# Wires: A Geometric Deformation Technique

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# Free-Form Deformations & Variants

- Popular for deformed modeling/animation
- Geometric control
- Definition/deformation of lattice
- Mapping from lattice to object
- Detail dictated by density of lattice
- Arbitrarily shaped lattices cumbersome

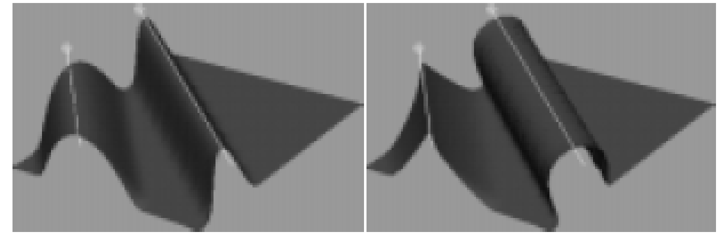
# Axial Deformations

- More compact representation
- One-dimensional primitive used to define implicit global transformation

# Wire Deformations

- Related to axial deformations
- Desire to bring geometric and deformation modeling closer together
- Likened to constructive sculpting approach
- Wire curves rough approximation to object
- Independent of complexity of object model
- Stage of process
  - Object bound to set of wires
  - Manipulation of wires affects deformation

# Wire

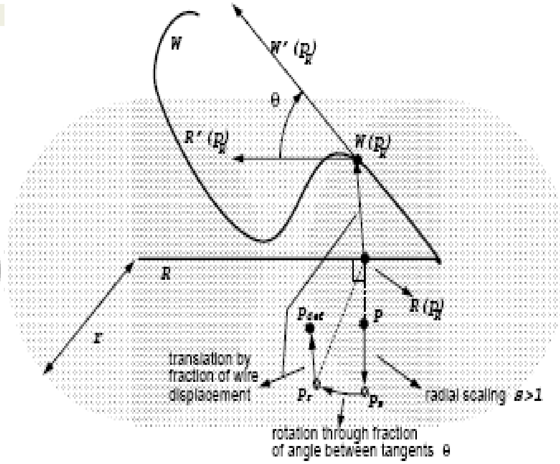


(a) Varying $r$ (b) Varying $s$

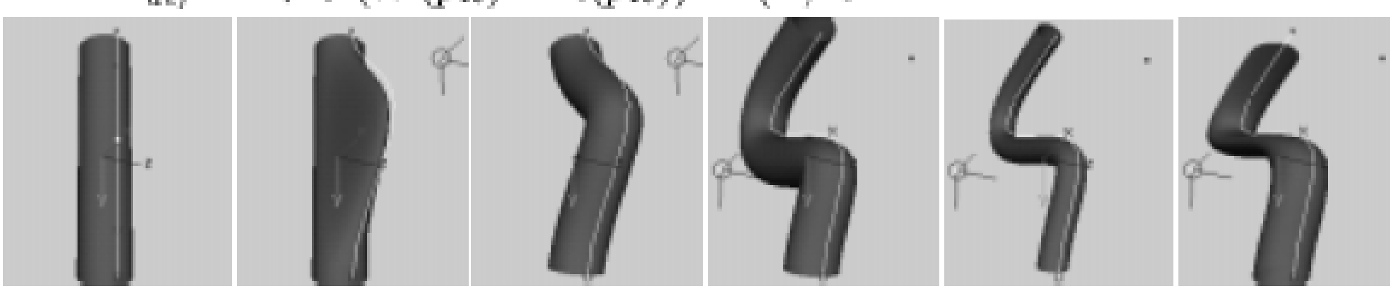
- Curve whose manipulation deforms surface
- Tuple <W, R, s, r, f>
  - W and R: free-form parametric curves (wire, reference)
  - s: scalar controlling radial scaling
  - r: scalar defining radius of influence
  - f: $\mathbf{R}^+ \rightarrow [0,1]$ in literature called "density function"
    - C1, monotonically decreasing w/ f(0)=1, f(x)=0 for x≥1 & f'(0)=0, f'(x)=0
- f and r used to define volume
- Given r & f, with s, wired defined by W and R
- Manipulating W results in change btw. W/R

