

ATTENUATION-BASED LIGHT FIELD DISPLAYS

Bachelor Thesis

Adrian Wälchli

June 3, 2016

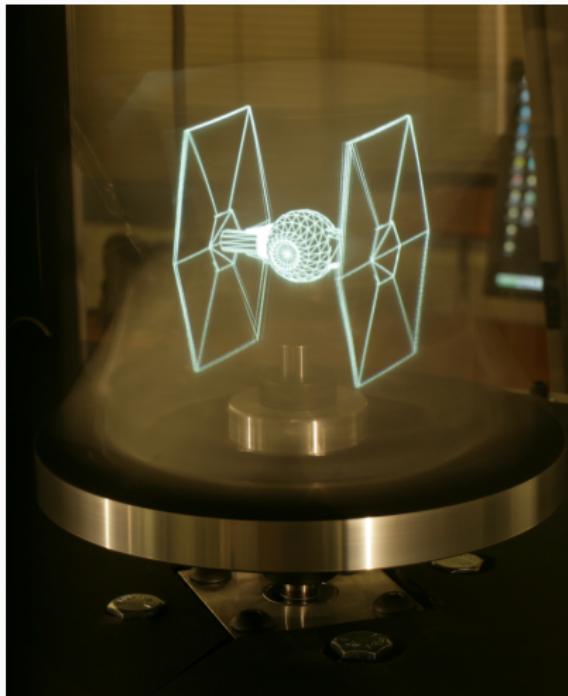
Institut für Informatik und angewandte Mathematik

OUTLINE

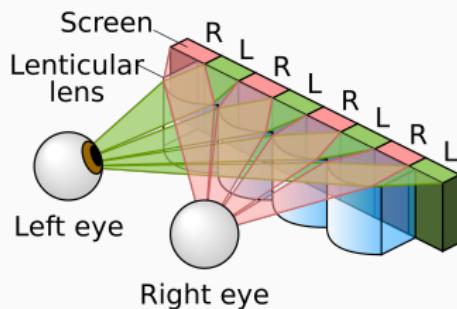
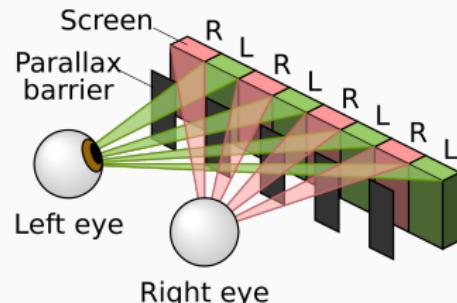
1. Introduction
2. Light Fields
3. Attenuation Display
4. Assessment
5. Conclusion

INTRODUCTION

EXISTING 3D DISPLAYS



Jones et al.

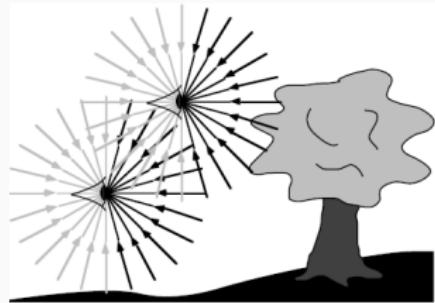


en.wikipedia.org/wiki/Autostereoscopy

LIGHT FIELDS

THE PLENOPTIC FUNCTION

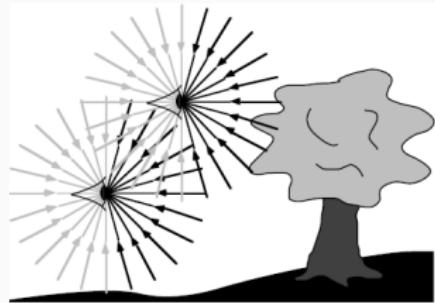
- Measures light in the world
- Position, viewing direction
- Time, Wavelength
- $P(x, y, z, \theta, \phi, t, \lambda)$
- 7D



Adelson and Bergen [1991]

THE PLENOPTIC FUNCTION

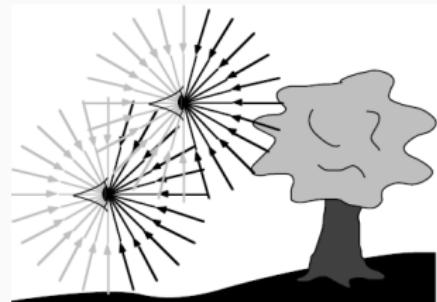
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THE PLENOPTIC FUNCTION

