ATTENUATION-BASED LIGHT FIELD DISPLAYS

Bachelor Thesis

Adrian Wälchli

June 3, 2016

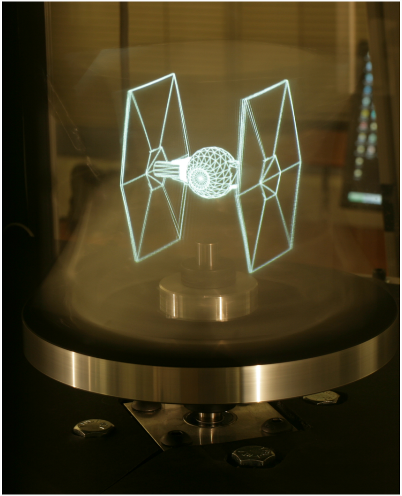
Institut für Informatik und angewandte Mathematik

OUTLINE

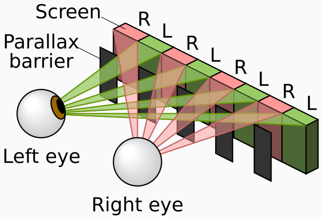
1. Introduction
2. Light Fields
3. Attenuation Display
4. Assessment
5. Conclusion

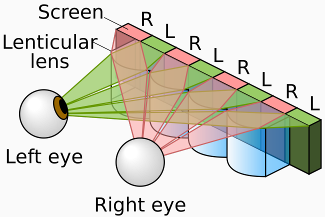
INTRODUCTION

EXISTING 3D DISPLAYS



Jones et al.





en.wikipedia.org/wiki/Autostereoscopy

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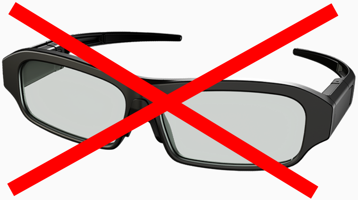
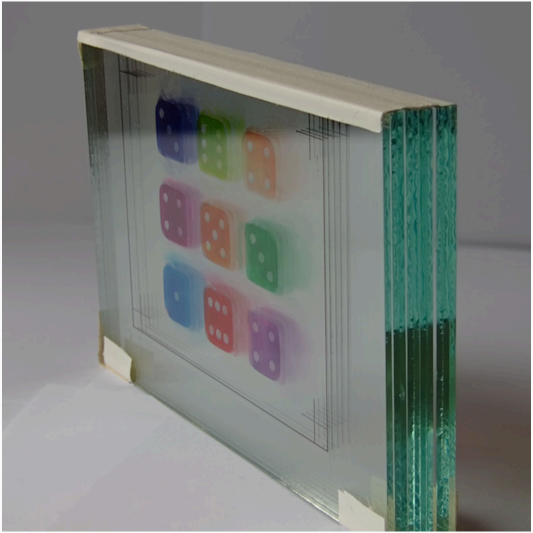


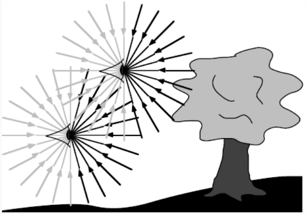
TODAY...



LIGHT FIELDS

THE PLENOPTIC FUNCTION

- Measures light in the world
- Position, viewing direction
- Time, Wavelength
- $P(x, y, z, \theta, \phi, t, \lambda)$
- 7D



Adelson and Bergen [1991]

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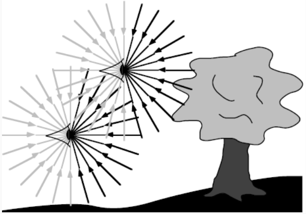

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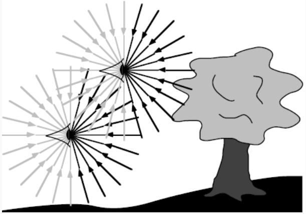

