ATTENUATION-BASED LIGHT FIELD DISPLAYS

Bachelor Thesis

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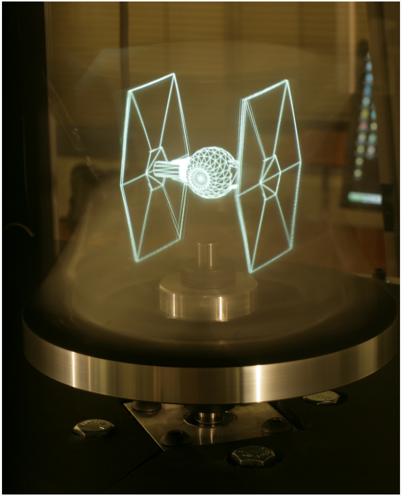
Institut für Informatik und angewandte Mathematik

OUTLINE

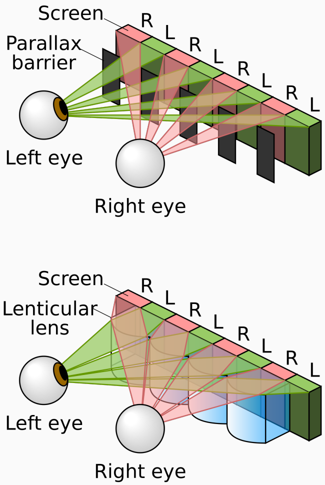
1. Introduction
2. Light Fields
3. Attenuation Display
4. Assessment
5. Conclusion

INTRODUCTION

EXISTING 3D DISPLAYS



Jones et al.



en.wikipedia.org/wiki/Autostereoscopy

EXISTING 3D DISPLAYS

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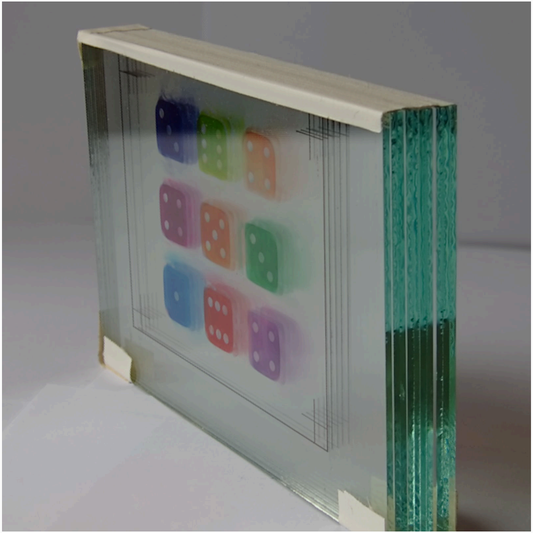
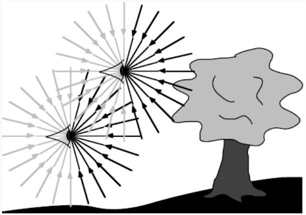
TODAY...



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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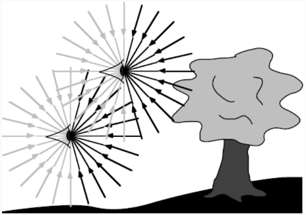

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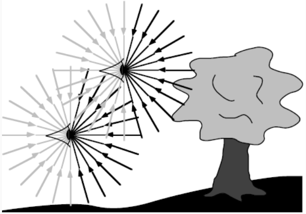

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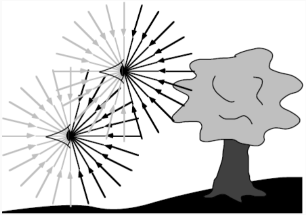

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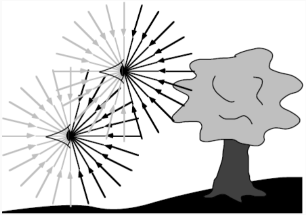

Adelson and Bergen [1991]

