Haptic Surface Manipulation

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Overview

- Review
  - Applications of Surface Manipulation
    - Simulation versus Design
    - Level of Control
  - Existing Methodologies and Implementations
- Issues With Novel Interfaces
  - Data Structure Implications
  - User Interface and Physical Interface
- A Novel Touch-Enabled Interaction Method

Surface Manipulation

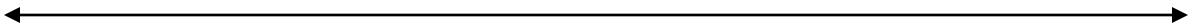
- What for ?
  - Medical Applications
  - Entertainment
    - Movies
    - Videogames
  - Design and Manufacturing
    - Fashion
    - Electronics, Appliances
    - Automotive

Simulation Versus Design

Medical Applications

Entertainment

Manufacturing



Simulation

Design

Simulation: How Realistic ?

Entertainment

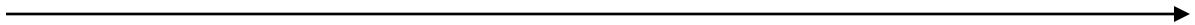
Medical Applications

Believable

Accurate reproduction

Design: How Accurate ?

Entertainment Manufacturing



Accuracy,
Level of control

Level Of Control

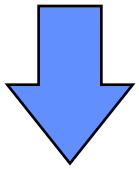
- Function of application
  - Critical for Manufacturing
- Exactly the designer intent
  - Not just a good shape, but the desired shape
- Quality
  - Accurate, fair, smooth

Design And Manufacturing

- Data structure/User interface
- Physical/Digital
- Issues with force-feedback interfaces
- Overview of existing methods/packages
  - providing force-feedback interaction

Different Data Representations

- Traditionally:
  - Voxmaps (CFD)
  - Tessellated meshes (CAE, CFD)
  - Free-form surfaces (CAD)



- Boundaries are getting fuzzier!
- User-Interface as the New Differentiator

Clay as a Data Structure

- Clay is not entirely “free-form”!
  - Clay is just a medium
  - Different interfaces and levels of control:
    - CNC machines
    - Tools to trace arcs and straight lines
    - Free-hand
- Main issues with clay are lack of integration and poor reusability

Force-feedback Interfaces

- What is unique about using force-feedback?
- Does it add “value” ?
- What if it is turned-off ?
  - Passive manipulation using 3D mouse
    - Magellan™, MicroScribe™

Force-feedback Interfaces

- Better sense of space
- Better hand-eye coordination
- Clay-like “feeling”

- Poorer control ?
  - Lack of data on human perception
    - Lederman, Klatzky, Tan, Srinivasan, …

Force-feedback Interfaces

- Quality of interaction
  - function of computational refresh rate
  - haptic device structure/bandwidth

- Clay Buck: multi-fingered, two handed, dexterous manipulation

Overview of Methods/Applications

- FreeForm
  - SensAble Technologies
- inTouch
  - Gregory, Ehmann, Lin
  - University of North Carolina
- D-NURBS Haptic Sculpting
  - Dachille, Qin, Kaufman, El-Sana
  - State University of New York at Stony Brook

FreeForm™

- Voxmap based
- Clay like paradigma
- Math modeling tools
- Surfacing tools
- Commercial package (SensAble)

inTouch

- Polygonal-mesh based
- Multi-resolution
- Painting & Sculpting
- Mesh collision detection (H-Collide)
- Slide-mode / Stick-mode
- Research platform (U. North Carolina)

