Video Data and Motion Analysis in Comparative Biomechanics Research

Étienne-Jules Marey, 1882

Beth Brainerd
Brown University
High-speed film: standard and X-ray

Lauder and Liem, 1979

Sibbing, 1982
Digital High-Speed Video

Tom Roberts
3D High-Speed Video: MoCap

Problems:
- many joints not visible
- skin movement
- stick figure

Kirk et al., 2005
Want to know skeletal motion

Étienne-Jules Marey
X-ray Reconstruction of Moving Morphology (XROMM)

markerless XROMM

marker-based XROMM
Dual Fluoroscopy (X-ray Video)
Alligator coracoid bone
XROMM

video by D. Baier
Suction Feeding
Suction Feeding
X-ray Reconstruction of Moving Morphology (XROMM)

Largemouth bass XROMM animation by Ariel Camp
XROMM Animation

- maxilla
- neurocranium
- mandible
- operculum
- ceratohyal
- suspensorium
- urohyal
- cleithrum
- body reference plane

Camp and Brainerd, ICB 2015
XROMM Animation
accuracy and precision <0.1 mm

Camp and Brainerd
Measure Instantaneous Rate of Volume Change (dV/dt)

Dynamic Endocast Method

Camp, Roberts and Brainerd, PNAS 2015
Pressure x dV/dt = Suction Power

Camp, Roberts and Brainerd, PNAS 2015
Muscle Strain, Velocity and Power Capacity

Camp, Roberts and Brainerd, PNAS 2015
“Swimming muscles” power suction feeding in largemouth bass

>95% of power for high-performance strikes from axial musculature

Camp, Roberts and Brainerd, PNAS 2015
Suction feeding is powered by “swimming” muscles

n = 1 out of >30,000 species of ray-finned fishes
Bamboo Shark

Scott, Wilga and Brainerd, in prep
Pelvic motion in turtles

Mayerl, Brainerd, and Blob, 2016
Pelvic motion in turtles

Mayerl, Brainerd, and Blob, 2016
Pelvic motion in turtles

Mayerl, Brainerd, and Blob, 2016
Pelvic motion in turtles

Mayerl, Brainerd, and Blob, 2016
Complexity of XROMM data sets framespec file
3D models of the bones and beads
Marker Tracking
Autodesk Maya Animation
The X-ray Motion Analysis Portal is a web environment for management of XROMM data. Non-logged-in users should go to All Studies to explore the organization of the XMA Portal. Click on a Public Study to view video data, and click on Browse (Metadata) to explore the organization and contents of a non-public study.

Use XMA Portal to store and share:

- X-ray videos
- Calibration images
- CT scan data
- Metadata (individuals, treatments, annotations)
- Processed data files
- Access your data from anywhere

Tools for Data Management:

- Metadata Pool for organizing species, individuals, behaviors and treatments
- Multi Camera Viewer for viewing multiple X-ray images simultaneously
- Annotation fields for tagging data points
- Nearly lossless jpg compression
- Interface with companion software
90 Projects from 11 institutions

<table>
<thead>
<tr>
<th>Study Name</th>
<th>Identifier</th>
<th>Created</th>
<th>Metadata</th>
<th>Public Access</th>
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<tbody>
<tr>
<td>Data for Software and Hardware Validation (Public Study)</td>
<td>BROWN17</td>
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<td>Alligator Hindlimb Cartilage</td>
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<td>Amphibian and lungfish breathing and feeding</td>
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<td>2015-01-13</td>
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<td>Anuran Locomotion</td>
<td>BROWN53</td>
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<td>Bamboo Shark Feeding</td>
<td>LB11</td>
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The Zoological Motion Analysis Portal is a web environment for management of video data for studies of animal motion. Non-logged-in users should go to All Studies to explore the organization of the ZMA Portal. Click on a Public Study to view data, and click on Browse (Metadata) to explore the organization and contents of a non-public study.

