Linked Spatial and Temporal Normalization for Analysis of Cyclical 4D Skeletal Motion Data

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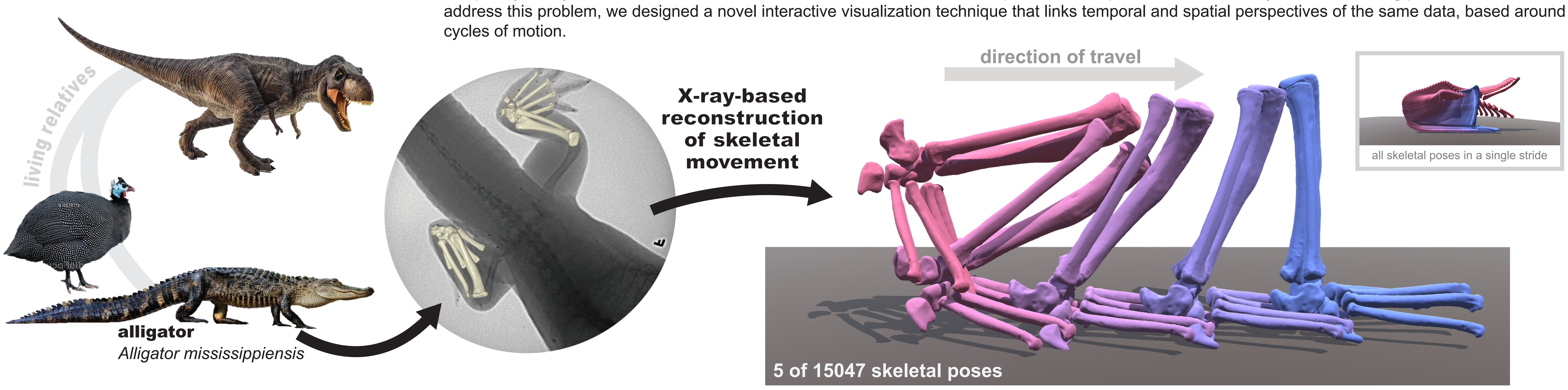
Abstract

We introduce a new interactive visualization technique that links temporal and spatial perspectives of cyclical skeletal motion data to help evolutionary biologists relate bone form and function.

Introduction

Visualizing and measuring skeletal motion from live animals is a key research pathway into understanding how extinct animals like dinosaurs once walked the earth. Our visualization research is motivated by a collection of skeletal motion data that is particularly challenging to acquire and analyze. The alligator hindlimb motion dataset pictured here represents some of the more complex skeletal motion data acquired using living animals [1,2], and poses a significant challenge for skeletal form-function analyses. While scientific motion ensembles [3,4] have been developed to facilitate the exploration of this motion complexity, many of these lack visual and interactive coordination between spatial and temporal data that are key to understanding patterns in motion. To address this problem, we designed a novel interactive visualization technique that links temporal and spatial perspectives of the same data, based around cycles of motion.



Visualizations of X-ray-based reconstructions of alligator hindlimb skeletal motion used for research on the evolution of locomotion in extinct animals [1].

Motion Data Processing

Due to the cyclical nature of many animal movements, we divided the data into "Motion Clips" based on a table of observed key events, such as initial and last contact of a foot hitting the ground during a walk cycle. This technique of "clipping" consistent units of motion data from longer sequences of varied animal behavior permits analysis of patterns within the cycles of motion.

