

ATTENUATION-BASED LIGHT FIELD DISPLAYS

Bachelor Thesis

Adrian Wälchli

June 3, 2016

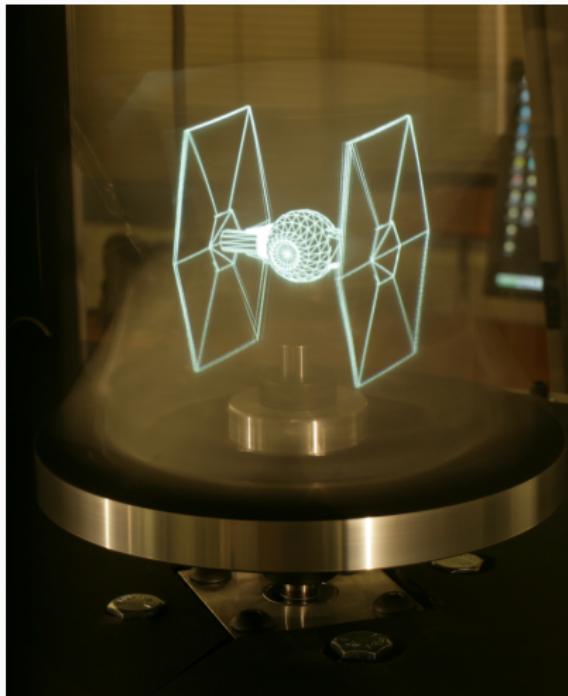
Institut für Informatik und angewandte Mathematik

OUTLINE

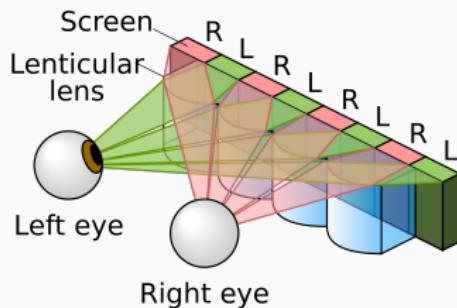
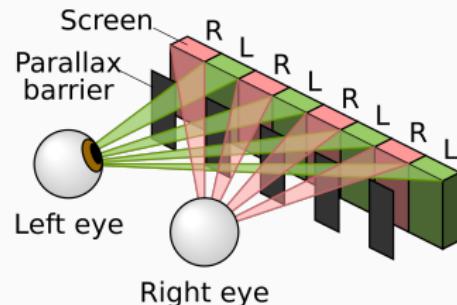
1. Introduction
2. Light Fields
3. Attenuation Display
4. Assessment
5. Conclusion

INTRODUCTION

EXISTING 3D DISPLAYS



Jones et al.

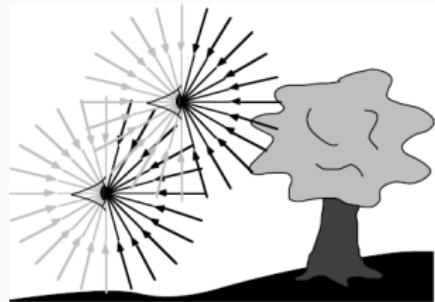


en.wikipedia.org/wiki/Autostereoscopy

LIGHT FIELDS

THE PLENOPTIC FUNCTION

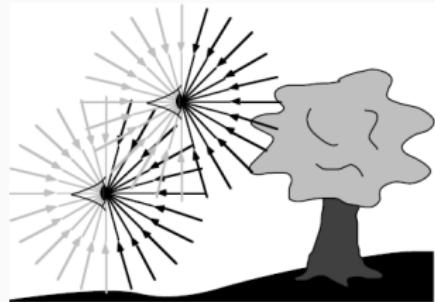
- Measures light in the world
- Position, viewing direction
- Time, Wavelength
- $P(x, y, z, \theta, \phi, t, \lambda)$
- 7D



Adelson and Bergen [1991]

THE PLENOPTIC FUNCTION

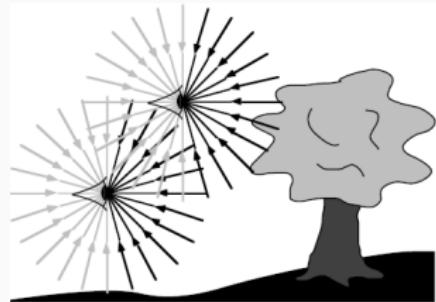
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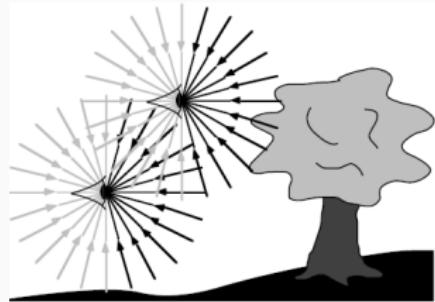
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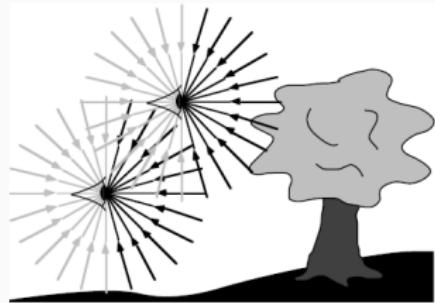
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Adelson and Bergen [1991]

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- Measures light in the world
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Adelson and Bergen [1991]

