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GPU TECHNOLOGY CONFERENCE

High Performance Prototyping with Julia + OpenCL.jl : Patient-Specific Modeling Respiratory Motion Simulation

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1. Introduction

Using Julia language with OpenCL.jl [Jake Bolewski 2013], we have implemented a high performance prototype of nonlinear finite element (FE) model of respiratory motion.

Long-term goal: Develop patient-specific models to predict tumor motion in the lungs during radiation therapy.

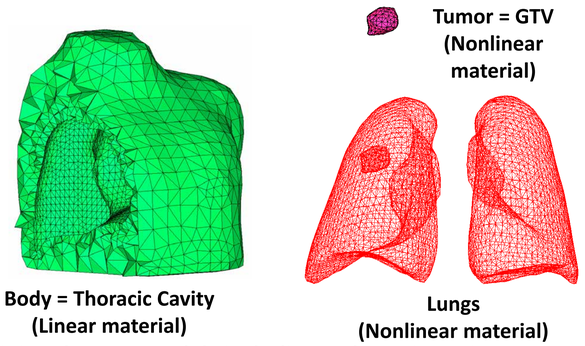
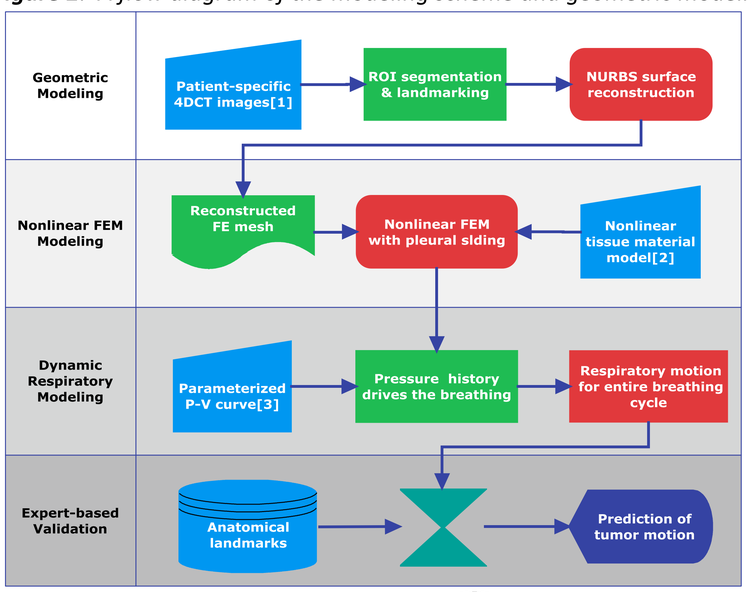
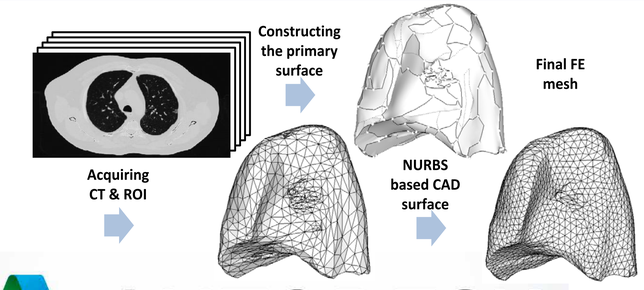


***Figure 1**: Finite element models including a thoracic cavity, a tumor (gross target volume for radiation treatment purposes) and lungs*

2. Methods and Materials

***Figure 2**: A flow diagram of the modeling scheme and geometric modeling*





Julia is a dynamic language for technical computing with familiar, script-friendly syntax, an extensive mathematical library and array-oriented computing built-in, and a high performance (< 2x of C code) just-in-time compiler.

```
import OpenCL
const cl = OpenCL

const sum_kernel = "
  __kernel void sum(__global const float *a,
                    __global const float *b,
                    __global float *c)
  {
    int gid = get_global_id(0);
    c[gid] = a[gid] + b[gid];
  }
"
a = rand(Float32, 50_000)
b = rand(Float32, 50_000)

device, ctx, queue = cl.create_compute_context()

a_buff = cl.Buffer(Float32, ctx, (:r, :copy), hostbuf=a)
b_buff = cl.Buffer(Float32, ctx, (:r, :copy), hostbuf=b)
c_buff = cl.Buffer(Float32, ctx, :w, length(a))

p = cl.Program(ctx, source=sum_kernel) |> cl.build!
k = cl.Kernel(p, "sum")

cl.call(queue, k, size(a), nothing, a_buff, b_buff, c_buff)
r = cl.read(queue, c_buff)
```

