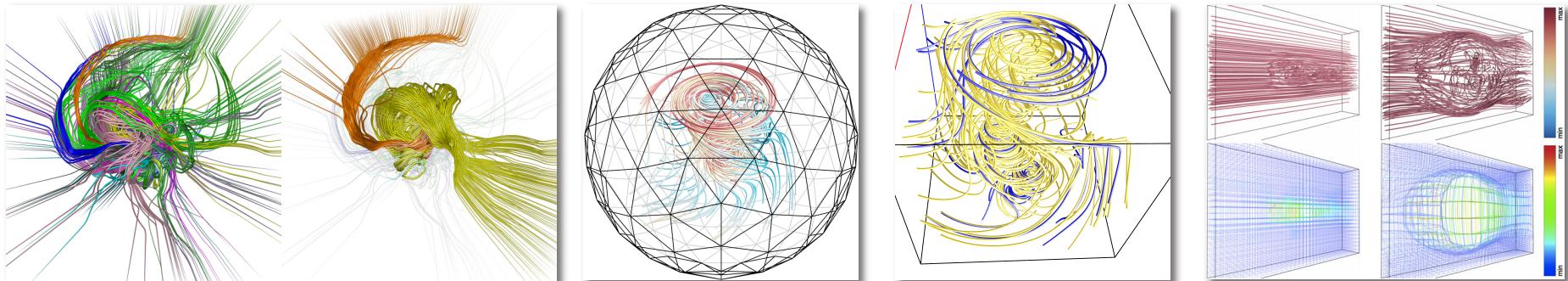


IEEE VIS 2013 Tutorial
State-of-the-Art Flow Field Analysis and Visualization
Atlanta, GA, 13 Oct 2013

Streamlines in 3D: Techniques beyond seed placement

Chaoli Wang
Michigan Technological University

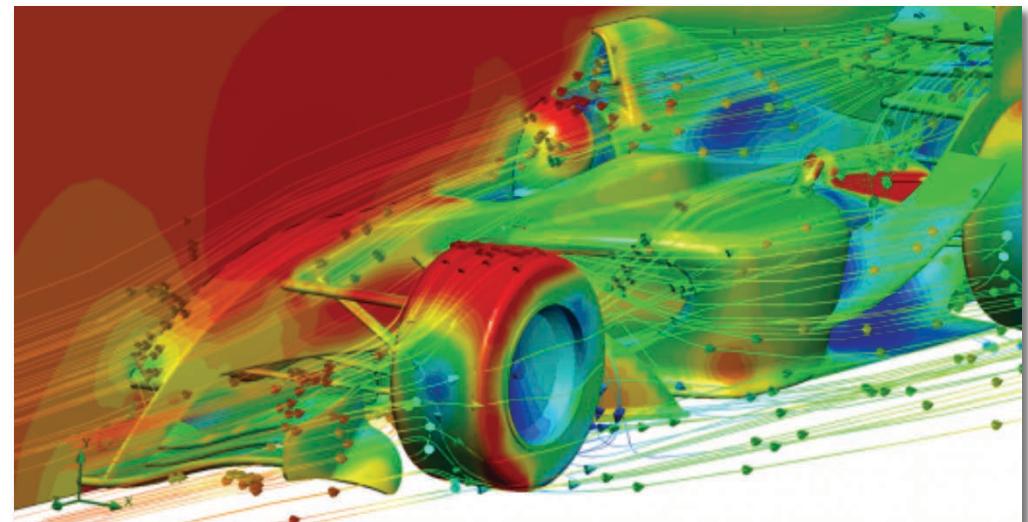
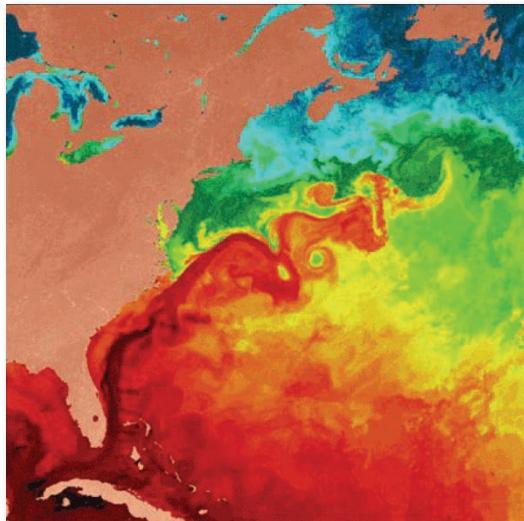


Outline

- Introduction and motivation
- Streamline placement
 - Seed placement in 3D
 - Remaining issues and challenges
- Alternative techniques
 - Hierarchical streamline bundling
 - View-independent streamline selection
 - View-dependent streamline selection
 - Streamline repositioning
- Summary

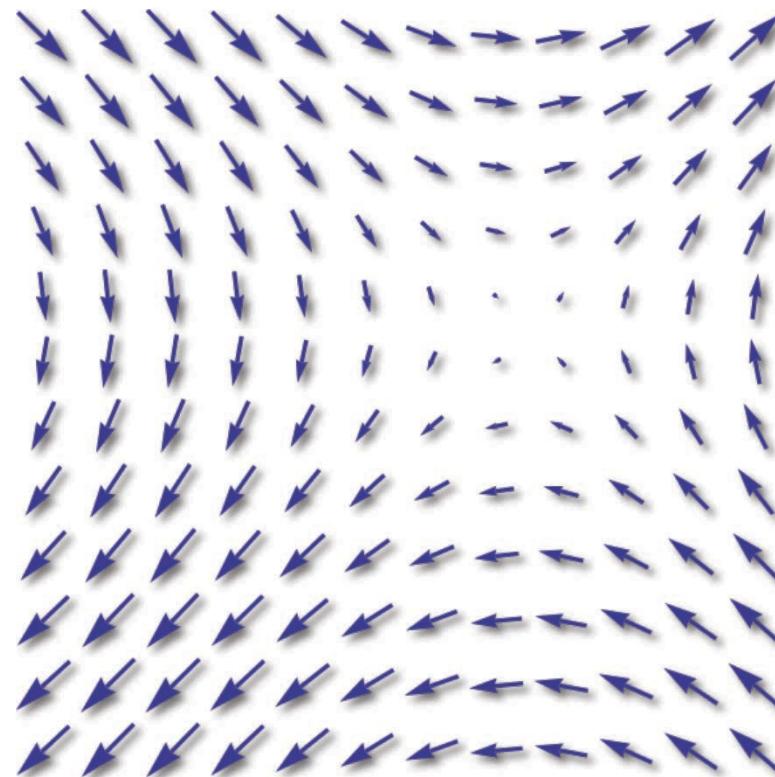
Introduction and motivation

Flow fields



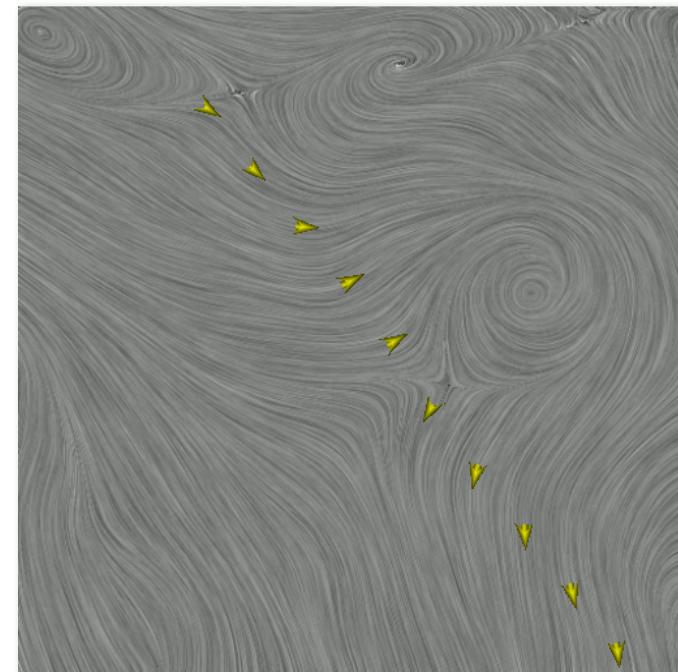
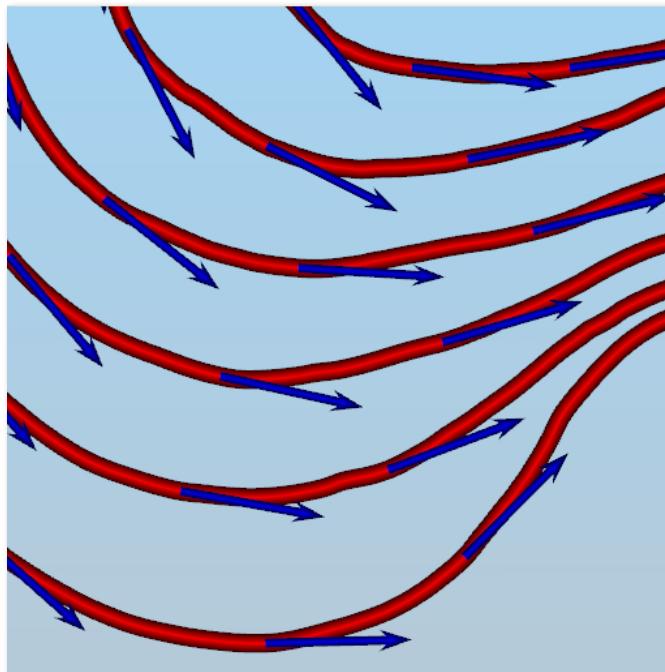
Flow (vector) field

- A vector field: $F(U) = V$
 - U : field domain (x, y) in 2D; (x, y, z) in 3D
 - V : vector (u, v) in 2D; (u, v, w) in 3D
- Like scalar fields, vectors are defined at discrete points



Streamlines and pathlines

- Streamline
 - A curve tangent to a flow field everywhere
 - The path of a particle in a steady flow field
- Pathline
 - The trajectory of a particle in an unsteady flow field

