Vectorising Bitmaps into Semi-Transparent Gradient Layers

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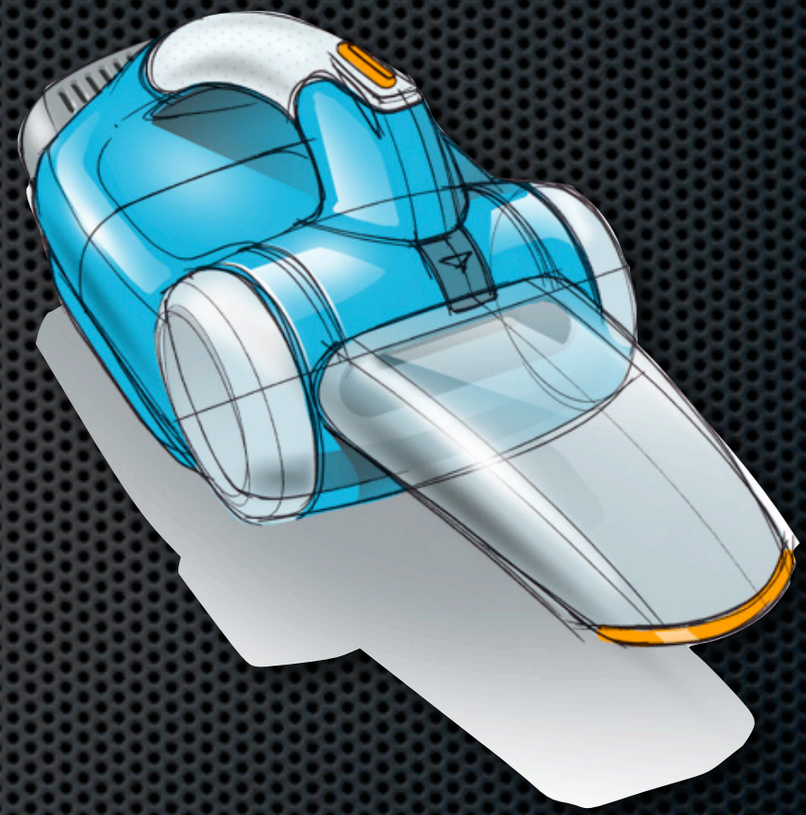
photos

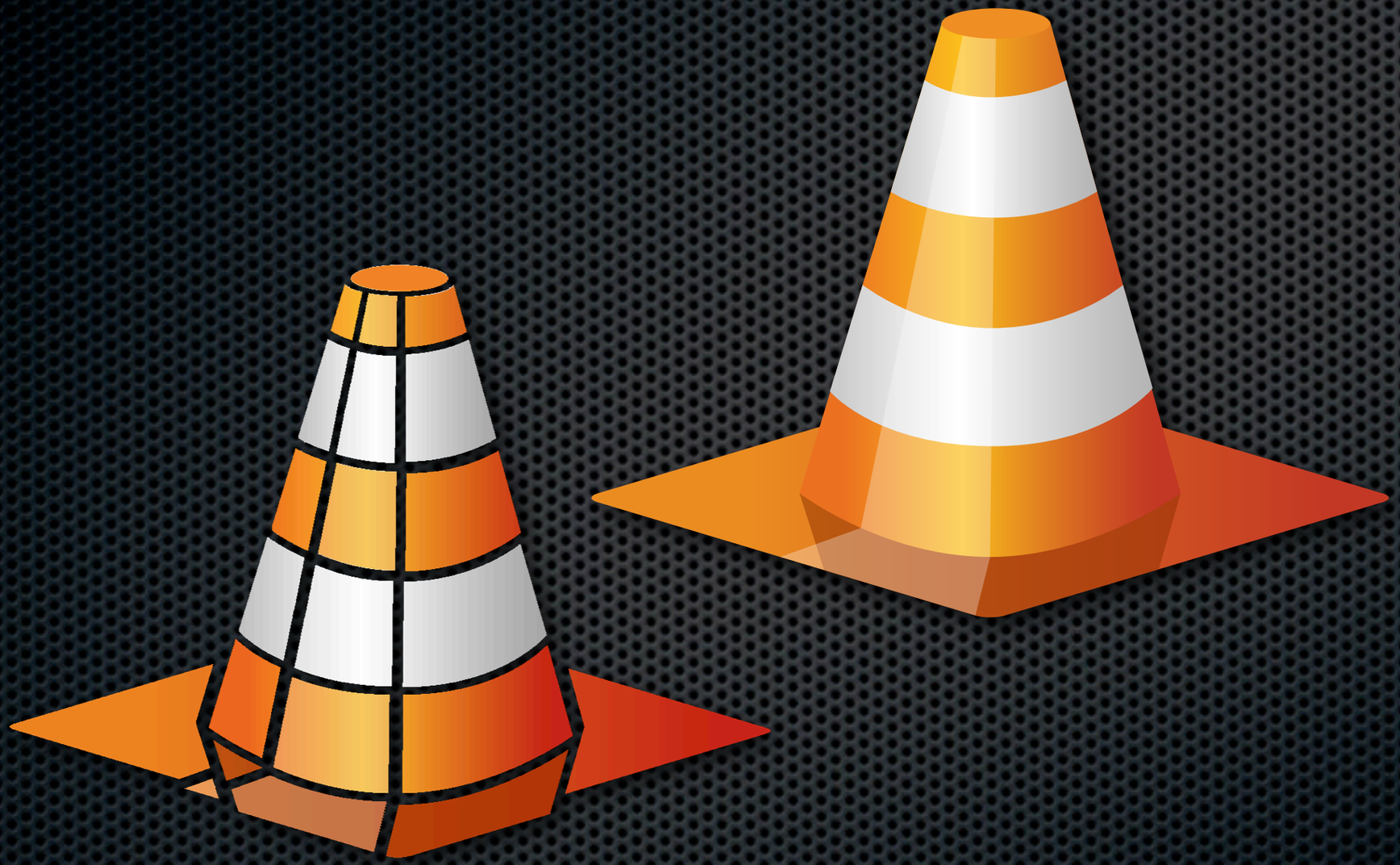
vector art



drawings

Vector art representations

Vector art representations



single layer

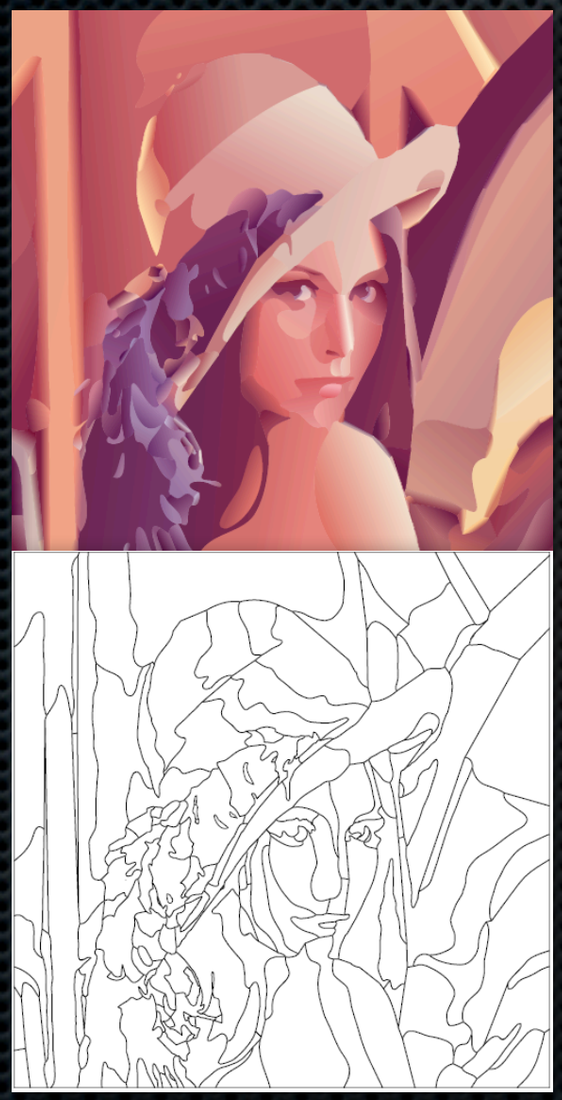
Vector art representations

single layer

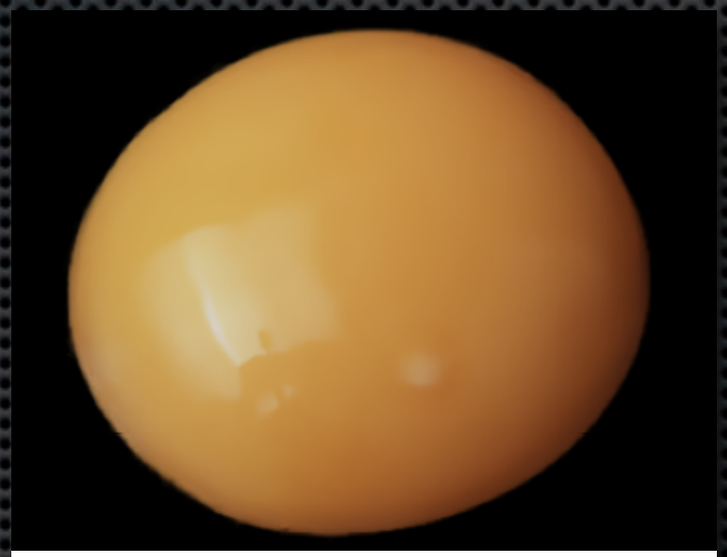
multiple layers

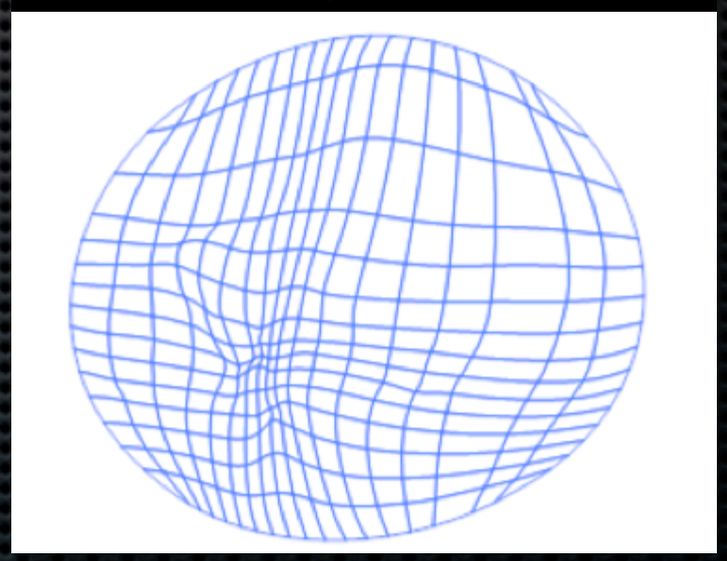
Image vectorisation

Ardeco
[Lecot & Lévy 2006]



Gradient meshes
[Sun+ 2007]





Diffusion curves
[Orzan+ 2008]

Our interactive workflow

Shutterstock/George Dolgikh

Our interactive workflow

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Our interactive workflow

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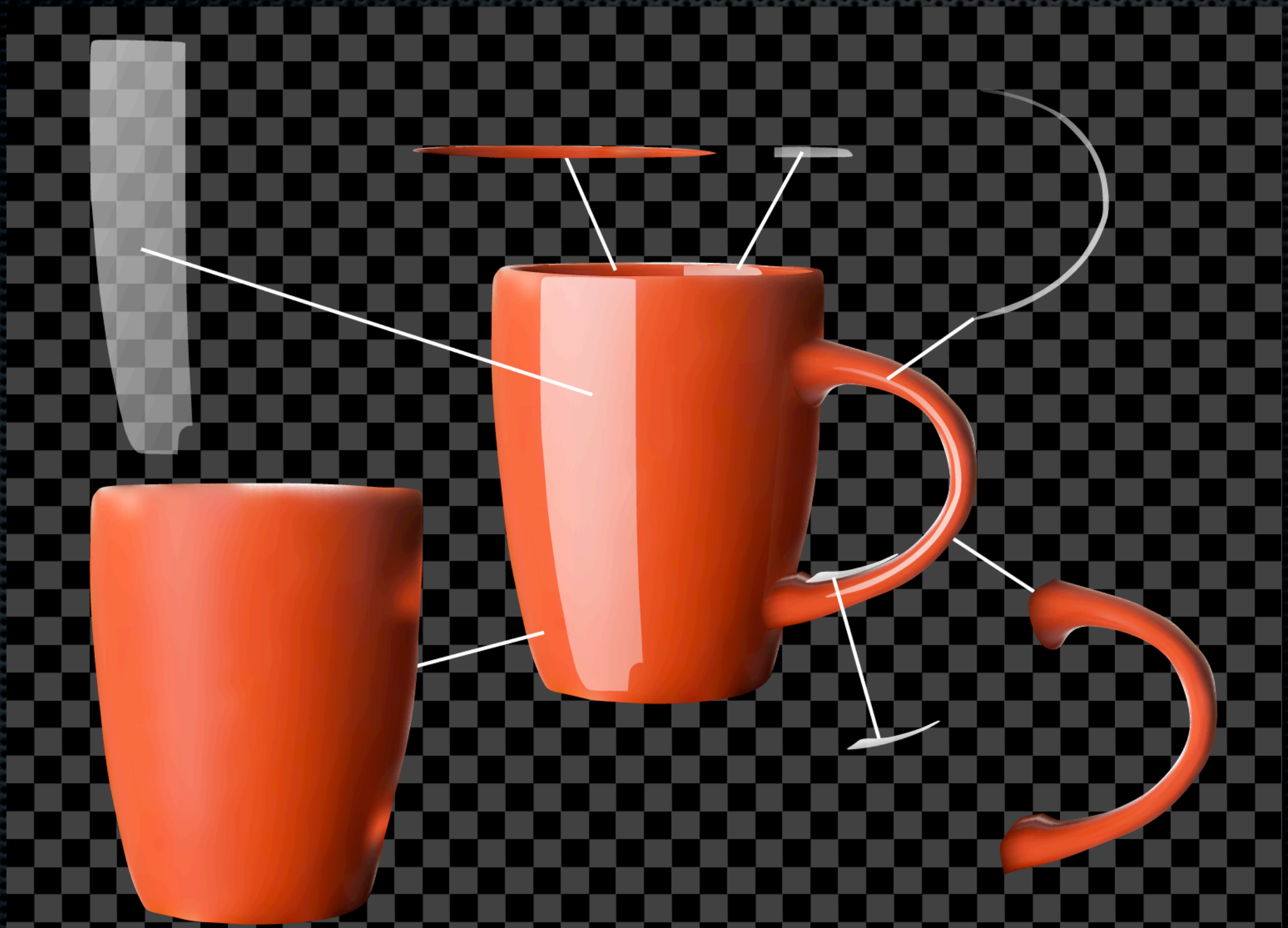
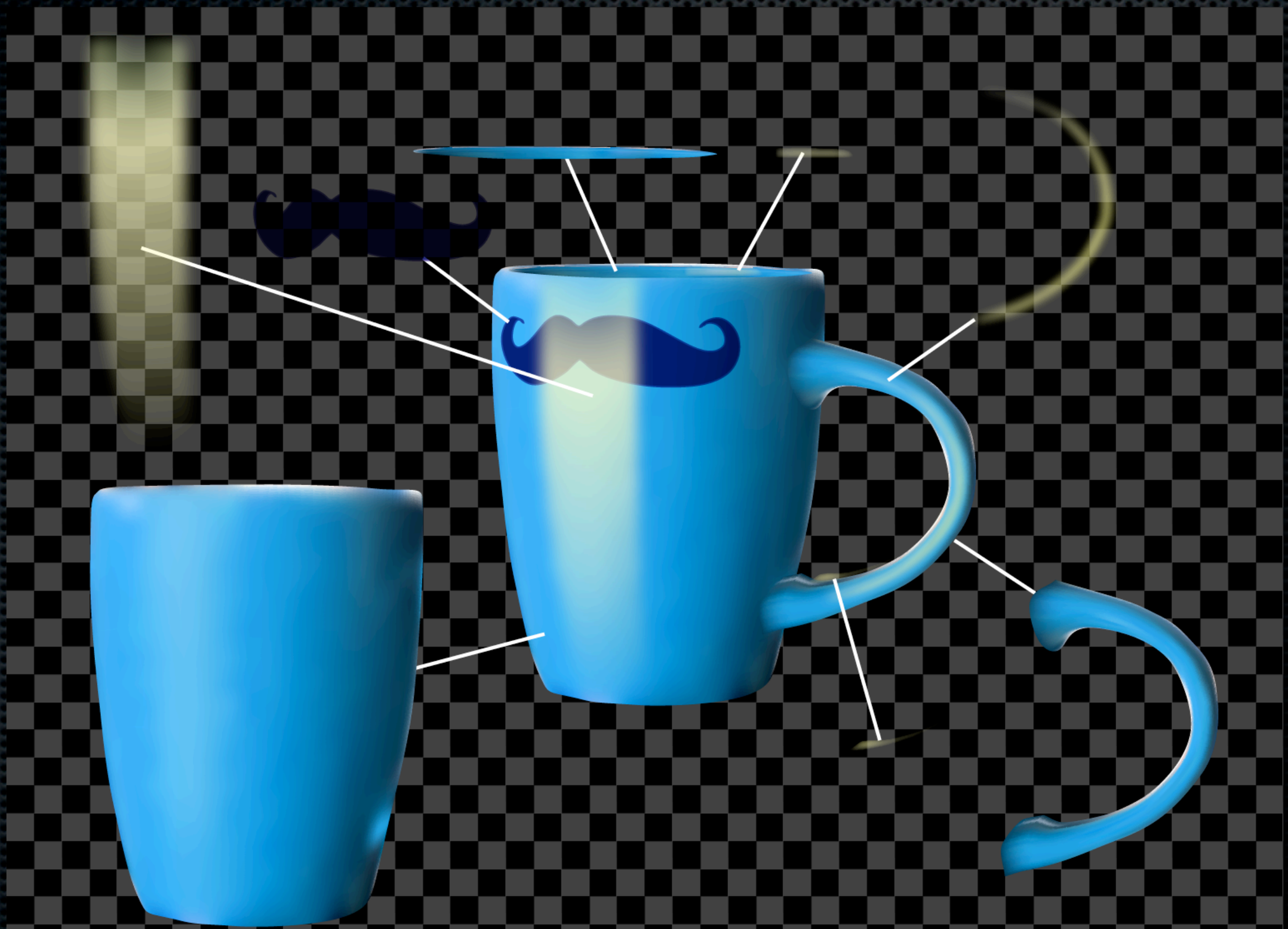
Our interactive workflow

