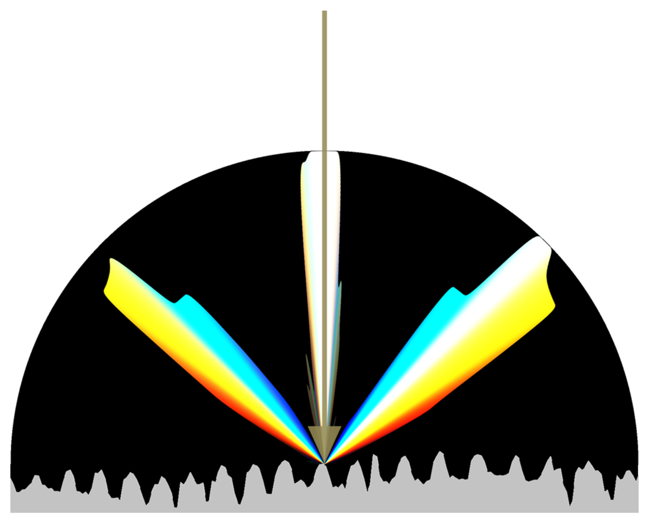

INTERACTIVE DIFFRACTION FROM BIOLOGICAL NANOSTRUCTURES

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PROBLEM

(a) Xenopeltis (b) Its nanostructure

- Rendering structural colors due to diffraction.
- Using actual measured biological nanostructures.
- At interactive rates.

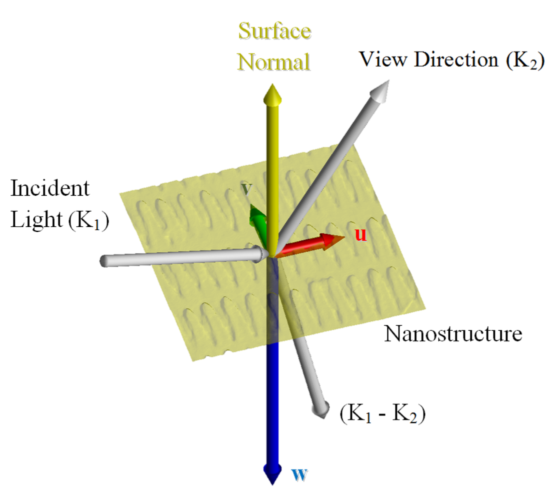
Challenges are :

1. Modelling the statistical distribution of the height bumps for a "general" nanostructure.
2. Performing complex computations in real-time at high resolution.

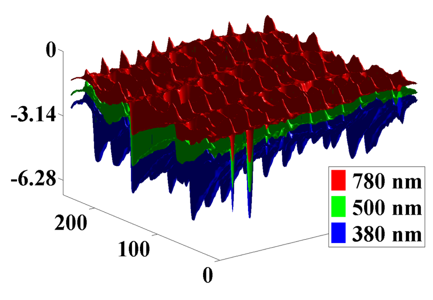
CONTRIBUTIONS

- A method to render structural colors due to diffraction gratings directly based on physical measurements with atomic force microscopy (No assumptions about the distribution).
- An algorithm for interactive rendering leveraging precomputed look-up tables.

METHOD



(a) Optical Geometry



$$\Phi(x, y) = \frac{2\pi}{\lambda} wh(x, y)$$
$$p(x, y) = e^{\Phi(x,y)}$$

(b) Phase shifts $\Phi(x, y)$ for different wavelengths

Bidirectional reflection distribution function [1]:

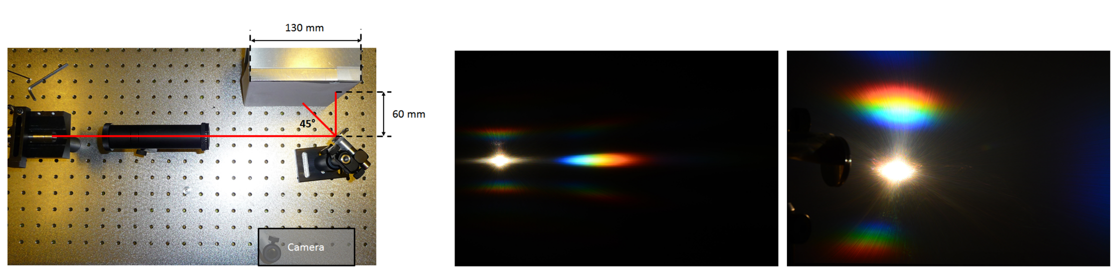
$$BRDF_\lambda(\omega_i, \omega_r) = \frac{F^2 G}{\lambda^2 A w^2} \left\langle \left| P\left(\frac{u}{\lambda}, \frac{v}{\lambda}\right) \right|^2 \right\rangle,$$

$$Y = \int_\lambda BRDF_\lambda(\omega_i, \omega_r) S_y(\lambda) \mathrm{d}\lambda,$$

Key Ideas:

- Exploit properties of Fourier transforms to use discrete Fourier transforms.
- Use spatial coherence length to compute response for non-discrete frequencies.
- Separate λ and optical geometry related terms.
- Pre-compute integration over wave spectrum for discretized optical geometry space ($u - v$).
- Use relative reflectance for tone-mapping.

OBSERVATIONS

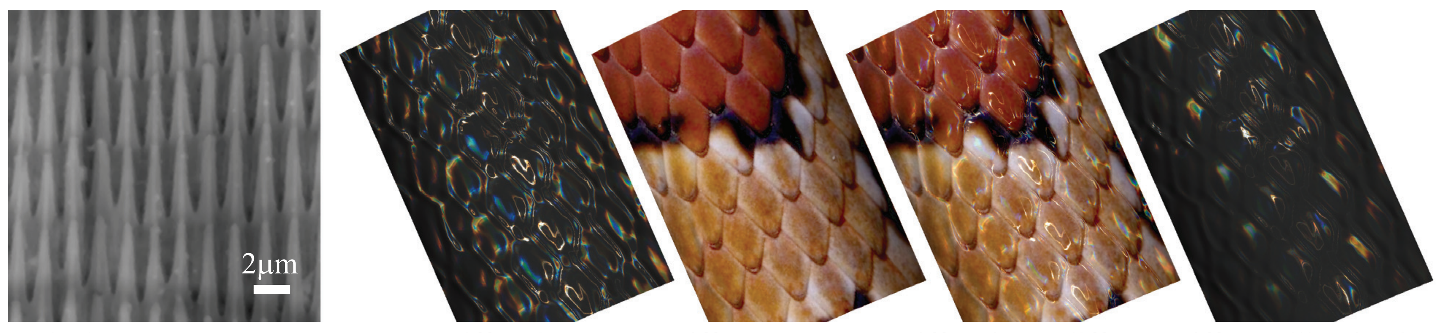


Lab setup Elaphe Diffraction Xeno Diffraction

REFERENCES

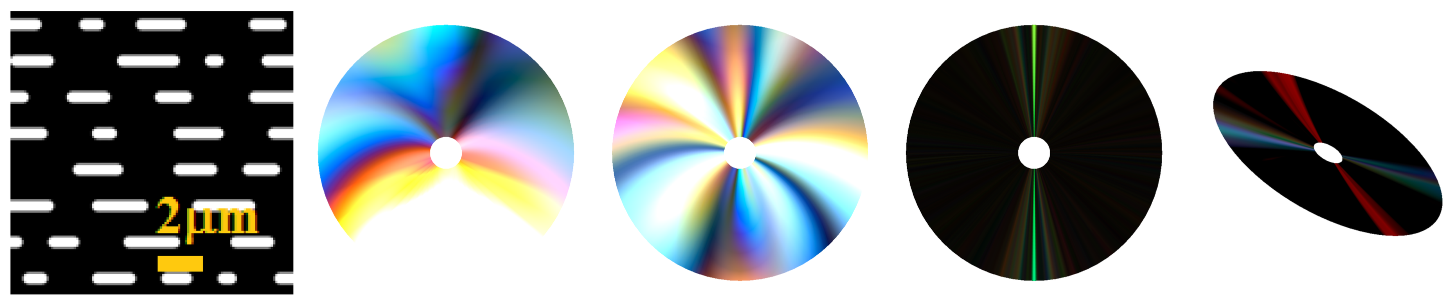
[1] Jos Stam, "Diffraction Shaders", In *Proceedings of the 26th annual conference on computer graphics and interactive techniques, SIGGRAPH '99*