THE 4D LIGHT FIELD

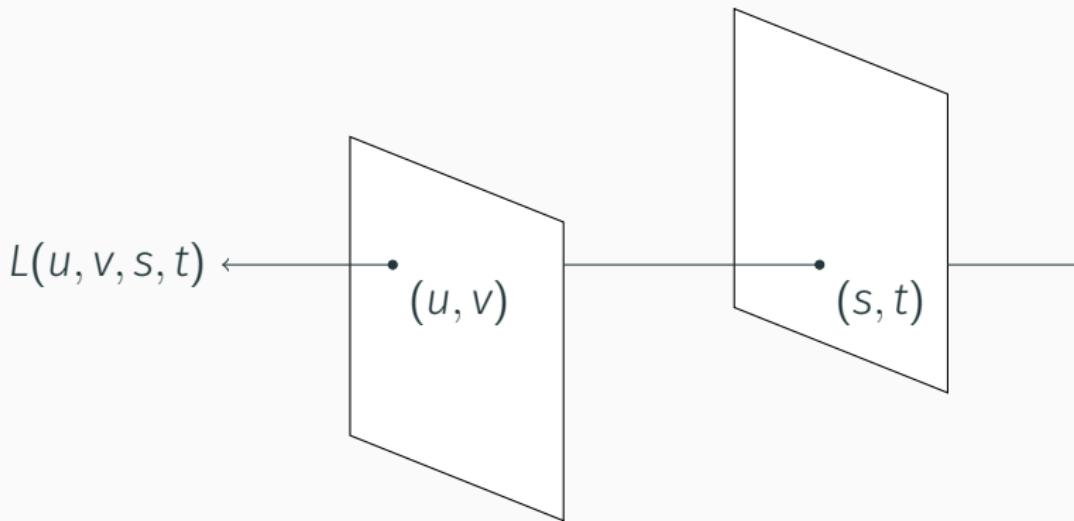
- Reduce dimensions of P
- $L(u, v, s, t)$
- Defined by two planes

THE 4D LIGHT FIELD

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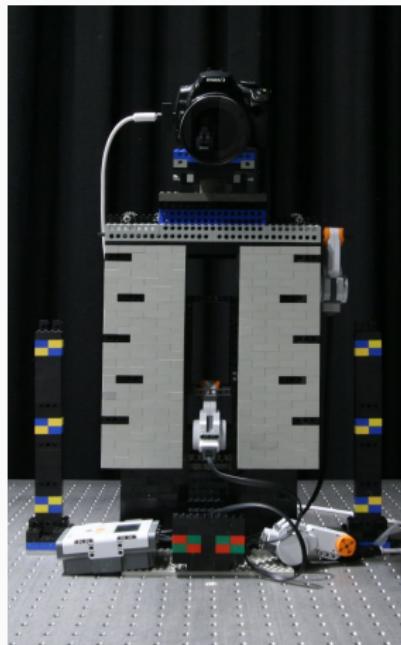


LIGHT FIELD ACQUISITION



Stanford camera array. Source: lightfield.stanford.edu

LIGHT FIELD ACQUISITION



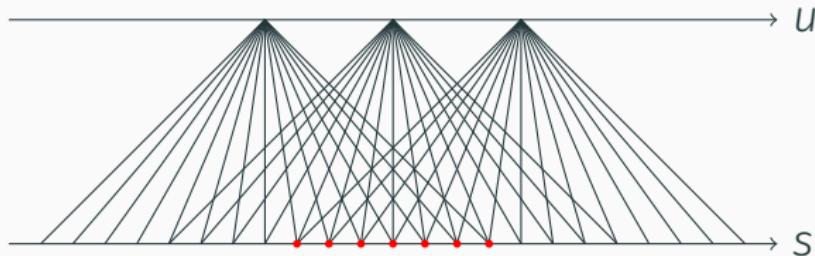
Lego gantry. Source: lightfield.stanford.edu

LIGHT FIELD ACQUISITION

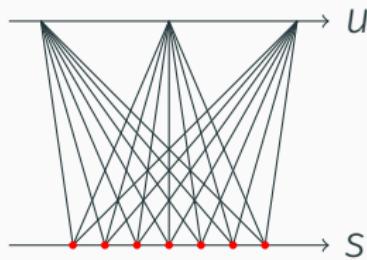
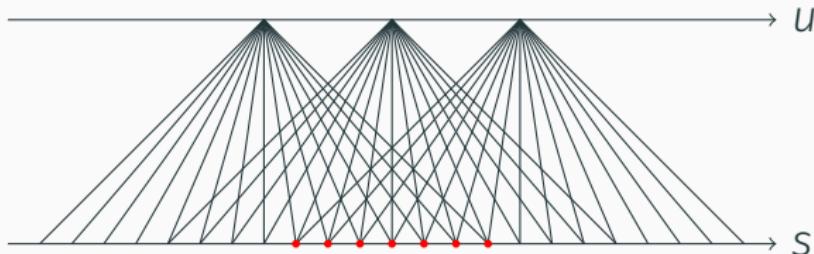


