

# Data and Data Management for Finite Element Analysis in Joint Biomechanics

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**July 8, 2015**

*Mobilizing Data: Research at the Intersection of Data Science and Biomechanics*  
**XXI ISEK Congress**

# PRESENTATION GOALS

- ❖ To provide an overview of **data needs** for finite element analysis, with specific attention to joint biomechanics
- ❖ To describe **data management strategies** for effective modeling, promoting reproducibility and reusability.

# POPULARITY OF FEA

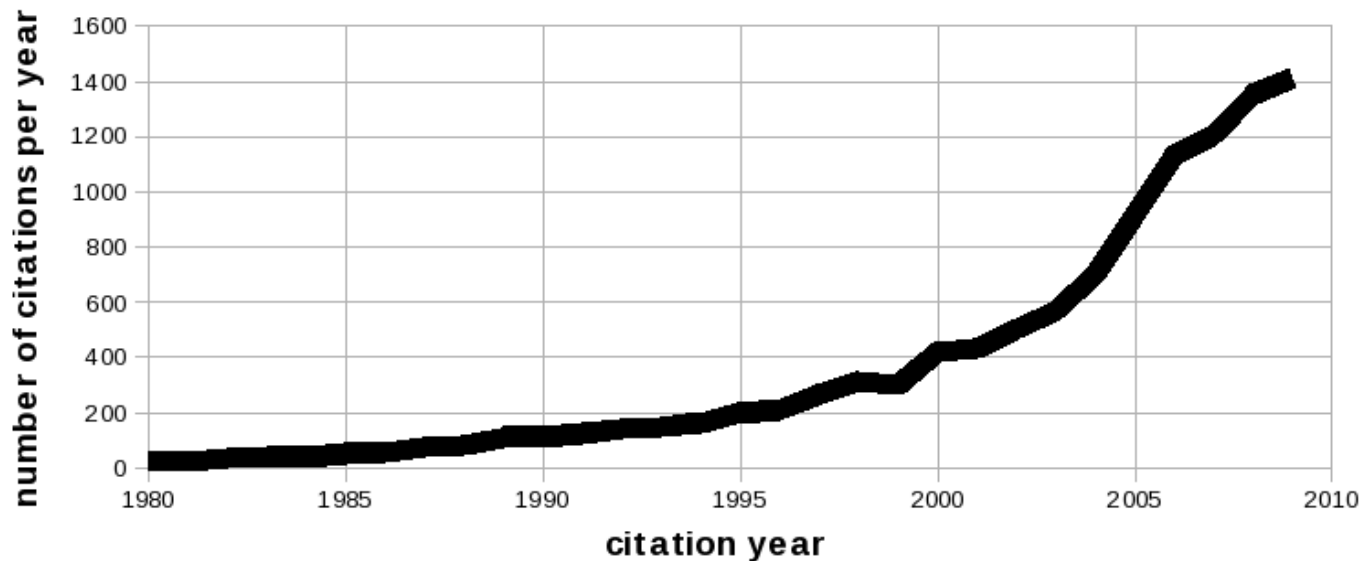
PubMed

"finite element"

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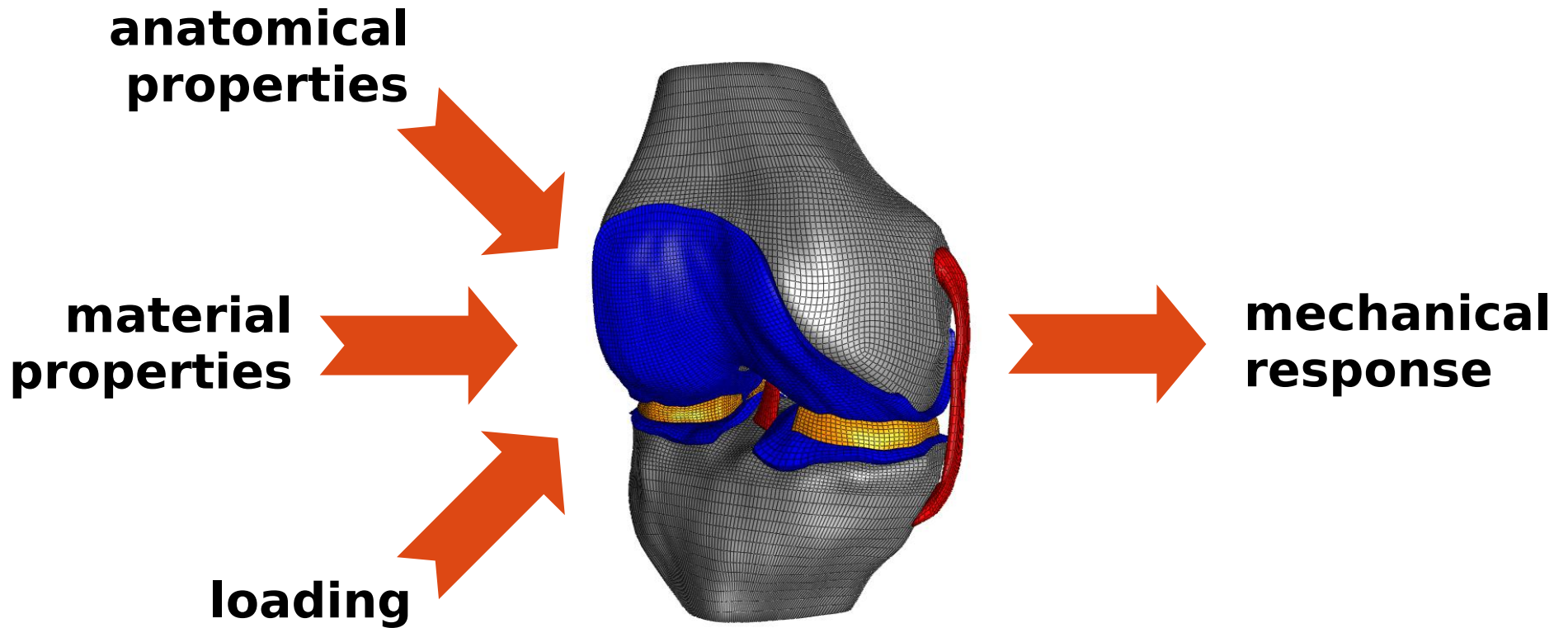
(as of Sep 7, 2015)



