VIRTUAL REALITY BASED LAPAROSCOPIC SURGERY SIMULATION

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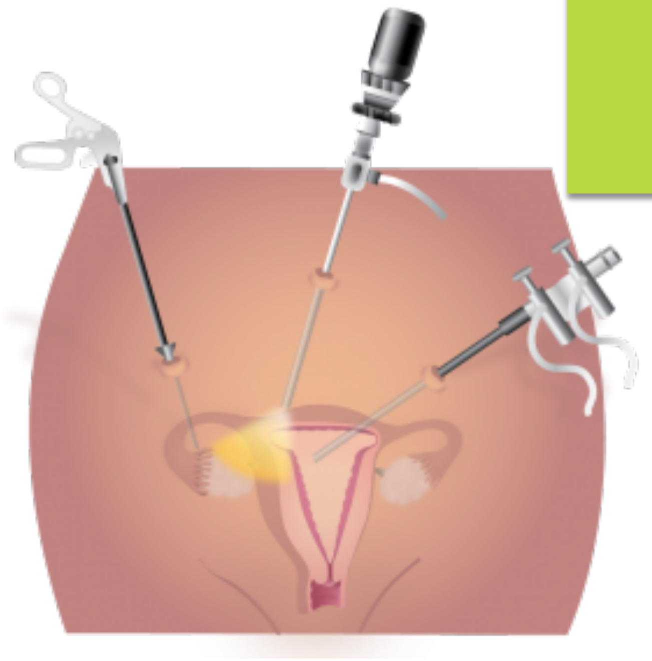
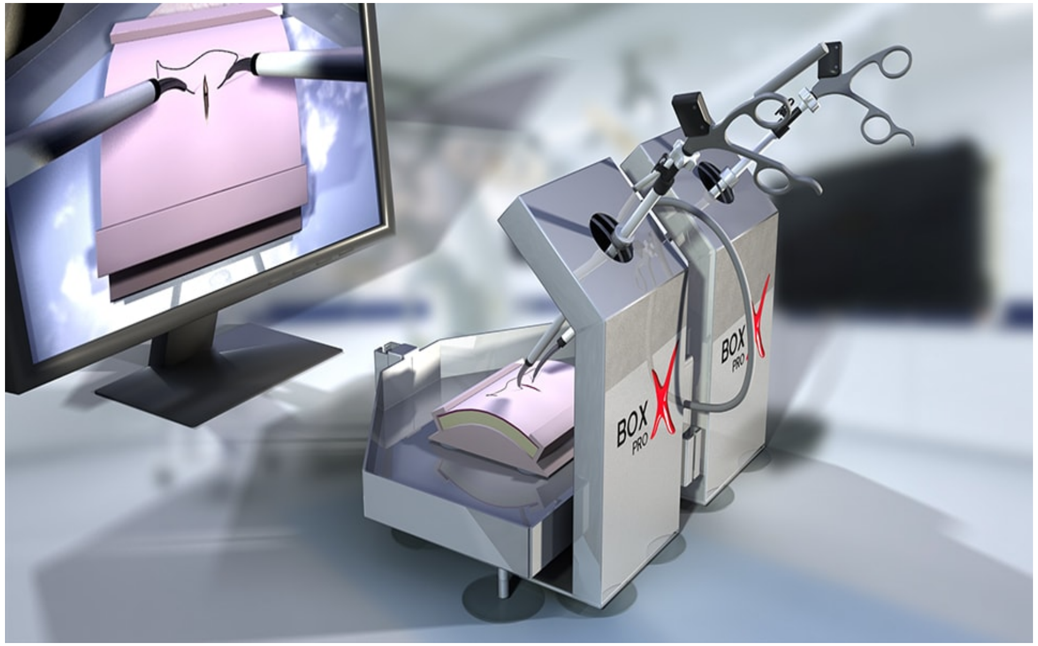
INTRODUCTION + DEFINITIONS

What does laparoscopy mean?

- "keyhole" surgery
- minimally invasive (5-10mm incisions instead of 20cm)
- instruments into the abdomen
- cholecystectomy, rectum surgery





What does it look like?

WHY do we need VR?

Problem:

- 57% of medical error-caused death surgical
- limitation of manipulation space+viewing angle
- high risk of damaging organs

- Basic skills:
- ambidexterity, hand-eye coordination
- <u>Recognition of cues to provide a sense of depth!</u>

Current facilities and their kickbacks

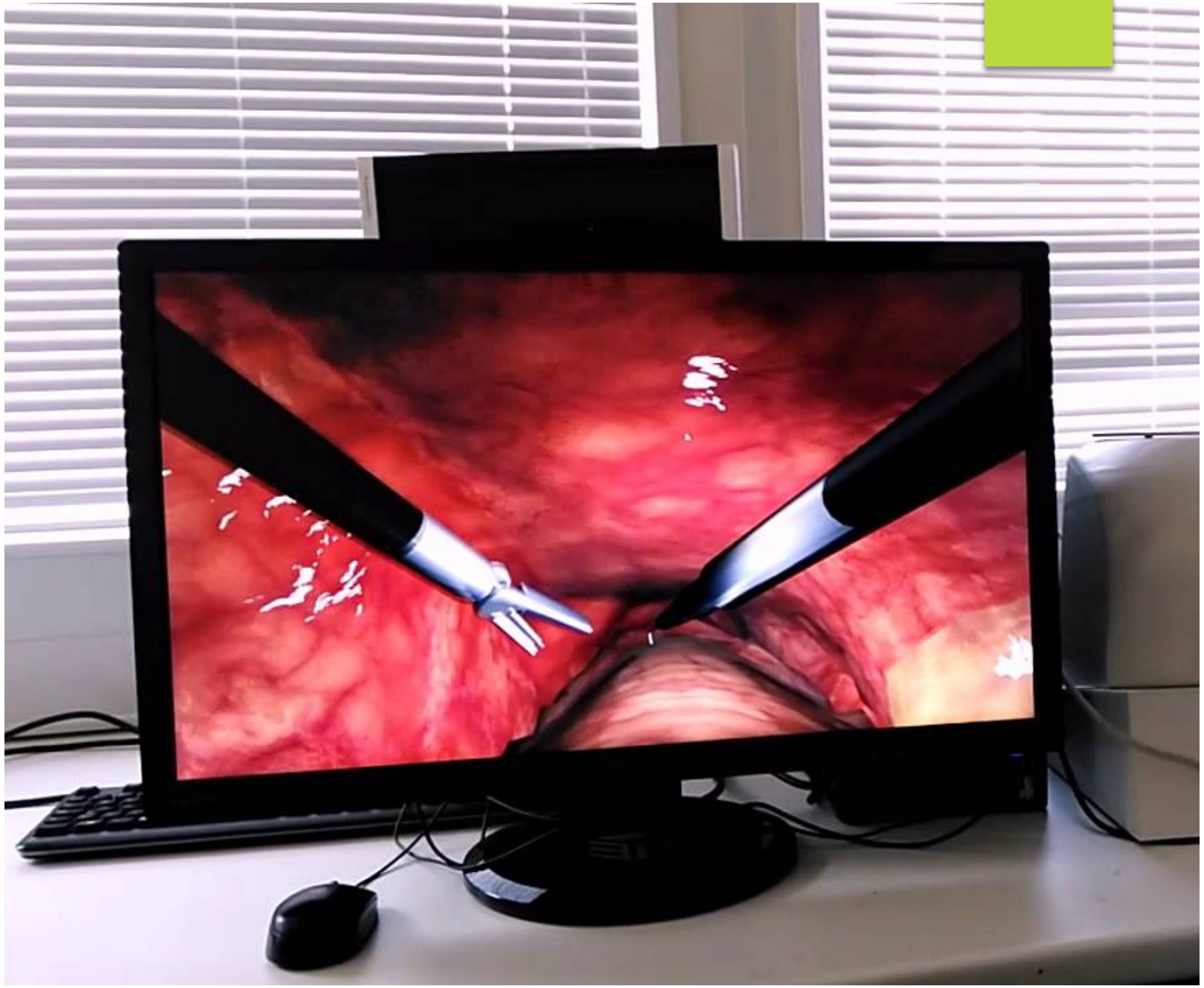
Training modes:

- physical: box trainers (not lifelike)
- virtual: LapSim (realistic but pricey)
- augmented(hybrid)

- biggest issue: all represent routines!
- planning the procedure not possible
- this paper: tackling some of the problems

What needs to be done?