THE 4D LIGHT FIELD

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

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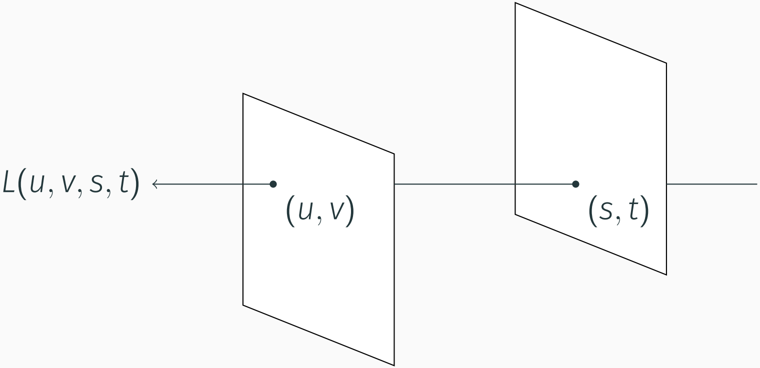


LIGHT FIELD ACQUISITION

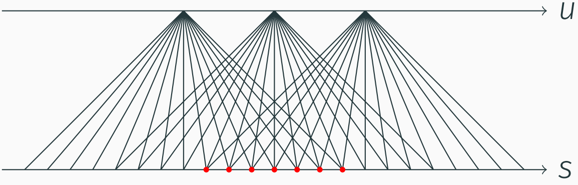
Stanford camera array. Source: lightfield.stanford.edu

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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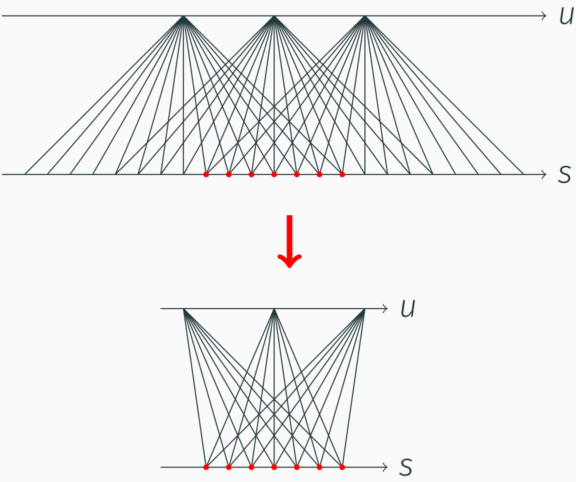

RE-PARAMETERIZATION TO GLOBAL COORDINATES

Raw

Rectified

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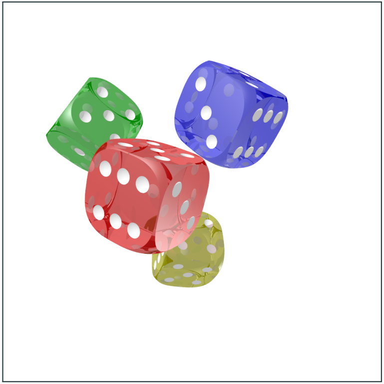
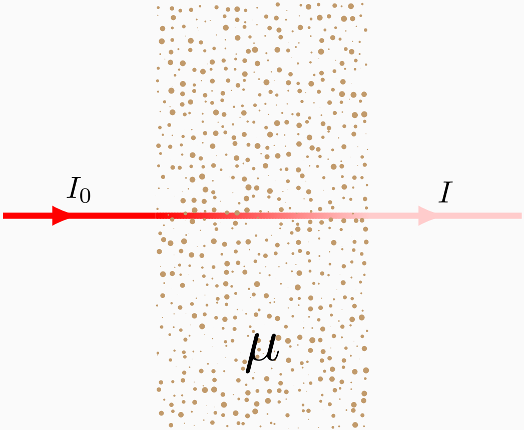