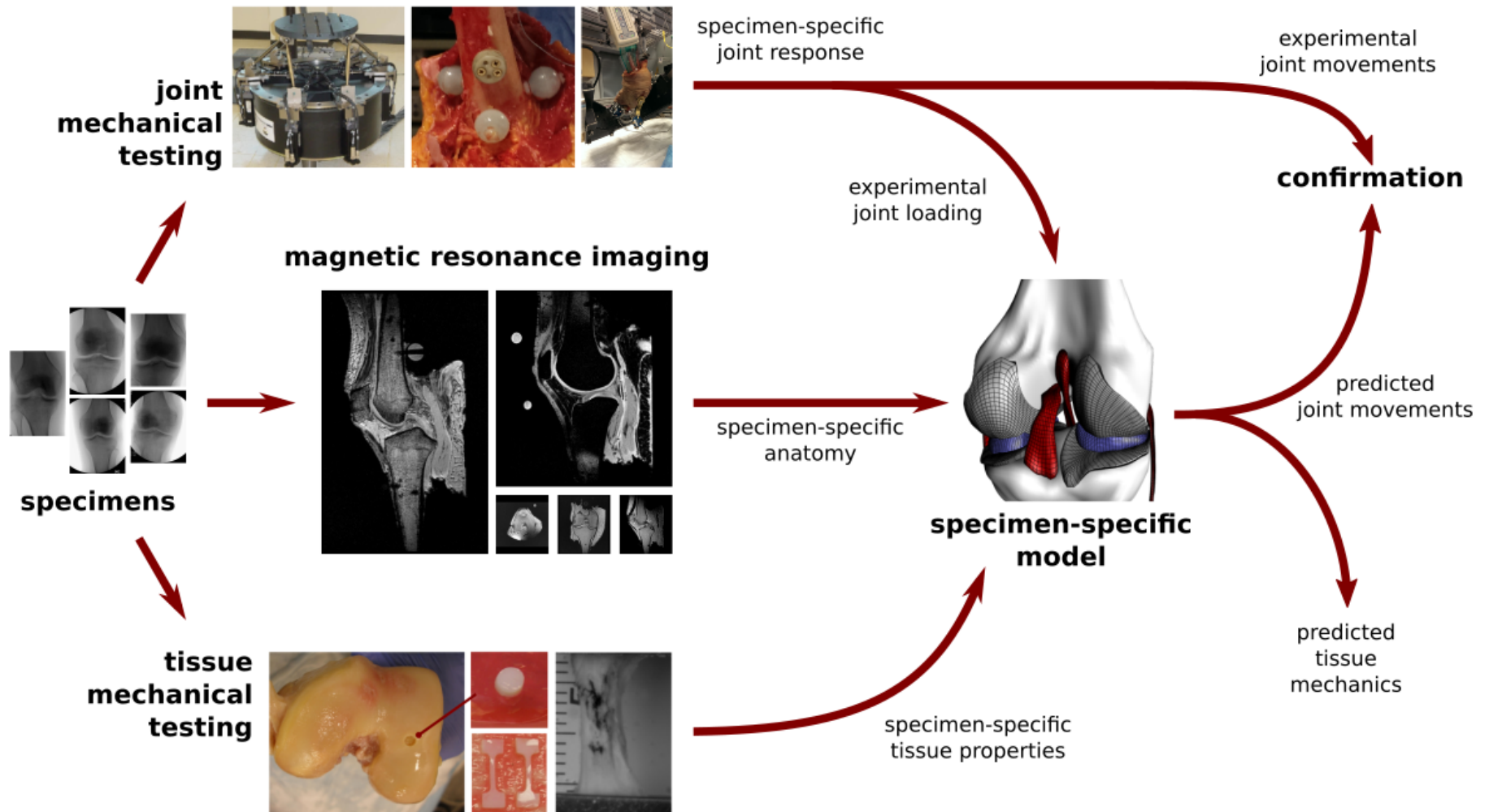
**FINITE ELEMENT  
ANALYSIS IN  
MEDICINE**

