Image Inpainting: An Overview

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With C. Ballester, V. Caselles, J. Verdera, M. Bertalmio, A. Bertozzi

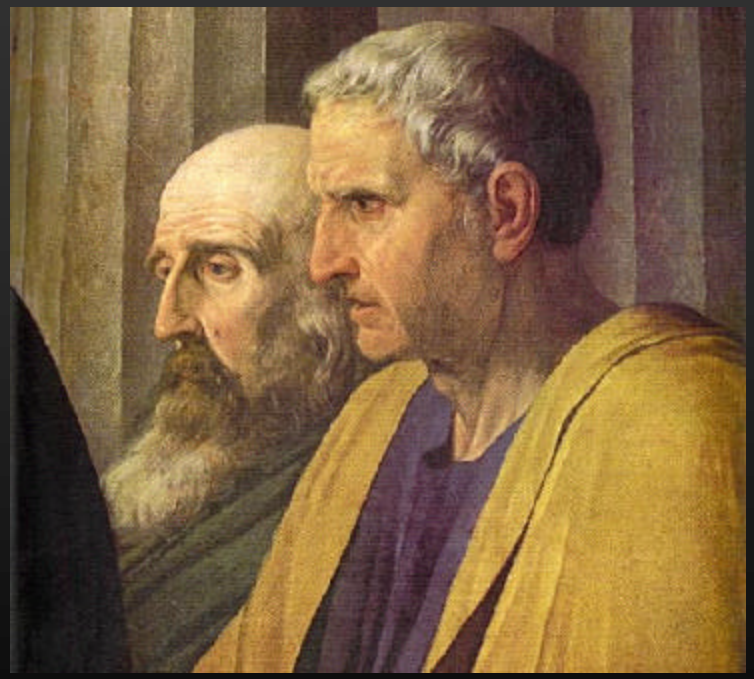
A Vancouver/ICCV example

Overview

- Goal
- Related work
- Filling-in
- Examples
- Concluding remarks

What is inpainting?

- Modifying an image in a non-detectable form

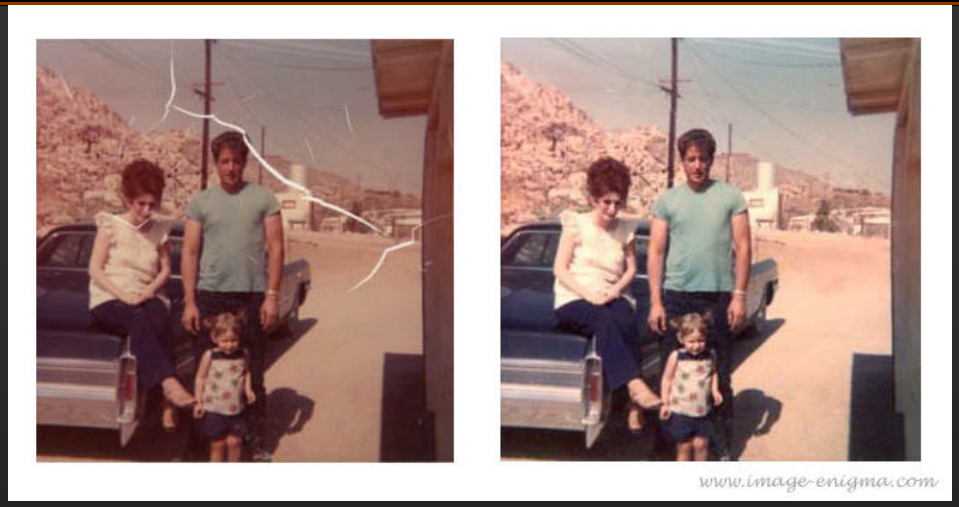


Detail of "Cornelia, Mother of the Gracchi" by J. Suvee (Louvre).
Taken from Emile-Male “The Restorer’s Handbook of easel painting”.

Another example

From Geary Gallery

Real world example: Photo restoration



- Restorations courtesy of Photo Imaging Studio, Image Enigma, Alleycat Designs

Real world example: Object removal

- From D. King, “The Commissar vanishes”.

Real world example: Object removal

Lenin and friend Trotsky

Where is Trotsky?

- **From www.newseum.org**

Real world example: Object removal and missing information

- From ProSpec-UK.

Related work: Films

- e.g. Kokaram et al.

