Printed Perforated Lampshades for Continuous Projective Images

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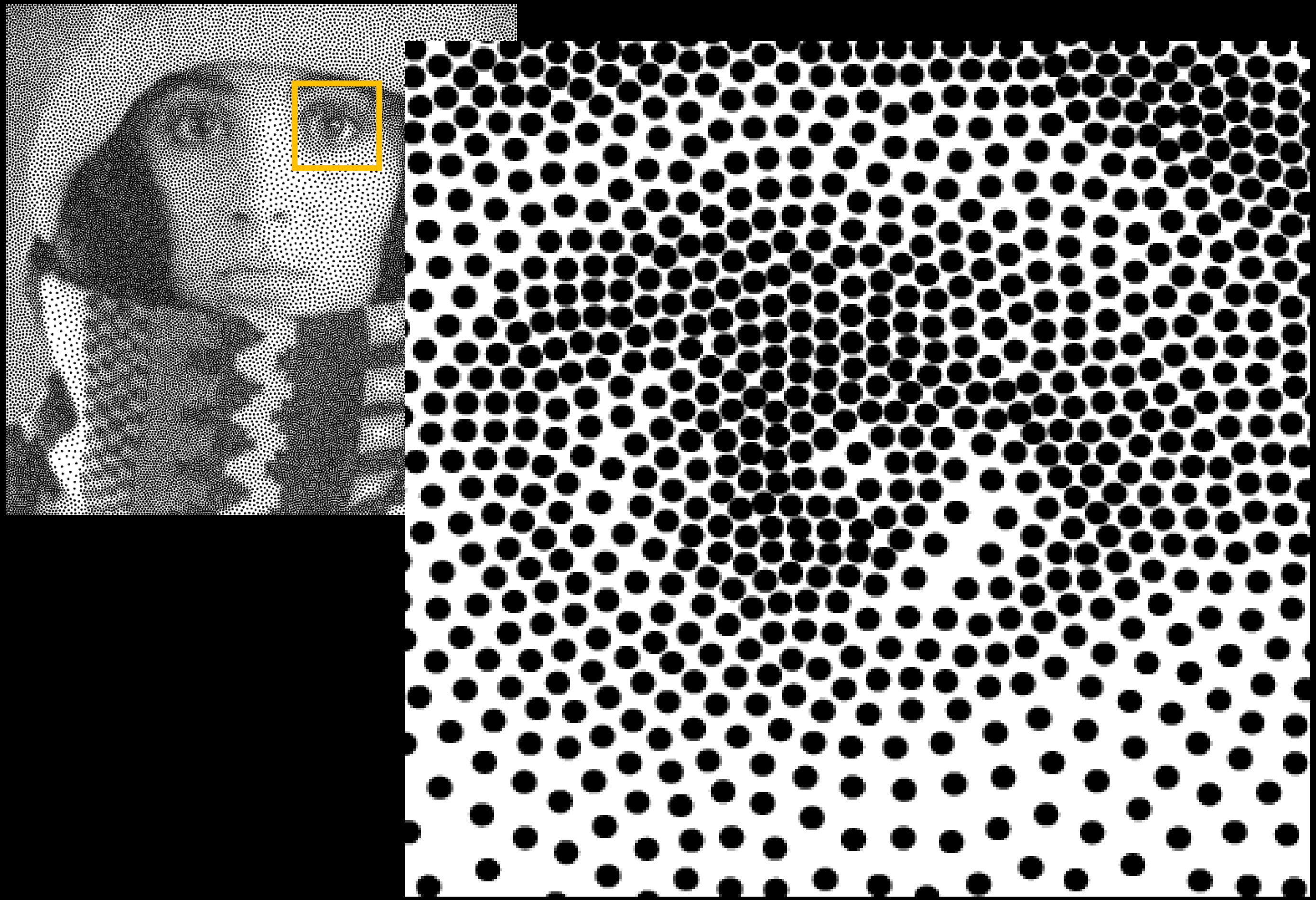
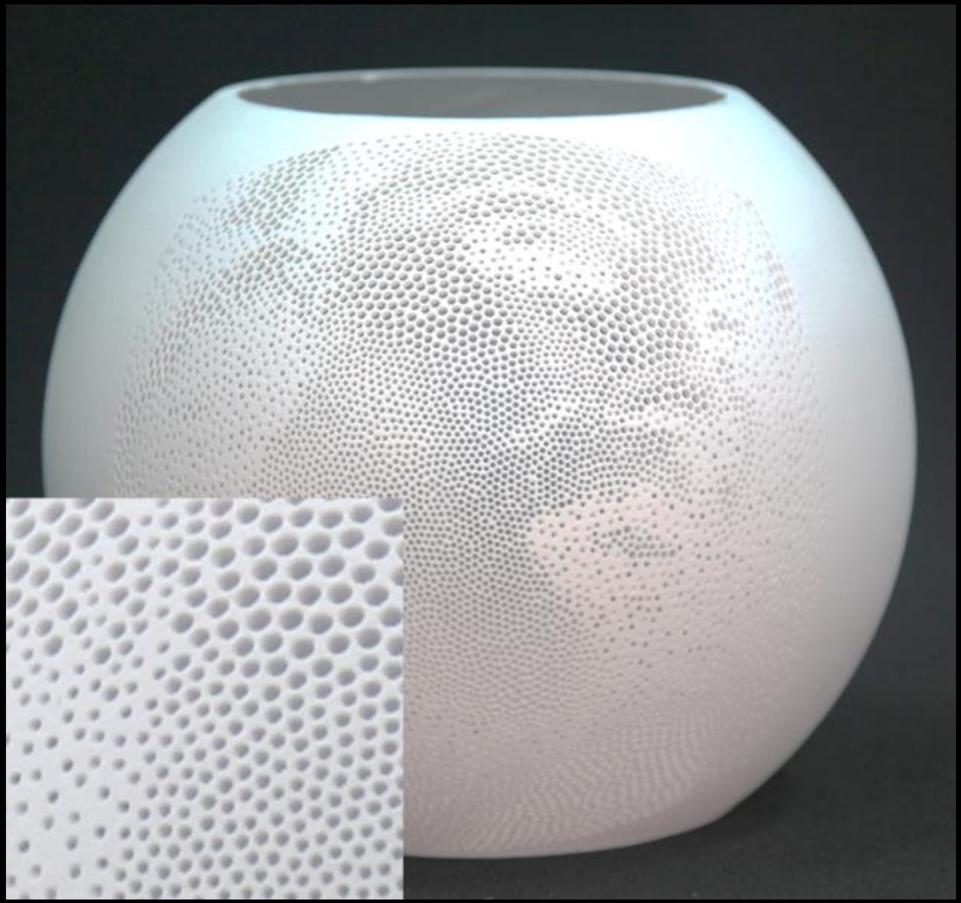
From traditional halftoning to 3D printing



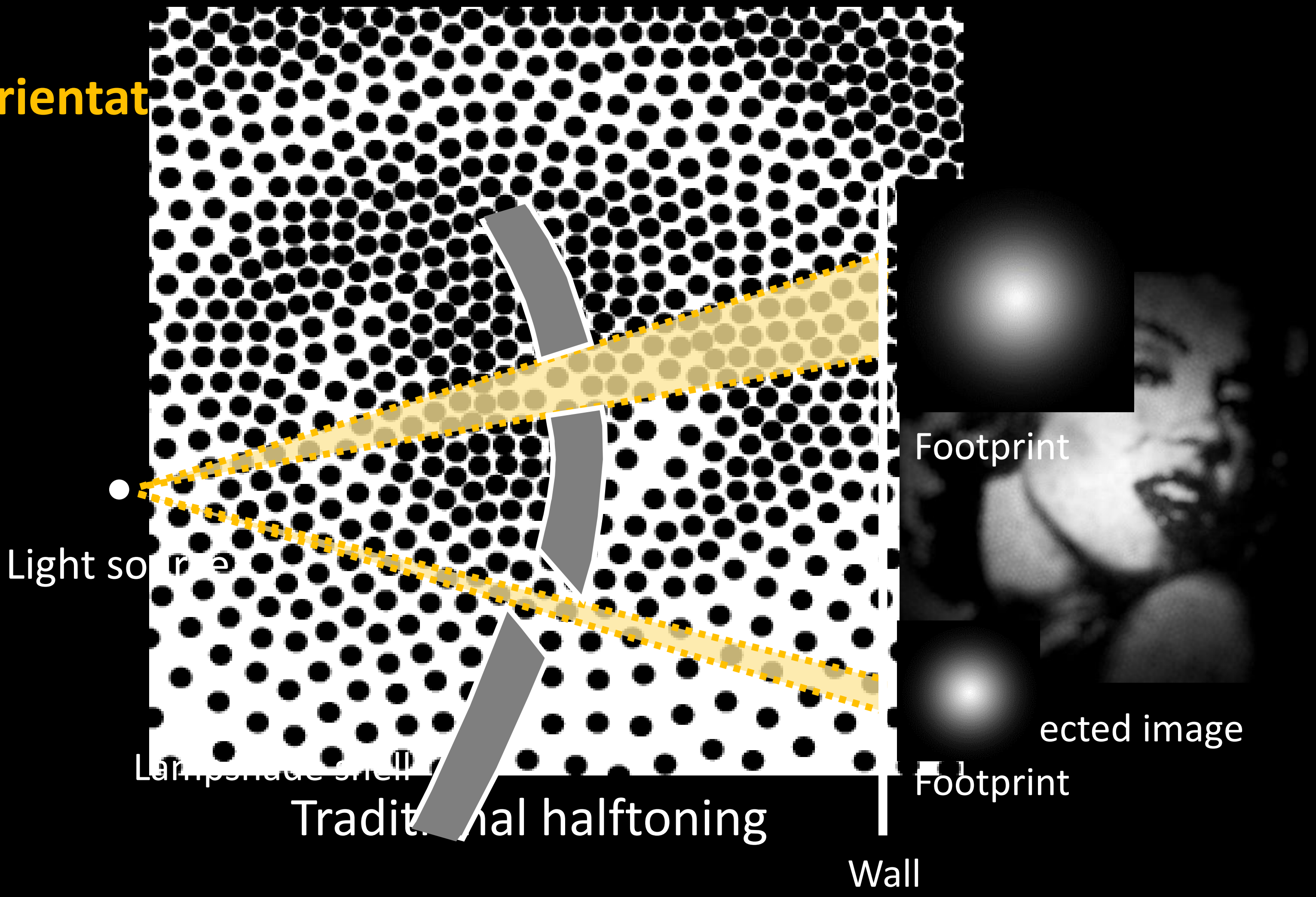
Traditional halftoning



3d halftoning/halftoning with light

3D halftoning/halftoning with light

- Basic elements
  - 2D dots / 3D tubes (radius, orientat
- Continuous sizes
- Resulting image



