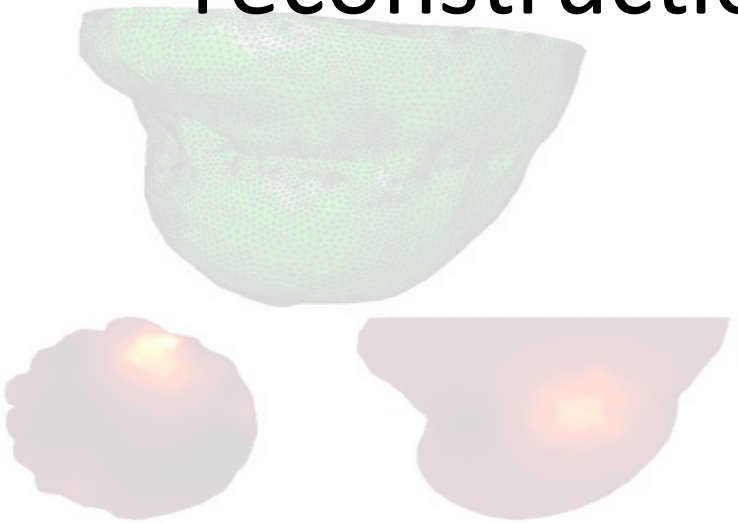
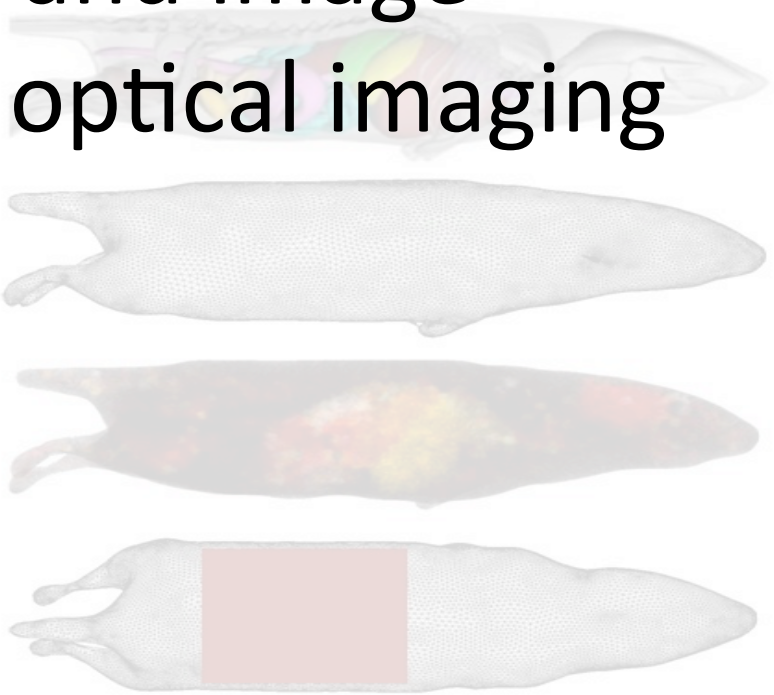


NIRFAST:
An interactive GUI driven toolbox for modeling and image reconstruction in optical imaging





Acknowledgements

Dartmouth College, USA

Kitware Inc. USA

University of Birmingham

Washington Uni, St Louis, USA

National Centre for the Replacement Refinement & Reduction of Animals in Research

National Cancer Institute

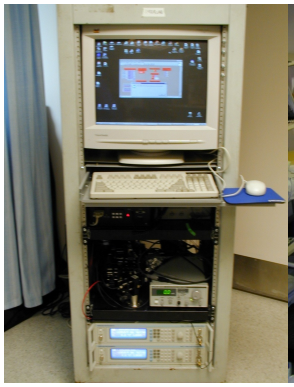
Engineering and Physical Sciences Research Council

The EU Framework Programme for Research and Innovation HORIZON 2020

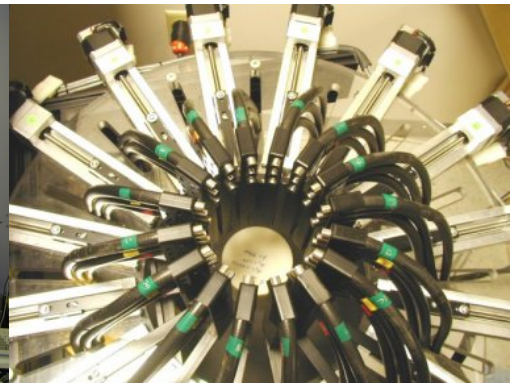
The Beginning: August 2001

Develop 3D finite element model and imaging algorithms for Breast Imaging system









Do it in Fortran!



The Beginning: August 2001

Can I develop this under MATLAB?



