VO Rendering
SS 2010

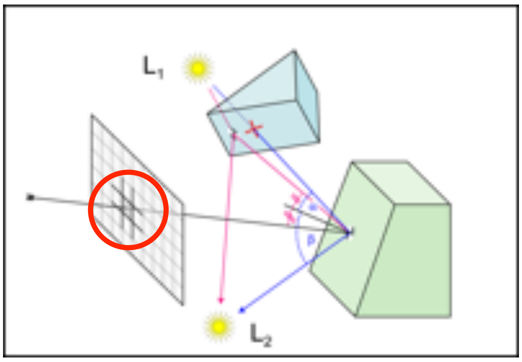
Unit 5: Spectral Rendering

Sources:

Overview

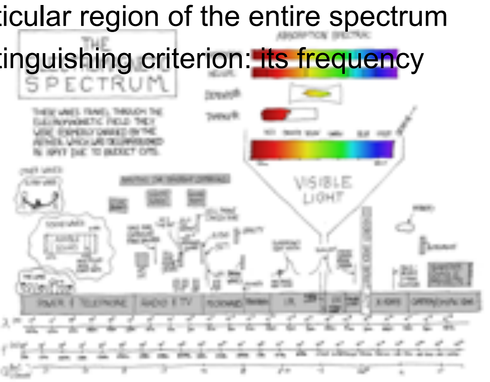
- Quantities used for light calculations in ray tracers
  - Colour space vs. Spectral rendering
- Spectral Representations
- Spectral Effects

What do we compute here?



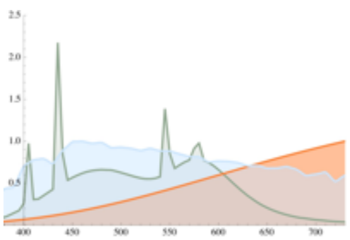
Light – Basic Properties

- Visible light is electromagnetic radiation in a particular region of the entire spectrum
- Distinguishing criterion: its frequency

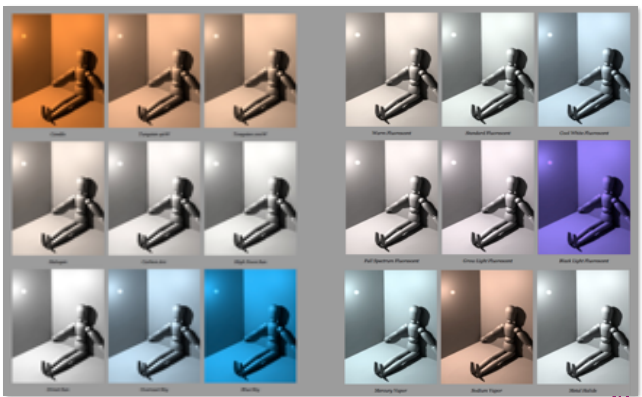


Light – Spectrum

- Normally, a ray of light contains many different waves with individual frequencies
- The associated distribution of wavelength intensities per wavelength is referred to as the spectrum of a given ray or lightsource



Lighsources Are Not White



http://planetpixelemporium.com/tutorialpages/light.html

Shading Calculation Quantities

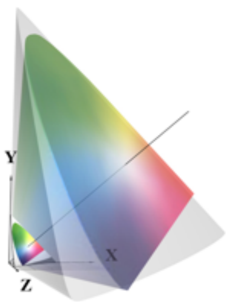
- Two main types of rendering engine exist:
- Conventional colour space based renderers
  - RGB space (majority)
  - CIE XYZ space
- Spectral Renderers
  - Very few products available
    - Maxwell renderer, LuxRender, Indigo, …
    - PBRT 2.0 (Summer 2010)
    - Often few details of internal workings known

RGB (Tristimulus) Rendering

- Three wavelength (corresponding to red, green, blue) define light source and material properties
- Process 3 samples separately throughout rendering calculation
- Device dependent
- RGB representation not ideal

CIE XYZ

- A tristimulus colour system derived from RGB and based on imaginary primaries referred to as XYZ was defined in 1931
- All three are outside the human visual gamut
- Hence only positive XYZ values can occur
- Valid colours a subspace of the first octant - XYZ not closed under multiplication!

