# Modelling and Analyzing Electrocardiogram Events Using Timed Coloured Petri Nets*

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**Abstract** A formal model of generating realistic synthetic electrocardiogram (ECG) events is presented. Timed Coloured Petri Nets (TCPN) and CPN tools are adopted as modelling tools. The model, which includes various suitable parameters, covers numerous identified characteristics of cardiac rhythms in substantial detail. The model can assist not only in facilitating a better understanding of ECG events but also in providing customizable data to fully evaluate and optimize different ECG algorithms and techniques. The obtained results prove the reliability and validity of this model in producing various cardiac rhythms while demonstrating the expressive power and convenience of TCPN.

**Keywords:** Electrocardiography · Biomedical signals · Electrocardiogram · Timed Coloured Petri Nets · Biomodelling.

## 1 Introduction

The accuracy of new biomedical signal processing algorithms is commonly analyzed with available real databases.Nevertheless, in different clinical settings with a range of noise levels and sampling frequencies, assessing the overall performance and validity can be challenging. Further analysis with formal artificial ECG events may effectively and comprehensively improve the overall outcomes. The mathematical formal representation of ECG events must be inclusive and comprehensive to present a wide variety of rhythms, yet it must also be uncomplicated to facilitate the formulation of different algorithms. In this paper, a new methodology for constructing a graphical and mathematical model is described. The model precisely presents and produces a wide variety of time-based cardiac rhythms.

## 2 TCPN-based Modelling of ECG Events

For the sake of flexible structure and clear presentation, the proposed model is composed of six interconnected sub-models: the event-structure sub-model, the atrial-depolarization sub-model, the AV-node sub-model, the ventricular-depolarization sub-model, the ST-segment sub-model, and the ventricular repolarization sub-model. The functions and connection between these sub-models are described as follows: The event-structure model represents the common places or elements among other sub-models. It is part of almost all other sub-models that exchange data across it. In a healthy heart, the cardiac cycle begins with the firing of SA node (i.e. the natural pacemaker) followed by the depolarization of atrial musculature producing the recordable P-wave in the ECG. These activities are captured via the atrial-depolarization sub-model. When the atria depolarization ends, action potentials spread through the AV node resulting in the PR segment in ECG. PR segment is the flat line between the end of the P wave and the start of the QRS complex. This event is addressed by the AV-node sub-model. Then, the right and left ventricles start to depolarize and generate the recordable QRS complex, which is processed via the ventricular-depolarization sub-model. The time interval between the depolarization and repolarization of the ventricular, called ST segment in ECG, is addressed via the ST-segment sub-model. Eventually, the ventricular-repolarization sub-model, as the name suggests, presents the ventricular repolarization, which is last stage of the cardiac cycle.

## 3 Analysis Results

The model was analyzed through interactive and automatic simulations with different values of its parameters.Consequently, several errors were identified and resolved in the design. The simulations show that the model appears to correctly terminate in the desired consistent state in accordance with its parameters.

In addition, the model was analyzed by generating the occurrence graph and its corresponding Strongly Connected Component (SCC) graph. The numbers of nodes and arcs in the SCC graph are always identical to the corresponding numbers of the state space. As expected, this implies that the model has no cyclic behaviour. Also, as the model terminated intentionally when the desired limited value of generated heartbeat was reached, a single dead marking is reported which causes the model to have no live transition instances. In contrast, the model has no dead transition instances, which indicates that all of the specified actions were executed.

## 4 Conclusion

In this paper, a formal TCPN-based model generating real ECG events was proposed. Through various suitable parameters, this model covers numerous identified characteristics of cardiac rhythms. The model is composed of six sub-models which augment its legibility and adaptability. The analysis results of the model reflect its reliability and validity. The model can assist not only in facilitating better understanding of ECG events but also generating customizable data to fully evaluate and optimize different ECG algorithms and techniques.