

Rotation-Minimizing Space Deformations for the Analysis of Lagrangian Vortex Corelines

Julio Rey Ramirez, Xingdi Zhang, Markus Hadwiger, Peter Rautek

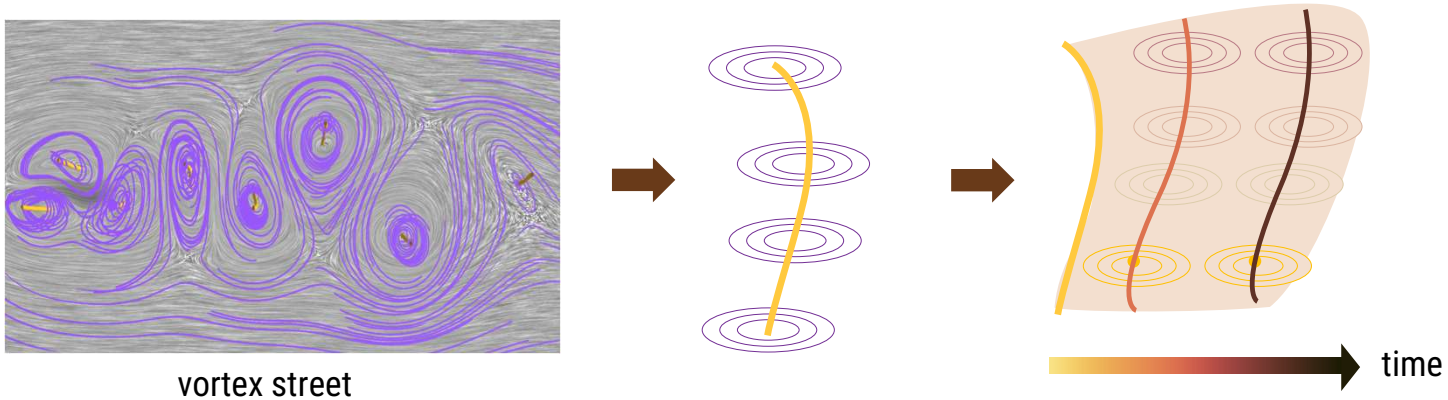
جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology



Vortex Cores and Reference Frames

In reference frame following a vortex, streamlines should be circles/spirals

- Single reference frame cannot follow 3D vortex or multiple 2D/3D vortices
- Pathlines more representative for unsteady flow than streamlines



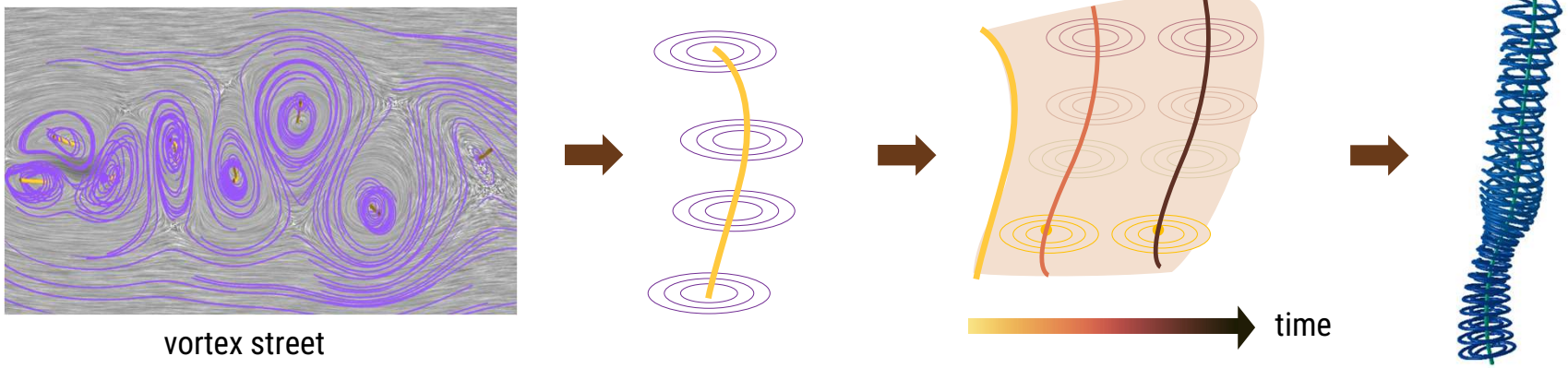
vortex street

Vortex Cores and Reference Frames

In reference frame following a vortex, streamlines should be circles/spirals

- Single reference frame cannot follow 3D vortex or multiple 2D/3D vortices
- Pathlines more representative for unsteady flow than streamlines

Instead of visualizing streamlines,
visualize pathlines transformed into reference timestep



