# Motion Capture Interpolation

## Spring 2025 CSCI 520 Assignment 2

Pranav Rathod (psrathod@usc.edu)

## Introduction

In this assignment, I implemented different interpolation techniques to reconstruct missing motion capture data. The goal was to interpolate human motion sequences obtained from an optical motion capture system using four different methods: **Linear Euler, Bezier Euler, SLERP Quaternion, and Bezier SLERP Quaternion**.

The motion data is provided in **ASF/AMC format**, where the ASF file defines the skeleton structure, and the AMC file contains motion data (joint angles and root position) over time. Given an input motion sequence, I generated keyframes by **dropping every N frames** and then applied interpolation to estimate the missing frames. This allowed me to analyze how different interpolation methods affect motion quality.

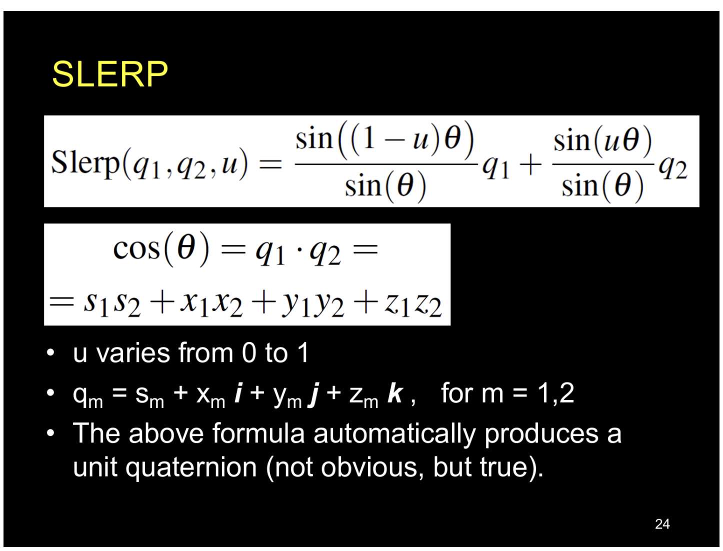
Euler-based interpolation methods operate directly on joint angles but are prone to **gimbal lock** and discontinuities. Quaternion-based methods, particularly **SLERP (Spherical Linear Interpolation)** and **Bezier SLERP**, provide smoother and more natural rotations. In this assignment, I also ensured that the **root translation** was interpolated separately from rotation, following the guidelines for combining **Euler interpolation for position** and **quaternion interpolation for orientation**.

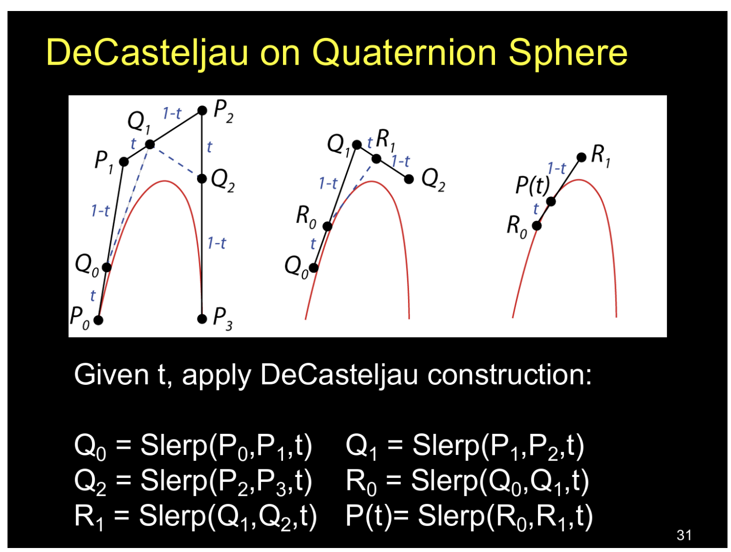
To evaluate the effectiveness of these techniques, I generated **four graphs** comparing the interpolation methods at specific joints and frames. Additionally, I created **three videos** demonstrating the motion differences using **martial arts motion data**. Through this assignment, I gained a deeper understanding of motion capture data processing and the mathematical foundations of **quaternion interpolation**.

