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Multitouch Sketch Based Modeling System

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Multitouch Sketch-Based Modeling

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- In this talk we will show an approach for multitouch sketch-based modeling system development.
- Multitouch systems uses a natural interface.
- In windows-based systems, it is impossible to interact with a curve using several fingers.
- Actually there are many WIMP (Window, Icon, Menu, Pointer) systems to modeling of curves, but there are not efficient multitouch sketch-based modeling.

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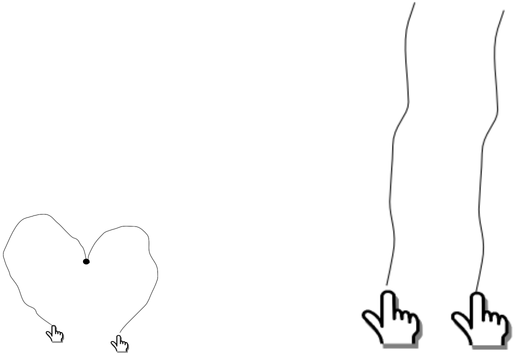
Why Multitouch Systems to sketch-based modeling?

New possibilities!

Modeling and manipulation with several fingers.

New possibilities!



Modeling with several fingers.

New possibilities!

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New possibilities!

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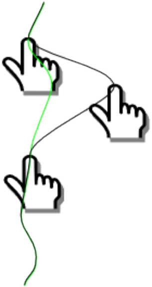
New possibilities!



Problems

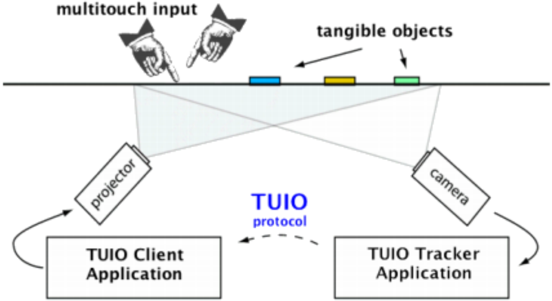
- The Multitouch and WIMP systems arquitecture are different.
- There is no mathematical model to simultaneously manipulate several points in a spline curve.

Multitouch Sketch Based Modeling System

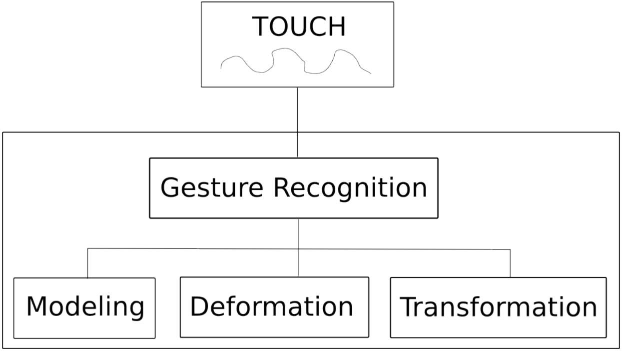
Technologies:

- iTable;
- TUIO Protocol;
- Reactivision;
- TUIO Client Framework;

Multitouch System Architecture



Application Architecture



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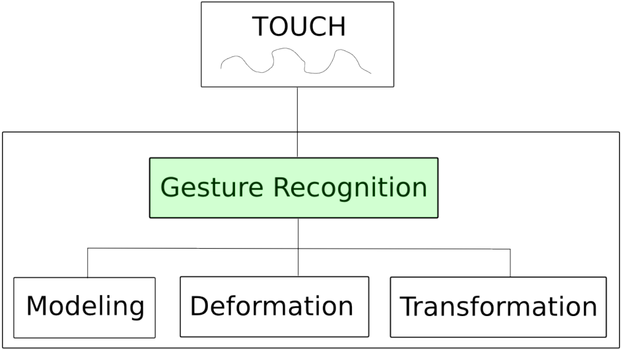
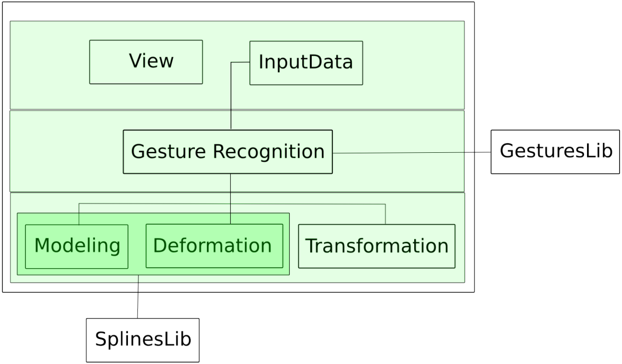
Gesture Recognition



