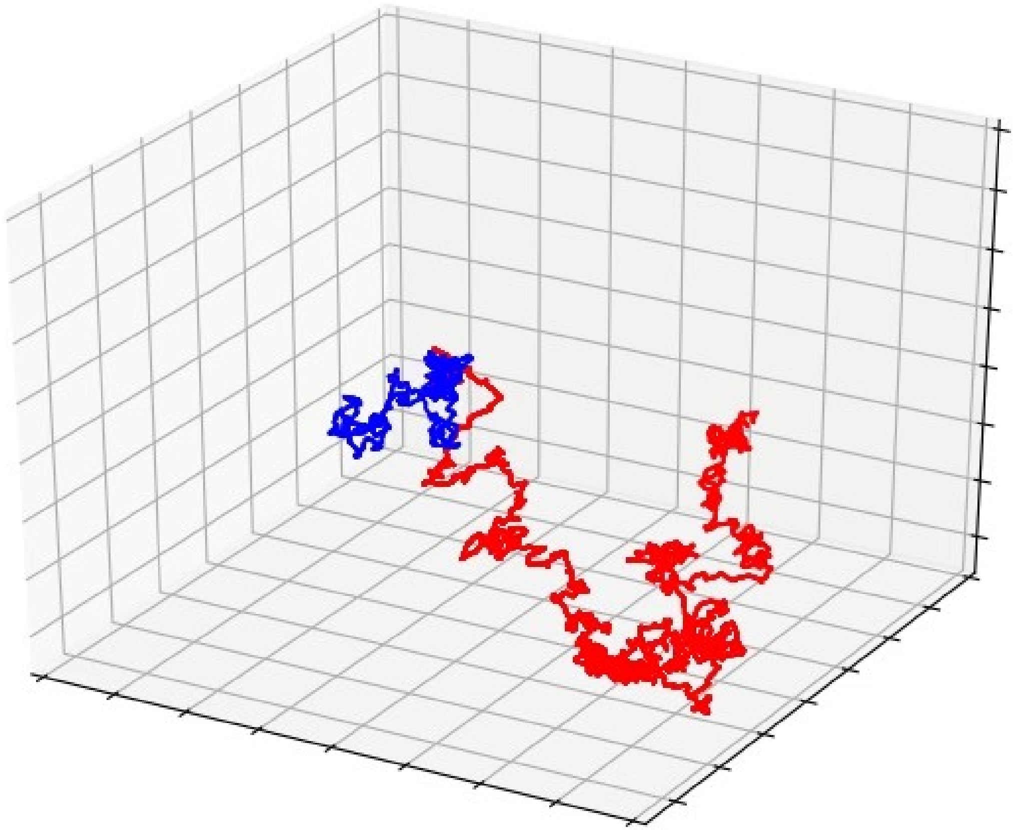
Monte Carlo radiation transfer and computational physics



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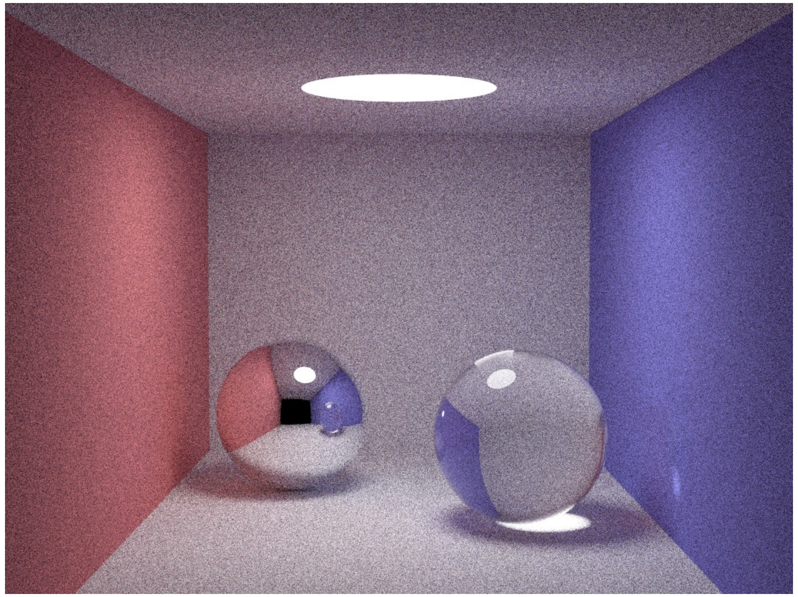
Supervisors:
Dr. K. Wood
Prof. C.T.A. Brown