Rectified

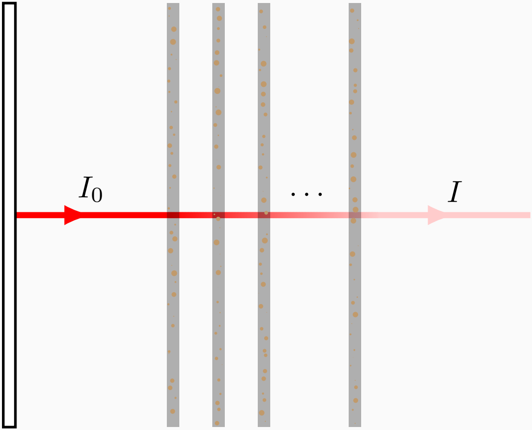
ATTENUATION DISPLAY

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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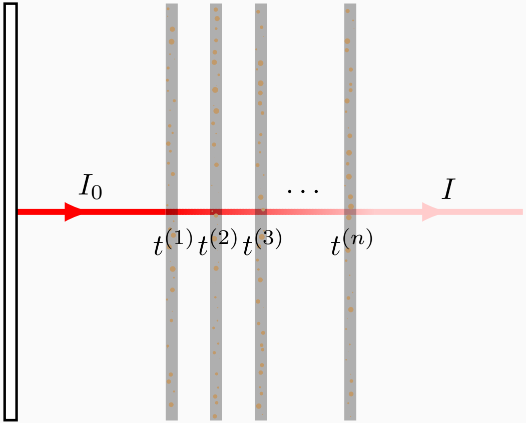

$$\frac{I}{I_0} = \exp\left(-\int_{\mathcal{R}} \mu(r)\mathrm{d}r\right) = \prod_i t^{(i)}$$

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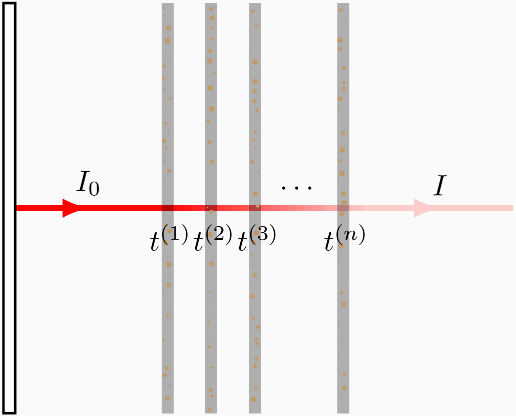
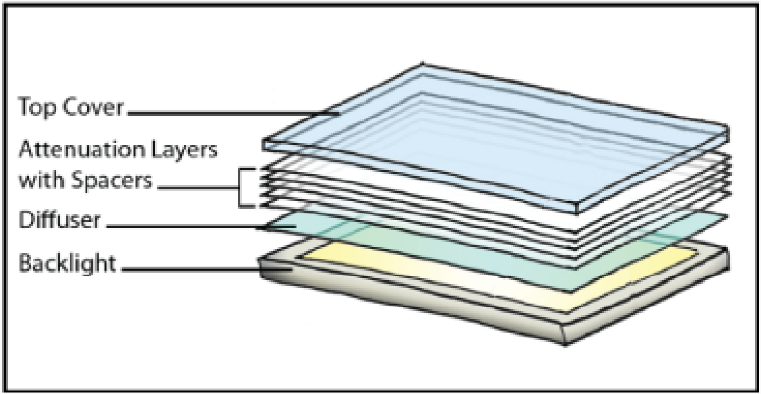


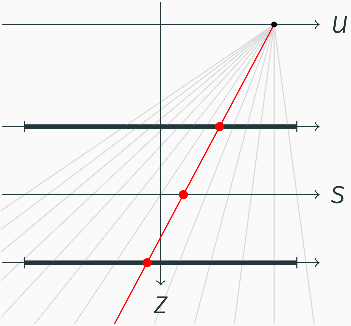
$$\frac{I}{I_0} = \exp\left(-\int_{\mathcal{R}} \mu(r)\mathrm{d}r\right) = \prod_i t^{(i)} = \exp\left(-\sum_i a^{(i)}\right)$$

DISPLAY ARCHITECTURE



Wetzstein et al. [2011]

LIGHT TRANSMISSION



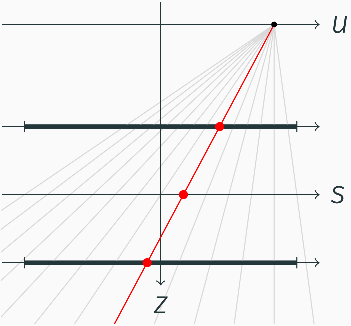
$$L_m = L_0 \prod_{n=1}^{N} t^{(n)}(h(m,n))$$

L_m Color of ray m

t Transmission

h Intersection

LIGHT TRANSMISSION



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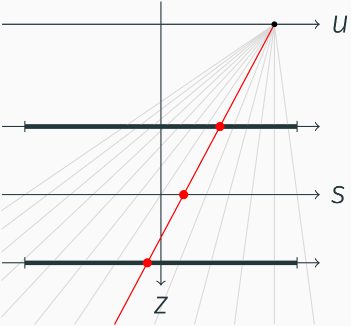

