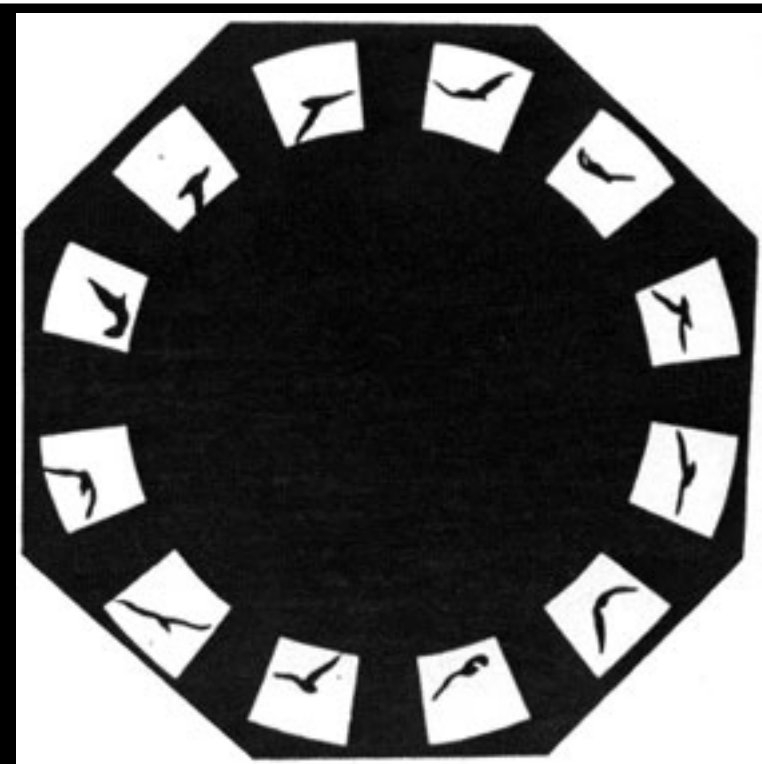
Video Data and Motion Analysis in Comparative Biomechanics Research