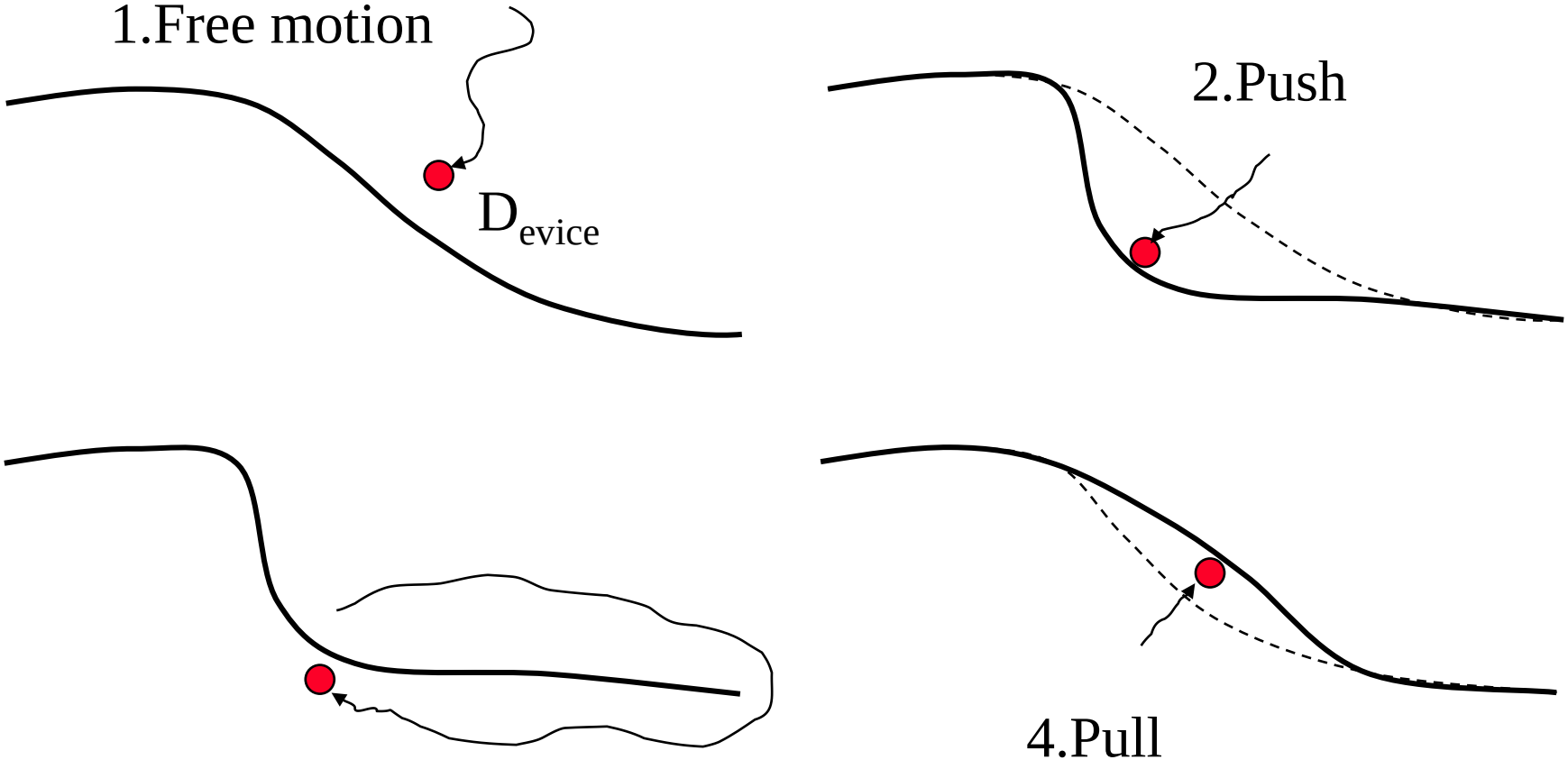
D-NURBS Haptic Sculpting

- D-NURBS Based
- Physical modeling
- Mass-points
- Rope tool

Surface Sculpting

- Physical Approach
  - Push / Pull
  - Add / Remove
- Abstract Approach
  - Rope tool
  - Slide to / Stick to

Push / Pull Implementation



Stick-to-surface/Stick-to-pen

- The user interface is constrained to follow the surface contour (Browsing) and at the same time the surface is manipulated to follow the user's motion (Sculpting).
- This method was initially developed to sculpt rational B-splines.

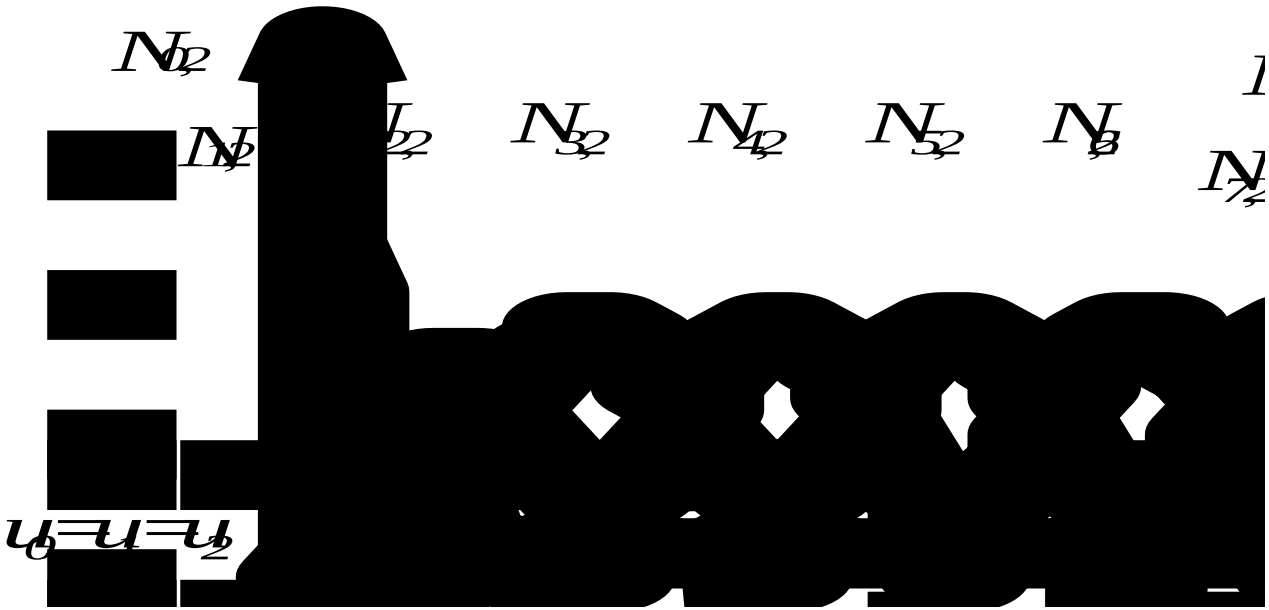
NURBS Surfaces

- A non-rational, non-periodic, B-spline surface is defined by the following:

$$S(u,v) = \sum_{i=0}^{n} \sum_{j=0}^{m} N_{i,p}(u) N_{j,q}(v) \mathbf{P}_{i,j}$$

- where the basis functions $N_{i,p}(u)$, $N_{j,q}(u)$ are piecewise polynomials of order p and q respectively, recursively defined over two sets of non-decreasing knot sequences in the parametric domain, respectively, $u_0,\ldots u_n$, and $v_0,\ldots,v_m$.

NURBS Surfaces

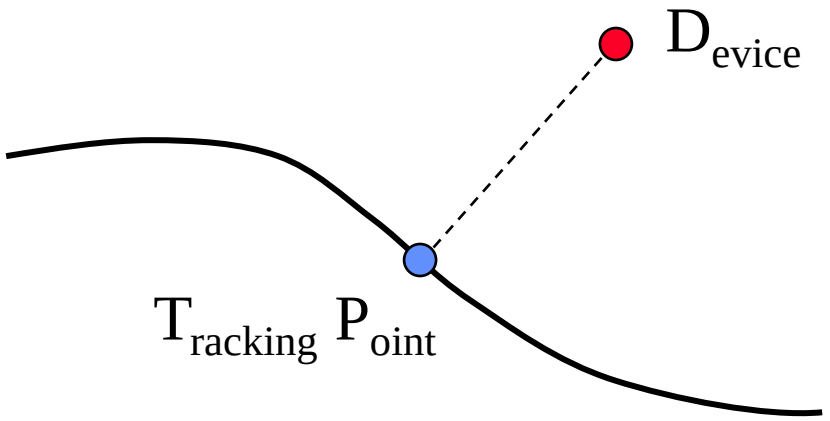


- Knots, basis functions and basis-maximum-points for a 3rd order B-spline.

