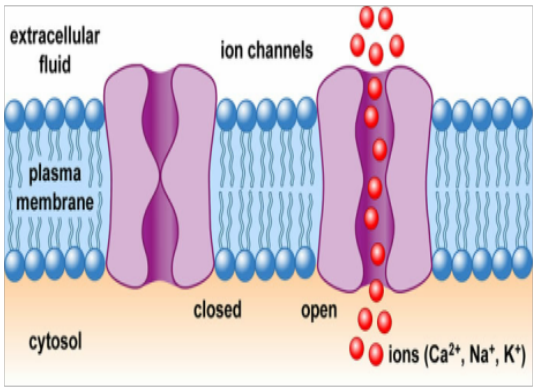
Ion channel mesh generation project

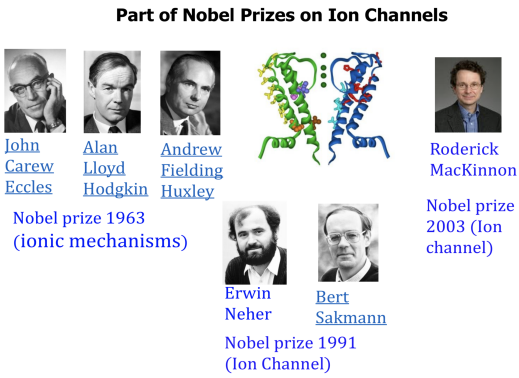
Zhen Chao
Department of Mathematics, University of Michigan

1 Motivation

We know that all living things are composed of cells, although cells have differences in structure and function, all of them have a cell membrane. As the outside of our skin separates our body from the environment, the biological cell membrane separates the contents of the cell from its exterior environment. It is the protective barrier that prevents unwanted material from passing in and has lots of functions, but one important function is to transport important materials into the cell to support necessary life functions. The cell membrane is made up of a double adjacent layer of lipids, which forms the basis of the cell membrane. There are many different proteins embedded within the membrane that have various functions and structures. One important type of these proteins is the pore-forming membrane protein, because these proteins are concerned with ion transport, they are referred to as ion channels, see Figure 2a.



(a) Ion channels are proteins with a hole down their middle, picture from Google.



(b) Nobel Prizes on Ion Channels

Figure 1: Ion Channels.

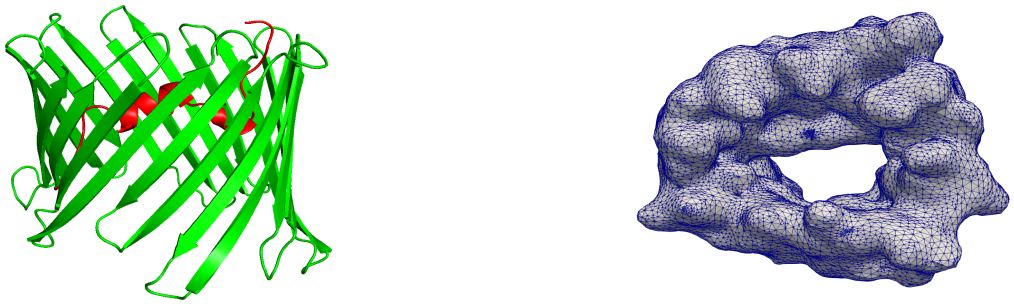
Ion channels play essential roles in the pathophysiology of various diseases. The study of ion channels has been for several decades and great progress has been made in understanding functions and structures of them, but there still exists lots of key open questions and basic issues. Over the past few decades, ion channel methodological progresses in X-ray crystallography and electron microscopy have led to tremendous progress in determining the structure of ion channels. This high resolution structural information can help us to better understand and capture some important functions. However, some microscopic activities that happen as ions pass through a channel – e.g., conformational changes in the protein, solvation/desolvation of ions along the journey – are

almost impossible to obtain by experimental approaches. It is also impossible to detect by X-ray crystallography if the electron density is too small. Fortunately, they can be obtained by computational or theoretical approaches, which can help address some of the shortcomings of experimental methods.

2 Method

To solve an ion channel model by the finite element method, we need an ion channel mesh generation package to generate an interface fitted unstructured tetrahedral mesh for a box simulation domain. Actually, how to construct a high quality mesh for the ion channel simulation is one of the important and challenge topic in this field due to the irregular shape of proteins, see Figure 2. Due to different boundary conditions need to be enforced on different parts of the boundary, and different equations are defined on different regions. To handle them, we need to mark all the triangles of a triangular mesh on the interfaces/boundaries and all the tetrahedra of a mesh of the box domain in different labels. The low quality mesh may significantly affect the accuracy of a finite element solution. Thus how to develop an efficient and robust mesh generation packages and tools is very important for ion channel simulations. Up to now, there is only one ion channel mesh generation is available in open domain, but does not work well for complicated ion channels.

Our mesh generation algorithm primarily includes five parts: 1) A protein surface mesh generation; 2) a surface mesh of the box domain generation; 3) the corresponding volume mesh generation; 4) the membrane region construction



(a) mVDAC1 ion channel (b) Surface mesh of mVDAC1

Figure 2: Ion Channels.

3 Goals

In this project, we will focus on the following topics:

(1) I have developed one package for on channel mesh generation but the efficient is not good, especially for large proteins, we need to improve the efficiency of it, this is main step of this project.

(2) How to improve the current protein surface mesh generation package, such as TMSmesh.

(3) If we have more time, we can compare our package with others, then apply our mesh to some ion channel model, such as Poisson-Nernst-Planck Equation.