- 1. Deformation simulation
- 2. Colllision detection
- 3. Soft tissue dissection
- 4. Realistic rendering



Task 1 : DEFORMATION SIMULATION

1.DEFORMATION SIMULATION

- all biomedical behaviours controlled by parameters
- two methods: finite element / PBD method
- finite element: high comp. cost
- PBD (= position based dynamics): the better choice

1.1 SIMULATING TISSUES

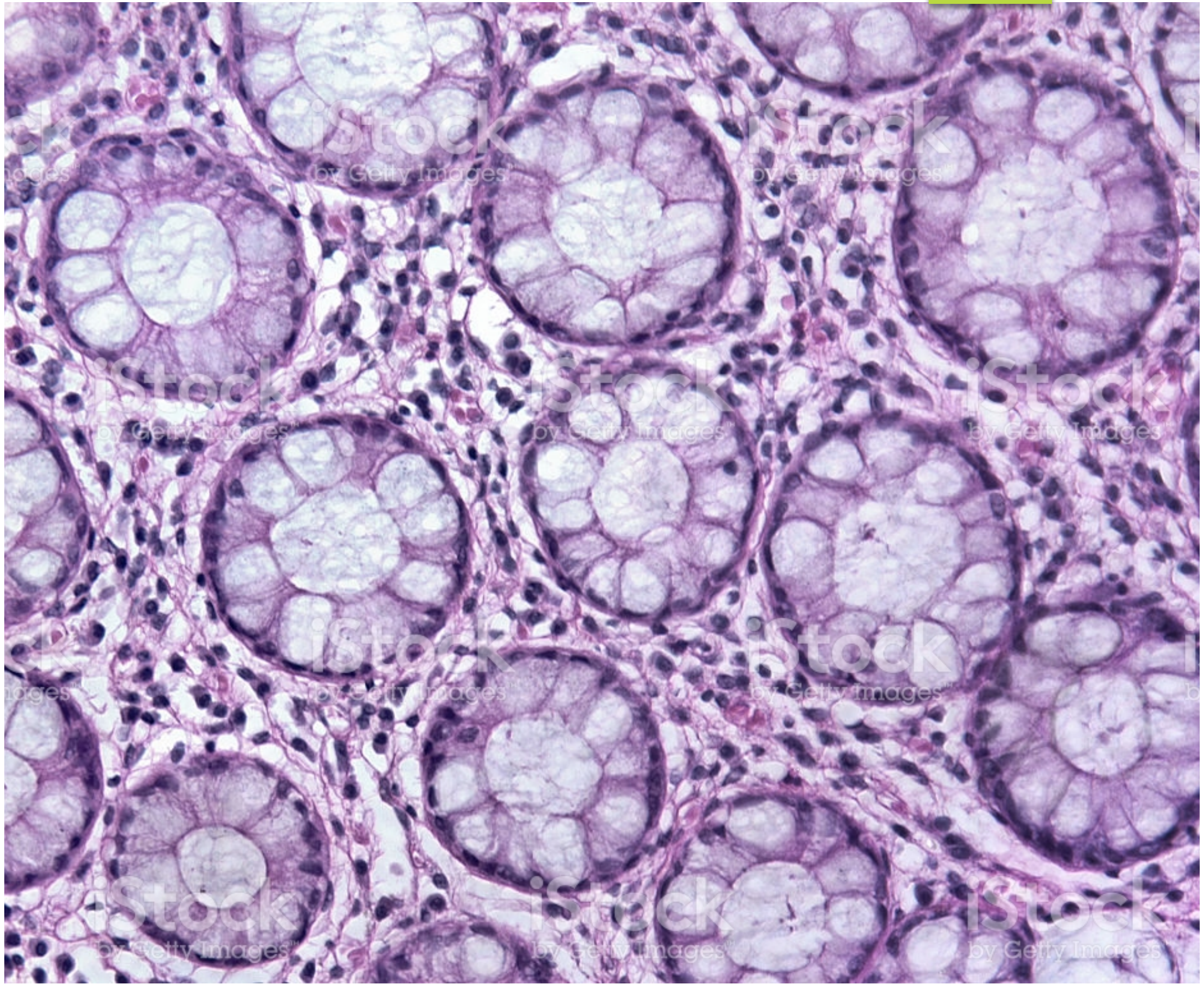
- 3 types: volumetric, fascia, glandular

What to keep in mind?

- deformation only in local contact area
- algorithm: needs to do 2 things:

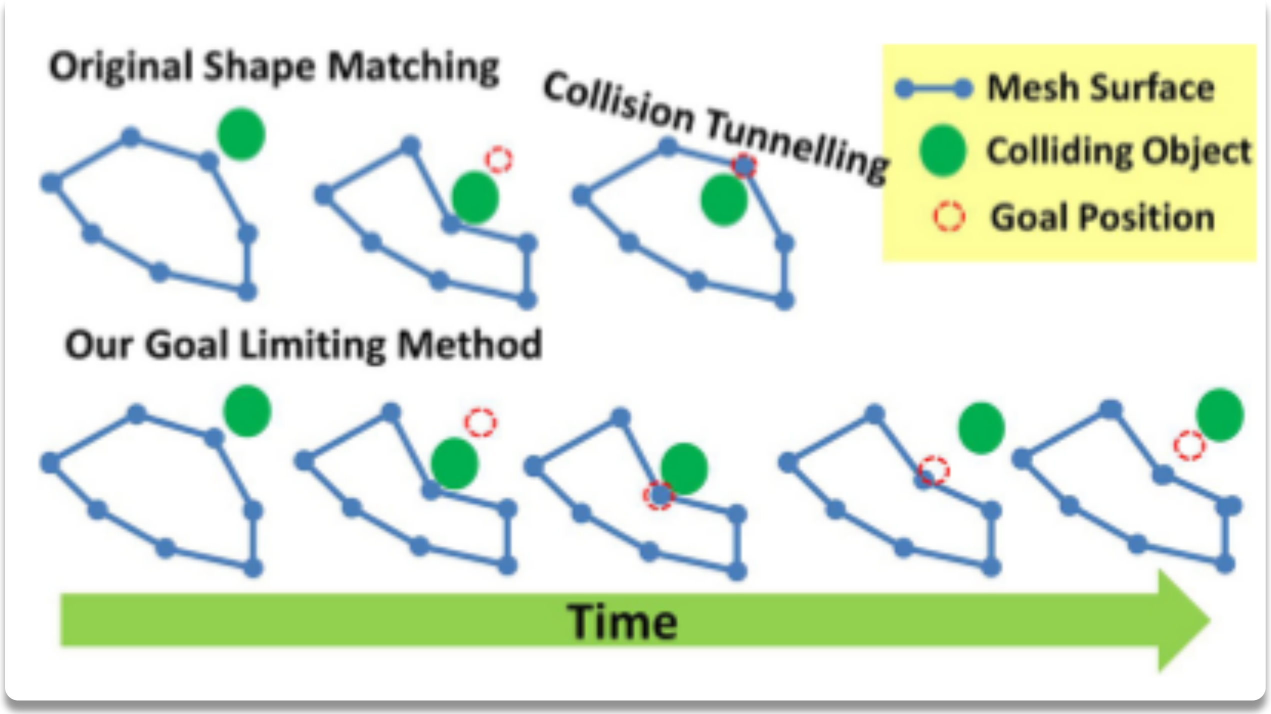
 - keep global shape

 - keep local deformation



1.1 Volumetric tissue

- shape matching: finding the optimal best-fit transformation
- each vertex dragged towards goal position
- recovering to original shape
- problem solved: by limiting the tendency of going back to goal position