Browsing and Sculpting

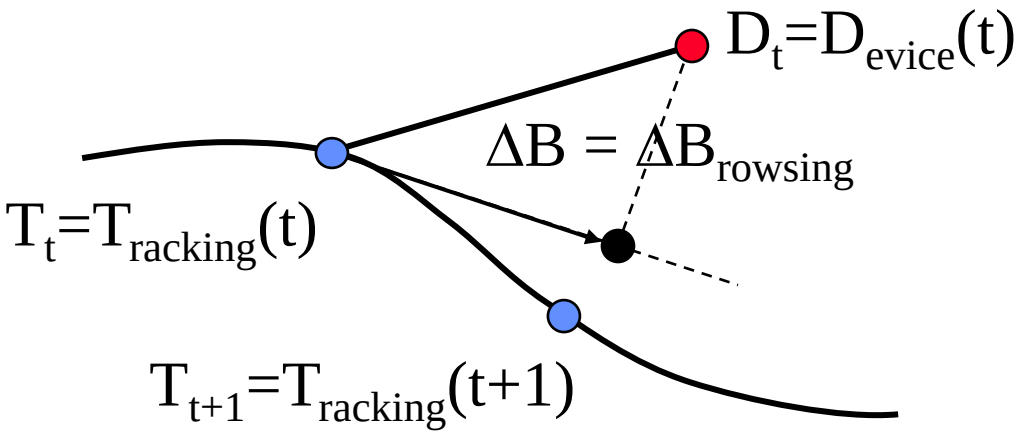
1. Motion in the Browsing Space determines the new interaction/tracking point.
2. Motion in the Manipulation Space determines the new shape of the surface.
3. The trade-off between "who's tracking who" is achieved by decomposing the Cartesian space into the manipulation and browsing orthogonal subspaces.

Browsing



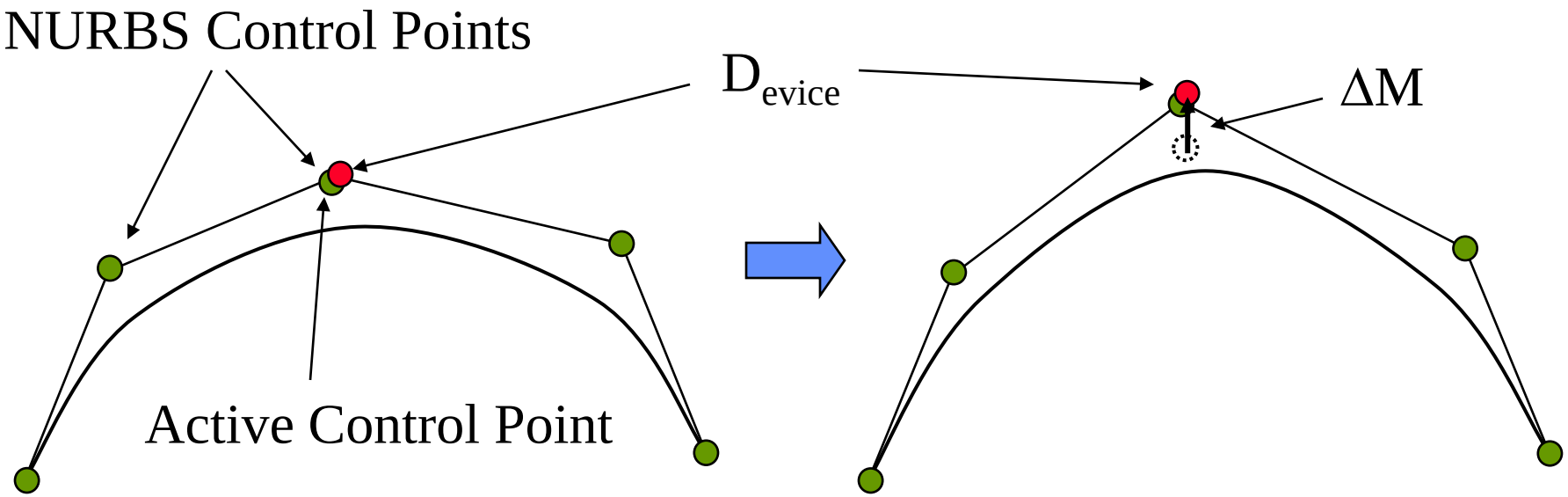
- Goal: find point on surface in contact with haptic device
  - Closest Point, Interaction Point, Constrained Position
  - GOD point – Salisbury, Zilles
  - Proxy – Ruspini, Kolarov
  - Tracking Point – Thompson, Cohen

Browsing



- FRL: Combination of Newton-Raphson, & others
- Linear Approximation, Thompson, U. of Utah