# Deformation of Point P

- Scale P about $R(p_R)$ → $P_s$
  - $P_s = P + (P - R(p_R)) \cdot (1 + (s-1) \cdot F(P, R)$




- $W'(p_R)$ tan to W at $p_R$, Θ angle btw $W'(p_R)$ & $R'(p_R)$. Rotate $P_s$ by Θ·F(P,R), around axis $W'(p_R) \times R'(p_R)$, at point $R(p_R)$. → $P_r$
- Translate $(W(p_R)-R(p_R))\cdot F(P,R)$
  - $P_{def} = P_r + (W(p_R) - R(p_R)) \cdot F(P, R$



(a) no deformation (b) deform with small $r$ (c) increase $r$ (d) more deformation (e) reduce $s$ (f) attenuate rotation

# Properties of Formulation

- Objects not deformed upon wire frame creation
- Object points outside r never deformed
- Points on R track exactly
- Deformation between R and outside r is smooth and intuitive
- For s=1, cross-section of object in plane perpendicular wire curve at a point closely resembles profile of f

# Axial Deformations

- Also use notion of reference curve R and closest point computation $p_R$ for point P
- Relates two Frenet frames attached at $W(p_R)$ on deformed curve and $R(p_R)$ on reference curve

# Wire Differences from Axial

- Separation of scale/rotation/translational components provides more selective control over deformation
- Frenet frames harder to control/orient
- Simple non-linear transformations can be incorporated seamlessly
- Implicit function to control spatial influence makes technique more accessible

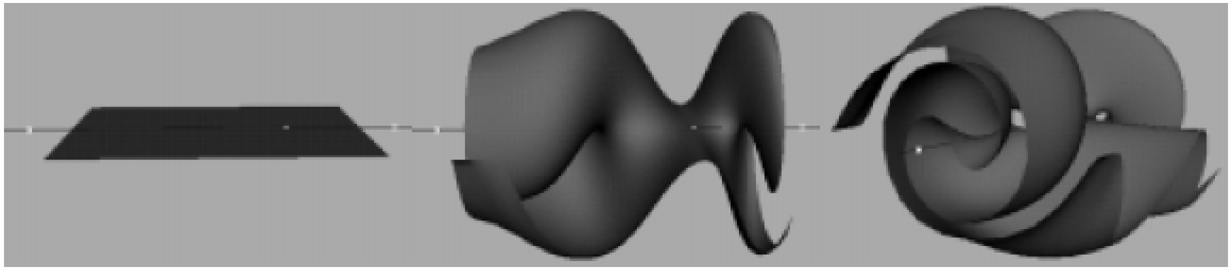
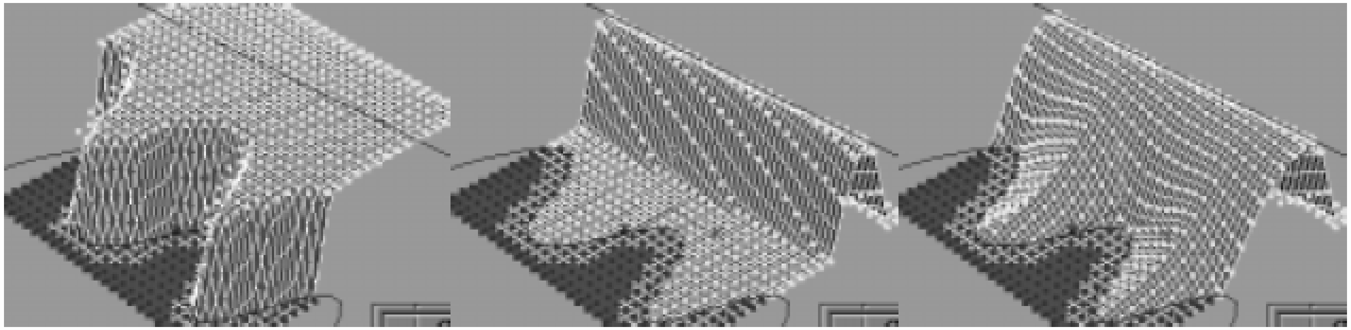


Figure 4: Interpolated twist around a wire.