vortex street

Vortex Cores in 3D Flow

Coreline tracks center of vortex

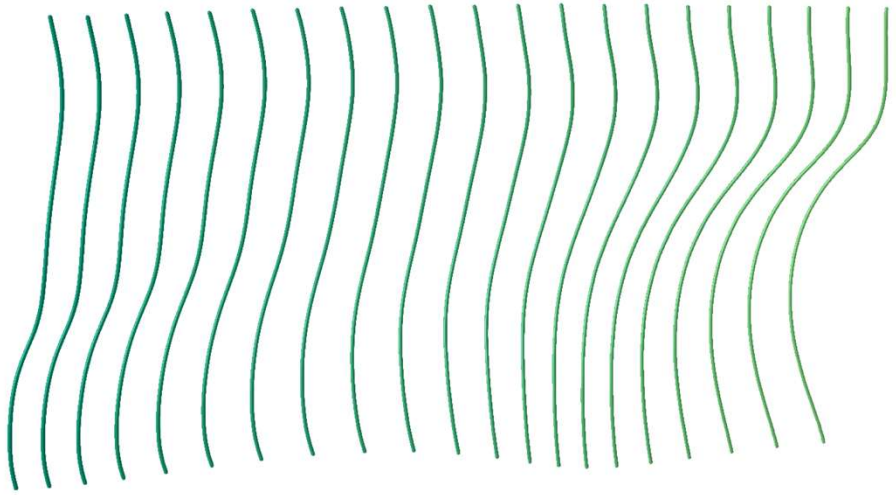


Vortex Cores in 3D Flow

Coreline tracks center of vortex

Lagrangian coreline is material curve

- Spacetime surface defined by flow map



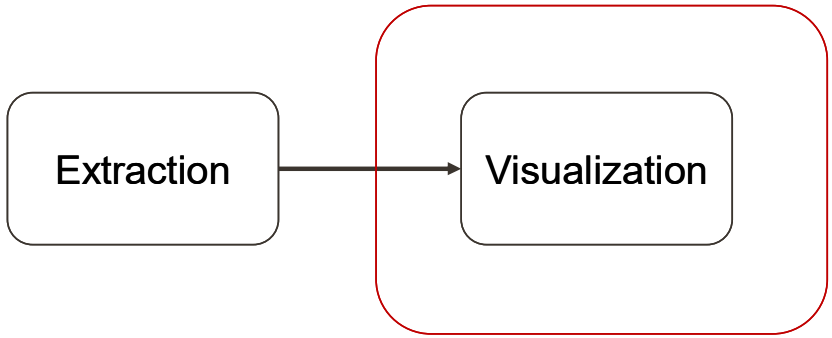
Vortex Cores in 3D Flow

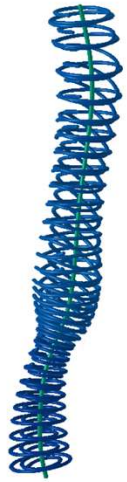
Coreline tracks center of vortex

Lagrangian coreline is material curve

- Spacetime surface defined by flow map

Coreline extracted before,
our focus is **visualization**



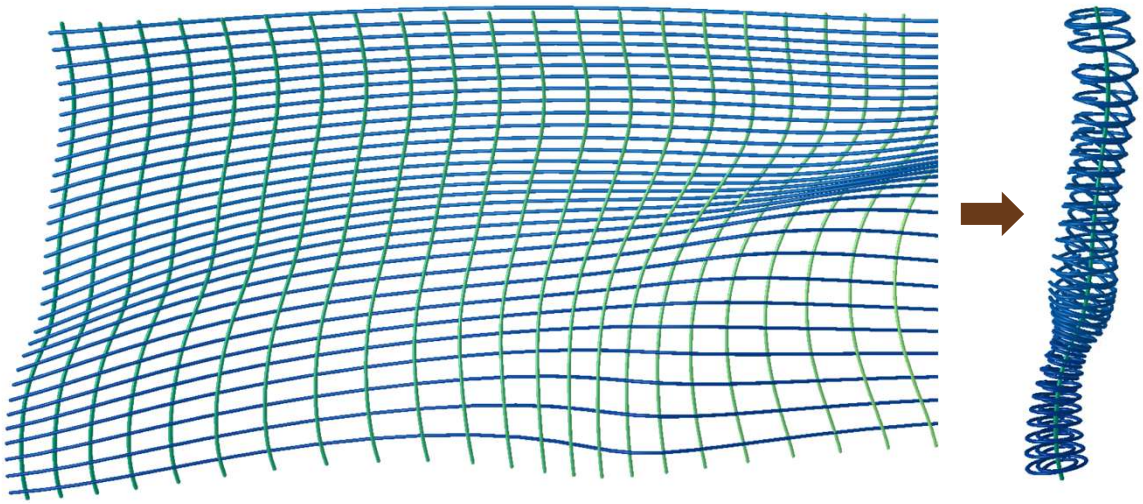


Motivation

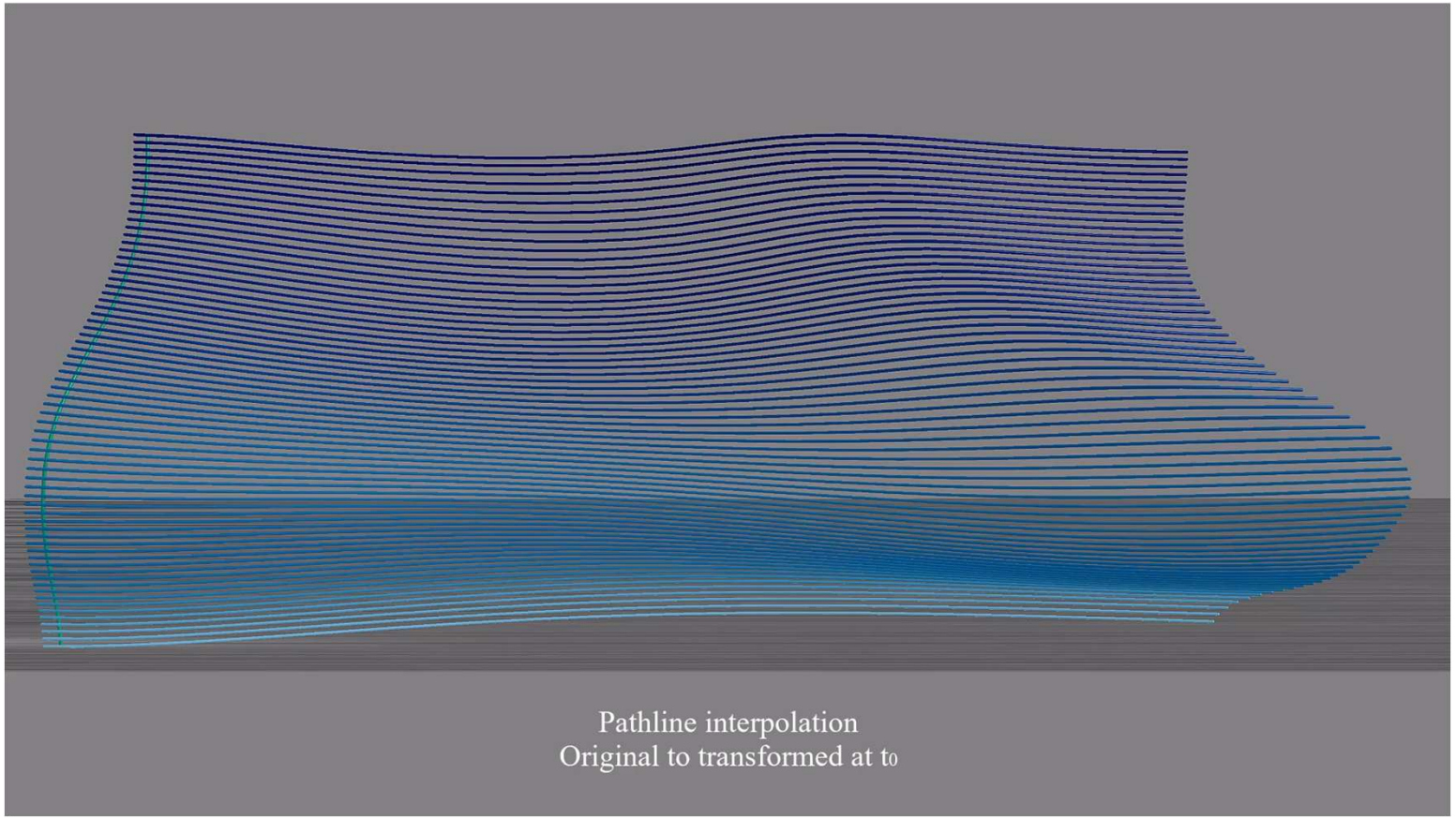
Streamlines: snapshot in time, depends on observer

Pathlines in lab frame: rotation hidden by bulk flow

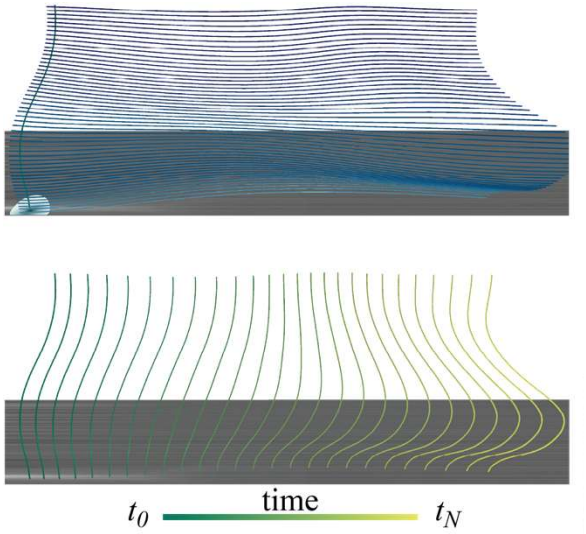
Can we isolate the rotation of pathlines near corelines?



