Nuovo Indirizzo:
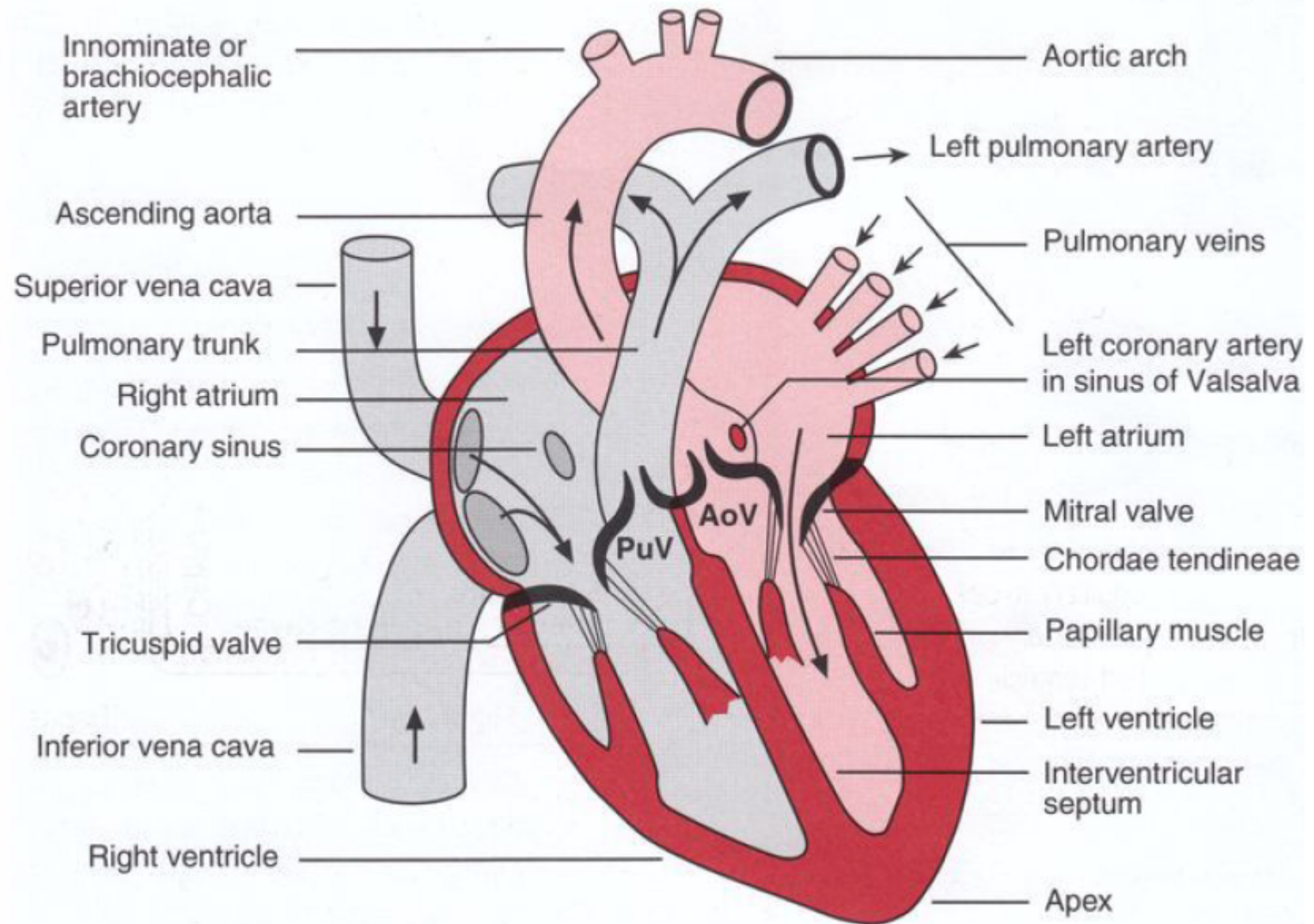
Modelling and Simulation for Biomedical Applications