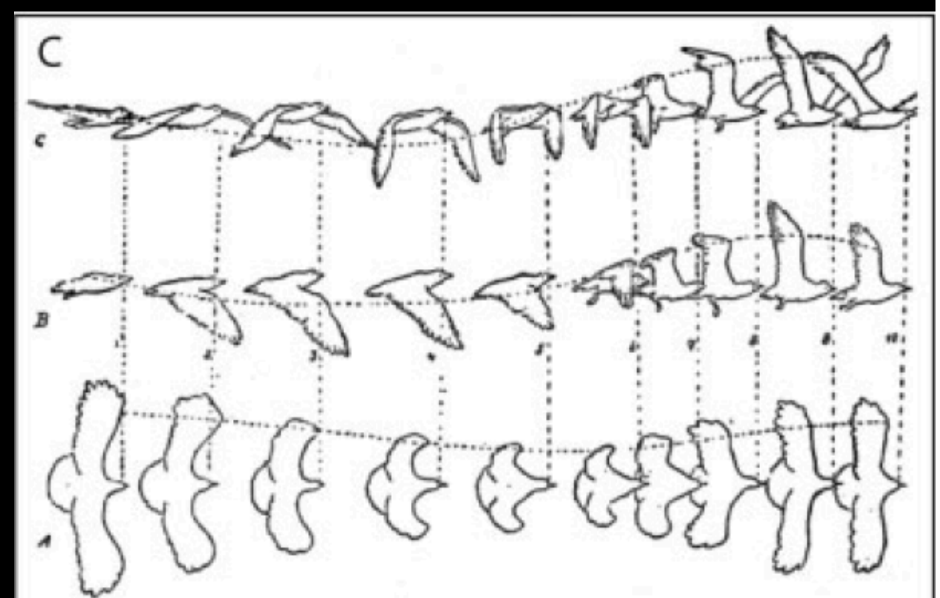
Étienne-Jules Marey, 1882

BROWN

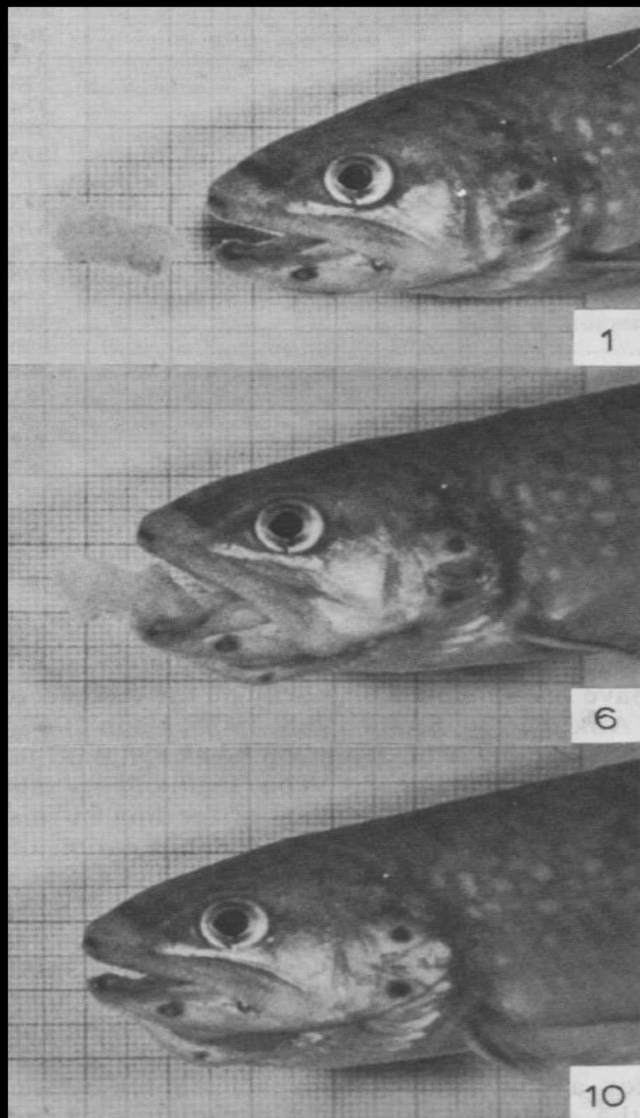
Beth Brainerd
Brown University



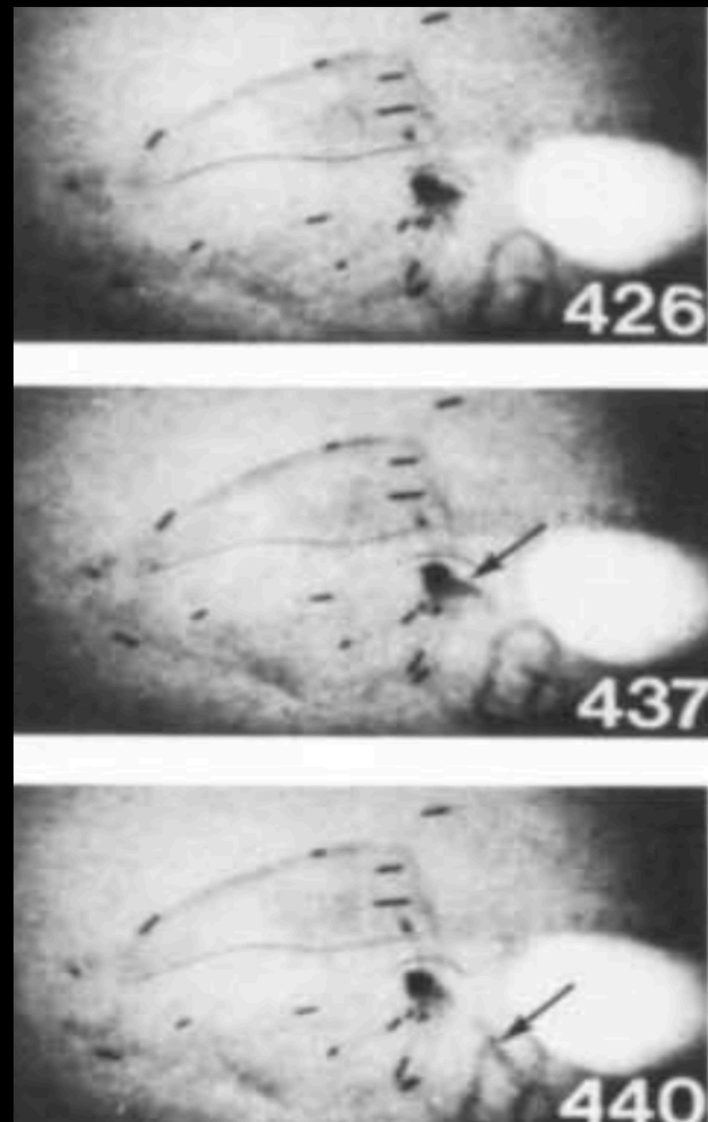
Étienne-Jules Marey



High-speed film: standard and X-ray

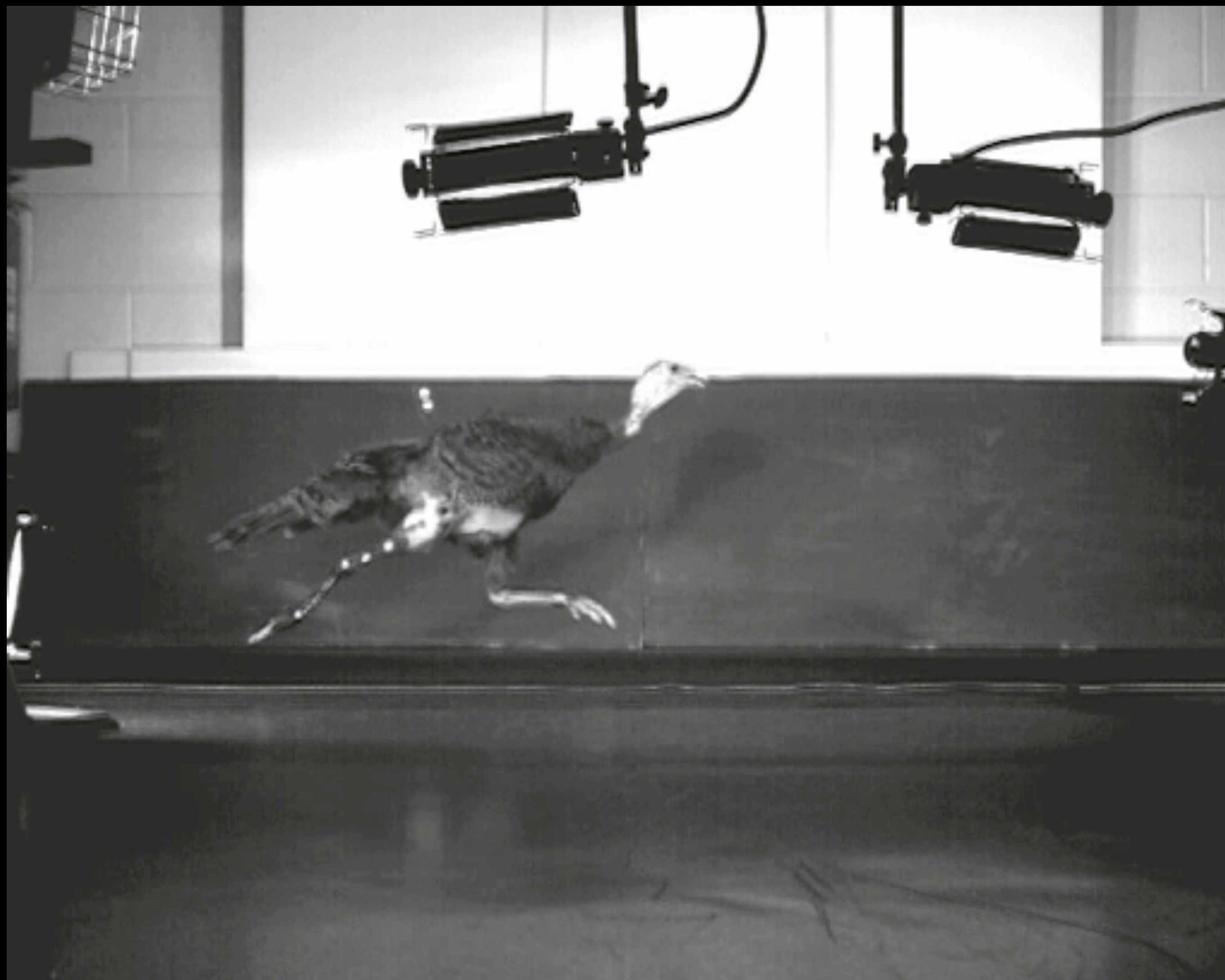


Lauder and Liem, 1979



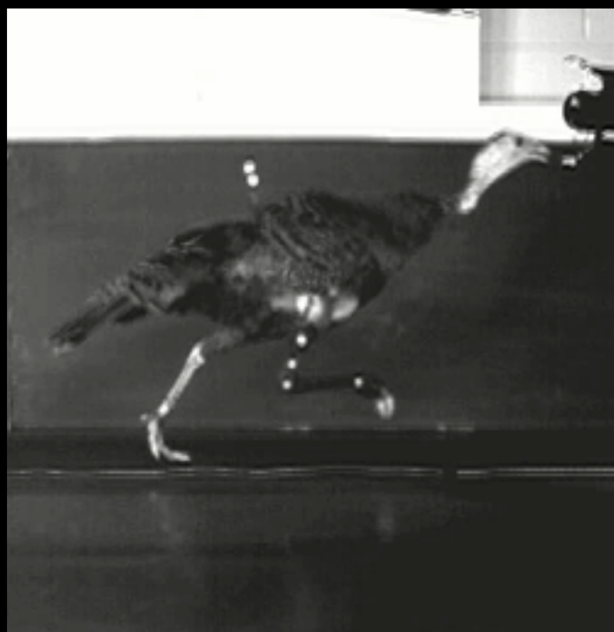
Sibbing, 1982

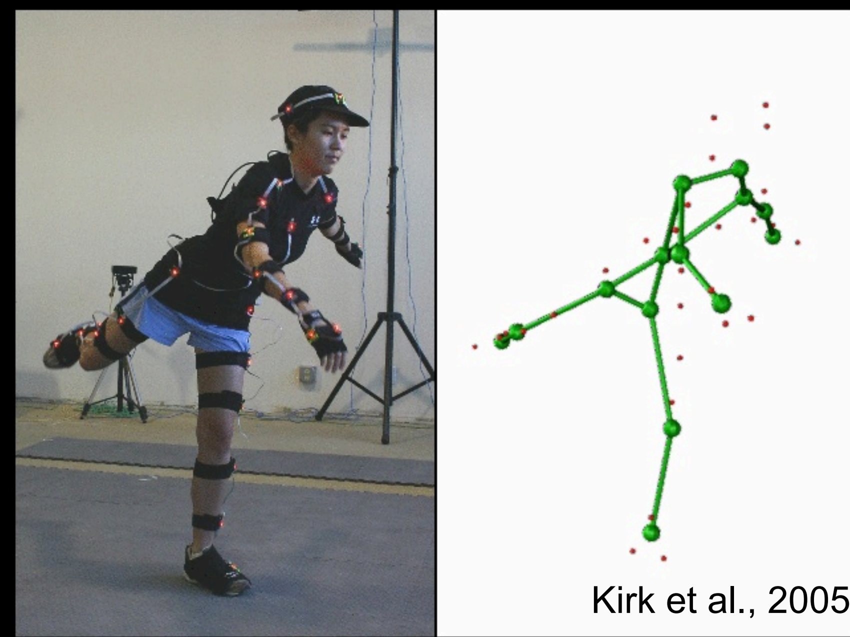
Digital High-Speed Video



Tom Roberts

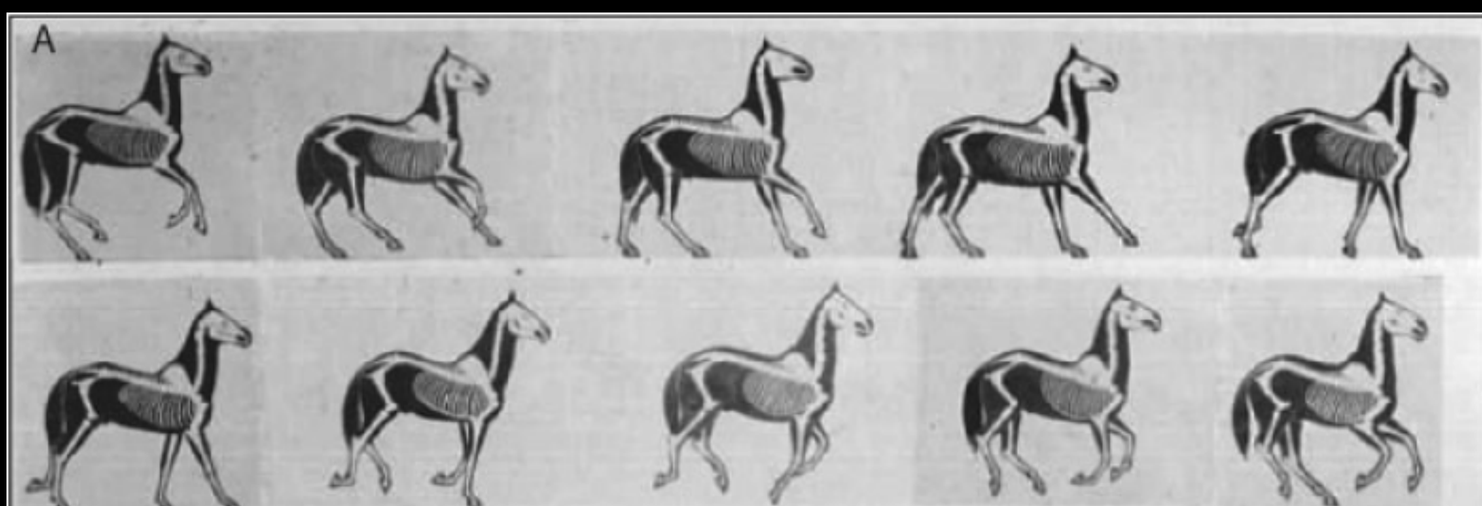
3D High-Speed Video: MoCap





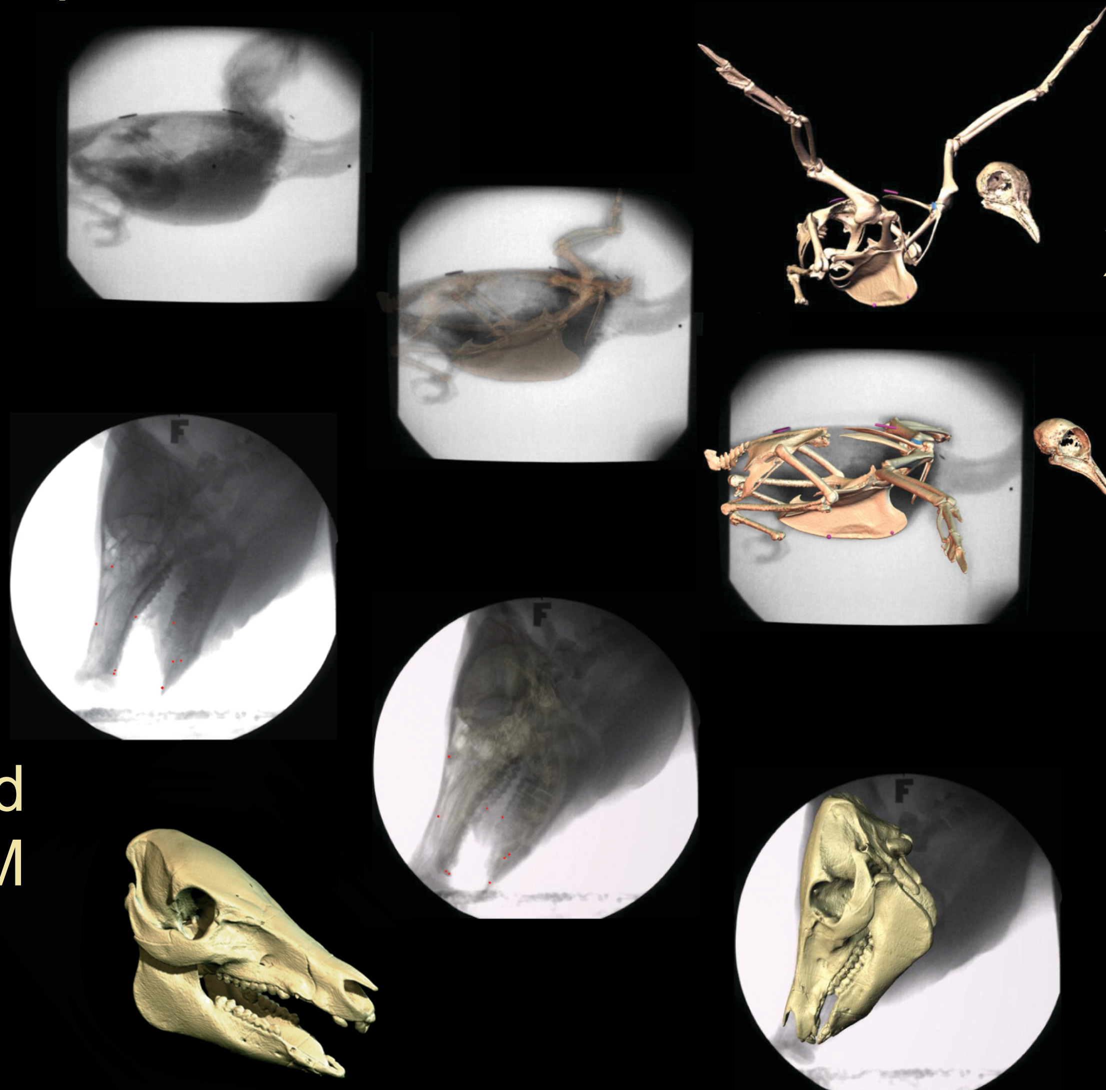
Problems:
•many joints not visible
•skin movement
•stick figure

Want to know skeletal motion



Étienne-Jules Marey

X-ray Reconstruction of Moving Morphology (XROMM)

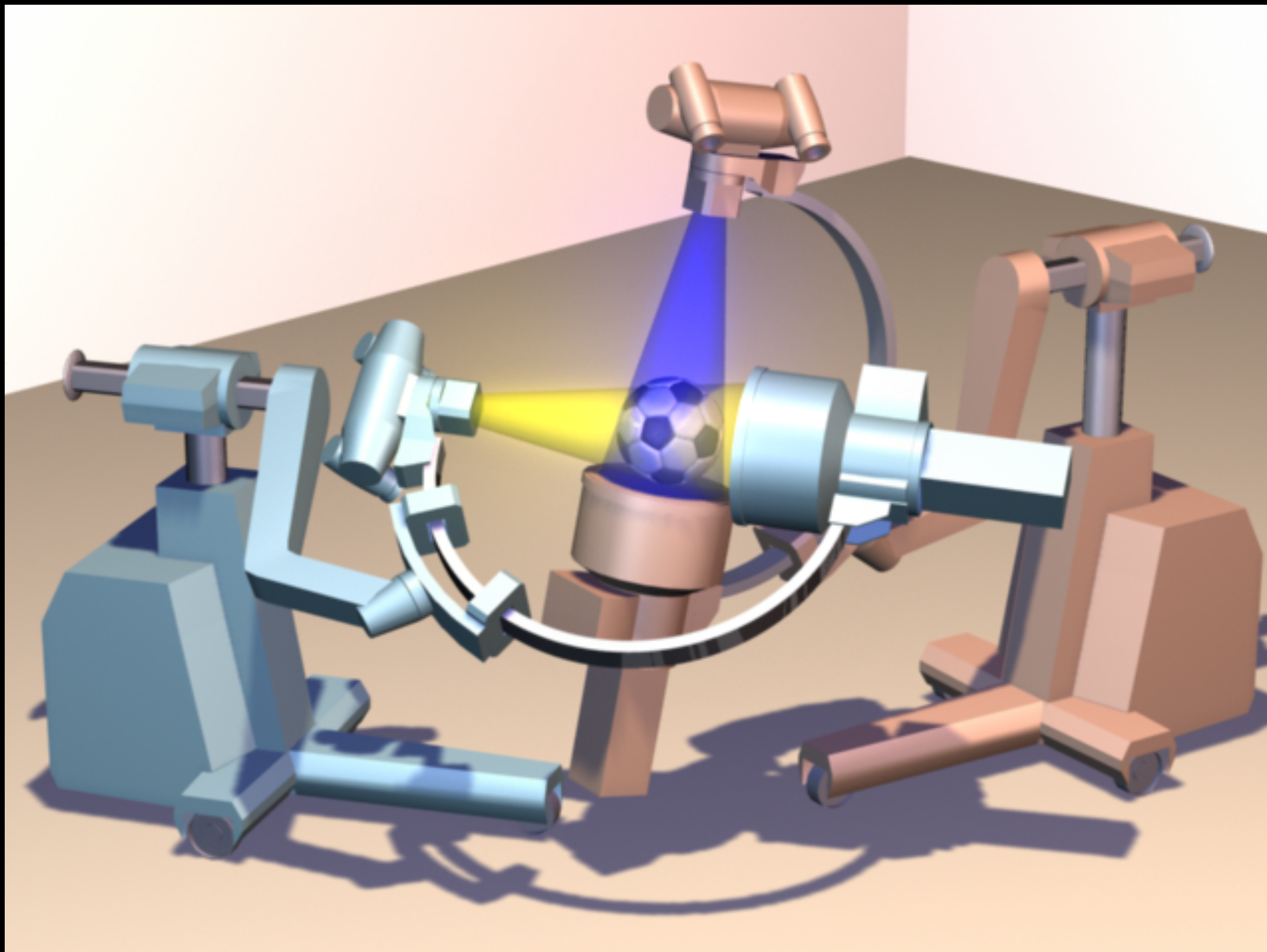


markerless
XROMM

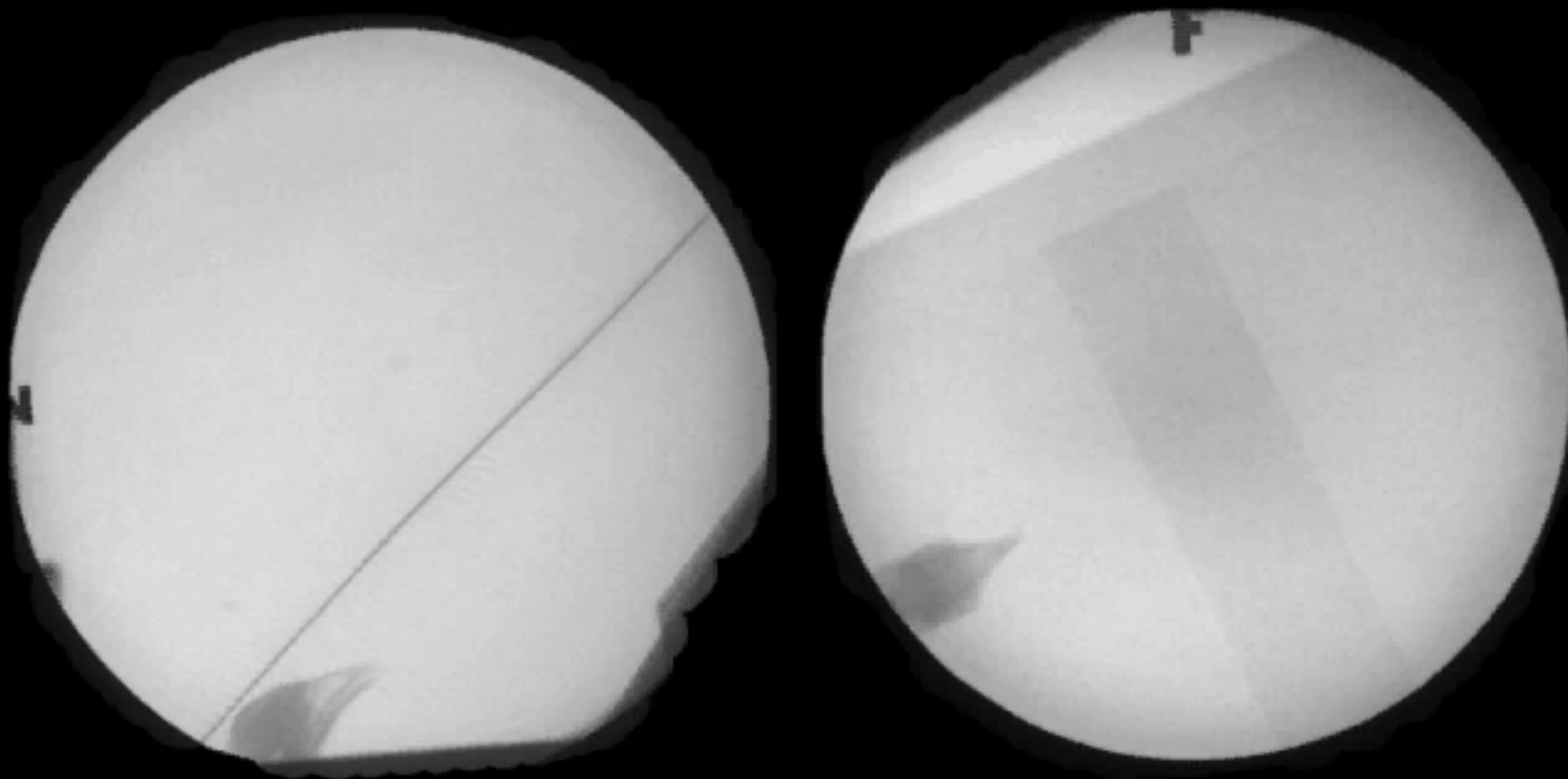
marker-based
XROMM

BROWN

Dual Fluoroscopy (X-ray Video)

