Automatic Illumination of Flat-Colored Drawings By 3D Augmentation of 2D Silhouettes

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Context : Tools for Digital Illustration

A typical workflow for producing digital illustrations involves these 3 steps:

1) **Lineart creation**
2) Flat colorization
3) Illumination

← **Lineart =** gray-levels strokes on a transparent or white background

(lineart, courtesy of D. Revoy, from his webcomic "***Pepper & Carrot***")

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← **Flat Colorization =** additional background layer with constant colors

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A Fast and Efficient Semi-guided Algorithm for Flat Coloring Linearts.
(S. Fourey, D. Tschumperlé, D. Revoy).
EUROGRAPHICS International Symposium on Vision, Modeling and Visualization 2018, Stuttgart, October 2018.

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← **Illumination =** additional foreground layer that adds light & shadows

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Our Goal: Automatic Creation of an Illumination Layer

Our Goal: Define an **algorithm** that:

- Automatically generates an illumination layer from an input 2D silhouette;
- Is computationally lightweight.

← **Input 2D silhouette**

← **Estimated illumination layer**

Proposed Method

Our algorithm has two steps:

- **STEP 1: Estimate a plausible 3D elevation map from the 2D silhouette.**
- **STEP 2:** Create the illumination layer from the corresponding 3D normal map.

(*a*) Flat-colored drawing (*b*) Estimated 3D elevation map (*c*) Estimated normal map

Proposed Method

Our proposed algorithm has two steps:

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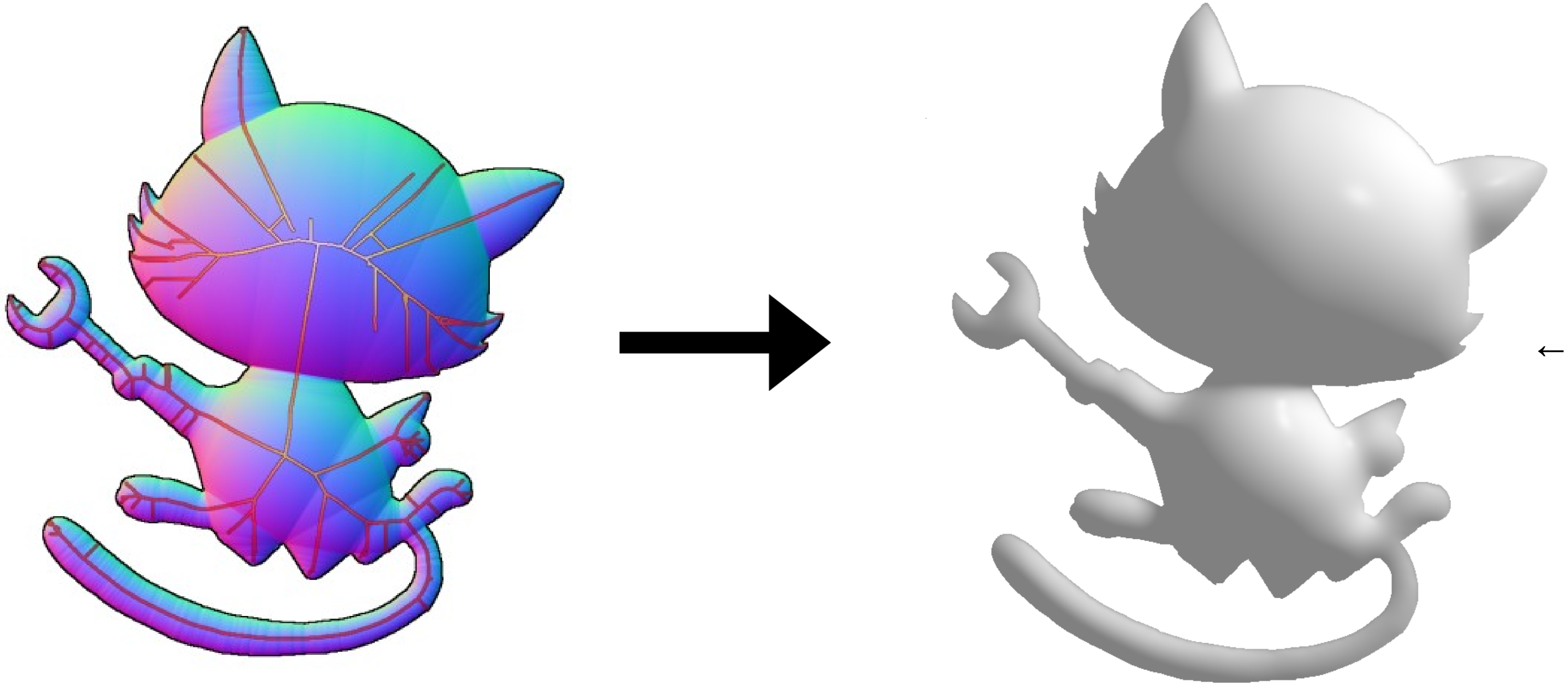
- **STEP 2: Create the illumination layer from the corresponding 3D normal map.**



