Modeling techniques for geometrical models of muscle cells

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Outline

- Problem overview
- Model development
- Modeling language
- Results
- Future work

Motivation

- Progress in biological sciences asks for development of virtual biological models
- Modeling of micro-world structures is still a challenge
- No works in the area of muscle cell models

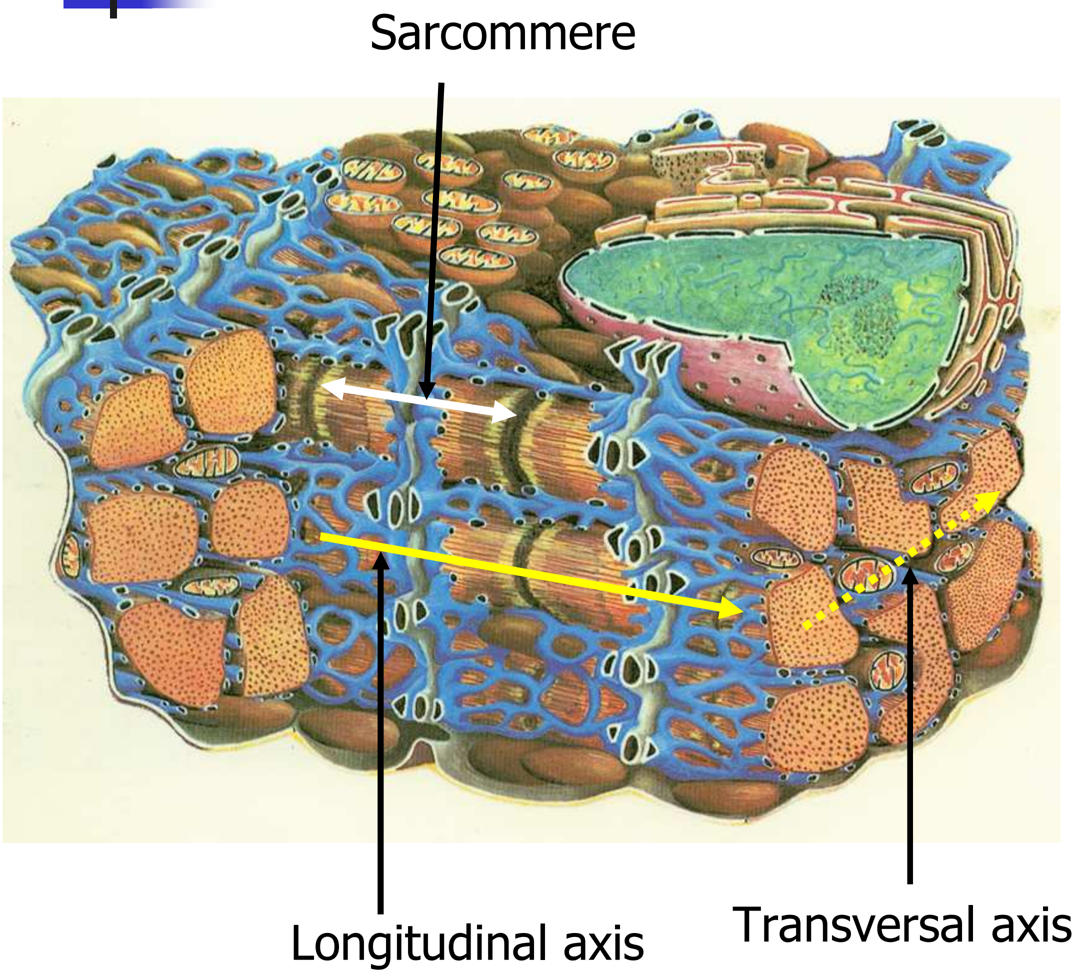
What is the aim?

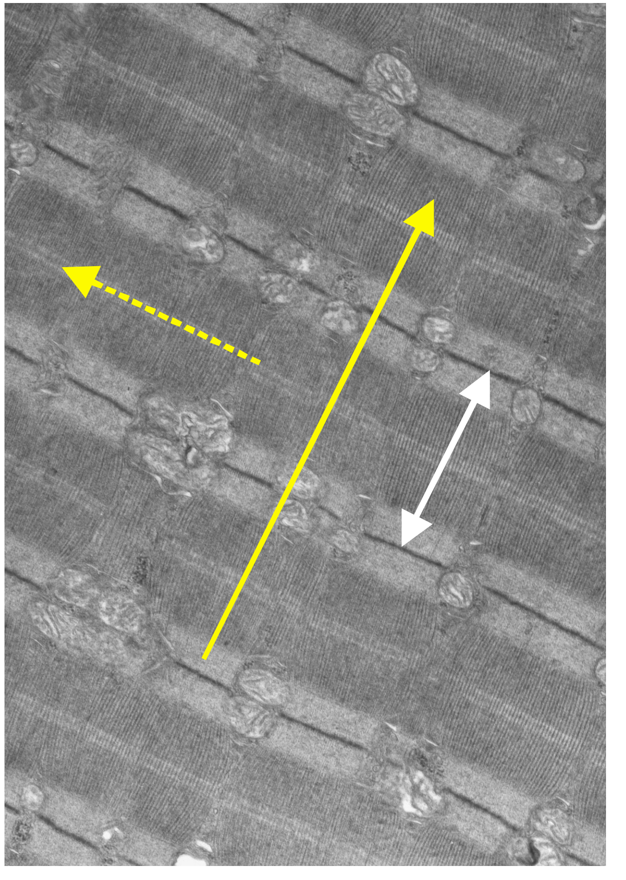
- Build modeling tools capable of creating arbitrary muscle cell geometrical models in an automatic way
- Resultant models should contains organelles according to morphological and stereological properties

What is the purpose?