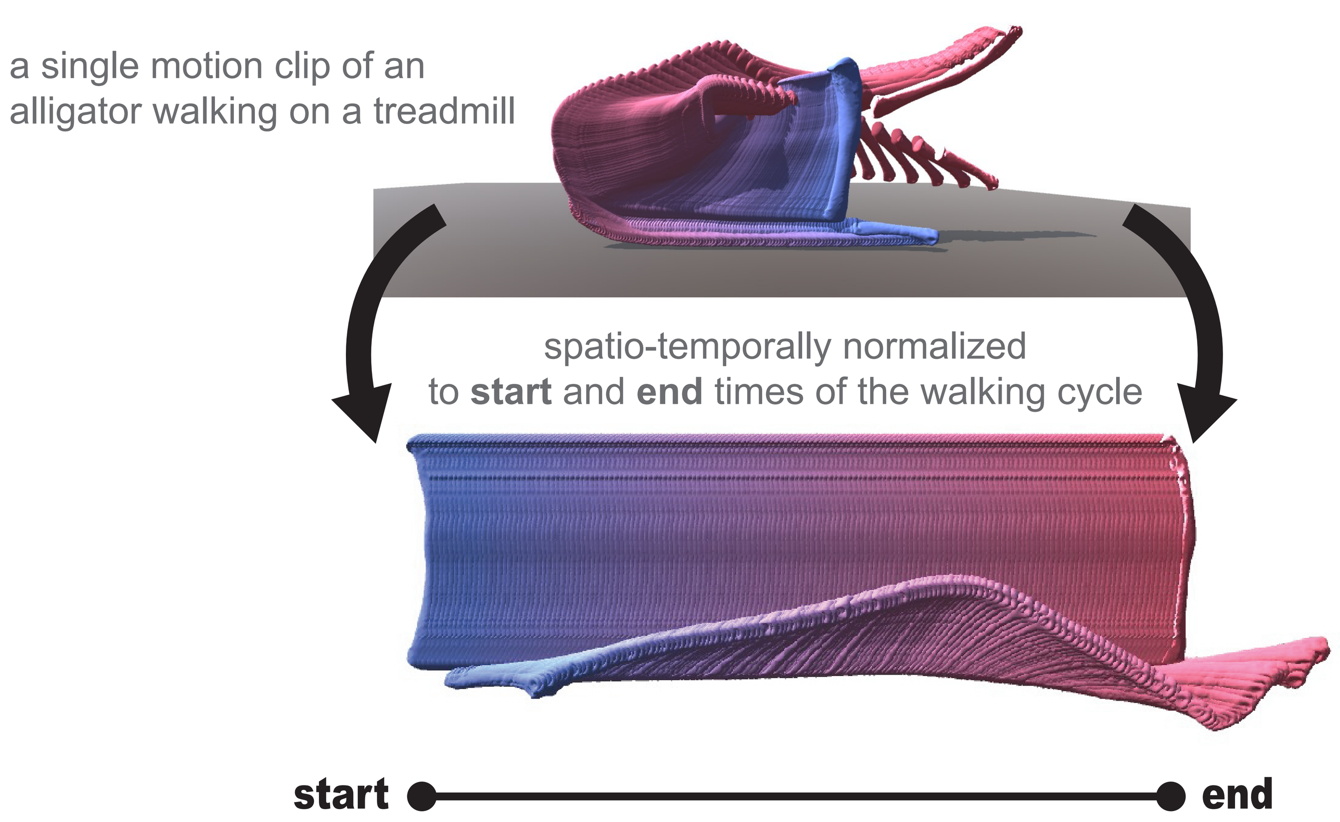
Rendering Normalized Spatial and Temporal Views

The **3D bone renderings** were implemented using the Unity-based Artifact-Based Rendering (ABR) technique [5]. High-resolution bone meshes were instancerendered for each frame of transformation matrix data from the skeletal animation. Scatterplot rendering used an instanced particle system to enable large point datasets like those produced by XROMM. 2D data were displayed using a Unity canvas.

To create the **temporally normalized views** of 2D data, the start and end frames of the motion cycles were used to normalize the time-based scalar data that occured during each cycle.

start —— motion cycle —— **end**

To create the **spatio-temporally normalized views** of 3D data, the original transformation matrices from the experimental recordings underwent a series of transformations such that 1) the motion of each skeletal pose was viewed relative to a user-defined reference bone, and 2) skeletal poses were registered with and equally spaced along a horizontal axis.