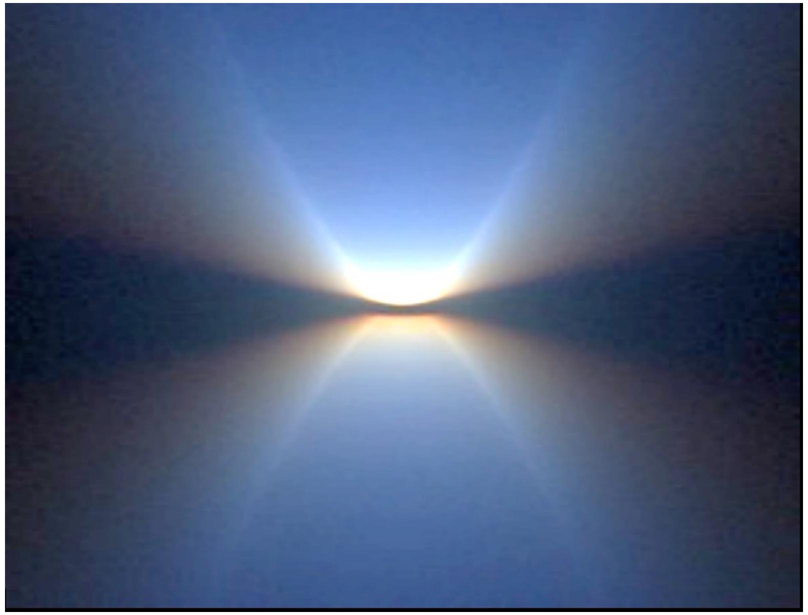
github.com/lewisfish

Monte Carlo Radiation Transfer

http://www.atomicarchive.com

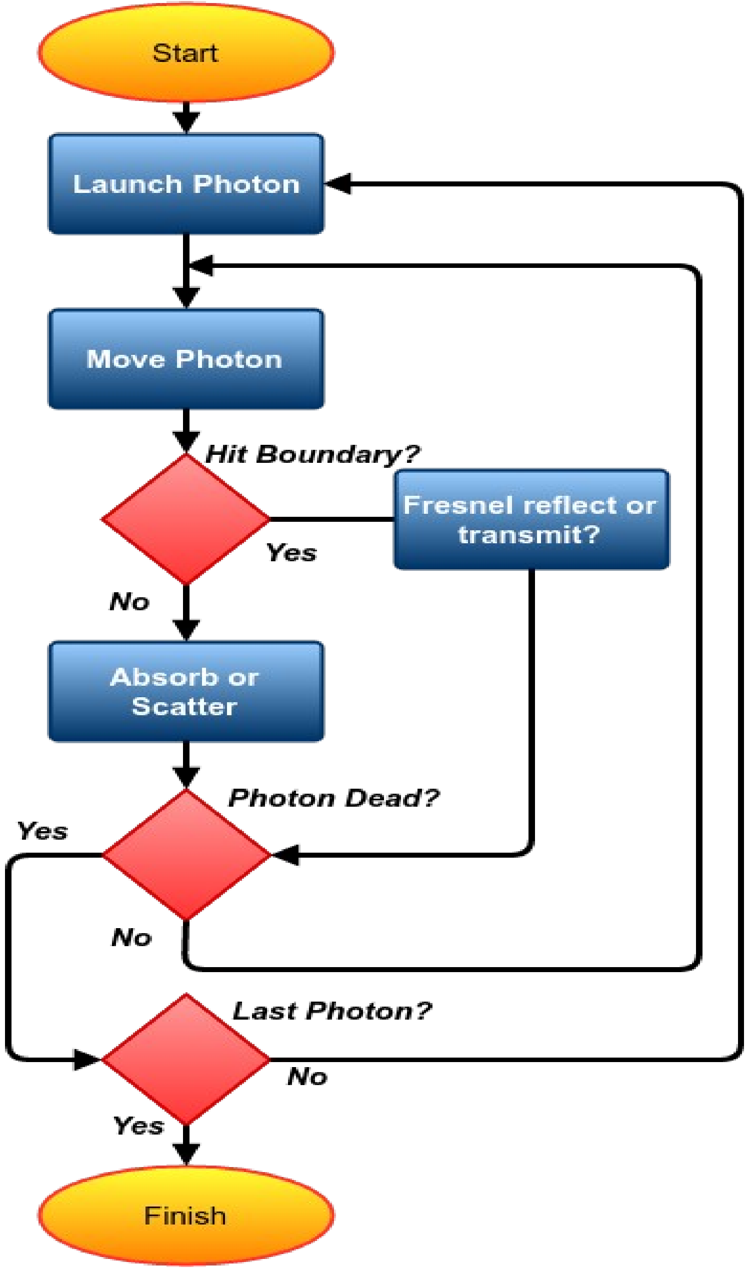


www.kevinbenson.com

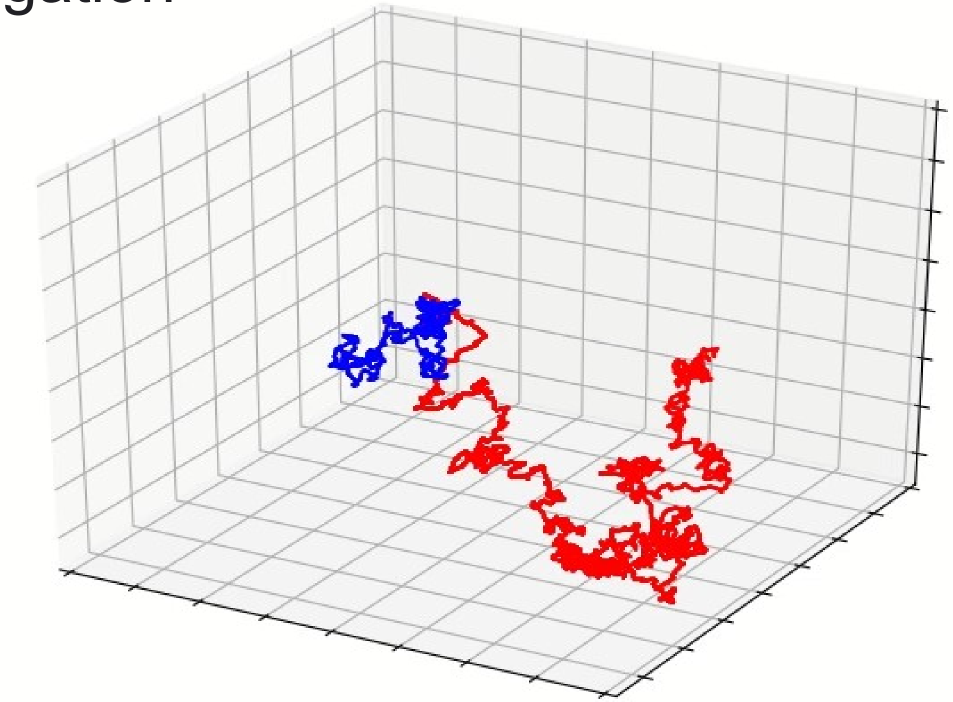


T. Robitallie SAMCSS 2015

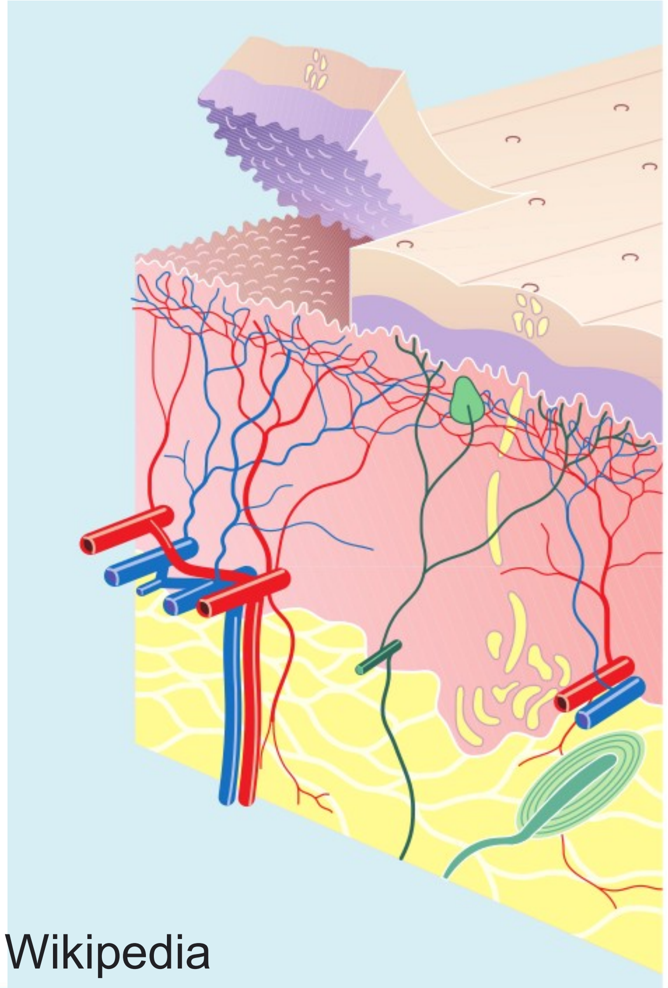
Monte Carlo Radiation Transfer



Uses random numbers and interaction probabilities to simulate photon propagation



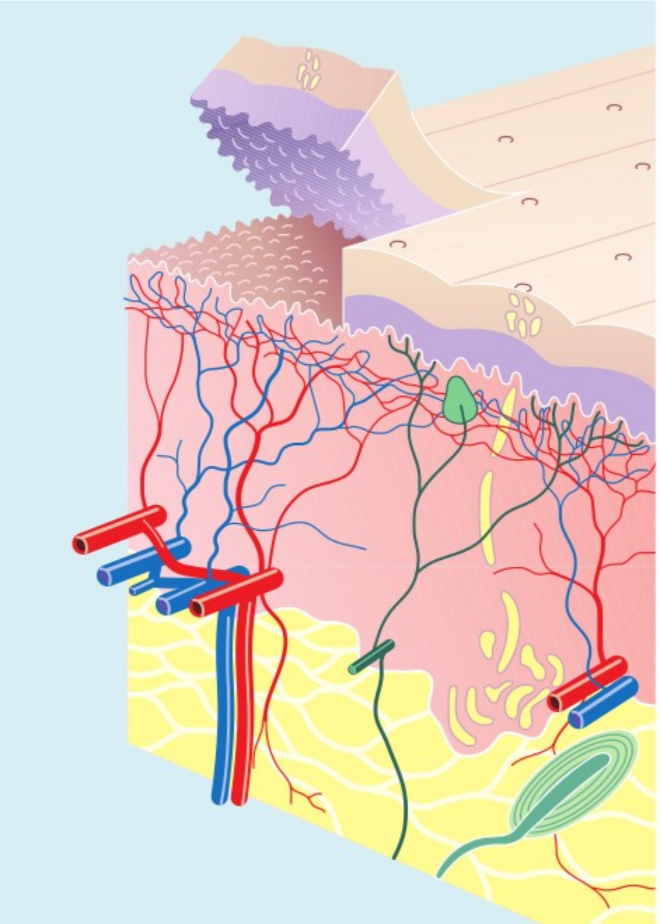
Voxel Model



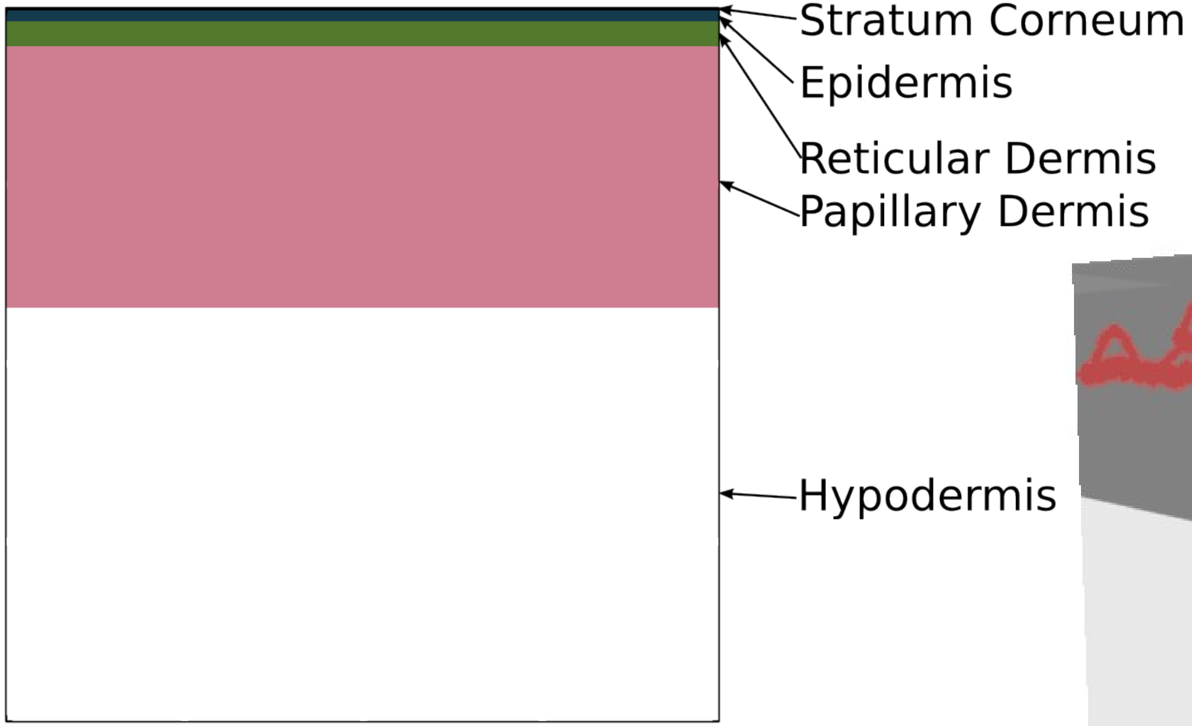
Wikipedia

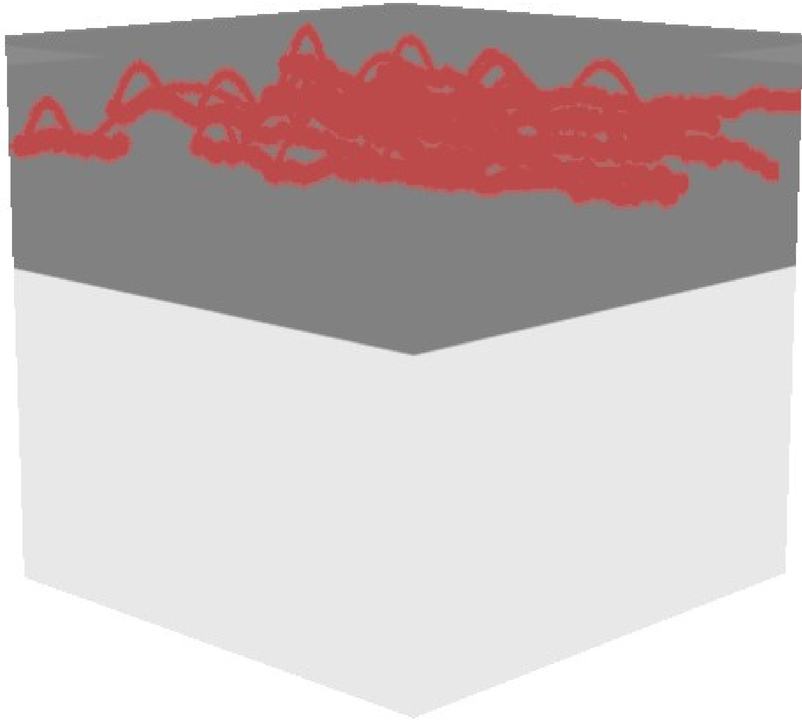
Hubble telescope

Voxel Model

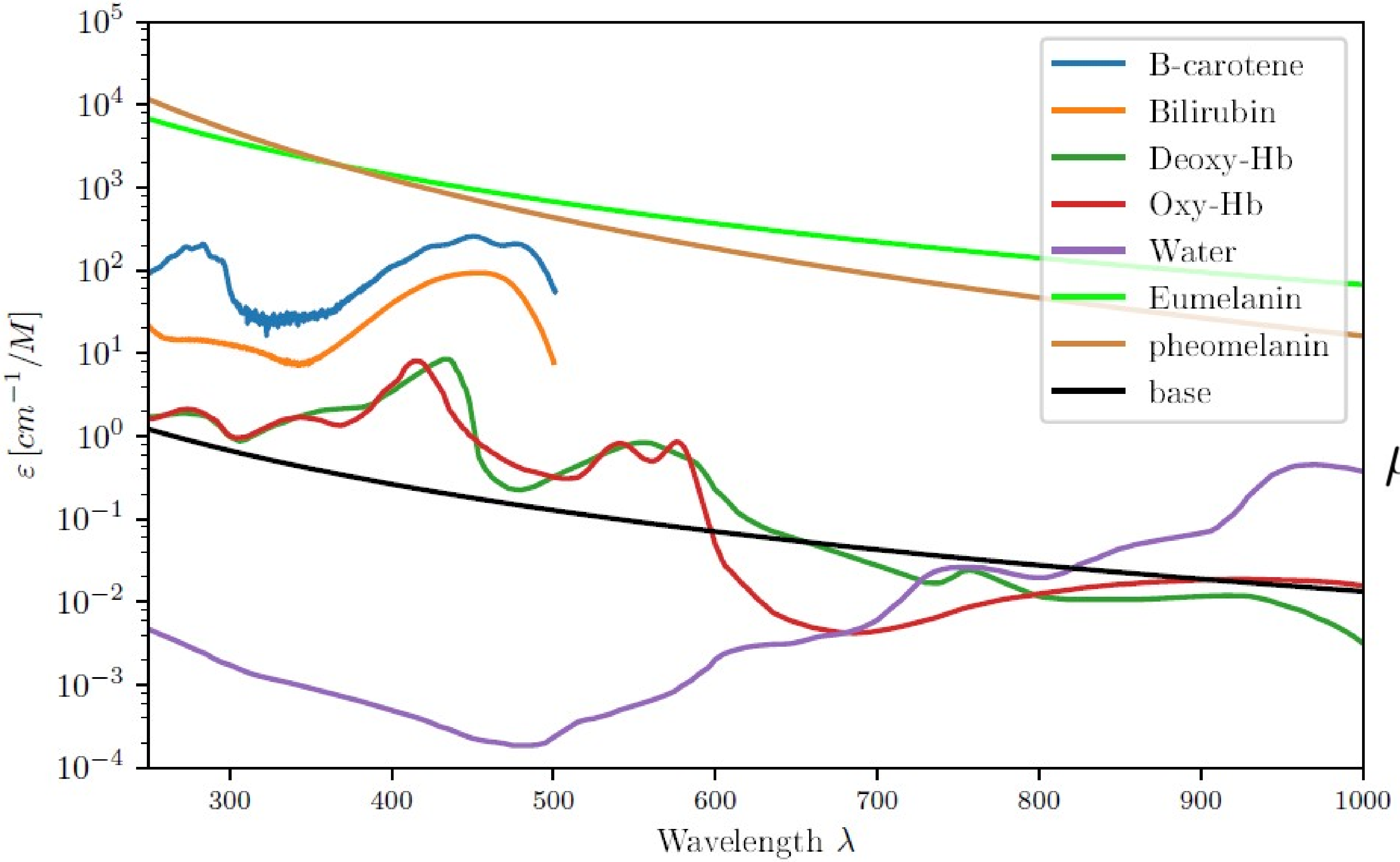


Wikipedia





5 layer skin model

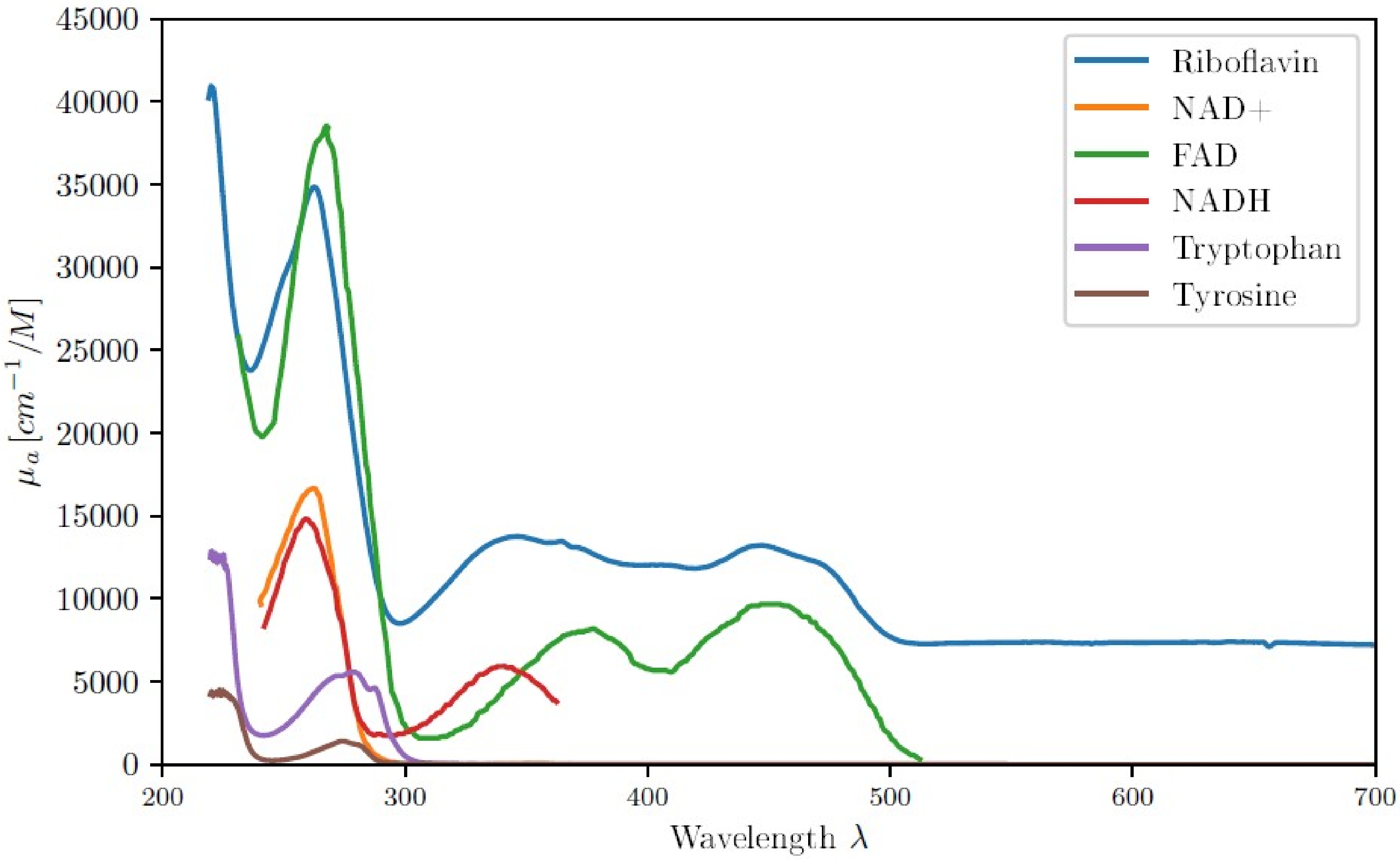


- 5 layer skin model
- Various absorbers: Blood, Melanin, Bilirubin, water, fat...

$$\mu_a^{layer} = 2.3 \sum_i C_i \mathcal{E}_i + \sum_j f_{v.j} \mu_{a.j}$$

5 layer skin model

- 5 layer skin model
- Various absorbers: Blood, Melanin, Bilirubin, water, fat...
- Various fluorophores: NADH, FAD, Riboflavin, Tyrosine...



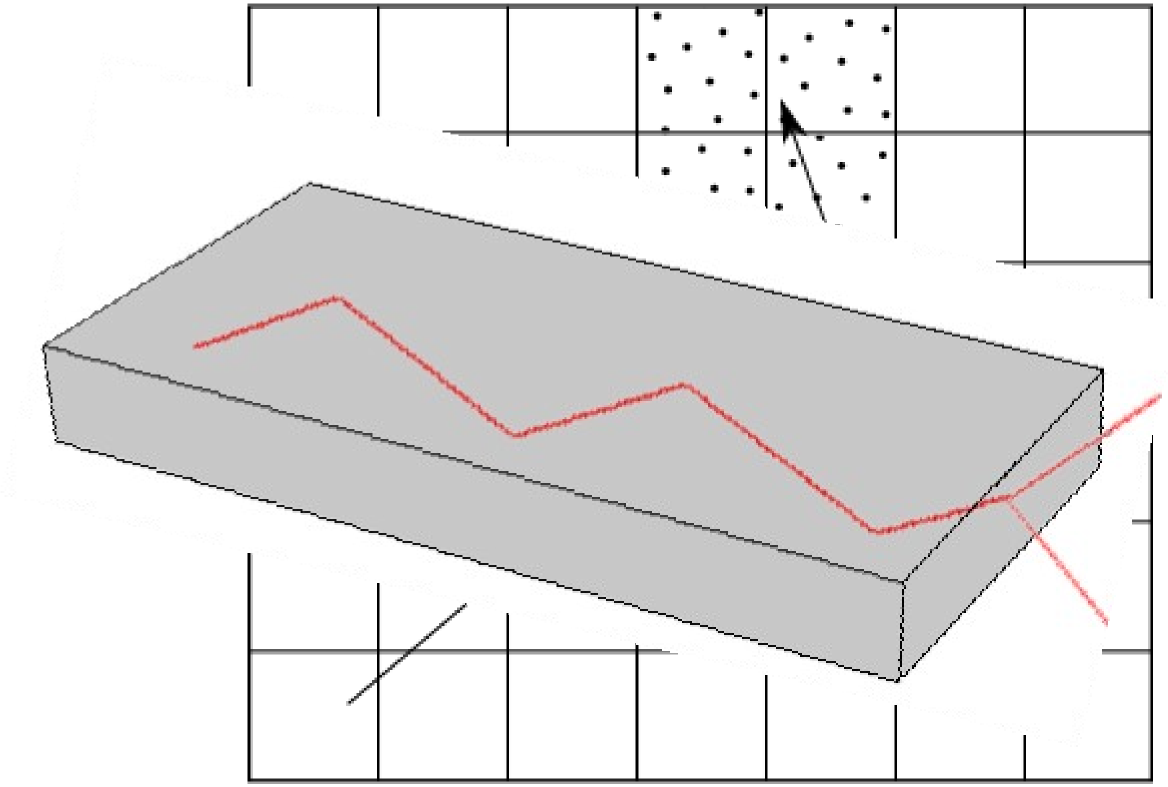
Fresnel Reflections/Refractions

- Model this at voxel boundaries

$$R_s = \left| \frac{n_1 cos\theta_i - n_2 cos\theta_t}{n_1 cos\theta_i + n_2 cos\theta_t} \right|^2$$

$$R_t = \left| \frac{n_1 cos\theta_t - n_2 cos\theta_i}{n_1 cos\theta_t + n_2 cos\theta_i} \right|^2$$