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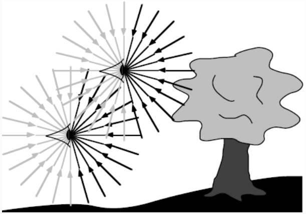

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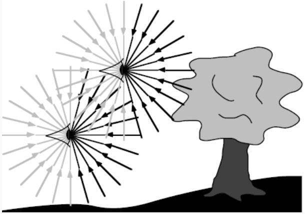

Adelson and Bergen [1991]

THE 4D LIGHT FIELD

- Reduce dimensions of P
- $L(u, v, s, t)$
- Defined by two planes

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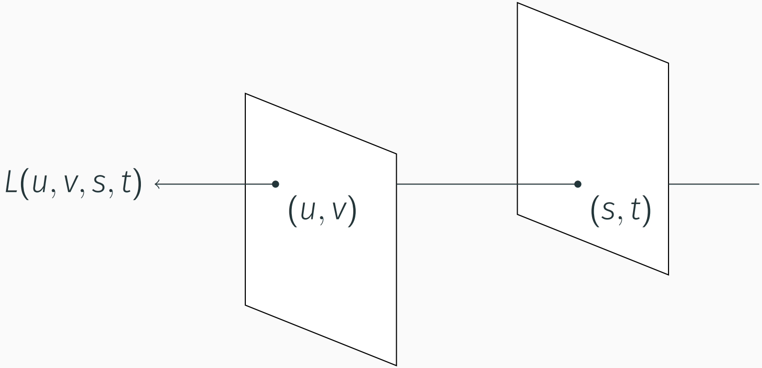


LIGHT FIELD ACQUISITION

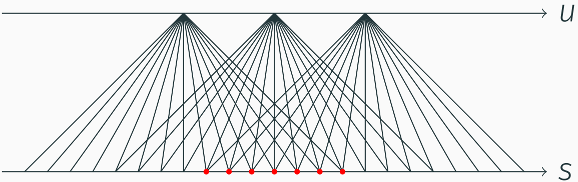
Stanford camera array. Source: lightfield.stanford.edu

LIGHT FIELD ACQUISITION

Lego gantry. Source: lightfield.stanford.edu

Lytro plenoptic camera. Source: de.wikipedia.org/wiki/Lytro

RE-PARAMETERIZATION TO GLOBAL COORDINATES



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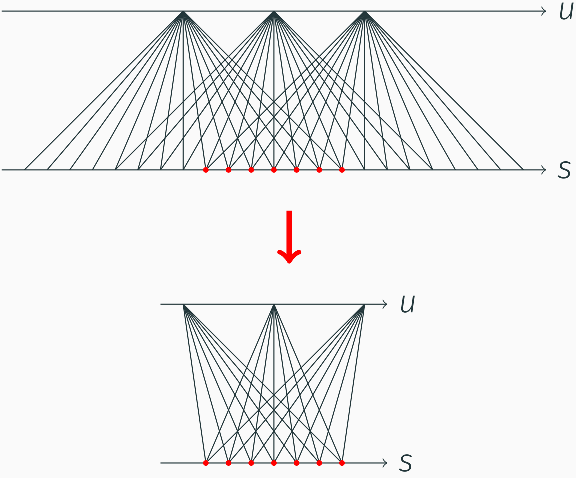