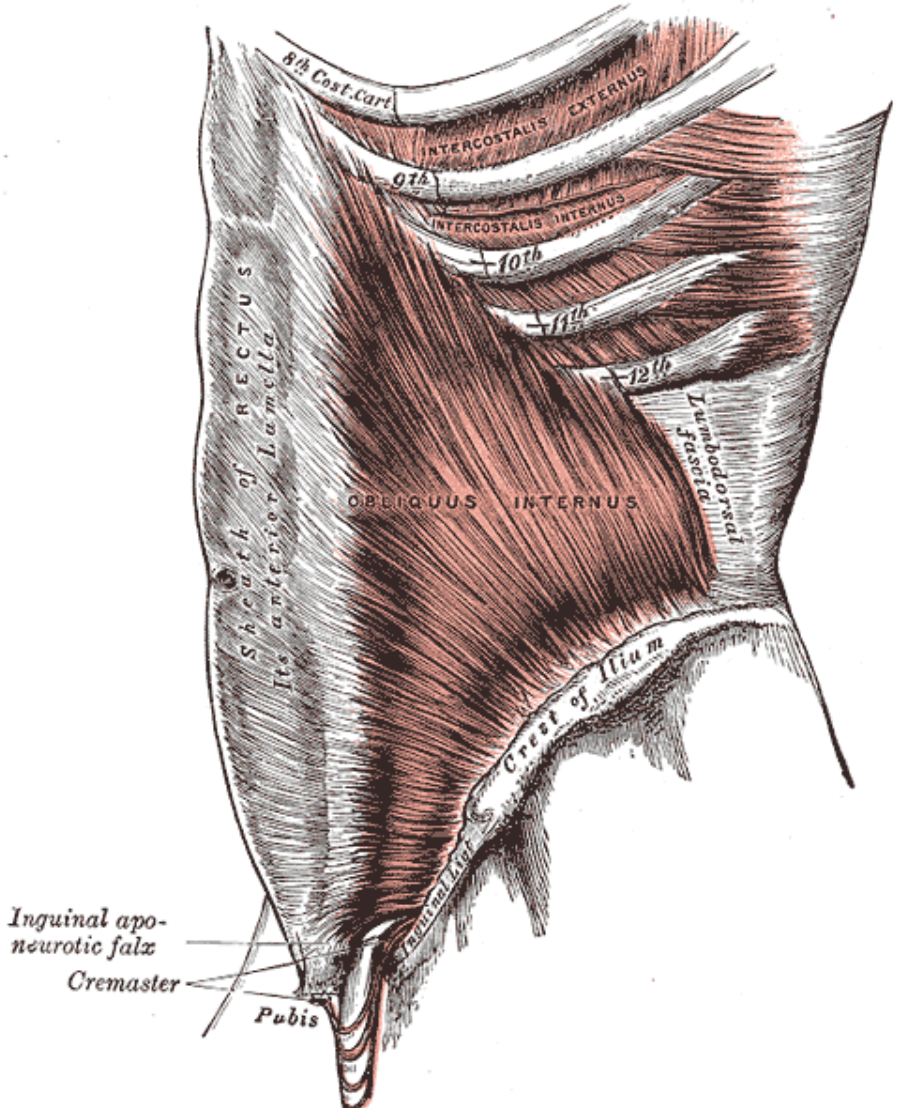
1.2 Fascia simulation

- problem: extensibility → looking like a piece of clothing
- solution : long-range attachment constraint(LRA)
- idea: confining unconstrained vertices within the distance

of attached vertices

- Two steps: 1. initial distance calculation

  2. if out of range, project it back



1.2 Fascia simulation

- taking advantage of fast convergence rate of LRA
- making relaxation to the LRA constraint

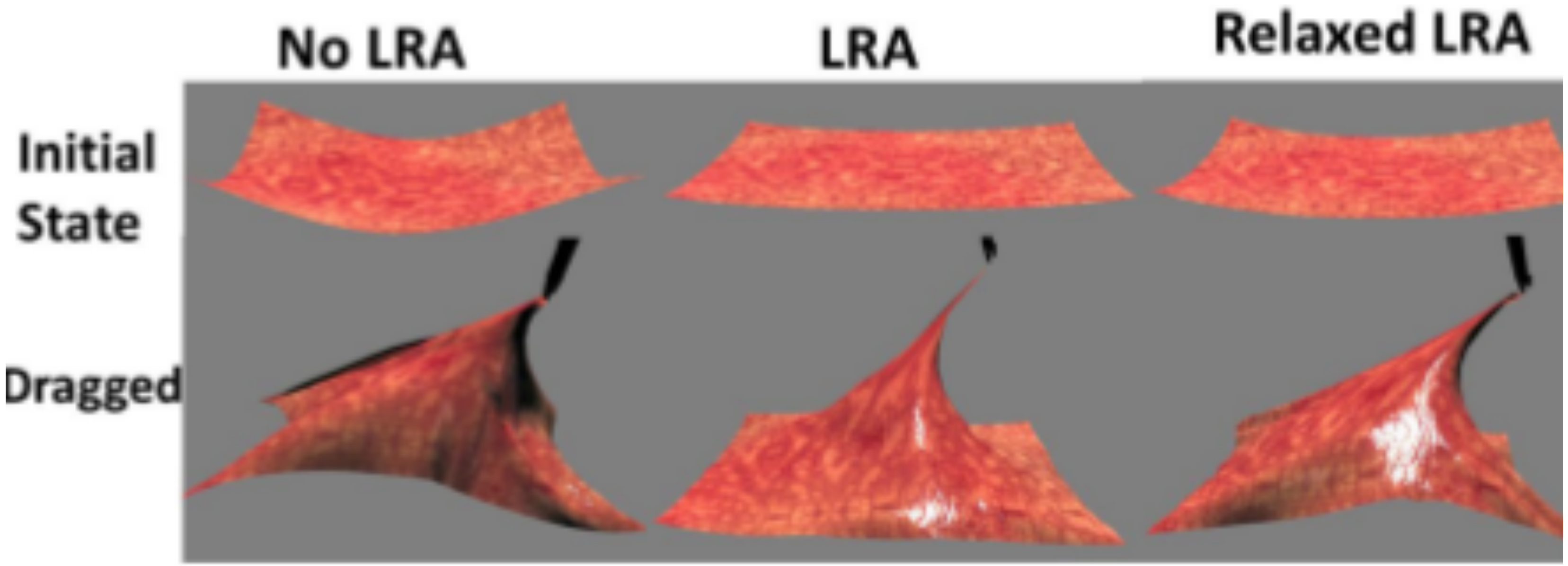
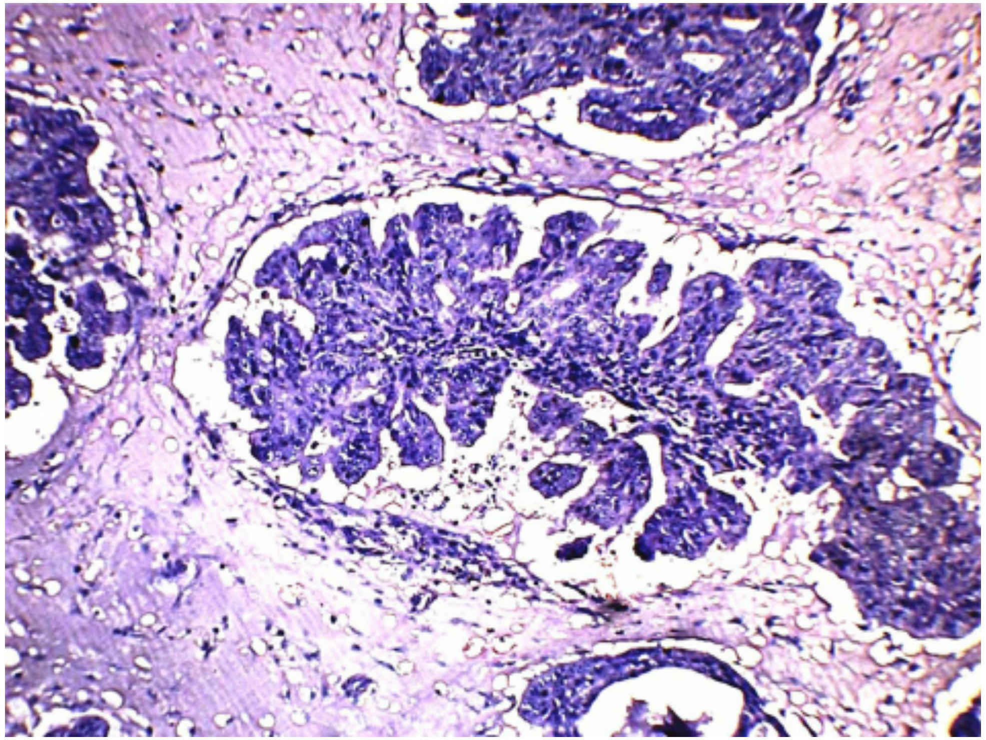


Figure 4: *The improvement by using relaxed LRA*

1.3 Tubiform and glandular tissue

- nonlinearity characteristic
- volume/shape does NOT remain constant
- bending, stretching, pressure!
- (previous methods won't work)
- solution: filling the tissue with
elastic truss structure
- high movement flexibility with different stiffness