adapted from *Erdemir et al. (2012)*

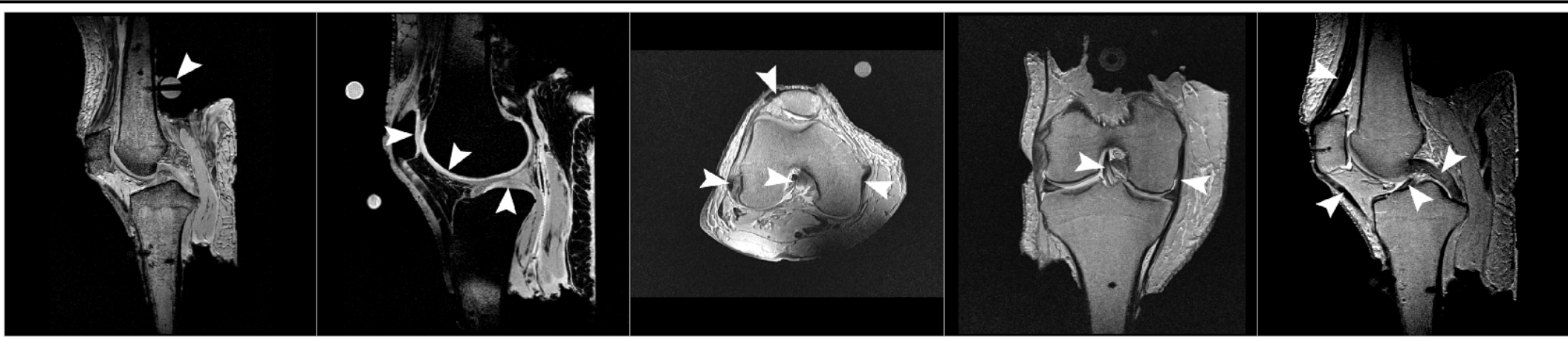
# PREMISE OF FEA



# FEA WORKFLOW



# DATA: ANATOMY

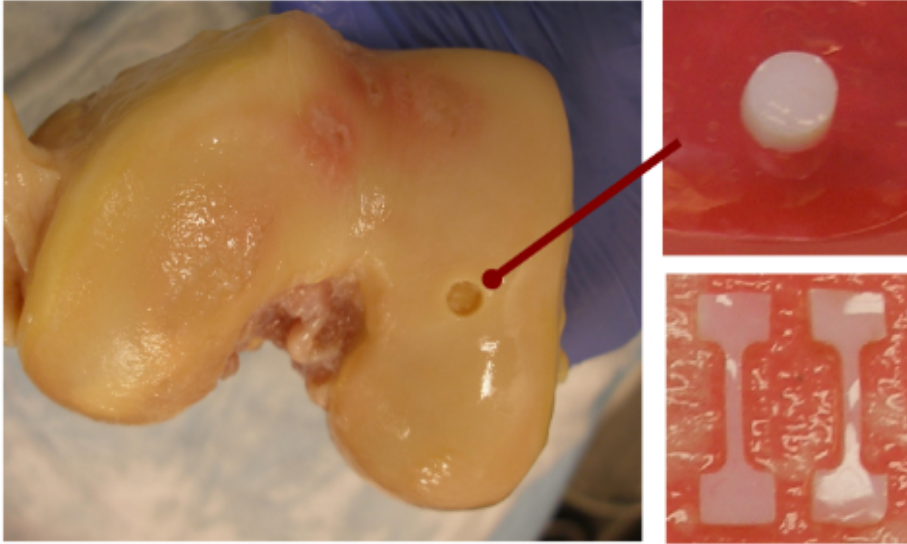


**Modalities** magnetic resonance imaging  
computed tomography  
various microscopy

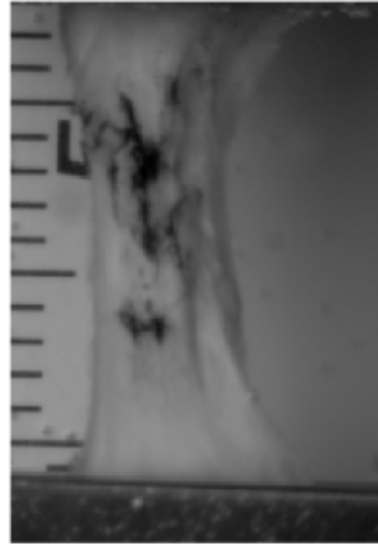
**Formats/Standards** DICOM  
Digital Imaging and Communications in Medicine  
  
NIFTI  
Neuroimaging Informatics Technology Initiative  
  
various image formats