# Implementation

Each interpolation method offers a different approach to reconstructing missing motion frames, with varying levels of smoothness and accuracy.

- **Linear Euler interpolation** simply applies linear interpolation (LERP) to each Euler angle independently. While it is easy to implement and computationally efficient, it often results in **abrupt transitions** and suffers from **gimbal lock**, which can lead to incorrect rotations.
- **Bezier Euler interpolation** improves on Linear Euler by using **Bezier curves and De Casteljau's algorithm** to create smoother transitions. While this method reduces sudden changes in rotation, it still operates in Euler space and does not prevent **gimbal lock** or ensure the shortest rotation path.
- **SLERP Quaternion interpolation** provides a more natural way to interpolate rotations by smoothly transitioning between two quaternions along a great circle. This method **avoids gimbal lock** and maintains consistent angular motion, but it does not adjust for acceleration or deceleration between frames, leading to **potentially unnatural velocity changes**.
- **Bezier SLERP Quaternion interpolation** extends SLERP by introducing **Bezier control points in quaternion space**, ensuring not only smooth transitions but also **continuous velocity changes**. This method produces the **most natural motion**, closely following the input animation. However, it is computationally more expensive and requires special handling for boundary conditions.

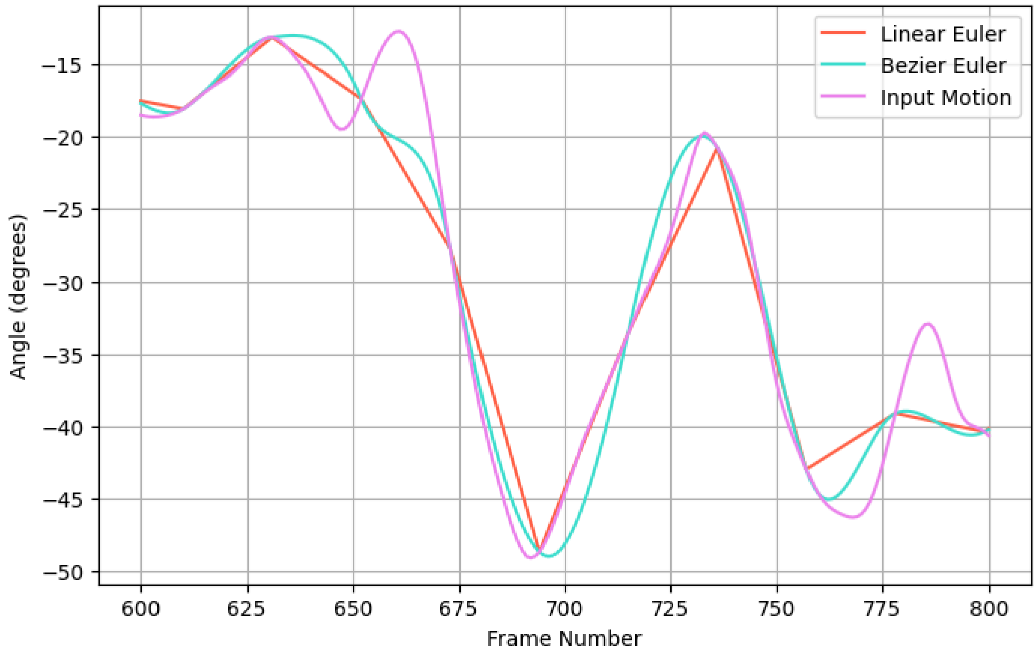


# Graph Analysis

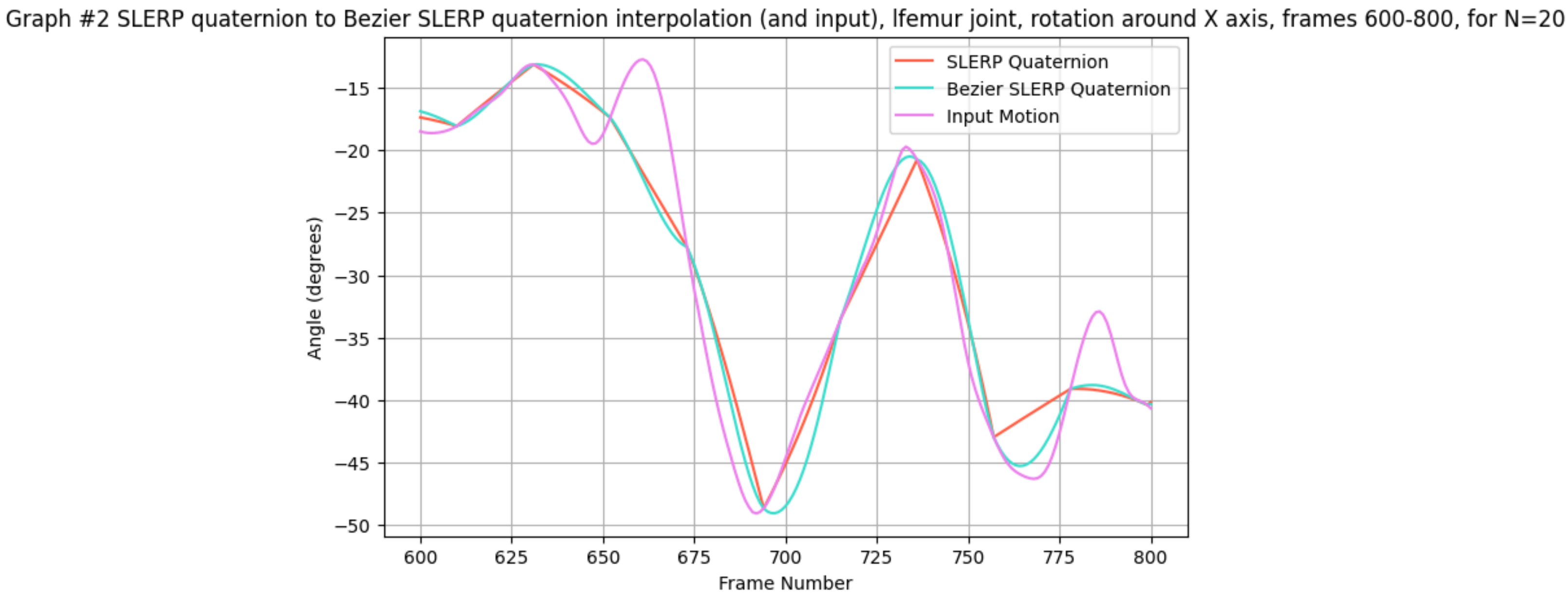
## Graph #1: Linear Euler vs. Bezier Euler (lfemur, X-axis, frames 600-800, N=20)

Graph #1 Linear Euler to Bezier Euler interpolation (and input) - lfemur joint, rotation around X axis, frames 600-800, for N=20,



