Leaf surface representations

Birgit Loch

Centre for Systems Biology
Department of Maths & Computing
University of Southern Queensland
lochb@usq.edu.au
www.sci.usq.edu.au/staff/lochb
Overview

• Motivation
• Leaf models in the past (pre 2004)
• Why a new type
• The process
• Application example
• Future work
Motivation

Virtual plants
Virtual leaves
Leaf models in the past (pre 2004)

- Simulation of light interception in a canopy
  - estimate how much light is captured by a leaf
  - effects of shading on photosynthetic activity

- Generation of visually pleasing, realistic models of leaves as parts of larger plant models
Functional leaf models

From Lang, 1973 (top) and Sinoquet et al. 1998 (bottom)
Visual leaf models

Bloomenthal 1985

Lintermann and Deussen 1999

Mündermann et al. 2003

L-Studio
I considered the visual aspect; the representations may be extended and used to model functionality.
Why a new type

- Accuracy, based on data
- Level of detail
- Realism
- Mathematical description of surface
- Applications such as droplet running along surface
- (damage, growth)
The process

- digitising
- surface fitting and visualisation
- the boundary
Digitising

Laser scanner
Sonic digitiser
Issues

• reflective properties, movement, wind, magnetic interference, daylight, wilting, …
Examples:

Frangipani

Flame tree
Surface fitting

Scattered data interpolation problem:

Given \( n \) scattered data point triples \( (x_i, y_i, z_i), i = 1..n \), find an interpolant \( f : \mathbb{R}^2 \rightarrow \mathbb{R} \) satisfying

\[
f(x_i, y_i) = z_i.
\]

\( n \) may be small (sonic digitiser) or large (laser scanner)
• One function over the whole domain or several functions?
• FEM: triangulation
  (reference plane)
  nodes
  polynomials

• Need to find a function on each triangle

• Simple finite element: linear triangle (3 nodes)
• Result: piecewise linear surface

• If we want C1 continuity we need at least 21 nodes (quintic triangle)
• Or: split triangle into subtriangles, find piecewise cubic on each triangle and make sure transitions between subtriangles and complete triangles are C1
• For example the Clough-Tocher triangle only needs 12 pieces of information
• I used the linear triangle (PLM) and the CT triangle (CTM)
• I had the luxury of using a laser scanner, but what if a computational plant scientist only has a sonic digitiser (they are a lot cheaper!)? Can we tell this person which points to digitise?

• Do we really need all these points? Can we reduce the size of the data set on which the surface function is based? Without giving up too much accuracy to the data?
An adaptive approach:

1. Begin with an initial set of data points, for example some points along the boundary.
2. Fit the surface to these points. Calculate how well the remaining points have been approximated. Have we reached some error tolerance limit? If yes then stop.
3. Add one of the remaining points to the set of interpolated points.
4. Go to 2.

But which point should be added?

It turns out that the maximum error point is a good choice, although a better choice may exist.
Accuracy is measured in terms of a maximum error associated with a fit relative to the maximum variation in \( z \) pointwise.

<table>
<thead>
<tr>
<th>leaf type</th>
<th>method</th>
<th>boundary points</th>
<th>total points</th>
<th>points for accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>frangipani</td>
<td>PLM</td>
<td>17</td>
<td>10473</td>
<td>55      131          323</td>
</tr>
<tr>
<td></td>
<td>CTM</td>
<td>17</td>
<td>10473</td>
<td>62      185          327</td>
</tr>
<tr>
<td>flame tree</td>
<td>PLM</td>
<td>61</td>
<td>5706</td>
<td>127     306          587</td>
</tr>
<tr>
<td></td>
<td>CTM</td>
<td>61</td>
<td>5706</td>
<td>142     331          607</td>
</tr>
</tbody>
</table>
Visualisation - triangulations

5% PLM 55 pts
5% CTM 62 pts
1% PLM 323 pts
1% CTM 327 pts
5% PLM 55 pts
5% CTM 62 pts
1% PLM 323 pts
1% CTM 327
Applications

• Water droplet simulation
• Accurate shadows
• Insect movement
• Photo-realistic images
Application example

• Droplet running along a leaf surface

• e.g. to simulate spreading of pathogens by a droplet, or the distribution of a pesticide on the leaf surface.

Simplified conditions:

• piecewise linear surface
• negative gradient direction
• The droplet falls off the surface at the boundary
• The velocity of the droplet is zero as it crosses from one element to the next
Droplet movement on leaf surface
Some leaf surface shapes
The problem

- Boundary is piecewise linear curve.
- How can it be improved using the same surface fitting techniques?
- Extension/reduction to make surface fit a parametric boundary curve?
The solution
Extension/reduction

reduce

curve lies on surface
reduction of domain

extend

• extrapolation
• interpolation
• subdivision

split in two
Extension: extrapolation

- 2D curve given
- Evaluation of surface function outside triangular domain = extension of domain
- Problem: can show bad behaviour depending on triangle orientation and chosen boundary curve
- “Extrapolation is usually considered as a bad way to approximate functions…” (Dyn, Levin, Rippa, 1992)
Extension: interpolation

- 3D curve given
- Piecewise (pcw) linear interpolation between edge 3 and curve segment c
- Less smooth transition because of linear fit
- Use pcw cubic interpolation instead?
Extension: subdivision

- A triangle is added in region between edge 3 and curve segment c, this method can be repeated for remaining regions.
- Third corner of new triangle found either on 3D curve or by extrapolation of surface function.
- Similar to approach by Levin (1999).
Example
More examples
More examples
Outlook

• Different curves possible – depending on boundary type
• Capture variation
• Example: serrated edge based on sine functions
Immediate future work

• boundary improvement
  • What is a good boundary?
  • Can we compare two boundary segments?
  • How do you compare to curves in space?
  • Numerical or visual judgment?

• different derivative estimate method
  • More accurate fit with fewer data points?

• droplet movement on surface
  • How detailed does surface need to be?
  • Compare to movement in reality
More distant future work

- integrate in plant models
  (conversion to other types of surface functions?)
- average models
- curled leaves
- dynamic model
- compare shading results to those for less detailed models
- functionality
- boundary, other surface fitting/derivative estimate methods, droplet movement
- venation