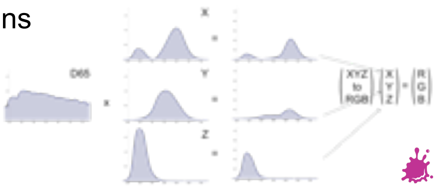


CIE XYZ vs.RGB

- Problem does not exist for RGB spaces:
  - They occupy the entire first octant, are closed under multiplication
- RGB cannot represent all visible colours
  - XYZ is no alternative due to the discussed problems!
  - Older literature still recommends using XYZ!
- Alternative: **Spectral Rendering**

Spectral Rendering Steps

- (Get spectrum)
- Prepare spectrum
- Process spectral samples separately throughout rendering calculation
- Compute final display color using CIE color matching functions and standard transformations



Step 1: Measuring Spectra

- Spectra can be measured with a spectroradiometer
- First step: Calibration of measurement device
- Reference standard needed
  - A source of known emissivity
    - Blackbody
    - Reference Lamps
  - A detector with an exactly known response
  - A surface with exactly known reflectivity

Reference Lamps

- Specially designed lamps of known SPD as standards
- Repeatability of lamp manufacturing is good enough to duplicate these standard lamps
- Tungsten halogen lamps of 1000, 200 and 45 W was developed for general use
- Burning time of these devices is limited

Gretag Macbeth Spectrolino

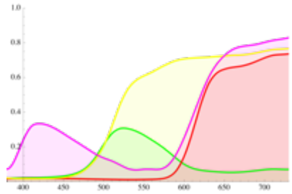
- Handheld device, nowadays called iOne
- 10nm resolution, 380 to 780nm
- Not particularly useful without the accompanying software
- Serial interface fully documented
- Less repeatability, less inter-device agreement than previous device
- Several similar devices are being offered by the industry

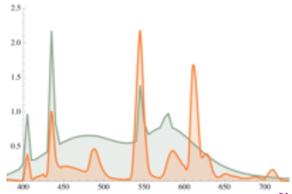
Spectroscan

- Used for fast, routine scanning of opaque and transparent colour charts and printouts
- Main use: colour charts are created during printing equipment calibration
- A Spectrolino-type device is used as measurement device

Step 2: Preparation

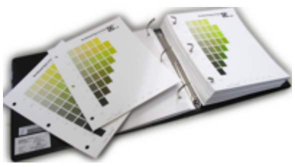
- Represent light as frequency distribution
  - Usually smooth
  - Sometimes sharp peaks (fluorescent lightsources, spectral colours)
- How do we store the data?





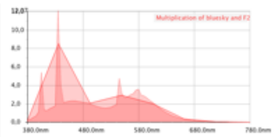
Colour Collections

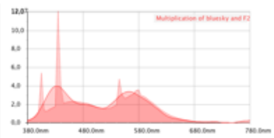
- Munsell Book of Color
  - Based on the Munsell system
  - 1269 colours
- NCS Colour Atlas
  - 1750 colours
- RAL
  - RAL Classic: 190 colours
  - RAL Design: 1714 colours

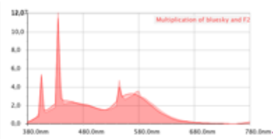


How to discritize these distributions?

- Regularly sampled spectra
  - Aliasing
  - Fast Convolution
- Linear or higher order representations
  - Efficient storage
  - Slow convolution
- Hybrids
  - Slow, but even more efficient w/r to storage

