

Dynamic Simulation and Comparative Analysis of Cardiac Flow Using Hexa Graph Computational Structures

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Abstract: This paper introduces Right and Left Hexa Graph Topologies as structured models for representing human heart blood circulation. The heart is abstracted as a directed graph, where vertices denote key anatomical components and edges represent the directional flow of blood. The Right Hexa Graph models deoxygenated blood flow from the body to the lungs, while the Left Hexa Graph models oxygenated blood flow from the lungs to the body. Lower, upper, and boundary hexa subgraphs are constructed for each pathway, providing a systematic framework to visualize and analyze circulatory connectivity and flow within the human heart.

Keywords: Hexa graph through lungs to body, Hexa graph through body to lungs

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1. Introduction and preliminaries

The human cardiovascular system is a complex and highly organized network responsible for the continuous circulation of blood throughout the body. Accurate modeling of heart blood circulation is essential for understanding physiological processes, analyzing cardiac function, and supporting applications in biomedical engineering and computational biology. Traditional anatomical descriptions, while detailed, often lack the structural abstraction needed for mathematical and topological analysis. Graph theory provides a powerful framework for modeling biological systems by representing components as vertices and their interactions as edges. In this paper, the human heart's blood circulation is modeled using directed graph structures, with an emphasis on hexa graph topologies.

Two distinct models are introduced: the Right Hexa Graph Topology, representing the flow of deoxygenated blood from the body to the lungs, and the Left Hexa Graph Topology, representing the flow of oxygenated blood from the lungs to the body. By decomposing each circulation pathway into lower, upper, and boundary hexa subgraphs, the proposed approach captures essential physiological pathways while maintaining mathematical simplicity. These models offer a structured and systematic way to visualize, analyze, and study the connectivity and directional flow within the human heart.

Definition 1.1. Let G be an undirected graph with at least 3 edges and let $J_h(s)$, $h = 1, 2, 3, 4, 5, 6$ denotes six graph decomposition of G . Consider six subgraph $S_1, S_2, S_3, S_4,$

Dynamic Simulation and Comparative Analysis of Cardiac Flow Using Hexa Graph Computational Structures

S_5, S_6 are subsets of the edge set $E(G)$ where each $S_i \subseteq E(G)$ for $i = 1, 2, 3, 4, 5, 6$ and $\zeta_H(S_i) = \{G, \phi, H^-(S_i), H^+(S_i), B_H(S_i)\}$. Then a pair $\zeta_H(S_i)$ is known as Hexa graph topology on G with respect to the subgraph S_i of G provided that $\zeta_H(S_i)$ satisfies the following axioms

- (1) $G, V_o \in \zeta_H(S_i)$, where $G =$ full graph, $V_o =$ Null graph
- (2) Any union of elements of $\zeta_H(S_i)$ is in $\zeta_H(S_i)$
- (3) The finite intersection of the elements of $\zeta_H(S_i)$ is in $\zeta_H(S_i)$.

We call the pair $(G, \zeta_H(S_i))$ as the Hexa graph topological space on G . The elements of Hexa graph topological spaces are regard as Hexa open subgraph of G and the complement is the Hexa open subgraph of G induced by the edge set is called Hexa closed subgraph of G . A subgraph which is Hexa open and Hexa closed is called Hexa clopen subgraph.

Summary of Blood Flow Through the Heart.

- (1) Deoxygenated blood from the body enters the heart through the superior and inferior vena cavae and flows into the right atrium.
- (2) Contraction of the right atrium propels the blood through the tricuspid valve into the right ventricle.
- (3) The right ventricle contracts and pumps the blood through the pulmonary valve into the pulmonary arteries, which carry it to the lungs for oxygenation.
- (4) Oxygenated blood returns from the lungs to the left atrium via the pulmonary veins.
- (5) Contraction of the left atrium forces the blood through the mitral valve into the left ventricle.
- (6) The left ventricle contracts and ejects oxygenated blood through the aortic valve into the aorta, distributing it to the rest of the body.

The human heart acts as the body's central pump, analogous to a computer's Power Supply Unit (PSU) by supplying the vital "energy" (blood/oxygen) needed to keep all systems running. Both systems operate on a rhythm—a heartbeat versus a CPU clock—to maintain, regulate and move necessary resources. This coordinated sequence of contractions and valve operations ensures efficient circulation, supplying oxygen and nutrients to body tissues while facilitating the removal of metabolic waste products.