RE-PARAMETERIZATION TO GLOBAL COORDINATES

Raw

Rectified

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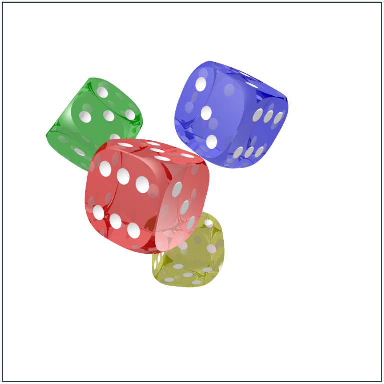
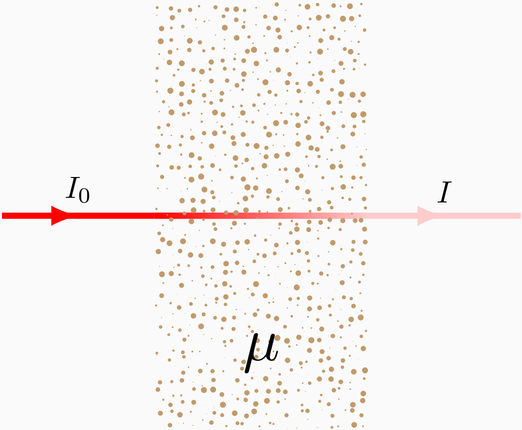


Rectified

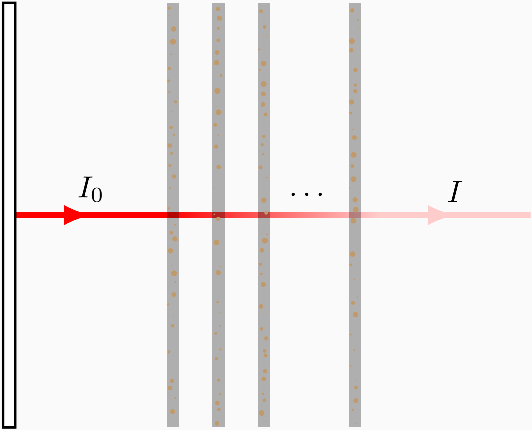
ATTENUATION DISPLAY

THE BEER-LAMBERT LAW



$$\frac{I}{I_0} = \exp\left(-\int_{\mathcal{R}} \mu(r)\mathrm{d}r\right)$$

THE BEER-LAMBERT LAW



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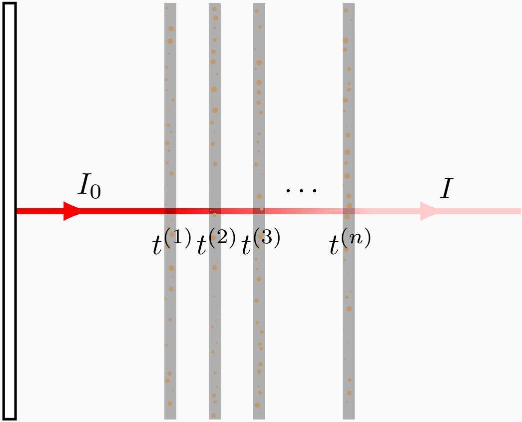

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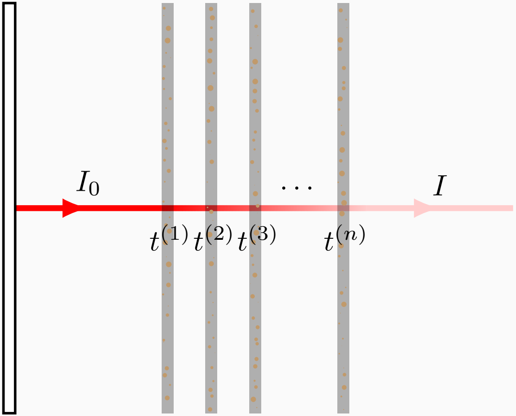
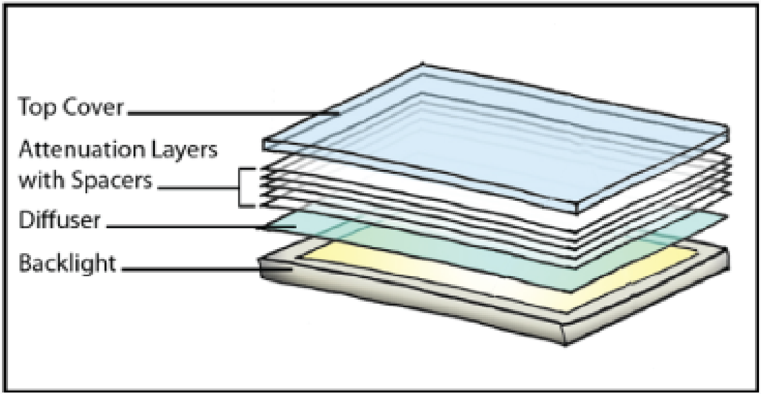


