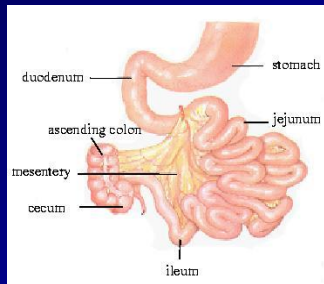


Real-time Simulation of Self-Collisions for Virtual Intestinal Surgery



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A joint lab of CNRS, INPG, INRIA and UJF

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Overview

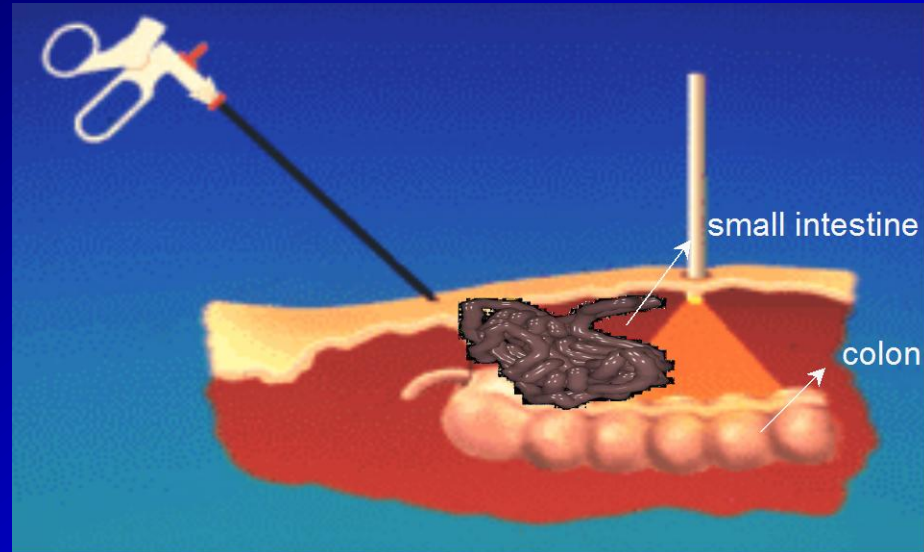
- Scope
 - Surgical trainer for colon cancer removal
 - Issues: Intestine modeling & collision processing
- Related Work
- Contribution
 - Geometric and mechanical modeling
 - Efficient collision processing
- Results, Demos & Discussion



Intestinal Surgery



Laparoscopic technique



Surgery objective

- remove cancerous colon tissues

Critical task

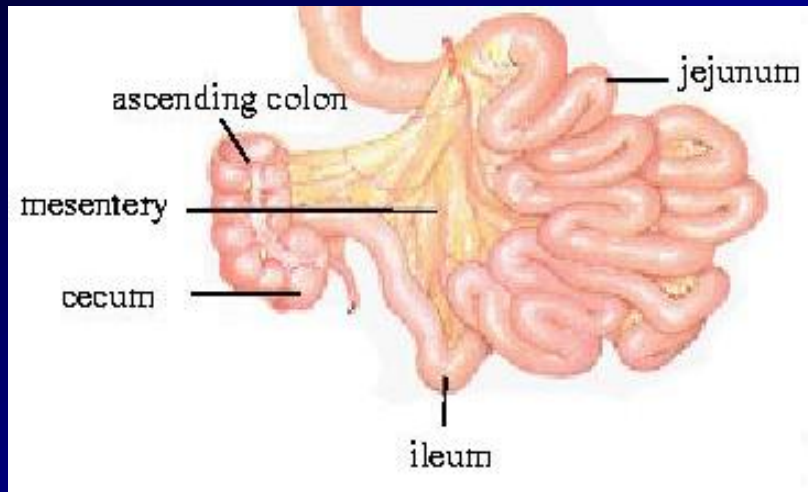
- move the small intestine aside

Aim: Train the surgeons to do this task





Challenges



Small Intestine

4 m length, 2 cm thick

Mesentery

Folded surface 15 cm width

Connects intestine with main vessels

- Model the complex anatomy
- Detect multiple self-collisions
- Provide a stable collision response



Related Work

Real-time deformable models

- Multiresolution models [*Capell02, Debunne01, Grinspun02*]
- Soft-tissue models [*Cotin00, James99, James02, Meseure00*]

Objects in isolation or interacting with a rigid tool => Different Situation

Skeletal model for intestine [*France02*]

- Chain of masses and springs
- Implicit surface representation for smooth rendering
- 3D grids for self-collision and collision with environment

