

Fast Generation of NURBS Using Neural Networks

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Overview

- Problem and Significance
- Automatic initialization of NURBS
- Automatic optimization of NURBS fit to data
- Jump-starting the optimization using neural networks.
- Results and Remaining Problems

Background...

- ▶ Models created through design & animation software typically are NURBS (*Non-Uniform Rational B-Splines*).
- ▶ Models built from acquired data (*e.g., from CT, MRI, EM*) are typically polygonal mesh or volumetric models.
- ▶ Each can be “rendered” for visualization purposes, however NURBS:
 - ❖ are the most compact
 - ❖ can be smoothly and locally manipulated
 - ❖ are the de-facto CAD standard

State of the Practice

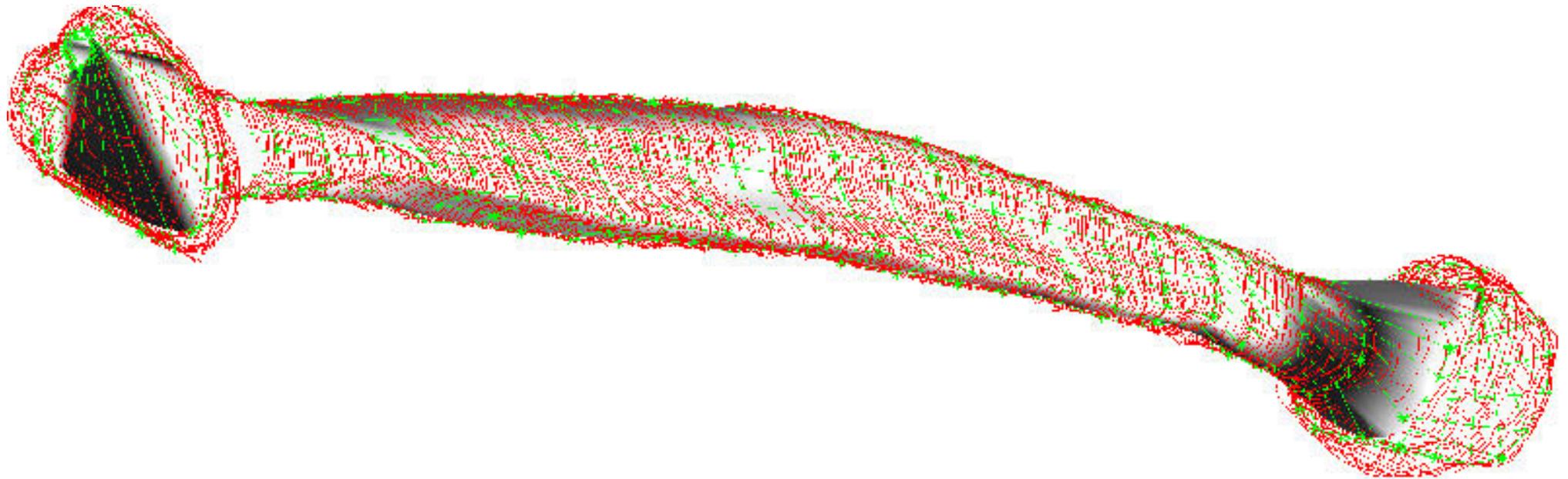
- ▶ Polygons → NURBS is a hard task. It involves a large, non-linear optimization problem.
- ▶ Some few companies attempt it (Alias, Imageware, Materialise), but:
 - ❖ detail is not there in representing the complex structures required by anatomical models
 - ❖ they are very expensive (~\$20,000)

Problem & Significance

- ▶ Visible Productions has thousands of polygonal models of human anatomical structures (*derived from the NLM's Visible human project*)
- ▶ Clients are requesting NURBS-based models to use with their CAD systems:
 - ❖ surgical instrument makers
 - ❖ animators (for education & surgery rehearsal)
- ▶ A new market: other small companies with data-based models looking for NURBS conversions...

