Biological networks are used to transport fluids, such as blood, throughout an organism. In analogy with ‘inorganic’ networks, biological networks have structure with a complex branching pattern that reflects the competition between extending the network and the cost associated with its construction, maintenance and losses during the transport through the network. A benchmark for vascular systems, one of the most basic type of biological network, was proposed by the physiologist Cecil Murray in 1926 as a compromise between the frictional and metabolic costs, which was expressed as a ‘cost function’. The formulation of a minimum energy hypothesis led to a scaling law, \( Q \propto D^3 \), where \( Q \) and \( D \) are the volumetric flow rate and the diameter of a blood vessel segment, respectively. This scaling law is universal for all tree whose internal flows are laminar.

There are several levels of description of physical and biological networks. In the ‘coarse-grained approach that is the domain of statistical mechanics [1], the statistical properties of the ‘skeletal’ network are of primary interest. At a more microscopic level, the main interest focusses on the function of the network, such as the flow of nutrients [2], to characterize, in the case of vascular networks, the flow rate and the length and diameter of vessel branches. Quite apart from the analysis of fully developed networks is the question of how they are formed, i.e. their growth. It is in this arena that the coarse-grained and macroscopic approaches come together because the spreading of the network is driven by the fulfillment of a function, such as the delivery of nutrients, but limited by the overall cost incurred by extending the network.

This project is based on the development of a model for the vascular network and the morphology of the human placenta by modeling a network of blood vessels with an appropriate cost function that accounts for the balance between the distribution of nutrient against the ‘cost’ of extending the network and transporting the nutrient through the network. The scientific goals of this research are to use the model for the vascular structure (i) as a basis for modelling the growth and development of the placenta, which would be used to (ii) provide an explanation of the variability of the shape of the placenta. This, in turn, (iii) could be used as a basis for studies that attempt correlate such deviations with the development of the fetus and the health of the child throughout life. In the longer term, we will (iv) assess the extent to which the placental growth model can be modified at various stages of development, which would have profound and far-reaching implications for the application of this model in a clinical environment.

**Student skills required.** This project is based on the analysis of actual vascular data from human placentas, so skills in data manipulation and the graphical representation of that data are essential. At a more quantitative level, a background in the analysis of networks is desirable. Basic fluid mechanics can learned as needed, as can machine learning methods, which will be used in the latter stages of the project.
