Human tissue optical properties measurements and light propagation modelling

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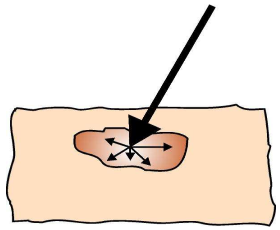
About *‘Biomedical Optics’*...

- BO is the study of the optical properties of living biological material, especially its scattering and absorption characteristics, and their significance to light propagation within the material.
- BO is highly multidisciplinary uniting disciplines such as:
  - *Physics*
  - *Medicine*
  - *Engineering*
  - *Biology*
  - *Biochemistry*
  - *Computer modelling*
  - *Multivariate data analysis.*
- BO techniques and applications are often fast, small-size, and relatively in-expensive.
- In general, BO applications may relieve the patients of much of the discomfort associated with more conventional medical techniques.

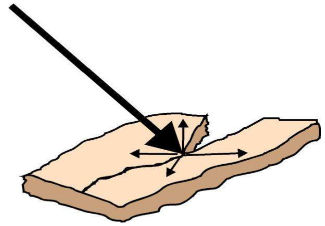
Some Biomedical Optics applications

Therapy



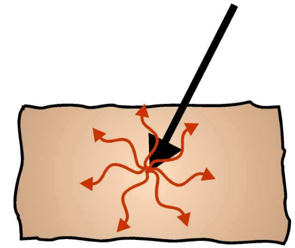
Photodynamic Therapy

(less pain and scars)



Laser Surgery

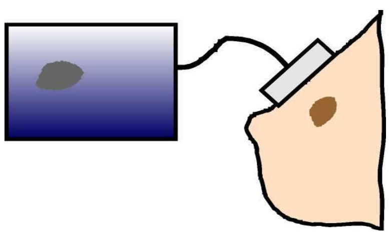
(sterile, pinpoint precision, minimal bleeding)



Low Level Laser Therapy

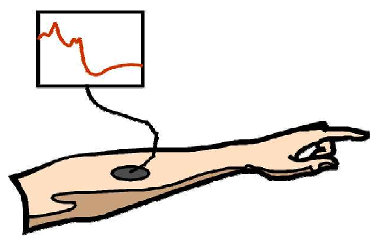
(selective deposition of energy)

Diagnostics



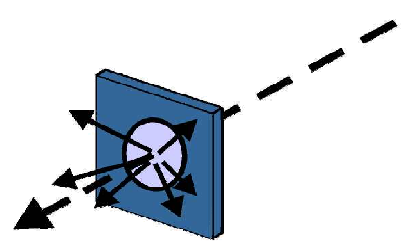
Optical Tomography

(non-ionizing imaging)



Optical biopsy

(Non-invasive analysis)



***In vitro* diffuse spectroscopy**

(small samples / fast analysis)

Tissue Optical properties

- **Absorption and scattering coefficients**

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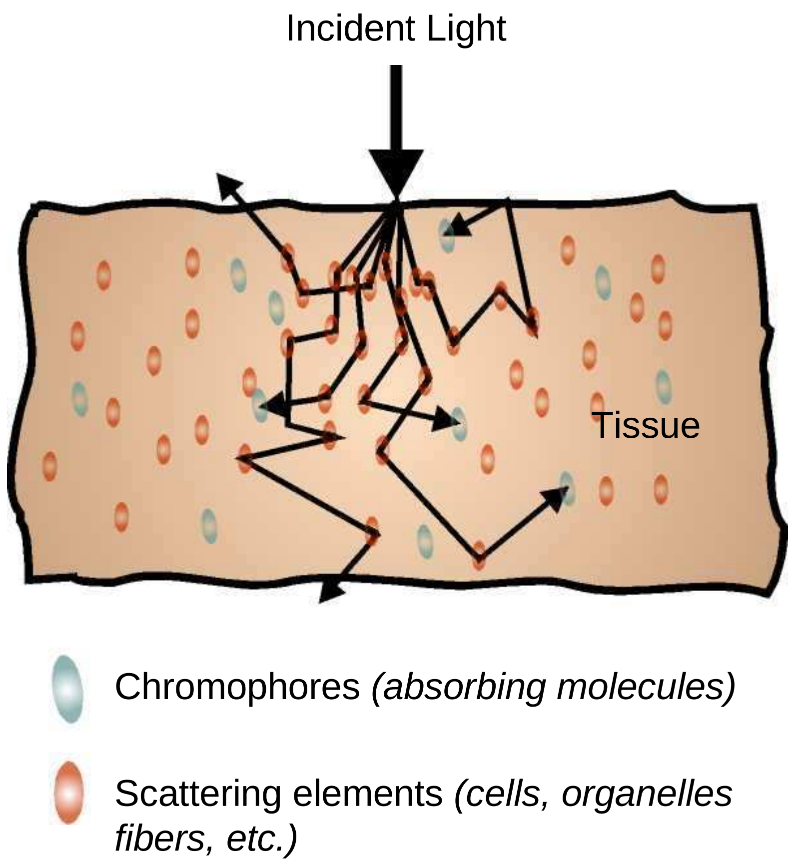
Optical properties of turbid biological media