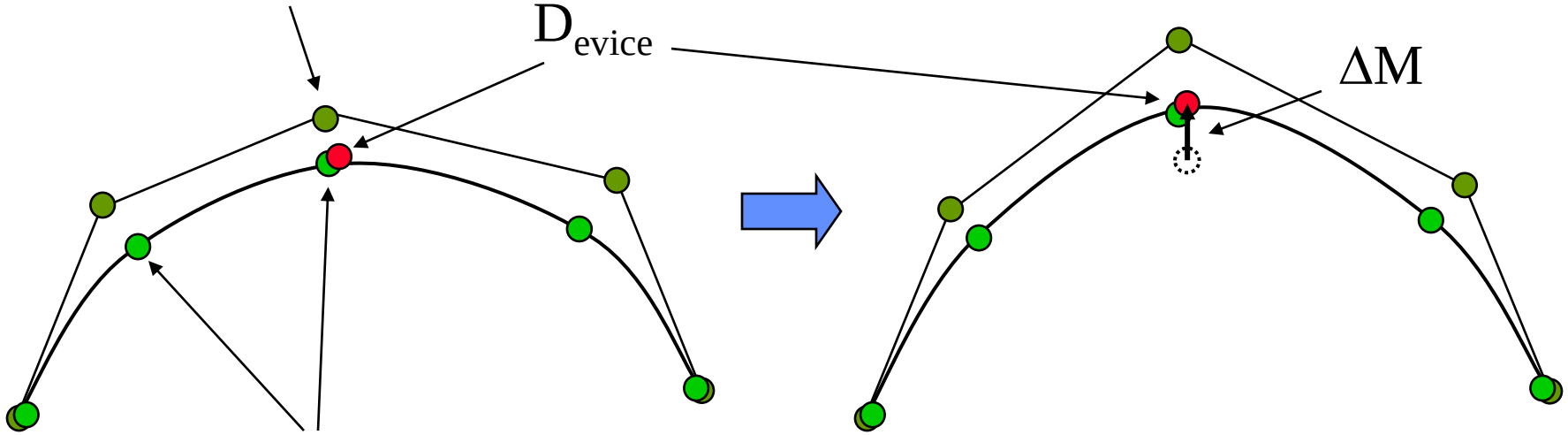
Sculpting



- Direct manipulation of Control Points

Sculpting

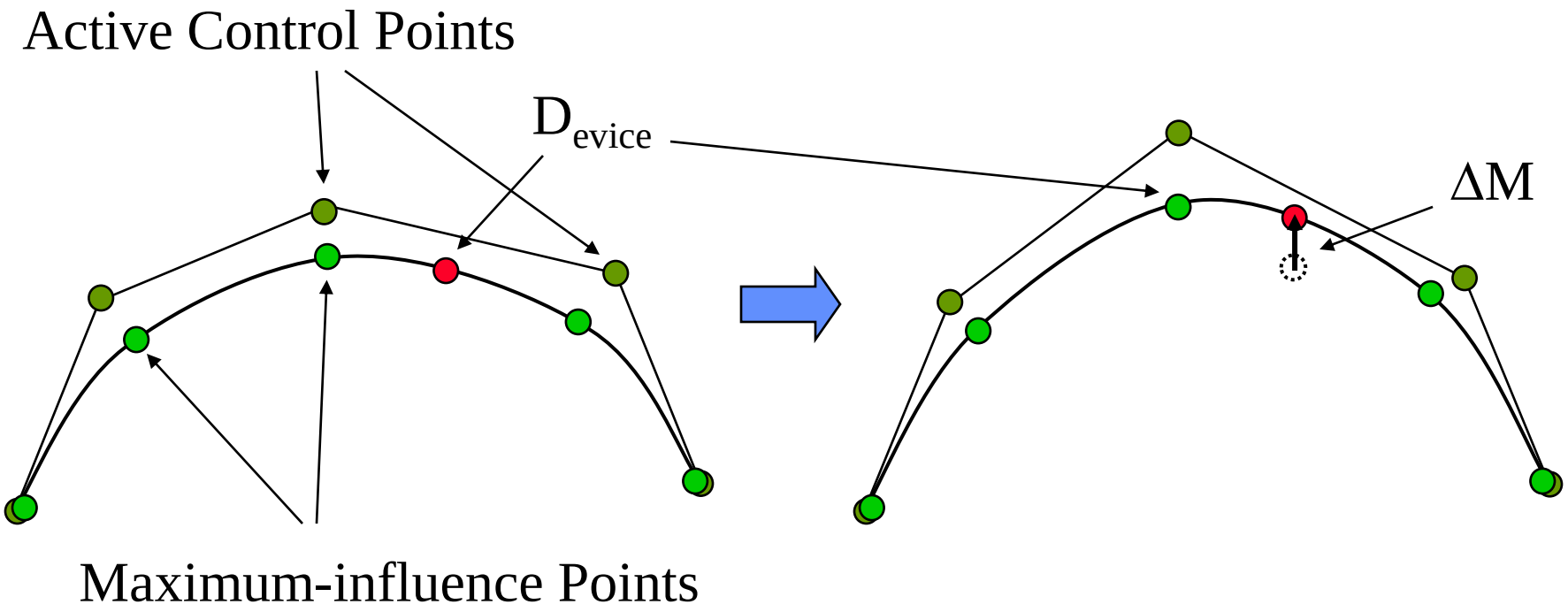
Active Control Point



Maximum-influence Points

- Manipulation at the Maximum-influence Points

Sculpting



- Manipulation of multiple control points
  - More details in P.Buttolo, P.Stewart, Y.Chen, “Force-enabled sculpting of CAD models,” ASME DCS, Orlando, Nov 2000