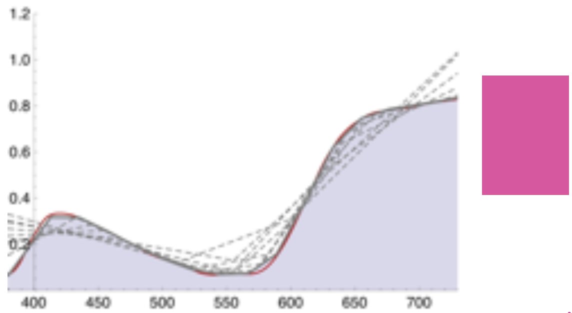






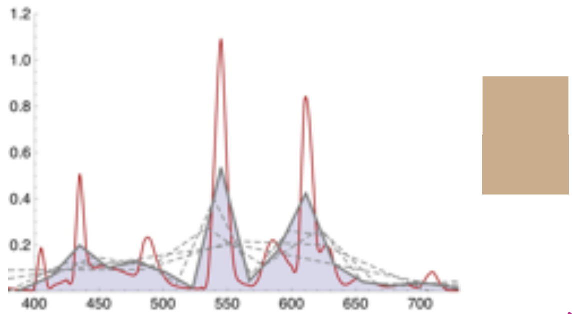
How Many Samples Do We Need?

- Depends on spectrum

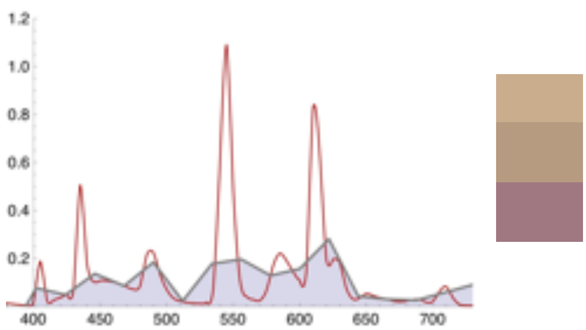


Fluorescent Spectra (CIE F11)

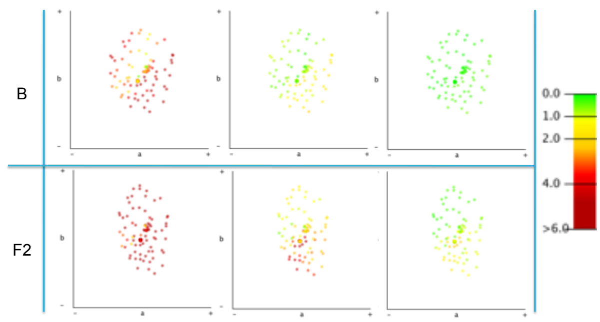
- More samples are needed for spectra with sharp peaks



CIE F11 - Representations



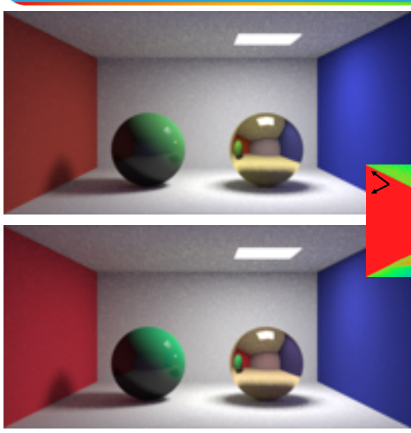
Error Map Sampling Points



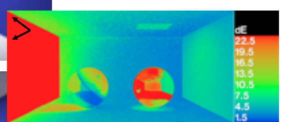
Spectral vs. RGB

- RGB Rendering
  + Fast, widely supported
  - Limited accuracy (sharp spectra, different illuminants)
- Spectral Rendering
  + Accuracy, prediction of nature possible
  - High cost, Aliasing, data mixing, input data, more complicated to write

Comparison Spectral/Tristimulus

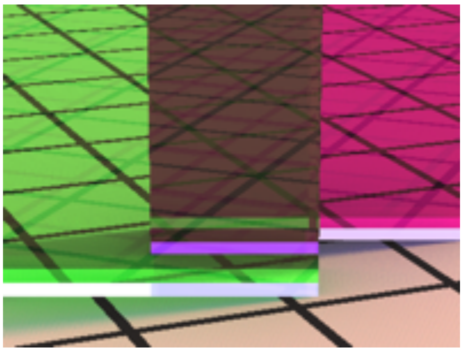


Full spectral rendering
(Fluorescent source)