$$R = \frac{1}{2}(R_s + R_p)$$

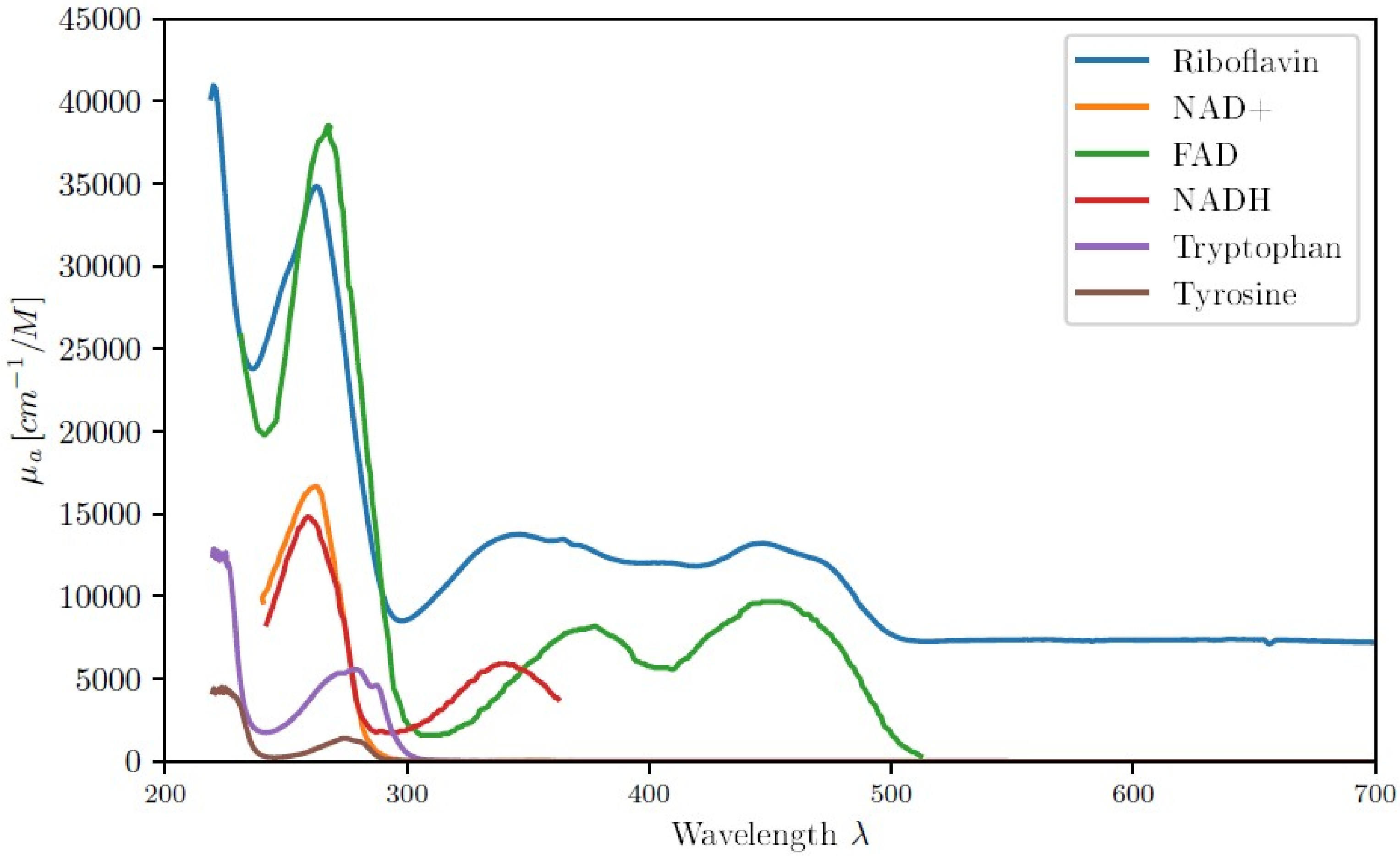


Motivation

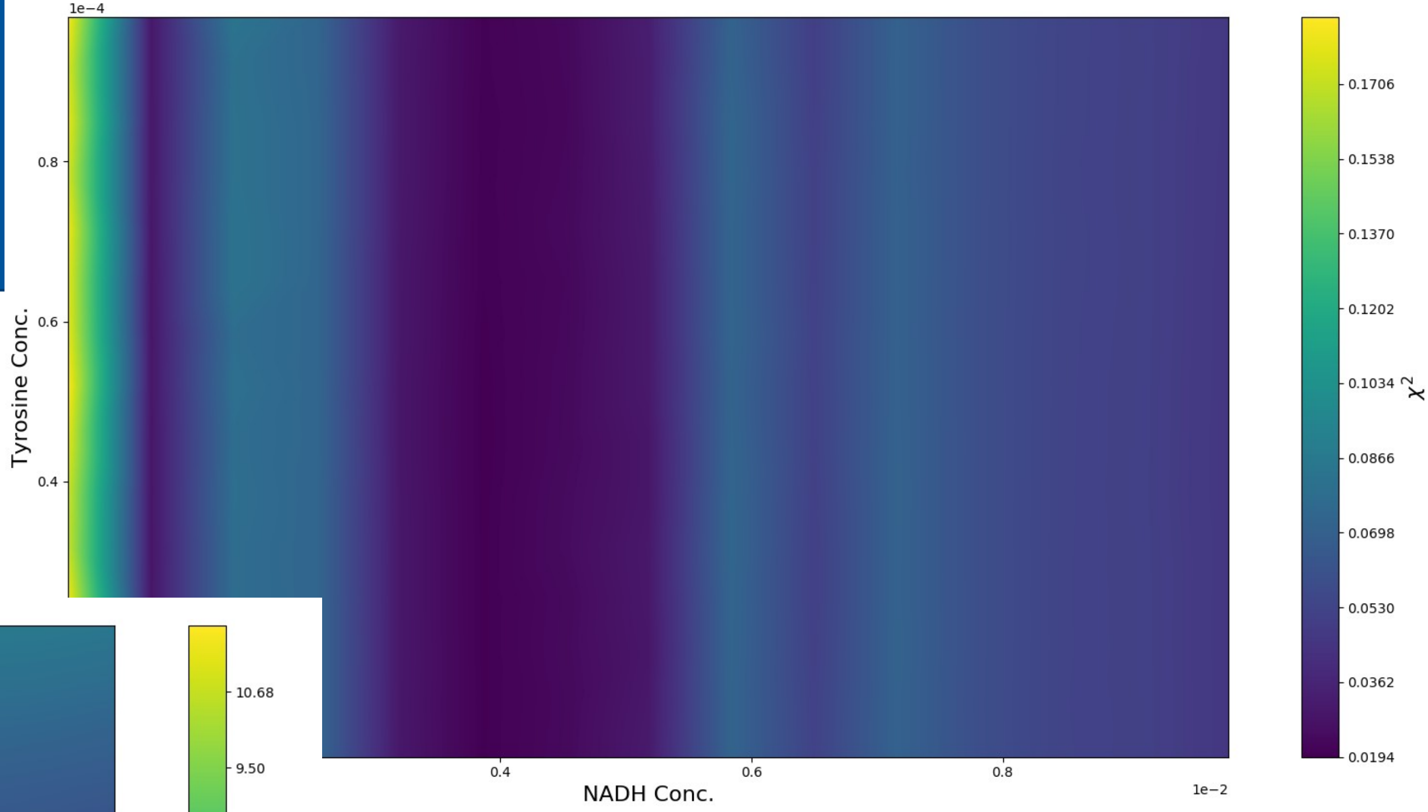
- Cardiovascular disease one of the largest causes of death
- Traditional factors do not fully explain incidence of disease
- Research towards novel biomarkers

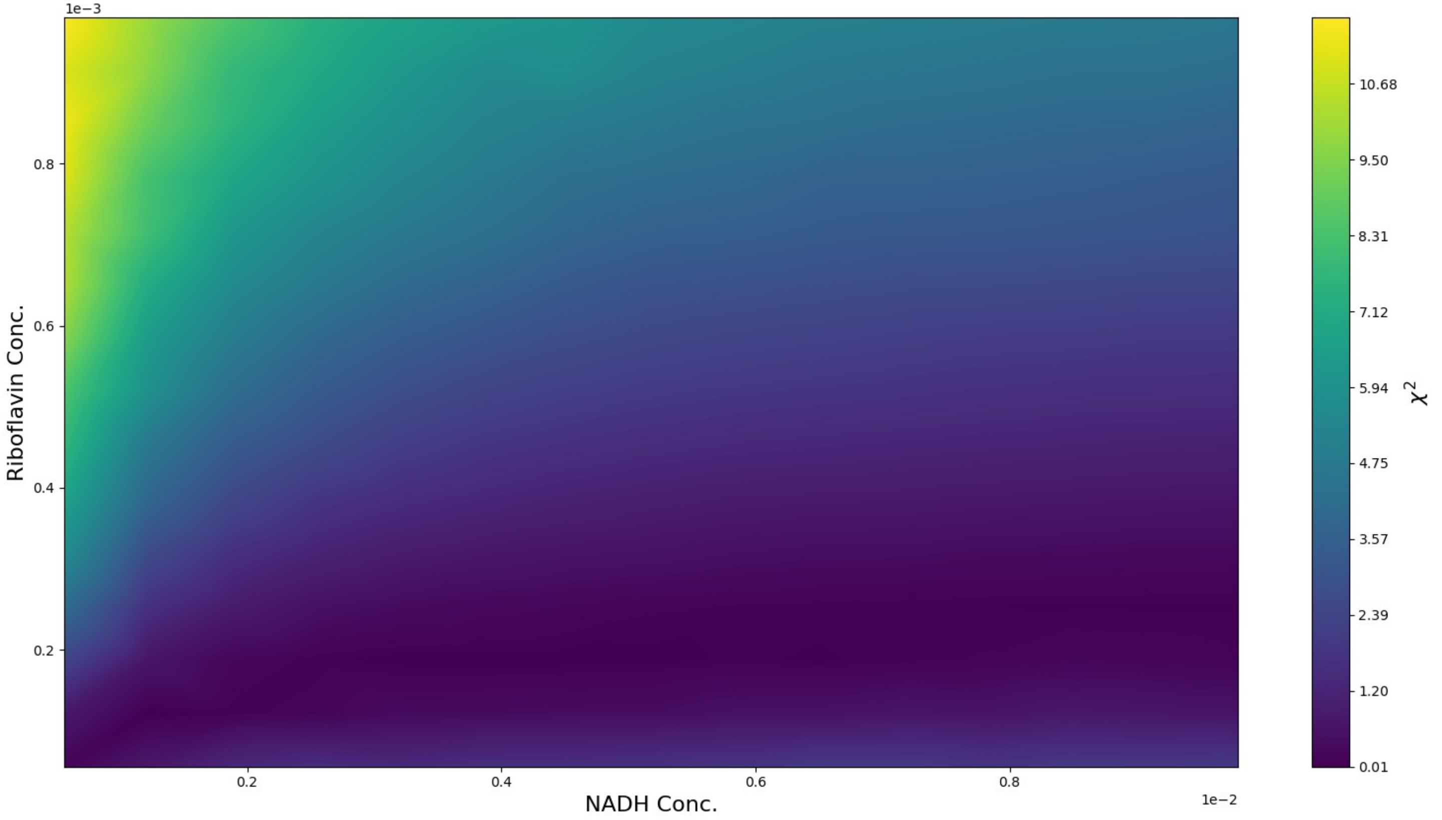
Autofluorescence

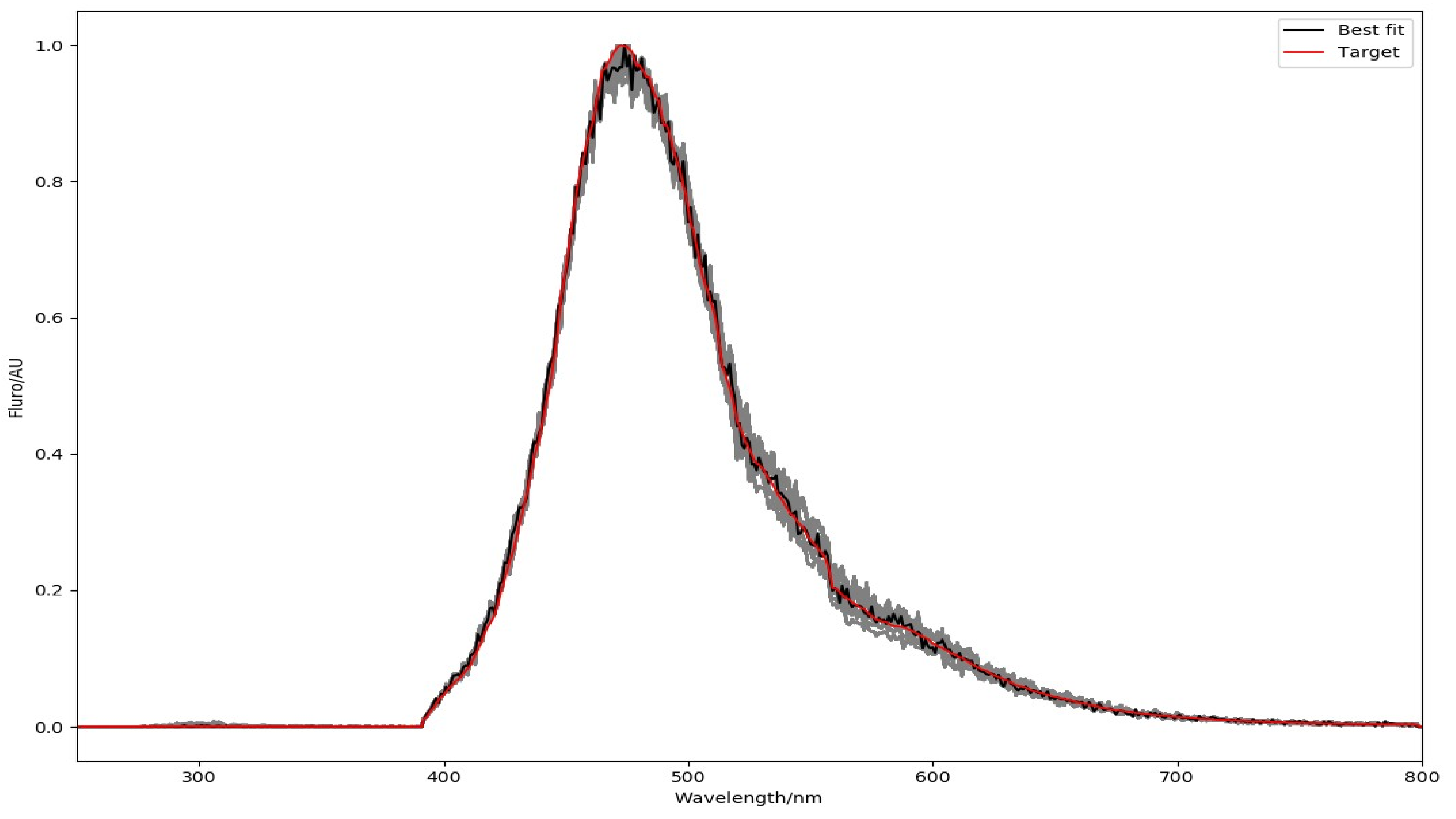
- No literature values for concentration of fluorophores



