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Bond graph modelling of the cardiac action potential

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Bond graphs are an energy-based framework for modelling physical systems while adhering to thermodynamic and physical constraints, and they have recently been extended and applied to biochemical and electrophysiological systems. Here we describe a bond graph model of the cardiac action potential and use it to explore the issue of drift in mathematical models of electrophysiology, which is a cause of inaccuracy. Previous studies have linked drift to stimulus currents that violate conservation laws, but those analyses were restricted to individual models and relied upon the manual identification of conservation laws. Due to their adherence to conservation principles, bond graphs are well-suited for studying conservation laws under a more general framework. Using our bond graph approach, we found that the conservation law derived in previous studies is an example of a 'conserved moiety' within the bond graph modelling and metabolic analysis frameworks. Conserved moieties explain the occurrence of drift for a general class of models, demonstrating that bond graphs can provide a systematic approach that can be used to identify hidden conservation laws and check for the presence of drift.

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