Functional modeling of articulation based on biomechanics

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Outline

- Background
- Goal of Research
- State of Art
- Our Proposal
- Current Progress
- Future Work

Background

- Articulation

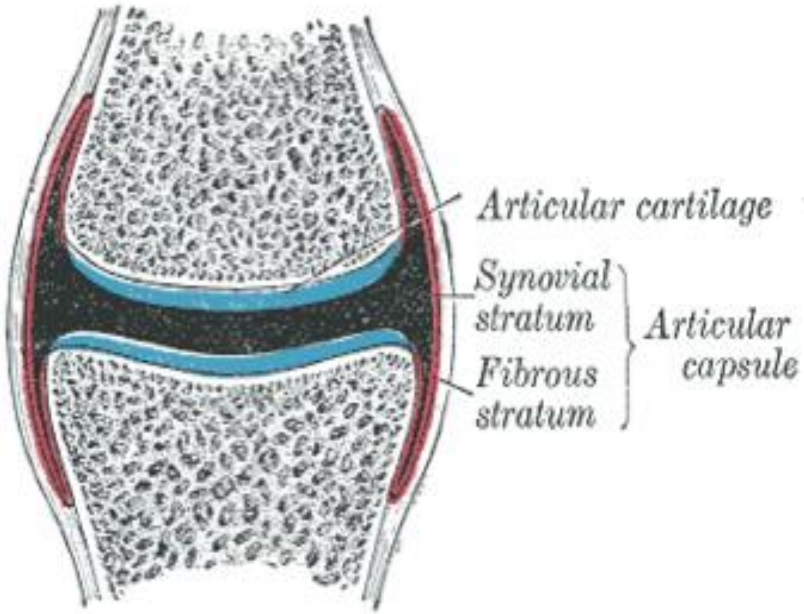
-- also known as “joints”

