Digital Image

(B4M33DZO, Summer 2024)

Lecture 6:

Image Editing

https://cw.fel.cvut.cz/wiki/courses/b4m33dzo/start

Daniel Sýkora & Ondřej Drbohlav

Department of Cybernetics

Faculty of Electrical Engineering

Czech Technical University in Prague

Image stitching

How to stitch two similar images?

We can use histogram mapping to reach similar intensity level.

Problem: local changes still remain visible along the seam.

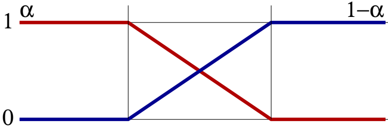
Linear blending

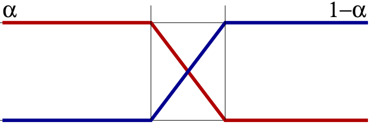
Spatially weighted linear combination of images:

$$\mathbf{I}[x,y] = \alpha \cdot \mathbf{I}_a[x,y] + (1-\alpha)\cdot \mathbf{I}_b[x,y]$$

too wide – ghosts

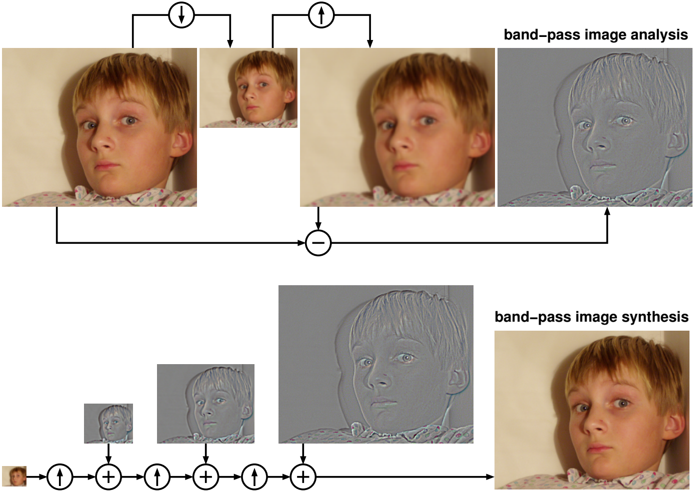
too narrow – seam





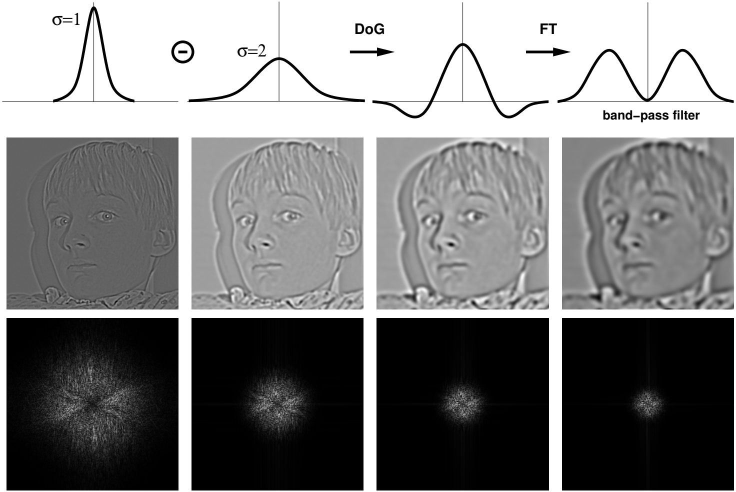
Multi-band blending

Band-pass image analysis and synthesis using Laplacian pyramid:



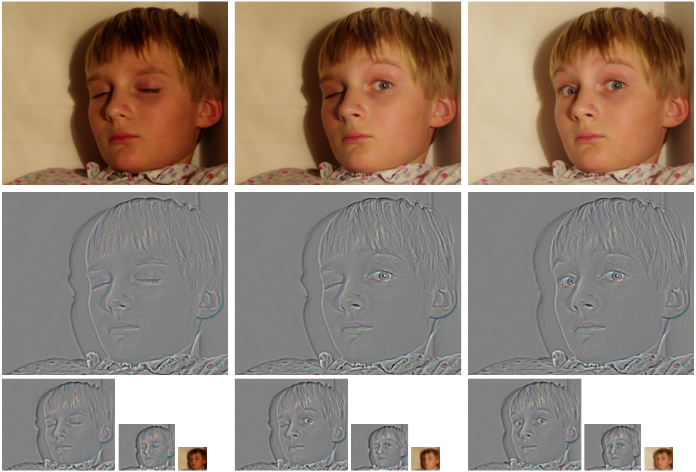
Multi-band blending

Difference of Gaussians ≈ Laplacian of Gaussian (band-pass filter):