PD Manipulation Loop

- *Update the surface:*

$$S_{t+1}(u,v) = S_t(u,v) + f_m(\Delta M)$$

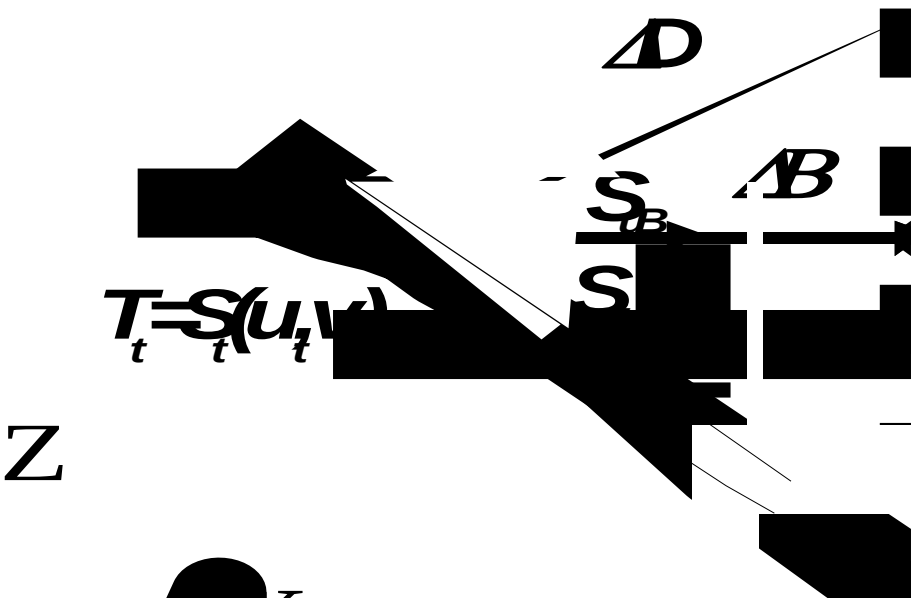
- *One-Step manipulation:*

$$f_m(\Delta M) = \Delta M$$

- *PD Control*

$$f_m(\Delta M) = K_P \Delta M + K_V \Delta M$$

Space Decomposition



- Example:
  Browsing on X,
  Sculpting on Z

  $\Delta D = \Delta B + \Delta M$

- One way of finding browsing and editing motion is to use projection matrices.
- For example, these are for Editing Space: Z and Browsing Space: X

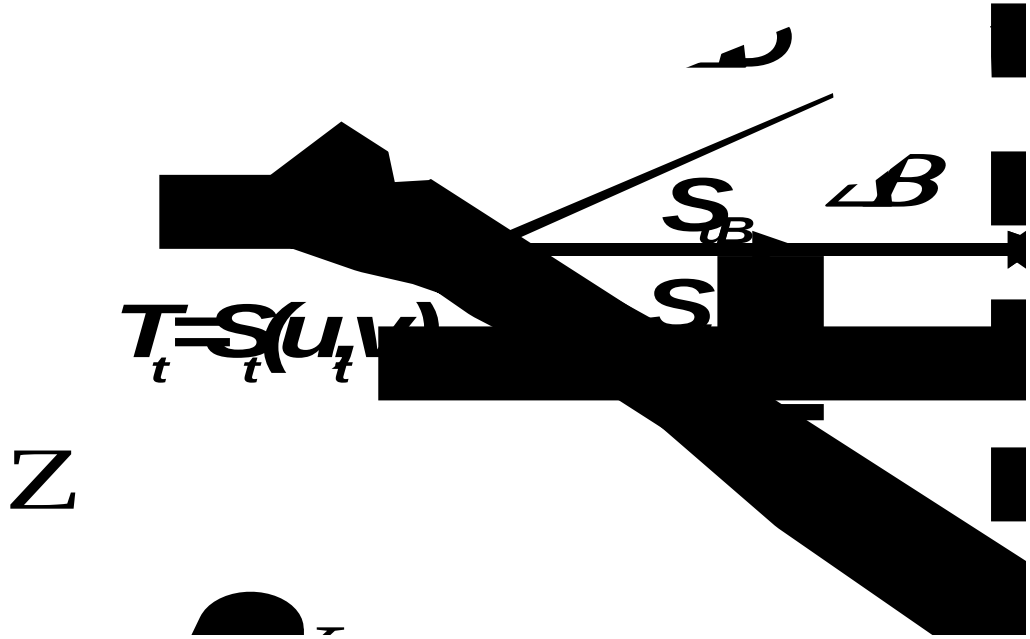
$$M_M = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\Delta\mathbf{M} = M_M \Delta\mathbf{D} = \begin{pmatrix} 0 & \Delta D_z \end{pmatrix}^T$$

$$M_B = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

$$\Delta B = M_B \Delta\mathbf{D} = \begin{pmatrix} \Delta D_x & 0 \end{pmatrix}^T$$