- Reasons:
  - Platform independent tool
  - Well developed and optimized tools
  - Easy to write
    - Easy to read
  - Multi-user development
- Open Source

Light Transport Model

Light transport in tissue is turbid (scatter-dominated), modelled by *diffusion equation*:

$$\underbrace{\frac{i\omega\Phi(r,\omega)}{c}}_{\text{Frequency variation}} \underbrace{-\nabla\cdot\kappa(r)\nabla\Phi(r,\omega)}_{\text{diffusion}} \underbrace{+\mu_a(r)\Phi(r,\omega)}_{\text{absorption}} = \underbrace{q_0(r,\omega)}_{\text{source}}$$

Field Φ: photon density

μ_a = Absorption Coefficient

$\kappa = 1/3(\mu_a + \mu_s`)$

Boundary condition: $\Phi(\xi,\omega) + \alpha\vec{n}\cdot\nabla\Phi(\xi,\omega) = 0$

Dehghani et al, Applied Optics 2003

What is FEM

FEM: Method for numerical solution of field problems.

Description

- FEM cuts a structure into several elements (pieces of the structure).
- Then reconnects elements at "nodes" as if nodes were pins or drops of glue that hold elements together.
- This process results in a set of simultaneous algebraic equations.

Number of degrees-of-freedom (DOF)

Continuum: Infinite

FEM: Finite

(This is the origin of the name, Finite Element Method)

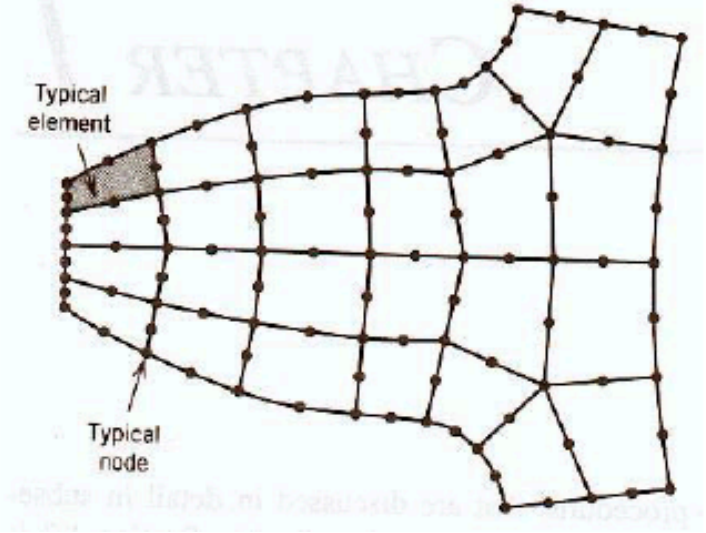


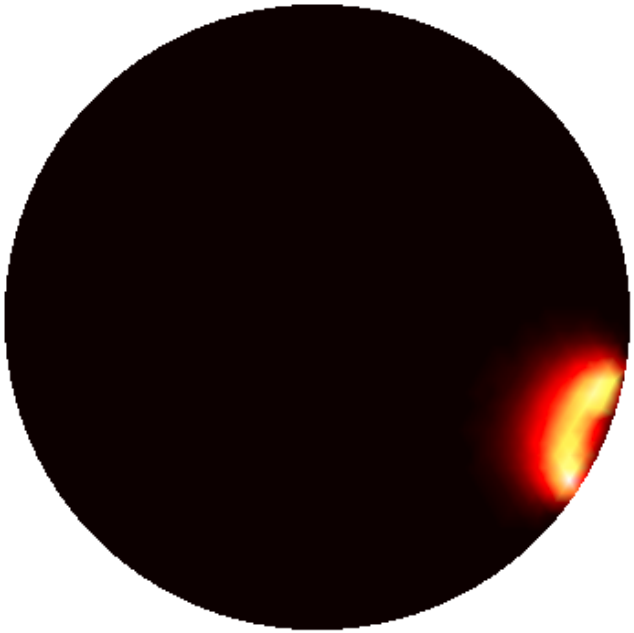
Image Reconstruction

Minimisation of cost function

data model

$$\Psi = \sum_{i=1}^{N} \left(\frac{y_i - F_i[\mu_a, \kappa]}{\sigma_i} \right)^2$$

std.dev.