# Continuity

- May be comprised of parts of object surface defined by control vertices that are selectively deformed
- Proposed solutions
  - Locators
  - Domain curves



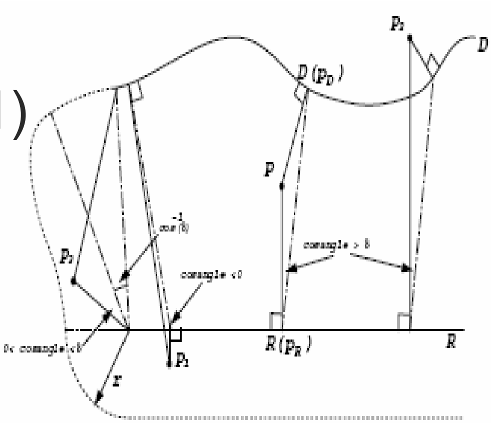
(a) sharp vertical decay (b) sharp horizontal decay (c) smooth decay

# Locators

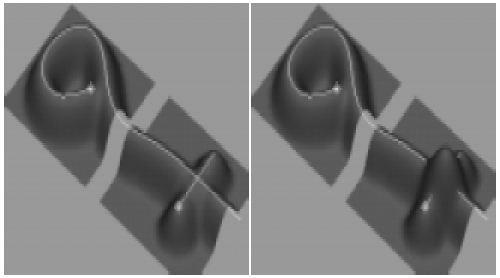
- Along wire curve to specify values of parameters
- Can be places along curve to control radius of influence r and other attributes
  - Interpolation between attribute values specified at two locators that bracket P
- Provide radially symmetric control along and around a wire curve

# Domain Curves

- Provide anisotropic directional control
- Domain curves, with reference curve, define implicit primitive function over finite volume
- One-sided curve
  - cosangle = $(D(p_D)-R(p_R))\cdot(P-R(p_R))$
  - If cosangle>0, domain curve D used to define f at P
    - Attempts to select points P on same side of R as D
    - $F(P,R) = f\left(\frac{\|P - R(p_R)\|}{\|R(p_R) - D(p_D)\|}\right)$
  - For cosangle $\epsilon$ $[0,\delta]$ where $\delta$ $\epsilon$ $(0,1)$
    - $F(P,R) = f\left(\frac{\|P - R(p_R)\|}{Interp(cosangle)}\right)$
    - Interp gives smoothly interpolated value from r to $\|R(p_R)-D(p_D)\|$ as cosangle varies from 0 to $\delta$



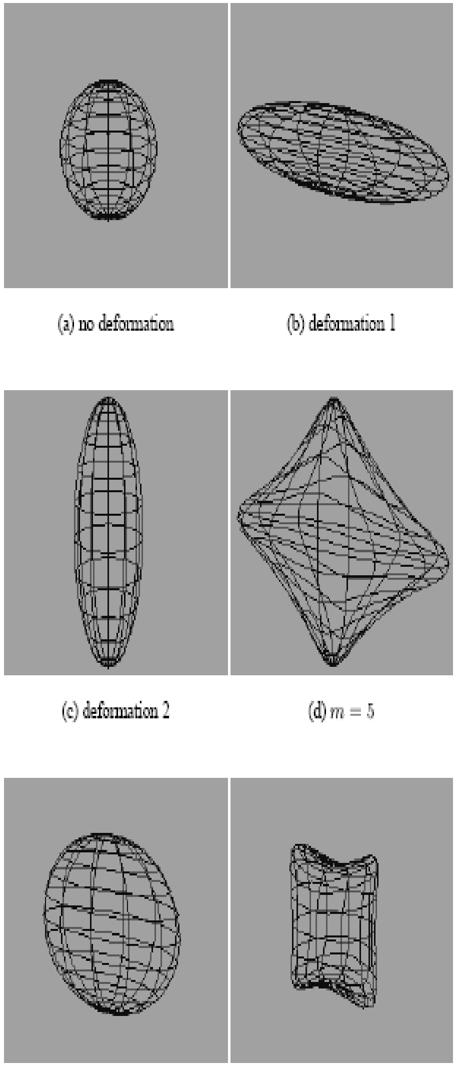
# Removing Aggregate Blobs 1/2



- $i^{th}$ wire curve deforming object → $<W_i, R_i, s_i, r_i, f_i>$
- Deformation of point P induced by i → $P_{def_i}$
- $\Delta P_i = P_{def_i} - P$