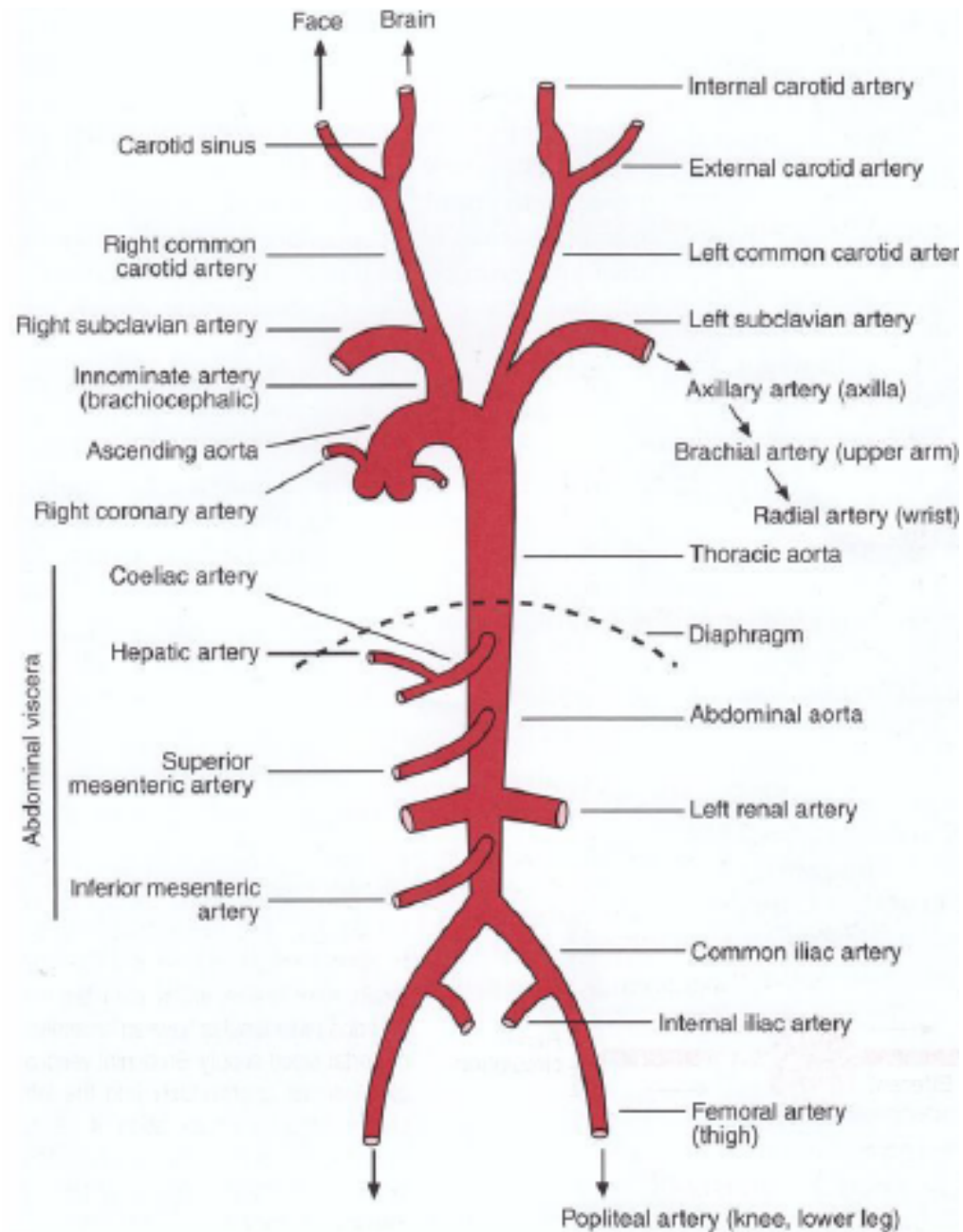
Eleuterio Toro, Albrto Valli, Ana Alonso
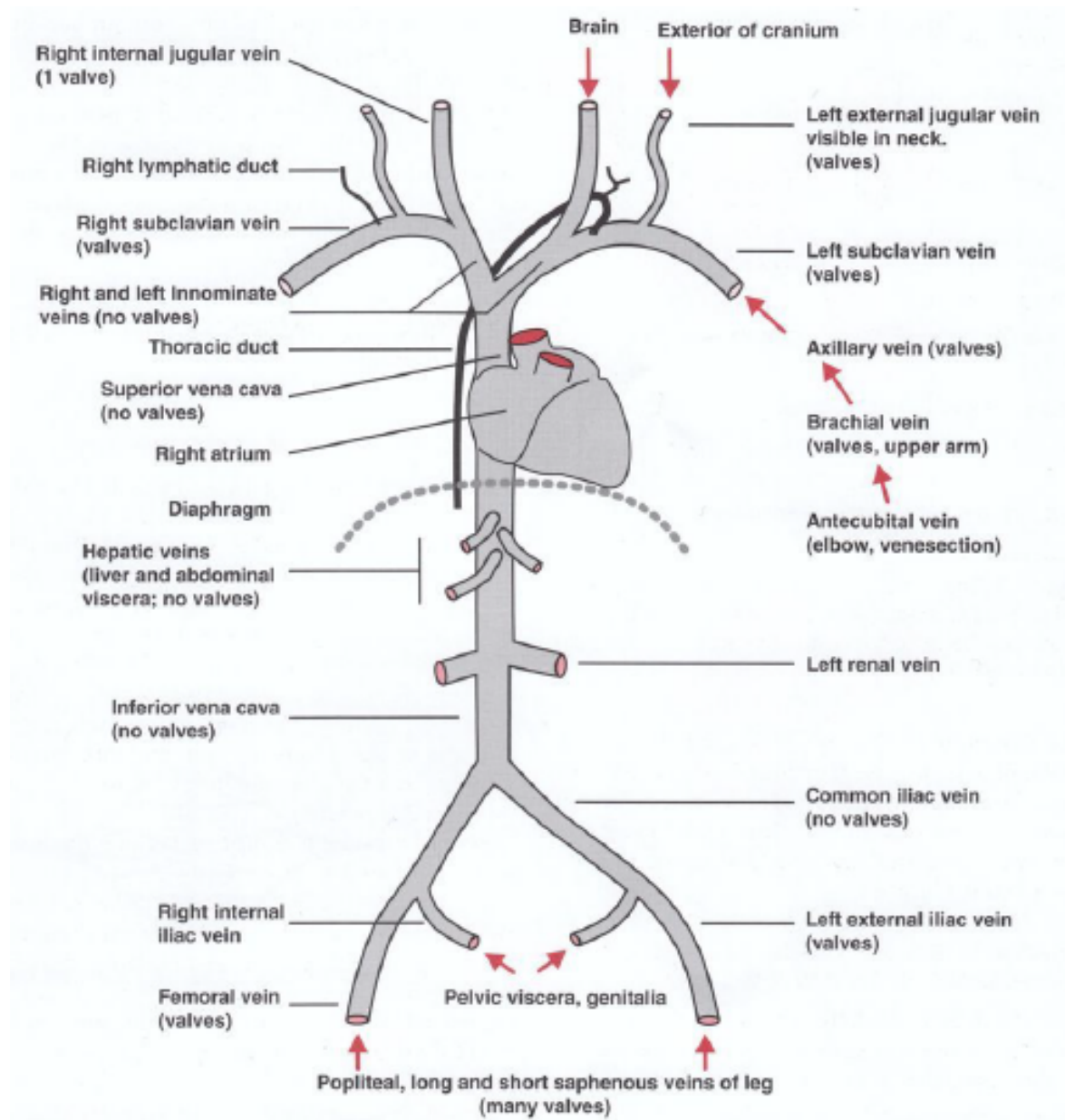
BACKGROUND