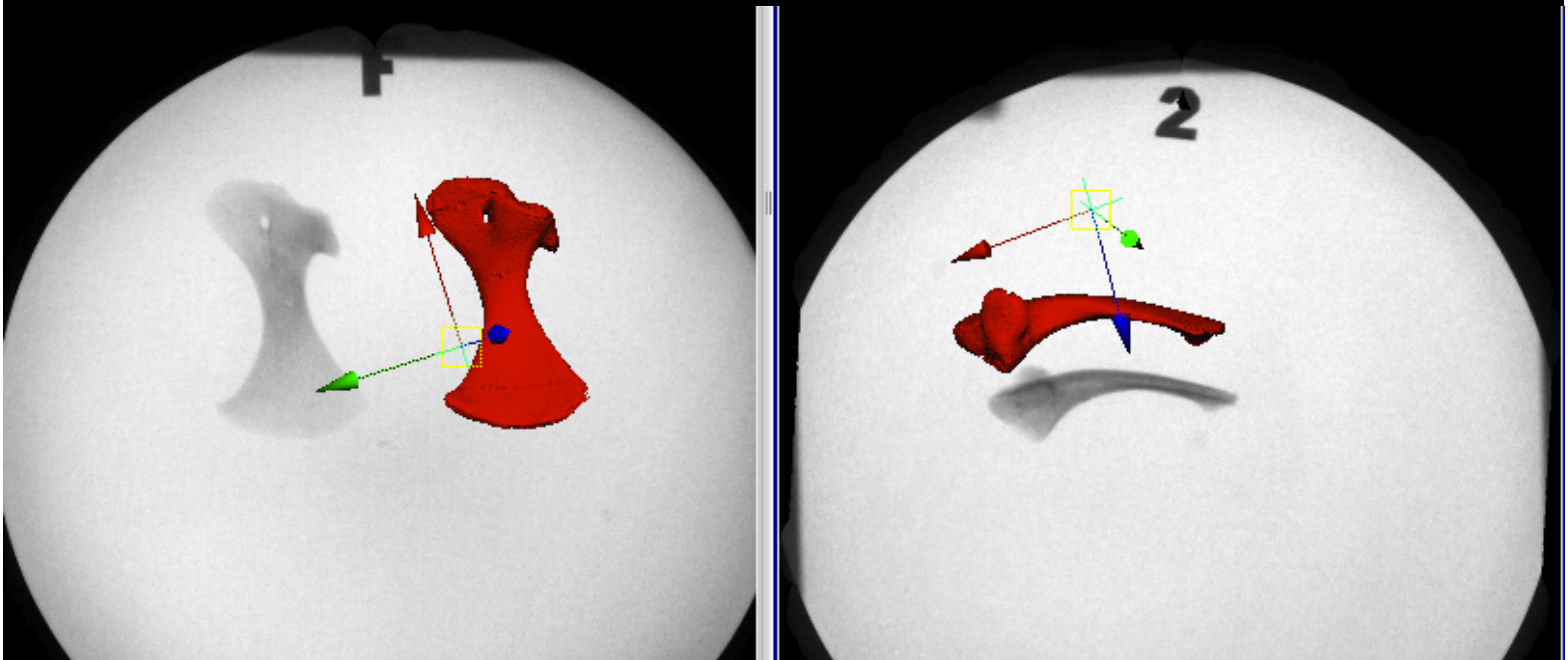


Dual Fluoroscopy (X-ray Video)



Dave Baier
Ken Dial
Steve Gatesy

X-ray Reconstruction of Moving Morphology (XROMM)

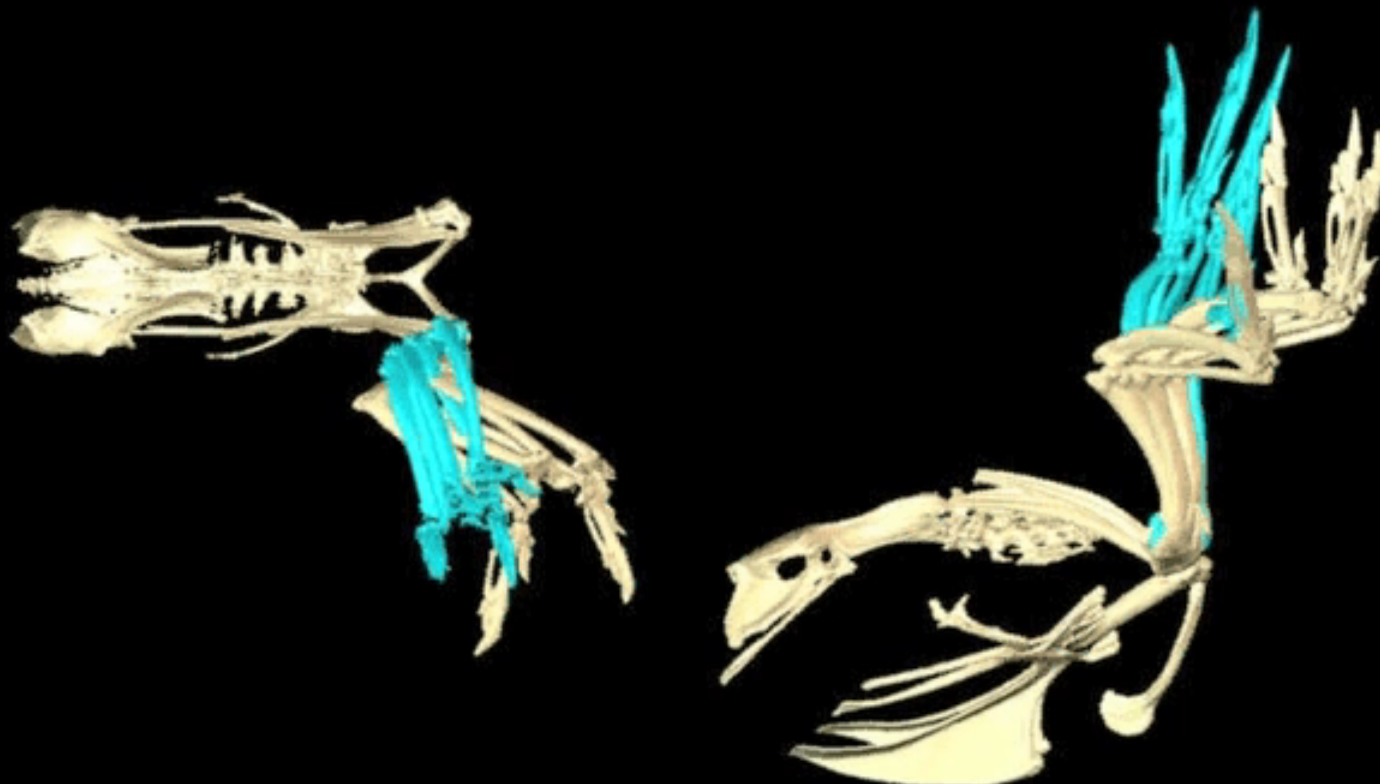


Alligator coracoid bone

XROMM

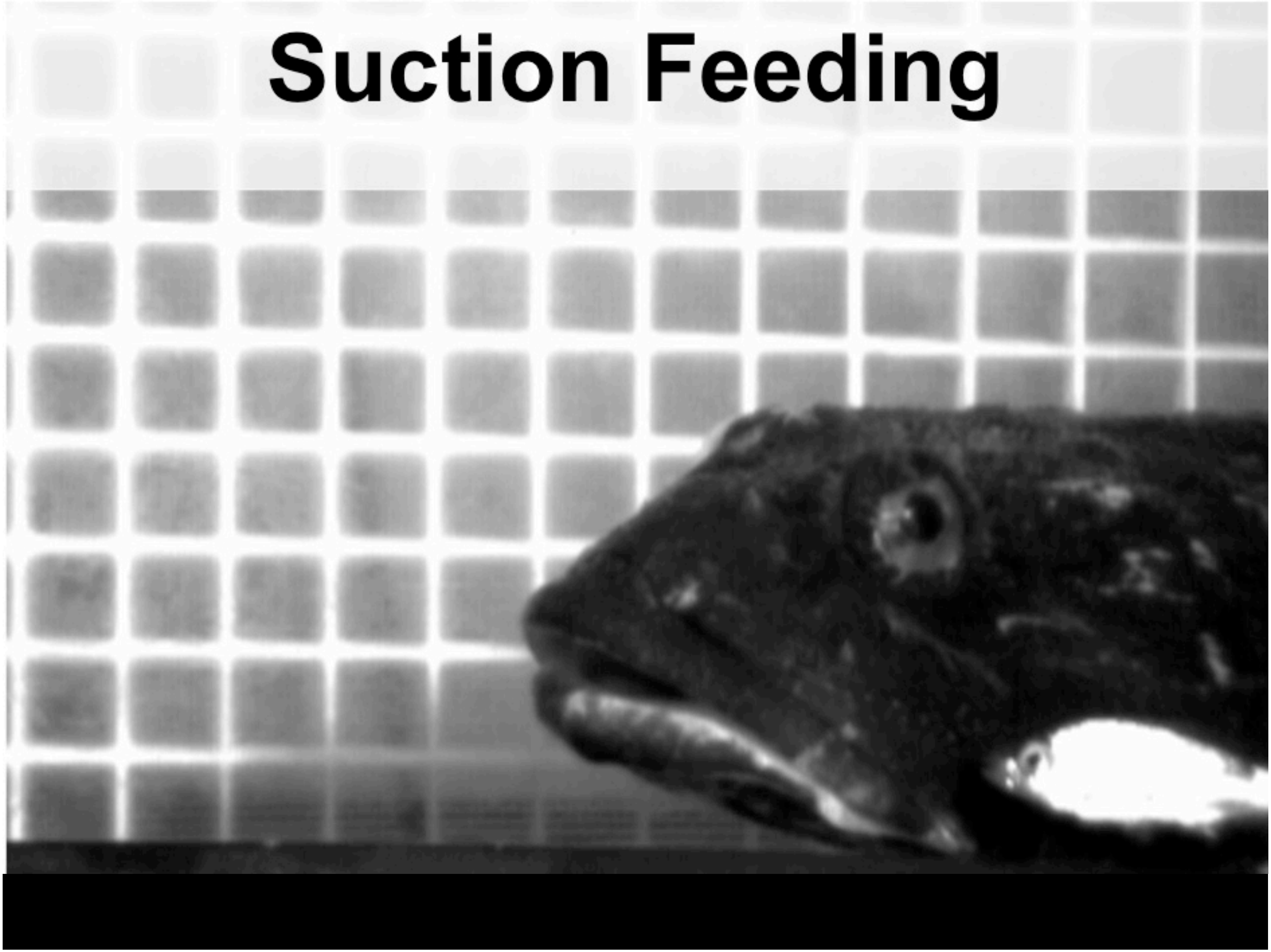
video by D. Baier

Dave Baier
Ken Dial
Steve Gatesy



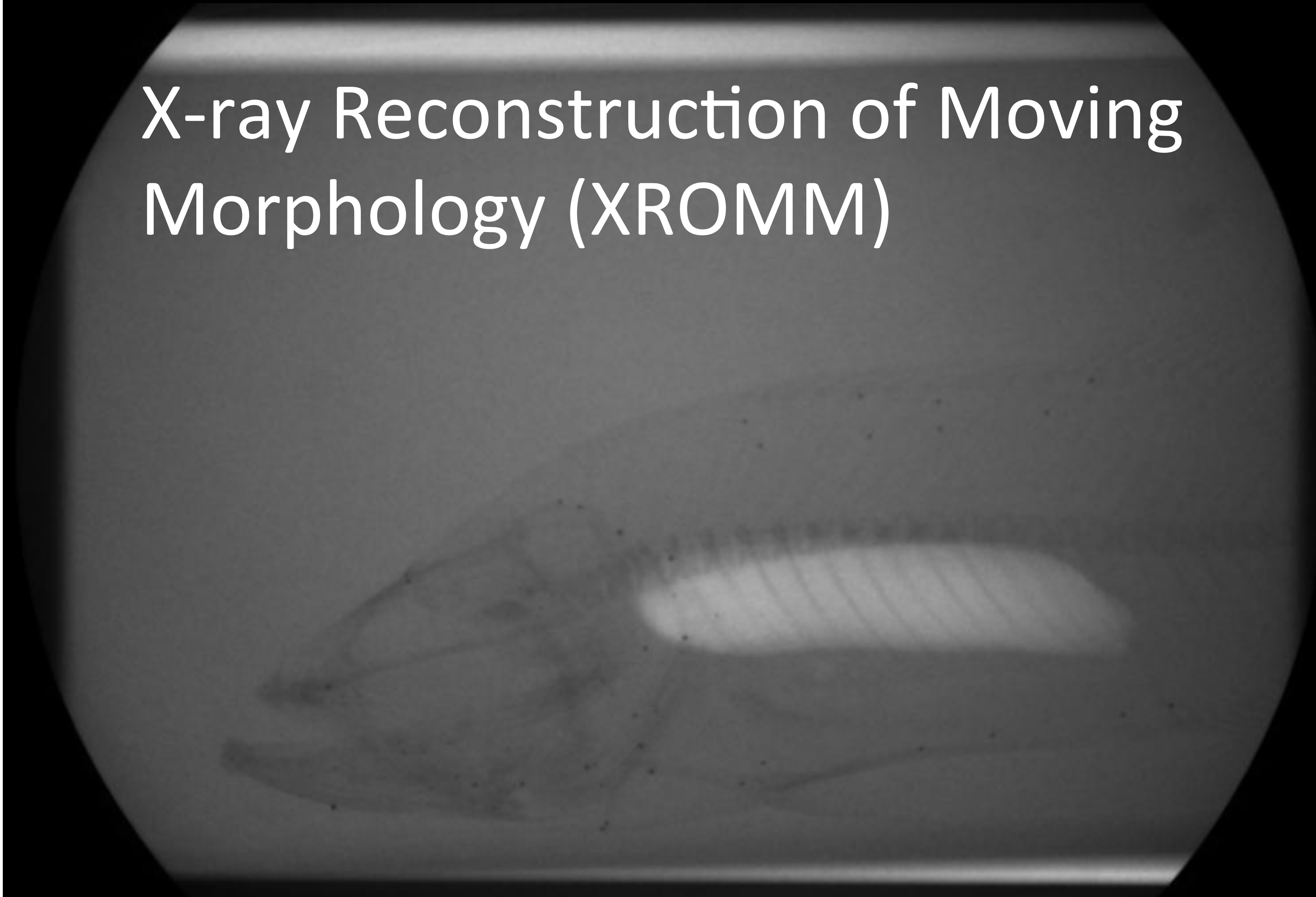
Dave Baier
Ken Dial
Steve Gatesy

Suction Feeding



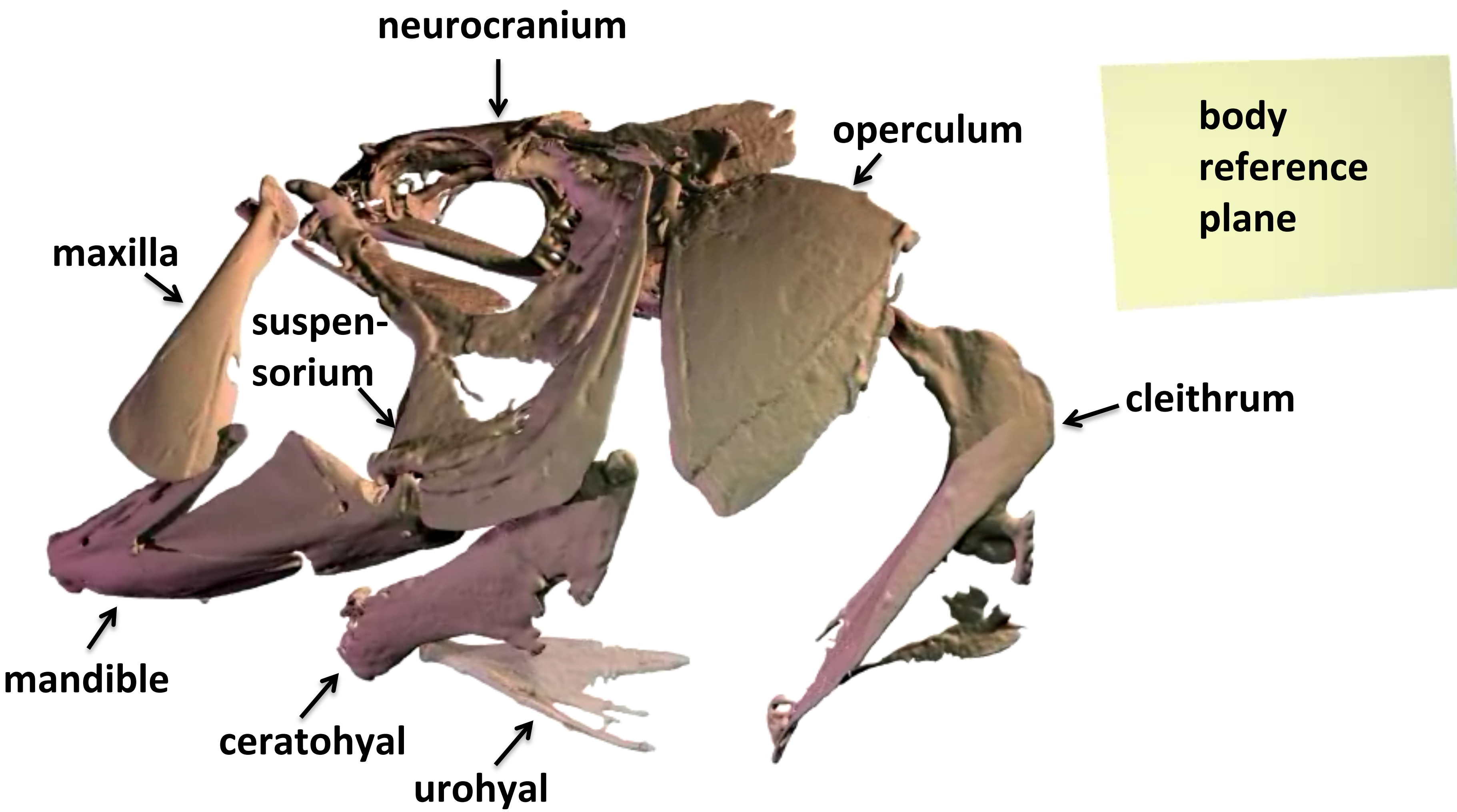
Suction Feeding

X-ray Reconstruction of Moving Morphology (XROMM)