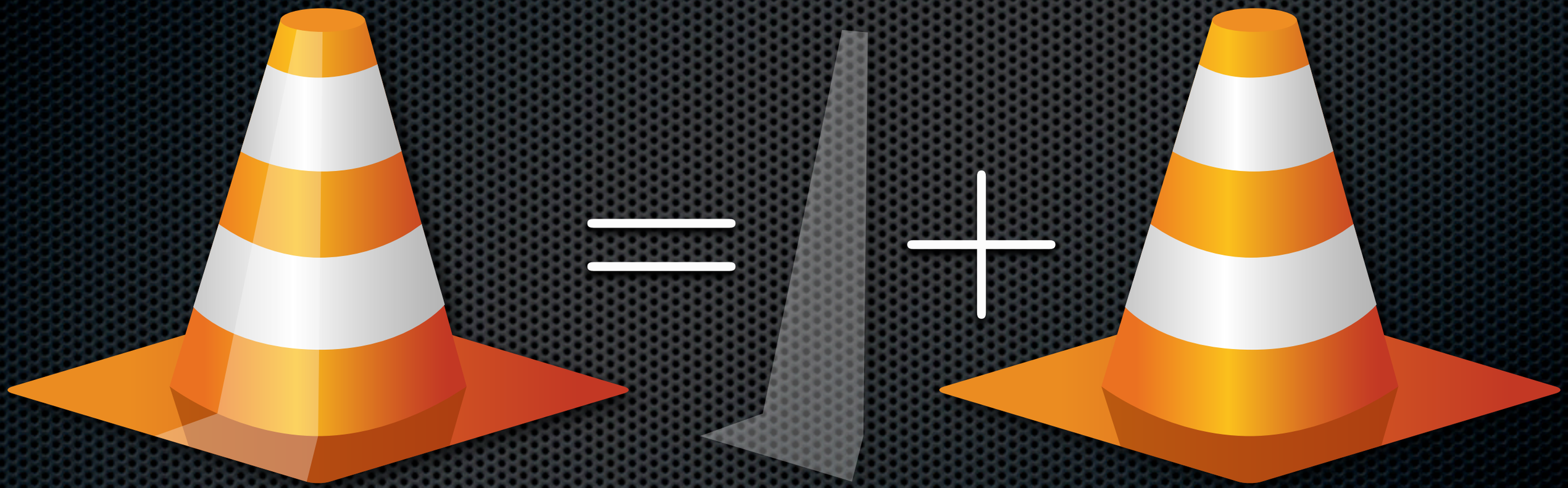
Vectorised result



Editing result



Similarity to matting



$$\mathbf{I} = \alpha \cdot \mathbf{F} + (1 - \alpha) \cdot \mathbf{B}$$

compositing equation

[Porter & Duff 1984]

The matting problem

[Smith & Blinn 1996]

$$\mathbf{I} = \alpha \cdot \mathbf{F} + (1 - \alpha) \cdot \mathbf{B}$$

we have 3 equations: one each for R, G, B

The matting problem

[Smith & Blinn 1996]

$$\mathbf{I} = \alpha \cdot \mathbf{F} + (1 - \alpha) \cdot \mathbf{B}$$

we have 3 equations: one each for R, G, B

know	solve for	# unknowns	
$\mathbf{I}$	$\alpha\ \mathbf{F}\ \mathbf{B}$	7	underconstrained
$\mathbf{I}\ \mathbf{B}$	$\alpha\ \mathbf{F}$	4	underconstrained

Solving the matting problem

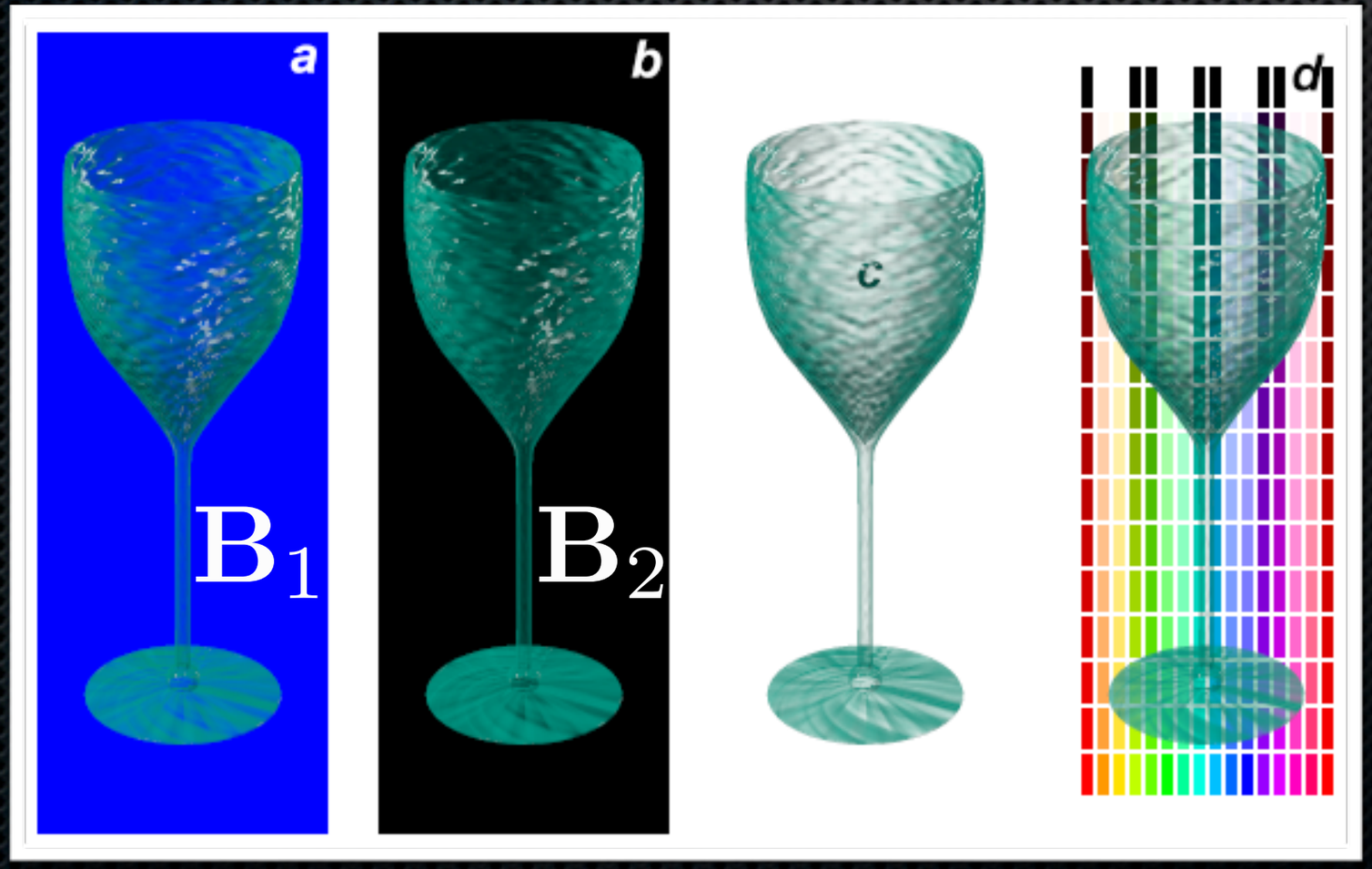
[Smith & Blinn 1996]

$$\mathbf{I}_1 = \alpha \cdot \mathbf{F} + (1 - \alpha) \cdot \mathbf{B}_1$$

$$\mathbf{I}_2 = \alpha \cdot \mathbf{F} + (1 - \alpha) \cdot \mathbf{B}_2$$

we know:

$\mathbf{I}_1$ $\mathbf{I}_2$ $\mathbf{B}_1$ $\mathbf{B}_2$



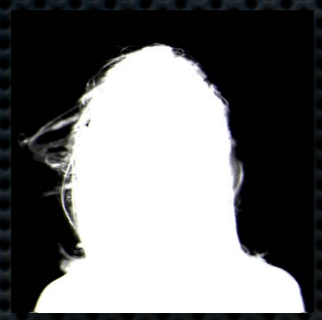
solve for:

α $\mathbf{F}$

6 equations,
4 unknowns

great!

Image decompositions

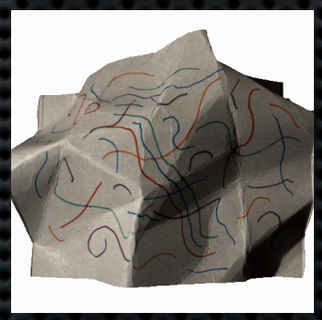


Alpha matting

[e.g. Smith+ 1996, Chuang+ 2001, Levin+ 2008]

Reflection separation

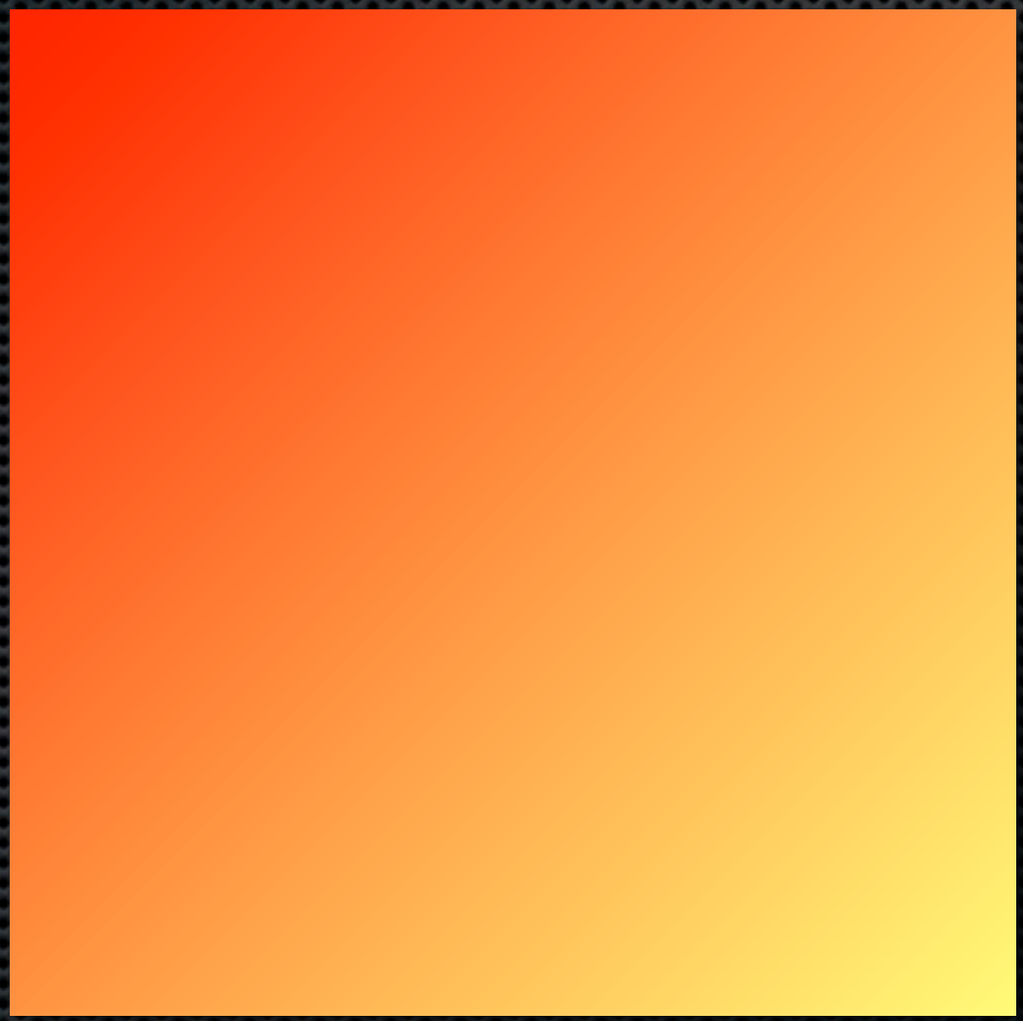
[e.g. Levin+ 2004/2007, Kim+ 2013, Li & Brown 2014]