Absorption coefficient	μ_a
Scattering coefficient	μ_s
Anisotropy factor	g
(Refractive index)	n

Light propagation modelling in tissue

- Monte Carlo simulations

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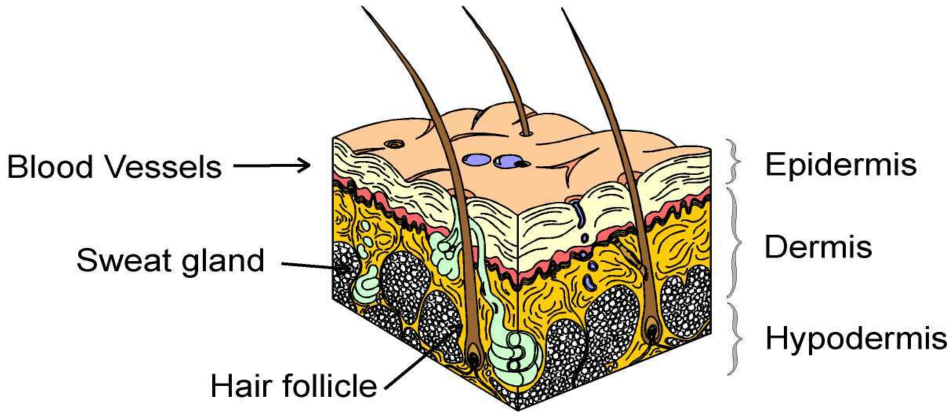
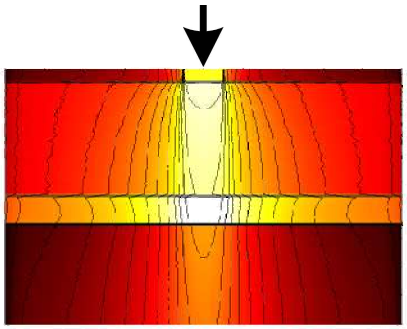
Light propagation in tissue

Skin tissue example



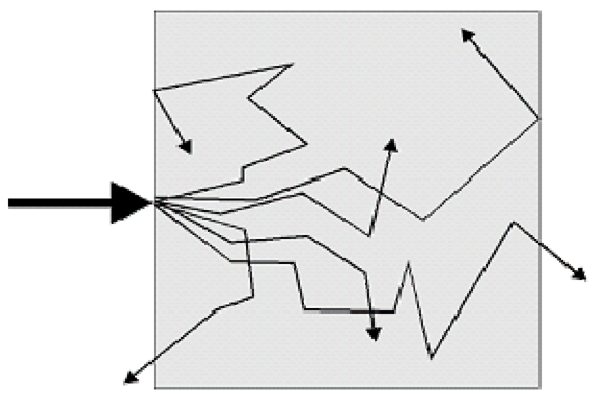


Multi-layer MC simulation (Energy deposition)

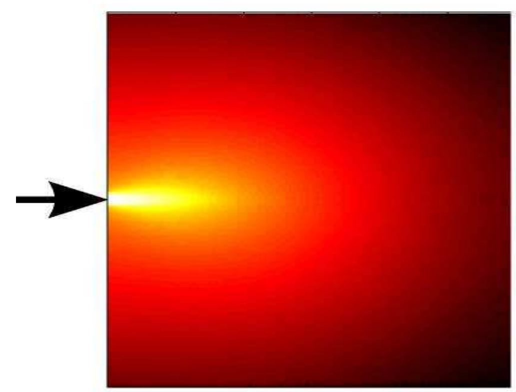
Monte Carlo simulations

“calculating, calculating, calculating…”