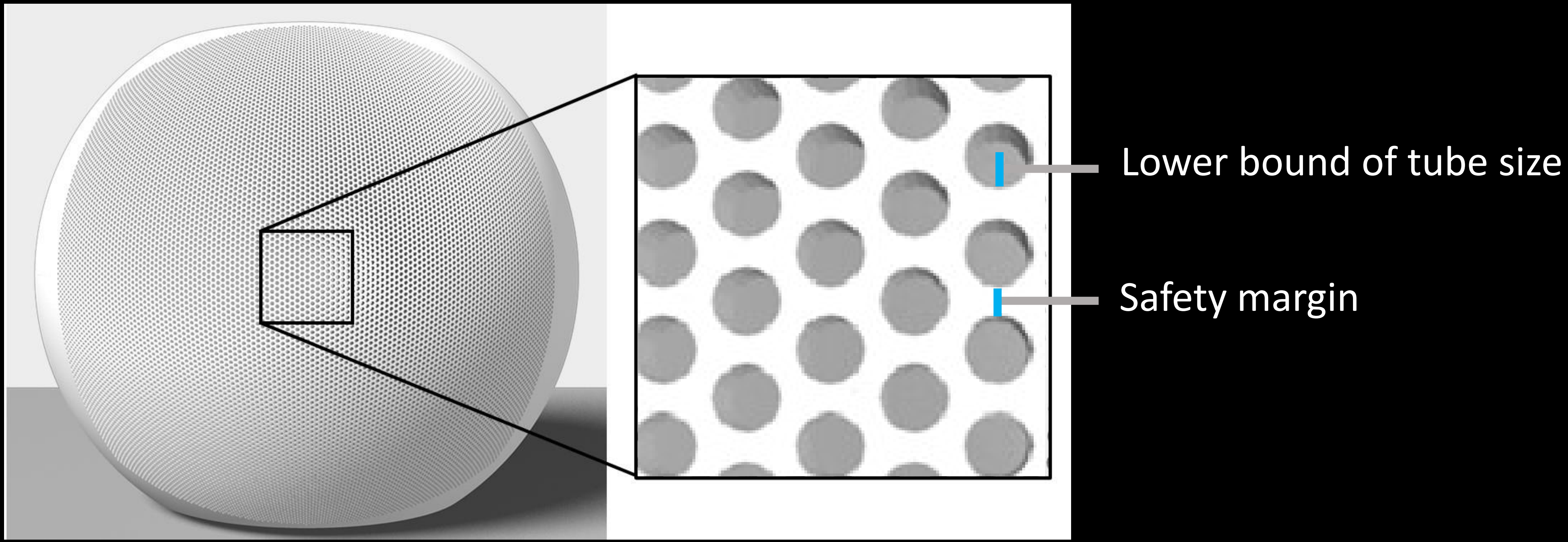
Our goal

Given a target image I^{t}, configure a set of tubes perforating the lampshades shell, with its projected image I^{p}, which can:

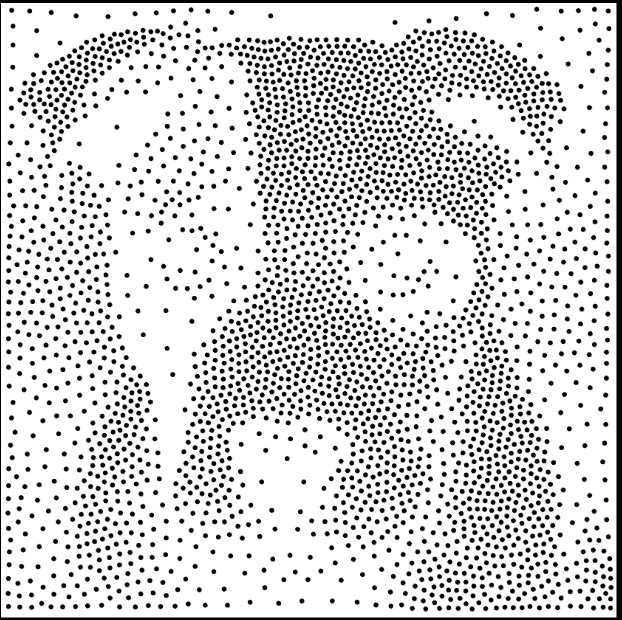
- approximates I^{t} as close as possible
- display **continuous tones**, with fine spatial detail
- satisfying the fabrication constraints

Challenges – low spatial resolution

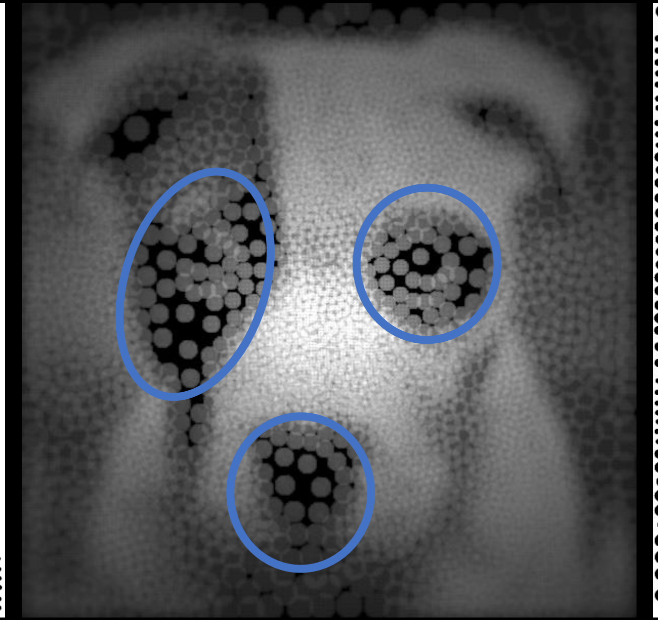
- Each tube cannot be too small.
- The tubes cannot overlap.