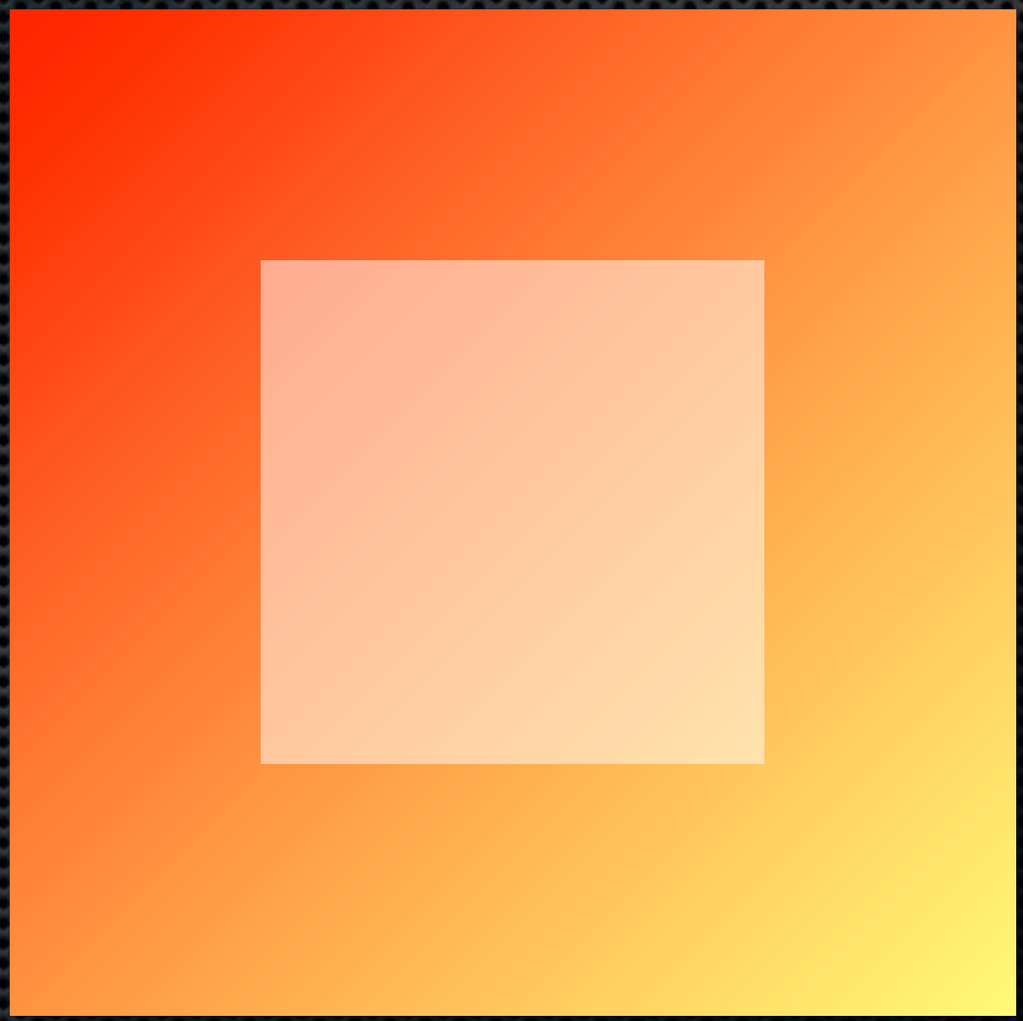
Intrinsic images

[e.g. Bousseau+ 2009, Carroll+ 2011]

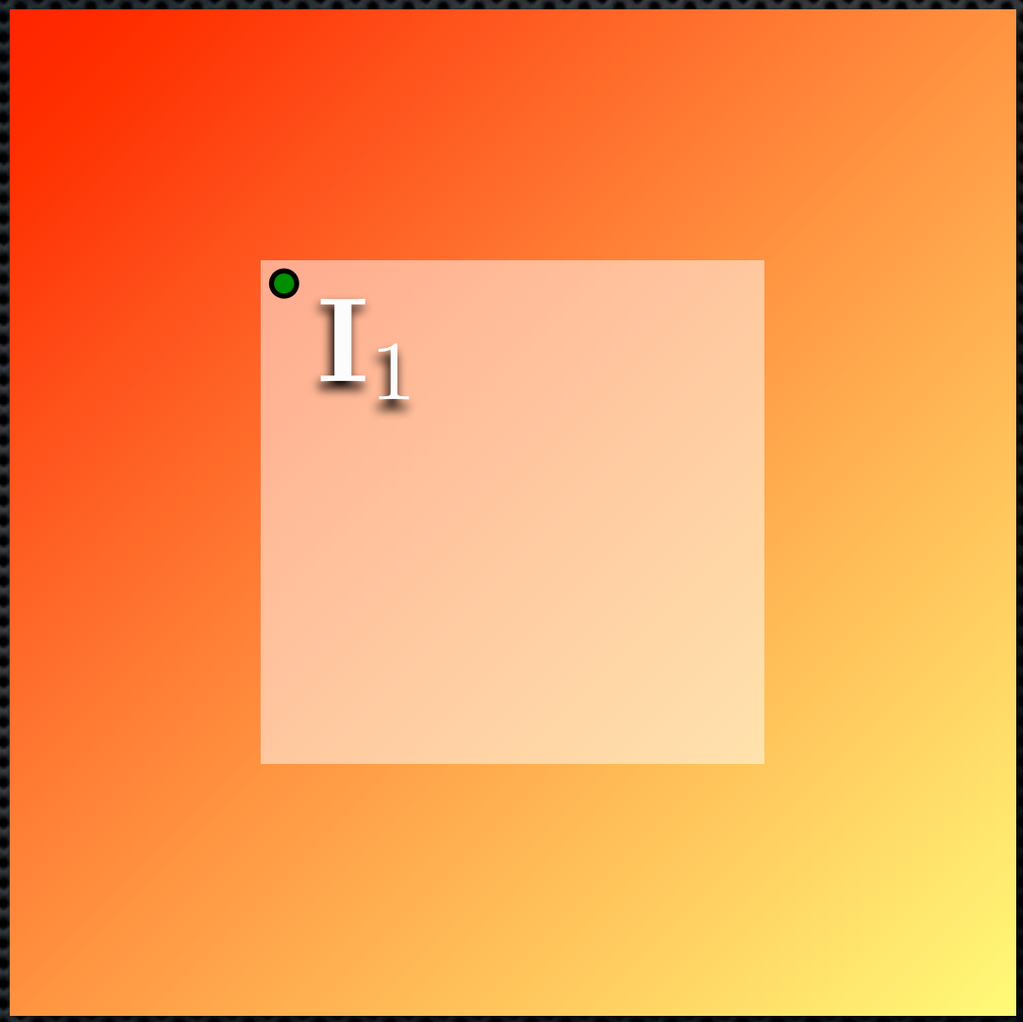
Decompositing



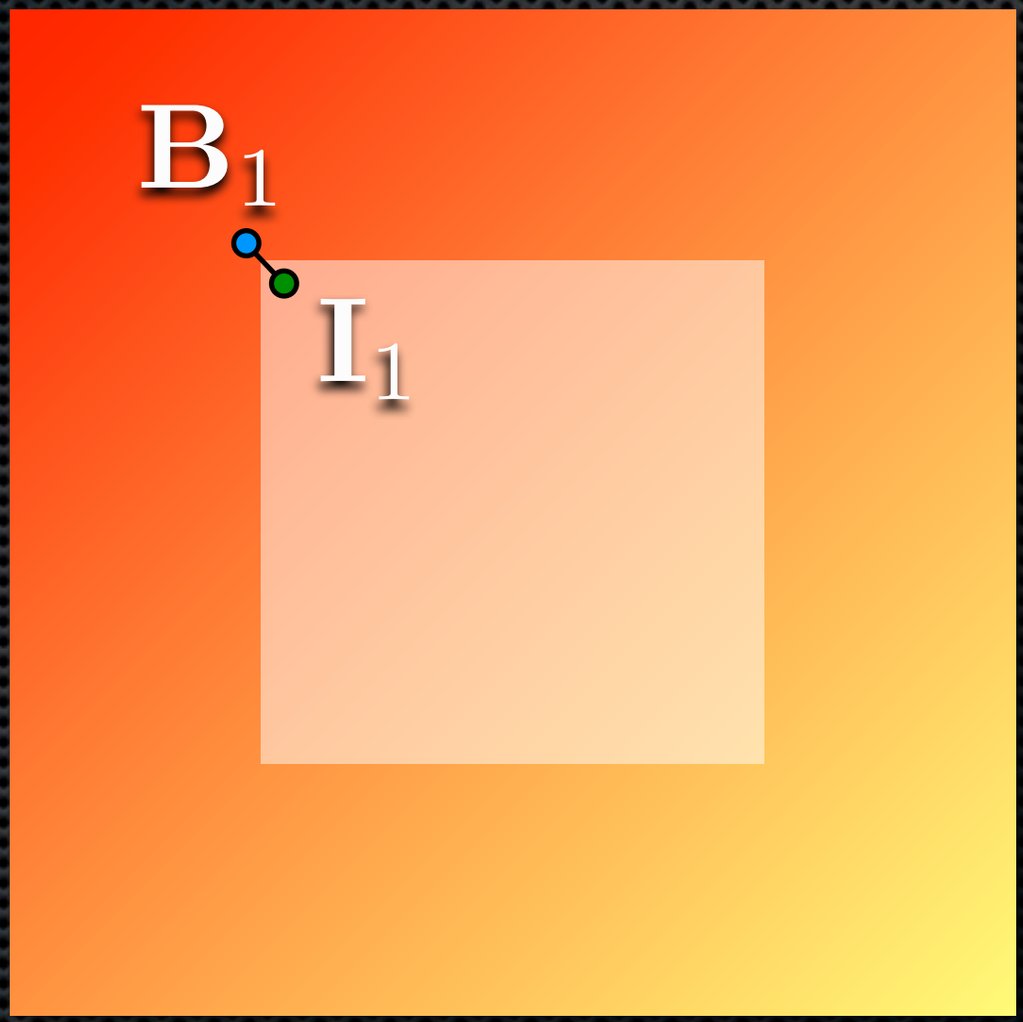
Decompositing



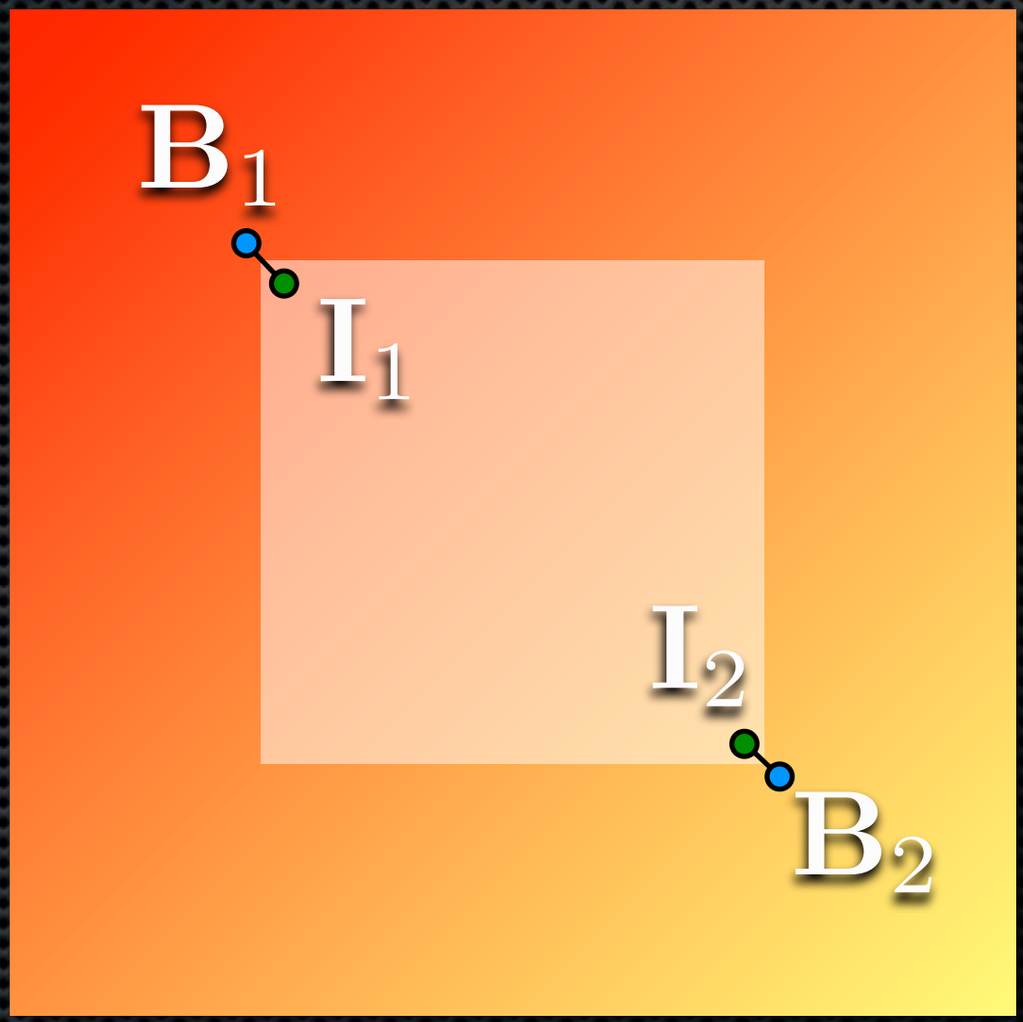
Decompositing



Decompositing



Decompositing



Decompositing

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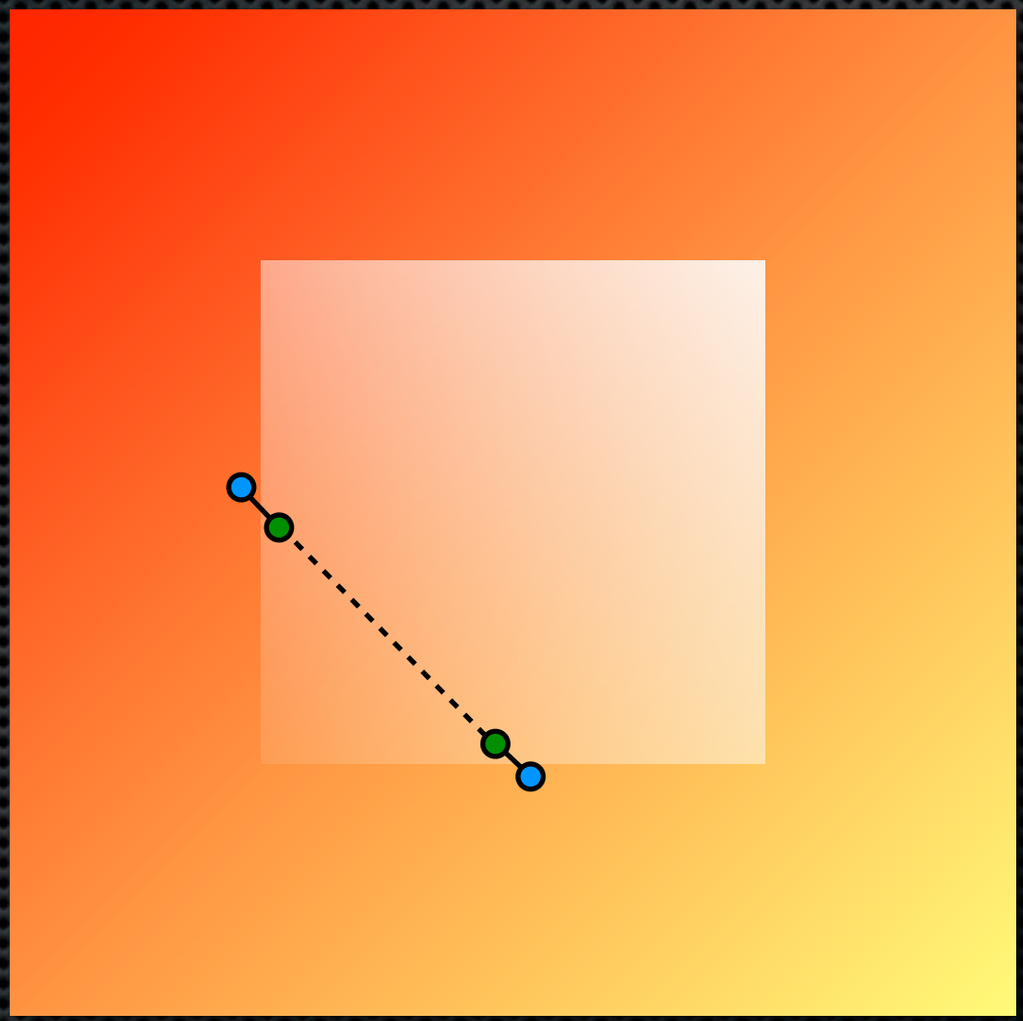