***Figure 3**: Quick Example from OpenCL.jl homepage; self explanatory command and inteface*

Julia and OpenCL.jl allows to use GPU with less hassles: Each step of explicit integration scheme easily encapsulated

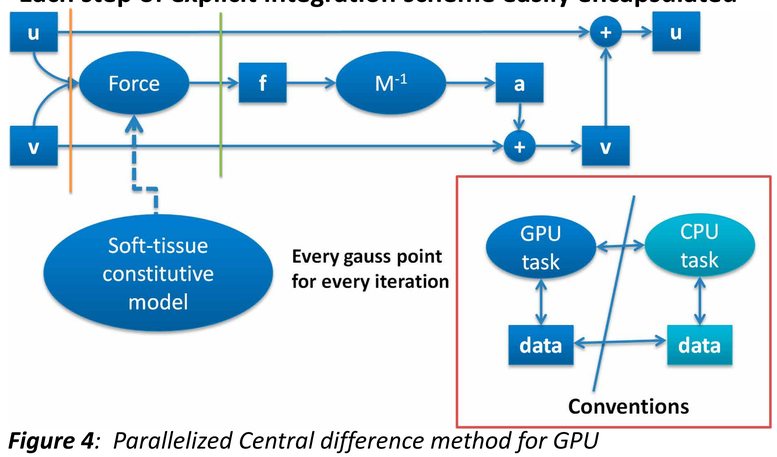


***Figure 4**: Parallelized Central difference method for GPU (Orange bar for Gather op. Green bar for Scatter op.)*

***Table 1**: Summary of finite element model*

	Features
Geometric model	ROIs segmented from 4D CT scan dataset of POPI-model [Vandemeulebroucke etal. 2007] Lung dimension: LR=29.64 cm, AP=22.30 cm, SI=21.46 cm
Finite element mesh	66704 linear tetrahedral elements with 55947 dofs
Material properties	Lung tissue: Homogeneous isotropic, hyperelastic model[Zeng etal. J Biomech. 1987] Ribcage: Homogeneous isotropic, elastic model[Brock etal. MedPhys 2005]
Contact model	Surface based master-slave frictionless contact condition
Load and boundary conditions	Uniform intrapleural pressure assumption over the lung surface: sinusoidal pressure amplitude history with pressure amplitude captured from P-V curve data[Lujan etal. MedPhys 1999, Santhanam etal 2006] Fixed displacement boundary condition applied to root of lung(trachea-lung junction)

3. Results and Discussion

Expert based validation: Validation of model was performed using **51** anatomical landmarks, *The average differences in position is seen to be **0.07 cm (SD = 0.20 cm) in LR, 0.07 cm (0.15 cm) in AP, and 0.22 cm (0.18 cm) in SI**.*

The prediction over **full breathing cycle** has **The mean error in the different breathing phases < 3mm**

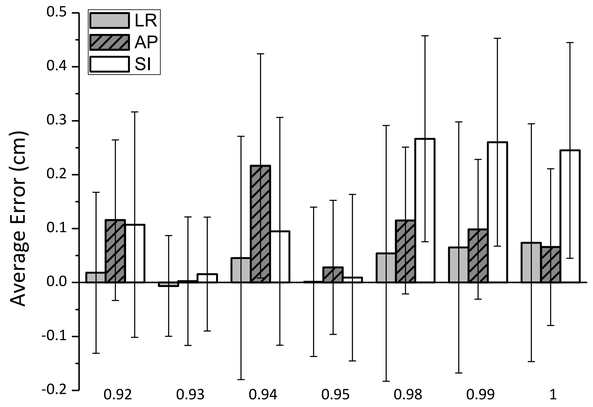


***Figure 5**: deviation of finite element model prediction from 4D CT data at different breathing phases (e.g. V_{EE} = 0.86 V_{EI} = 1.0)*

The developed simulation application test on a computer with 4 GB of main memory and a Intel Core Quad Q8200 CPU, running at 2.33 GHz with 4 MB of L2 cache, and an NVIDIA Geforce GTX 285(30 Streaming Multiprocessors (SMs) with 1 GB). The initial GPU implementation show 15x faster compared against the serial-oriented program of the CPU implementation.

4. Conclusions

- **Julia language with OpenCL.jl** give high performance prototype in the early stage of lung motion simulation research; 15x faster than CPU only simulation
- **Nonlinear finite element model of lung motion** was developed with hyperelastic tissue model and intra-pleural contact mechanics. **Model driven by physiologically relevant boundary condition** (PV curves)
- The model was **validated by landmarks** from4D CT data: **Mean error level during full breathing cycle is less than 3mm**

The next step is to include **multiple organs** and use the motion simulating finite element model for radiation dosimetry studies

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