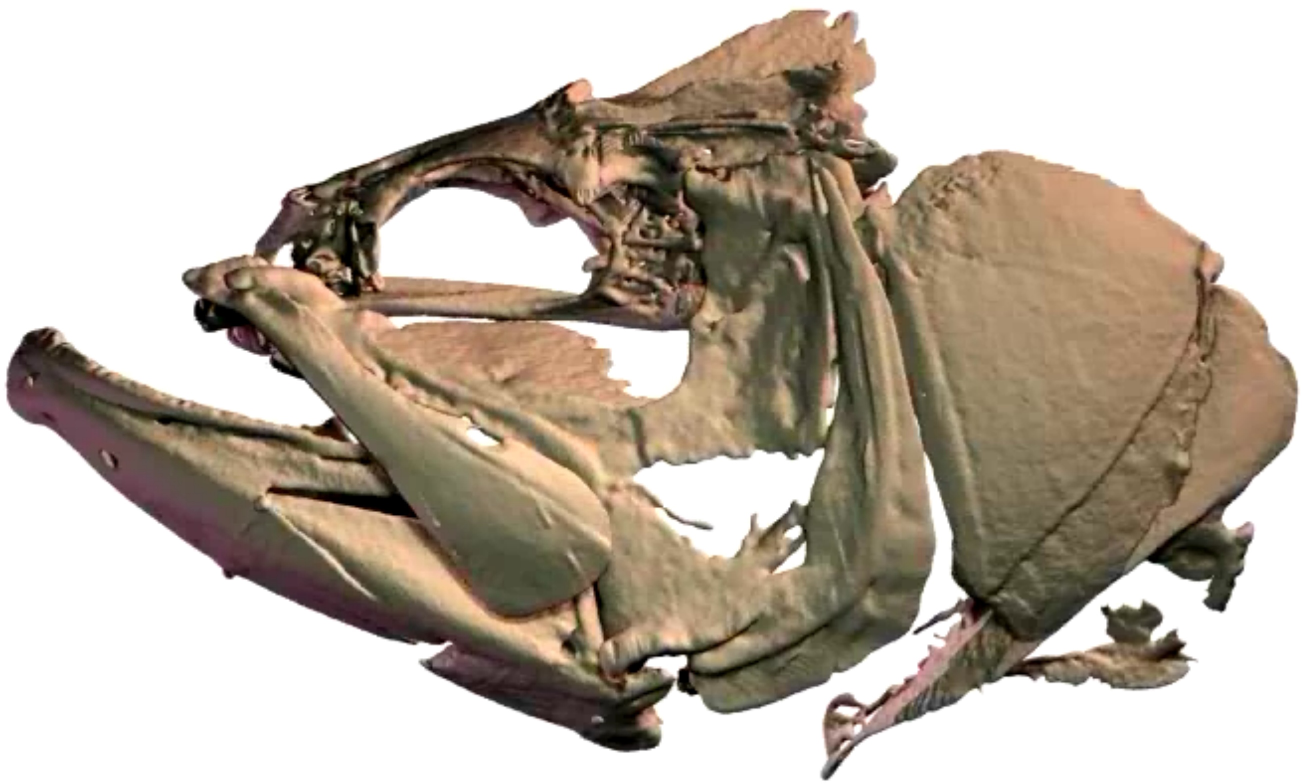
Largemouth bass XROMM animation by Ariel Camp

XROMM Animation



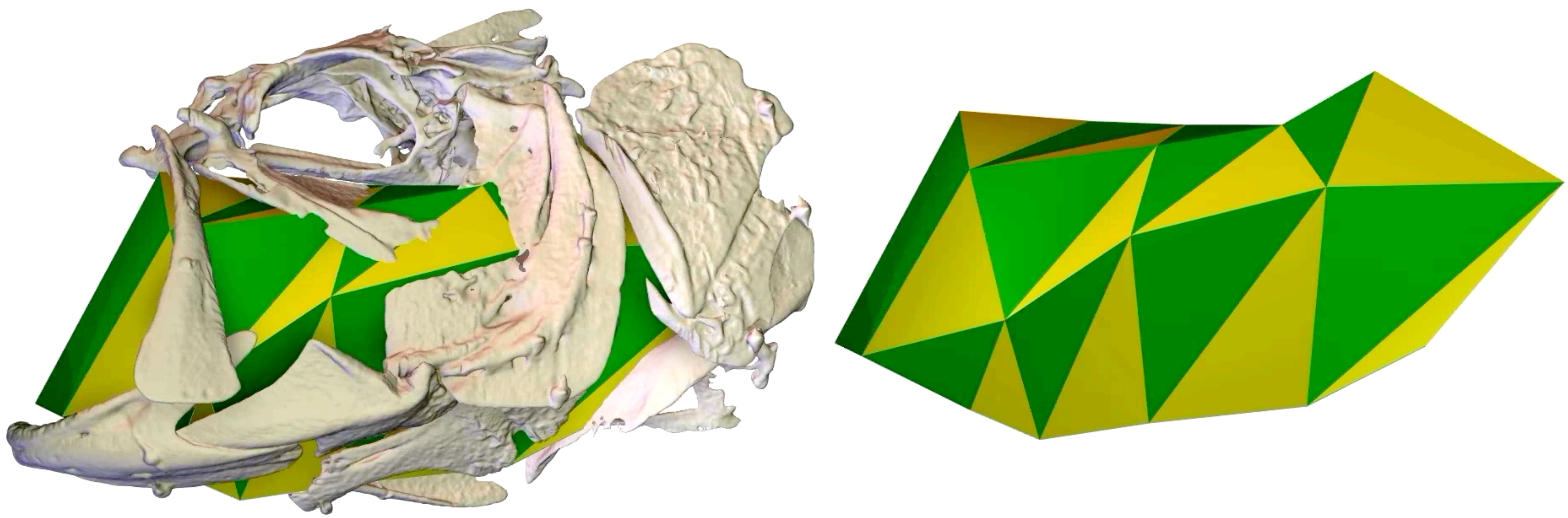
Camp and Brainerd, ICB 2015

XROMM Animation accuracy and precision <0.1 mm



Camp and Brainerd

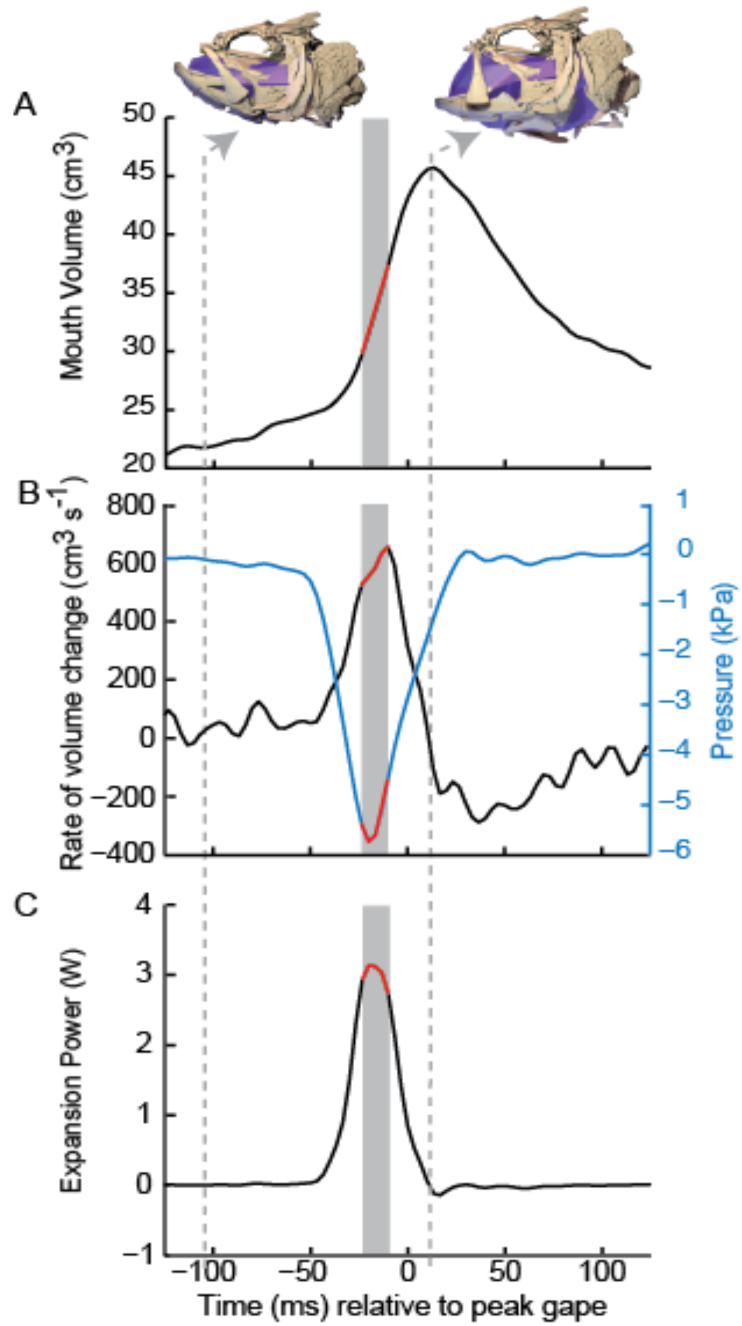
Measure Instantaneous Rate of Volume Change (dV/dt)



Dynamic Endocast Method

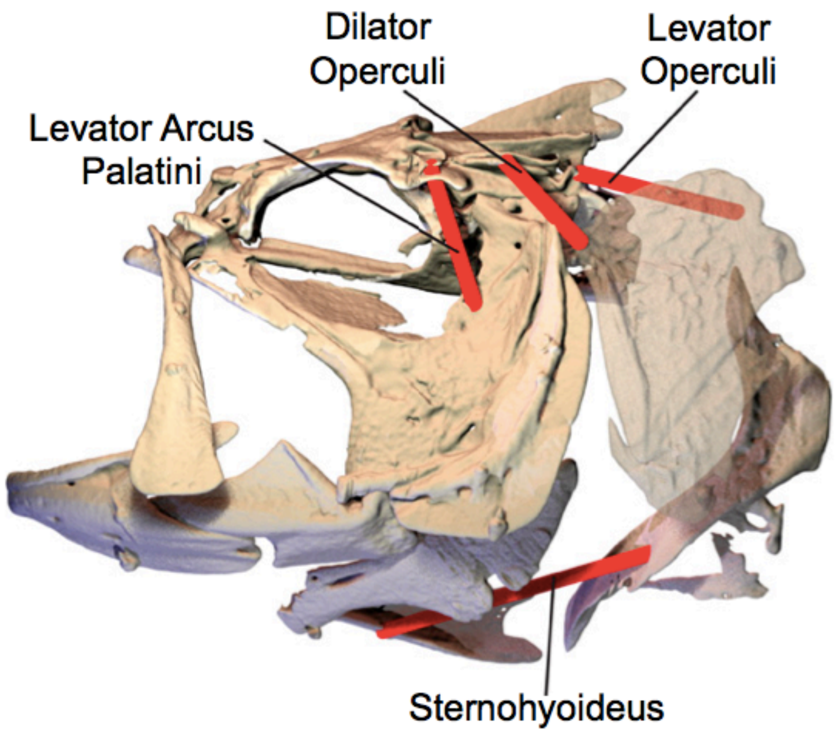
Camp, Roberts and Brainerd, PNAS 2015

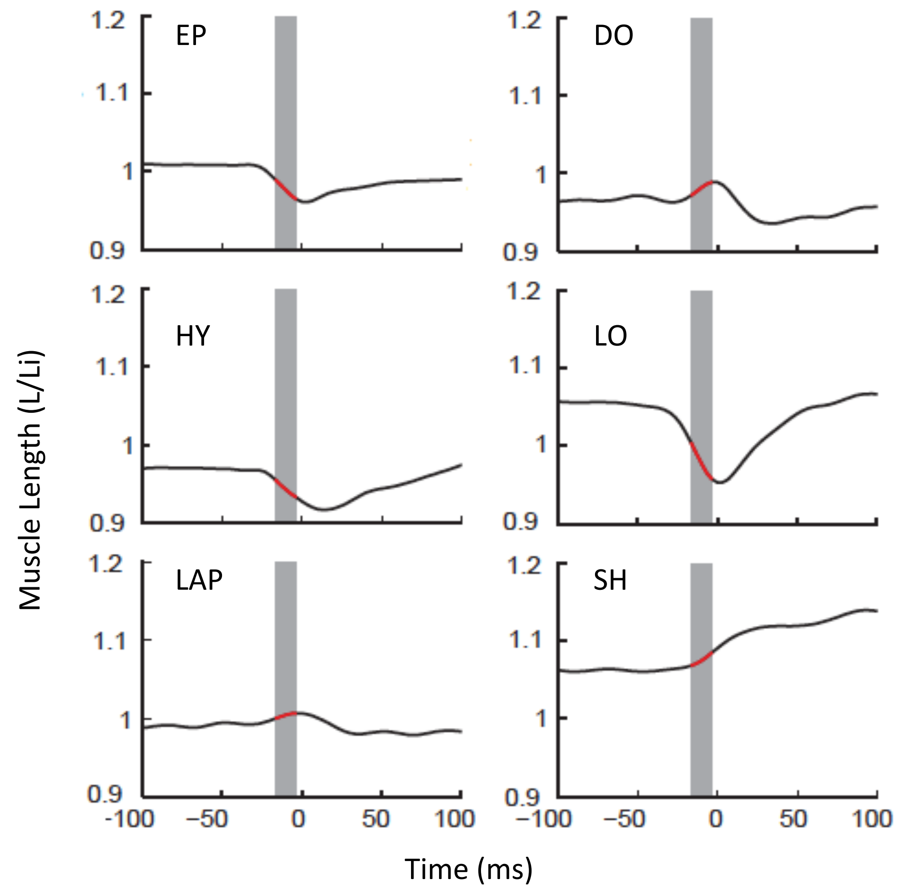
Pressure x dV/dt
= Suction Power



Camp, Roberts and Brainerd, PNAS 2015

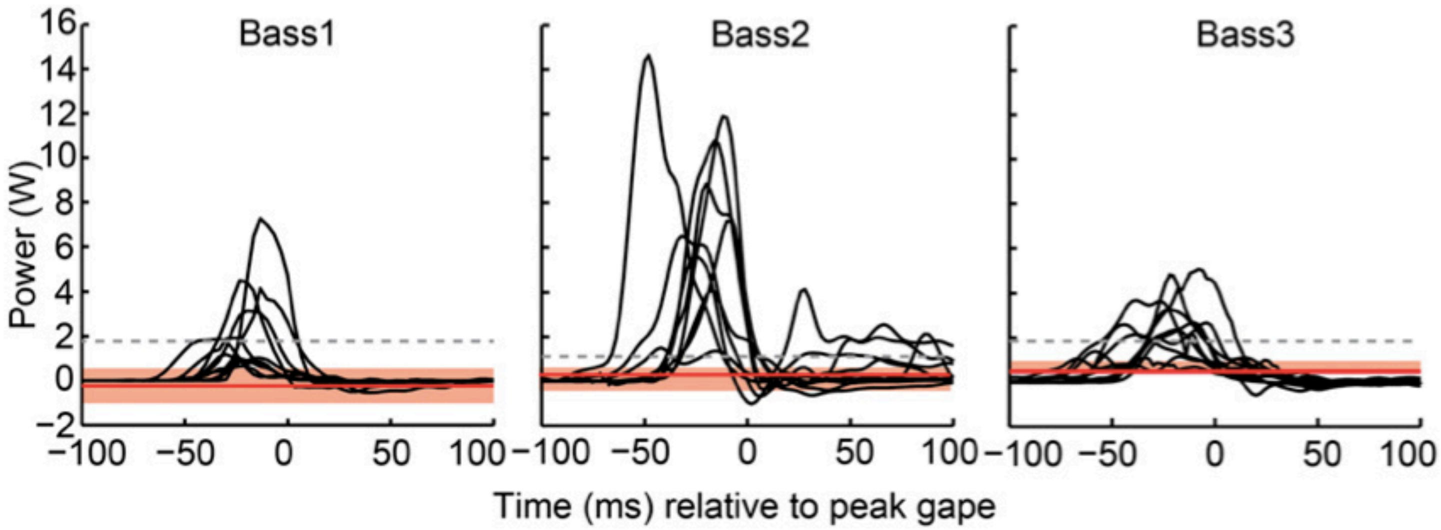
Muscle Strain, Velocity and Power Capacity