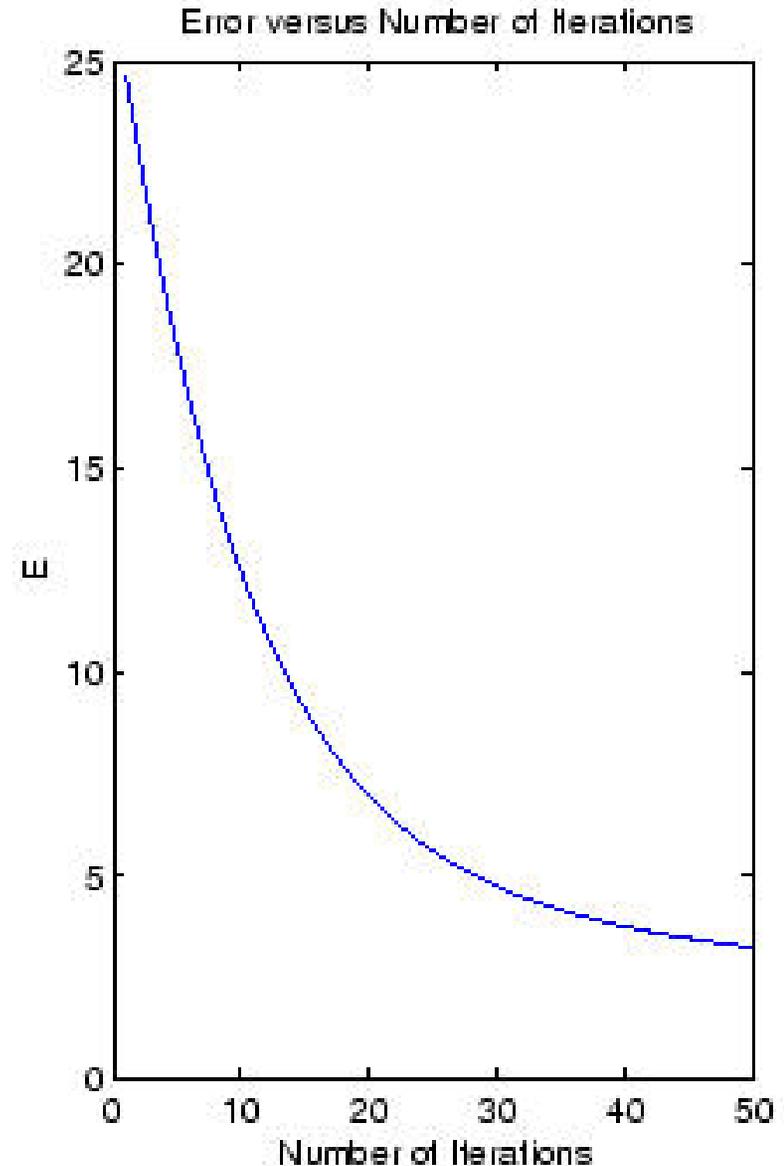
Initial Placement of Control Points

- ▶ Red points show contours drawn by hand, slice by slice.
- ▶ Green points show grid of initial control points, placed by interpolating the red data points.



