Software for Practical Annotation and Exchange of Virtual Anatomy: Design Considerations

by Erdemir, Enquobahrie, Arikatla, Bray, Landis, Thompson

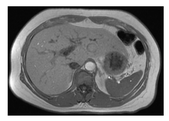
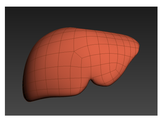
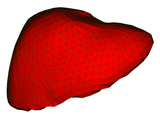
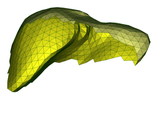
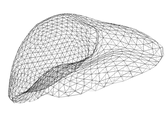
PROBLEM

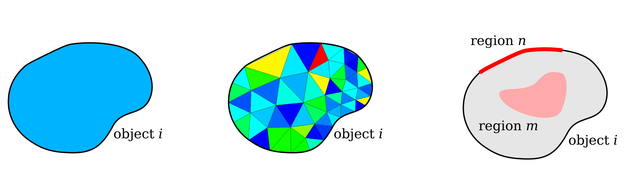
- Interactions with **virtual anatomy** are **foundational** for biomedical research, clinical care, and medical training.
- **Workflows**, from acquisition to generation, modification, annotation, and exchange of virtual anatomy, are **highly diverse**.
- Software **ecosystem** to manage and work with virtual anatomy is **fragmented**.
- Experience levels of users **demand for flexible means** to utilize software to generate and use virtual anatomy.
- Seamless **traceability** of virtual anatomy during its lifecycle is **questionable**.
- Robust and **unified annotation** capabilities, to label anatomical regions, assign properties, harmonize physiological data, and embed metadata, do **not exist**.
- **Exchange** of anatomy across workflows and disciplines is **hindered** by specialized formats.
- **New technologies** (artificial intelligence, cloud computing, big data analytics, multiscale mechanistic modeling, and individualized medicine) **necessitate** management, analysis, and reuse of virtual anatomy in an **unsupervised** and **high-throughput** fashion.

Our **goal** is to **design**, develop, and test a **unified & extensible software platform** to leverage virtual anatomy in a large variety of biomedical workflows.

→ **(F)**indable
(A)ccessible
(I)nteroperable
(R)eusable
VIRTUAL ANATOMY

FOUNDATIONS

	IMAGE BASED		CAD BASED	MESH BASED					
									**FORMS/TYPES OF ANATOMICAL REPRESENTATION**
	medical image	**image label** (segmentation)	**NURBS**	**volume mesh**	**volume mesh clipped**	**surface mesh clipped**	**wire mesh**	**point cloud**	
	.dcm .dicom	.nii	.nrrd	.stp .step	.igs .iges	.med	.vtk .vtp .vtu	.stl	.xml (FieldML)	.feb	.inp	**COMMON FORMATS**
	ITK	OPENCASCADE	VTK	SMTK	MOAB	MED MEDCoupling	FEBio	**TOOLKITS/LIBRARIES FOR DEVELOPMENT** FREE AND OPEN SOURCE
	3DSlicer	FreeCAD	SALOME PLATFORM	NETGEN	TetGen	Gmsh	Blender	MeshLab	CMB	ParaView	**SOFTWARE TO INFORM DESIGN** FREE AND OPEN SOURCE



Object i has the property/state.

Object i has the location-dependent properties/states.

Object i has the volume region m and surface region n.

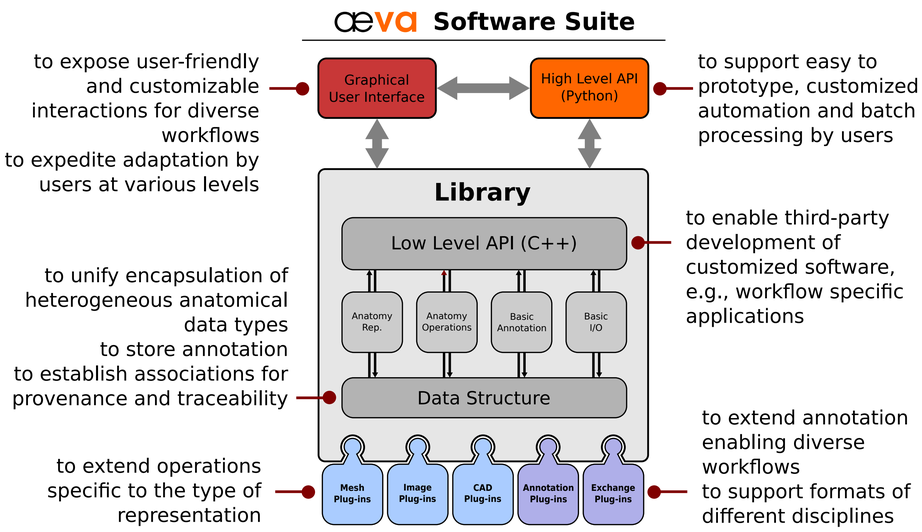
Object $i(j)$ connects to object $j(i)$ at region $m(n)$.