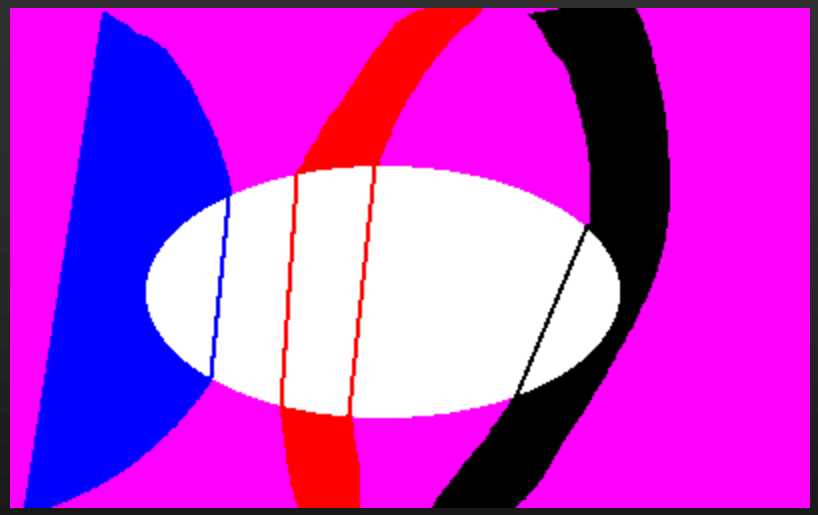
- Doesn’t work for stills or static objects

Related work: Texture synthesis

- Hirani, Efros, Heeger, DeBonet, Simoncelli, Zhu, etc.
- Not practical for rich regions
- Not designed for structured regions
- “Copy” information instead of “see and interpolate”

Related work: Disocclusion

- Masnou-Morel, Nitzberg-Mumford, etc.



- Limitations: Topology, angles

See also Jacobs, Basri, Zucker, etc, and Chan-Shen ‘00, Zhu-Mumford

Our Contribution

- User only selects region to inpaint
- Rich background and topology not an issue
- Less than 1 minute on a PC

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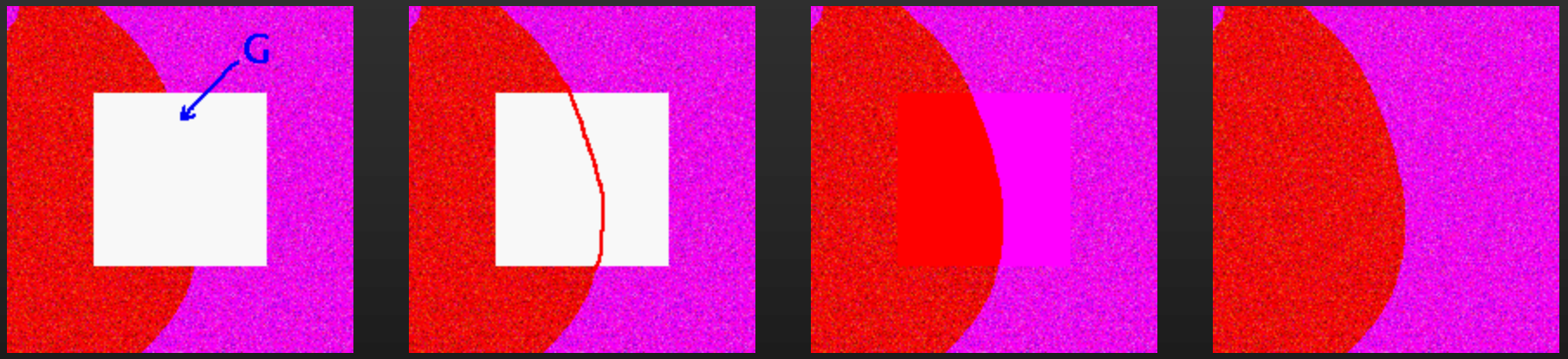
How conservators inpaint