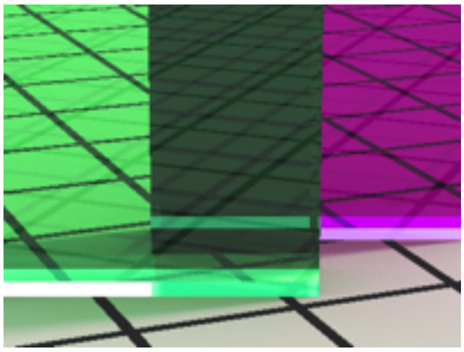
Naïve tristimulus rendering
(CIE *XYZ*)

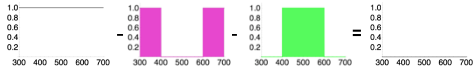
RGB Rendering



(255,255,255) - (147,51,187) - (70,106,148) = (77,0,39)

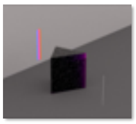
16 Spectral Samples





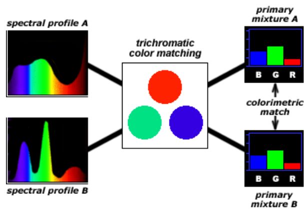
Spectral Effects

- Effects that require spectral representation of light:
  - Metamerism
  - Volume absorption
  - Dispersion (prisms, rainbows)
  - Interference and diffraction
  - Fluorescent materials and light sources
- RGB insufficient to accurately reproduce such effects



Metamerism

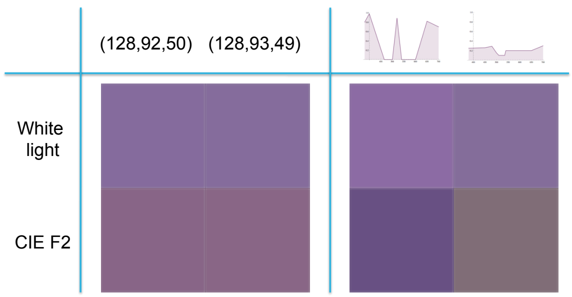
- Occurs frequently
- One of the most interesting problems in the paint and pigment industry
- Makes rediction of object appearance by colourspace renderer impossible



Metamerism Example

4 patches of different types of blue paint, illuminated with white LED and a quartz-halogen white light

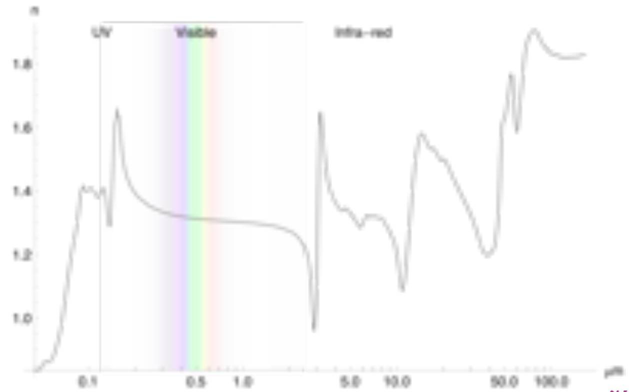
RGB vs. Spectral: Metamerism



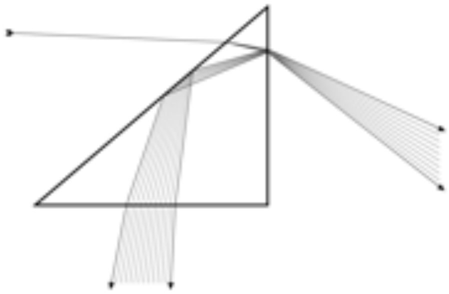
Dispersion

- Wavelength dependency of interference and refraction
  - Linear for interference
  - Nonlinear for refraction
- Sellmeier coefficients for glass and crystals characterize behaviour