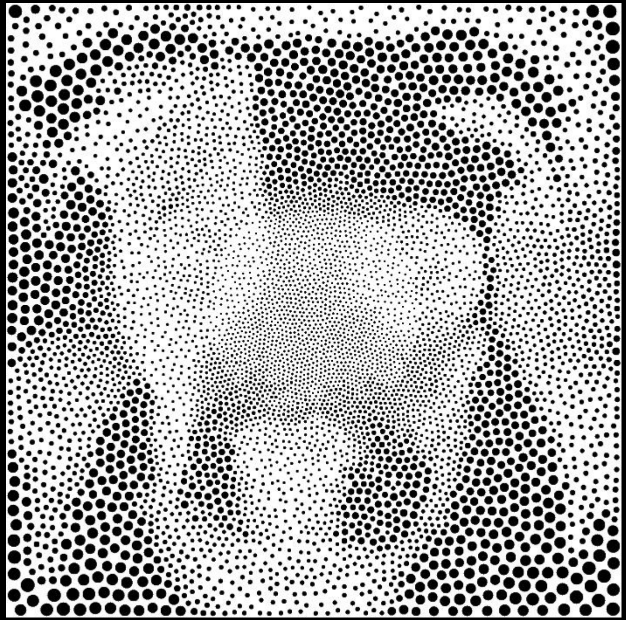
Straightforward method



Halftoning distribution
[De Goes, et al., SIG 2012]
≈ 3000 tubes

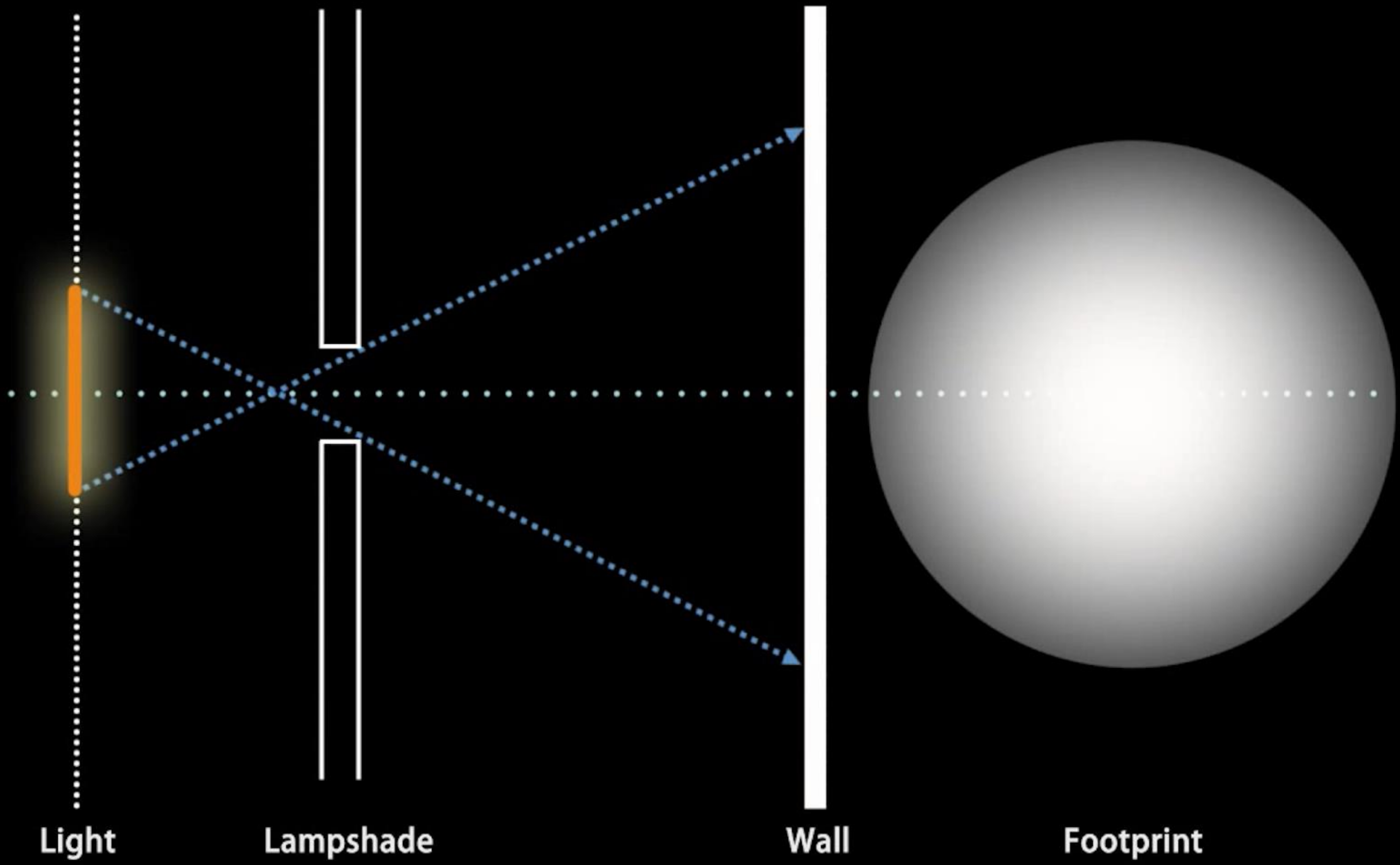


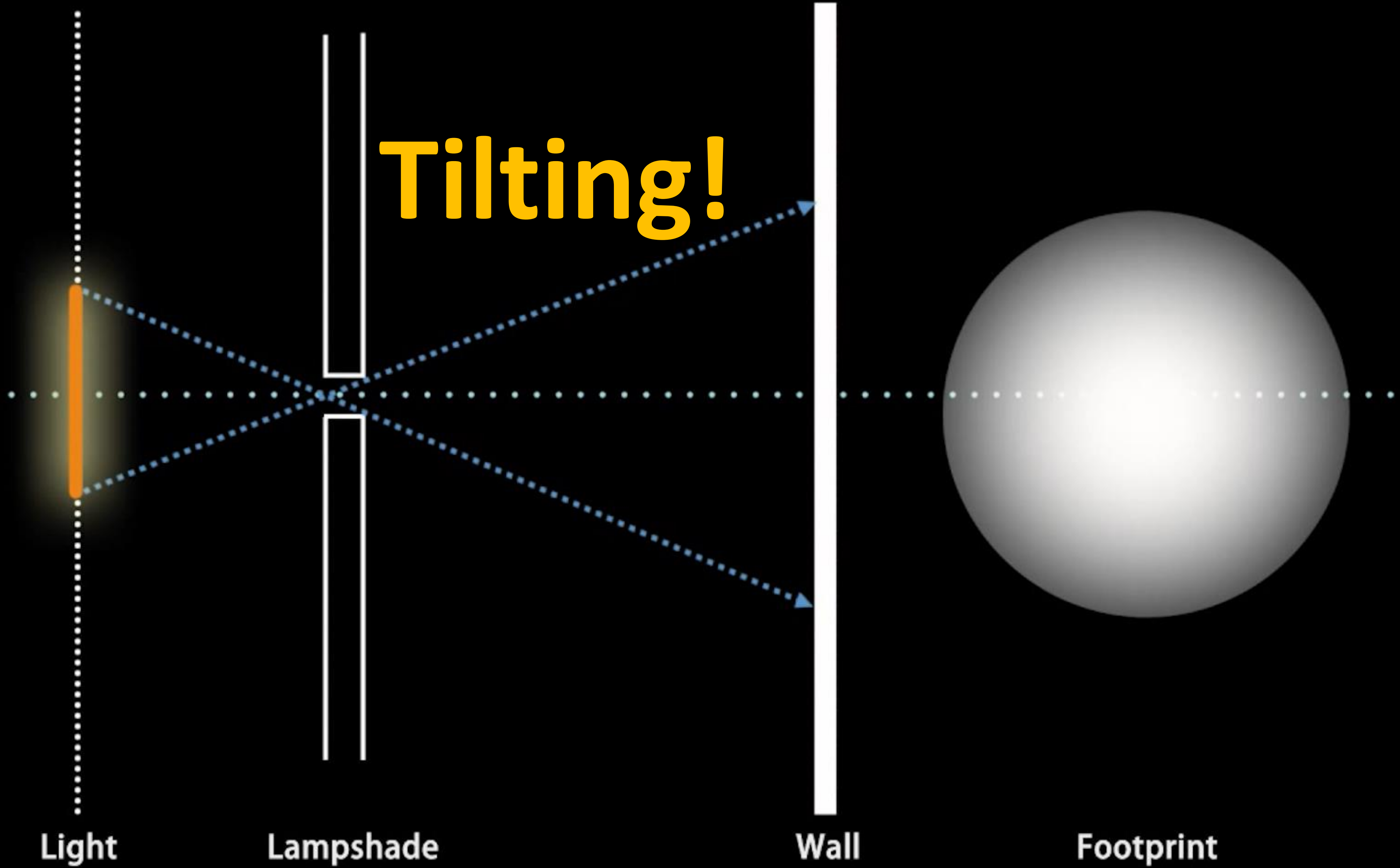
Projected image



Our result
≈ 6000 tubes

Projected image

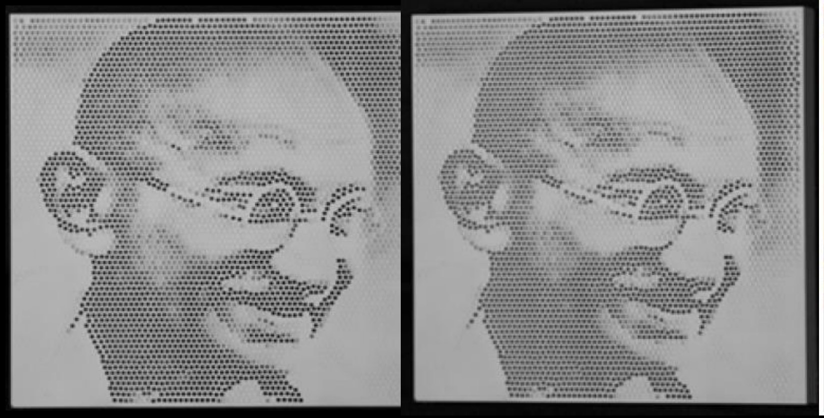

Light
Lampshade
Wall
Footprint



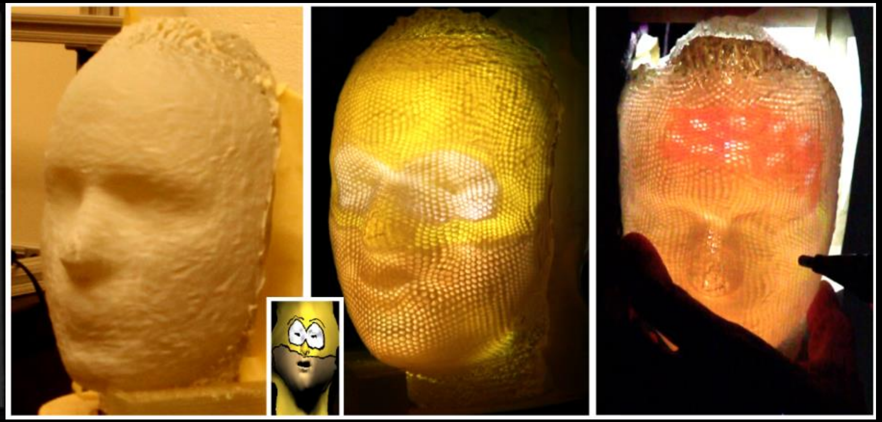
Tilting!
Light
Lampshade
Wall
Footprint

Related: Illumination effect

[Mitra et al, SIG Asia 2009]

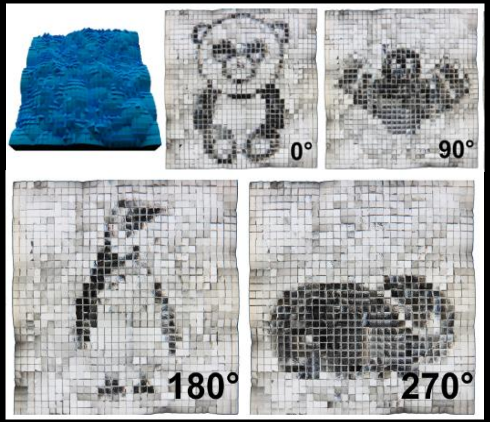


[Alexa et al, Computers & Graphics 2012]



[Pereira et al, TOG 2014]

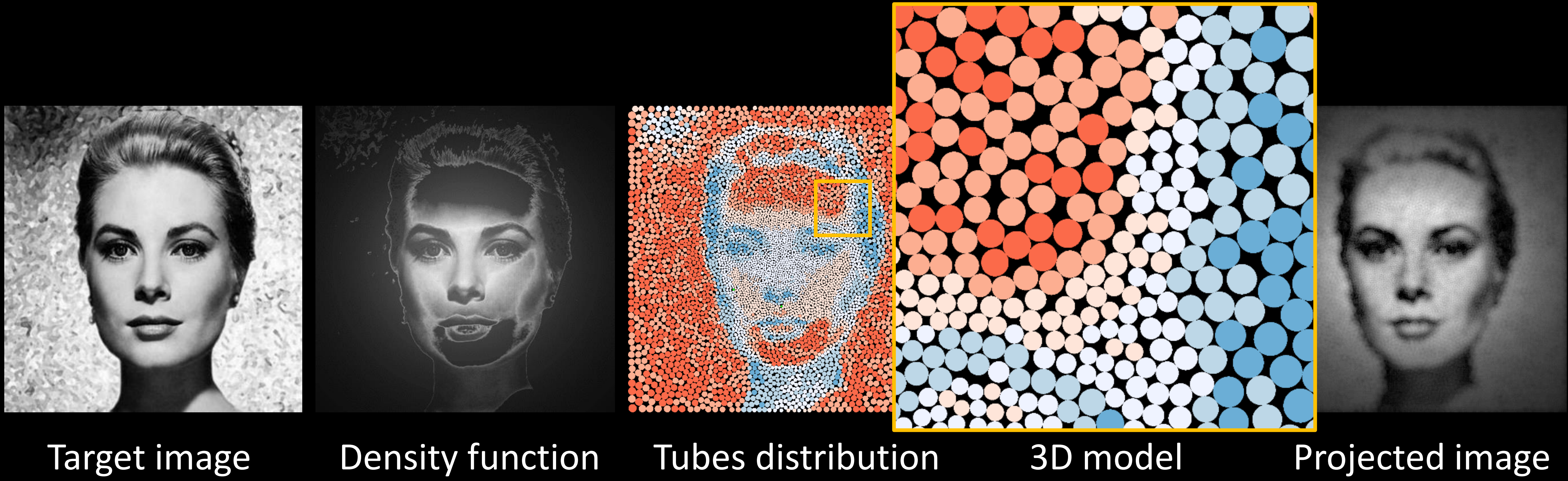
[Weyrich et al, CGF 2011]



[Papas et al, TOG 2012]

[Schwartzburg et al, SIG 2014]

Pipeline


Target image
Density function
Tubes distribution
3D model
Projected image

Density function computing

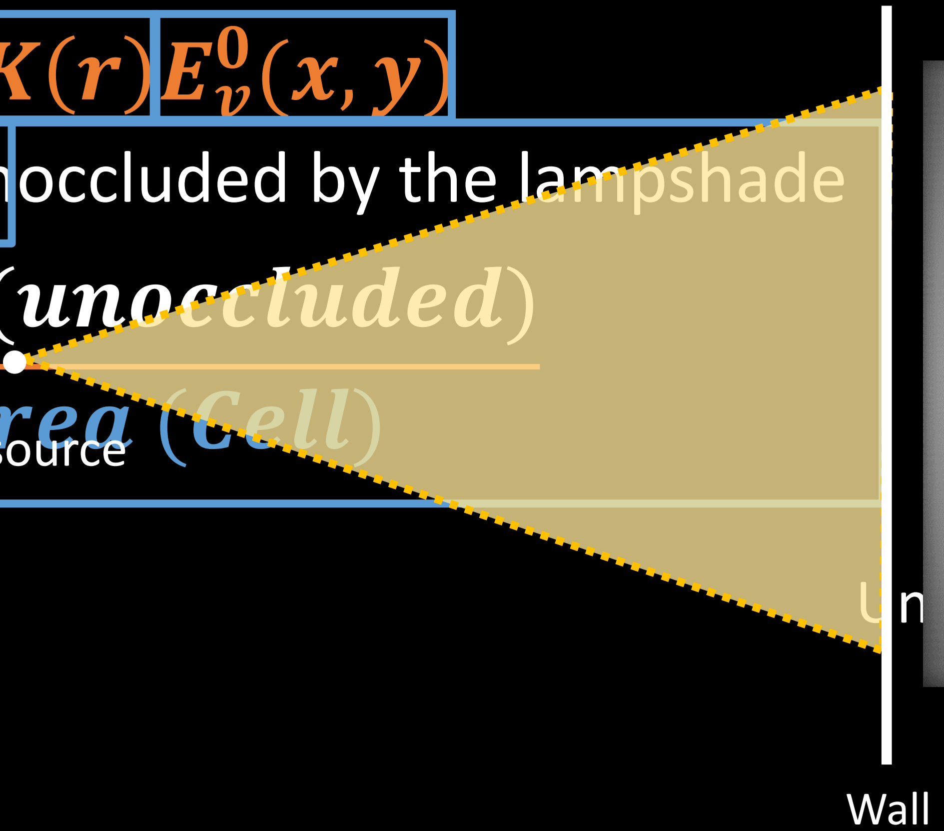
For location (x, y) of the projecting region, its target illuminance $I^t(x, y)$ is corresponding to **a specific percentage of light** unoccluded by the lamp:

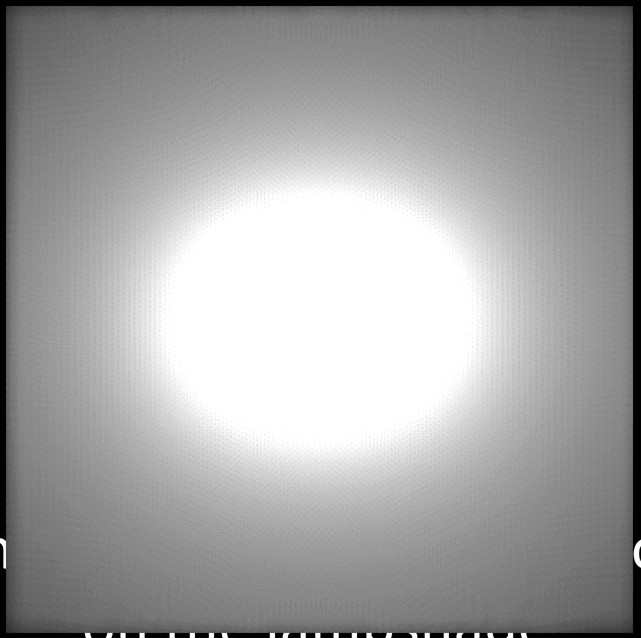
$$I^t(x, y) = K(r) E_v^0(x, y)$$

Target illuminance

Percentage of light unoccluded by the lampshade

$$K = \frac{Area(unoccluded)}{Area\ (Cell)}$$

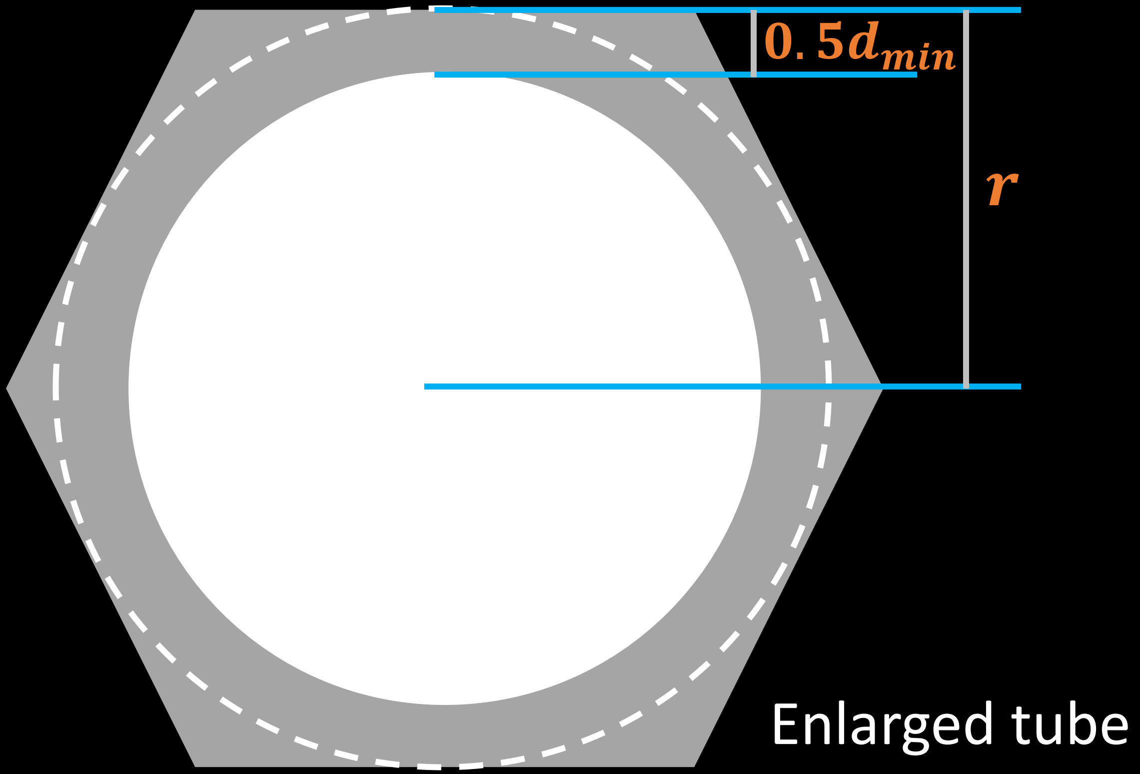


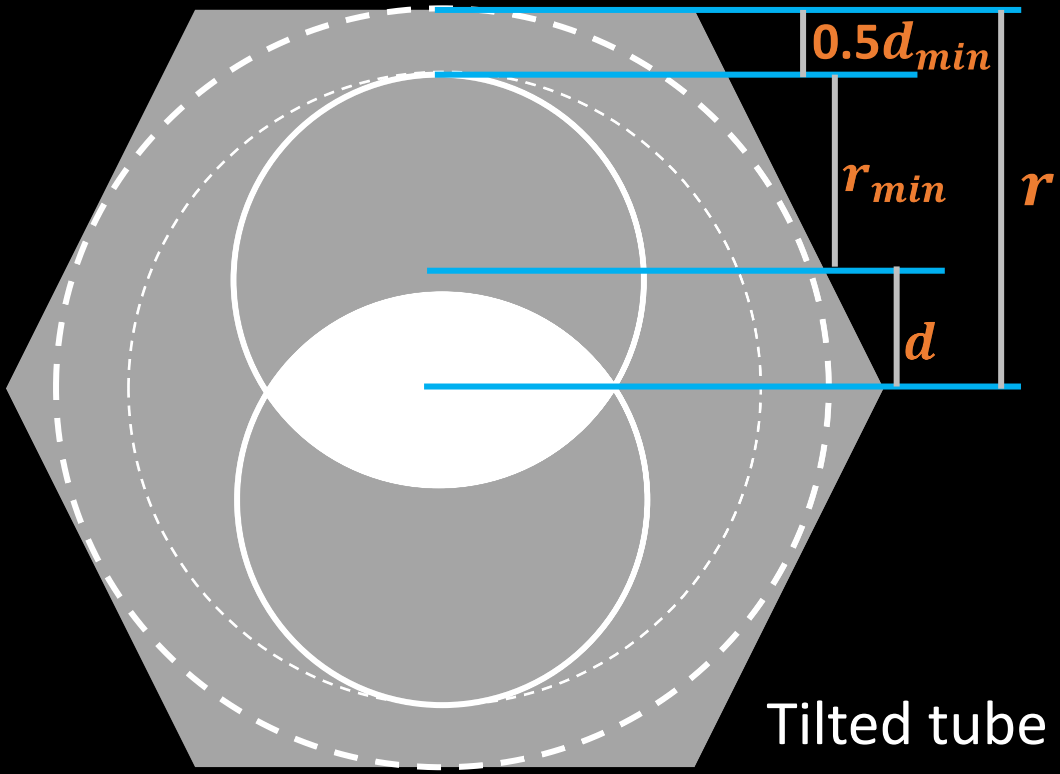


E_v^0

Density function computing

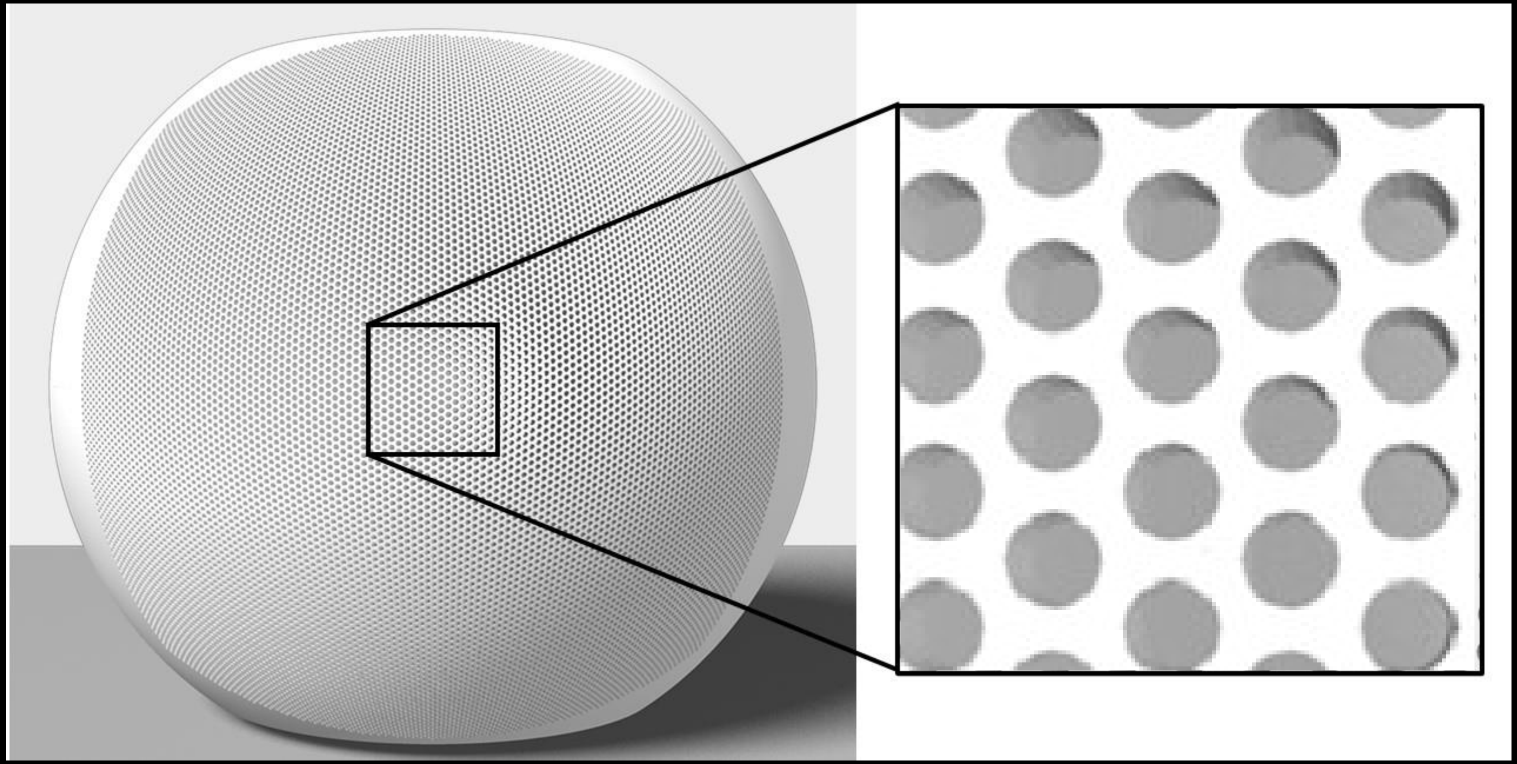
- Two cases of desired tubes



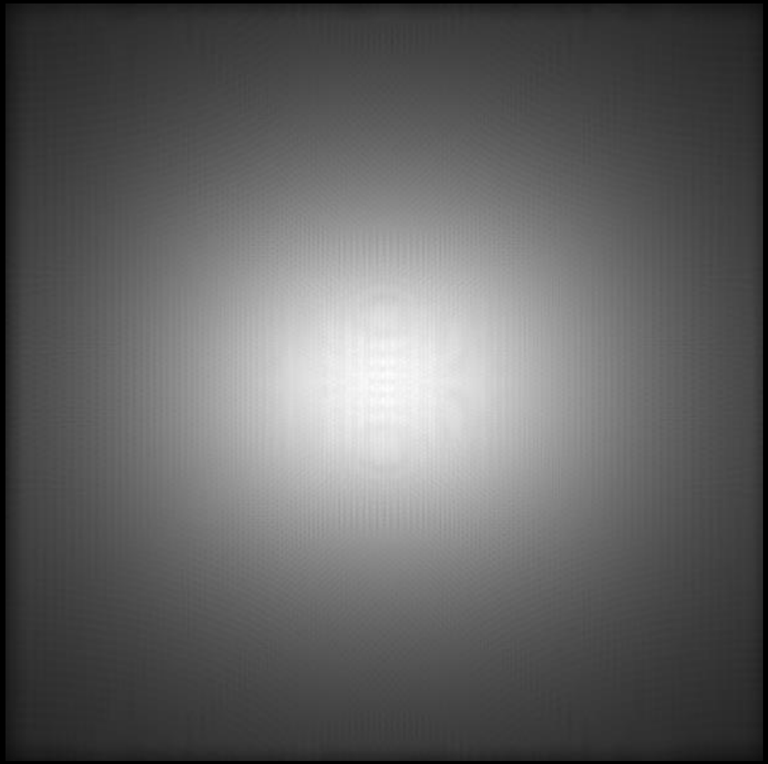


d_{min}: safety margin r_{min}: lower bound of tube radius

Density function computing

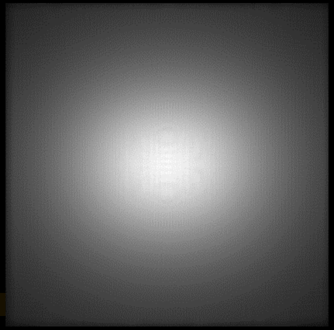


Densest packing of minimal tubes



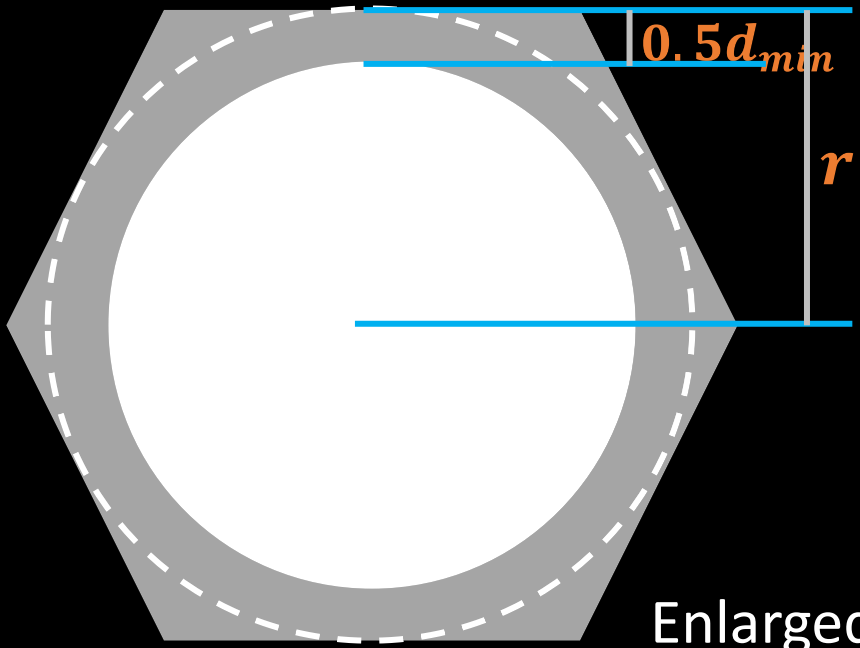
Reference Image B_0

Density function computing



B_0

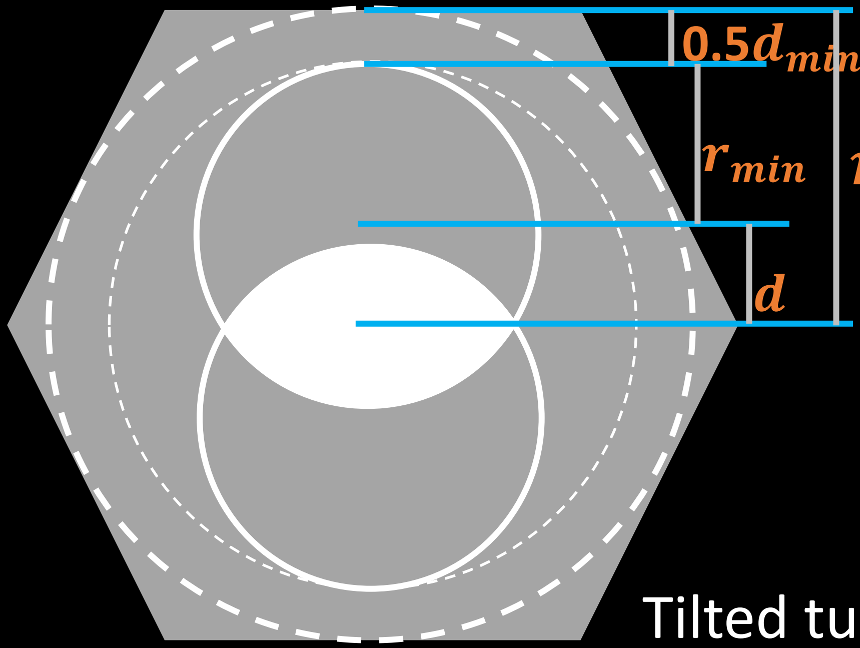
Brighter tones



Enlarged tube

$$K(r) = \frac{\pi(r - 0.5d_{min})^2}{2\sqrt{3}r^2}$$

Darker tones



Tilted tube

$$K(r) = \frac{r_{min}^2 cos^{-1}(d/r_{min}) - d\sqrt{r_{min}^2 - d^2}}{\sqrt{3}r^2}$$

Density function computing