Transform Pathlines into Reference Time

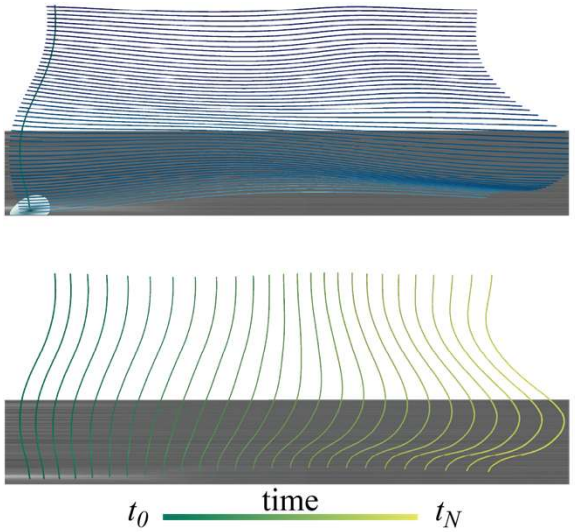


Pipeline

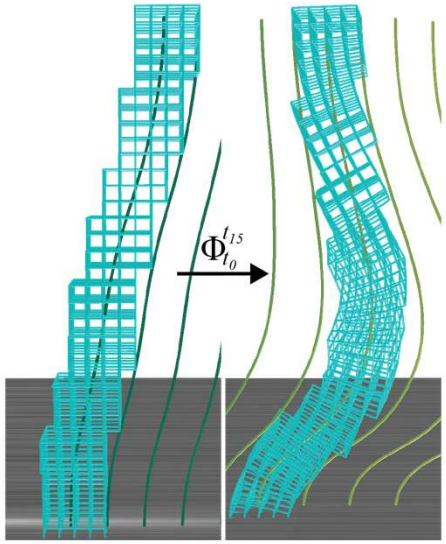


advect vortex coreline

Pipeline

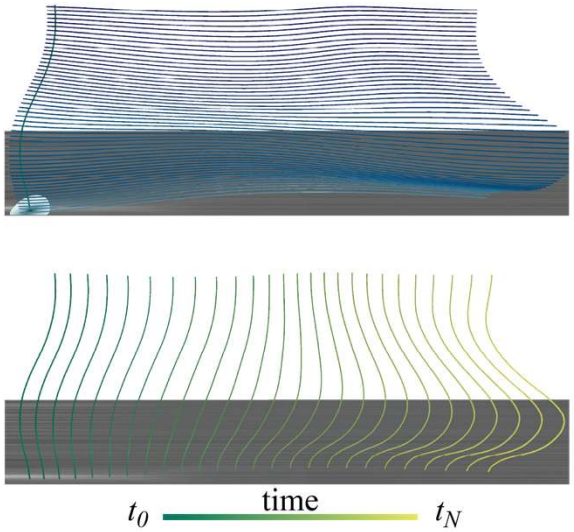


advect vortex coreline

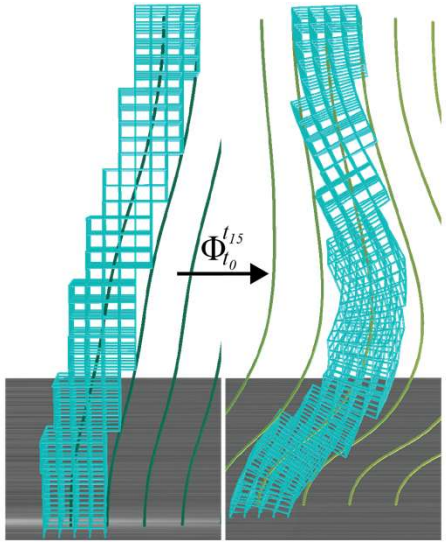


compute transformation

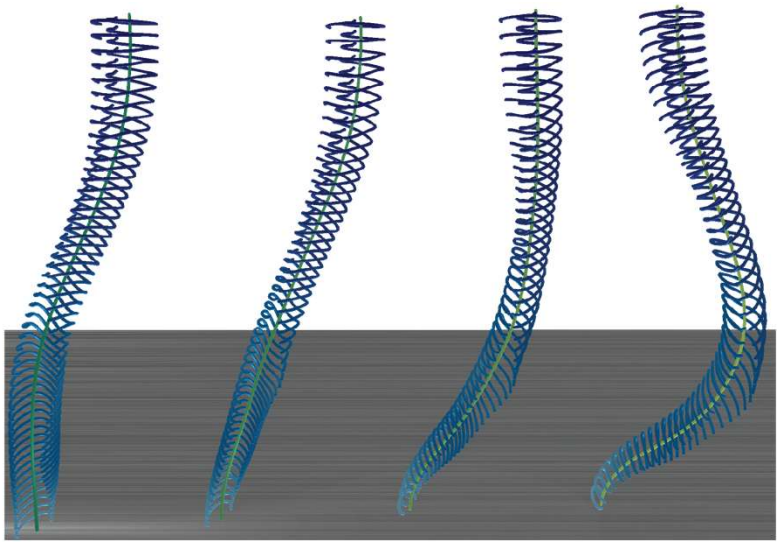
Pipeline



advect vortex coreline

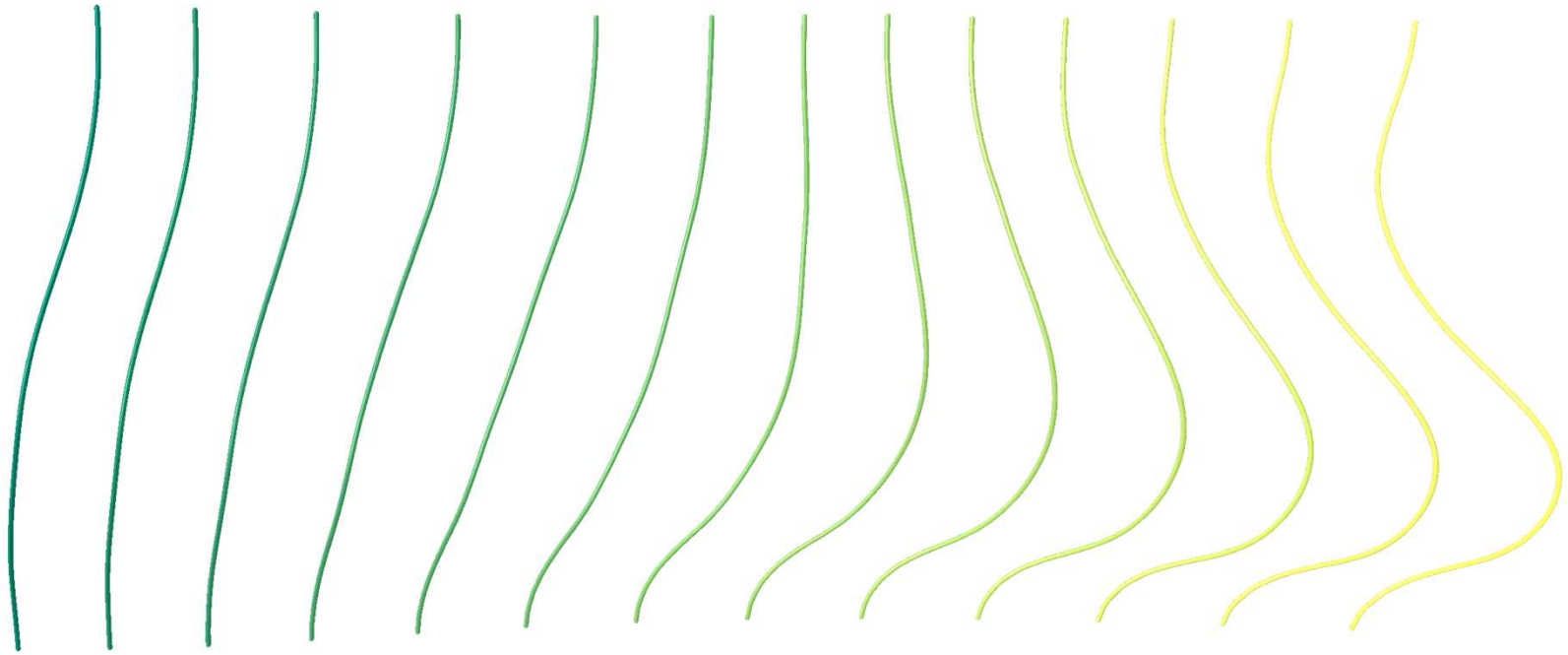


compute transformation