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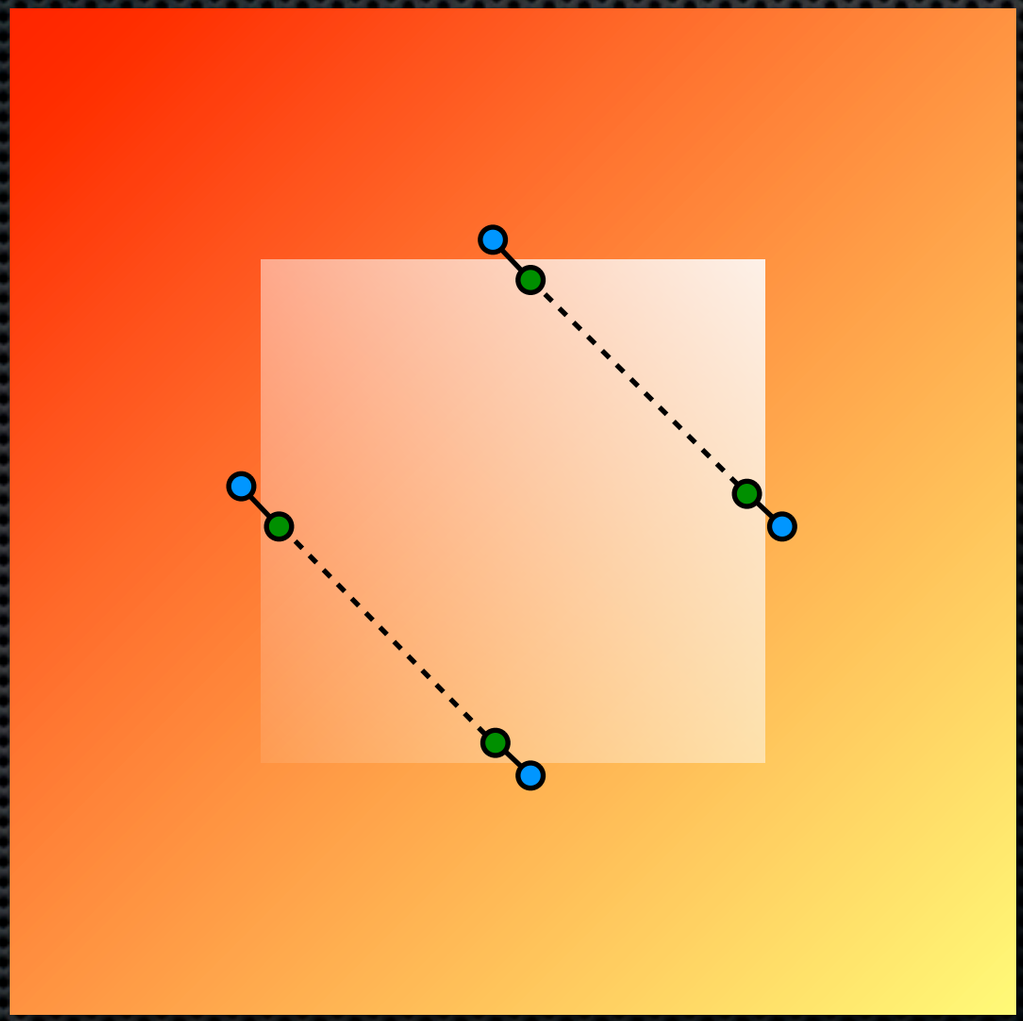

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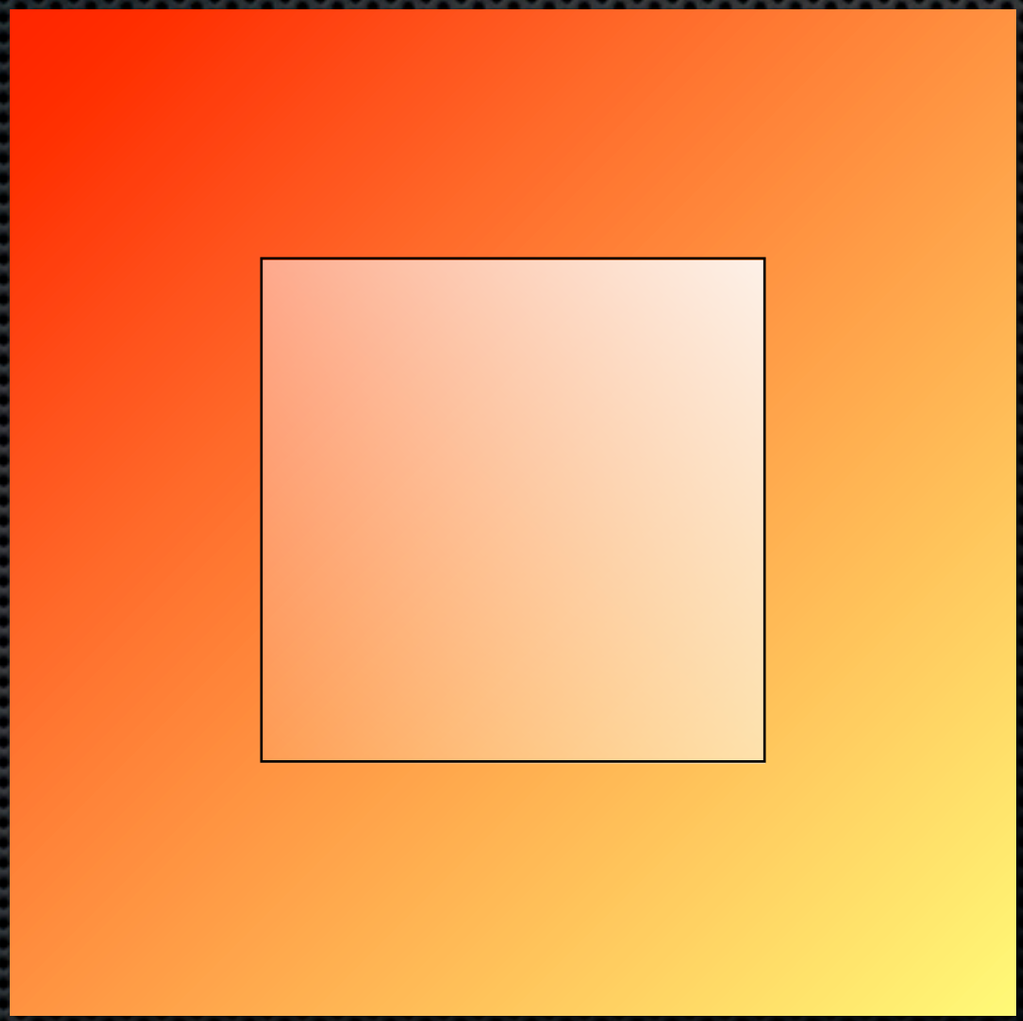

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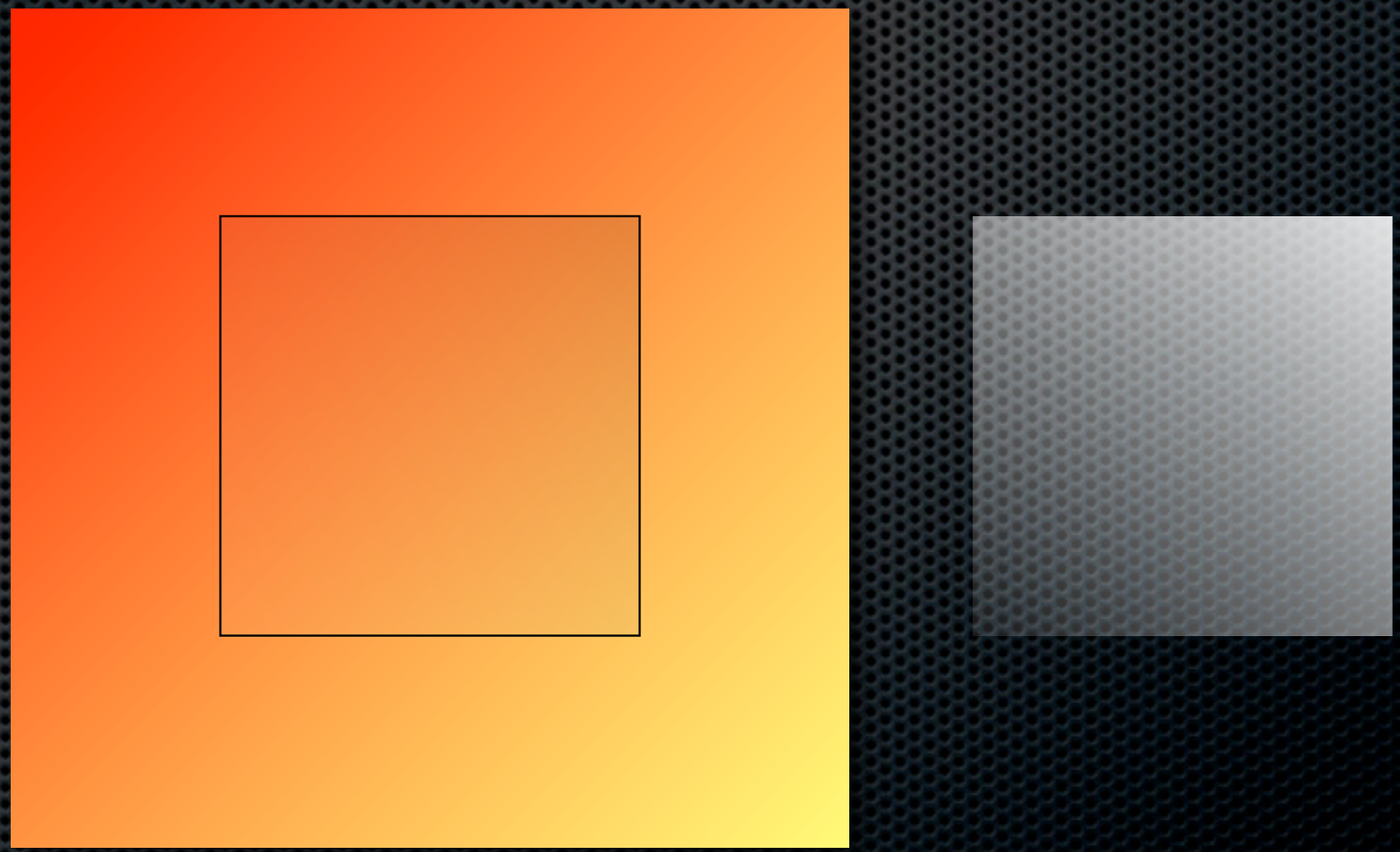

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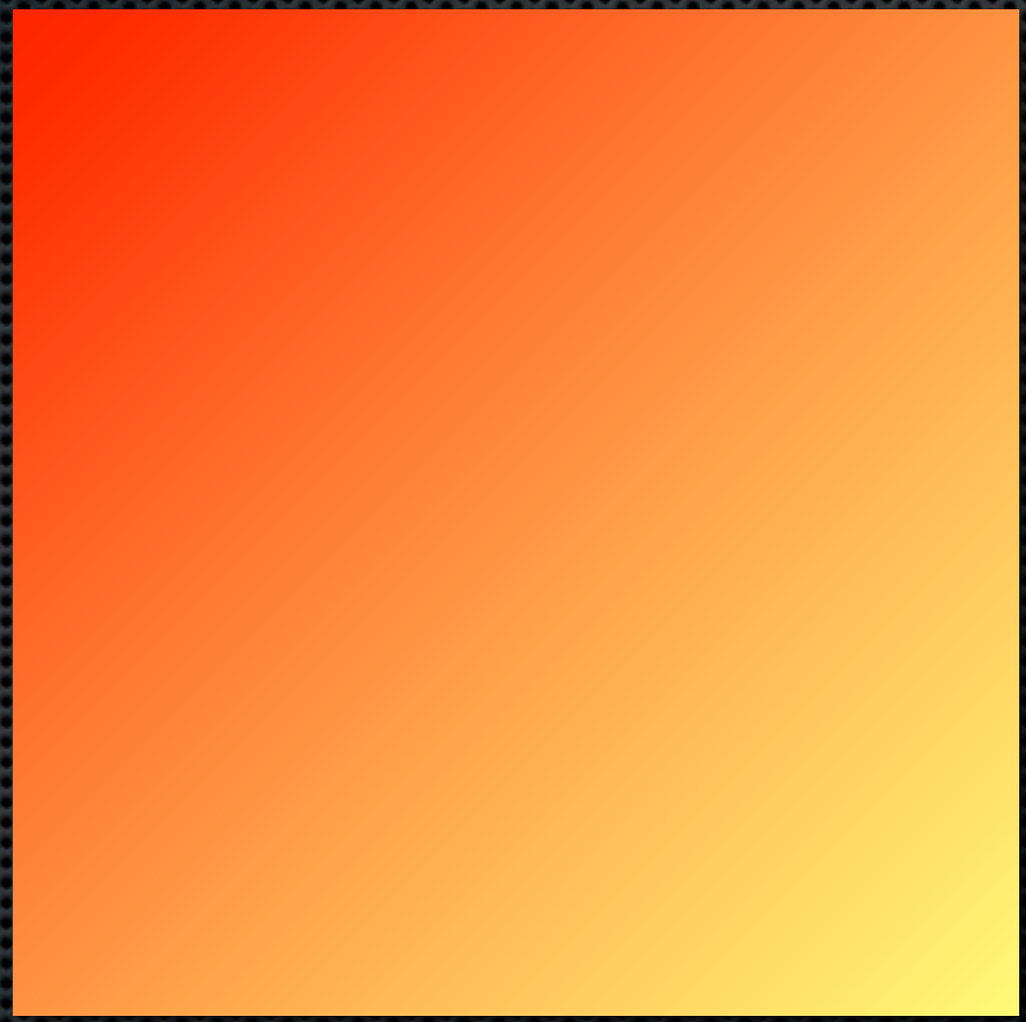

Parametric gradient functions

$$\boldsymbol{f} = \boldsymbol{c} \circ \boldsymbol{g} = \boldsymbol{c}(\boldsymbol{g}(\mathbf{x}, \boldsymbol{\theta}), \boldsymbol{\theta})$$

