

Anatomy of Finite Element Analysis *in* Biomechanics

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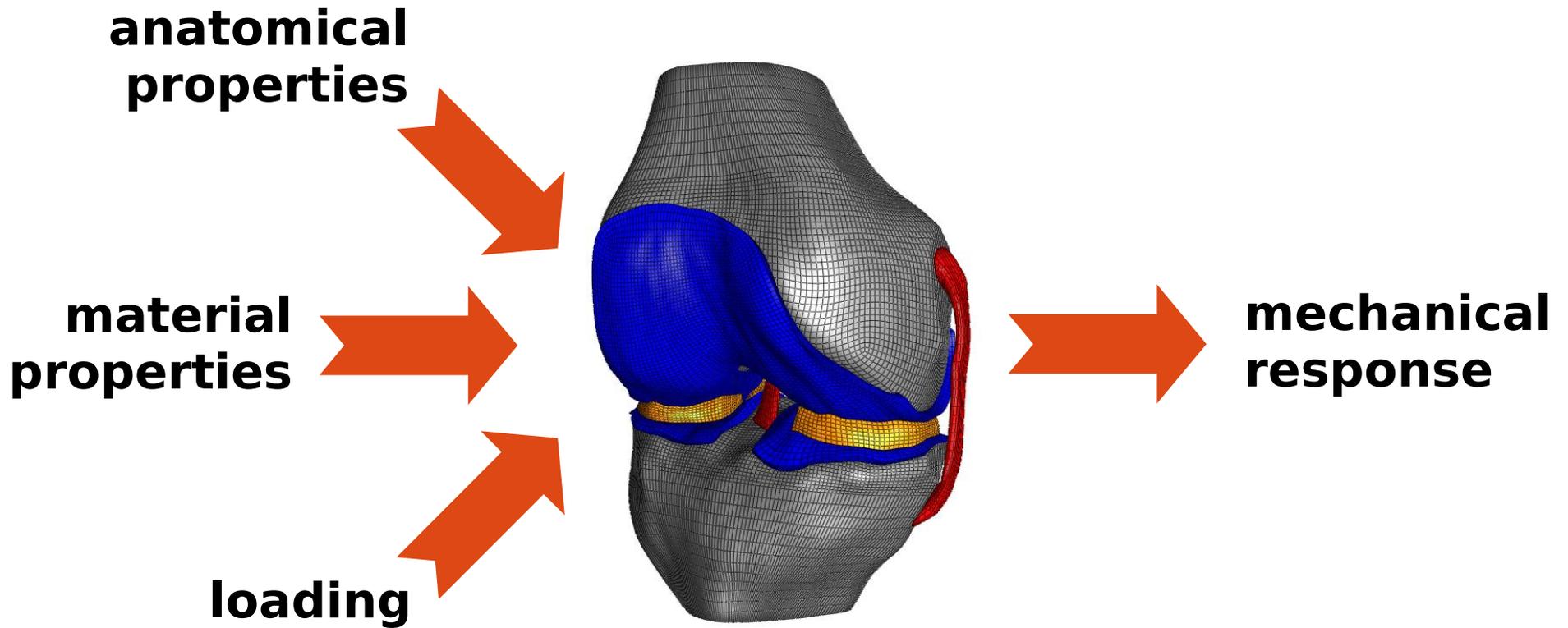
September 10, 2015

Satellite Meeting on
Overview and Use of Standards and Formats Relevant to MSM
2015 MSM Consortium Meeting

PRESENTATION GOALS

- ❏ To provide an overview of a **common workflow** for finite element analysis (FEA) in biomechanics
- ❏ To establish an understanding of the **components** of the FEA workflow
 - raw/derivative data - submodels - ...*
- ❏ To illustrate **technologies** to assist the FEA workflow
 - formats/standards - markup languages*
 - simulation software - auxiliary software*
 - computing strategies - repositories*
 - ...*

PREMISE OF FEA



POPULARITY OF FEA

PubMed

"finite element"