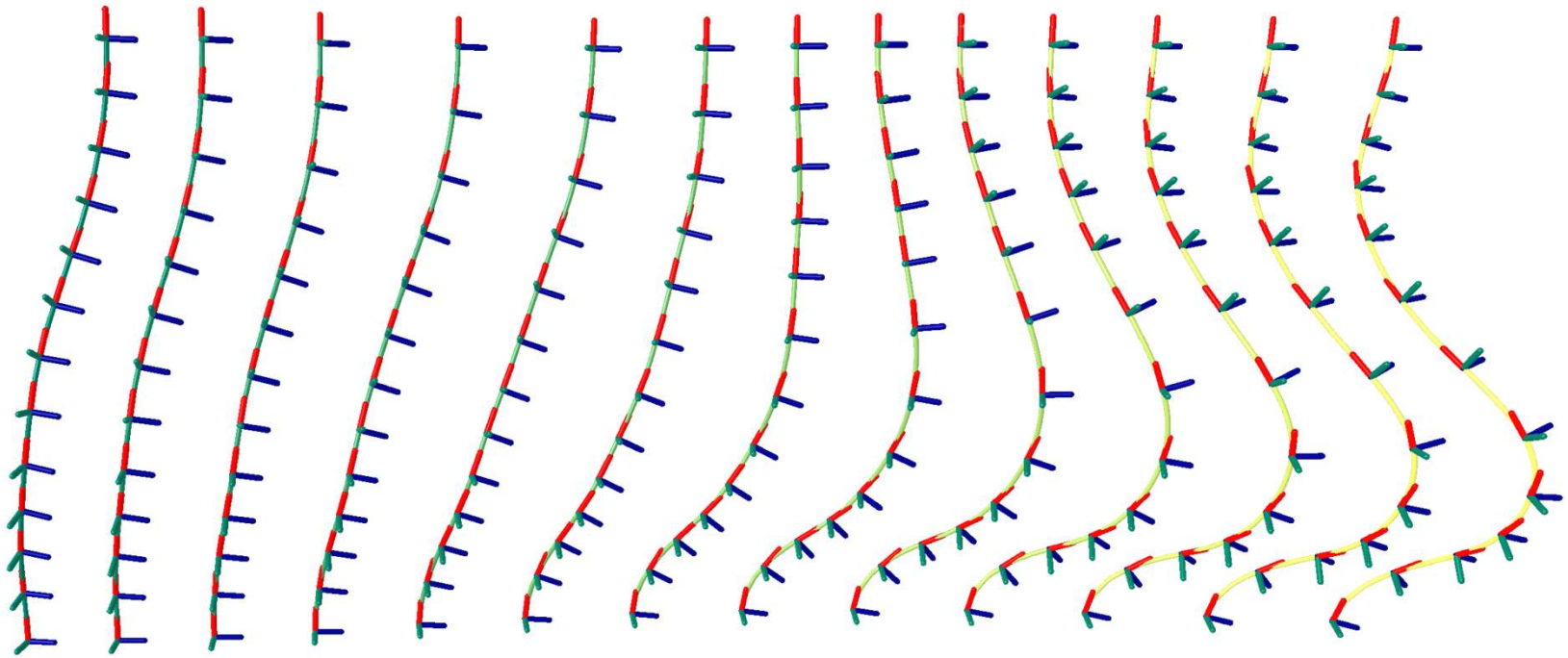


compute transformed pathlines

Moving Frame on Coreline



Moving Frame on Coreline



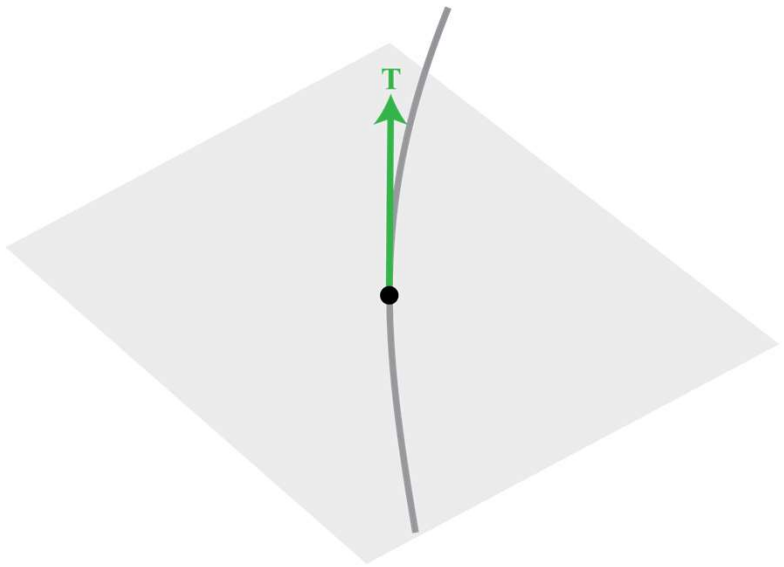
Rotation-Minimizing Moving Frame



t_0

reference time

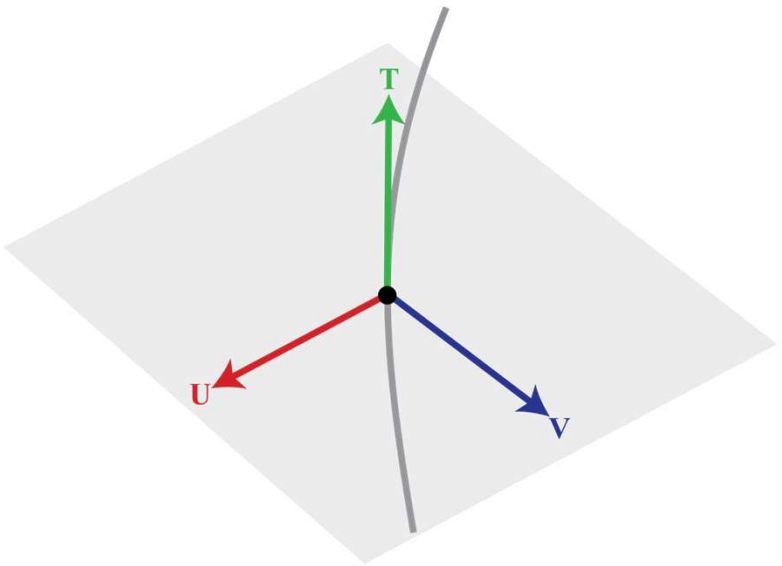
Rotation-Minimizing Moving Frame



t_0

reference time

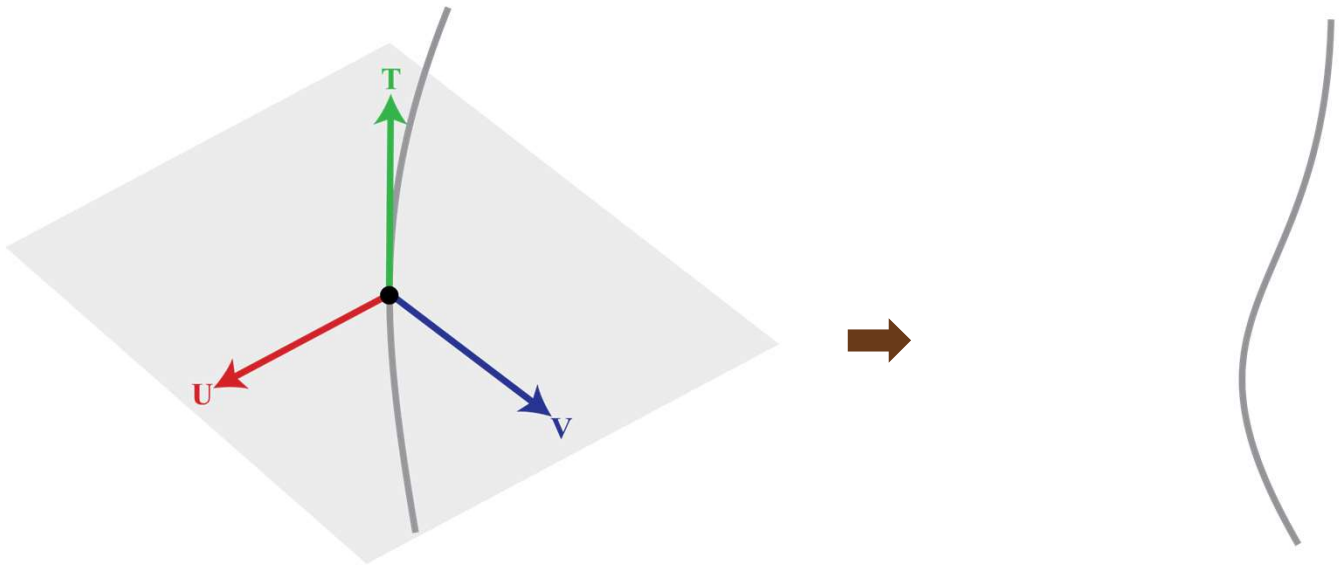
Rotation-Minimizing Moving Frame



t_0

reference time

Rotation-Minimizing Moving Frame