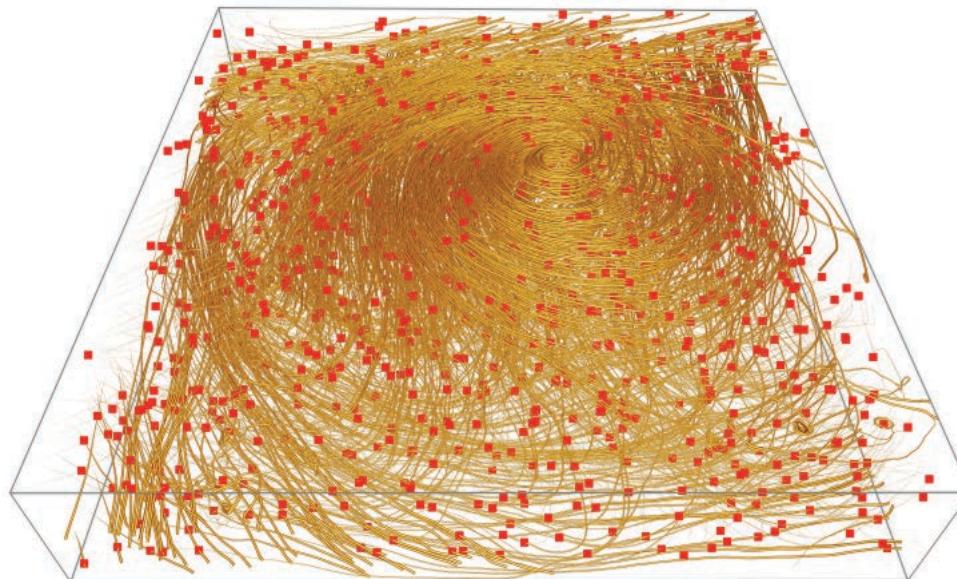


FlowVisual download: <http://www.cs.mtu.edu/~chaoliw/2dflowvis.html>

Seed placement

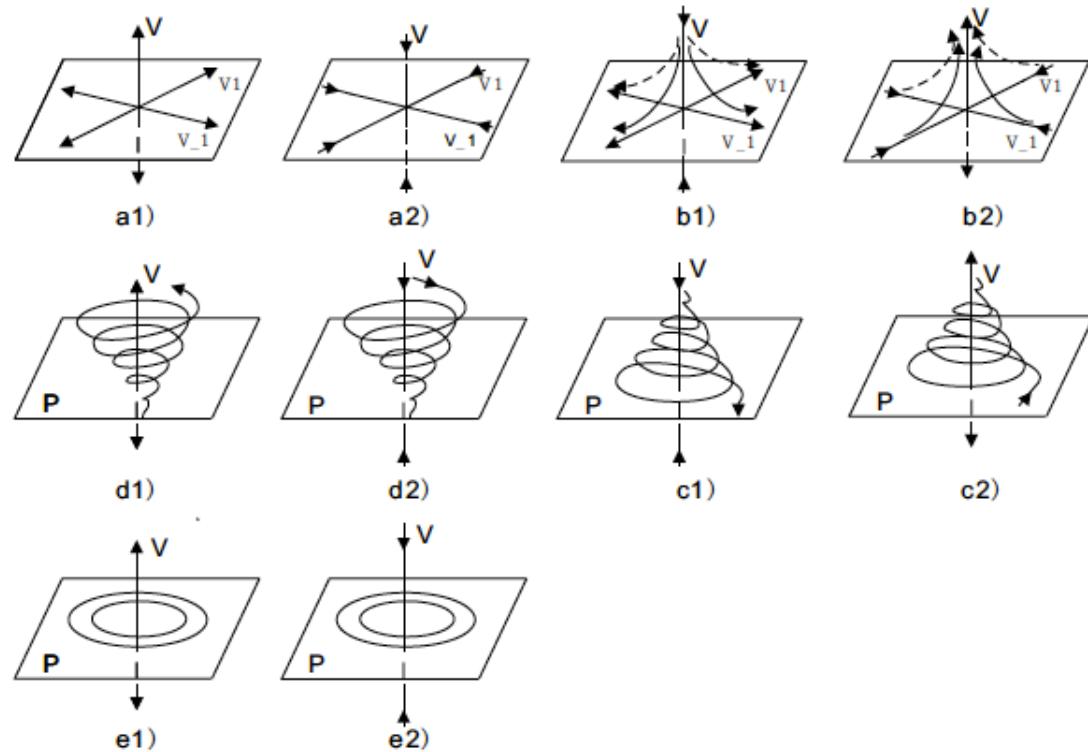
3D seed placement

- The placement of seeds directly determines the visualization quality
 - Too many: scene cluttering
 - Too little: no pattern formed
- It has to be in the right place and in the right amount!



A bad seeding example

Related work (1/6)



3D flow-guided seeding
templates [Ye et al.
2005]

Related work (2/6)

(a)

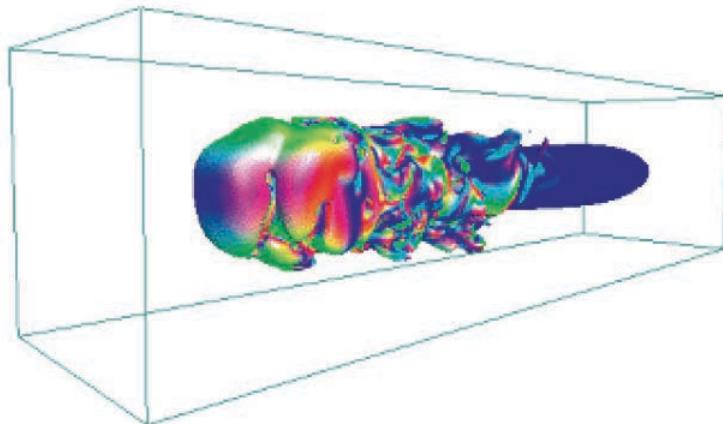
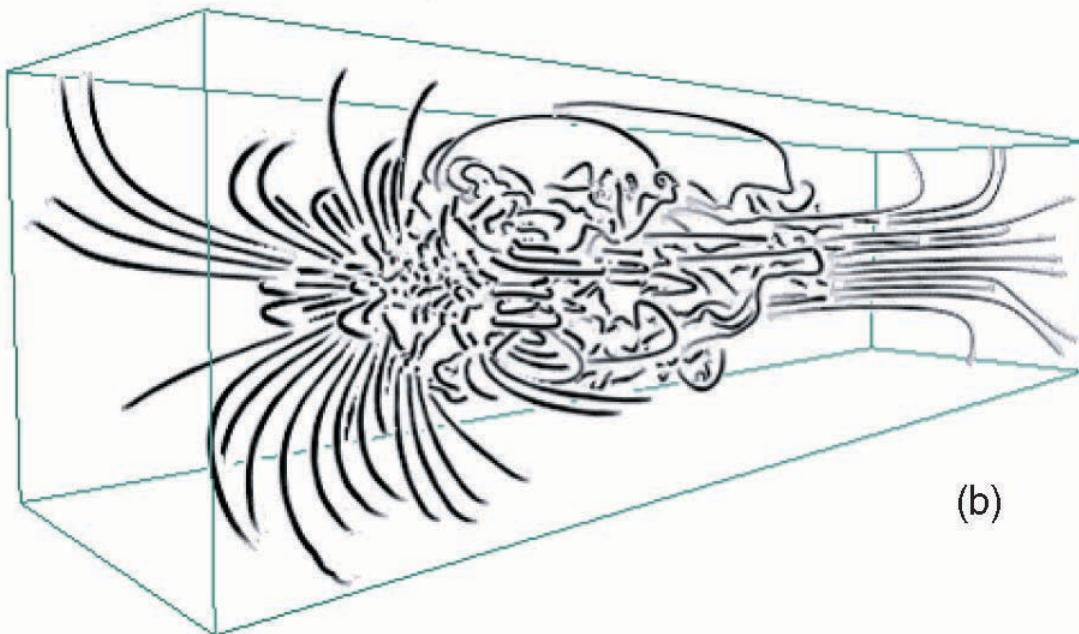
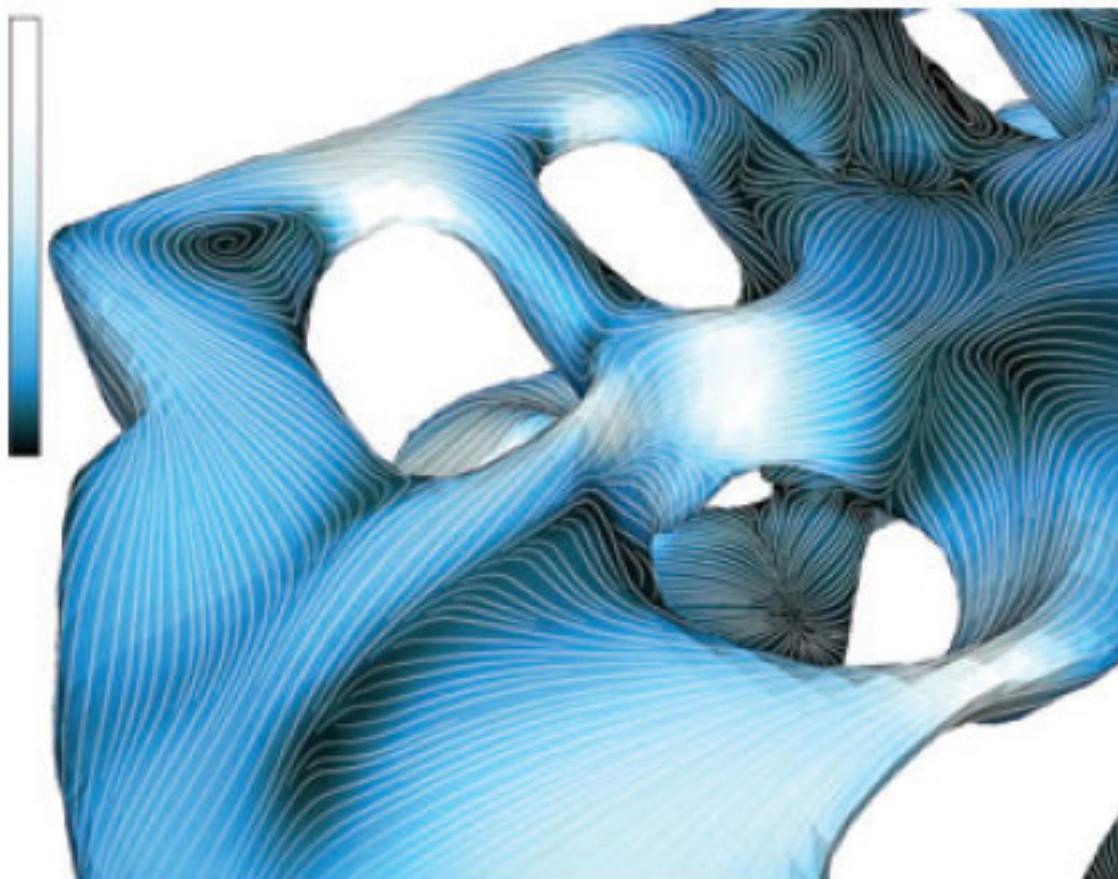