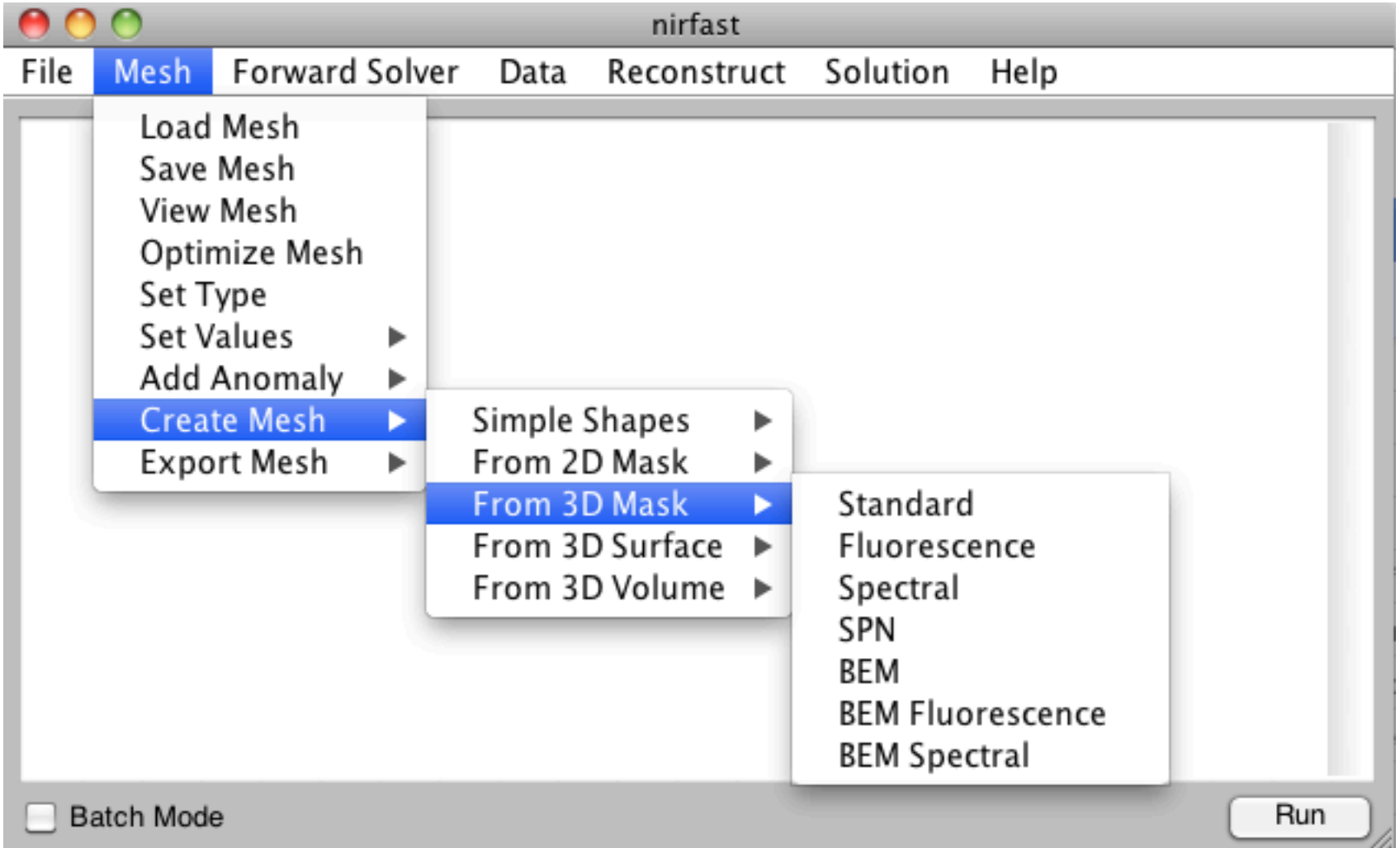


To find μ_a and $\mu_s`$ we use a Levenberg-Marquardt algorithm, where we solve the generalised inverse problem:

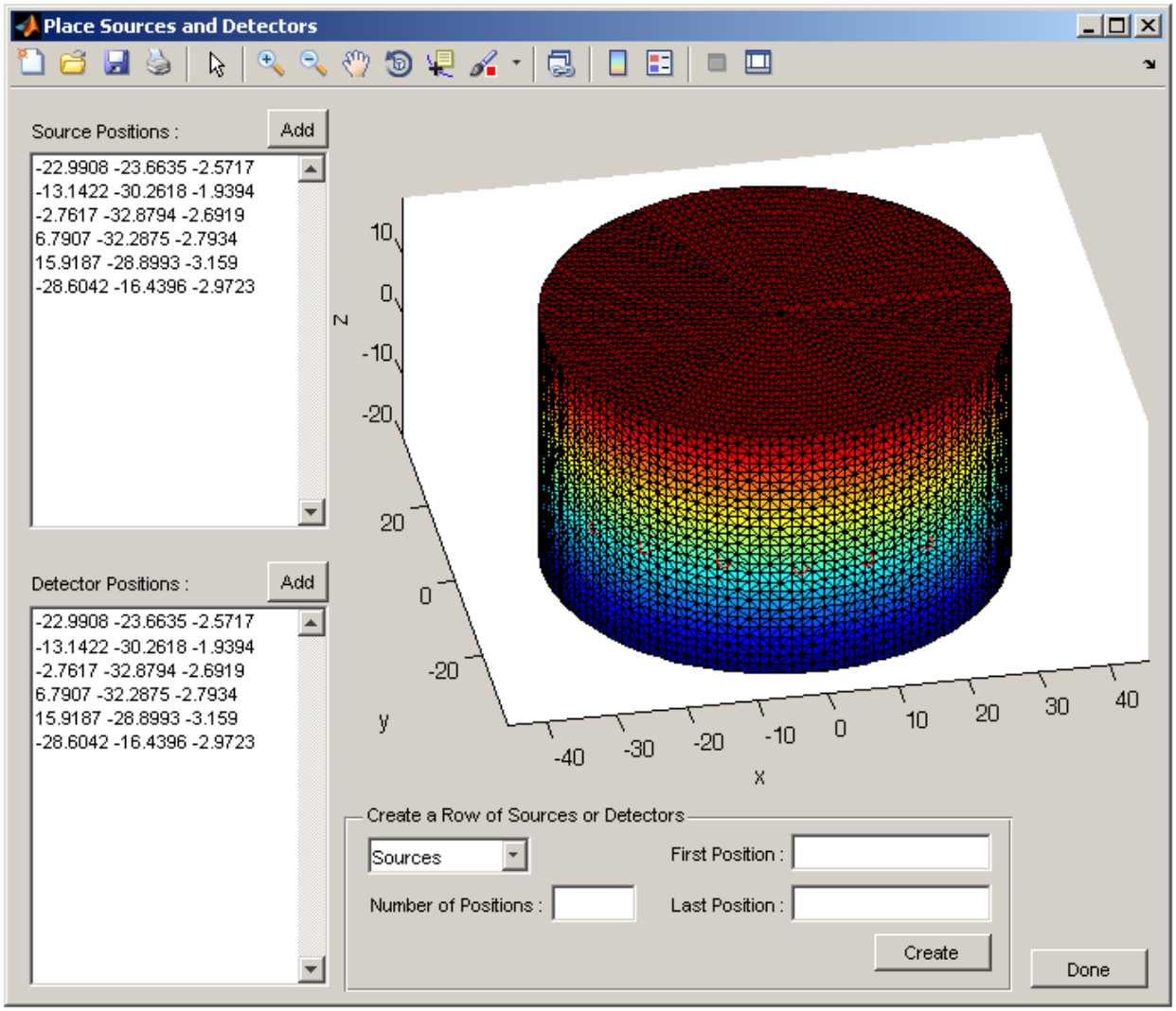
$$\delta[\mu_a ; \mu_s`] = J^T(JJ^T+\lambda I)^{-1}\delta y$$

