Modelbased Manipulations of B−Spline Surfaces to simulate Deformations of the Facial Tissue

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Outline:

- Overview
- Medical Foundations
- Modelbased Simulation
- Triangular B−Splines
- Results & Discussion
- Conclusions

Overview

Modelbased Simulation:

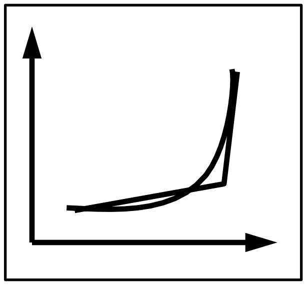
- mass spring system within five layers [Waters, Terzopoulos, 1990]
- manipulations of positions of nodes cause distortion
  of equilibrium of springsystem
- calculate new equilibrium
- render top layer with spline method to improve resolution

- Waters, Terzopoulos: Manipulation of springs
  with artifical muscle actors
- in this work: direct manipulation of spring nodes
  within the layer, which represent bone layer

Medical Foundations (1)

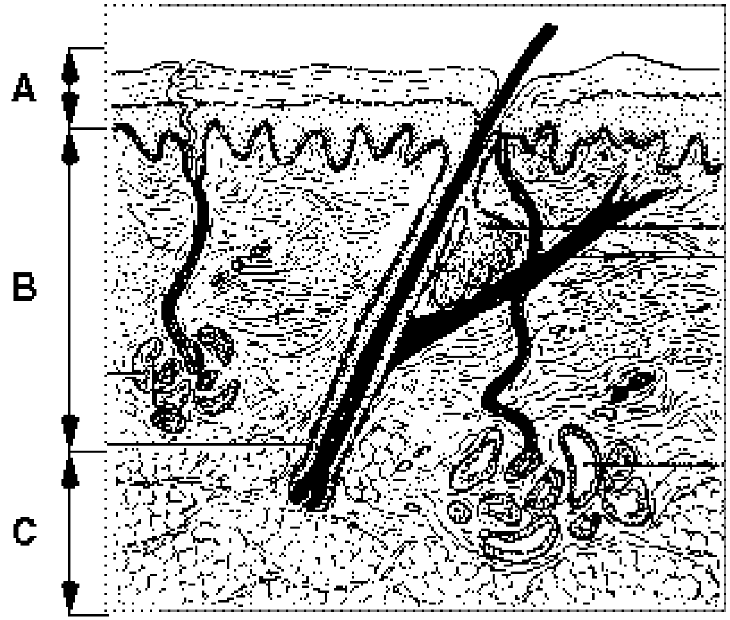
Mechanical properties of facial tissue:

- epidermis (A)
- dermis (B)



- subcutis (C)
- fascia
- bone

Facial tissue has an inhomogeneous, and non−directional behavior.

