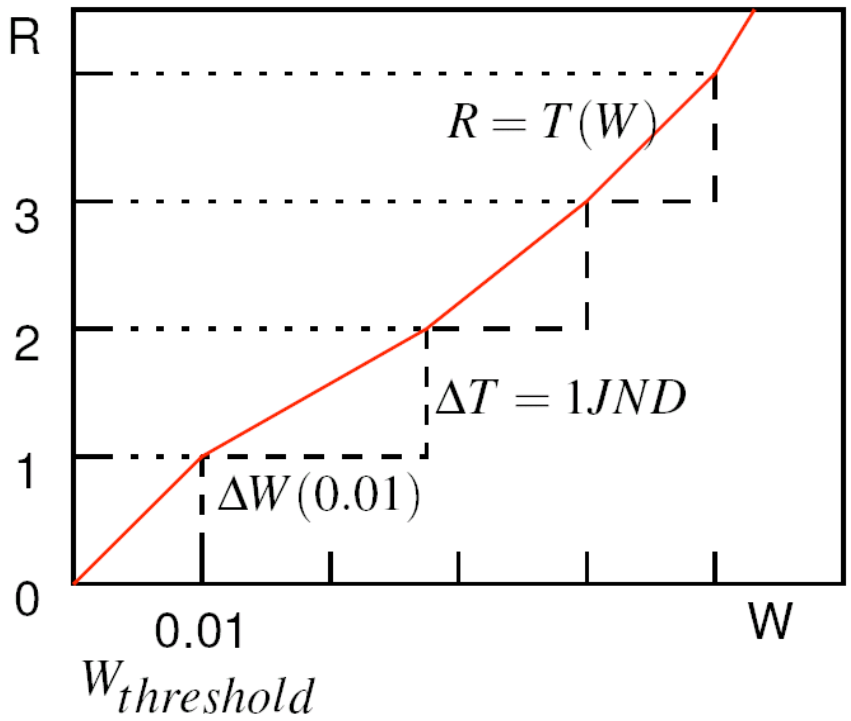
Contrast Discrimination Function



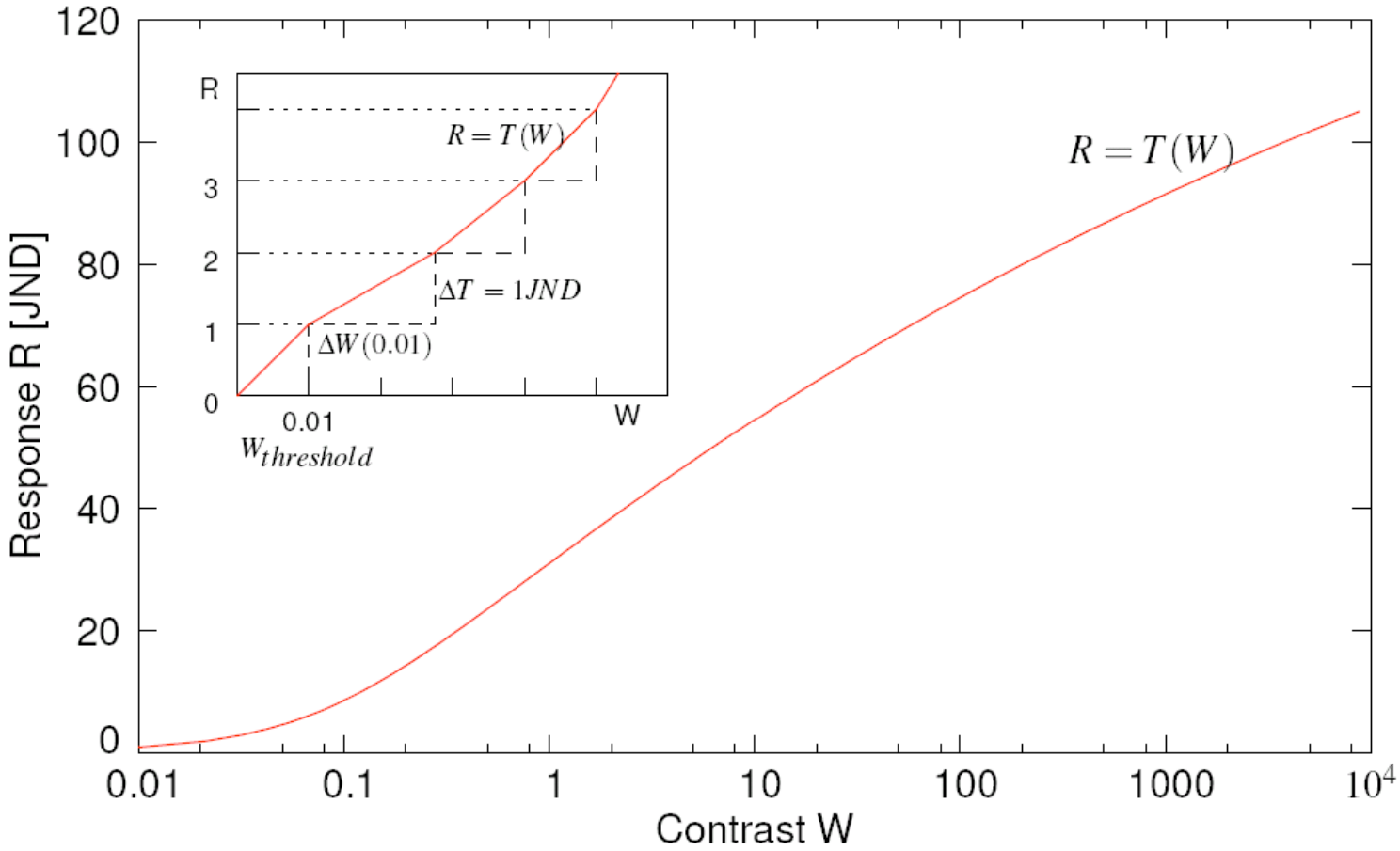
- Data from [Whittle 1986]
- Very high contrast (important for HDR images)
- Measure of contrast: Weber fraction rather the Michelson's contrast