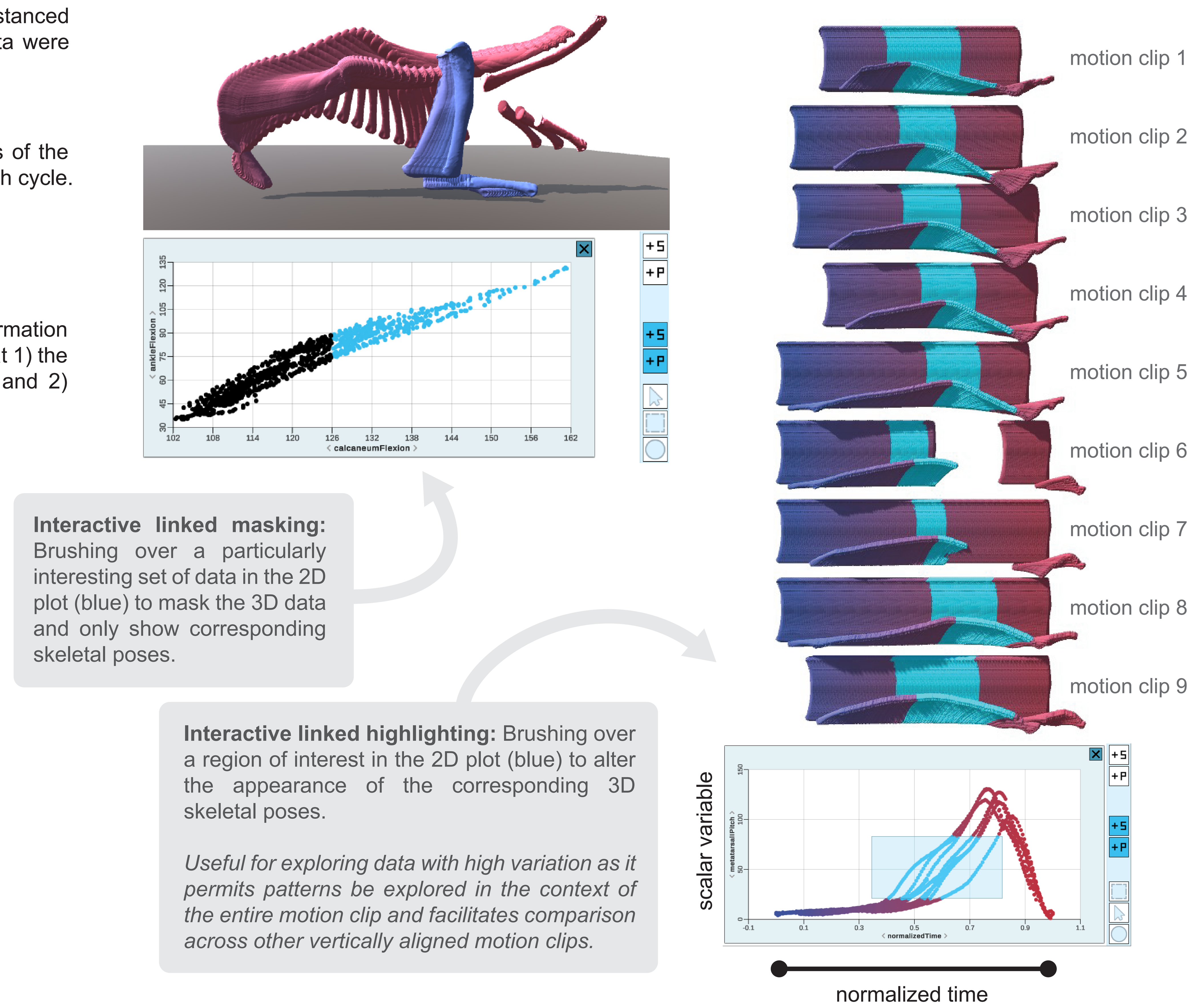


Linked Multidimensional Plots and Space-Time Views

As the data analysis requires more than just understanding the spatial and temporal relationships, we designed the visualization to also incorporate several standard multidimensional data visualization techniques, such as scatter plots. These 2D plots appear in separate view windows adjacent with the normalized 3D views. To facilitate exploratory analysis, all of the views support linked brushing and highlighting.

identifying relationships within multidimensional data

exploring patterns across multiple walking cycles



Conclusions and Future Work

Our linked spatial and temporal visualization for 4D biomechanical skeletal motion data provides a new technique of analyzing complex experimental data. By linking 2D and 3D data and dividing cyclical motion into 'motion clips', our technique permits simultaneous temporal and spatial context, critical to understanding complex 4D motion.

One immediate area of future work is addressing the problem of data occlusion. With hundreds of motion cycles in the alligator dataset, the density of skeletal geometry quickly occludes patterns and spatial relationships within the motion. This presents an exciting future visualization challenge for how to interact with temporal variables and/or spatial geometry to mask data in a way that enables domain researchers to quickly identify patterns among the entire dataset, without being inhibited by the large datasets themselves. How might multiple spatial variables be encoded in the visualization to intuitively indicate how those ankle bones coordinate across walking cycles, without occluding a motion pattern of interest? Visualizations with this level of complexity are important for researchers to answer key biomechanical questions in investigating the evolution of dinosaur locomotion.

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