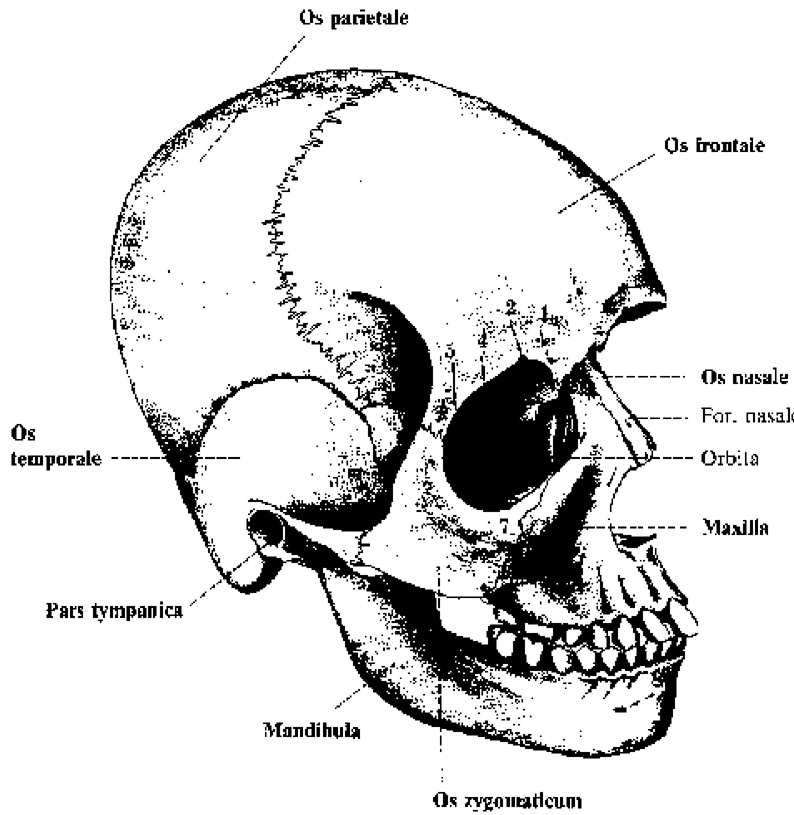


[From: PZ90]

Medical Foundations (2)

Human skull:

We manipulate the position of the
- Maxilla
- Mandibular

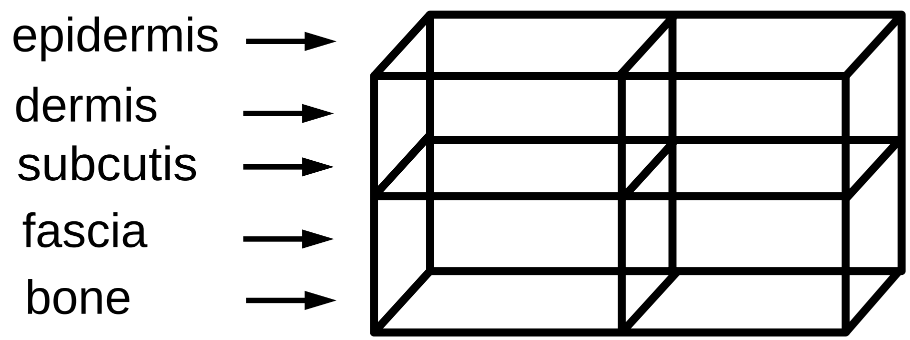


[From: Rohe90]

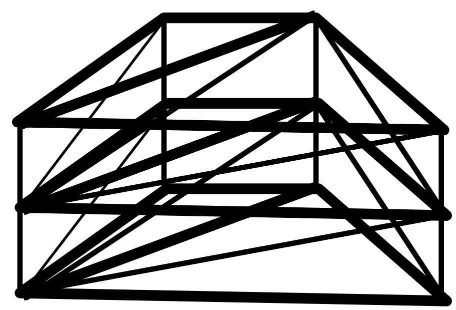
Modelbased Simulation (1)

- Each edge represents a spring in a mass spring system.

