Scattering-aware Texture Reproduction for 3D Printing

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Motivation: Color Printing in 3D

computational fabrication of highly detailed textures
(slabs above are 1 cm thick)

Enabler: Multi-material Printing

Stratasys J750 (poly-jetting printer)

Cyan

Magenta

Yellow

blacK

White

‘Vero Opaque’ materials (not actually opaque!)

Color in the Wild

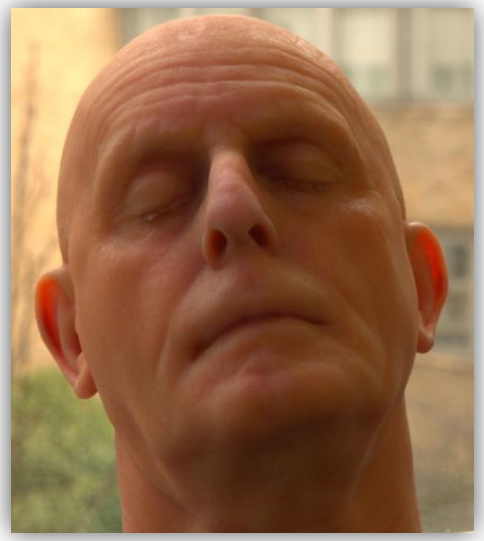
[Stratasys]

State of the Art

[Hašan et al. @ SIGGRAPH 2010]

[Dong et al. @ SIGGRAPH 2010]

[Brunton et al. @ ToG 2015]



we can fabricate translucent appearance rather well…

State of the Art

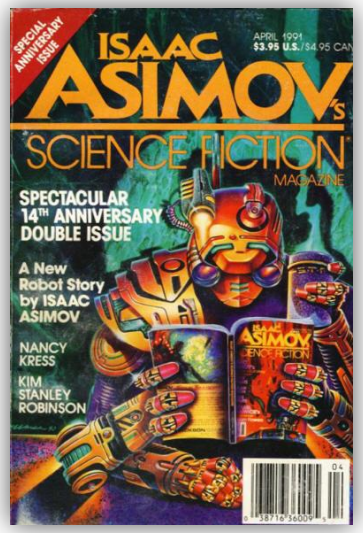
[Babaei et al. @ SIGGRAPH 2017]

target →

← print

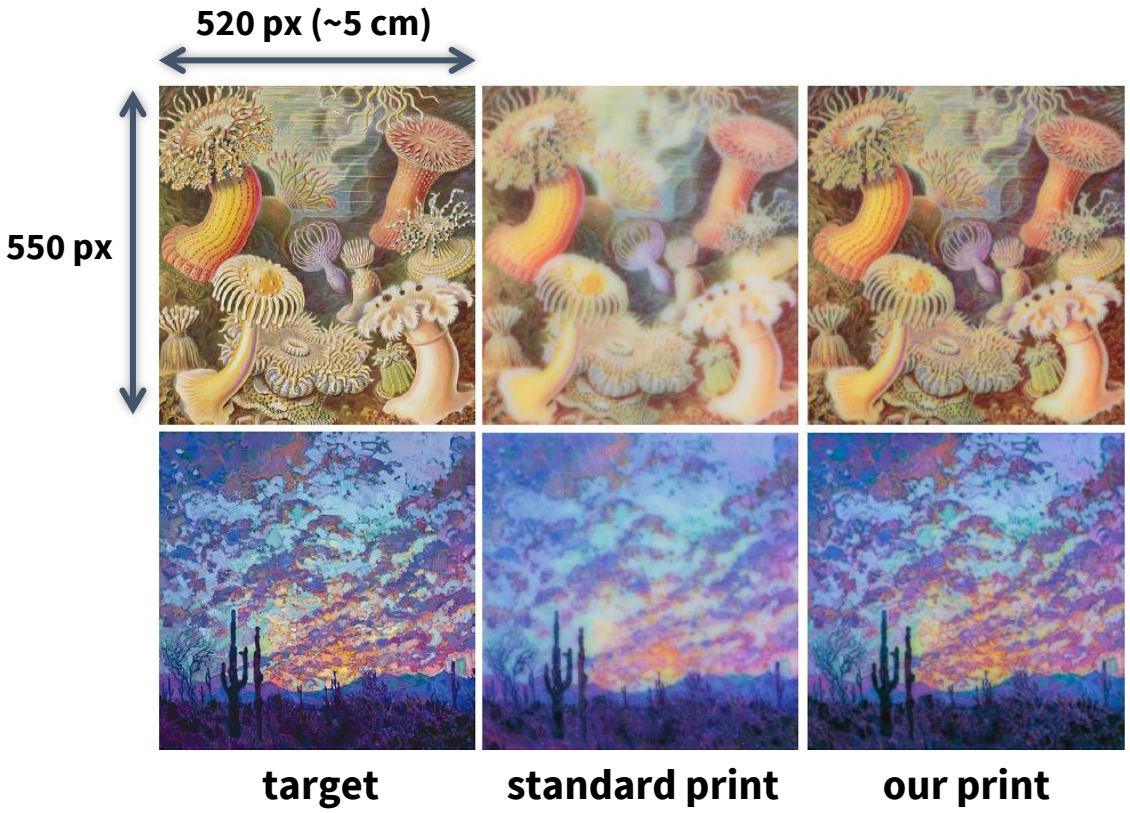
…however, fine details are problematic

“The Dream”

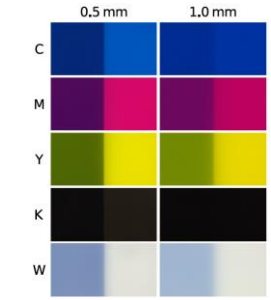


achieving quality and reproducibility of 2D prints

Our Achievement



Our Inverse Pipeline



intrinsic material parameters

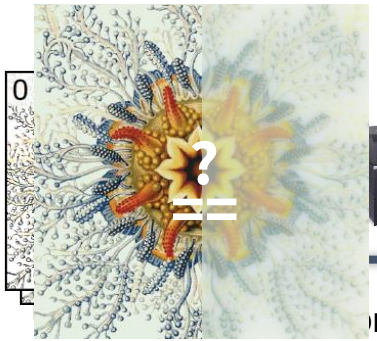
target appearance

solution refinement

optimization

current solution (proxy RGB)