For each location (x, y) with its target illuminance $I^t(x, y)$, determine the desired radius $r(x, y)$:

- if $I^t(x, y) \geq \boldsymbol{B_0(x, y)}$, the relevant tubes must be enlarged:

$$\boldsymbol{K(r) = \frac{\pi(r - 0.5d_{min})^2}{2\sqrt{3}r^2}}$$

- if $I^t(x, y) < \boldsymbol{B_0(x, y)}$, the relevant tubes must be tilted:

$$\boldsymbol{K(r) = \frac{r_{min}^2 cos^{-1}(d/r_{min}) - d\sqrt{r_{min}^2 - d^2}}{\sqrt{3}r^2}}$$

Density function computing

For each location (x, y) with its target illuminance $I^t(x, y)$, the desired radius $r(x, y)$, the density value $\rho(x, y)$:

$$\rho(x, y) \propto 1/r(x, y)^2$$

Target image

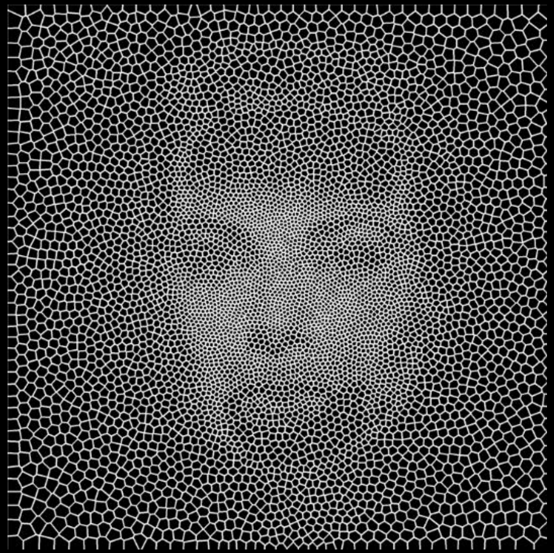
Density function computing

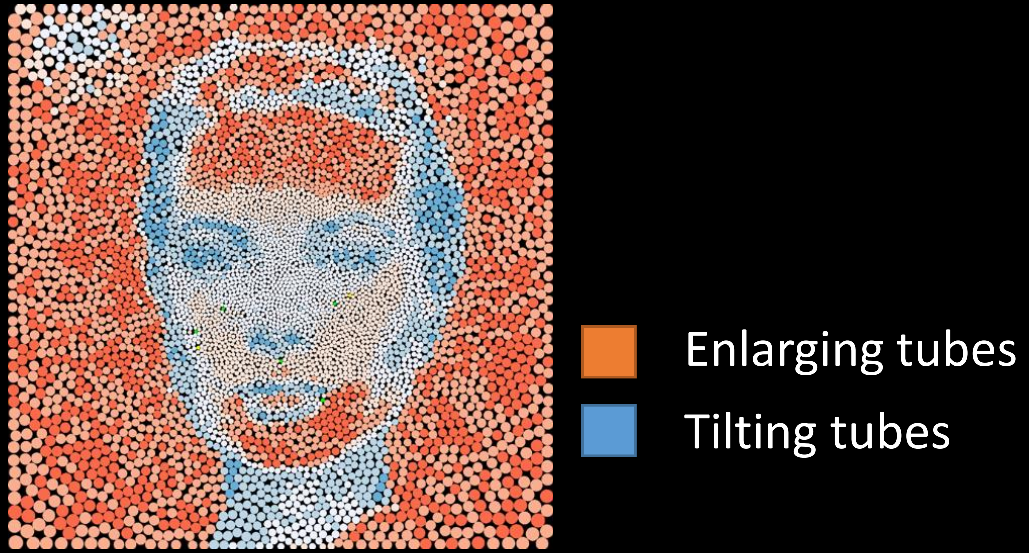
Density function

Disk distribution computing

- Density function ρ, and a tubes number N
- CCVT with de Goes's method
- Maximal inscribed disk inside each of the tessellation cells