J is the Jacobian, calculated using the adjoint method

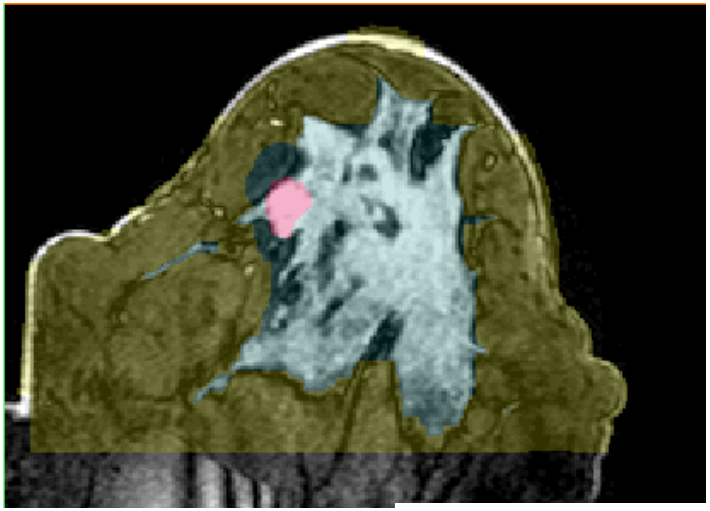
Graphical User Interface: Mesh Creation

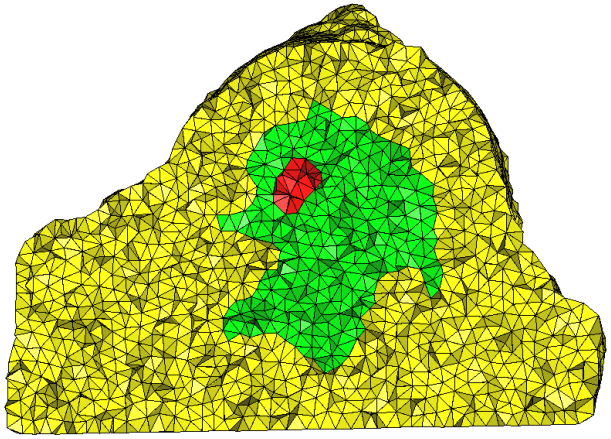