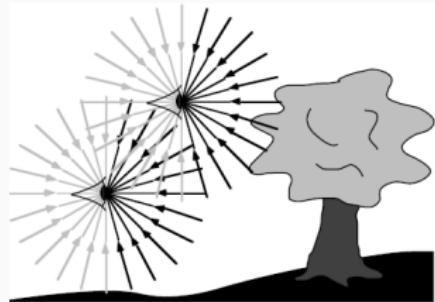
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THE PLENOPTIC FUNCTION

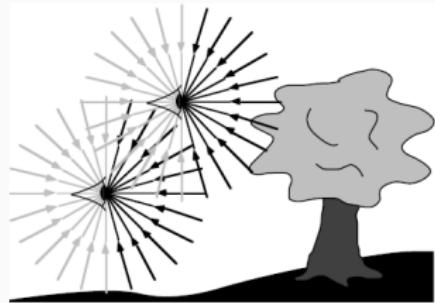
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Adelson and Bergen [1991]

THE PLENOPTIC FUNCTION

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

THE 4D LIGHT FIELD

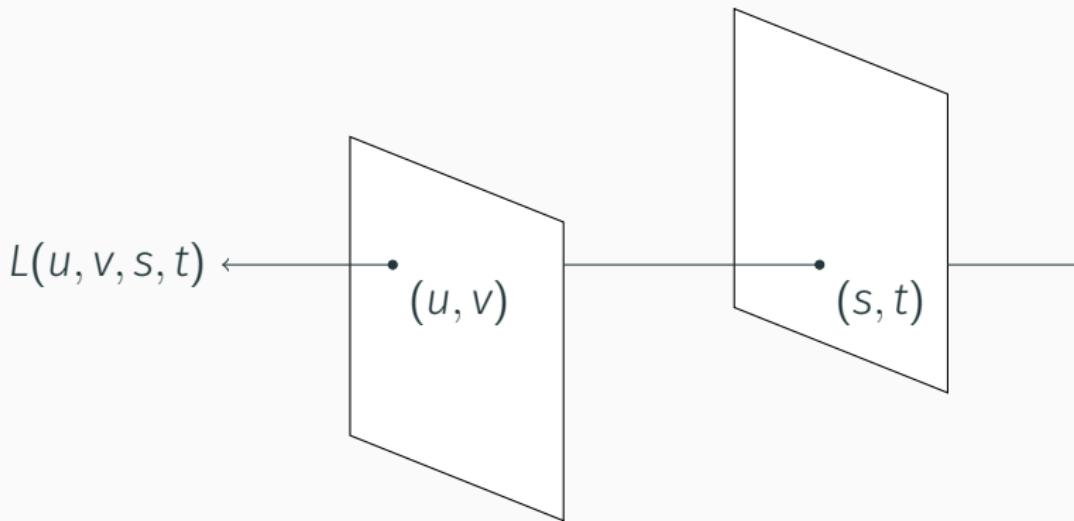
- Reduce dimensions of P
- $L(u, v, s, t)$
- Defined by two planes

THE 4D LIGHT FIELD

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THE 4D LIGHT FIELD

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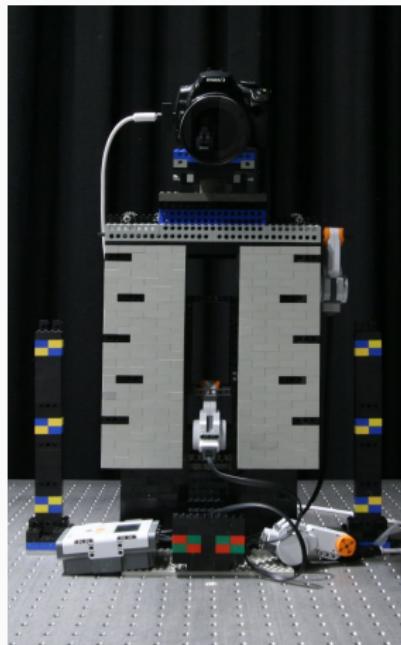


LIGHT FIELD ACQUISITION



Stanford camera array. Source: lightfield.stanford.edu

LIGHT FIELD ACQUISITION



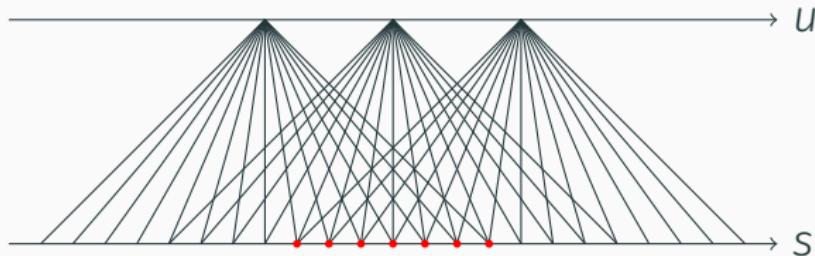
Lego gantry. Source: lightfield.stanford.edu