- The study of the ultra-structure of muscle cell
- Testing hypothesis, e.g. stereology
- Presentations, teaching, …
- Virtual experiments

Cell axes and sarcommere





Modeling approach

- Based on implicit surfaces
  - Round shaped objects
  - Representation of an object interior
  - Detection of collision
  - Conversion to volumetric representation
  - Estimation of volume and surface areas

Implicit surfaces (implicits)

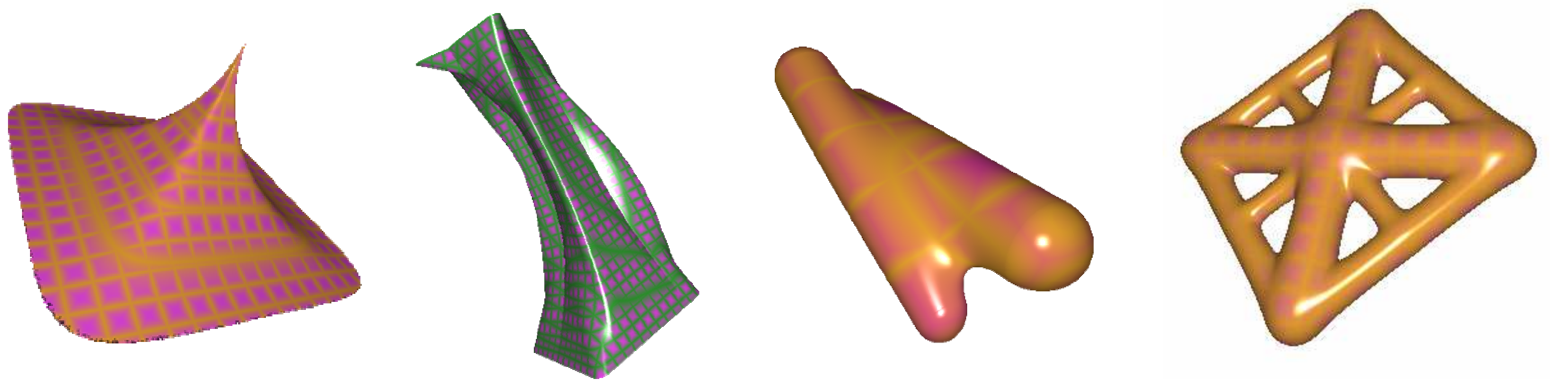
- An implicit surface is defined as a set of points that satisfies implicit function *f(**x**)=0*

$$f_1(\mathbf{x}) = 1 - (x^2 + (y+1.5)^2 + z^2)$$
$$f_2(\mathbf{x}) = 1 - (x^2 + (y-1.5)^2 + z^2)$$

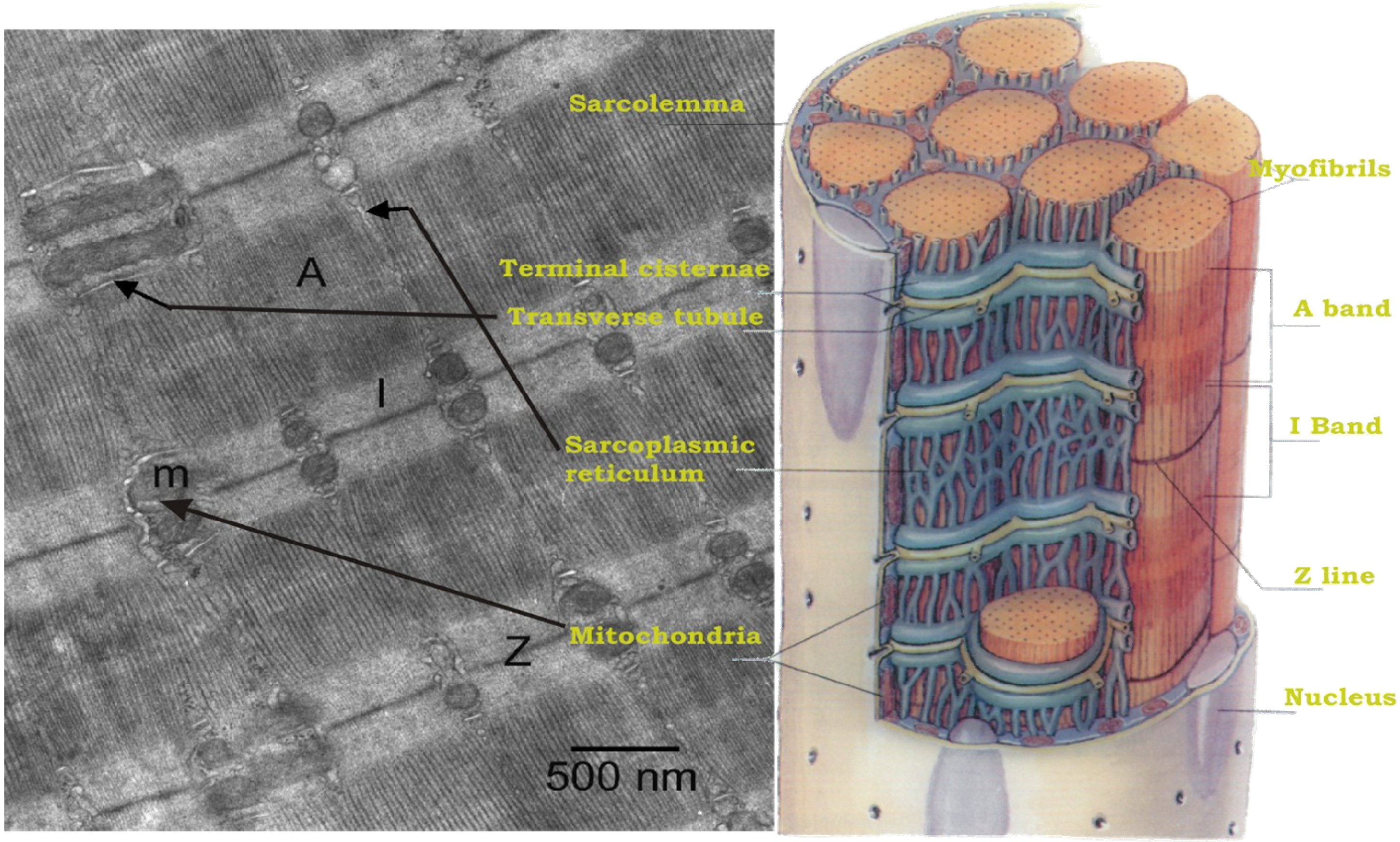
$$f_3(\mathbf{x}) = f_1(\mathbf{x}) + f_2(\mathbf{x}) + \sqrt{f_1(\mathbf{x})^2 + f_2(\mathbf{x})^2} + \frac{1.4}{1 + \left(\frac{f_1(\mathbf{x})}{0.3}\right)^2 + \left(\frac{f_2(\mathbf{x})}{0.3}\right)^2}$$

XISL – development tool for Implicits

- XISL components
  - XML based scripting language
  - Supporting software package
  - Provides various forms of implicits and operations on them