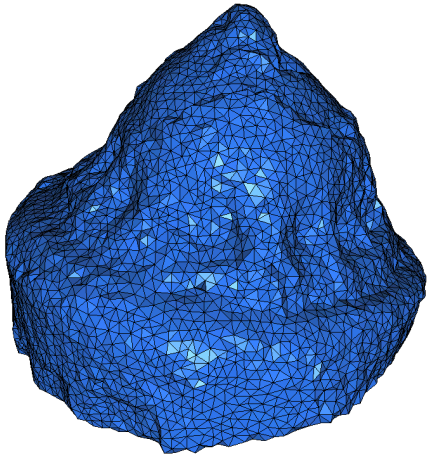
Mesh Creation: Simple Shapes

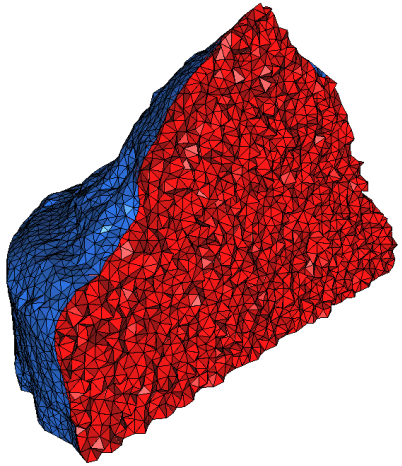


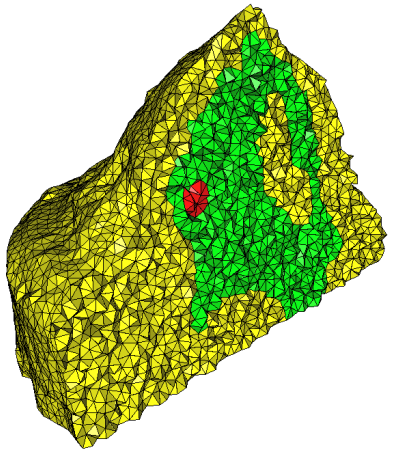
Mesh Creation: Using Masks