Transducer Function

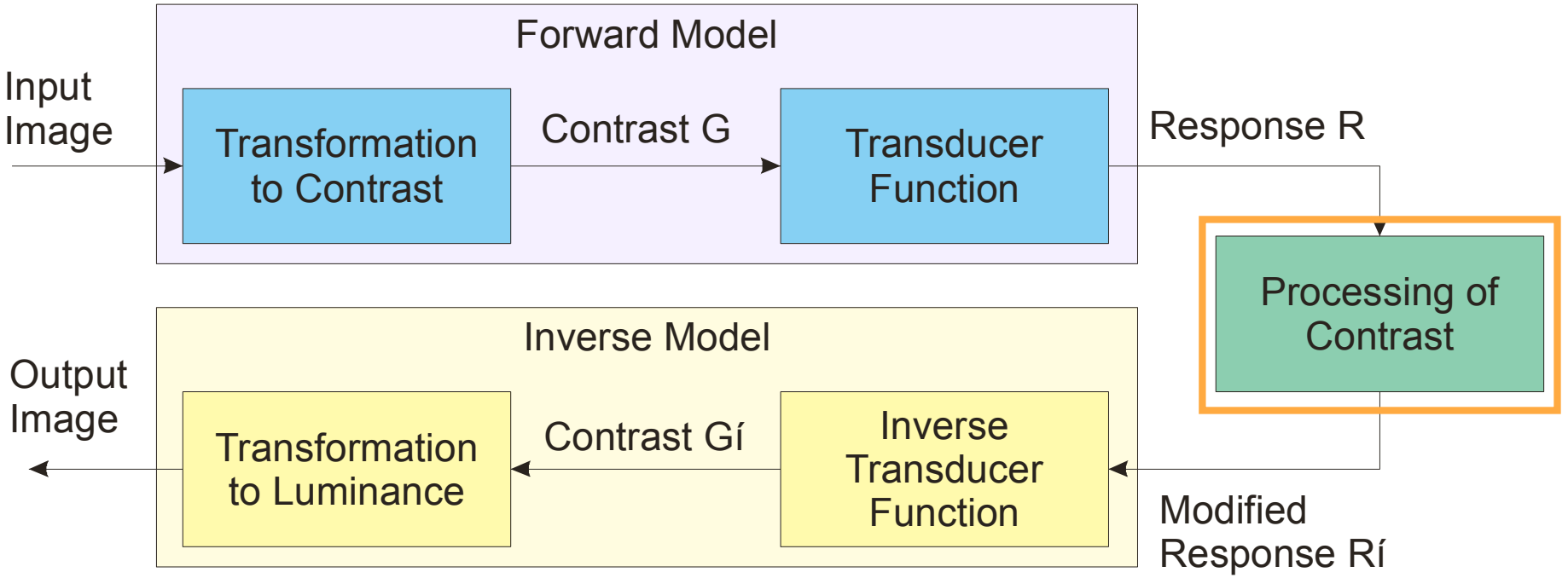
- Response of the HVS
- Derived by summing up thresholds ΔW