# DATA: PHYSIOLOGY

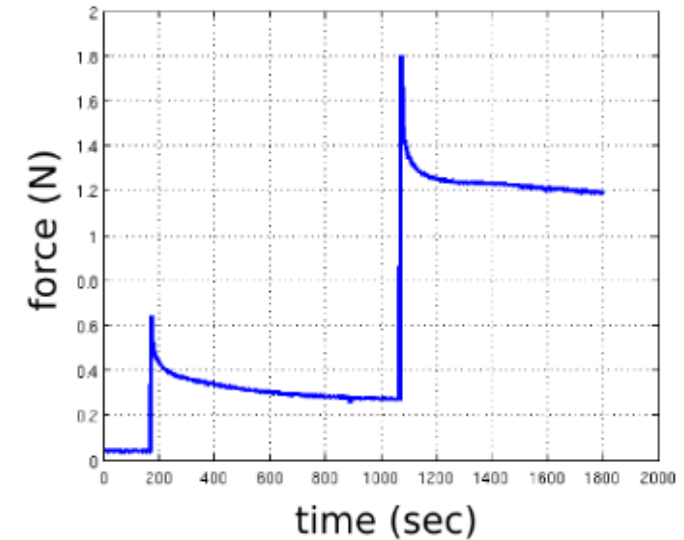
## Tissue Sampling



## Uniaxial Testing



## Stress Relaxation



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

**Formats/Standards** various text formats

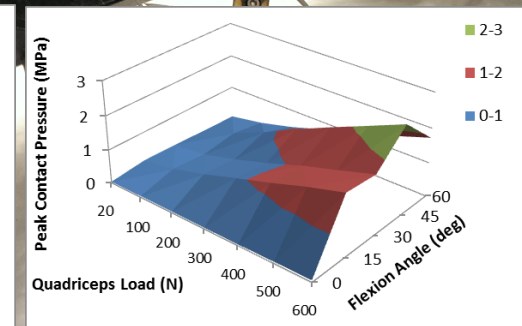
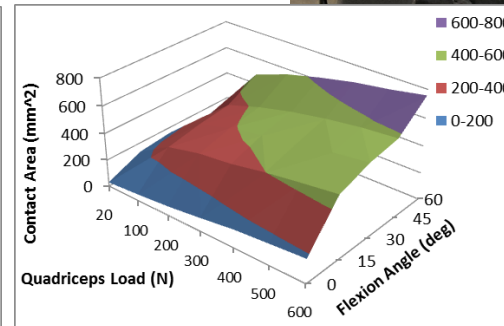
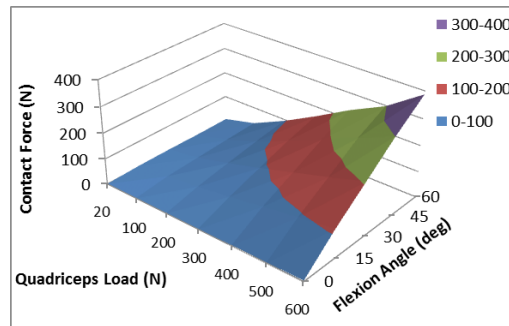
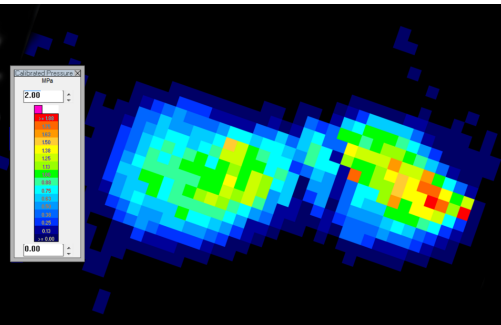
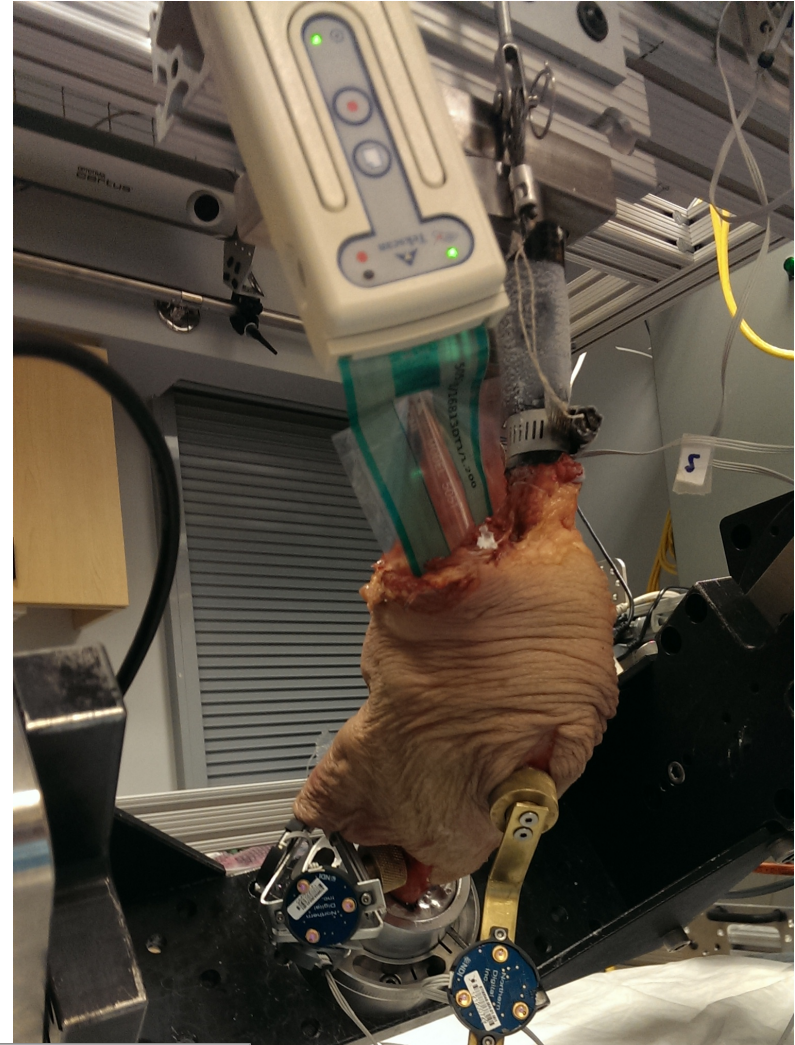
# DATA: LOADING