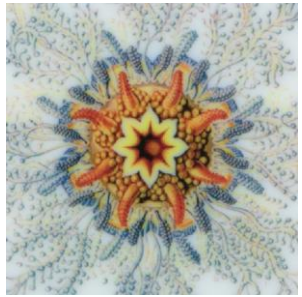
RGB → CMYKW conversion



3D material distribution

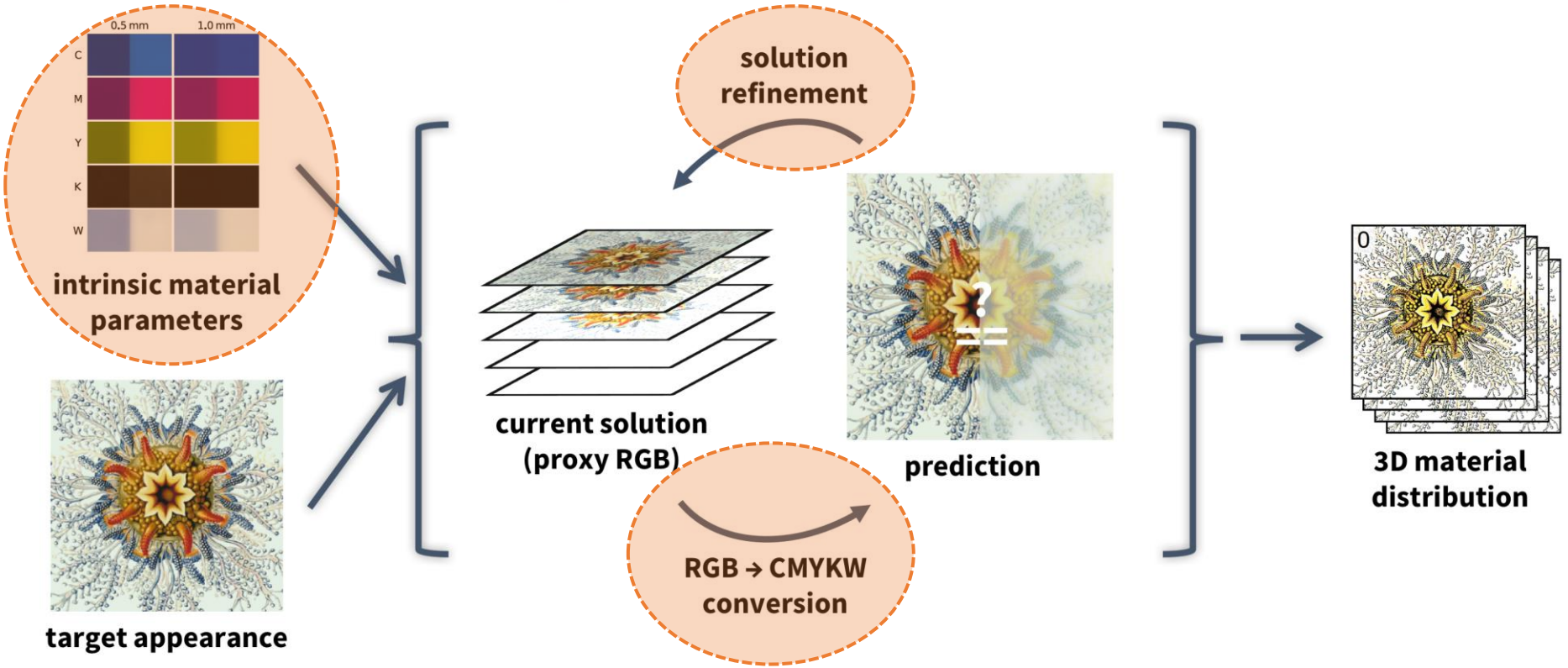
prediction

printing

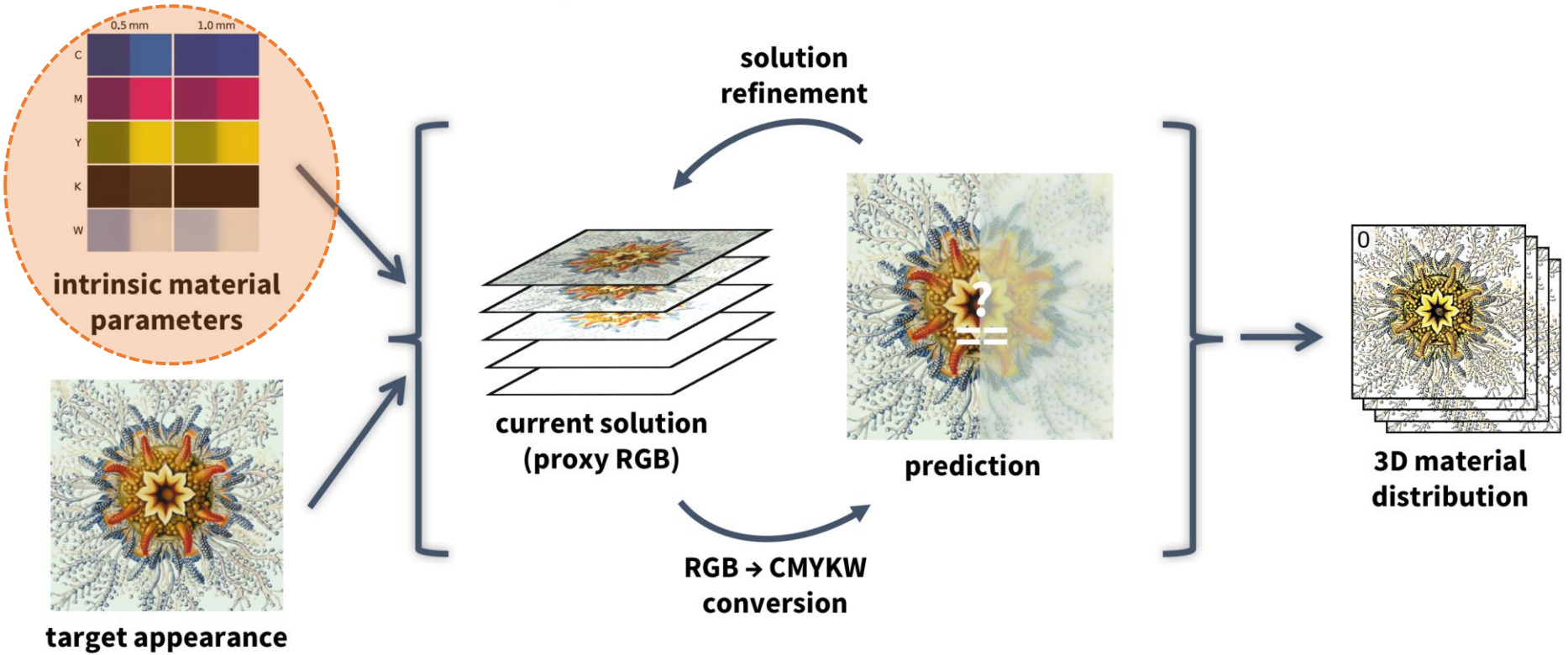


physical printout

Technical Contributions



Material Calibration



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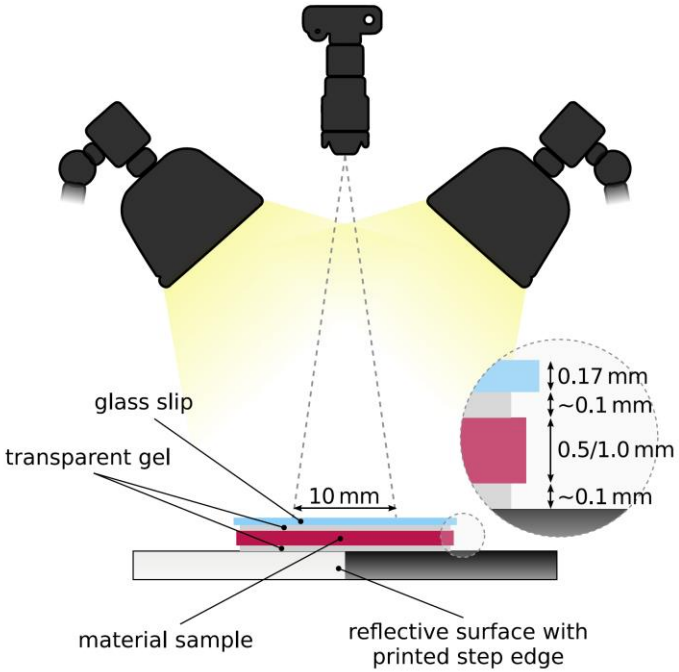
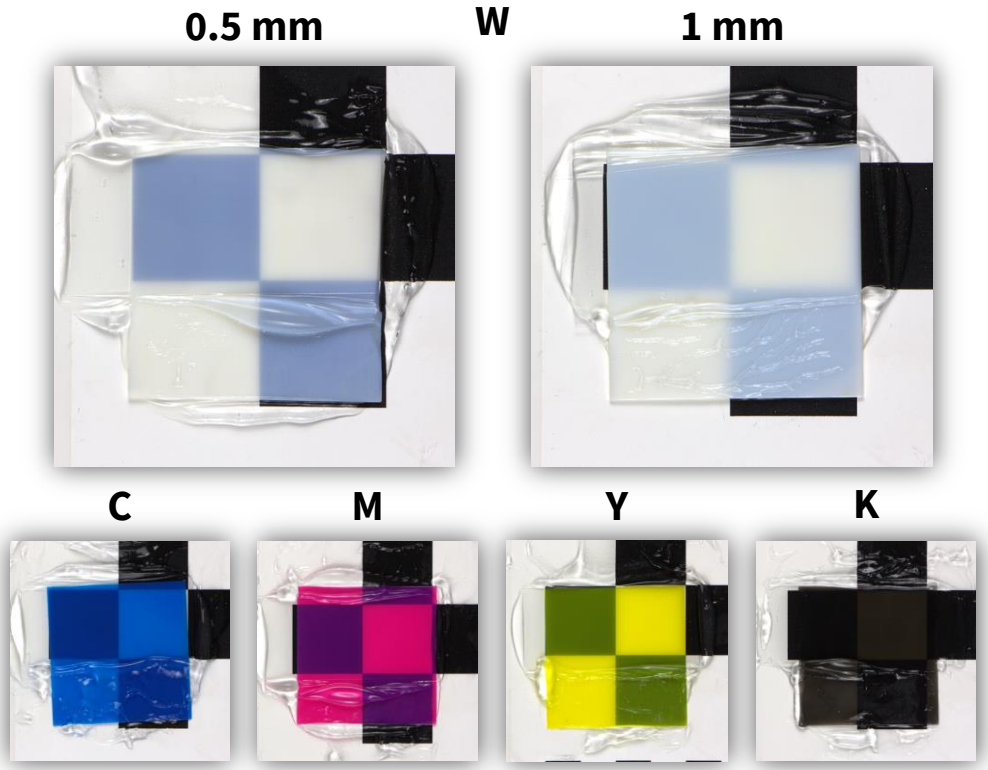