-- connects the bones

- Components

-- bones

-- soft tissue



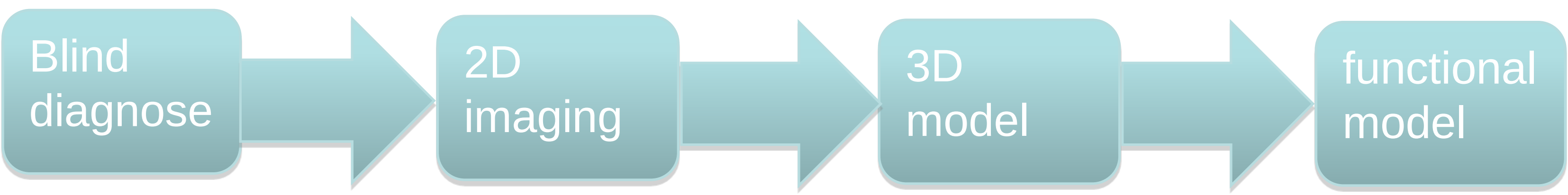
Background

- Pathologies around articulation is normal

  --Three “jumps” in the technology of medical diagnose

    --kinematical and geometrical information is not enough

    --need physical information



- A functional model can provide these physical information

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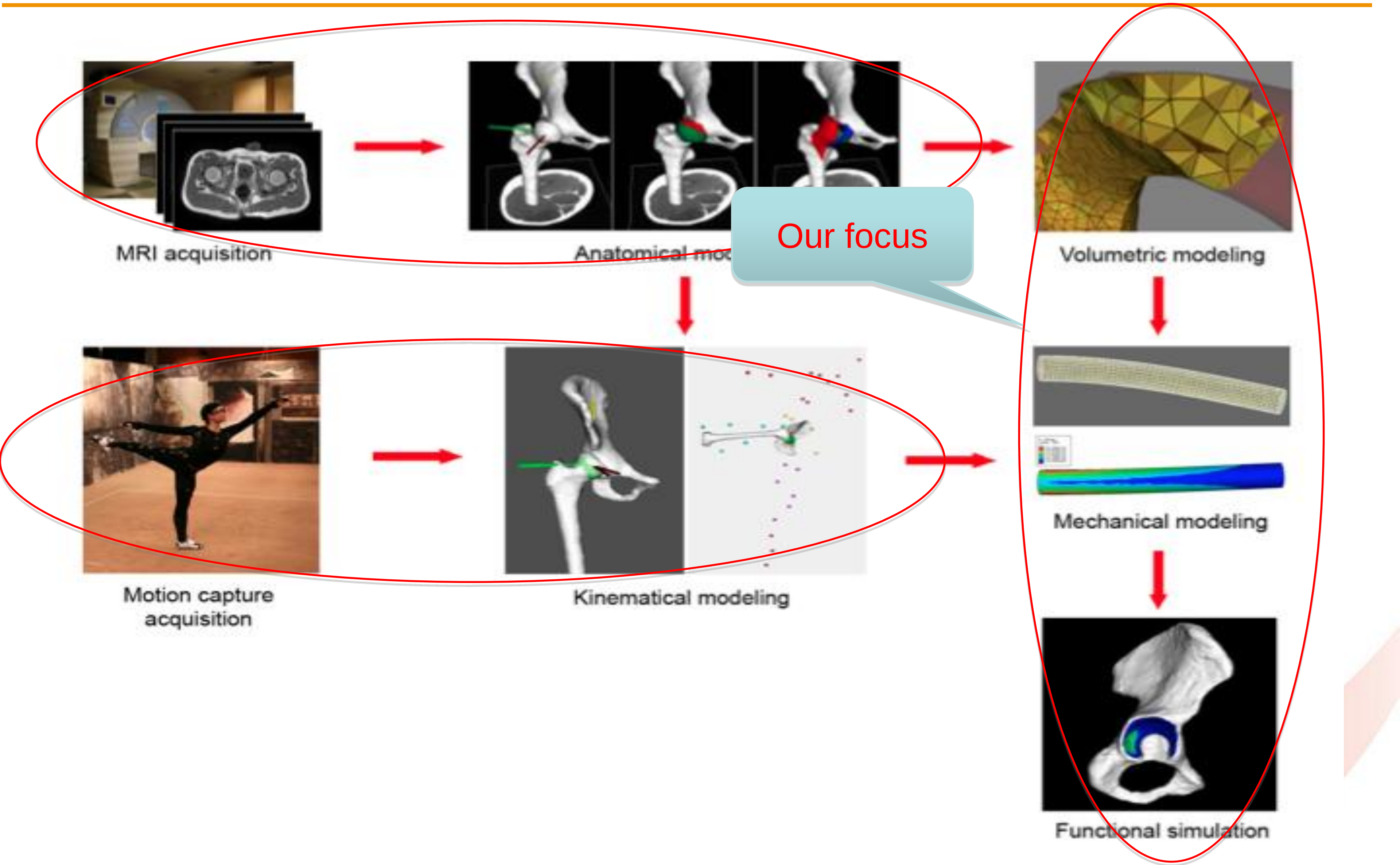
Work flow


MRI acquisition
Anatomical mod
Our focus
Volumetric modeling
Mechanical modeling
Functional simulation
Motion capture acquisition
Kinematical modeling

Goal of Research

- Build a functional model of human articulation

    --allows physical simulation

        --stress distribution computation

        --motion range estimation

        --material parameter estimation

        --etc

    --accurate and efficient enough

State of Art

- For efficiency and accuracy, most of the existed models use two-level scheme:

  -- rigid model for bones (very stiff)

  -- deformable model for soft tissue

    --mass spring system

    --continuum model (Finite Element Method)

State of Art

- A. Maciel (2005)

  --mass spring system

    --use spherical mass region

    --statistical method to derive spring stiffness

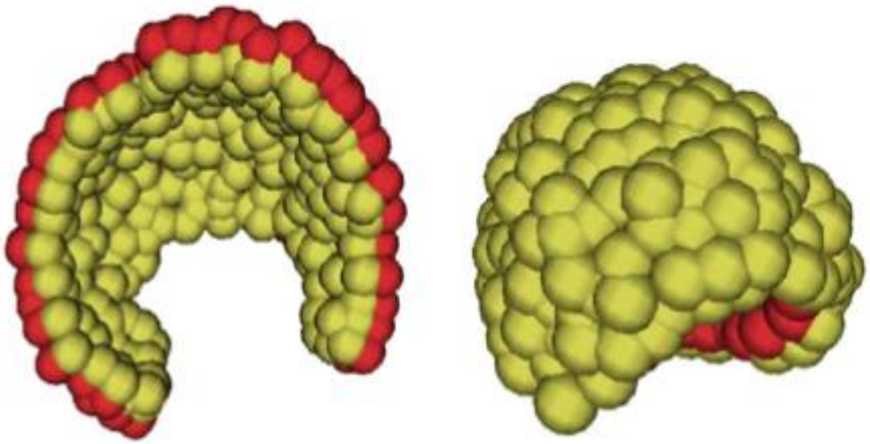
  --explicit time stepping

- Limitation

  --not accurate

  --explicit time stepping

  needs small time step



A. Maciel, Nov. 2005 “A Biomechanics-Based Articulation Model for Medical Applications,” PhD thesis, EPFL, Lausanne, Switzerland,