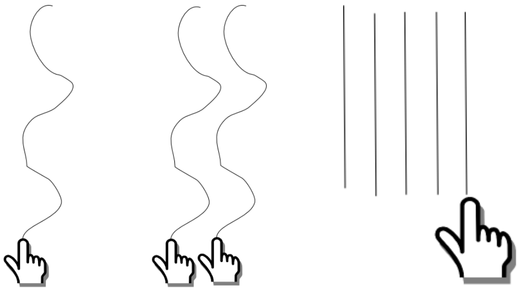
Gesture Recognition



Gesture Recognition

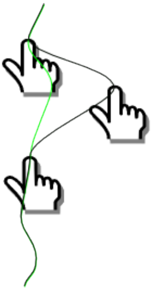
- Controller of Application;
- Gestures are interpreted to choose between modeling or deforming curves, or transforming the coordinate systems.
- Type of gestures (our classification):
  - Complete Gestures
  - Modifiers Gestures

Complete Gestures



(a) Simple (b) Parallel (c) Linked

Modifiers Gestures



Modifiers Gestures

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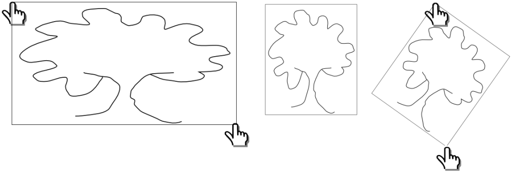


Trace Analysis

- Using discrete derivative;
  - Angle Histogram;
  - Online Analysis.
- Machine Learning Algorithms;
- Traces quantity;
- Total time of traces;

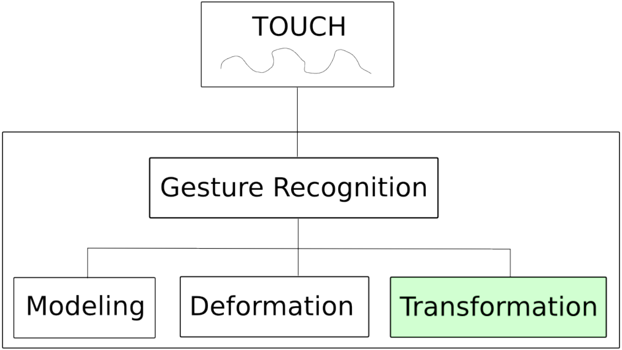
Gestures Choice: an example.

- One touch: Modeling
- Two Parallel touch:
  - If down touches in a curve: Deformation; else: space transformation.
- Two cross linked touch: Delete curve.

Gestures Choice: future work.

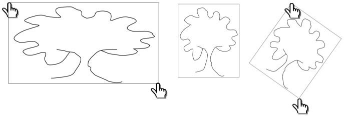
- I intend to do an experiment with people, showing some situations and ask: which natural gesture that you would do, in these situations?

Space Transforms

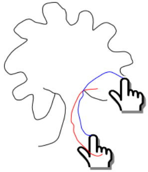


Space Transforms

- Transform the global coordinate system;
- Transform a coordinate system of a curve control points.

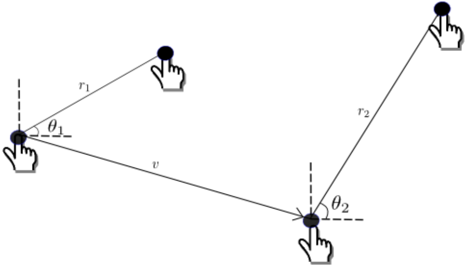


(d) Global



(e) Local

Space Transform



$$T(z) = z\frac{r_2}{r_1}e^{(\theta_2-\theta_1)i} + v$$

Modeling

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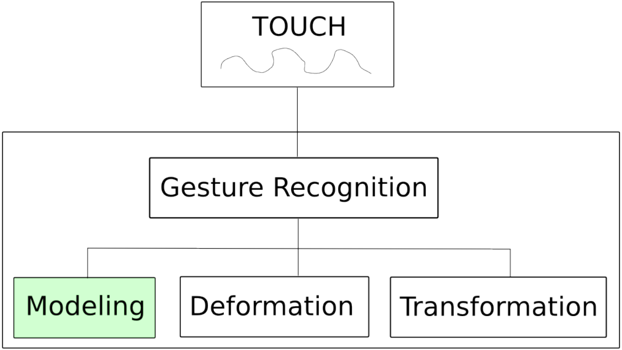

Modeling

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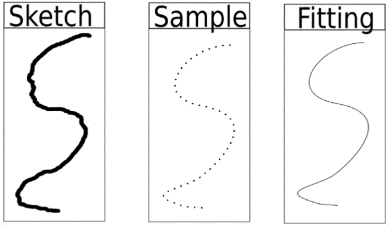
- The most direct way to trace a curve is to sketch it.
  - It is not intuitive to manipulate a sketch curve.
- Spline curves are good to manipulate.
  - Define a spline curve determining the position of control points is not intuitive.
- Splines are piecewise polinomial curves, generated by approximations of control points.