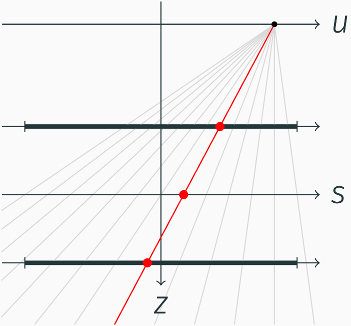
$$\frac{I}{I_0} = \exp\left(-\int_{\mathcal{R}} \mu(r)\mathrm{d}r\right) = \prod_i t^{(i)} = \exp\left(-\sum_i a^{(i)}\right)$$

DISPLAY ARCHITECTURE



Wetzstein et al. [2011]

LIGHT TRANSMISSION



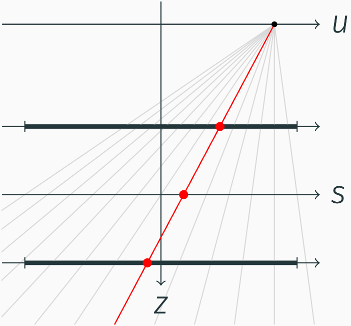
$$L_m = L_0 \prod_{n=1}^{N} t^{(n)}(h(m,n))$$

L_m Color of ray m

t Transmission

h Intersection

LIGHT TRANSMISSION



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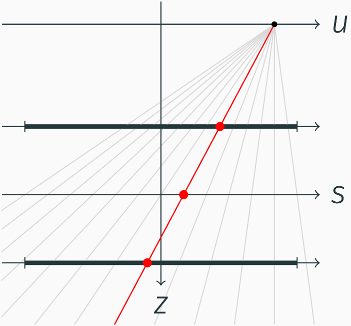

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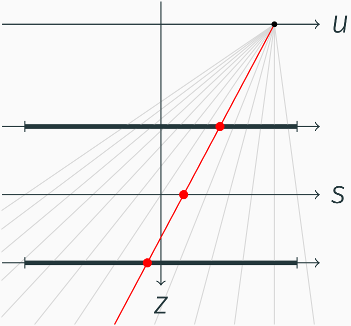

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From now on: $L_0 = 1$

FROM TRANSMISSION TO ABSORBANCE

- Transmission values unknown

$$L_m = \prod_{n=1}^{N} t^{(n)}(h(m,n))$$

FROM TRANSMISSION TO ABSORBANCE

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- Solve equations simultaneously for all rays

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- This is hard

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FROM TRANSMISSION TO ABSORBANCE

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- Solve equations simultaneously for all rays
- This is hard
- Transform to log-domain

$$L_m = \prod_{n=1}^{N} t^{(n)}(h(m,n))$$

$$\Big\downarrow \quad t = e^{-a}$$

$$\log(L_m) = -\sum_{n=1}^{N} a^{(n)}(h(m,n))$$

FROM TRANSMISSION TO ABSORBANCE

- Transmission values unknown
- Solve equations simultaneously for all rays
- This is hard
- Transform to log-domain
- Solve for absorbance

$$L_m = \prod_{n=1}^{N} t^{(n)}(h(m,n))$$

$$\Big\downarrow \quad t = e^{-a}$$

$$\log(L_m) = -\sum_{n=1}^{N} a^{(n)}(h(m,n))$$

RAY CASTING

- One linear constraint per ray
- Create a big matrix P
- Matrix encodes intersections