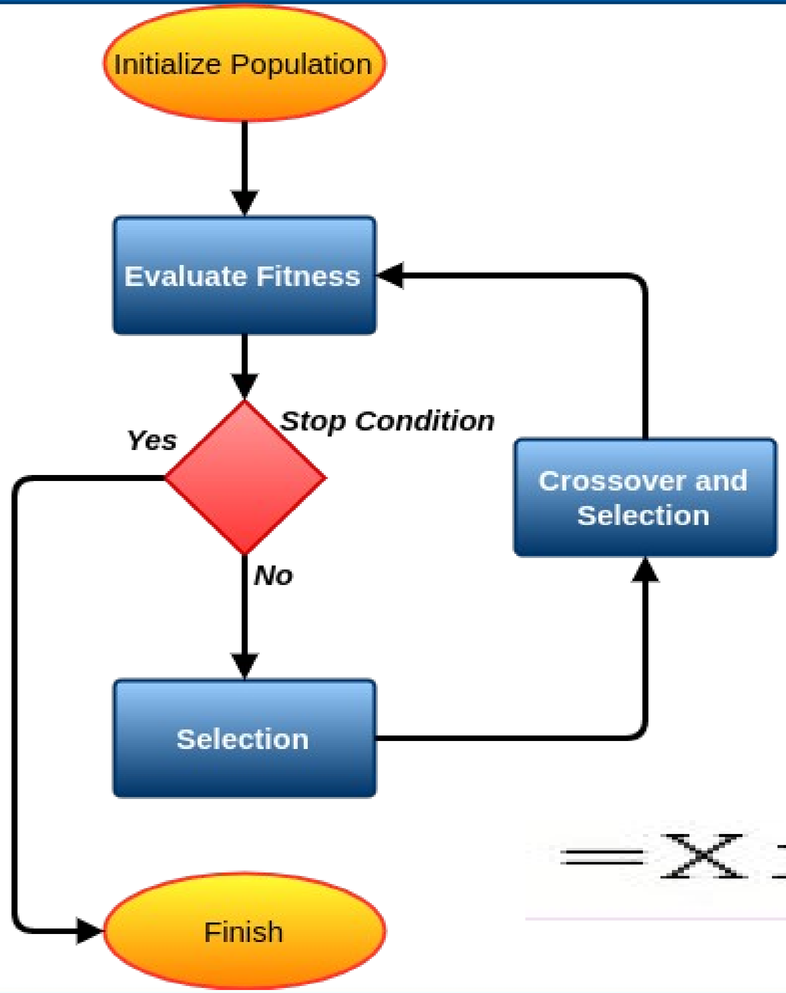
Autofluorescence

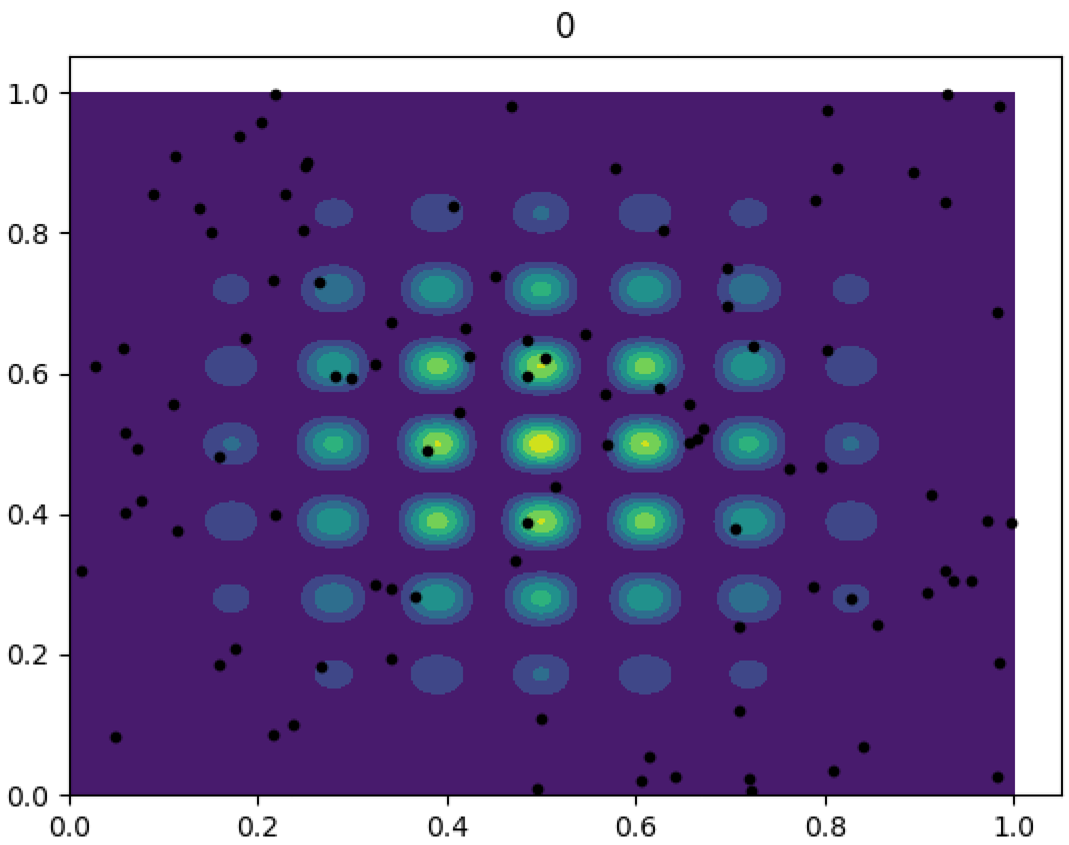





Best fit
Target
Fluro/AU
Wavelength/nm
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800

Genetic Algorithms





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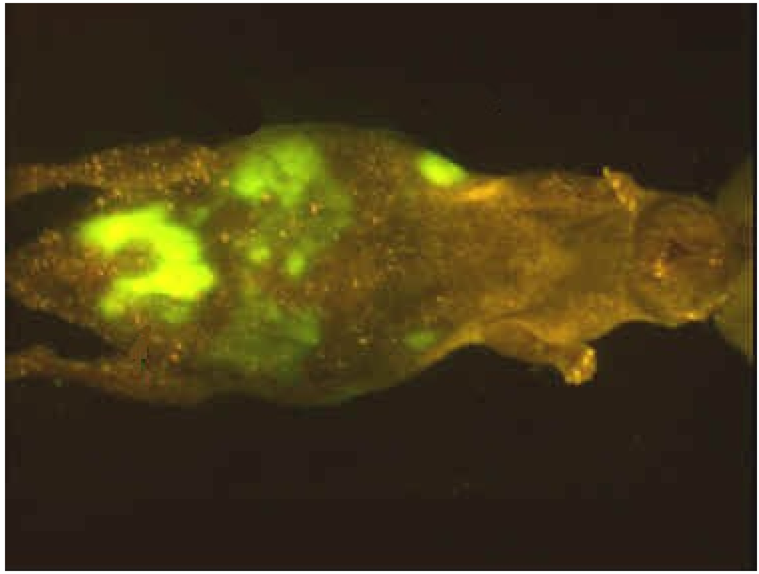
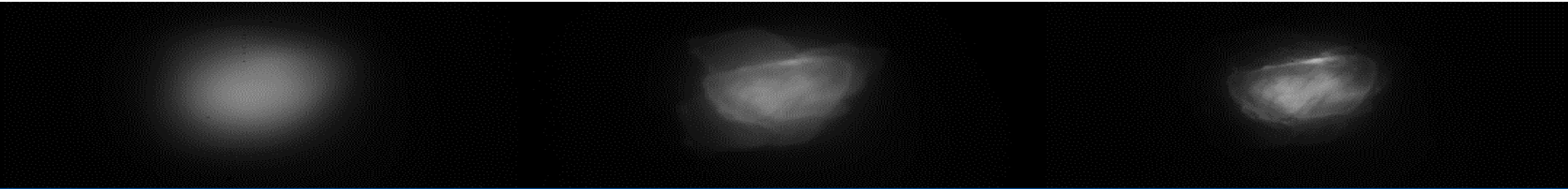
Genetic Algorithms

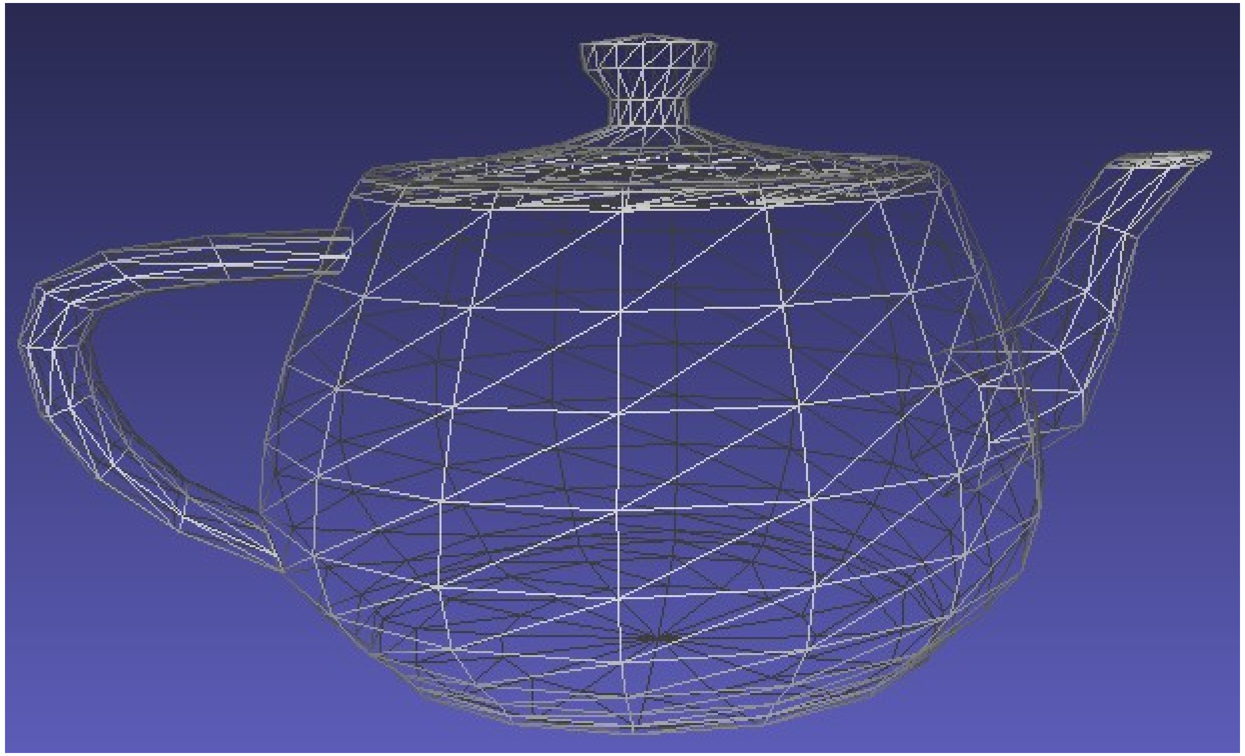
- Determine depth of fluorescence
- Use GA + experimental images
- Tumor location, diseased organs...