RESULTS

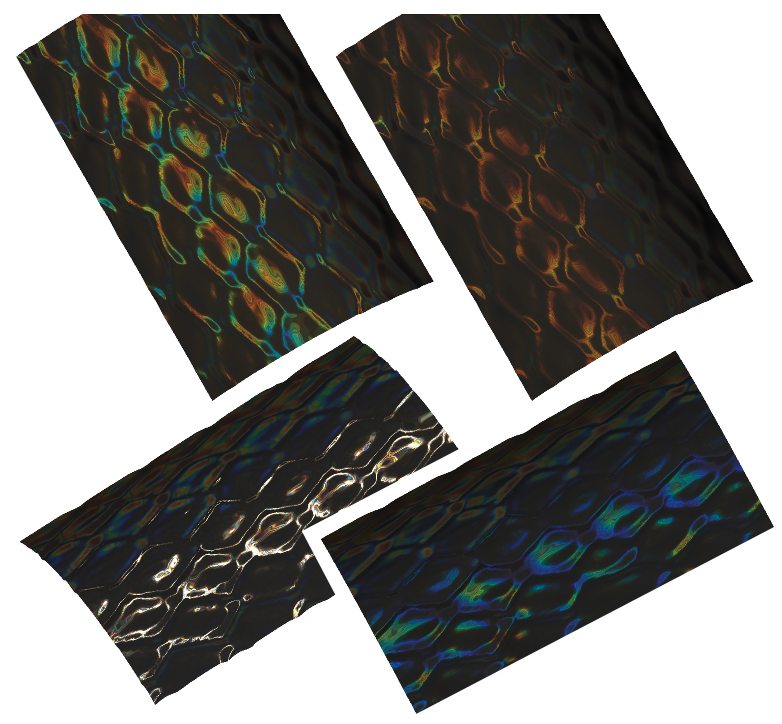


Elaphe nanostructure Diffraction Diffuse texture Diffraction + diffuse Different illumination

(a) Elaphe Guttata Guttata

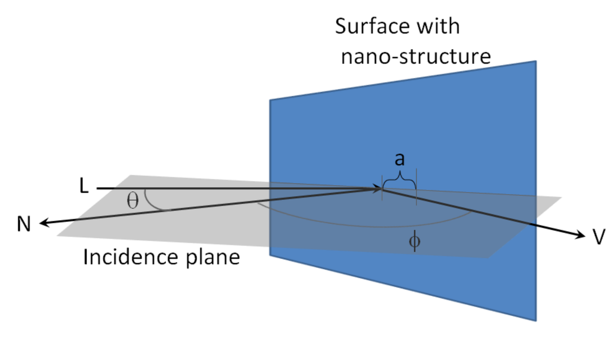


(b) Synthetic Compact Disk (its nanostructure and different renderings)