IOR Example



Intersection Geometry



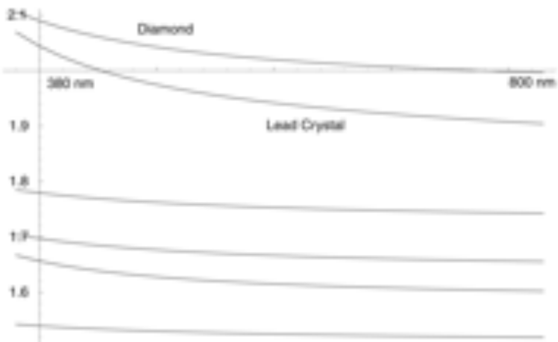
Sellmeier's Formula

- Approximation to dispersion curves of real materials

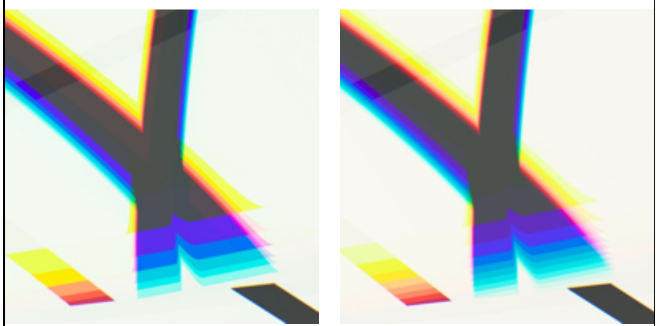
$$n_\lambda^2 = 1 + \sum_{i=0}^{n} \frac{A_i \lambda^2}{\lambda^2 - \lambda_i^2}$$

- Sum of quadratic terms with empirical coefficients
- Alternative: Cauchy's formula

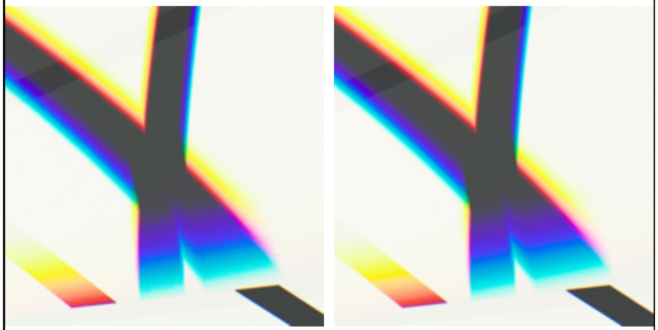
Sample Dispersions



Dispersion Sampling 1



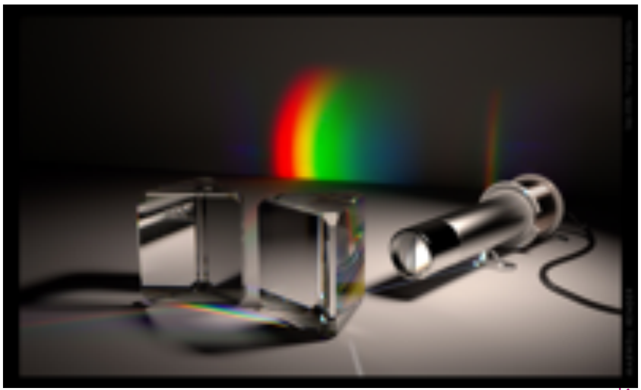
Dispersion Sampling 2



Dispersion Sampling

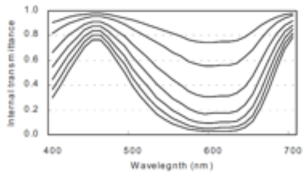
- Either:
  - Breadth-first in a normal raytracer (turning it into a partial distribution raytracer)
    - Regular sampling yields aliasing artifacts
    - Stochastic jitter by a single offset for all channels
  - Single wavelength in a path tracer (but choose wavelength only once!)