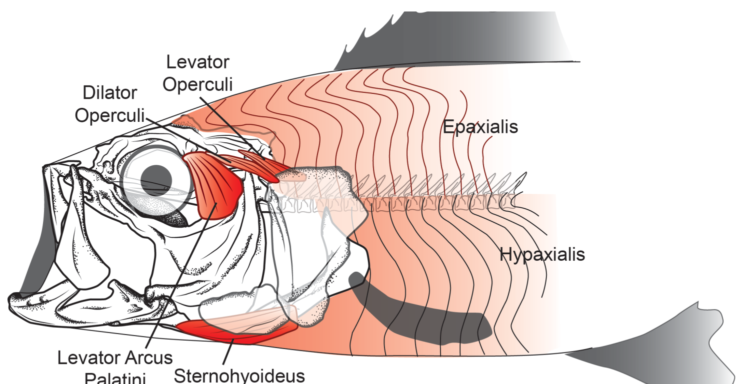




Camp, Roberts and Brainerd, PNAS 2015

“Swimming muscles” power suction feeding in largemouth bass

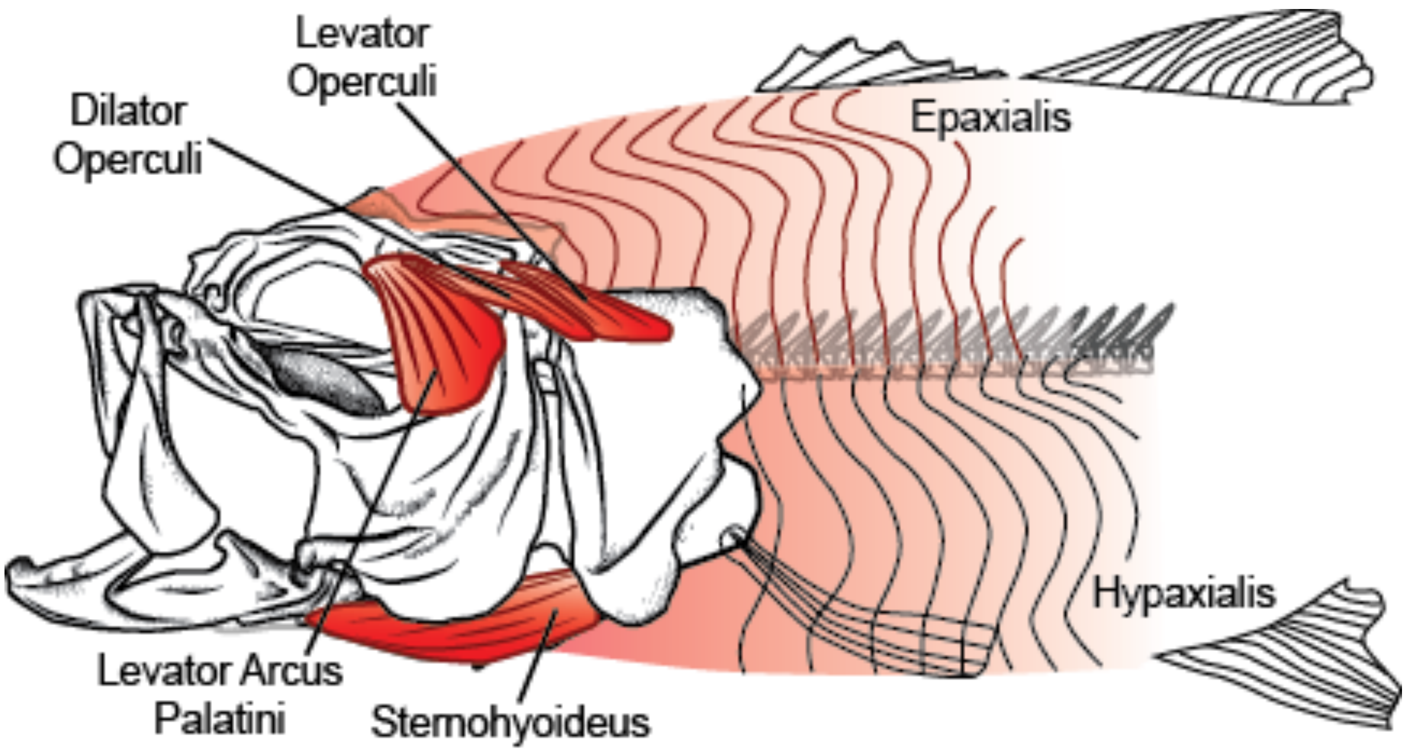




>95% of power for high-performance strikes from axial musculature

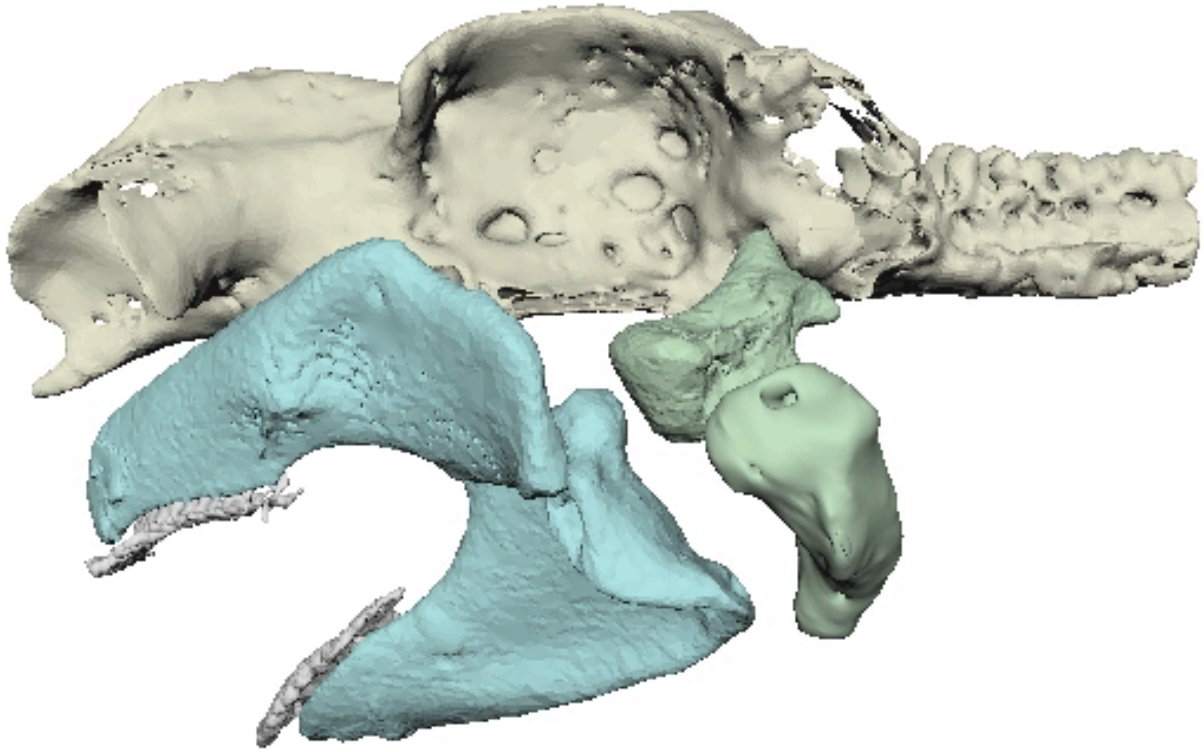
Camp, Roberts and Brainerd, PNAS 2015

Suction feeding is powered by "swimming" muscles



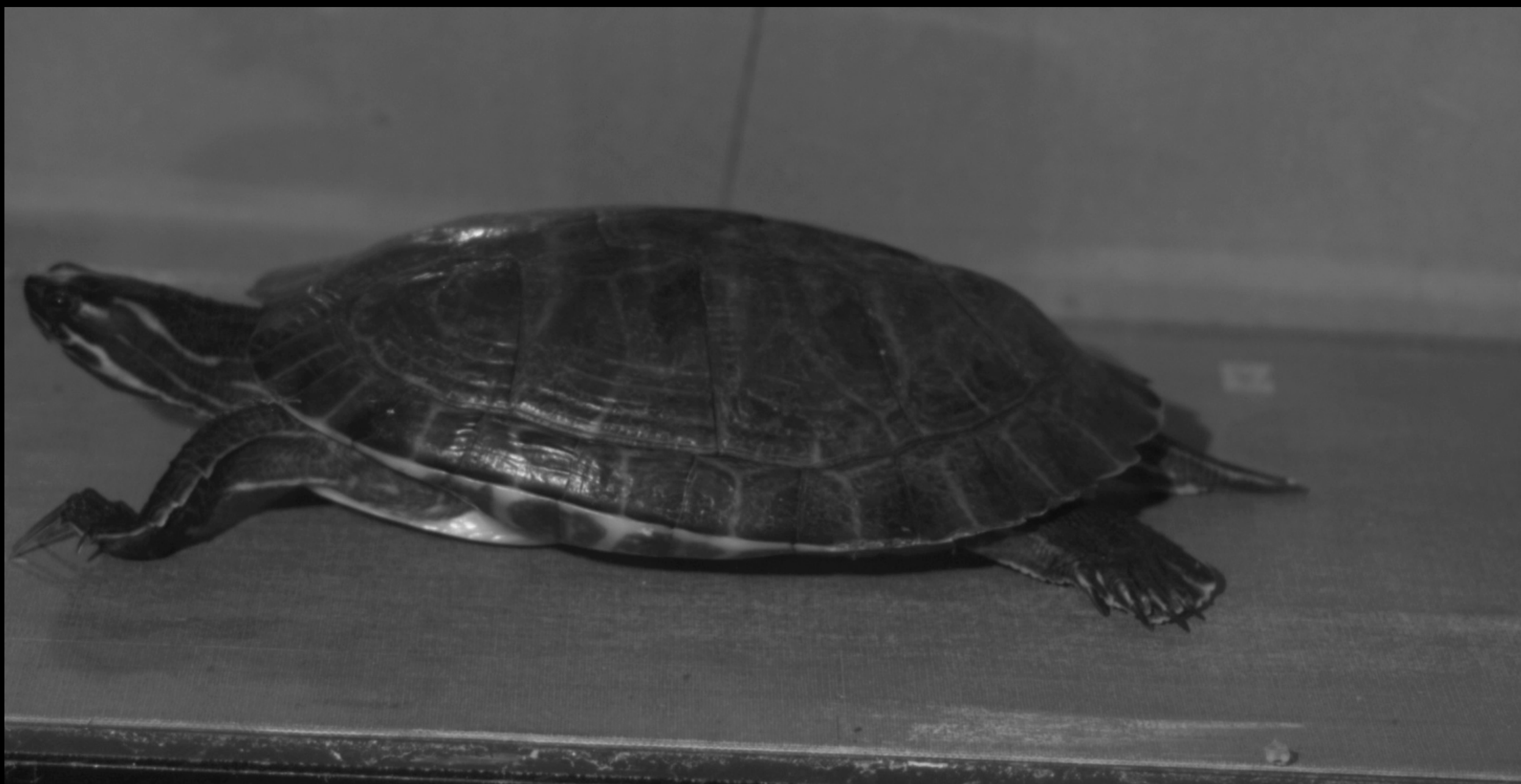
n = 1 out of >30,000 species of ray-finned fishes