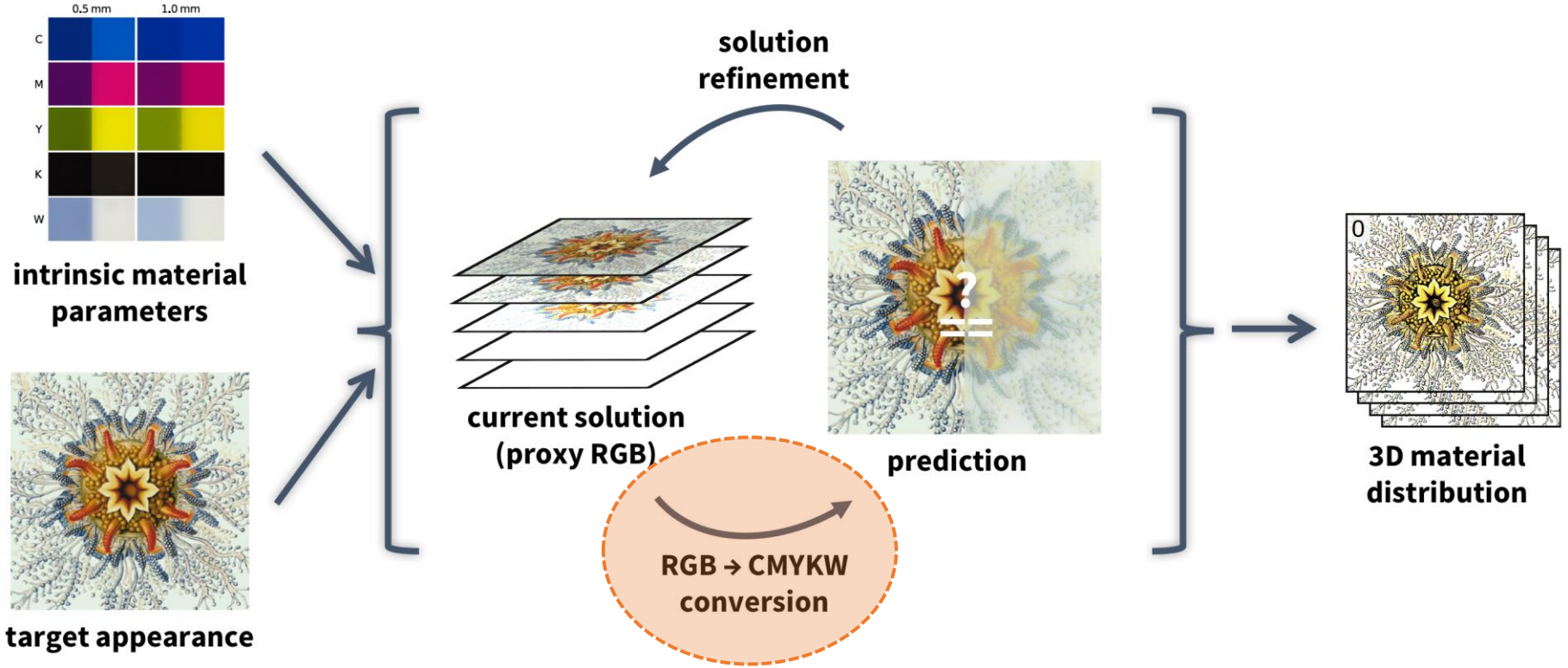


affordable optical calibration setup based on transmissive measurement

Material Calibration

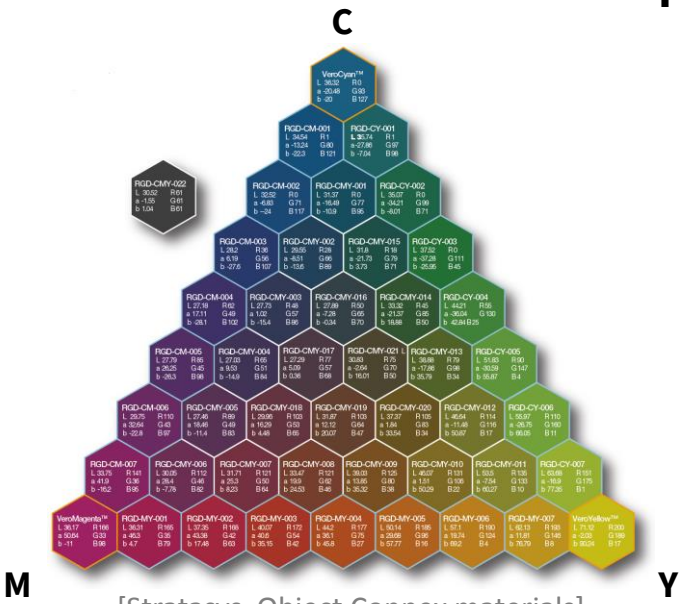
$\sigma_t \in [0, \infty)$ **optical density** | $\alpha \in [0, 1]$ **scattering albedo** | $g \in (-1, 1)$ **scattering anisotropy**

Material Mapping



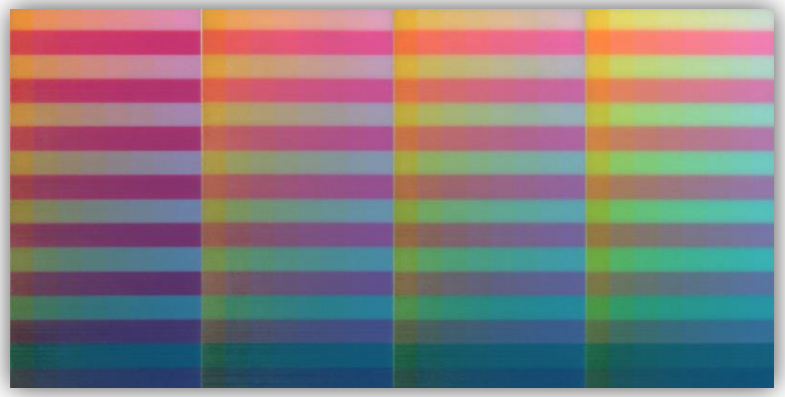
Material Mapping

Task: mapping RGB ↔ CMYKW



[Stratasys, Object Connex materials]

C × M × Y × W

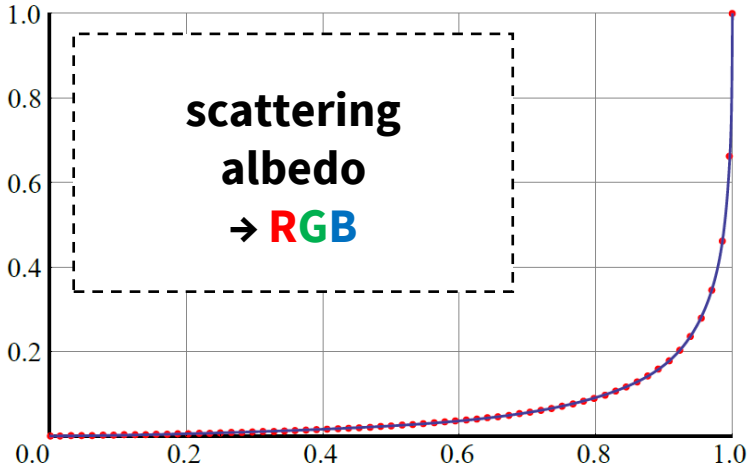


[Brunton et al. @ ToG 2015]