Not applicable for mesentery

Hierarchical BV detection [*Bradshaw02, Cohen95, Gottschalk96, van den Bergen97*]

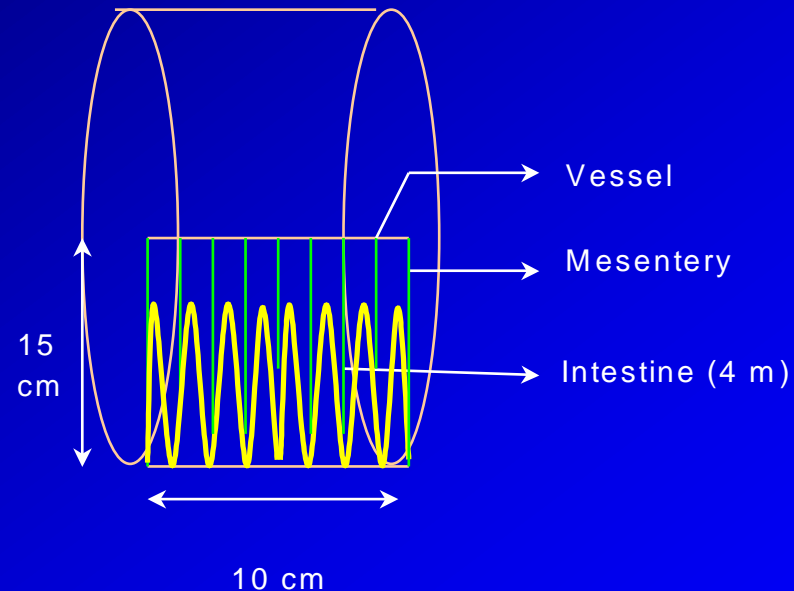
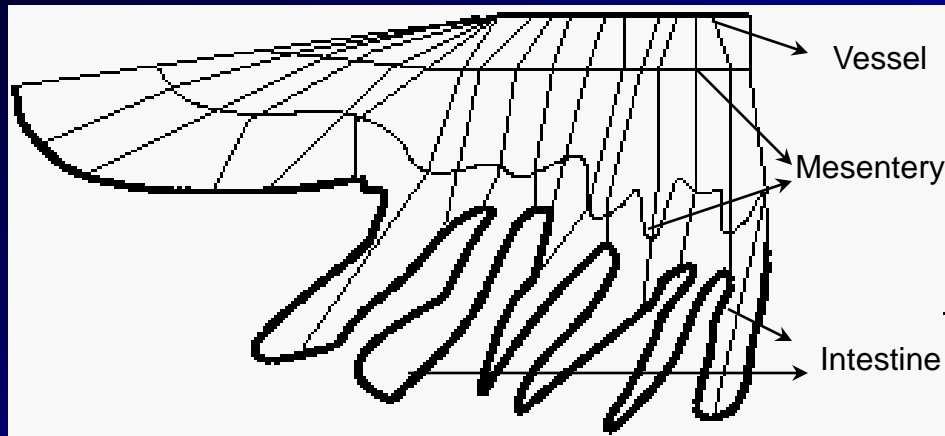
- Sphere-trees, OBBs, AABBs, etc.

Expensive tree updates for large-scale deformation





Geometric model

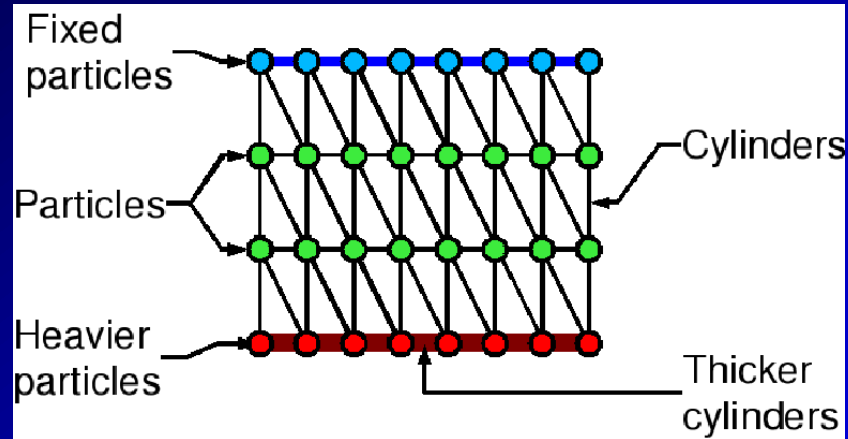


- Mesentery surface
 - suspends from the vessel
- Intestine
 - borders the mesentery
 - skinning at rendering