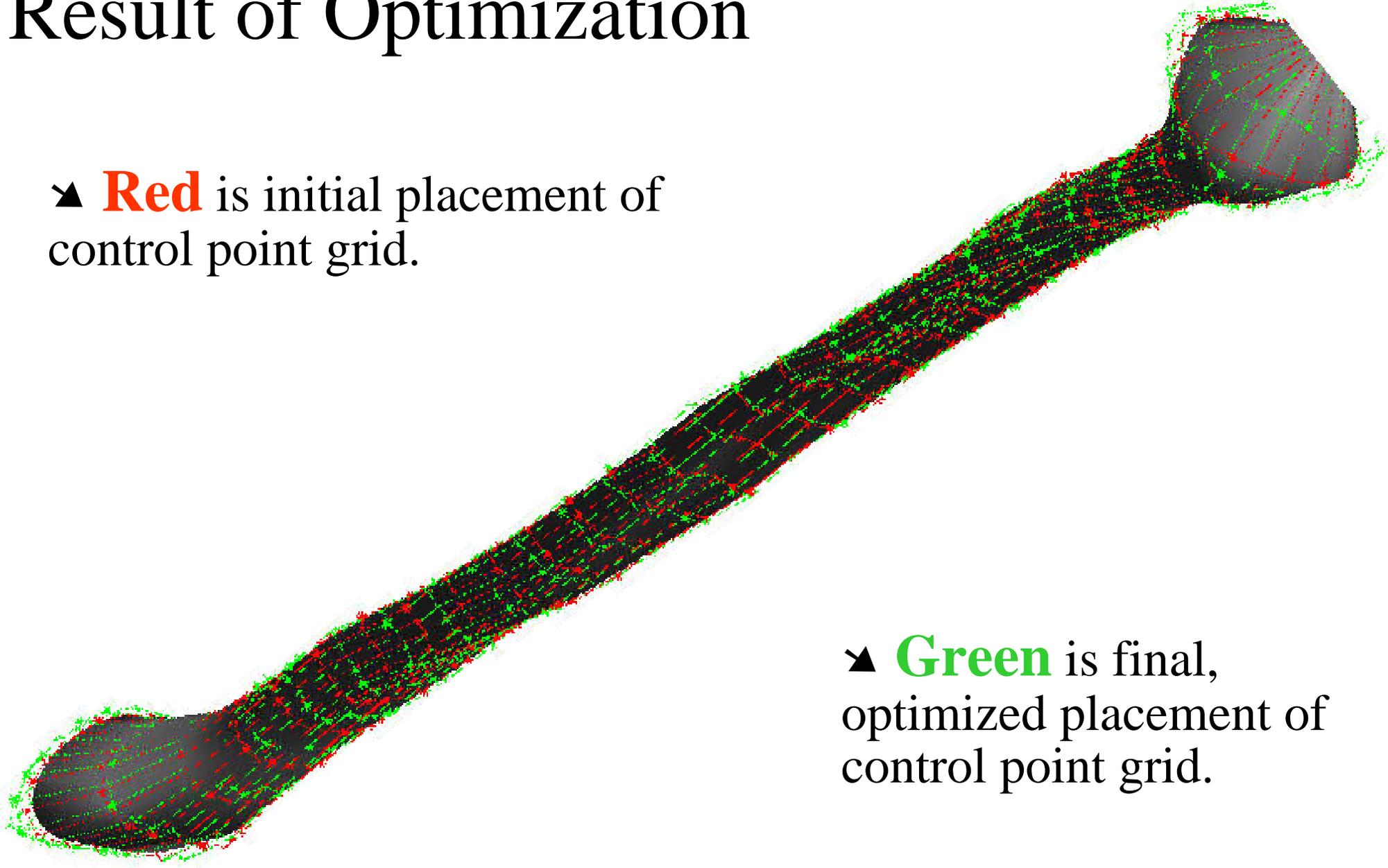
Optimizing the NURBS

- ❖ Calculate the error between the hand-traced points and the corresponding points on the NURBS surface.
- ❖ Calculate the gradient of this error with respect to the NURBS control points and weights.
- ❖ Adjust the control points and weights a bit along this gradient to decrease the error.
- ❖ Repeat for a number of iterations, until error no longer decreases significantly.