Density function

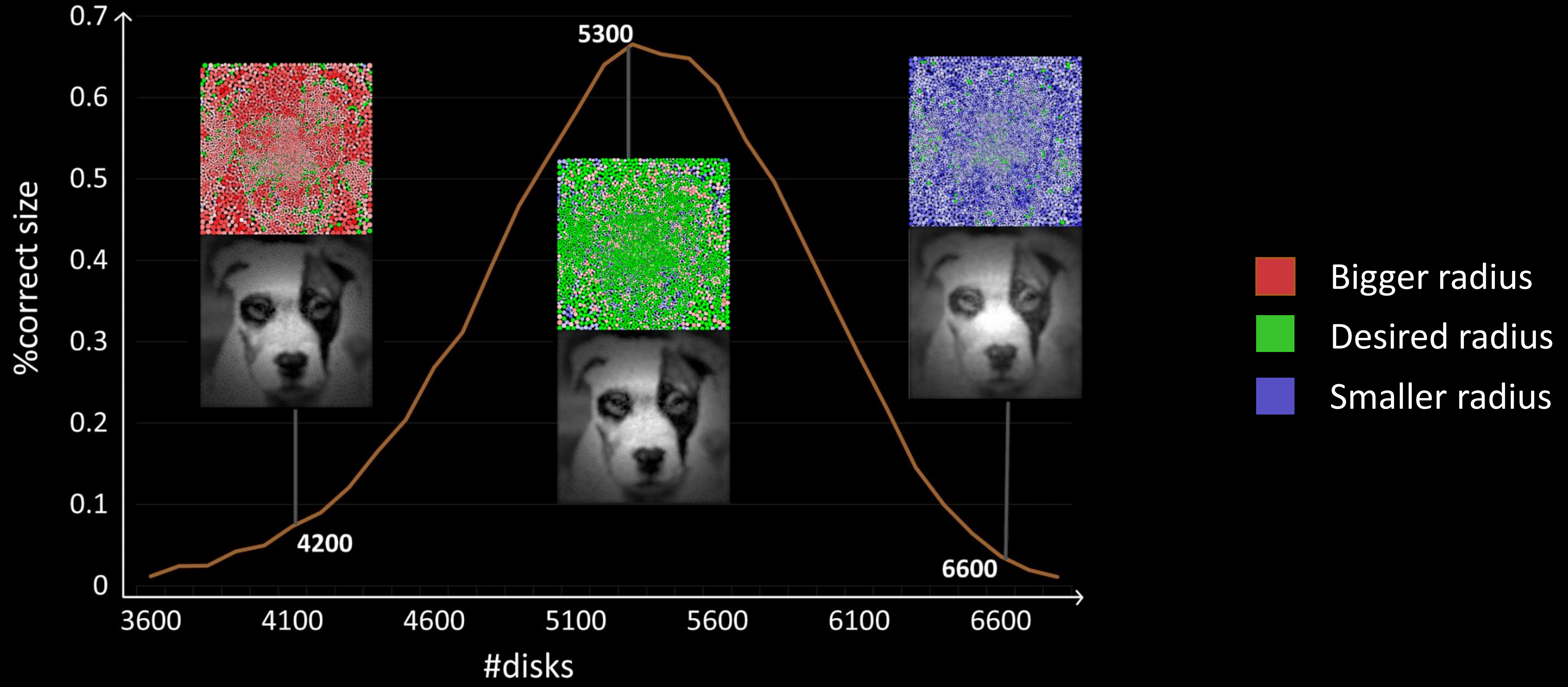

CCVT distribution



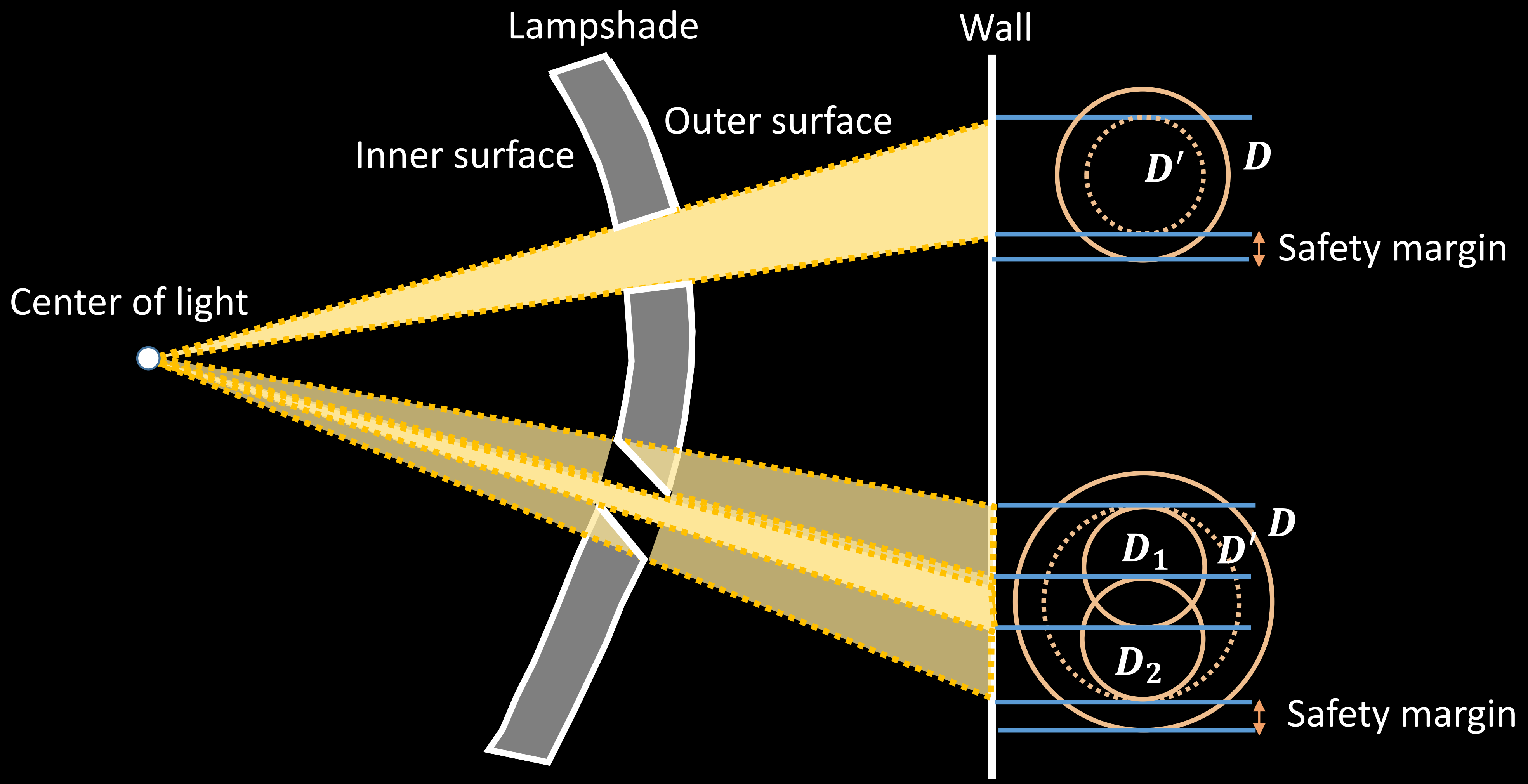
Disks distribution

Disk distribution computing

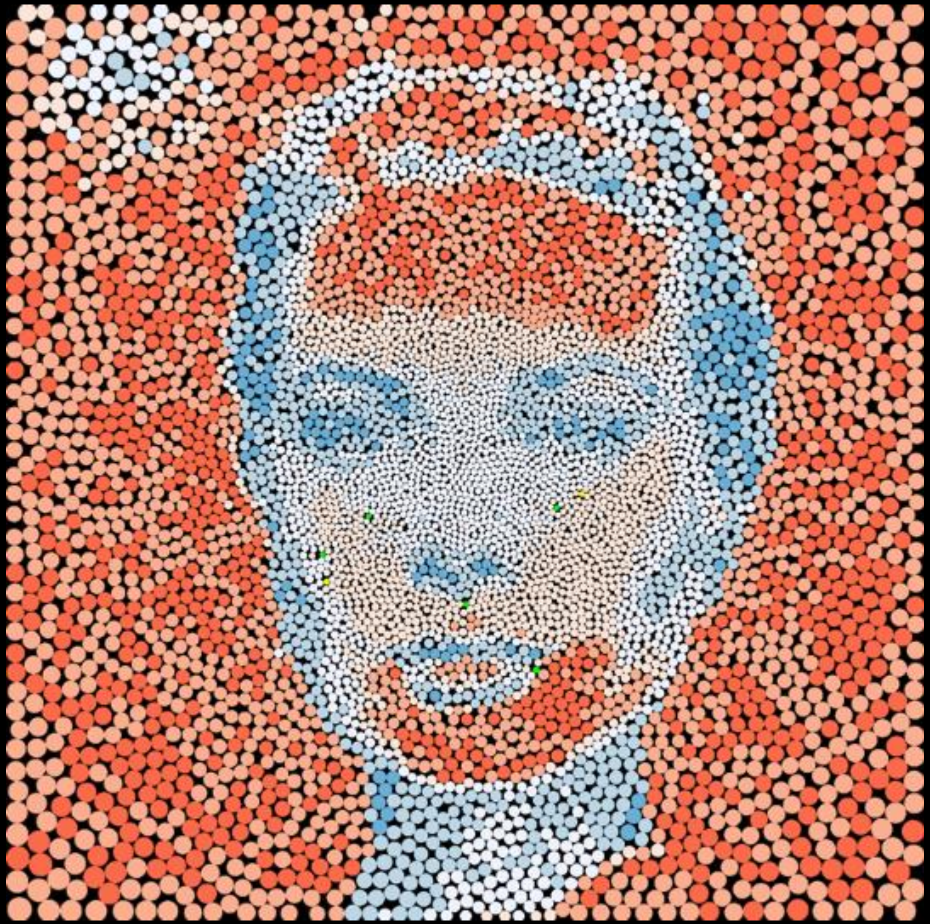
- N: the percentage of tubes which achieve their desired radius is greatest