Image-based
streamline placement
[Li and Shen 2007]

(b)

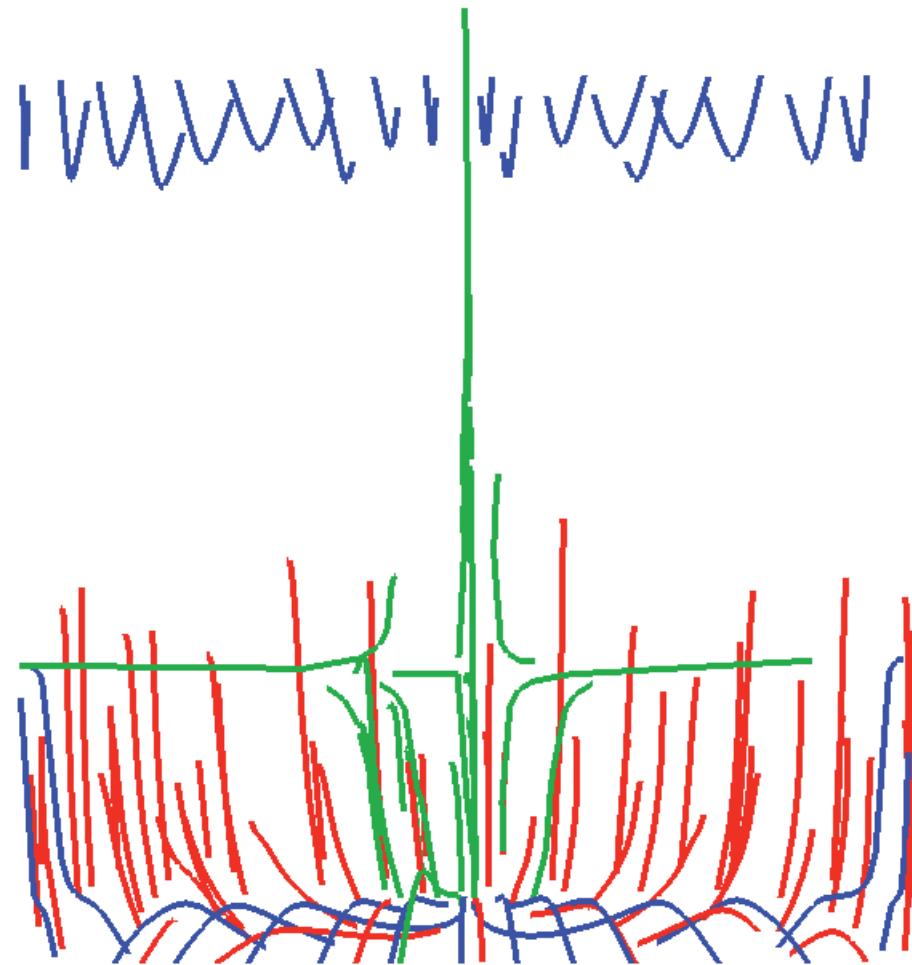


Related work (3/6)



Evenly-spaced
streamlines on surface
[Spencer et al. 2009]

Related work (4/6)



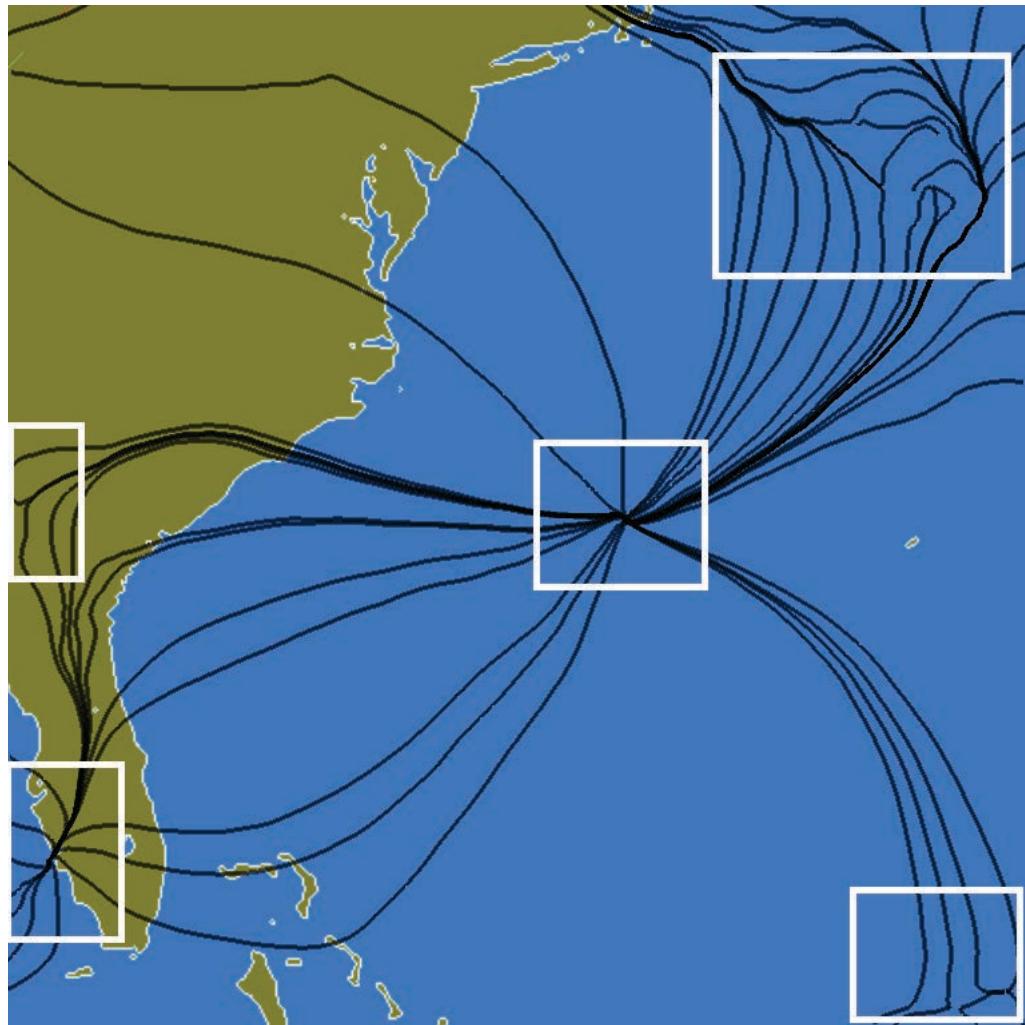
Priority streamlines
[Schlemmer et al. 2007]

Related work (5/6)



Dual streamline
seeding [Rosanwo
et al. 2009]

Related work (6/6)



Entropy-guided seed placement [Xu et al.
2010]

Open issues

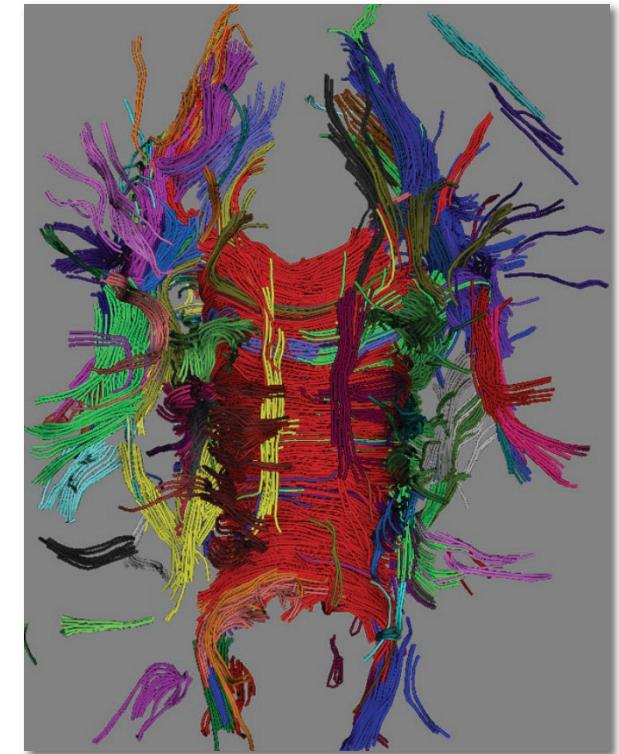
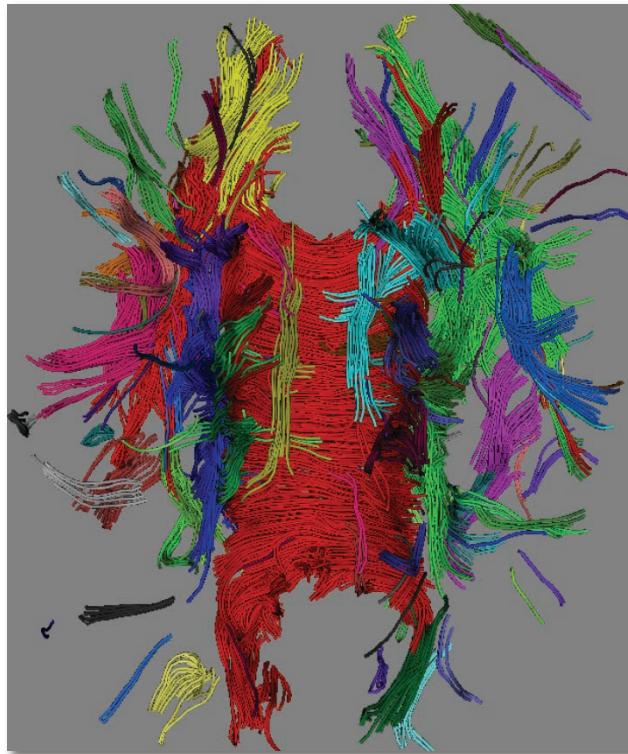
- Seed placement in 3D (occlusion and clarity)
- Techniques for handling big data
- Flow field navigation and interaction
- Human perception and user evaluation

Hierarchical streamline bundling

Objectives

- Target three-dimensional flow fields
- Capture important flow features
- Allow hierarchical exploration
- Create line bundling effects

