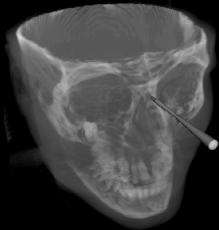
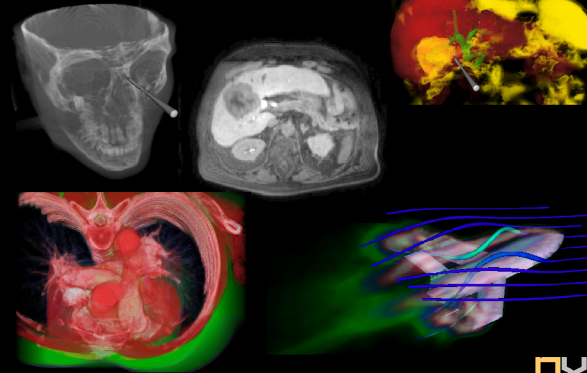


## Techniques and Applications for Volume Haptics



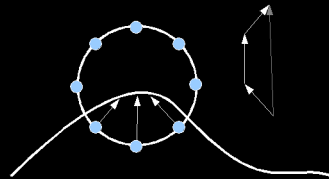
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## Volumetric Data



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## Bone Milling



Agus et al. 2003

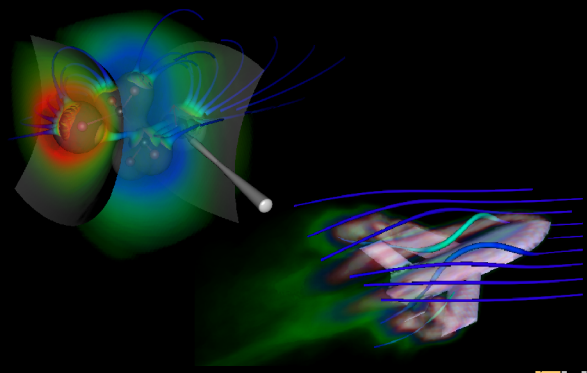
Real-time Haptic and Visual Simulation of Bone Dissection

Petersik et al, 2002

Realistic haptic volume interaction for petrous bone surgery simulation

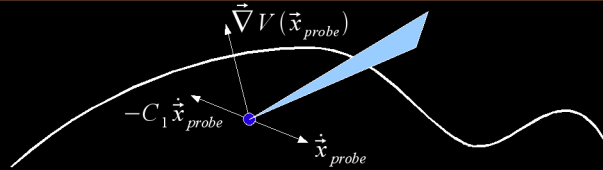
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## Scientific Visualization



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## Force Functions

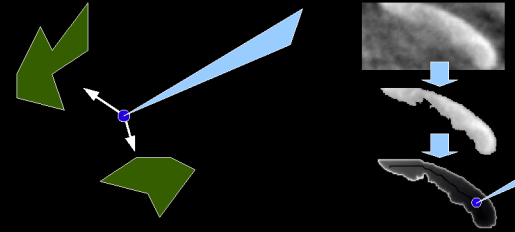


$$\vec{f} = -C_1 \dot{\vec{x}}_{probe} - C_2 \nabla V(\vec{x}_{probe})$$

$$\vec{f} = C_1 \vec{V}(\vec{x}_{probe}) + C_2 (\nabla \times \vec{V}(\vec{x}_{probe})) \times \vec{V}(\vec{x}_{probe})$$

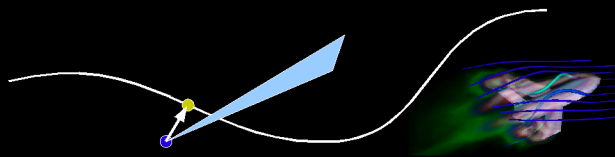
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## Non-local Force Function Effects



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## Constraint-based Volume Haptics

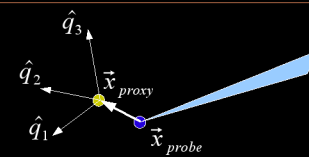


$$\vec{x}'_{proxy} = \vec{x}_{proxy} + \vec{F}(V(\vec{x}_{proxy}), \vec{x}_{proxy})$$

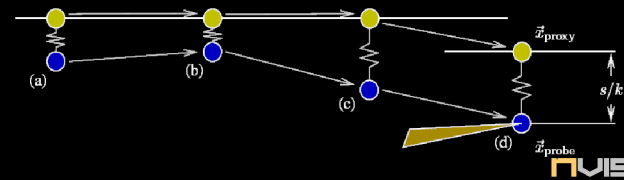
$$\vec{f} = -k_s (\vec{x}_{probe} - \vec{x}_{proxy}) - k_d (\dot{\vec{x}}_{probe} - \dot{\vec{x}}_{proxy})$$