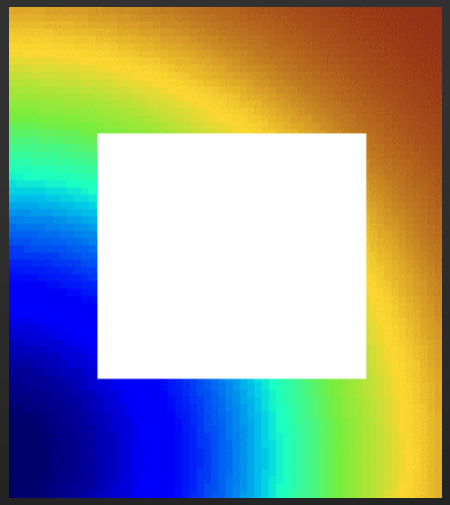
- Minneapolis Institute of Art

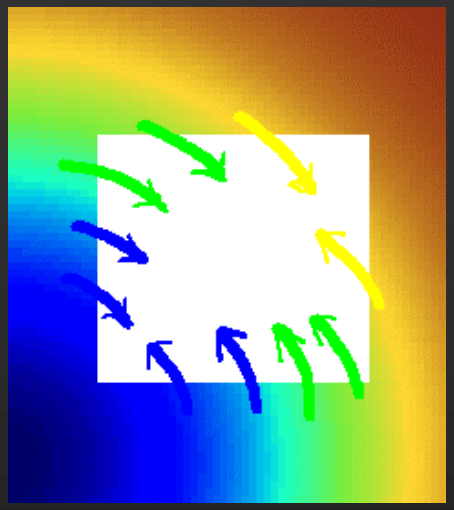


Approach 1

Bertalmio, Sapiro, Caselles, Ballester,
SIGGRAPH 2000

Automatic digital inpainting

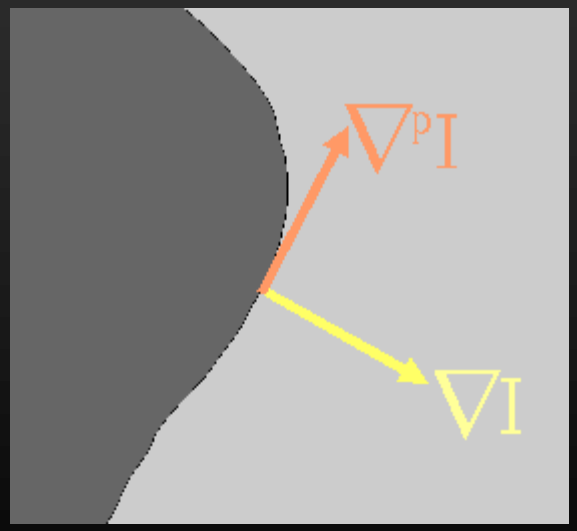


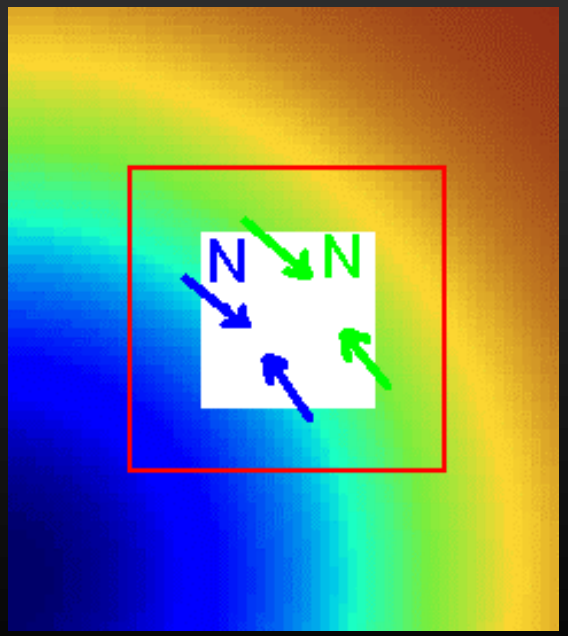


- Propagate information $\nabla \mathbf{L} \bullet \vec{\mathbf{N}} = \mathbf{0}$
- Evolutionary form $\frac{\partial \mathbf{I}}{\partial \mathbf{t}} = \nabla \mathbf{L} \bullet \vec{\mathbf{N}}$

Digital inpainting (cont'd)

- L = smoothness estimator (Laplacian)
- N = isophote direction (time variant)

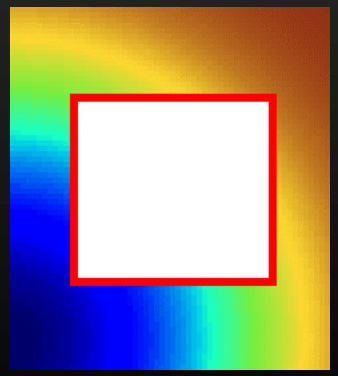




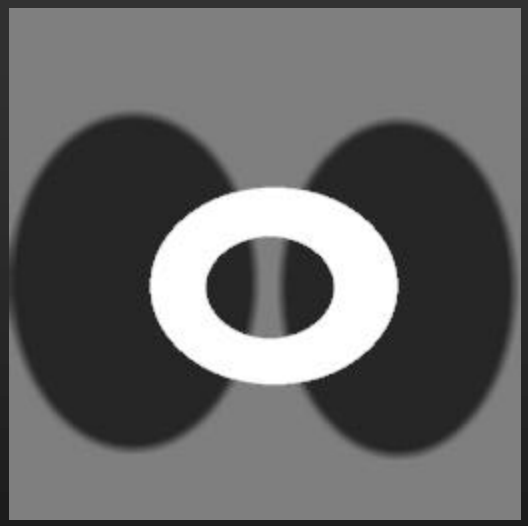
The equation

$$\frac{\partial I}{\partial t} = \nabla(\ddot{A}I) \bullet \nabla^{\perp} I$$

- **Plus numerical schemes (Osher)**
- **Boundary conditions**
  - Gray values (in a band)
  - Directions (in a band)