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State of Art

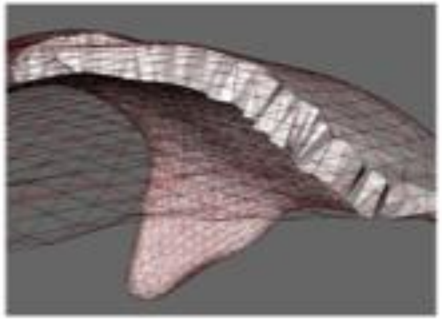
- Assassi, L. et al (2009)   -- hip joint

  --continuum model

  --both implicit and explicit time stepping

  --non-linear material

  --penalty method for collision response



- Limitation

  --slower than mass spring model

  --penalty force magnitude is hard to decide

  --no physical faith-constraints

ASSASSI, L.; CHARBONNIER, C.; SCHMID, J.; VOLINO, P.; MAGNENAT- THALMANN, N. 2009 “From MRI to Anatomical Simulation of the Hip Joint”, John Wiley and Sons, p.53–66.

State of Art

- Heimann T. et al (2010) --knee joint

  --continuum model

  --model incompressibility of soft tissue

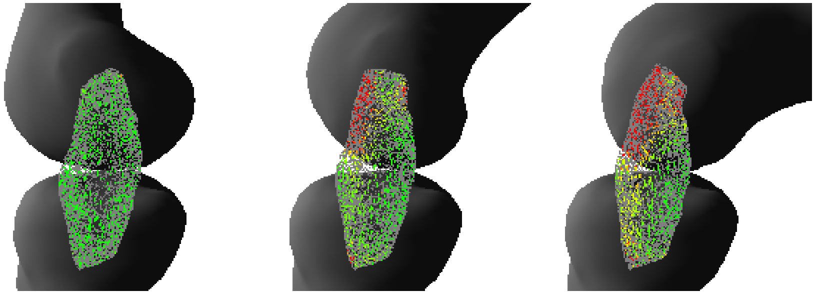
  --non-linear material

  --implicit time stepping

- Limitation:

  --add constraints to energy to model incompressibility

  --cause instability



Heimann, T., Chung, F., Lamecker, H., Delingette, H.: 2010 Subject- specific ligament models: towards real-time simulation of the knee joint. In: Computational Biomechanics for Medicine. Springer, Berlin

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State of Art

- Existed articulation model is not good enough

  --mass spring model is fast while not accurate

  --continuum model is more accurate but slow

  --no or few physical-faith constraints

Our Proposal

- Adopt the two-level scheme
- Adopt the FEM framework due to its higher accuracy
- Use quasi-static approach instead of time stepping

  --reported a speed up of one to two order compared to explicit schemes
- Physical faith-constraints (e.g. incompressibility)

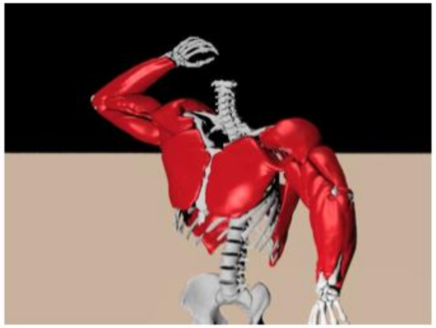
Quasi-Static Approach

- Joseph Teran et al. 2005

--assume the accelerations and velocities are zero (zero inertia)

--the object is in equilibrium state at any time

--deformation is dominantly caused by boundary condition



TERAN, J., SIFAKIS, E., IRVING, G., AND FEDKIW, R. 2005. Robust quasi-static finite elements and flesh simulation. In Proceedings of the 2005 ACM SIGGRAPH/Eurographics Symposium on Computer Animation. 181–190

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Quasi-Static Approach--Problems

- Invalid for unconstrained state

  --e.g. free fall

- Can not be used directly with position correction method in collision response

  --the external force needs to be known

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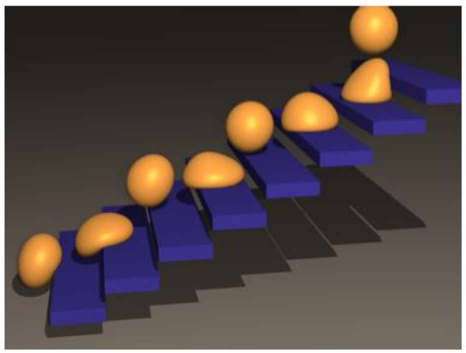
Physical faith-constraints