- Spring stiffness with respect to mechanical behavior

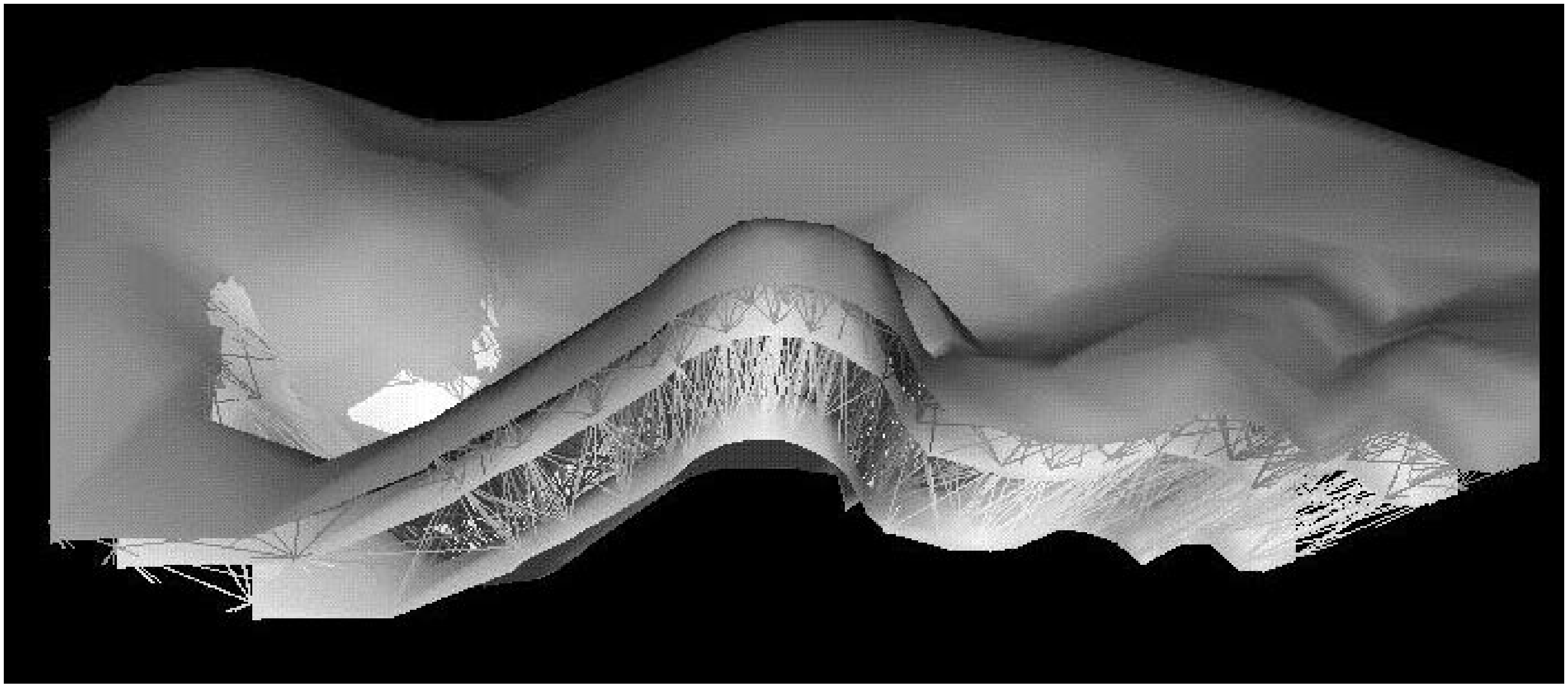


3D laser scanner data: triangulation



Modelbased Simulation (2)

Spring system after median cut



Modelbased Simulation (3)

$$f_i = m_i \cdot a_i(t) + \gamma_i \cdot v_i(t) + g_i \, , \qquad i \; \varepsilon \; \{0..N\}$$

$$\text{where } g_i = \sum_{j \, \varepsilon \, N_i} \frac{c_{ij} \, (\|r_{ij}\| - l_{ij})}{\| r_{ij} \|} \cdot r_{ij}$$

- equation describes balanced spring system
- moving of spring nodes causes distortion
- to compute new balance, use iteration method

Modelbased Simulation (4)

$$a_i(t) = (f_i - g_i \cdot v_i(t) - g_i) \cdot B_i/m_i$$

- using a two step numerical integration method (Euler):

$$K_1 = H(y_n , t_n) = a(v_n, x_n)$$

$$v_{n+1} = v_n + \Delta t \cdot K_1$$

$$x_{n+1} = x_n + \Delta t \cdot v_{n+1}$$

Modelbased Simulation (5)

Algorithm:

```
determine processing steps and the
   dedicated regions in bone layer

foreach processing step do
  select all points in region
  do
     apply translation vector
     to points
     while points have not reached
           target positions
od
```