## Modalities

*in vitro* testing  
*in vivo* testing  
model based estimation

## Formats/Standards

various binary formats  
various text formats

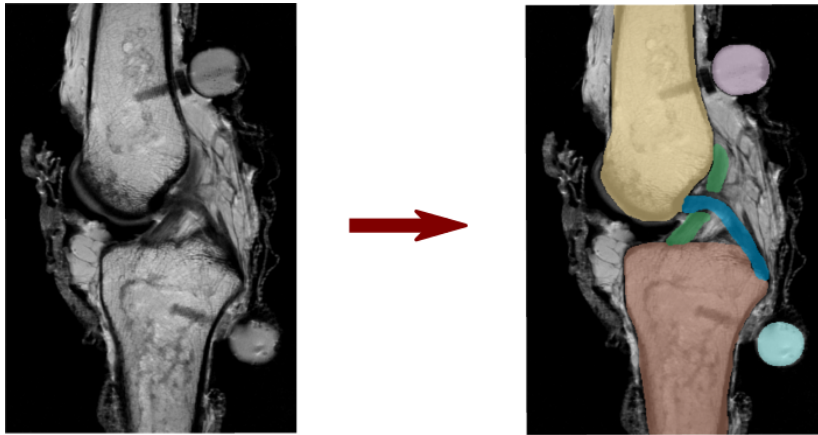






# DERIVATIVE DATA: GEOMETRY

## SEGMENTATION



### DERIVATIVE DATA

tissue volume  
voxel-based

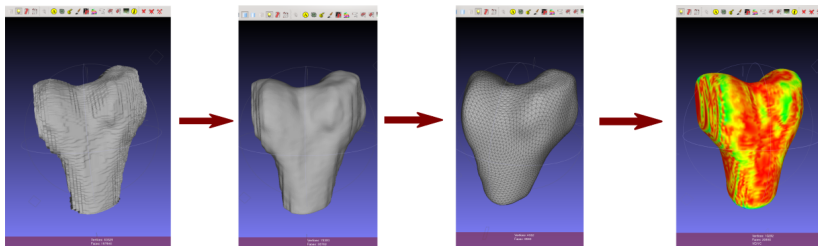
### FORMATS & STANDARDS

DICOM  
NifTI  
various IMG

### SOFTWARE

FOSS  
*3D Slicer*  
*ITK-SNAP*  
commercial  
*Mimics*  
*Simpleware*

## GEOMETRY GENERATION

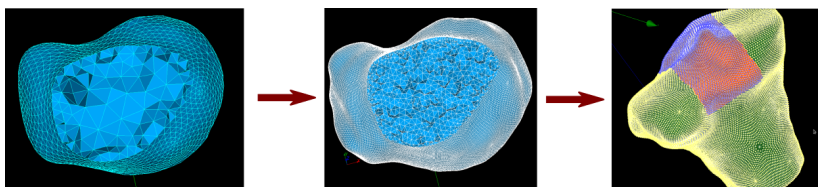


surface  
geometry  
*parametric*  
*or explicit*

STL  
IGES  
STEP

FOSS  
*MeshLab*  
*SALOME*  
commercial  
*various CAD*

## MESH GENERATION

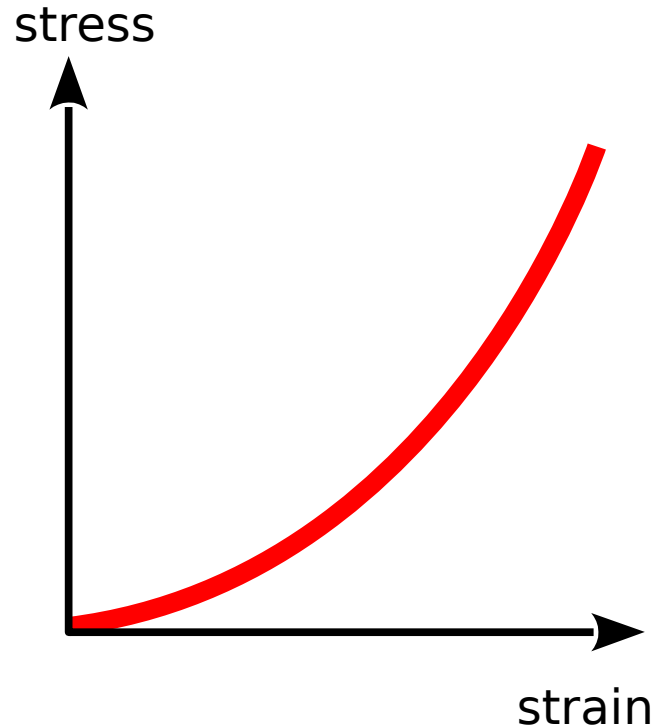


volume  
mesh  
*nodes*  
*elements*  
*sets*

various TXT  
various XML  
various HDF

FOSS  
*Netgen*  
*IA-FEMesh*  
commercial  
*various FEA*  
*TrueGrid*

# DERIVATIVE DATA: 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

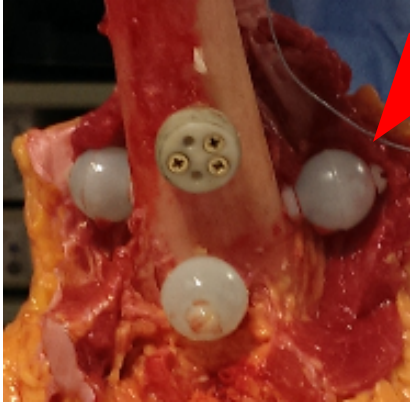
### FORMATS & STANDARDS

various TXT  
coefficients in publications

### SOFTWARE

various for data fitting  
scripting languages

# DERIVATIVE DATA: 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

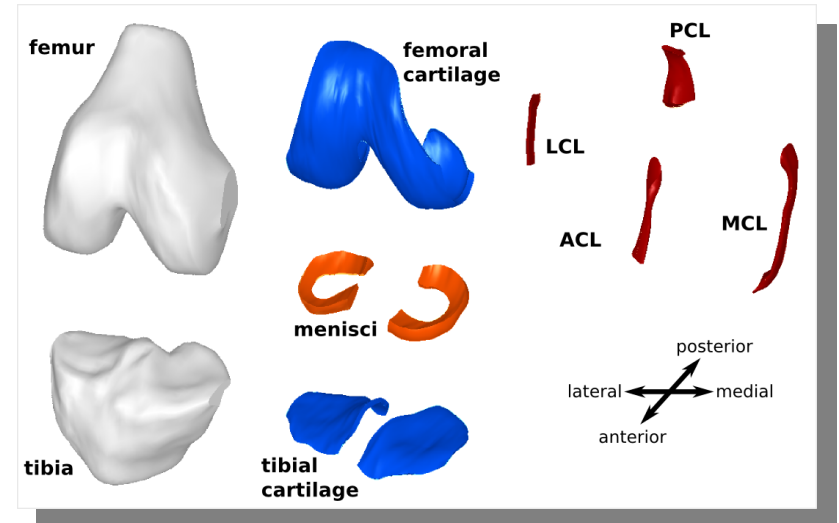
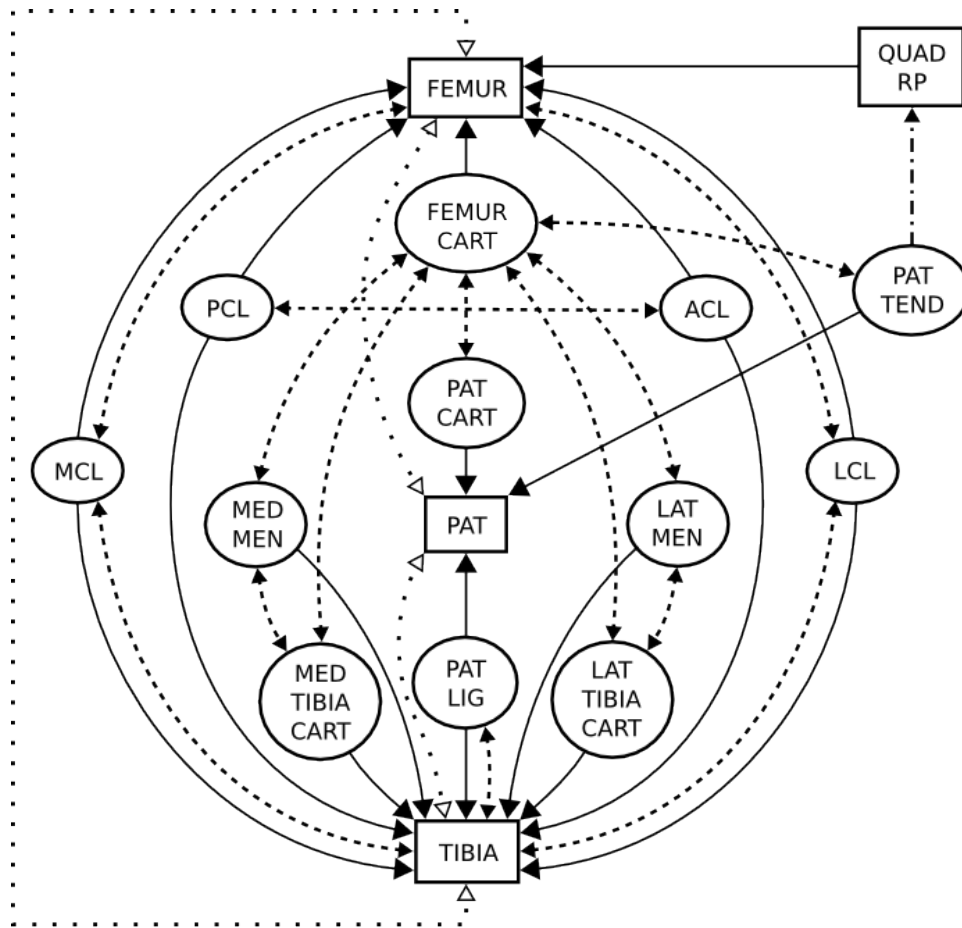
## FORMATS & STANDARDS