- **Nelle nazioni industrializzate la gente vive piu' a lungo.**

- **Conseguenza: servizi sanitari sotto grosse pressioni.**

- **Studio e ricerca possono essere di grande aiuto.**

- **Problemi bio-medici sono *multidisciplinari.***

Il corpo umano richiede:

- trasporto di ossigeno e nutrienti alle cellule.

- raccolta degli scarti.

Innominate or brachiocephalic artery

Ascending aorta

Superior vena cava

Pulmonary trunk

Right atrium

Coronary sinus

Tricuspid valve

Inferior vena cava

Right ventricle

Aortic arch

Left pulmonary artery

Pulmonary veins

Left coronary artery in sinus of Valsalva

Left atrium

Mitral valve

Chordae tendineae

Papillary muscle

Left ventricle

Interventricular septum

Apex

PuV

AoV

Face   Brain

Internal carotid artery

Carotid sinus

External carotid artery

Right common carotid artery

Left common carotid artery

Right subclavian artery

Left subclavian artery

Innominate artery (brachiocephalic)

Axillary artery (axilla)

Ascending aorta

Brachial artery (upper arm)

Right coronary artery

Radial artery (wrist)

Thoracic aorta

Coeliac artery

Diaphragm

Hepatic artery

Abdominal aorta

Superior mesenteric artery

Left renal artery

Inferior mesenteric artery

Common iliac artery

Internal iliac artery

Femoral artery (thigh)

Popliteal artery (knee, lower leg)

Abdominal viscera

Brain

Exterior of cranium

Right internal jugular vein
(1 valve)