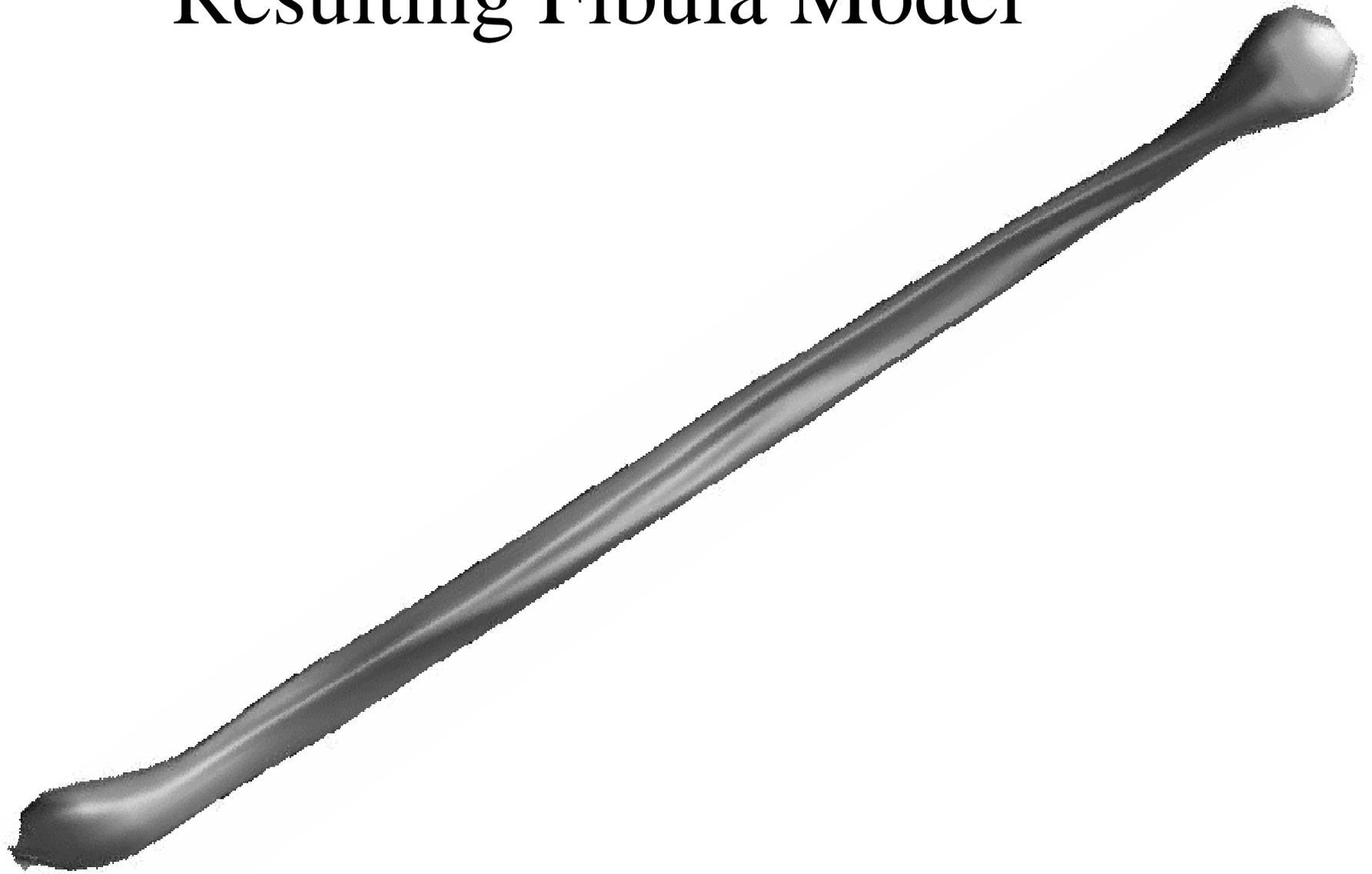
Result of Optimization

▶ **Red** is initial placement of control point grid.