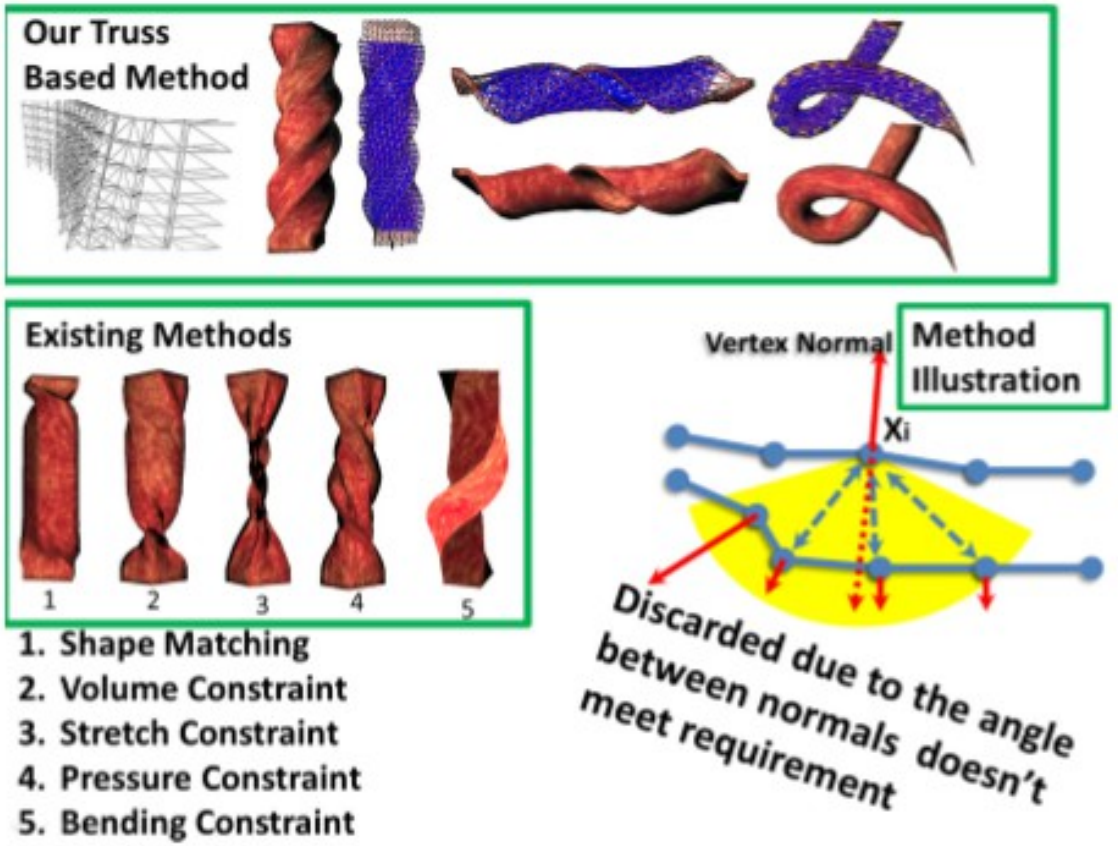


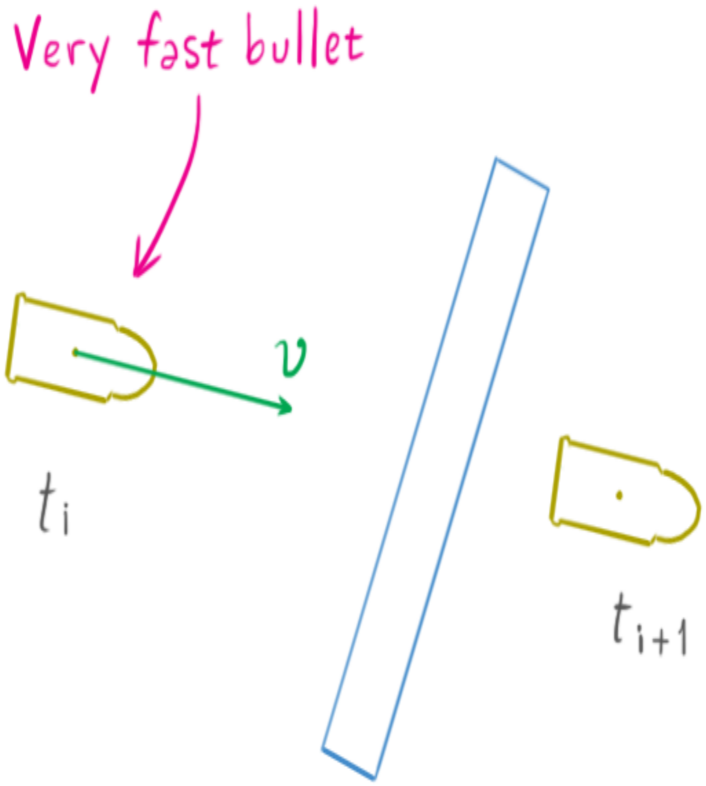
Figure 5: *Truss structure based deformation and comparison of the deformation results using existing constraints*

1.3 Tubiform and glandular tissue

Task 2: COLLISION DETECTION

2. COLLISION DETECTION

- essential for interactive real-time application
- becomes the bottleneck for complex simulation
- in this paper: a dynamically generated circumsphere structure
- based on local geometry features
- PBD framework: accelerating convergence without visual artefacts
- prevention to collision tunnelling



2.1 Method overview

Two phases:

- 1. bounding sphere phase: checking potentionally colliding pairs
- 2.circumsphere phase: test for overlapping of underlying primitives in circumsphere + resolution

2.1 How is it done?

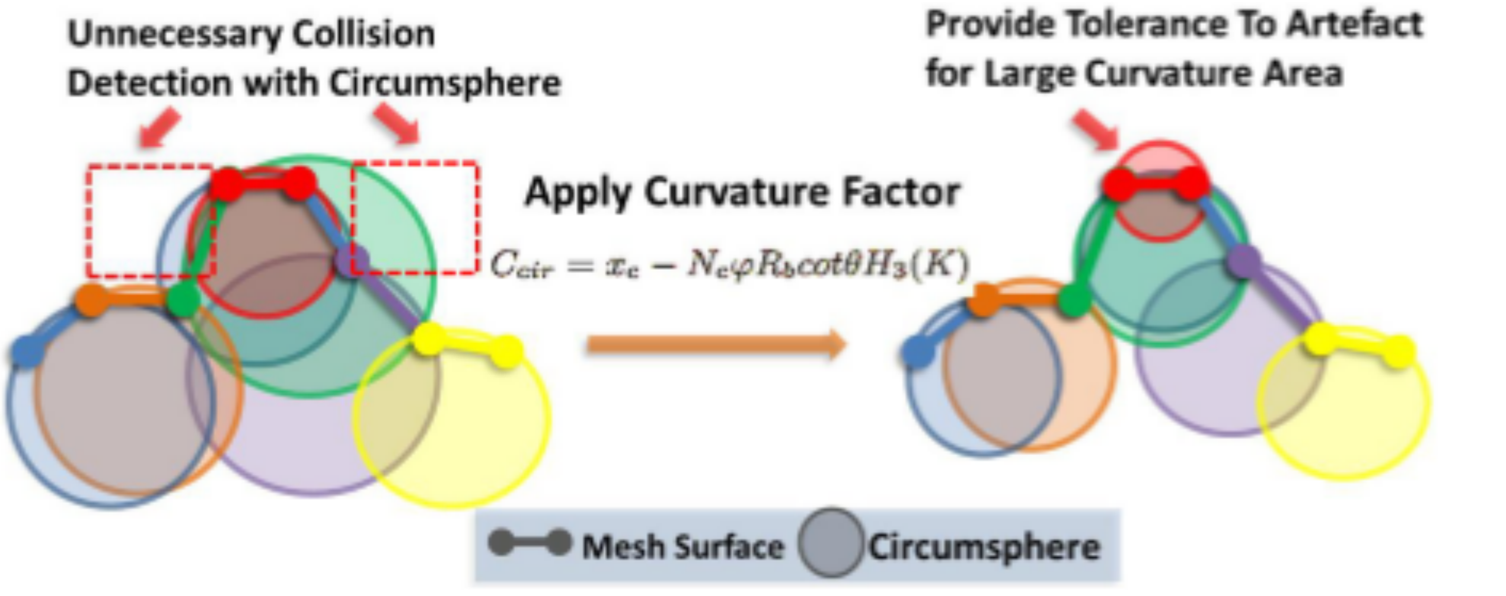
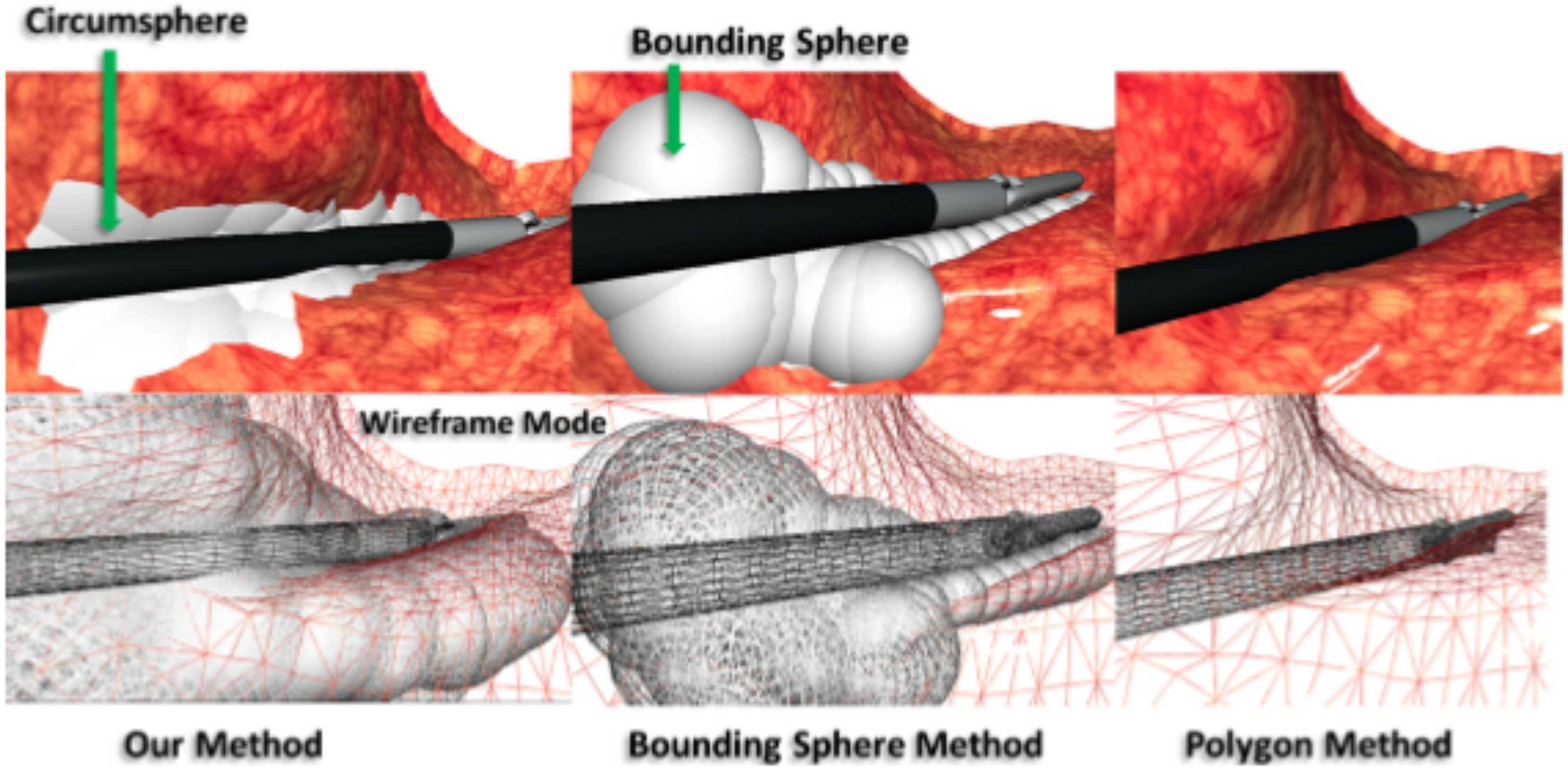