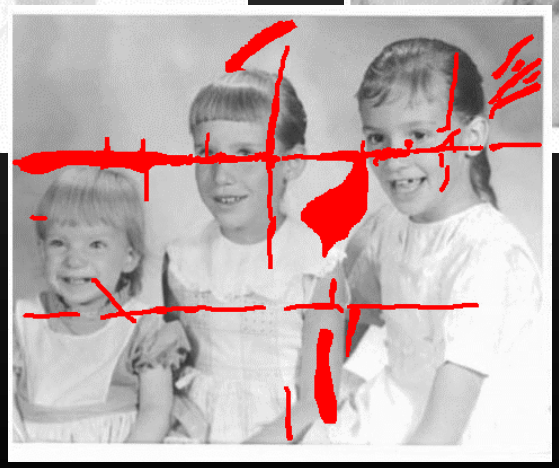


Example



Example: Text removal

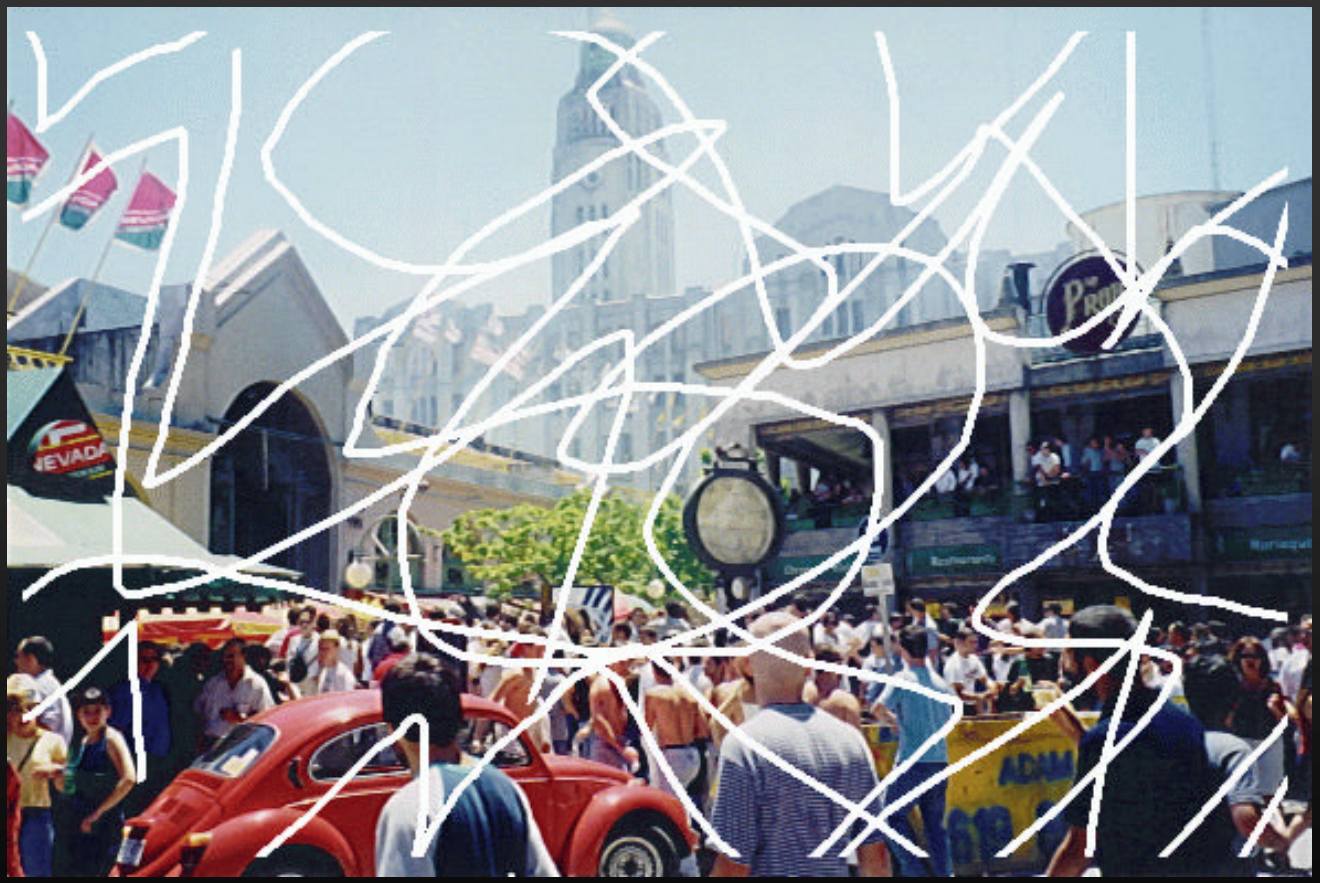
Example: Photo restoration



Example: Special effects

Example: Scratch removal

Example: The evolution



Approach 1: Concluding remarks

- **Technique imitates professionals**
- **Key concepts**
  - Information propagation
  - Both gray values and directions are needed
  - Use a band surrounding the region
- **Sharp results**
- **Low complexity**
- **Texture is not reproduced**

Concluding remarks (cont.)