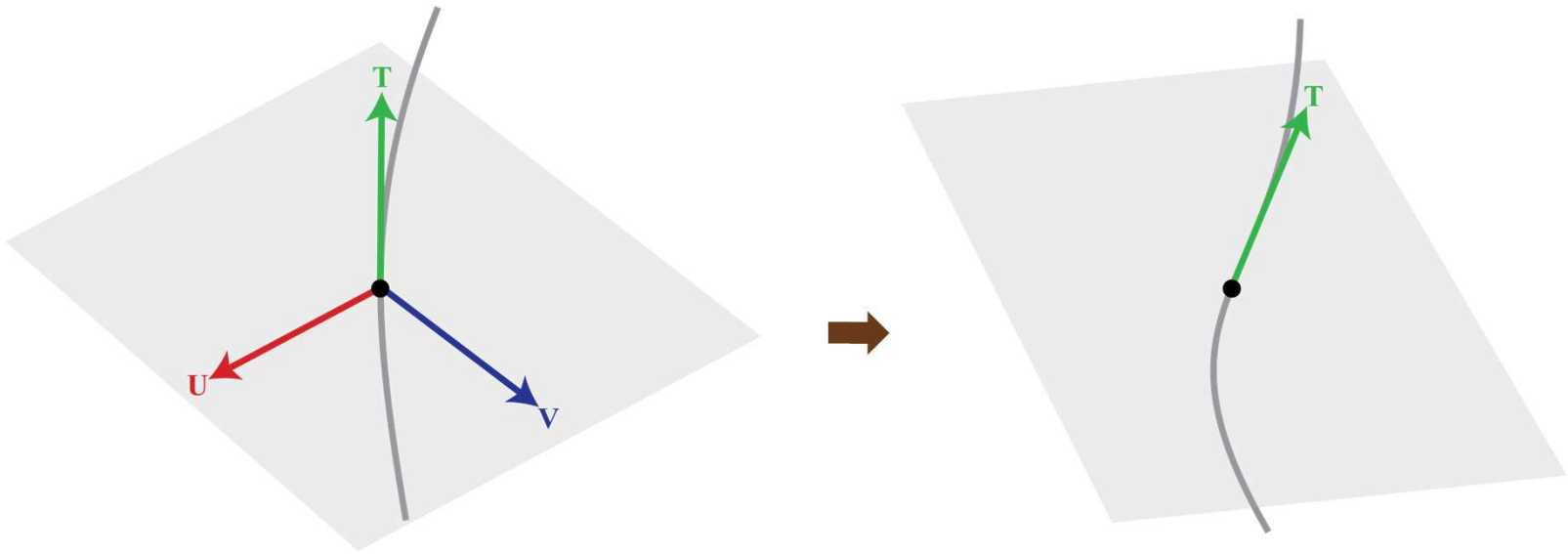


t_0

reference time

t_1

Rotation-Minimizing Moving Frame

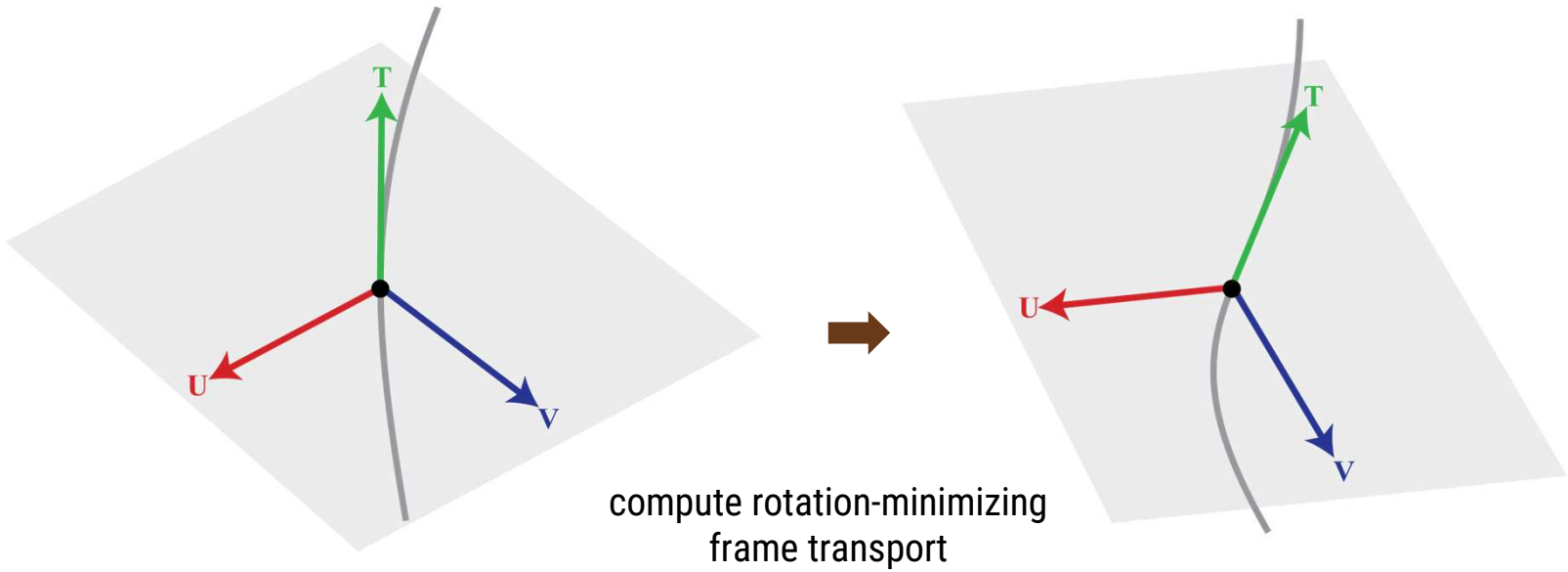


t_0

reference time

t_1

Rotation-Minimizing Moving Frame

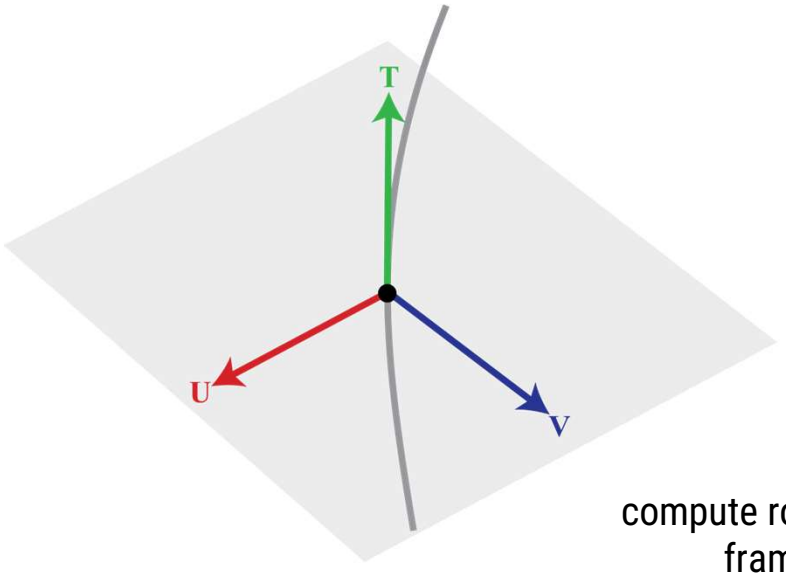


t_0

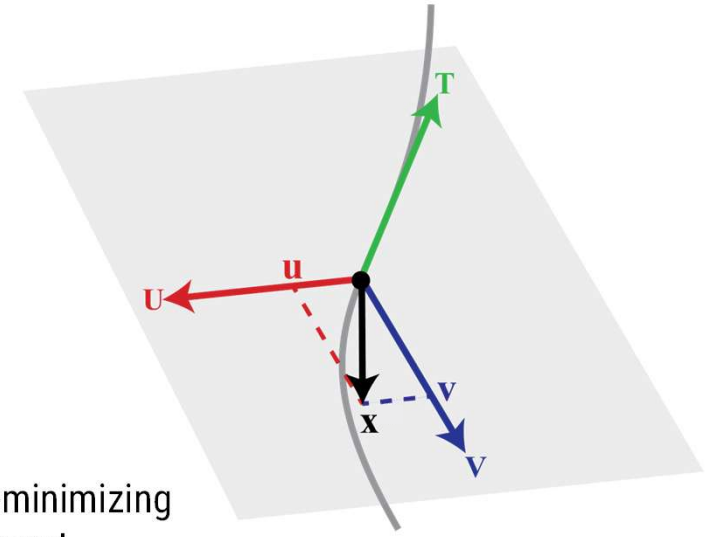
reference time

t_1

Rotation-Minimizing Moving Frame



compute rotation-minimizing
frame transport

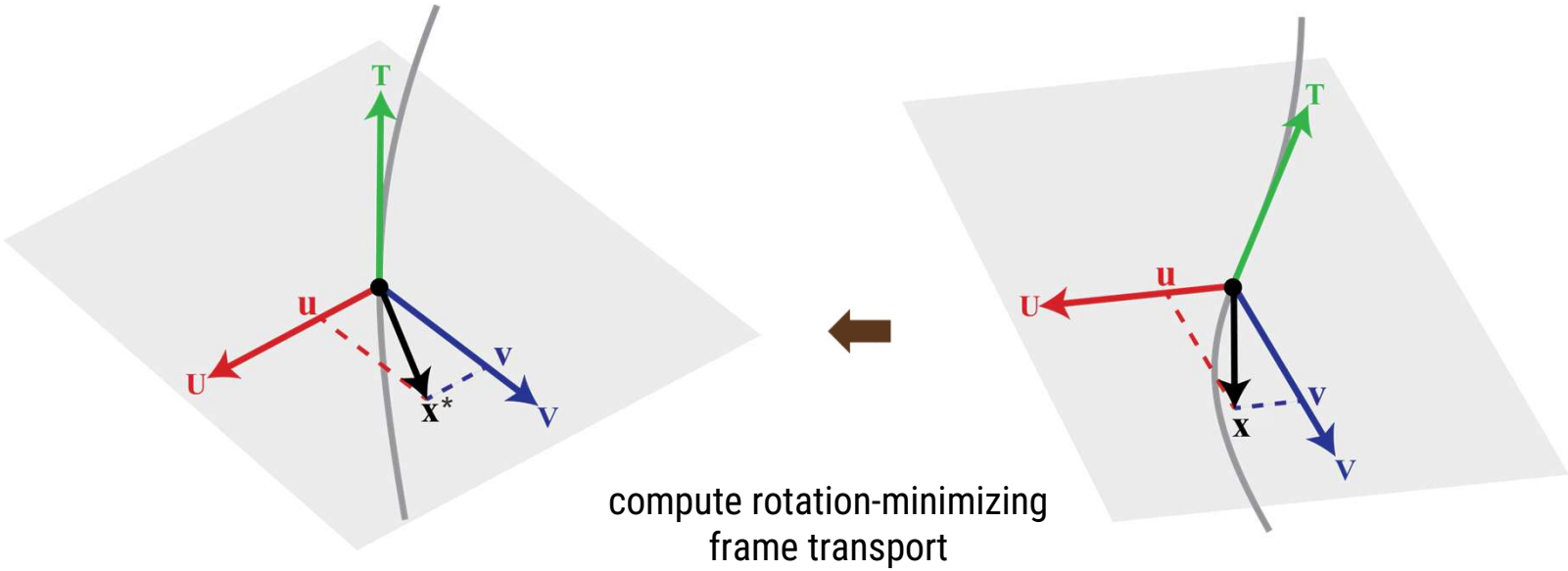


t_0

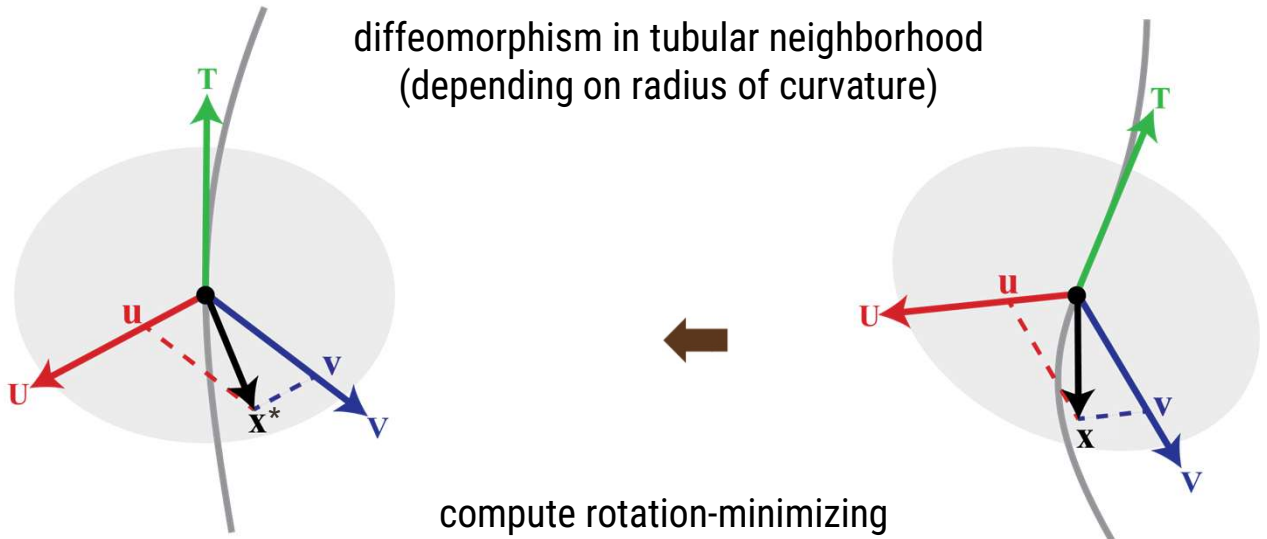
