Cardiovascular Interactions Tutorial: An Update

John M. Gersting, Ph.D.

Department of Computer and Information Science Indiana University – Purdue University at Indianapolis Indianapolis, IN 46202

A. P. (Pete) Shepherd, Ph.D.

University of Texas Health Science Center San Antonio, TX 78229

Tony Ma, MD, Ph.D.

Baylor College of Medicine Houston, TX 77030

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ABSTRACT:

The Cardiovascular Interaction (CVI) simulation model was developed by Carl Rothe (1929-2016) as an interactive computer simulation in the form of a tutorial. The original tutorial was based on a five-compartment model (Venous Bed, Right Heart, Lung Bed, Left Heart, and Arterial Bed). This work examines the simulation Dr. Rothe developed based on a six-compartment model (Systemic Veins, Right Ventricle, Pulmonary Arteries, Pulmonary Veins, Left Ventricle, and Systemic Arteries). Both models were originally developed in Visual Basic. Both models have been reimplemented in C# WPF for Windows and in LabVIEW for Windows 10 and Mac OS X.

INTRODUCTION:

The goal of the CVI (Cardiovascular Interaction) project was to develop a computerized tutorial to allow learners (users) to investigate the integration and control of the cardiovascular system. Recent publications in *Advances in Physiology Education* are concluding that new methods for teaching physiology are more effective than old ones if they get students actively involved [1]. Rothe's models and the Lab Book can be used either for classroom discussions or for self instruction. Both ways of using his models can get students actively involved. This goal has not changed; however, it was necessary to update the implementation to continue to attain this goal.

The original five-compartment model, discussed in references [2] and [3], was a two-part implementation consisting of a Lab Book in the form of a tutorial as a Microsoft Word document that drives the cardiovascular simulation model. The six-compartment model had a similar structure. Both models were implemented in Visual Basic. Due to changes in the Windows operating system, the interactive tutorial is no longer functional. The models, however, are fully functional and can stand alone.

A recent effort was undertaken to reimplement the cardiovascular simulation models so they can be run on the current operating systems. (The Lab Book can still be followed, and the learner still gets the benefit of that process.) While updating the implementation of the models, it was discovered that information on the six-compartment model had never appeared in the literature. The focus of what follows is the six-compartment model.

The computational results for both the five and six compartment models for the three implementations (C# Windows Presentation Foundation, and LabVIEW for both Windows and Mac OS X) have been validated against the original Visual Basic implementations.

SIX-COMPARTMENT MODEL:

The Six-Compartment model has additional features not included in the five-compartment model discussed in references [2] and [3]. Additional detail involving modeling the systemic and pulmonary circulations has been added.

Using the same experiment from the Lab Book cited in [2] involving left ventricular failure, the experiment involves reducing E_{max} to 14% of normal for the left ventricle. Emax is the ventricular contractility. The following results were produced by the three different implementations: Rothe's original Visual Basic implementation, recoded C# version, and the new LabVIEW implementation.

Cardiovascular Model					
Time (min) =	1.001 Pressure	Click Flow	<mark>on yellow</mark> Volume	cell to cha Compliance	nge parameter. :e. Besistance
Segment	(mmHg)	(ml/min)	Vstress (i	ml) (% Control) (% Control)
Systemic Artery	64.	3 377	<mark>0.</mark> 129	9. <mark>100.0</mark>	100.0
Systemic Vein	4.	7 377	0. 480	6. <mark>100.0</mark>	100.0
Rght Vent,End Di	as O.	9 377	0. 10	3. <u>100.(</u>)
Pulmonary Artery	y 17.	9 377	0. 24	1. <u>100.0</u>	0 100.0
Pulmonary Vein	14.	2 377	0. 25	4 . 100.0	0 100.0
Left Vent,End Dia	as 13.	2 377	0. 18	7. 83.5	
Blood Pressure	e = 82	2 / 56			
S V	troke olume	EDV I	ESV Eje frac	ction Ema tion	<mark>× Heart</mark> Rate K2
Right Ventricle	52.4	102.7	50.4 0).51 100	0 72.0 1.0
Left Ventricle	52.4	187.2	134.8 0	.28 14	.0 72.0 1.0
				Left V	/o <u>4.3</u>
		Left EDV	/ > 175 ml	Blood Ve	olume (ml)
V stressed =	1400.	V uns	tressed =	3600. To	tal = <mark>5000.</mark>
Pra = 0.89 Pla = 13.23 P intrathor = -4.0					
		Model Erro	r(mi) U.U.		59
Restart Show	Piot S ata L	ayout	Show % Normal	Hun Mode	To Main Menu
Options =					
Original Parameter Set					
Lab Book File					

Figure 1: Rothe's Visual Basic implementation - Model display during left ventricular failure (E_{max} 14% of normal for the left ventricle);

