Diffraction Shaders

From microsurface models to reflection models

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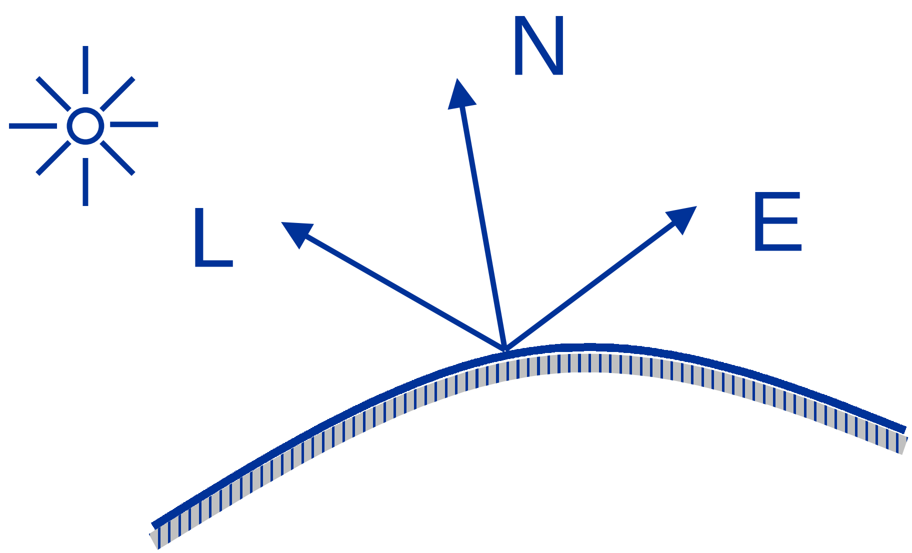
Alias | wavefront
Seattle, WA USA