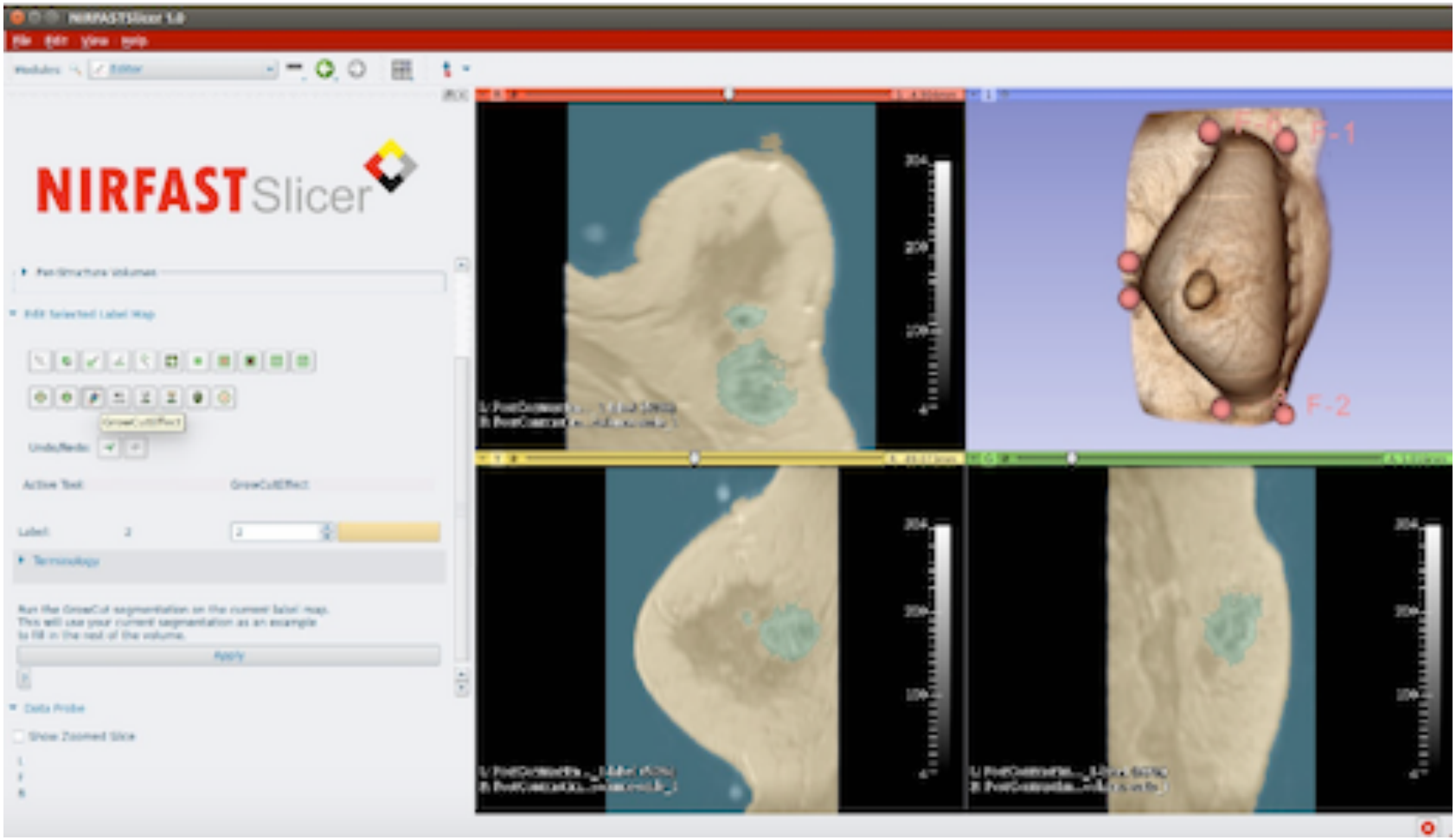






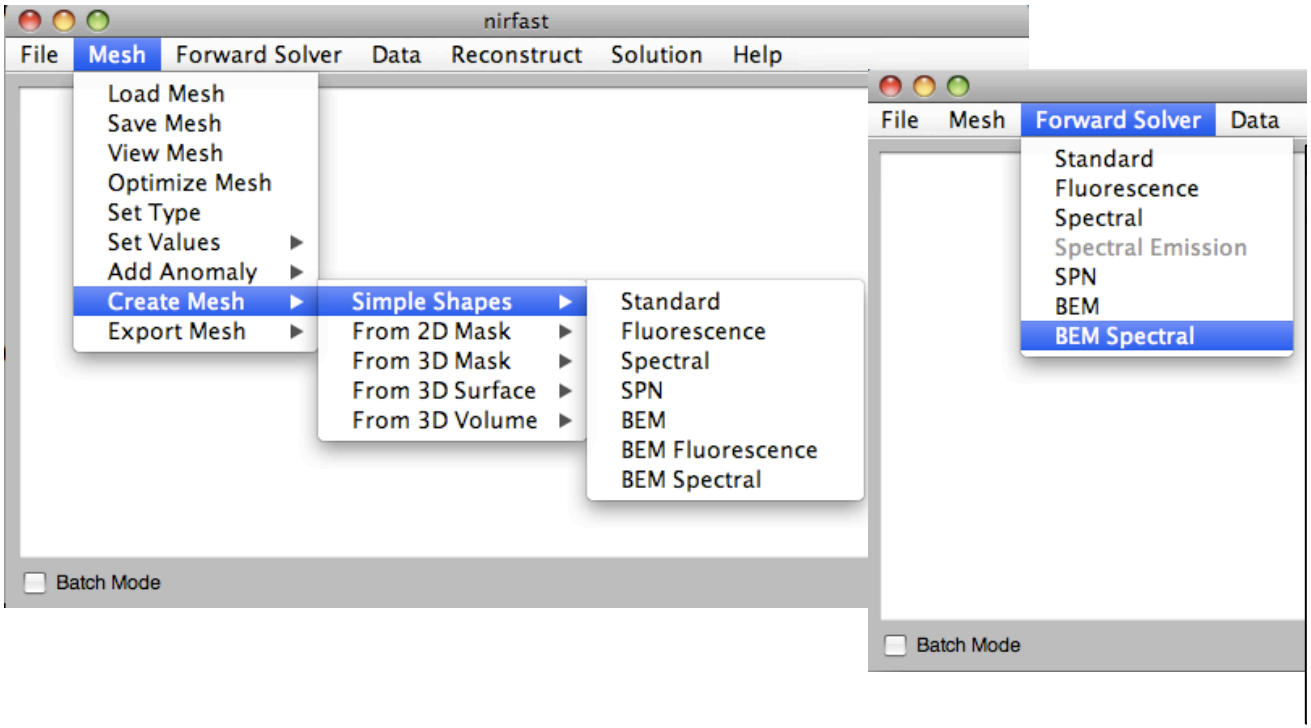


NIRFASTSlicer, 2016



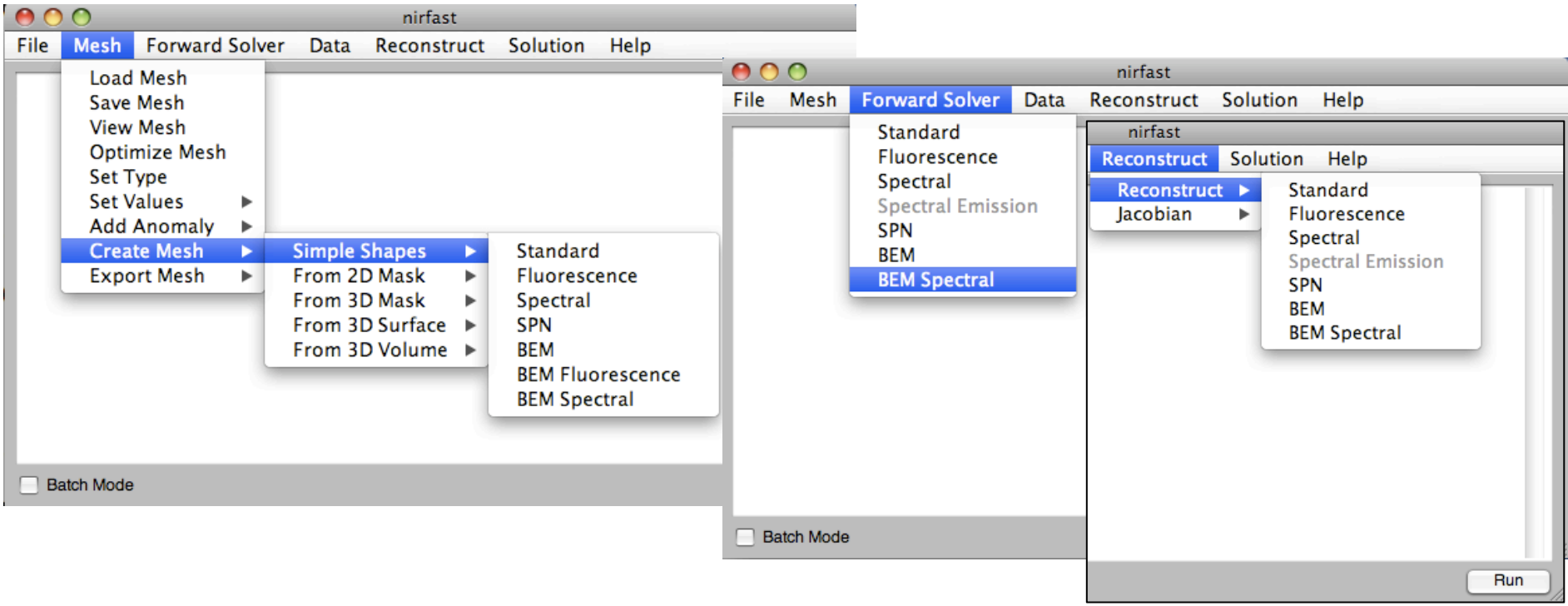
Graphical User Interface: Forward Models