← **Estimated illumination layer**

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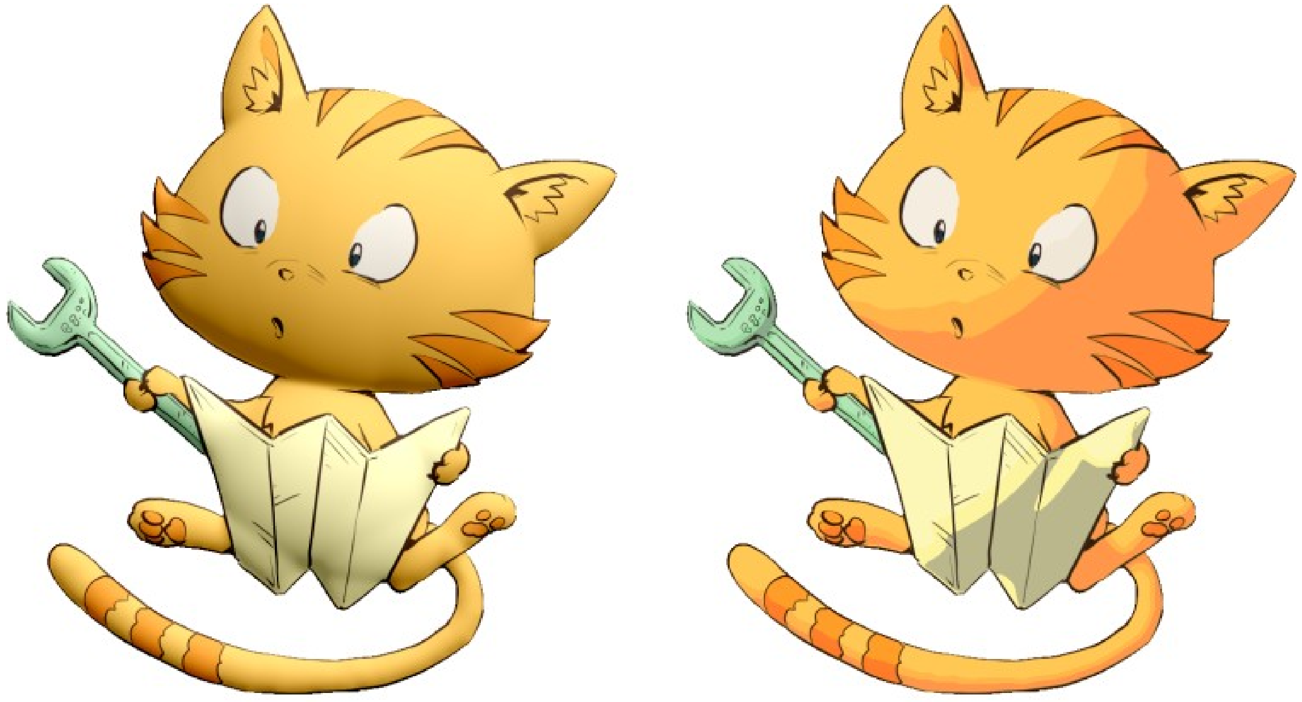

(d) Two examples of automatic illumination rendering

STEP 1 : Estimation of a 3D Elevation Map

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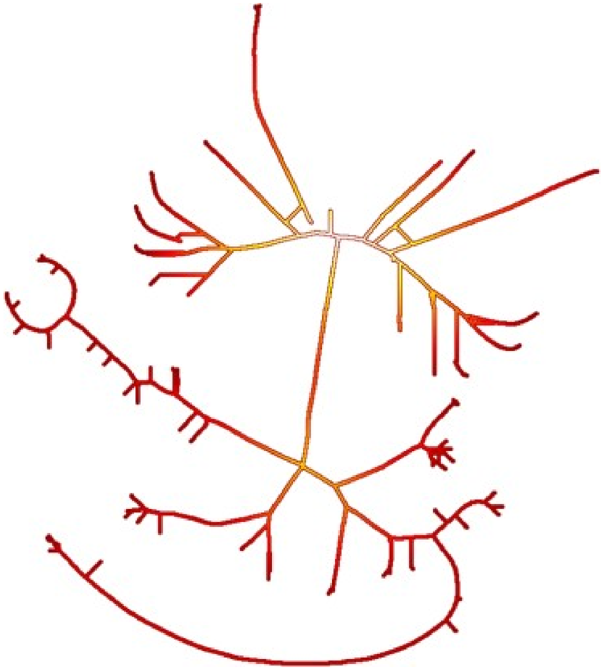
Estimation of a 3D Elevation Map

The 3D elevation map **B** (a.k.a. b*ump map*) is reconstructed from the skeleton **K** of the 2D silhouette **S**. (**K**, computed as the medial axis: Harry Blum (1967). "*A transformation for extracting new descriptors of shape*").