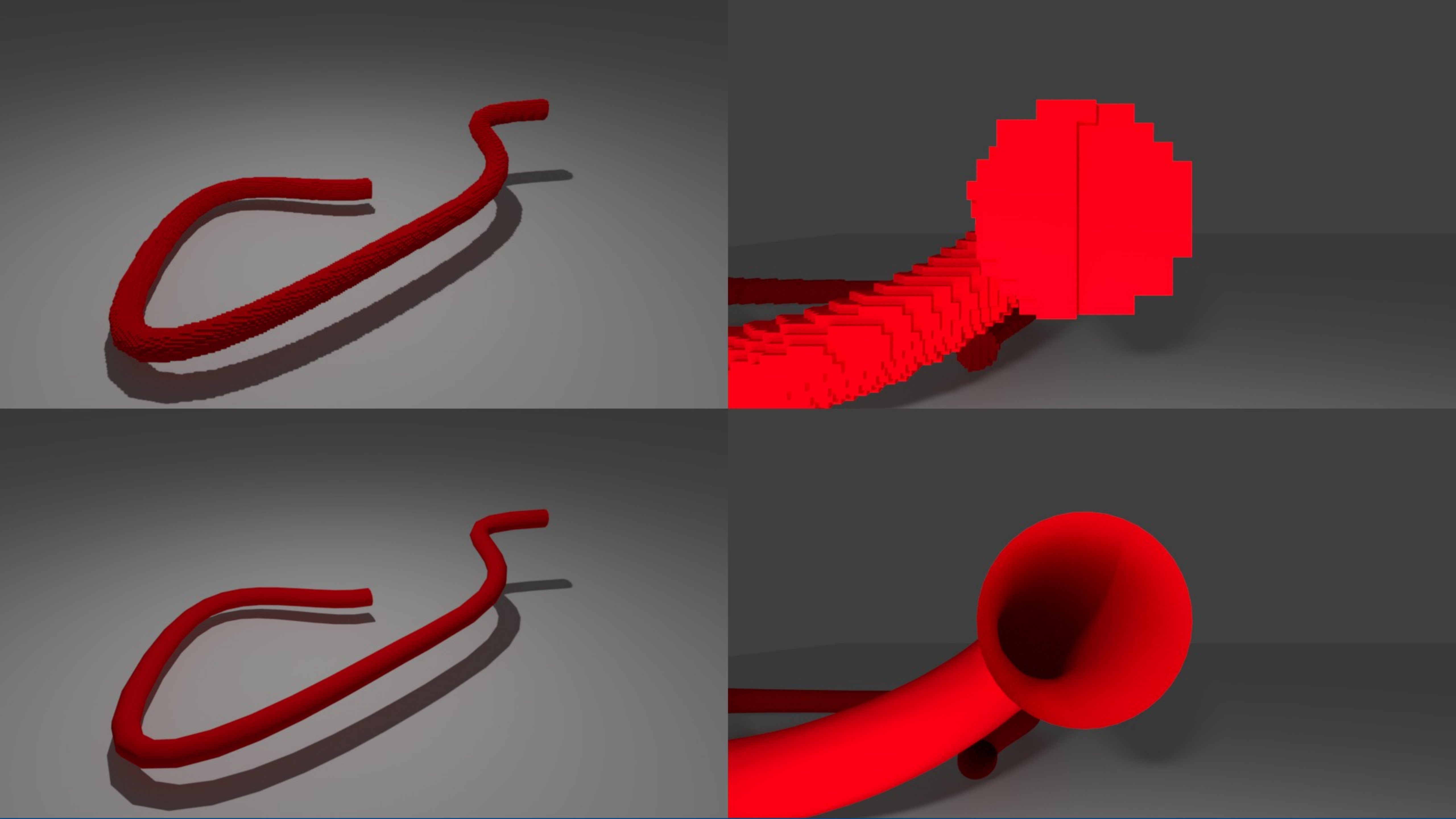
metamouse.com



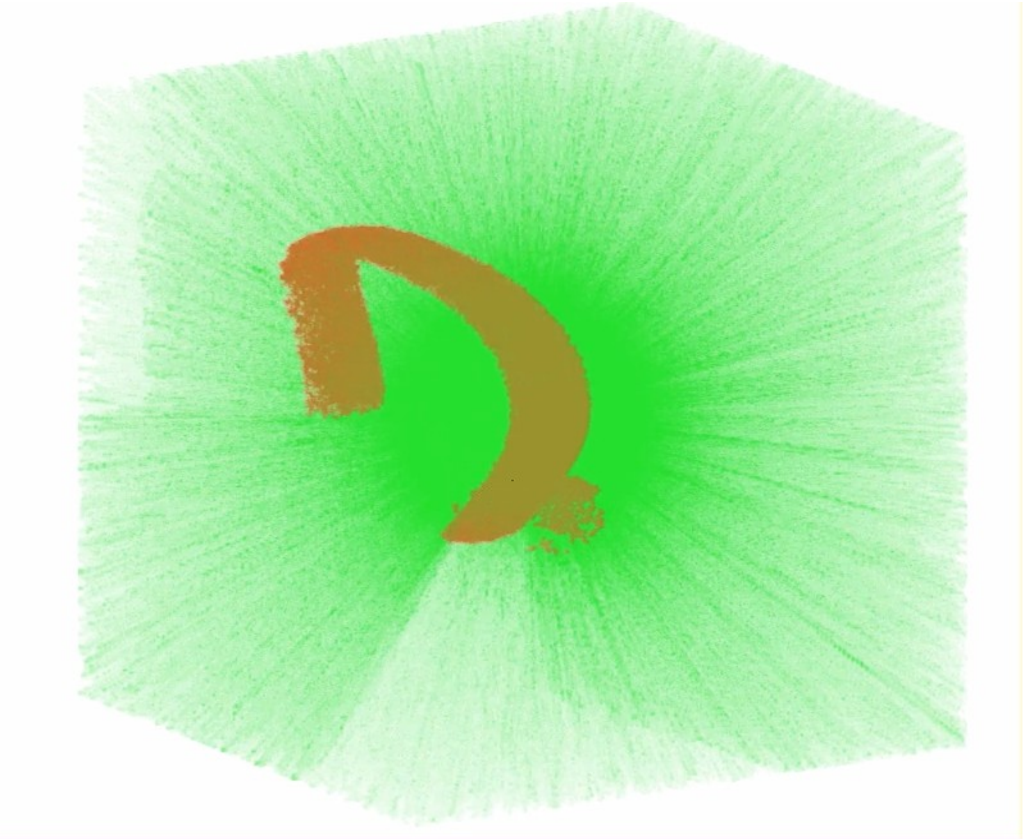
Mesh based Monte Carlo

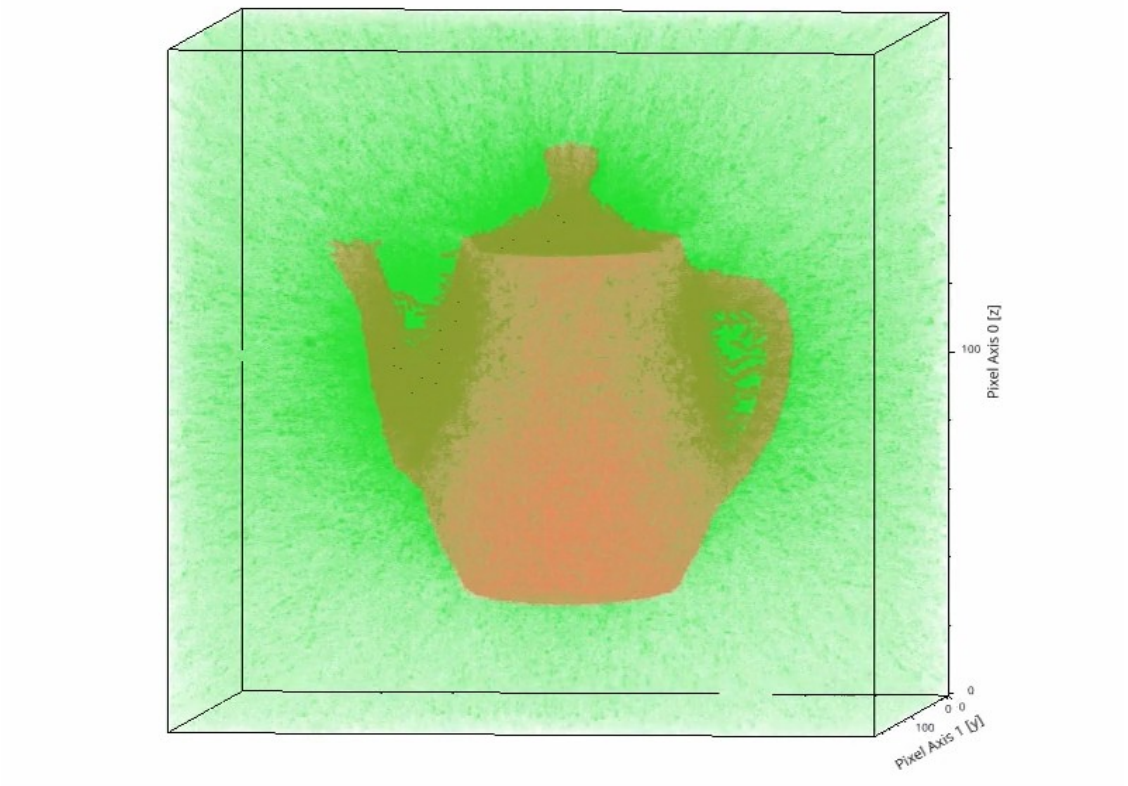


- Triangular meshes
- Can form smooth surfaces with enough triangles
- Used in Movie and video game industries

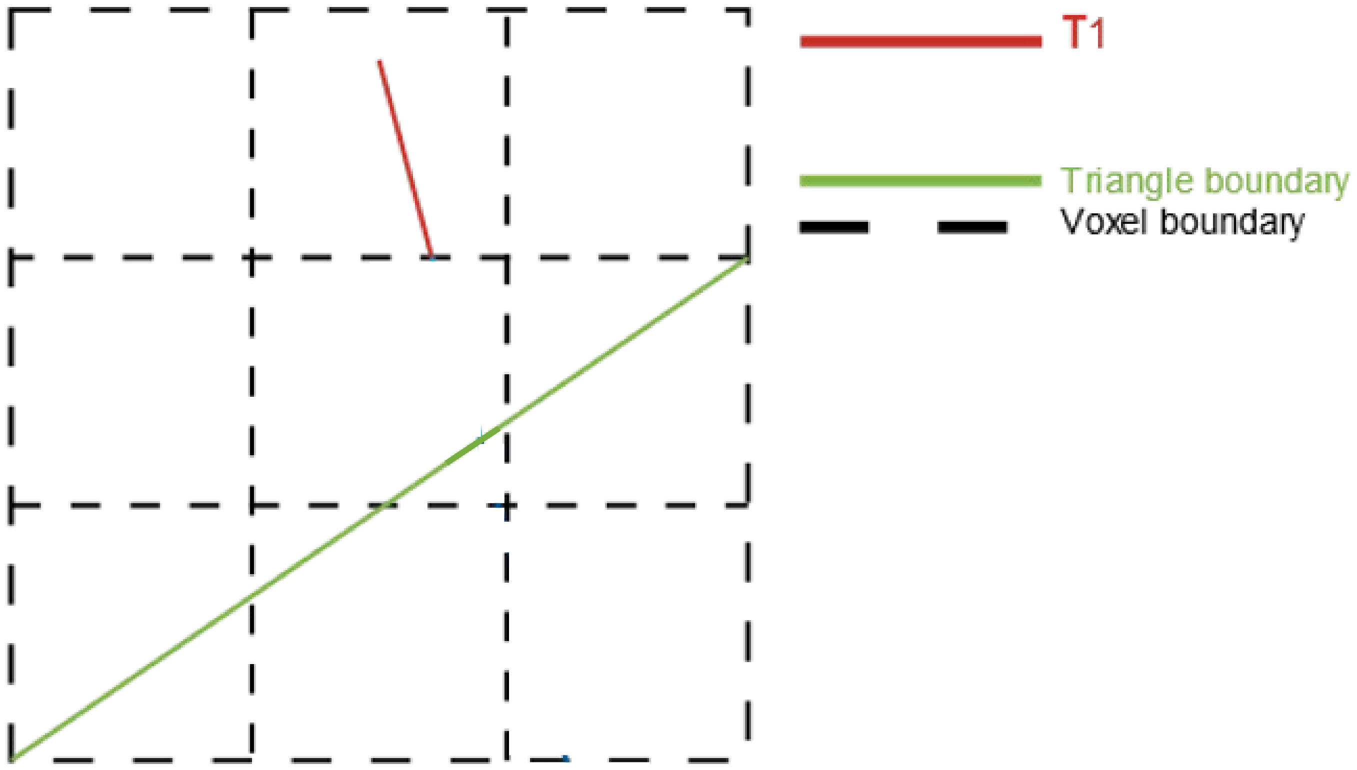


Mesh based Monte Carlo



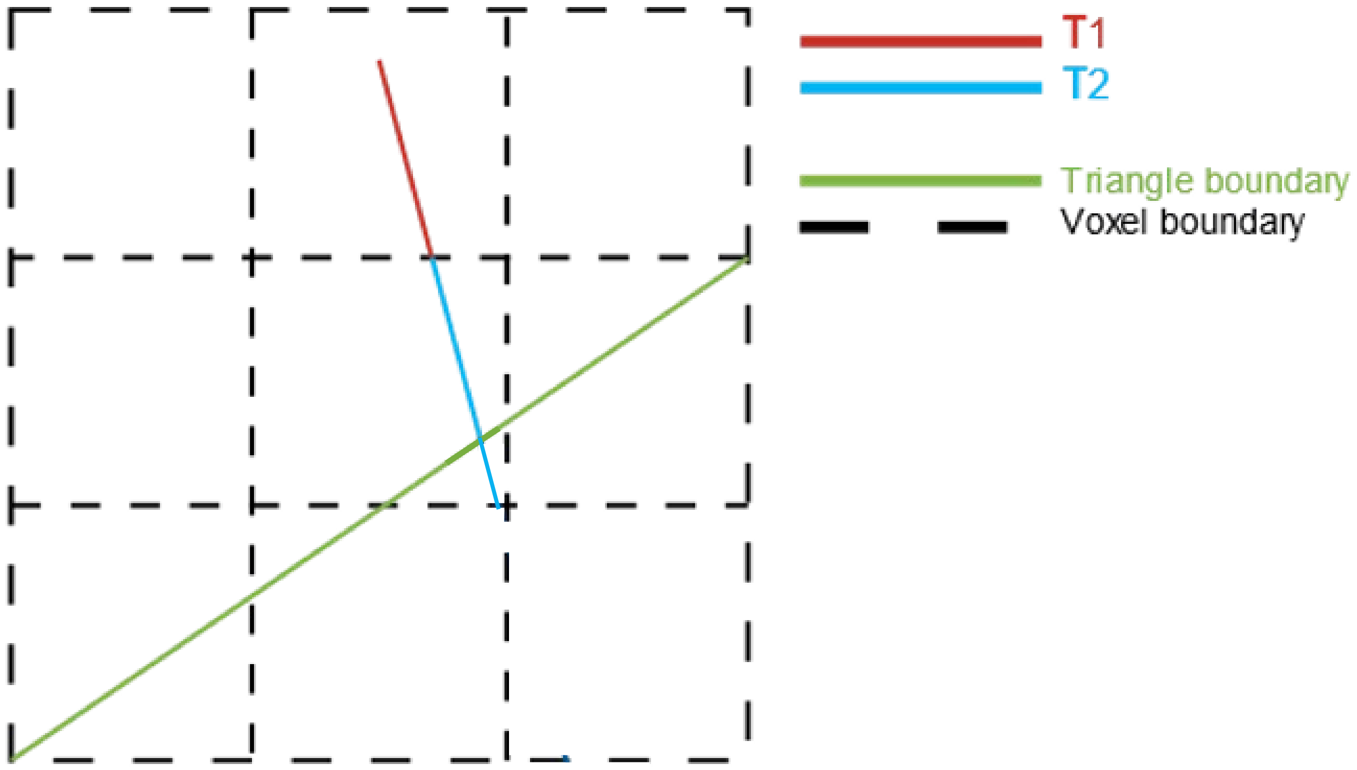


Mesh based Monte Carlo



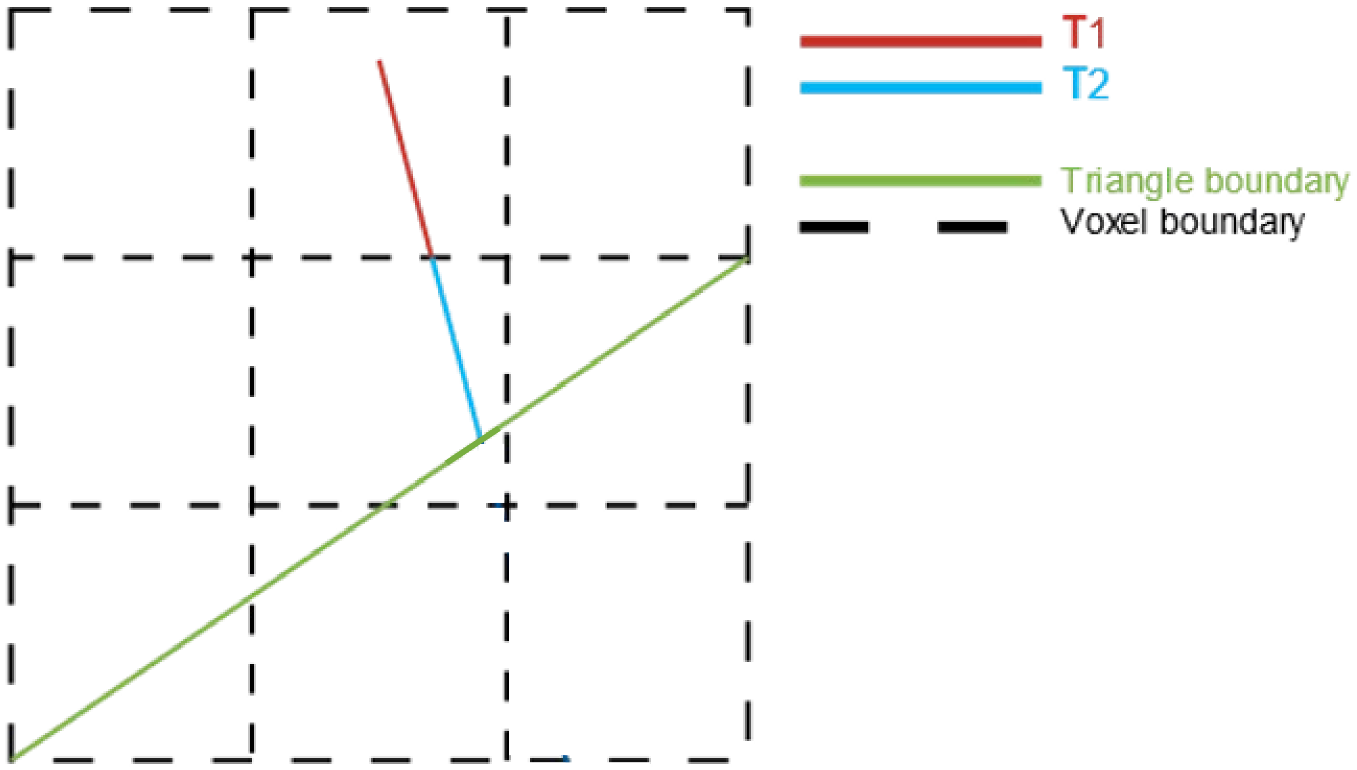
- Photon propagates in (nx, ny, nz) direction
- In voxel model calculate distance to edge of current voxel
- In triangular mesh calculate $T_{triangle}$ distance to triangle

Mesh based Monte Carlo



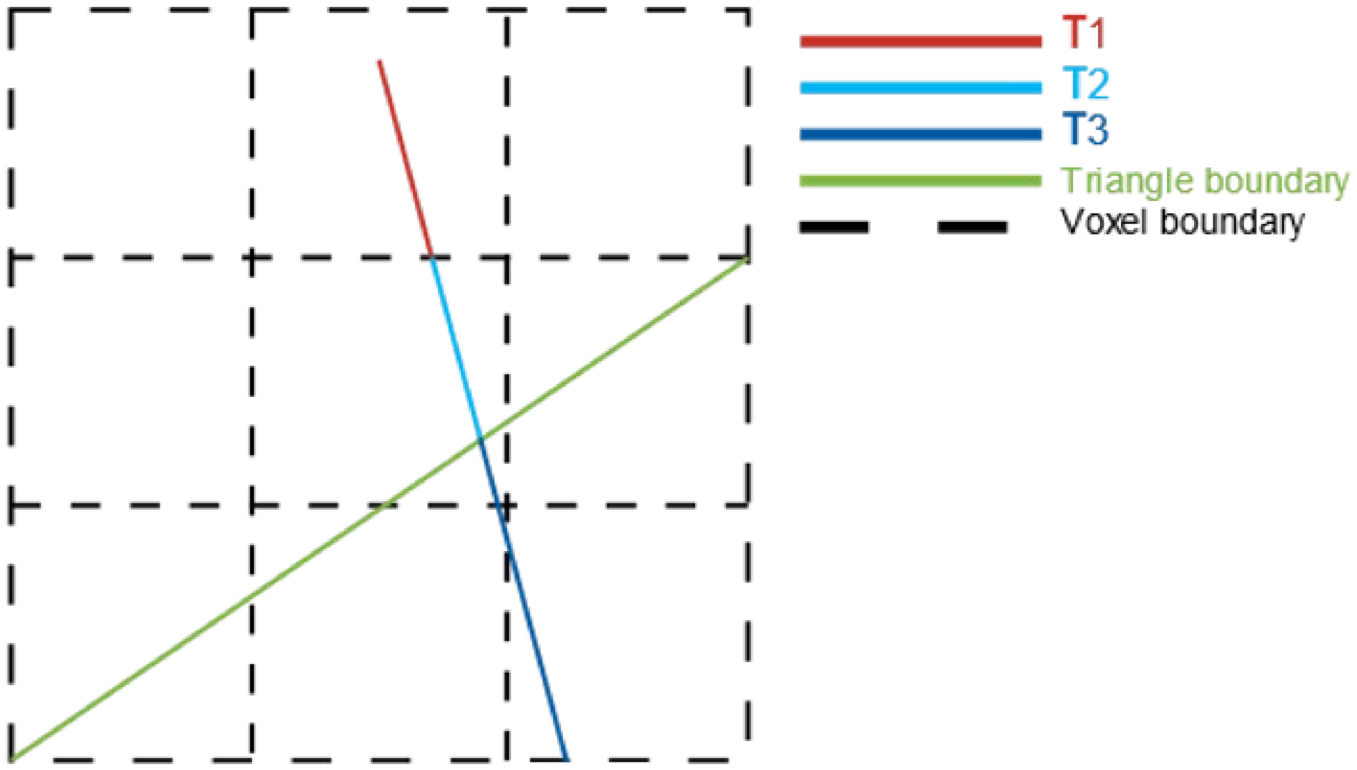
- If $T_1 + T_2 > T_{triangle}$ then hits triangle else continues as normal