Modeling - Solution

The user's sketch is sampled and then approximated by a spline.



B-Spline curves

A b-spline curve is a piecewise polynomial, of degree $k-1$

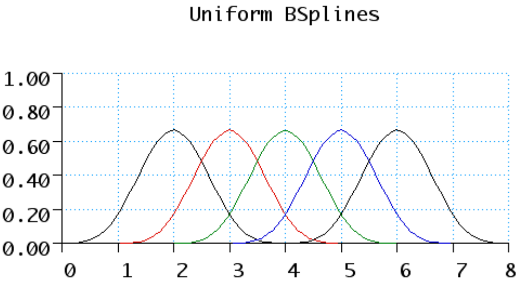
$$c(t) = \sum_{0 \leq i \leq n} P_i N_i^k(t) \tag{1}$$

- $P = [P_0, P_1, ..., P_n]$ is the vector of control points
- $N_i^k(t)$ is the b-spline function, of order k and degree $k-1$, defined by Cox-Boor Algorithm:

$$N_i^1(t) = \begin{cases} 1, x_i \leq t \leq x_{i+1} \\ 0, otherwise \end{cases}$$

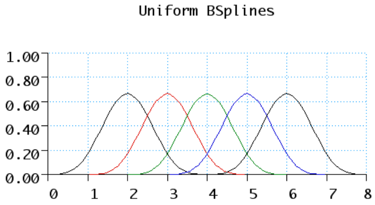
$$N_i^k(t) = \frac{(t - x_i)\, N_i^{k-1}(t)}{x_{i+k-1} - x_i} + \frac{(x_{i+k} - t)\, N_{i+1}^{k-1}(t)}{x_{i+k} - x_{i+1}}$$

Base Spline



k=3

B-Spline curves



Matrix representation:

$$c(t) = \begin{bmatrix} N_0^4(t) & N_1^4(t) & N_2^4(t) & N_3^4(t) \end{bmatrix} \begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ P_3 \end{bmatrix}$$

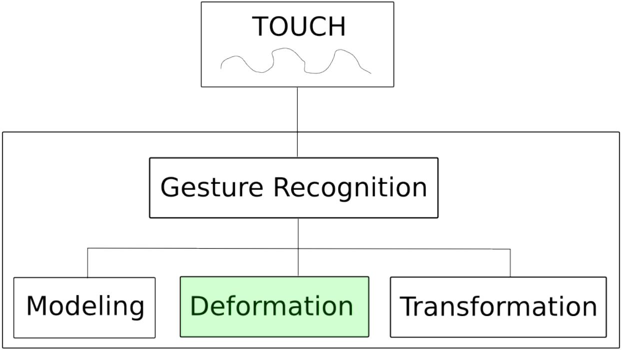
B-Spline curves

To simplify, the equation 1 can be represented as:

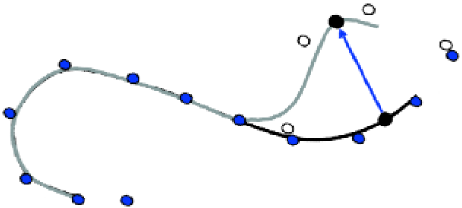
$$c(t) = N(t)[P] \quad (2)$$

where $N(t) = \begin{bmatrix} N_0^4(t) & N_1^4(t) & N_2^4(t) & N_3^4(t) \end{bmatrix}$ and $P = [P_0, P_1, P_2, P_3]$.