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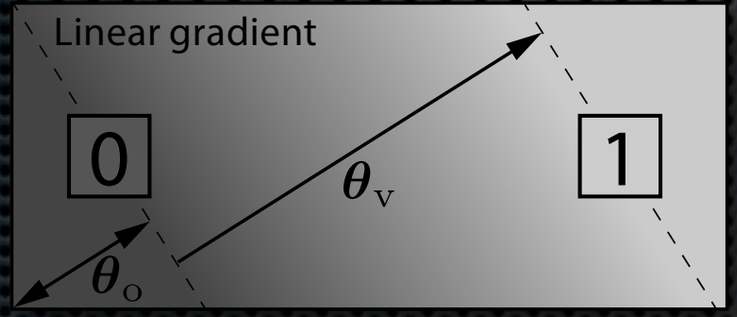
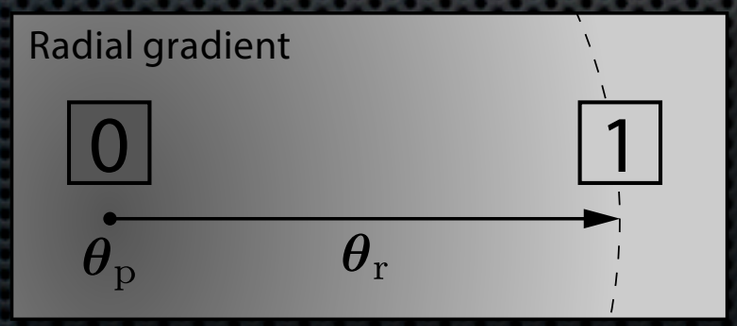
$$\boldsymbol{f} = \boldsymbol{c} \circ \boldsymbol{g} = \boldsymbol{c}(\boldsymbol{g}(\mathbf{x}, \boldsymbol{\theta}), \boldsymbol{\theta})$$

gradient function $\boldsymbol{g}(\mathbf{x}, \boldsymbol{\theta})$



$$g_{\text{linear}}(\mathbf{x}, \boldsymbol{\theta}) = \frac{\mathbf{x} \cdot \boldsymbol{\theta}_{\text{v}}}{\|\boldsymbol{\theta}_{\text{v}}\|^2} + \boldsymbol{\theta}_{\text{o}}$$



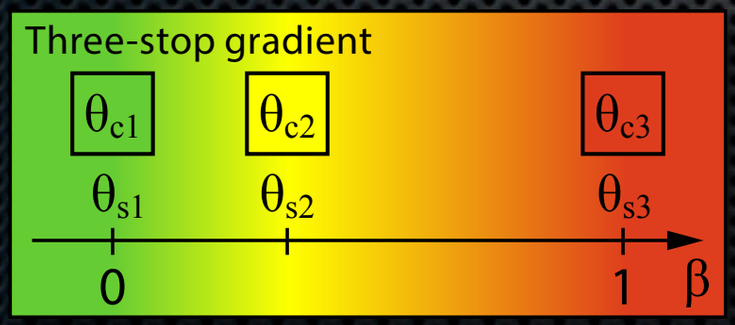
$$g_{\text{radial}}(\mathbf{x}, \boldsymbol{\theta}) = \frac{\|\mathbf{x} - \boldsymbol{\theta}_{\text{p}}\|}{\boldsymbol{\theta}_{\text{r}}}$$

Parametric gradient functions

$$\boldsymbol{f} = \boldsymbol{c} \circ \boldsymbol{g} = \boldsymbol{c}(\boldsymbol{g}(\mathbf{x}, \boldsymbol{\theta}), \boldsymbol{\theta})$$

colour function $\boldsymbol{c}(\beta, \boldsymbol{\theta})$

$$\boldsymbol{c}_2(\beta, \boldsymbol{\theta}) = \mathrm{mix}(\boldsymbol{\theta}_{\mathrm{c1}}, \boldsymbol{\theta}_{\mathrm{c2}}, \beta)$$



$$\boldsymbol{c}_3(\beta, \boldsymbol{\theta}) = \begin{cases} \mathrm{mix}\left(\boldsymbol{\theta}_{\mathrm{c1}}, \boldsymbol{\theta}_{\mathrm{c2}}, \frac{\beta}{\boldsymbol{\theta}_{\mathrm{s2}}}\right) & \beta \leq \boldsymbol{\theta}_{\mathrm{s2}} \\ \mathrm{mix}\left(\boldsymbol{\theta}_{\mathrm{c2}}, \boldsymbol{\theta}_{\mathrm{c3}}, \frac{\beta - \boldsymbol{\theta}_{\mathrm{s2}}}{1 - \boldsymbol{\theta}_{\mathrm{s2}}}\right) & \beta > \boldsymbol{\theta}_{\mathrm{s2}} \end{cases}$$

$$\mathrm{mix}(\mathbf{a}, \mathbf{b}, t) = (1 - t) \cdot \mathbf{a} + t \cdot \mathbf{b}$$

Foreground estimation

$$\mathbf{I} = \alpha \cdot \mathbf{F} + (1 - \alpha) \cdot \mathbf{B} = \mathbf{F} \circ \mathbf{B}$$

$$\mathbf{I}(\mathbf{x}) = \mathbf{F}(\mathbf{x}) \circ \mathbf{B}(\mathbf{x})$$

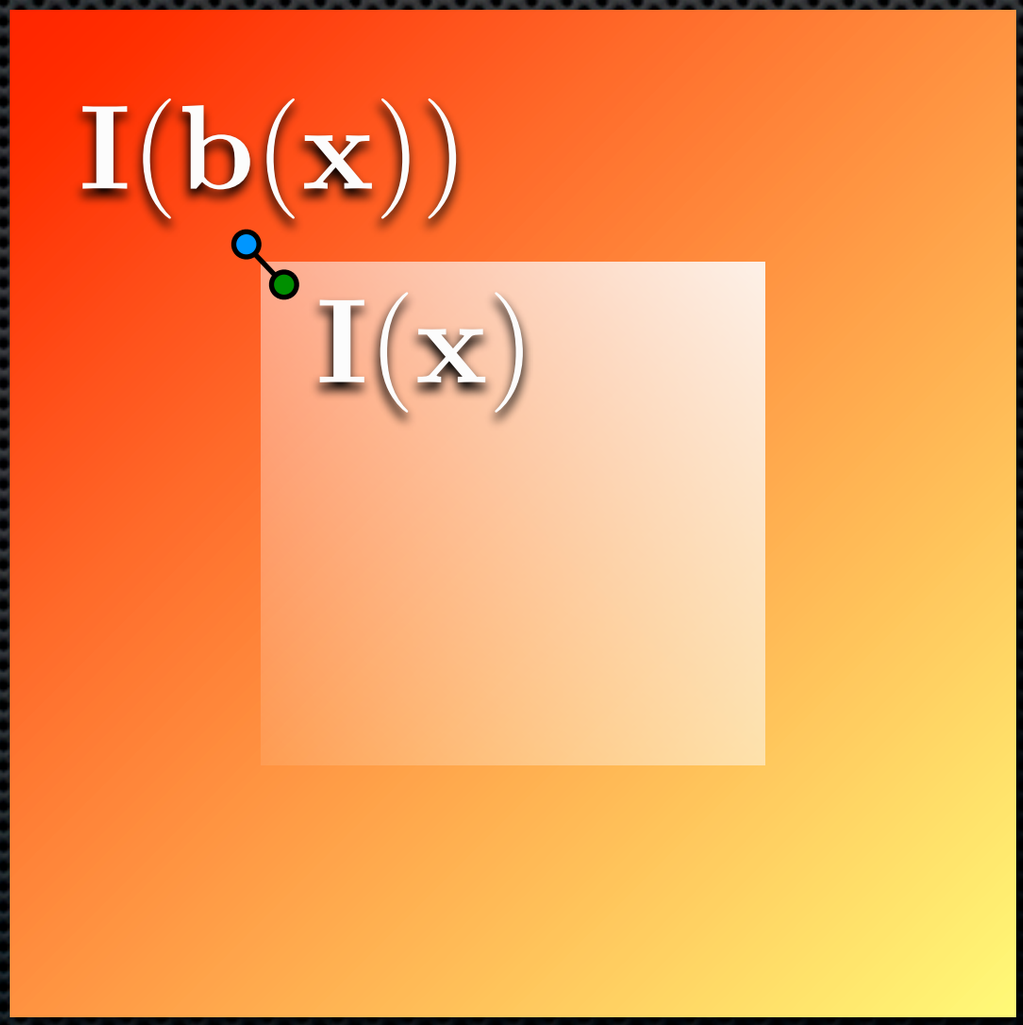
$$\mathbf{I}(\mathbf{x}) = \boldsymbol{f}(\mathbf{x}, \boldsymbol{\theta}) \circ \mathbf{B}(\mathbf{x})$$

$$\arg\min_{\boldsymbol{\theta}, \mathbf{B}} \sum_{\mathbf{x} \in R} \left(\mathbf{I}(\mathbf{x}) - \boldsymbol{f}(\mathbf{x}, \boldsymbol{\theta}) \circ \mathbf{B}(\mathbf{x}) \right)^2$$

- $\mathbf{x}$ pixel position
- $\boldsymbol{\theta}$ gradient parameters
- R selected image region

Foreground estimation

$$\arg\min_{\boldsymbol{\theta},\mathbf{B}} \sum_{\mathbf{x}\in R} \left(\mathbf{I}(\mathbf{x}) - \boldsymbol{f}(\mathbf{x},\boldsymbol{\theta}) \circ \mathbf{B}(\mathbf{x})\right)^2$$



- $\mathbf{x}$ pixel position
- $\boldsymbol{\theta}$ gradient parameters
- R selected image region
- $\mathbf{b}$ background sample

Foreground estimation

$$\arg\min_{\boldsymbol{\theta}} \sum_{\mathbf{x}\in\partial R} \left(\mathbf{I}(\mathbf{x}) - \boldsymbol{f}(\mathbf{x},\boldsymbol{\theta}) \circ \mathbf{I}(\mathbf{b}(\mathbf{x}))\right)^2$$

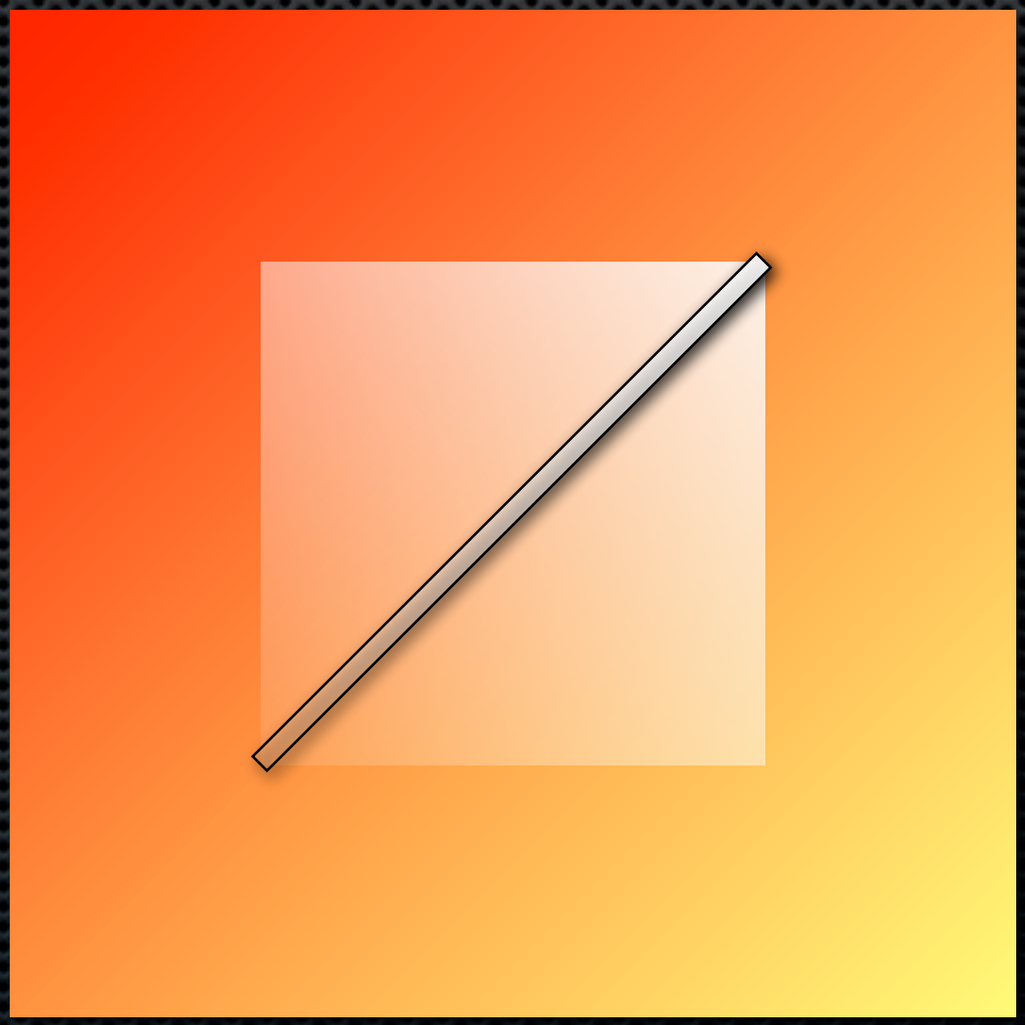
$$\mathbf{I}(\mathbf{b}(\mathbf{x})) \approx \mathbf{B}(\mathbf{x})$$

$\mathbf{I}(\mathbf{x})$

- $\mathbf{x}$ pixel position
- $\boldsymbol{\theta}$ gradient parameters
- R selected image region
- $\mathbf{b}$ background sample
- ∂R region boundary

Foreground estimation

$$\arg\min_{\boldsymbol{\theta}} \sum_{\mathbf{x}\in\partial R} \left(\mathbf{I}(\mathbf{x}) - \boldsymbol{f}(\mathbf{x},\boldsymbol{\theta}) \circ \mathbf{I}(\mathbf{b}(\mathbf{x}))\right)^2$$



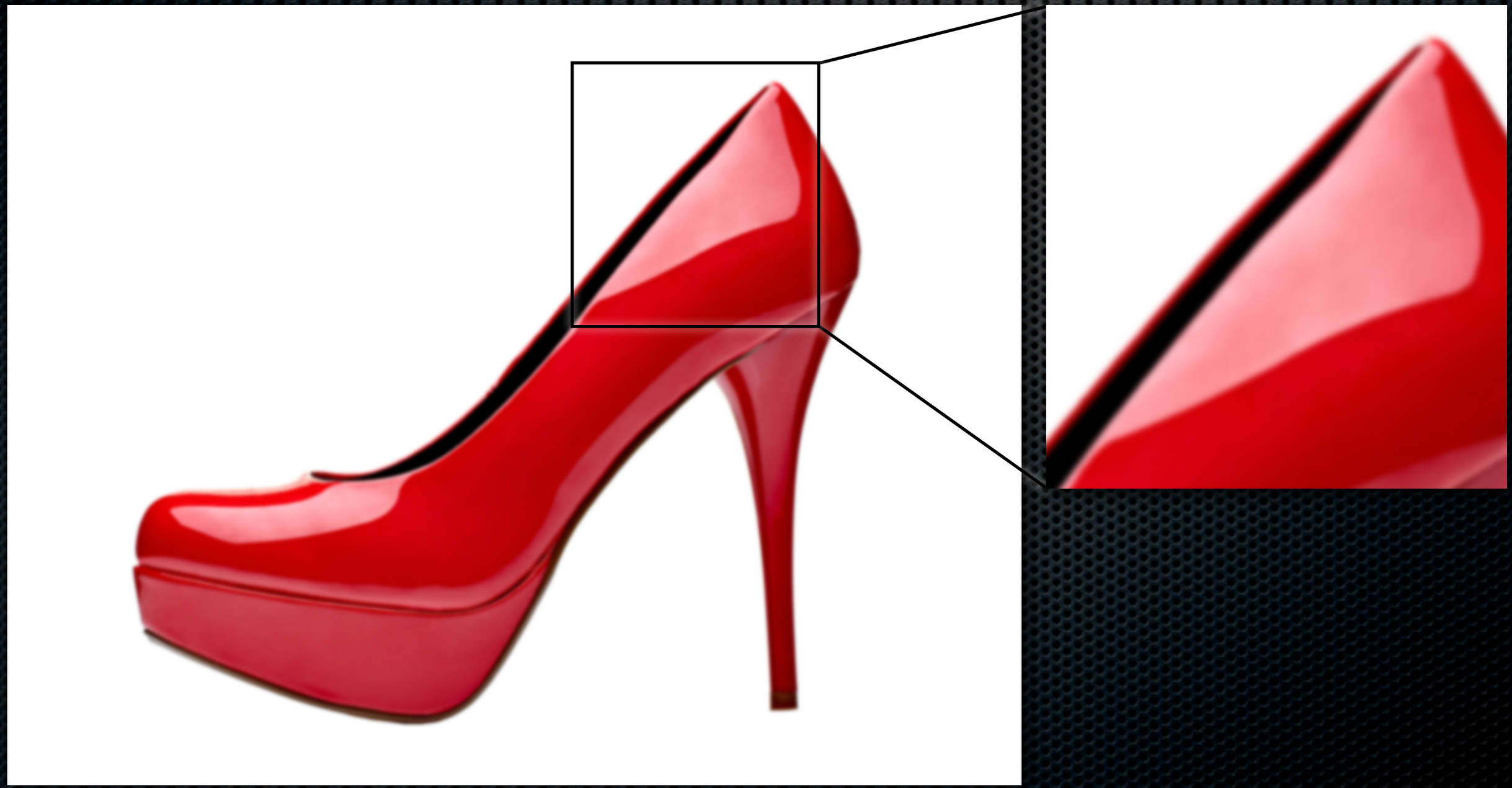
- $\mathbf{x}$ pixel position
- $\boldsymbol{\theta}$ gradient parameters
- R selected image region
- $\mathbf{b}$ background sample
- ∂R region boundary