LIGHT FIELD ACQUISITION

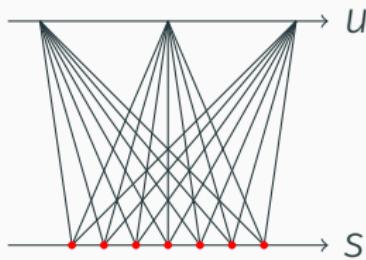
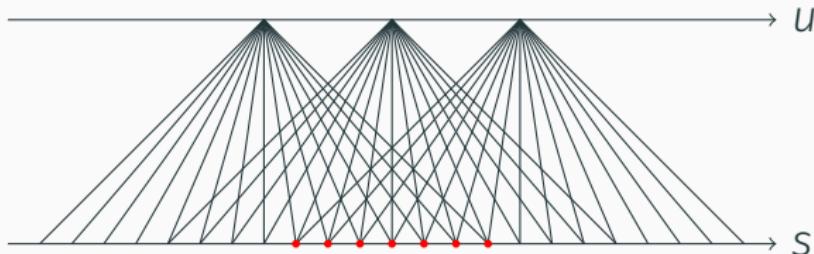


Lytro plenoptic camera. Source: de.wikipedia.org/wiki/Lytro

RE-PARAMETERIZATION TO GLOBAL COORDINATES



RE-PARAMETERIZATION TO GLOBAL COORDINATES



RE-PARAMETERIZATION TO GLOBAL COORDINATES

Raw



Rectified



RE-PARAMETERIZATION TO GLOBAL COORDINATES

Raw

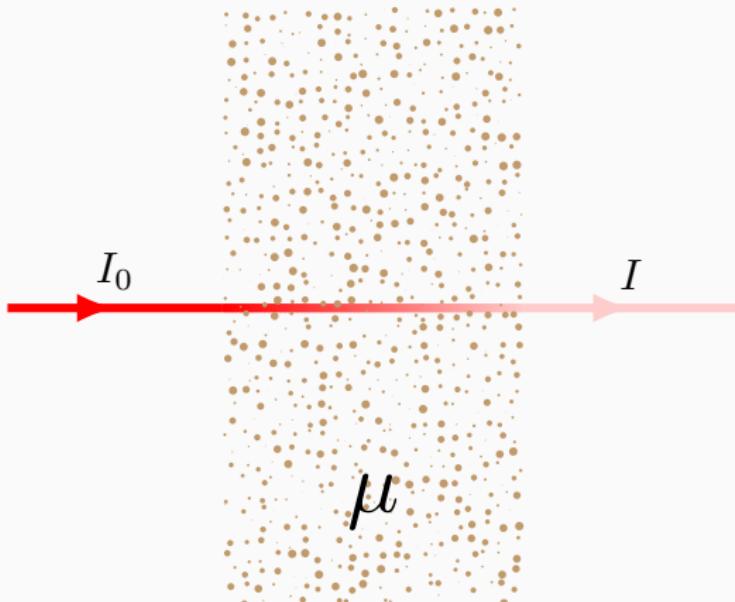


Rectified



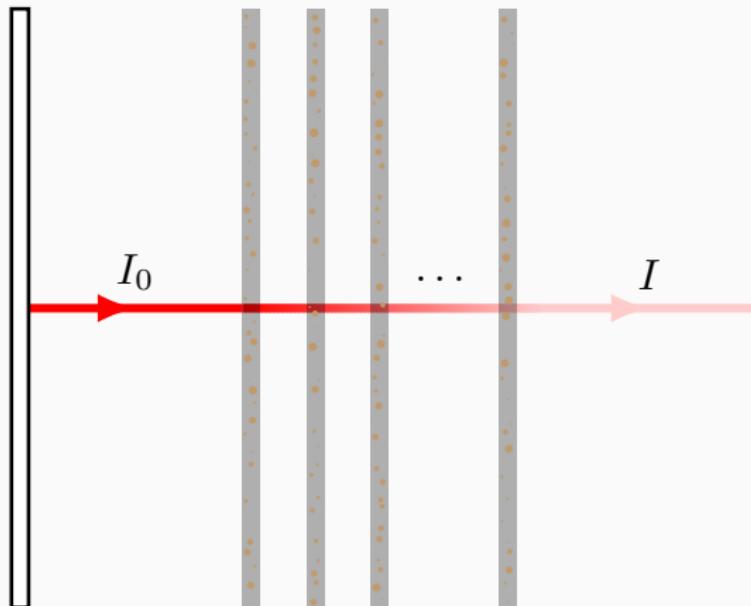