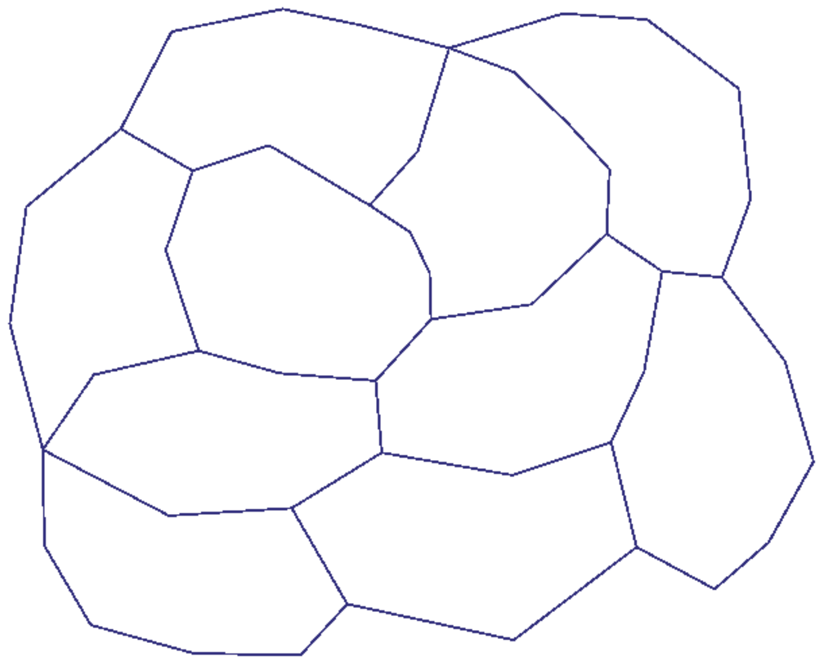


Muscle cell structure



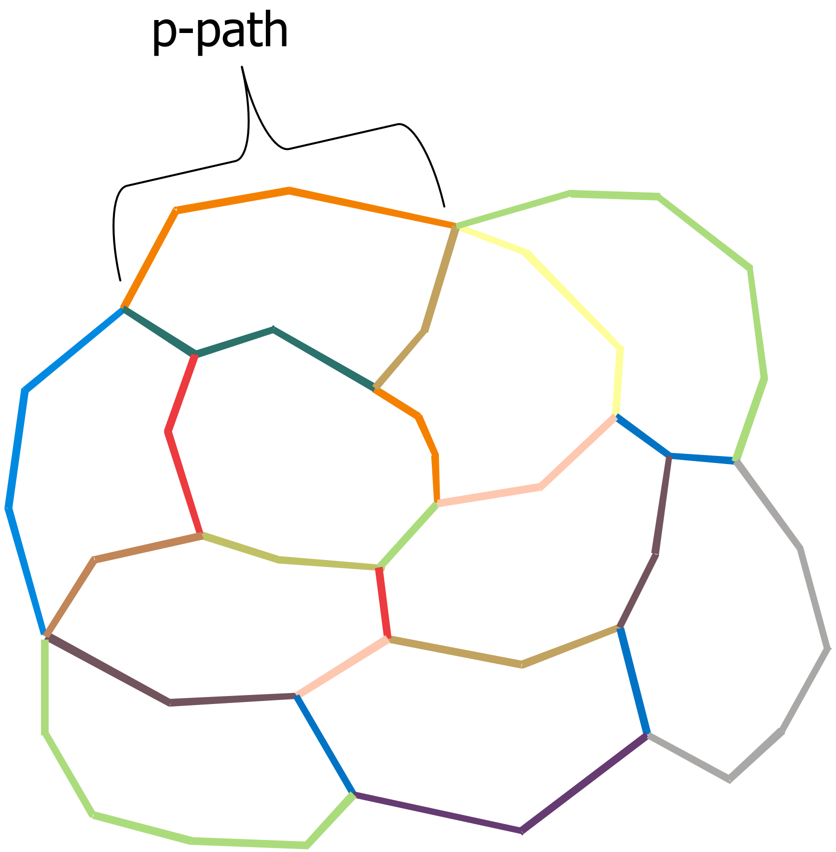
Modeling plane

- Produces underlying skeletons for all modeled organelles
- Represented as a continuous planar graph which divides the plane into a finite number of closed non-intersecting polygons.



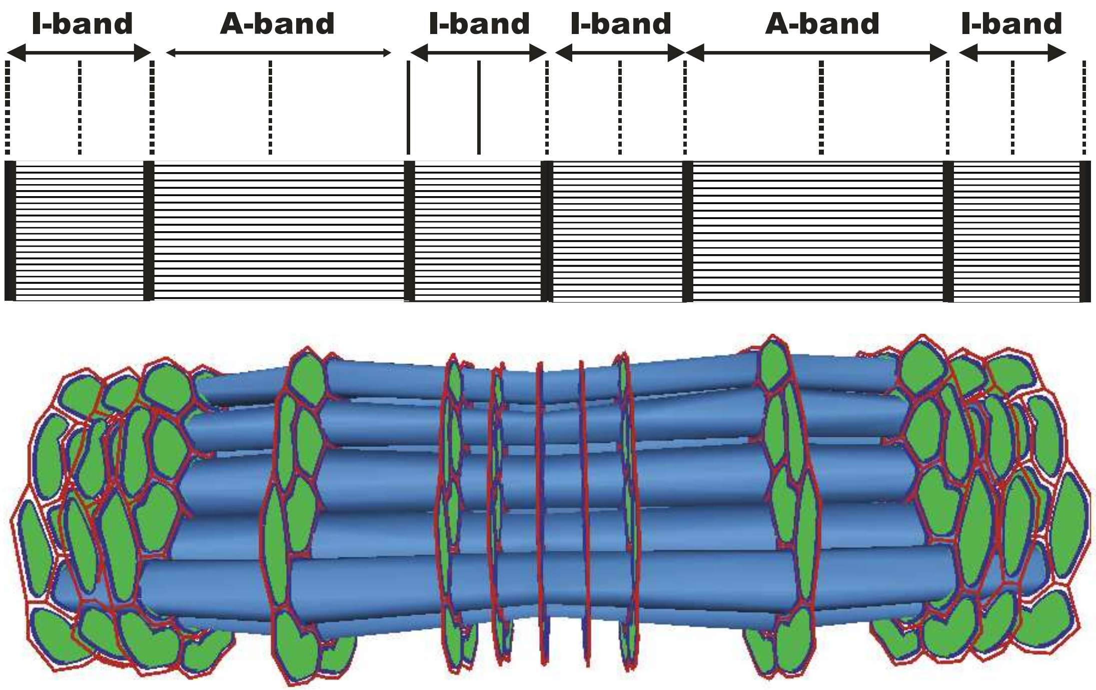
P-paths

- A continuous path, i.e. set of line segments, between the points of an modeling plane, which have more than two adjacent line segments