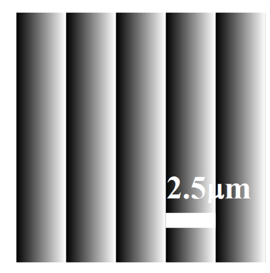


(c) Xenopeltis

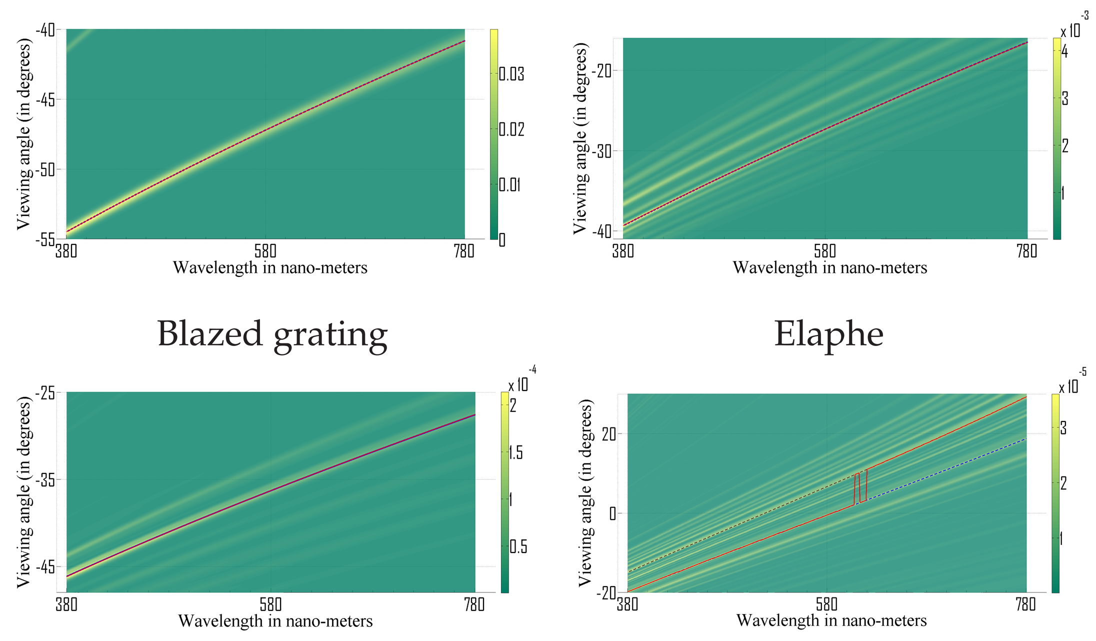
VALIDATION



(a) Experimental Setup



(b) Synthetic blazed grating (nanostructure)



Blazed grating Elaphe

Xeno : Along nano-fingers Xeno : Across nano-fingers

(c) Relative spectral reflectance for incidence angle fixed at 75°

We validate our method in comparison with an idealized diffraction grating defined by,