Deformation



Deformation



Deformation Algorithm

- First we can select a point in a curve, ie, to determine the segment and the parameter $(\tilde{t})$ of this point;
- The equation of b-spline curve segment has the form:

$$[c(\tilde{t})] = [N(\tilde{t})][P] \tag{3}$$

Deformation Algorithm

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- And, we can move these.
- So, its necessary to calculate the difference of selected point position ($\Delta c(\tilde{t})$).
- And we need solve the equation:

$$[c(\tilde{t}) + \Delta c(\tilde{t})] = [N(\tilde{t})][P + \Delta P]$$

- ie, find a variation of control points $[\Delta P]$.
- This equation can be solved by Minimum-Length Method (MLM):

$$[\Delta P] = N(\tilde{t})^T (N(\tilde{t}) N(\tilde{t})^T)^{-1} [\Delta c(\tilde{t})] \quad (4)$$

Free geometry deformation

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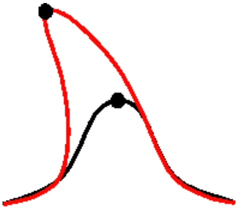


$$[\Delta P] = N(\tilde{t})^T (N(\tilde{t}) N(\tilde{t})^T)^{-1} [\Delta c(\tilde{t})]$$

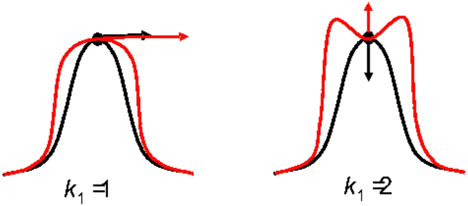
Deformation of one point

- We can calculate the derivative of $[c(\tilde{t})] = [N(\tilde{t})][P]$:

$$[c(\tilde{t})]^{(1)} = [N(\tilde{t})]^{(1)}[P]$$
$$[c(\tilde{t})]^{(2)} = [N(\tilde{t})]^{(2)}[P]$$

- And, we can modify the vector of first or second derivative.

Deformation of one point



$$[\Delta P] = [N(\tilde{t})^{(j)}]^T \left(N(\tilde{t})^{(j)} (N(\tilde{t})^{(j)})^T \right)^{-1} [\Delta c(\tilde{t})^{(j)}]$$

Deformation of one point with constraints

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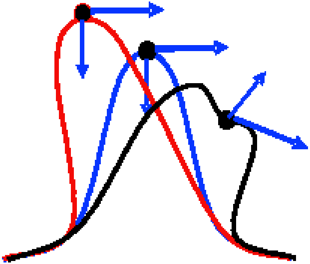
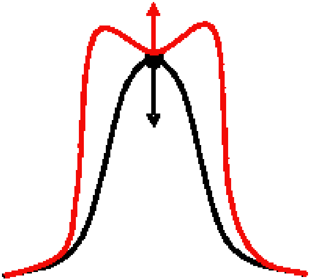
We can manipulate the position, first and second derivative simultaneously.



Deformation of one point with constraints

Example:



$$\Delta P = [N(\tilde{t})^{(j)}]^T \left(N(\tilde{t})^{(j)} (N(\tilde{t})^{(j)})^T \right)^{-1} \begin{bmatrix} 0 \\ 0 \\ c(\tilde{t})^{(2)} \end{bmatrix}$$

Deformation of several points

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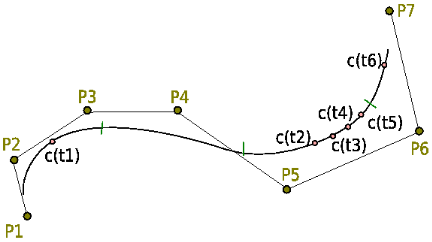


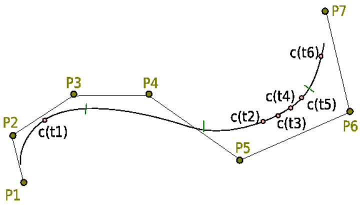
Deformation of several points

- The previous approach was showed in [2].
- But we do not find an approach to deform several points simultaneously.
- Our approach is like the Bartels and Fowler approach, ie, we use a MLM.
  - To use a MLM in equation 2 is necessary guarantee that the rows of $[N]$ are LI.

Concepts

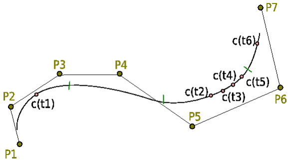
- The distance of two points is the quantity of segments between them and we will denoted by $D(p,q)$
- The set of points $c(t_1), \ldots, c(t_n)$ is ordered if: $\bar{t}_1 \leq \cdots \leq \bar{t}_n$.