Use ZMA Portal to store and share:
- Videos of animal motion
- Calibration images
- Metadata (individuals, treatments, annotations)
- Processed data files

Tools for Data Management:
- Metadata Pool for organizing species, individuals, behaviors and treatments
- Multi Camera Viewer for viewing synchronized videos
- Annotation fields for tagging later analysis
- Nearly lossless jpg compressed download
XMA Lab: Motion Analysis

Ben Knorlein

BROWN

NSF
XMALab software – Bitbucket

<table>
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<th>Last updated</th>
<th>2016-02-11</th>
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<td>Language</td>
<td>C++</td>
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<td>Access level</td>
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1 Branch
0 Tags
0 Forks
3 Watchers

XMA Lab is new software for marker-based XMA and XROMM. The developer is Dr. Ben Knorlein, a computer-vision expert and software engineer at the Center for Computation and Visualization at Brown University.

XMA Lab integrates distortion correction, calibration, marker tracking, rigid body calculations and filtering all into one program. XMA Lab replaces all components of the MATLAB X-ray Project workflow. For marker-based XROMM, XMA Lab generates animation matrices suitable for animating bones in Autodesk Maya.

XMA Lab development is supported by the US National Science Foundation through an Advances in Biological Informatics grant to PI Elizabeth Brainard and CoPIs Stephen Gatesy and David Bailer.

Visit the XMA Lab Bitbucket Wiki for User Manual and Version History

Join the XMA Lab Google Group to be notified of future releases and pose questions to the group.

Download the latest binary release
Version 1.3.2: Mac and Windows
XMAPortal Data Management

Organize, Store and Share X-ray Motion Data with XMA Portal

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BROWN  
NSF
ICB PERSPECTIVES

Data Management Rubric for Video Data in Organismal Biology

Elizabeth L. Brainerd, Richard W. Blob, Tyson L. Hedrick, Andrew T. Creamer and Ulrike K. Müller

*Department of Ecology and Evolutionary Biology, Brown University, Providence, RI 02912, USA; †Department of Biological Sciences, Clemson University, Clemson, SC 29634, USA; ‡Department of Biology, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA; §Brown University Library, Brown University, Providence, RI 02912, USA; ¶Department of Biology, California State University Fresno, 2555 E San Ramon Avenue, Fresno, CA 93740, USA

E-mail: elizabeth_brainerd@brown.edu

Synopsis Standards-based data management facilitates data preservation, discoverability, and access for effective data reuse within research groups and across communities of researchers. Data sharing requires community consensus on standards for data management, such as storage and formats for digital data preservation, metadata (i.e., contextual data about the data) that should be recorded and stored, and data access. Video imaging is a valuable tool for measuring time-varying phenotypes in organismal biology, with particular application for research in functional morphology.
# Data Management Rubric for Video Data in Organismal Biology

