HumMod Explorer: A Multi-Scale Time-Varying Human Modeling Navigator

Liming Xu* Zhejiang University
Jeremy Lyle† USM
Yubao Wu ‡ USM
Zhigeng Pan § Zhejiang University
Mingmin Zhang¶ Zhejiang University
David H. Laidlaw ‖ Brown University
Robert L. Hester ** University of Mississippi Medical Center
Jian Chen†† USM

Abstract

We present HumMod Navigator, a multiple-scale physiology data browser for exploring casual relationships of time-varying human modeling data. The visualization makes use of a circular layout and hierarchical relations to effectively visualize interactions between model parameters in an attempt to obtain both a local and comprehensive view of the physiological modeling environment.

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1 Introduction

Recent success in real-time modeling and simulation of human physiology has imposed grant challenges to data analysis which enable scientists to understand how precisely organism functions intricately and exquisitely by the laws of physics and chemistry. In 1972, Guyton et al. [Guyton AC 1972] published a landmark paper giving an integrative model for the circulatory system involving multiple body organ systems. This model was remarkable because of its successful integration of multiple physiological systems, as well as its conciseness and clarity in describing interactions between parameters and portraying a comprehensive view of the model. The Guyton model has been extended to a more comprehensive modeling environment, HumMod [Hester et al. 2011], which models interactions between the cardiovascular, respiratory, renal, neural, endocrine, skeletal muscle, and metabolic physiologies.

An important use for the model is to understand physiological mechanisms and interactions that are not evident, allowing one to observe higher level emergent properties of the complex physiological systems. In order to accomplish this, one of the difficulties which must be overcome with HumMod is the fact that the number of parameters is prohibitive in developing a clear and comprehensive view of the interactions between parameters. Currently the HumMod model contains more than 5000 variables. The integrative modeling of HumMod is accomplished by assimilating over 40 years worth of published physiological models for the interactions between parameters. Therefore, good visualization techniques are needed to discern non-obvious relationships between variables.

*email: xuliming@zjucadcg.cn
†email: samuel.lyle@usm.edu
‡email: yubao.wu@eagles.usm.edu
§email: zgpan@cad.zju.edu.cn
¶email: zmm@cad.zju.edu.cn
‖email: dhl@cs.brown.edu
**e-mail: rhester@umc.edu
††e-mail: jian.chen@usm.edu

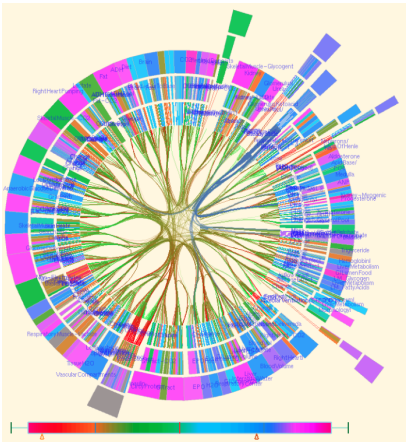

Figure 1: *View of Hierarchical Tree around inner ring. The node at the center of the figure corresponds to the level 0 name. From the adjacent node on the left, the nodes clockwise around the cycle correspond to the level 2 names given on the right. Edges from these nodes to the root have been suppressed, except for the rightmost and leftmost neighbor. The level 2 names can be projected downward onto the inner circle to determine their associated global name parameters.*

2 Description of Parameter Interactions

2.1 Structure of HumMod

To describe the parameter interactions in HumMod, it is necessary to first give a short description of the structure and environment of HumMod. In order to simplify the process of updating the model, All aspects of the model are stored as XML documents. A C++ parser, which additionally includes functionality for solving the equations involved in the model, is used to parse and execute the model. To update the model, it is only necessary to edit or add XML files. Both the parser and XML files are freely available online at *http://hummod.org/*. Parameter interactions can be classified into two types, hierarchical and functional.

2.2 Parameter Interactions: Hierarchical relationships

Every parameter used in HumMod has an assigned "global" name. For example, Co2Total includes the parameters or global names of `CO2.CO2Total.Inflow` and `CO2.CO2Total.Outflow`. Each global name is made up of three distinct components, namely `CO2`, `CO2Total`, and `Inflow`, and `CO2`, `CO2Total`, and `Outflow`. This represents the fact that within the folder describing `CO2`, and the specific file describing `CO2Total`, there are local elements corresponding to both `Inflow` and `Outflow`.

To simplify our explanations, we will refer to the components of the name of a model parameter as the level x name, where x refers to the depth. Therefore, for the parameter `CO2.CO2Total.Inflow`, the level 0 name is `CO2`, the level 1

name is `CO2Total`, and the level 2 name is `Inflow`. In HumMod, there is no inherent restriction on the possible depth of global names, however, currently the majority of global names are composed of a level 0, a level 1, and a level 2 name.