Example



- Six points are chosen in four adjacent segments.
- Each $\{c(t_j)\}_{j=1,\ldots,6}$ satisfies the equation 2. Then, is possible join these six matrix in one matrix equation $[c] = [N][P]$, where:
  $[c] = \begin{bmatrix} c(t_1) & c(t_2) & c(t_3) & c(t_4) & c(t_5) & c(t_6) \end{bmatrix}^T$,
  $[P] = \begin{bmatrix} P1 & P2 & P3 & P4 & P5 & P6 & P7 \end{bmatrix}^T$

Example



Base Matrix ($[N]$):

$$\begin{bmatrix} N_1[t_1] & N_2[t_1] & N_3[t_1] & N_4[t_1] & 0 & 0 & 0 \\ 0 & 0 & N_3[t_2] & N_4[t_2] & N_5[t_2] & N_6[t_2] & 0 \\ 0 & 0 & N_3[t_3] & N_4[t_3] & N_5[t_3] & N_6[t_3] & 0 \\ 0 & 0 & N_3[t_4] & N_4[t_4] & N_5[t_4] & N_6[t_4] & 0 \\ 0 & 0 & N_3[t_5] & N_4[t_5] & N_5[t_5] & N_6[t_5] & 0 \\ 0 & 0 & 0 & N_4[t_6] & N_5[t_6] & N_6[t_6] & N_7[t_6] \end{bmatrix}$$

Example

$$\begin{bmatrix} c(t_1) \\ c(t_2) \\ c(t_3) \\ c(t_4) \\ c(t_5) \\ c(t_6) \end{bmatrix} = \begin{bmatrix} N_1[t_1] & N_2[t_1] & N_3[t_1] & N_4[t_1] & 0 & 0 & 0 \\ 0 & 0 & N_3[t_2] & N_4[t_2] & N_5[t_2] & N_6[t_2] & 0 \\ 0 & 0 & N_3[t_3] & N_4[t_3] & N_5[t_3] & N_6[t_3] & 0 \\ 0 & 0 & N_3[t_4] & N_4[t_4] & N_5[t_4] & N_6[t_4] & 0 \\ 0 & 0 & N_3[t_5] & N_4[t_5] & N_5[t_5] & N_6[t_5] & 0 \\ 0 & 0 & 0 & N_4[t_6] & N_5[t_6] & N_6[t_6] & N_7[t_6] \end{bmatrix} \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \\ P7 \end{bmatrix}$$

- Note that by Cox-Boor algorithm the base $N_j(t_i)$ is equal to zero when t varies out off the support of the function
- Because of this, $N_j(t_i) = 0$ if $j < D(c(t_1), c(t_i))$ or $j > D(c(t_1), c(t_i)) + 4$.

Theorem 1

Taken $c(t_1), \ldots, c(t_n)$ different ordered points in a curve of degree k, if for all $j \leq k+1$ any subset $\{c(t_i), \ldots, c(t_{i+j})\}$ satisfies $j \leq D(c(t_i), c(t_{i+j})) + k$ then the positions of these points can be manipulated by MLM.

Discussing Theorem 1

- When satisfied the assumptions of Theorem 1, we can guarantee the solution to the problem of manipulation of the position of points by MLM.
- This test has complexity $O(n)$.
- If the set of manipulated points not satisfy this theorem, we can insert control points in segments, in such a way that does not change the geometry of the curve. Thus, the new matrix of the base attends the assumptions of the theorem.
- The Theorem 1 include cases as the manipulation of two chosen points are independent. We will discuss when this occurs, in following theorem.

Theorem 2

- *Taken a uniform b-spline curve of degree k, and a set of n ordered points $X = \{c(t_1), \ldots, c(t_n)\}$ if some pair of adjacent points $c(t_i)$ and $c(t_{i+1})$ are such that $D(c(t_i), c(t_{i+1}) > k$ then the manipulation problem can be sub-divided in isolated minor problems.*

Discussing Theorem 2

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- Based on Theorem 2 we can divide a manipulation problem in several minor problems, when two adjacents points satisfy $distance(P_i, P_{i+1}) > k$.
- This procedure is good to reduce the quantity of the calculations on MLM. Furthermore, the matrix N, in this case, would have a high degree of sparse and may increase the runtime.

Discussing MLM

- There are some cases, than those already presented in the theorem, that is possible to use the MLM. We can cite if the user manipulate in two points, the position and the first derivative. In this case, the base matrix will be LI, so is possible use the MLM.
- When the MLM is not possible to solve (2) we can use the Least-Square Method (LSM). This result is an aproximated solutions.
- A generic solution for this problem is not possible using MLM. In fact, this is an Hermite Birkoff Interpolation Problem. An indepth discussion can be found in [3].

Ideas

- To use Hermite Birkoff Interpolation to solve a generic deformation with constraints.
- To use mulresolution to deformation curves.
- To generate surfaces from curves.
- To manipulate a curve on a surface.
- To create a multitouch modeling system with stereoscopic visualization.

Thank you!!!

References

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