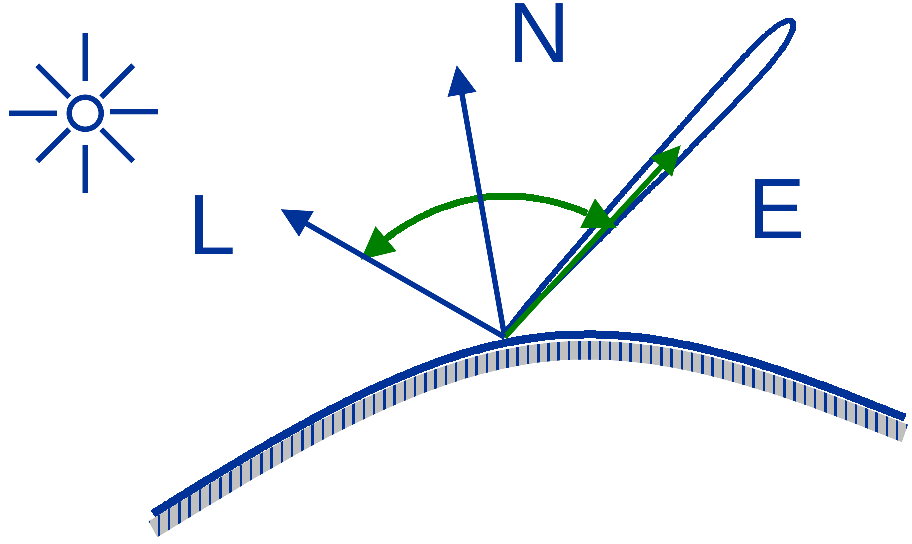
Shaders

Model reflection from surfaces



Shaders

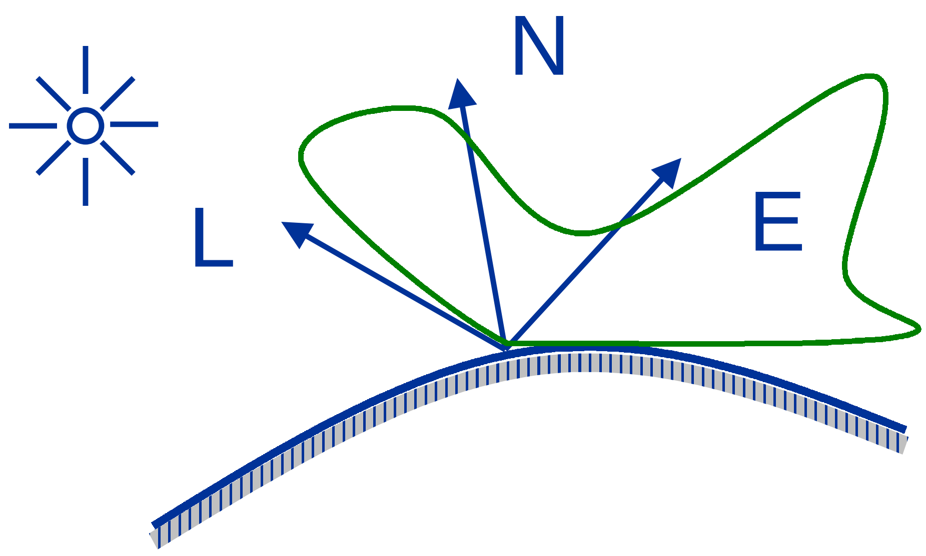
Perfectly smooth surface



Not very interesting

Shaders

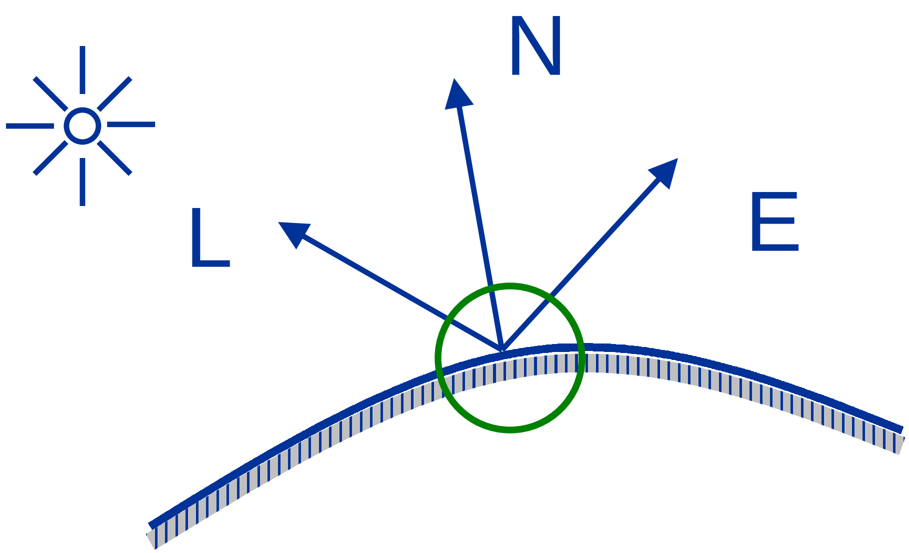
Rough surfaces



More interesting

Shaders

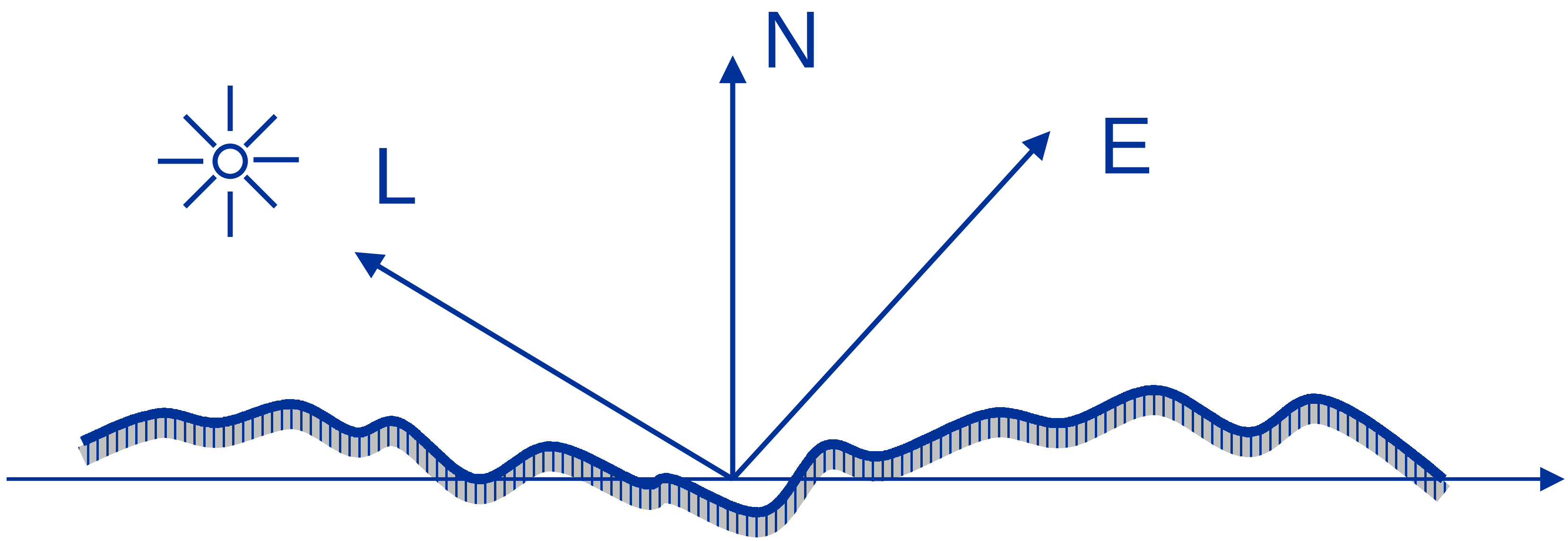
Rough surfaces



Zoom in on microstructure

Shaders

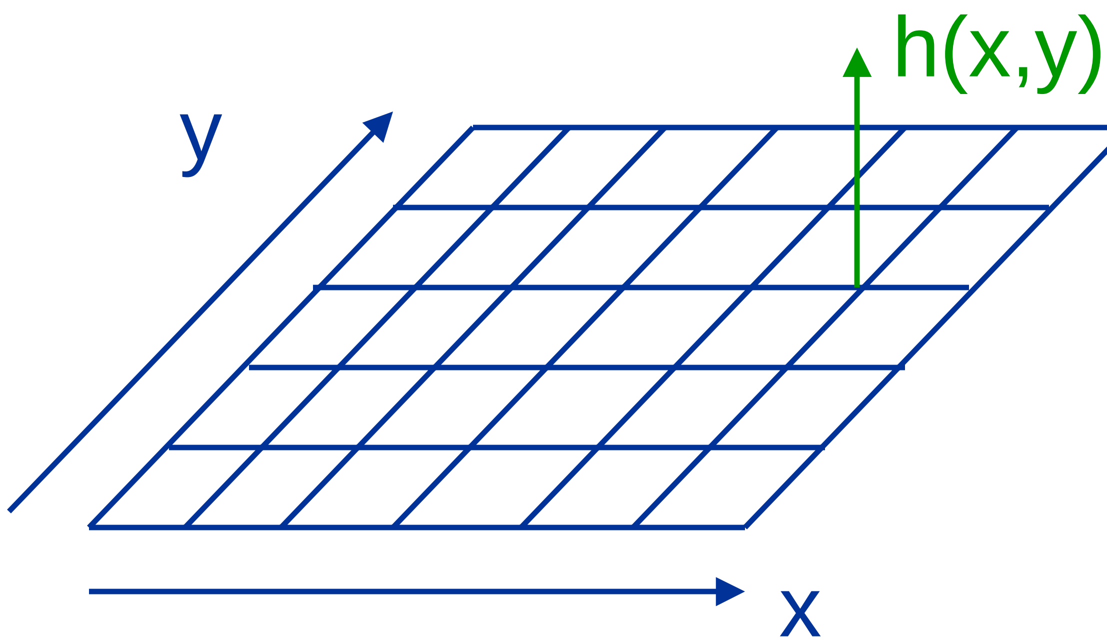
Rough surfaces



Reflection depends on the microsurface

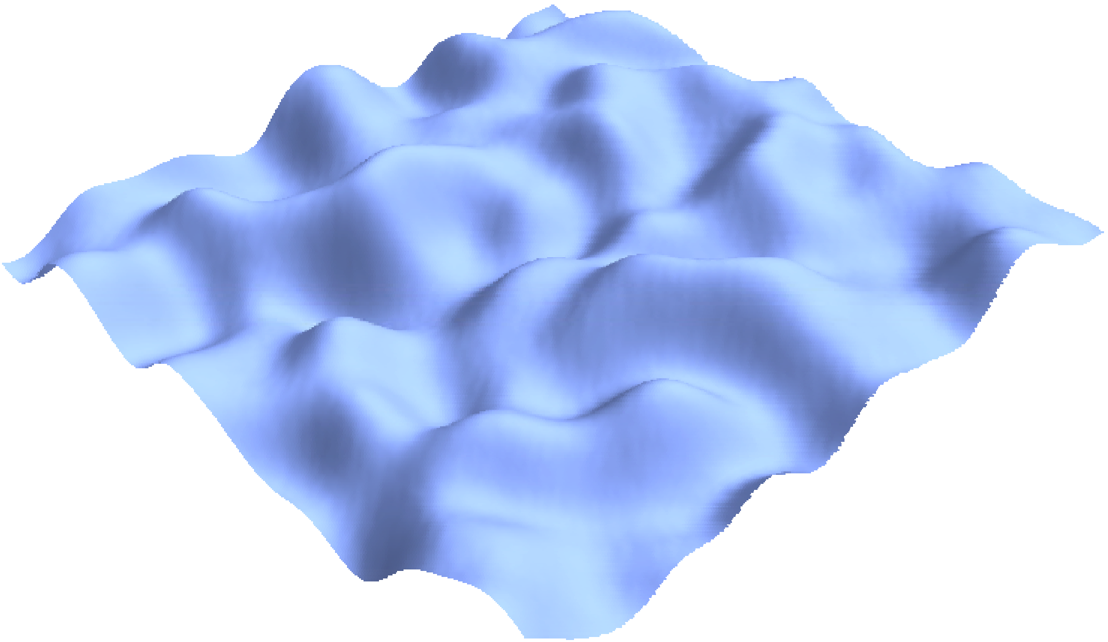
Microsurface Models

Model surface as a two-dimensional (random) height field



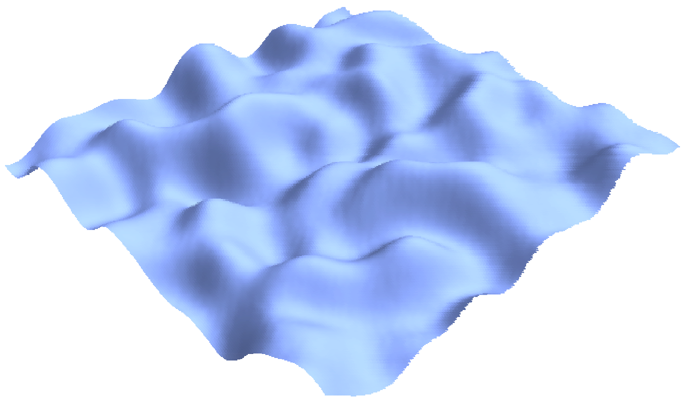
Microsurface Models

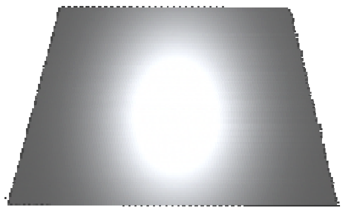
Isotropic Gaussian (smooth)

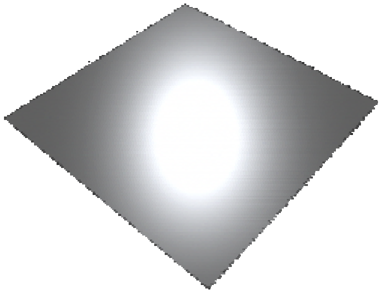


Microsurface Models

Isotropic Gaussian (smooth)

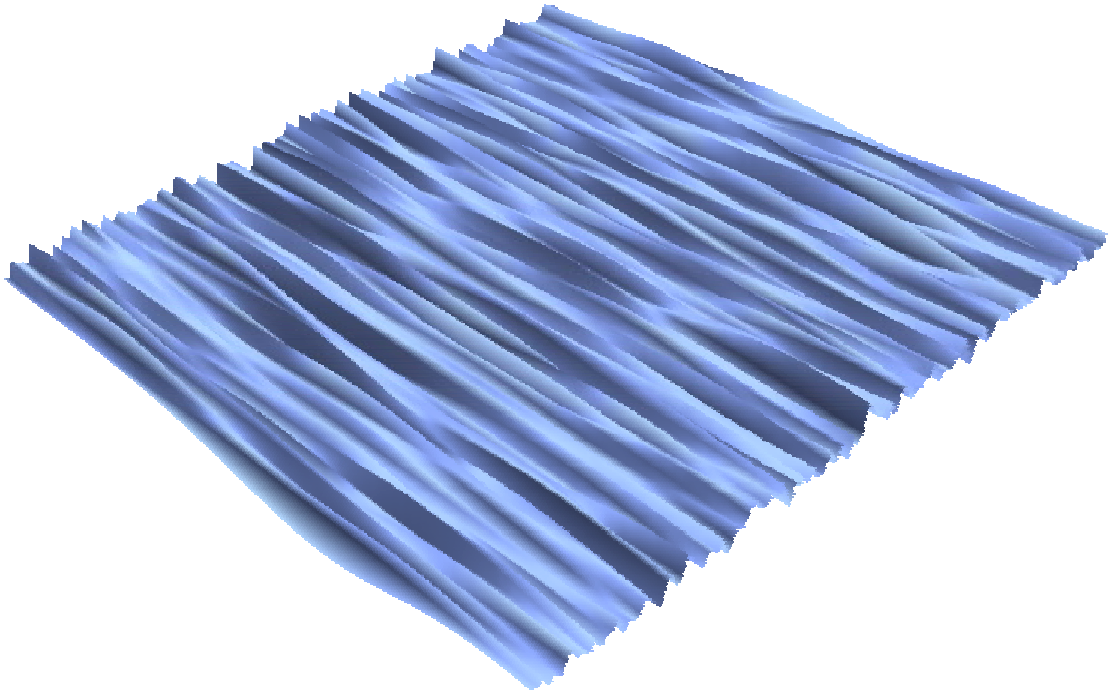






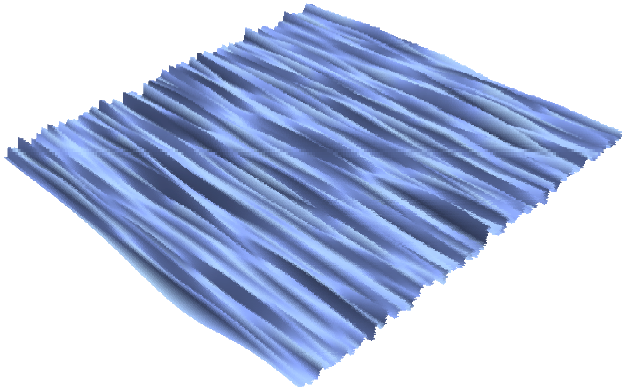
Microsurface Models

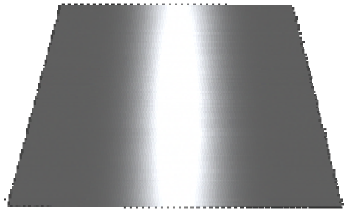
Anisotropic Gaussian (brushed metal)

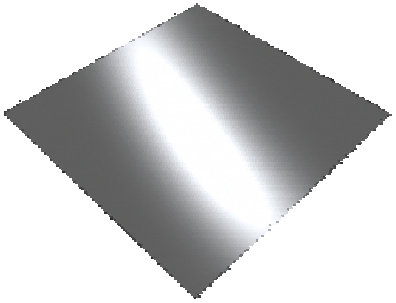


Microsurface Models

Anisotropic Gaussian (brushed metal)