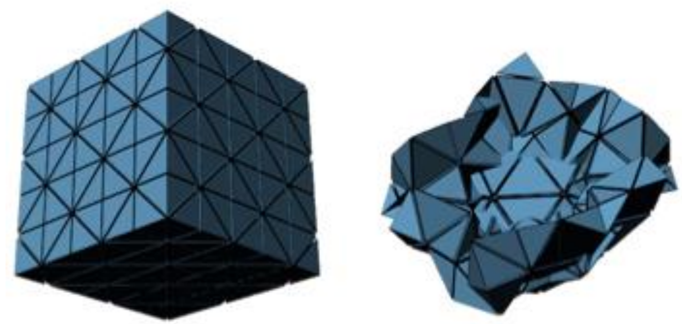
- Simulation should be faithful

  -- the soft tissue is highly incompressible (Irving et al 2007)

  -- element inversion leads unrealistic negative volume (R. Schmedding et al 2008)

  -- others





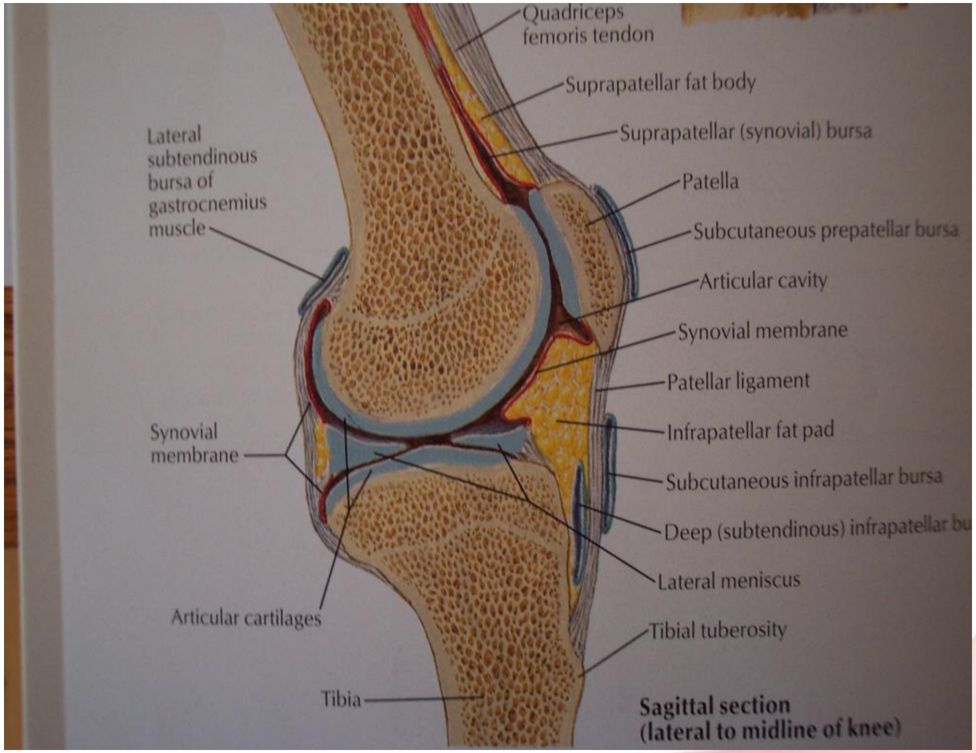
IRVING G., SCHROEDER C., FEDKIW R. 2007, “Volume conserving finite element simulations of deformable models”, In Proc. SIGGRAPH, pp. 13:1–13:6.

R. Schmedding, M. Teschner, 2008 "Inversion Handling for Stable Deformable Modeling,” The Visual Computer, vol. 24, no. 7-9 (CGI 2008 Special Issue), pp. 625-633.

Case Study--knee joint

- Largest and one of the most complex articulation
- Bear most of the weight

--suitable for quasi-static method



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Current Progress

- Current Progress

  -- elastic force deriving for soft tissue

  -- collision detection & response between soft tissue

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Future Work

- Future Work

  --By April 2011

  Add physical faith-constraints (incompressibility) to soft tissue model

  --By Jun 2011

  , Construct the 3D anatomical knee joint model

  Kinematic modeling of the constructed knee joint model

  --By Sep 2011

  Modify quasi-static method to fit into the knee joint model

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Thank you !