DTI fiber bundles

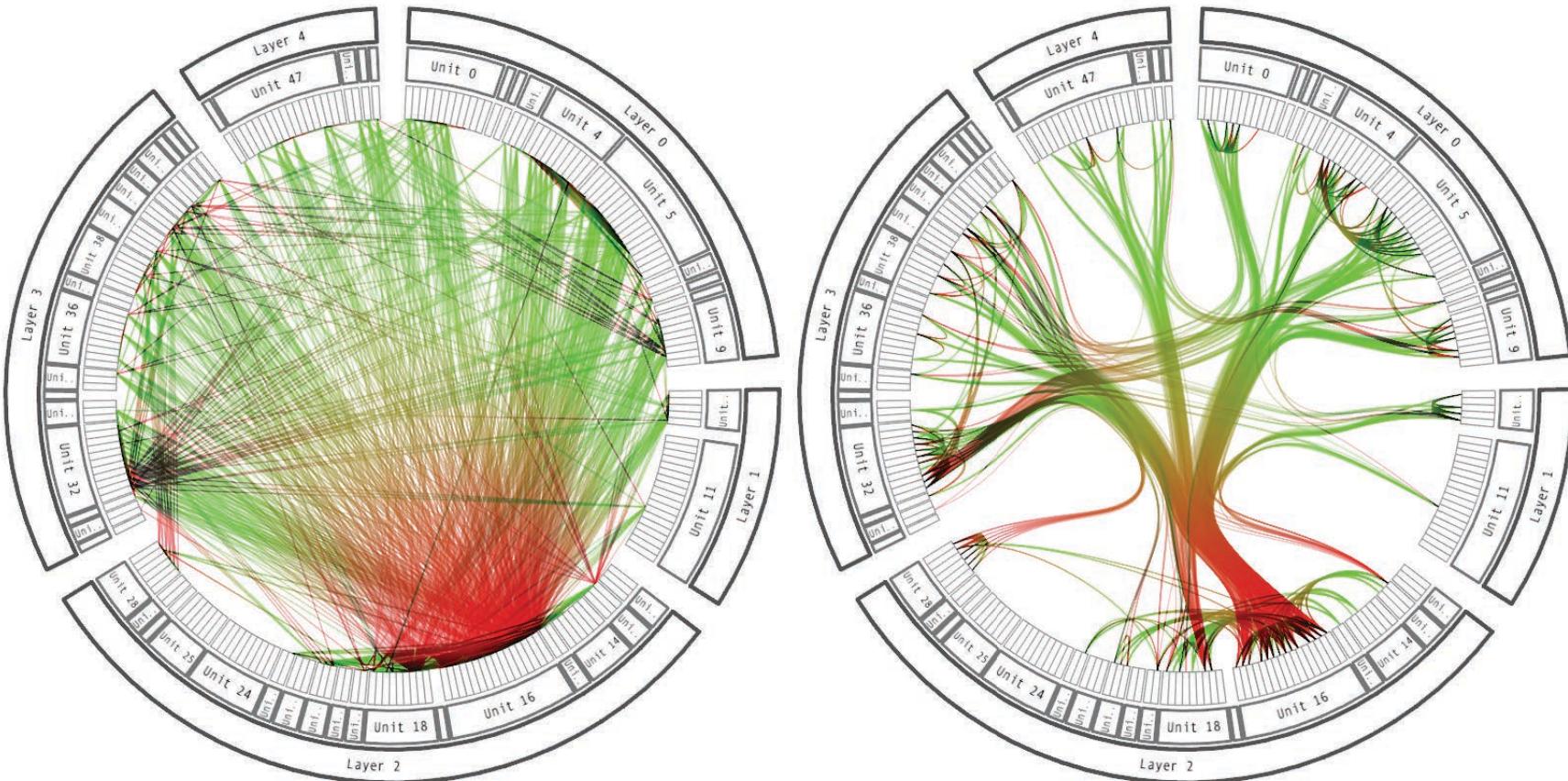


B. Mloberts, A. Vilanova, and J. J. van Wijk

Evaluation of Fiber Clustering Methods for Diffusion Tensor Imaging

Proceedings of IEEE Visualization Conference, pages 65-72, 2005.

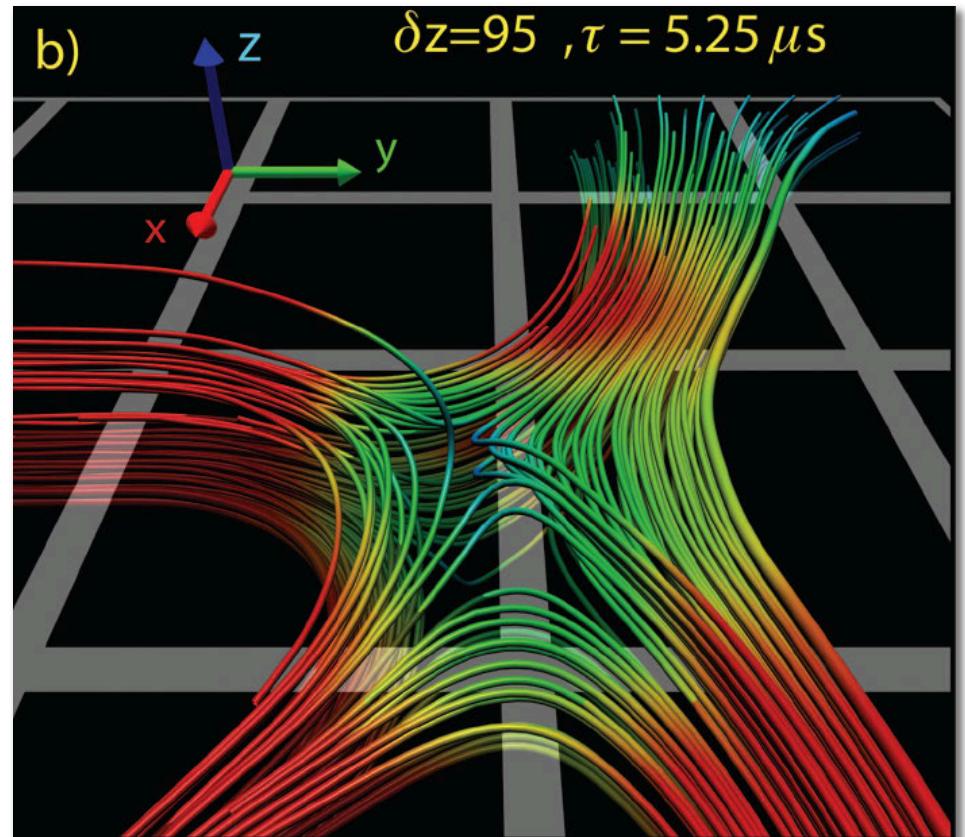
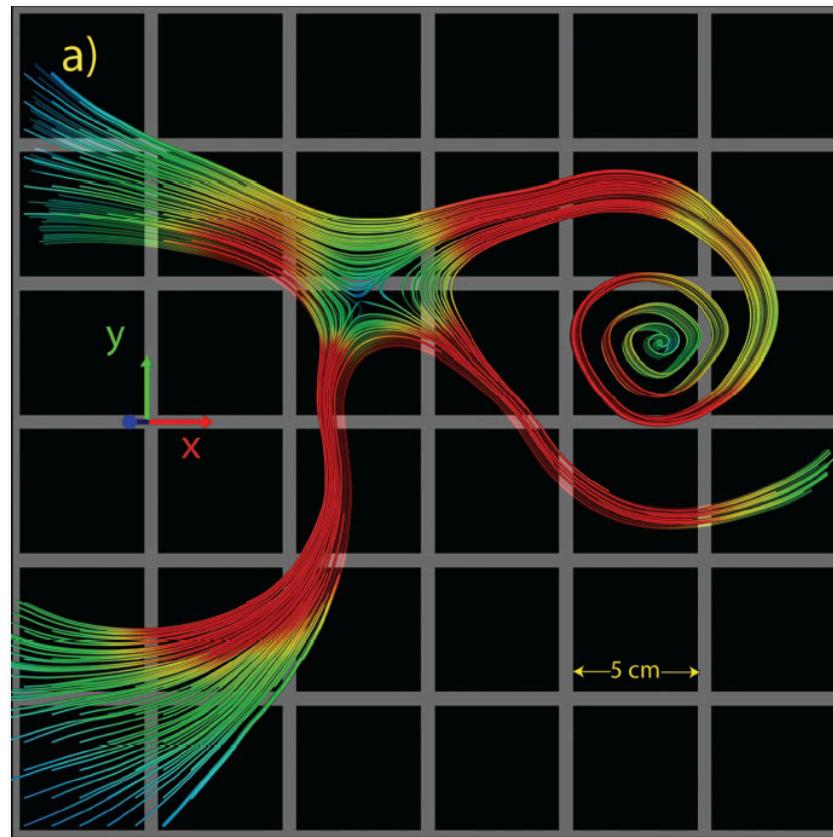
Edge bundles



D. Holten

Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data
IEEE Transactions on Visualization and Computer Graphics, 12(5):741-748, 2006.

