

Large-scale integrative modeling of the human heart

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Abstract

The contraction of the heart is triggered by an electrical impulse that propagates from one muscle cell to another. This organized activity generates a potential field that can be measured as an electrocardiogram (ECG) on the body surface, or with a catheter inside the heart. The measured signals provide a wealth of diagnostic information. This information has traditionally been decoded by clinicians in a strictly empirical way. As more and more becomes known about the underlying processes in the cell membrane, it becomes more common to hypothesize links between malfunctions on the cellular level and ECG abnormalities. Due to the startling complexity of the basic processes and the heart's anatomy, large-scale mathematical modeling can be necessary to verify such hypotheses. The dynamics of the heart are described by a coupled system of elliptic and parabolic differential equations. Spatial step sizes have to be as small as 0.1 mm in some cases. This leads to systems of hundreds of millions of linear equations when a whole human heart is modeled. The difficulty of solving such large systems has for some time limited the size of heart models to those of mice and rabbits, requiring only about a million equations. A breakthrough was obtained two years ago when we found a combination of algorithms that could solve a system of 60 million equations. Deployed on a newly arrived SGI Altix system, these methods allowed us to model an entire human heart. This heart model has since then provided important new insights in a wide range of cardiological subjects from myocardial ischemia to repolarisation measurement in the heart. The more recent arrival of a 768-processor Altix 4700 system has allowed us to test our methods on an even larger scale. With its 1.5 TB memory, this machine could handle a model with 2 billion equations. A short test showed convergence with an iteration count that was not much larger than for much smaller systems. Currently, we cannot obtain such resources for routine work. However, our test shows that it is only a matter of time before heart models with over a billion nodes can be used. We expect that this will have a great impact on the understanding of sudden cardiac death syndromes related to congenital cardiomyopathies degenerative diseases that cause fragmentation of the heart muscle on a sub-millimeter scale.