Bamboo Shark



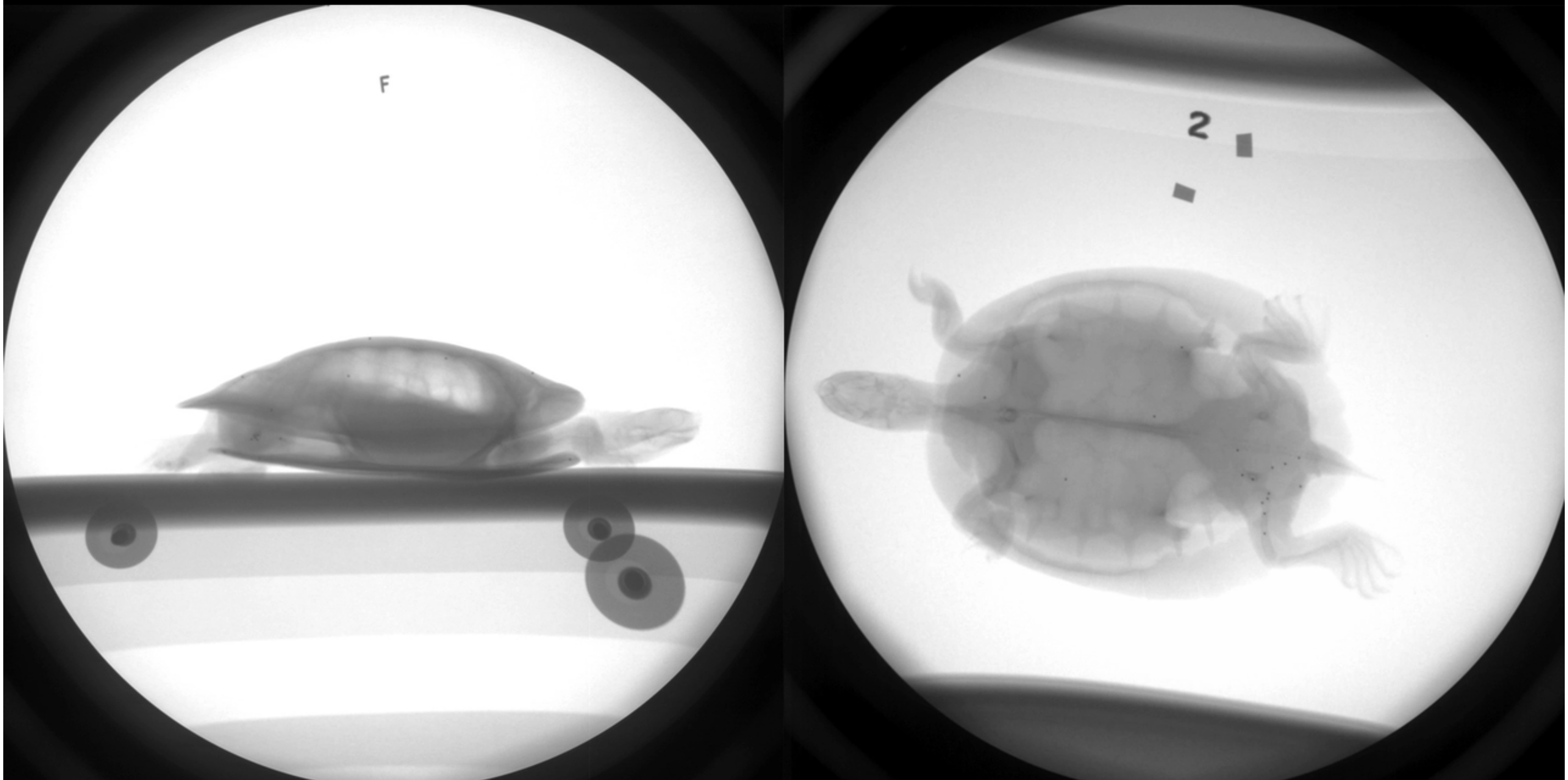
Scott, Wilga and Brainerd, in prep

Pelvic motion in turtles



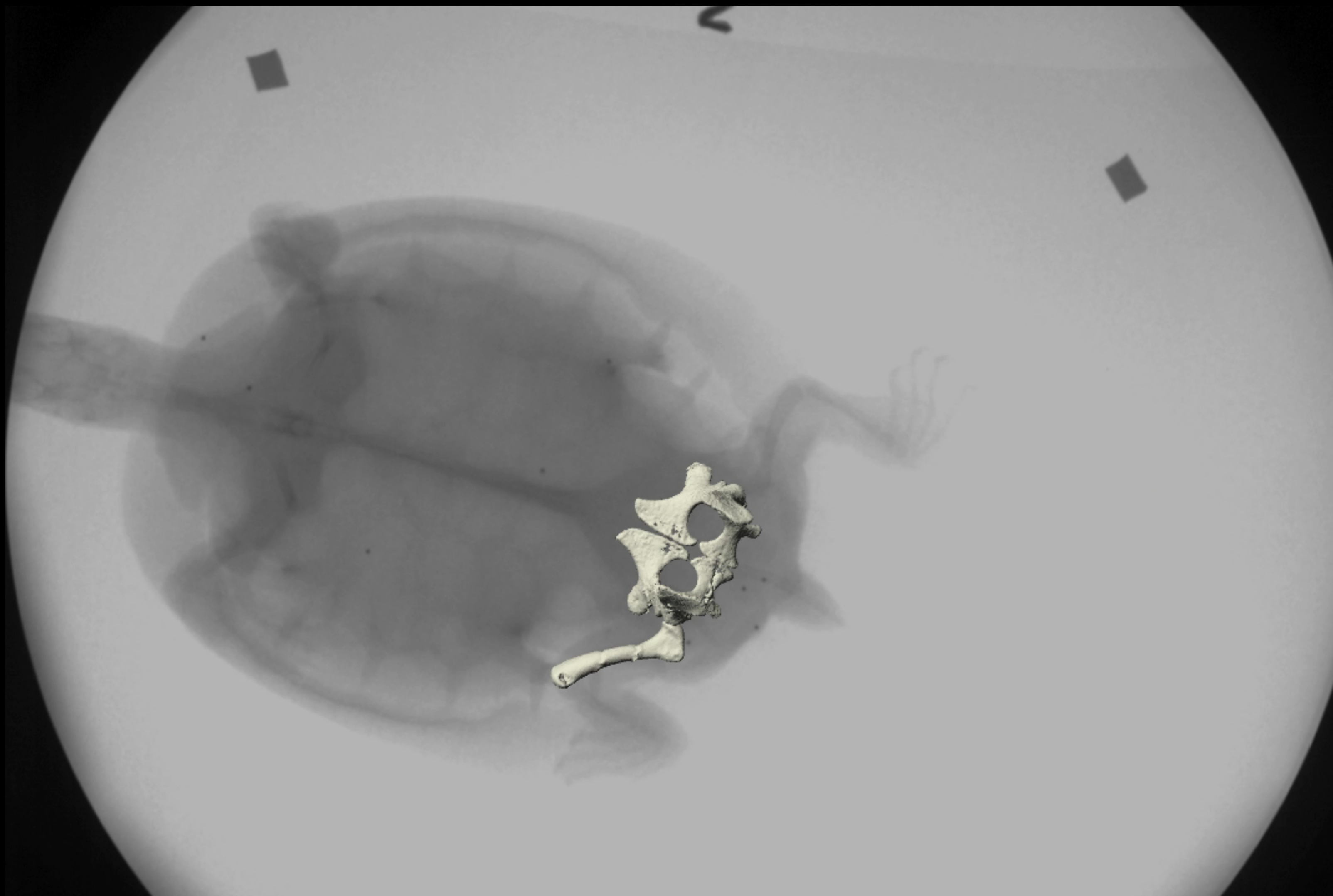
Mayerl, Brainerd, and Blob, 2016

Pelvic motion in turtles



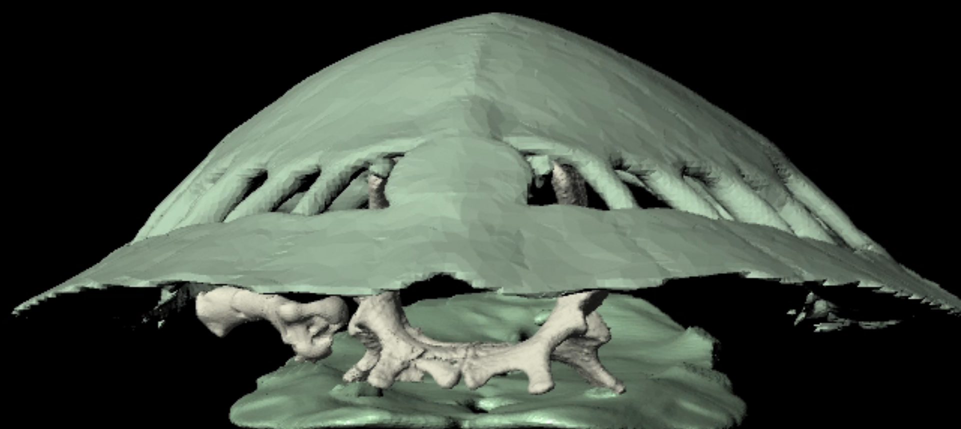
Mayerl, Brainerd, and Blob, 2016

Pelvic motion in turtles



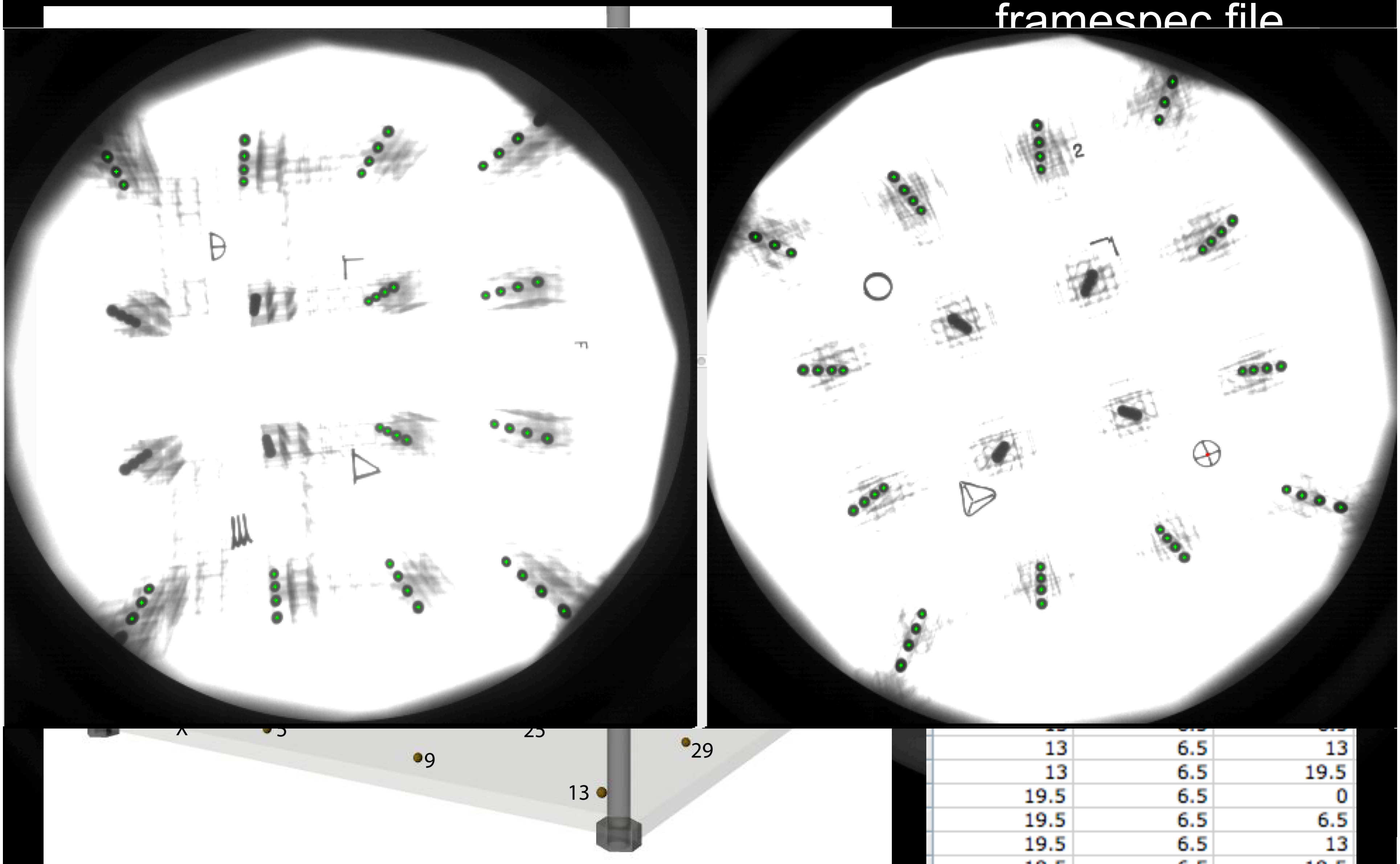
Mayerl, Brainerd, and Blob, 2016

Pelvic motion in turtles

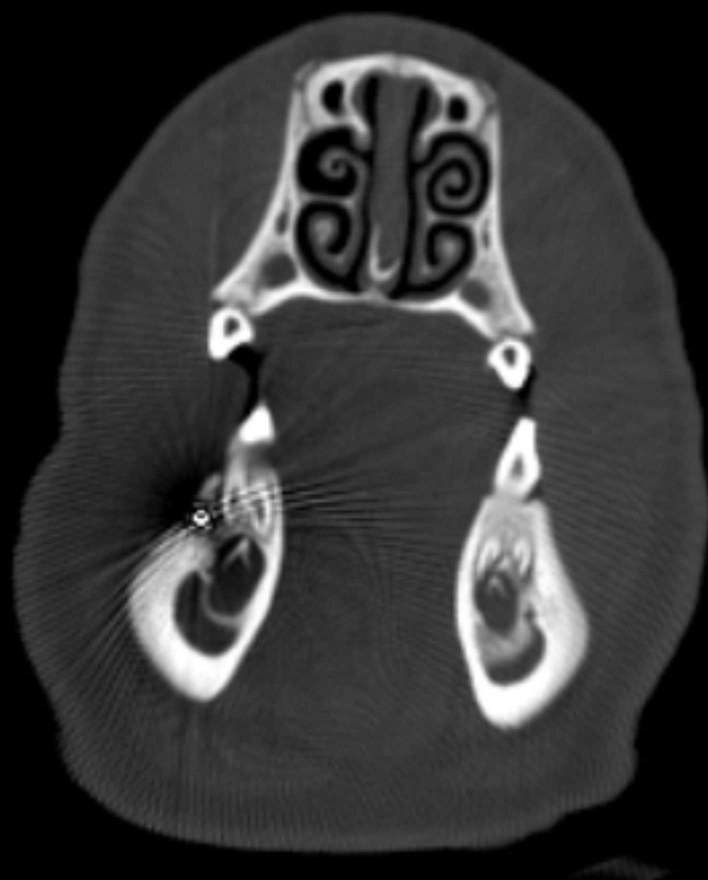


Mayerl, Brainerd, and Blob, 2016

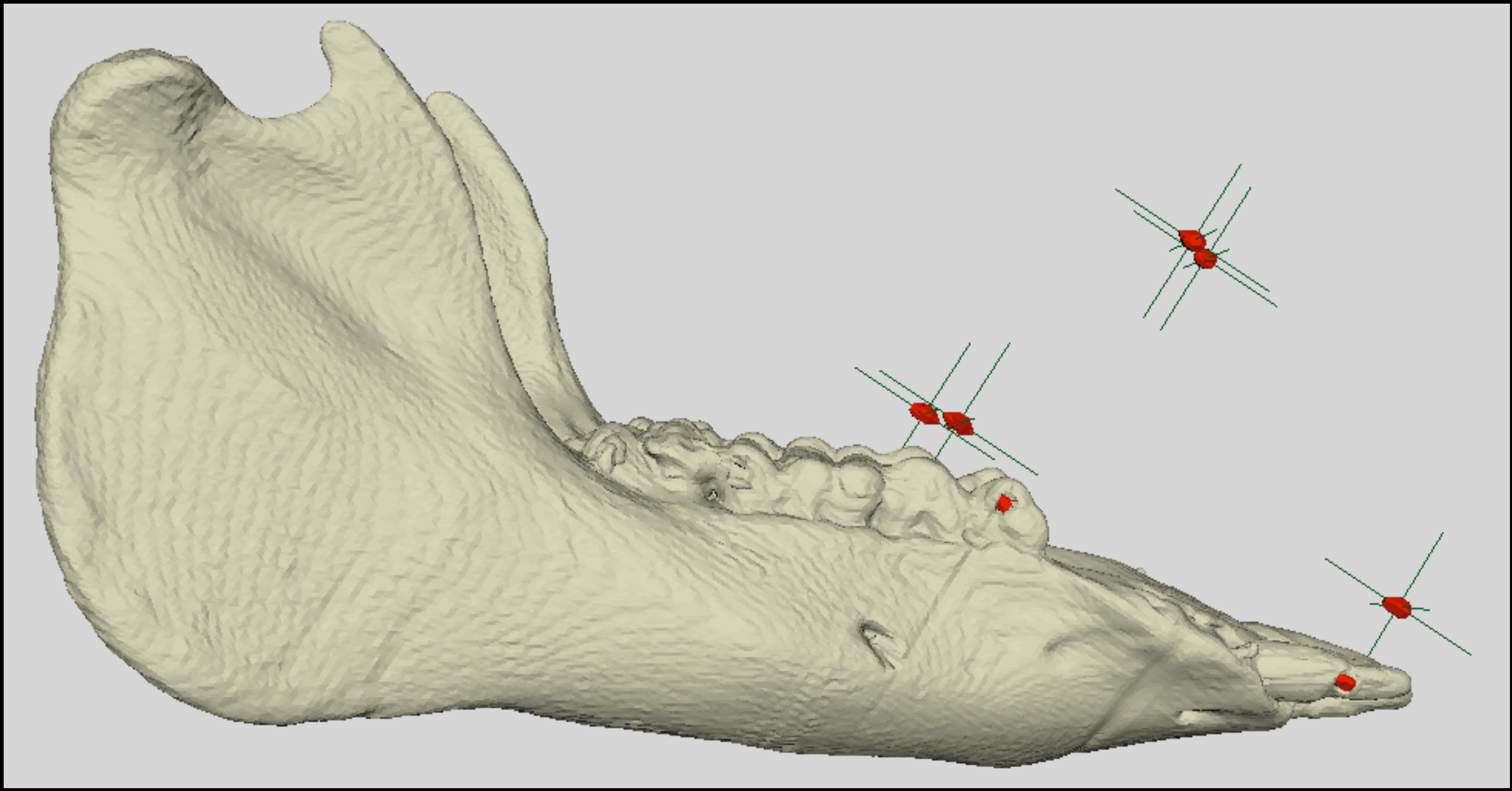
Complexity of XROMM data sets



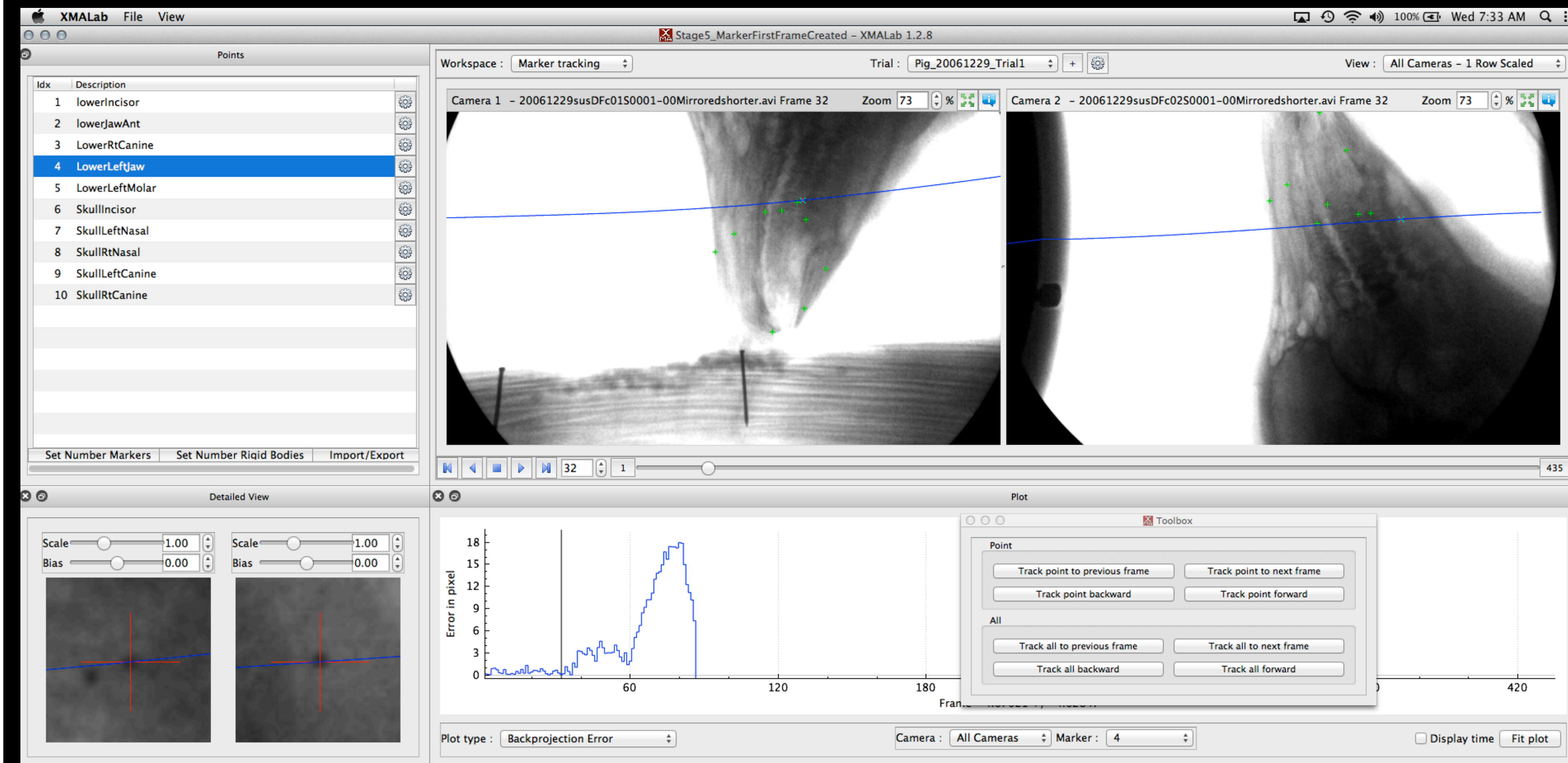
CT Scan



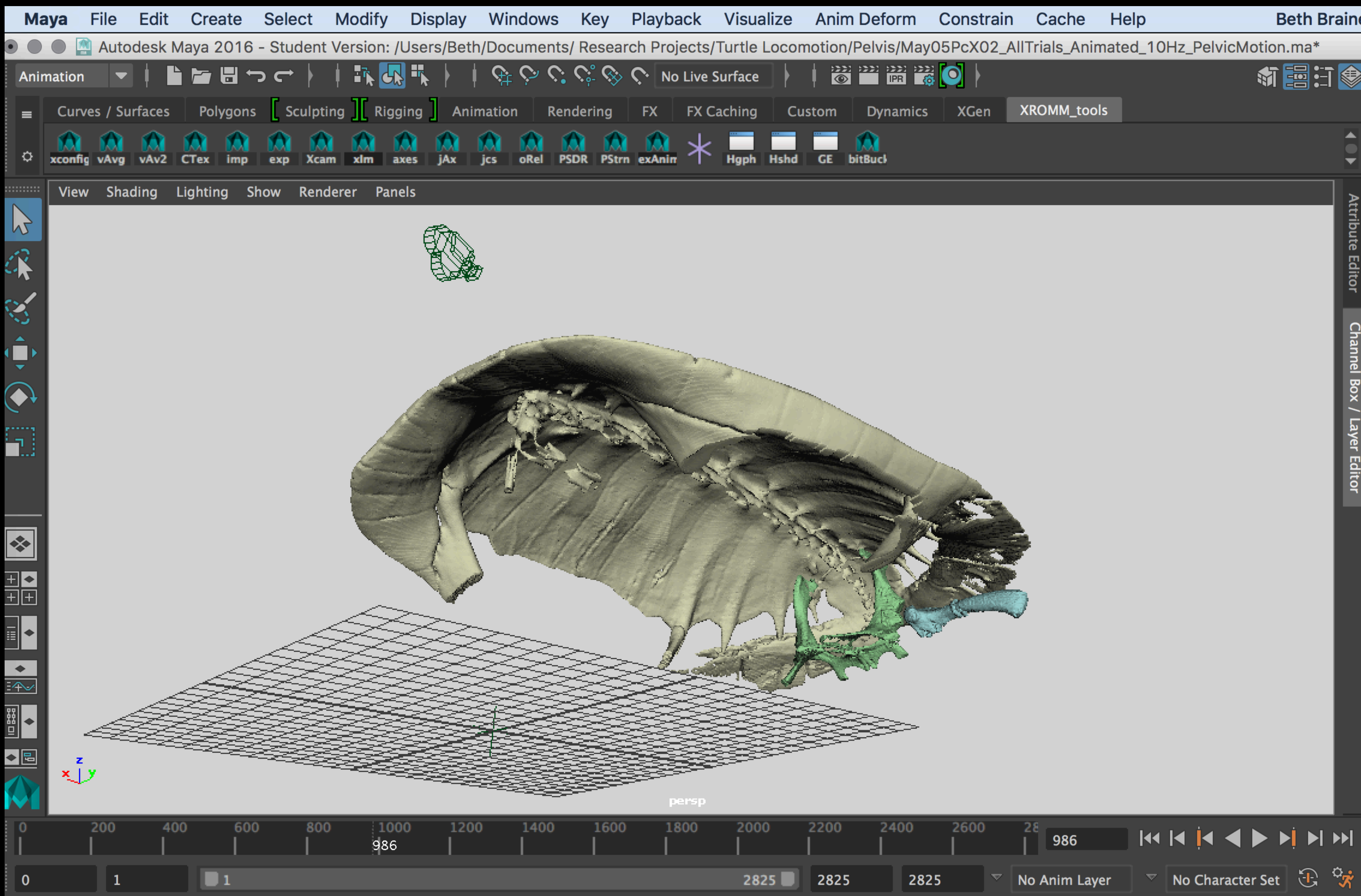
3D models of the bones and beads



Marker Tracking



Autodesk Maya Animation



XMA Portal Data Management

XMA PORTAL
X-RAY MOTION ANALYSIS RESEARCH PORTAL

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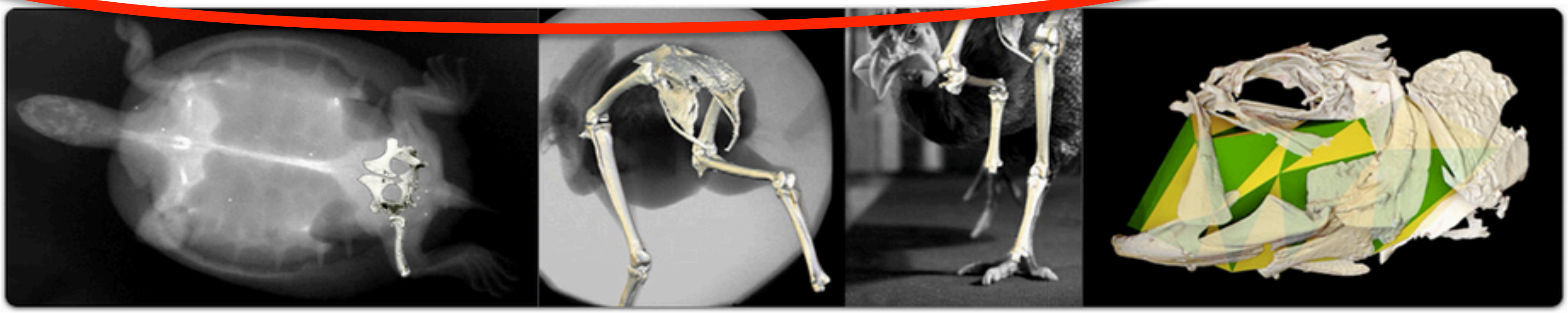
Login

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



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 vi
- Annotation fields for taggi
- Nearly lossless jpg compre
- Interface with companion

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XMAPORTAL X-RAY MOTION ANALYSIS RESEARCH PORTAL

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Home » All Studies

Login

All studies