Mesh based Monte Carlo



- If $T_1 + T_2 > T_{triangle}$ then hits triangle else continues as normal

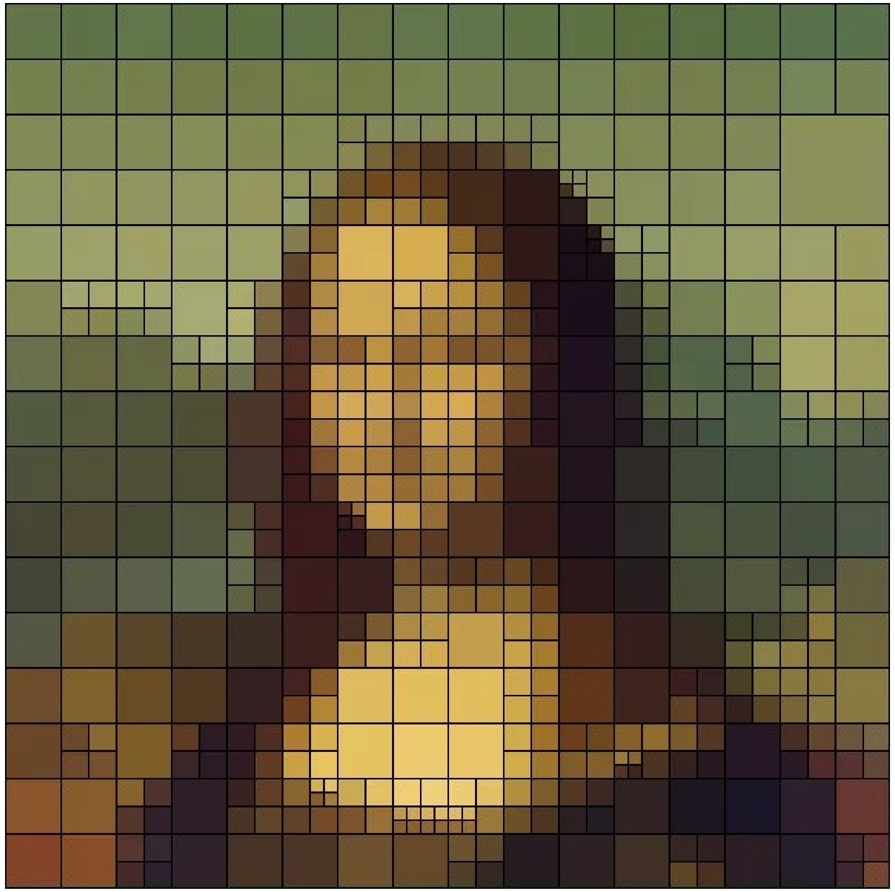
Mesh based Monte Carlo

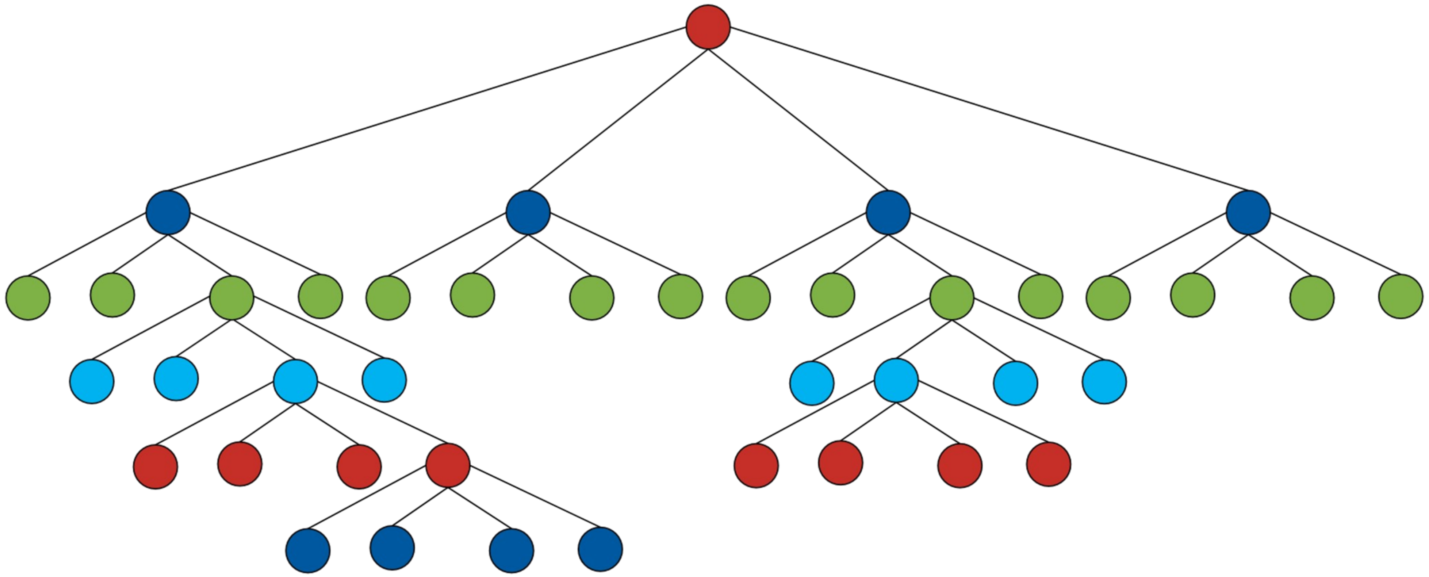


- If $t_1 + t_2 > t_{triangle}$ then hits triangle else continues as normal
- Hits triangle, change optical properties continue…