data-driven approaches: impractical for multi-material, translucent printing

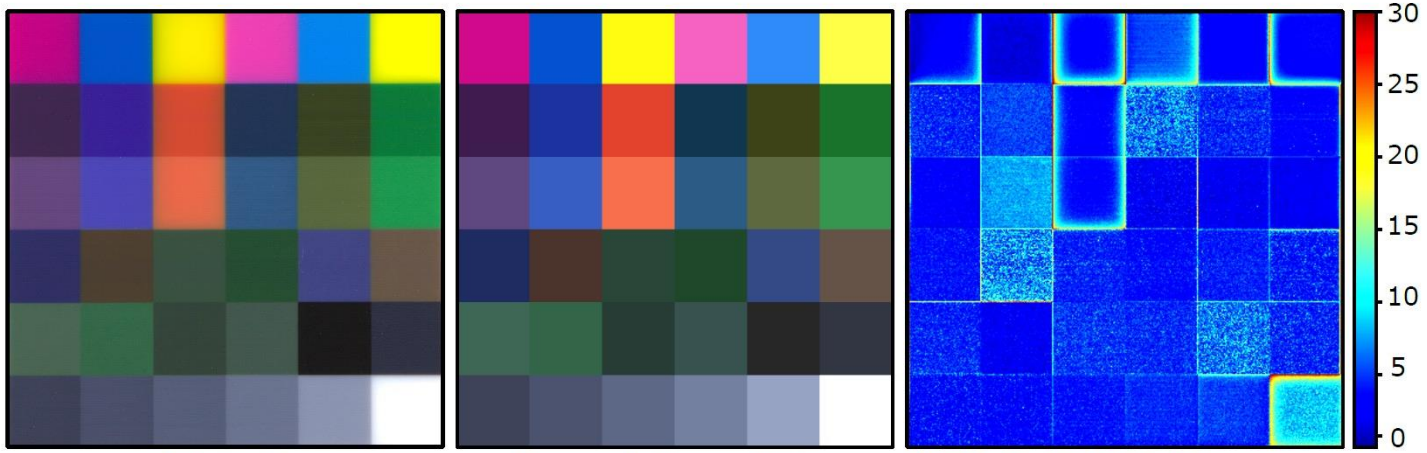
Material Mapping

Our solution: RGB ↔ Optical parameters ← CMYKW

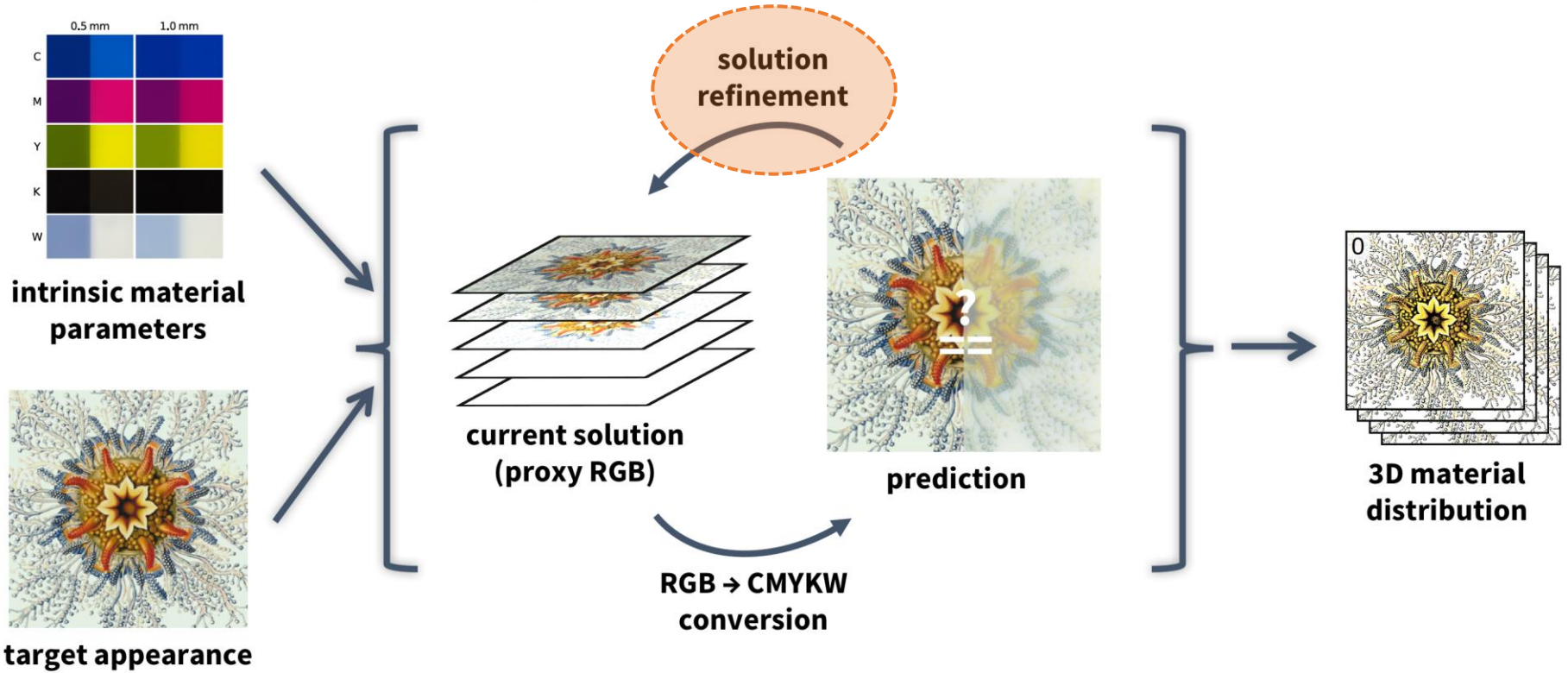


Material Mapping

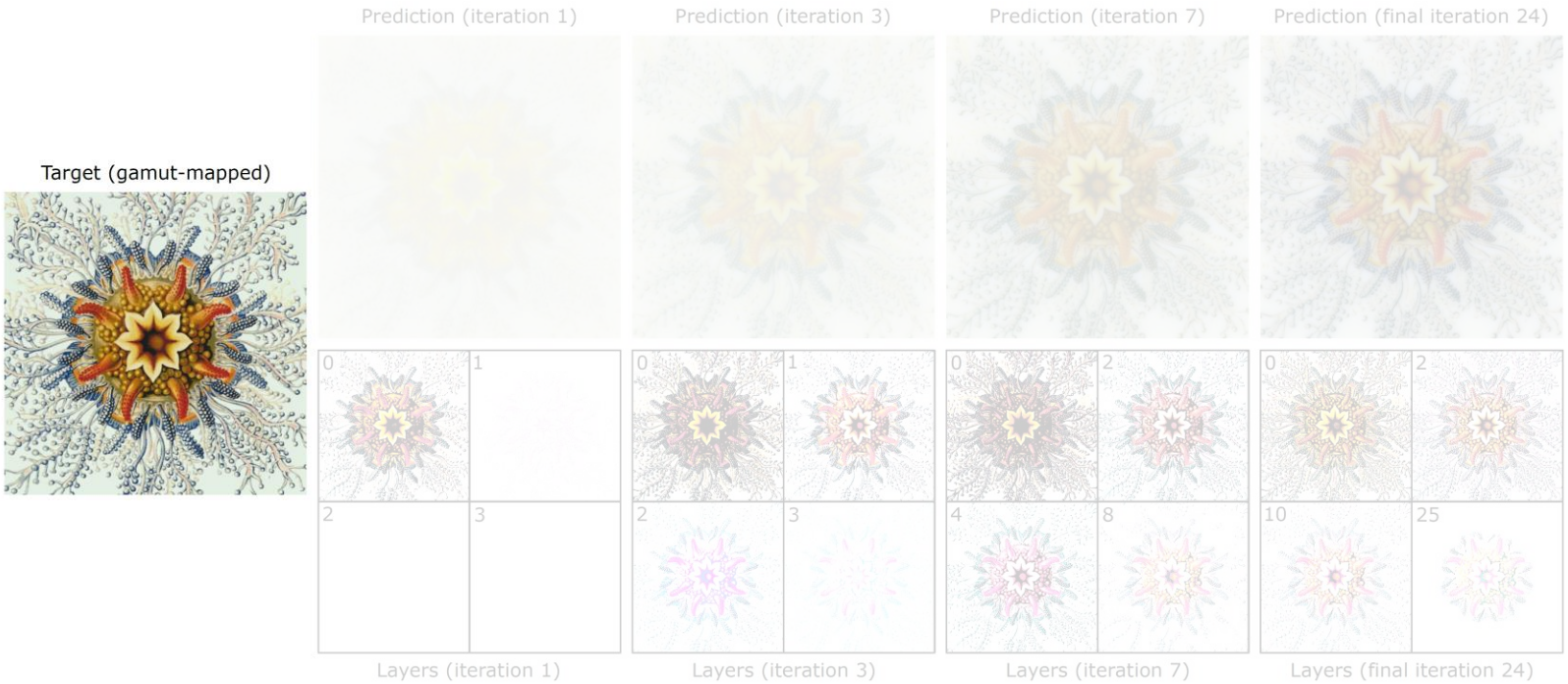
Our solution: RGB ↔ optical parameters ← CMYKW