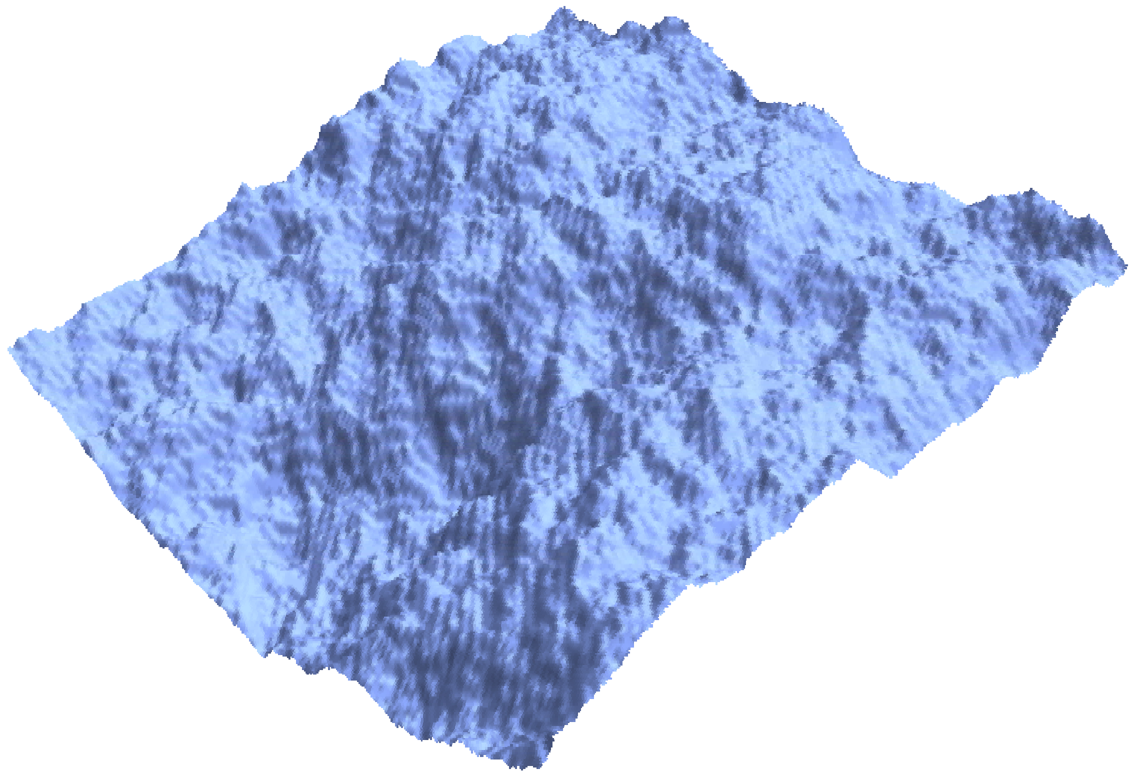






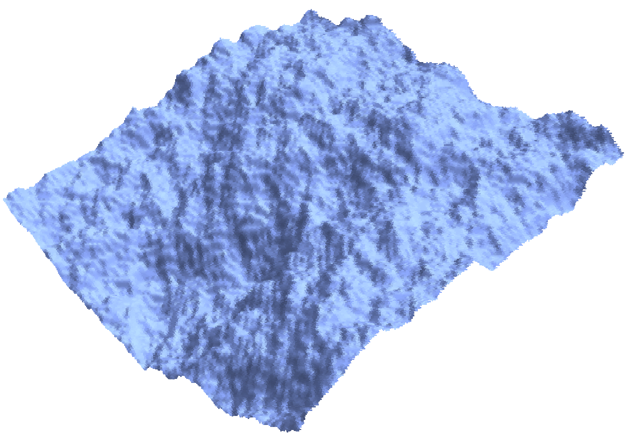
Microsurface Models

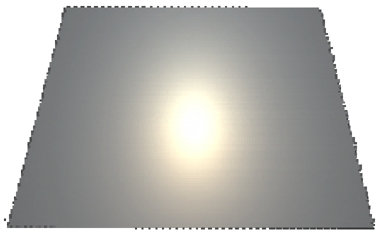
Fractal

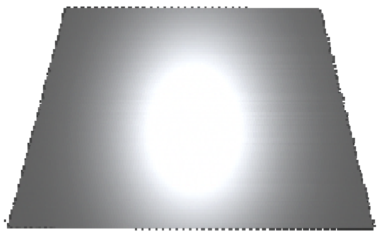


Microsurface Models

Fractal

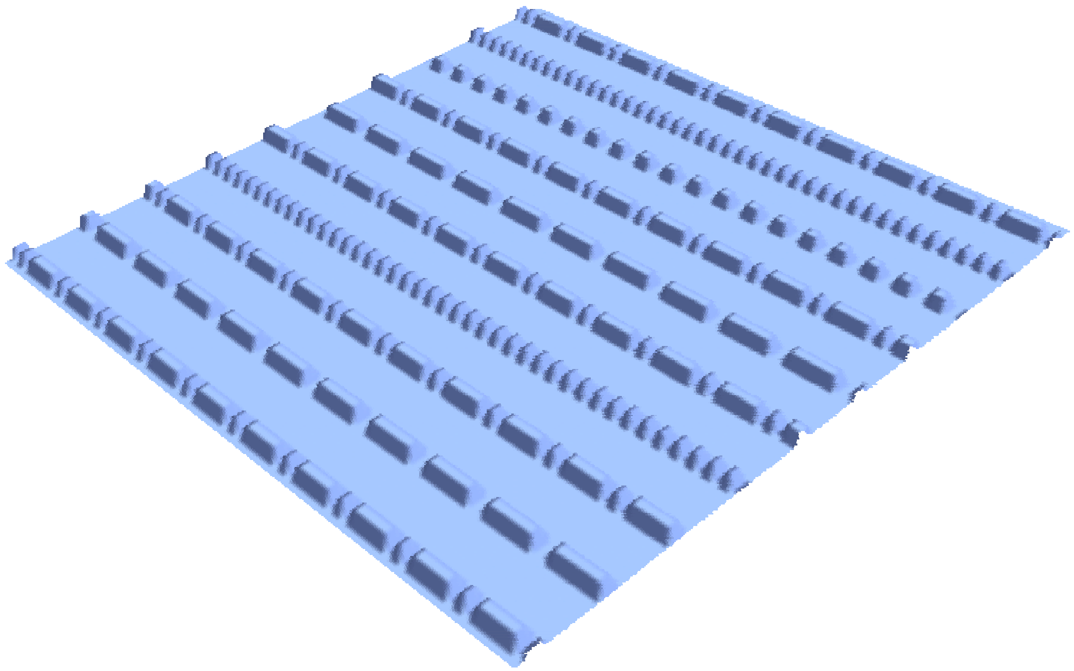






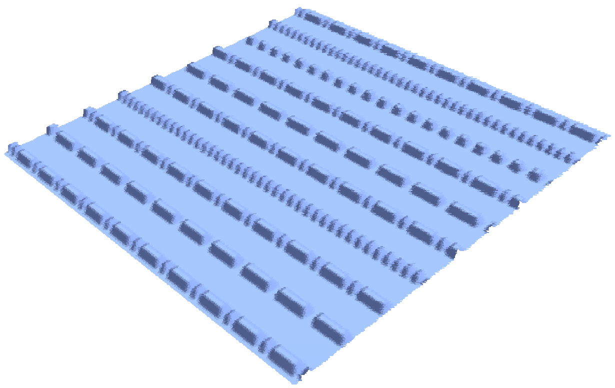
Microsurface Models

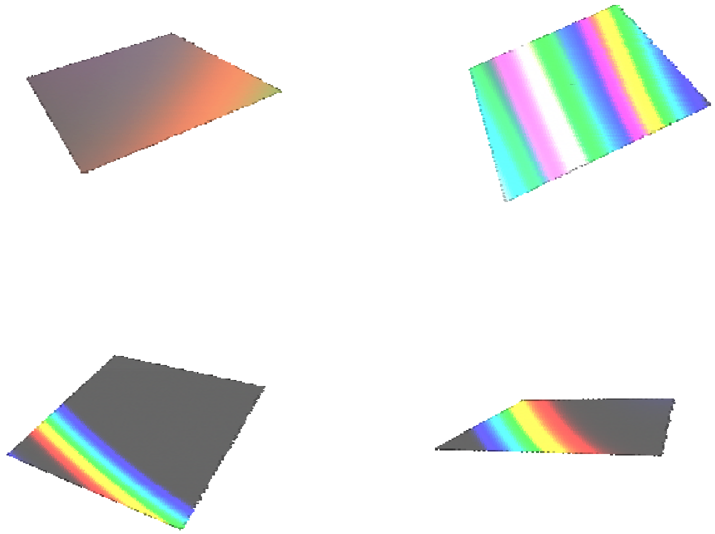
Periodic (compact disk)



Microsurface Models

Periodic (compact disk)





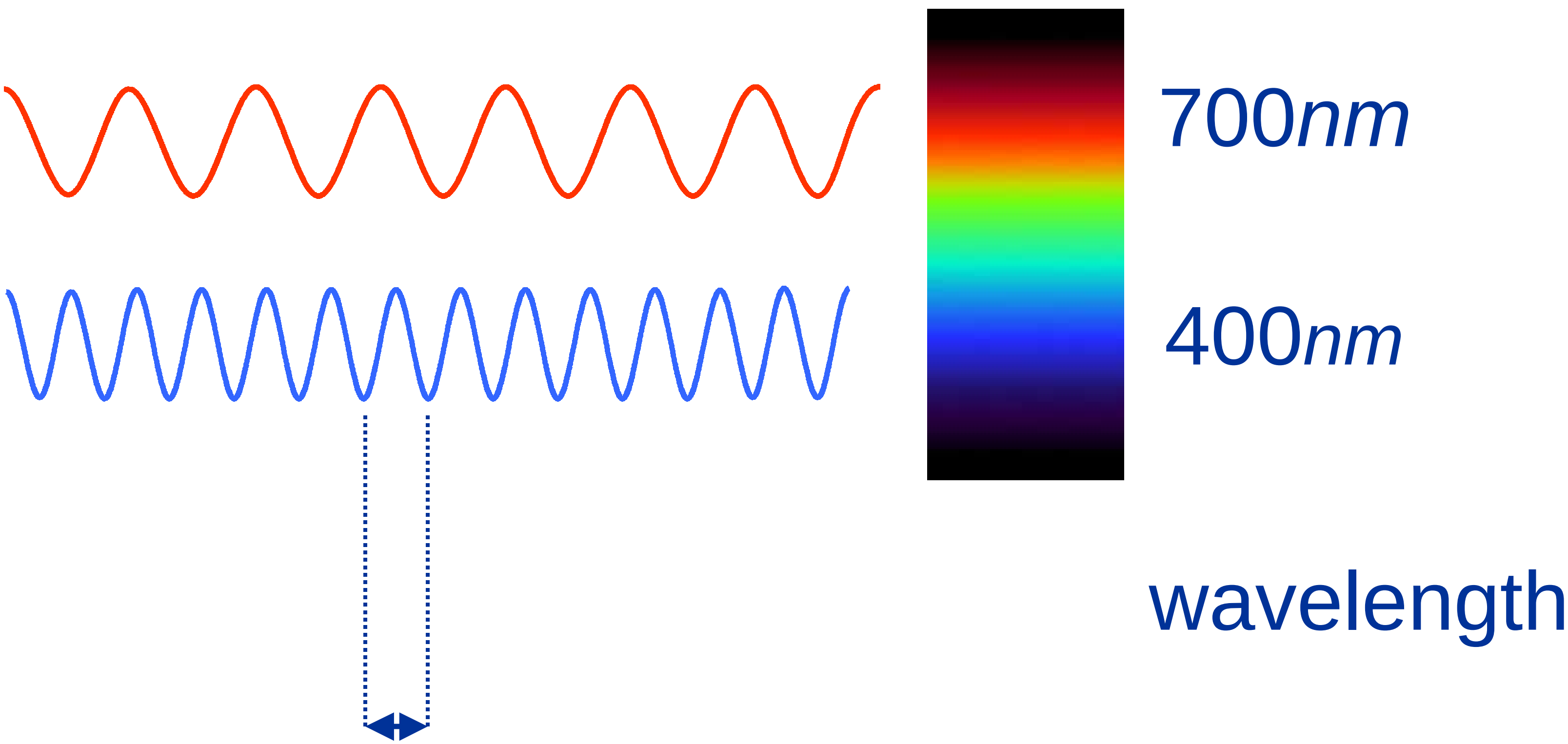
Our Approach

Use waves to model both

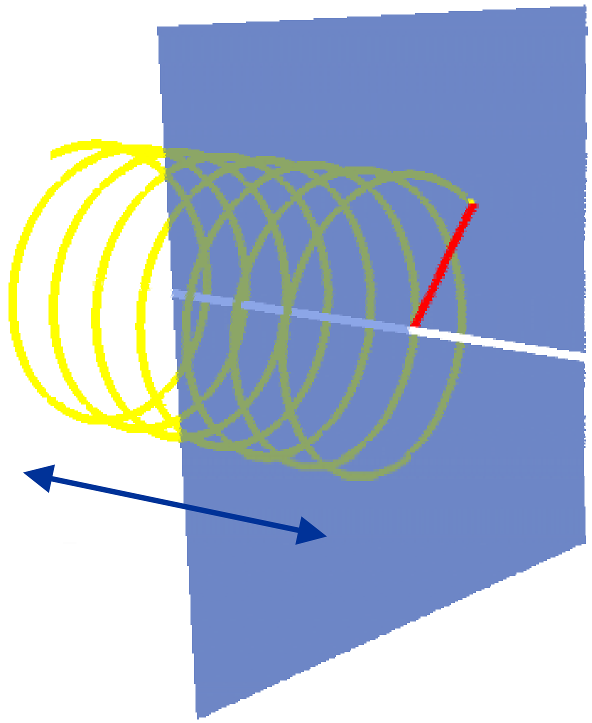
- the propagation of light
- the microsurface (Fourier Analysis)

Generalization of previous models

Wave Theory of Light

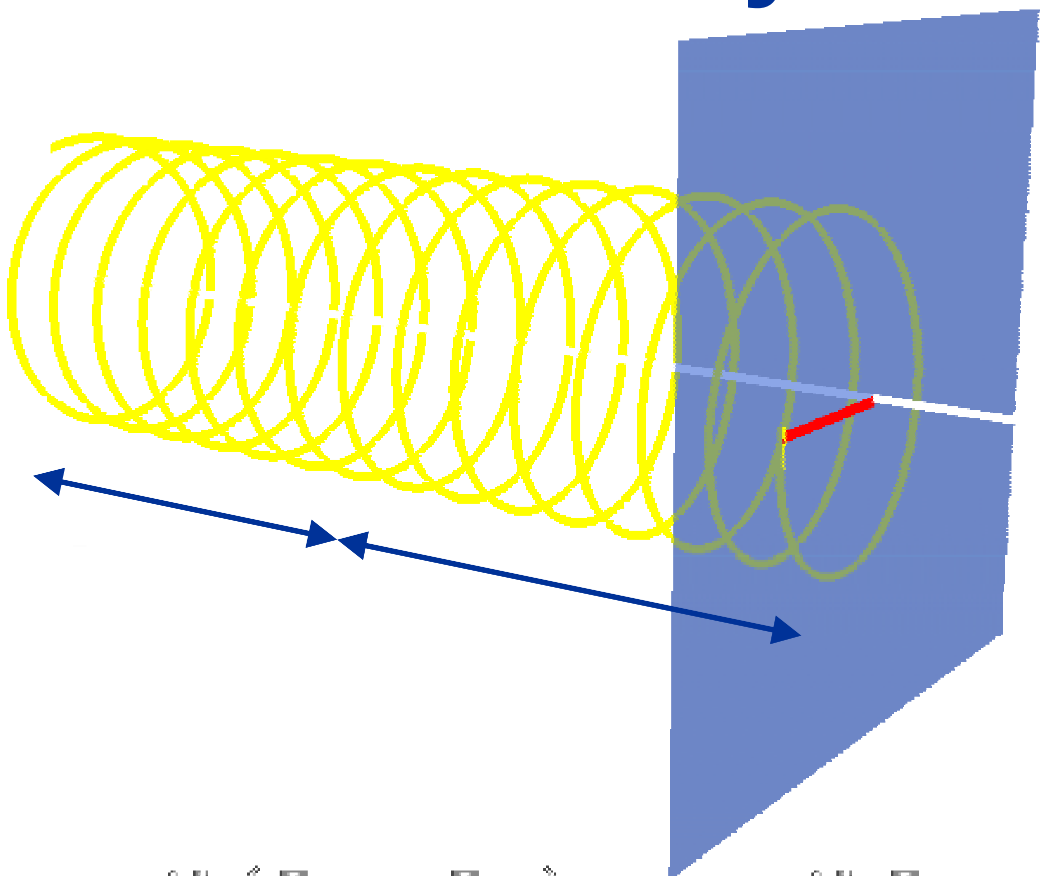


Wave Theory of Light



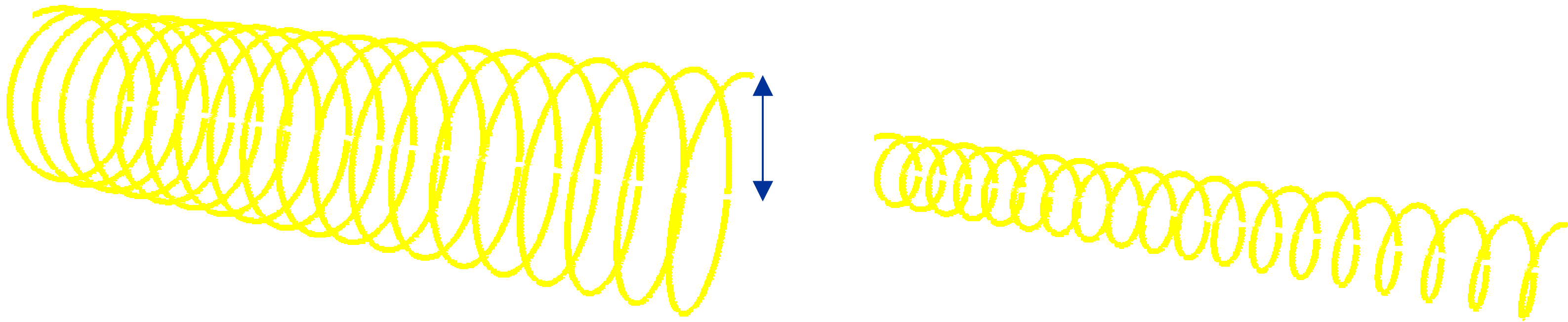
$$e^{ikL_1} = \cos(kL_1) + i\sin(kL_1)$$