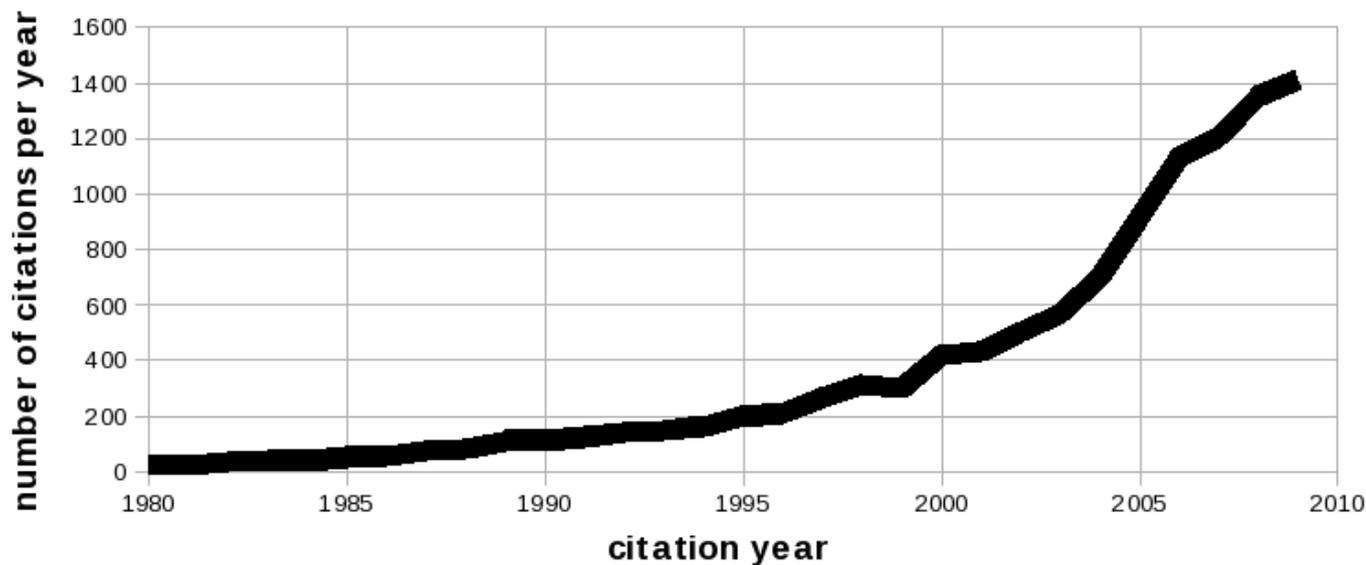
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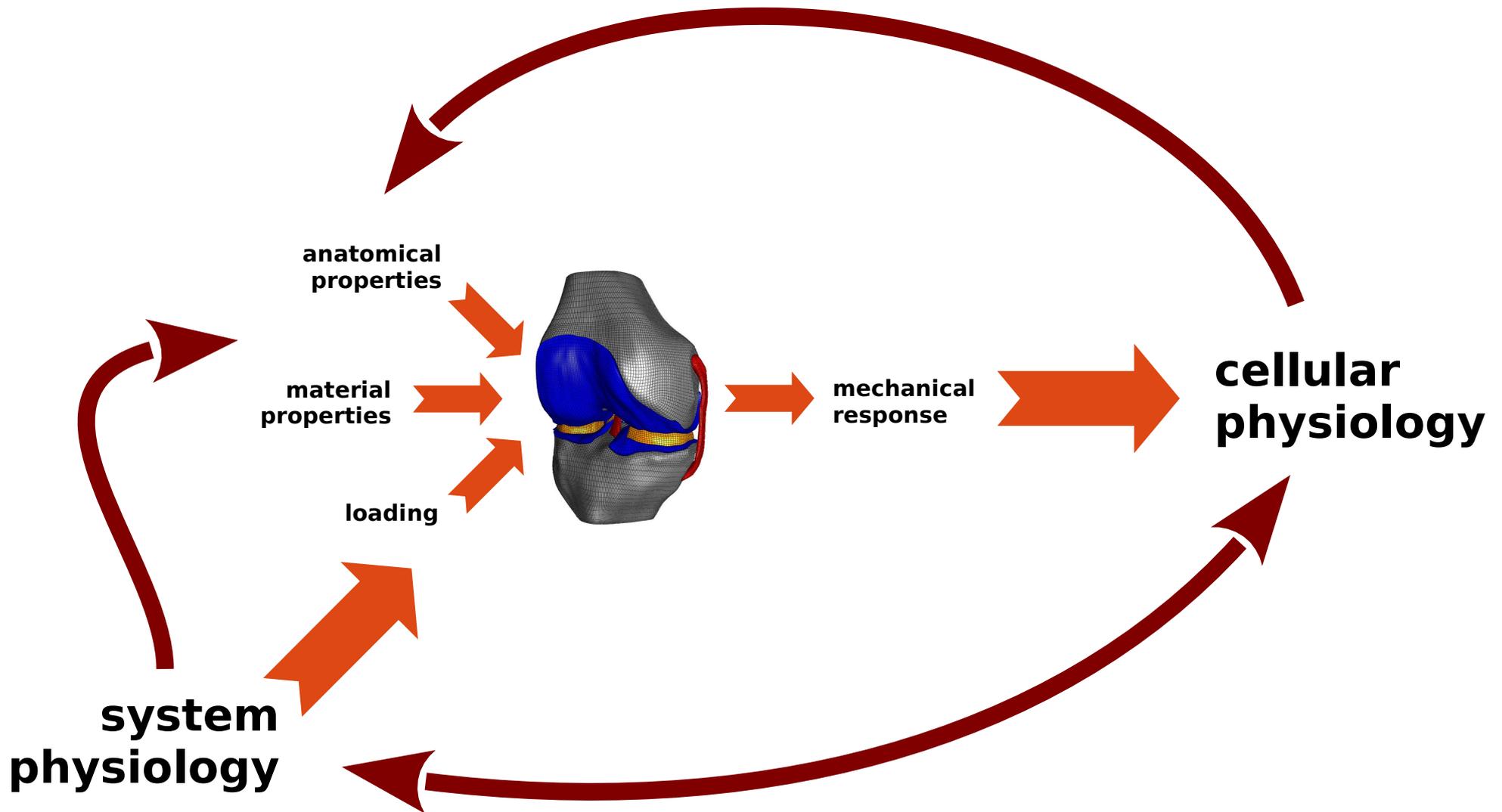
(as of Sep 7, 2015)