$$sin(\theta) = sin(\phi) + m\lambda/a, \quad (1)$$

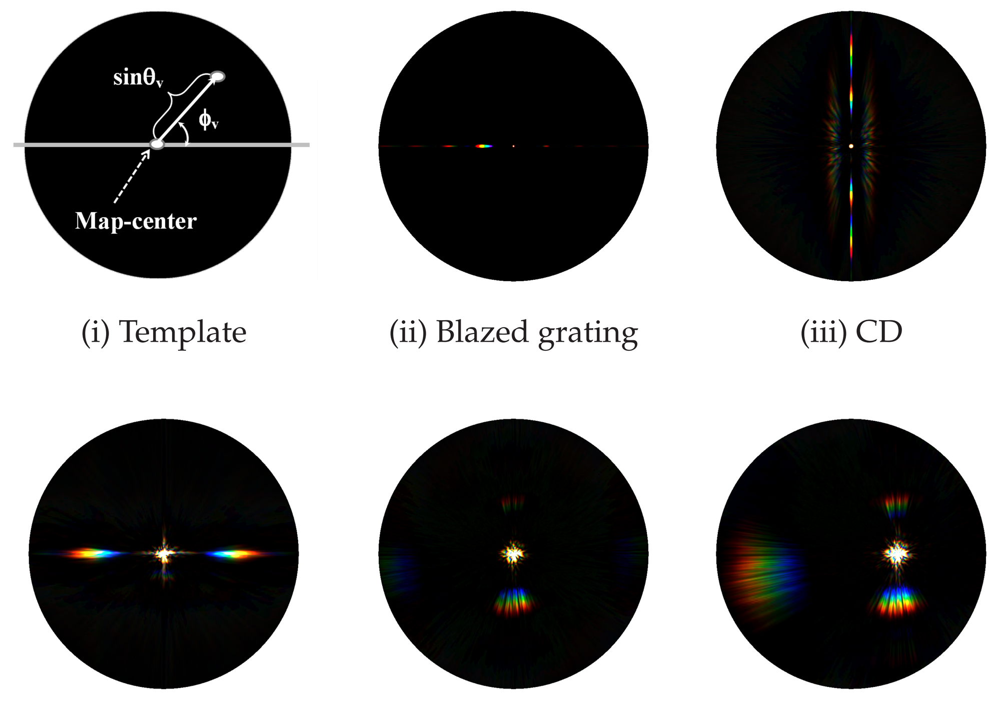
where θ is the angle of incidence, ϕ is the viewing angle, λ is a wave frequency and a is the idealized periodicity of a grating. In our setup, Fig (a) above, L is the light direction, V is the viewing direction and N is the surface normal. 'a' represents the periodicity. We plot reflectances obtained using our BRDFs at different viewing angles over visible wavelengths. The BRDFs exhibit typical 'peak-viewing-angles' corresponding to idealized gratings with matching periodicities (table below).

Data	Estimated Periodicity	
	Mean (in nm)	Variance (in nm)
Blazed grating (2500nm)	2500.34	0.16
Elaphe	1144.28	0.15
Xenopeltis (Along fingers)	1552.27	0.45
Xenopeltis (Across fingers)		
- Blue curve in Figure (c)	605.89	0.12
- Brown curve in Figure (c)	536.13	0.04

A FUTURE DIRECTION

To extend our method for modeling diffraction from other biological nanostructures such as multilayer arrangement on butterfly wings.