Projecting Motion on Browsing Subspace



$$\frac{\Delta B_u}{\Delta B} = \frac{S_u}{S_{uB}}$$

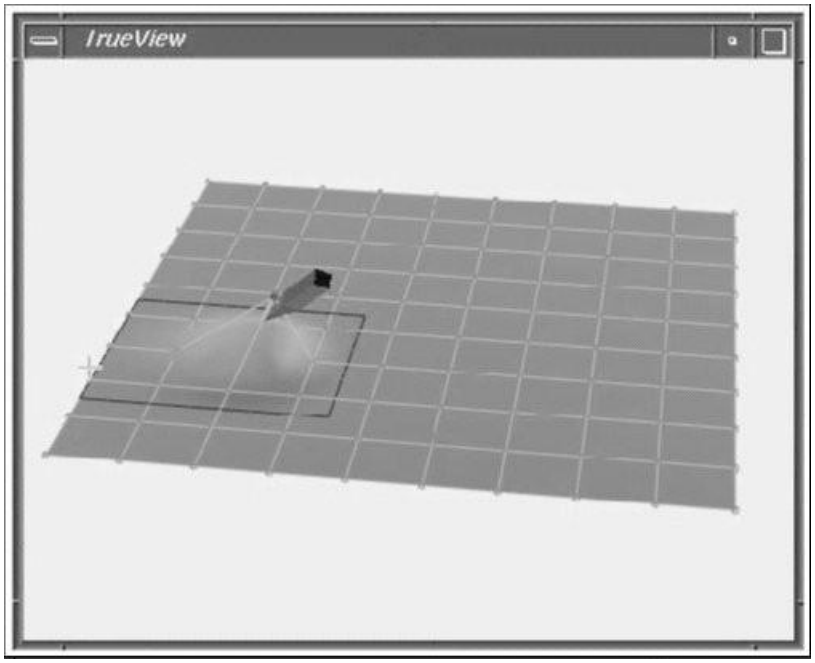
$$\Delta B_u = \Delta l$$

Sculpting surface at the tracking point

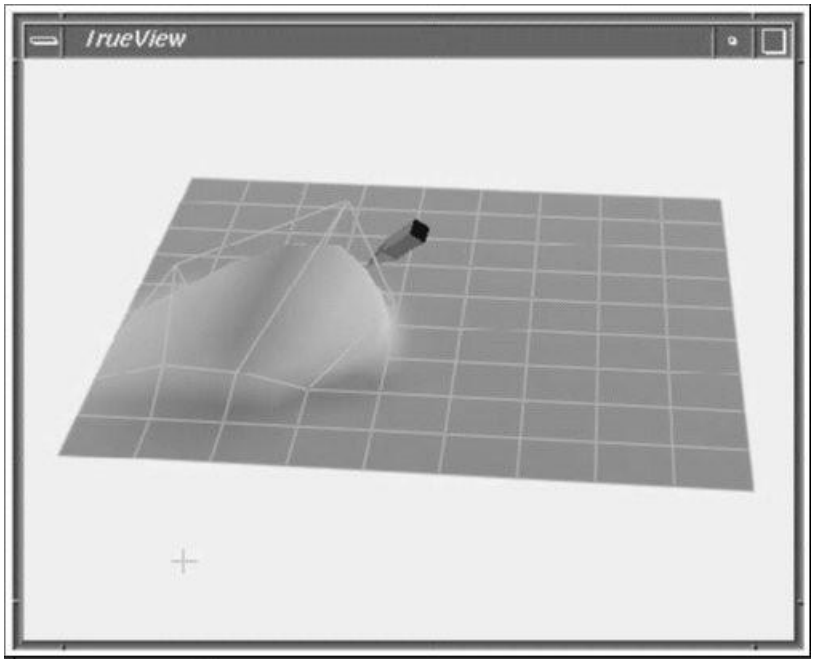
- Convergence speed for three difference control gains

A Few Examples of Manipulation

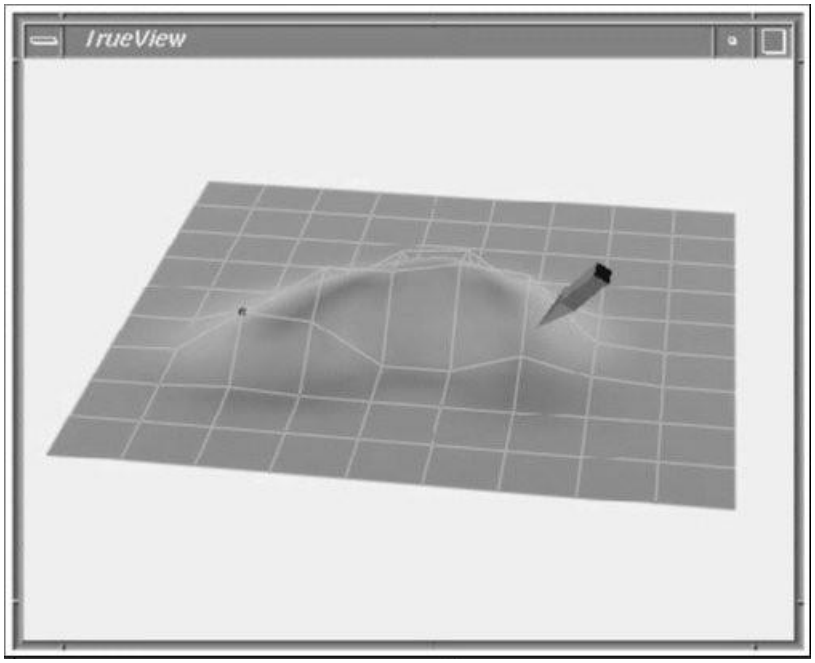
- Movies:
  1. Direct Manipulation of Control Points
  2. Editing Space: Normal, Browsing Space: Tangent
  3. Editing Space: Z, Browsing Space: X,Y
  4. Editing Space: Z, Browsing Space: X
  5. Editing Space: Y, Browsing Space: X
  6. Editing Space: Y,Z, Browsing Space: X
  7. Averaging by Repeated Motion
  8. An Example of More Complex Manipulation