Interaction between model parameters with a common level x name is to be expected, as common names indicate a measure of similarity in the model parameters. In fact, this provides a natural clustering of parameters which should be preserved in any visualization. These hierarchical relationships can be visualized by labeling a disjoint set of rooted trees, one tree for each distinct level 0 name. Global names can then be viewed as the paths from the root to the leaves of these hierarchical trees.

2.3 Parameter Interactions: Functional relationships

In addition to containing local names, each XML file for a parameter details the dependence of its value on the value of other parameters. For example, the XML file details the dependence of the value of `CO2.CO2Total.Inflow` on the value of parameters corresponding to the outflow of CO2 from other body organs, as well as the dependence of the value of `CO2.CO2Total.Outflow` on the values of `Lung.LungCO2.Expired` and `CO2.CO2Tools.LitersToMols`. These relationships constitute the functional relationships between different global parameters. Currently, neither the type of functional relationship (e.g. linear, nonlinear) nor the "direction" of dependence is taken into account in identifying functional relationships.

3 Methods

Our work of edge bundling is inspired by the work of Holten [Holten 2006], specifically to show the directed connections between pairs. Nodes corresponding to each parameter are equally spaced along an inner circle. Parameters are clustered according to level x names. By this, we mean that if parameters p_i and p_j, corresponding to nodes i and j, share a common level x name, then all nodes will be arranged counterclockwise around the circle from i to j. By placing contiguously all nodes with the same level x name, we can represent explicitly the hierarchical relationships between parameters. Trees representing the hierarchical relationships are drawn outward (parent) from the inner circle (children). This forest of hierarchical trees allows one to easily see (and select) the parameters which share a common level x name.

To draw the portion of the graph corresponding to the functional interactions, we first determine a circular ordering of the nodes. To do so, we consider a reduced graph G', constructed in the following way: Each node of G' corresponds to a disjoint tree in the forest of hierarchical trees, and nodes corresponding to trees t_i and t_j are adjacent if and only if there is an edge from a leaf of t_i to a leaf of t_j. This graph represents the interactions between level 0 names. Consider the reduced graph G' as drawn with a circular layout on the unit circle and straight edges. To reorder the nodes of the reduced graph G', we use the following iterative process to minimize the sum of the squared edge lengths, developed by Gansner and Koren [Gansner and Koren 2007]. Visiting each node in turn, the position of a node is determined by finding the intersection of the unit circle and the line passing through the origin and the barycenter of its neighbors. Every few iterations, nodes are repositioned so as to be uniformly spaced along the circle, preserving the circular ordering. This ordering of nodes in G' corresponds to a reordering of hierarchical trees in the original graph, which can be extended to a reordering of the original graph in the obvious way.

To combine both the hierarchical and functional interactions, we employ the technique of Holten [Holten 2006] which uses hierarchical information to induce edge bundling. Cubic splines are used for the edges, and the possible control points are determined by drawing the hierarchical trees along circular rings moving inward. Possible control points along the innermost ring (those points corresponding to level 0 names) may be thought of as being connected by an inner cycle. The control points for an edge between nodes i and j are chosen to be the points corresponding to a shortest path between i and j along the interior nodes of the circle.

Each parameter is time varying and interpreting such data imposes cognitive and perceptual load to physiologists. To address this issue, we further show variations through a perceptually unformed coloring space. A color space is said to be perceptually uniform if the perceptual difference between any two colors in just noticeable difference units is equal to the Euclidean distance between the two colors in that color space. Figure 1 shows the result of the parameter variances coloring mapped to the L*a*b color space at L=60 for a half-an-hour simulation of a normal person.

4 Results

The methods described above were applied to the graph obtained by constructing the set of nodes correspond to the set of global level names, where edges are determined by functional interactions. The results of this are demonstrated in Fig. 1. The first important aspect of that view was that it gave a clear local view of parameter interaction. This is accomplished in our graph by the following added feature. Each node in the surrounding forest of hierarchical trees can be selected. Upon selection, this highlights the adjacent nodes (and corresponding edges) for all descendants of the selected node. At the lowest level, this gives a local view of parameter interaction. Selecting a node at a higher level in the hierarchical tree gives a semi-local, semi-global view of parameter interaction. The second important aspect of the diagrammatic view of the model was that the overall structure of the model could be viewed at a glance. Node reordering gave a measurable improvement on the edge clutter across the middle of the graph. Hierarchical edge bundling clearly differentiates among edges between parameters which share a common level x name, and edges edges between parameters that do not. However, the effectiveness of this bundling is somewhat limited by the fact that even the reduced graph corresponding to the level 0 names is still a large graph.

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