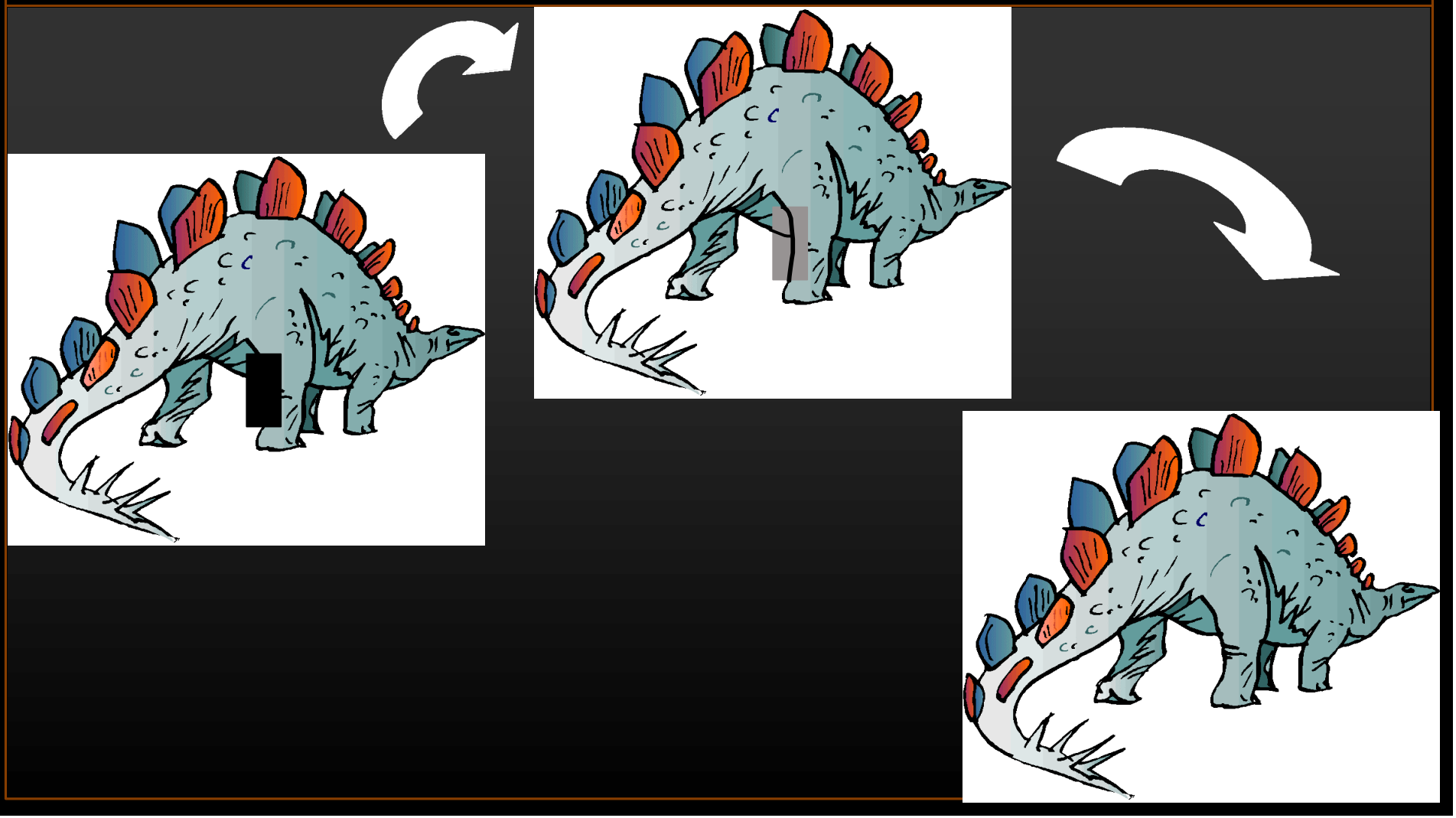
- Connected to fluid dynamics (see next talk, A. Betozzi)
- Opens then door to high order PDE's
- Extended to a variational formulation: Approach 2...