- Implemented with MATLAB parallelization toolbox where available



Graphical User Interface: Image Reconstruction

- Implemented with MATLAB parallelization toolbox where available



NIRFAST Basics

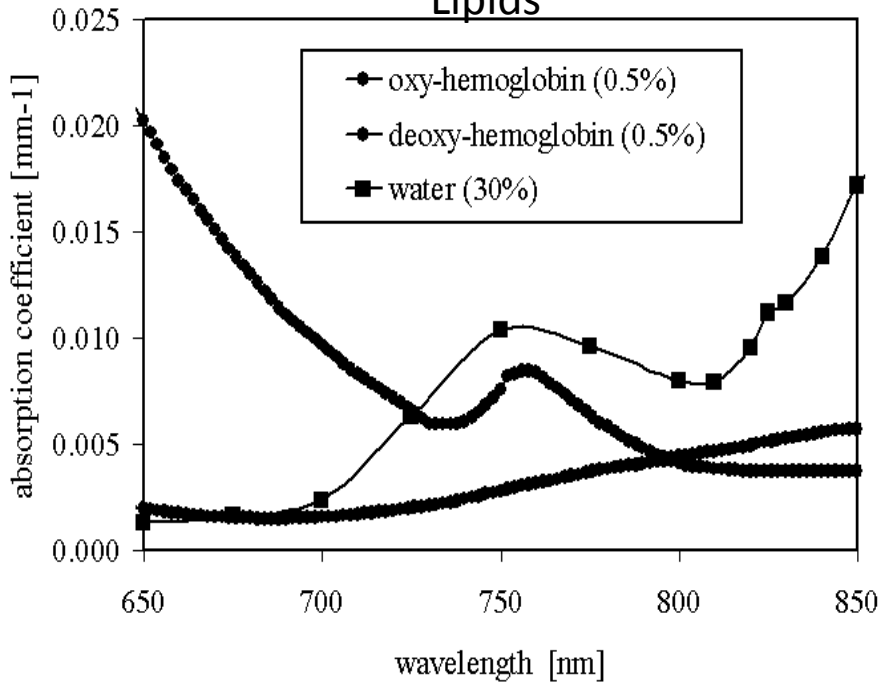
- When you generate a mesh (model) you are creating 6 files (ALL units mm):
  - *.node — This is coordinates of the mesh nodes
  - *.elem — This is the element connectivity
    - 3 nodes make an element in 2D
    - 4 nodes make an element in 3D
  - *.param — This is nodal optical properties
  - *.source — The coordinates of sources
  - *.meas — The coordinates of detectors
  - *.link — The paring (linking) of each source and detector
  - *.region — Region label of each node (optional)

NIRFAST Basics

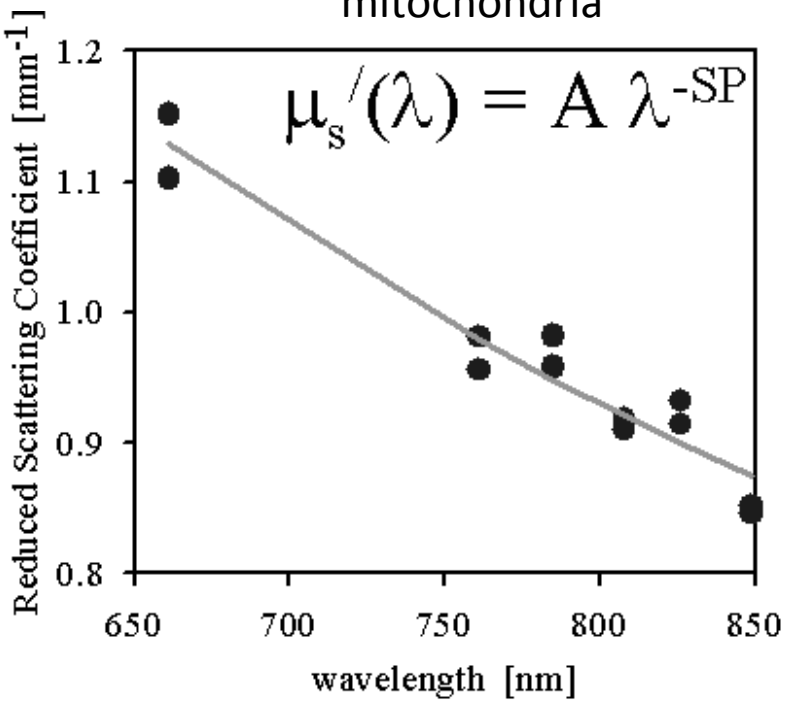
- All files are the same, regardless of the problem you are solving, except *.param which decides if it is
  - Single wavelength
  - Spectral
  - Fluorescence