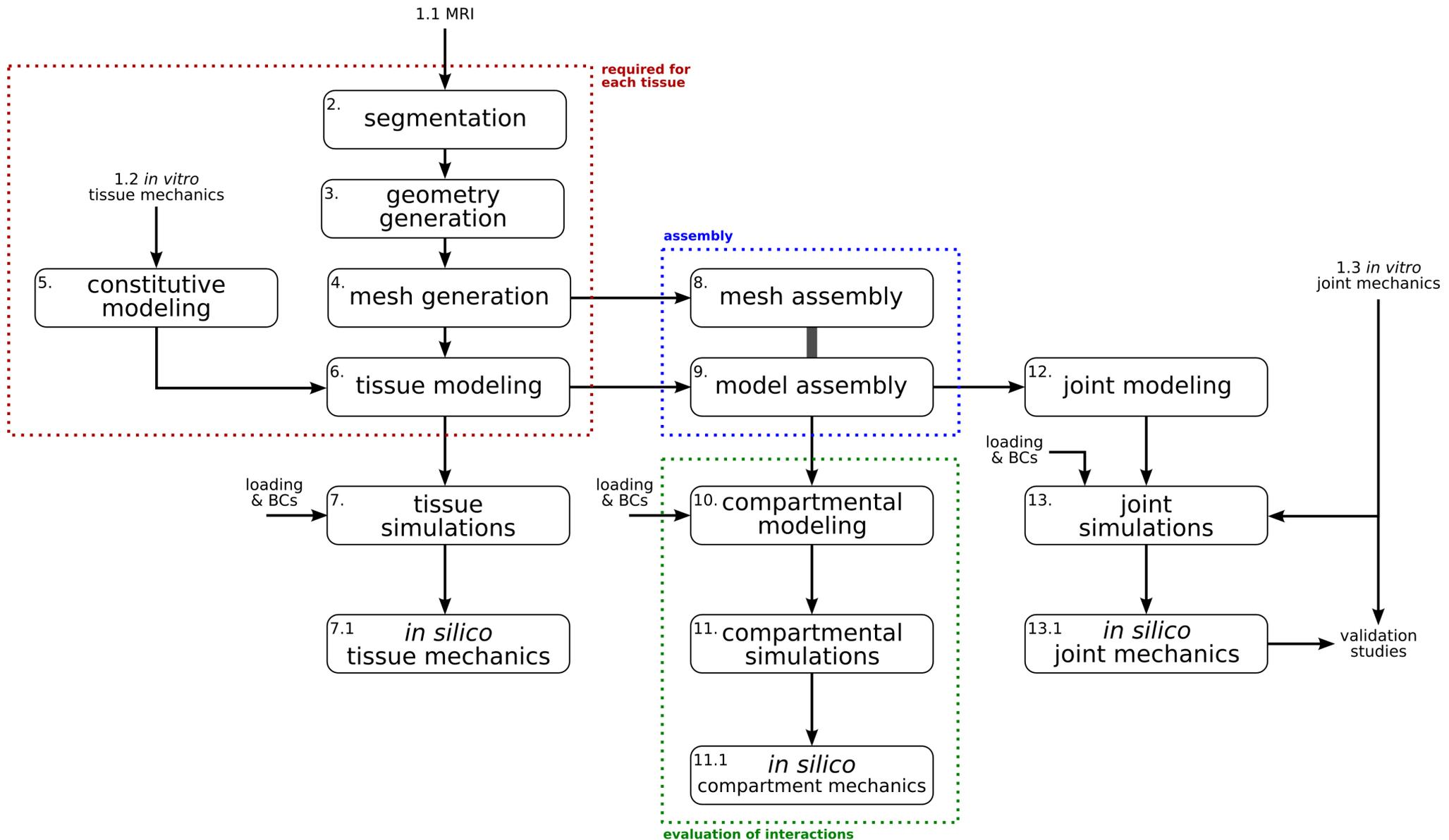
**FINITE ELEMENT
ANALYSIS IN
MEDICINE**

adapted from *Erdemir et al. (2012)*

FEA IN MULTISCALE M&S



COMMON FEA WORKFLOW



DATA: ANATOMY



Modalities magnetic resonance imaging
computed tomography
various microscopy

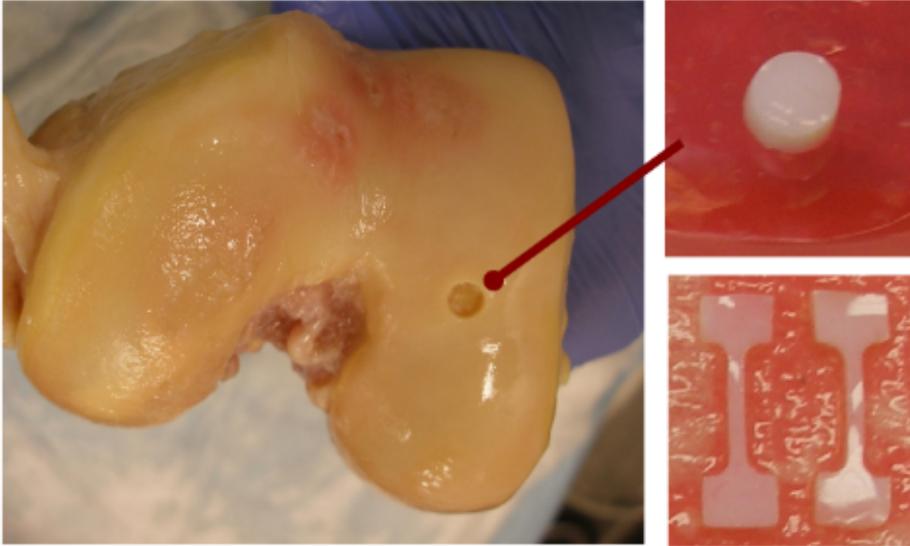
Formats/Standards DICOM
Digital Imaging and Communications in Medicine

NIFTI
Neuroimaging Informatics Technology Initiative

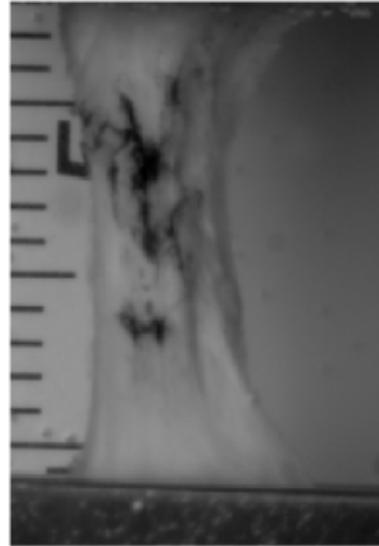
various image formats

DATA: PHYSIOLOGY

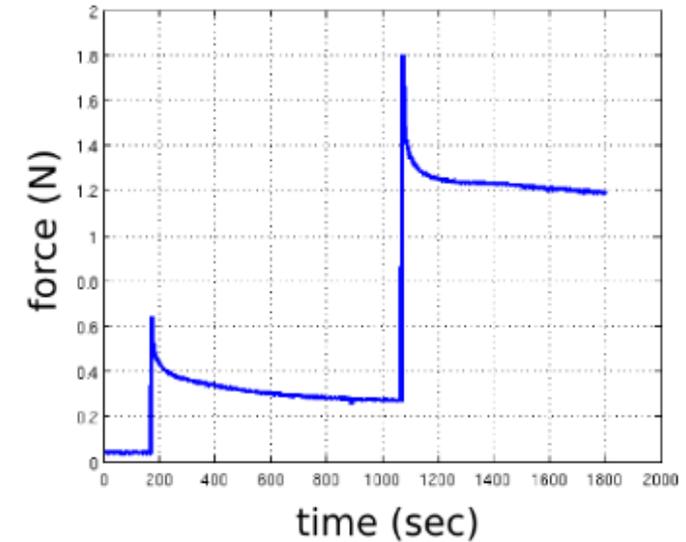
Tissue Sampling



Uniaxial Testing



Stress Relaxation



Modalities testing of isolated tissue samples
in situ testing + inverse analysis
imaging based estimation