Figure 7: *Adjust the size of circumsphere according to curvature*

- collision happens
- bounce away the collided pair
- firstly:localizing where it happened
- secondly: updating

2.2 Method analysis



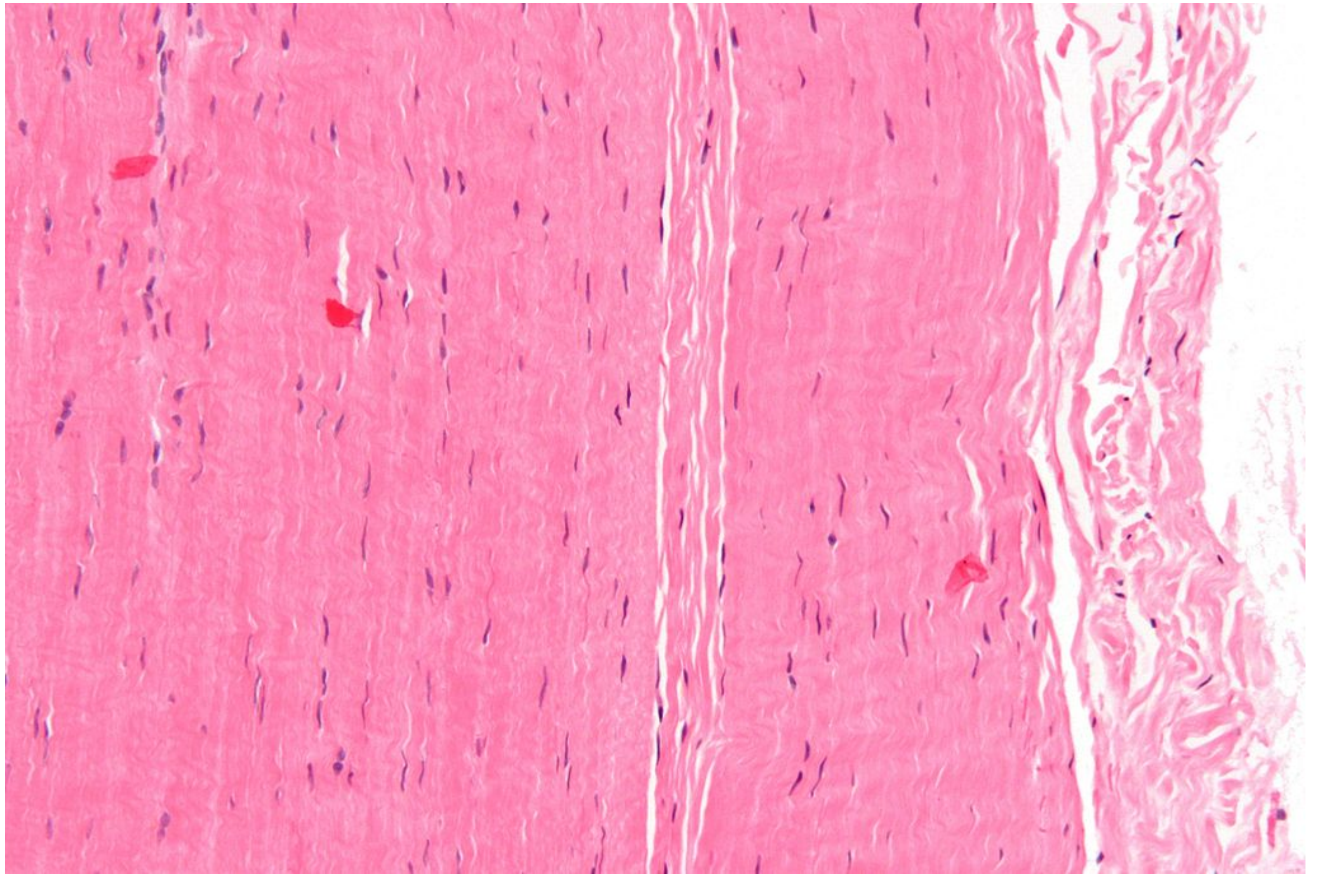
<u>Stability?accuracy?</u>

- ❑stable method
- ❑good approximation
- ❑adds fewer unstable factors to the process
- ❑Time efficiency: re-calc. needed