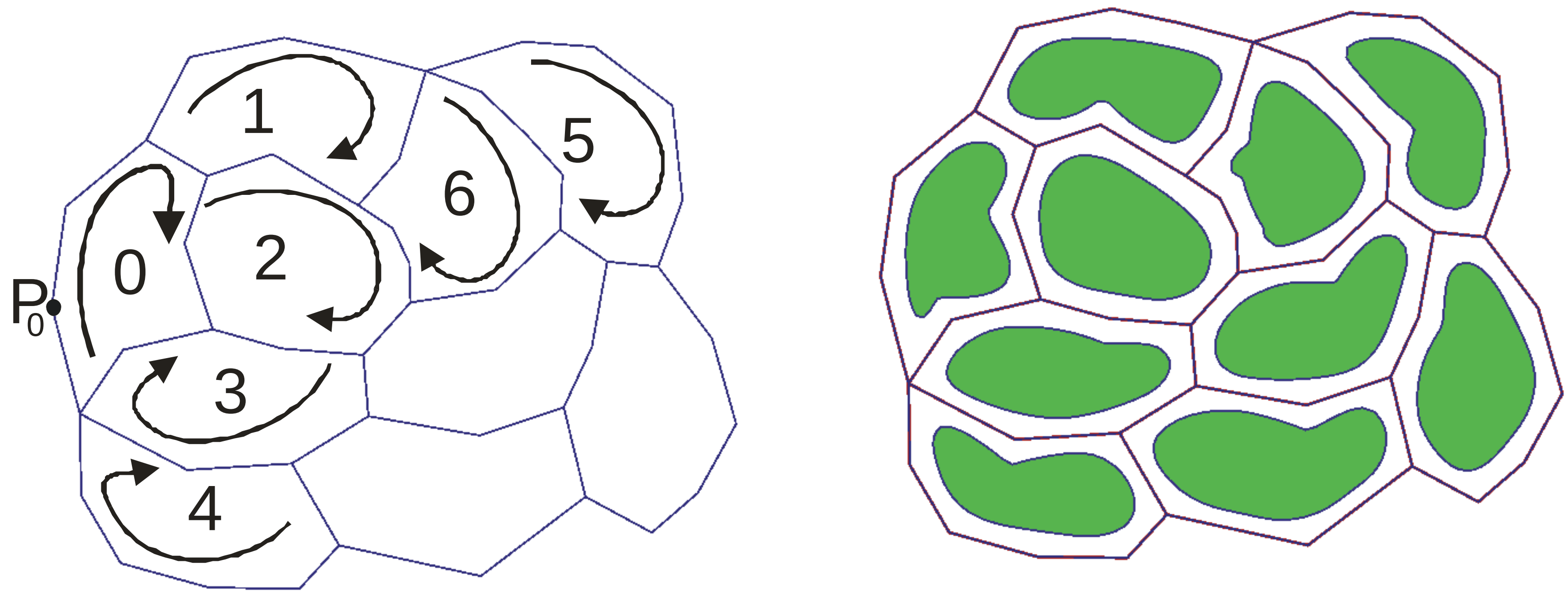
Myofibrils

- Defined as a set of cross-sections in a system of parallel modeling planes
  - 3D model is obtained by interpolation



Myofibrils

- 2D implicit shapes are obtained from polygons which are created by decomposition of modeling plane

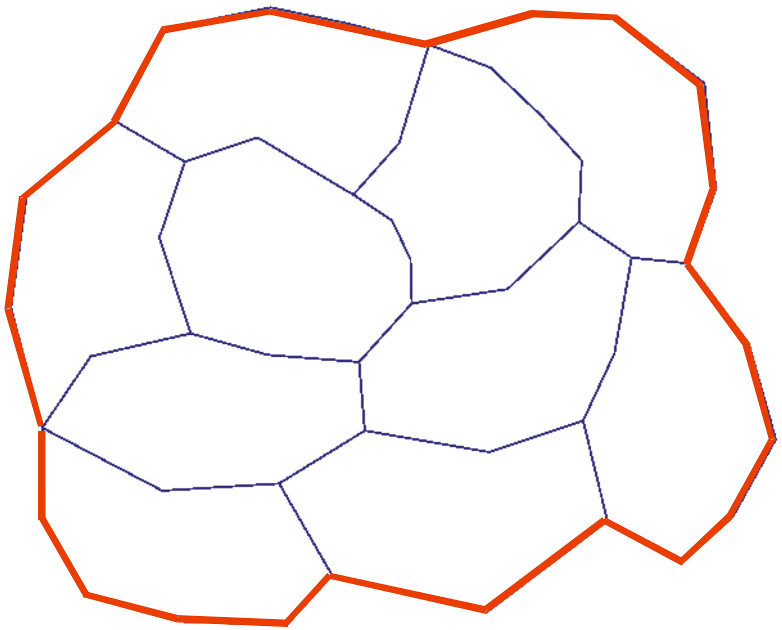


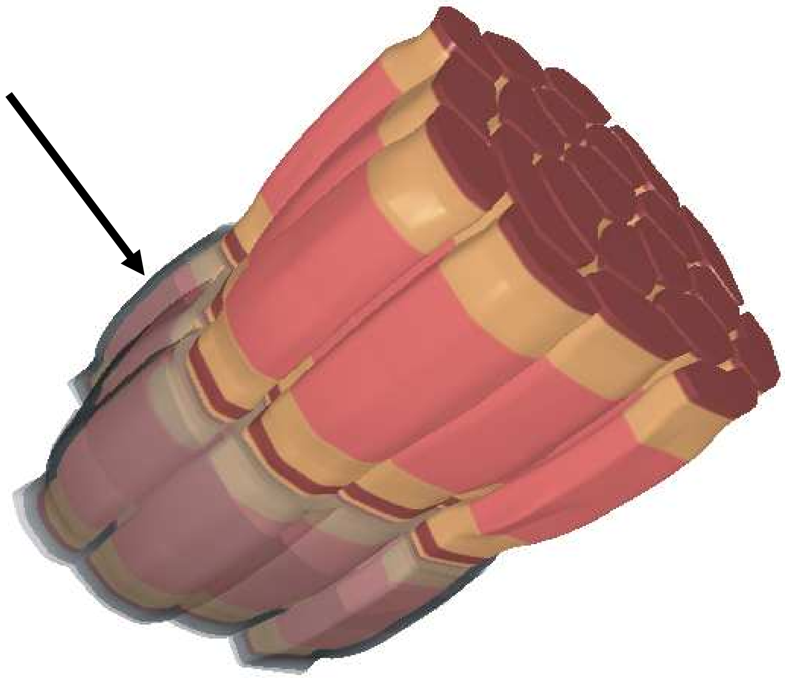
Sarcolemma

- Sarcolemma is a membrane envelope, tightly surrounding the muscle cell, that defines cell volume
  - Required for estimation of volume and surface densities