Lytro plenoptic camera. Source: de.wikipedia.org/wiki/Lytro

RE-PARAMETERIZATION TO GLOBAL COORDINATES



RE-PARAMETERIZATION TO GLOBAL COORDINATES



RE-PARAMETERIZATION TO GLOBAL COORDINATES

Raw



Rectified



RE-PARAMETERIZATION TO GLOBAL COORDINATES

Raw

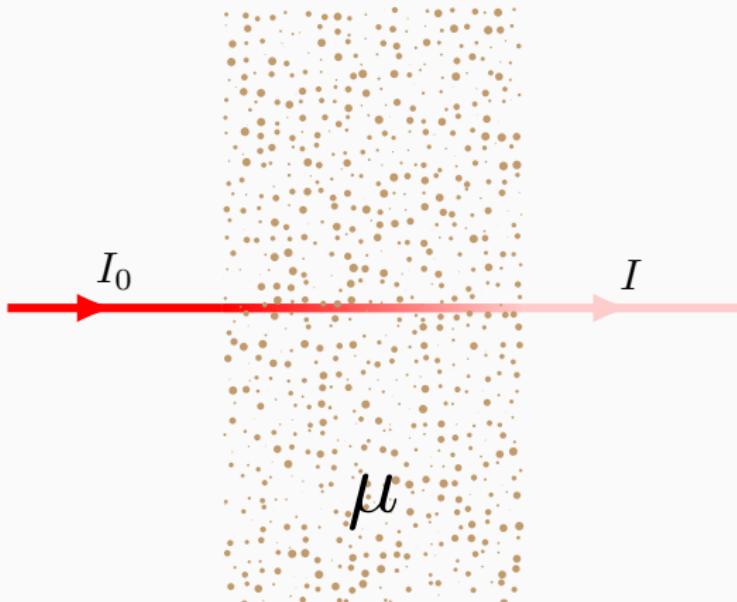


Rectified



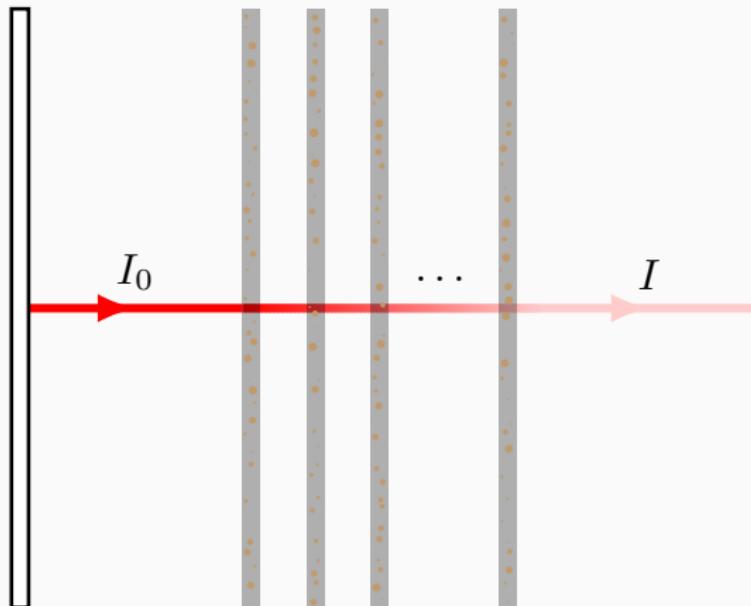
ATTENUATION DISPLAY

THE BEER-LAMBERT LAW



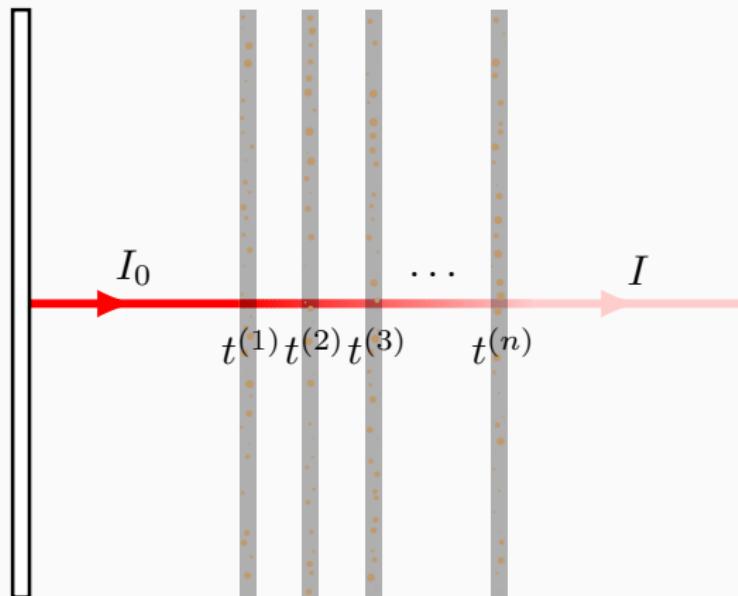
$$\frac{I}{I_0} = \exp \left(- \int_{\mathcal{R}} \mu(r) dr \right)$$

THE BEER-LAMBERT LAW



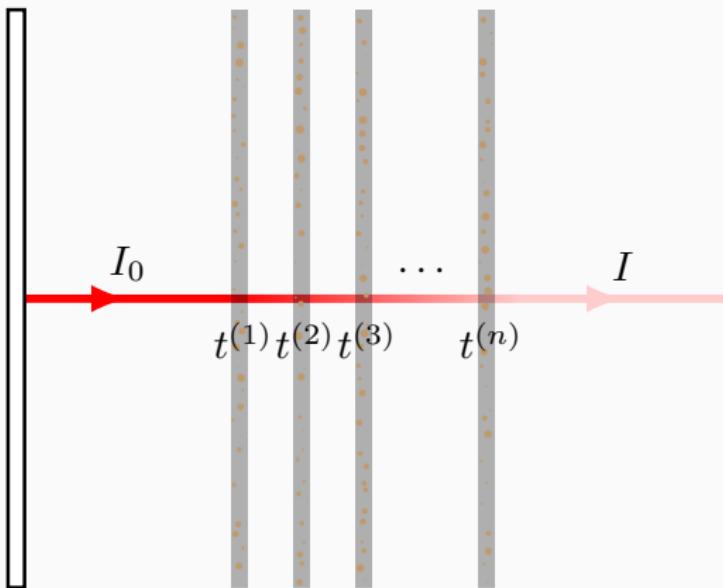
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THE BEER-LAMBERT LAW



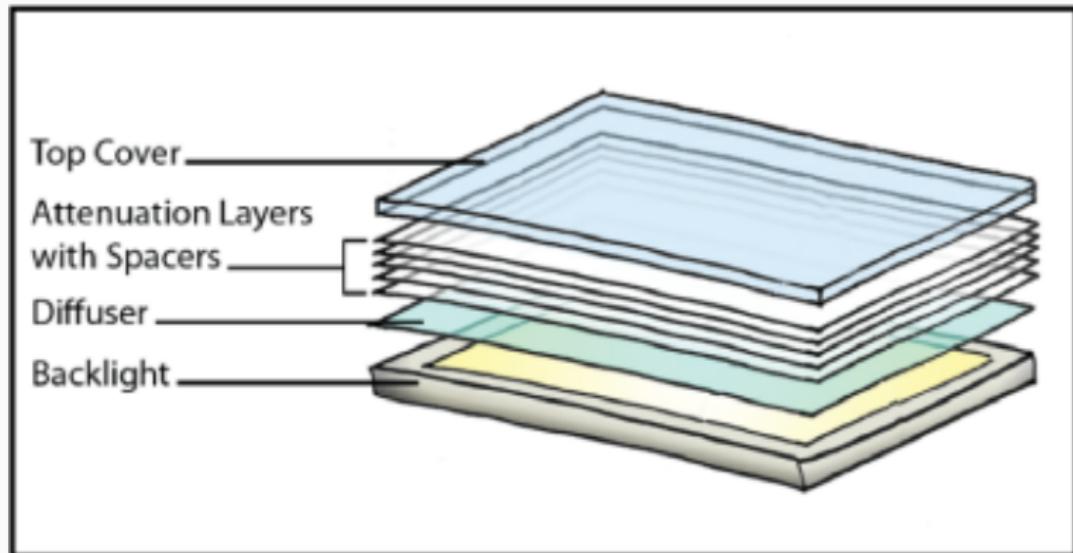
$$\frac{I}{I_0} = \exp \left(- \int_{\mathcal{R}} \mu(r) dr \right) = \prod_i t^{(i)}$$