Approach 2

C. Ballester, V. Caselles, J. Verdera, M. Bertalmio, G. Sapiro
IEEE Trans. IP 2001

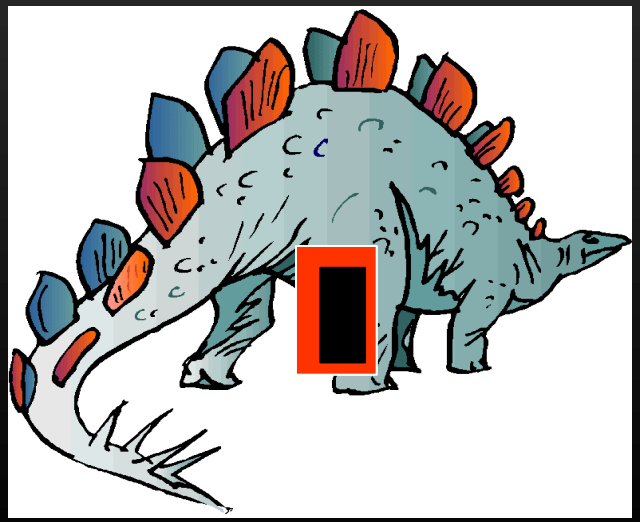
How conservators fill-in

(Minneapolis Institute of Art)

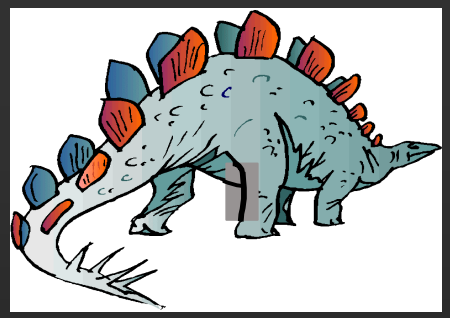


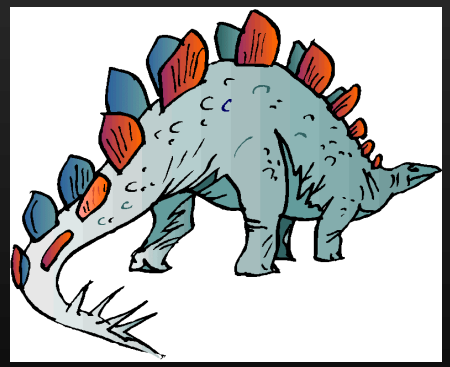
Our approach

- Jointly continue/interpolate level-lines (geometry) and gray values (photometry) in a smooth fashion



Interpolate the gray values given the edges





$$\text{è} = \text{normalized gradient} \Rightarrow \text{è} \bullet \nabla I = \|\nabla I\|$$

$$\min(I) \int_{\Omega \cup Band} (\|\nabla I\| - \text{è} \bullet \nabla I)\, d\Omega$$

$$\frac{\partial I}{\partial t} = div\left(\frac{\nabla I}{\|\nabla I\|}\right) - div(\text{è})$$