Sarcolemma

- Created similarly as myofibrils, but underlying polygons are created from outer edges of modeling planes



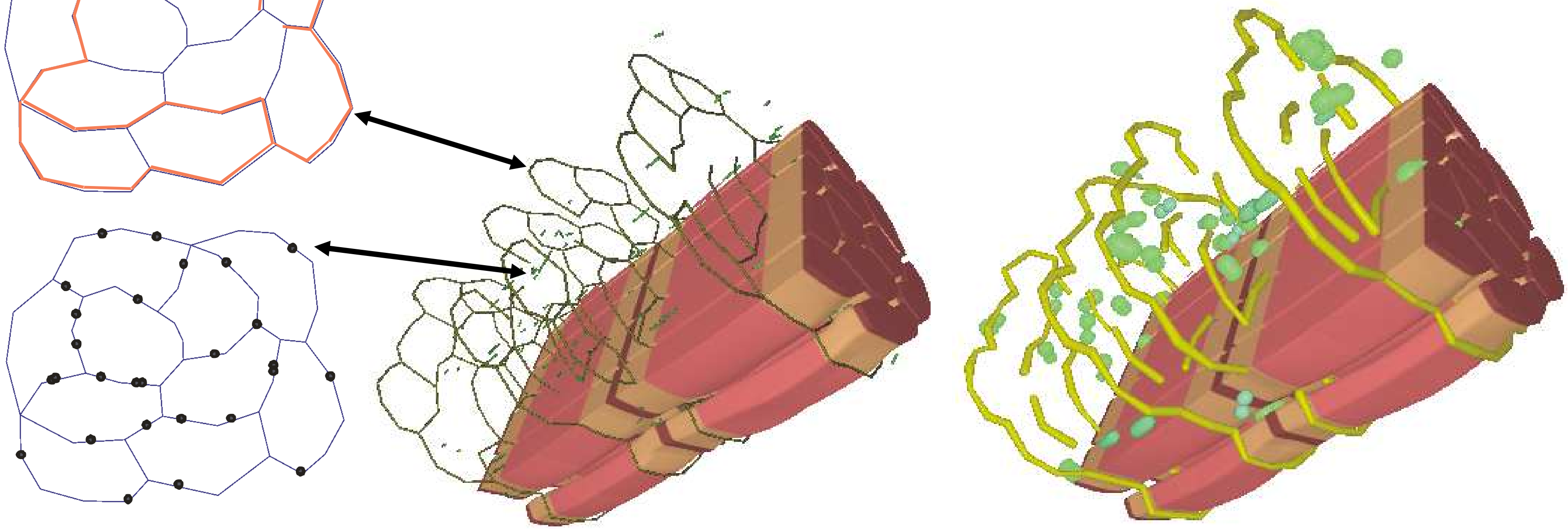


T-tubules and mitochondria

- The t-tubules form a planar network around and between myofibrils
  - They run at the interface of I-A bands
- Mitochondria are elliptically shaped organelles of irregular smooth form and variable size
  - They are frequently localized within I-bands,
  - Small amount is located within A-bands
  - Some are at the interface of Z-lines

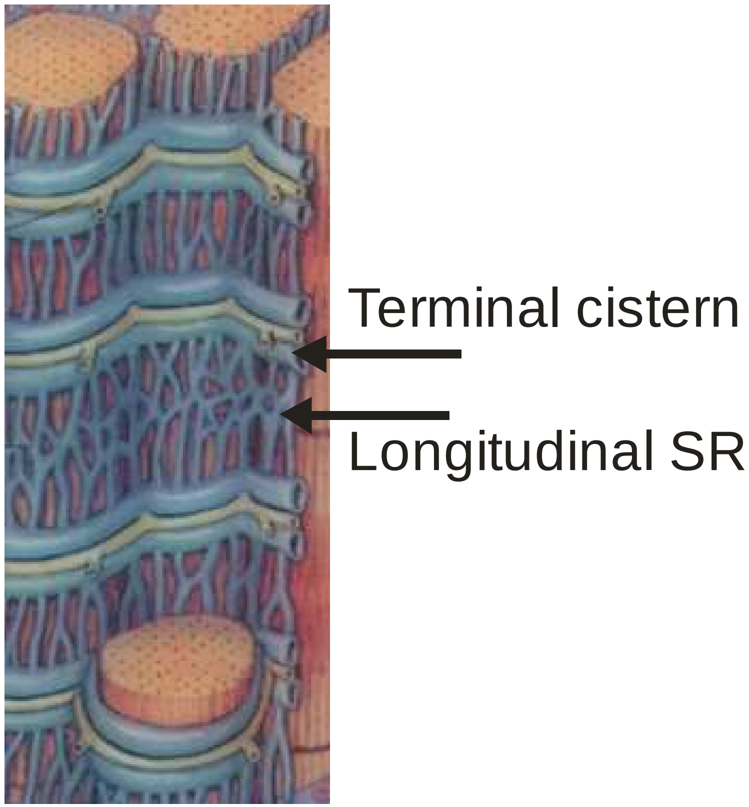
T-tubules and mitochondria

- Convolution of line segments acquired from p-paths



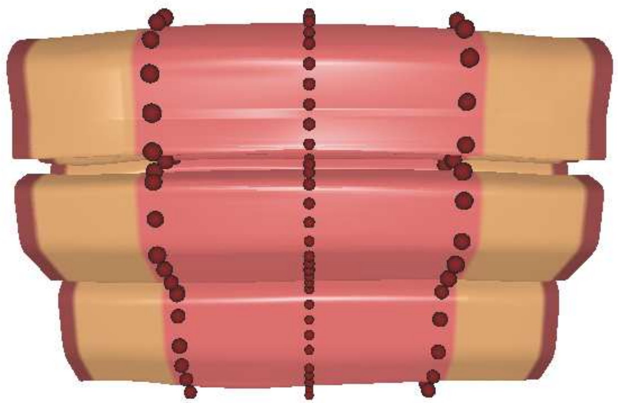
Sarcoplasmic reticulum (SR)