THE BEER-LAMBERT LAW



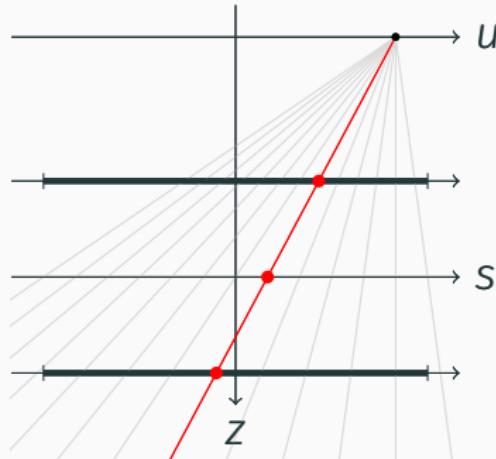
$$\frac{I}{I_0} = \exp \left(- \int_{\mathcal{R}} \mu(r) dr \right) = \prod_i t^{(i)} = \exp \left(- \sum_i a^{(i)} \right)$$

DISPLAY ARCHITECTURE



Wetzstein et al. [2011]

LIGHT TRANSMISSION



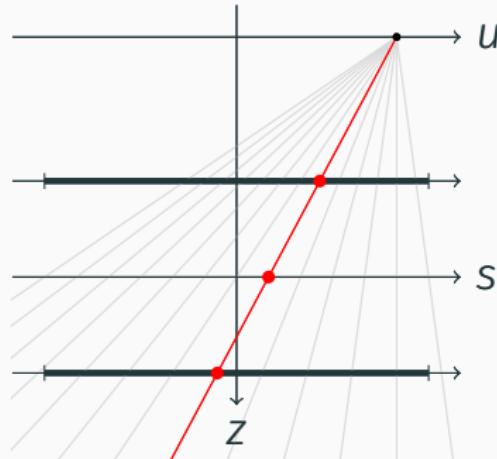
$$L_m = L_0 \prod_{n=1}^N t^{(n)}(h(m, n))$$

L_m Color of ray m

t Transmission

h Intersection

LIGHT TRANSMISSION



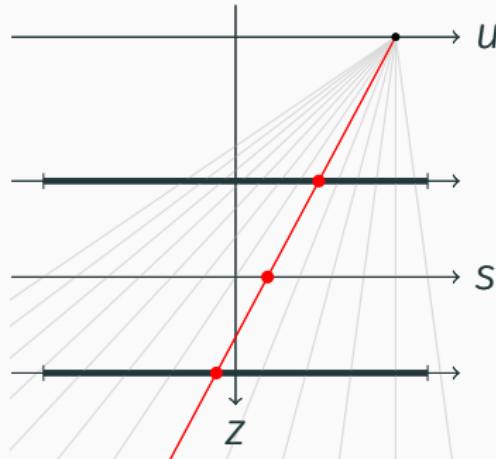
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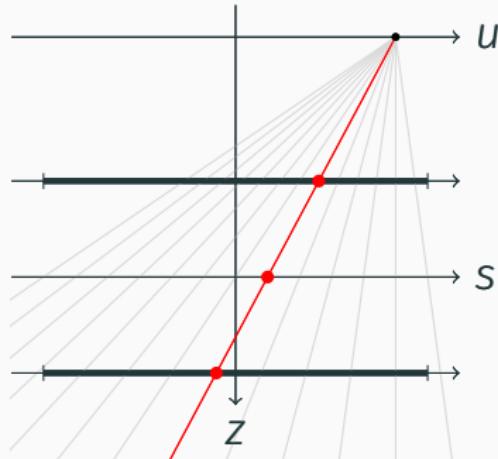
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LIGHT TRANSMISSION



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

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

- Transmission values unknown
- Solve equations simultaneously for all rays

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FROM TRANSMISSION TO ABSORBANCE

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- This is hard

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FROM TRANSMISSION TO ABSORBANCE

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

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

 $t = e^{-a}$

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

FROM TRANSMISSION TO ABSORBANCE

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

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

 $t = e^{-a}$

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

RAY CASTING

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

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RAY CASTING

$$P = \begin{pmatrix} & \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 & \alpha_7 & \alpha_8 & \alpha_9 & \alpha_{10} \\ \bar{L}_1 & & & 1 & & & & 1 & & & \\ \bar{L}_2 & & & & 1 & & & & 1 & & \\ \bar{L}_3 & 1 & & & & & & & 1 & & \\ \bar{L}_4 & & 1 & & & & & & & 1 & \\ \hline \bar{L}_5 & & & & 1 & & & & & 1 & \\ \bar{L}_6 & & & 1 & & & & 1 & & & \\ \bar{L}_7 & 1 & & & & & & & & 1 & \\ \hline \bar{L}_8 & & & & 1 & & & 1 & & & \\ \hline \bar{L}_9 & & 1 & & & & & & 1 & & \\ \bar{L}_{10} & & & 1 & & & & & & 1 & \\ \hline \bar{L}_{11} & & & 1 & & & & & & 1 & \\ \bar{L}_{12} & & & 1 & & & & & & & 1 \end{pmatrix}$$