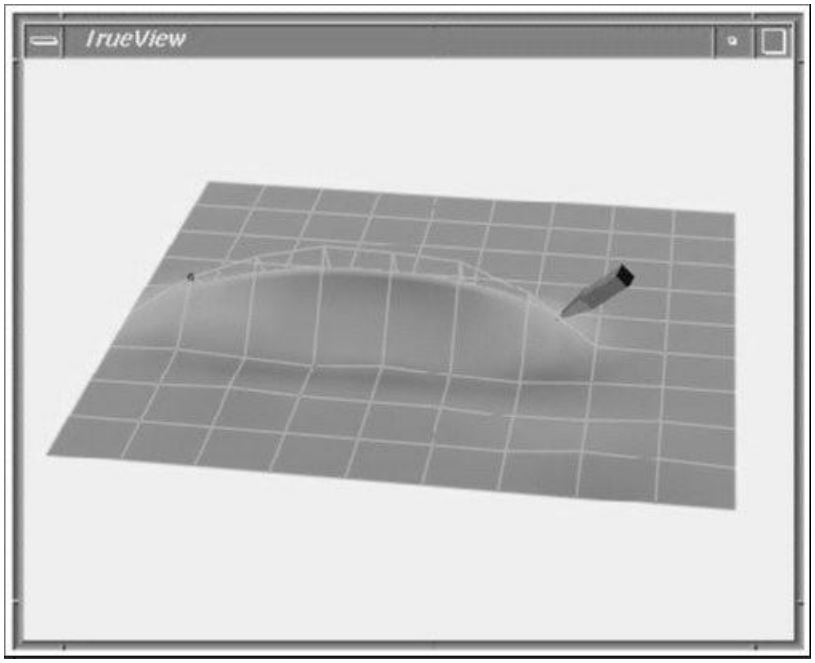
Direct Manipulation of Control Points



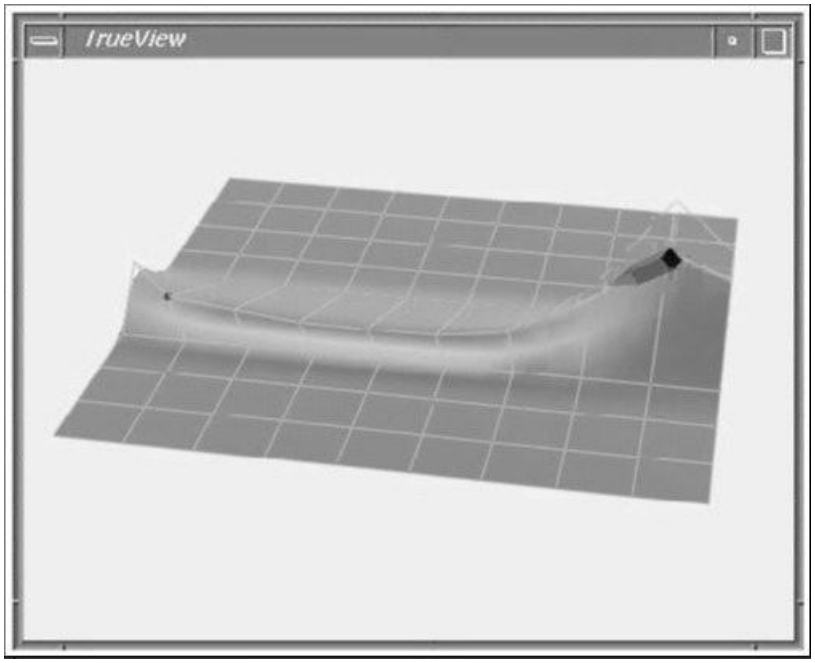
Editing Space: Normal, Browsing Space: Tangent