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$$
P = \begin{array}{cc}
 & \begin{array}{cccccccccc} \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 & \alpha_7 & \alpha_8 & \alpha_9 & \alpha_{10} \end{array} \\
\begin{array}{c} \overline{L}_1 \\ \overline{L}_2 \\ \overline{L}_3 \\ \overline{L}_4 \\ \overline{L}_5 \\ \overline{L}_6 \\ \overline{L}_7 \\ \overline{L}_8 \\ \overline{L}_9 \\ \overline{L}_{10} \\ \overline{L}_{11} \\ \overline{L}_{12} \end{array} &
\left(\begin{array}{ccccc|ccccc}
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\end{array}\right)
\end{array}
$$

THE EQUATION

$$\log(L) = -P\alpha$$

- $\log(L)$ Vectorized log light field
- α Vector holding unkowns

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OPTIMIZATION PROBLEM

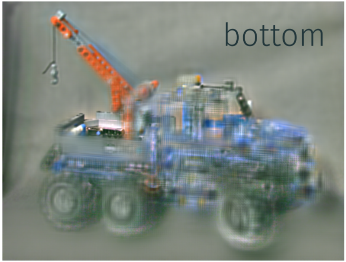
$$\begin{aligned} \underset{\alpha}{\text{argmin}} \quad & \|P\alpha + \log(L)\|^2 \\ \text{subject to} \quad & \alpha \geq 0. \end{aligned}$$

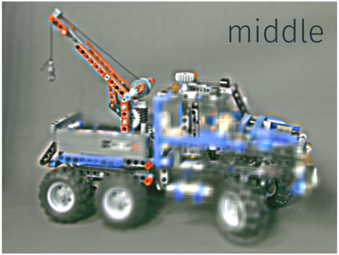
- Proposed by Wetzstein et al. [2011]
- System is overdetermined
- Need iterative solver

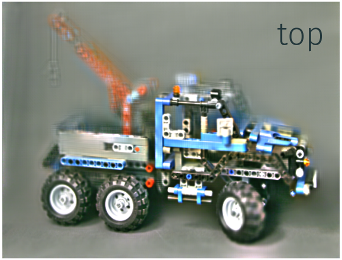
THE CONSTRAINT $\alpha \geq 0$

- Negative absorption ($\alpha < 0$) is physically not possible
- The theoretical model supports negative absorption
- Constraint reduces the space of possible solutions