THE EQUATION

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

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

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OPTIMIZATION PROBLEM

$$\operatorname{argmin}_{\alpha} \|P\alpha + \log(L)\|^2$$

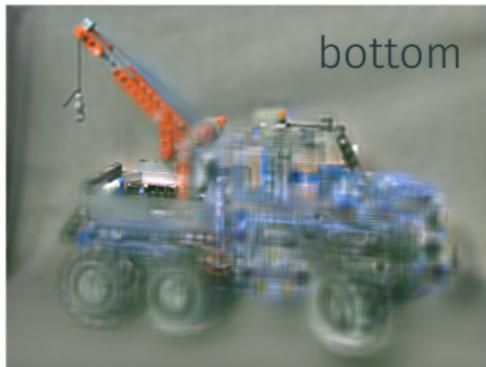
subject to $\alpha \geq 0.$

- 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

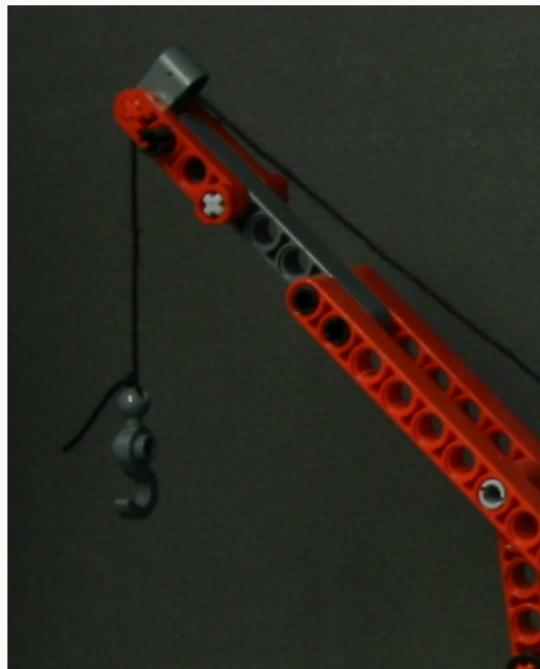


Simulation

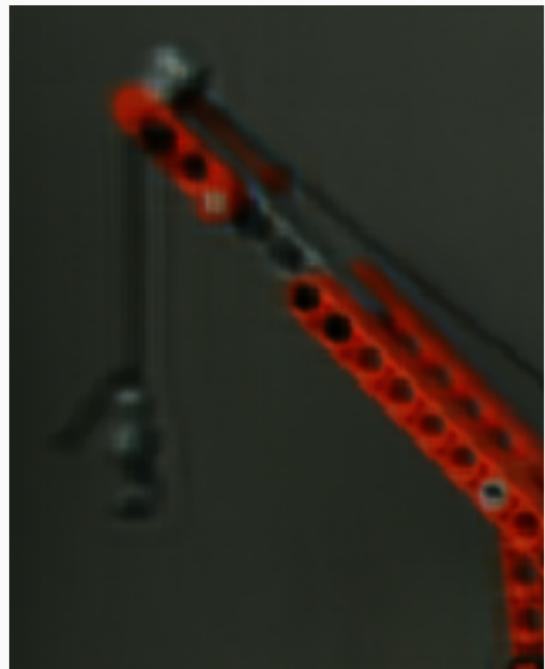


3 LAYERS

Original

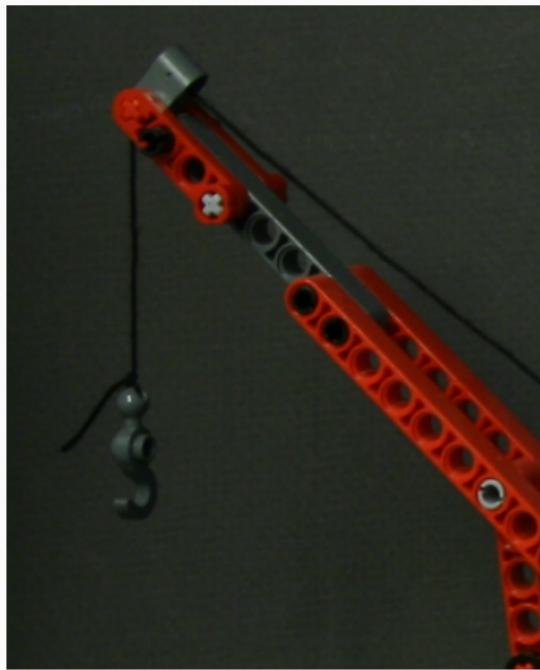


Simulation