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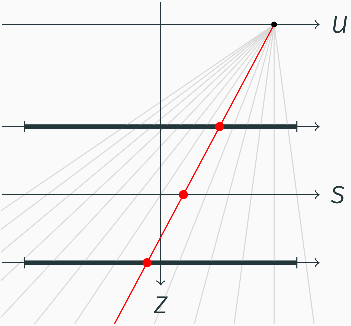

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L_m Color of ray m

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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

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

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

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

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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$$
P = \begin{array}{cc}
 & \begin{array}{cccccccccc} \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 & \alpha_7 & \alpha_8 & \alpha_9 & \alpha_{10} \end{array} \\
\begin{array}{c} \overline{L}_1 \\ \overline{L}_2 \\ \overline{L}_3 \\ \overline{L}_4 \\ \overline{L}_5 \\ \overline{L}_6 \\ \overline{L}_7 \\ \overline{L}_8 \\ \overline{L}_9 \\ \overline{L}_{10} \\ \overline{L}_{11} \\ \overline{L}_{12} \end{array} &
\left(\begin{array}{ccccc|ccccc}
 & & 1 & & & 1 & & & & \\
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\end{array}\right)
\end{array}
$$

THE EQUATION

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

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

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OPTIMIZATION PROBLEM

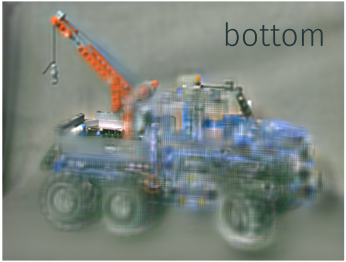
$$\begin{aligned} \underset{\alpha}{\operatorname{argmin}} \quad & \|P\alpha + \log(L)\|^2 \\ \text{subject to} \quad & \alpha \geq 0. \end{aligned}$$

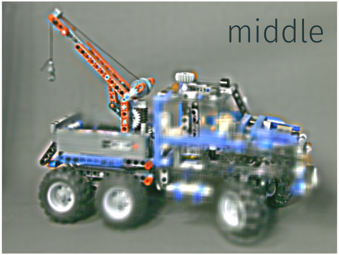
- Proposed by Wetzstein et al. [2011]
- System is overdetermined
- Need iterative solver

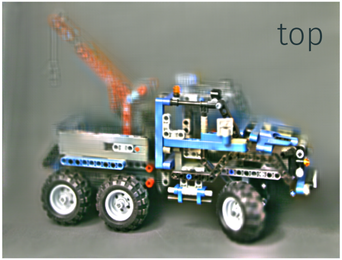
THE CONSTRAINT $\alpha \geq 0$

- 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

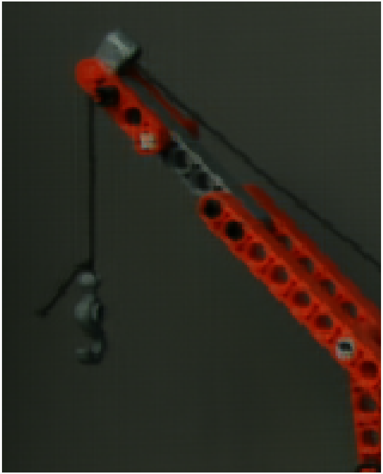
5 LAYERS

Original

Simulation

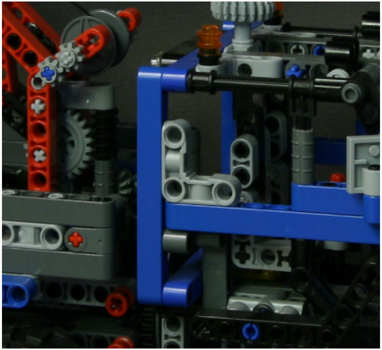
Original

Simulation

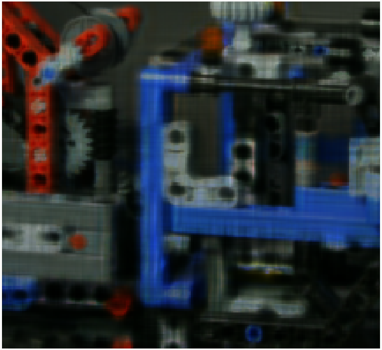


3 LAYERS

Original



Simulation



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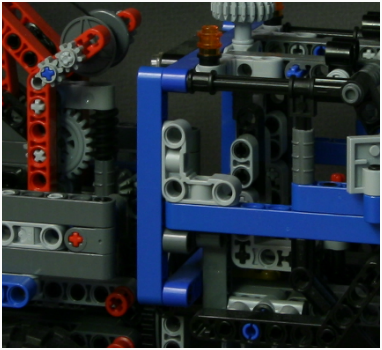