Left external jugular vein
visible in neck.
(valves)

Right lymphatic duct

Right subclavian vein
(valves)

Left subclavian vein
(valves)

Right and left Innominate
veins (no valves)

Axillary vein (valves)

Thoracic duct

Superior vena cava
(no valves)

Brachial vein
(valves, upper arm)

Right atrium

Diaphragm

Antecubital vein
(elbow, venesection)

Hepatic veins
(liver and abdominal
viscera; no valves)

Left renal vein

Inferior vena cava
(no valves)

Common iliac vein
(no valves)

Right internal
iliac vein

Left external iliac vein
(valves)

Femoral vein
(valves)

Pelvic viscera, genitalia

Popliteal, long and short saphenous veins of leg
(many valves)

Modelling
and
Simulation

???

Ossigeno e nutrienti per le cellule

Table 1.1 Time taken for a glucose molecule to diffuse specified distance in one direction

Distance (x)	Time (t)[a]	Example *in vivo*
0.1 μm	0.000005 s	Neuromuscular gap
1.0 μm	0.0005 s	Capillary wall
10.0 μm	0.05 s	Capillary to cell
1 mm	9.26 min	Skin, artery wall
1 cm	15.4 h	Left ventricle wall

[a]Einstein's equation statest $t = x^2/2D$, where D is solute diffusion coefficient (glucose, 0.9×10^{-5} cm^2 s^{-1} at 37°C; oxygen in water, 3×10^{-5} cm^2 s^{-1}, 37°C).

(Einstein A. *Theory of Brownian Movement* (trans. by Fürth R, Cowper AD, 1956). New York: Dover Publications, 1905.)

Ossigeno e nutrienti per le cellule

Trasporto veloce: **convection**
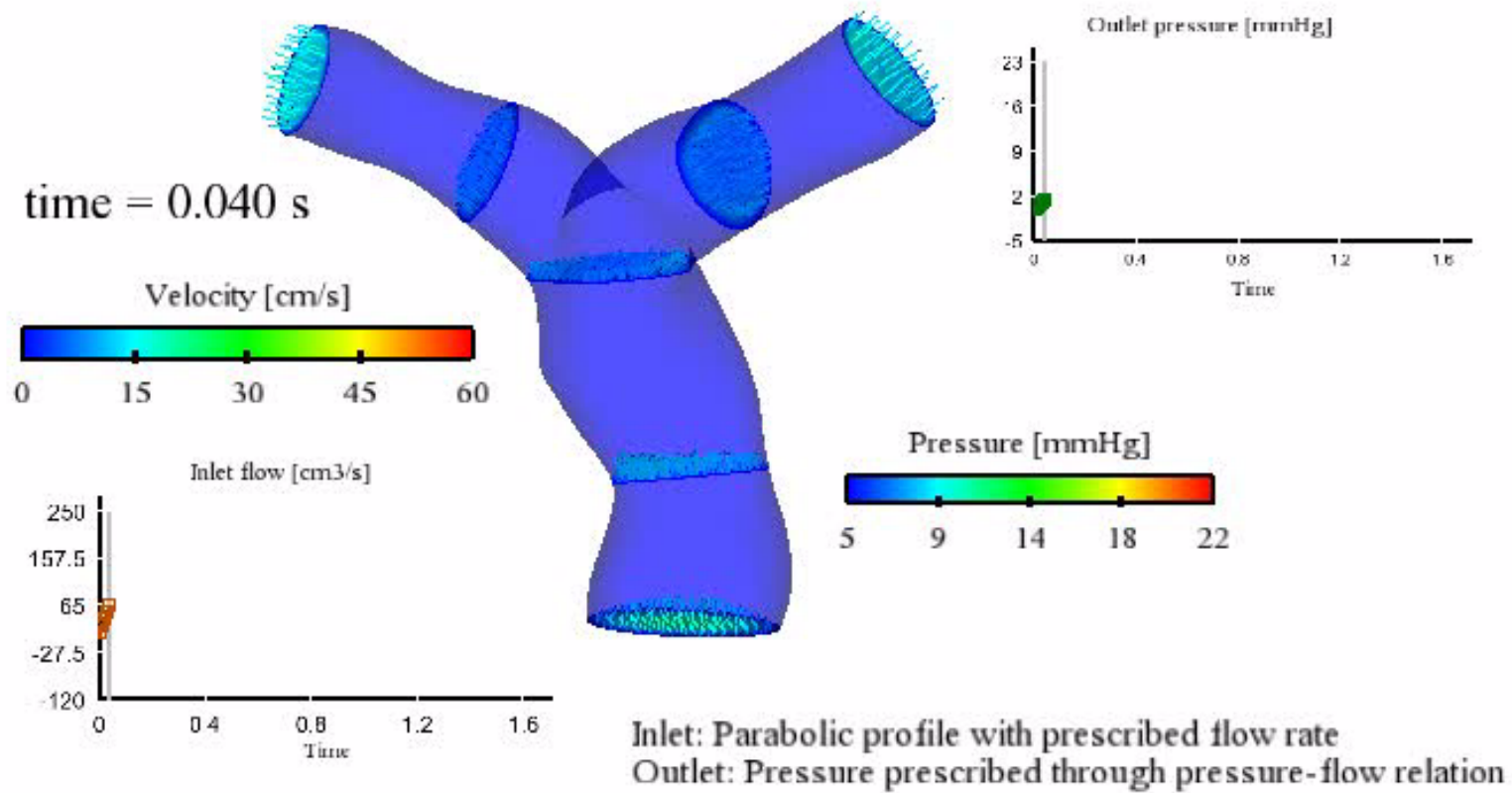
$$\partial_t q + \lambda \partial_x q = 0$$