EXAMPLE: LEGO TRUCK







$6 \times 6 \times 480 \times 640$

~ 2 minutes

EXAMPLE: LEGO TRUCK

Goal: Simulate viewing experience before assembly

$$I = e^{-P\alpha}$$

Original

Simulation

Original

Simulation

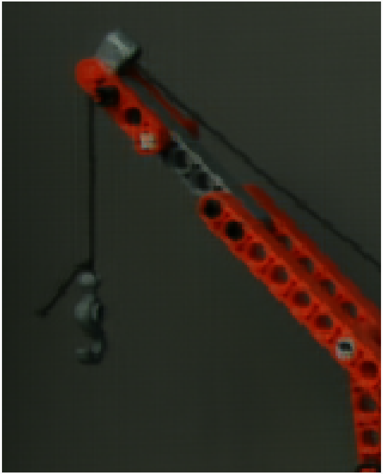
Original

Simulation

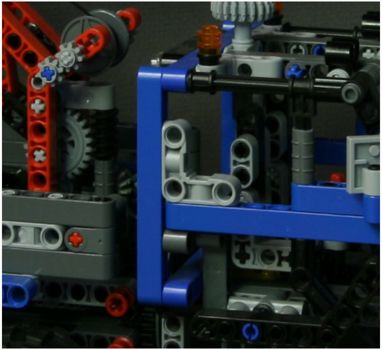
10 LAYERS

Original

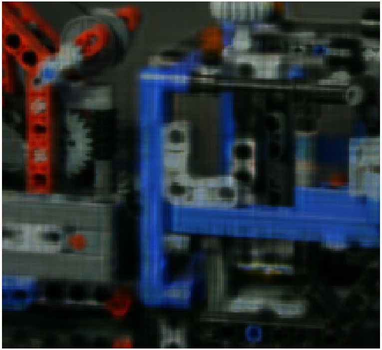
Simulation



Original

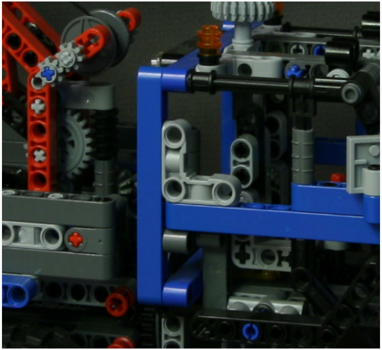


Simulation



5 LAYERS

Original



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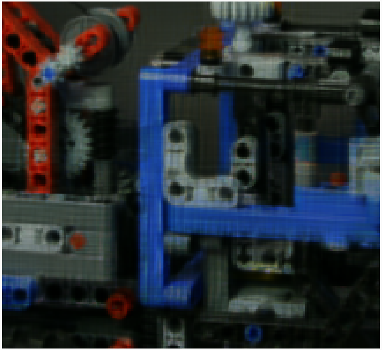

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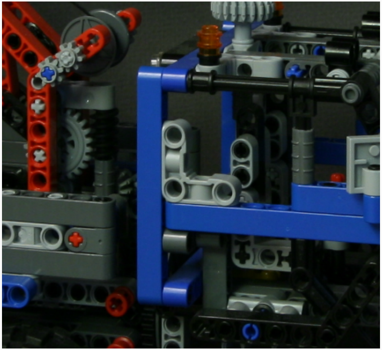

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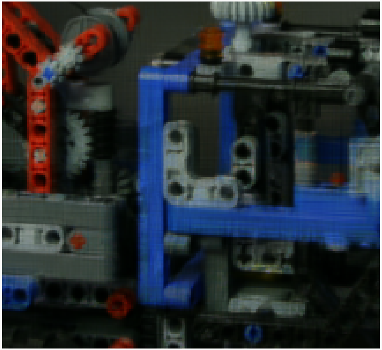
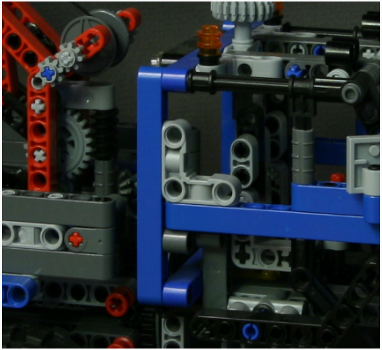


10 LAYERS, HIGHER ANGULAR RESOLUTION

Original



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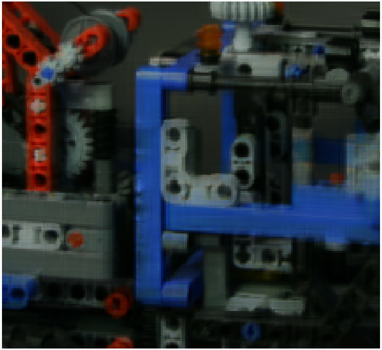

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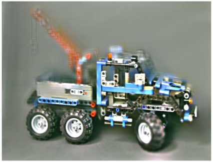
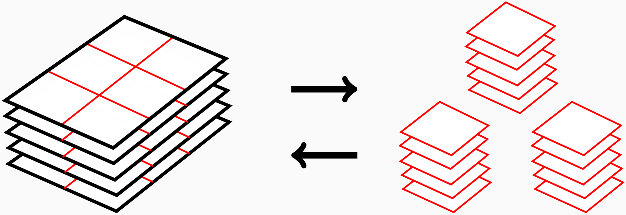


- A lot of memory is needed:
  - Light field (uncompressed)
  - Propagation matrix (? nnz entries)
  - Additional matrices for solver
- Memory usage grows with resolution
- Solution: Slice the attenuator