- Collision-free initial position



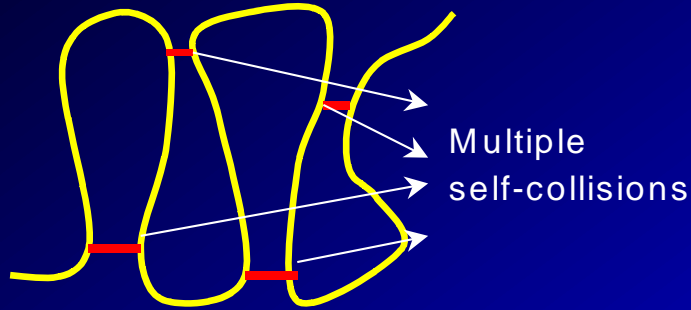
Mechanical model



- Mass-spring model
- 100 fixed particles representing vessels
- 300 animated particles
 - 200 particles for the mesentery
 - 100 particles with modified mass for intestine



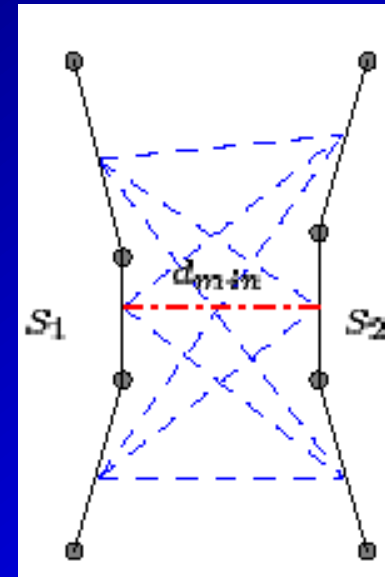
Collision Detection (Intestine)



Aim: Find colliding segments

Inspiration

- Temporal coherence
 - Track pairs of closest features
[Lin-Canny92]
- Handle non-convex objects
 - Stochastic sampling
[Debunne02]
- Maintain list of active pairs
- For each segment-pair
 - Update by local search



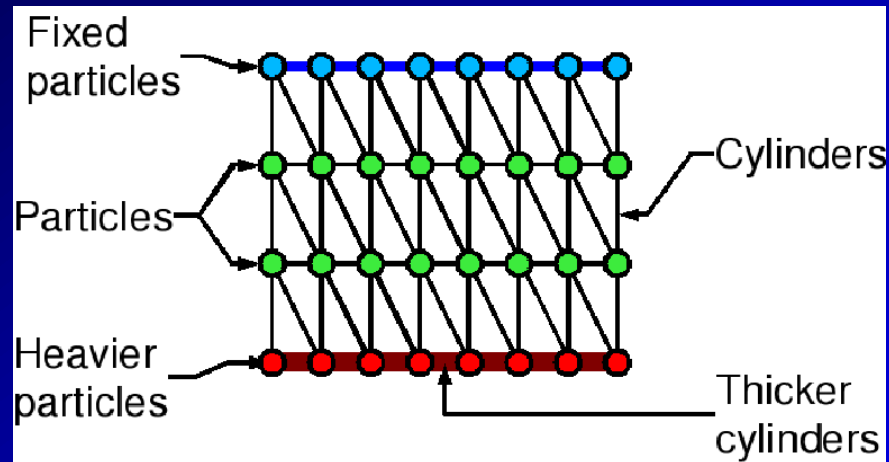


Algorithm

- At each step
 - Compute new positions and velocities
 - Add n pairs by random selection
 - For each pair:
 - Propagate to a smaller distance
 - Remove unwanted pairs
 - For each pair:
 - if $d_{\min} < radius_sum$
 - Expand to local collision area
 - Apply collision response



Collision adapted to mesentery



- Thin mesentery will have little impact on simulation
⇒ Neglect mesentery-mesentery interaction
- Mesentery-Intestine: Two-step pair propagation
 - Find nearest intestine segment (3 distance computations)
 - Find nearest mesentery segment (11 distance computations) $O(n+m)$ complexity instead of $O(n*m)$



Collision Response

(1) Condition for **velocity correction**:

$$(\mathbf{v}_{\text{new}} - \mathbf{v}'_{\text{new}}) \cdot \mathbf{u} = 0$$

(2) New velocities in terms of unknown f :