Input 2D silhouette **S**

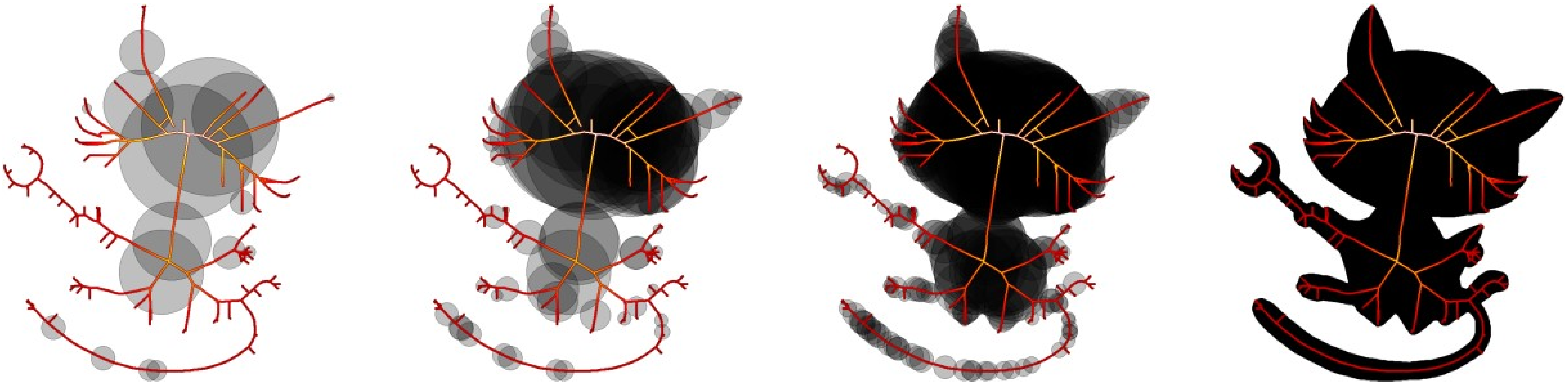


Skeleton **K**

Estimation of a 3D Elevation Map

Fact: It is possible to reconstruct the 2D binary silhouette **S** from its skeleton **K.**

- At each point **P=(x,y)** of **K**, draw a disk of radius **R(P)**.
- **R(P)** has to be the distance from **(x,y)** to the closest border of **S** (distance function).
- The intersection of all these disks gives **S** back.

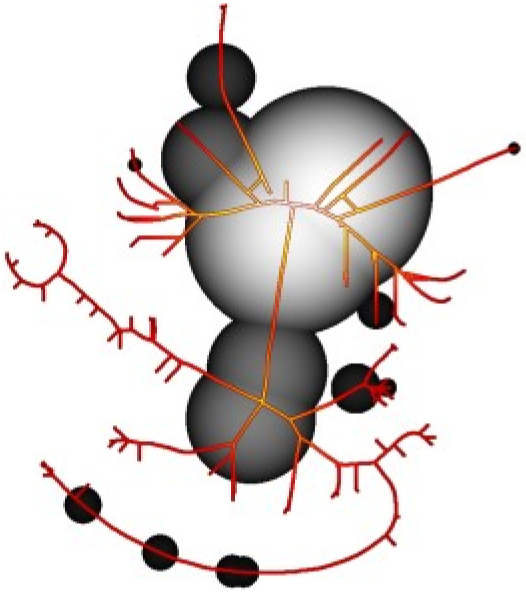


15 disks | 50 disks | 150 disks | All disks: Reconstructed silhouette **S**

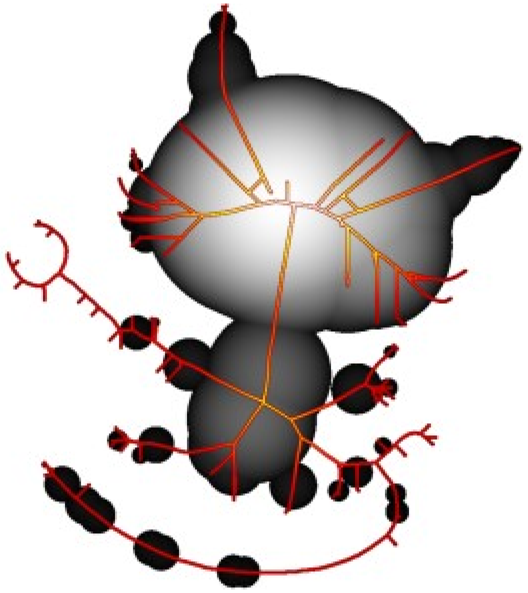
Estimation of a 3D Elevation Map

Idea: Rather than drawing 2D disks, we draw elevations of 3D semi-spheres instead:

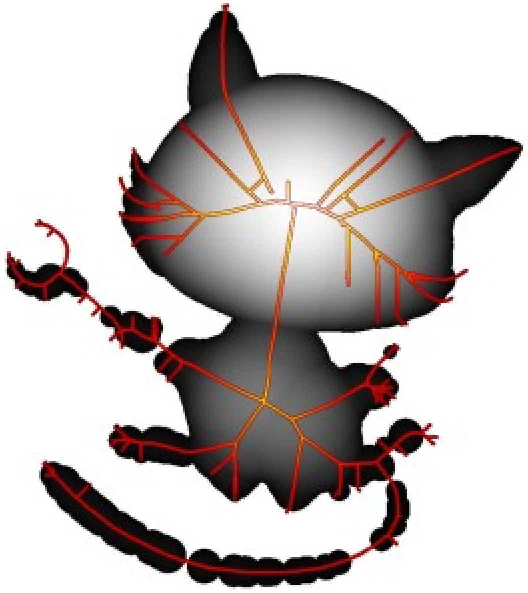
- At each point **(x,y)** of **K**, draw the 2D function that is the elevation of a semi-sphere of radius **R(P).**
- **R(P)** is chosen to be the distance from **(x,y)** to the closest border of **S** (distance function).
- The “intersection” (***max(…)***) of all these functions estimates a 3D elevation map **B**.