Multi-band blending

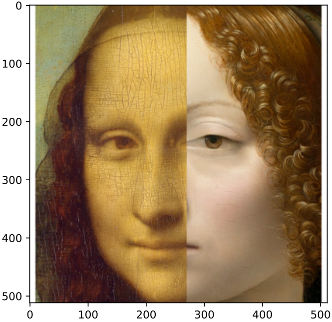
Blend each level of Laplacian pyramid and synthesize the image:



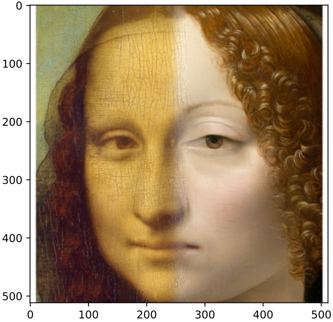
Multi-band blending

With images from lab task:

concatenation



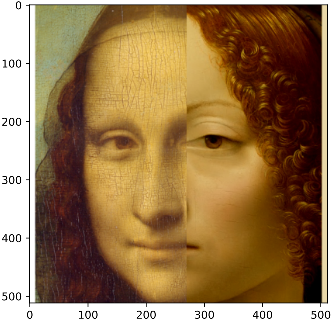
fusion



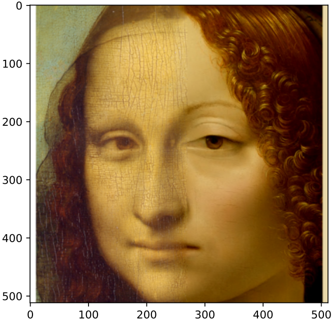
Multi-band blending

After color adjustment:

concatenation



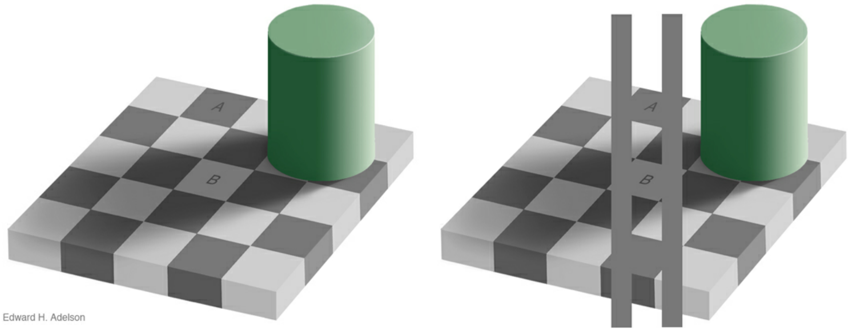
fusion



Gradient domain

Human visual system is not very sensitive to absolute intensity.

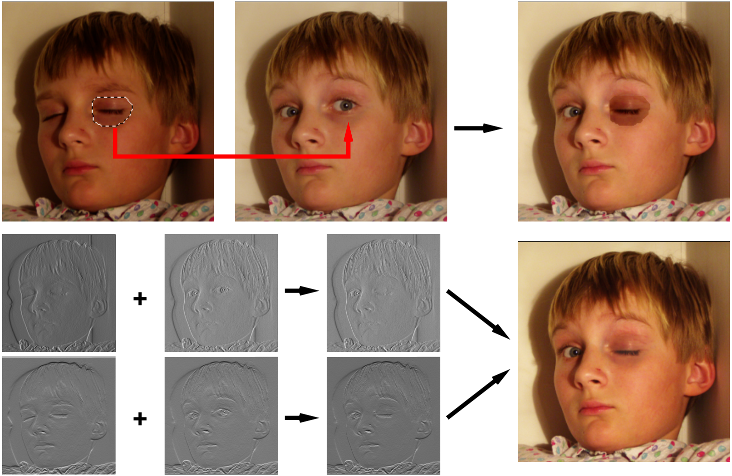
Adelson's checkerboard illusion:



Local intensity changes (gradients) are much more important.

Gradient domain

New approach: modify gradients and then reconstruct intensity.



Gradient domain

Problem: only conservative gradient field can be integrated in 2D.

$$\nabla I = G \quad \Longrightarrow \quad I = \iint G \quad \Longleftrightarrow \quad \oint G = 0$$

Gradient domain

Problem: only conservative gradient field can be integrated in 2D.

$$\nabla I = G \quad \Longrightarrow \quad I = \iint G \quad \Longleftrightarrow \quad \oint G = 0$$

Solution: find an image I^* of which gradient field is close to G.