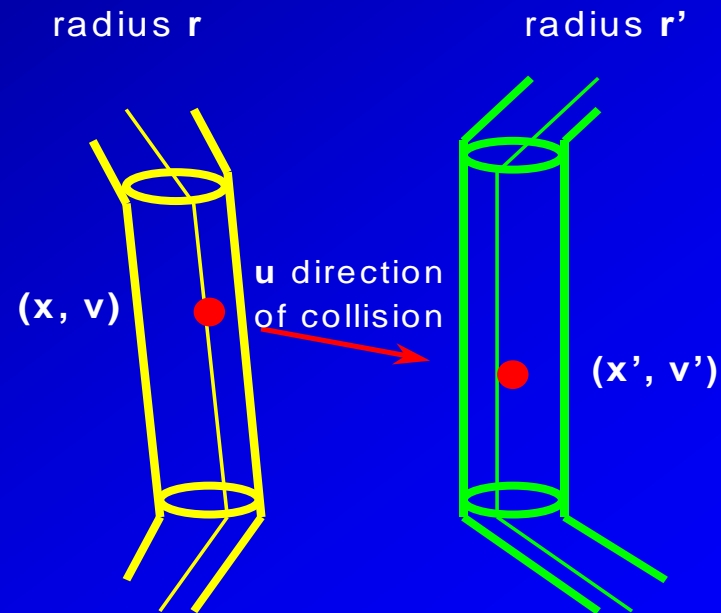
$$\mathbf{v}_{\text{new}} = \mathbf{v} + K_1 f \mathbf{u}$$

$$\mathbf{v}'_{\text{new}} = \mathbf{v}' + K_2 f \mathbf{u}$$

(3) Solve for f and determine \mathbf{v}_{new} and \mathbf{v}'_{new}

(4) Similarly, **position correction** using:

$$(\mathbf{x}_{\text{new}} - \mathbf{x}'_{\text{new}}) \cdot \mathbf{u} = r + r'$$





Validation

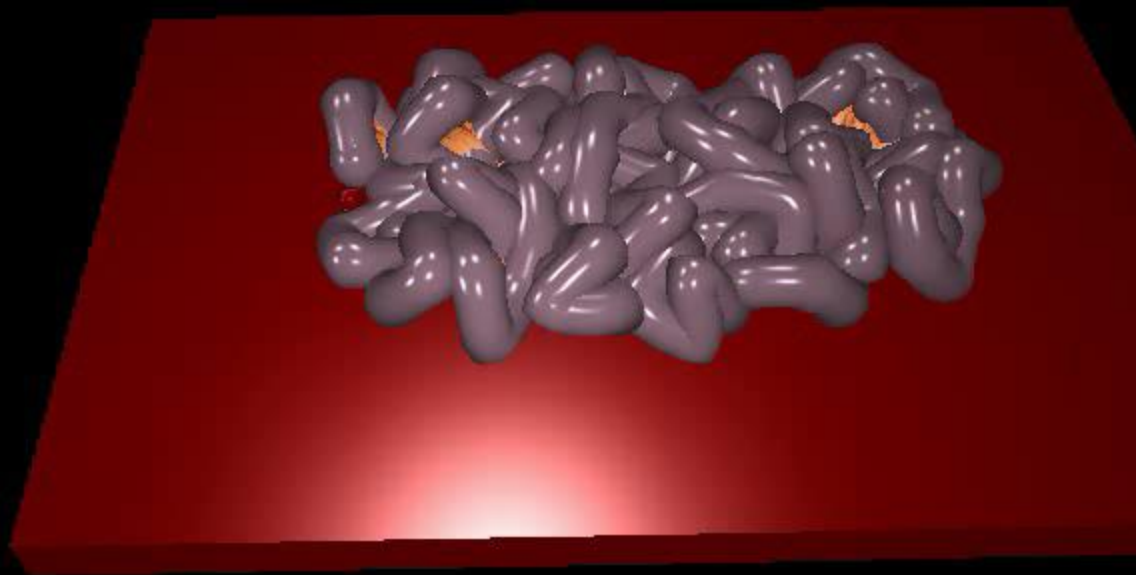
- Correctness
 - No theoretical proof that all collisions detected
 - Good experimental results for intestine
- Efficiency
 - Intestine in isolation

Number of segments	Computation time (ms)	
	O(n ²)	Stochastic
50	30	10
100	120	17
200	473	27