Object $i(j)$ interacts with object $j(i)$ at region $m(n)$.

Object i contains object j.
Object j is contained by object i.

ANNOTATION OF
PROPERTIES
STATES
RELATIONS
HIERARCHIES

ARCHITECTURE & DEVELOPMENT



to expose user-friendly and customizable interactions for diverse workflows
to expedite adaptation by users at various levels

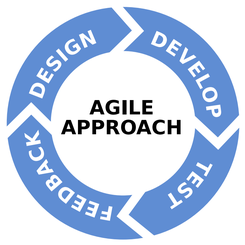
to support easy to prototype, customized automation and batch processing by users

to enable third-party development of customized software, e.g., workflow specific applications

to unify encapsulation of heterogeneous anatomical data types
to store annotation
to establish associations for provenance and traceability

to extend operations specific to the type of representation

to extend annotation enabling diverse workflows
to support formats of different disciplines

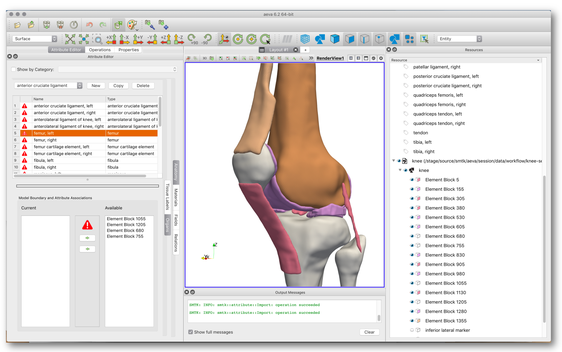


DEVELOPMENT PLATFORMS

CMake · git · CDash · Qt · JSON · python · HDF · C++ · SWIG

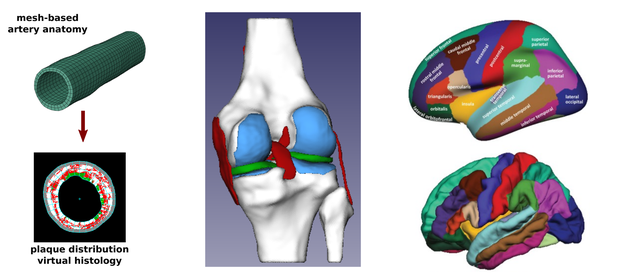
PROTOTYPING

Integration of toolkits and templating with ontology



USER IN-THE-LOOP DEVELOPMENT & TESTING

Scientifically or clinically relevant, diverse use cases



cardiovascular
image based
artery properties

musculoskeletal
knee joint assembly
and tissue connectivity

neurological
regional brain labeling
and segmentation

DESIGN PRINCIPLES

1 Unification

unified data structure for input/output and storage of heterogeneous data types ● import/export of common data formats ● generation & modification within and across types of representation

2 Rich annotation capabilities

region selection and labeling within forms ● transfer of annotation within and across forms ● common data elements ● metadata to promote F.A.I.R. principles ● ontology support ● harmonization with physiology

3 Rich exchange capabilities

tools for access to native data structure and format ● input/output in common and legacy formats ● support for image, mesh, cad based data ● annotation import/export if supported by third-party formats

4 Interactivity & automation

robust interactivity for region selection and attribute assignment ● automated annotation transfer ● automated region identification and labeling ● ontology based annotation templates ● batch processing ● automated scripting by replay of interactions

5 Provenance & credibility

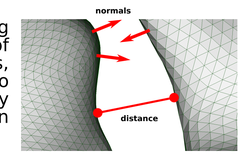
compliance to existing data acquisition and storage standards ● accommodating good workflow practices ● auto transfer of metadata of origin to derivative data ● versioning ● data elements for lifecycle management and governance

6 Extensibility & reusability

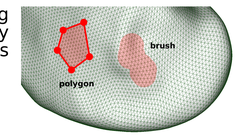
user-driven development ● aware of workflow diversity ● single tissue, organ, body; atlases; cohorts; longitudinal data ● multiscale representation ● plug-in architecture ● high and low level customization ● cross-platform ● free and open source for academic and commercial use

Taxonomy for anatomical relations, e.g., from the *Foundational Model of Anatomy*,can be used to automatically label regions to indicate connections and containments

Geometric metrics, along with the definition of anatomical relationships, can be used to automatically identify regions for annotation



Interactive region labeling can be streamlined by robust selection tools

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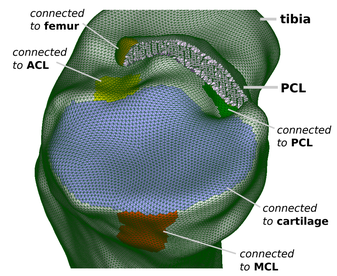

Pointers to anatomical representations and definition of relationships (left) can assist automated annotation of anatomy in spatial space, e.g., region identification and labeling (right)

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Project Funding: NIBIB, NIH (R01EB025212)
Project Website (source code): https://gitlab.kitware.com/aeva/
Project Website (workflows): https://simtk.org/projects/aeva-apps/
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