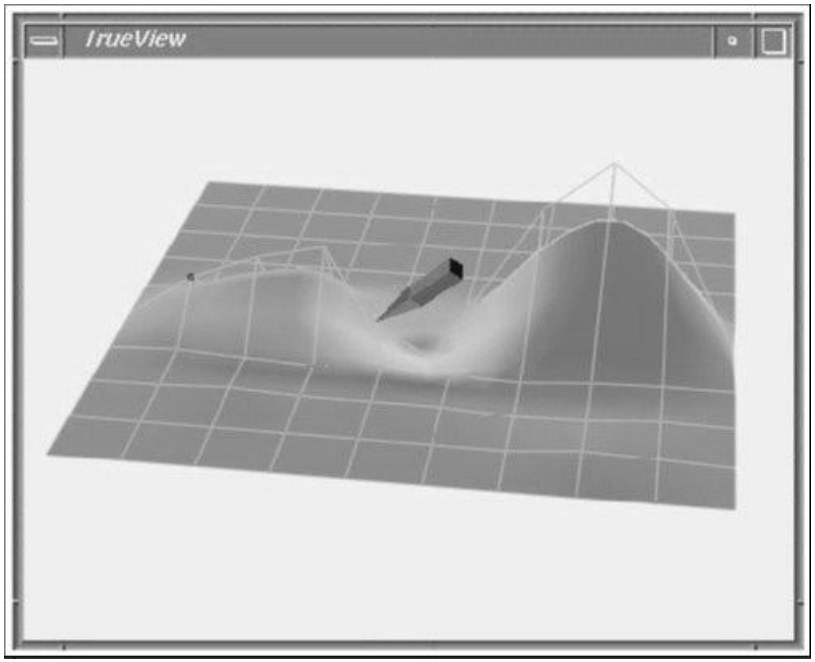
Editing Space: Z, Browsing Space: X,Y



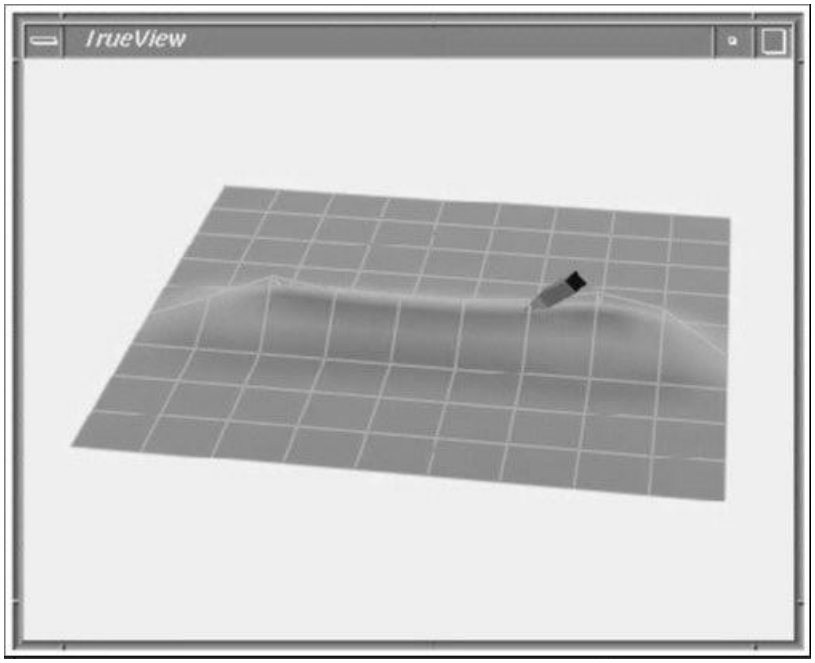
Editing Space: Z, Browsing Space: X



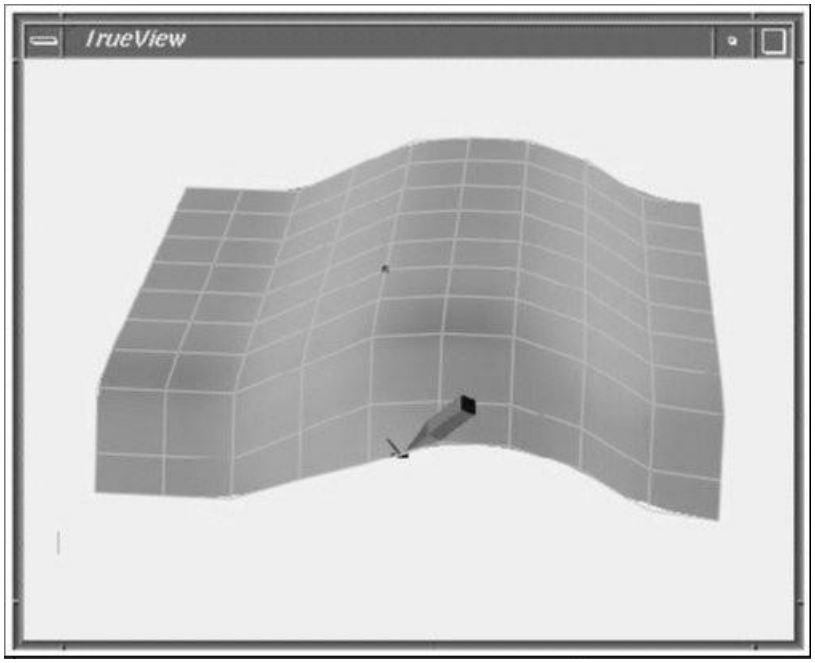
Editing Space: Y, Browsing Space: X



Editing Space: Y,Z, Browsing Space: X

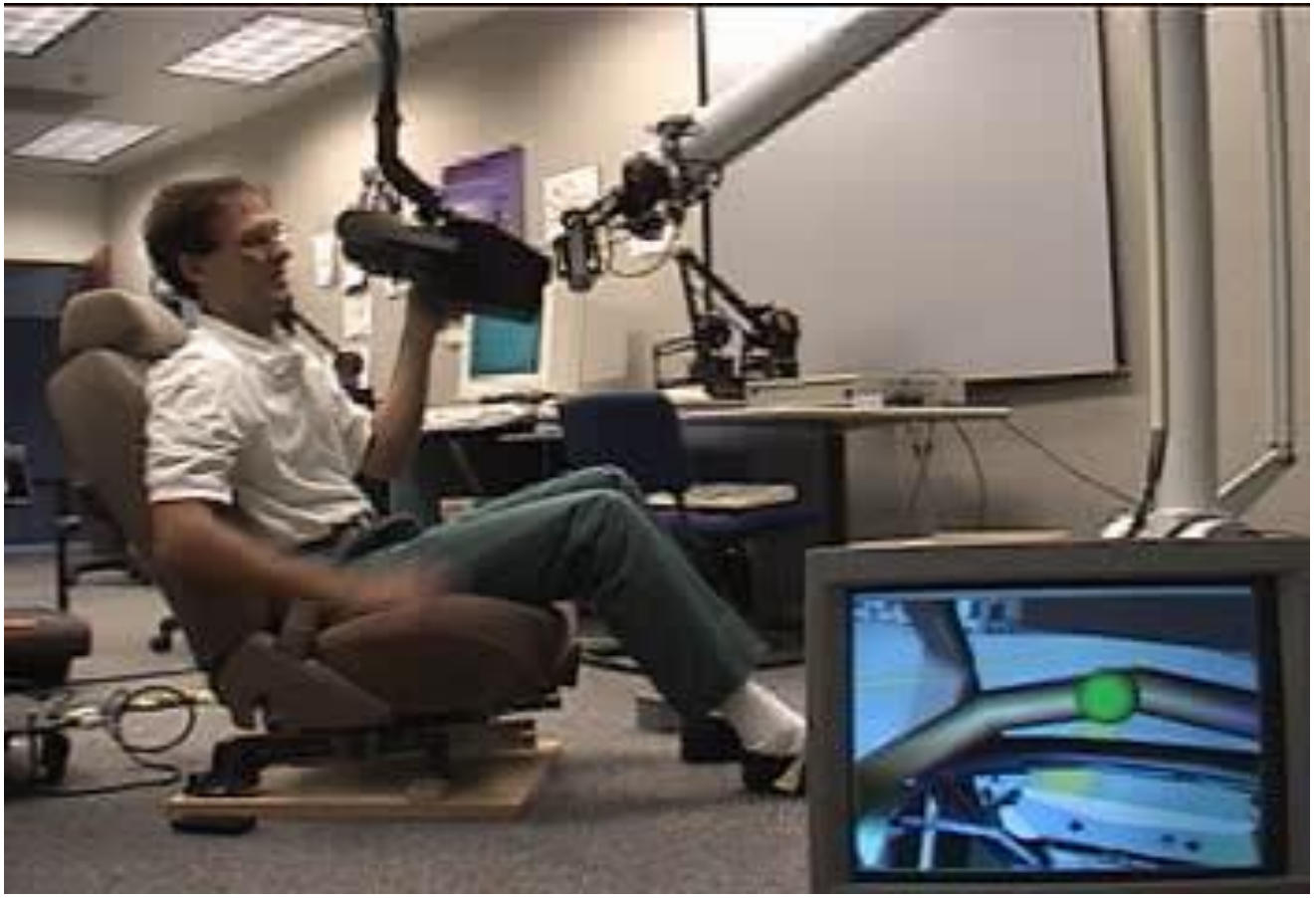


Averaging by Repeated Motion



An Example of More Complex Manipulation

Other Research at FRL: The Haptic Buck



More details in P.Stewart, P.Buttolo, “Putting People Power Into Virtual Reality,” Design 2000, Special Issue of ASME Mechanical Engineer Design, http://www.memagazine.org/medesign/putting/putting.html