- Intestine + Mesentery: **30 fps with 400 particles on standard PC**



Demo 1*



**captured at the prototype simulator at LIFL, Lille*

Skinning based-on [Grisoni03]

Hardware: Bi-Athlon 1.2 GHz 512MB with nVIDIA GeForce 3

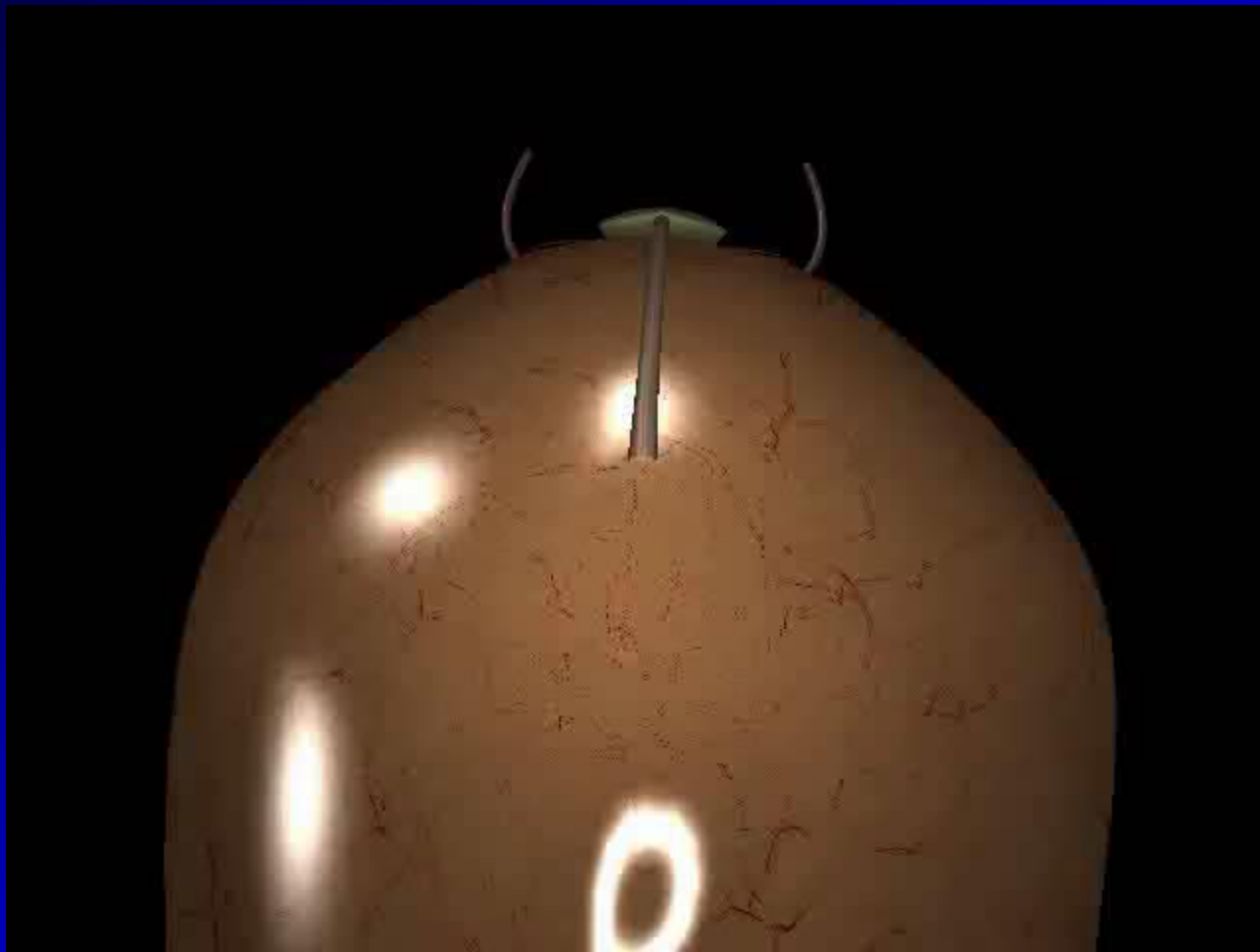
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Demo 2*



**captured at the prototype simulator at LIFL, Lille*

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Conclusions

- Real-time simulation of complex organs
- Efficient self-collision detection
- Work-in-progress
 - Optimization of the update algorithm
 - Use triangles for mesentery collision detection
 - Handling fast motion for thin objects
 - Continuous-time collision detection



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Thank You

<http://www-evasion.imag.fr>

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Questions / Comments ?

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