Non-logged in users: select a Public Study to view data, including raw data videos. Click on Browse (Metadata) to explore the organization and contents of a non-public study. Not all studies allow metadata browsing.

Number of studies: 90

90 Projects from 11 institutions

+ Create New Study

Filter studies by: Search

Study Name	Identifier	Created	Metadata	Public Access
Data for Software and Hardware Validation (Public Study)	BROWN17	2012-06-02	Browse	Yes
Iguana Lung Ventilation (Public Study)	BROWN5	2011-05-31	Browse	Yes
Mallard Duck Feeding Study (Public Study)	BROWN9	2012-01-30	Browse	Yes
Minipig Feeding Study (Public Study)	BROWN11	2012-02-15	Browse	Yes
Pelvic Mobility in Turtles (Public Study) Public Profile	BROWN40	2014-06-17	Browse	Yes
Pharyngeal Jaw Function in Black Carp (Public Study)	BROWN12	2012-03-19	Browse	Yes
ACLd	RIH1	2015-04-28	Browse	No
Alligator Hindlimb Cartilage	BROWN58	2016-04-11	Browse	No
Alligator Knee Mechanics	BROWN18	2012-07-26	Browse	No
Alligator Lung Ventilation	BROWN10	2012-02-06	Browse	No
Amphibian and lungfish breathing and feeding	BROWN47	2015-01-13	Browse	No
Anuran Locomotion	BROWN53			
Bamboo Shark Feeding	URI1			

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ZMA Portal
Zoological Motion Analysis Research Portal

My Studies | All Studies | Search | Documentation | Administer

Login

Organize, *Store* and *Share* Video Motion Data with ZMA Portal

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 tag later analysis
- Nearly lossless jpg com download