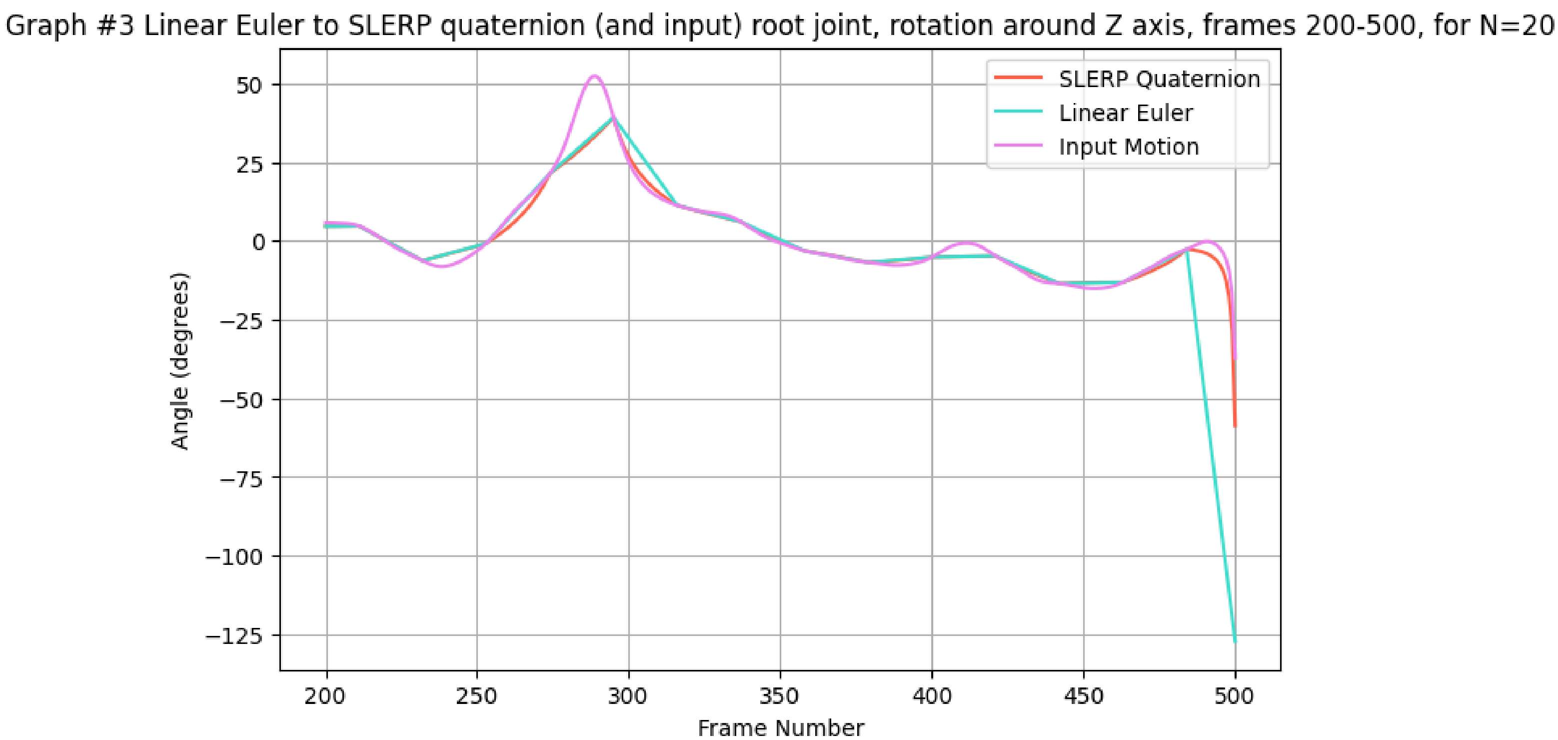

Here we see that Linear Euler (orange) has more abrupt changes in rotation in the interpolating frames while performing Bezier Euler interpolation is showcased with a more smooth curve. If we focus on the frames 650 to 670 we see that neither bezier euler nor linear euler have an increase in angle because they are interpolating between two keyframes that do not show any increase in the rotation angle.

## Graph #2: SLERP Quaternion vs. Bezier SLERP Quaternion (lfemur, X-axis, frames 600-800, N=20)




Here we see that SLERP Quaternion and Bezier SLERP Quaternion both give interpolation values that are fairly close or within a certain threshold but a key observation is that Bezier SLERP Quaternion produces a much smoother curve than SLERP Quaternion. We also see that the Bezier SLERP Quaternion curve is giving similar values that are closer to the Input Motion angles. This implies that Bezier SLERP Quaternion is the best interpolation method to produce the smoothest rotations closest to the actual expected motion.