Triangular B−Splines (1)

- surface: triangulation / unstructured grid

  ➡ Tensor product−B−Splines not appropriate

  ➡ Triangular B−Splines (DMS−Splines)
  (Dahmen, Micchelli, Seidel 1992)

- properties:
  - piecewise polynomial
  - locality
  - positivity
  - optimal smoothness
  - affine invariant
  - convex hull
  - local control

Triangular B−Splines (2)

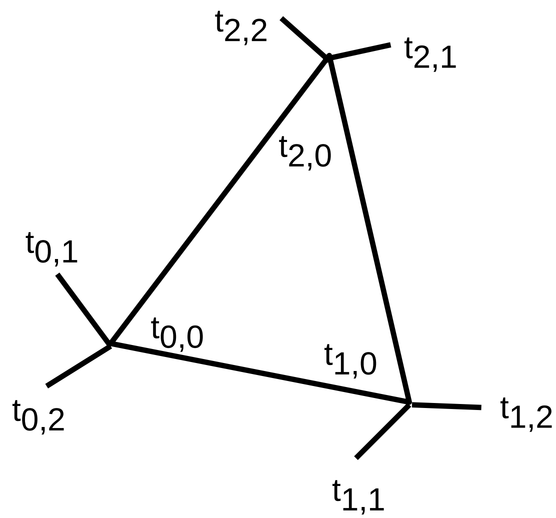
Mathematical foundations:

- based on
  - Simplex Splines (Dahmen, Micchelli 1982)
  - B−Patches (Seidel 1991)

- Computation of selected Simplex Splines, with respects to a triangulation and a set of knot clouds (parametrization)

- half−open convex hull

- barycentric coordinates (positive oriented triangles)



Triangular B−Splines (3)

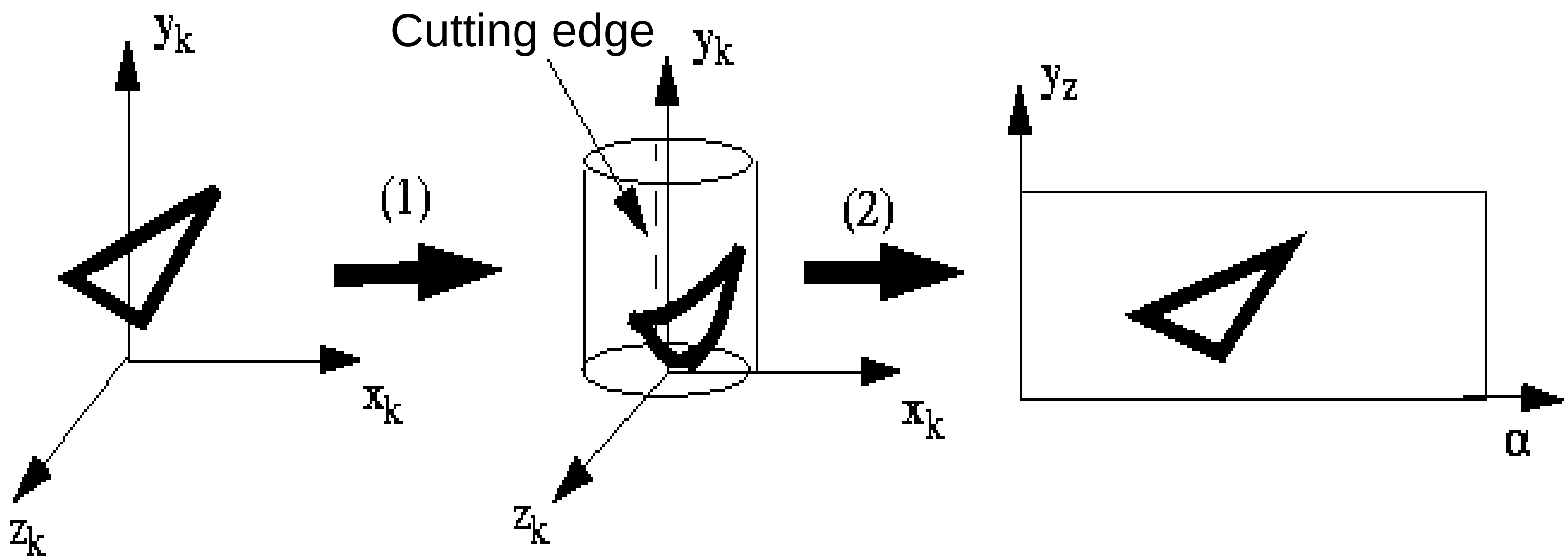
Four major problems to be solved:

- Construction of a proper parametrization
- Construction of a proper control net
- Construction of evaluation points in $\mathbb{R}^2$
- Evaluation of Triangular B−Spline base functions at the evaluation points

Triangular B−Splines (4)

Problem 1: parametrization

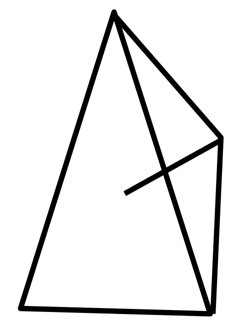
• Take advantage of the "scan property" of the triangulation in $\mathbb{R}^3$



Triangular B−Splines (5)

Construction of the knot cloud

```
foreach ti,0 e T do
   if ti,0 on_rim_of_T then
     estimate maximal_region m
     estimate neighborhood of ti,0
     select knot within m with best
         quality concerning neighborhood
   else
     estimate neighborhood of ti,0
     estimate knot with best quality
         concerning neighborhood
   fi
od
```

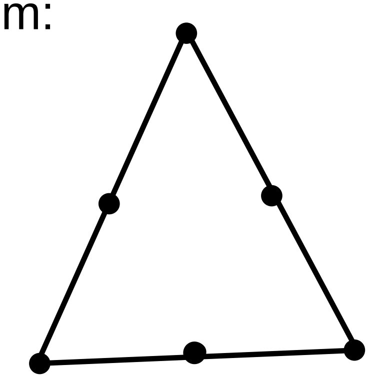


With respects to:

- affine independent
- guaranteed partition of one
- no intersection of edges
- no degenerated triangles

Triangular B−Splines (6)

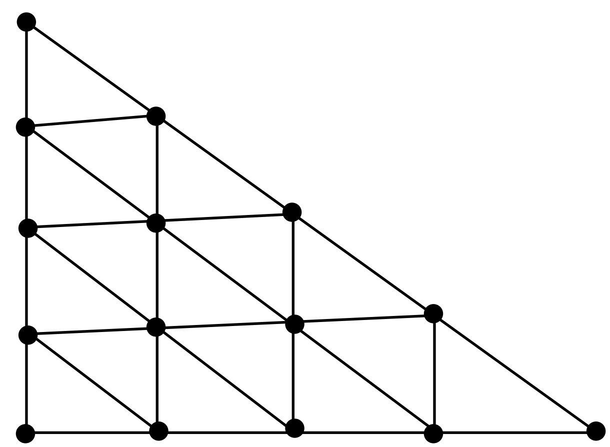
Problem 2: control net ... is an approximation problem:



- Simple approximation by vertex identification
  Pros: fast, simple, robust
  Cons: bad quality

- Least−Square−Approximation (LES)
  Pros: better quality
  Cons: high space and time complexity ($O(n^3)$)
  (really huge design matrix)

Problem 3: Evaluation points



- $n(n+1)/2$ evaluation points per patch

- $n=5$ ➡ 15 evaluation points:

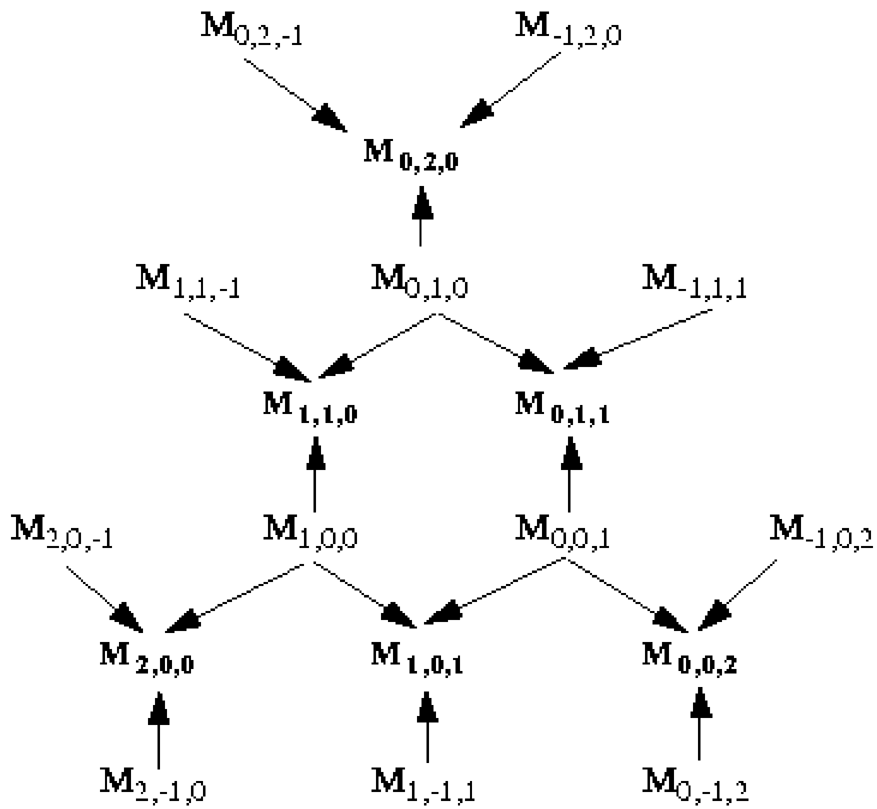
Triangular B−Splines (7)

Problem 4: evaluation of base function

Algorithm
(Pfeifle, Seidel 1994) is

- a modification of deBoor algorithm
- limited to quadric Triangular B−Splines

→ C^1 smoothness



Results & Discussion (1)

data set: #vertices/ #triangles	P/[s]	n=3 E/[s]	n=3 #vertices #triangles	n=5 E/[s]	n=5 #vertices #triangles	n=7 E/[s]	n=7 #vertices #triangles
A: 552/1012	31	22	2115 4048	94	8277 16192	344	18487 36432
B: 1157/2273	68	60	4586 9092	392	18263 36368	1966	41032 81828
C: 1502/2976	102	193	5979 11904	780	23861 47616	3423	107136 53647
D: 8641/17001	584	2517	34282 47616	25156	136567 272016	150000[1]	1000000[1] 623036

Computed on a Onyx RealityEngine^2, only using one processor (R4400)

1: estimate

Results & Discussion (2)

Problems:

- simplified tissue model:
  - homogeneous conditionalization within every layer
  - bone layer is approximated with a copy of a triangulation of the epidermis layer
  - no detail models (lips, eyes, ears,...)
  - no muscle model (but easy to implement)

- results are strongly dependent on selection of vertices and translations

  ➡ planning and reproduction is difficult

- method is not surgical oriented (at this stage)

- numerical problem with "bad" triangulations of the face

Conclusion & Future Work

Conclusion:

- tissue model out of spring systems
- epidermis layer is rendered with Triangular B−Splines

Future Work:

- improvement of the tissue model
- improvement of the construction of the control net
- error correction of "bad" numerical data
- high potential in parallelization

References

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