15 semi-spheres



50 semi-spheres



150 semi-spheres

All semi-spheres:
Estimated bump map **B**

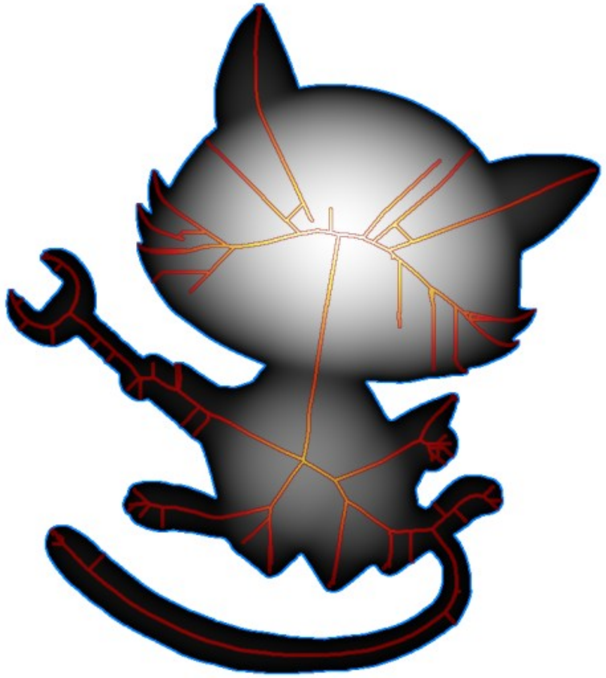
Estimation of a 3D Elevation Map

Algorithm in a nutshell:

$$B(P) = \max_{Q \in \mathcal{K}} \; g_Q(P), \quad \text{with} \quad g_Q(P) = \sqrt{\max(0, D(Q)^2 - \|P-Q\|^2)}$$

and $$D(P) = \min_{Q \in \Omega} \|P - Q\| \quad | \quad S(Q) = 0$$

2D silhouette **S**



Bump map **B**

STEP 2 : Estimation of the Illumination Layer

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Generation of the Illumination Layer

The illumination layer **J** is generated by applying the **Phong Illumination Model**
(B.T. Phong (1975), "*Illumination for computer generated pictures*"):

$$J(P) = K_a + K_d\,(\hat{L}(P) \cdot \hat{N}(P)) + K_s\;\max(0, R(P) \cdot \hat{V}(P))^{\alpha}$$

where

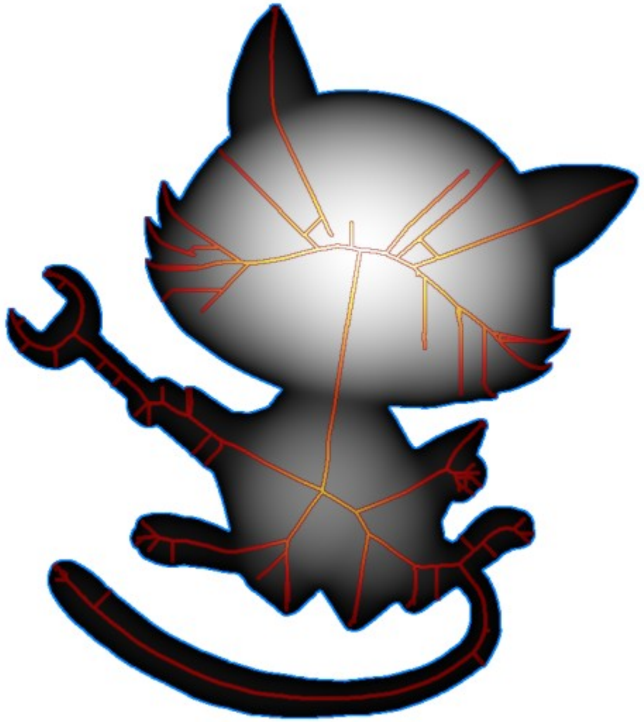
$$\begin{cases} L(P) & = & (L_x - P_x, L_y - P_y, L_z)^T \\ V(P) & = & (C_x - P_x, C_y - P_y, C_z)^T \\ R(P) & = & 2\,(\hat{N}(P) \cdot \hat{L}(P))\,\hat{N}(P) - \hat{L}(P) \end{cases}$$

→ Sum of an ambient light (**Ka**), a diffuse component (**Kd**) and a specular component (**Ks**).
→ Parameters of the model :
Light position **L = (Lx,Ly,Lz)**, Camera position **C = (Cx,Cy,Cz)**, Specularity coefficient **α**.
→ Require **N(P)**, 3D normal to any point **P** → Computation of the normal map **N** from the bump map **B**.

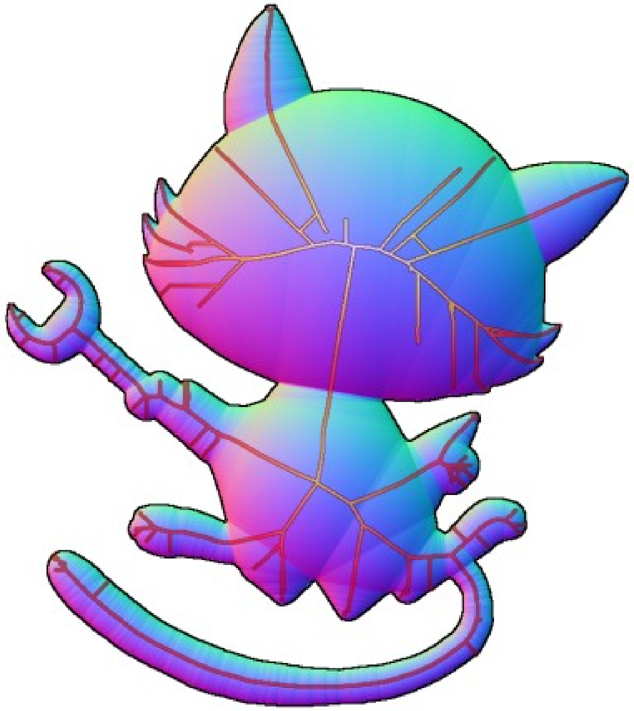
Generation of the Normal Map

Transformation of the bump map **B** into the normal map **N**:

For any point P, $$N(P) = \left(\frac{\partial B}{\partial x}(P), \frac{\partial B}{\partial y}(P), -1 \right)^T$$ (+ normalization to unit vector).