Plasma physics

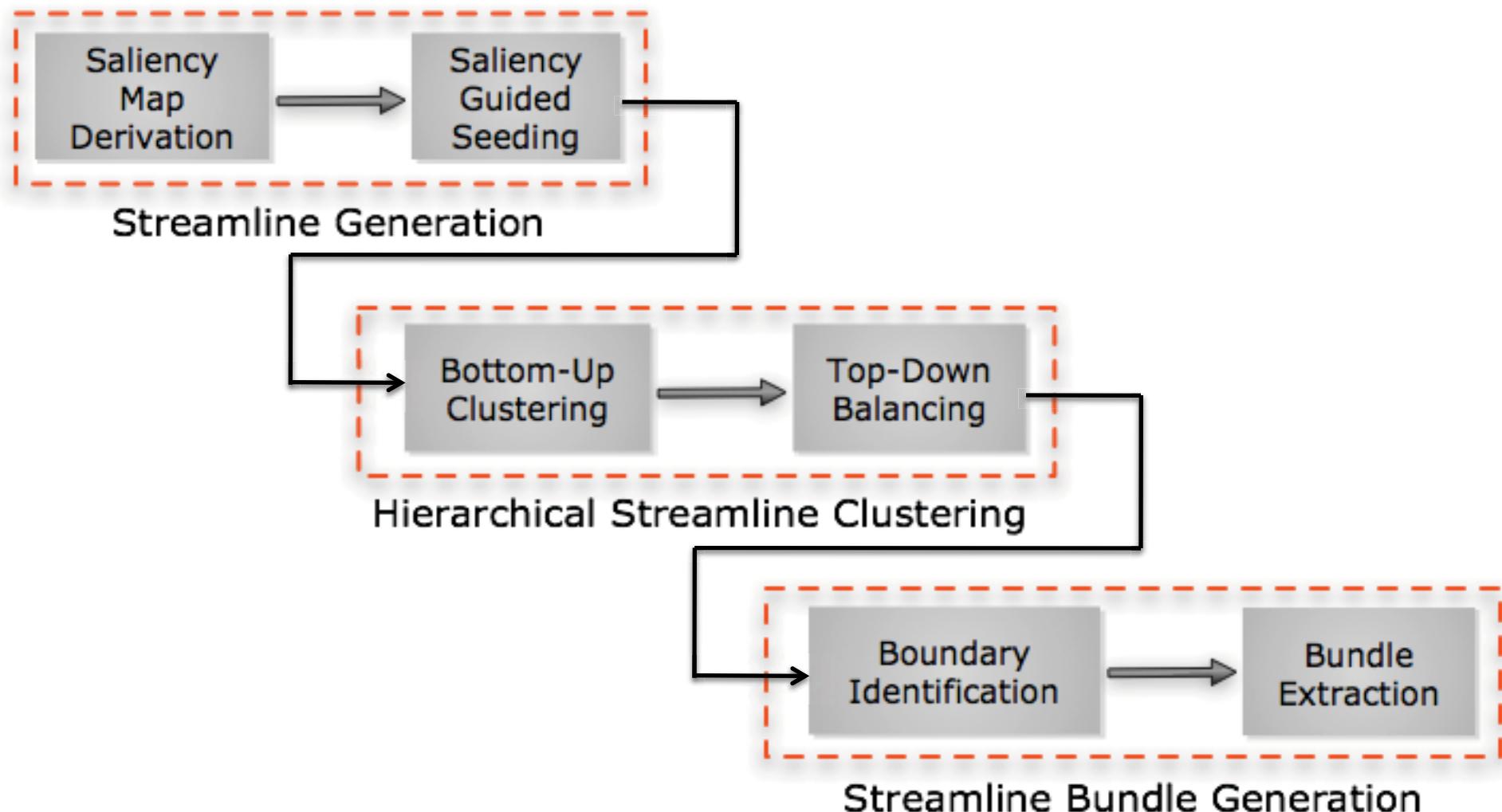


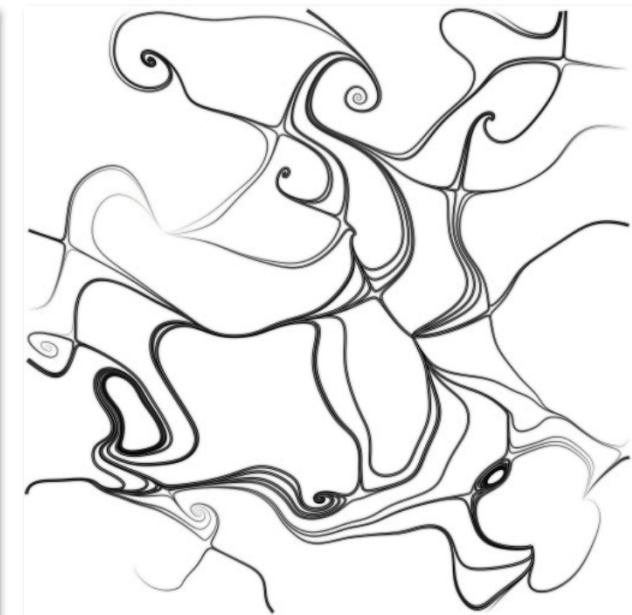
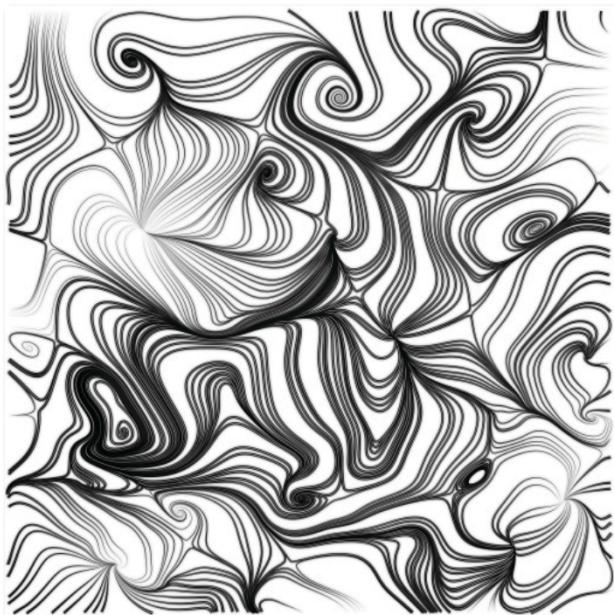
W. Gekelman, A. Collette, and S. Vincena

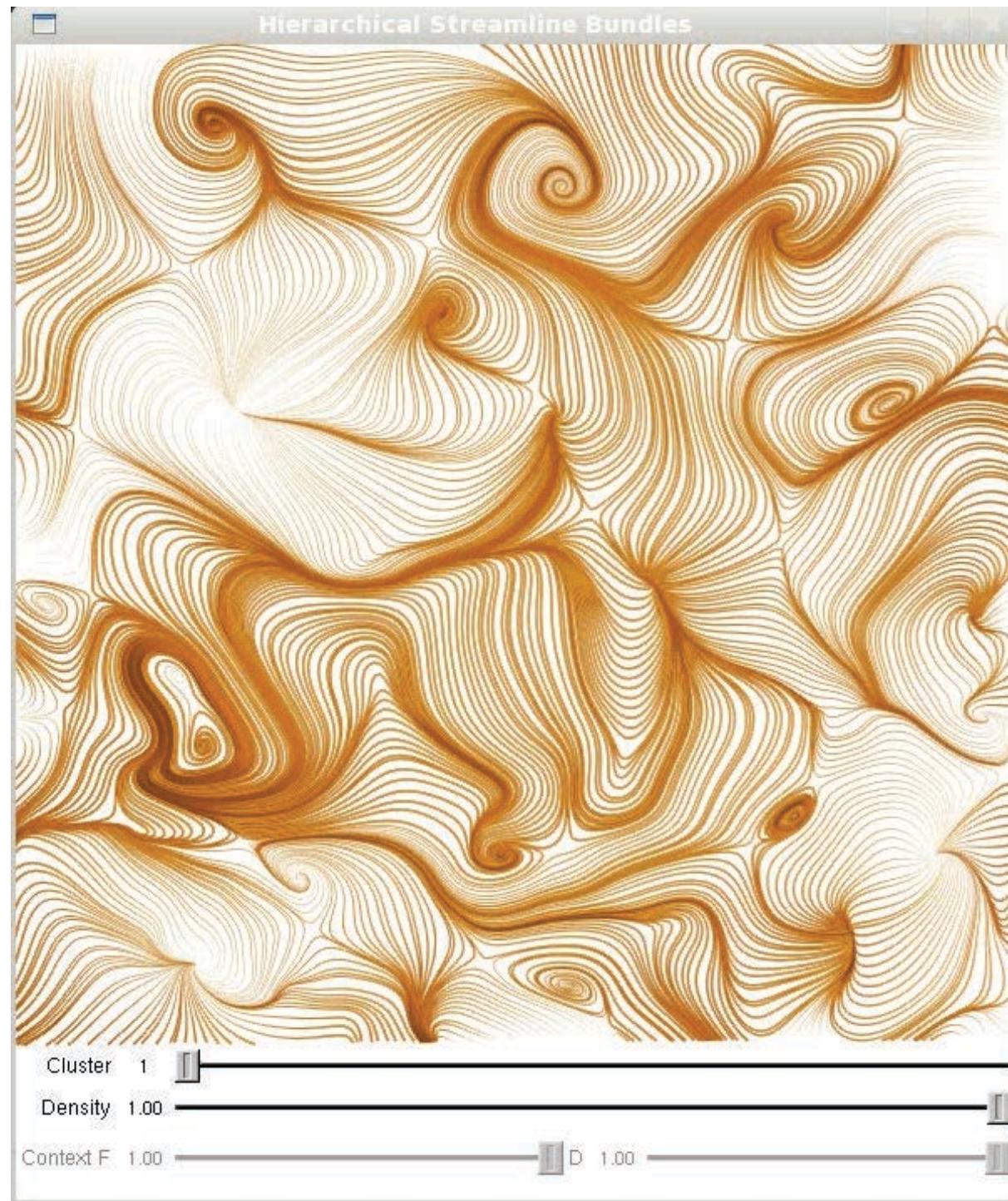
Three-Dimensional Current Systems Generated by Plasmas Colliding in a Background Magnetoplasma

Physics of Plasmas 14, 062109 (2007)