various TXT  
publications

## SOFTWARE

scripting languages  
other M&S  
musculoskeletal  
systems models

# ASSEMBLING MODEL



Representation of whole model

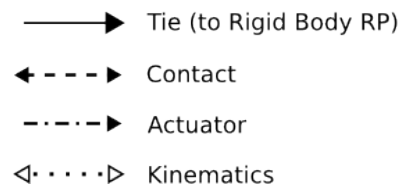
Customization to swap components

Compartmental modeling

## OBJECT TYPES:



## MECHANICAL RELATIONSHIPS:



# 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

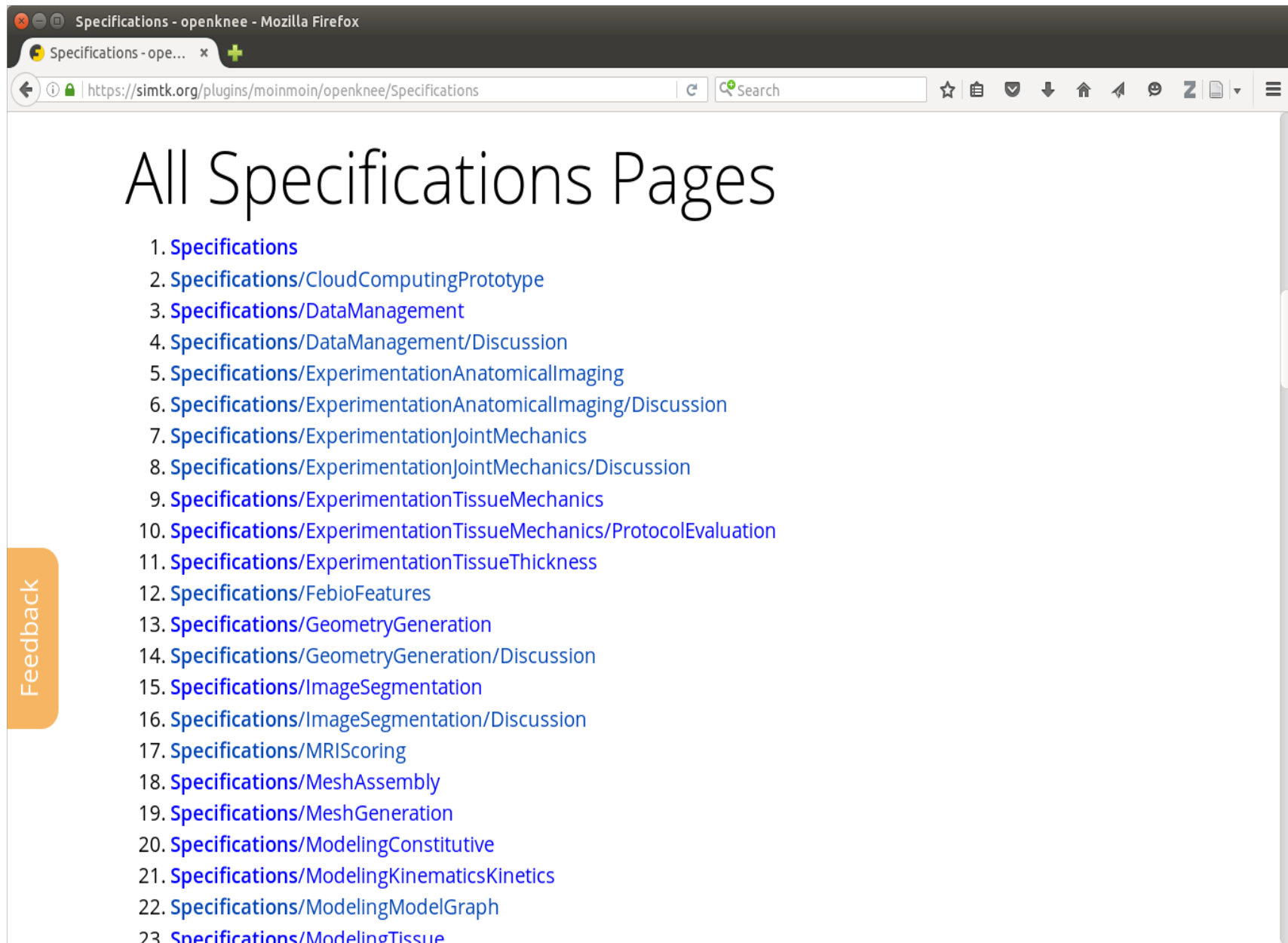
FEBio  
Continuity 6  
etc.

## FREE & OPEN SOURCE

Code Aster  
OpenCMISS  
etc.



# MANAGING KNOW-HOW



The image shows a screenshot of a Mozilla Firefox browser window. The address bar displays the URL <https://simtk.org/plugins/moinmoin/openknee/Specifications>. The main content area features a large heading "All Specifications Pages" followed by a numbered list of 23 links. On the left side of the browser window, there is a vertical orange button labeled "Feedback".

Specifications - openknee - Mozilla Firefox

Specifications - ope... x +

https://simtk.org/plugins/moinmoin/openknee/Specifications

## All Specifications Pages

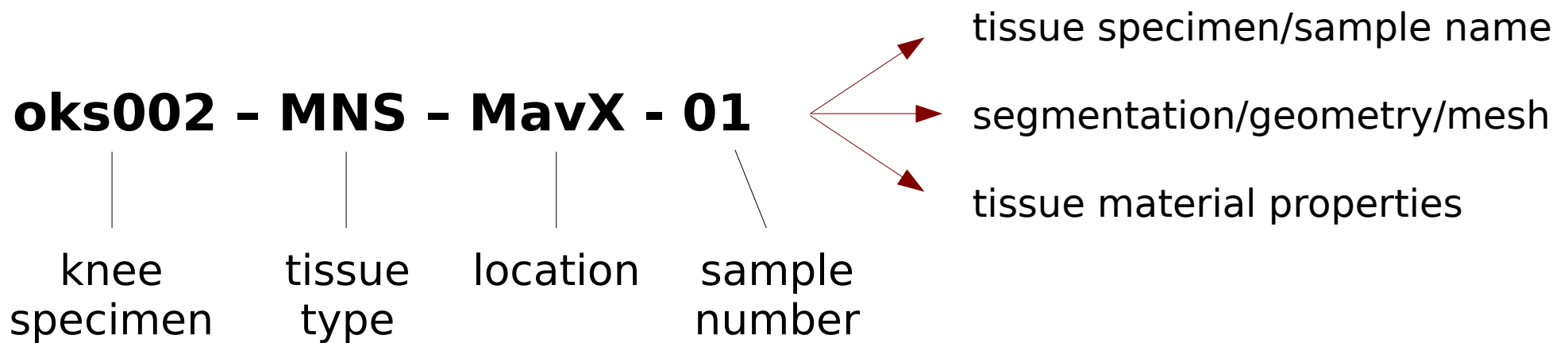
1. [Specifications](#)
2. [Specifications/CloudComputingPrototype](#)
3. [Specifications/DataManagement](#)
4. [Specifications/DataManagement/Discussion](#)
5. [Specifications/ExperimentationAnatomicalImaging](#)
6. [Specifications/ExperimentationAnatomicalImaging/Discussion](#)
7. [Specifications/ExperimentationJointMechanics](#)
8. [Specifications/ExperimentationJointMechanics/Discussion](#)
9. [Specifications/ExperimentationTissueMechanics](#)
10. [Specifications/ExperimentationTissueMechanics/ProtocolEvaluation](#)
11. [Specifications/ExperimentationTissueThickness](#)
12. [Specifications/FebioFeatures](#)
13. [Specifications/GeometryGeneration](#)
14. [Specifications/GeometryGeneration/Discussion](#)
15. [Specifications/ImageSegmentation](#)
16. [Specifications/ImageSegmentation/Discussion](#)
17. [Specifications/MRIScoring](#)
18. [Specifications/MeshAssembly](#)
19. [Specifications/MeshGeneration](#)
20. [Specifications/ModelingConstitutive](#)
21. [Specifications/ModelingKinematicsKinetics](#)
22. [Specifications/ModelingModelGraph](#)
23. [Specifications/ModelingTissue](#)