ATTENUATION DISPLAY

THE BEER-LAMBERT LAW



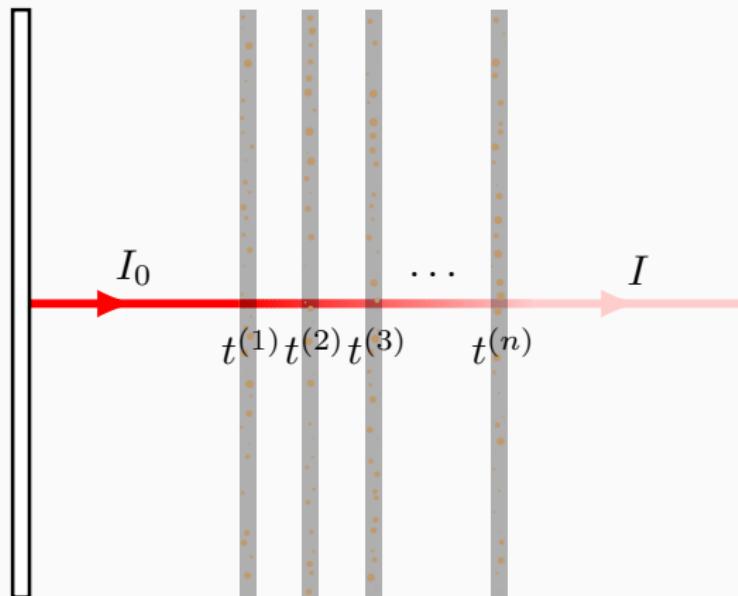
$$\frac{I}{I_0} = \exp \left(- \int_{\mathcal{R}} \mu(r) dr \right)$$

THE BEER-LAMBERT LAW



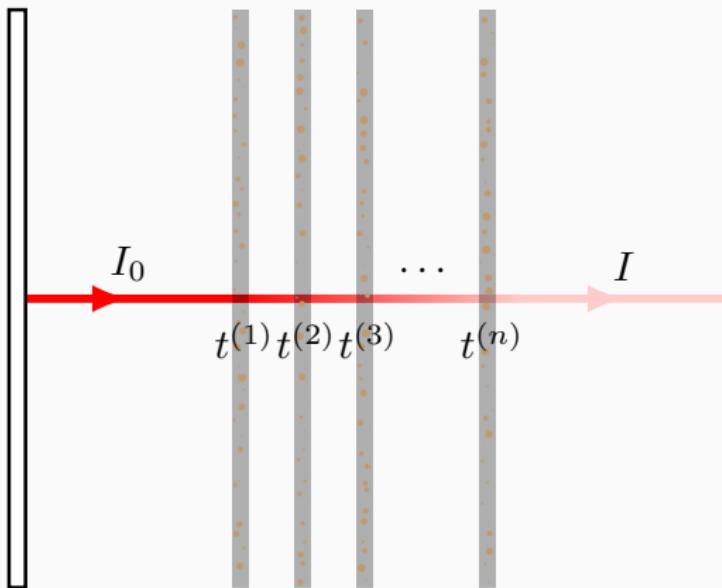
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THE BEER-LAMBERT LAW



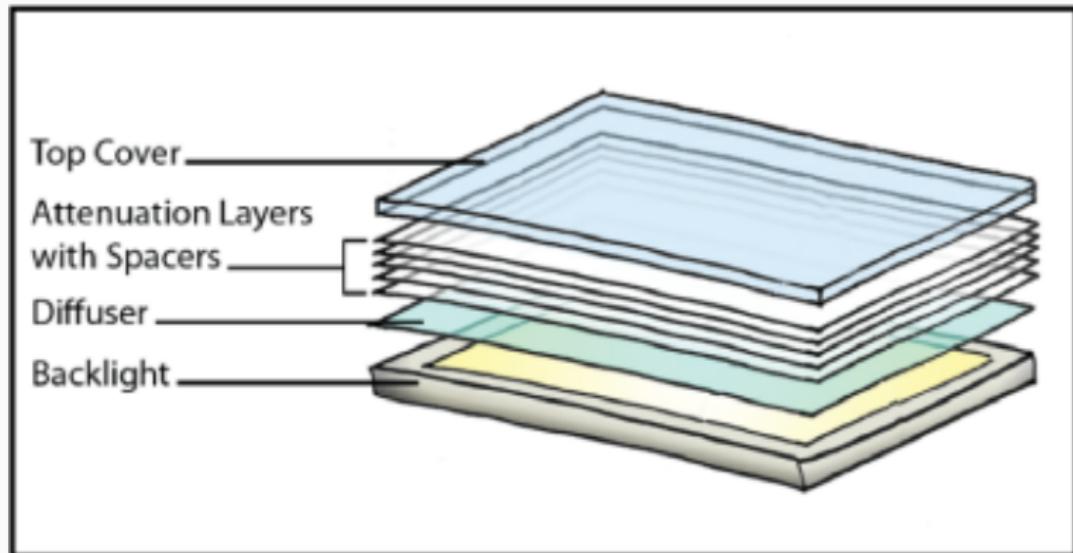
$$\frac{I}{I_0} = \exp \left(- \int_{\mathcal{R}} \mu(r) dr \right) = \prod_i t^{(i)}$$