Background estimation

Shutterstock/Picsfive

Input photo (slightly blurred)

Background estimation



Shutterstock/Picsfive

Input photo (slightly blurred)

Background estimation

Shutterstock/Picsfive

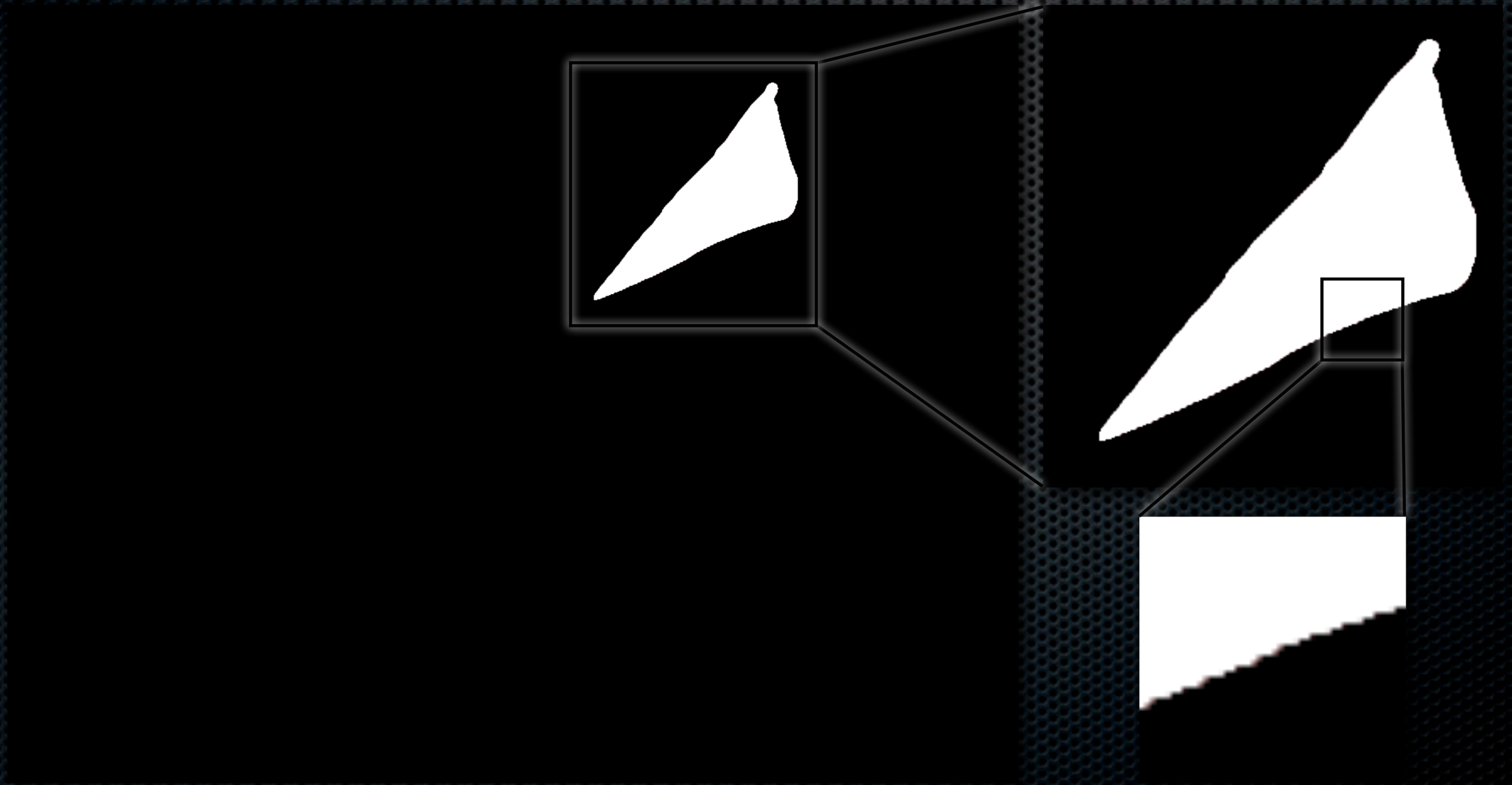
Input photo (slightly blurred)