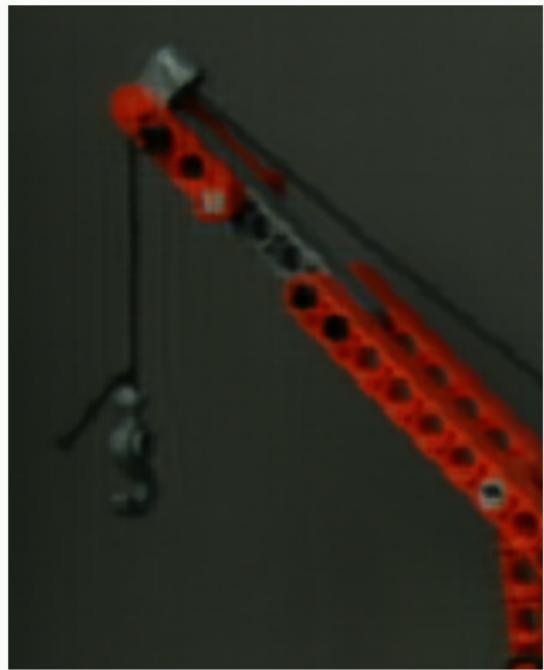


5 LAYERS

Original

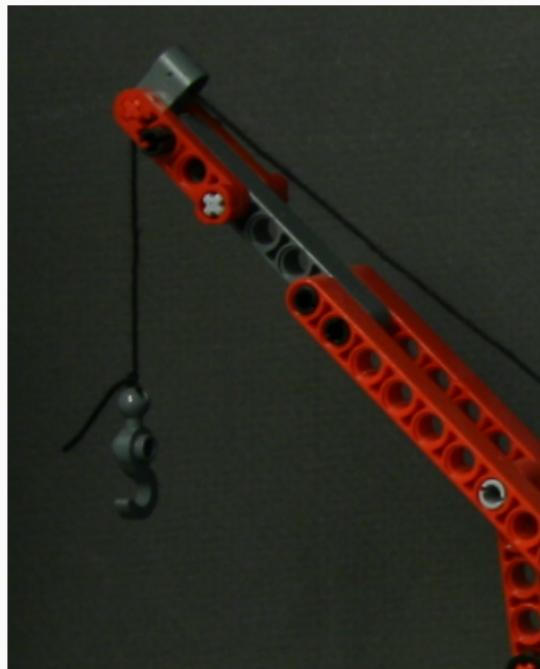


Simulation

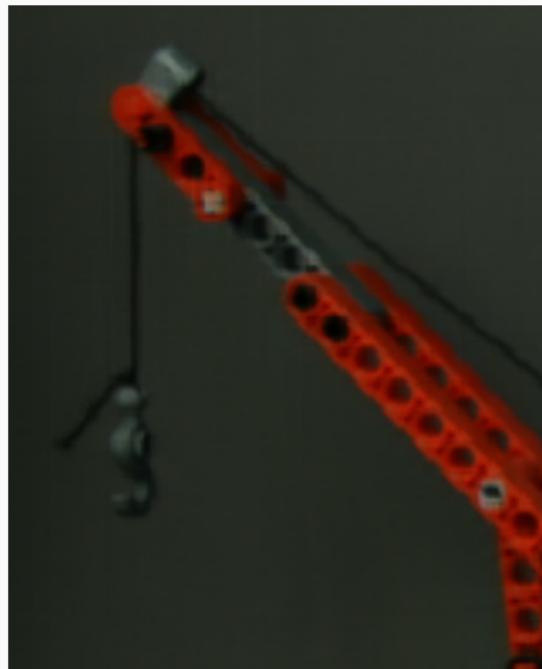


10 LAYERS

Original

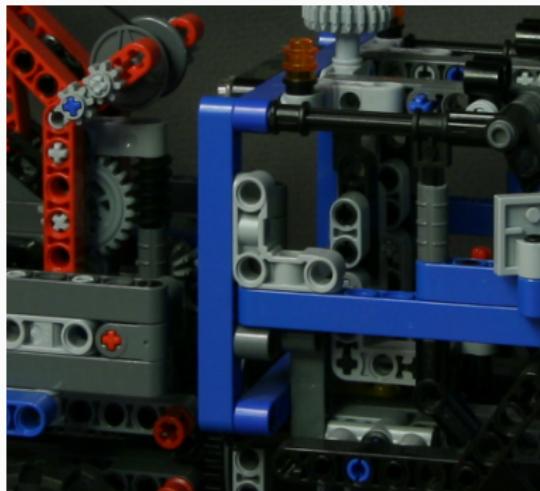


Simulation

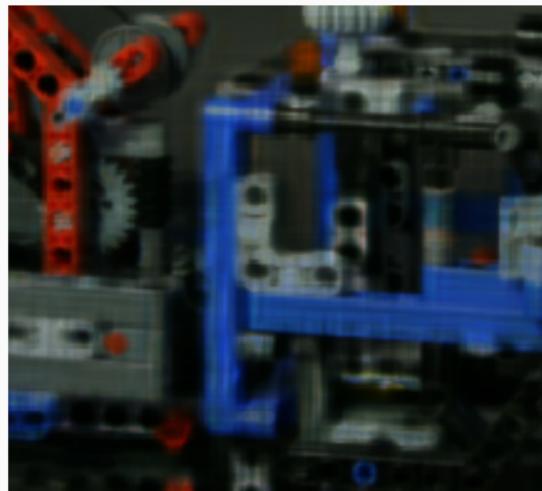


3 LAYERS

Original

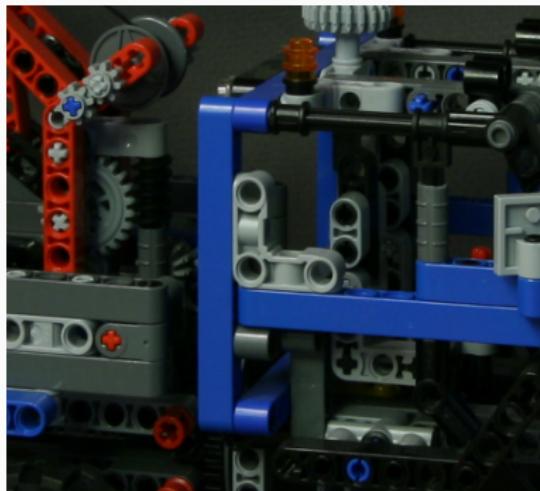


Simulation

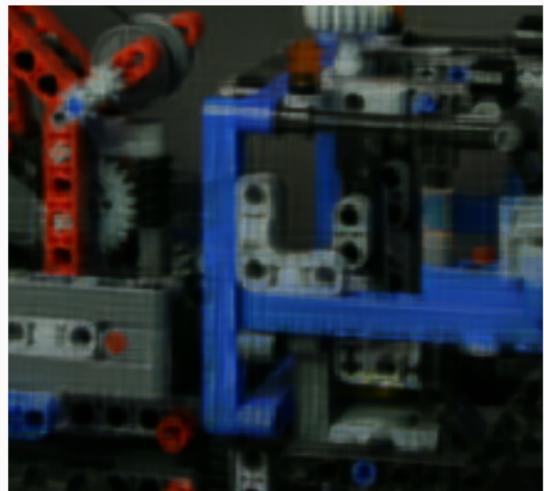


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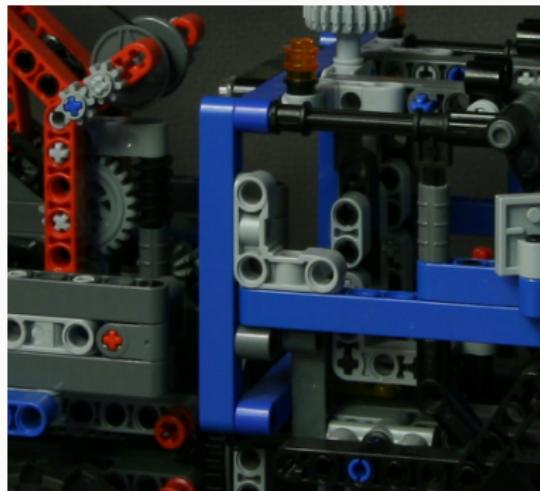


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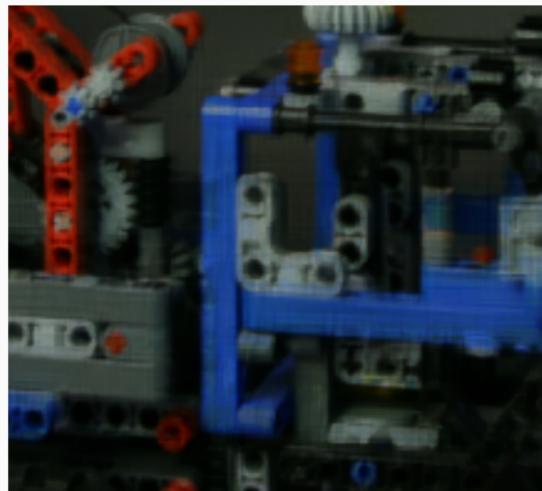