Formats/Standards various text formats

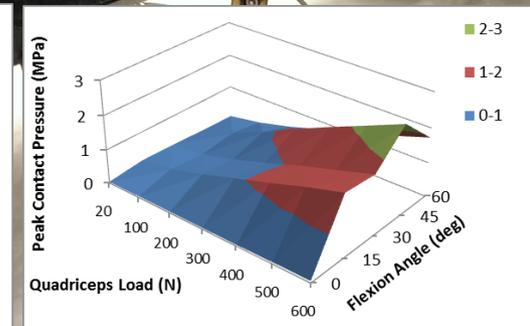
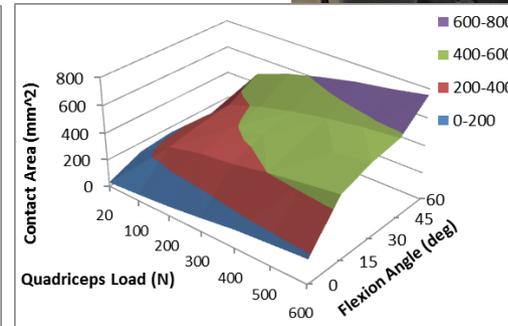
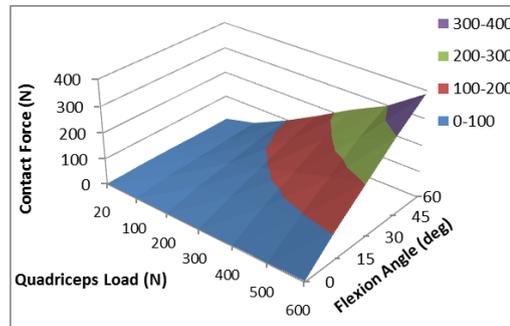
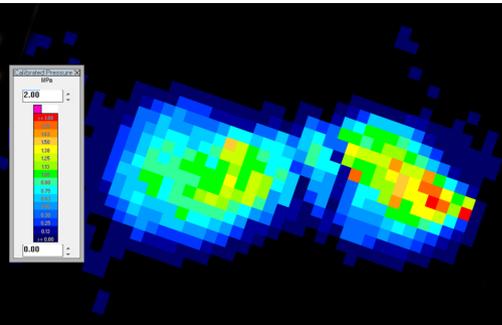
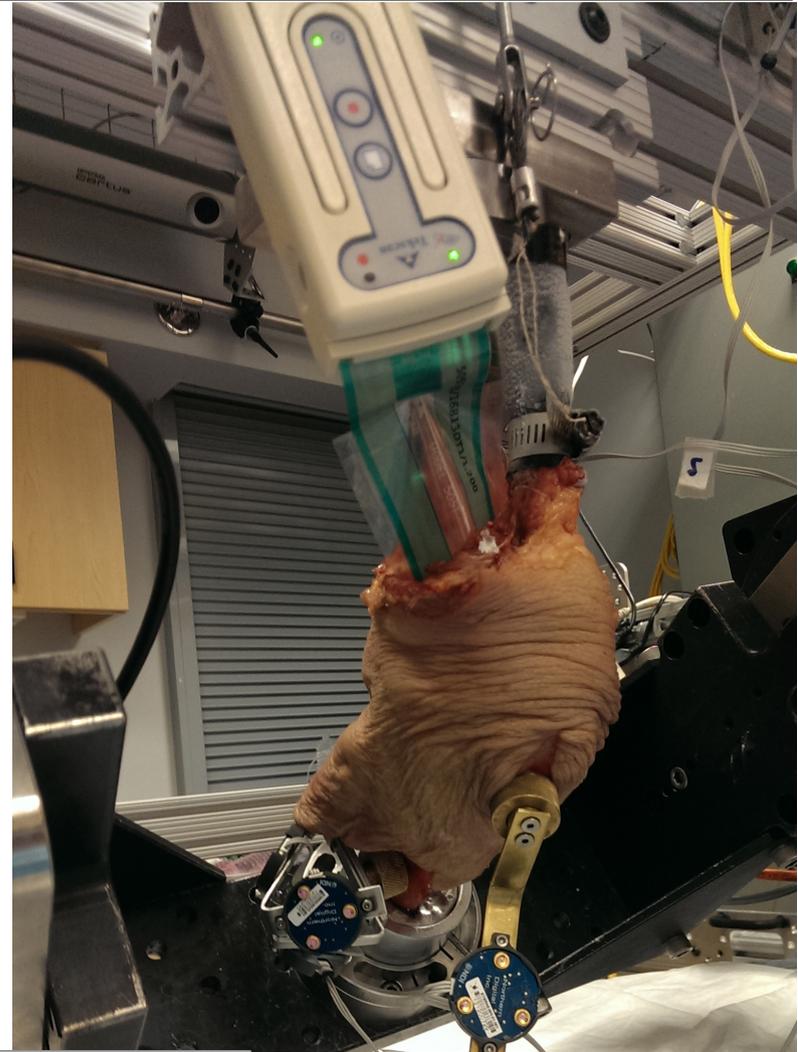
DATA: LOADING