THE BEER-LAMBERT LAW



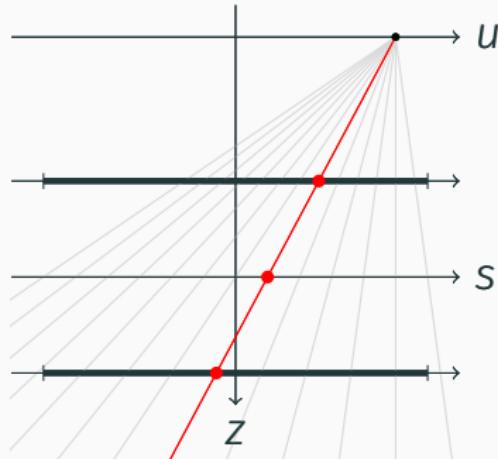
$$\frac{I}{I_0} = \exp \left(- \int_{\mathcal{R}} \mu(r) dr \right) = \prod_i t^{(i)} = \exp \left(- \sum_i a^{(i)} \right)$$

DISPLAY ARCHITECTURE



Wetzstein et al. [2011]

LIGHT TRANSMISSION



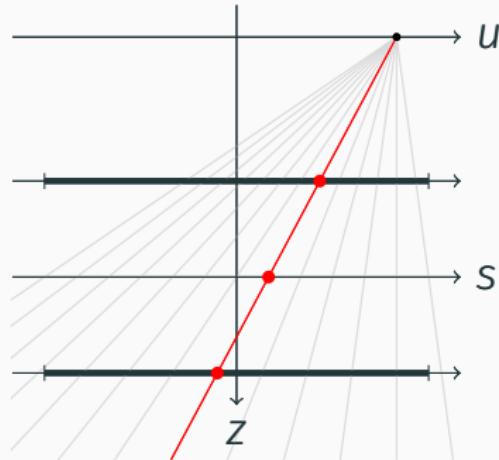
$$L_m = L_0 \prod_{n=1}^N t^{(n)}(h(m, n))$$

L_m Color of ray m

t Transmission

h Intersection

LIGHT TRANSMISSION



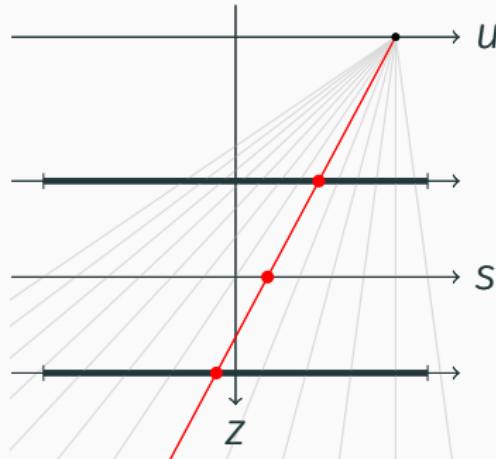
$$L_m = L_0 \prod_{n=1}^N t^{(n)}(h(m, n))$$

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LIGHT TRANSMISSION



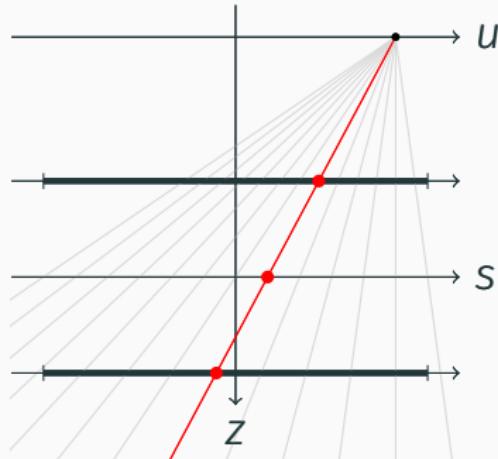
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LIGHT TRANSMISSION



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

L_m Color of ray m

t Transmission

h Intersection

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

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

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

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

THE EQUATION

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

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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



$6 \times 6 \times 480 \times 640$
 ~ 10 minutes

EXAMPLE: LEGO TRUCK

Original



Simulation



Show enlarged parts of images
Compare to more layers!