Wave Theory of Light



$$e^{ik(L_1+L_2)} = e^{ikL_1} \; e^{ikL_2}$$

Intensity of a Wave

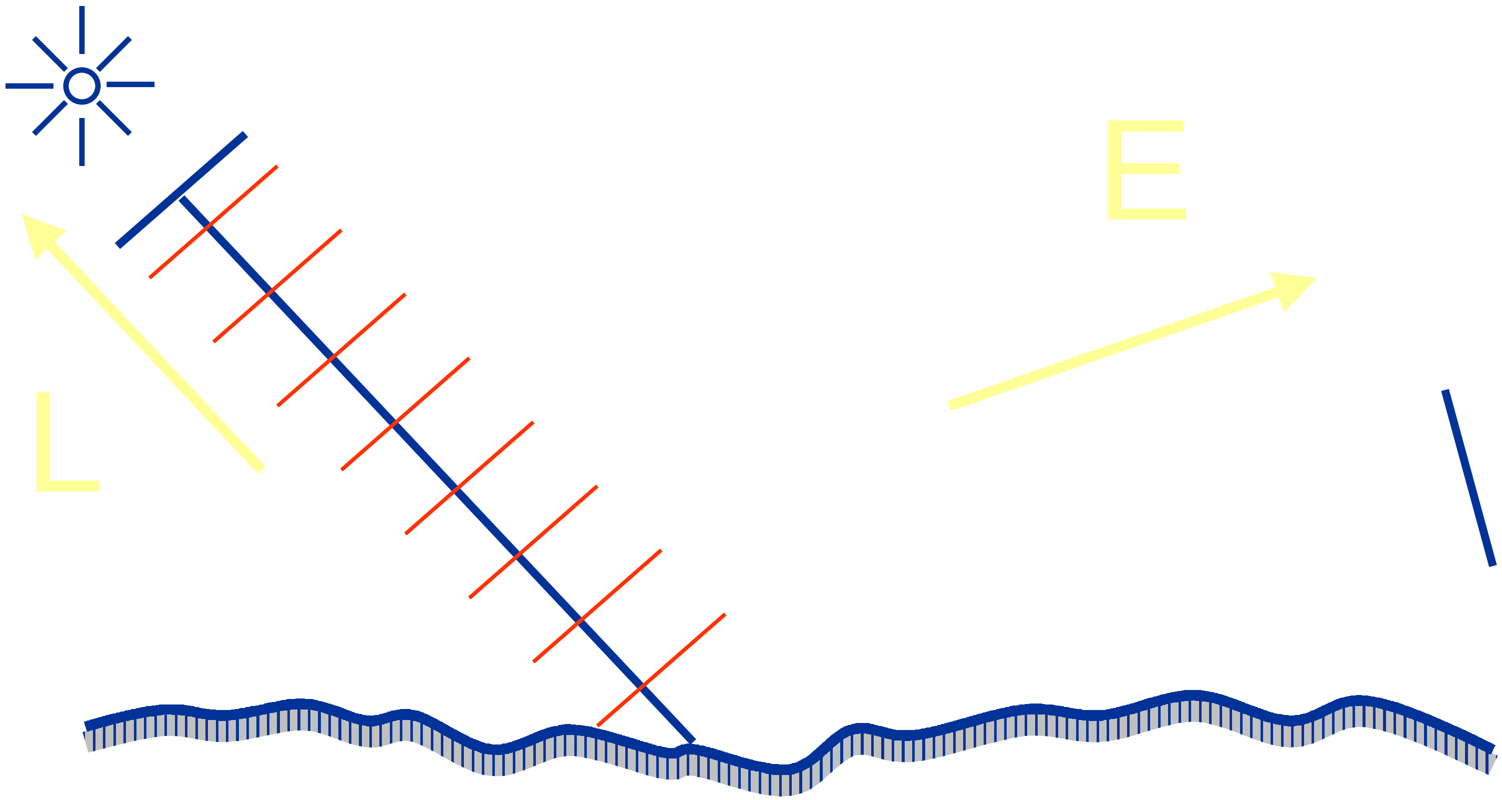


Diffraction

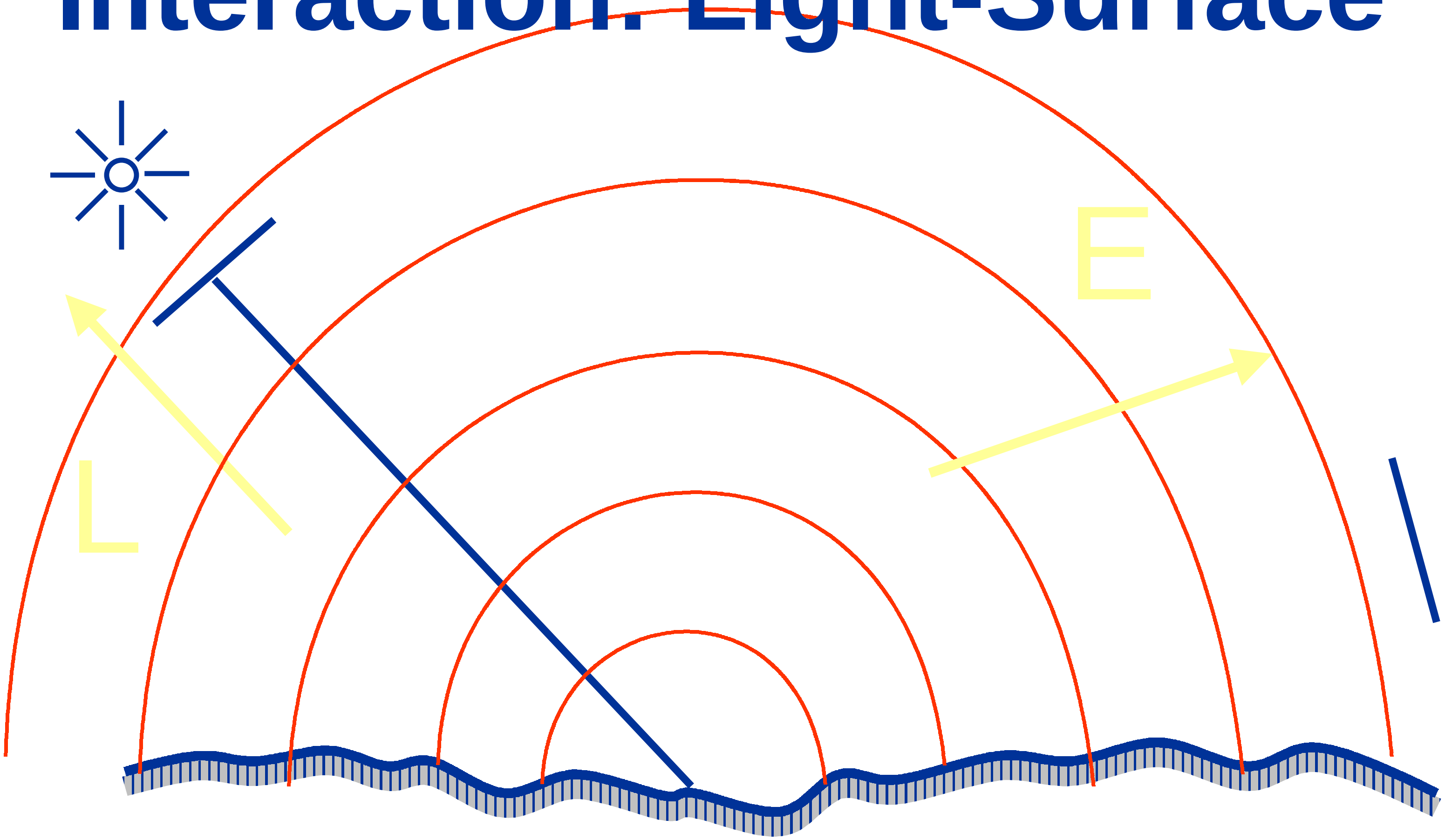
$$\left| A_1 e^{ikr_1} + A_2 e^{ikr_2} \right|^2 \neq A_1^2 + A_2^2$$