Optimization

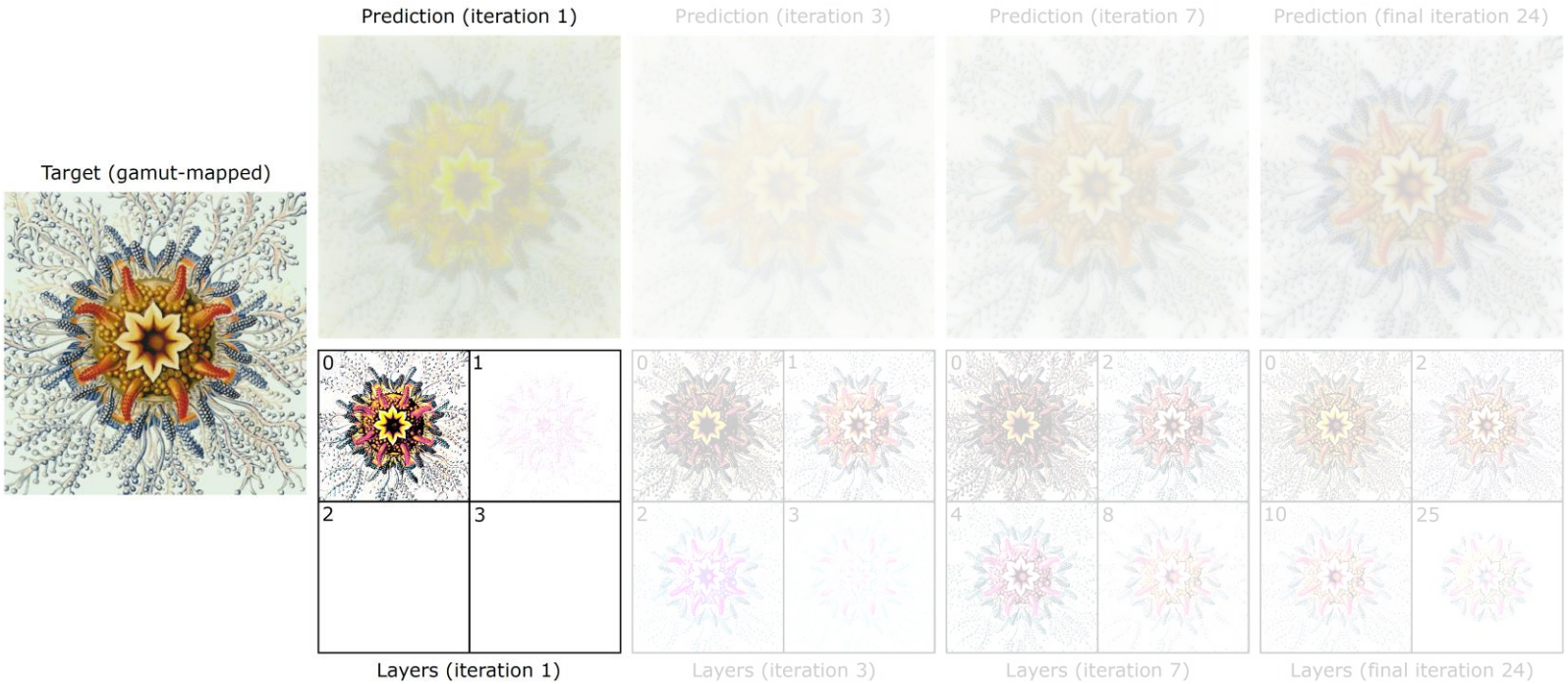


Optimization



despite the non-linearity of the appearance, it changes monotonically
→ simple residual energy minimization

Optimization



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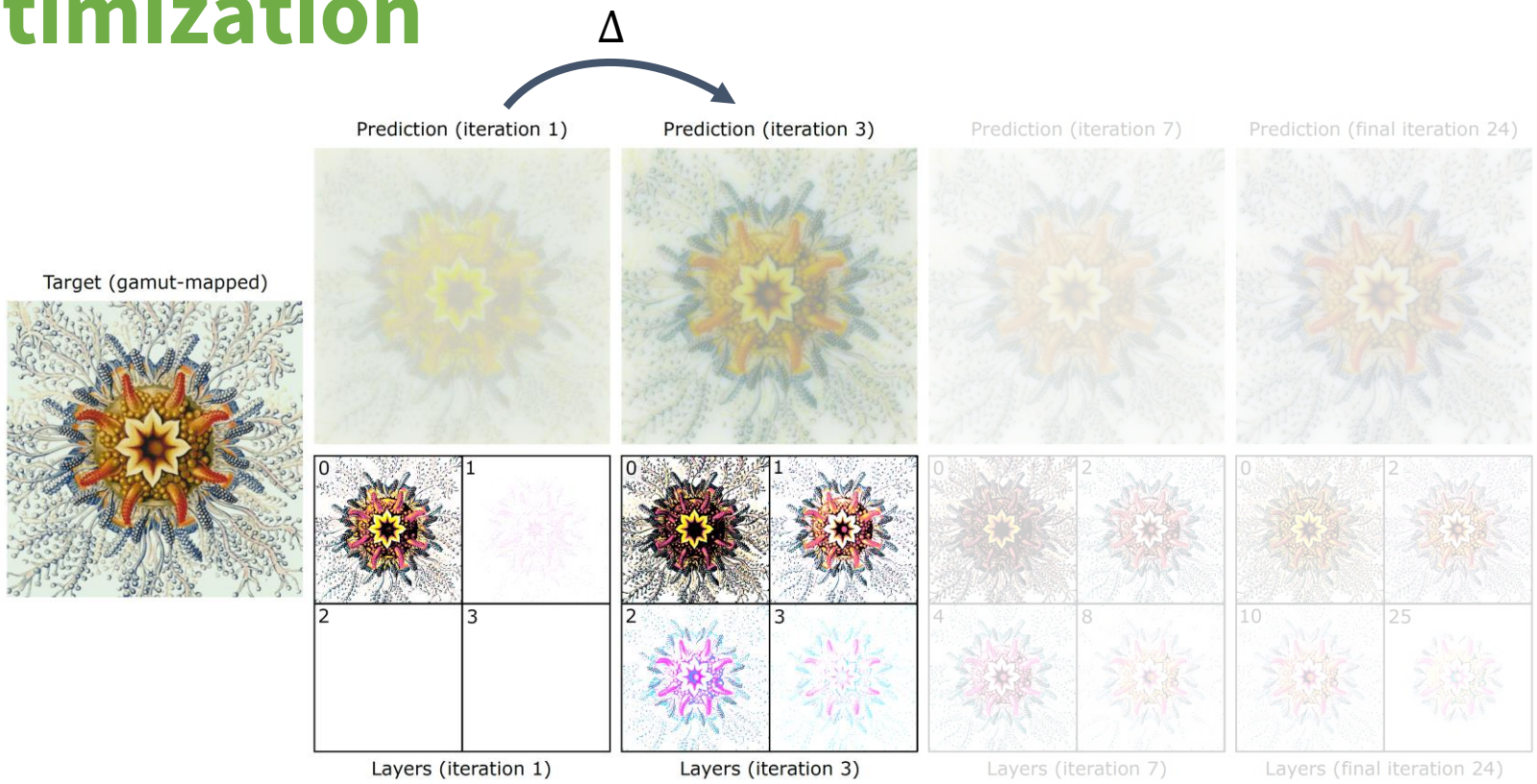

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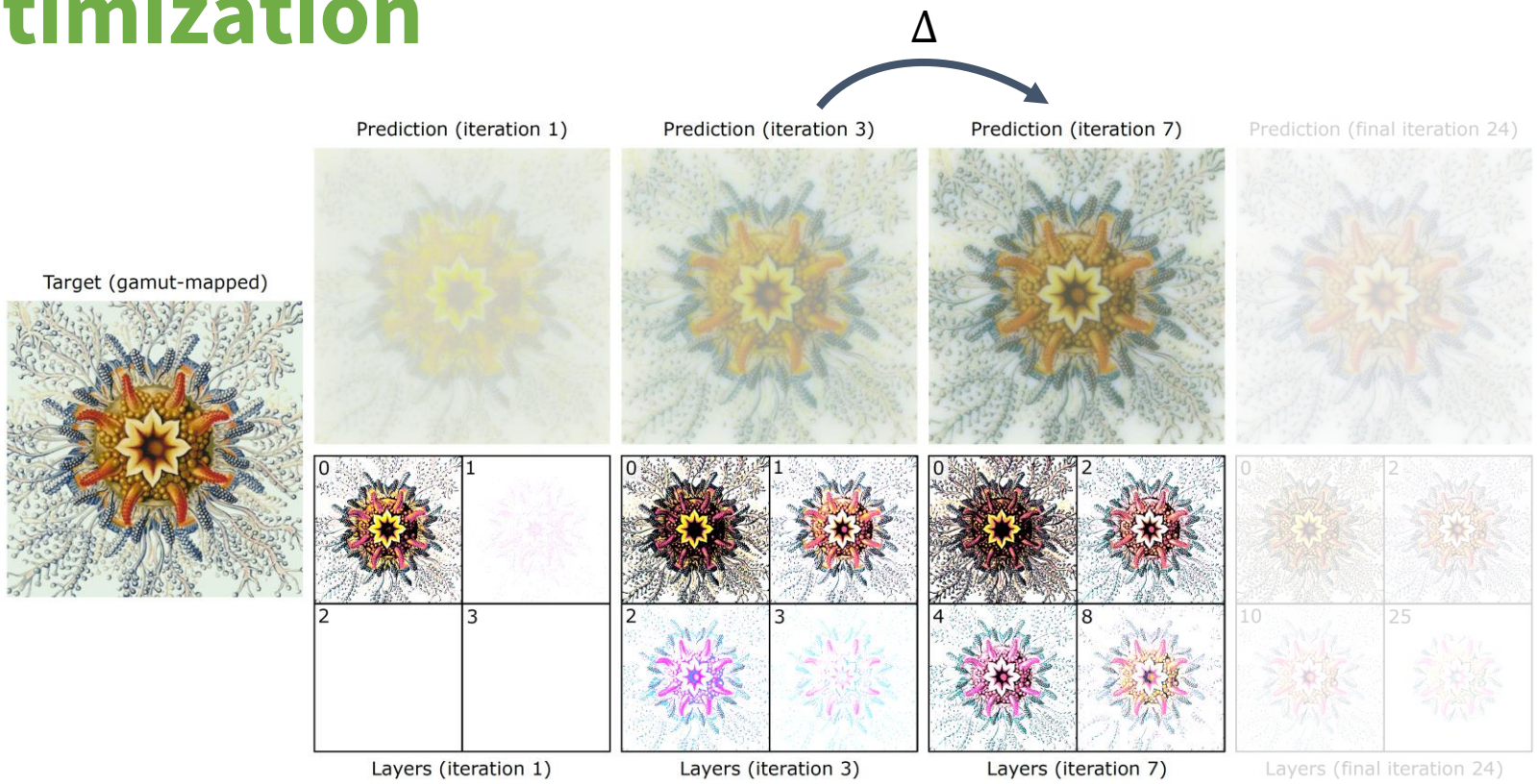