ATTENUATOR TILING

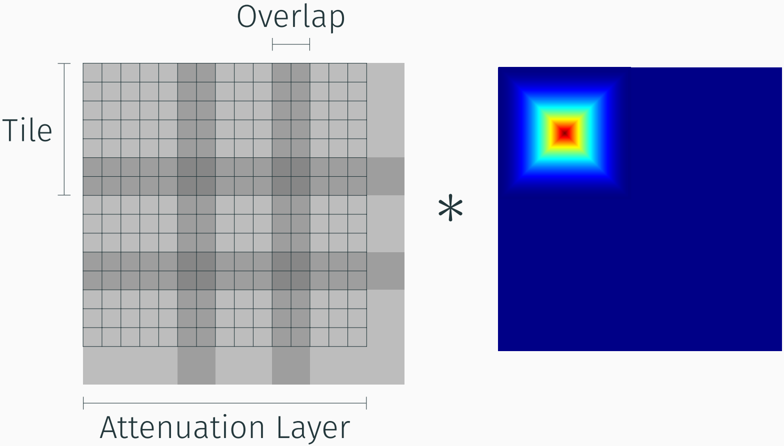
1. Slice attenuator into smaller pieces
2. Solve optimization problem for every slice
3. Reconnect the slices



ATTENUATOR TILING

- Problem: Rays can overlap with multiple slices at borders
- Slices need to overlap too
- Blend slices with mask

TILE BLENDING



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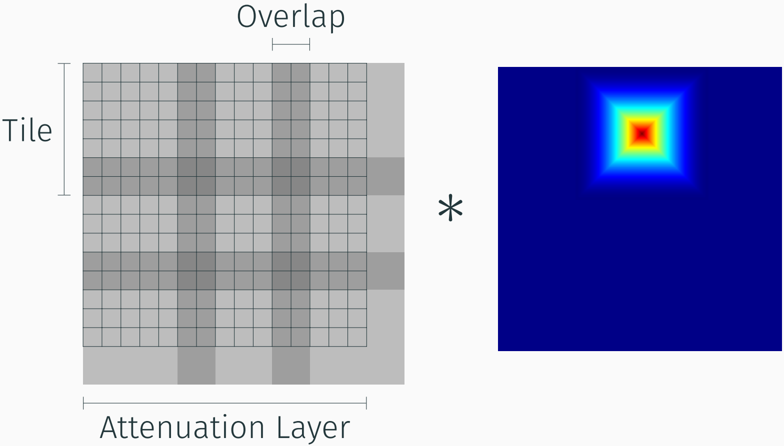

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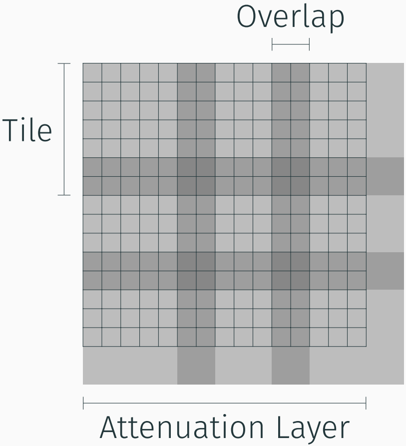

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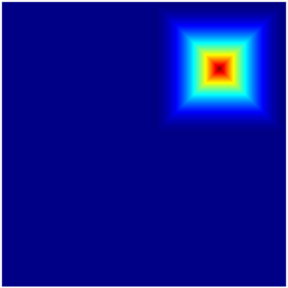
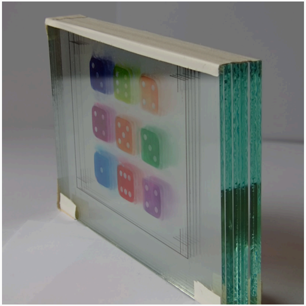


THE FINISHED PRODUCT

- Finally, print images on transparent sheets
- Glass plates hold sheets in place
- Combine with backlight