Random walk by 6 photons



Random walk by 10^6 photons



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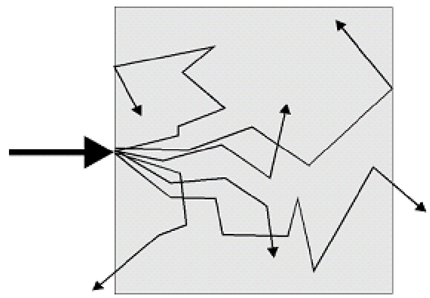
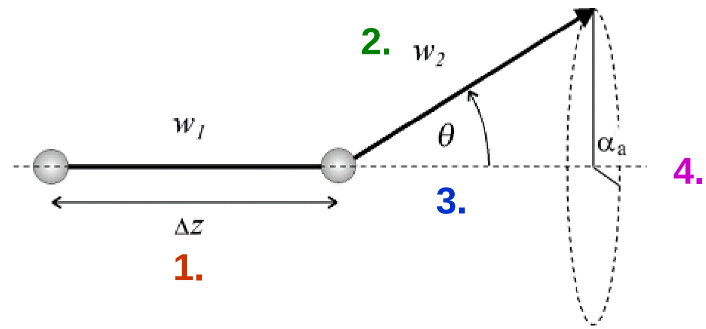
The Monte Carlo mechanics…