Modalities

in vitro testing
in vivo testing
model based estimation

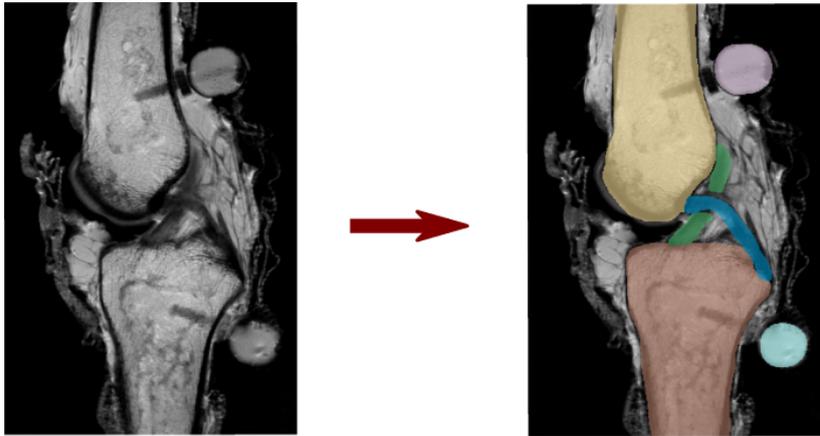
Formats/Standards

various binary formats
various text formats



PRE-PROCESSING: GEOMETRY

SEGMENTATION



DERIVATIVE DATA

tissue volume
voxel-based

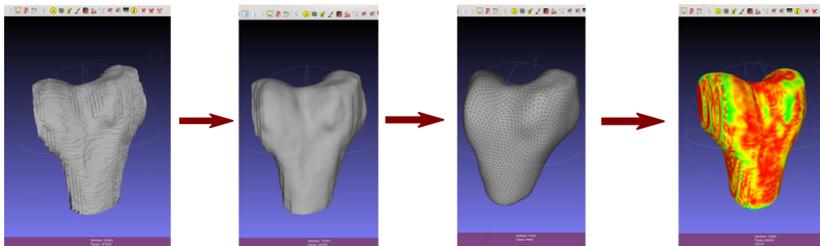
FORMATS & STANDARDS

DICOM
NifTI
various IMG

SOFTWARE

FOSS
3D Slicer
ITK-SNAP
commercial
Mimics
Simpleware

GEOMETRY GENERATION

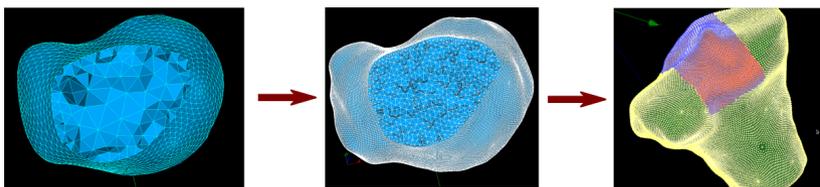


surface
geometry
parametric
or explicit

STL
IGES
STEP

FOSS
MeshLab
SALOME
commercial
various CAD

MESH GENERATION

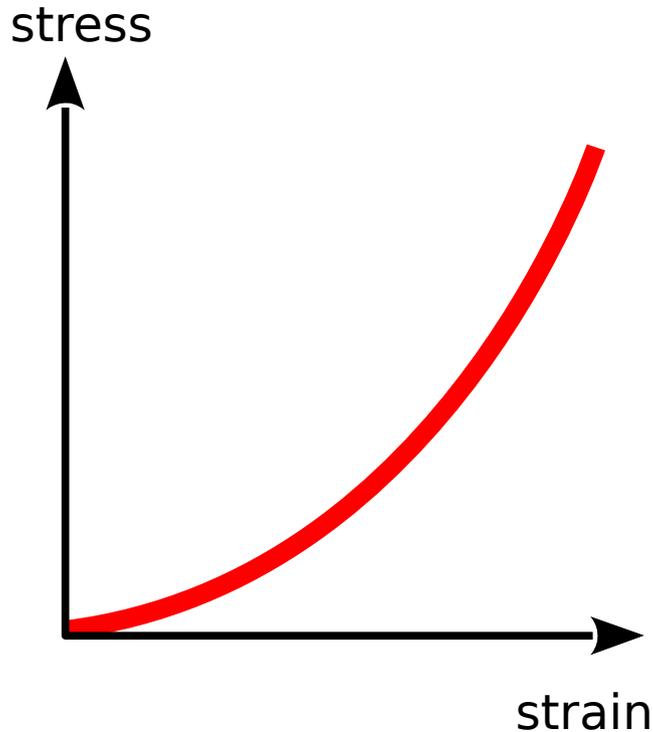


volume
mesh
nodes
elements
sets

various TXT
various XML
various HDF

FOSS
Netgen
IA-FEMesh
commercial
various FEA
TrueGrid

PRE-PROCESSING: MATERIAL PROPERTIES



CONSTITUTIVE MODELING

$$\rightarrow W = \sum_{i=1}^N \frac{\mu_i}{\alpha_i} \left(\overline{\lambda_1^{\alpha_i}} + \overline{\lambda_2^{\alpha_i}} + \overline{\lambda_3^{\alpha_i}} - 3 \right) \rightarrow \mu_i, \alpha_i$$

DERIVATIVE DATA

stress-strain data
constitutive coefficients

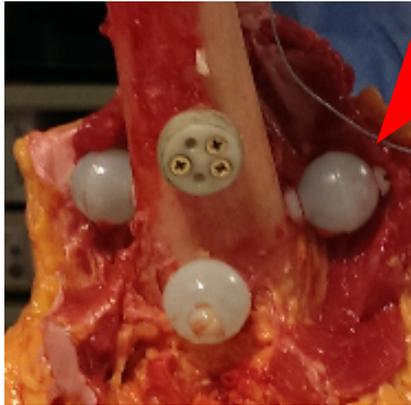
FORMATS & STANDARDS

various TXT
coefficients in publications

SOFTWARE

various for data fitting
scripting languages

PRE-PROCESSING: LOADING & BCS



- ❑ Representation of loading time history in a usable manner
- ❑ Spatial registration of anatomy and loading
- ❑ Establishment of reference states
- ❑ May require other modeling strategies

DERIVATIVE DATA

load time history
boundary condition
descriptions

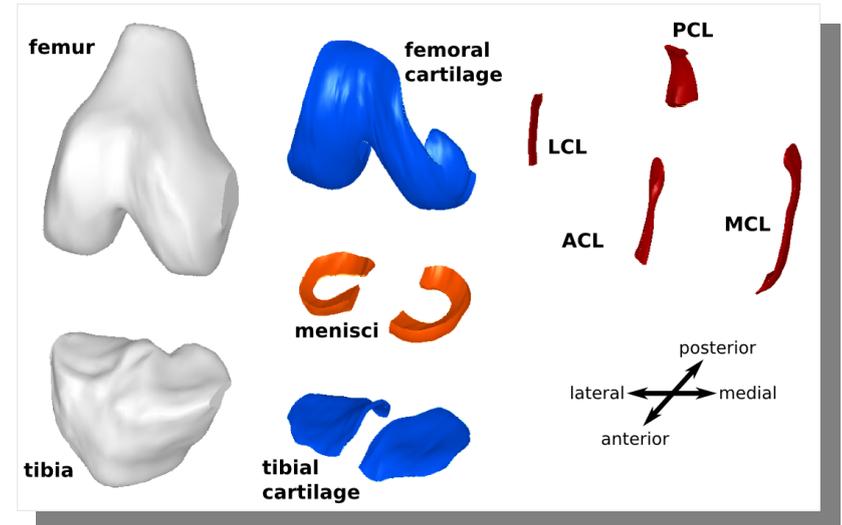
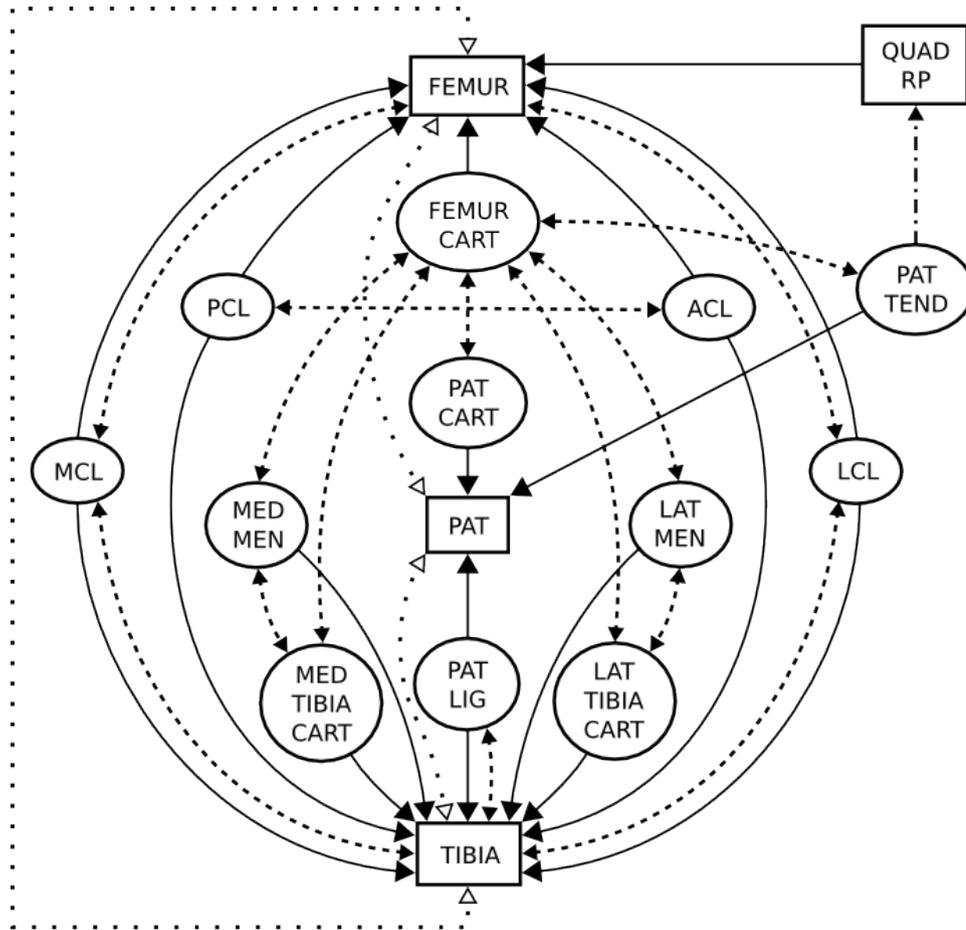
FORMATS & STANDARDS

