Implementation and comparison of cardiovascular models

Internship

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General context

This internship is part of the first year of the CSMI master's degree. This internship was an opportunity for me

- to broaden my knowledge on subjects such as the cardiovascular field
- to understand different existing models.

Subjects explanation

- The idea of the internship is to understand in particular a specific system proposed by the **Pulse Physiology Engine** platform.

Subjects explanation

- The idea of the internship is to understand in particular a specific system proposed by the **Pulse Physiology Engine** platform.
- Then we are interested in another model, that of the brain-eye coupling, which can be similar to the one of **Pulse**.

Project management

- mainly worked by searching the website associated with **Pulse Physiology Engine**
- reading articles

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Pulse Physiology Engine

The **Pulse Physiology Engine** is a C++ based, comprehensive human physiology simulator that drives medical education, research, and training technologies.

CDM

The Pulse architecture is built around a Common Data Model that defines the key data structures as well as many implementations of common algorithms needed for lumped parameter physiology modeling. The Common Data Model is a specification of all the data and relationships associated with writing physiology simulation software. Modeling objects define the scope and data required for physiologic simulation with the following concepts :

- Patient
- Conditions
- Actions

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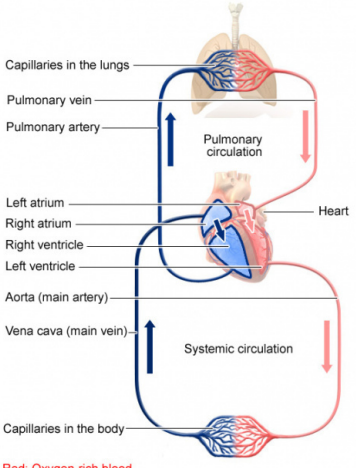
How it works?

The **cardiovascular system** is a large organ system comprised of the heart and the blood vessels. It serves as the body's primary transport and distribution system. The cardiovascular system is sometimes described as two separate circulations: the **systemic circulation** and the **pulmonary circulation**, which are connected.

How it works?


Capillaries in the lungs
Pulmonary vein
Pulmonary artery
Pulmonary circulation
Left atrium
Right atrium
Right ventricle
Left ventricle
Heart
Aorta (main artery)
Vena cava (main vein)
Systemic circulation
Capillaries in the body
Red: Oxygen-rich blood
Blue: Oxygen-poor blood

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Cardiovascular modeling

The state of the cardiovascular system is determined at each time step by a three-step process: **Pre-processing**, **Processing** and **Post-processing**. In the Pre-processing step, feedback from other systems, as well as internal system feedback, is processed to determine the system state. The Process step uses an already implemented function to calculate the new system state. The Post-processing step is used to prepare the system for the time advance.

Pre-processing

Cardiac cycle calculations include methodology for updating the driving force(heart contraction and relaxation) of the cardiovascular system throughout the duration of a cardio-vascular cycle (a single heart beat). This includes a set of systolic calculations that updates contractility at the beginning of the cycle to represent a heart contraction. For this, we need the implemented function **HeartDriver()**

Pre-processing

The method **BeginCardiacCycle()** is directed by HeartDriver(). It sets up the evolution of the current cardiac cycle. It is used to apply the effects of drugs or exercise on the cardiovascular system. These effects will persist until the end of the cardiac cycle, and this function will then be called again if there is no cardiac arrest. Modifications to heart rate and heart compliance are calculated by BeginCardiacCycle() and applied for the remained of the current cardiac cycle.

Pre-processing

```
1  void Cardiovascular::PreProcess()
2  {
3    // Locate the cardiac cycle in time (systole, diastole)
4    // and do the appropriate calculations based on the time location.
5    HeartDriver();
6    ProcessActions();
7    UpdateHeartRhythm();
8    // The heart rhythm is set to either Asystole (Asystole is defined
       as a cessation of the heart beat.) or NormalSinus based on if the
       patient has an active cardiac arrest or has triggered the asystole
        event some other way.
9
10 }
```

Listing 1: The method PreProcess()

Processing

Process : The function already implemented **CalculateVitalSigns()** takes the current time step's circuit quantities to calculate important system-level quantities for the current time step. The system pressures and flow rates related to shunting are calculated here. In addition, different cardiac events are triggered.

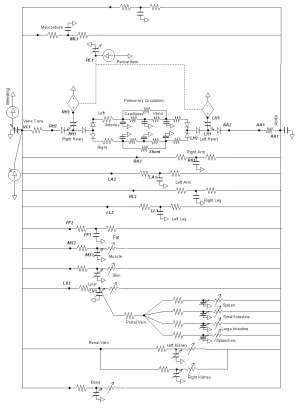
Post-Processing

Post-processing: The Post-process step moves everything calculated in Process from the next time step calculation to the current time step calculation. This allows all other systems access to the information when completing their Pre-process analysis for the next time step.

The Cardiovascular Circuit

The **cardiovascular circuit** estimates blood pressure, flow, and volume for organs that are represented by several compartments. These compartments are comprised of lumped parameter models that use resistors and capacitors. The system is discretized into nodes that are connected by paths.

The Cardiovascular Circuit



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Another model

We will look at another modelling approach, that of an eye-brain coupling, which may be similar to that of Pulse.

Context

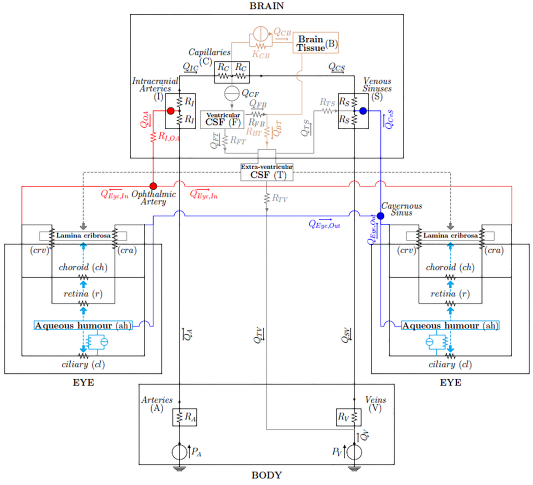
Microgravity conditions have been observed to induce structural and functional changes in the eyes of many astronauts, posing serious problems for both the astronauts and their missions in space. This syndrome, also known as **Spaceflight Associated Neuro-ocular Syndrome**, is characterized by many apparently unrelated and often non-concurrent symptoms such as choroidal folds.

The model

It is a lumped parameter model of the brain and eyes, connected with a highly simplified model of the body. Studies suggest that two main mechanisms may be involved in the syndrome pathophysiology :

- changes in the vascular system and fluid distribution
- changes in the brain/central nervous system and intracranial pressure

The model


BRAIN
Brain Tissue (B)
Capillaries (C)
Intracranial Arteries (I)
Venous Sinuses (S)
Ventricular CSF (F)
Extra-ventricular CSF (T)
Ophthalmic Artery
Cavernous Sinus
Lamina cribrosa
choroid (ch)
retina (r)
Aqueous humour (ah)
ciliary (cl)
EYE
Arteries (A)
Veins (V)
BODY

Conclusion

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