<table>
<thead>
<tr>
<th>Standards</th>
<th>Level 0: unacceptable</th>
<th>Level 1: good</th>
<th>Level 2: better</th>
<th>Level 3: best</th>
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<tbody>
<tr>
<td>(1) Data storage</td>
<td>Single copy, local disk storage only (such as on a hard drive).</td>
<td>A local working copy plus an archival video copy in professionally managed/cloud storage OR two additional local archival copies, one in a separate physical location. All plain disk copies migrated to fresh media on a set schedule. All server copies subjected to regular file integrity checks.</td>
<td>One archival video copy in professionally managed/cloud storage plus at least two additional local copies in separate locations. All local copies migrated to fresh media on a planned schedule if on plain disks or subjected to regular file integrity checks if on a server.</td>
<td>Archival video copy stored in a data repository with a stated mission of digital data preservation.</td>
</tr>
<tr>
<td>(2) Video file formats</td>
<td>Video files compressed, resized, or at a different frame rate from the original video files (e.g., YouTube or Vimeo).</td>
<td>Original, archival video files, even if format includes codecs or file types that are not widely accessible by common viewing software.</td>
<td>Level 1 plus version converted to a widely accessible format with maximum data preservation in the conversion.</td>
<td>Level 2 plus compressed/converted version(s) for viewing and greater accessibility online.</td>
</tr>
<tr>
<td>(3) Metadata linkage</td>
<td>Metadata absent or separate from video files (such as in lab notebooks): substantial effort required to share.</td>
<td>Metadata contained in digital files in a widely used format. Metadata files linked to video files by similar file names OR by bundling each video file together with its metadata into an uncompressed archive, such as zip, tar or hdf5.</td>
<td>Same as Level 1 except metadata files linked to video files by similar file names AND by bundling each video file together with its metadata: OR metadata text embedded in the video file itself.</td>
<td>Metadata, including video file name, encoded in XML or other machine-readable format and contained within the video files themselves or by bundling each video file together with its metadata.</td>
</tr>
<tr>
<td>(4) Video data and metadata access</td>
<td>Not directly accessible online; substantial effort required to share.</td>
<td>Video data and metadata available in an Internet-accessible location, such as in commercial cloud storage or on a local drive on a network-connected computer.</td>
<td>Video data and metadata online in a public repository with a stated mission of providing public access to data.</td>
<td>Level 2 plus metadata stored in a manner to make the videos discoverable on the web; i.e., metadata searchable and viewable without downloading a large video bundle.</td>
</tr>
<tr>
<td>(5) Contact information and acceptable use</td>
<td>No contact information and no statement of terms of reuse.</td>
<td>Contact name and e-mail address and a clear statement about rights and acceptable reuse of the video.</td>
<td>Name, e-mail and assignment of an internationally-recognized content license.</td>
<td>Level 2 plus ORCID ID for contact person and the assignment of a unique identifier such as a digital object identifier that can be used for the data's discovery and citation.</td>
</tr>
<tr>
<td>(6) Camera settings</td>
<td>No metadata.</td>
<td>Frame rate (frames per second).</td>
<td>Frame rate and spatial calibration data and number of cameras and camera ID (camera used for this specific…</td>
<td>Level 2 plus four or more of the following: video resolution (in pixels); shutter speed/exposure time; audio (Y/N);…</td>
</tr>
</tbody>
</table>
About XROMM

X-ray Reconstruction of Moving Morphology (XROMM) is a 3D imaging technology, developed at Brown University, for visualizing rapid skeletal movement in vivo.

XROMM combines 3D models of bone morphology with movement data from biplanar x-ray video to create highly accurate (±0.1 mm) re-animations of the 3D bones moving in 3D space.

Rapid bone motion, such as during bird flight, frog jumping, and human running, can be visualized and quantified with XROMM.

3D Model | X-ray Movies | Re-Animation
--- | --- | ---
Description | Rotating 3D Models | 

Bone morphology data come from a 3D computer model of the bone surfaces from CT, laser scanning, or MRI. Each bone is an object that can be manipulated individually in computer animation space. These models are specific to specific bones and their corresponding movements.
Hardware

Two types of high-speed, biplanar x-ray video systems are in general use today: systems based on mobile C-arm fluoroscopes and custom-built biplanar x-ray rooms.

The advantage of mobile C-arm fluoroscopes is the relatively low cost of refurbished units (less than $200,000 for a biplanar system, including high-speed video cameras). The main disadvantages are low tube current (fluoroscopic levels, generally 20 mA maximum) and

Mobile C–arm Fluoroscopes

In the past, the high cost of cineradiographic equipment has limited the number of single plane systems dedicated to zoological work to a small handful, and no biplanar systems were available. The relatively low cost of refurbished C-arm fluoroscopes should now make it possible for more research groups in comparative biomechanics to

Biplanar x-ray rooms

In a custom-built biplanar videoradiography room, the x-ray equipment and physical layout can be designed specifically for the intended research projects. Compared with C-arms, there is the potential for larger IIIs, higher tube currents, and more flexible positioning of the x-ray tubes and IIIs. The disadvantage, relative to C-arms, is cost. The cost for the high-speed video cameras, x-ray generators, x-ray tubes, IIIs, and systems to position the equipment is expected to be in the
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