

# FINITE ELEMENT ANALYSIS II

## Modelization of hyperelastic behavior of the brain

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# Overview

## 1. FE vs Analytic - Comparative Plots

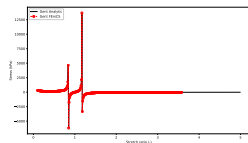
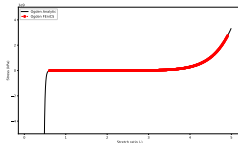
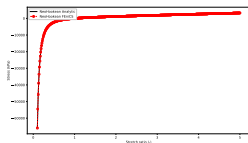
- Incompressible Models
- Compressible Models

## 2. Optimization

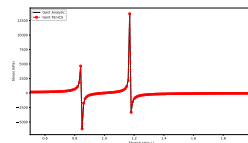
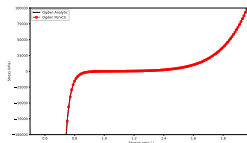
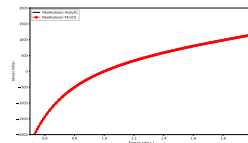
- Cortex
- Basal Ganglia
- Corona Radiata
- Corpus Callosum

# Incompressible Models

General



Zoom



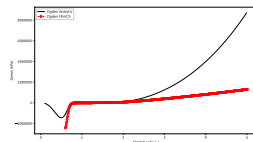
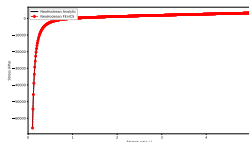
Neo-Hookean

Ogden

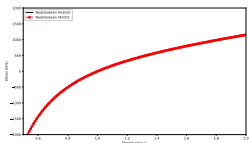
Gent

## Compressible Models

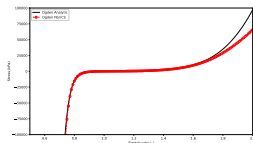
General



Zoom

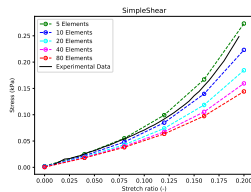
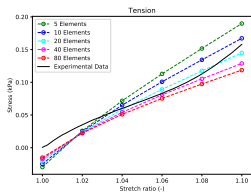
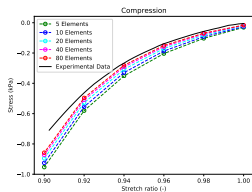


Neo-Hookean



Ogden

# Compressible Ogden Sensitivity



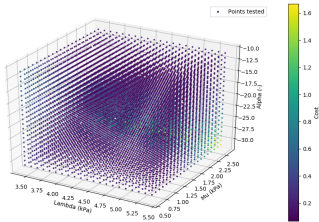
# General

- Optimization first performed in the  $\lambda$ ,  $\mu$ , and  $\alpha$  space
- Boundary conditions:
  1. All displacement blocked at the boundaries
  2. Displacement imposed according to the loading case
- Compressible Ogden formulation
- Optimization using *scipy.optimize.minimize* with the *L-BFGS-B* method
- Starting parameters choose according to a review publication (Budday et al.)
- Equal weighting of the loading cases in the computation of the cost function

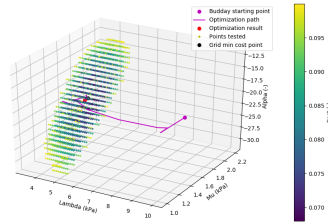
# Cortex - Optimization Settings

	$\lambda(kPa)$	$\mu(kPa)$	$\alpha(-)$
<b>Starting Point</b>	10	1.43	-19.0
<b>Optimization Results</b>	4.437	1.566	-21.136

# Cortex - Cost Function Grid



(a) Complete grid

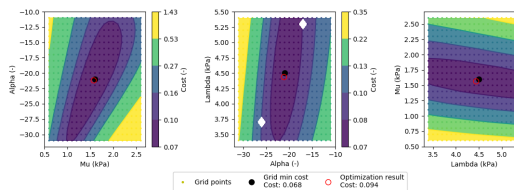


(b) Filtered grid

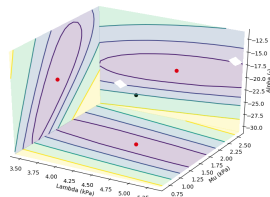
Cost function computed points



## Cortex - Cost Function Grid



(a) 2D plot



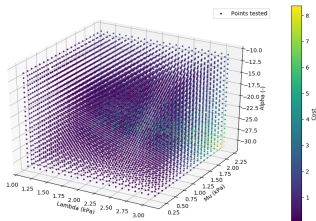
(b) 3D plot

Projection of the cost function at the minimum cost point

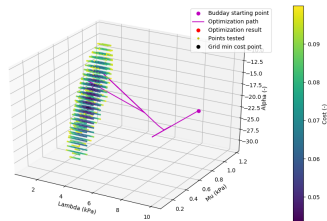
# Basal Ganglia - Optimization Settings

	$\lambda(kPa)$	$\mu(kPa)$	$\alpha(-)$
<b>Starting Point</b>	10	0.7	-18.7
<b>Optimization Results</b>	2.105	0.74	-21.558