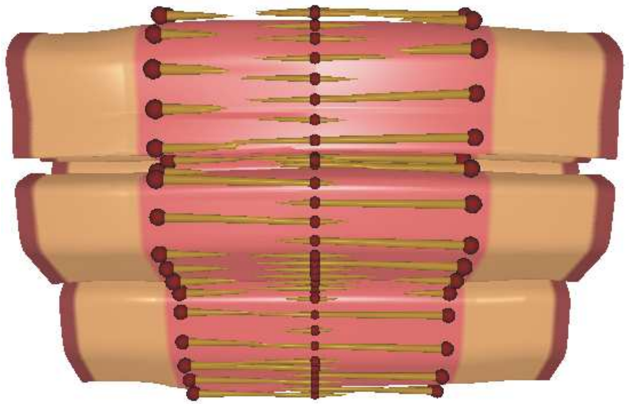
- Geometrically the most complex
- Consists of two compartments
  - The longitudinal SR (LSR)
  - Terminal cisterns of the SR (TSR)



Sarcoplasmic reticulum (LSR)

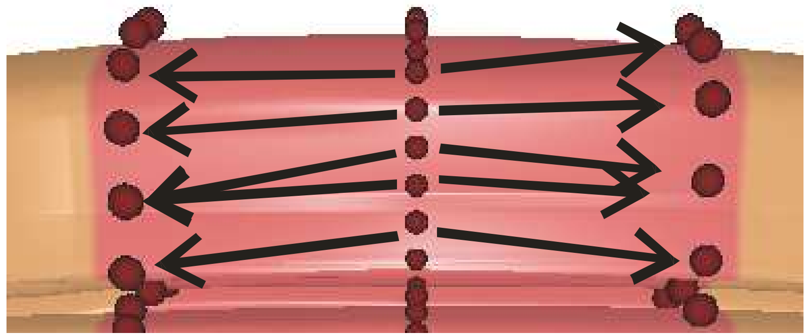
- Generated from points obtained from p-paths of modeling planes
- Each point produces a 2D implicit sphere
- Using classical interpolation techniques gaps can occured

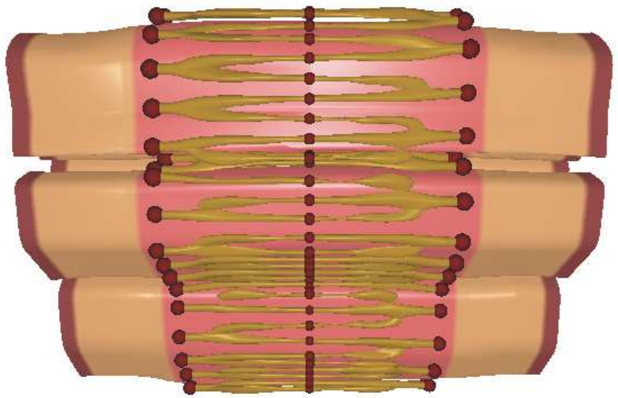




Sarcoplasmic reticulum (LSR)

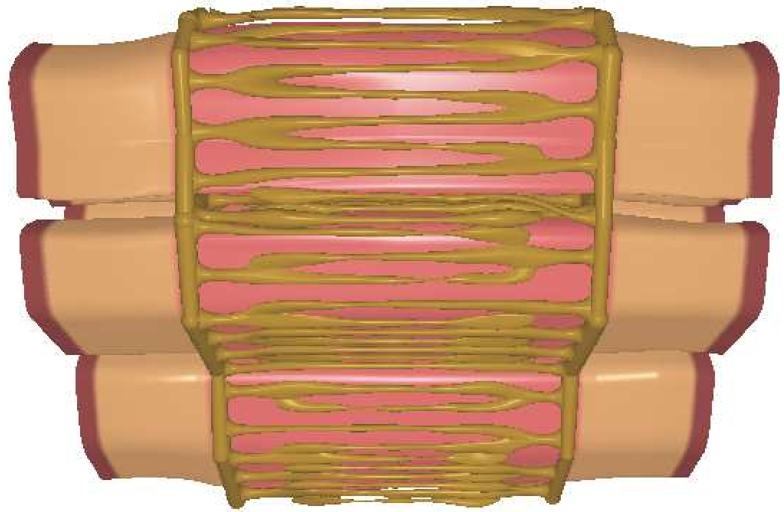
- To avoid gaps we use space warping method
  - Deform the space by defining the extra relationship between the points in the source and the destination object





Sarcoplasmic reticulum (TSR)

- Terminal cisterns are created as union of tubes obtained from p-paths skeletal lines where the points were generated
- The final SR model is achieved by the blend union of LSR and TSR



Muscle cell modeling language

- Textual language that is used to develop various muscle cell models
  - Is kept very simple according that end users are mainly biologist
  - Based on XML technology

Language overview

- Contains tags that specify the global modeling data
  - Size of a single sarcommere, numbers of sarcommers, the modeling plane, distribution of modeling planes, …

```
<muscleCell name="cell_name">
        <data length="2000"
              sarcNum="4"
              iBandPerc="0.35"
              aBandPerc="0.6"
              zLinePerc="0.05"/>

        <modelingPlane file="../mp/mp22/mp_22_4.txt"
                    aBandMod="30"
                    iBandMod="30"
                    zLineMod="30"
                    alterMin="5"
                    alterMax="10"
                    alterSize="30"
                    alterPos="25"
                    iBandScaleMin="1.95"
                    iBandScaleMax="2.02"
                    aBandScaleMin="2.07"
                    aBandScaleMax="2.14"/>
</muscleCell>
```