reference time

t_1

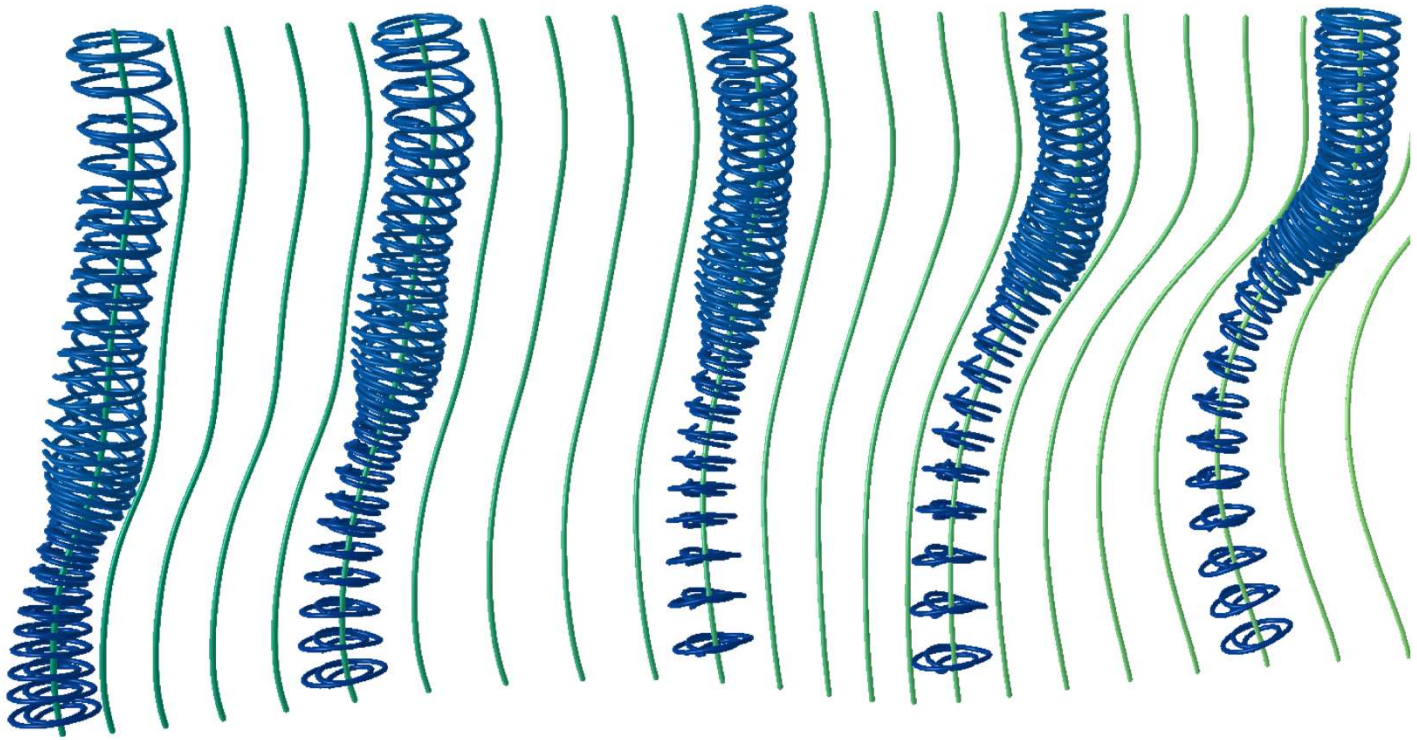
Rotation-Minimizing Moving Frame



Rotation-Minimizing Moving Frame

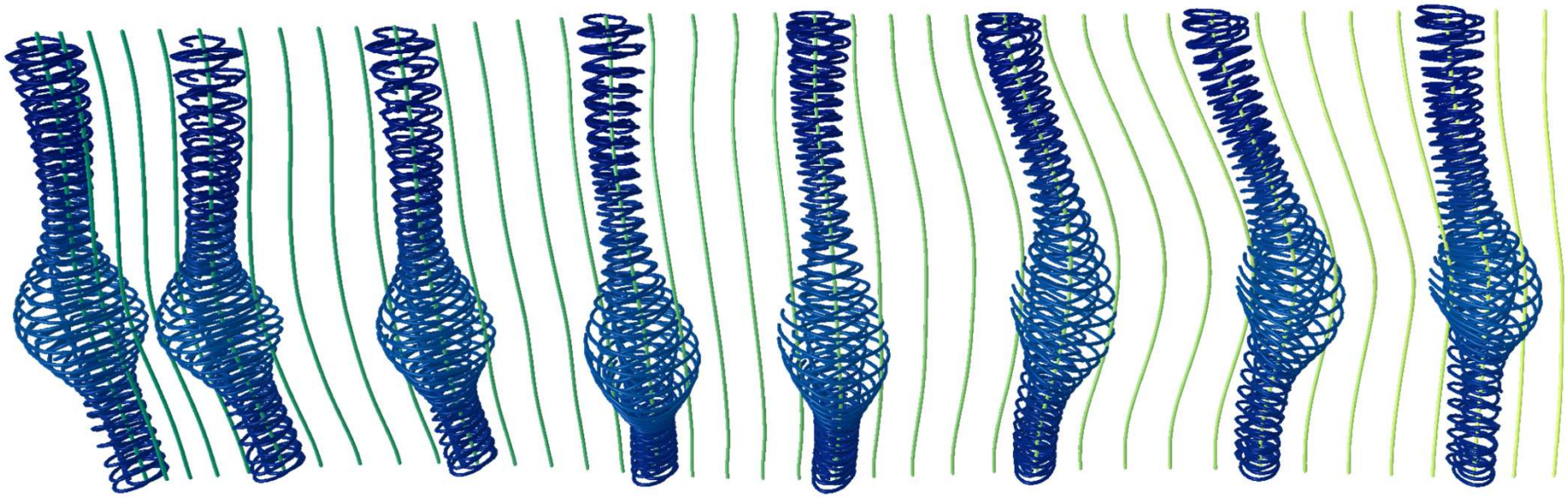


Example 1



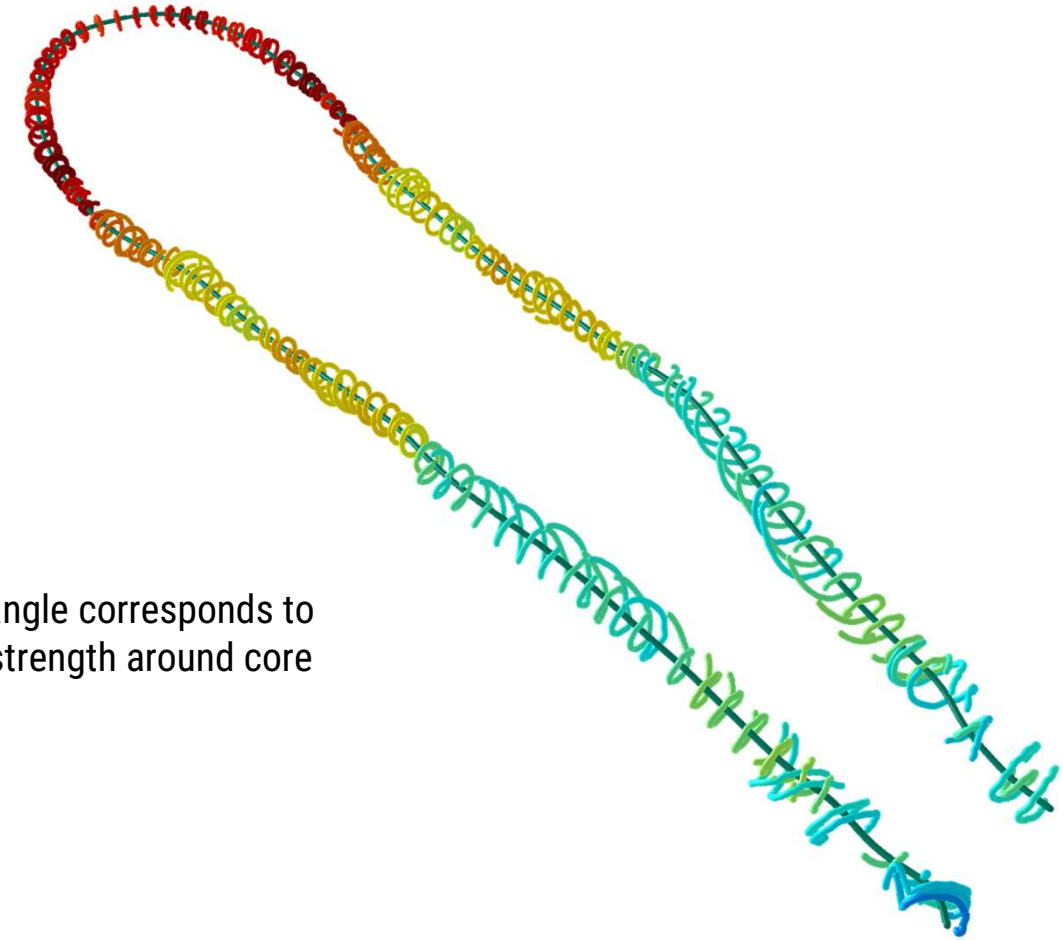
particles move along core

Example 2



particles rotate away from core

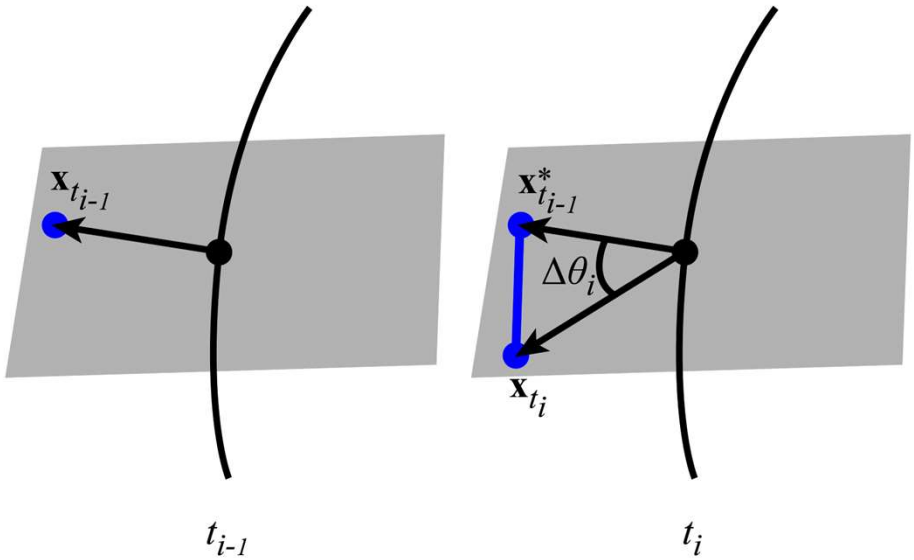
Example 3





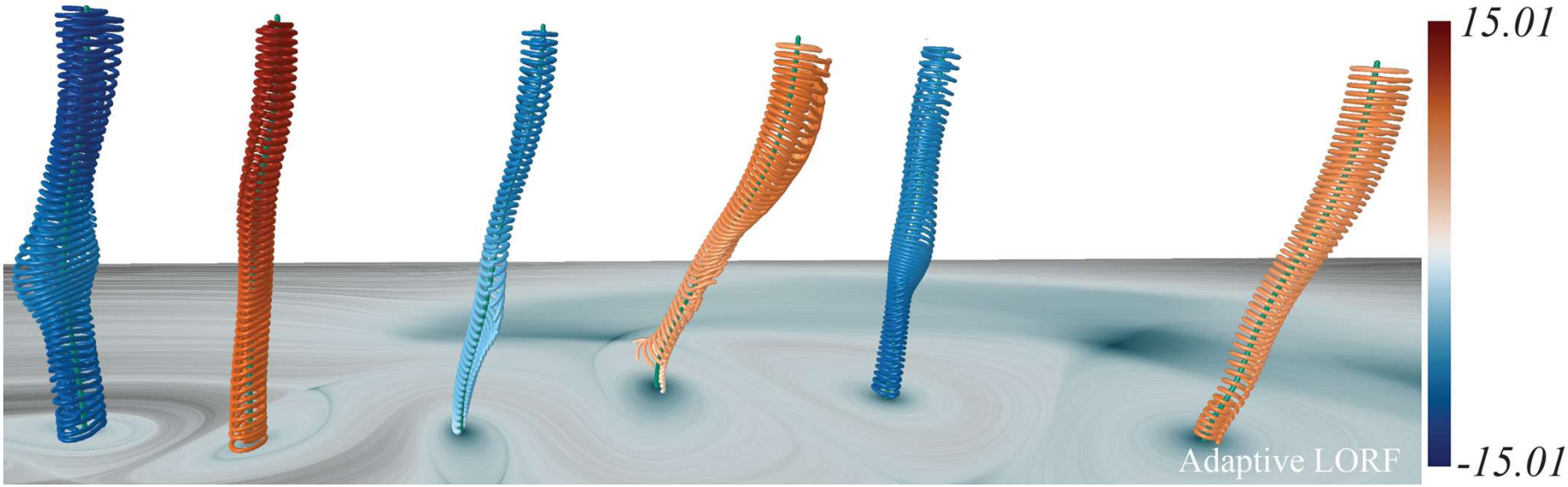
winding angle corresponds to
rotation strength around core