# Removing Aggregate Blobs 2/2

- $P_{def} = P + \frac{\sum_{i=1}^{n} \Delta P_i \cdot ||\Delta P_i||^m}{\sum_{i=1}^{n} ||\Delta P_i||^m}$
  - Varies with m from avg of $\Delta P_i$ at m=0 to max{$\Delta P_i$} for large m
  - As m gets increasingly negative, displacement approaches min{$\Delta P_i$}
- For typical m≥1
  - One relevant wire→result is deformation of that wire
  - Several wires with same deformation→result is any
  - Result is algebraic combination of individual wire deformations, with bias controlled by m



(a) no deformation (b) deformation 1

(c) deformation 2 (d) $m = 5$

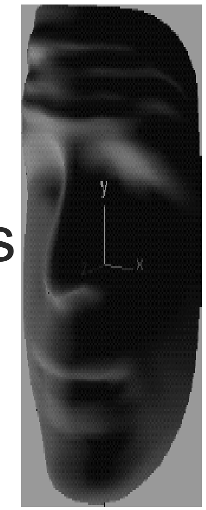
(e) $m = 0$ (f) $m = -2$

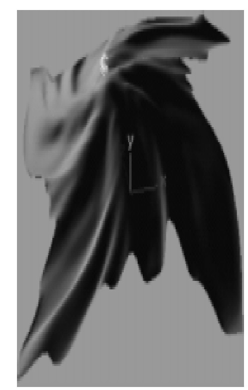
# Applications

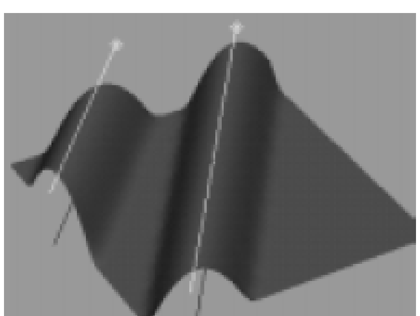
- Wrinkle formation and propagation
  - Surface oriented
- Stitching and tearing geometry
  - Surface oriented
- Flexible skeletal curve used to bind articulated geometry as a wire
  - Volume oriented

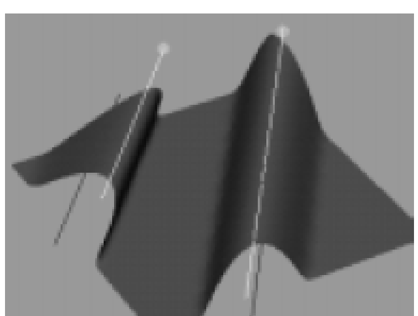
# Wrinkles 1/2

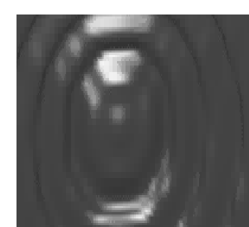
- Thickness, intensity, stiffness of material captured by wire deformation parameters
- Wrinkles can propagate along surface
- Wrinkles can be procedurally generated by specifying parameters such as number of crease lines, thickness, intensity, stiffness, and resistance to propagation



