Title: Introductory nonlinear mechanics of soft biological tissues

Instructor: Luca Deseri, Ph.D.
Hours and credits: From 20 to 30 hours – 3 ECTS)

Description: The mechanics of soft biological tissues is a multidisciplinary and rapidly expanding topic of studies. In spite of the large number of papers published in the last fifty years within the broader area of biomechanics, this subject of research is fast growing. Indeed, understanding how vegetable and animal tissues bear loadings while undergoing growth and remodeling has yet to reach its full potential. It is because of (i) the actual complexities of the sub-macroscopic architectural organizations of biological structures at all scales (e.g. from cells to tissues) and of (ii) the coexistence of phases, that the mechanics of many of such active systems has still to be unveiled. Novel and more physically based frameworks are still in high demand. Time-space multiscale approaches are targeted to provide more reliable coarse-grained models, informed by the geometrical features of the relevant evolving microstructures, their growth and remodeling, and by the associated kinetics, mechanics and energetics.
The aim of this introductory course is threefold: (a) to briefly describe how highly deformable continua experience strains and rotations relative to their observed macroscopic geometrical changes, how those systems respond and how do balance laws ultimately govern the behavior of such bodies; (b) how do growth and remodeling actually influence the observed macroscopic geometrical changes and how do they couple with balance of forces/energy; (c) highlight how microscopically based paradigms for selected soft biological tissues reflect themselves at the macrolevel.

Prerequisites: Tensor Algebra and Tensor Calculus; Introductory Solid and Fluid Mechanics.

Summary of Topics:
Kinematics of soft tissues
- Kinematics of large deformation;
- Microstructures of biological tissues and related two-scales geometry.

Stress, balance and constitutive response
- Stress in the context of continua experiencing large deformations;
- Balance of linear and angular momentum for highly deformable continua;
- Constitutive laws: general principles
    - nonlinear elasticity: relationships among the various measures of stress and the corresponding strain measures; incompressible and compressible continua.

A brief Introduction to Growth and remodeling
- Introduction to Growth in plants and animal tissues; mass, density and their balance in growing bodies; phenomenological kinematics of growth;
- Introduction to Remodeling of active tissues;
- Examples of Models for the kinetics of growth and remodeling.

A proposal for microscopically informed coarse-grained approach for soft biological tissues
- Structured Deformations: brief introduction; kinematics of sub-macroscopically deformable continua; fluxes: densities, stresses, flows;
- Introductory multiscale balance and constitutive laws;
- A few words on paradigms for active microscopic architectures and the multiscale response of soft biological tissues.

References

A. Goriely (2018) The Mathematics and Mechanics of Biological Growth. Springer-Verlag
S. C. Cowin, S. B. Doty (2007) Tissue Mechanics. Springer
L. Gibson (2012) The hierarchical structure and mechanics of plant materials, Journal of the Royal Society-Interface 9, 2749–2766
D. Bigoni (2012) Nonlinear Solid Mechanics. Cambridge University Press.
D. Bigoni (2015) Extremely Deformable Structures - CISM Lecture Notes No. 562. Springer doi 10.1007/978-3-7091-1877-1
G. Del Piero, D. R. Owen (2004) Multiscale Modeling in Continuum Mechanics and Structured Deformations - CISM Lecture Notes No. 447. Springer ISBN 978-3-7091-2770-4, doi 10.1007/978-3-7091-2770-4_7
L. Deseri, D. R. Owen (2019) Elasticity of hierarchical bodies predicted with multilevels Structured Deformations, 135 (1-2), 149-182
N. Nguyen, N. Nath, L. Deseri, E. Tzeng, S.S. Velankar, L. Pocivavsek (2020).Wrinkling instabilities for biologically relevant fiber-reinforced composite materials with a case study of Neo-Hookean/Ogden–Gasser–Holzapfel bilayer, Biomech. Modeling Mechanobiol., 1-21, https://doi.org/10.1007/s10237-020-01345-0