Tube generation



Tube generation



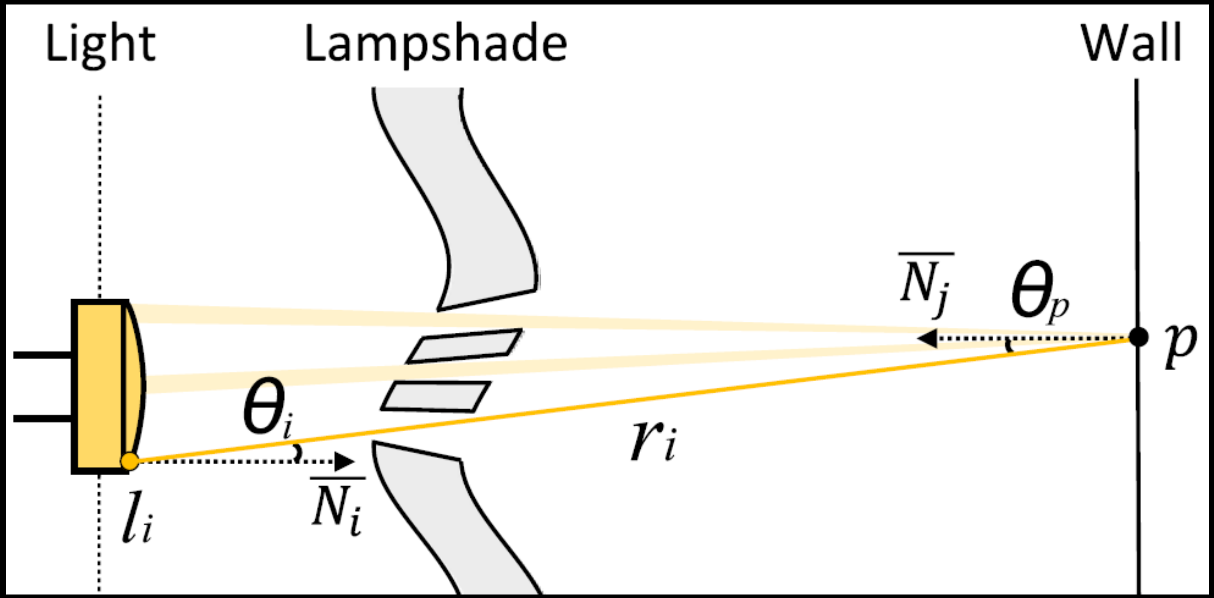
Disks distribution

Tube generation

3D model

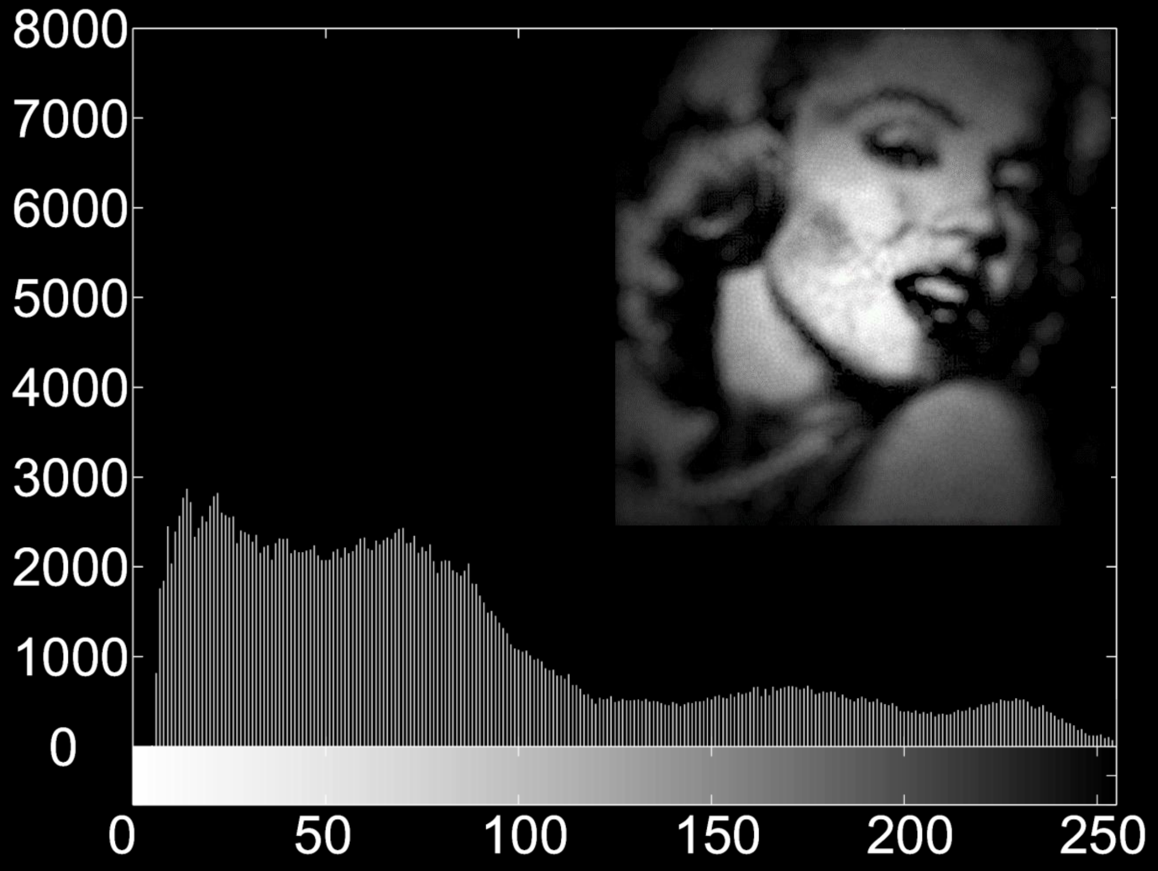
Projected image simulation

- Light source: a collection of n point light sources $\{l_i\}_{i=1}^{n}$
- Compute the **illuminance** of each point on the wall

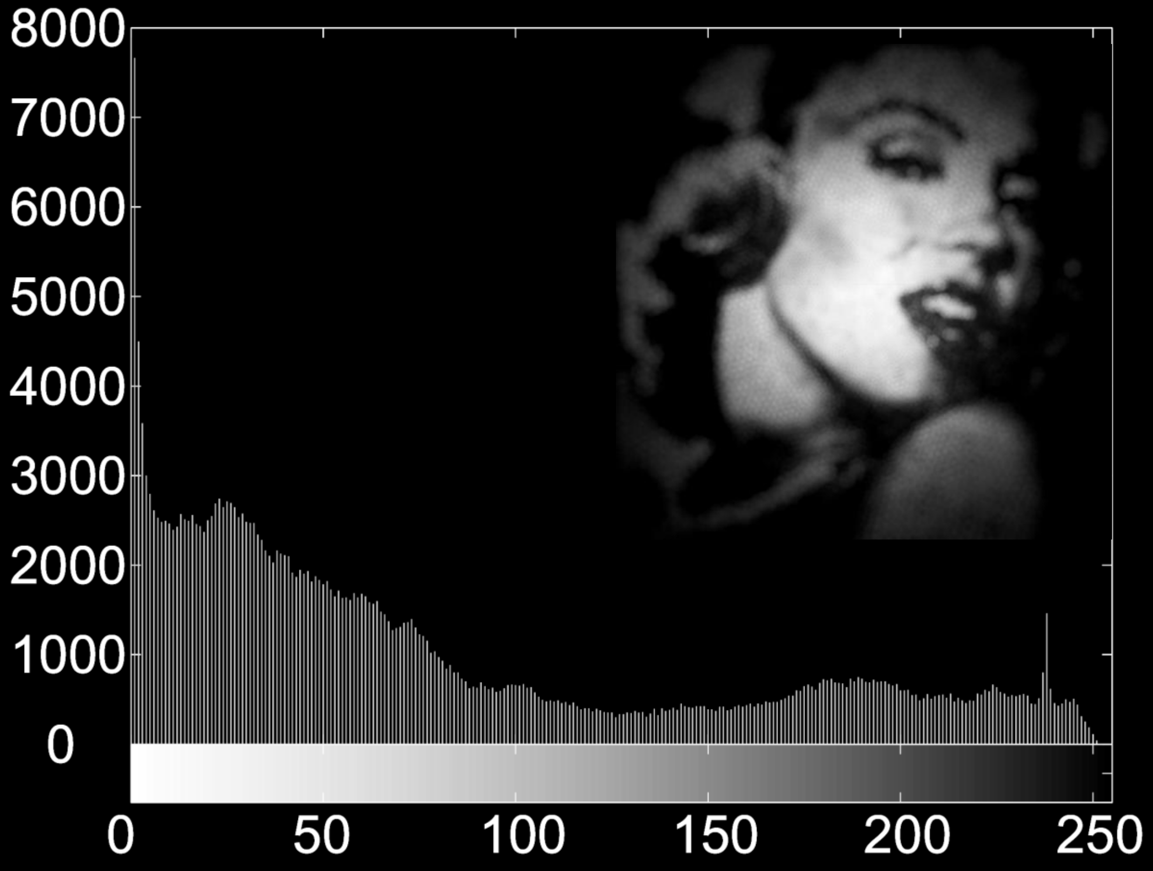


$$E_v(p) = \sum_i \frac{\phi_i}{\pi r_i^2} cos(\theta_i) cos(\theta_p) V(p, l_i)$$