10 LAYERS

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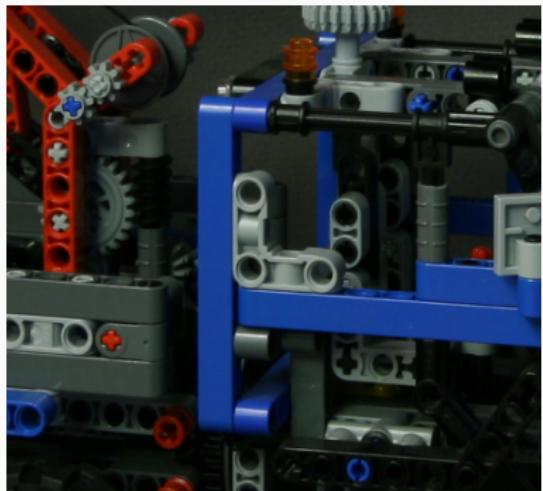


Simulation

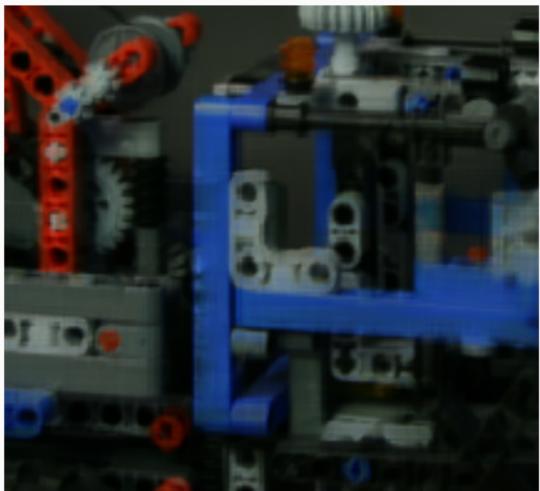


10 LAYERS, HIGHER ANGULAR RESOLUTION

Original



Simulation



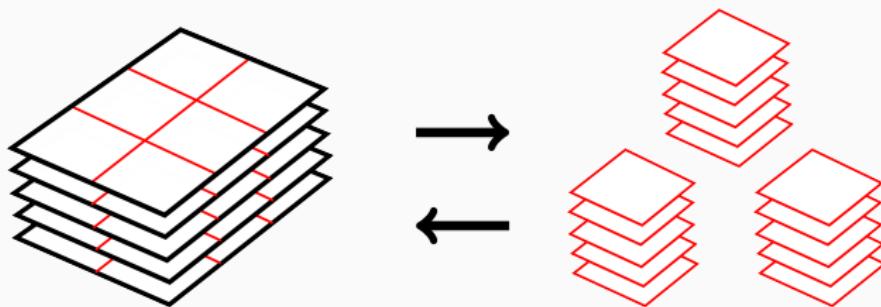
EXAMPLE: LEGO TRUCK



- 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

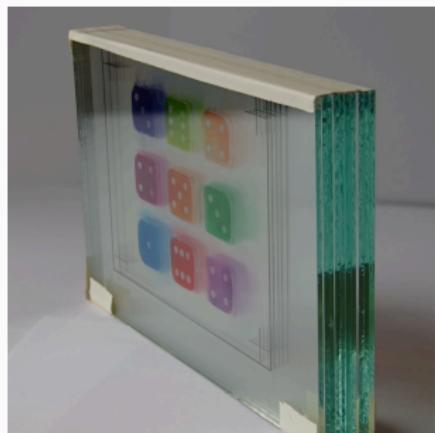
1. Slice attenuator into smaller pieces
2. Solve optimization problem for every slice
3. Reconnect the slices