Transformed Pathlines and Winding Angle



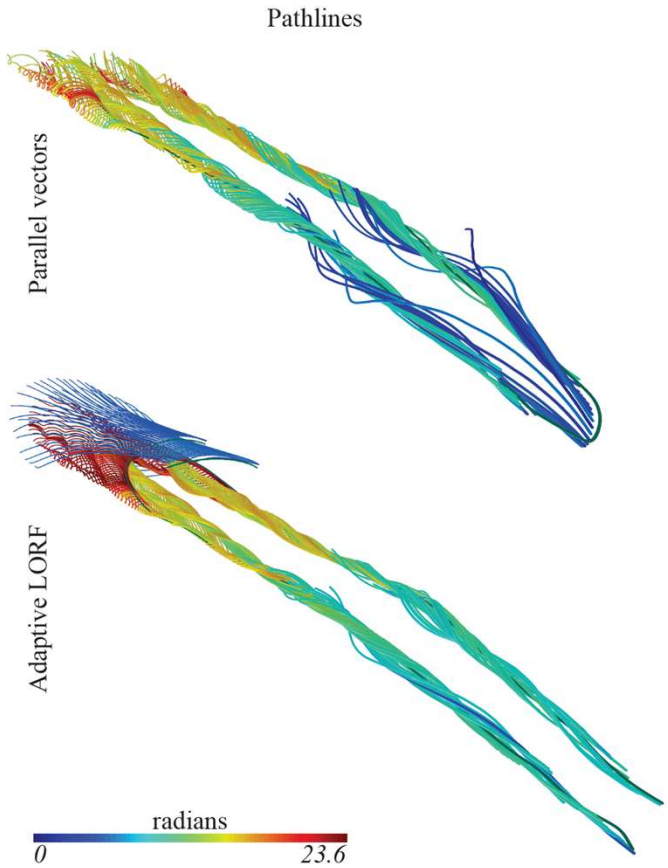
compute winding angle of pathline around
core line in (any) reference time

Vortex Street

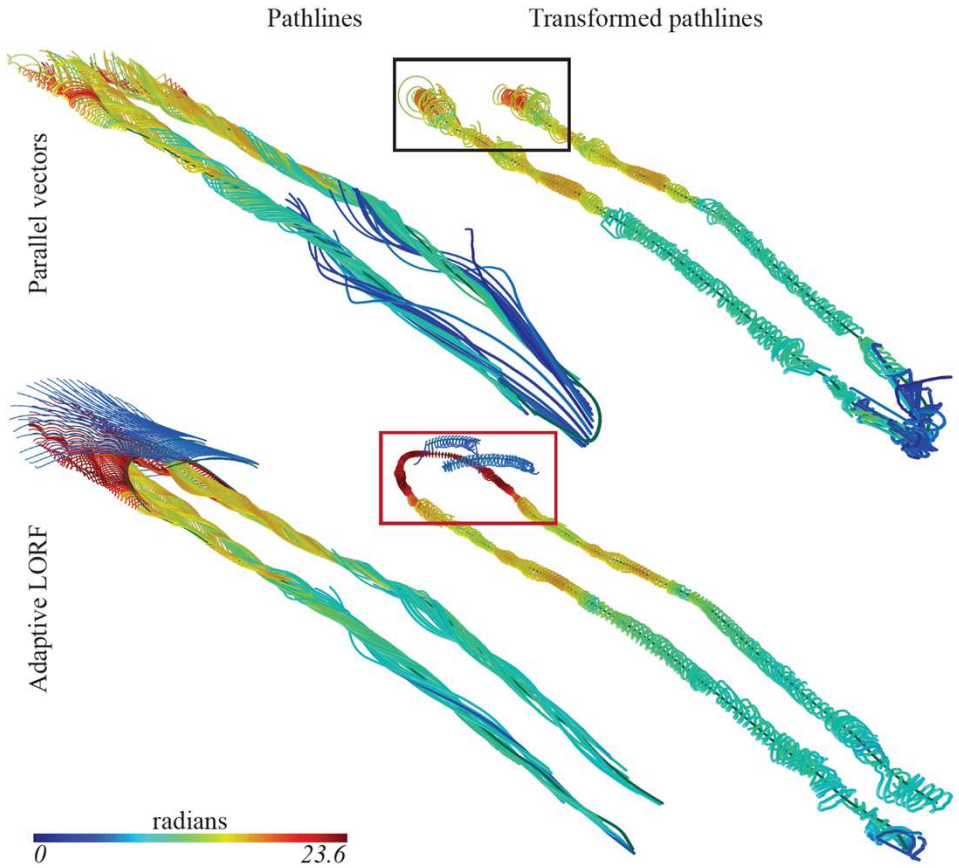


Locally optimal reference frames (LORF) [Günther et al. 2017]
Adaptive LORF [Rey Ramirez et al. 2025]