Trasporto lento: **diffusion**

$$\partial_t q = \alpha \partial_x^{(2)} q + \beta q$$

Modelling and Simulation
=
Mathematical model (equations)
+
Numerical methods
+
Computer
+
Processing and interpretation of results
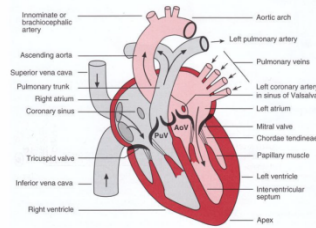
Blood flow in pulmonary artery in pathologic conditions (absence of pulmonary valve)

time = 0.040 s

Velocity [cm/s]

0   15   30   45   60

Inlet flow [cm3/s]

Outlet pressure [mmHg]

Pressure [mmHg]

5   9   14   18   22

Inlet: Parabolic profile with prescribed flow rate
Outlet: Pressure prescribed through pressure-flow relation

CORSI

I anno

I semestre

Theoretical biomechanics (9 crediti)
Solid bio-mechanics (Prof. D Bigoni)
Fluid bio-mechanics (Prof. G Rosatti)

Partial differential equations in biology (9 crediti)
(Prof. M Iannelli and Prof. A Valli)

Integral transforms (6 crediti)
(Prof. Tubaro)

Statistical models (3 crediti)
(Prof. A Pugliese)

Physiology (6 crediti)
(Prof. Y. Bozzi)

II semestre

Scientific computing (6 crediti)
 (Prof. Dumbser)

Biomedical imaging (6 crediti)
(Prof. R Antolini)

Mathematical aspects of bioelectromagnetism imaging (6 crediti)
Prof. Ana Alonso)

Mathematical biology (9 crediti)
(Prof. M Iannelli and Prof. A Pugliese)

II anno

III semestre

Models and numerical methods for blood flow
(9 crediti)
(Prof. E Toro)

Physiological flow and transport in porous tissues (6 crediti)
(Prof. A Bellin)

Medical applications (6 crediti) (design in progress)

Theoretical biomechanics (D Bigoni)

The course is divided into

- structural biomechanics and

- solid biomechanics.

The aim is to show how forces influence shape and growth of biological systems and how to treat deformation and stress of biological tissues.

Basic models to answer the following questions:

- what is the mechanics of DNA segments and of the cellular cytoskeleton,
- how animals move,
- how fracture develops in bones,
- how arteries deform under increasing blood pressure,
- how the cardiac muscle deforms and
- how brain tissue behaves under slow increasing deformation.

Theoretical biofluid-mechanics
(G Rosatti)

Il corso fornirà gli strumenti matematici di base per lo studio generale del moto dei fluidi viscosi e turbolenti per poi soffermarsi sulle peculiarità dei fluidi biologici, con particolare riferimento al comportamento reologico del sangue.

Il corso proseguirà affrontando in particolare lo studio del moto sangue nei grandi vasi dalla formulazione matematica in termini di equazioni differenziali, alla soluzione esatta di casi notevoli.

Il corso sarà corredato da una serie di seminari tenuti da esperti dell'Ospedale di Trento riguardante aspetti biologici, medici e patologici relativi all'emodinamica nel corpo umano.