Diagram of Human Heart:



Representation of Hexa Graph Topology for Blood Circulation in Human Heart

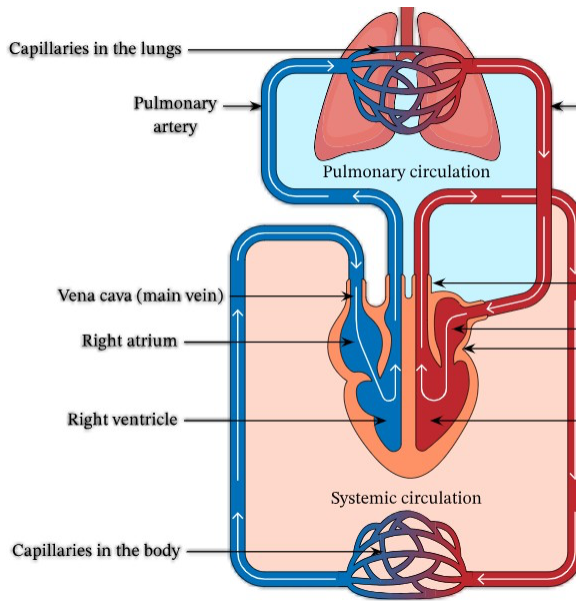
Let $G = (V, E)$ be a directed graph representing the human heart, where $V = \{v_1, v_2, v_3, v_4, v_5, v_6\}$ denotes the set of vertices corresponding to major anatomical components and E denotes the set of directed edges representing the flow of blood between these components. The vertices and edges abstract key structures involved in cardiac circulation, including the superior vena cava (SVC), inferior vena cava (IVC), right atrium (RA), tricuspid valve (TV), right ventricle (RV), pulmonary valve (PV), pulmonary arteries (PA), pulmonary veins (PV), left atrium (LA), mitral valve (MV), left ventricle (LV), aortic valve (AV) and aorta. The circulation is divided into two distinct pathways deoxygenated blood flow (right heart circulation) and oxygenated blood flow (left heart circulation). These pathways are represented using corresponding hexa graph topologies as summarized in Table 1

Deoxygenated Blood Flow	Oxygenated Blood Flow
Superior/Inferior Vena Cava	Pulmonary Veins
Right Atrium	Left Atrium
Tricuspid Valve	Mitral (Bicuspid) Valve
Right Ventricle	Left Ventricle
Pulmonary Arteries	Aortic Valve
Lungs	Aorta

This hexa graph representation provides a structured and topologically consistent framework for modeling blood circulation within the human heart. By abstracting anatomical components into vertices and directional blood flow into edges, the model enables

Dynamic Simulation and Comparative Analysis of Cardiac Flow Using Hexa Graph Computational Structures

systematic visualization and mathematical analysis of cardiac circulation dynamics. Working of Human Blood Circulation Heart:



Representation of Hexa Graph Topology from Lungs to Body

The circulation of oxygenated blood from the lungs to the body is modeled as a directed graph representing the left side of the human heart.

Graph Construction. Let $V = \{L, PV, LA, MV, LV, AV, B\}$ be the set of vertices, where L denotes lungs, PV pulmonary veins, LA left atrium, MV mitral valve, LV left ventricle, AV aortic valve, and B the body.

Directed Edges. The directed edges represent the direction of blood flow:

- (L, PV) — blood flows from the lungs to the pulmonary veins.
- (PV, LA) — blood flows from the pulmonary veins to the left atrium.
- (LA, MV) — blood flows from the left atrium through the mitral valve.
- (MV, LV) — blood flows from the mitral valve to the left ventricle.
- (LV, AV) — blood flows from the left ventricle through the aortic valve.
- (AV, B) — blood flows from the aortic valve to the body.

Thus, the blood circulation pathway is represented by the directed path $L \rightarrow PV \rightarrow LA \rightarrow MV \rightarrow LV \rightarrow AV \rightarrow B$.