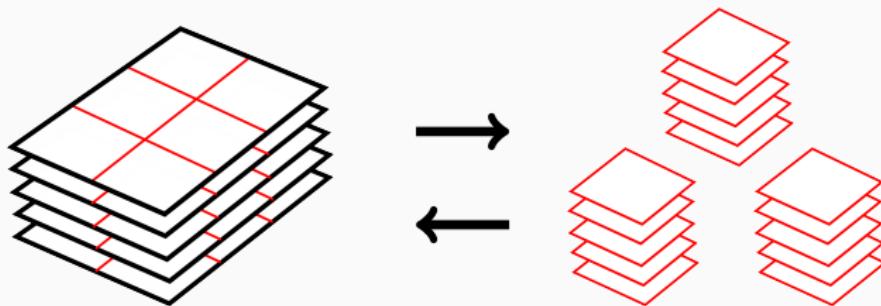
EXAMPLE: LEGO TRUCK



- 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

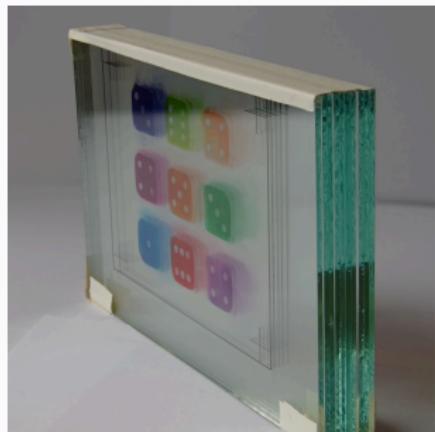
1. Slice attenuator into smaller pieces
2. Solve optimization problem for every slice
3. Reconnect the slices