Intensities don't add up in general

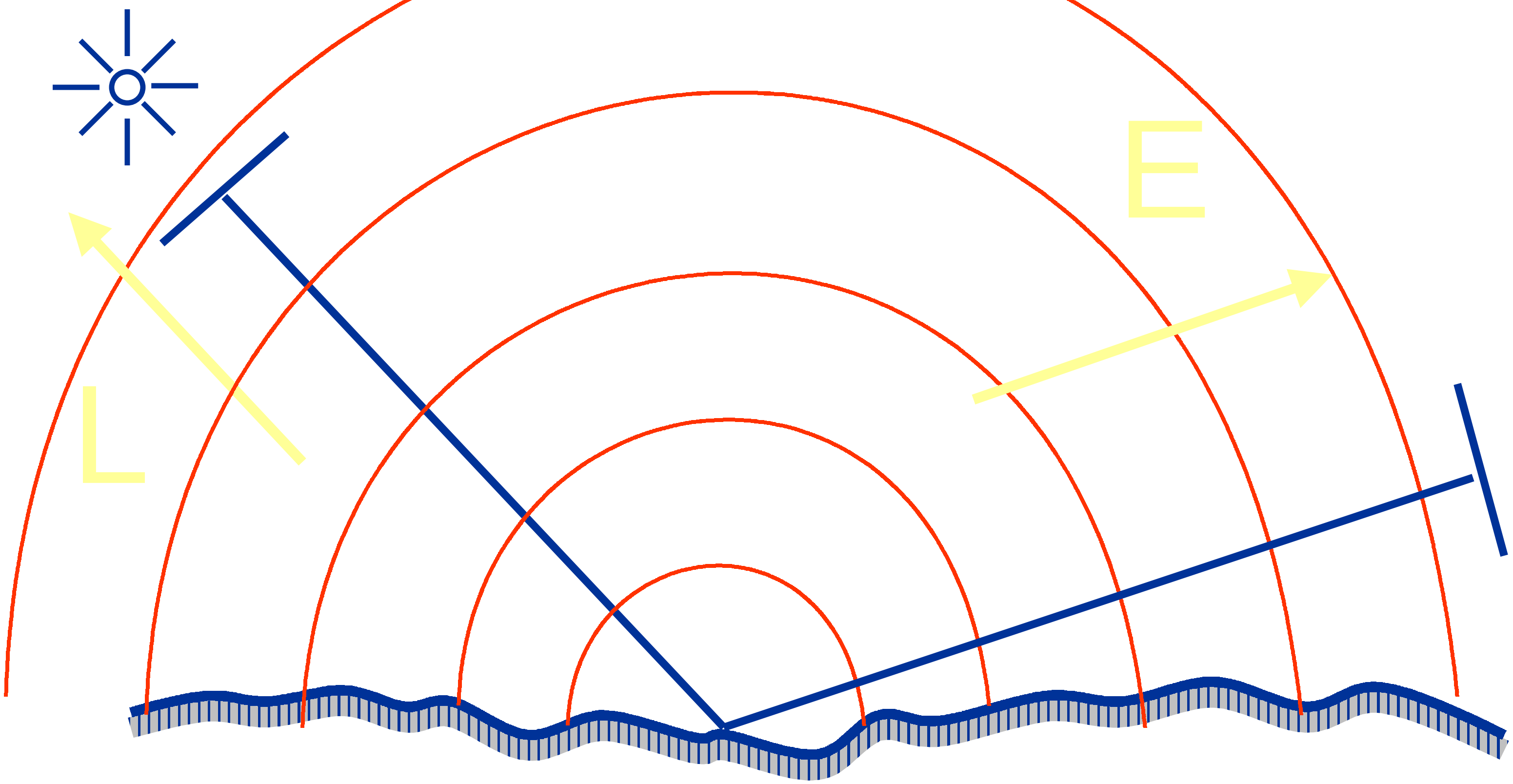
Interaction: Light-Surface



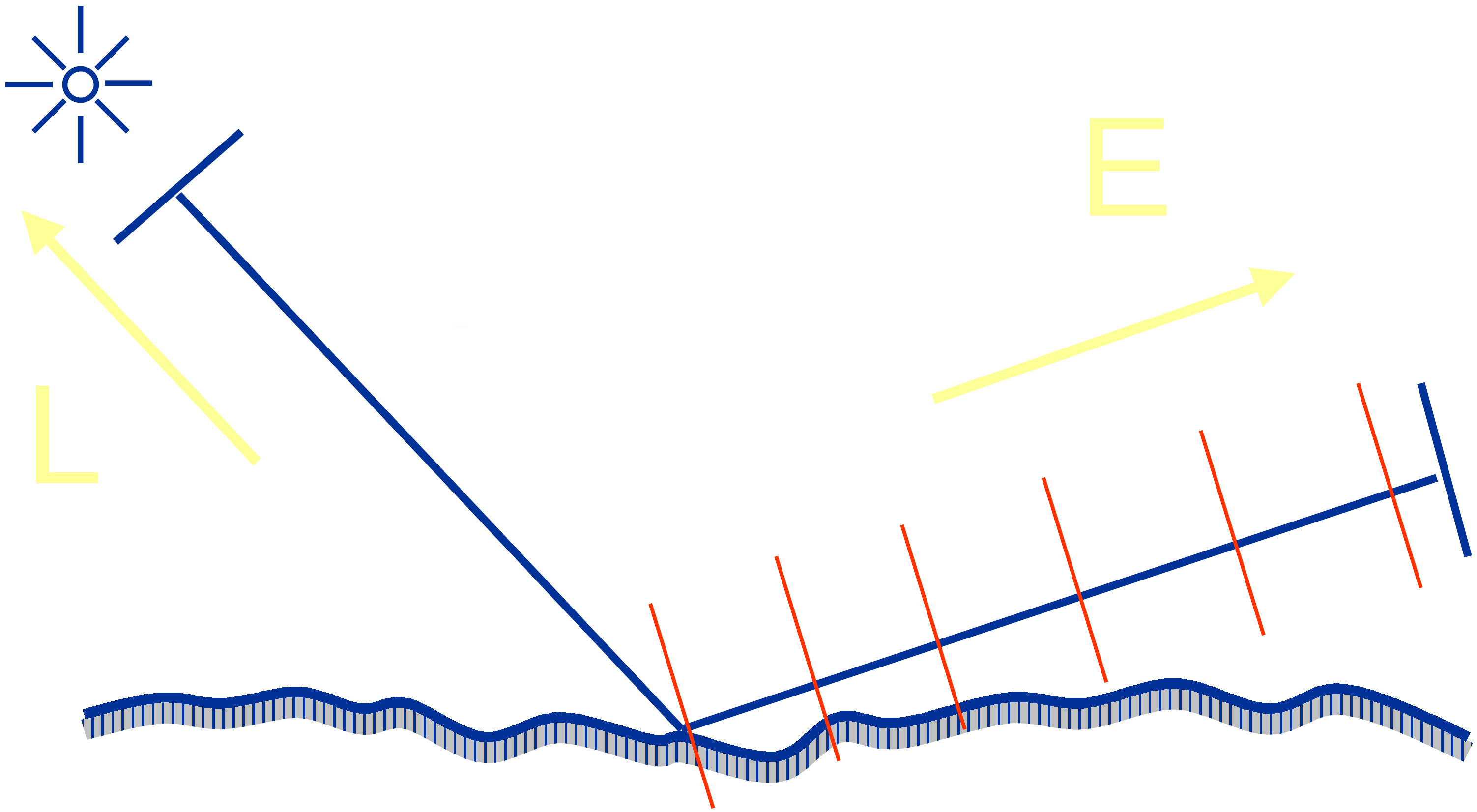
Interaction: Light-Surface



Interaction: Light-Surface

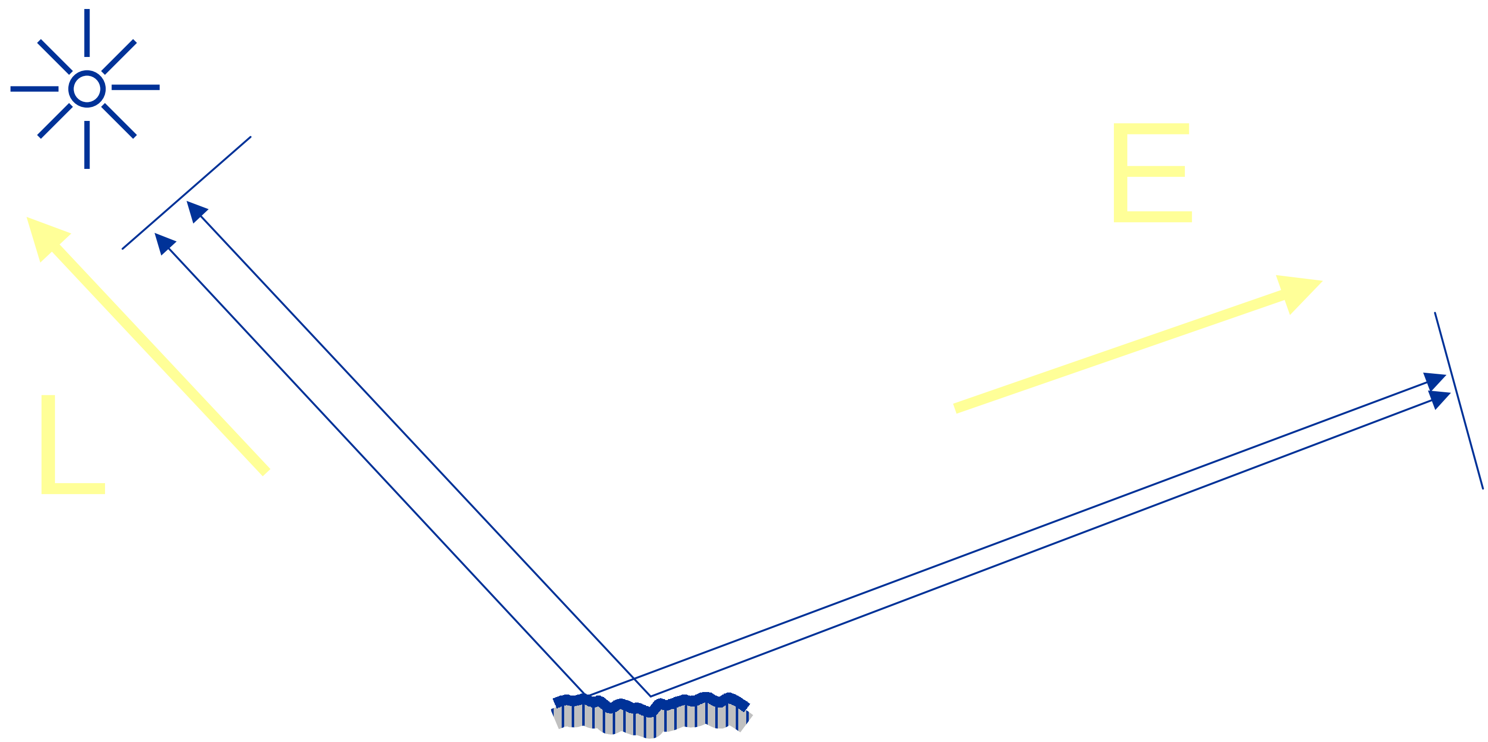


Interaction: Light-Surface



$$e^{ik(T_1+T_2)} = e^{ikT_1}\ e^{ikT_2}$$

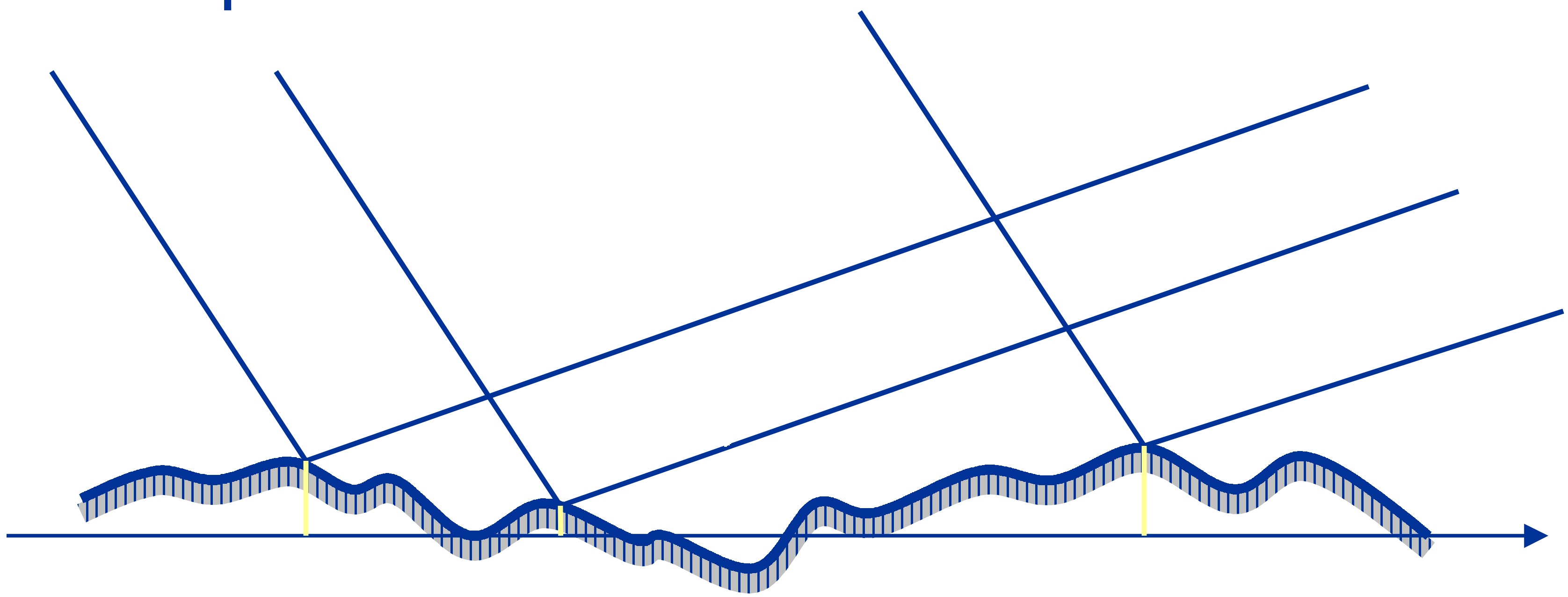
Interaction: Light-Surface



Source and observer “far away”