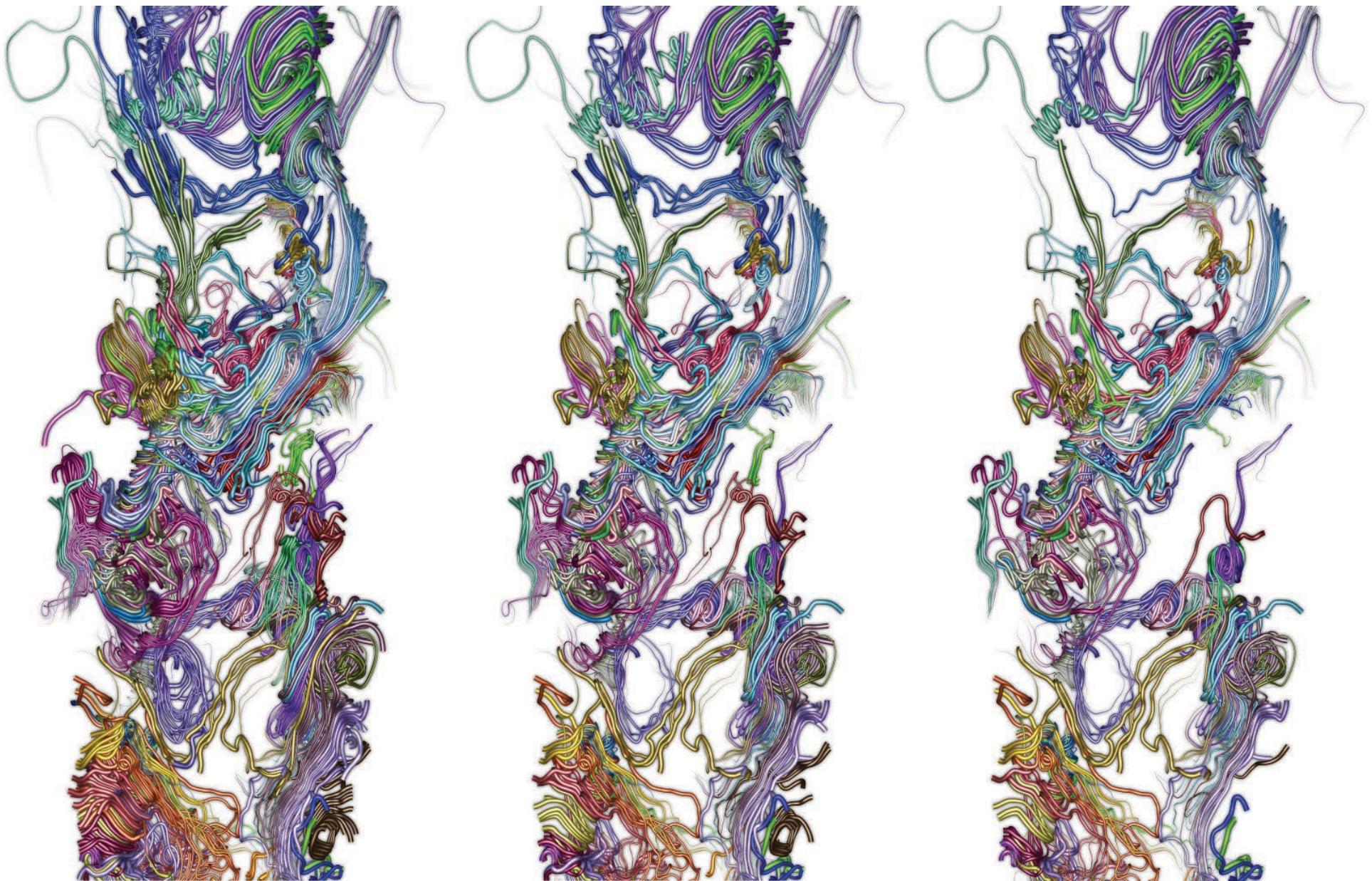
Overview of approach

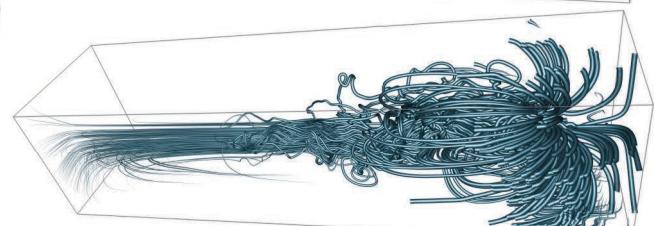
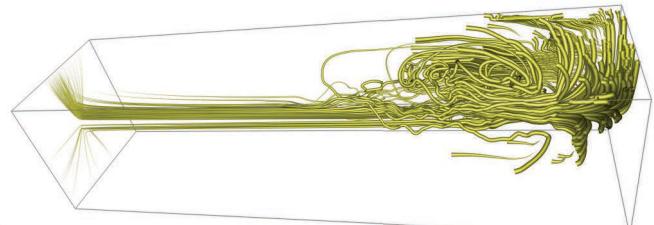
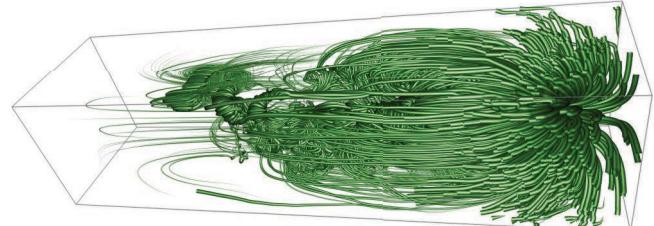
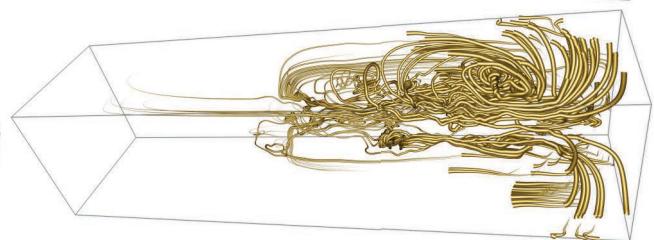
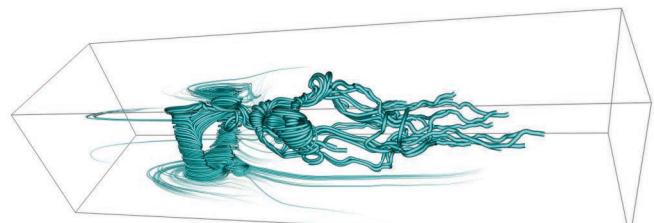
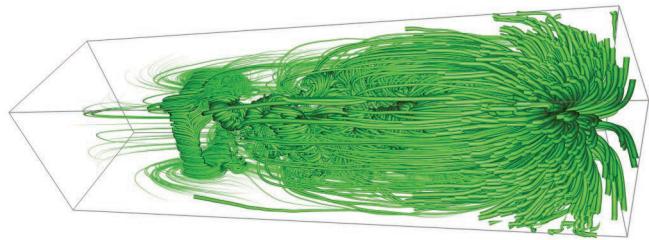
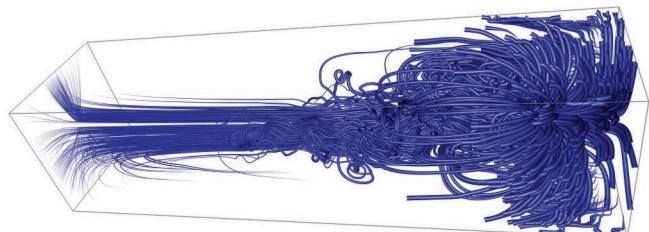
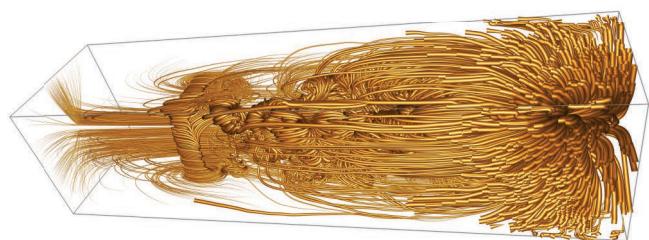
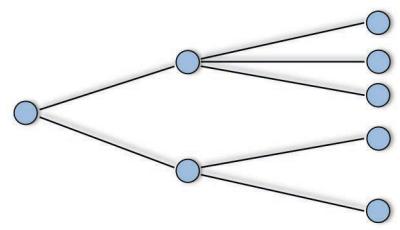