Language overview

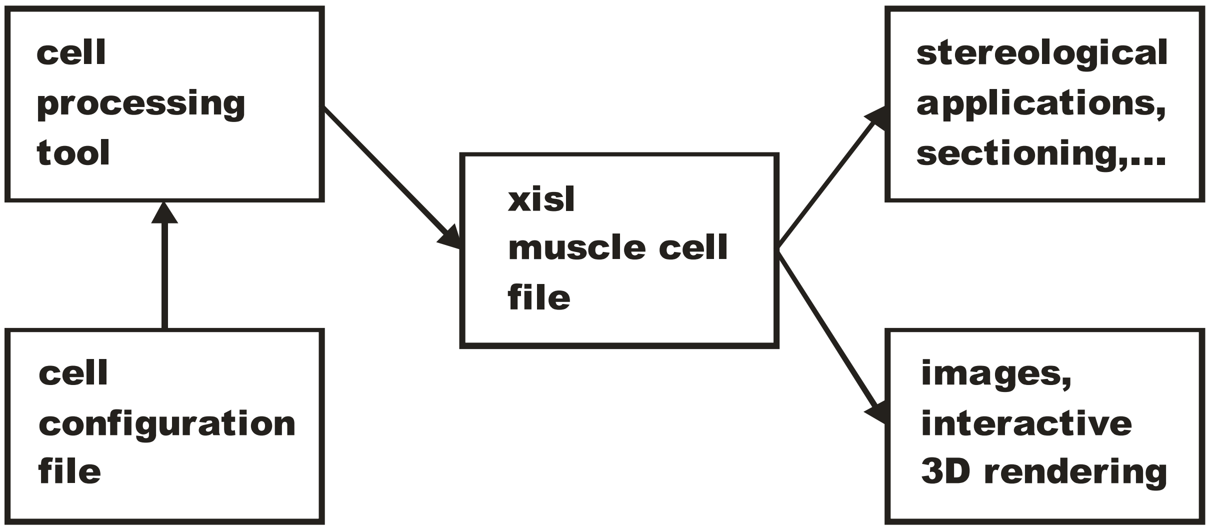
- Tags representing which type organelles will be added
  - Parameters specify the probability of occurance, sizes,….

```
<srI num="16"
     space="170"
     spaceEps="40"
     minSize="15"
     maxSize="17"
     blendSize="3"
     blendImpact="0"/>

<mitch_IBandTO prob="0.2"
               minLength="50"
               maxLength="70"
               minSize="30"
               maxSize="50"/>
```

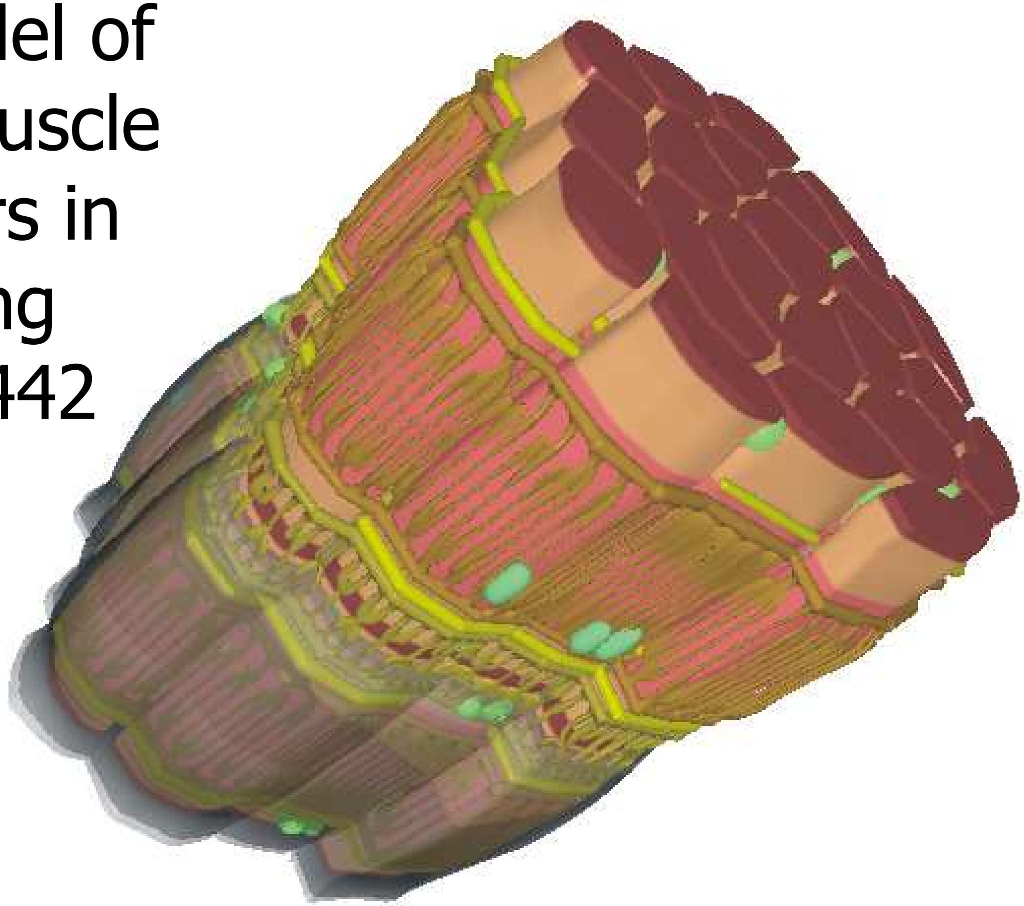
Global concept

- Cell configuration file contains various models that are sent to cell processing tool which produces all geometrical models of organelles in XISL language