Gradient domain

Problem: only conservative gradient field can be integrated in 2D.

$$\nabla I = G \quad \Longrightarrow \quad I = \iint G \quad \Longleftrightarrow \quad \oint G = 0$$

Solution: find an image I^* of which gradient field is close to G.

$$I^* = \arg\min_I \iint ||\nabla I - G||^2$$

Gradient domain

Problem: only conservative gradient field can be integrated in 2D.

$$\nabla I = G \quad \Longrightarrow \quad I = \iint G \quad \Longleftrightarrow \quad \oint G = 0$$

Solution: find an image I^* of which gradient field is close to G.

$$I^* = \arg\min_I \iint ||\nabla I - G||^2$$

$$I^* = \arg\min_I \iint \left(\frac{\partial I}{\partial x} - G_x\right)^2 + \left(\frac{\partial I}{\partial y} - G_y\right)^2$$

Gradient domain

We want to minimize:

$$\iint \underbrace{\left(\frac{\partial I}{\partial x} - G_x\right)^2 + \left(\frac{\partial I}{\partial y} - G_y\right)^2}_{F}$$

Gradient domain

We want to minimize:

$$\iint \underbrace{\left(\frac{\partial I}{\partial x} - G_x\right)^2 + \left(\frac{\partial I}{\partial y} - G_y\right)^2}_{F}$$

Variational Principle (Euler-Lagrange equation):

$$\frac{\partial F}{\partial I} - \frac{d}{dx}\frac{\partial F}{\partial I_x} - \frac{d}{dy}\frac{\partial F}{\partial I_y} = 0 \quad \Rightarrow \quad 2\left(\frac{\partial^2 I}{\partial x^2} - \frac{\partial G_x}{\partial x}\right) + 2\left(\frac{\partial^2 I}{\partial y^2} - \frac{\partial G_y}{\partial y}\right) = 0$$

Gradient domain

We want to minimize:

$$\iint \underbrace{\left(\frac{\partial I}{\partial x} - G_x\right)^2 + \left(\frac{\partial I}{\partial y} - G_y\right)^2}_{F}$$

Variational Principle (Euler-Lagrange equation):

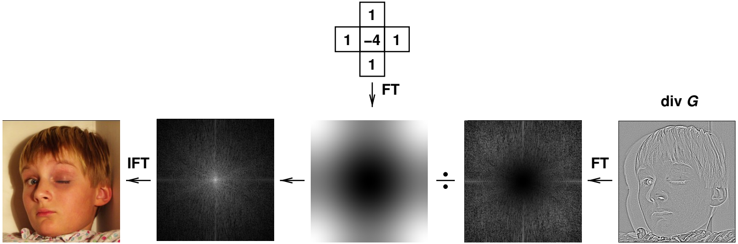
$$\frac{\partial F}{\partial I} - \frac{d}{dx}\frac{\partial F}{\partial I_x} - \frac{d}{dy}\frac{\partial F}{\partial I_y} = 0 \quad \Rightarrow \quad 2\left(\frac{\partial^2 I}{\partial x^2} - \frac{\partial G_x}{\partial x}\right) + 2\left(\frac{\partial^2 I}{\partial y^2} - \frac{\partial G_y}{\partial y}\right) = 0$$

Poisson equation:

$$\frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2} = \Delta I \qquad \boxed{\Delta I = \operatorname{div} G} \qquad \operatorname{div} G = \frac{\partial G_x}{\partial x} + \frac{\partial G_y}{\partial y}$$

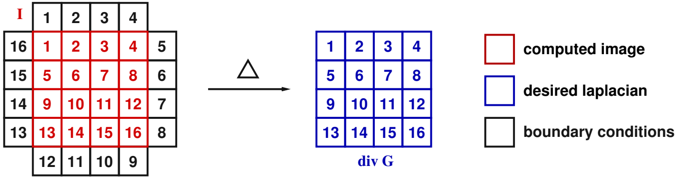
Gradient domain

Deconvolution:



Gradient domain

Discretization of Poisson equation:



$$
\begin{array}{cccccccccccccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16
\end{array}
$$

$$
\begin{bmatrix}
-4 & 1 & & & 1 & & & & & & & & & & & \\
1 & -4 & 1 & & & 1 & & & & & & & & & & \\
& 1 & -4 & 1 & & & 1 & & & & & & & & & \\
& & 1 & -4 & & & & 1 & & & & & & & & \\
1 & & & & -4 & 1 & & & 1 & & & & & & & \\
& 1 & & & 1 & -4 & 1 & & & 1 & & & & & & \\
& & 1 & & & 1 & -4 & 1 & & & 1 & & & & & \\
& & & 1 & & & 1 & -4 & & & & 1 & & & & \\
\end{bmatrix}
\cdot
\begin{array}{ccccccc}
\boxed{1} & = & \boxed{1} & - & \boxed{1} & - & \boxed{16} \\
\boxed{2} & = & \boxed{2} & - & \boxed{2} & & \\
\boxed{3} & = & \boxed{3} & - & \boxed{3} & & \\
\boxed{4} & = & \boxed{4} & - & \boxed{4} & - & \boxed{5} \\
\boxed{5} & = & \boxed{5} & - & \boxed{15} & & \\
\boxed{6} & = & \boxed{6} & & & & \\
\boxed{7} & = & \boxed{7} & & & & \\
\boxed{8} & = & \boxed{8} & - & \boxed{6} & & \\
\end{array}
$$

Gradient domain

Large but very sparse system of linear equations:

$$\mathbf{A}_{[N^2 \times N^2]} \cdot \mathbf{I}_{[N^2]} = \mathbf{b}_{[N^2]}$$

$\mathbf{A}$ not stored in memory $\Rightarrow$ direct computation

Gradient domain

Large but very sparse system of linear equations:

$$\mathbf{A}_{[N^2 \times N^2]} \cdot \mathbf{I}_{[N^2]} = \mathbf{b}_{[N^2]}$$

$\mathbf{A}$ not stored in memory $\Rightarrow$ direct computation

Gauss-Seidel:

$$\mathrm{I}'[x,y] = \tfrac{1}{4}\left(\mathrm{I}[x+1,y] + \mathrm{I}[x-1,y] + \mathrm{I}[x,y+1] + \mathrm{I}[x,y-1] - \mathrm{b}[x,y]\right)$$

Gradient domain

Multi-resolution scheme:

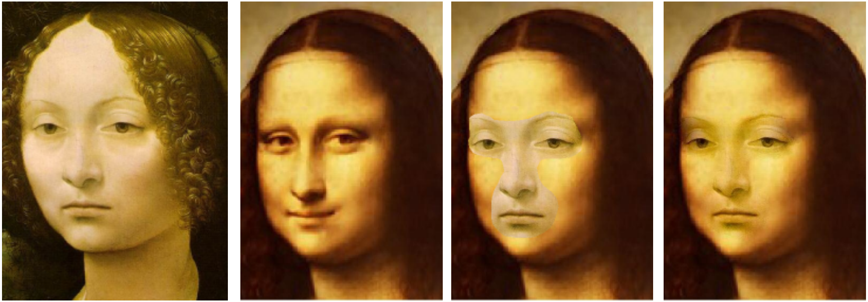
Compute initial solution at lower resolution and refine.

Gradient domain

seamless panorama:

Gradient domain

seamless cloning:



Gradient domain

seamless concealment:

HDR image synthesis:

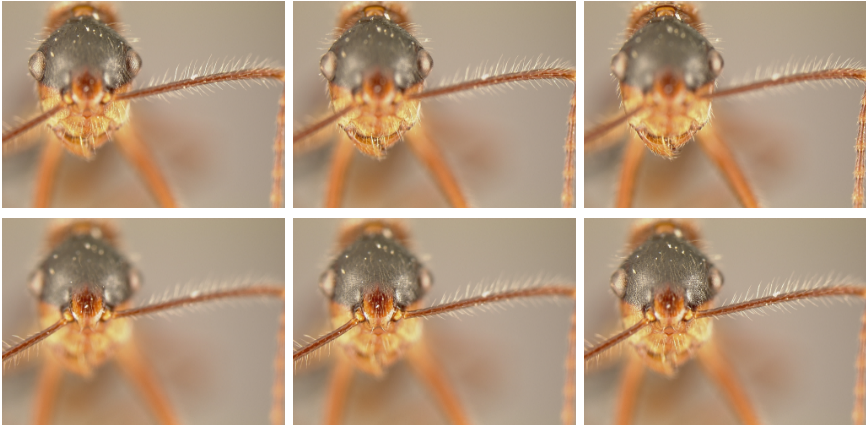
+

Gradient domain

HDR image synthesis:

Gradient domain

sharp image synthesis:



Gradient domain

sharp image synthesis:

Gradient domain

group photo synthesis:

Gradient domain

group photo synthesis:

Gradient domain

group photo synthesis:

Gradient domain

group photo synthesis:

Gradient domain

group photo synthesis:

Gradient domain

group photo synthesis:

Gradient domain

color to gray-scale conversion:

intensity

gradients