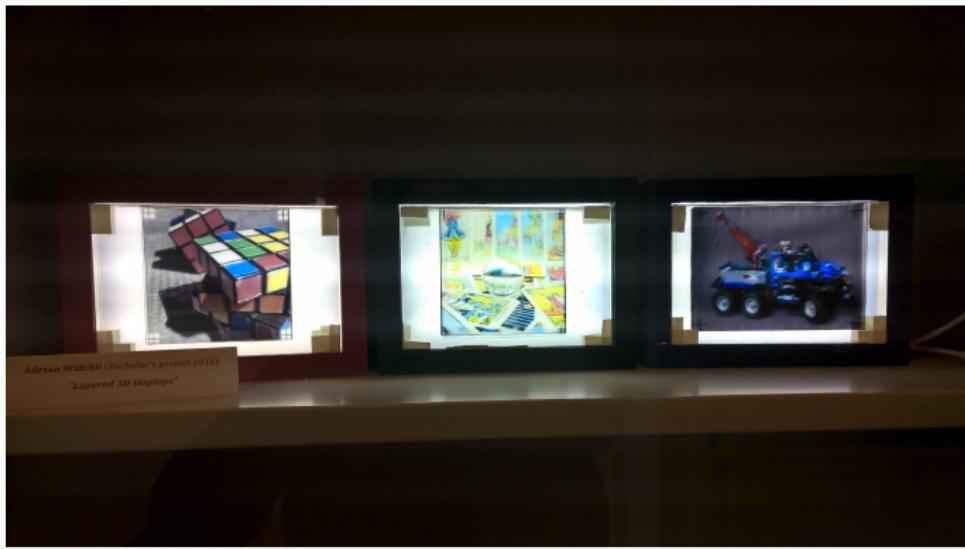
ATTENUATOR TILING

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

THE FINISHED PRODUCT



THE FINISHED PRODUCT

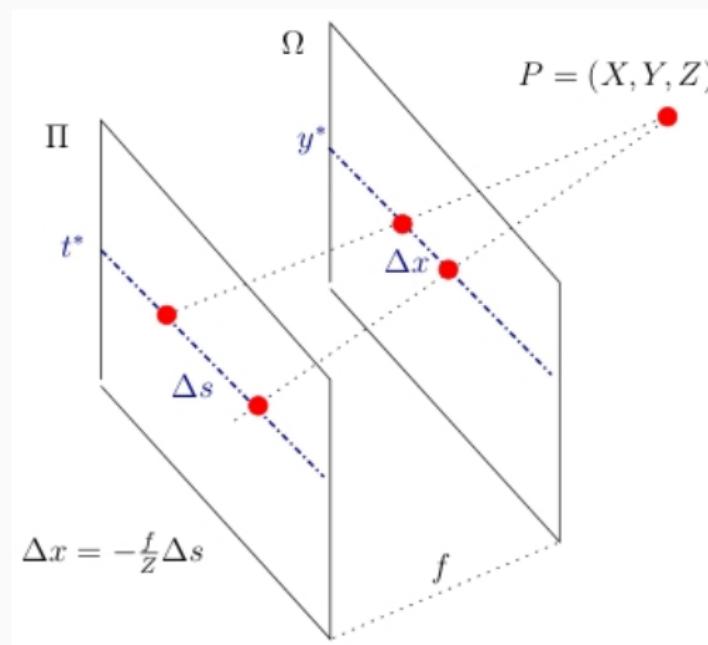


QUESTIONS

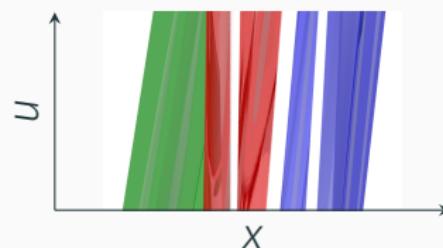
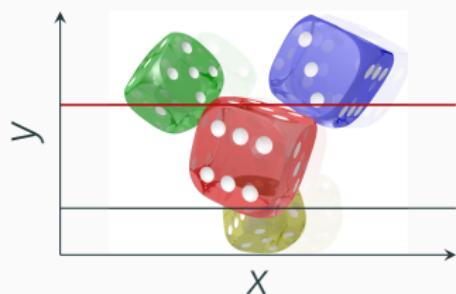
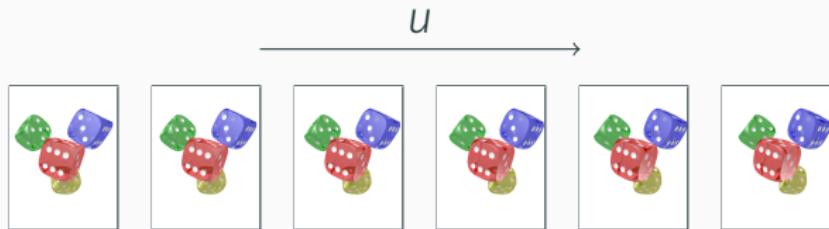
- Impact of more layers?
- Does thickness of display matter?
- What are the limitations?

ASSESSMENT

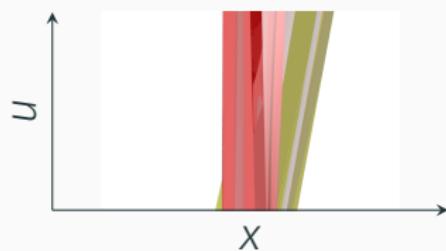
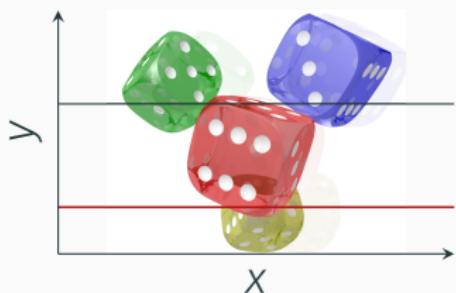
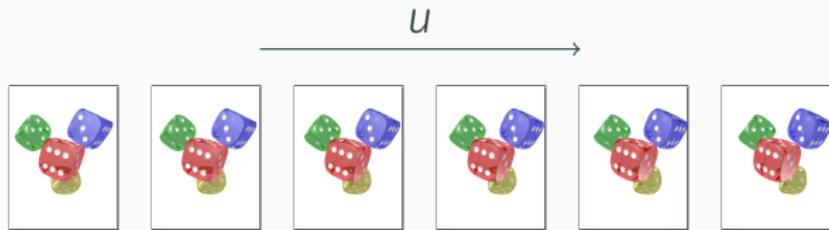
EPIPOLAR PLANE GEOMETRY



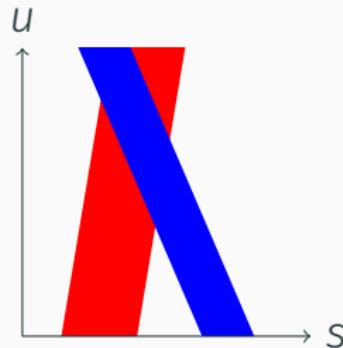
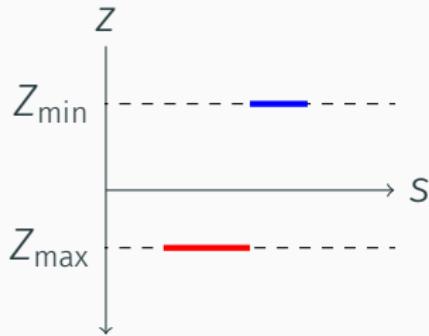
EPIPOLAR PLANE IMAGE