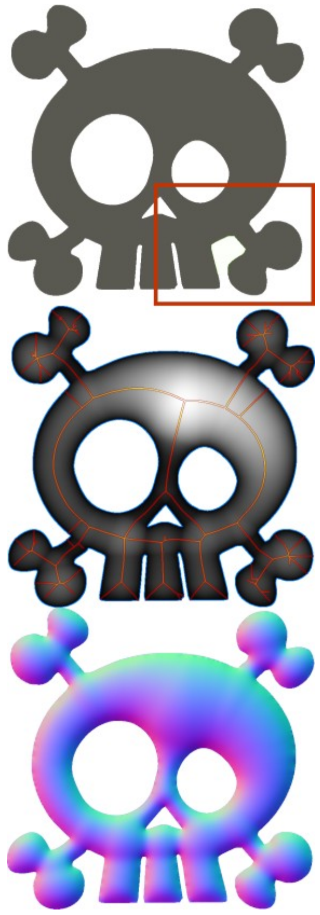
Bump map **B**

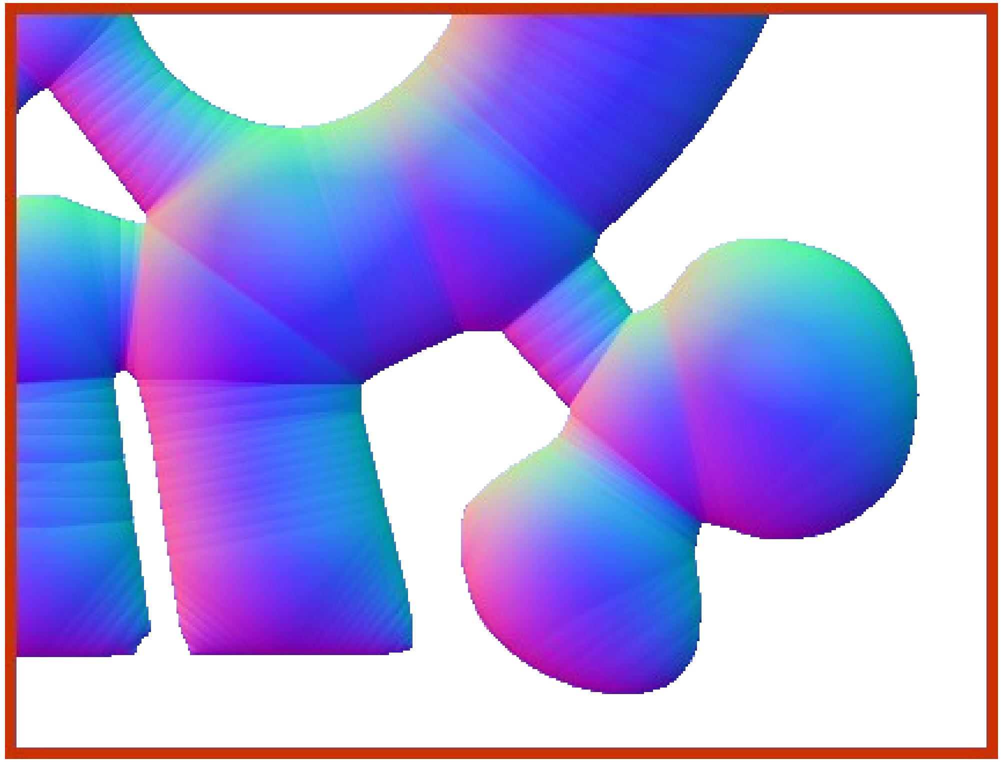


Normal map **N**

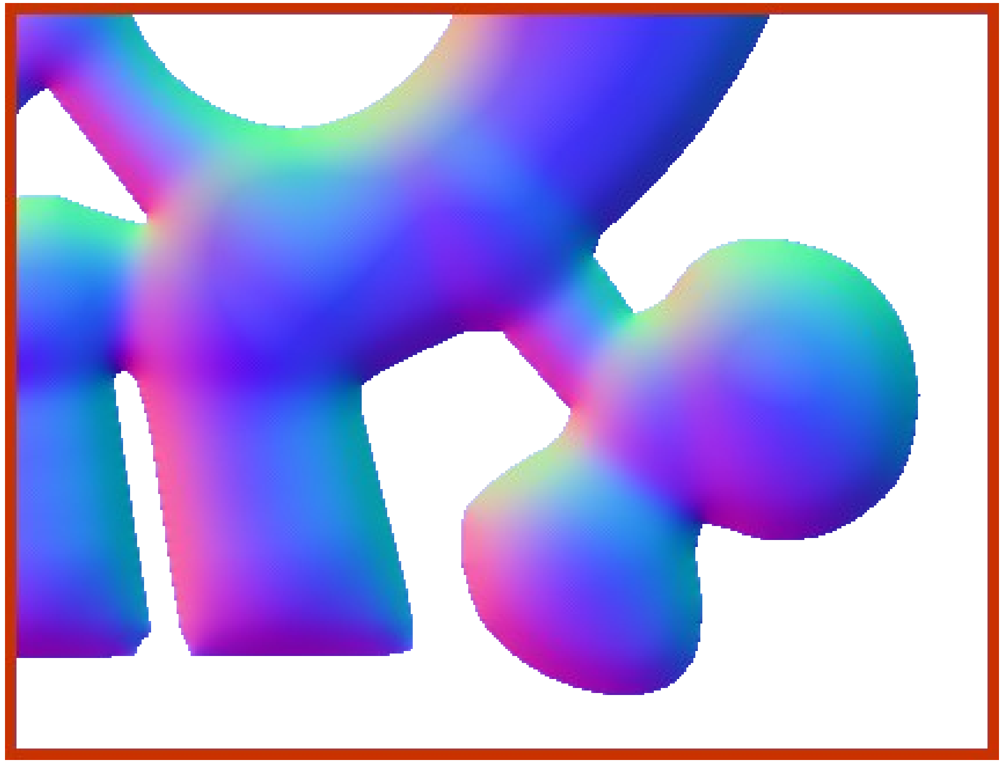
Normal Map Regularization

The fusion of semi-spheres may produces visible discontinuities in the normal map **N.**
→ **Guided filtering** (applied on map **N**) can be used to get rid of those, using the silhouette **S** as a guide.
(K. He, J. Sun, and X. Tang (2012), “*Guided image filtering*”).





Normal map **N** *without regularization* (zoom)



