Scanning Physical Interaction Behavior of 3D Objects

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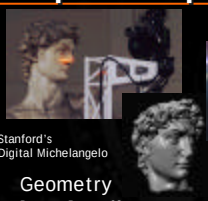
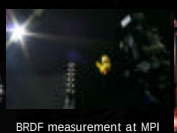
Traditional Focus of Scanning in Computer Graphics



Stanford's
Digital Michelangelo

Geometry
Bouguet Perona 98
Curless Levoy 96
Hoppe et al 94
Levoy et al 00
Roth Wibowoo 97
Sato et al 1997
Cyberware, NRCC
...
many companies...



BRDF measurement at MPI

Reflectance
Dana et al 99
Debevec et al 00
Greenberg et al 97
Lensch et al 01
Rushmeier et al 98
Sato et al 1997
...

Motion capture
Popovic Witkin 99
Zordan Hodgins 99
...
very many companies...

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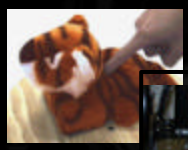
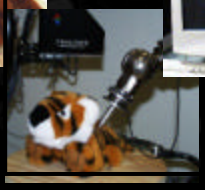
Our Focus: Scanning Contact Interaction Behavior





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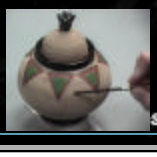
Overview

ACME, a robotic facility for scanning contact behavior

Scanning

- contact deformation models
- contact texture models
- contact sound models



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ACME

The UBC Active Measurement Facility

[Pai,Lang,Lloyd,Woodham '99]

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Preview: Scanning Contact Friction

Video

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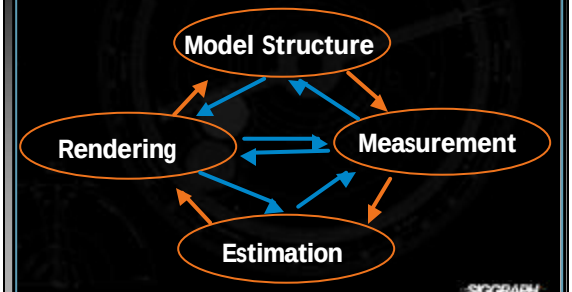
A Framework for Scanning Reality-based Models



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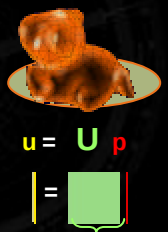
Scanning Deformation Behavior

Model Structure: Green's Functions

Linear Elastostatic Model
+Reference boundary conditions
Green's functions U relate
u, vertex displacements to
p, applied vertex tractions

Can be computed analytically *if* material distribution is known
e.g., [JamesPai99, Cotin et al 96,…]



Green's Functions

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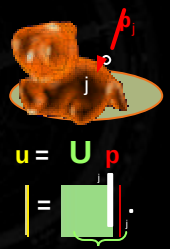

Green's Functions

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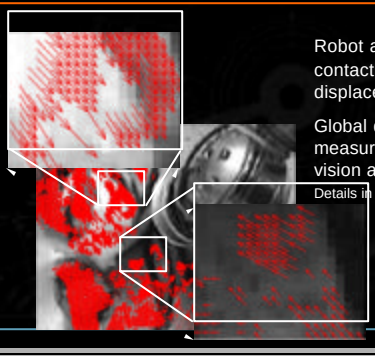
Measurement



Robot arm measures contact force and local displacement

Global displacement measured with stereo vision and range flow
Details in [LangPai01]

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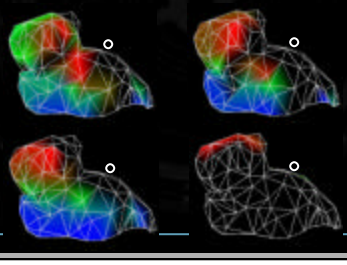
Parameter Estimation

- Excite vertex *j* with several p_j^k
  estimate vertex displacement u_i^k from range flow