"Let the dices roll…" $(0 < \eta < 1)$

1. Calculate the step size *Δz* and move the 'photon packet'

$$\Delta z = \frac{-\ln(\eta)}{\mu_a + \mu_s}$$

2. Decrement the 'weight' *w* of the photon packet

$$w_2 = w_1 \Delta w, \qquad \Delta w = 1 - \frac{\mu_a}{\mu_a + \mu_s}$$

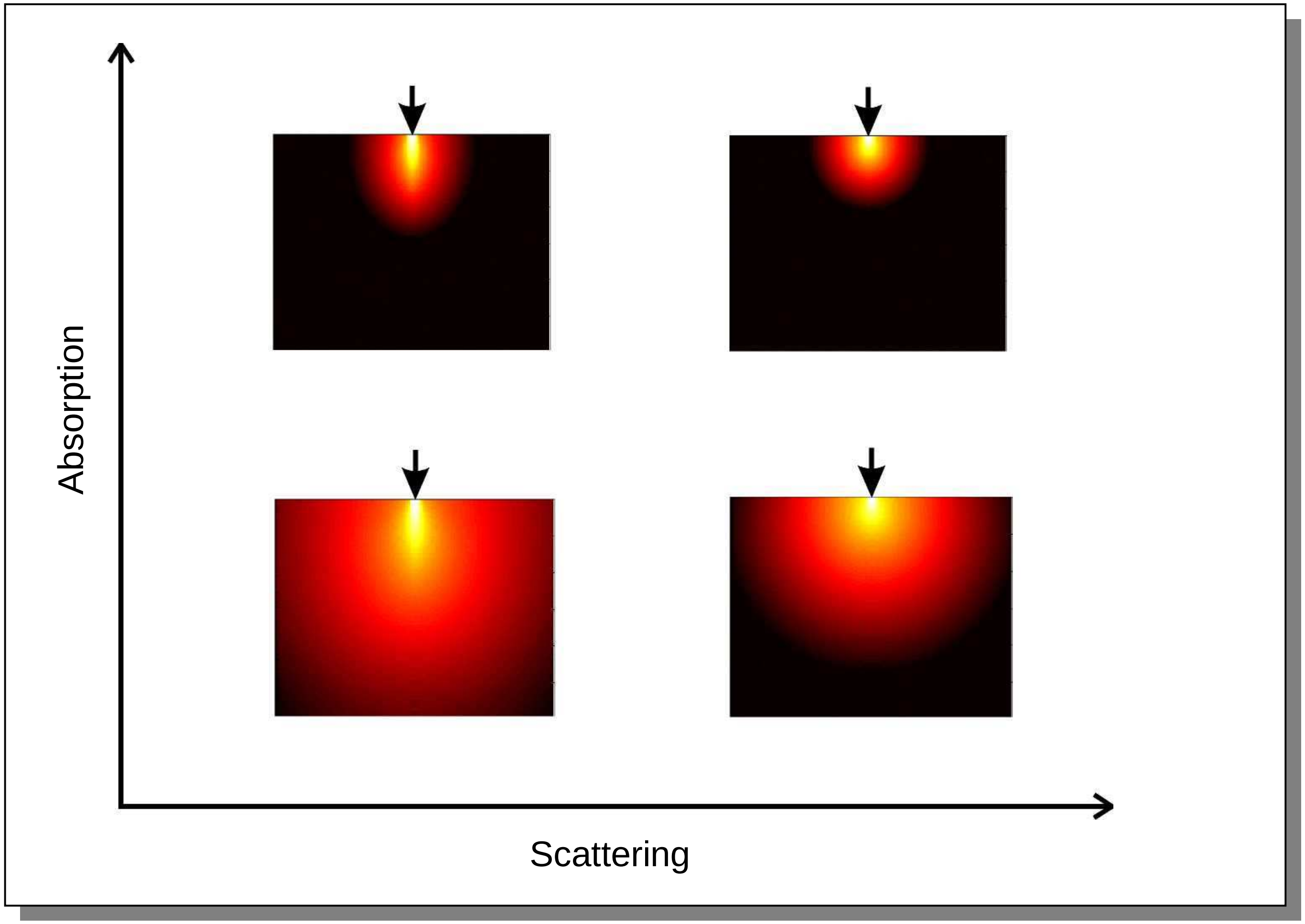
1. Calculate the scattering angle *θ*

$$\cos\theta = \begin{cases} \frac{1}{2g}\left(1 + g^2 - \left(\frac{1-g^2}{1-g+2g\eta}\right)^2\right) & \text{if } g \neq 0 \\ 2\eta - 1 & \text{if } g = 0 \end{cases}$$

2. Calculate the azimuth angle *α*a

$$\alpha_a = 2\pi\eta$$

Varying absorption and scattering example…



Determination of tissue optical properties

- Integrating Sphere measurements
- Multiple polynomial calibration model
- Newton-Raphson prediction algorithm

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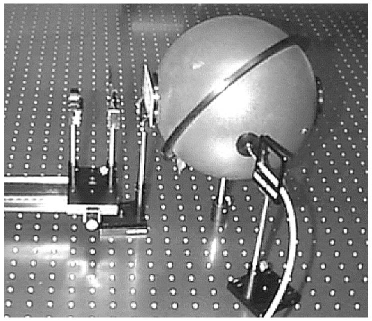
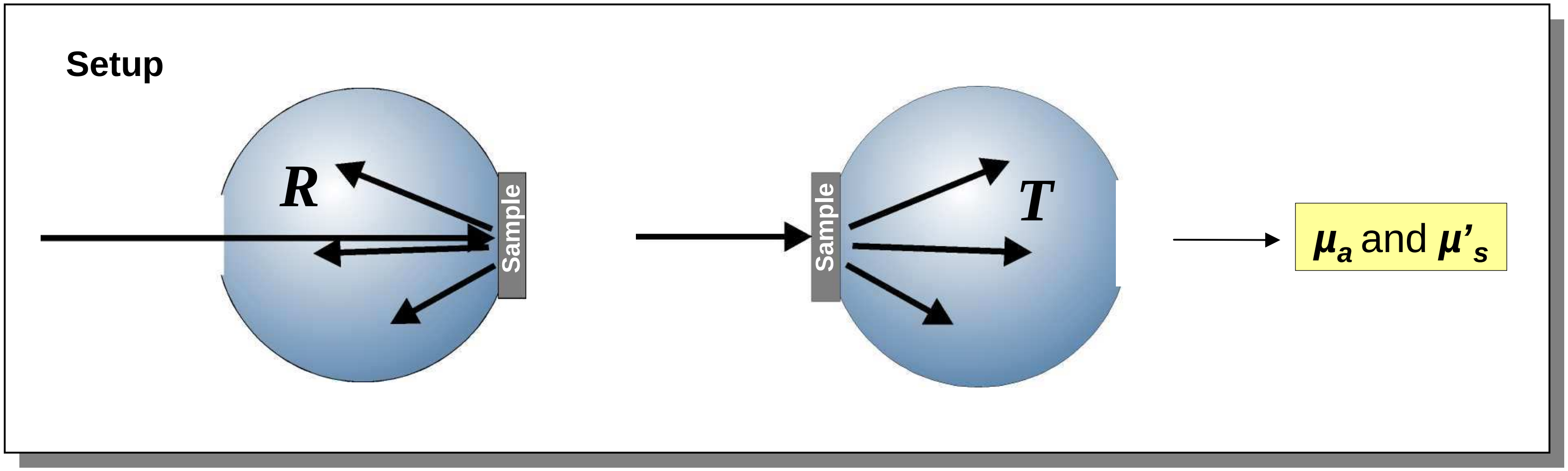
Integrating Sphere measurements