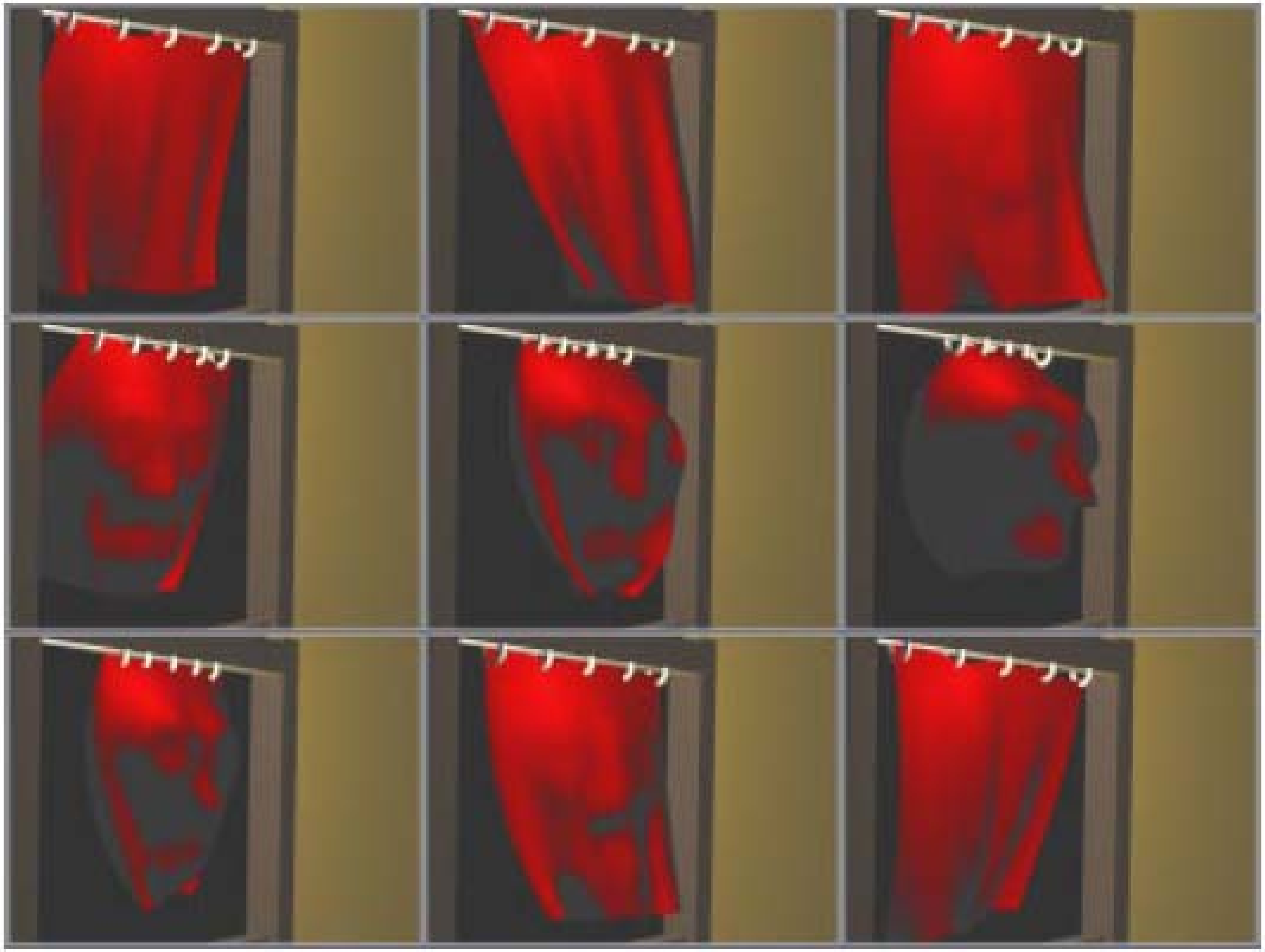




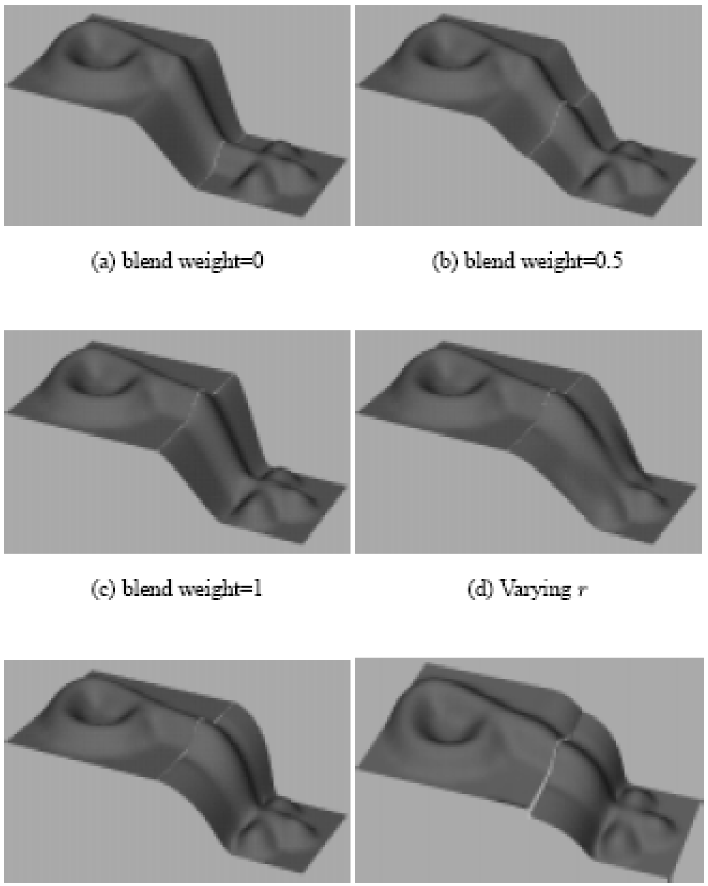




# Wrinkles 2/2



# Stitching Object Surfaces

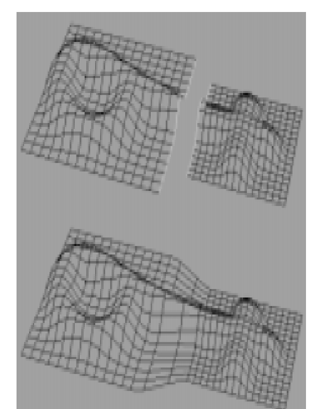


(a) blend weight=0 (b) blend weight=0.5

(c) blend weight=1 (d) Varying $r$

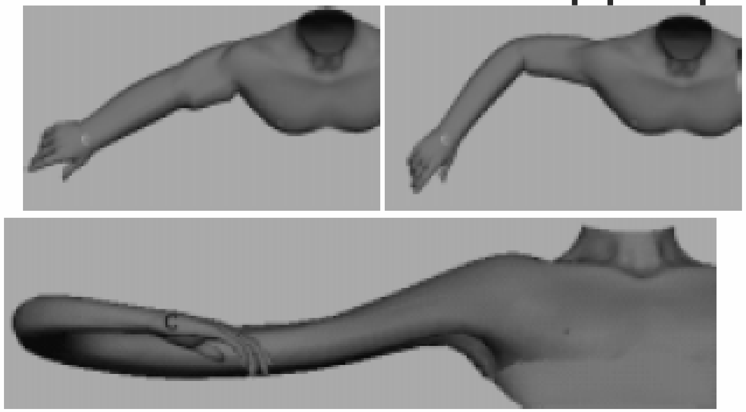
(e) Varying $s$ (f) Tear propagation

- Creation of wire curves
- Curves blended pairwise
- Track seam, resulting in stitch
- Reparameterize edges to common domain
- Shortcomings
  - High orders of continuity not guaranteed



# Kinematics for Flexible Skeletons

- Most inverse kinematic solvers have problems with non-uniformly scaling segments
- Replace joint chain with curve
- Rubberband-like behavior by transforming control points proportionally along joint chain
- Large r, so all points track equally and precisely
- Arc length used to maintain appropriate s



# Discussion

- Used in Maya production modeling, animation, and rendering graphics product
- Slowest part of algorithm is closest point calculation
  - Can be pre-computed for all P, change with R
- In implementation, some geometric algorithms could be made more efficient