Jean.Combaz@imag.fr
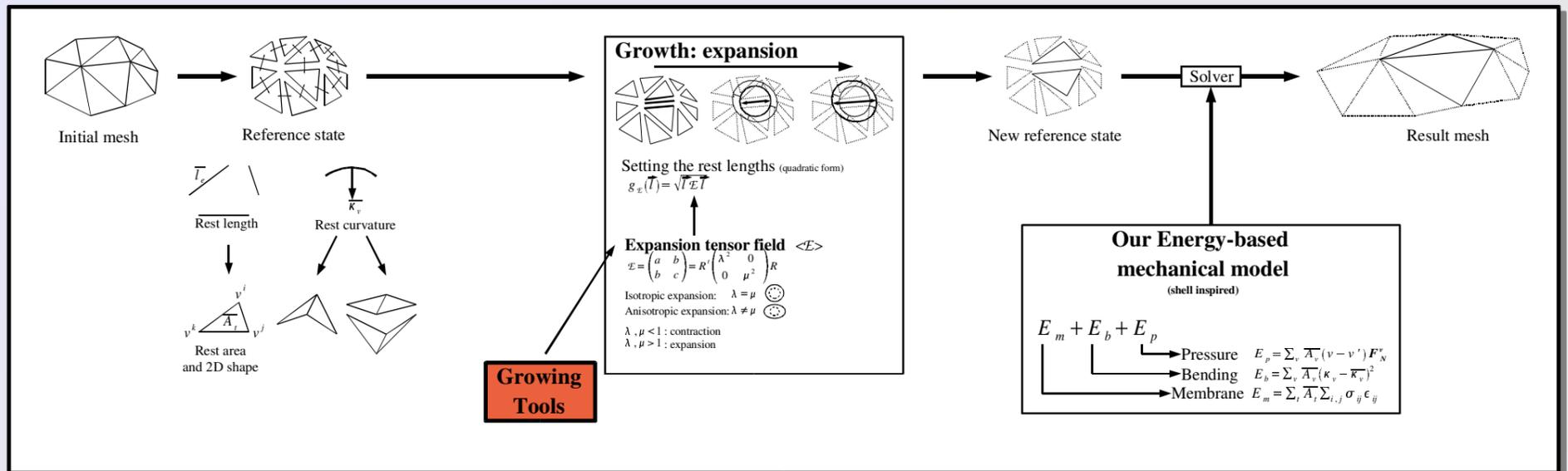Fabrice.Neyret@imag.fr

SEMI-INTERACTIVE MORPHOGENESIS

Goal

Simulate **growth phenomena**.
Application to the modeling of complex **organic shapes** and **folded surfaces**.
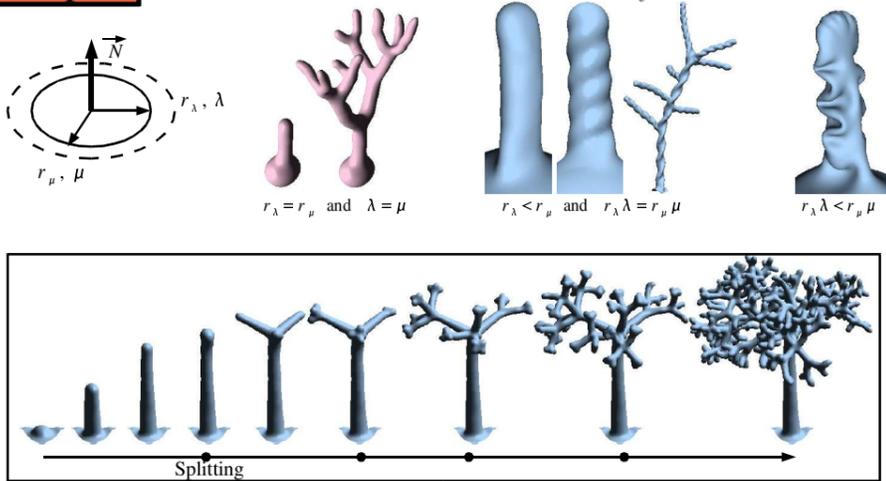
Approach