Interaction: Light-Surface

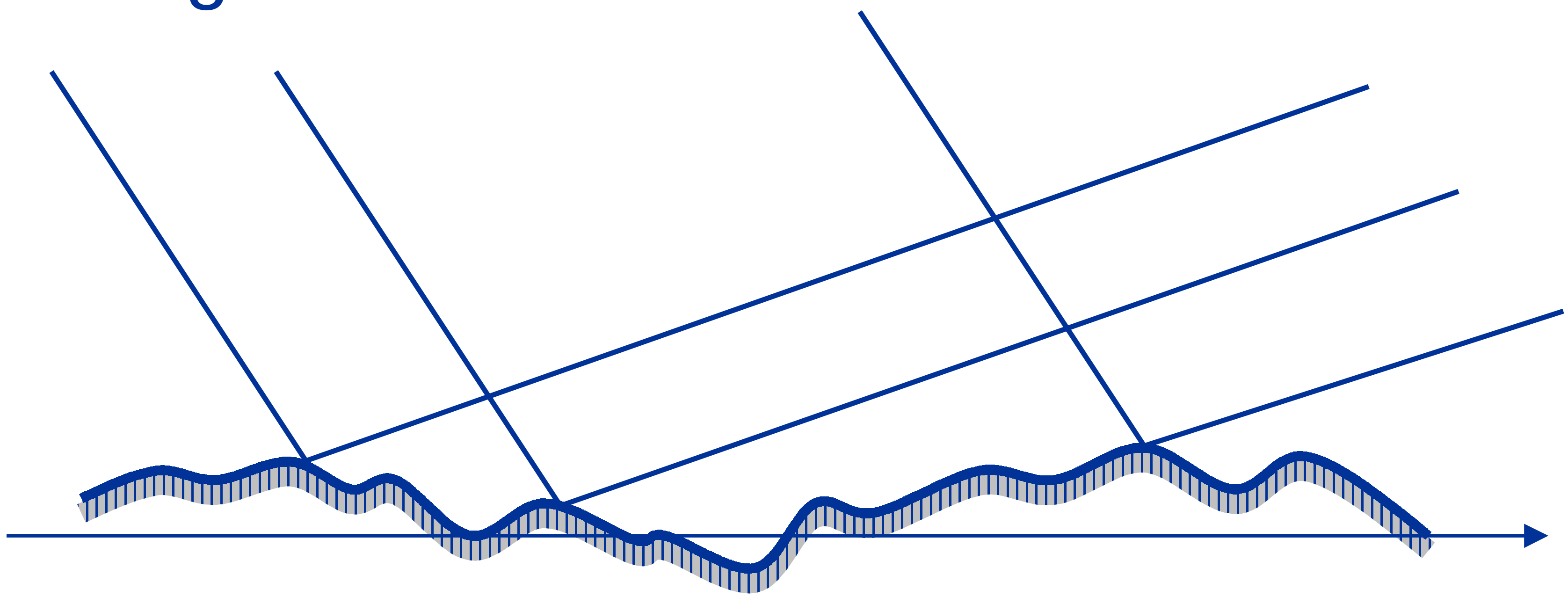
Add up contributions



$$\psi = e^{ikT_i(x_1)} + e^{ikT_i(x_2)} + e^{ikT_i(x_3)} + \ldots$$

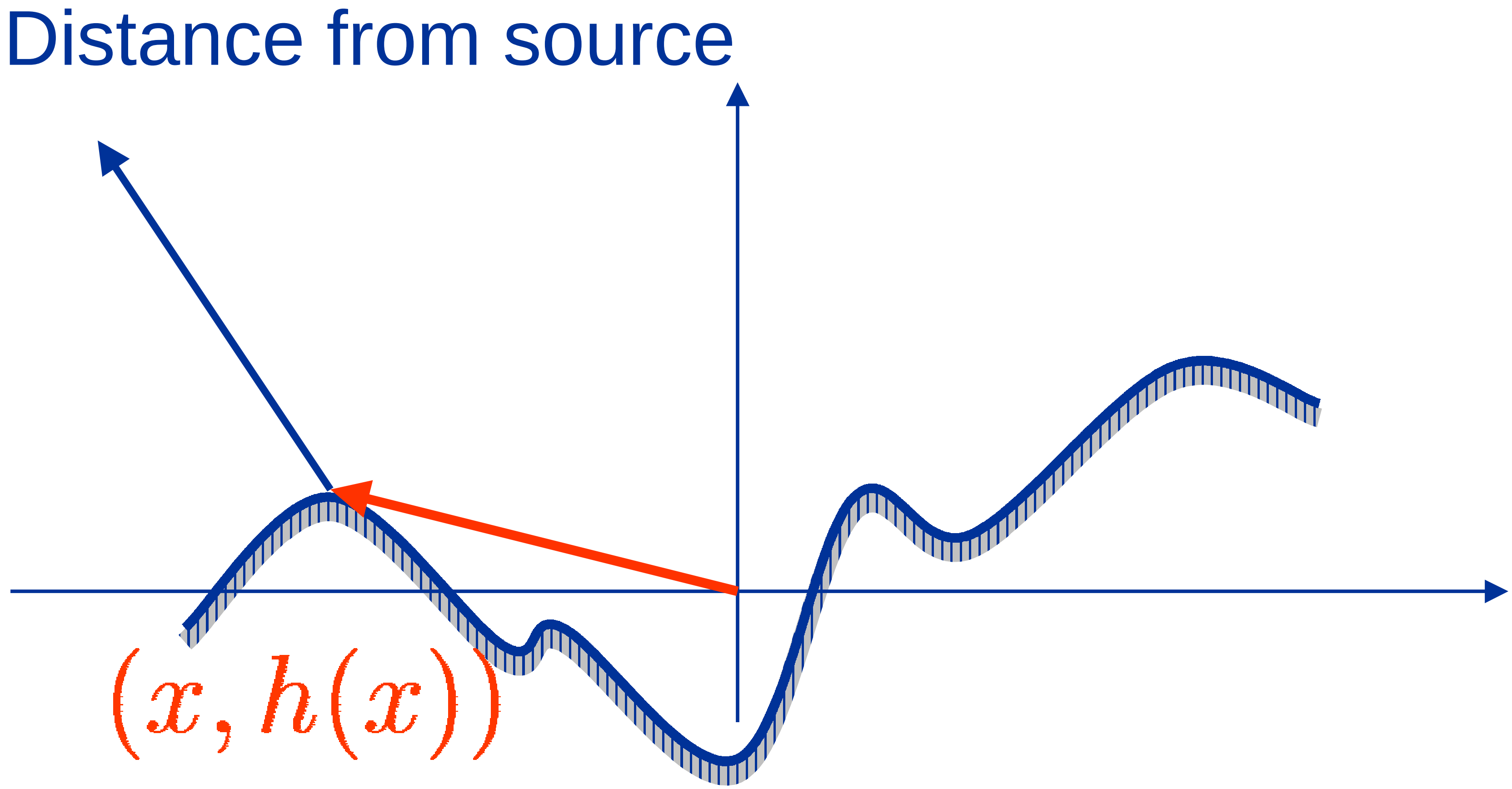
Interaction: Light-Surface

Integral in the limit



$$\psi = \int e^{ikT_r(x)}\, dx$$

Compute Path Length



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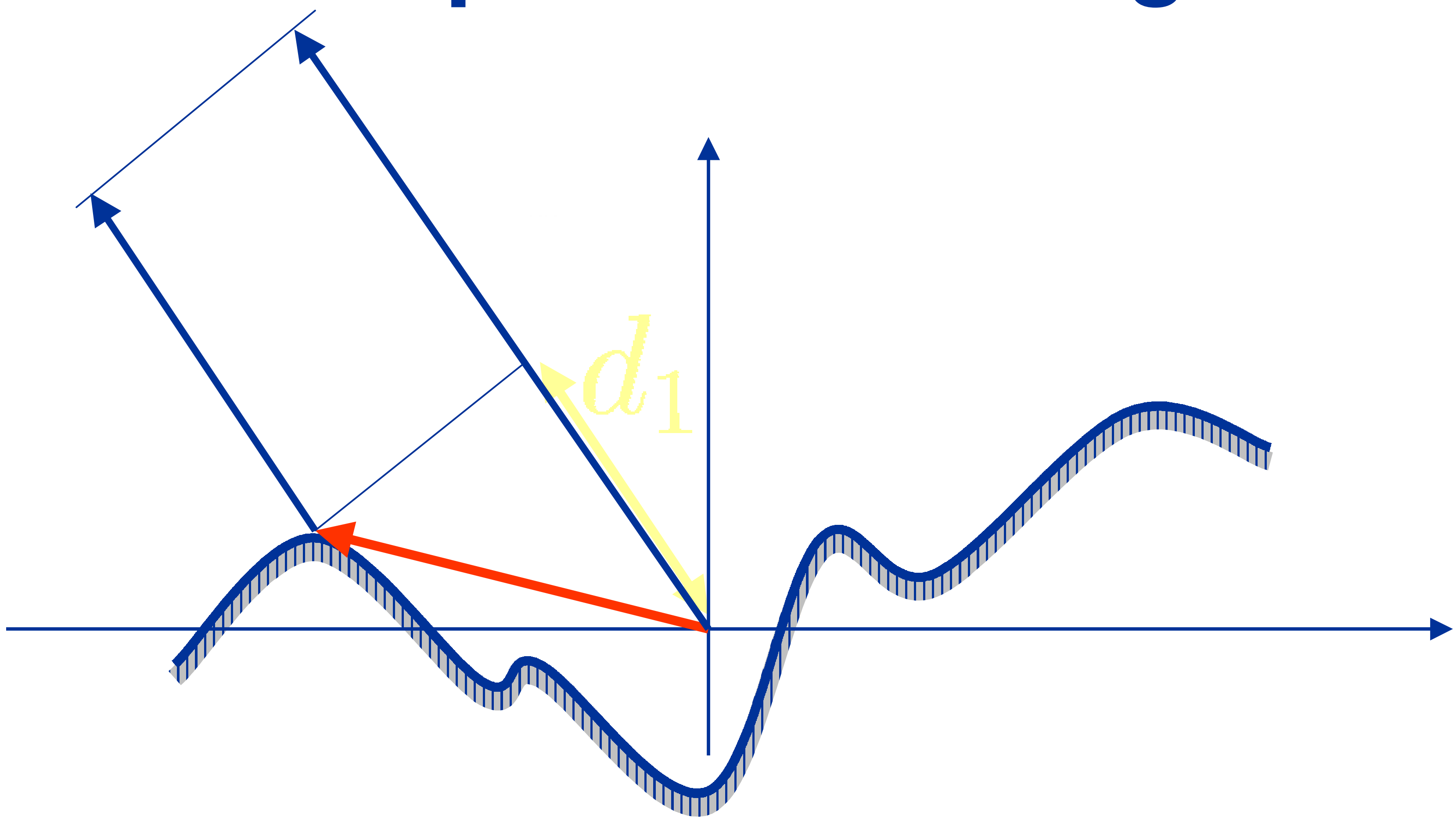

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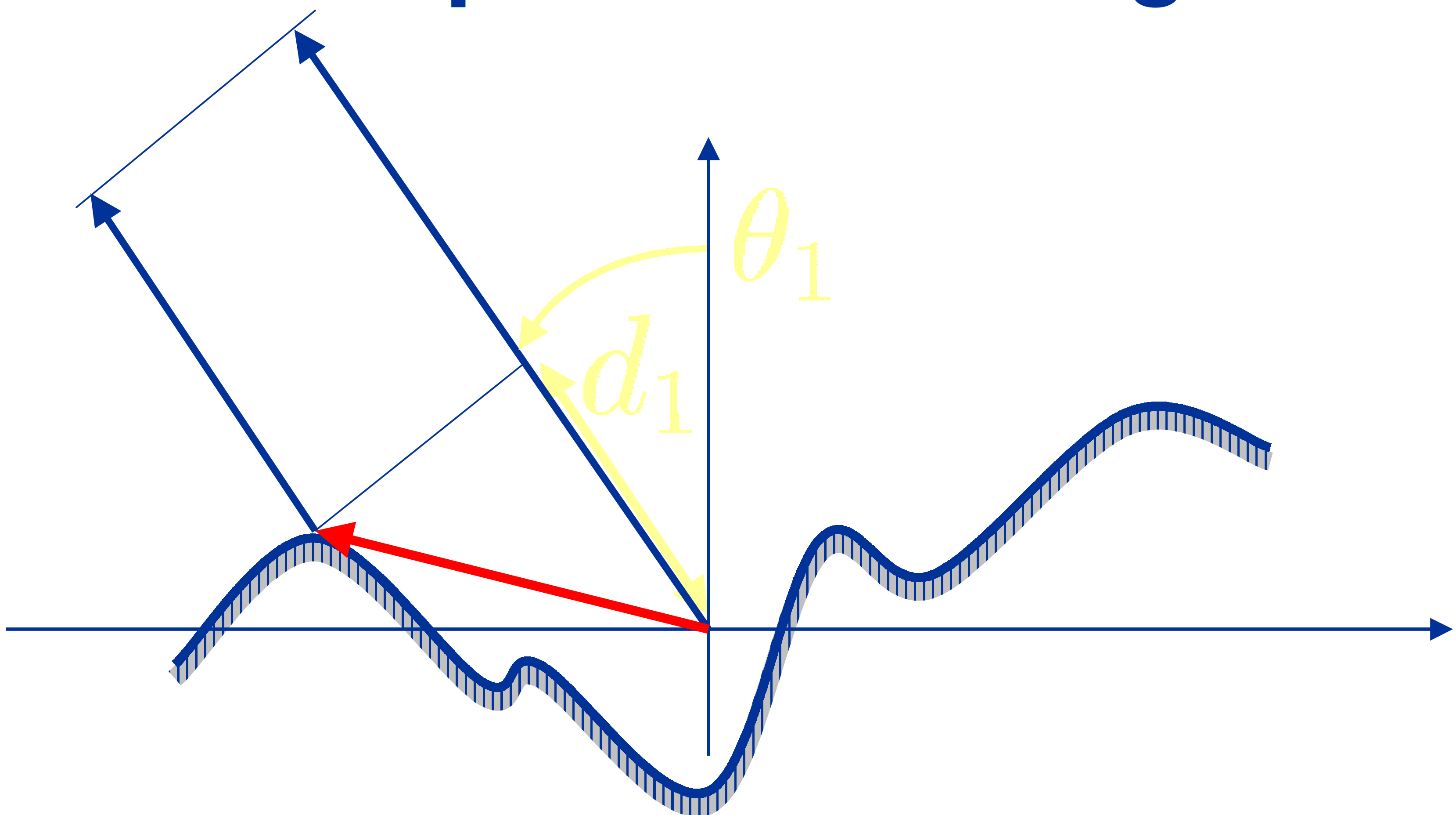
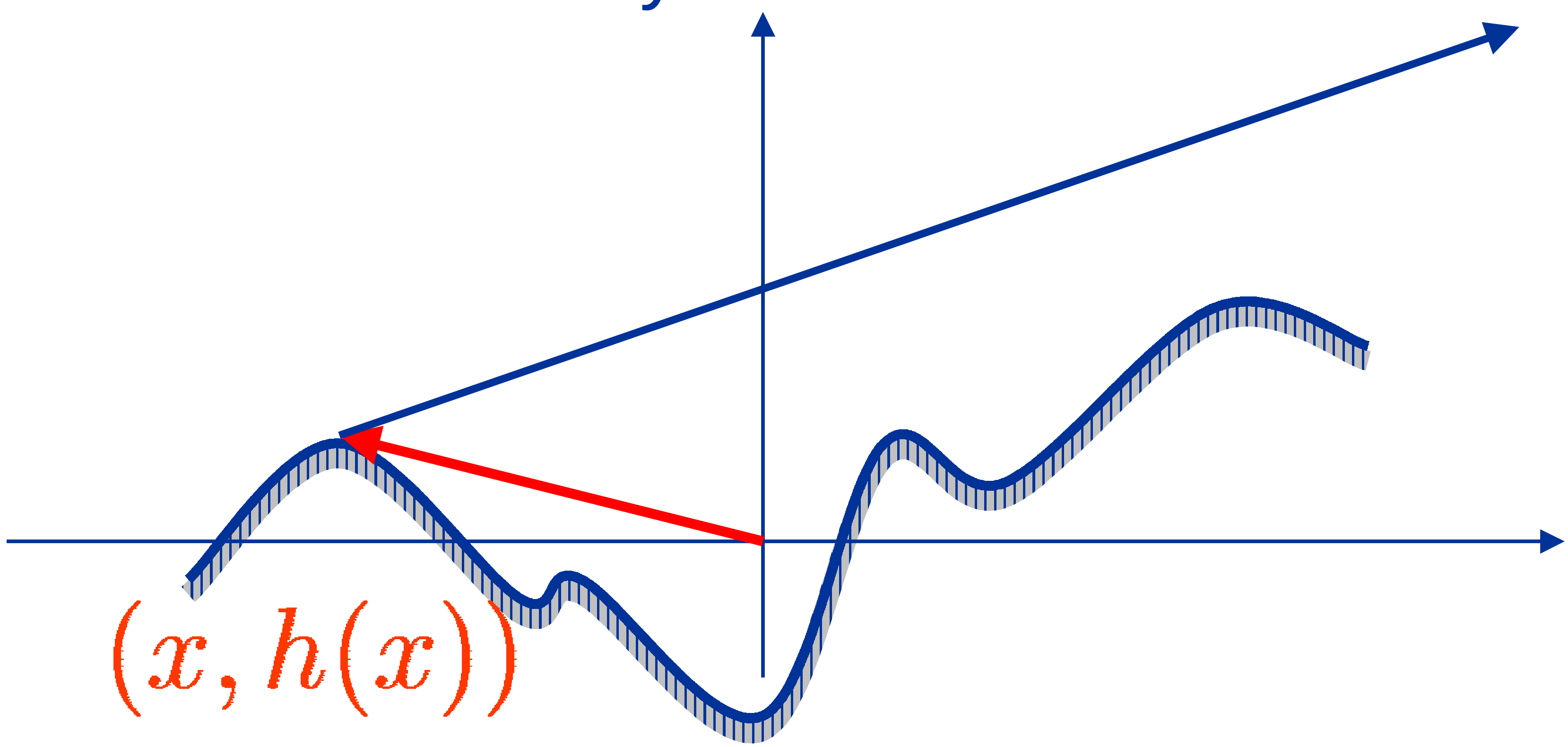