"Measurements of the total transmittance and reflectance of a thin slab-shaped multiple scattering sample can yield the absorption- and the reduced scattering coefficient of the sample"



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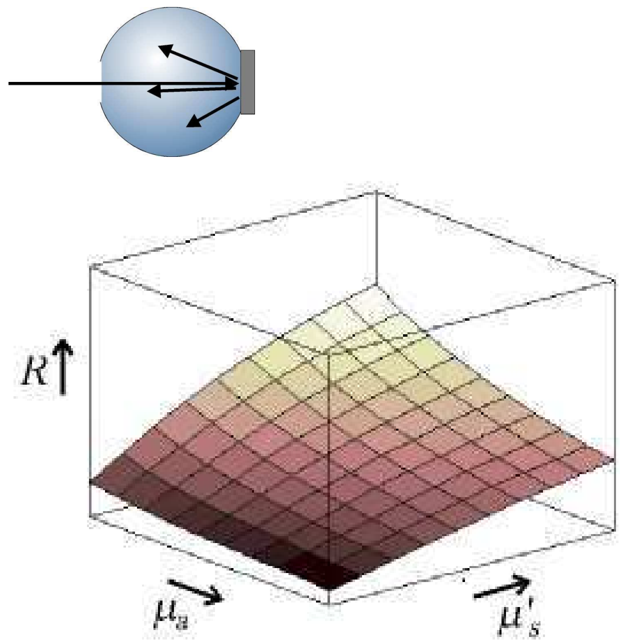
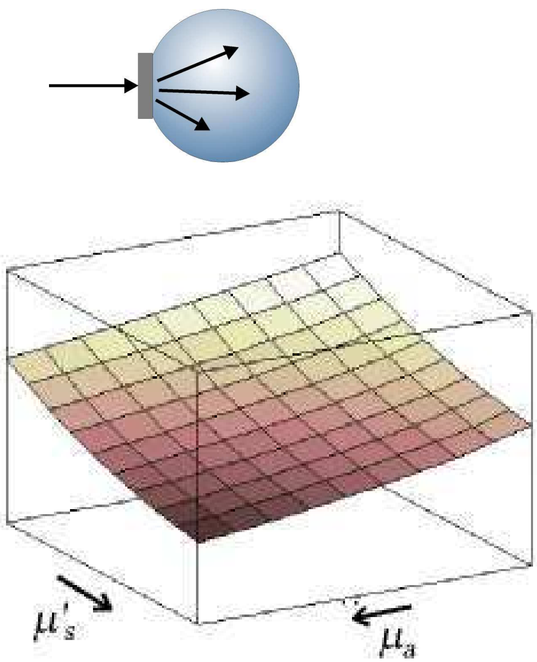
Multiple Polynomial Regression (MPR)





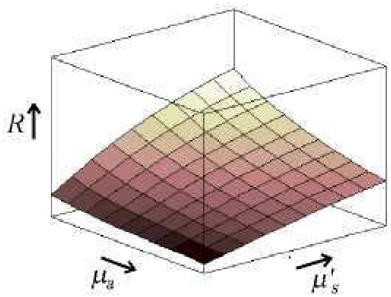
Third order double polynomials fits nicely…