Theorem: **The minimizer exists in BV space**

Example

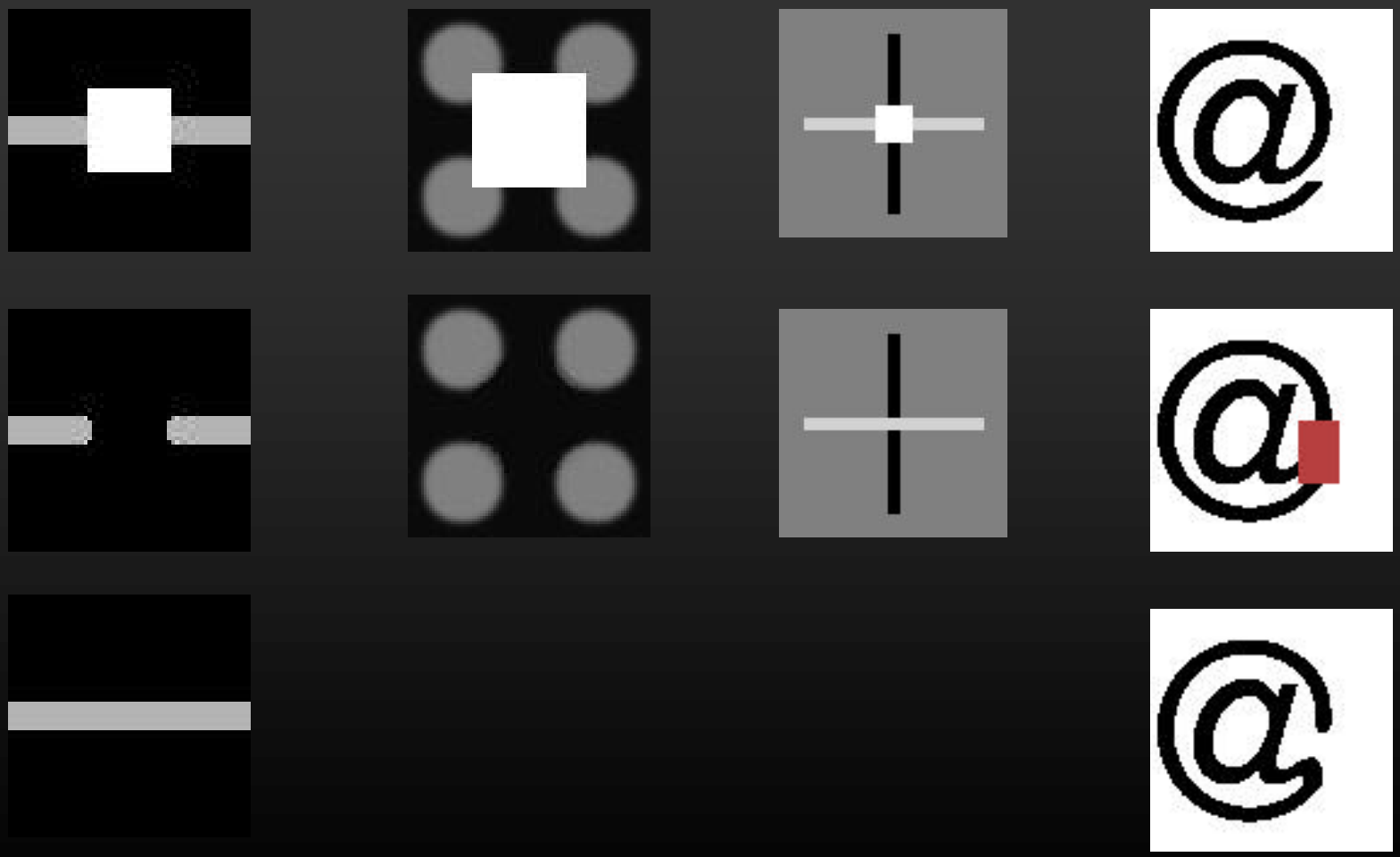
The full functional

$$\min(u,\text{è}) \int_{\Omega \cup Band} div(\text{è})^p (a + b\|\nabla G * u\|) + c(\|\nabla u\| - \text{è} \bullet \nabla u)$$

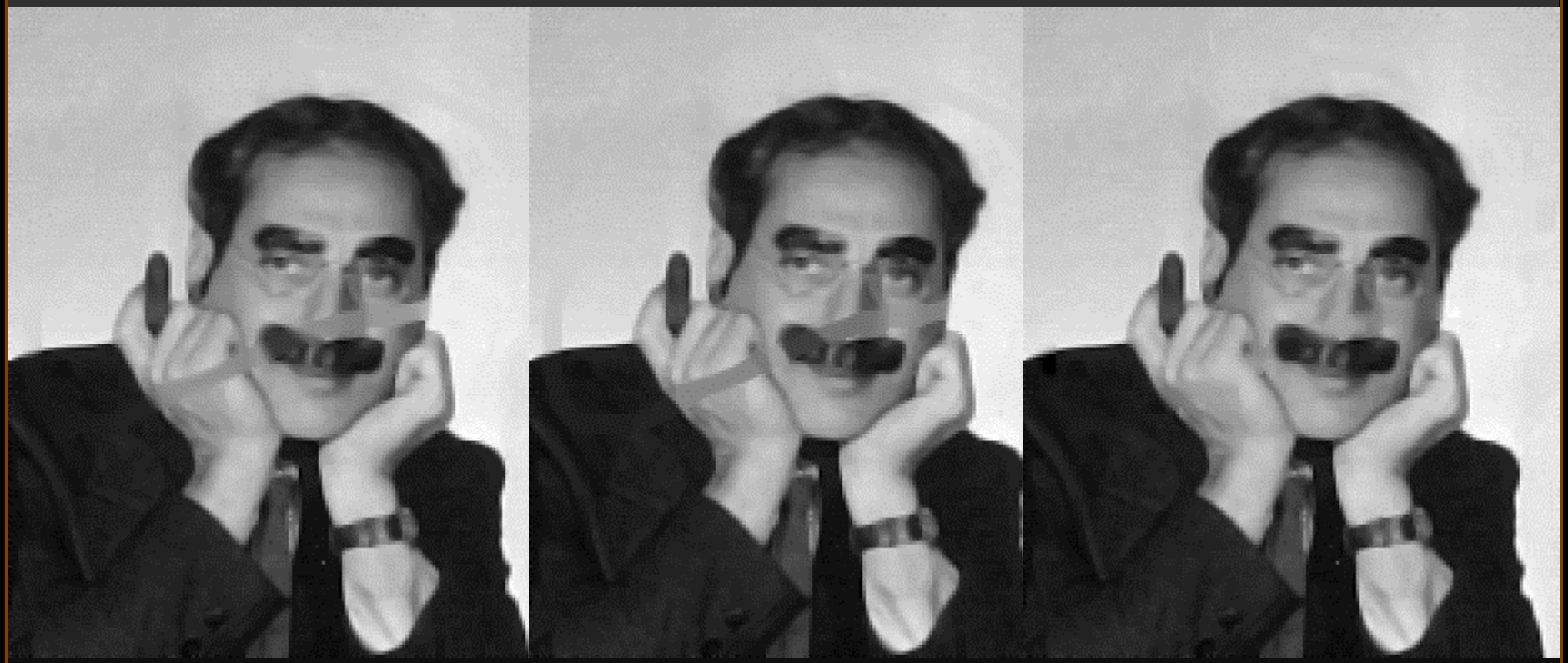
- Solved via E-L: Coupled 2nd order PDE's
- Implicit discretization used
- Connected to Euler's elastica (Mumford)