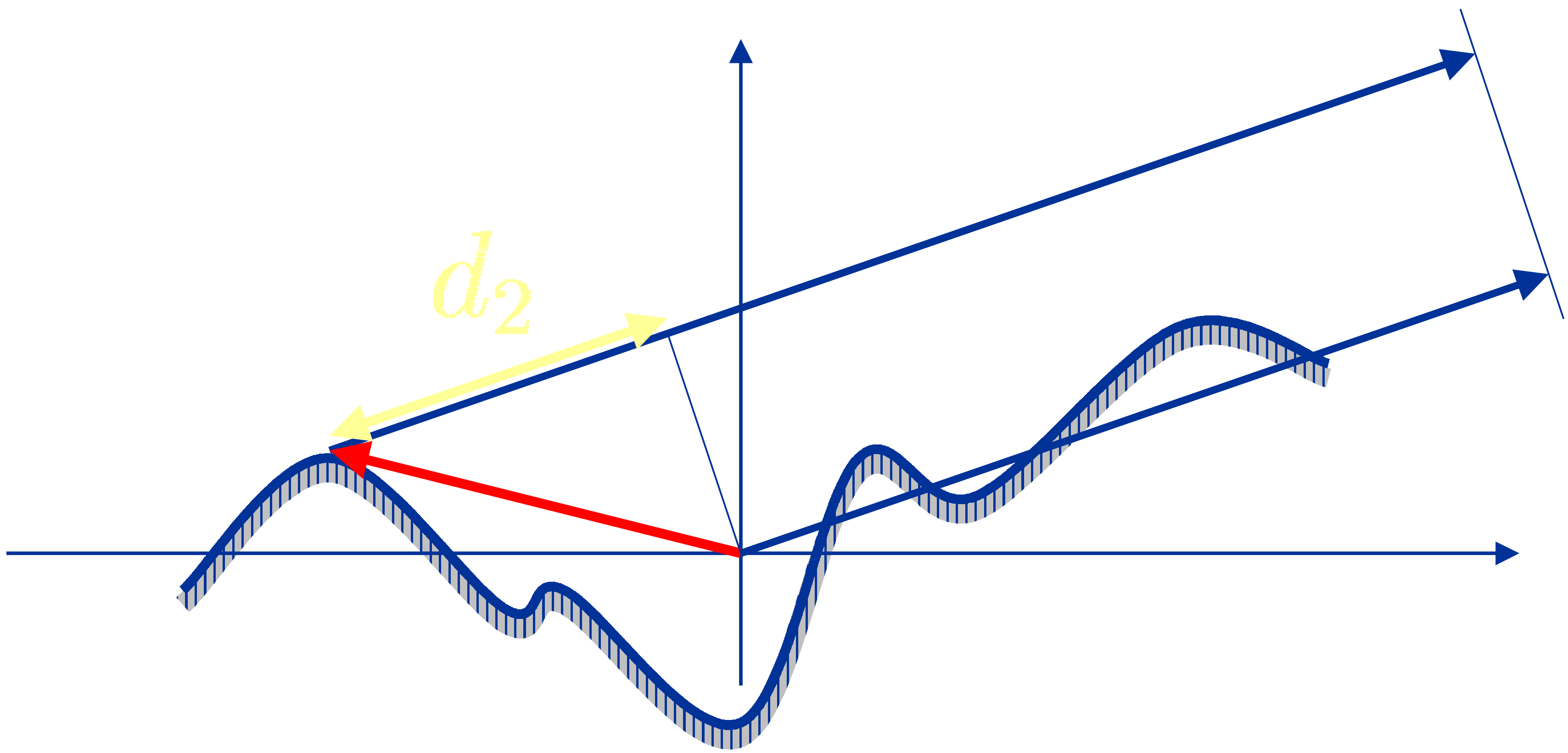
$$L_1 = R_1 + x\sin\theta_1 - h(x)\cos\theta_1$$

Compute Path Length

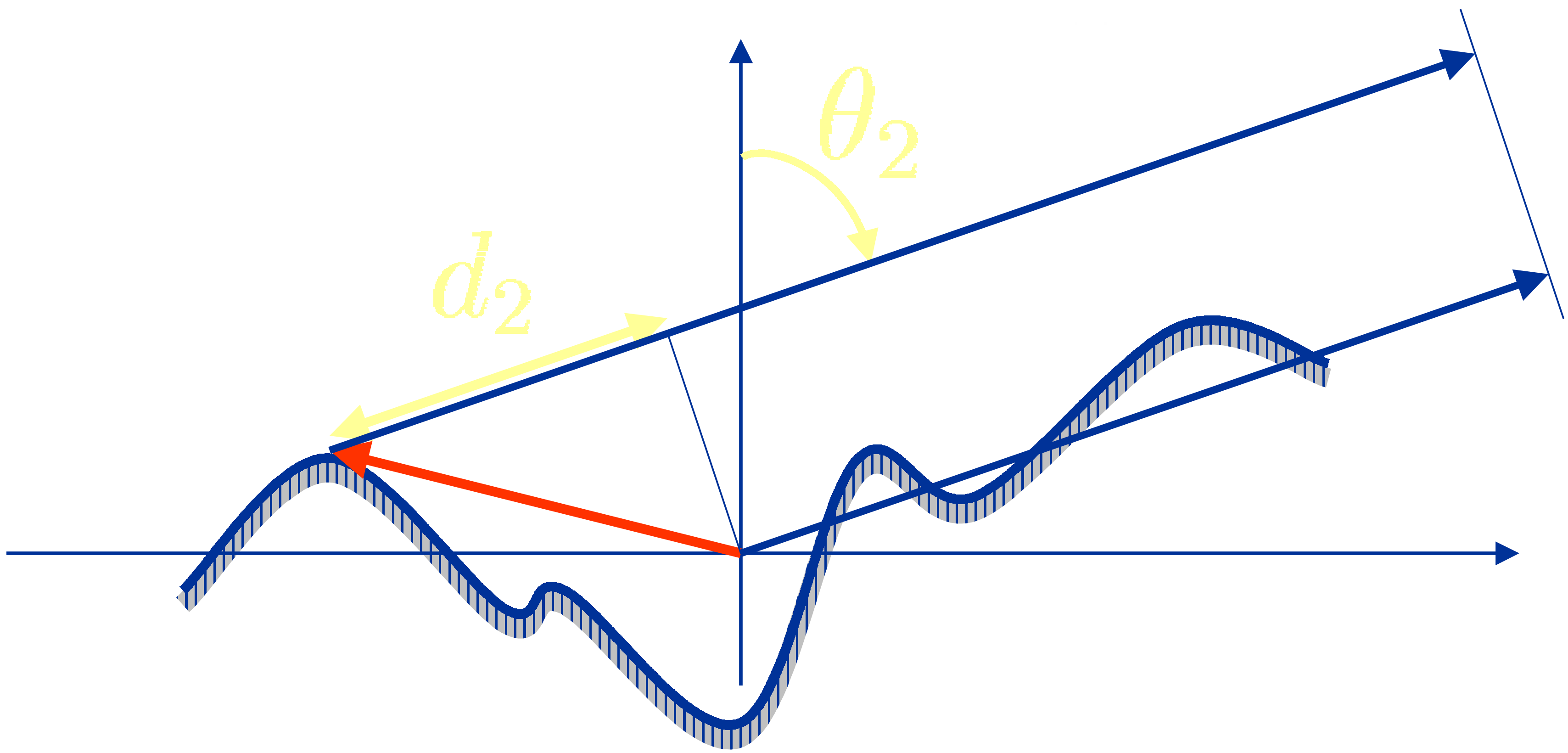
Distance to the eye



Compute Path Length



Compute Path Length



$$L_2 = R_2 - x\sin\theta_2 - h(x)\cos\theta_2$$

Compute Path Length

Putting the two together:

$$
\begin{aligned}
L_1 &= R_1 + x \sin\theta_1 - h(x)\cos\theta_1 \\
L_2 &= R_2 - x \sin\theta_2 - h(x)\cos\theta_2
\end{aligned}
$$

Compute Path Length

Putting the two together:

$$L_1 = R_1 + x\sin\theta_1 - h(x)\cos\theta_1$$

$$+\quad L_2 = R_2 - x\sin\theta_2 - h(x)\cos\theta_2$$

$$L(x) = R_1 + R_2 + ux + wh(x)$$

Reflected Wave

Now integrate over the surface:

$$L(x) = R_1 + R_2 + ux + wh(x)$$

$$\psi = \int e^{ikL(x)}\, dx$$

Reflected Wave

$$L(x) = R_1 + R_2 + ux + wh(x)$$

$$\psi = C \int e^{ikwh(x)} \, e^{ikux} \, dx$$

Fourier Transform

$$\psi = C \int_{-\infty}^{\infty} p(x)\, e^{ikux}\, dx$$

Key insight

Fourier Transform

Key insight

Fourier Transform

Simple relationship:

Example

Smooth surface:

Example

Almost smooth surface:

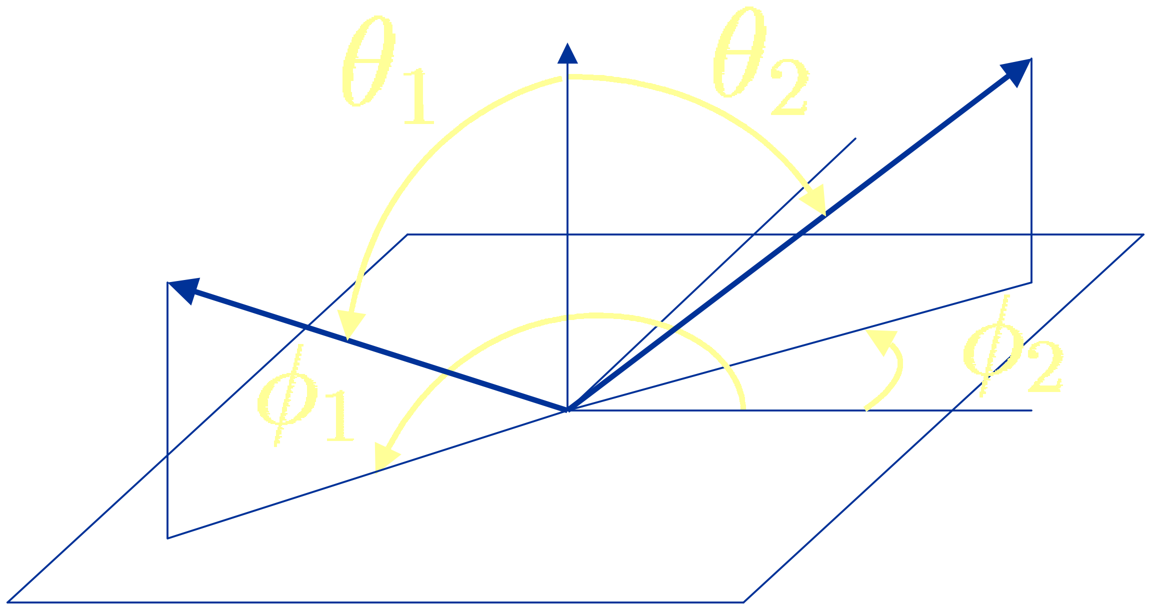
$$p(x) = e^{ikwh(x)} \approx 1 + ikwh(x)$$

$$P(ku) = \delta(ku) + ikwH(ku)$$

$$|P(ku)|^2 = \delta(ku) + k^2 w^2 |H(ku)|^2$$

Two dimensions

Previous derivation extends to 2D



Two dimensions

$$
\begin{aligned}
u &= -\cos\phi_1 \sin\theta_1 - \cos\phi_2 \sin\theta_2 \\
v &= \sin\phi_1 \sin\theta_1 - \sin\phi_2 \sin\theta_2 \\
w &= -\cos\theta_1 - \cos\theta_2
\end{aligned}
$$