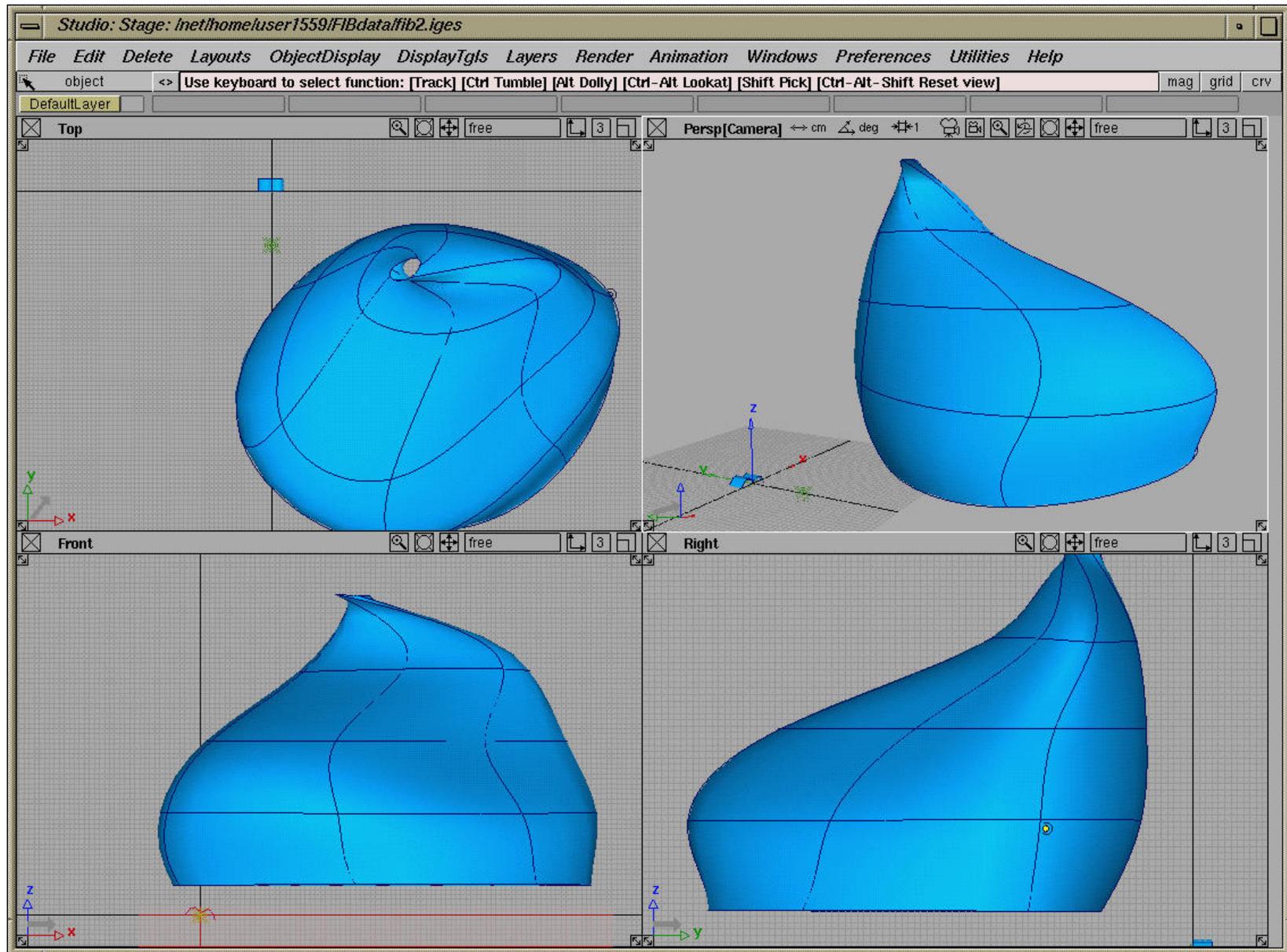


▶ **Green** is final, optimized placement of control point grid.

Resulting Fibula Model



Model Imported into CAD Tools



But, Optimization Not Practical..

- ▶ Optimizing the NURBS model for the single fibula model takes several hours.
- ▶ For Visible Productions, the conversion of all of their models (~10,000) is too time consuming.
- ▶ Others domains (e.g. MRI) need immediate models.
- ▶ Need to:
 - ❖ capitalize on the similarities of the many optimizations.
 - ❖ leverage the results of each optimization to reduce the time of subsequent optimizations.

Neural Networks

- ▶ Chose to use neural networks to capture results of optimizations.
- ▶ Neural networks can be trained to approximately reproduce optimizations, augmented by local, linear methods when the appropriate neighborhood is established.

Neural Nets to Speed Up Optimization

- ▶ The ideal NURBS initialization procedure would initially place control points near their optimal positions.
- ▶ Cannot know the ideal position a priori, but can estimate it by training a neural network based on past results.
- ▶ Training procedure for 2-dimensional NURBS curve:
 - (1) Optimize a NURBS fit to data curve,
 - (2) For every sequence of four control points,
 - ❖ Use first three points and corresponding data points as input to the network,
 - ❖ Train the network to output the position of the fourth control point.
 - (3) Using the net to predict fourth point given any three.