- **Theorem:** For p>1 the minimizer exists

Examples



No edge information (just gray values, TV)



Examples

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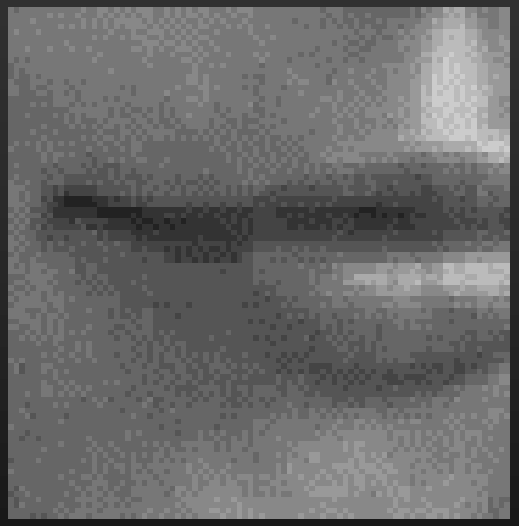
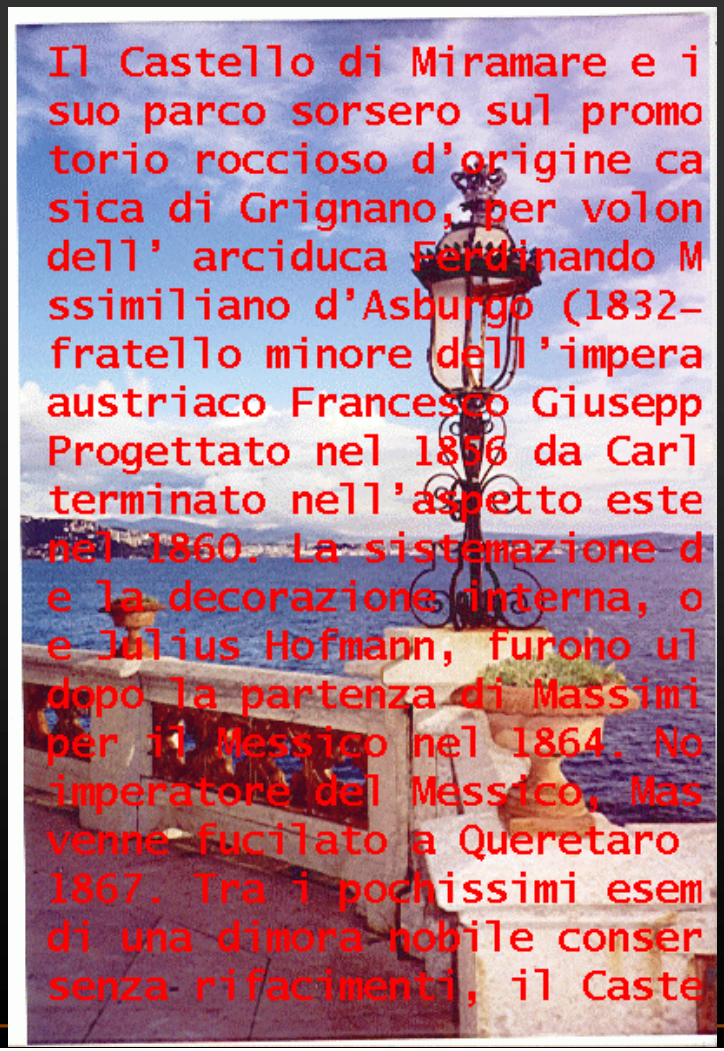


Examples


Il Castello di Miramare e i
suo parco sorsero sul promo
torio roccioso d'origine ca
sica di Grignano, per volon
dell' arciduca Ferdinando M
ssimiliano d'Asburgo (1832-
fratello minore dell'impera
austriaco Francesco Giusepp
Progettato nel 1856 da Carl
terminato nell'aspetto este
nel 1860. La sistemazione d
e la decorazione interna, o
e Julius Hofmann, furono ul
dopo la partenza di Massimi
per il Messico nel 1864. No
imperatore del Messico, Mas
venne fucilato a Queretaro
1867. Tra i pochissimi esem
di una dimora nobile conser
senza rifacimenti, il Caste

Approach 2: Concluding remarks

- **Technique imitates professionals**
- **Key concepts**
  - Information propagation
  - Both gray values and directions are needed
  - Use a band surrounding the region
- **Sharp results**
- **Low complexity**
- **Texture is not (yet) reproduced** **(Zhu et al, Acton et al.)**

Acknowledgments

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The end

Thank you