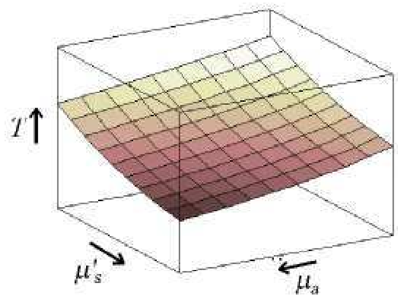
$$R_{fit}(\mu_a, \mu'_s) = (a_0 + a_1\mu_a + a_2\mu_a{}^2 + a_3\mu_a{}^3)(b_0 + b_1\mu'_s + b_2\mu'_s{}^2 + b_3\mu'_s{}^3)$$

$$T_{fit}(\mu_a, \mu'_s) = (c_0 + c_1\mu_a + c_2\mu_a{}^2 + c_3\mu_a{}^3)(d_0 + d_1\mu'_s + d_2\mu'_s{}^2 + d_3\mu'_s{}^3)$$

Newton-Raphson prediction algorithm

1) Make calibration model using MPR (previous slide)





2) Perform measurements and define…

$$F(\mu_a, \mu'_s) = R_{fit} - R_{meas}$$

$$G(\mu_a, \mu'_s) = T_{fit} - T_{meas}$$

3) Run consecutive calculations of μ_a and μ'_s until h_a and h_s < e.g. 10^{-6}

$$\left.\begin{aligned} -\begin{bmatrix} F(\mu_{a,k},\mu'_{s,k}) \\ G(\mu_{a,k},\mu'_{s,k}) \end{bmatrix} &= \begin{bmatrix} \frac{\partial F}{\partial \mu_a} & \frac{\partial F}{\partial \mu'_s} \\ \frac{\partial G}{\partial \mu_a} & \frac{\partial G}{\partial \mu'_s} \end{bmatrix} \begin{pmatrix} h_{a,k} \\ h_{s,k} \end{pmatrix} \\ \begin{pmatrix} \mu_{a,k+1} \\ \mu'_{s,k+1} \end{pmatrix} &= \begin{pmatrix} \mu_{a,k} \\ \mu'_{s,k} \end{pmatrix} + \begin{pmatrix} h_{a,k} \\ h_{s,k} \end{pmatrix} \end{aligned}\right\} \quad k = 0,1,2,3,\ldots,$$

Experimental results (an example)

- Non-invasive spatially resolved diffuse reflectance

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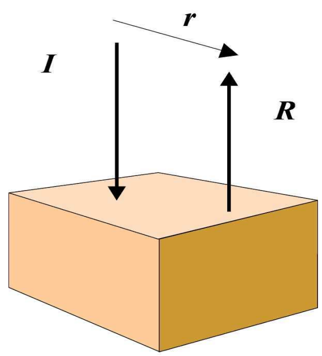
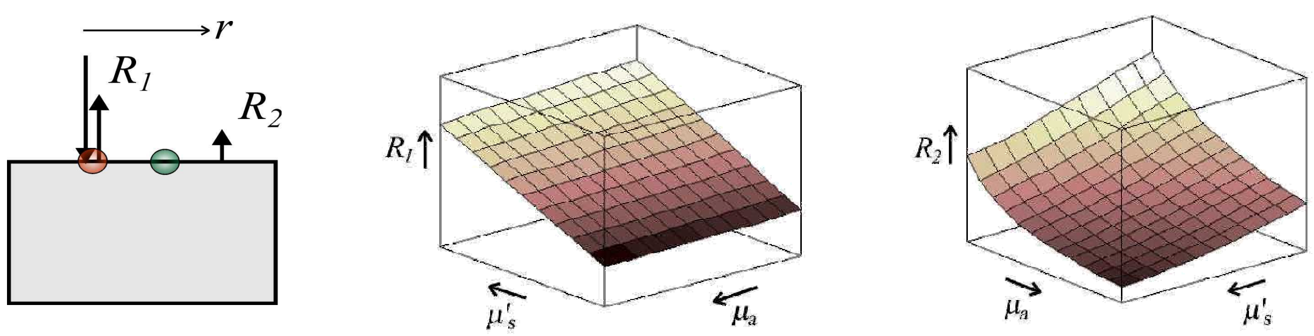
Spatially resolved diffuse reflectance