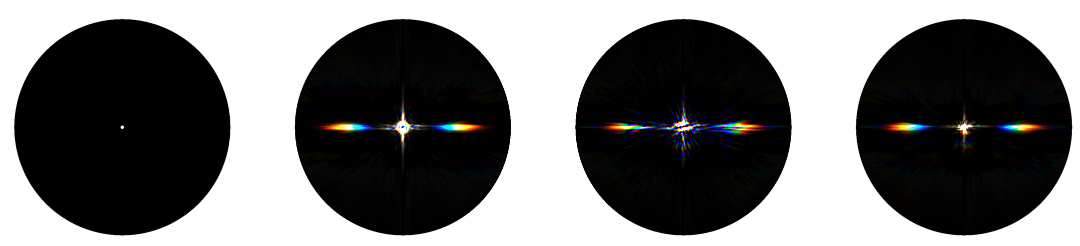
BRDF MAPS



(i) Template (ii) Blazed grating (iii) CD

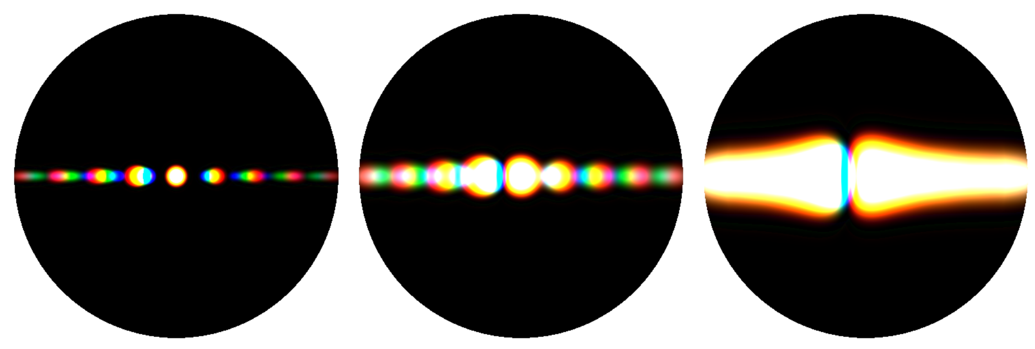
(iv) Elaphe (v) Xeno (vi) Xeno

(a) (i)-(v) shows BRDF maps generated using normal incident light for different viewing directions (θ_r, ϕ_r). (vi) Shows BRDF map for Xeno with incident light at an angle of 20°



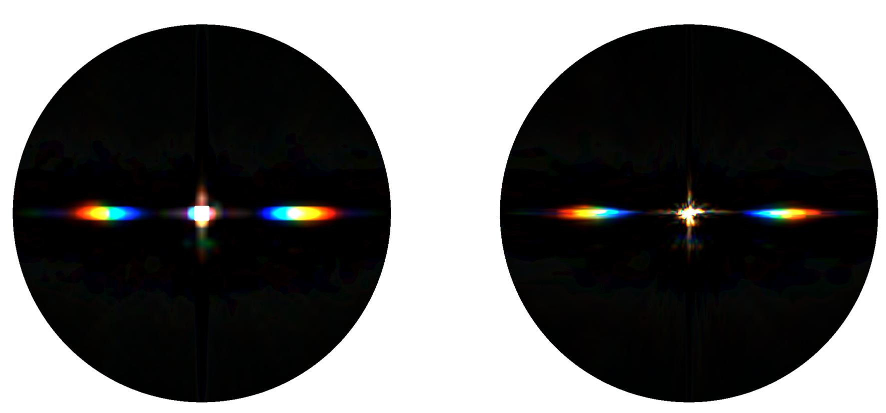
(i) $N = 0$ (ii) $N = 1$ (iii) $N = 3$ (v) $N = 9$

(b) Convergence of the Taylor series with higher values for N for Elaphe nanostructure.



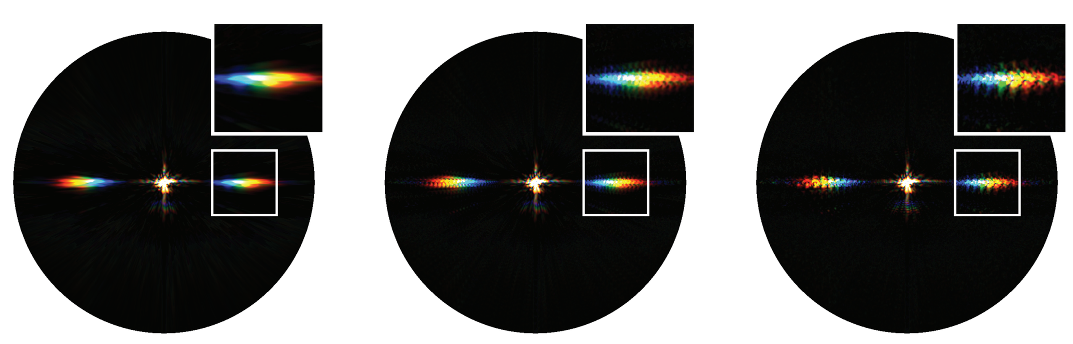
$4\sigma_s = 13\mu m$ $4\sigma_s = 6.5\mu m$ $4\sigma_s = 3.25\mu m$

(c) Effects of coherence length



Linear Non-linear

(d) $u - v$ space discreization for lookup tables @ 101×101.



$\Delta\lambda = 5nm$ $\Delta\lambda = 25nm$ $\Delta\lambda = 50nm$

(e) Effects of different λ step-size on numerical integration.

CONCLUSION

Our approach achieves interactive performance (upto 20 FPS) by precomputing spectral integrals into look-up tables using a Taylor series expansion.