Model - Rothe's Cardiovascular Interactions Model								
Time(min) 1.101 Double-Click on yellow cell to change parameter								
	al.	Pressure	Flow	Volume	Complia	nce Resi	stance	
Segme	nt	(mmHg)	(ml/min)	Vstress(ml)	(%Cont	trol) (%Co	ntrol)	
Systemic Arte	ery	64.3	3770	129	100.0	100.0	0	
Systemic Veir	۱	4.7	3770	486	100.0	100.0	D	
Rght Vent, Er	d Dias	0.9	3770	103	100.0			
Pulmonary A	rtery	17.9	3770	241	100.0	100.0	D C	
Pulmonary V	ein	14.2	3770	254	100.0	100.0	0	
Left Vent, En	d Dias	13.2	3770	187	83.5			
Blood F	ressure=	82 / 50	5					
	Stroke Volume	EDV	ESV	Ejection Fraction	Emax	Heart Rate Separate Heart Ra	K2 ates	
Right Ventricle	52.4	102.7	50.4	0.51	100.0	72.0	1.0	
Left Ventricle	52.4	187.2	134.8	0.28	14.0	72.0	1.0	
					Left Vol	4.3		
			eft EDV > 1/	75 ml Blood Volum	es (ml)			
V st	ressed =	1400	V unstresse	d = 3600		Total= 5000		
Pra =	0.89	Pla	= 13.23		P intrat	thor = -4.0		
Pmcf (calc) 8.48 Model Error (ml) -0.000000000091								
Restart Da	ow Plot of tat	Show N Layout	lodel	Print	Show % Normal	Run Model	Done	
Cardiovascular 6 Build 18								

Figure 2: C# implementation - Model display during left ventricular failure (E_{max} 14% of normal for the left ventricle);



Figure 3: LabVIEW implementation - Model display during left ventricular failure (E_{max} 14% of normal for the left ventricle)

The displays in Figures 1-3 allow the user to change one or more of the independent variables in the simulation (highlighted with a color background). Independent variables can be changed in sequence to carry out the more complex experiments posed in the Lab Book.

Each of the implementations also has a second display providing more detailed information about the cardiovascular system. Figure 4 is the model layout display from the C# implementation

Model Layout	Model Layout - Rothe's Cardiovascular Interactions Model — 🛛 🔿							
Right Vent	ricle	Pulmona	ry Veins L	.eft Ventricle	Systemic	Arteries	Left Ve	ntricle
Out Flow	3770			\sim	,		Out Flow	3770
EDP	0.9			$\Delta \square$			EDP	13.2
P ra	0.89		Lung	\checkmark	Body	THE I	P la	13.23
Heart Rate	72.0		Capillaries	\sim	Capillaries		Heart Rate	72.0
RV K2	1.000			$\rightarrow \leftarrow$	(\bigcirc	LV K2	1.000
EDV	102.7	Pulmona	ry Arteries	ic Veins	EDV	187.2		
ESV	50.4							134.8
sv	52.4		Blood Press		SV	52.4		
Eject f	0.51		bioou riess	uie- <u>-</u> ,			Eject f	0.28
EMax	0.38	S	yst Artery	Syst Vein	Pulm Art	Pulm Vein	EMax	0.49
Vo	3.0	Out Flow	3770	3770	3770	3770	Vo	4.3
Pstress = El	DP - Pit	Pressure	64.3	4.7	17.9	14.2		
Vstress	102.7	Vstressed	128.6	486.0	241.2	254.2	Vstress	187.2
Vunstrs	5.0	Vunstress	553.0	2905.1	60.0	72.0	Vunstrs	5.0
V total	107.7	V total	681.6	3391.1	301.2	326.2	V total	192.2
Compliance	21.00	Compliance	2.00	104.00	11.00	14.00	Compliance	10.86
Resist Out	zero	Resistance	0.01582	0.00100	0.00100	0.00024	Resist Out	zero
Variable		Total Stress V	1399.9	Pmcf	8.4	8	Time	1.101
Computed	То	tal Unstressed	3600.1	Pit	- 4.	0		
Parameter	rameter Total Blood Volume 5000.0 C pericardium 2.0							
Changed Paran	1					Print Law	out	Return
Fixed Paramete	e r Car	diovascular 6 Build 18						Netulii

Figure 4: Model Layout display from the C# implementation.

The C# implementation also includes the plot option from the Visual Basic version (Figure 5).

Plot Data - Rothe's Cardiovascular Interactions Model							
	Blood Pressure	Cardiac Output	Venous Return				
				^			
^0	Time ->	^1 minute	^2 Print	Hide			
Cardiovas	cular 6 Build 18						

Figure 5: Plot from the C# implementation.

FINAL THOUGHTS:

The updated versions of Carl Rothe's Cardiovascular Simulation mode have been validated against the original Visual Basic versions of the code. The updated versions will all run on current versions of the Windows operating system and there is a LabVIEW version that will run on Mac computers under OS X.

The updated versions can run the experiments suggested in the Lab Book mentioned in [2] without the integrated interface.

The updated code and the original Visual Basic versions are available at the Life Sciences Teaching Resource Community (LifeSciTRC) digital library:

http://www.lifescitrc.org/resource.cfm?submissionID=10473

REFERENCES

- 1. Luchi, K., Montrezor, L. and Marcondes, F., Effect of an educational game on university students' learning about action potentials, *Advances in Physiology Education*, 41: 222-230, 2017.
- 2. Gersting, J. M and Rothe, C. F., Cardiovascular Interactions Tutorial: Architecture and Design, *Journal of Medical Systems*, 26: 29-38, 2002.
- 3. Rothe, C. F. and Gersting, J. M., Cardiovascular Interactions: An interactive tutorial and mathematical model, *Advances in Physiology Education*, 26: 98-109, 2002.