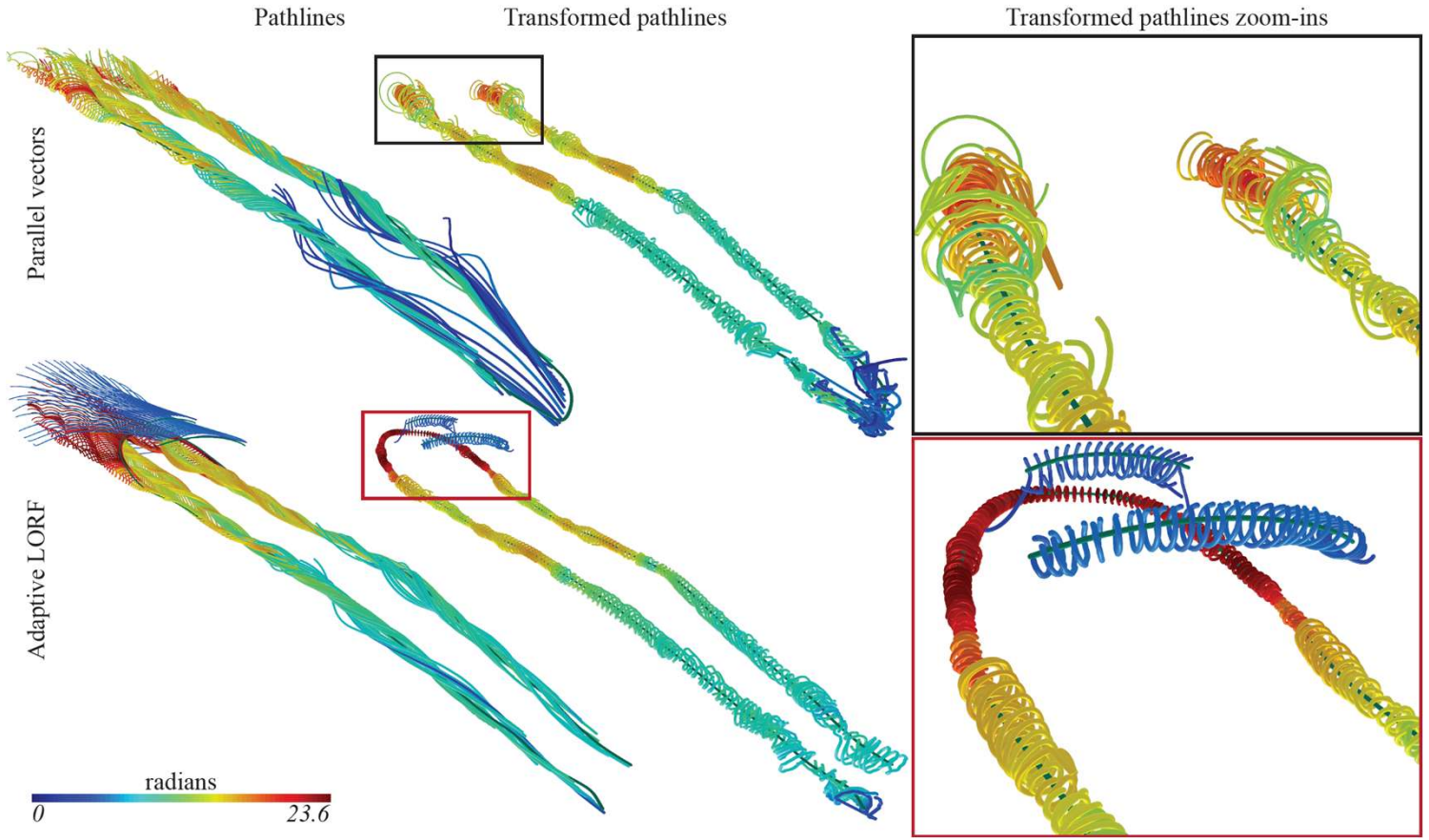
Comparing Coreline Extraction Methods



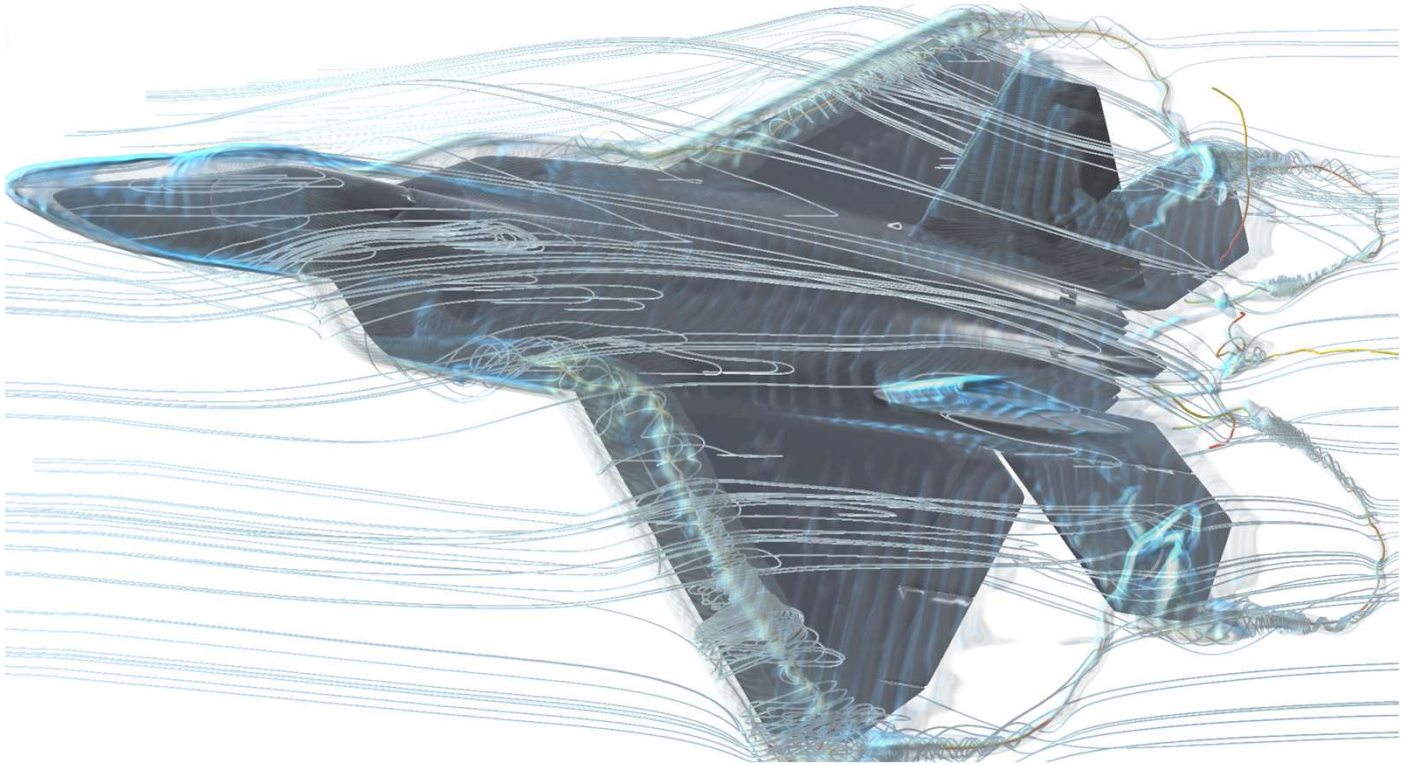
Comparing Coreline Extraction Methods



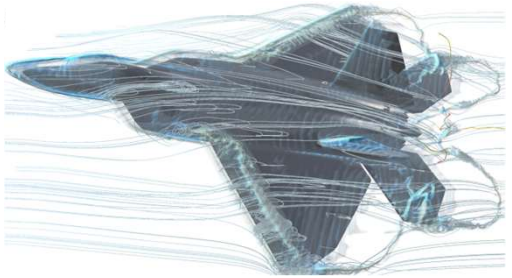
Comparing Coreline Extraction Methods

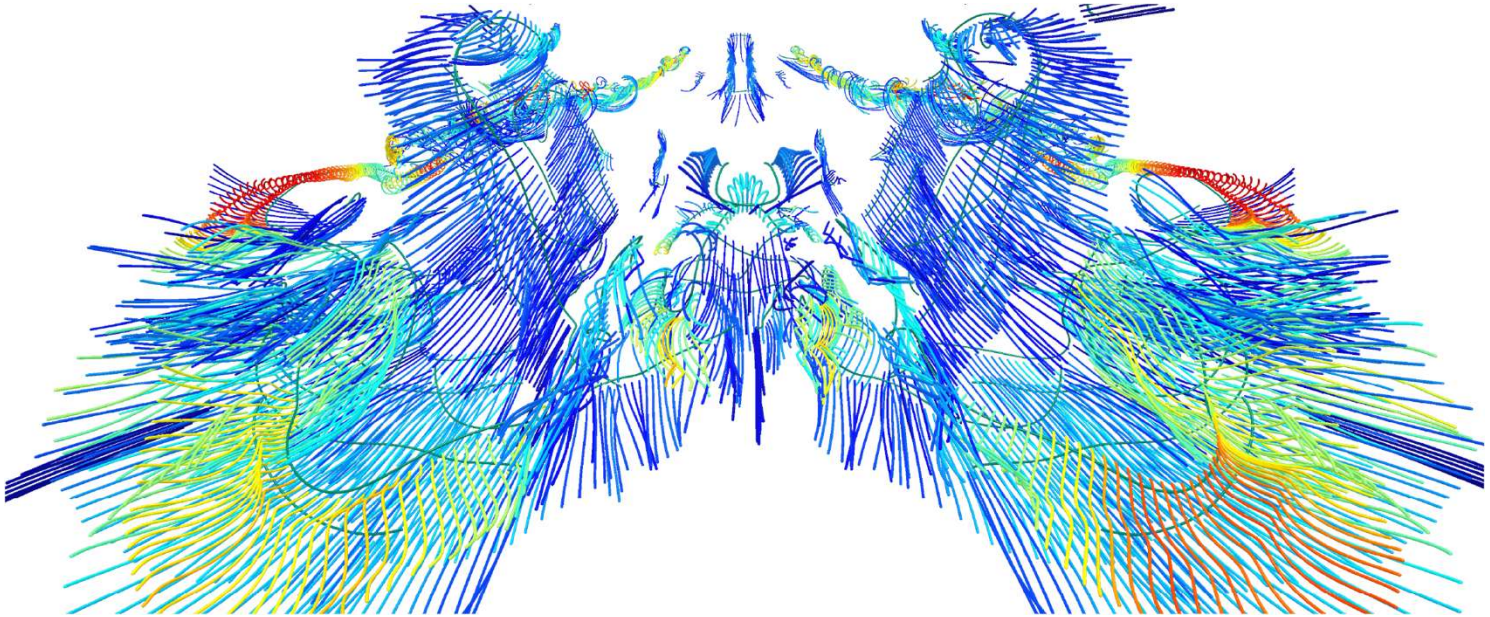


Raptor

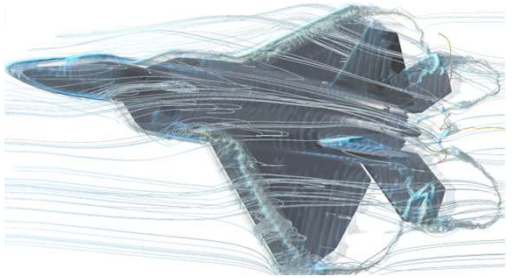


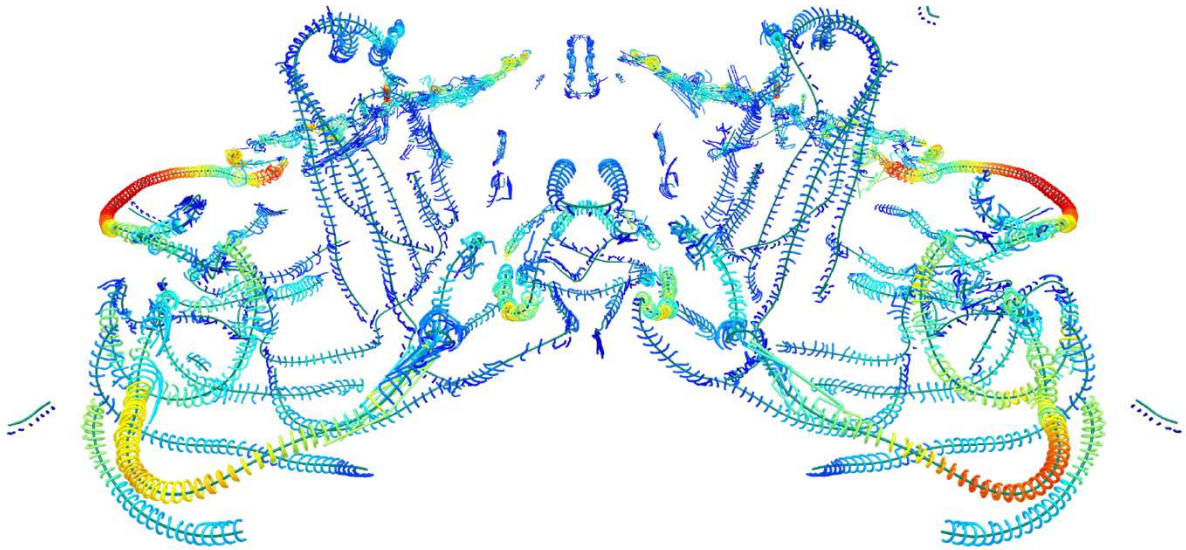
Raptor





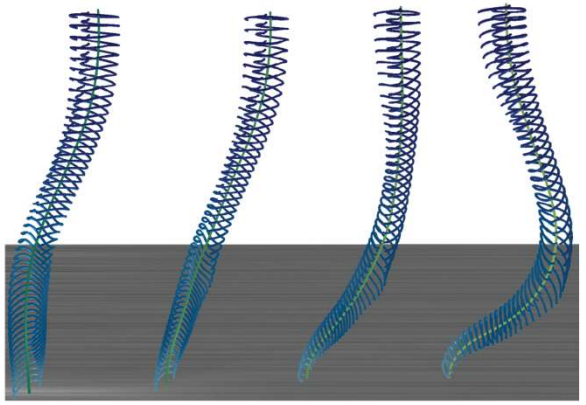
Raptor







Conclusions



Visualization of flow around 3D vortex corelines

- Pathlines transformed into one time step, instead of instantaneous streamlines
- Fast & simple: Transformation only requires frame field on coreline, not full deformation field

Basis for further analysis and comparison of vortex corelines

- Quantitative measures such as winding angle
- Compare corelines determined by different methods

Thank You!

Questions? julio.reyramirez@kaust.edu.sa

High-Performance Visualization @ KAUST