Neural Network Details

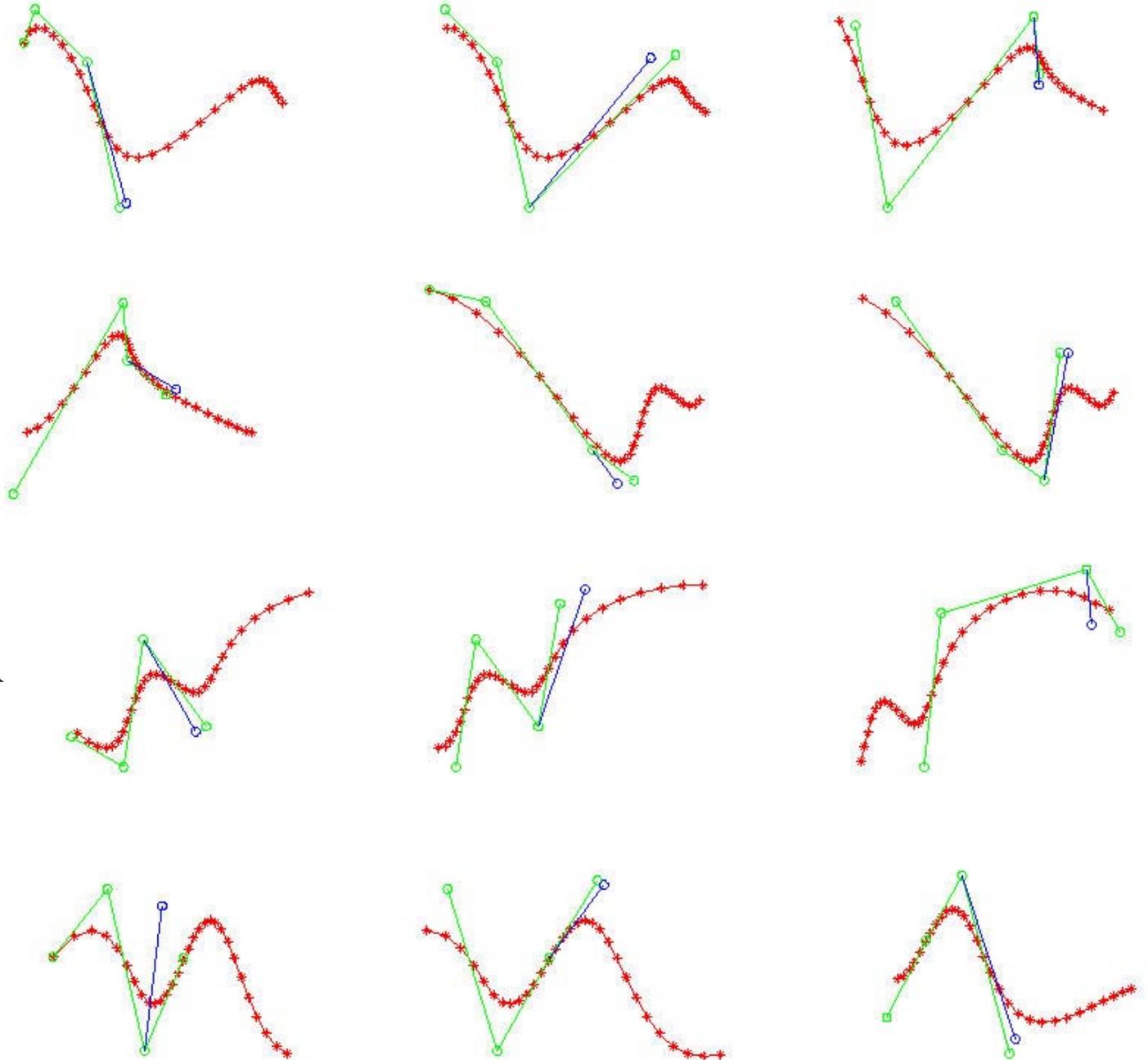
- Standard, two-layer, feed-forward neural network.
- Units use sigmoid transfer function.
- Trained using error backpropagation.
- Data is normalized to have zero mean and unit variance.
- Early-stopping used to improve the generalization ability of the neural network.
- Discovered that small networks, of less than 10 hidden units, was adequate for our tests.

Using Trained Neural Network

➤ **Red:**
data points

➤ **Green:**
optimized
control points

➤ **Blue:**
predicted position
of fourth control
point



Results and Remaining Problems

- ▶ Successful automatic generation of single NURBS surface for fibula.
- ▶ Demonstration of the feasibility of using neural networks to decrease the time need to optimize the fit of a NURBS surface to contour data.
- ▶ Successful seed: awarded an NSF SBIR Phase I grant to develop a polygon → NURBS tool prototype.
- ▶ Outstanding problems:
 - ❖ Best neural network architecture?
 - ❖ How much data needed to train the network?
 - ❖ Different networks needed for different structures?
 - ❖ Determine the best quantity of control points?