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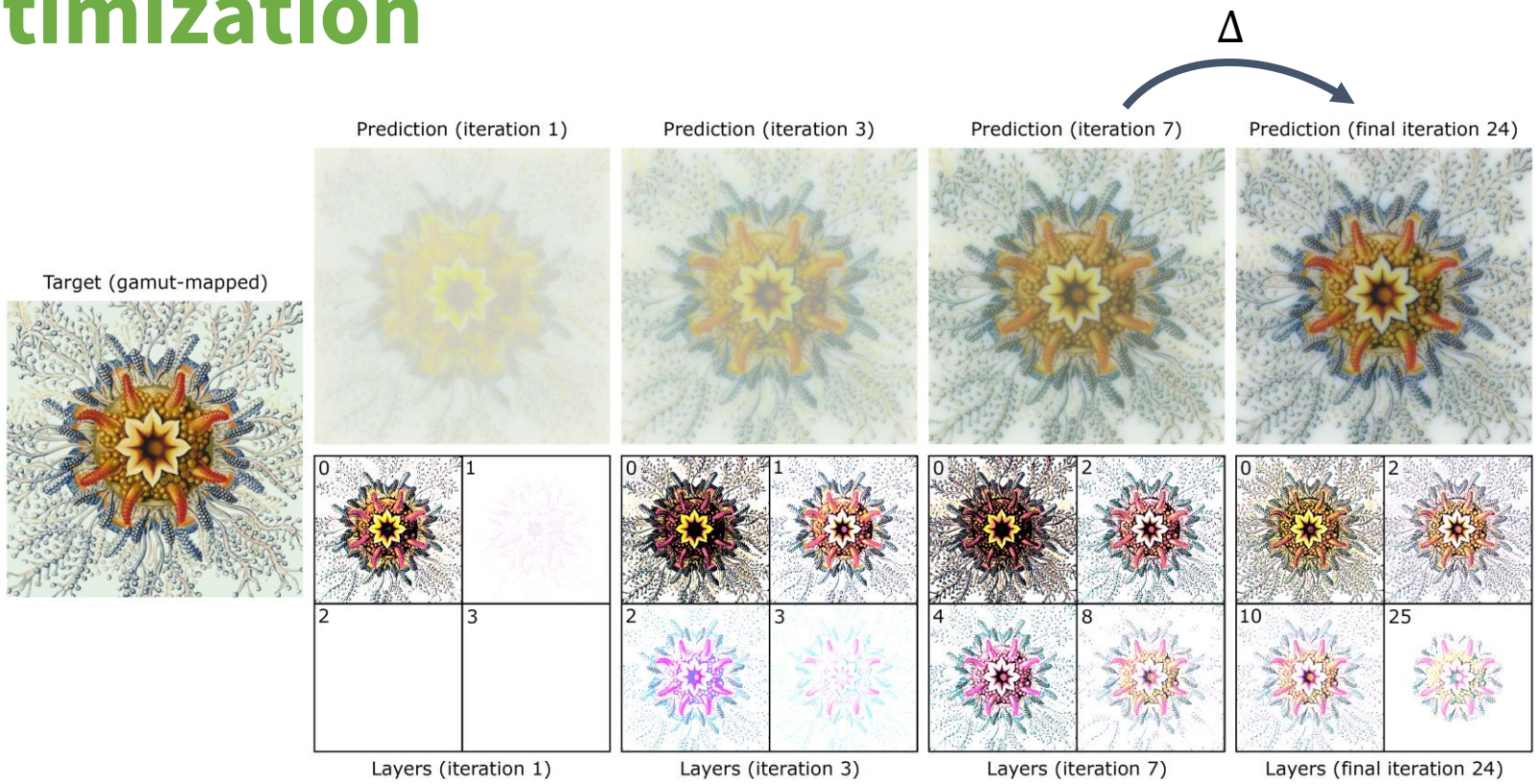
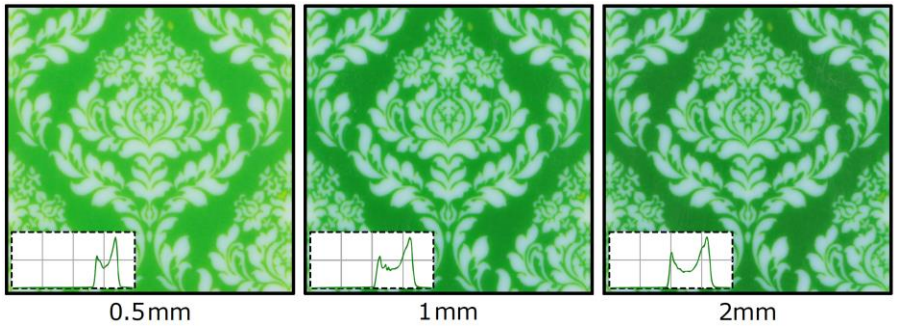
Optimization



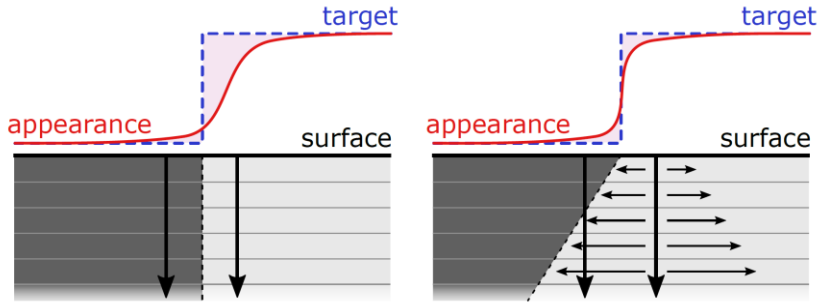
despite the non-linearity of the appearance, it changes monotonically
→ simple residual energy minimization

Solution Refinement

- **difficult: we have 2D appearance gradient → 3D material distribution**
- **two key heuristics to achieve balanced color and sharp structure**

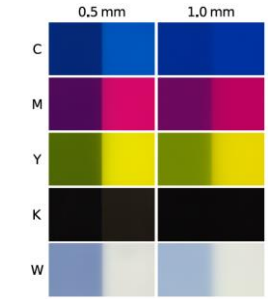


adaptive ‘vertical’ color placement



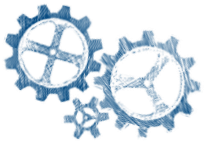
‘horizontal’ edge erosion

Results

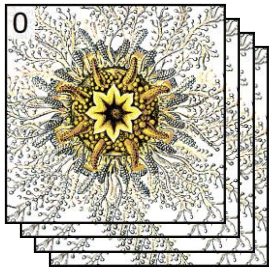


intrinsic material parameters

target appearance



optimization



3D material distribution

printing

physical printout

Alternatives?

optimization

[Cignoni et al. @ VAST 2008]

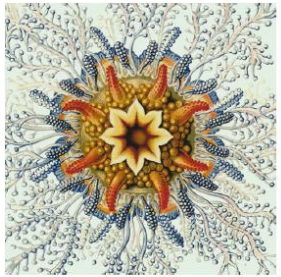
image enhancement
(e.g. unsharp masking)

[Babaei et al. @ SIGGRAPH 2017]

approximate deconvolution

Results

“Timmy”



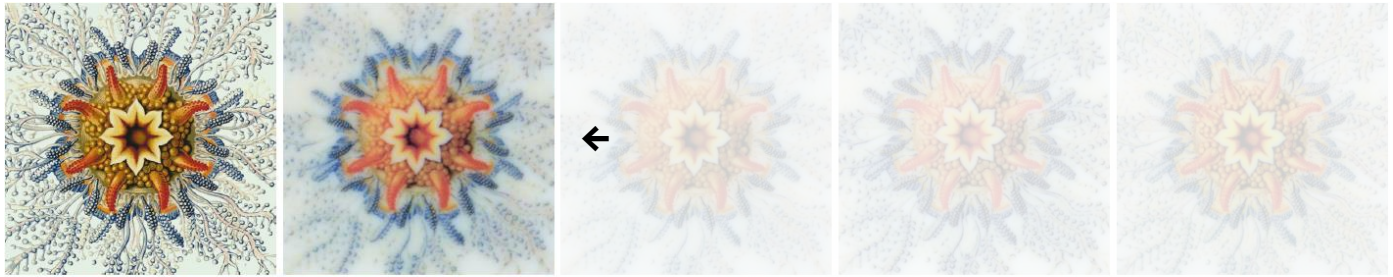
“marine”