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## Yielding Constraints



$$\vec{x}'_{proxy} = \vec{x}_{proxy} + \sum_i \hat{q}_i \min(0, \hat{q}_i (\vec{x}_{probe} - \vec{x}_{proxy}) - s/k)$$



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## Yielding Constraints



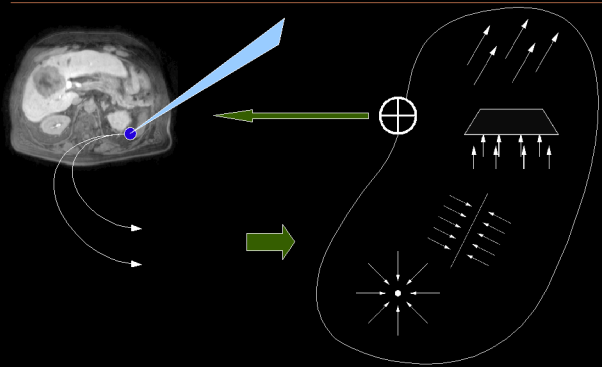
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## Yielding Constraints



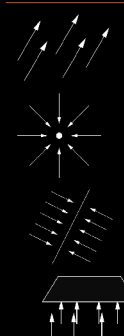
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## Haptic Primitives



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## Haptic Primitives



$$\begin{aligned} \ominus_{\vec{q}}^s(\vec{x}_{\text{proxy}}) &= s\vec{q} \\ \odot_{\vec{x}}^s(\vec{x}_{\text{proxy}}) &= \begin{cases} \vec{0}, & \text{if } |\vec{x} - \vec{x}_{\text{proxy}}| = 0 \\ s \frac{\vec{x} - \vec{x}_{\text{proxy}}}{|\vec{x} - \vec{x}_{\text{proxy}}|}, & \text{if } |\vec{x} - \vec{x}_{\text{proxy}}| \neq 0 \end{cases} \\ \oplus_{\vec{q}, \vec{x}}^s(\vec{x}_{\text{proxy}}) &= \begin{cases} \vec{0}, & \text{if } |\vec{m}| = 0 \\ s \frac{\vec{m}}{|\vec{m}|}, & \text{if } |\vec{m}| \neq 0 \end{cases} \\ \vec{m} &= \vec{q}[\vec{q} \cdot (\vec{x}_{\text{proxy}} - \vec{x})] - (\vec{x}_{\text{proxy}} - \vec{x}) \\ \oplus_{\vec{q}, \vec{x}}^s(\vec{x}_{\text{proxy}}) &= \begin{cases} 0, & \text{if } (\vec{x}_{\text{proxy}} - \vec{x}) \cdot \vec{q} \geq 0 \\ s\vec{q}, & \text{if } (\vec{x}_{\text{proxy}} - \vec{x}) \cdot \vec{q} < 0 \end{cases} \end{aligned}$$

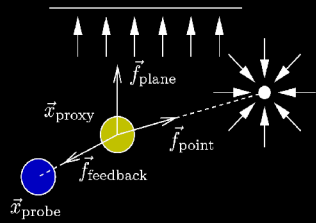
$$\vec{f}(\vec{x}_{\text{proxy}}) = k(\vec{x}_{\text{probe}} - \vec{x}_{\text{proxy}})$$

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## Haptic Primitives

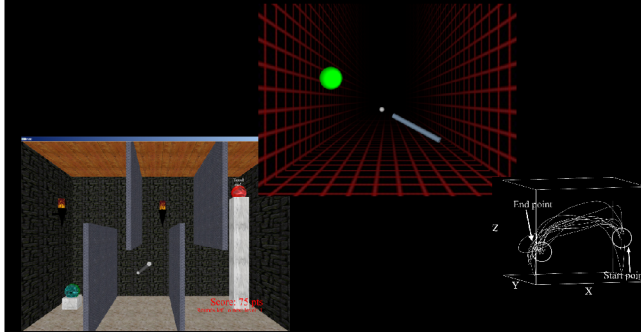
$$\operatorname{argmin}_{\vec{x}_{\text{proxy}} \in \mathcal{R}^3} |\vec{\varepsilon}(\vec{x}_{\text{proxy}})|$$

$$\begin{aligned} \vec{\varepsilon}(\vec{x}_{\text{proxy}}) = & -\vec{f}(\vec{x}_{\text{proxy}}) \\ & + \sum_i \ominus_{\vec{q}_i}^{s_i}(\vec{x}_{\text{proxy}}) \\ & + \sum_i \odot_{\vec{x}_i}^{s_i}(\vec{x}_{\text{proxy}}) \\ & + \sum_i \otimes_{\vec{q}_i, \vec{x}_i}^{s_i}(\vec{x}_{\text{proxy}}) \\ & + \sum_i \oplus_{\vec{q}_i, \vec{x}_i}^{s_i}(\vec{x}_{\text{proxy}}) \end{aligned}$$



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## Stroke Rehabilitation



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Thank you for the attention!

Questions?

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