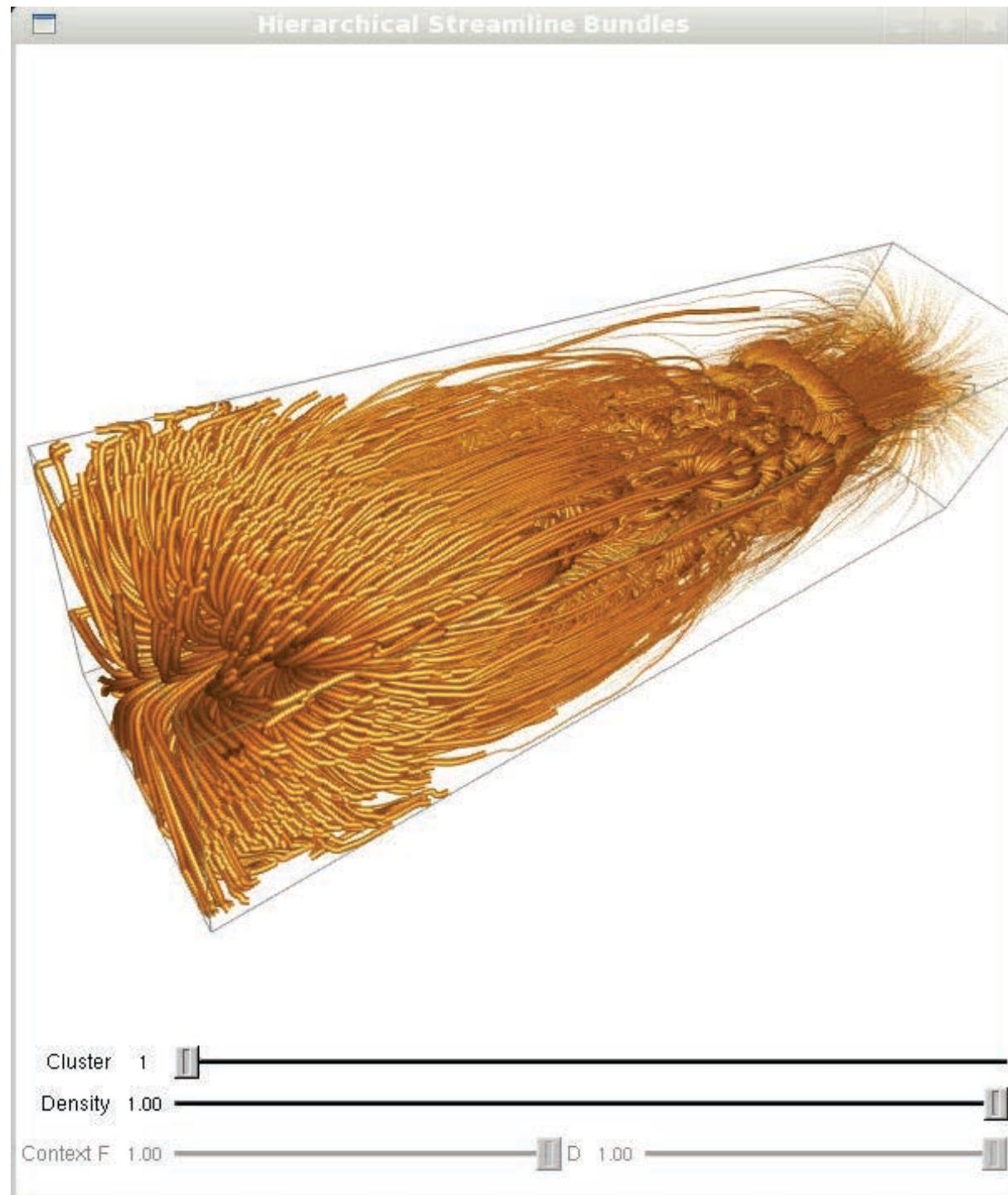








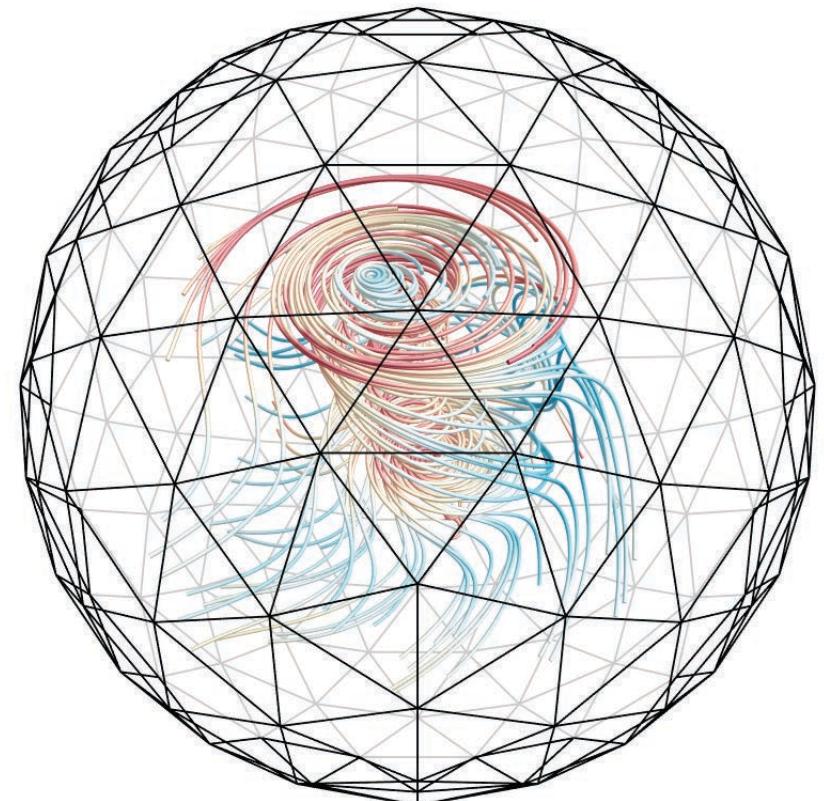




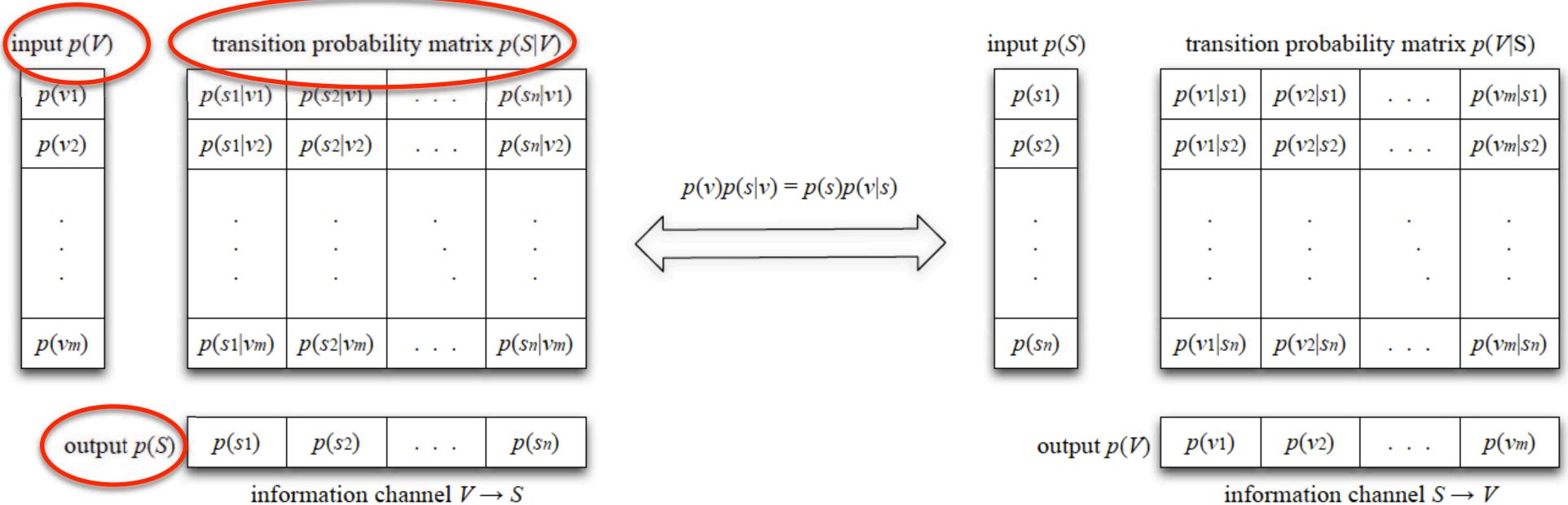
View-independent streamline selection

Objectives

- Select streamlines from a large pool of candidate streamlines
- Select good viewpoints from a list of sample viewpoints
- Solve both selection problems in a single framework



Information channel (1/3)



- **Transition probability matrix $p(S|V)$**
 - $p(s|v)$ represents the probability of “seeing” streamline s from viewpoint v (i.e., the importance of s with respect to v)
- **Input probability distribution $p(V)$**
 - $p(v)$ represents the probability of selecting viewpoint v
- **Output probability distribution $p(S)$**
 - $p(s)$ represents the average probability that streamline s is seen from all viewpoints V

Information channel (2/3)

input $p(V)$

$p(v_1)$
$p(v_2)$
.
.
.
$p(v_m)$

transition probability matrix $p(S|V)$

$p(s_1|v_1)$	$p(s_2|v_1)$	...	$p(s_n|v_1)$
$p(s_1|v_2)$	$p(s_2|v_2)$	...	$p(s_n|v_2)$
.	.	.	.
.	.	.	.
.	.	.	.
$p(s_1|v_m)$	$p(s_2|v_m)$	...	$p(s_n|v_m)$

input $p(S)$

$p(s_1)$
$p(s_2)$
.
.
.
$p(s_n)$

transition probability matrix $p(V|S)$

$p(v_1|s_1)$	$p(v_2|s_1)$	...	$p(v_m|s_1)$
$p(v_1|s_2)$	$p(v_2|s_2)$	...	$p(v_m|s_2)$
.	.	.	.
.	.	.	.
.	.	.	.
$p(v_1|s_n)$	$p(v_2|s_n)$	...	$p(v_m|s_n)$

$$p(v)p(s|v) = p(s)p(v|s)$$

output $p(S)$	$p(s_1)$	$p(s_2)$...	$p(s_n)$
---------------	----------	----------	-----	----------

information channel $V \rightarrow S$

output $p(V)$	$p(v_1)$	$p(v_2)$...	$p(v_m)$
---------------	----------	----------	-----	----------

information channel $S \rightarrow V$

- Invert the information channel by swapping input and output probability distributions
- Transition probability matrix $p(V|S)$
 - $p(v|s)$ represents the probability of selecting viewpoint v given streamline s

Information channel (3/3)

input $p(V)$

$p(v_1)$
$p(v_2)$
.
.
$p(v_m)$

transition probability matrix $p(S|V)$

$p(s_1|v_1)$	$p(s_2|v_1)$	...	$p(s_n|v_1)$
$p(s_1|v_2)$	$p(s_2|v_2)$	...	$p(s_n|v_2)$
.	.	.	.
.	.	.	.
$p(s_1|v_m)$	$p(s_2|v_m)$	...	$p(s_n|v_m)$

input $p(S)$

$p(s_1)$
$p(s_2)$
.
.
$p(s_n)$

transition probability matrix $p(V|S)$

$p(v_1|s_1)$	$p(v_2|s_1)$	...	$p(v_m|s_1)$
$p(v_1|s_2)$	$p(v_2|s_2)$	...	$p(v_m|s_2)$
.	.	.	.
.	.	.	.
$p(v_1|s_n)$	$p(v_2|s_n)$	...	$p(v_m|s_n)$

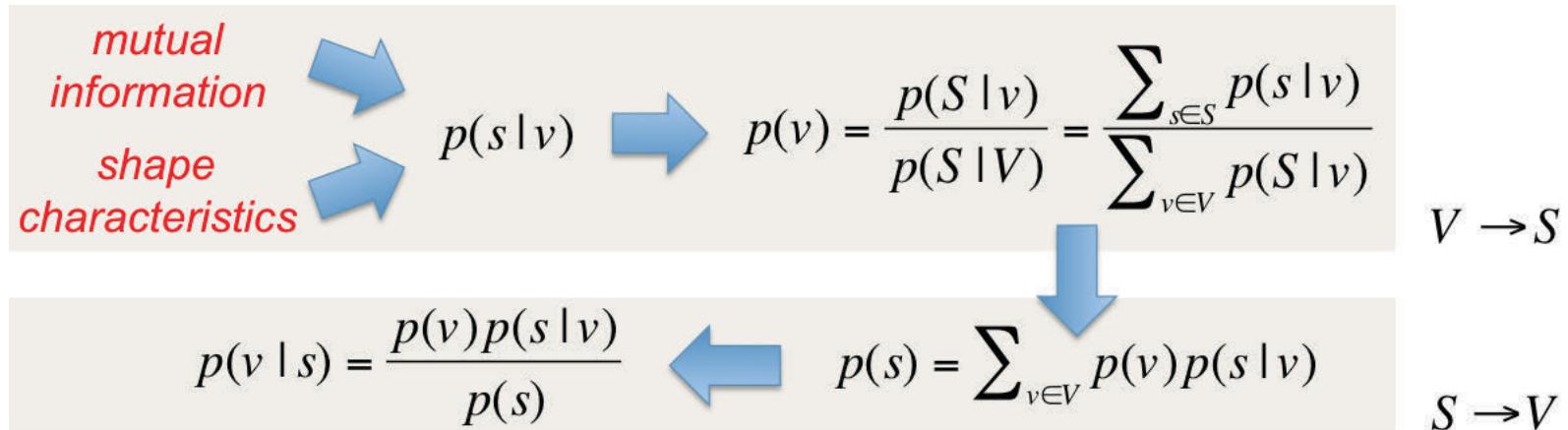
output $p(S)$	$p(s_1)$	$p(s_2)$...	$p(s_n)$
---------------	----------	----------	-----	----------

information channel $V \rightarrow S$

output $p(V)$	$p(v_1)$	$p(v_2)$...	$p(v_m)$
---------------	----------	----------	-----	----------