PDEs in Biology (Iannelli/Valli)

Starting from basic results about the classification of linear 2nd order PDEs and methods to find explicit solutions of simple equations, the course on the one hand will build a theoretical background for the equations of fluid mechanics; on the other hand it will study the class of reaction-diffusion equations, widely used in biology, analyzing phenomena like travelling-wave solutions, and mechanisms for pattern formation.

Integral transforms (Tubaro)

Aim: to introduce to the theory of Fourier and (to a limited extent) Laplace transform, and their applications especially in PDEs.

Statistical models (A Pugliese)

A short introduction to the methods of statistics, especially linear models, in data analysis with the use of specialized software on test data.

Physiology (mutuata dal corso di Laurea in Scienze e Tecnologie Biomolecolari) (Y Bozzi).

L'obiettivo è quello di fornire agli studenti una visione integrata del funzionamento dei vari organi ed apparati del corpo umano.

Scientific Computing (Dumbser)

Basic and advanced scientific programming skills for coding numerical algorithms using modern programming languages: Fortran 90, Fortran 2003 or C. Mixed-language programming.

Applications will involve linear algebra, ordinary and partial differential equations taken from science and engineering.

Basic parallelization strategies for modern multi-core CPU systems will be discussed and implemented in practice.

Computer laboratory sessions, practical programming issues, efficient code writing and debugging, scientific data visualization.

Desirable prerequisites: Elementary numerical analysis, ODEs, PDEs.

Biomedical Imaging (R Antolini)

Introduction to mathematical, physical, and computational principles underlying modern medical imaging systems.

Fundamentals of X-ray radiography, X-ray computed tomography (CT), ultrasonic imaging, nuclear imaging, magnetic resonance imaging (MRI).

General concepts required for the above, such as linear systems theory, Fourier Transform and numerical optimization.

Basic concepts of biomedical image computing (visualization, segmentation, and analysis of image data).

Applications of medical imaging, such as image-guided intervention.

Mathematical aspects of biomagnetic source imaging (A Alonso)

There are many biomedical imaging modalities that use different physical principles for signal generation and detection:

- electro- and magneto-encephalography
- X-ray tomography,
- magnetic resonance imaging,
- impedance tomography

All of them involves a **direct problem** concerning how the experimental data are collected and an **inverse problem** concerning the reconstruction of the image from the measured data.

For instance, **magneto-encephalography** measures the magnetic flux away from the head due to neuronal current sources within the brain.

(Alonso, cont.)

• The **direct problem** consists in the computation of the magnetic field for a given current source (Maxwell equations).

• From the point of view of medical diagnosis we are interested in the corresponding **inverse problem** that consists in the reconstruction of the neural current source from measurements of the external magnetic flux.

This course provides the mathematical tools that are essential for the understanding of different imaging techniques with particular emphasis on those based on bio-magnetic properties:

• Maxwell equations,
• integral transforms,
• fundamental solutions and layer potentials
• inverse problems and regularization techniques.

Models and numerical methods for blood flow (E Toro)

Aim: to contruct mathematical models and numerical methods for the computer simulation of blood flow in humans.

- Basics on theory and numerical methods for hyperbolic equations.

- Advanced methods for model hyperbolic problems.

- Governing equations for blood flow in medium to large vessels.

- Zero-dimensional models. Numerical methods.

- One-dimensional models. Theoretical study of the models. Tube laws. Simplified models and analytical solutions. Advanced numerical methods.

- Methods for junctions (bifurcations).

- Simplified networks.

- Practical project and seminars.

Physiological flow and transport in porous tissues (A Bellin)

This course deals with the mechanisms leading to transport of oxygen, nutrients, waste products and heat around the body rapidly.

- rapid convective transport in the main vessels,
- transport processes occurring between micro-vessels and the tissue.

Such exchange is crucial for carrying oxygen and nutrients to the cells and wash out metabolic waste, through the lymphatic system.

Modeling these processes may contribute to unveil the origin of a large class of diseases, including neurodegenerative diseases and better tailor treatments, for example through a better understanding of drug delivery.

Mathematical Biology (Iannelli/Pugliese)

qualitative models in population ecology, epidemiology and few topics in molecular/cellular biology

Riassunto

L'indirizzo fornisce competenze:

- matematiche,
- fisiologiche
- fisiche
- numeriche e
- computazionali

che sono applicabili ad un vasto *range* di discipline:
(nella medicina, industria farmaceutica, servizi sanitari, enti di ricerca, enti di assicurazione, ecc.)

Transferable skills

Grazie