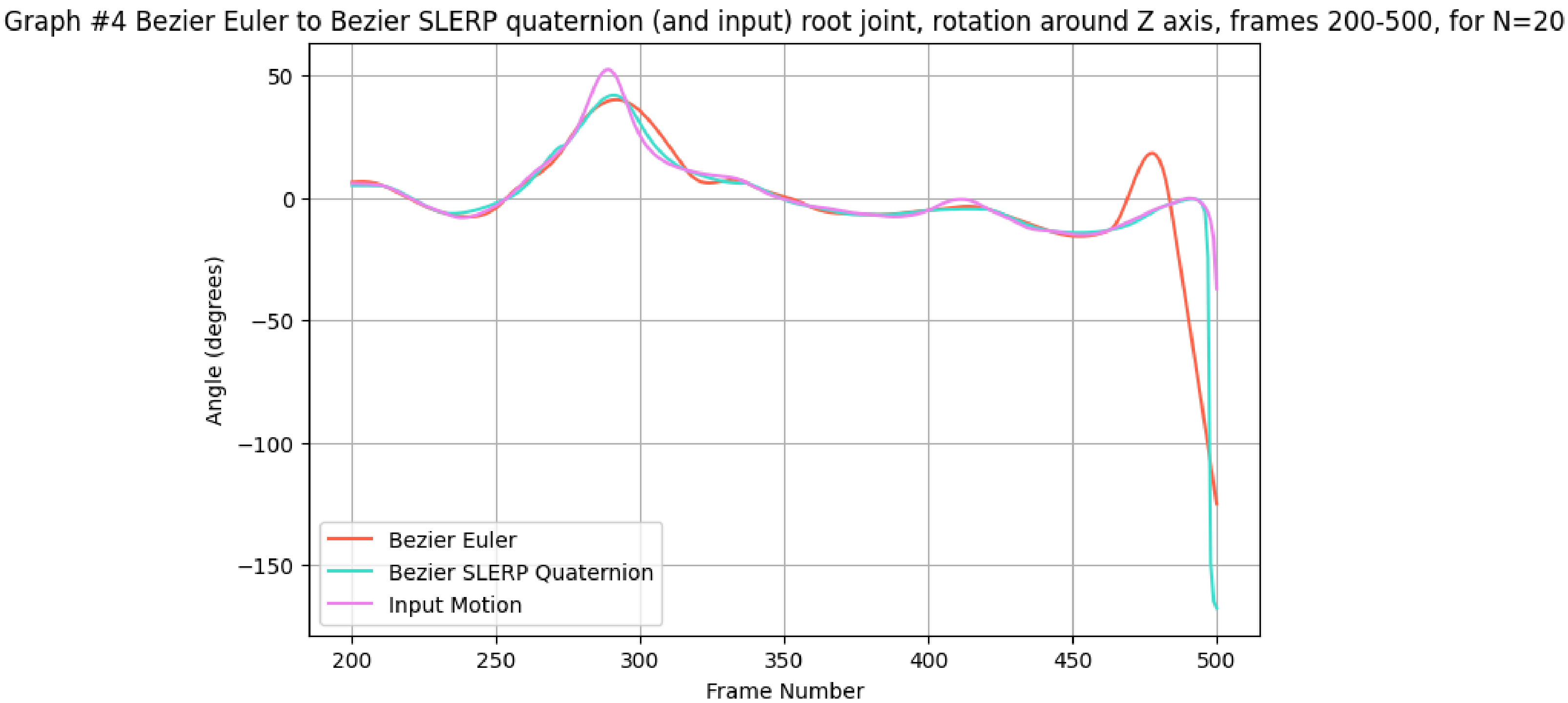
Graph #3: Linear Euler vs. SLERP Quaternion (root, Z-axis, frames 200-500, N=20)




Here we see the Z axis rotation of the root joint from Frame 200 - 500. I observe that the the Linear Euler Interpolation is the the most abrupt interpolation with sudden increase and decrease in the Z axis angle between frames - this also explains the abrupt rotations when the skeleton is moving.