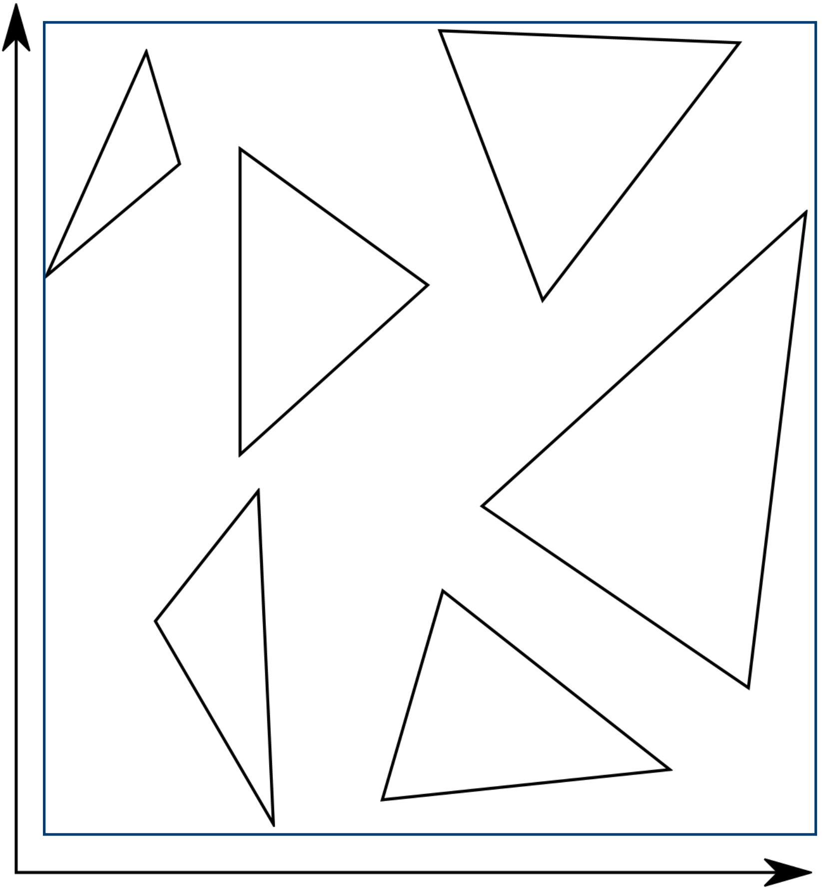
Adaptive meshes

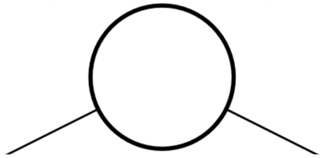
Adaptive meshes





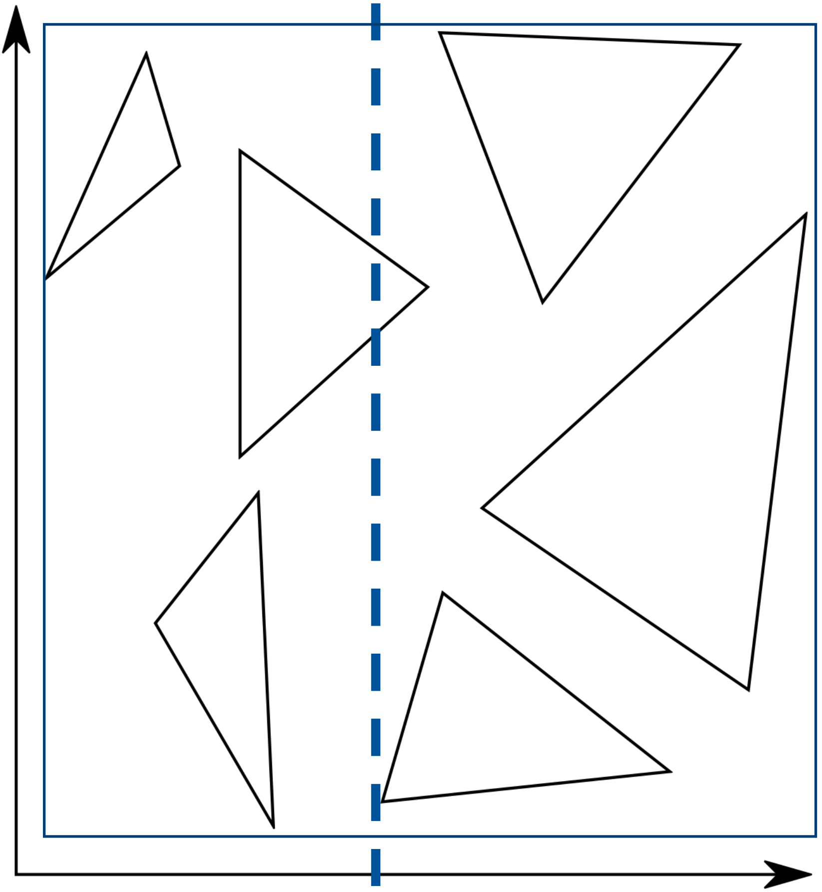
Mesh based Monte Carlo

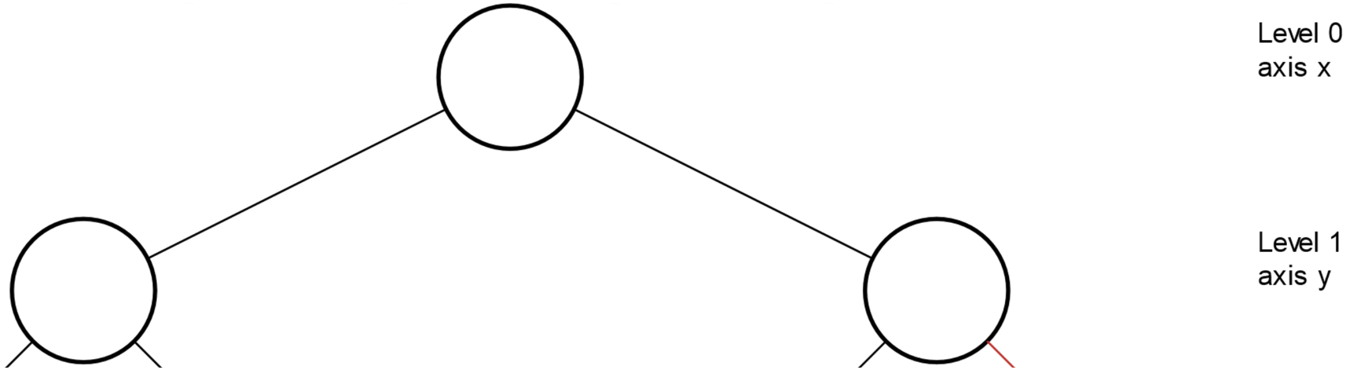




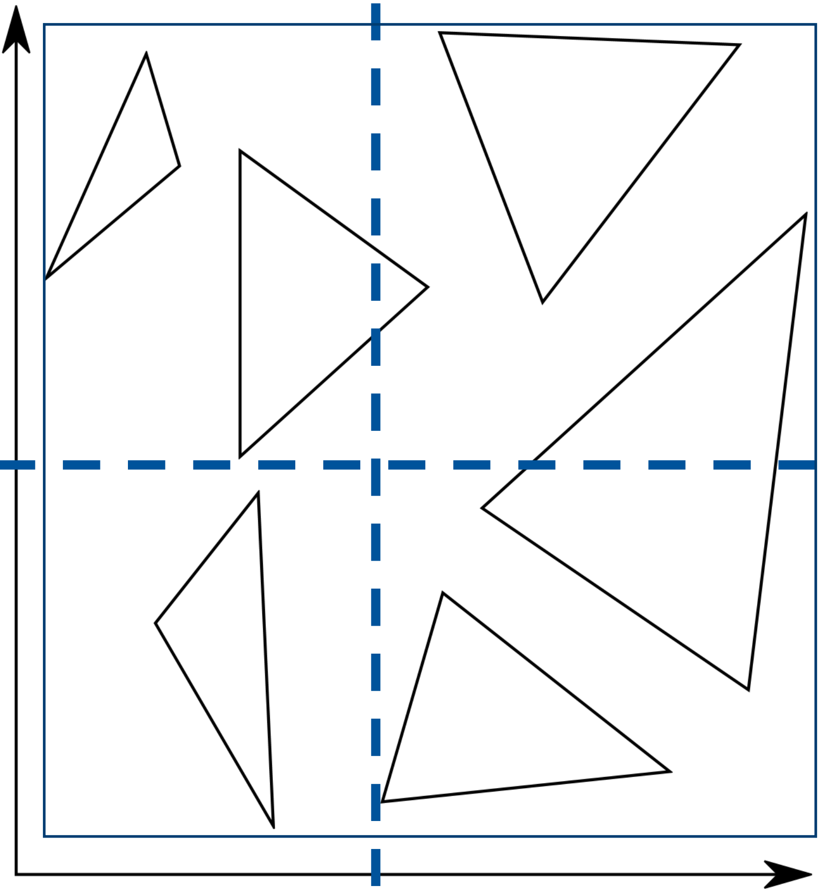
Level 0
axis x

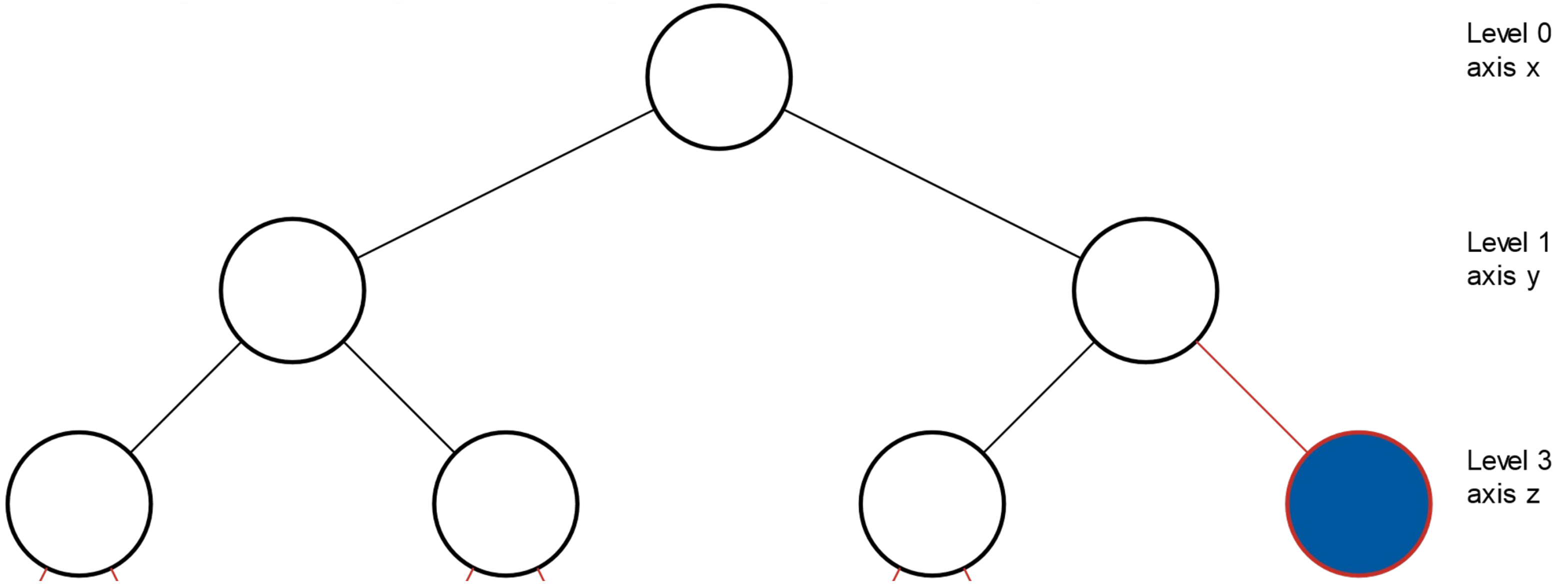
Mesh based Monte Carlo



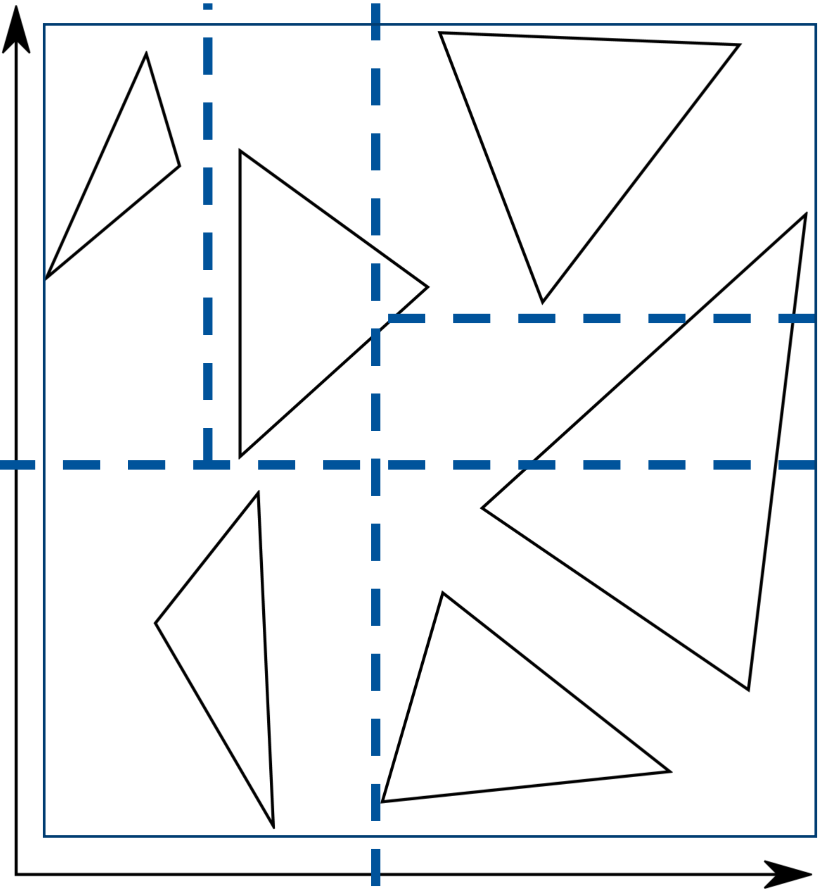


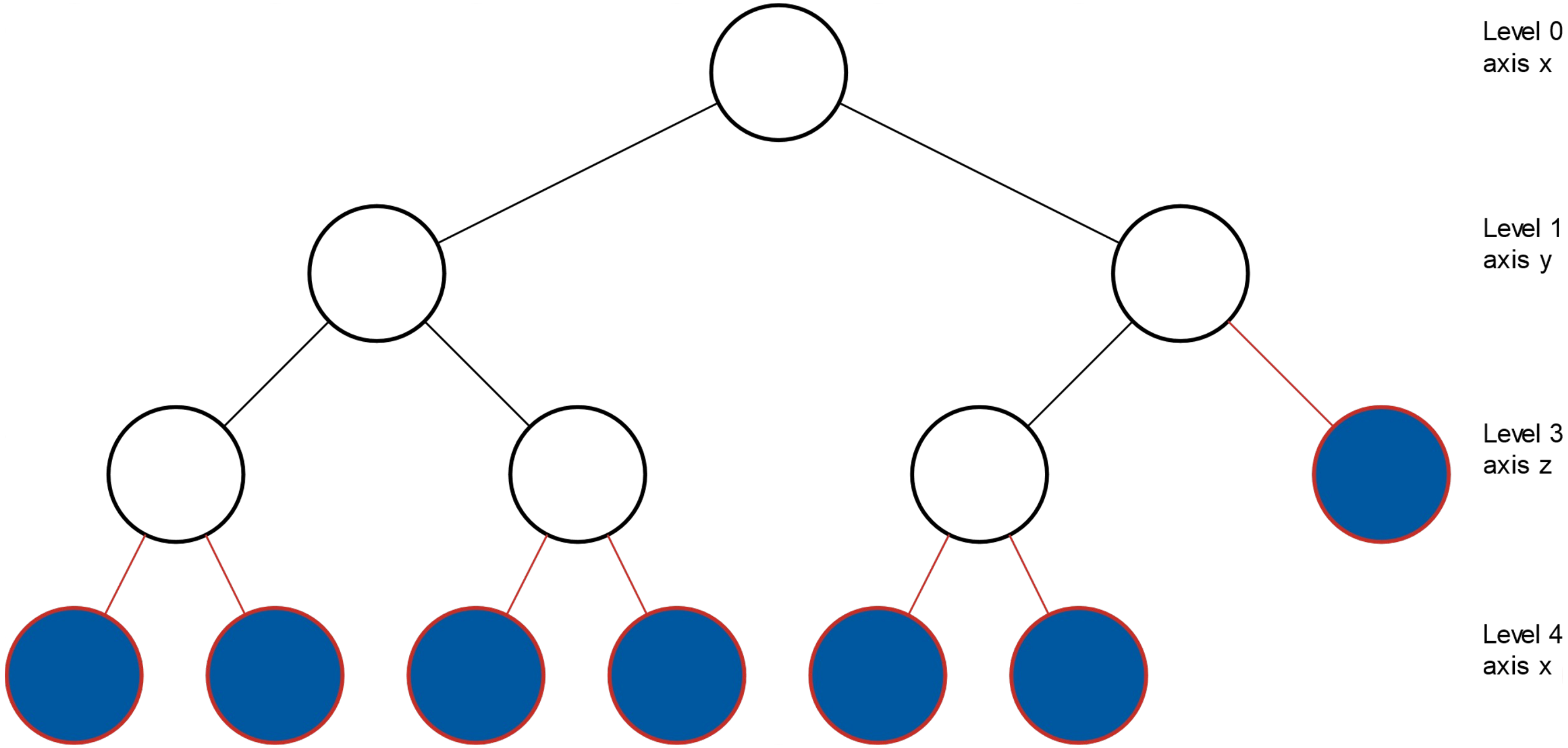
Mesh based Monte Carlo

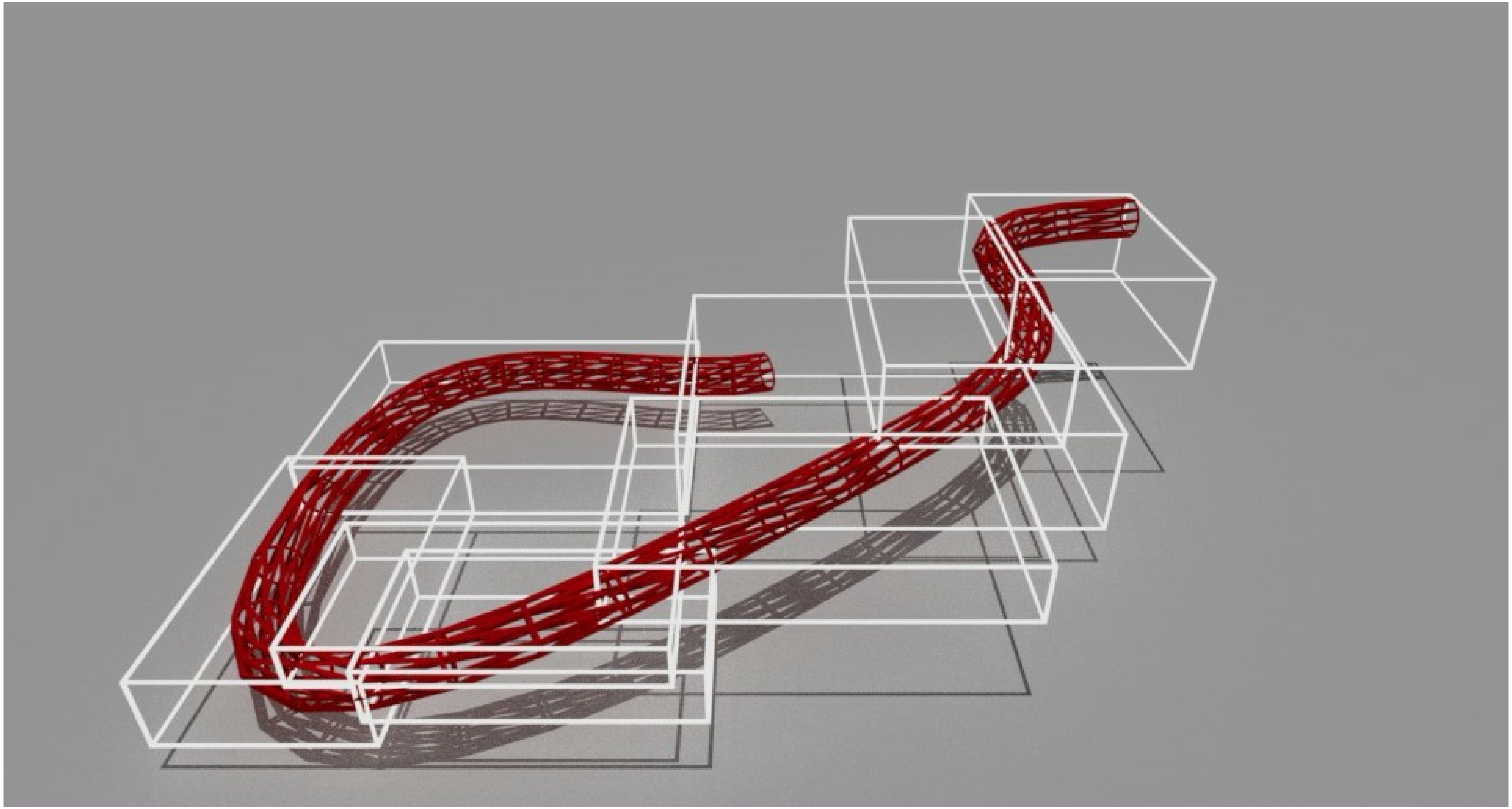


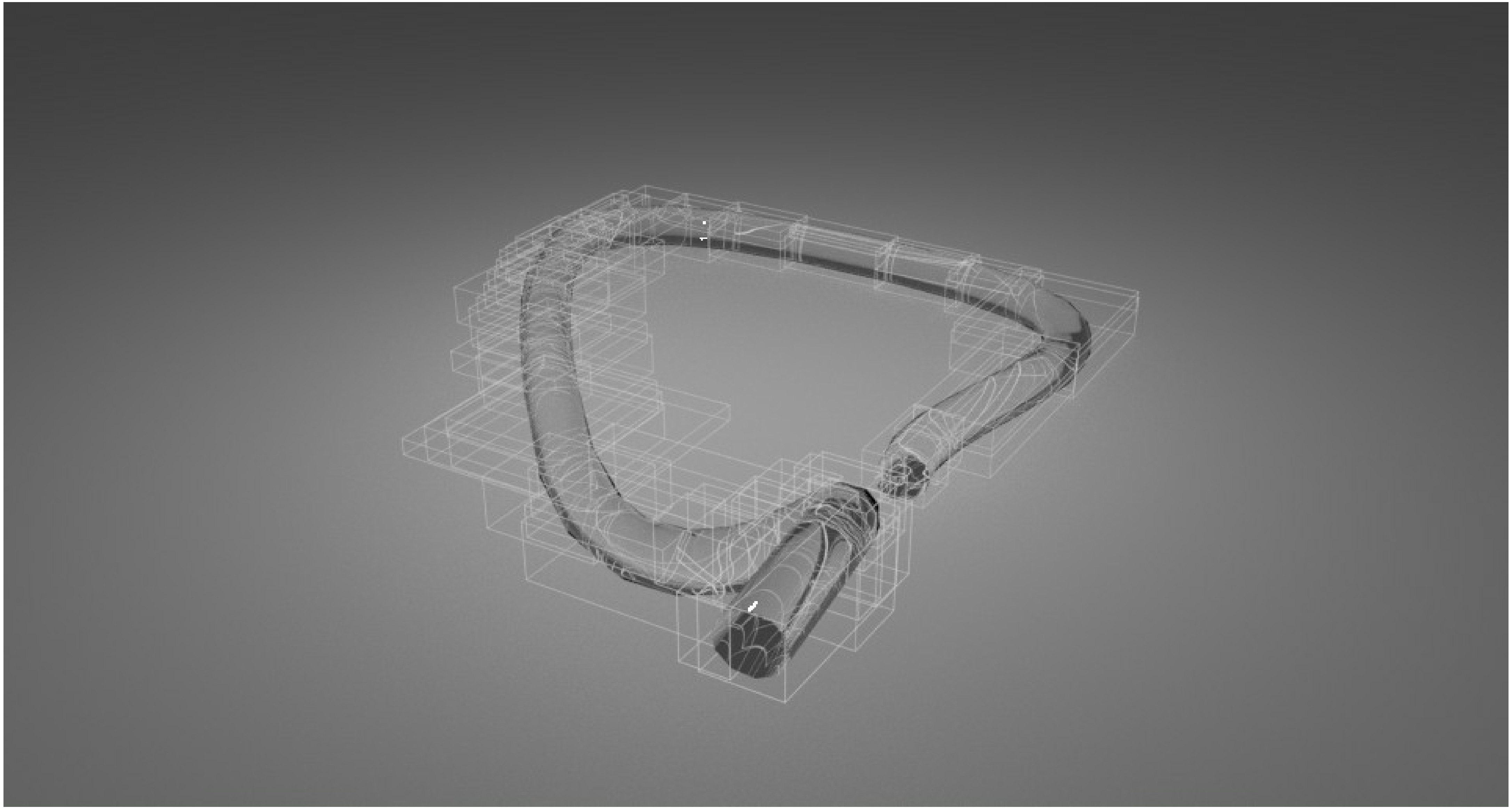


Mesh based Monte Carlo

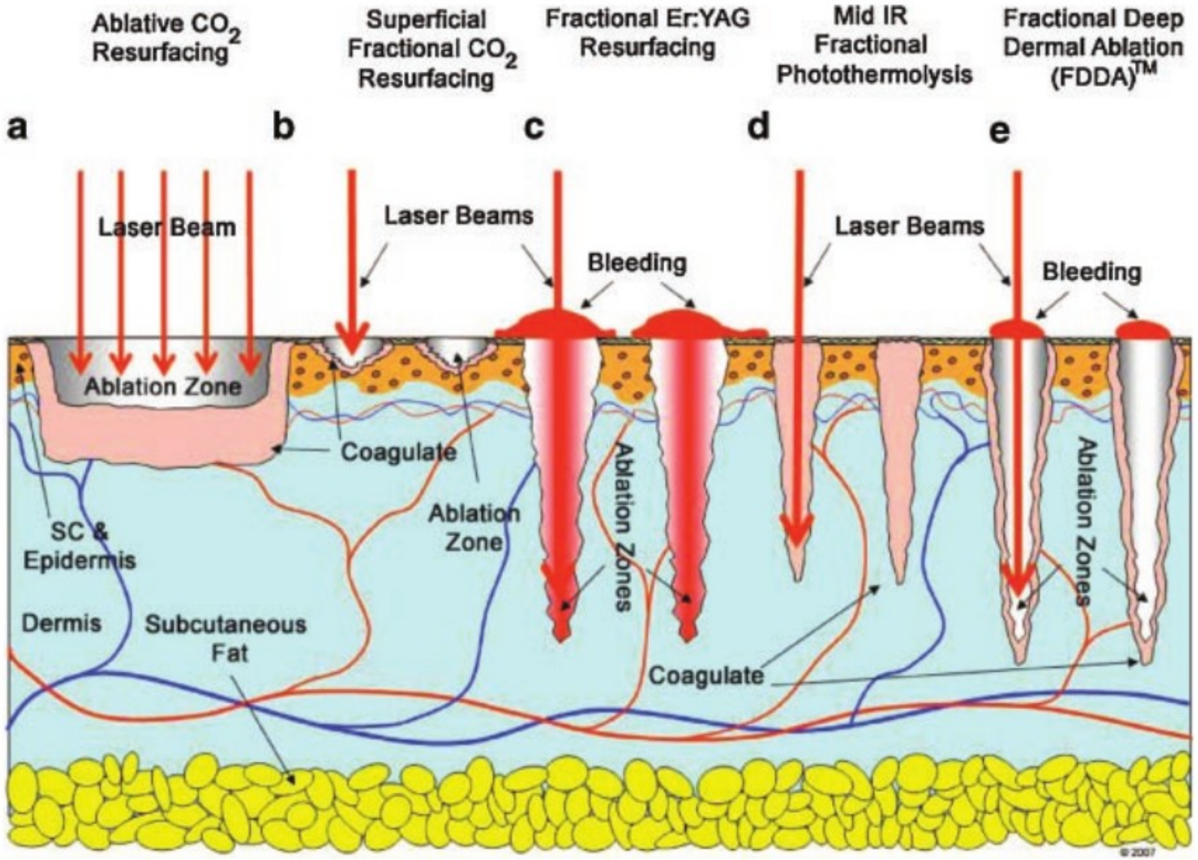




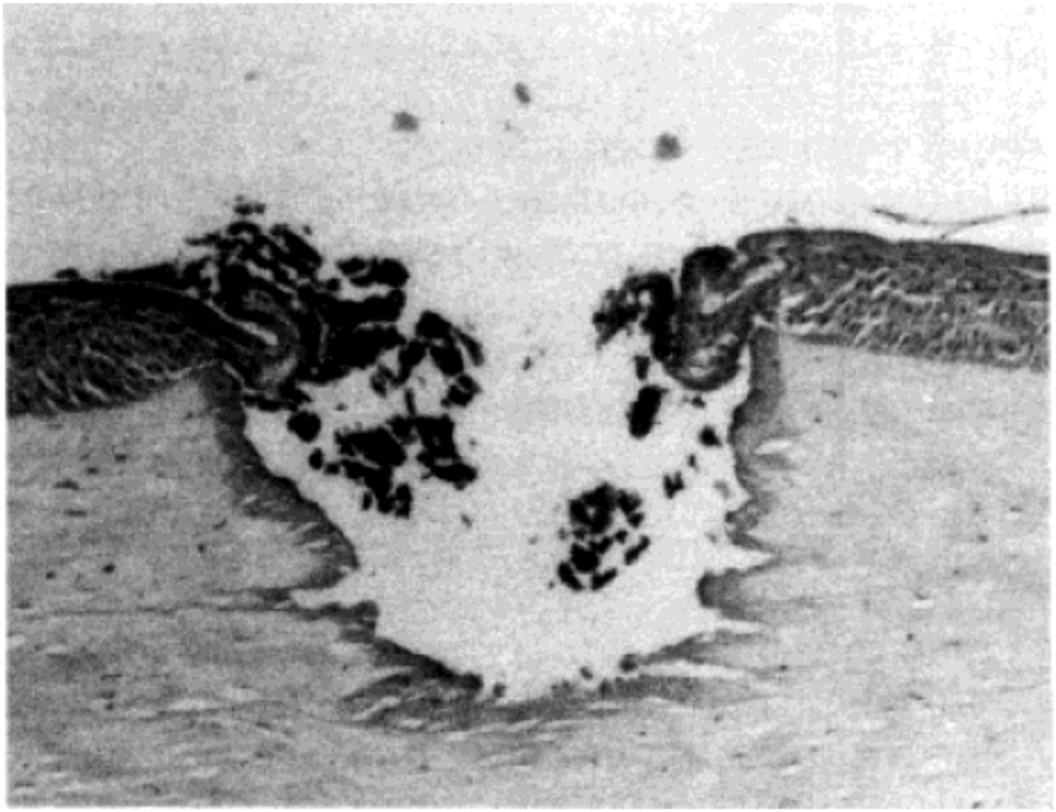




Tissue Ablation



Rahman *et al. Lasers in surgery (2009)*



J. Cummings *et al. Applied Optics (1993)*

Tissue Ablation

V. Maden, ukdermatologist.co.uk

Tissue Ablation

$$\frac{\partial u}{\partial t} = \alpha \nabla^2 u + S$$

$$S = -hA(T_\infty - T) - \sigma \varepsilon A(T_\infty^4 - T^4) + \dot{q}$$

Convective Radiative Laser Heat

Source

Tissue Ablation