Normal map **N** **with regularization** (zoom)

Generation of the Illumination Layer

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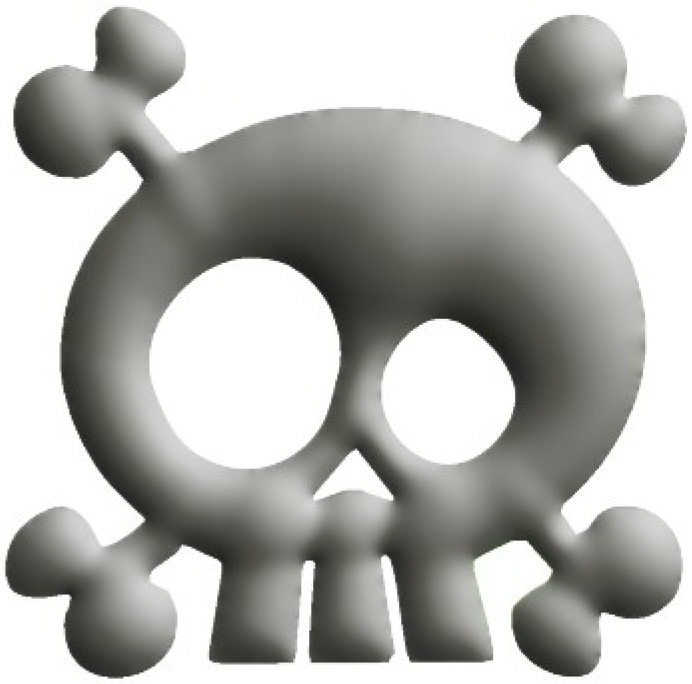
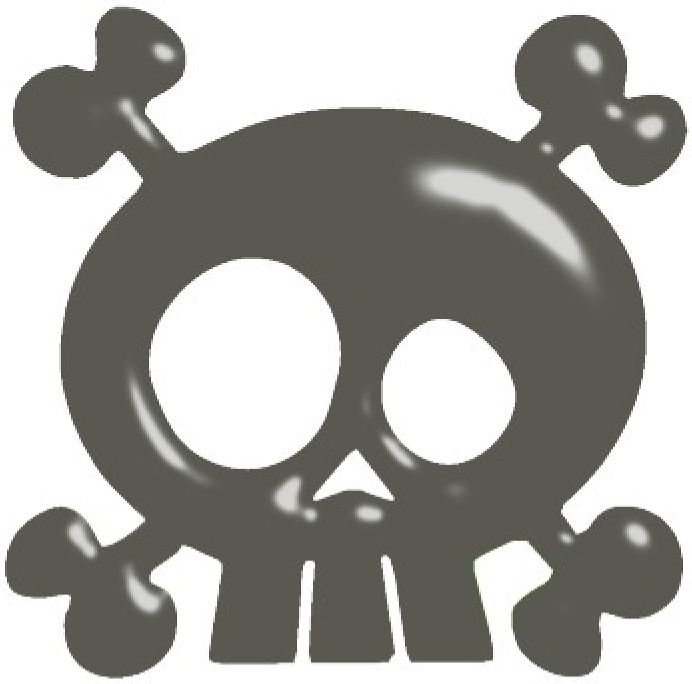


Ambient light (**Ka**) +
Diffuse component (**Kd**)



Specular component (**Ks**)

Output Illumination Layer **J**

APPLICATION RESULTS

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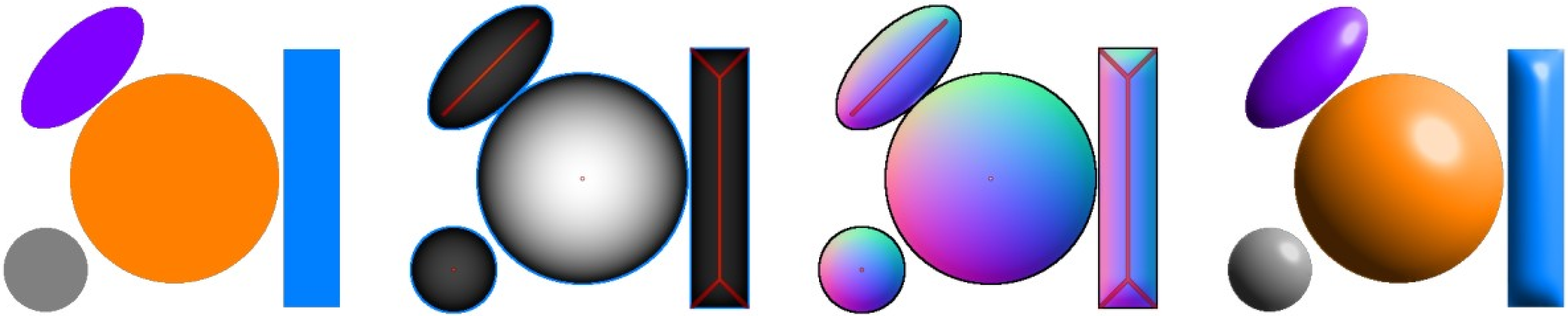
Result on Simple Shapes