Task 3: SOFT TISSUE DISSECTION

3.1 Overview and definitions

- fat, musles, nerves, blood vessels



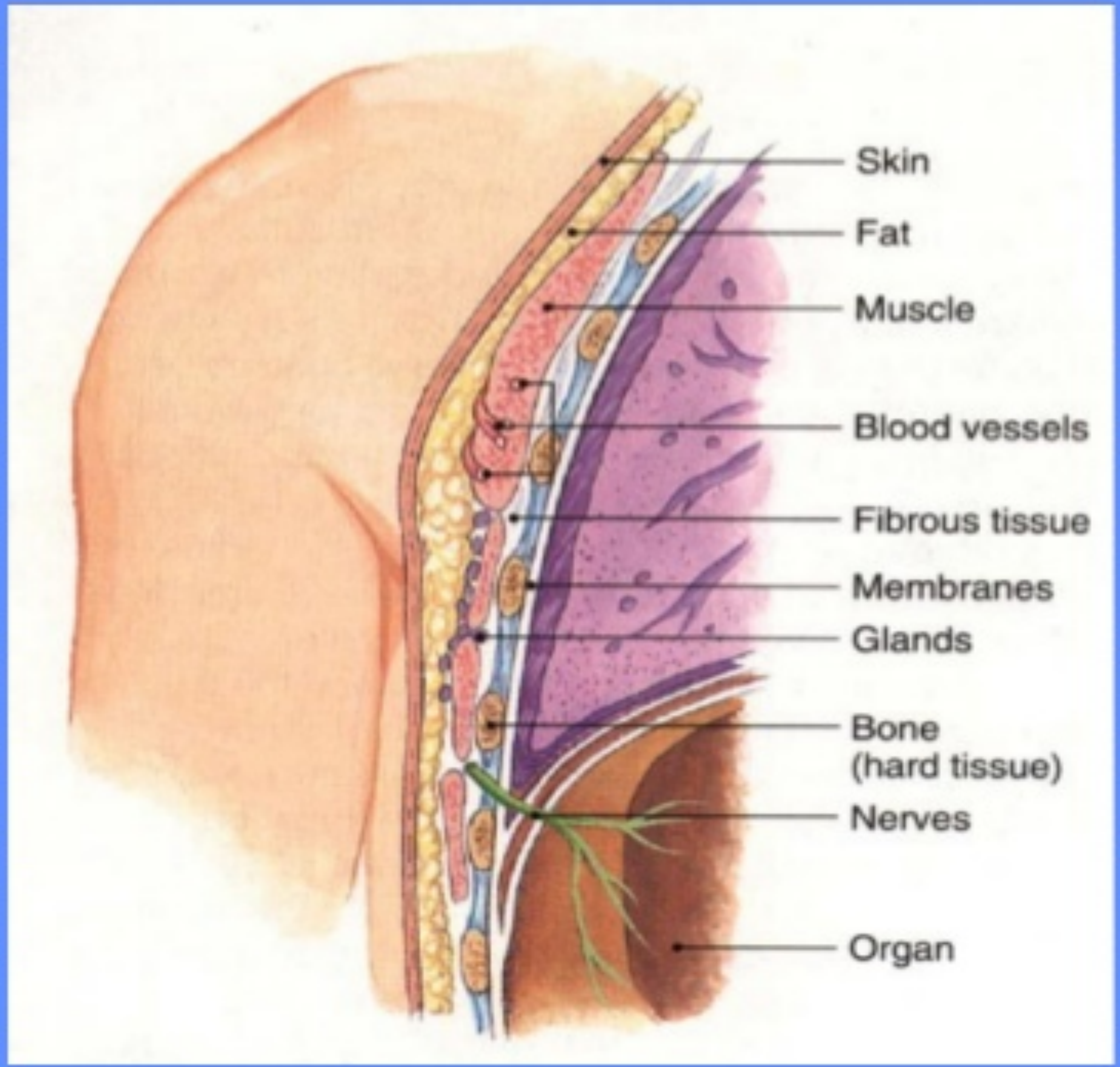
Dissection? How?

- 1.electrosurgical: surface mesh
- 2.scalpel: volumetric mesh

In computer graphics

- 1.tearing: splits original connections apart
- 2.cutting: changes mesh topology

Soft Tissues



3.2 How is it done?

- combination of implicit shapes → unifying to general framework
- a generalized method
- Surface mesh dissection:
- cutting + tearing
- mesh composed to triangle faces

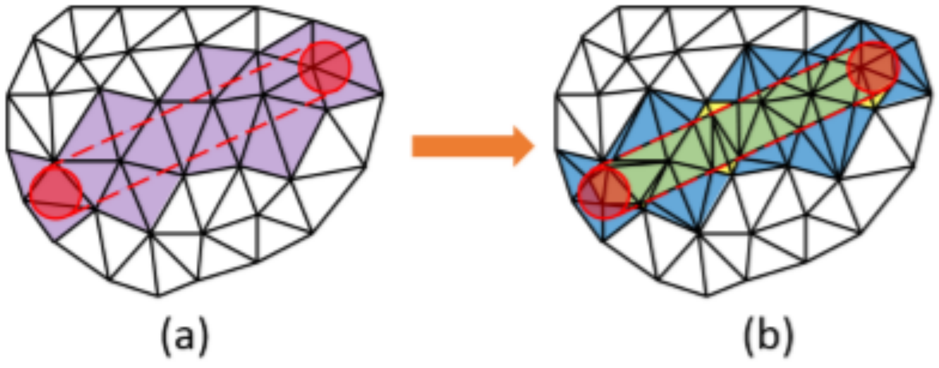
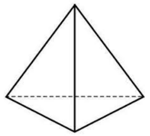


Figure 12: *The process of surface cutting. (a)The intersected triangles are in purple color. (b)After cutting, the green triangles (inside V_{sweep}) and yellow triangles (too small) are removed, blue triangles are reserved.*

3.3 Volumetric mesh dissection

- composed of tetrahedra elements ()
- finding intersections + subdividing primitives
- edge / face intersections

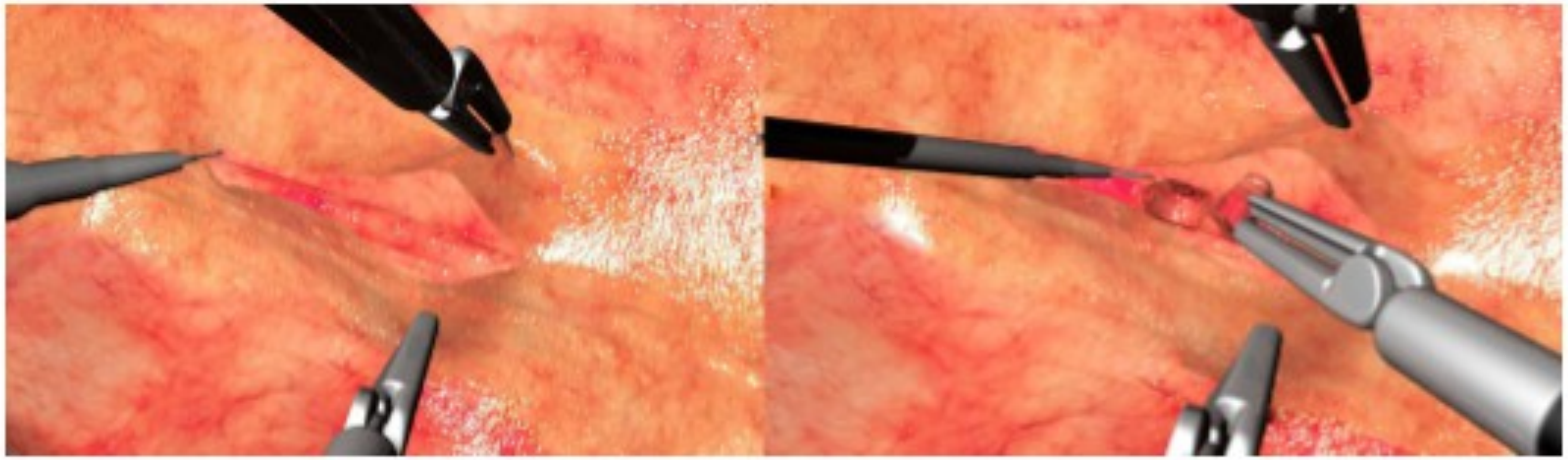
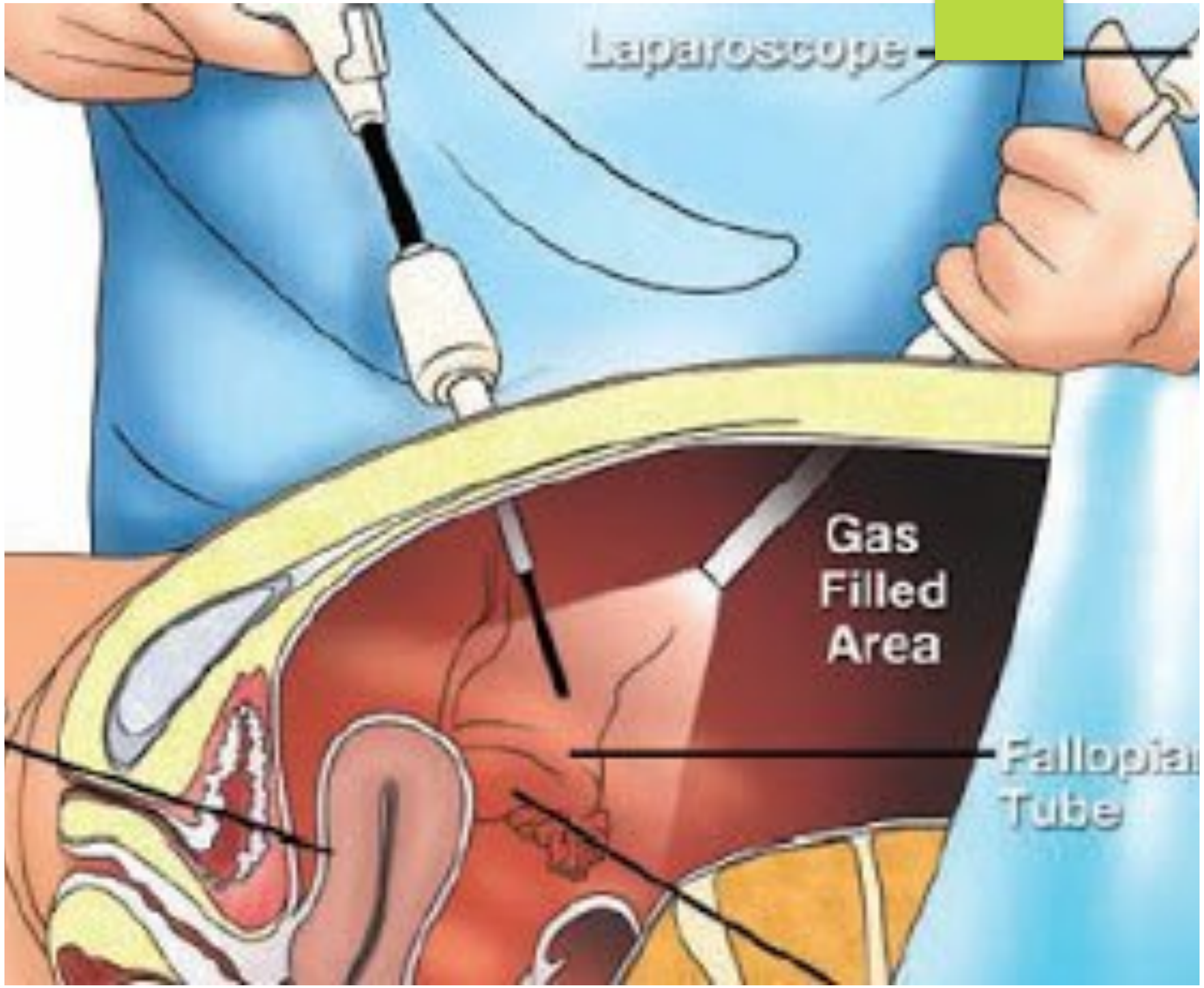


