

# Digital Surgery

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## Motivation

### Laparoscopic Surgery



- Advantages**
- Minimized trauma
  - Shorter hospital stays
- Challenges**
- Poor depth perception
  - Restricted field of vision
  - Unnatural hand-eye coordination
  - Limited force feedback
  - Extensive practice required

### Simulated Surgery for Training and Planning

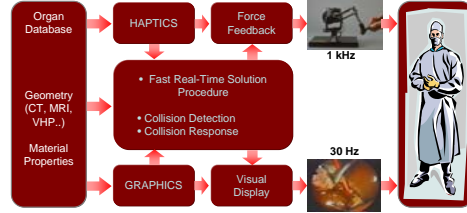


- Advantages**
- Realistic virtual experience
  - No need of human cadavers
  - No use of animals
- Challenges**
- Computationally intensive (Force calculations at 1000 Hz, rendering of complex insides at 30 Hz)
  - Nonlinear Viscoelastic response or organ tissues.

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## Digital Surgery: Concept and Challenges

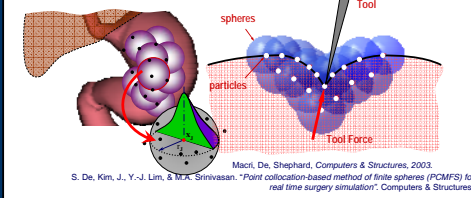
- Real time graphics update ~30Hz
- Real time haptics update ~1kHz!
- Complex soft tissue response
- Complex tool-tissue interaction



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## PAFF: Point Associated Finite Field

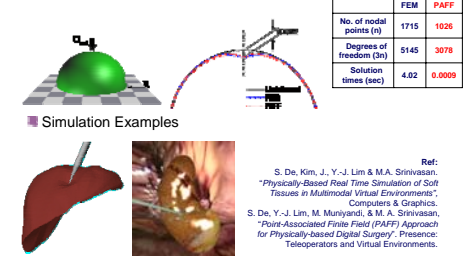
- Sprinkle nodes on the domain (Octree-based technique)
- Interpolate using MLS functions compactly supported on spheres
- Point collocation obviates numerical integration



MacI, D., Shephard, Computers & Structures, 2003.  
S. De, Kim, J., Y.-J. Lim, & M.A. Srivivasan. "Point collocation-based method of finite spheres (PCMFS) for real time surgery simulation." Computers & Structures.

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## Simulation Results



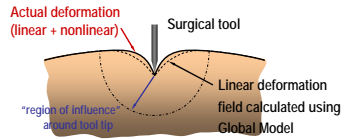
### Simulation Examples

Ref:  
S. De, Kim, J., Y.-J. Lim & M.A. Srivivasan. "Physically-Based Real Time Simulation of Soft Tissues in Multimodal Virtual Environments". Computers & Graphics.  
S. De, Y.-J. Lim, M. Munyandi, & M. A. Srivivasan. "Point-Associated Finite Field (PAFF) Approach for Physically-based Digital Surgery". Presence: Teleoperators and Virtual Environments.

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## Nonlinear Tissue Modeling

- Tissue response is highly nonlinear
- Fine resolution required for displaying deformations and forces around the tool-tissue contact region
- High resolution not necessary for regions far away

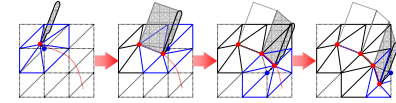


$$\text{Response in the vicinity of tool tip} = \text{Global response (linear model)} + \text{Local correction (nonlinear)}$$

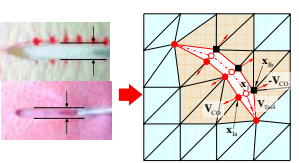
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## Surgical Cutting

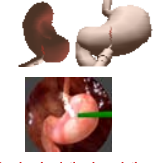
### Geometric node snapping - no new primitives, allows progressive cut



### Applying Cut Opening Displacement from Experiments



### Real-time Simulation results



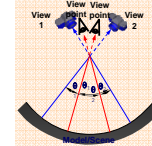
Smoke simulation by solution of Navier-Stokes equations

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## Image Based Rendering

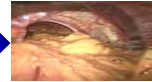
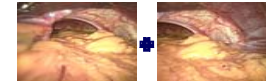
### View Dependant Texture Mapping

Synthesizing novel viewpoint images from the photographs from known viewpoints



### Image Mosaicing

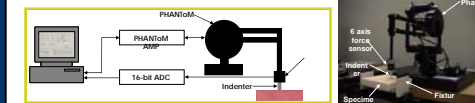
Collecting images, Registration, Compositing, and Eliminating Seams



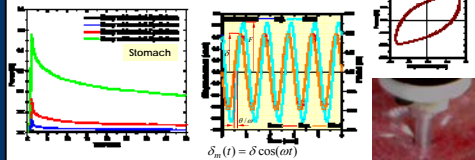
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## Experiments: Mechanical Property Determination

### Experimental Setup



### Results for Ramp and hold experiments



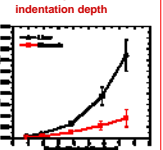
$$\delta_m(t) = \delta \cos(\omega t)$$

$$F_m(t) = F \cos(\omega t + \theta)$$

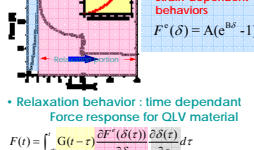
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## Nonlinear Viscoelastic Modeling

### Nonlinear response - Steady state force vs indentation depth



### Loading Portion: Strain-dependent behaviors



$$F^s(\delta) = A(e^{B\delta} - 1)$$

• Relaxation behavior: time dependent Force response for QLV material

$$F(t) = \int_0^t G(t-\tau) \frac{\partial F^s(\delta(\tau))}{\partial \delta} \frac{\partial \delta(\tau)}{\partial \tau} d\tau$$

Reduced Relaxation Function  
 $G(t) = G_0 \left( 1 - \sum_{i=1}^n \alpha_i \exp\left(-\frac{t}{\tau_i}\right) \right)$

Input Deformation History  
 $\delta(t) = \begin{cases} ct, & \text{for } 0 < t < t_c \\ \delta^c, & \text{for } t_c \leq t \end{cases}$

Extraction of parameters by Lavenberd-Marquardt Algorithm

Elastic Response Function  
 $F^s(\delta) = A(e^{B\delta} - 1)$

Effective modulus estimation

$$E = \frac{3P}{8a\delta}$$

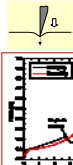
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## Experiments: Incision and Cutting

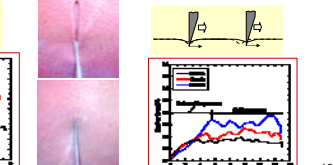
### Experimental Setup & Videomicroscopy System



### Incision Test

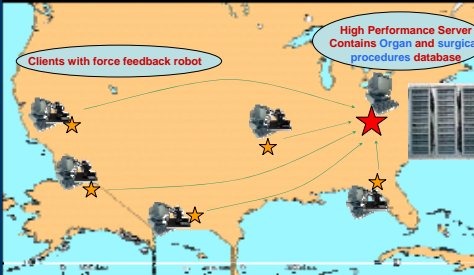


### Cutting Test



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## Distributed Dynamic Surgery



Medical schools across the nation may log into high performance clusters using high speed connections for virtual surgical training

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## Acknowledgements

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