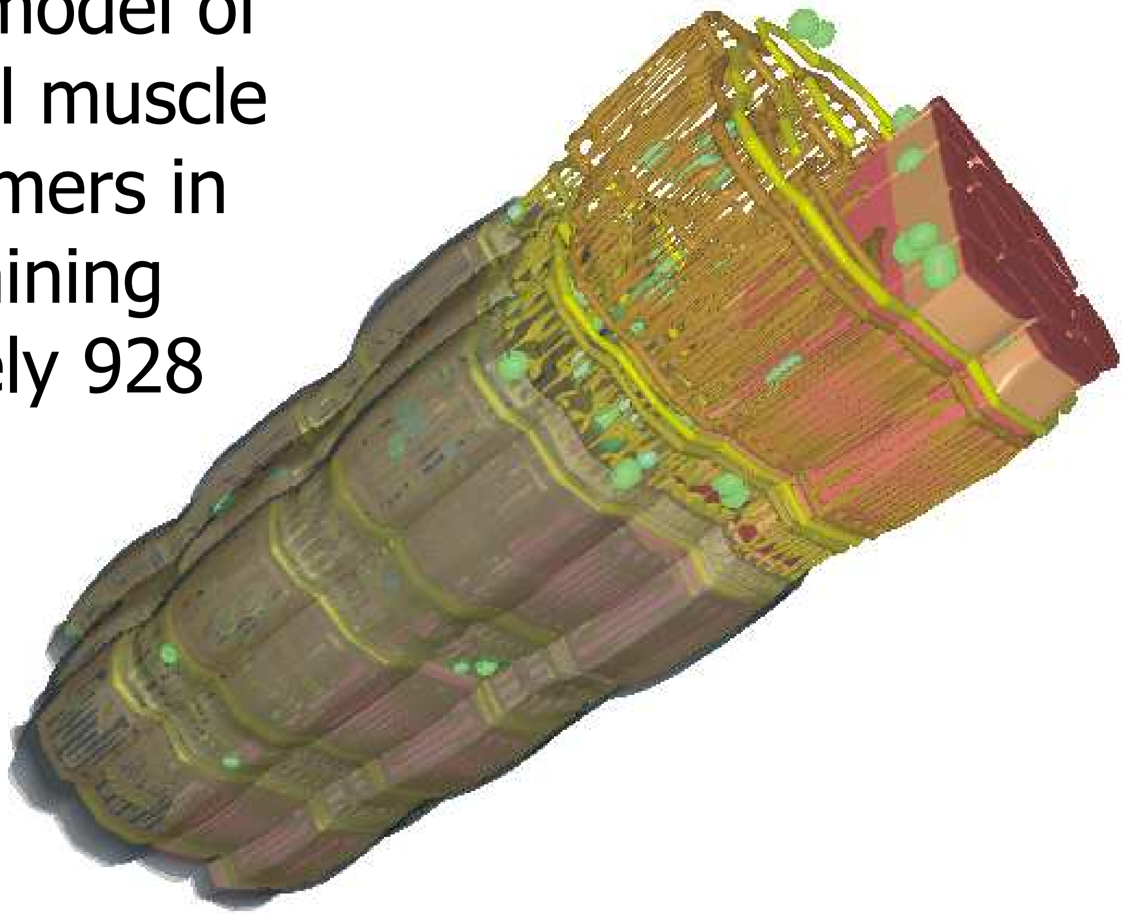
Results

- Muscle cell model of slow-skeletal muscle of 2 sarcommers in length containing approximately 442 objects



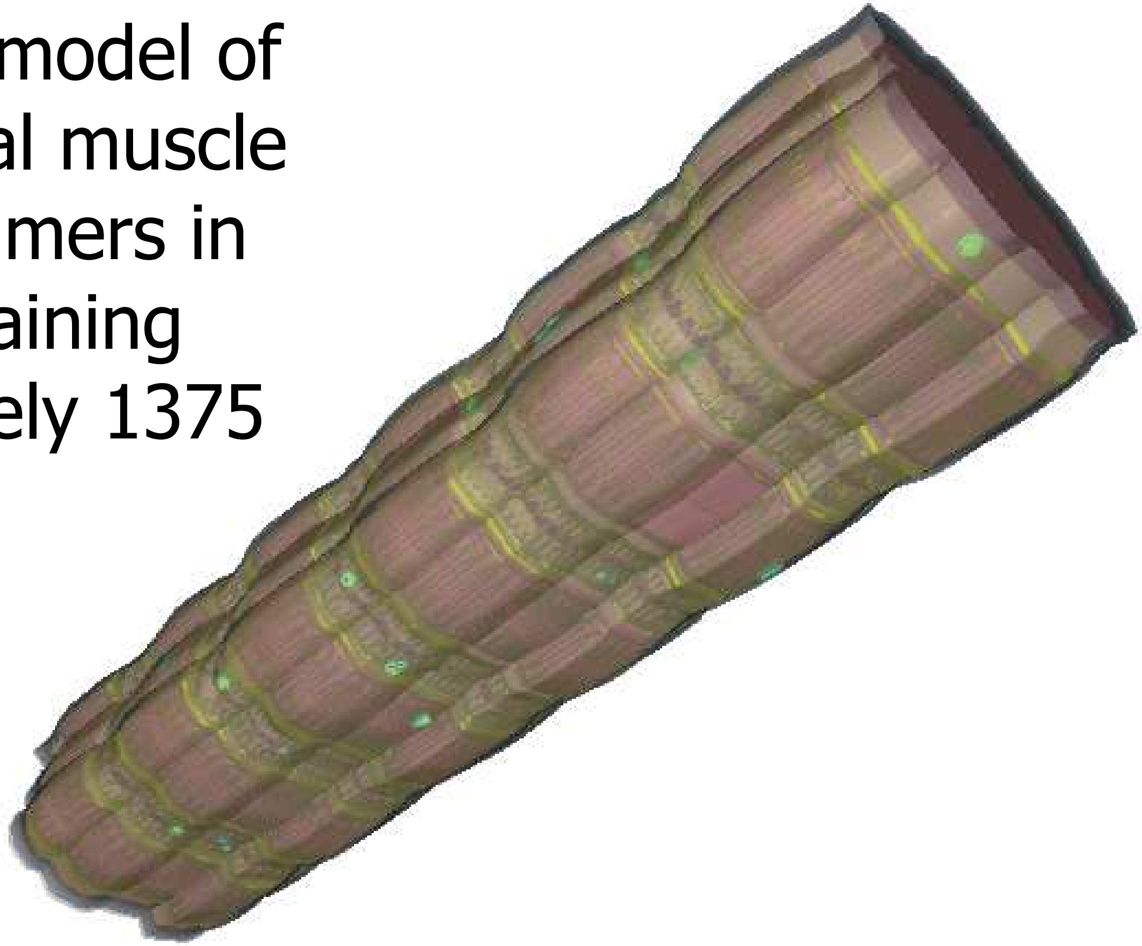
Results

- Muscle cell model of slow-skeletal muscle of 4 sarcommers in length containing approximately 928 objects



Results

- Muscle cell model of slow-skeletal muscle of 6 sarcommers in length containing approximately 1375 objects



Conclusion

- We have developed modeling methodology for automatic creation process of muscle cells
  - Cell description language
  - Tools for conversion to XISL format, which provides implicit description of created organelles
  - Binary tools aimed to interactive visualization, sectioning and stereological application of our models

Future work

- Models will be generated according to user specified (stereological, morphometrical,…) data