Figure 14: *The dissection of fascia and volumetric mesh.*

Task 4 : REALISTIC RENDERING

4.1 Make it all seem real?

- abdomen: very complex
- plenty of types of tissues/ membrane glistening
- previous method: shading models+gloss maps
- our method: physically based rendering (PBR)
- using realistic shading models with measured surface values



4.2 Different materials and lightning

- IBM = image based lightning
- representing incident light
- no expensive lightning computation
- time-consuming part: post–processing stage
- such as HDR, depth of field, motion blur etc. ⇒ expensive pixel operation

<u>Our rendering pipeline:</u>

- deferred shading
- focus on lights + materials

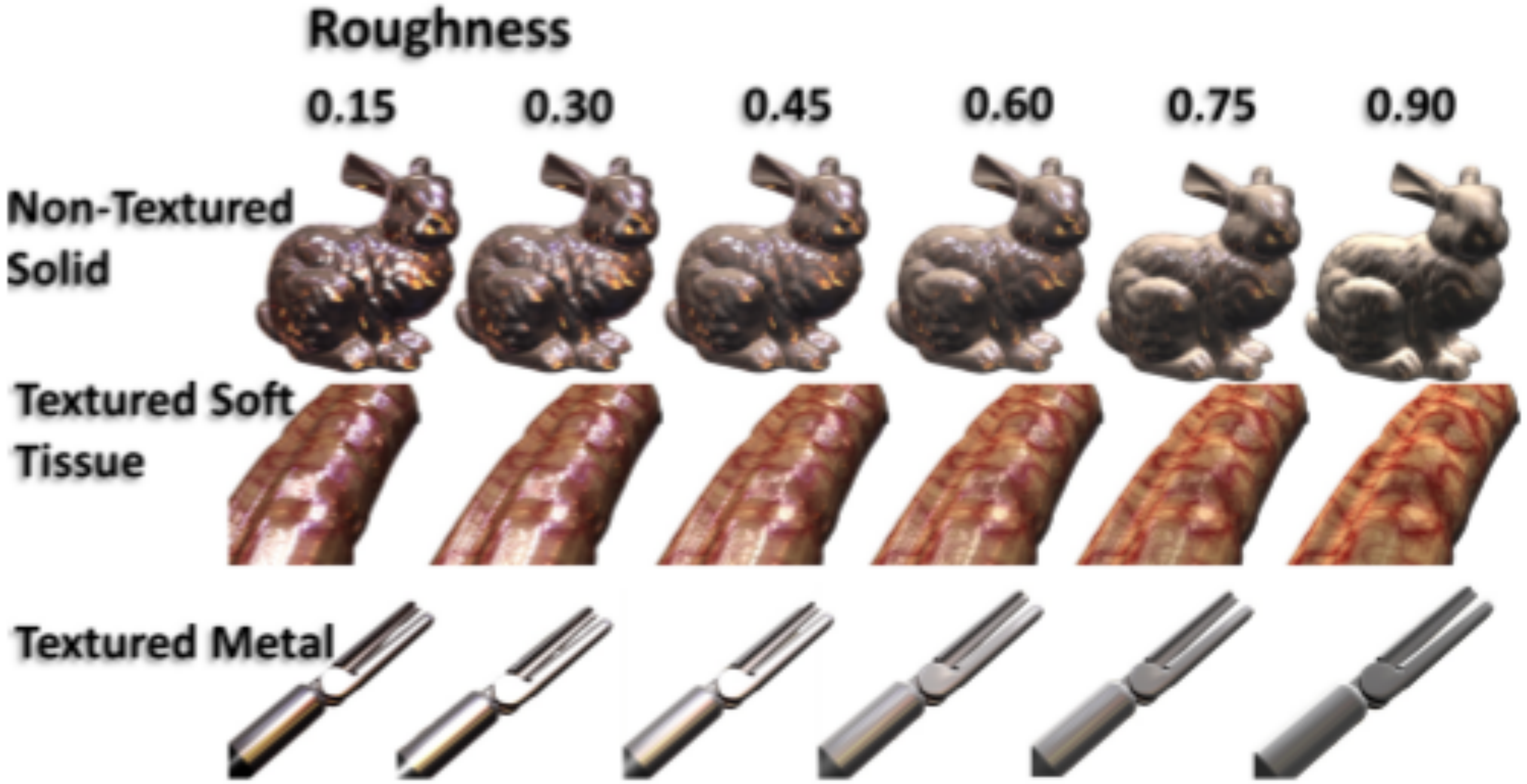


Figure 15: *Demonstration of objects using different material*

Rendering pipeline

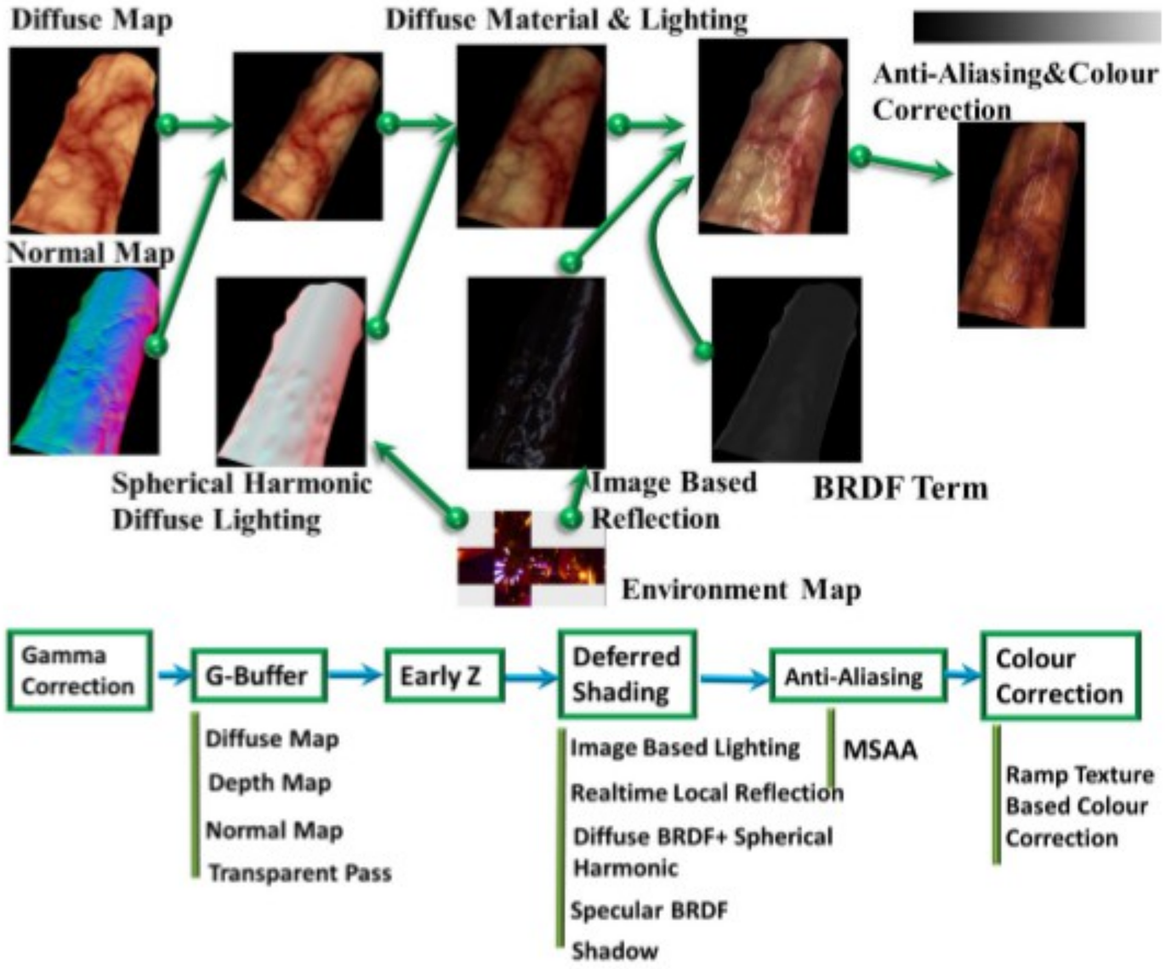


Figure 16: *Overview of the rendering procedure and pipeline*