Feedback

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

# MANAGING DATA

## Labeling Convention



# MANAGING DATA

## Metadata

Wiki pages for specimen description  
*unstructured*

Specimen/sample configuration files  
*structured*

### Contents

1. Specimen Characteristics
2. Experimentation
  1. Specimen
  2. Specimen Preparation
  3. Joint Imaging
    1. Specimen Preparation
    2. Imaging
  4. Joint Mechanics
    1. Equipment Preparation
    2. Specimen Preparation
    3. Testing
  5. Tissue Mechanics
    1. Specimen Preparation
    2. Testing
      1. oks004-FMC-ACXX-01
      2. oks004-FMC-ACXX-02
      3. oks004-FMC-ACuX-01
      4. oks004-MCL-CXXX-01
      5. oks004-PAT-CXXX-01
      6. oks004-PAT-CuXX-01
      7. oks004-PAT-CXXX-02
      8. oks004-MNS-MPXX-01
      9. oks004-MNS-MPXX-02
      10. oks004-MNS-MCwX-01
      11. oks004-ACL-CXXX-01
      12. oks004-PCL-CXXX-01
      13. oks004-LCL-CXXX-01
      14. oks004-PTL-CXXX-01
      15. oks004-QUAT-CXXX-01
      16. oks004-TIB-MAXX-01
      17. oks004-TIB-MAuX-01
      18. oks004-TIB-MAXX-02
      19. oks004-TIB-LAXX-01
      20. oks004-TIB-LAuX-01
      21. oks004-TIB-LAXX-02
3. Data Analysis
4. Modeling & Simulation

## Specimen Characteristics

Right knee

**Gender:** Female

**Age:** 46 years

**Race:** White

**Height:** 62 in. (1.575 m)

**Weight:** 120 lbs. (54.43 kg)

**BMI:** 21.9

**Serologically tested:** Yes

**X-Ray:**



# DISSEMINATION

SimTK: Open Knee(s): Virtual Biomechanical Representations of the Knee Joint: Downloads - Mozilla Firefox

File Edit View History Bookmarks Tools Help

SimTK: Open Knee(s):... x

https://simtk.org/frs/index.php?group\_id=485

SimTK Search for projects Projects About Ahmet

Open Knee(s): Virtual Biomechanical Representations of the Knee Joint

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## Downloads

5,274 downloads

46 forum posts

Last updated May 23, 2016

Project Statistics

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Feedback

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oks001 Open Knee(s) - Generation 2 - Specimen 1

g2-s1-v0.2.0.20150825 Notes AUG 25, 2015

Download Package

Download Links

1.3.12.2.1107.5.2.19.45406.2014100711193292568244326.0.0.0.nii APR 16, 2015  
21 mB Any Data/images/video  
Soft tissue imaging - axial plane (MRI in NIFTI format)

1.3.12.2.1107.5.2.19.45406.2014100710433217692143626.0.0.0.nii APR 16, 2015  
98 mB Any Data/images/video  
Cartilage imaging (MRI in NIFTI format)

1.3.12.2.1107.5.2.19.45406.2014100711262396541244530.0.0.0.nii APR 16, 2015  
21 mB Any Data/images/video  
Soft tissue imaging - sagittal plane (MRI in NIFTI format)

1.3.12.2.1107.5.2.19.45406.2014100711323578731244734.0.0.0.nii APR 16, 2015  
21 mB Any Data/images/video  
Soft tissue imaging - coronal plane (MRI in NIFTI format)

Ahmet Erdemir

Adapted from Open Knee(s), refer to [https://simtk.org/frs/index.php?group\\_id=485](https://simtk.org/frs/index.php?group_id=485).

# COMING SOON: COMPUTING

The image shows a screenshot of a web browser window displaying a form for configuring a simulation job. The browser's address bar shows the URL: `simtk.org: Open Knee: A Three-Dimensional Finite Element Representation of the Knee Joint: Advanced Fe`. The browser's menu bar includes File, Edit, View, History, Bookmarks, Tools, and Help. The browser's address bar also shows the page title: `Simtk.org: Open Knee: A Three...`. The browser's search bar shows the text: `simtk.org: Open Knee: A Three...`. The browser's search bar also shows the text: `simtk.org: Open Knee: A Three...`. The browser's search bar also shows the text: `simtk.org: Open Knee: A Three...`.

The form is titled "Select Server" and "Select Software" and "Select Model" and "Modify Model?" and "Model Configuration File" and "Notification Email?". The form contains the following fields:

- Select Server:** Server 2
- Select Software:** FEBio 1.6.0
- Select Model:** model.feb
- Modify Model?:**  Yes  No
- Model Configuration File:** modify\_model.cfg
- Notification Email?:** erdemira@ccf.org

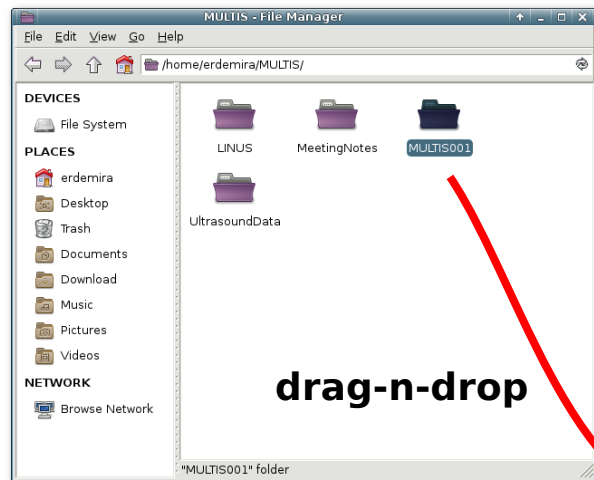
The form also includes a "SUBMIT" button. The form is highlighted with a red border.

The background of the browser window shows the Simtk.org website. The website has a navigation menu with links for Home, About Simtk, and How to Contribute. The website also has a sidebar with links for Overview, Team, Downloads, Documents, Wiki, Publications, News, and Public Forums. The website also has a footer with the text: "SimTK, the Simulation Toolkit, is supported through the NIH Roadmap for Medical Research."