“sunset”

← input (gamut-mapped)

Results

“Timmy”

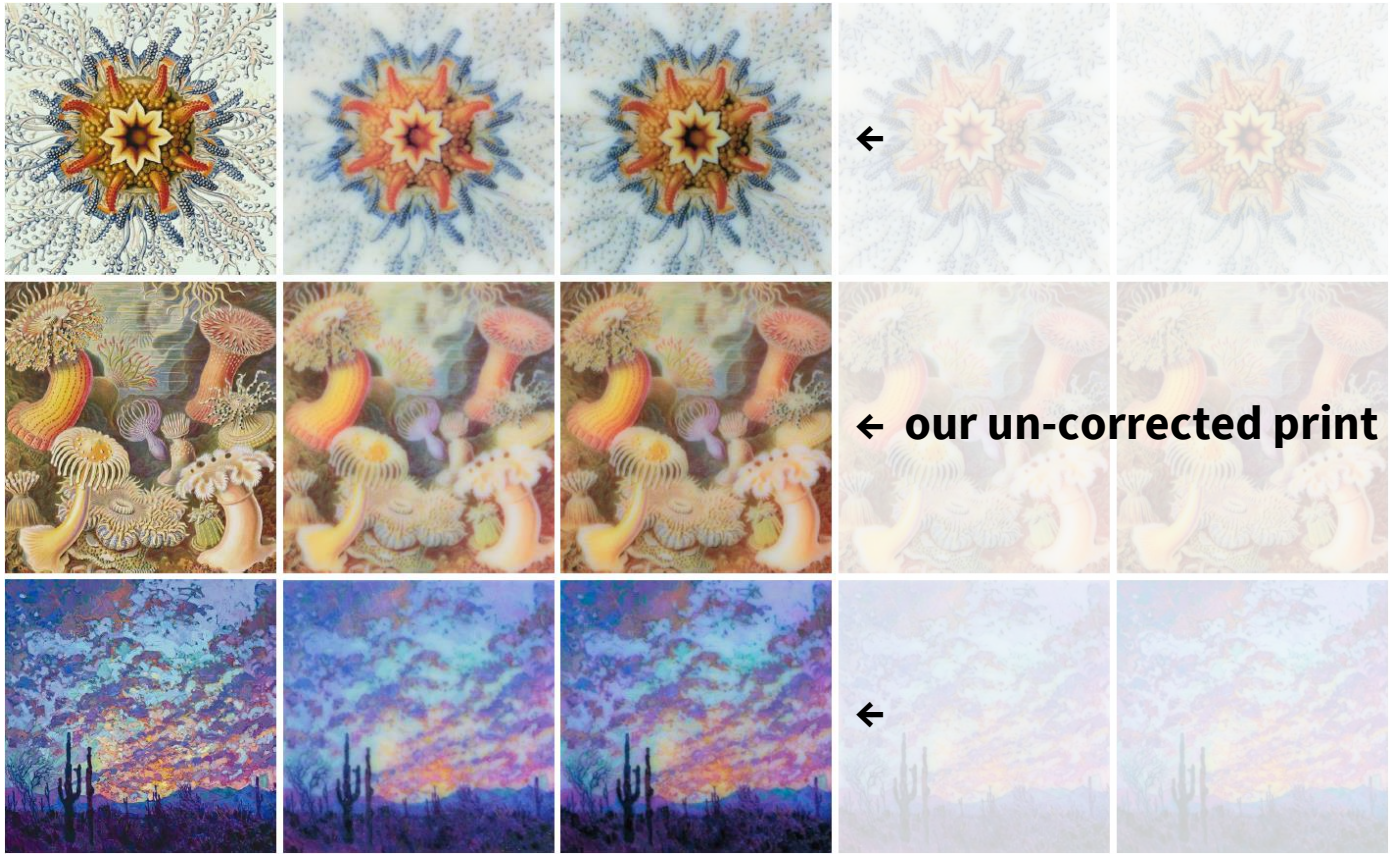


“marine”

“sunset”

← standard print

Results



Results

“Timmy”

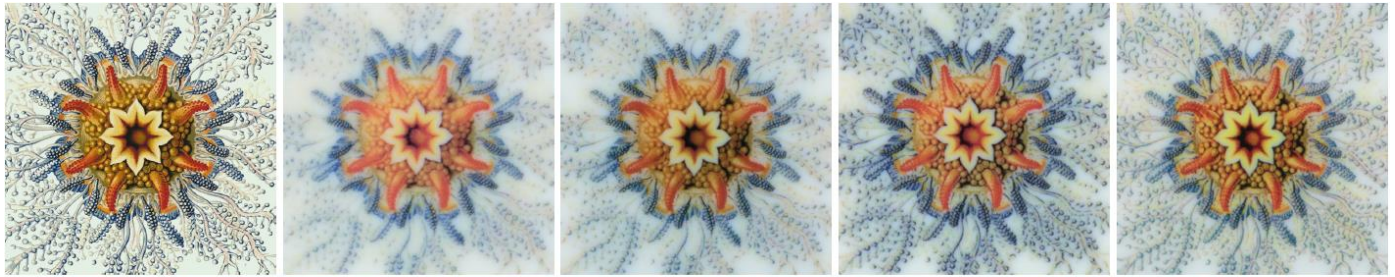
“marine”

“sunset”

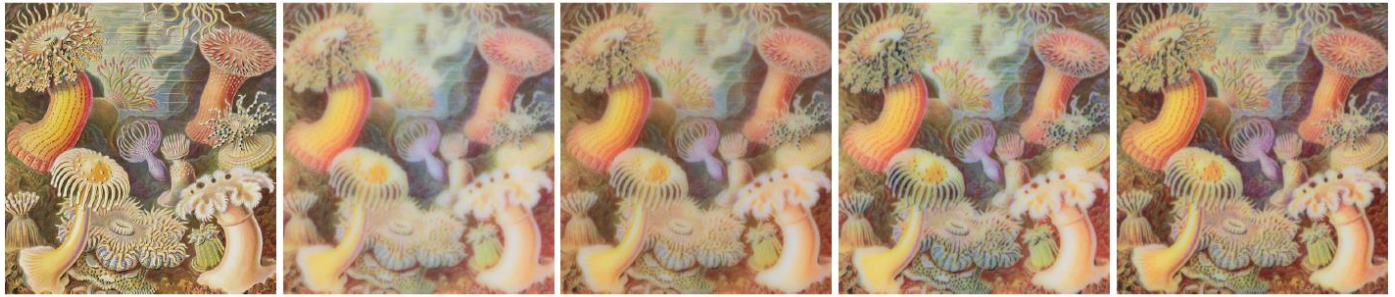
Results

our optimized print

“Timmy”