A new modeling system based on a set of **growing tools** and a **mechanical model**.
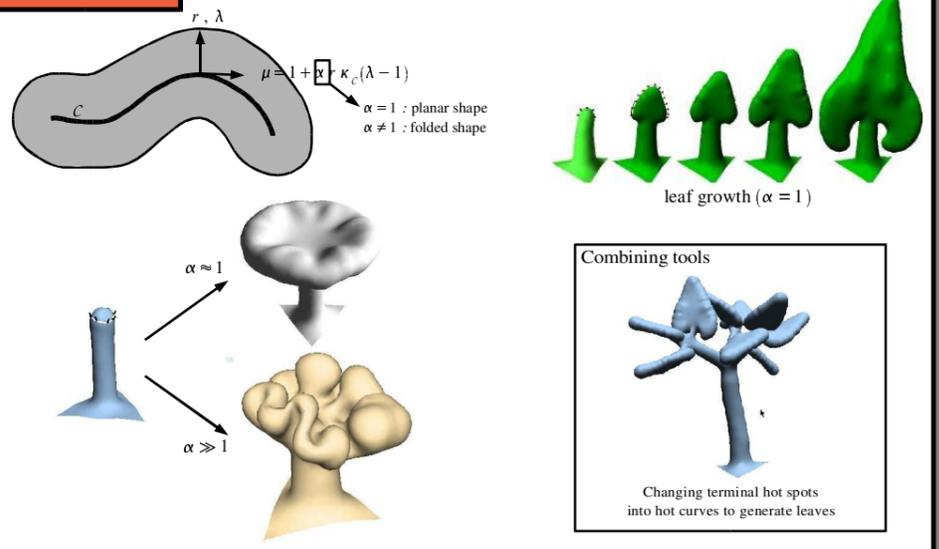Extension of [CN02] with more flexibility and interactive tools.

Our model

Initial mesh

Reference state

$\overline{l_e}$

Rest length

$\overline{\kappa_v}$

Rest curvature

v^i, v^k, A_i, v^j

Rest area and 2D shape

Growth: expansion

Setting the rest lengths (quadratic form)
$$g_{\mathcal{E}}(\overline{l}) = \sqrt{\overline{l}^t \mathcal{E} \overline{l}}$$

Expansion tensor field $\langle \mathcal{E} \rangle$

$$\mathcal{E} = \begin{pmatrix} a & b \\ b & c \end{pmatrix} = R^t \begin{pmatrix} \lambda^2 & 0 \\ 0 & \mu^2 \end{pmatrix} R$$

Isotropic expansion: $\lambda = \mu$
Anisotropic expansion: $\lambda \neq \mu$

λ, $\mu < 1$: contraction
λ, $\mu > 1$: expansion

Growing Tools

New reference state

Solver

Result mesh

Our Energy-based mechanical model
(shell inspired)

$$E_m + E_b + E_p$$

Pressure $\quad E_p = \sum_v \overline{A_v}(v - v') F_N^v$
Bending $\quad E_b = \sum_v \overline{A_v}(\kappa_v - \overline{\kappa_v})^2$
Membrane $\quad E_m = \sum_i \overline{A_i} \sum_{i,j} \sigma_{ij} \epsilon_{ij}$

Growing Tools

Hot Spots

$\vec{N}$, r_λ, λ, r_μ, μ

$r_\lambda = r_\mu$ and $\lambda = \mu$

$r_\lambda < r_\mu$ and $r_\lambda \lambda = r_\mu \mu$

$r_\lambda \lambda < r_\mu \mu$

Combining with rotation

Splitting

Hot Curves

r, λ

$\mu = 1 + \alpha \cdot \kappa_c (\lambda - 1)$

$\alpha = 1$: planar shape
$\alpha \neq 1$: folded shape

c

$\alpha \approx 1$

$\alpha \gg 1$

leaf growth ($\alpha = 1$)

Combining tools

Changing terminal hot spots
into hot curves to generate leaves

Hot Surfaces

Photograph

Painting tool

Expansion texture
($\langle \mathcal{E} \rangle$ field)

Growth

3D Surface

Specified $\mathcal{E}$ samples

Interpoled $\mathcal{E}$

Adding folds using a tensor Laplace interpolation

Morphogenesis simulations

Tool path

Adding details
with growth brushes