Multi-spectral NIR

Absorbing molecules:
Hemoglobin
Oxyhemoglobin
Water
Lipids



Scattering objects:
Collagen
Cell membranes
nucleus
mitochondria



*.param

- For single wavelength
  - Header : stnd (for Standard)
  - Each row for each node
    - Same order as nodes defined in *.node file
  - 1st Column: absorption coeff
  - 2nd Column: Diffusion coeff
  - 3rd Column: Refractive index

```
stnd
0.01 0.330033 1.33
0.01 0.330033 1.33
0.01 0.330033 1.33
0.01 0.330033 1.33
0.01 0.330033 1.33
0.01 0.330033 1.33
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0.01 0.330033 1.33
0.01 0.330033 1.33
0.01 0.330033 1.33
```

*.param

- For multi wavelength: Spectral
  - Header : spec(for Spectral)
    - Then definition of each attenuating parameter
  - Each row for each node
    - Same order as nodes defined in *.node file
  - 1st Column: 1st attenuating param
  - 2nd Column: 2nd attenuating param
  - …
  - Note: for absorbing parameters, units as mM, and water as fraction

```
spec
HbO
deoxyHb
Water
S-Amplitude
S-Power
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
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0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
0.01 0.01 0.4 1 1
```

*.param

- For multi wavelength: Spectral
  - We also need another file, ***.excoef** to define extinction coeff for each of these parameters at each wavelength of choice: NIRFAST has this and will create it for you, when you generate a spectral mesh

```
HbO
deoxyHb
Water
S-Amplitude
S-Power
661 0.0740741 0.85 0.00148
735 0.09889 0.24 0.0038
761 0.118519 0.329167 0.00428
785 0.15 0.205556 0.00378
808 0.174074 0.161111 0.00332
826 0.227778 0.161111 0.00396
849 0.237037 0.155556 0.00578
```

*.param

- For Flourescence
  - Header :
  - Each row for each node
    - Same order as nodes defined in *.node file
  - 1st Column: excitation absorption coeff
  - 2nd Column: excitation Diffusion coeff
  - 3rd Column: Refractive index
  - 4th Column: emission absorption coeff
  - 5th Column: emission Diffusion coeff
  - 6th Column: fluorophore absorption
  - 7th Column: quantum efficiency
  - 8th Column: : life time

```
fluor
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
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0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
0.00887519 0.251965 1.33 0.00620401 0.260398 0.00183034 0.1 0
```

NIRFAST basics

- In matlab to see all loaded variable, type:
  - whos
- For example, a mesh variable looks like:

```
>> circle2000_86_stnd

circle2000_86_stnd =

            name: '/Users/hamiddehghani/nirfast7p2/meshes/standard/circle2000_86_stnd'
           nodes: [1785x3 double]
          bndvtx: [1785x1 double]
            type: 'stnd'
             mua: [1785x1 double]
           kappa: [1785x1 double]
              ri: [1785x1 double]
             mus: [1785x1 double]
        elements: [3418x3 double]
       dimension: 2
          region: [1785x1 double]
          source: [1x1 struct]
            meas: [1x1 struct]
            link: [240x3 double]
               c: [1785x1 double]
             ksi: [1785x1 double]
    element_area: [3418x1 double]
         support: [1785x1 double]
```

Schedule

Thayer School of Engineering at Dartmouth College

8-9am	Breakfast, registration, and confirm participants can run NIRFAST
9-9:15am	Introduction to tissue optics and NIRFAST
9:15-9:45 am	**Using NIRFASTSlicer** – Understanding the basic functions of Slicer
9:45-11:00 am	**Case Tutorial 1: Small animal image-guided fluorescence tomography** *Students will learn (to):* Basic principles of fluorescence imaging Load and segment MRI DICOM image stack of a mouse Create 3-D meshes of the mouse from segmented images Reconstruct 3-D images of fluorescence activity using spatial priors (CW) Visualize 3-D images overlaid on MRI DICOM's
11:00-11:25 am	Break
11:25-12:30 pm	**Case Tutorial 2: Hands-on introduction using Head meshes** *Students will learn to:* Load MRI derived full head mesh (Hamid Dehghani) Generate forward data for a head mesh (Hamid Dehghani) Generate Jacobian for a head mesh (Hamid Dehghani) Import head mesh into NIRFAST slicer and place your own s/d
12:30-1:30pm	Lunch on your own
1:30-2:30pm	**Using NIRFASTMatlab** Working with simple shapes and running simulations.
2:30-3:30pm	**Case Tutorial 3: MRI-NIR breast tomography (frequency domain)** *Students will learn to:* Load and segment MRI DICOM image stack of the breast Create 3-D meshes of the breast from segmented images Calibrate optical data from the breast Reconstruct 3-D diffuse images Visualize 3-D images overlaid on MRI DICOM's
3:30-4:00pm	Break (optional short Survey)
4:00-4:45pm	**Help with user applications** Bring your own diffuse optics problems! Work with instructors to develop a workflow that works for your cases.
6:30pm	**NIRFAST Dinner: Venue to be confirmed**