5.IMPLEMENTATION AND RESULTS

5.1Implementation

- rectum cancer surgery simulator
- using C++, OpenGL, OpenHaptics
- value determination: help from practitioners
- aim: achieve the same effect as the actual operation

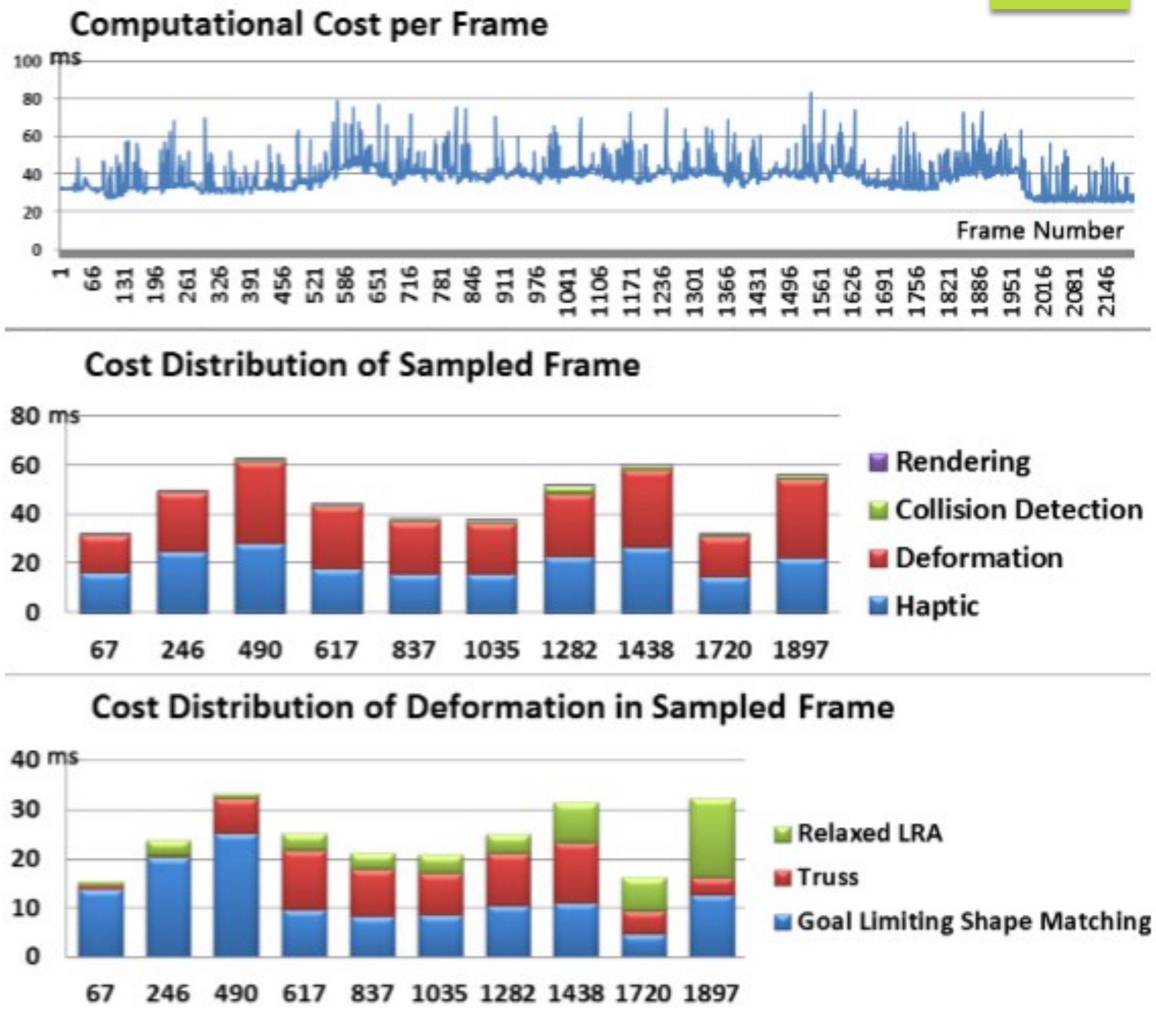
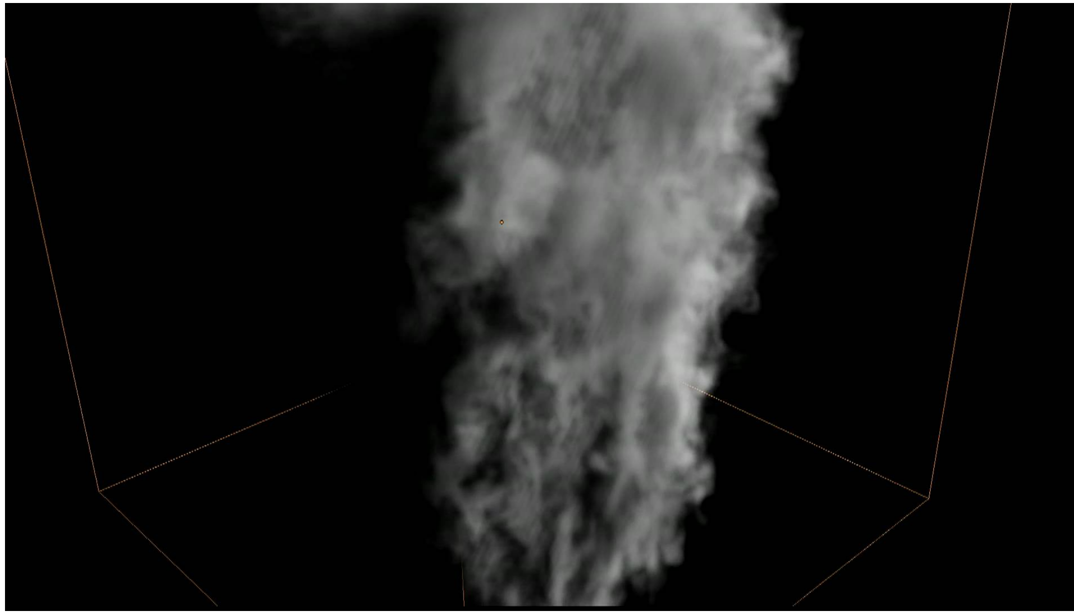


Figure 17: *Computatioanl cost distribution analysis*

5.2 FUTURE WORKS

- constraint solving procedure:
  consumes most computation resources
- solution: moving it to the GPU
  (graphics processing unit)
- parallel computing



- smoke and fluid simulation
  enhancing v[illegible]ffects

5.3 Video to see all the effects

- Video made for the paper

- Sources:
- -Virtual Reality Based Laparoscopic Surgery Simulation Kun Qian *1, Junxuan Bai 2, Xiaosong Yang 1, Junjun Pan2, and Jianjun Zhang1 1National Center for Computer Animation, Bournemouth University 2State Key Laboratory of Virtual Reality Technology and Systems, Beihang University