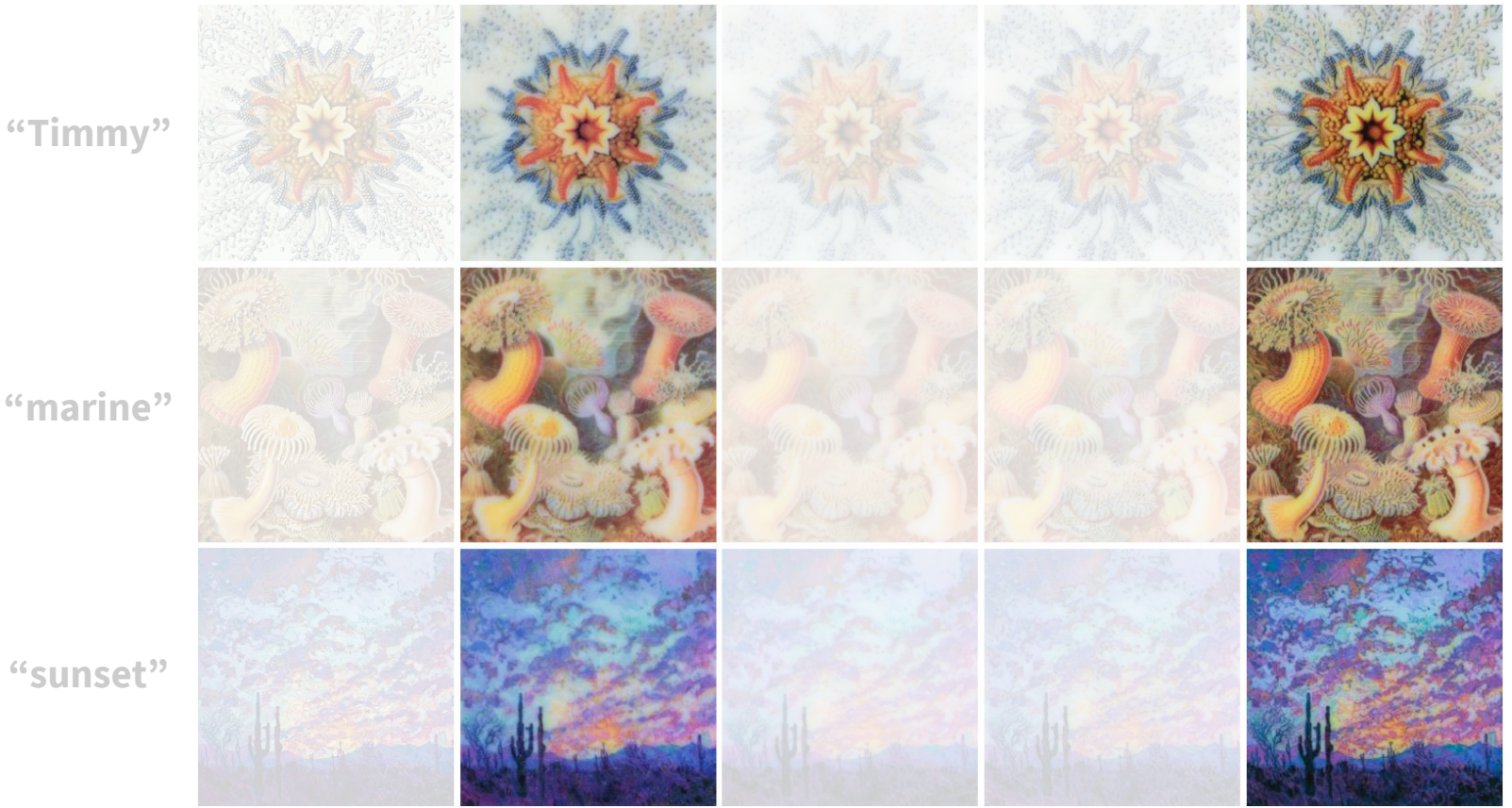


“marine”



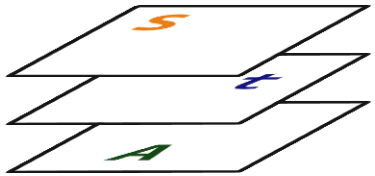
“sunset”

Results

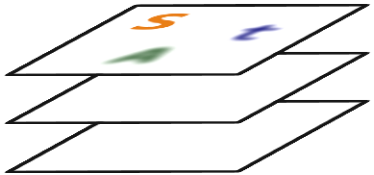


Results: Non-standard Composition

‘random’ structured target

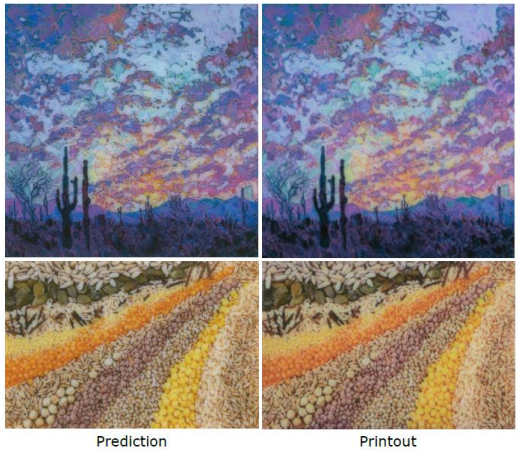


our reproduction

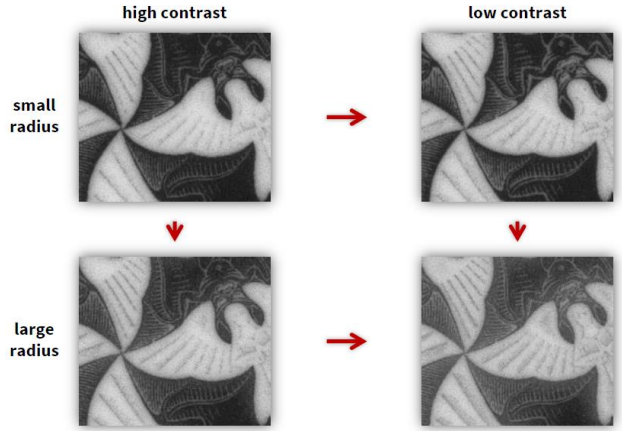


‘random’ target

Open Questions



[Babaei et al. @ SIGGRAPH 2017]



- **efficient prediction**
  - **VPT currently takes ~3 minutes on a small CPU cluster**
- **general 3D geometry**
  - **(near-)convex**
  - **arbitrary**
- **perceptual considerations**
  - **local contrast manipulation**
  - **“similar appearance”?**

Take-home Message

a de-scattering solution must consider full 3D material composition

→ inverse, constraint-based design is the key

SIGGRAPH ASIA 2017 BANGKOK

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max planck institut informatik

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UCL

DiSTRO

tinyurl.com/**TexFab**

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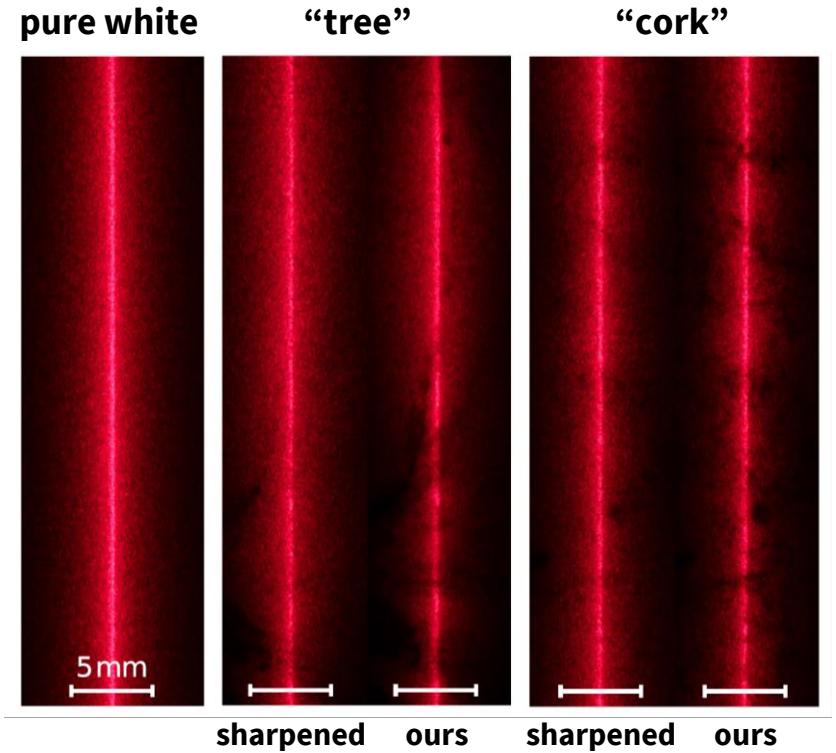
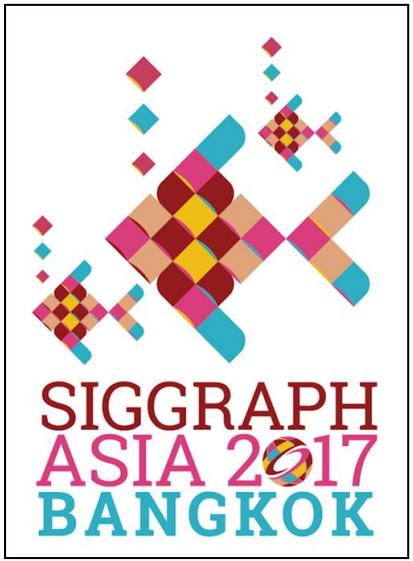
Extra: Non-standard Illumination

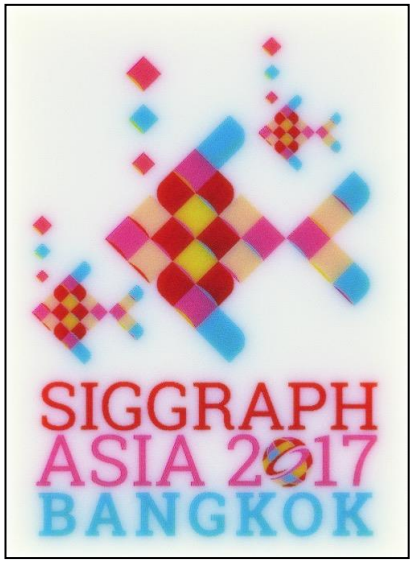


Extra: SGA Logo

target



standard print



our optimized print