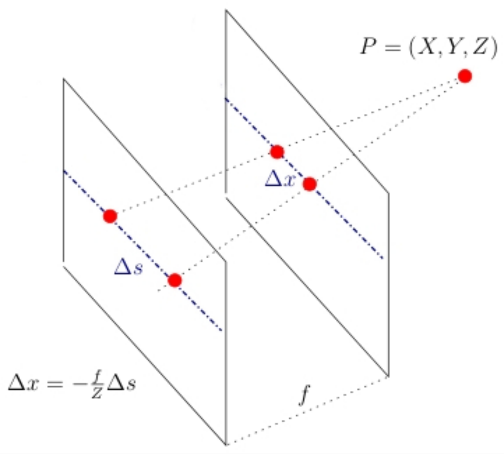
THE FINISHED PRODUCT

QUESTIONS

- Impact of more layers?
- Does thickness of display matter?
- What are the limitations?

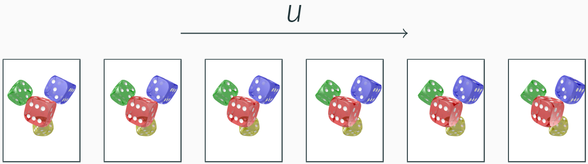
ASSESSMENT

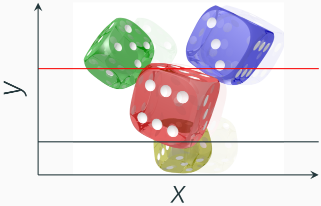
EPIPOLAR PLANE GEOMETRY

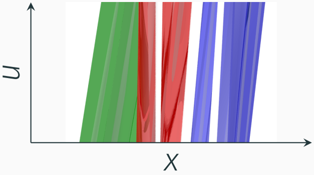


Source: klimt.iwr.uni-heidelberg.de

EPIPOLAR PLANE IMAGE







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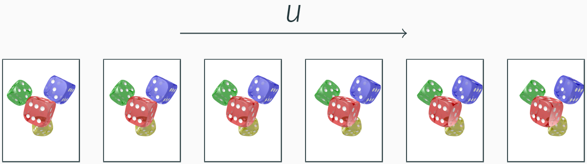
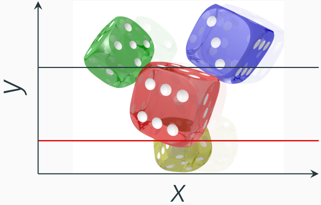
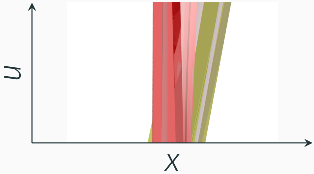
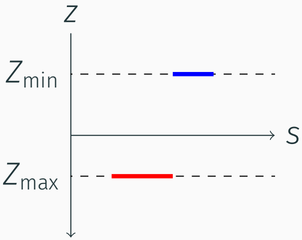
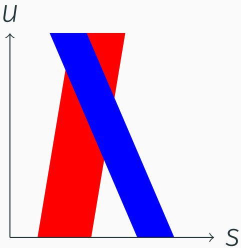






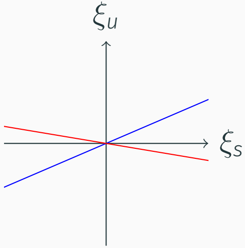
SPECTRAL ANALYSIS

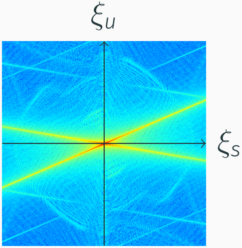




$$\frac{\mathrm{d}u}{\mathrm{d}s} = \frac{z - Z_u}{z - Z_s}$$

SPECTRAL ANALYSIS





CONCLUSION

SUMMARY

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Supervision by

Prof. Dr. Matthias Zwicker
Siavash Bigdeli

RESOURCES

Contact

adrian.waelchli@students.unibe.ch

Thesis and Resources

github.com/awaelchli/bachelor_thesis

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