CIS 4410 & 5410: Embedded Software for Life-Critical Applications

Smart Pacemaker-Challenge Project

Milestone 1: Modeling and Verification of Pacemaker

Due: 11: 59 pm, Friday, 14 November 2025

This assignment is the course project Milestone 1. Make sure you have already formed groups of two and you are ready to work together.

In this milestone, you will use the Uppaal modeling tool (available from www.uppaal.org) to create the formal models of a pacemaker controller and a heart.

(a) **VVI mode.** The VVI mode is a simple function of the pacemaker controller. (Refer to Section 3.5 of the pacemaker specification [1].) A straightforward model consists of two timed automata: one is a RandomHeart, and the other is a Ventricle controller. The RandomHeart mimics any heart behaviors (e.g., beating just randomly in a given range.). A RandomHeart in VVI mode receives only pacing signals to the ventricle and sends signals to the controller when an (instantaneous) heartbeat occurs. The Ventricle controller monitors the heart by sensing the heart signal and responds by sending a pacing signal to the heart if the heart fails to beat by itself for a certain time duration. (For a detailed description of how the pacemaker controller works under VVI mode, refer to Table 6 of the specification [1] and then read related descriptions of each checked item – most of them are in Section 5.) Please create Uppaal models that capture the behavior of the random heart as well as the behavior of the controller. (For the project, “Rate Smoothing” is not required.)

(b) Simulate your models and make sure they work as expected.

(c) Specify properties that are necessary to establish the correctness of your design. Note that each item in Table 6 should either be a constraint applied to the model in the design step or be a property to be verified in the verification step. For each of them, please explain/justify briefly why the logical formula corresponds to the property listed in the specification. (Hint: To observe how the RandomHeart and the Ventricle controller interact and to check if some properties are satisfied, it is convenient to create another automaton which captures signals to/from the RandomHeart/Ventricle controller. The observer can be designed on an extend-by-need basis.)

(d) Verify the properties identified in Step (c). Ideally, they should all be true unless you intentionally create a property that must not be satisfied.

To submit your work, please write a short description of your design, compress it with the Uppaal models and query files you created, and submit it via Canvas.

References

[1] Boston Scientific. "Pacemaker System Specification." Boston Scientific (2007). https://sqrl.cas.mcmaster.ca/_SQRLDocuments/PACEMAKER.pdf

Appendix

Parameter	AAT	VVT	AOO	AAI	VOO	VVI	VDD	DOO	DDI	DDD	AOOR	AAIR	VOOR	VVIR	VDDR	DOOR	DDIR	DDDR
Lower Rate Limit	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Upper Rate Limit	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Maximum Sensor Rate											X	X	X	X	X	X	X	X
Fixed AV Delay							X	X	X	X					X	X	X	X
Dynamic AV Delay							X			X					X			X
Sensed AV Delay Offset										X								X
Atrial Amplitude	X		X	X				X	X	X	X	X				X	X	X
Ventricular Amplitude		X			X	X	X	X	X	X			X	X	X	X	X	X
Atrial Pulse Width	X		X	X				X	X	X	X	X				X	X	X
Ventricular Pulse Width		X			X	X	X	X	X	X			X	X	X	X	X	X
Atrial Sensitivity	X			X					X	X		X					X	X
Ventricular Sensitivity		X				X	X		X	X				X	X		X	X
VRP		X				X	X		X	X				X	X		X	X
ARP	X			X					X	X		X					X	X
PVARP	X			X					X	X		X					X	X
PVARP Extension							X			X					X			X
Hysteresis				X		X				X		X		X				X
Rate Smoothing				X		X	X			X		X		X	X			X
ATR Duration							X			X					X			X
ATR Fallback Mode							X			X					X			X
ATR Fallback Time							X			X					X			X
Activity Threshold											X	X	X	X	X	X	X	X
Reaction Time											X	X	X	X	X	X	X	X
Response Factor											X	X	X	X	X	X	X	X
Recovery Time											X	X	X	X	X	X	X	X

The Lower Rate Limit (LRL) decides the longest time duration between a V event and the next ventricular pace. This can decide the lower bound of the heart rate.

The Upper Rate Limit (URL) decides the shortest time duration between a V event and the next ventricular pace. This can decide the upper bound of the heart rate.

The Ventricular Refractory Period (VRP) shall be a programmed time value following a ventricular event during which time ventricular senses shall not inhibit nor trigger pacing.

Parameter	Upper Bound	Lower Bound
Rate Limit	40 bpm (LRL)	180 bpm (URL)
VRP	150 ms	

Submission. To submit your work, write a simple document describing the UPPAAL models and properties. Zip this document and your UPPAAL models and submit to Canvas.

Last updated on 11/07/2025.