Full Dispersion Example



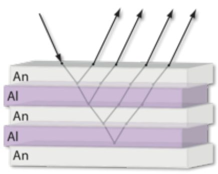
Volume Absorption

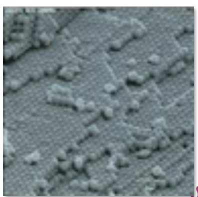
- Prediction of absorption in transparent materials difficult for colourspace renderers
- Deepening of colours not easy to match in colour space



Structural Colour

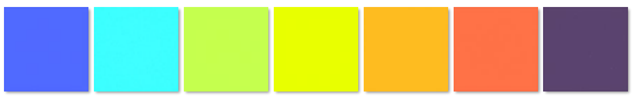
- Very small structures can evoke effects that depend on the wavelength of the incident light
- Interference: Subtly different propagation times lead to selective cancellation of reinforcement
- Diffraction in small structure



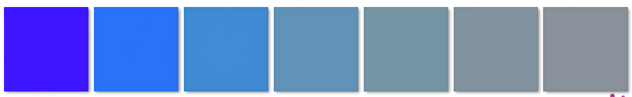


Interference: Influence of the Structure

- Shifts toward longer wavelengths with increasing thickness

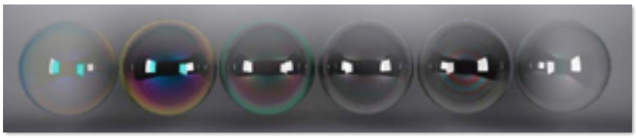


- With increasing variance, effect vanishes

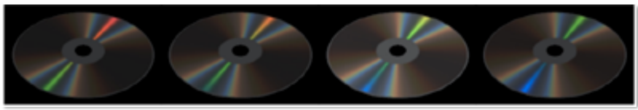


Renderings

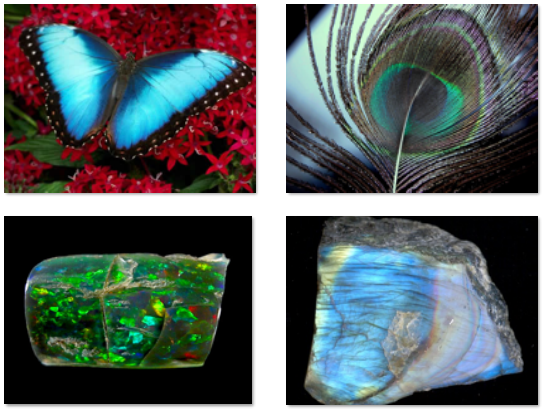
- Thin Layers



- Diffraction



Interference and Diffraction in Nature

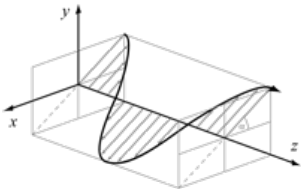


Polarisation Support

- Polarised light occurs quite frequently in nature
- Essential for predictive rendering of
  - crystals and transparent objects
  - outdoor scenes
- Sometimes visible with the naked eye
- Most scenes look plausible without it

Polarisation: Basics

- Normally each sample of a spectrum encodes just radiant intensity (or attenuation)
- Real electro-magnetic waves contain more information

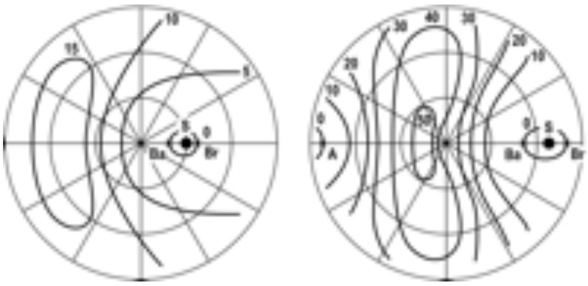


- Polarisation state can be described by taking the (x, y) components of the wavetrain and their phase difference into account

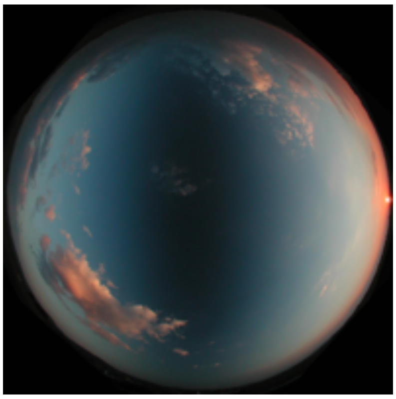
Reflection Without Filter

Reflection With Polarising Filter

Skylight Polarisation

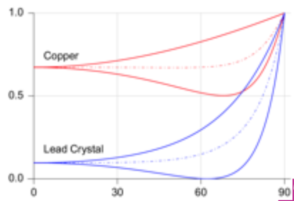


Sky Polarisation Pattern



Why Does This Matter?