SLERP Quaternion is a much smoother curve and even though it does not produce a result that is not exactly equal to the ground truth values (input motion), It is more promising in producing smooth fairly accurate interpolated rotated values.

Graph #4: Bezier Euler vs. Bezier SLERP Quaternion (root, Z-axis, frames 200-500, N=20)

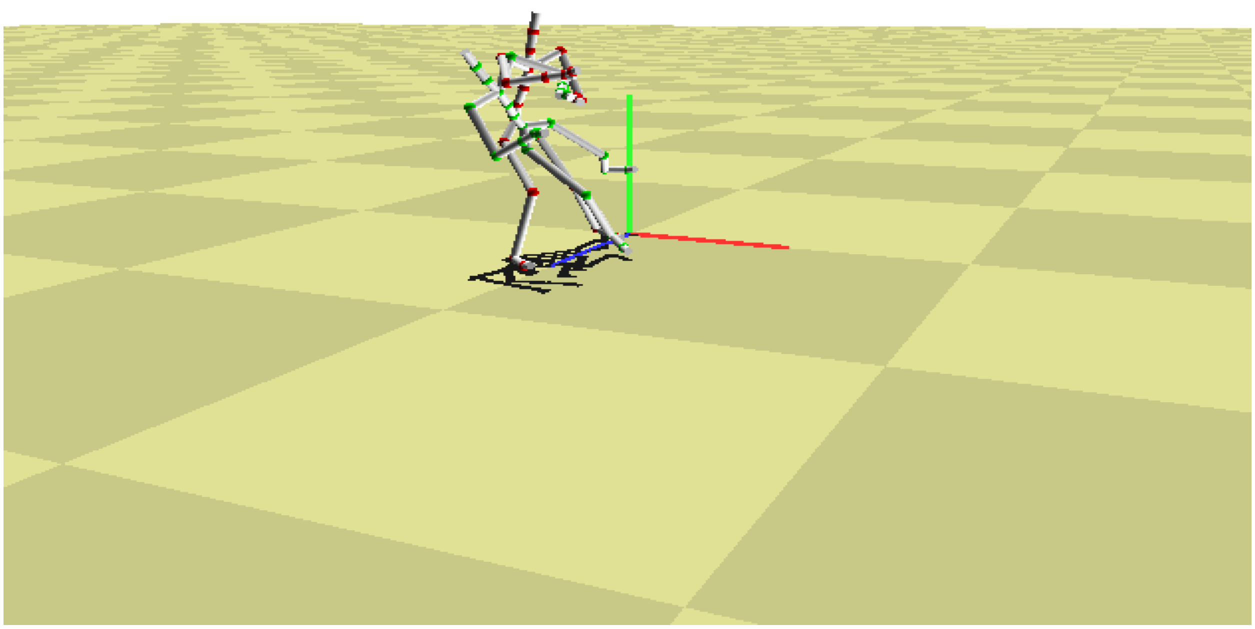



We see that Bezier SLERP Quaternion interpolation produces the value that are closest to the ground truth (violet). Bezier Euler - produces produces smooth interpolated rotations but still falls short between certain keyframes when being compared with Bezier SLERP Quaternion. This implies and shows that Bezier SLERP Quaterniona is the best interpolation technique against Linear Euler, Bezier Euler and SLERP Quaternion.

# Video Results

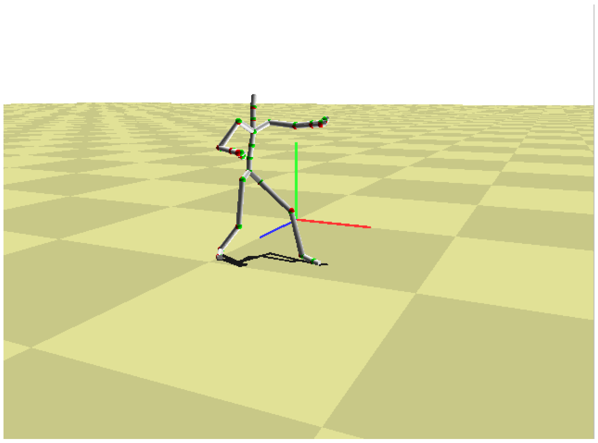
To visually analyze the effectiveness of different interpolation techniques, I generated three videos comparing the interpolated motion against the original motion using **N = 40** on the **135_06-martialArts.amc** dataset. Each video highlights the strengths and weaknesses of the respective interpolation methods.