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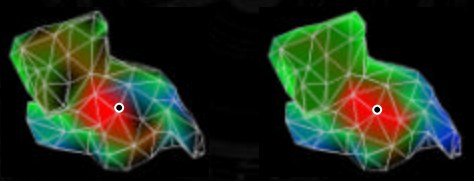
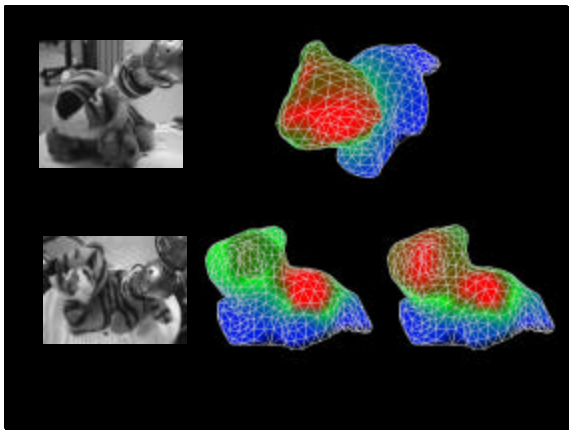
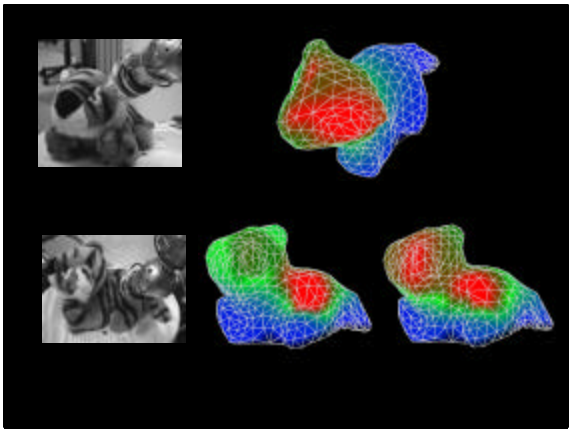
Parameter Estimation

- Estimate U_{ij} robustly using TSVD, TLS
- Interpolate missing observations







Results

Interactive Rendering Demo

Rendered using capacitance matrix algorithm with haptic force computation at 1KHz
[JamesPai99, JamesPai01]

Scanning Contact Texture

What is Contact Texture?

Physical parameters relevant to haptic texture perception [Lederman Klatzky]

Texture = friction + roughness + …

Model should support fast simulation for haptics (1 KHz) and audio (44.1 KHz)

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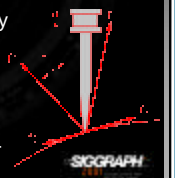
Friction

Model: Coulomb Friction $f_t = -m \, | f_n | \, u$

Measurement:

- Easy for small sample
- Hard for general object: uncertainty in surface normal, adaptation
- We use differential measurement technique for robust estimation



Estimate: normal and friction together

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Roughness

Traditionally » small scale variation in surface geometry

Our model: small scale variation in friction

- Equivalent to traditional model, for frictional contact
- Unifies friction and roughness haptic rendering

Statistical process models effective for many surfaces [Thomas 82, Perlin]

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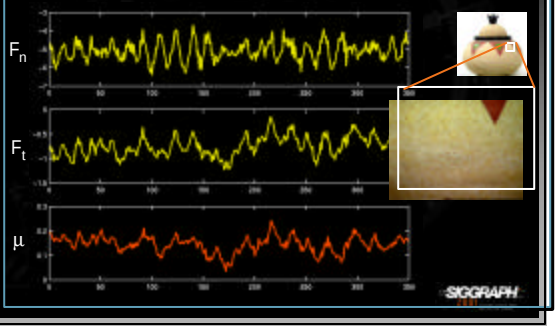
Example: Clay Pot



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Roughness

Model structure: AR(p) autoregressive model

$$m_e(x) = m + \tilde{m}(x)$$

$$\tilde{m}_k = \sum_{i=1}^{p} a_i \tilde{m}_{k-i} + se_k$$

- Captures randomness plus periodicities
- Small p sufficient for most surfaces

Estimate parameters: using covariance method

Rendering: Discrete convolution

Extremely fast and simple

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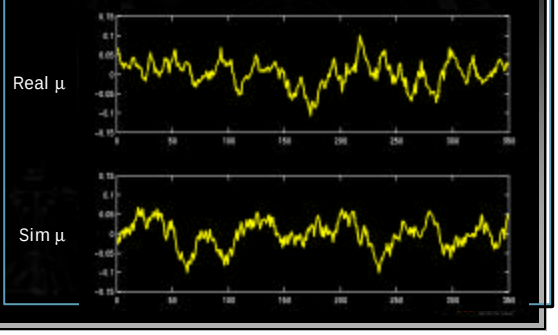
Real vs. Simulated Clay Pot