- Specular surfaces are governed by the Fresnel terms
- These show a large discrepancy for different orientations of already polarised incoming light – like e.g. skylight
- Specular scenes with water, glass, car roofs etc. all are affected

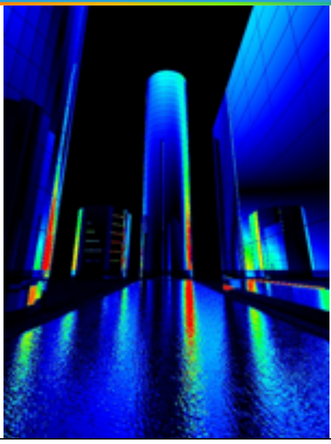


Specular Surfaces

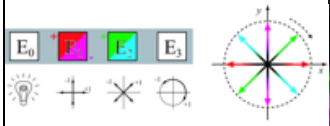
Nonpolarising Renderer

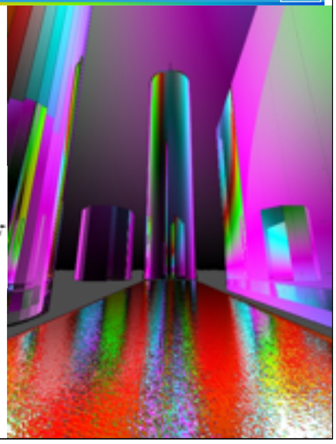
Polarised Skylight

Difference



Polarisation Falsecolour





Light vs. Attenuation

- Two types of energy-related entities exist in a rendering system:
  - **Radiant intensity**, e.g. emissions from lightsources („light")
  - **Attenuation**, i.e. the influence of surfaces and media („importance", or „filter")
- In most rendering systems they are not properly distinguished, and use the same data structures (i.e. RGB values)
- Both polarisation and fluorescence break this

Describing Polarisation #1

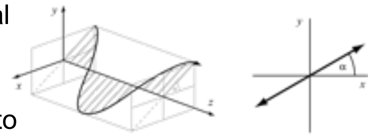
- Light:
  Coherency Matrices (CM)
  - 2 x 2 Hermitian matrix
  - Mathematically elegant
  - Complex components
  - Trace = intensity

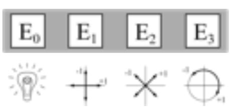
$$J = \begin{pmatrix} \langle E_x E_x^* \rangle & \langle E_x E_y^* \rangle \\ \langle E_y E_x^* \rangle & \langle E_y E_y^* \rangle \end{pmatrix}$$

- Filter (importance):
  CM modifiers
  - 2 x 2 complex values

Describing Polarization #2a

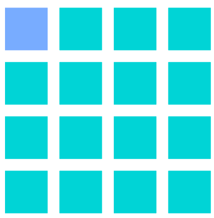
- Light: **Stokes vectors**
  - 4-vector with real elements
  - Range of first component is 0 to infinity, others -1 to 1
  - Blends in with nonpolarizing implementations





Describing Polarisation #2b

- Filter:
  Müller matrices
- 4 x 4 real matrices
- Element (0,0) is non-polarising filter
- Interaction of all components with each other is encoded



Filter examples

i	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

depolarizer

i	0	0	0
0	i	0	0
0	0	i	0
0	0	0	i

plain filter

	1	cos 2ϕ	sin 2ϕ	0
1 -- 2	cos 2ϕ	cos² 2ϕ	cos 2ϕ · sin 2ϕ	0
	sin 2ϕ	cos 2ϕ · sin 2ϕ	sin² 2ϕ	0
	0	0	0	0

ideal linear polarizer

Rendering VO Unit 4

The End

Thank you for your attention!