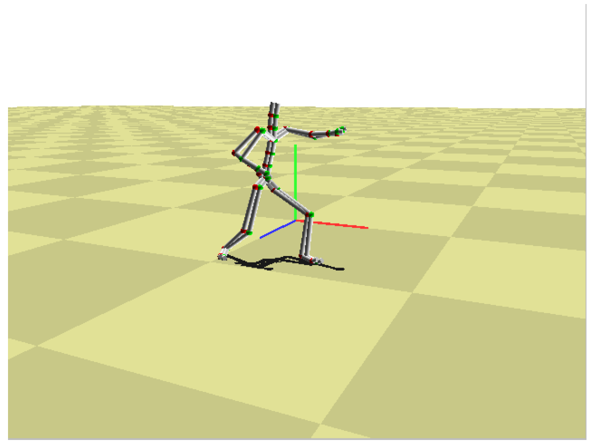
**Bezier Euler Interpolation** showed improvements over Linear Euler by introducing **smoother transitions** between keyframes using Bezier curves. However, because it still operates in **Euler space**, it remains susceptible to **gimbal lock**, which can cause rotational inconsistencies. In the video, Bezier Euler produces **less abrupt motion changes** than Linear Euler, but it struggles with **maintaining acceleration continuity**, leading to some **unnatural pauses or fluctuations** in motion.



In **SLERP Quaternion Interpolation**, the motion appears **smoother and more natural**, as quaternions eliminate **gimbal lock issues** and follow the shortest rotational path. However, because SLERP interpolates directly between keyframes, it does not inherently account for **changes in velocity**, leading to **some abrupt acceleration shifts** in fast-moving sequences.

**Bezier SLERP Quaternion Interpolation** produced the **smoothest and most visually natural** rotations. The use of **Bezier control points in quaternion space** helped maintain continuous acceleration changes. However, despite its smoothness, I noticed that **the interpolated frames were not perfectly aligned with the input motion**. This could be due to how the control points were computed, causing a slight **offset in rotation paths** compared to the original motion.





# Conclusion

This assignment explored different interpolation techniques for reconstructing missing motion capture frames, comparing **Linear Euler, Bezier Euler, SLERP Quaternion, and Bezier SLERP Quaternion**. Each method presented unique strengths and weaknesses, influencing how naturally motion was reconstructed.

**Euler-based methods** (Linear Euler and Bezier Euler) suffered from **gimbal lock** and unnatural transitions, with **Linear Euler performing the worst due to abrupt changes in rotation**. Bezier Euler improved smoothness by introducing **Bezier curves**, but it still lacked proper rotational continuity.

**Quaternion-based methods** (SLERP and Bezier SLERP) eliminated gimbal lock, producing **more natural and fluid motion**. SLERP ensured the shortest rotation path but did not account for **velocity consistency**, leading to sudden shifts in acceleration. Bezier SLERP introduced **Bezier control points in quaternion space**, producing the **smoothest rotations** and maintaining **better motion continuity**. However, **some interpolated frames were not perfectly aligned with the input motion**, suggesting potential limitations in how control points influence trajectory accuracy.

Overall, **Bezier SLERP Quaternion Interpolation provided the best results**, offering **smooth, natural motion** with fewer artifacts. However, careful tuning of control points may be needed to further refine alignment with the input motion. This study reinforced the advantages of **quaternion-based interpolation over Euler-based methods**, particularly for handling complex rotations in animation and motion capture.