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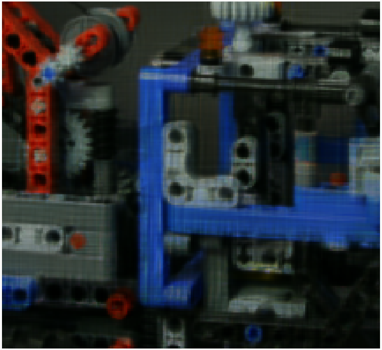
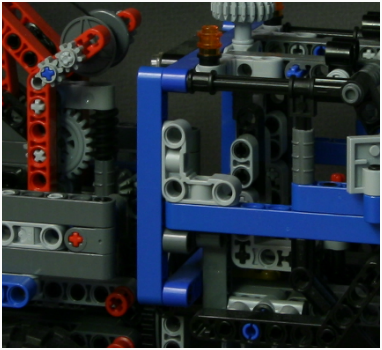
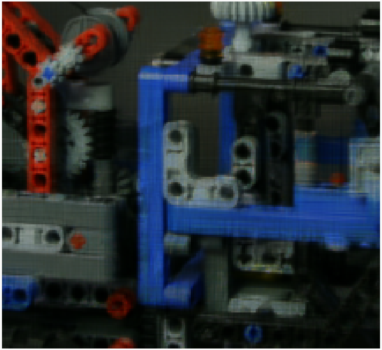


10 LAYERS

Original

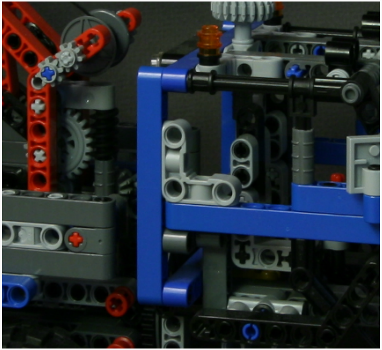


Simulation



10 LAYERS, HIGHER ANGULAR RESOLUTION

Original



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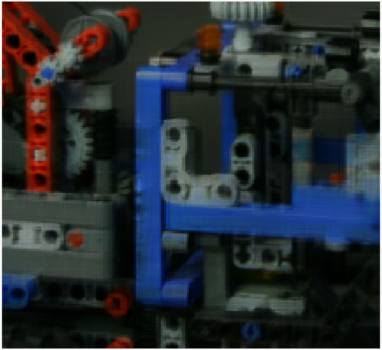

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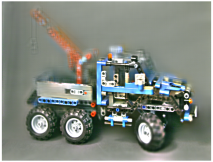
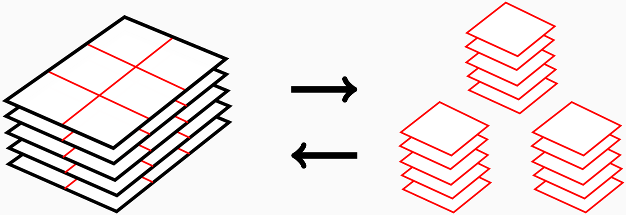


- A lot of memory is needed:
  - Light field (uncompressed)
  - Propagation matrix (? nnz entries)
  - Additional matrices for solver
- Memory usage grows with resolution
- Solution: Slice the attenuator