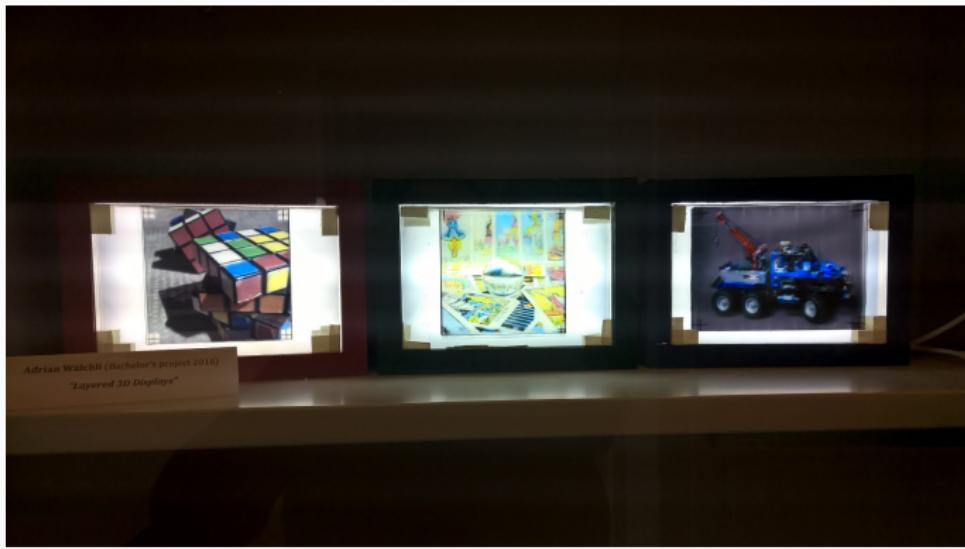
ATTENUATOR TILING

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

THE FINISHED PRODUCT



THE FINISHED PRODUCT

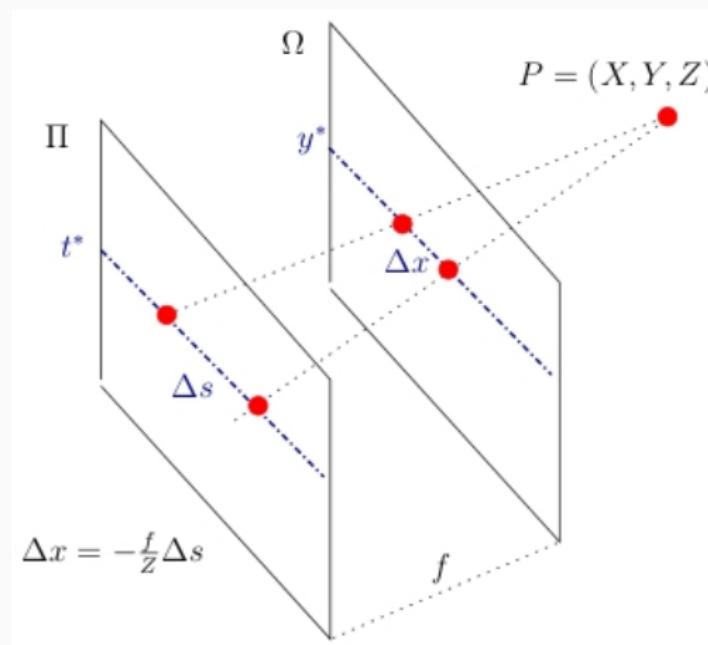


QUESTIONS

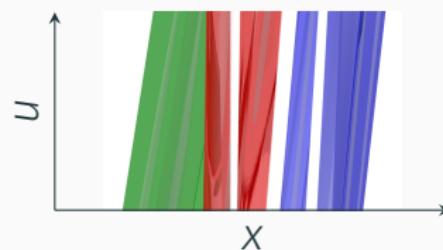
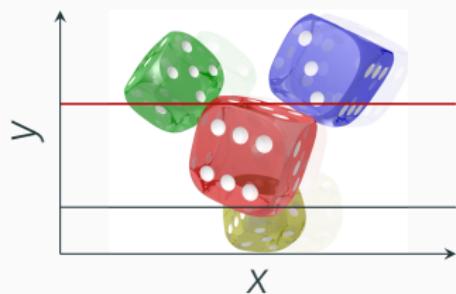
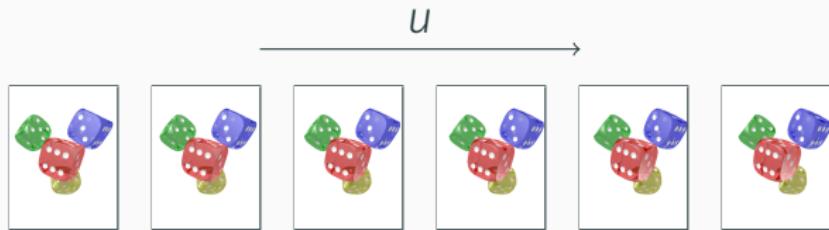
- Impact of more layers?
- Does thickness of display matter?
- What are the limitations?

ASSESSMENT

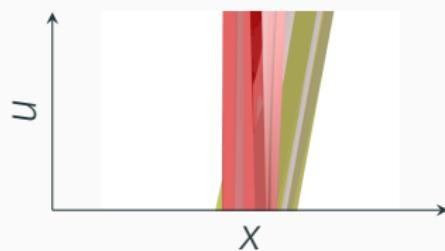
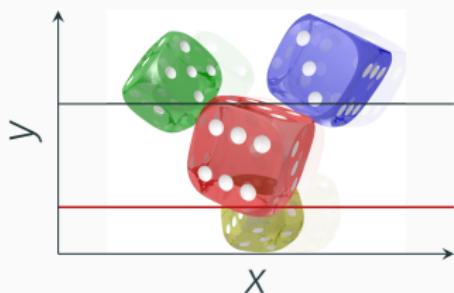
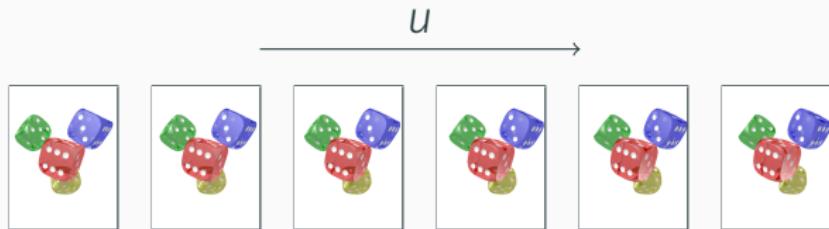
EPIPOLAR PLANE GEOMETRY



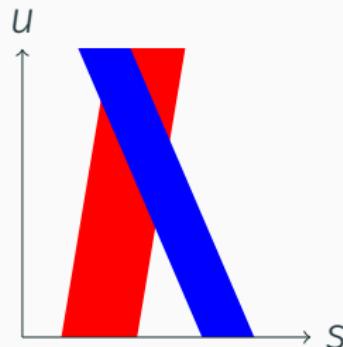
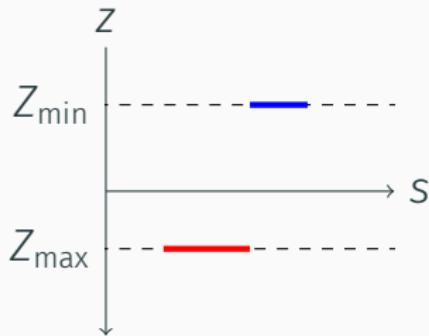
EPIPOLAR PLANE IMAGE



EPIPOLAR PLANE IMAGE

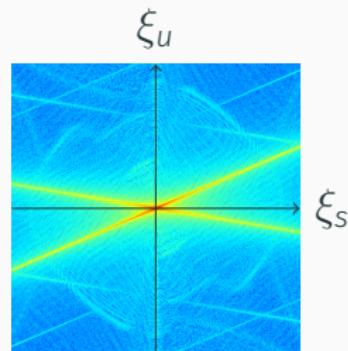
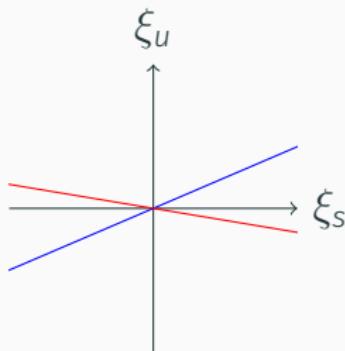


SPECTRAL ANALYSIS



$$\frac{du}{ds} = \frac{z - Z_u}{z - Z_s}$$

SPECTRAL ANALYSIS



$$\widehat{f}(\xi) = \int_{\mathbb{R}^n} f(x) e^{-2\pi i x \cdot \xi} dx$$

CONCLUSION

SUMMARY

ACKNOWLEDGEMENTS

Supervision by

Prof. Dr. Matthias Zwicker
Siavash Bigdeli

RESOURCES

Contact

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Thesis and Resources

github.com/awaelchli/bachelor_thesis

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