Computing Shaders

Shader = computing Fourier transforms

I have done this for:

- Gaussian random surfaces
- Fractal random surfaces
- Periodic surfaces

Details in http://reality.sgi.com/jstam_sea/Research/ps/diff.ps.gz

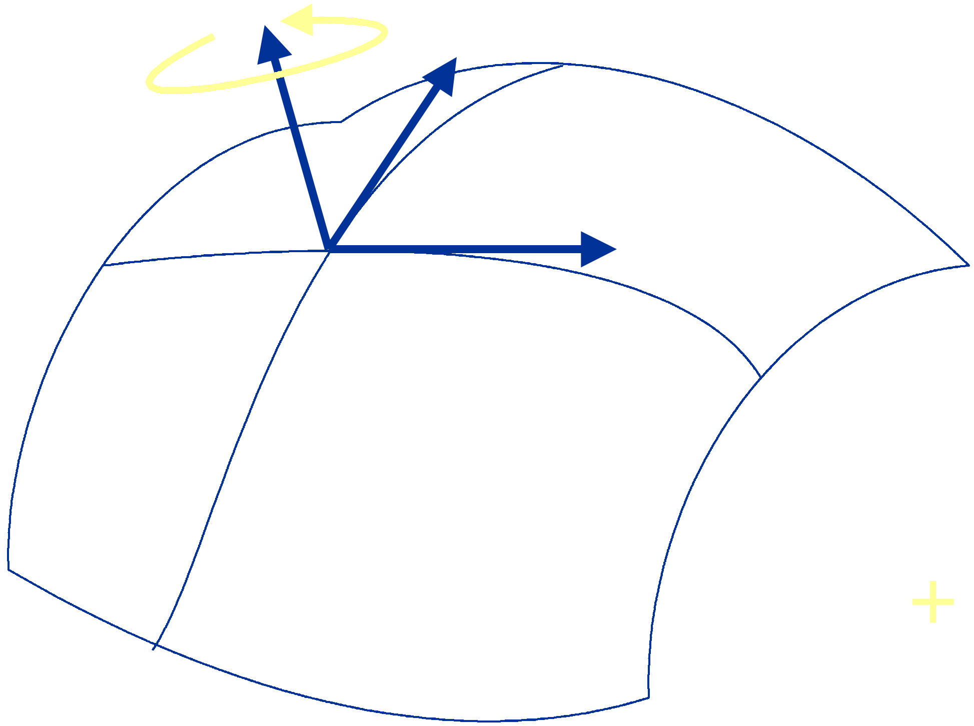
Implementation

Implemented as MAYA plugin

Straightforward

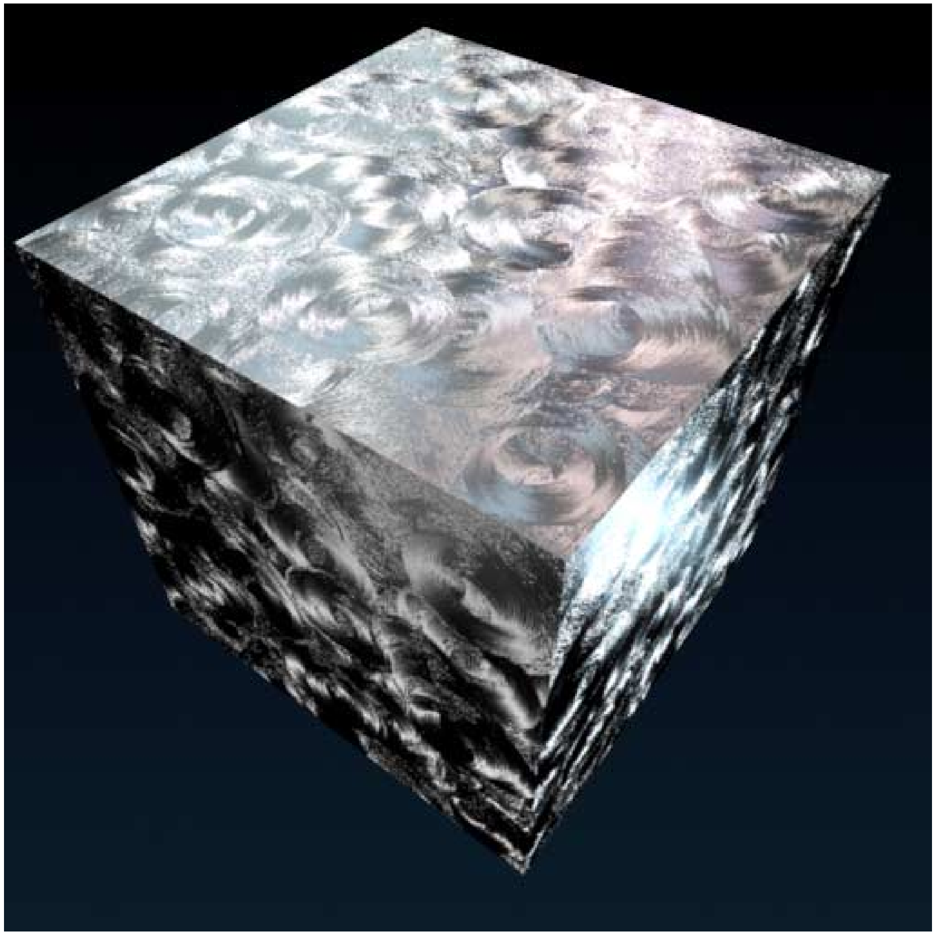
Implementation

Assign frame to the surface

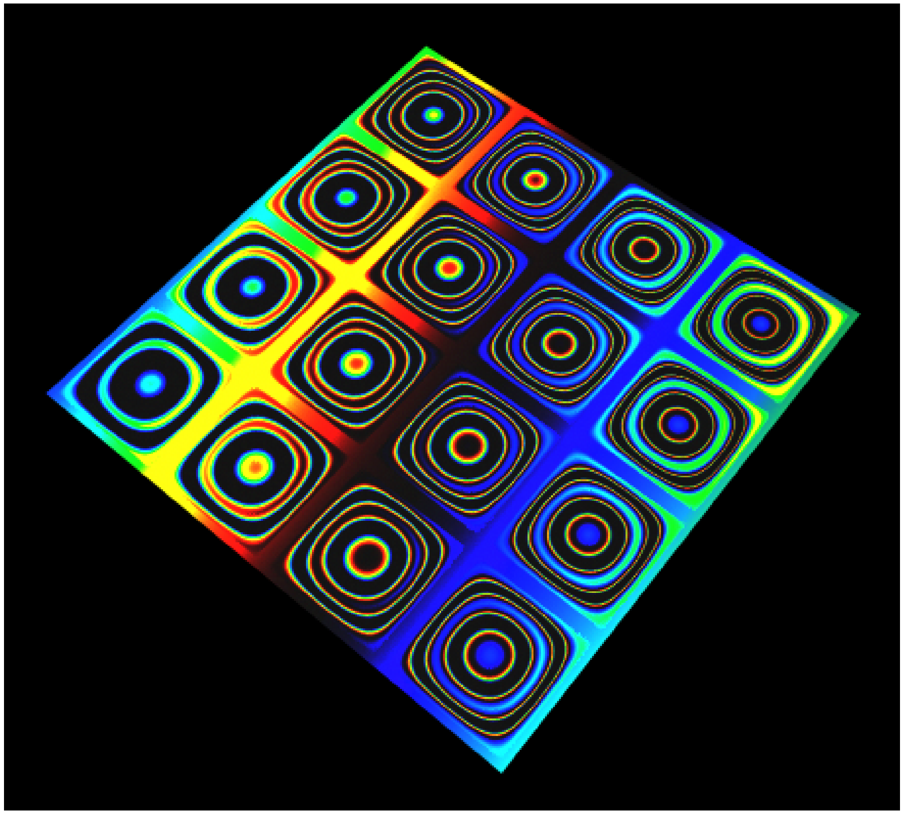


+ twist angle

Brushed Metal



Diffraction



Compact Disk

Used Physical Dimensions:

- bump height : 150 *nm*
- bump width : 500 *nm*
- separation between tracks : 2500 *nm*


COMPUTER GRAPHICS
PROCEEDINGS CD-ROM
8-13 August 1999
Los Angeles, California
A Publication of ACM SIGGRAPH

Results

Animations Rendered in MAYA 2.0

Conclusion

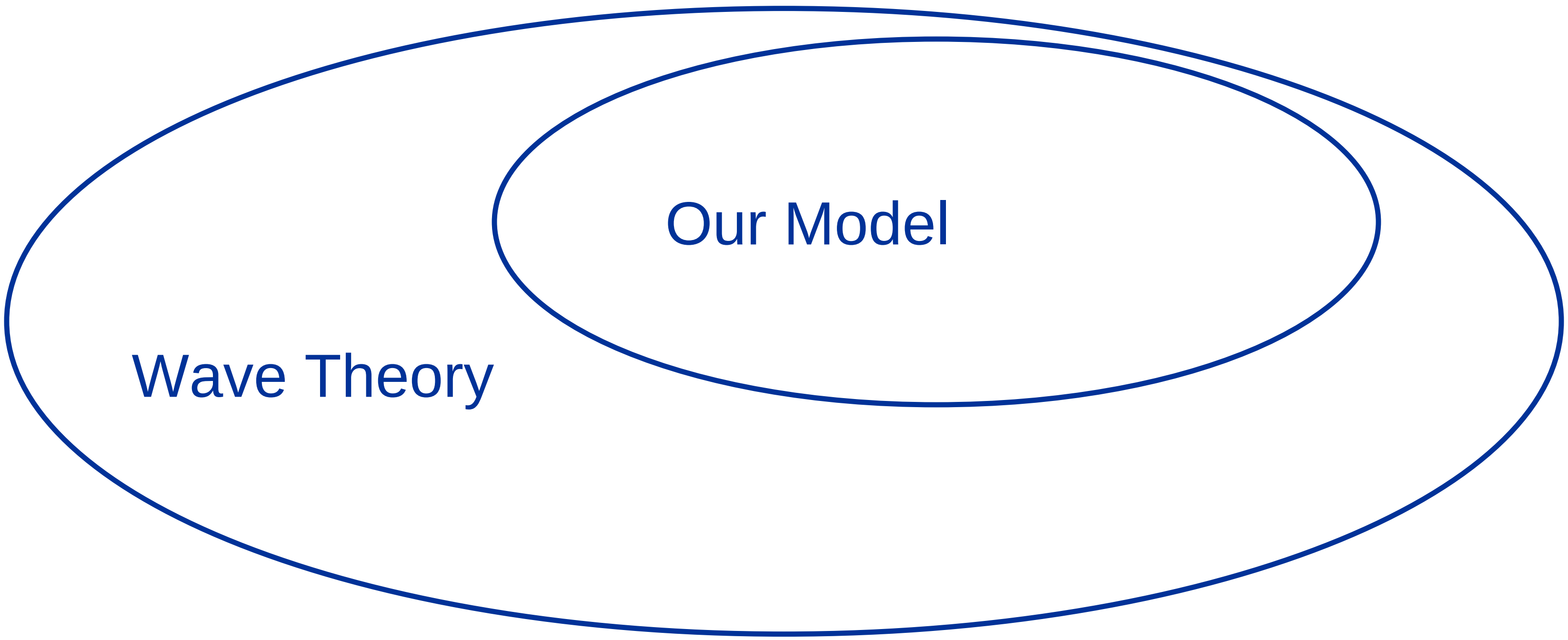
Fourier transform very powerful tool

Most general Illumination model in CG

He-Torrance special case

Experimental validation (?)

Future Work



Multiple scattering, varying Fresnel coefficient, any distances, polarization, non-height field surfaces, subsurface scattering, etc.