ATTENUATOR TILING

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

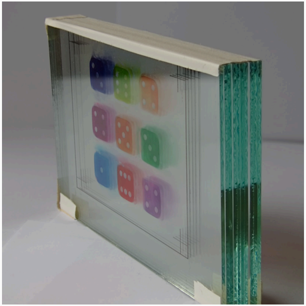


ATTENUATOR TILING

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

THE FINISHED PRODUCT

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



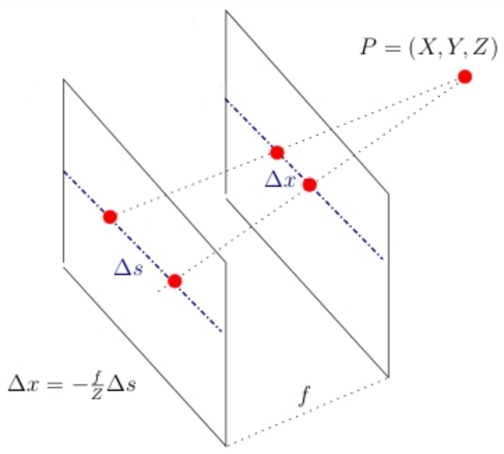
THE FINISHED PRODUCT

QUESTIONS

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

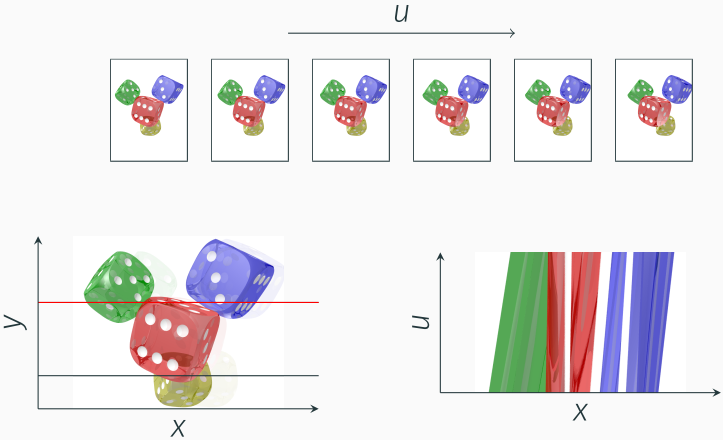
ASSESSMENT

EPIPOLAR PLANE GEOMETRY

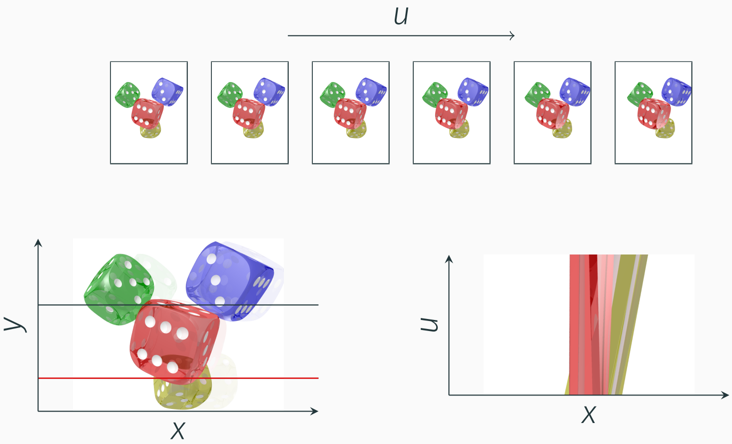


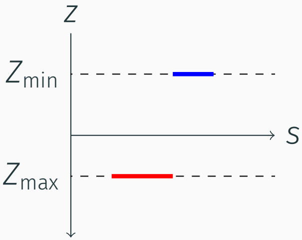
Source: klimt.iwr.uni-heidelberg.de

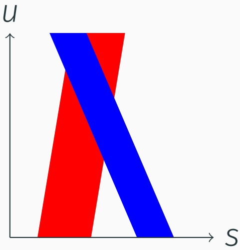
EPIPOLAR PLANE IMAGE



EPIPOLAR PLANE IMAGE

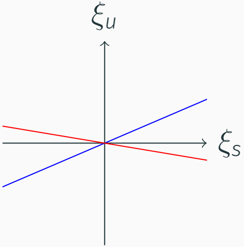


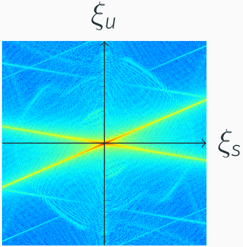




$$\frac{\mathrm{d}u}{\mathrm{d}s} = \frac{z - Z_u}{z - Z_s}$$

SPECTRAL ANALYSIS





CONCLUSION

SUMMARY

ACKNOWLEDGEMENTS

Supervision by

Prof. Dr. Matthias Zwicker
Siavash Bigdeli

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Thesis and Resources

github.com/awaelchli/bachelor_thesis

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