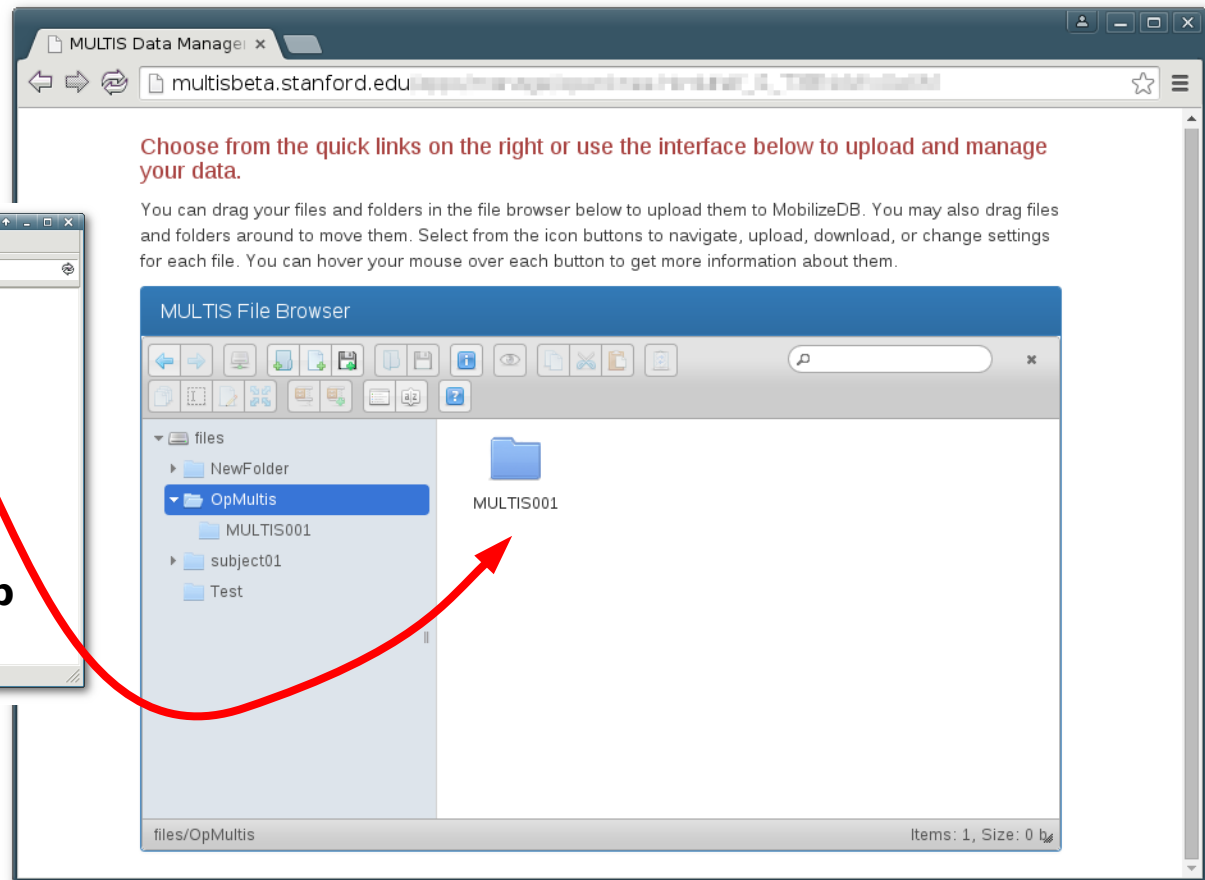
# COMING SOON: DATA MANAGEMENT

Web-based infrastructure - data management and query platform

data folders on local computer



**drag-n-drop**



web browser accessible data management server on cloud

# COMING SOON: DATA MANAGEMENT

Choose from the quick links on the right or use the interface below to request a specific subset of the data from the study.

Browse, Query, or Select All Data

This study provides knee joint mechanics data and models for multiple subjects. You can browse, query, or select all the data. Querying lets you filter the data by subject (e.g. gender) or knee performance criteria (e.g. AP Laxity Anterior Drawer) to receive a subset of the study data relevant to your query.

Browse Data **Query Data** Select All Data

AND OR Invert + Add rule + Add group

Subject Age less 20-80 Delete

Choose from the quick links on the right or use the interface below to request a specific subset of the data from the study.

Choose the data to retrieve.

Experimentation > Specimen

- Specimen Characteristics
- Subject Summary
- Subject ID
- Subject Gender
- Subject Age
- Subject Race
- Subject Height (m)
- Subject Weight (kg)
- Subject BMI

Experimentation > Specimen Preparation

- Exp. Spec. Leading Team Member
- Exp. Spec. Protocol Deviations
- Exp. Spec. Prep. Leading Team Member
- Exp. Spec. Prep. Protocol Deviations

General purpose imaging

- Cartilage imaging
- Soft tissue imaging - axial plane
- Soft tissue imaging - sagittal plane
- Soft tissue imaging - coronal plane

Get the Data

Filename multis-query-2016-07-07-10-06 .zip Get Data

# CONCLUDING REMARKS

- ❖ Data related **requirements** for FEA in joint biomechanics include
  - use of heterogeneous data*
  - management of heterogeneous data*
  - relying on various data formats*
  - using variety of software to process data*
- ❖ **Challenges** for appropriate integration of data to FEA workflow are
  - lack of unified and generally accepted formats*
  - lack of robust utility software for data format exchange*
  - lack of large databases and comprehensive repositories*
  - constraints for spatial association of data components*



# OPEN KNEE(S) ENABLED BY ...

## 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

Craig Bennetts  
Tara Bonner  
Snehal Chokhandre  
Robb Colbrunn  
Ahmet Erdemir

### CWRU

Chris Flask  
Shannon Donnola

### Stanford University

Scott Delp  
Joy Ku  
Henry Kwong

### University of Utah

Ben Ellis  
Steve Maas  
Jeff Weiss

### Community

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Omar Gad  
Callan Gillespie  
Nicholas Haas  
Connor Lough  
Raghav Malik  
Eryn Merico  
Nicole Nassif  
Jason Halloran  
Katie Stemmer  
Diana Suci  
Cara Sullivan  
Will Zaylor

### Advisory Board

Jack Andrish  
Yasin Dhaher  
Trent Guess  
Morgan Jones  
Rami Korhonen  
Paul Saluan  
Carl Winalski



NIH/NIGMS  
R01GM104139

<https://simtk.org/projects/openknee>

# CONTACT



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**Open Knee(s):** <https://simtk.org/projects/openknee>

**Open Knee(s) Wiki:** <https://simtk.org/plugins/moinmoin/openknee/>

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