Hexa Graph Topology. Let C be the set of edges

corresponding to blood circulation from the lungs to the body. The associated Hexa graph topology is defined as follows:

C	$J_h(C), h = 1, 2, 3, 4, 5, 6$	$H^-(C)$
$\{L, PV\}$	$\{\{L, PV, LA\}, \{MV, LV\}, \{AV, B\}\}$	ϕ
$\{PV, LA\}$	$\{\{L, LA, MV\}, \{PV, LV\}, \{AV, B\}\}$	ϕ
$\{LA, MV\}$	$\{\{L, LA\}, \{PV, MV\}, \{LV\}, \{AV, B\}\}$	ϕ
$\{MV, LV\}$	$\{\{L, MV\}, \{PV, LA\}, \{LV\}, \{AV, B\}\}$	$\{LV\}$
$\{LV, AV\}$	$\{\{L, PV, MV\}, \{LA, LV\}, \{AV, B\}\}$	ϕ
$\{AV, B\}$	$\{\{L, PV\}, \{LA, MV\}, \{LV\}, \{AV, B\}\}$	$\{AV, B\}$

The collection $H^-(C)$ is given by $\{\{L, PV, LA\}, \{L, LA, MV, PV, LV\}, \{L, LA, PV, MV\}, \{L, MV, LV\}, \{LA, LV, AV, B\}, \{AV, B\}\}$. Hence, the lower

hexa subgraph, upper hexa subgraph and boundary hexa subgraph are $H^-(N_i) =$

$\{LV, AV, B\}$, $H^-(N_i) = \phi$ and $B_h(N_i) = \{LV, AV, B\}$.

Therefore, $\zeta_H(N_i) = \{G, \emptyset, \{LV, AV, B\}\}$ defines a Hexa graph topology on G for blood circulation from the lungs to the body.

Representation of Hexa Graph Topology from Body to Lungs

The circulation of deoxygenated blood from the body to the lungs is modeled as a directed graph representing the right side of the heart. Let $V = \{B, IV, RA, TV, RV, PA, L\}$ be the set of vertices, where IV denotes the superior and inferior vena cava, RA the right atrium, TV the tricuspid valve, RV the right ventricle, PA the pulmonary arteries, and L the lungs. The blood flow is represented by the directed path $B \rightarrow IV \rightarrow RA \rightarrow TV \rightarrow RV \rightarrow PA \rightarrow L$. Let C be the set of edges corresponding to blood circulation from the body to the lungs.

C	$J_h(C), h = 1, 2, 3, 4, 5, 6$	$H^-(C)$
$\{B, IV\}$	$\{\{B, IV, RA\}, \{TV, RV\}, \{PA, L\}\}$	ϕ
$\{IV, RA\}$	$\{\{B, RA, TV\}, \{IV, RV\}, \{PA, L\}\}$	ϕ
$\{RA, TV\}$	$\{\{B, RA\}, \{IV, TV\}, \{RV\}, \{PA, L\}\}$	ϕ

$\{TV, RV\}$ $\{PA, L\}$	$\{B, TV\}$, $\{IV, RA\}$, $\{RV\}$	$\{RV\}$	$\{RV\}$
$\{RV, PA\}$	$\{B, IV, TV\}$, $\{RA, RV\}$, $\{PA, \phi\}$	ϕ	ϕ
$\{PA, L\}$	$\{B, IV\}$, $\{RA, TV\}$, $\{RV\}$, $\{PA, L\}$	$\{PA, L\}$	$\{PA, L\}$

The collection $H(C)$ is $\{\{B, IV, RA\}, \{B, RA, TV, IV, RV\}, \{B, RA, IV, TV\}, \{B, TV, RV\}, \{RA, RV, PA, L\}, \{PA, L\}\}$. Thus, the lower hexa subgraph, upper hexa subgraph and boundary hexa subgraph are $H_-(N_i) = \{RV, PA, L\}$, $H_+(N_i) = \phi$, and $B_H(N_i) = \{RV, PA, L\}$. Hence, $\zeta_H(N_i) = \{G, \emptyset, \{RV, PA, L\}\}$

is a Hexa graph topology on G for blood circulation from the body to the lungs.

Conclusion: The study successfully demonstrates that human blood circulation through the heart can be effectively modeled using hexa graph topology. By defining vertices and edges corresponding to physiological structures and blood flow paths, both the lungs-to-body (oxygenated blood) and body-to-lungs (de-oxygenated blood) circulations are represented through structured hexa graphs. The identification of lower hexa subgraphs, upper hexa subgraphs, and boundary hexa subgraphs further refines the understanding of critical junctures in blood movement. This topological representation not only aids in the mathematical modeling of biological systems but also offers a promising approach for future applications in medical diagnostics, simulation studies, and educational tools.

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