Projected image simulation

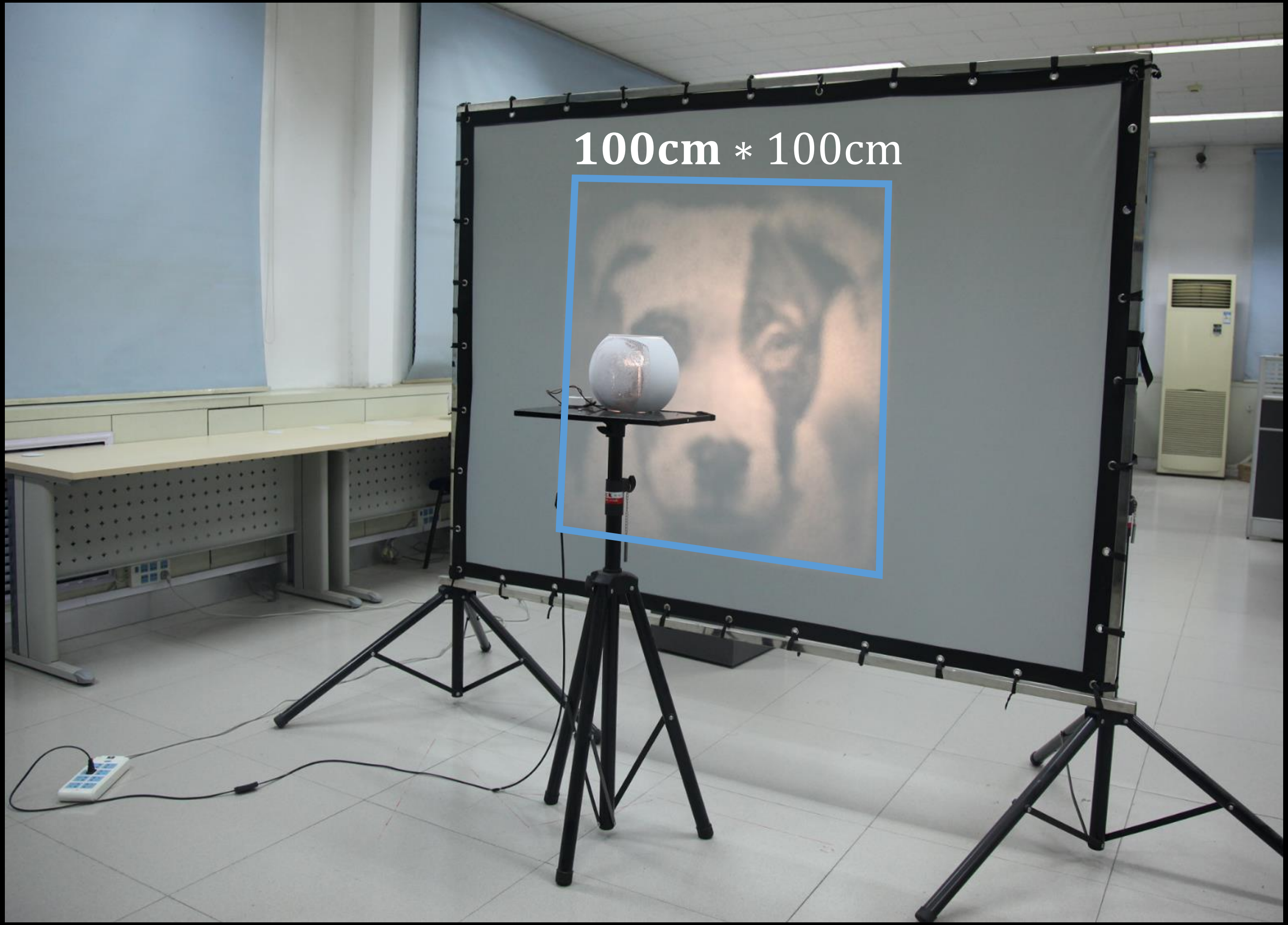


Photograph



Simulation

Testing environment setting



Creer® XLampr® CXA1507 LED
3000K color temperature
diameter of 9mm

Spherical lampshades

5914 tubes

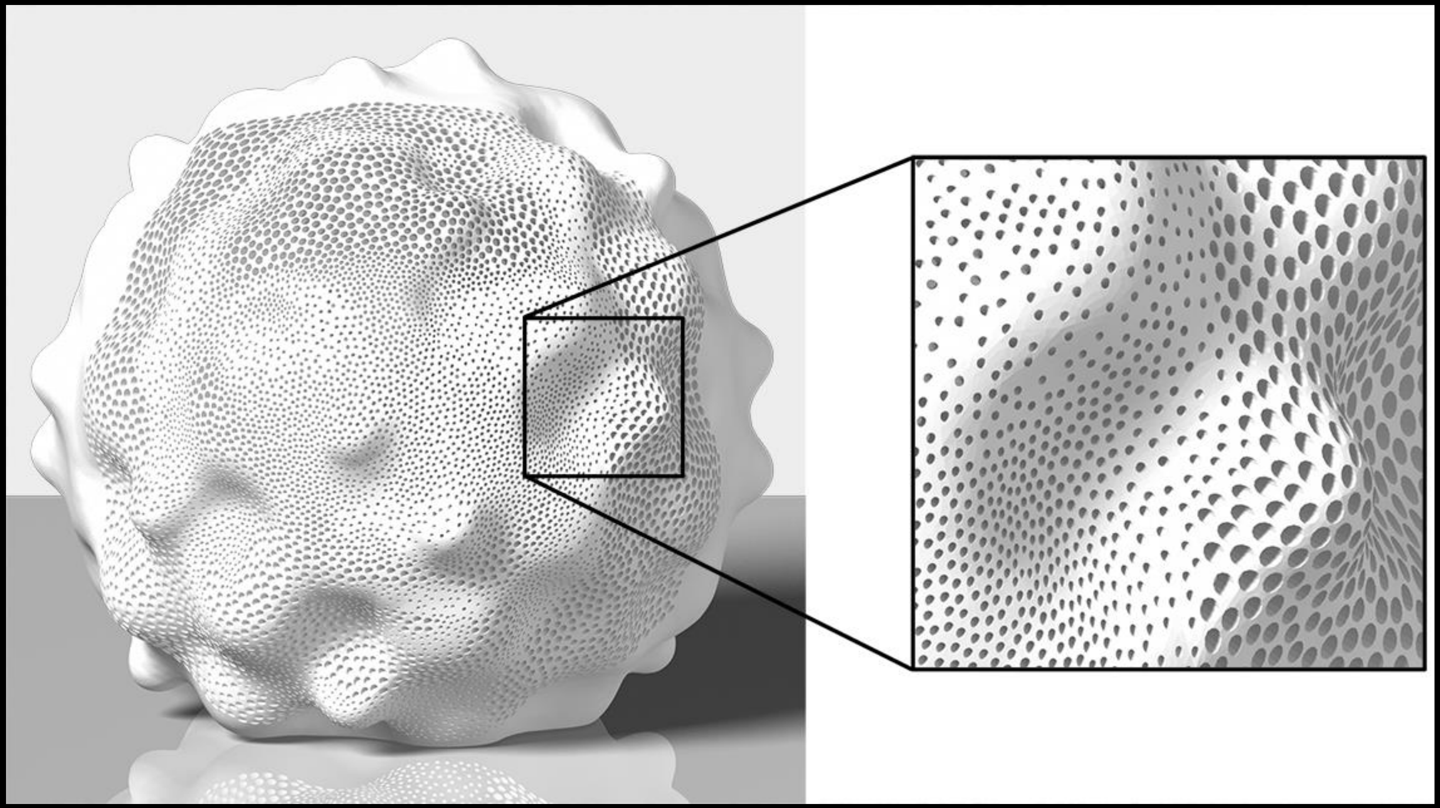
Projected image

$r_{min} = 0.6mm$
$d_{min} = 0.5mm$

Projet660 Pro (3D Systems)

Printing time: 16.5 hours
Drying time: 1 hour

Non-spherical lampshades



7248 tubes

Projected image

Robustness testing

- Lampshade moves from the original position

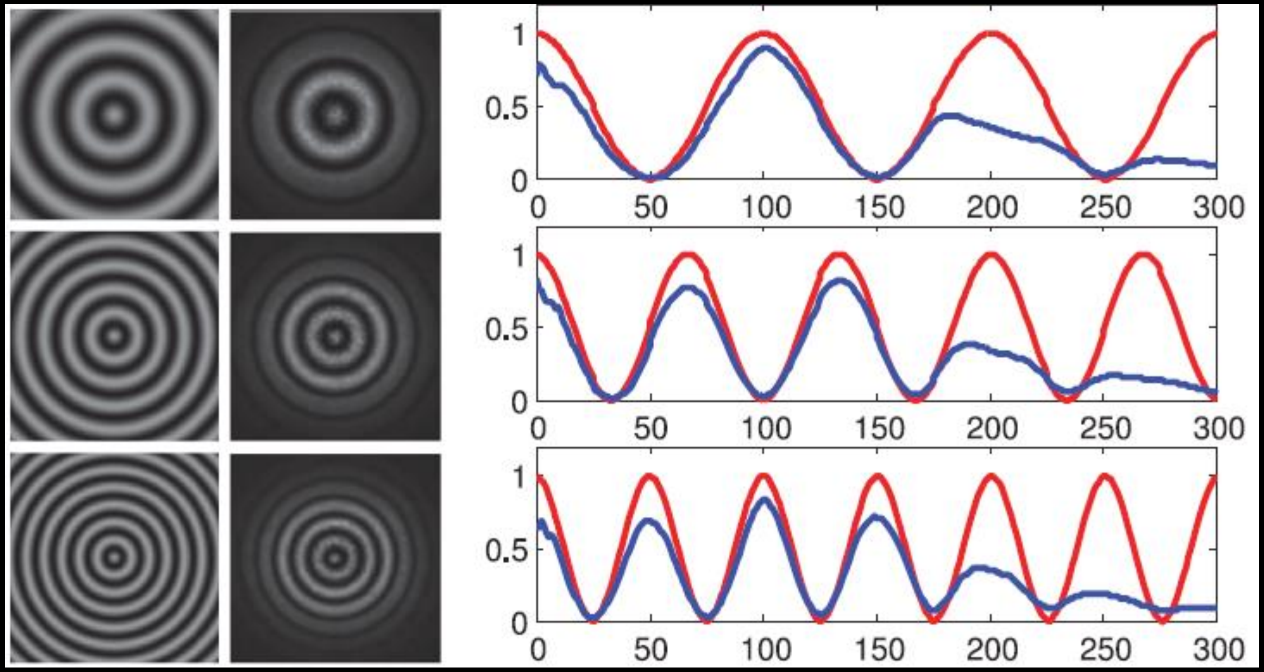
$-8mm$ $-4mm$ $-2mm$ $+2mm$ $+4mm$ $+8mm$

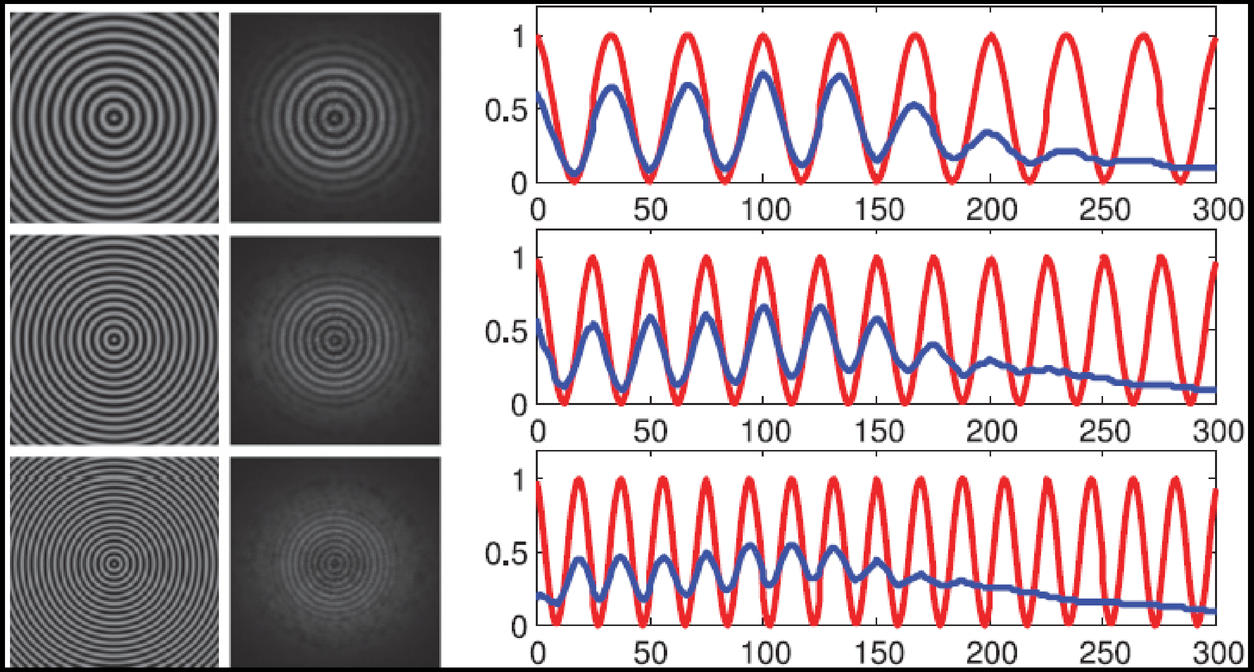
- Lampshade rotates around the light source center

-8^o -4^o -2^o $+2^o$ $+4^o$ $+8^o$

Quantitatively measure

- Radius cosine waves with different frequencies





Conclusion

- 3D-printed perforated lampshades that project **continuous grayscale images**
- Trade-off between **low resolution** and **continuity**

- Future works
  - More light sources
  - General receiving surfaces
  - Large scale lampshade

Acknowledgements

- Thank you for your attention!

http://irc.cs.sdu.edu.cn/Lampshades/