EPIPOLAR PLANE IMAGE

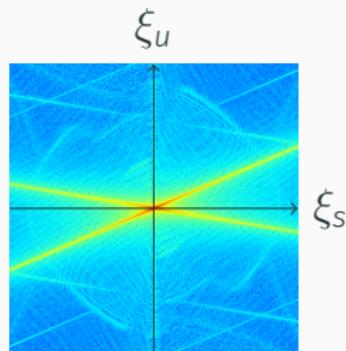
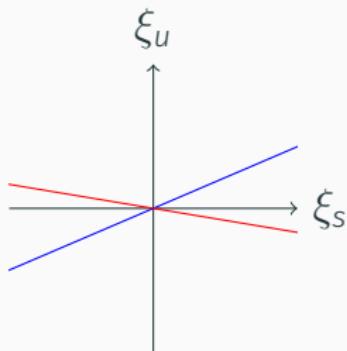


SPECTRAL ANALYSIS



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

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

adrian.waelchli@students.unibe.ch

Thesis and Resources

github.com/awaelchli/bachelor_thesis

REFERENCES

- E. H. Adelson and J. Bergen. The plenoptic function and the elements of early vision. *Computational Models of Visual Processing*, pages 3–20, 1991.
- A. H. Andersen and A. C. Kak. Simultaneous algebraic reconstruction technique (SART): A superior implementation of the ART algorithm. *Ultrasonic Imaging*, 6(1):81–94, 1984.
- B. G. Blundell and A. J. Schwarz. *Volumetric Three-Dimensional Display Systems*. Wiley-VCH, Mar. 2000. ISBN 0-471-23928-3.
- R. C. Bolles, H. H. Baker, and D. H. Marimont. Epipolar-plane image analysis: An approach to determining structure from motion. *International Journal of Computer Vision*, pages 7–55, 1987.

The *mtheme* is a Beamer theme with minimal visual noise inspired by the HSRM Beamer Theme by Benjamin Weiss.

Enable the theme by loading

```
\documentclass{beamer}  
\usepackage{m}
```

Note, that you have to have Mozilla's *Fira Sans* font and XeTeX installed to enjoy this wonderful typography.

SECTIONS

Sections group slides of the same topic

```
\section{Elements}
```

for which the *mtheme* provides a nice progress indicator

...

TYPOGRAPHY

The theme provides sensible defaults to `\emph{emphasis}` text, `\alert{accent}` parts or show `\textbf{bold}` re-

becomes

The theme provides sensible defaults to *emphasis* text,
accent parts or show **bold** results.

LISTS

Items	Enumerations
· Milk	1. First,
· Eggs	2. Second and
· Potatos	3. Last.

DESCRIPTIONS

PowerPoint Meeh.

Beamer Yeeeha.

ANIMATION

- This is important

ANIMATION

- This is important
- Now this

ANIMATION

- This is important
- Now this
- And now this

ANIMATION

- This is really important
- Now this
- And now this

FIGURES

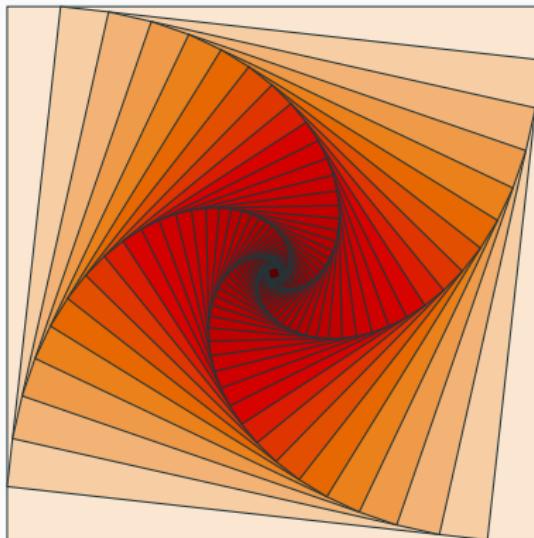


Figure: Rotated square from texample.net.

TABLES

Table: Largest cities in the world (source: Wikipedia)

City	Population
Mexico City	20,116,842
Shanghai	19,210,000
Peking	15,796,450
Istanbul	14,160,467

BLOCKS

This is a block title

This is soothing.

$$e = \lim_{n \rightarrow \infty} \left(1 + \frac{1}{n}\right)^n$$

QUOTES

Veni, Vidi, Vici

plainDark background



SUMMARY

Get the source of this theme and the demo presentation from

github.com/matze/mtheme

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plainQuestions?