Background estimation

Shutterstock/Picsfive

with hard region boundary

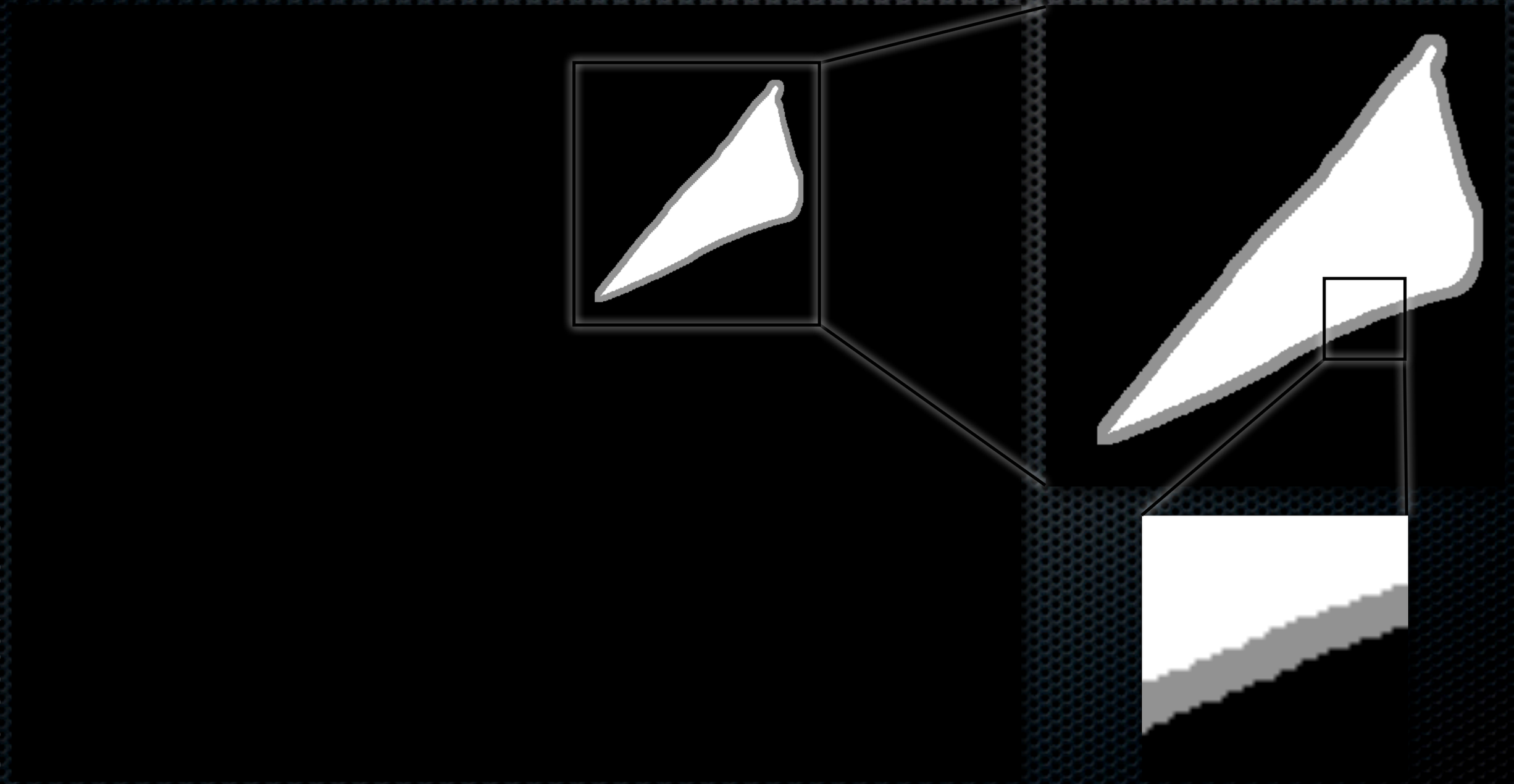
Background estimation



Shutterstock/Picsfive

hard region boundary

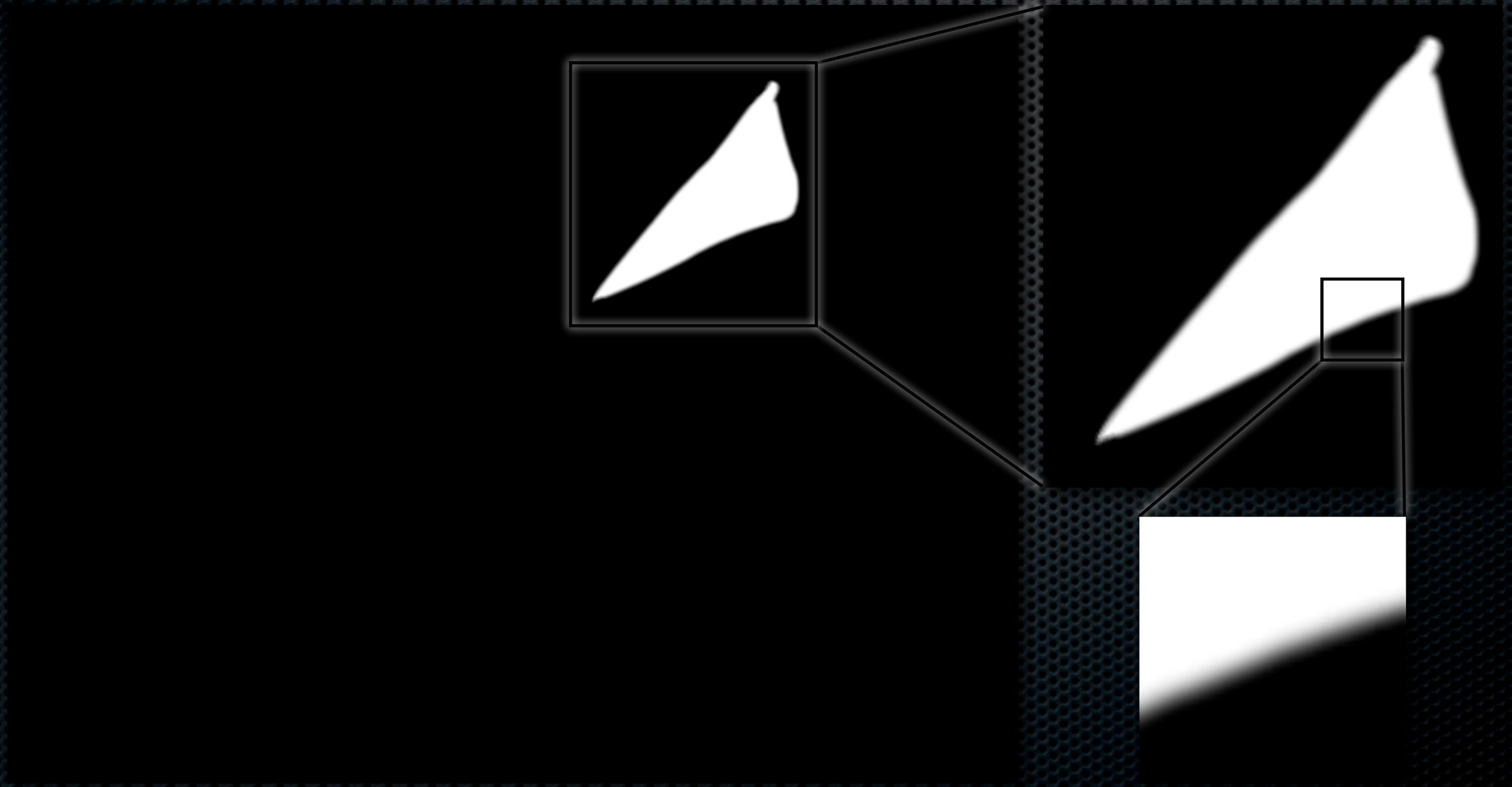
Background estimation



Shutterstock/Picsfive

trimap from hard region boundary

Background estimation



Shutterstock/Picsfive

matted region boundary

Background estimation

Shutterstock/Picsfive

with matted region boundary

Background estimation

Shutterstock/Picsfive

plus TV-smoothed region

Background estimation

Shutterstock/Picsfive

plus Poisson blending

Background estimation

Shutterstock/Picsfive

plus Poisson blending

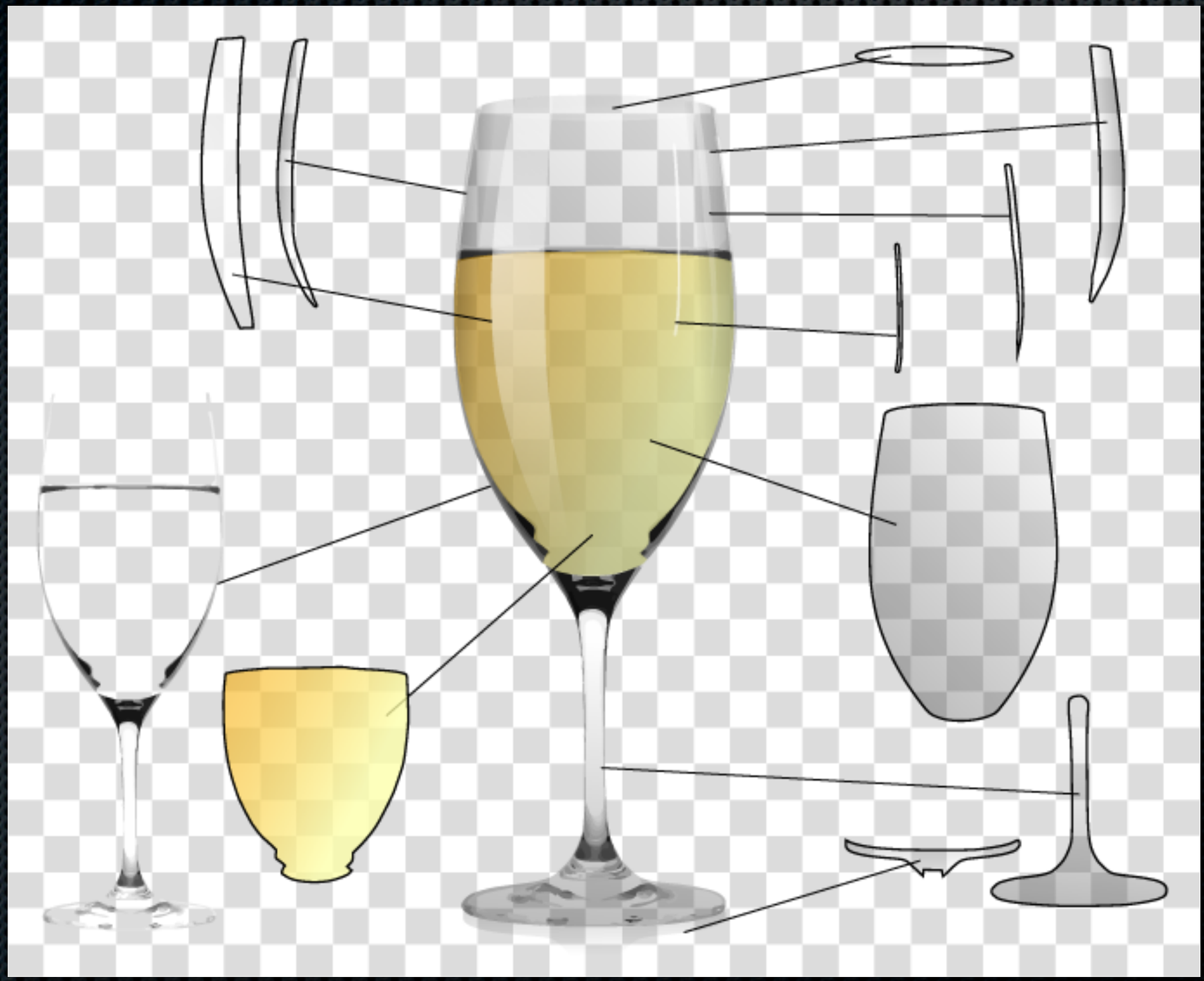
Summary

1. joint decompositing and vectorisation of foreground:
   - solving the matting problem around region boundary
   - strong prior on foreground + user input
2. background estimation by optimisation:
   - similar to inversion of compositing equation
   - additional terms to remove residuals:
     TV smoothness + Poisson blending

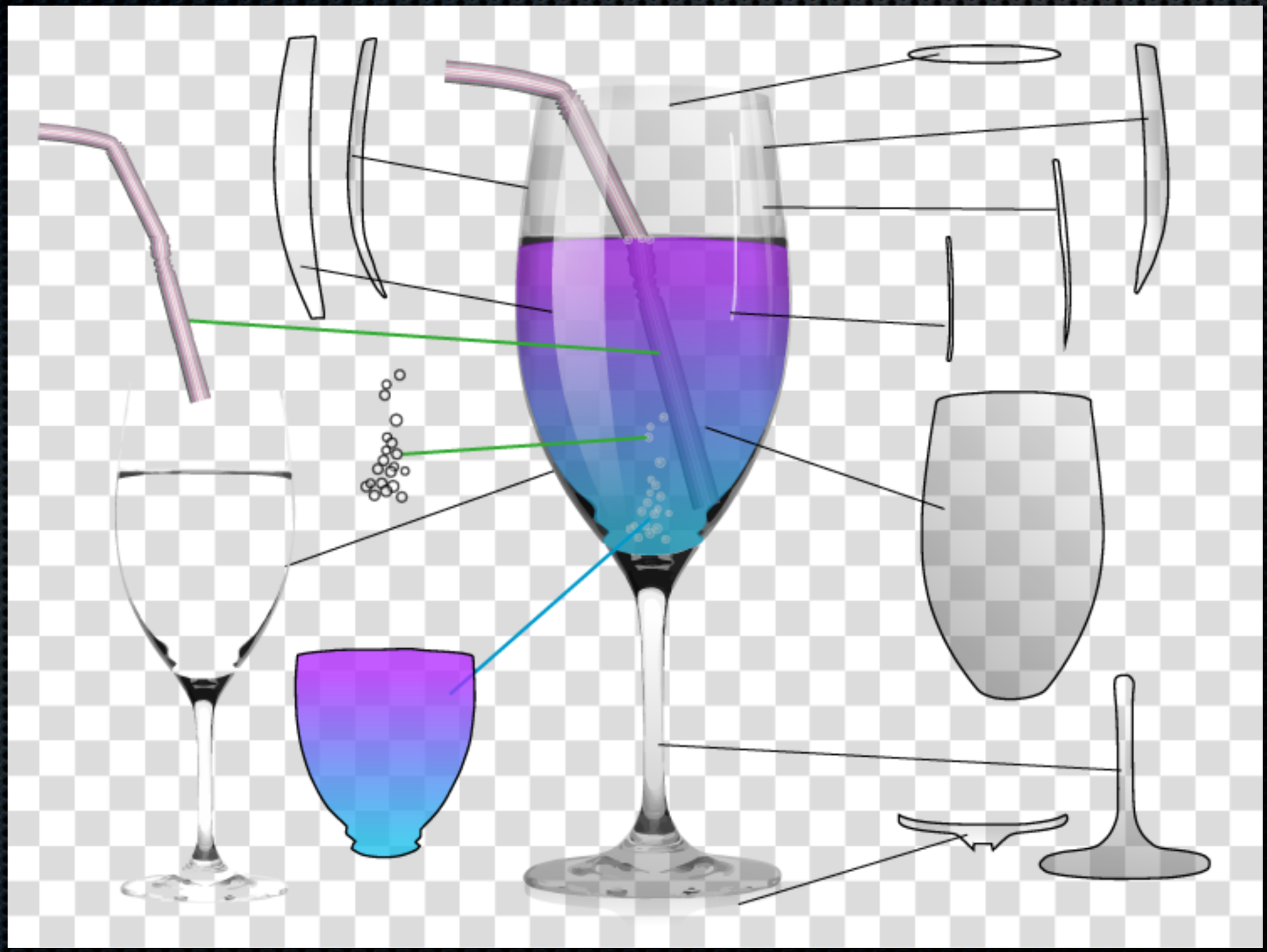
Input photo

Shutterstock/Givaga

Vectorised result



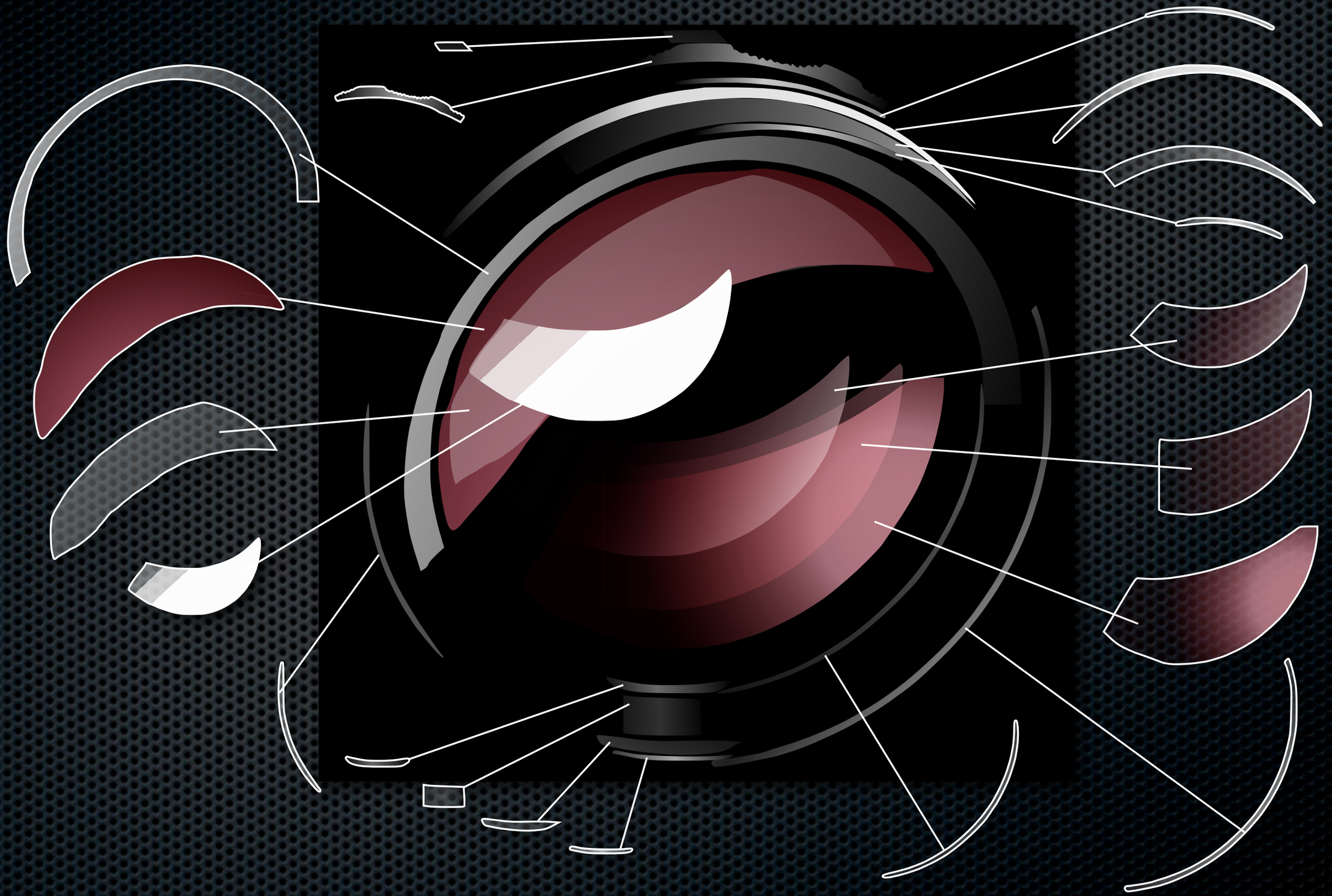
Editing result



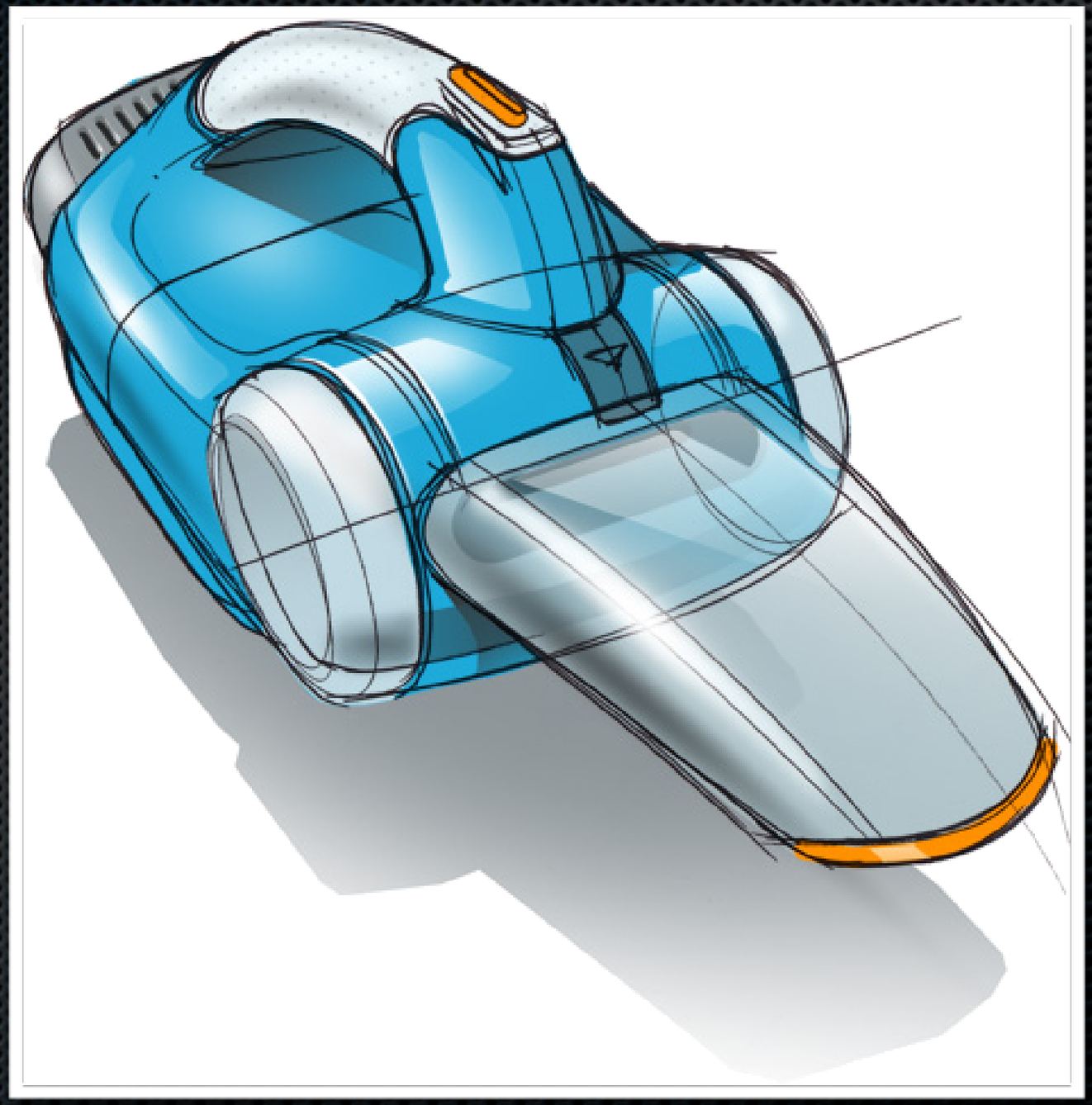
Input photo

Flickr/squinza (CC BY-SA 2.0)