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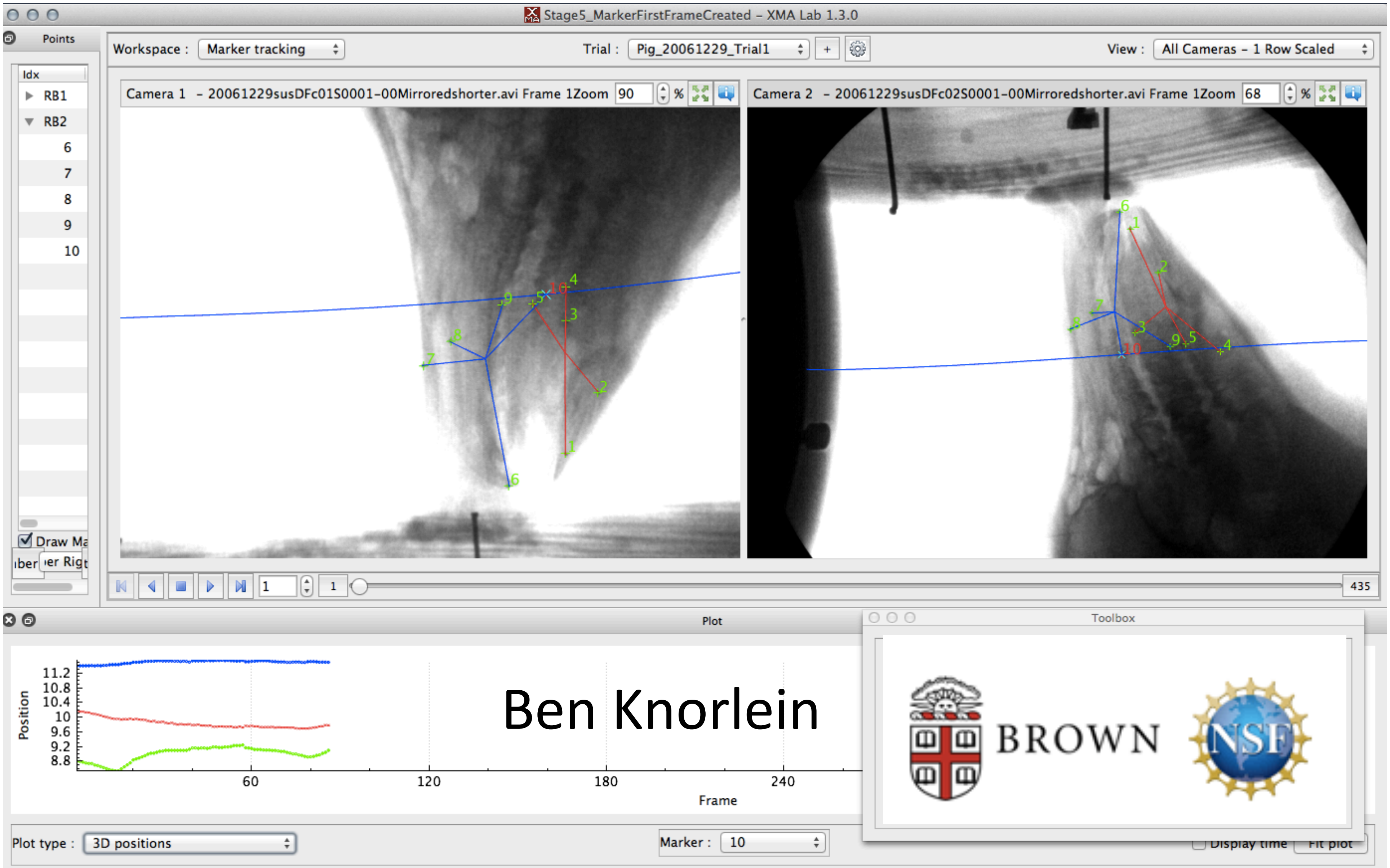
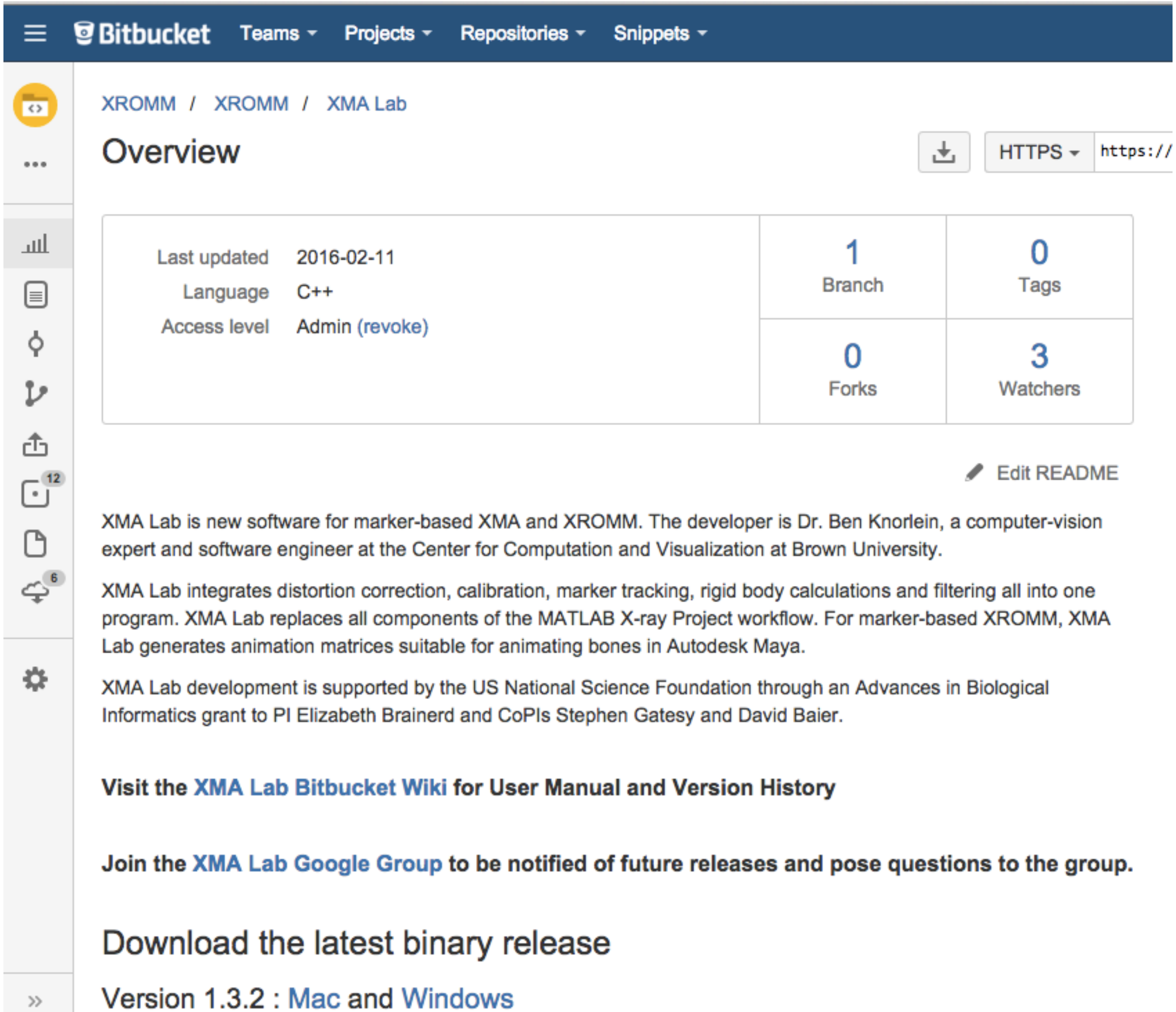
XMA Lab: Motion Analysis



Ben Knorlein

XMALab software – Bitbucket



Bitbucket Teams Projects Repositories Snippets

XROMM / XROMM / XMA Lab

Overview

HTTPS https://

Last updated	2016-02-11	1 Branch	0 Tags
Language	C++	0 Forks	3 Watchers
Access level	Admin (revoke)		

Edit README

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 Brainerd and CoPIs Stephen Gatesy and David Baier.

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

XMA Portal
X-ray Motion Analysis Research Portal

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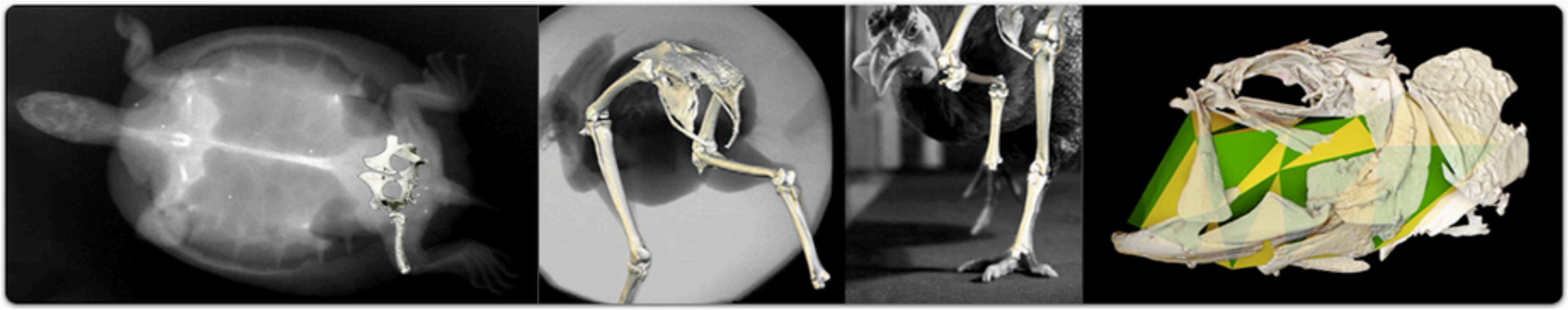
Organize, *Store* and *Share* X-ray Motion Data with XMA Portal



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- Interface with companion p

Page Proof: In Press

Integrative and Comparative Biology

Integrative and Comparative Biology, pp. 1–14
doi:10.1093/icb/icx060

Society for Integrative and Comparative Biology

ICB PERSPECTIVES

Data Management Rubric for Video Data in Organismal Biology

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AQ1 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

[1]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,

Integrative and Comparative Biology

Integrative and Comparative Biology, pp. 1–14
doi:10.1093/icb/icx060

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Data Management Rubric for Video Data in Organismal Biology

Table 1 Rubric for best practices in video data management for organismal biology research

Standards	Level 0: unacceptable	Level 1: good	Level 2: better	Level 3: best
(1) Data storage	Single copy, local disk storage only (such as on a hard drive).	A local working copy plus an archival[a] copy in professionally managed/cloud[b] 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.	One archival[a] copy in professionally managed/cloud[b] 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.	Archival[a] copy stored in a data repository[c] with a stated mission of digital data preservation.
(2) Video file formats[d]	Video files compressed, resized, or at a different frame rate from the original video files (e.g., YouTube or Vimeo).	Original, archival[a] video files, even if format includes codecs or file types that are not widely accessible by common viewing software.	Level 1 plus version converted to a widely accessible format with maximum data preservation in the conversion.	Level 2 plus compressed/converted version(s)[e] for viewing and greater accessibility online.
(3) Metadata linkage	Metadata absent or separate from video files (such as in lab notebooks); substantial effort required to share.	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.	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.	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.
(4) Video data and metadata access	Not directly accessible online; substantial effort required to share.	Video data and metadata available in an Internet-accessible location, such as in commercial cloud[b] storage or on a local drive on a network-connected computer.	Video data and metadata online in a public repository with a stated mission of providing public access to data[f].	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[g].
(5) Contact information and acceptable use	No contact information and no statement of terms of reuse.	Contact name and e-mail address and a clear statement about rights and acceptable reuse of the video.	Name, e-mail and assignment of an internationally-recognized content license[h].	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.
(6) Camera settings	No metadata.	Frame rate (frames per second).	Frame rate and spatial calibration data and number of cameras and camera ID (camera used for this specific	Level 2 plus four or more of the following: video resolution (in pixels); shutter speed/exposure time; audio (Y/N);

www.xromm.org

XROMM

X-RAY RECONSTRUCTION OF MOVING MORPHOLOGY

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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

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Software
Hardware
XMA Portal
XMA Lab
Scheduling
XROMM Wiki
Research Coordination Network (RCN)

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Hardware

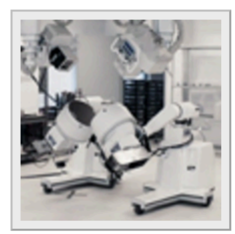
Two types of high-speed, biplanar x-ray video systems are in general use today: systems based on mobile C-arm fluoroscopes and custom-built biplanar x-ray rooms.

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 IIs, higher tube currents, and more flexible positioning of the x-ray tubes and IIs. The disadvantage, relative to C-arms, is cost. The cost for the high-speed video cameras, x-ray

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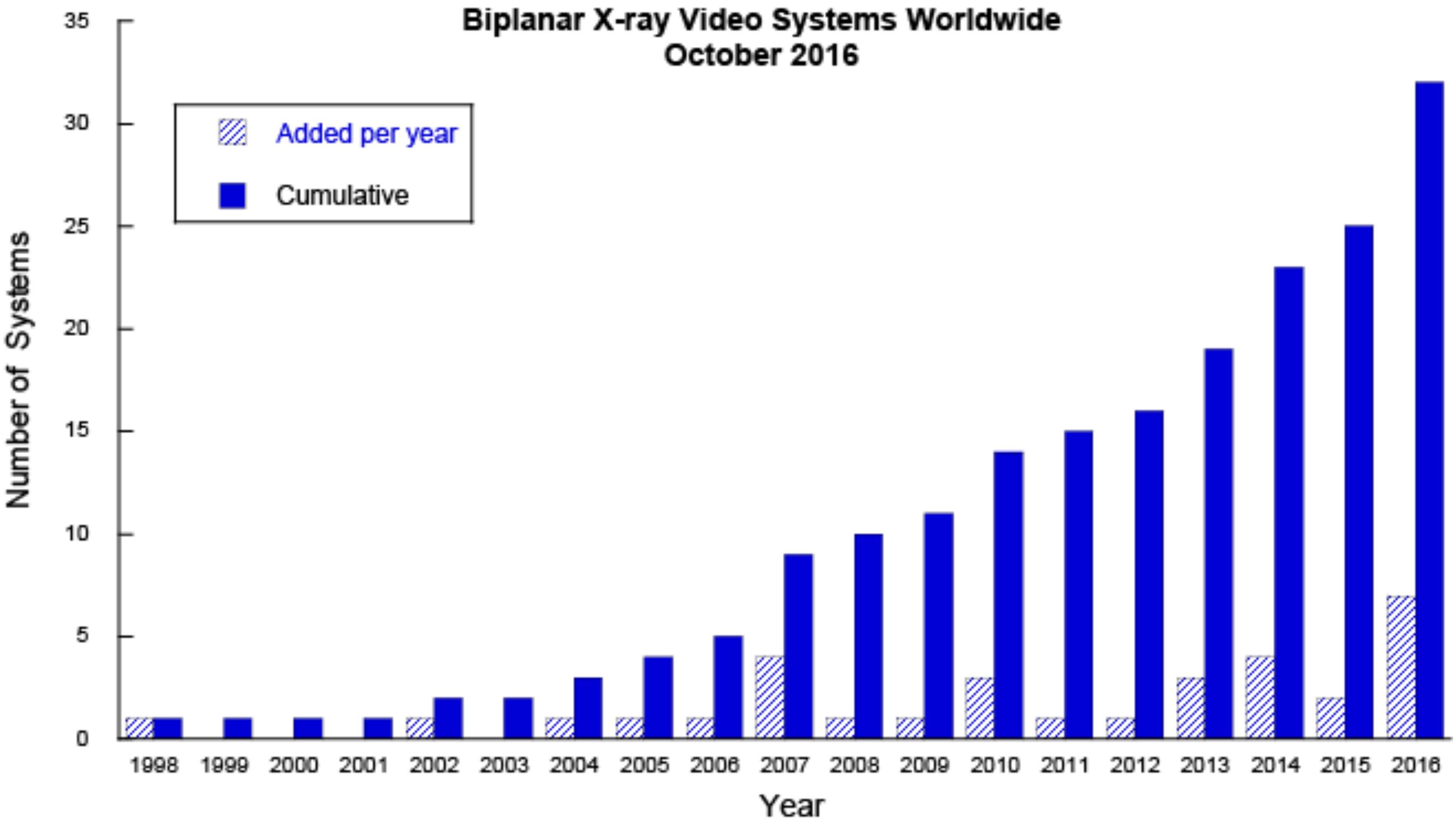
Scheduling
XROMM Wiki



Biplanar X-ray Video Systems Worldwide
October 2016
Added per year
Cumulative
Number of Systems
0
5
10
15
20
25
30
35
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year

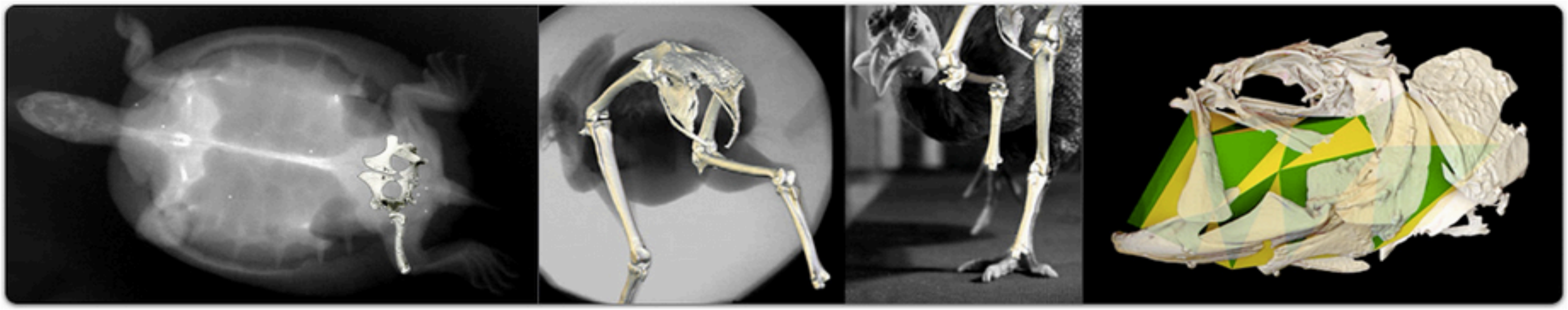
XMAPortal Data Management

XMA PORTAL
X-RAY MOTION ANALYSIS RESEARCH PORTAL

My Studies | All Studies | Search | Documentation | Administer

Login

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



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 vi
- Annotation fields for taggi
- Nearly lossless jpg compre
- Interface with companion p

BROWN

NSF

BROWN

Steve Gatesy

Beth Brainerd

Dave Baier

Tom Roberts

Sharon Swartz

Kia Huffman

Ben Knörlein

Trey Crisco

Doug Moore

Braden Fleming