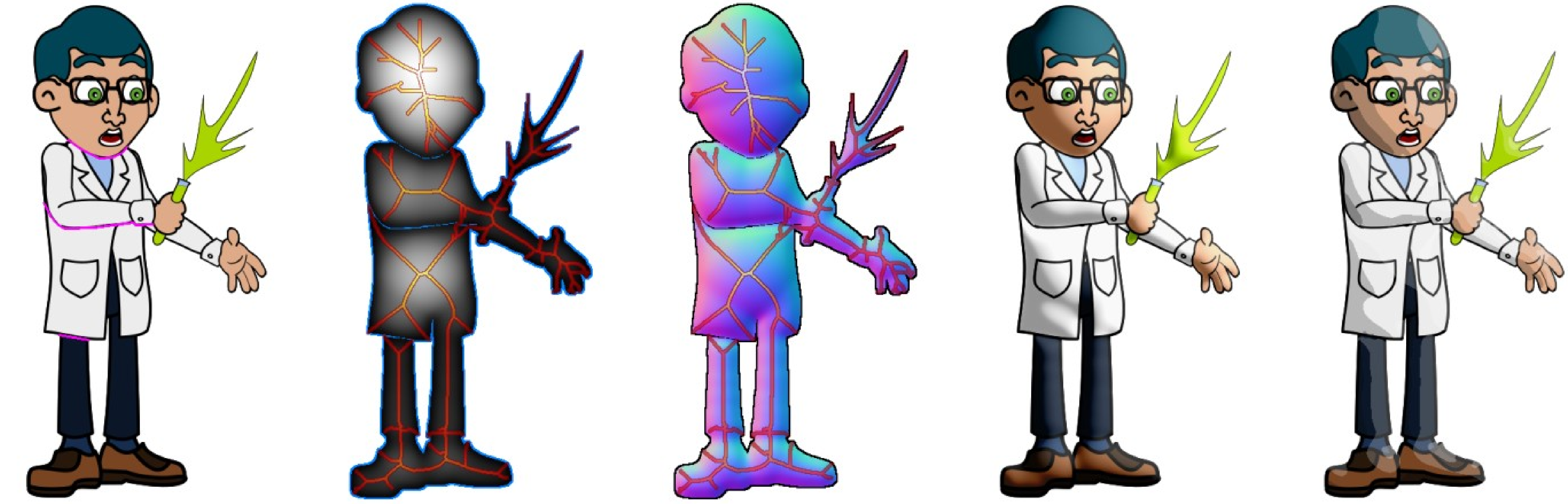


(a) Synthetic flat-colored drawing (b) Our estimated bumpmap (c) Our estimated normalmap (d) Our illumination result

Remark: A 2D silhouette with the shape of a **disk** will be illuminated as it is a **3D sphere**.

→ In that case, the skeleton **S** is reduced to a single point.
→ Only a single semi-sphere elevation is drawn in the bump map **B**.

Results on Real Images



(a) Flat-colored drawing with guiding lines (in magenta) *(b)* Our estimated bumpmap *(c)* Our estimated normalmap *(d)* Our illumination result *(e)* Our quantized illumination result (*cartoon* style)

Note: Different types of rendering for the illumination layer **J** can be obtained, by playing with the Phong model parameters and/or doing post-processing on **J** (e.g., *level quantization*, for result *(e)*).

Adding Guiding Lines

(*a*) Flat-colored drawing with guiding lines (in magenta) (*b*) Normalmap estimated from the silhouette only (*c*) Illumination generated from (*b*) (*d*) Normalmap taking into account guiding lines (*e*) Illumination generated from (*d*)

In the case of complex shapes with details inside, the user can add **guiding lines** (here shown in magenta), that are drawn as exterior pixels in the silhouette **S** before estimating the bump map **B**.

→ These pixels have 0-elevation in the estimated bump map **B**.
→ Explicitly add relief in the generated illumination layer **J.**

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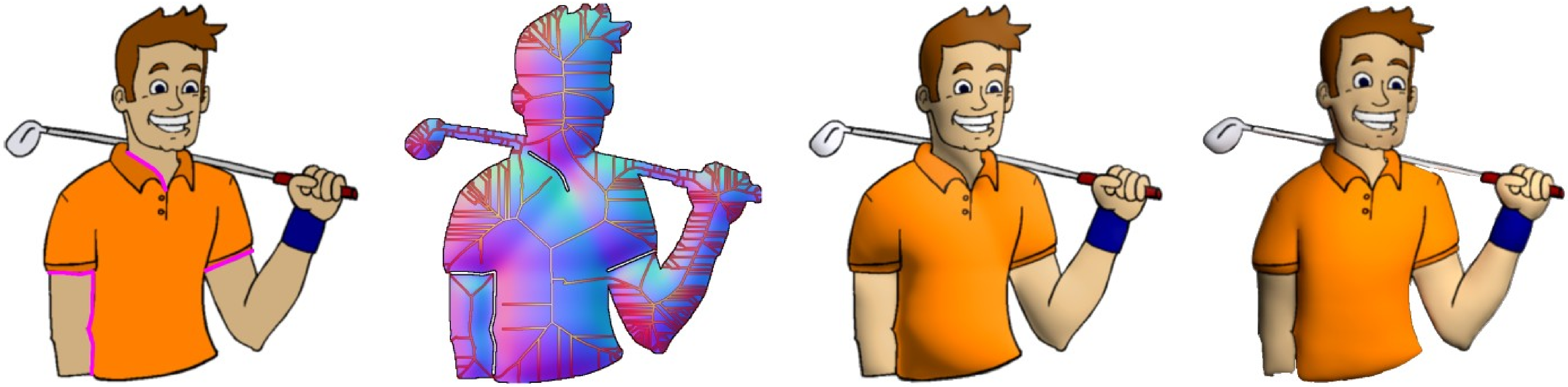
Comparison With Neural-Net Approach