# Basal Ganglia - Cost Function Grid



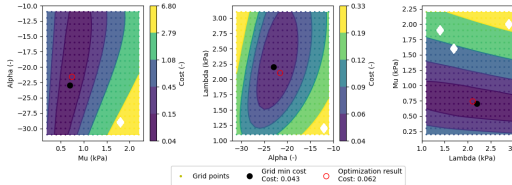
(a) Complete grid



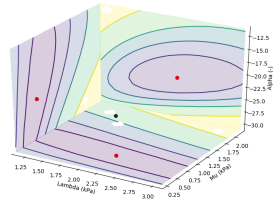
(b) Filtered grid

Cost function computed points

# Basal Ganglia - Cost Function Grid



(a) 2D plot



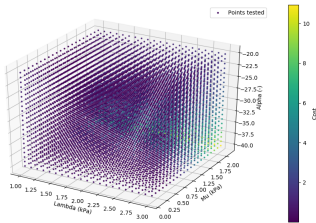
(b) 3D plot

Projection of the cost function at the minimum cost point

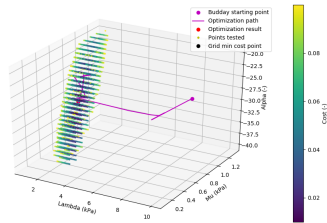
# Corona Radiata - Optimization Settings

	$\lambda(kPa)$	$\mu(kPa)$	$\alpha(-)$
<b>Starting Point</b>	10	0.66	-24.3
<b>Optimization Results</b>	2.057	0.659	-29.398

# Corona Radiata - Cost Function Grid



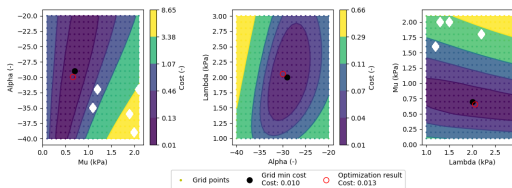
(a) Complete grid



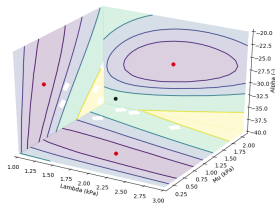
(b) Filtered grid

Cost function computed points

# Corona Radiata - Cost Function Grid



(a) 2D plot



(b) 3D plot

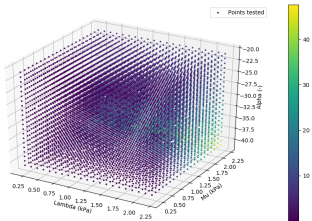
Projection of the cost function at the minimum cost point

# Optimization Settings

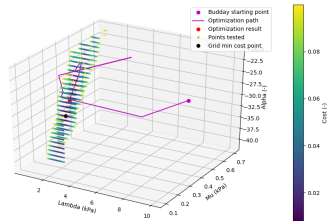
	$\lambda(kPa)$	$\mu(kPa)$	$\alpha(-)$
<b>Starting Point</b>	10	0.35	-25.3
<b>Optimization Results</b>	1.219	0.352	-30.573



# Corpus Callosum - Cost Function Grid



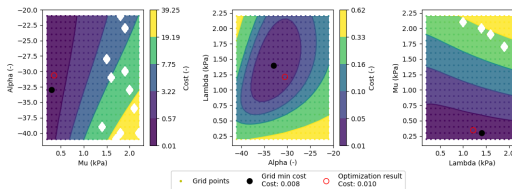
(a) Complete grid



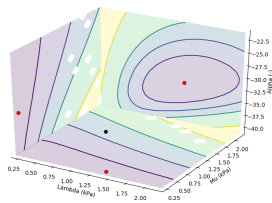
(b) Filtered grid

Cost function computed points

# Corpus Callosum - Cost Function Grid



(a) 2D plot



(b) 3D plot

Projection of the cost function at the minimum cost point