various TXT
publications

SOFTWARE

scripting languages
other M&S
musculoskeletal
systems models

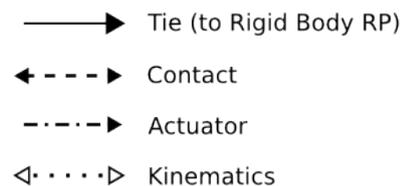
PRE-PROCESSING: ASSEMBLY



OBJECT TYPES:



MECHANICAL RELATIONSHIPS:



- ▣ Representation of whole model

- ▣ Customization to swap components

- ▣ Compartmental modeling

MODEL FORMAT



Specific to
simulation
software

TEXT FORMATS

Abaqus (.inp)
etc.

XML FORMATS

FEBio (.feb)
FieldML (.fml)
etc.

Model definition → mesh
material properties
loading & BCs

BINARY FORMATS

Abaqus (.cae)
etc.

MIXED FORMATS

COMSOL
FieldML
Code Aster
(mesh as binary)

SCRIPT FORMATS

Code Aster
(Python)

SIMULATION PROCESS



```
erdemir@ae-ultrabook:~$ febio2.lnx64 -i tf_joint_FEBio_v2.feb
```

SIMULATION SOFTWARE

- ❏ Commonly imported from manufacturing industry
- ❏ Commonly designed for the analysis of man made structures with a handful of recent exceptions
- ❏ Choice of simulation software highly depends on software capabilities, features, and cost

COMMERCIAL

Abaqus
COMSOL
etc.

ACADEMIC FREE

FEBio
Continuity 6
etc.

FREE & OPEN SOURCE

Code Aster
OpenCMISS
etc.

COMPUTING

Venues

High performance computing

XSEDE (academic)

GPGPU

Cloud computing

simtk.org (coming soon)

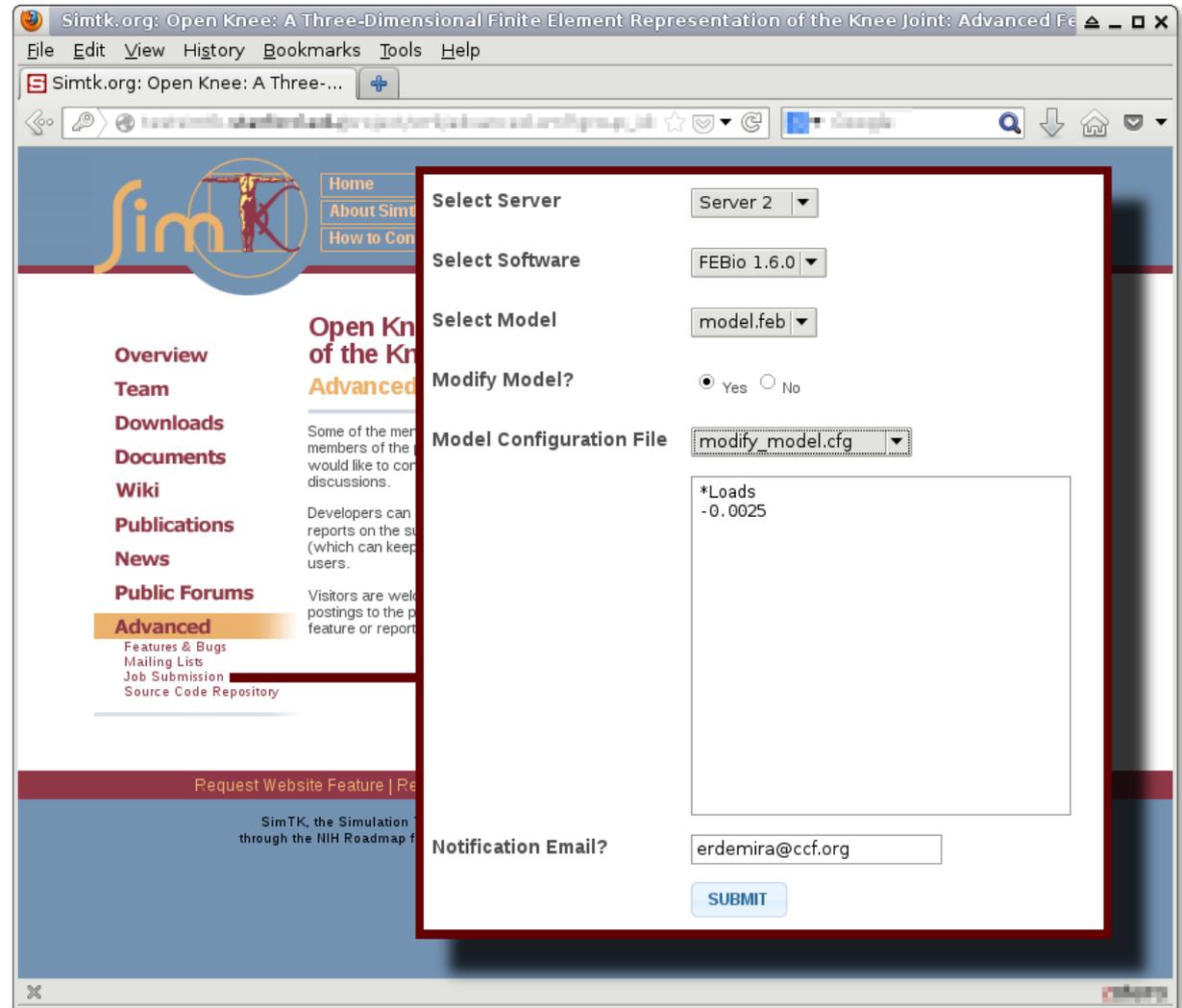
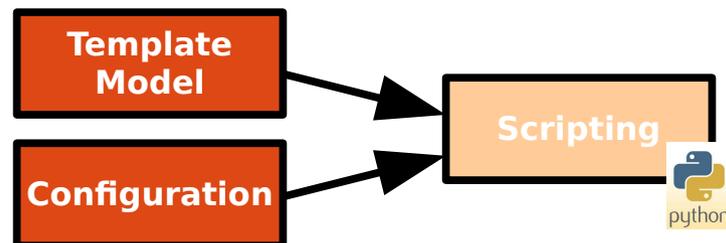
Galaxy