Vectorised result

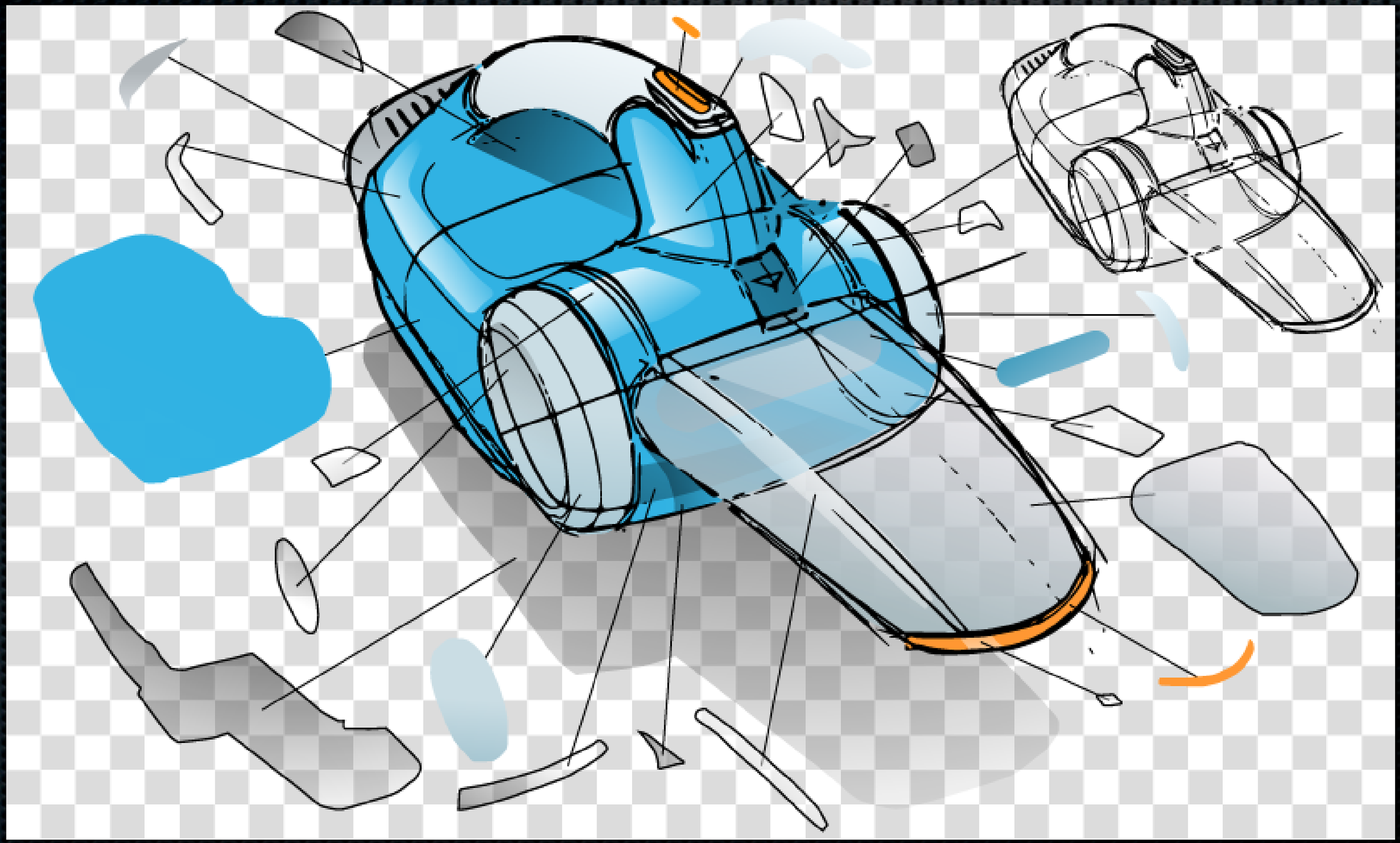


Input drawing

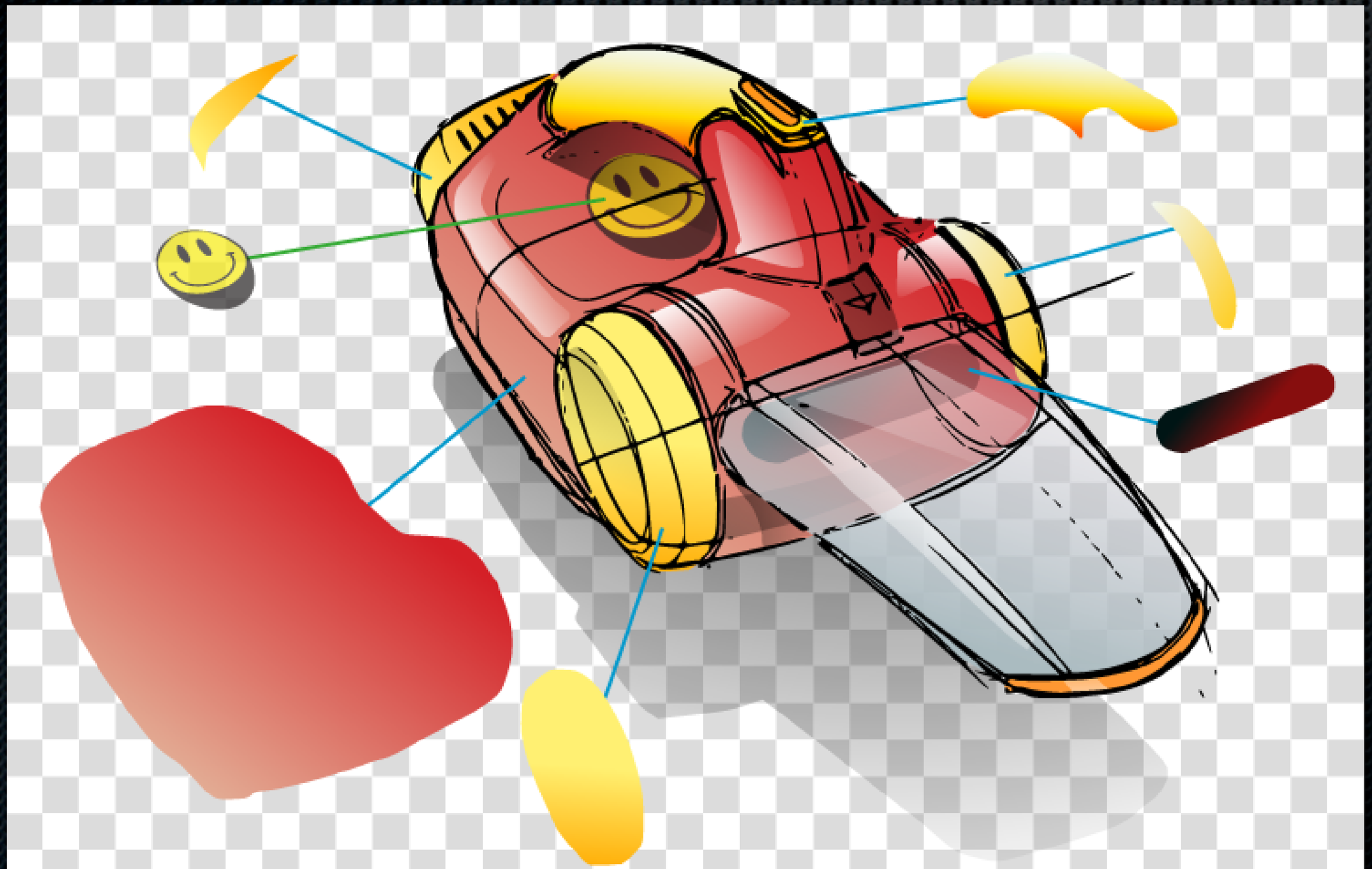


Spencer Nugent

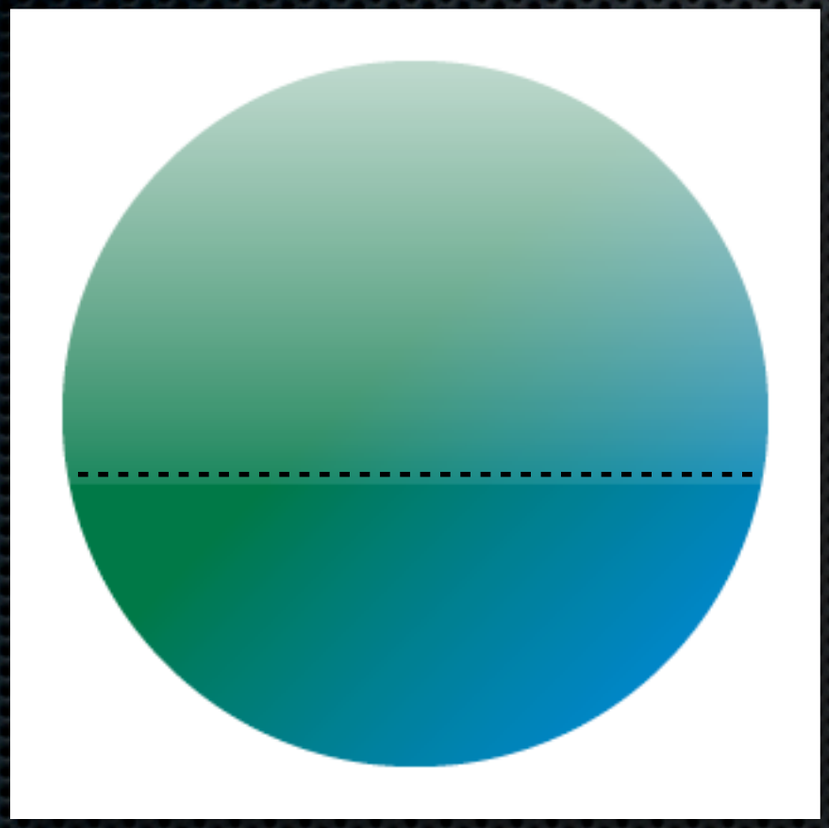
Vectorised result



Editing result

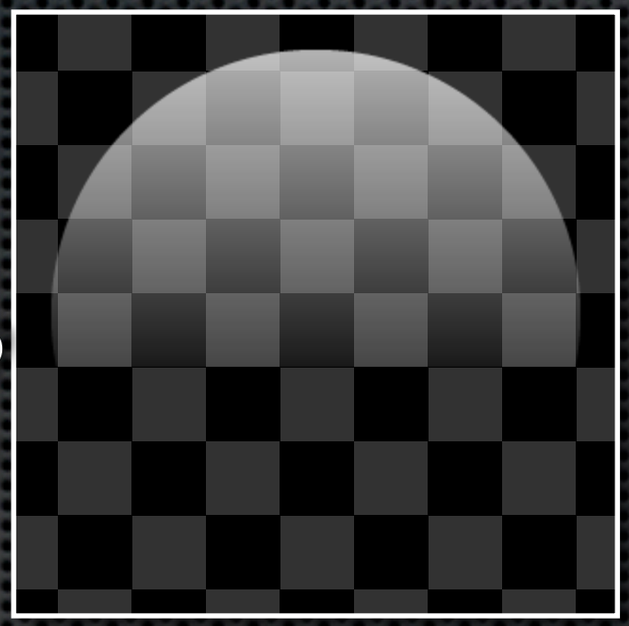


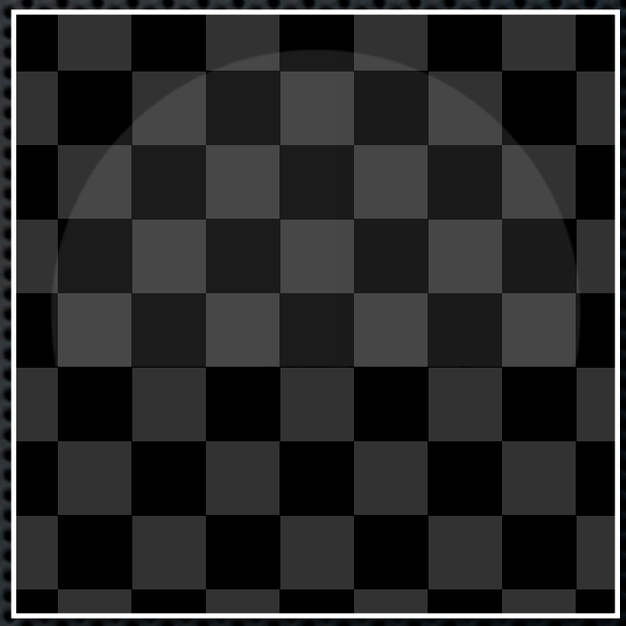
Limitation: few iso-contours



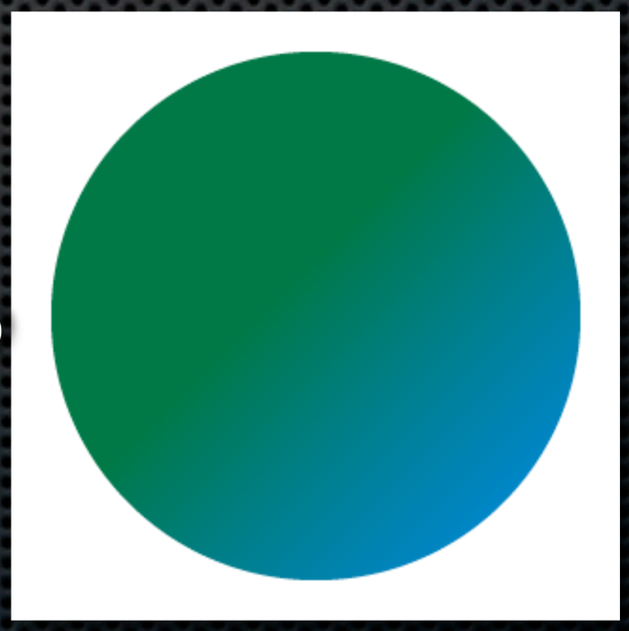
input image

foreground

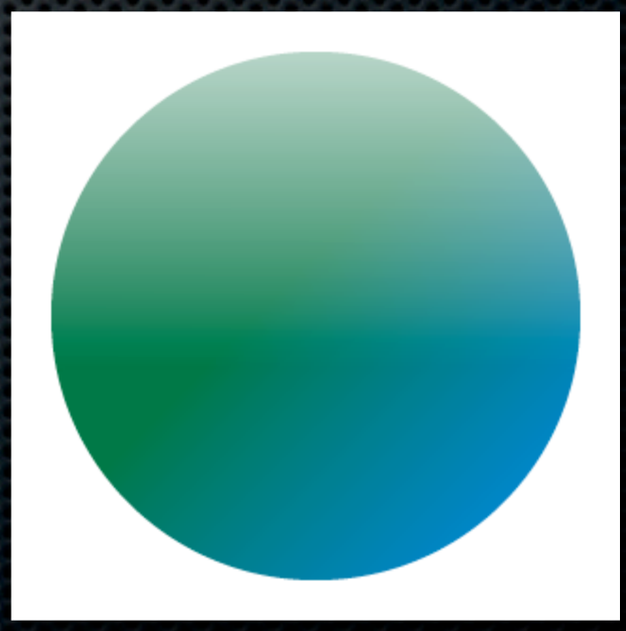




background



ground truth



our decomposition

Limitation: background textures

input photo

our recomposited result

Limitation: background textures

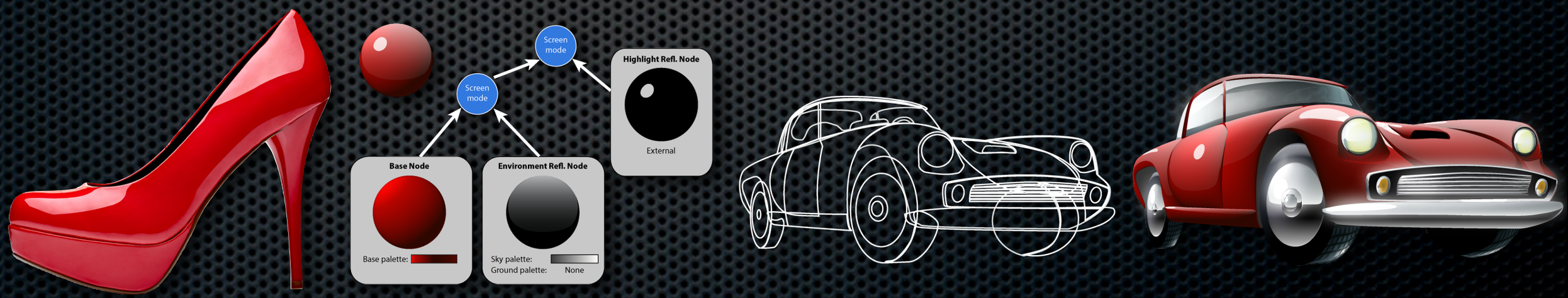
input photo

estimated background

Future work

- more complex semi-transparent vector primitives
- automatic segmentation and decompositing
- extract Vector Shade Trees [Lopez-Moreno+ 2013]

from exemplar materials



Conclusion

- key insight: complex images can often be explained by stacking simple layers
- first approach creating layered vector art from bitmaps:
  - opaque and semi-transparent gradient layers
  - produces a simple, editable stack of vector layers
  - valuable for professionals and novices alike

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