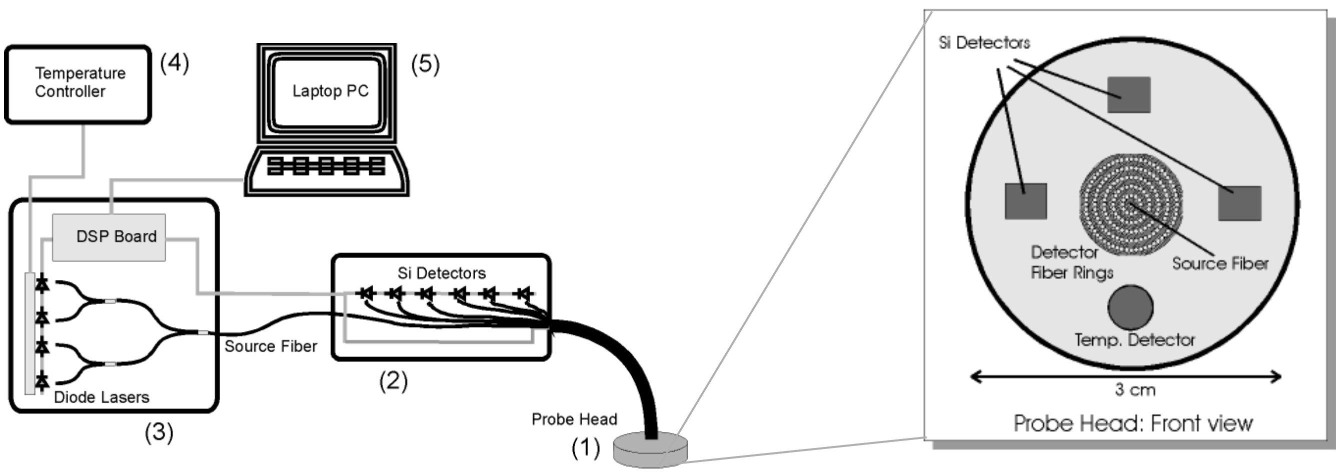


"Non-invasive spatially resolved diffuse reflectance measurements can also yield μ_a *and* μ'_s "

R(r) surface plots as a function of μ_a *and* μ'_s (*also well-suited for MPR!*)



Fibre probe system & experimental results



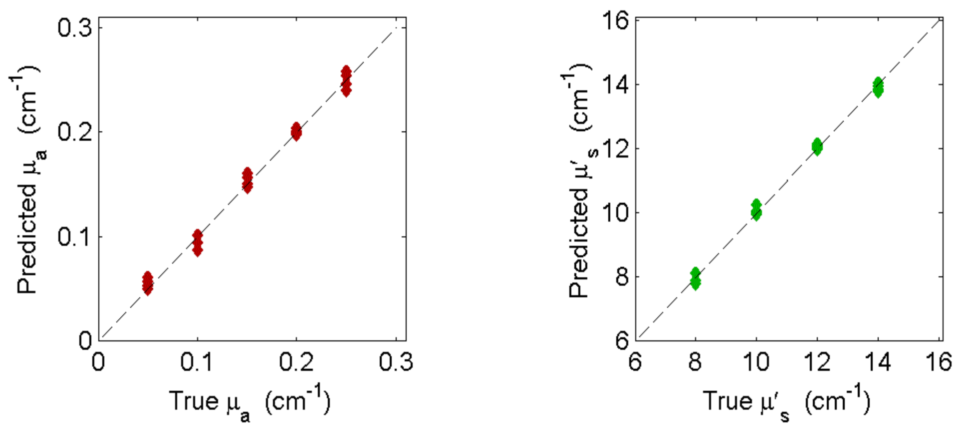
Experimental results

Leave-one-out cross validation tests on 42 Intralipid/Dye phantoms.

Mean errors (at 660 nm):

μ_a **: 2.5 %**

μ'_s**: 1.7 %**



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Some references…

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  J.S. Dam, C.B. Pedersen, T. Dalgaard, P. Aruna and S. Andersson-Engels, *Appl. Opt. 40, 1155-1164 (2001).*
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Thank you for your attention!

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