(*a*) Flat-colored drawing with guiding lines (in magenta)

(*b*) Our estimated bumpmap

(*c*) Our illumination result

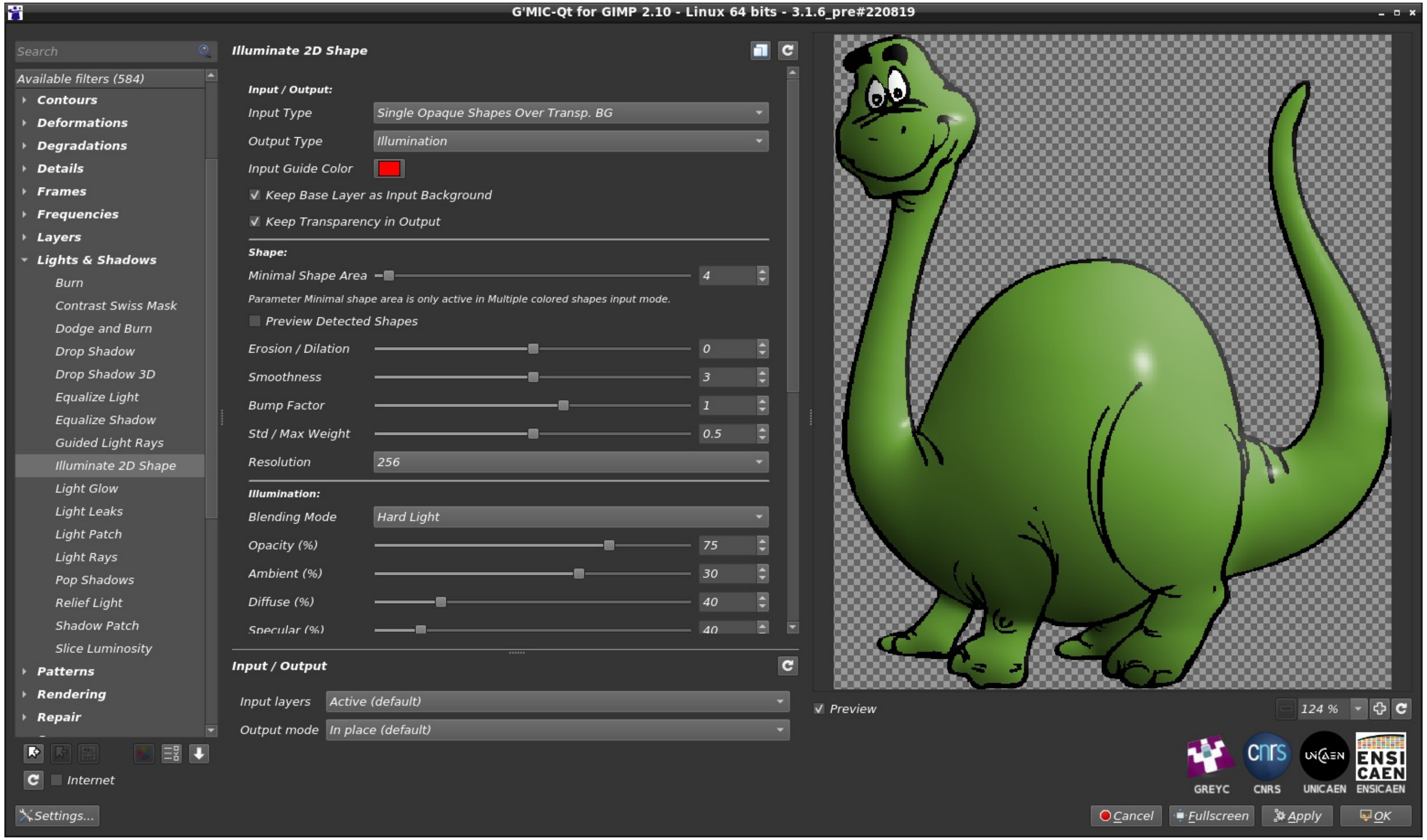
(*d*) Comparison: Result from neural network-based method

We compared our proposed method with:

M. Hudon, S. Lutz, R. Pagés, and A. Smolic (2019), “*Augmenting hand-drawn art with global illumination effects through surface inflation*,” in European Conference on Visual Media Production.

Results are very similar. However, our algorithm requires **no training** phase, **nor a lot of parameter** storage. It can run on a **low-cost machine**, without requirements for powerful GPUs.

Algorithm Integration Into G'MIC



Our algorithm has been integrated into **G'MIC**, an open-source framework for image processing.
You can test it on your own images (plug-in available for GIMP, Krita, Photoshop, Affinity Photo, …)

https://gmic.eu

Thanks for Your Attention !

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