Scanning the Clay Pot

Contact Texture Modeling

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Scanning Contact Sounds

Contact Sounds

- Provide cues of contact shape, location, force, and object material
- "Foley sounds" in radio and cinema
- Integrated with Simulation and Interaction [O'BrienCookEssl, DoelKryPai, Friday]
- and room acoustics [e.g., Tsingos et al., Friday]

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Model Structure

- Modal Synthesis [e.g., Doel&Pai 96-01, Cook 96]
- Impulse response model at boundary vertex

$$p(x,t) = \sum_{i=1}^{M} a_i(x)\, e^{-d_i t} \sin(2\pi f_i t)$$

- f_i is frequency of a vibration mode
- d_i is frequency-dependent damping
- Texture map $a_i(x)$ onto object surface

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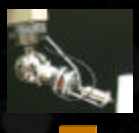
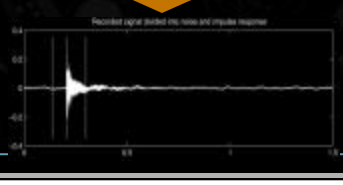
Measure Impulse Response





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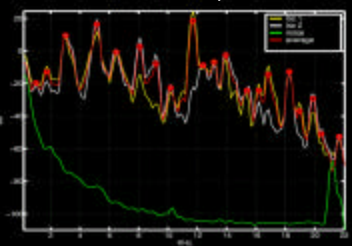
Estimate Parameters

First estimate modal frequencies f_i



Refine frequencies + estimate a_{ik} , d_i

[SteiglitzMcBride65, BrownPuckette93]

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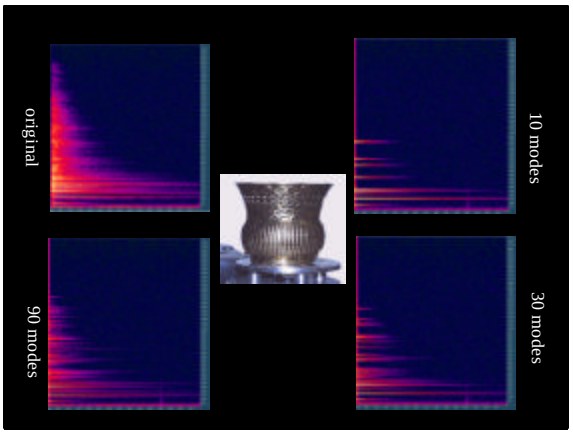

Rendering

Generate contact force at audio rates

- depends on contact texture, nominal force, and velocity
  [see DoelKryPai paper on Friday]

Convolve with audio impulse response

- efficient using modal resonator filter bank (4 flops/mode/sample)
- smoothly interpolate audio parameters $a_i(x)$ from mesh vertices

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Scanning the Clay Pot

Video

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Conclusions

It is now possible to scan multi-modal models of contact interaction behavior

Scannable behavior includes

- deformation (visual and haptic)
- friction and roughness texture
- sound response

Can be automated with ACME, a robotic measurement facility

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The Future?

Multi-modal virtual environments, with visual, auditory, and haptic interaction

A digital "Model Foundry"

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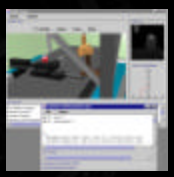
Demos at the CAL

- Telerobotics: measure an object in Vancouver with ACME
- Interaction with scanned models using force feedback and sound
- Times:

Wed & Thu 4 - 6 pm
Thu & Fri Noon - 2 pm



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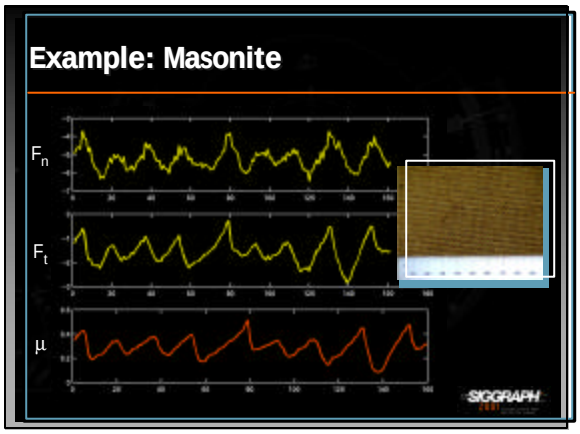
Example: Masonite
F_n
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