Transducer Function



Contrast Processing Framework



Application 1: Contrast Mapping

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- Tone mapping in contrast domain
  - Map contrast rather than luminance
- Reduce contrast proportionally to its visibility

- Operation: multiply contrast response, R, by a constant value, l:

$$\hat{R}^k_{i,j} = R^k_{i,j} \cdot l$$

Contrast Mapping: the effect of ‘l’

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l = 1.0

Contrast Mapping: the effect of ‘l’

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l = 0.7

Contrast Mapping: the effect of ‘l’

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l = 0.4

Contrast Mapping: the effect of ‘l’

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l = 0.1

Application 2: Contrast Equalization

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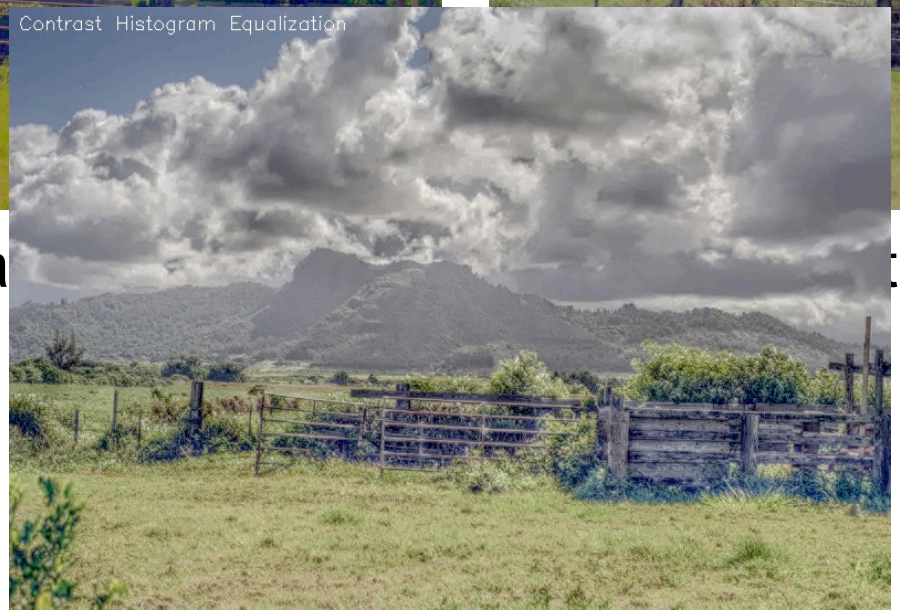
- High contrast regions:
  - Occupy only small part on an image
  - But are responsible for excessive dynamic range
- Contrast equalization
  - Redistribute contrast values across an image
  - Emphasize contrast that dominates in the image
  - Reduce contrast that occupy only small part of an image
- Algorithm
  - Histogram equalization of contrast magnitudes

Contrast Equalization: Examples



Log-Linea t mapping

Contrast equalization

Contrast Equalization: Examples

Log-Linear Sc rast mapping

Contrast equalization

Conclusions

- A framework for image processing
  - Operations on contrast rather than pixel values
  - Low-pass contrast to avoid halos
  - All spatial frequencies taken into account
  - Contrast rescaled to the response of the HVS
- Applications
  - Tone mapping: Contrast mapping
  - Tone mapping: Contrast equalization
  - Others...
    - Lightness perception
    - Color to gray mapping
    - Video/Image editing

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Thank you

More information and examples:

http://www.mpi-sb.mpg.de/~mantiuk/contrast_domain/