rescale (commercial)

Issues

Workflow automation

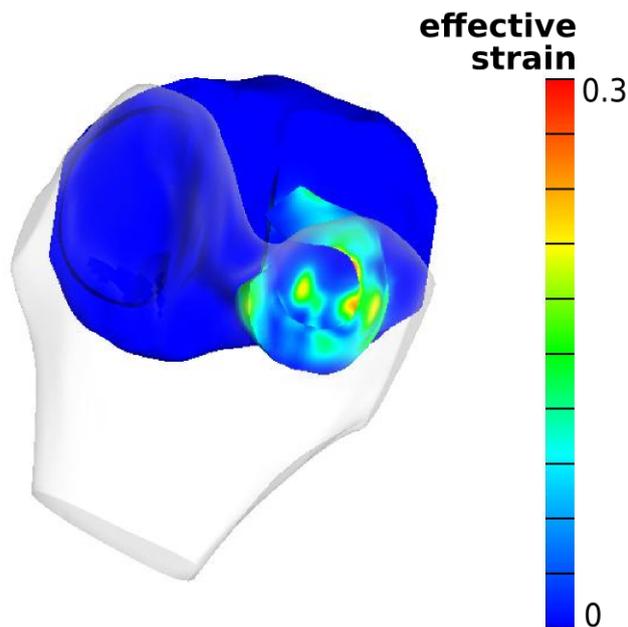
Incompatible licensing



Adapted from Open Knee(s), refer to <https://simtk.org/home/openknee>.

POST-PROCESSING

- Visualization (qualitative)
- Extraction of biomechanical markers (quantitative)
- Critical step for appropriate interpretation & evaluation

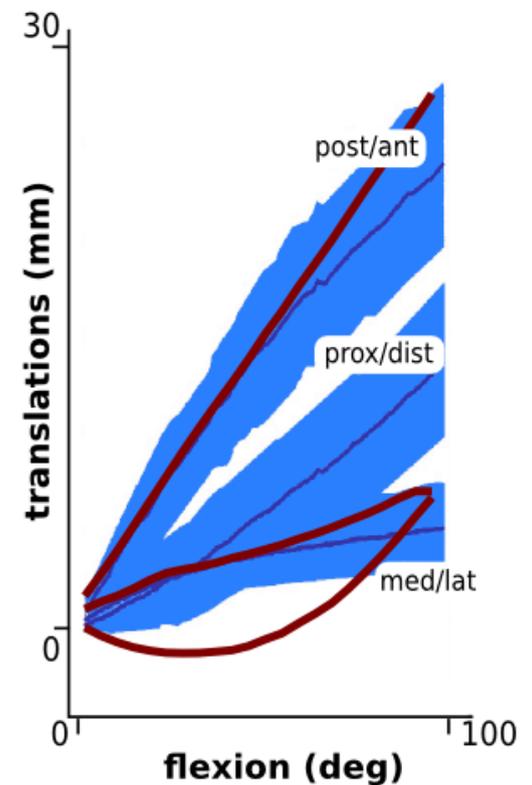
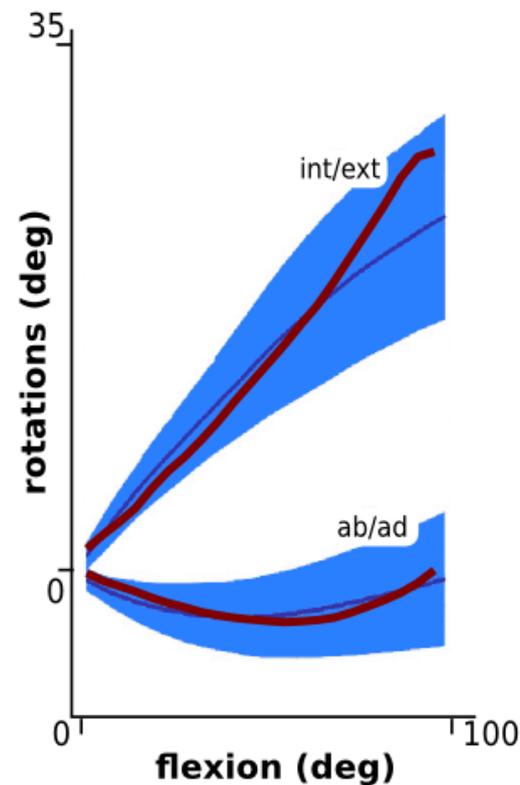


FORMATS

various TXT
various binary

SOFTWARE

various visualization
Python



REPORTING

Good reporting practice

clarifies uncertainty of **reproducibility**,
promotes **reusability**, and
establishes **accountability**.