$$U_x = r_x\left(T^n_{i-1,j,k} - 2T^n_{i,j,k} + T^n_{i+1,j,k}\right)$$

$$U_y = r_y\left(T^n_{i,j-1,k} - 2T^n_{i,j,k} + T^n_{i,j+1,k}\right)$$

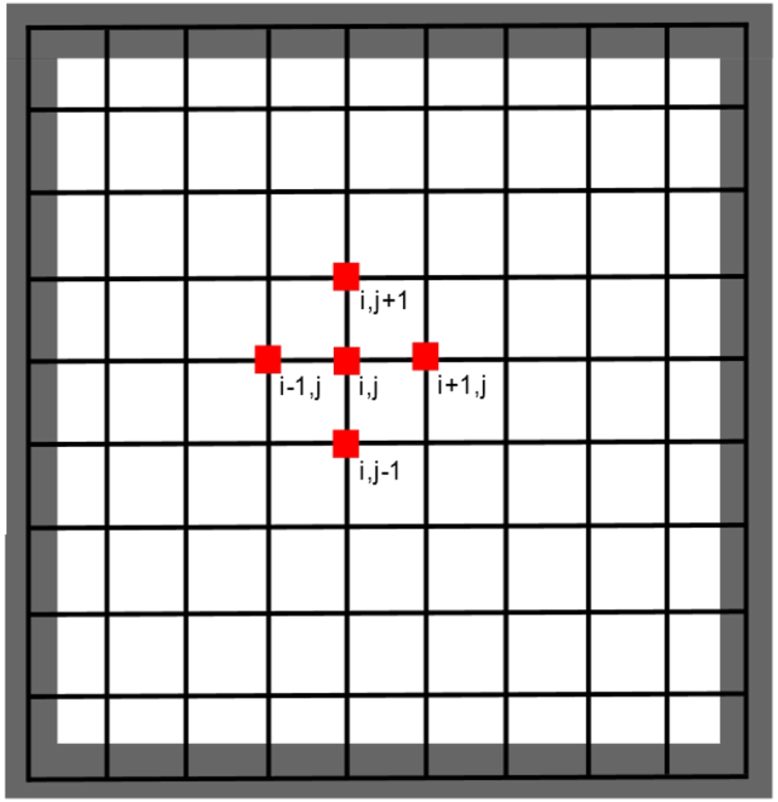
$$U_z = r_z\left(T^n_{i,j,k-1} - 2T^n_{i,j,k} + T^n_{i,j,k+1}\right)$$

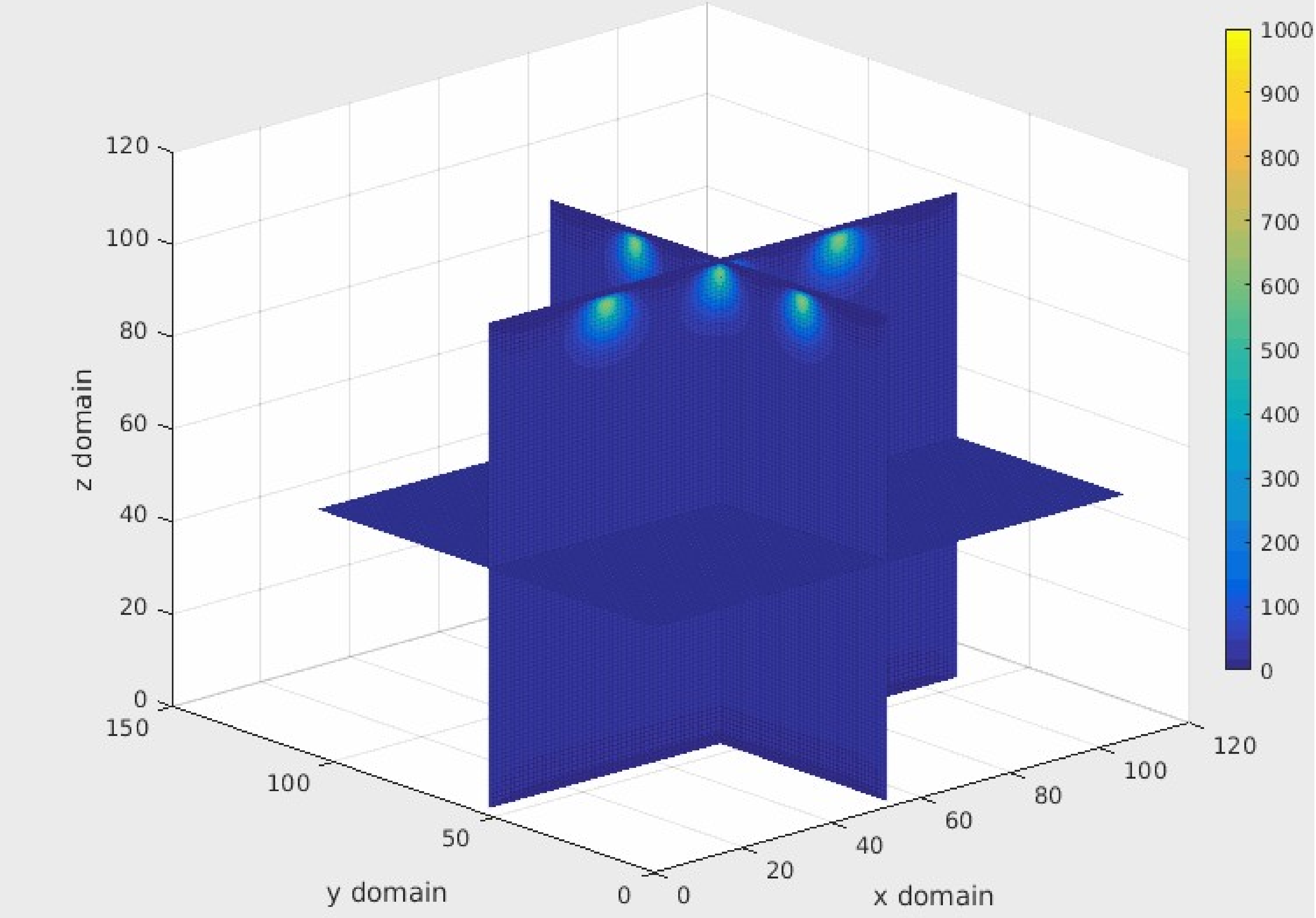
$$T^{n+1}_{i,j,k} = T^n_{i,j,k} + U_x + U_y + U_z$$

$$T^{n+1}_{i,j,0} = U_x\big|_{k=0} + U_y\big|_{k=0} + r_z(2T^n_{i,j,1} + 2\gamma - 2\beta T^n_{i,j,0} + \eta(T^4_\infty - T^4_{i,j,0}))$$

$$\gamma = \frac{\Delta_x h}{\kappa} t_\infty \qquad \eta = \sigma\varepsilon A\beta$$

$$\beta = 1 + \frac{\Delta_x h}{\kappa} \qquad r_p = \frac{\alpha_p \Delta_t}{\Delta_p}$$





z domain
y domain
x domain
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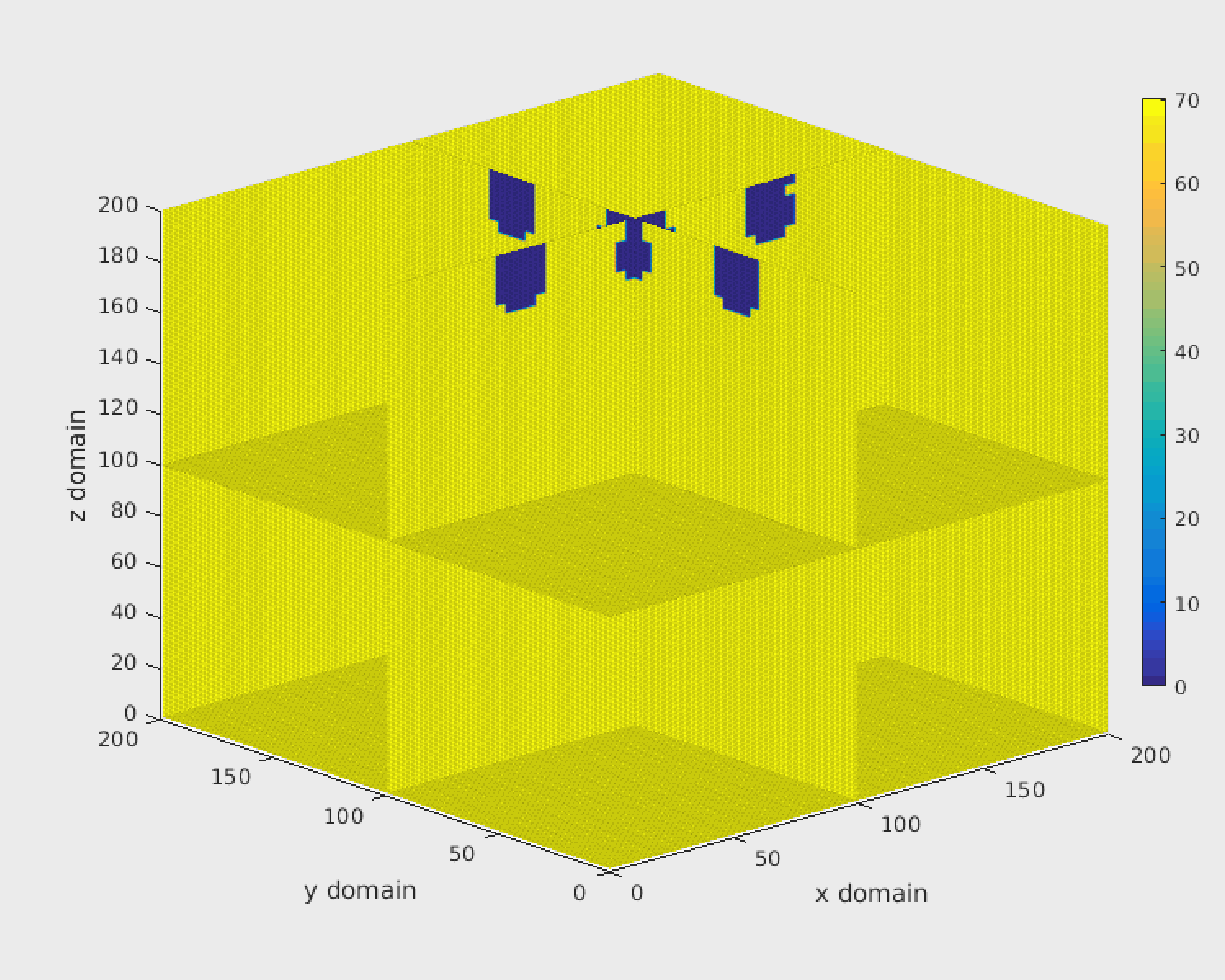
100
0

Modelling Tissue Ablation

$$\Omega(t) = \int_{t_0}^{t_f} A e^{(-\frac{\Delta E}{RT})} dT$$

- Arrhenius damage model
- Taken from chemistry
- Used widely in literature for tissue damage



Code & Cake

- Any Questions?
- Future talks

Github.com/lewisfish

(Code in modern Fortran…)