**CONFIDENCE
IN
MODELING & SIMULATION**

Journal of Biomechanics 45 (2012) 625–633



Contents lists available at [SciVerse ScienceDirect](#)

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com



Perspective article

Considerations for reporting finite element analysis studies in biomechanics

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^e Center for Devices and Radiological Health, Food and Drug Administration, Silver Spring, MD 20933, USA

adapted from *Erdemir et al. (2012)*

DISSEMINATION

Venues

Repositories

simtk.org

GitHub

Institutional repositories

Laboratory sites

Journals

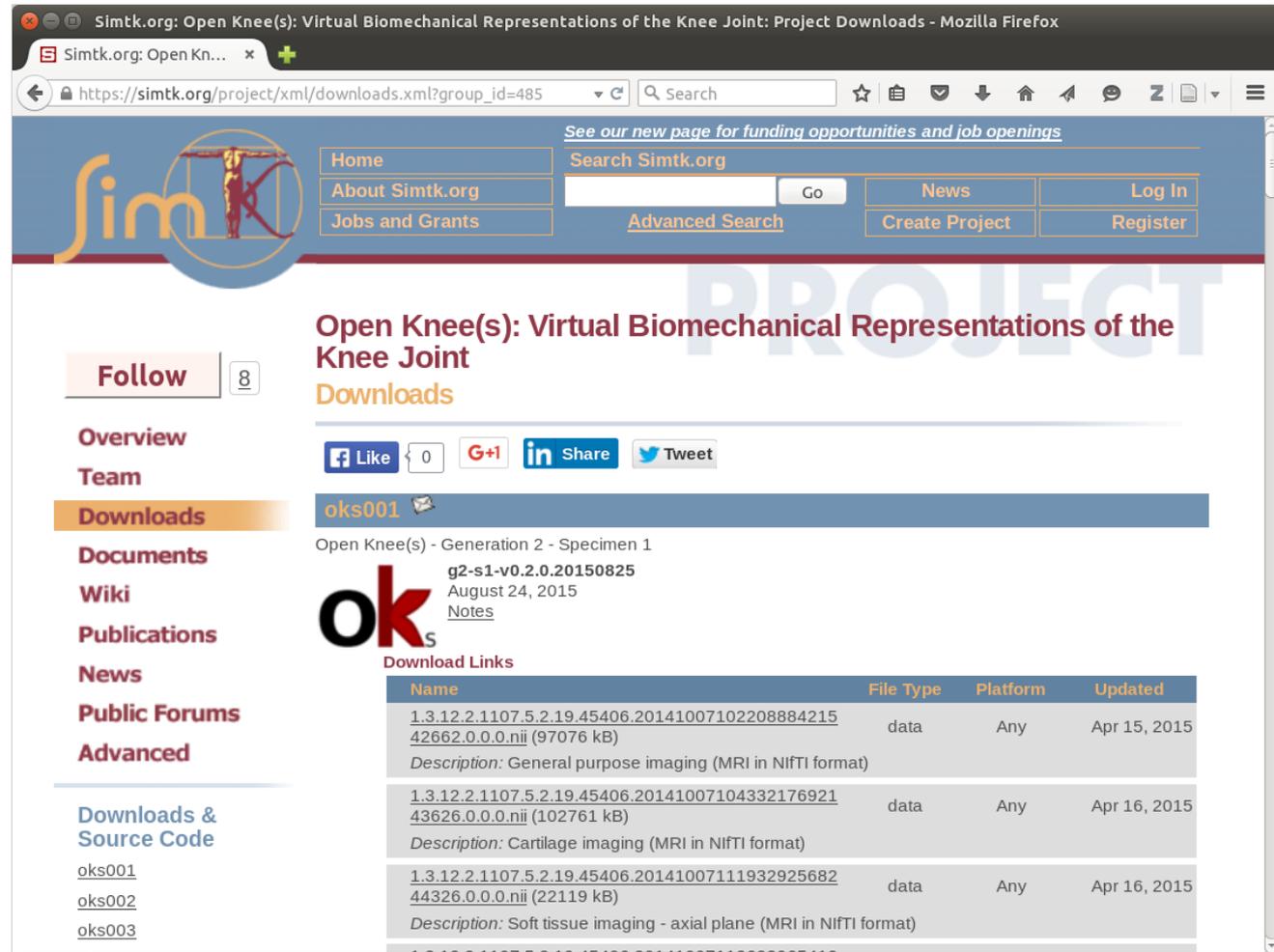
supplementary material

Issues

Scarce data

Limited sharing

Incompatible licensing



Simtk.org: Open Knee(s): Virtual Biomechanical Representations of the Knee Joint: Project Downloads - Mozilla Firefox

Simtk.org: Open Kn... x

https://simtk.org/project/xml/downloads.xml?group_id=485

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oks003

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oks001

Open Knee(s) - Generation 2 - Specimen 1

g2-s1-v0.2.0.20150825
August 24, 2015
Notes

Download Links

Name	File Type	Platform	Updated
1.3.12.2.1107.5.2.19.45406.20141007102208884215 42662.0.0.0.nii (97076 kB)	data	Any	Apr 15, 2015
Description: General purpose imaging (MRI in Nifti format)			
1.3.12.2.1107.5.2.19.45406.20141007104332176921 43626.0.0.0.nii (102761 kB)	data	Any	Apr 16, 2015
Description: Cartilage imaging (MRI in Nifti format)			
1.3.12.2.1107.5.2.19.45406.20141007111932925682 44326.0.0.0.nii (22119 kB)	data	Any	Apr 16, 2015
Description: Soft tissue imaging - axial plane (MRI in Nifti format)			

CONCLUDING REMARKS

- ❖ **Requirements** for FEA workflow in biomechanics include

use of heterogeneous data

relying on various data formats

model representation specific to simulation software

software to assist model development / customization

- ❖ **Challenges** for modularity, reusability, and reproducibility include

lack of unified and generally accepted formats

lack of robust utility software for mark-up conversion

lack of large databases and comprehensive repositories

constraints for spatial association of model components

ACKNOWLEDGMENTS



OPEN KNEE – GENERATION 1

Modeling

Craig Bennetts
Ahmet Erdemir
Randy Heydon
Scott Sibole

Data

Bhushan Borotikar
Antonie J. van den Bogert

Simulation Software

Ben Ellis
Steve Maas
David Rawlins
Jeff Weiss

NIH/NIBIB R01EB009643
NIH/NIGMS R01GM083925
NIH/NIAMS R01AR049735
Simbios

OPEN KNEE(S) – GENERATION 2

Cleveland Clinic

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Ahmet Erdemir
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Stanford University

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R01GM104139



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LICENSING

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