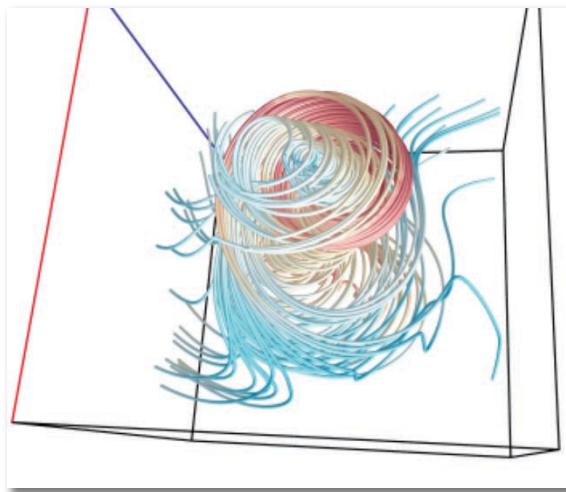
information channel $S \rightarrow V$

- The two channels are connected via the Bayes theorem

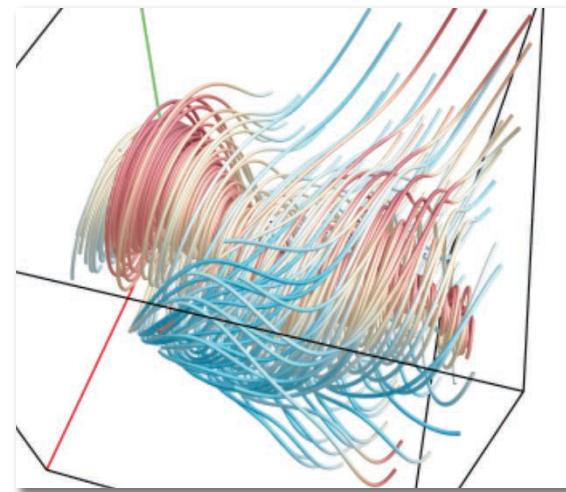


Conditional probability $p(s|v)$

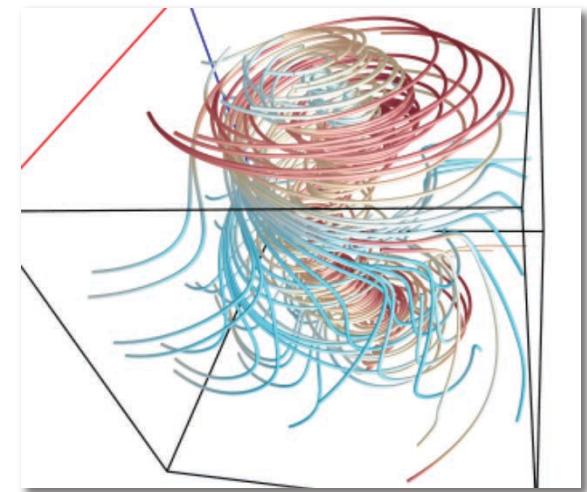
- Mutual information
 - Indicate how much information about streamline s is revealed in its 2D projection s_v under viewpoint v
- Shape characteristic
 - Indicate how stereoscopic the shape of streamline s is reflected under viewpoint v



Mutual information only



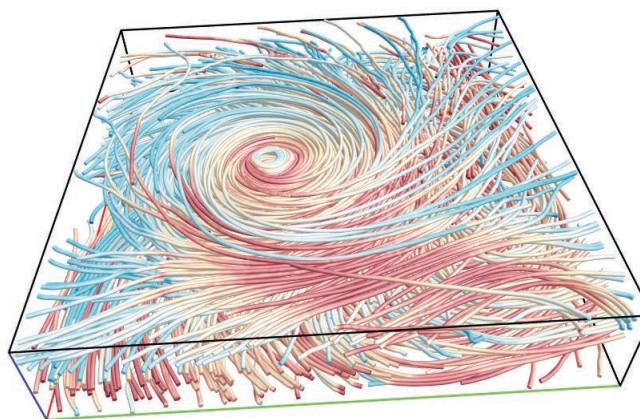
Shape characteristic only



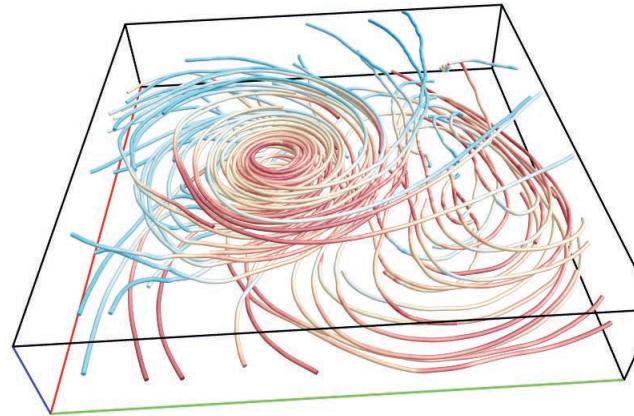
Both considered

Best streamline and best viewpoint selection

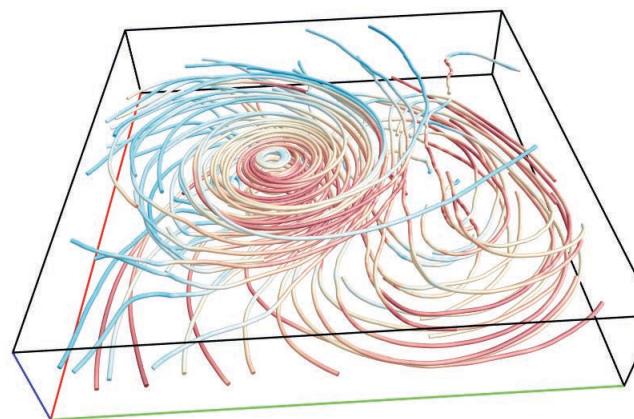
- Best streamline selection
 - $p(s)$
 - Streamline information (SI) $I(s;V)$
 - Streamline representativeness
 - Avoid similar streamlines through thresholding
- Best viewpoint selection
 - $p(v)$
 - Viewpoint information (VI) $I(v;S)$
 - Viewpoint representativeness
 - Avoid similar viewpoints through thresholding



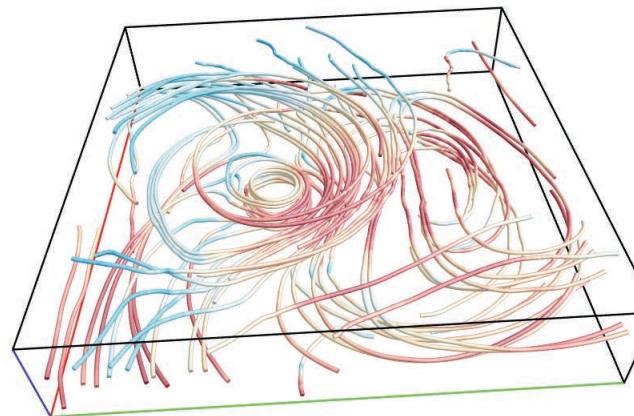
Initial pool



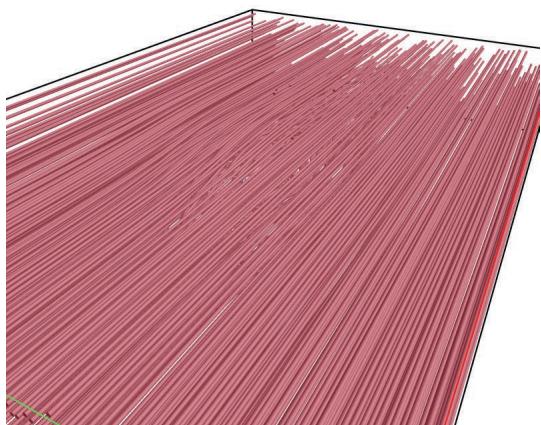
$$p(s)$$



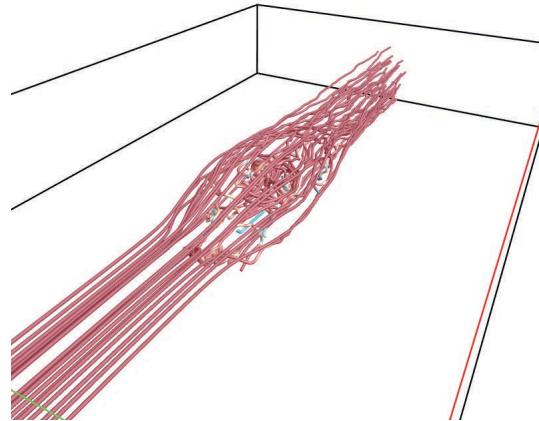
$$I(s;V)$$



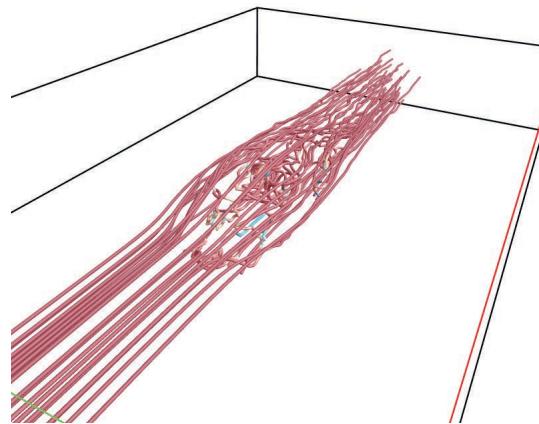
Representative



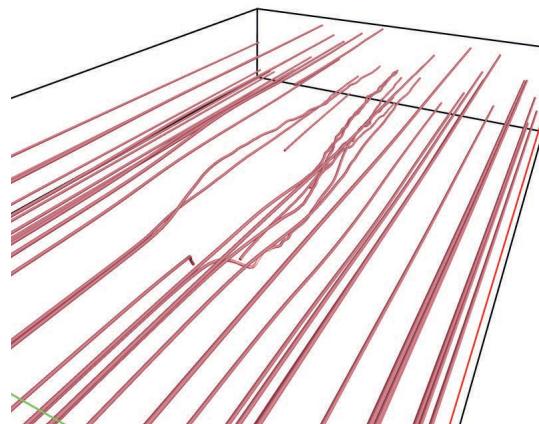
Initial pool



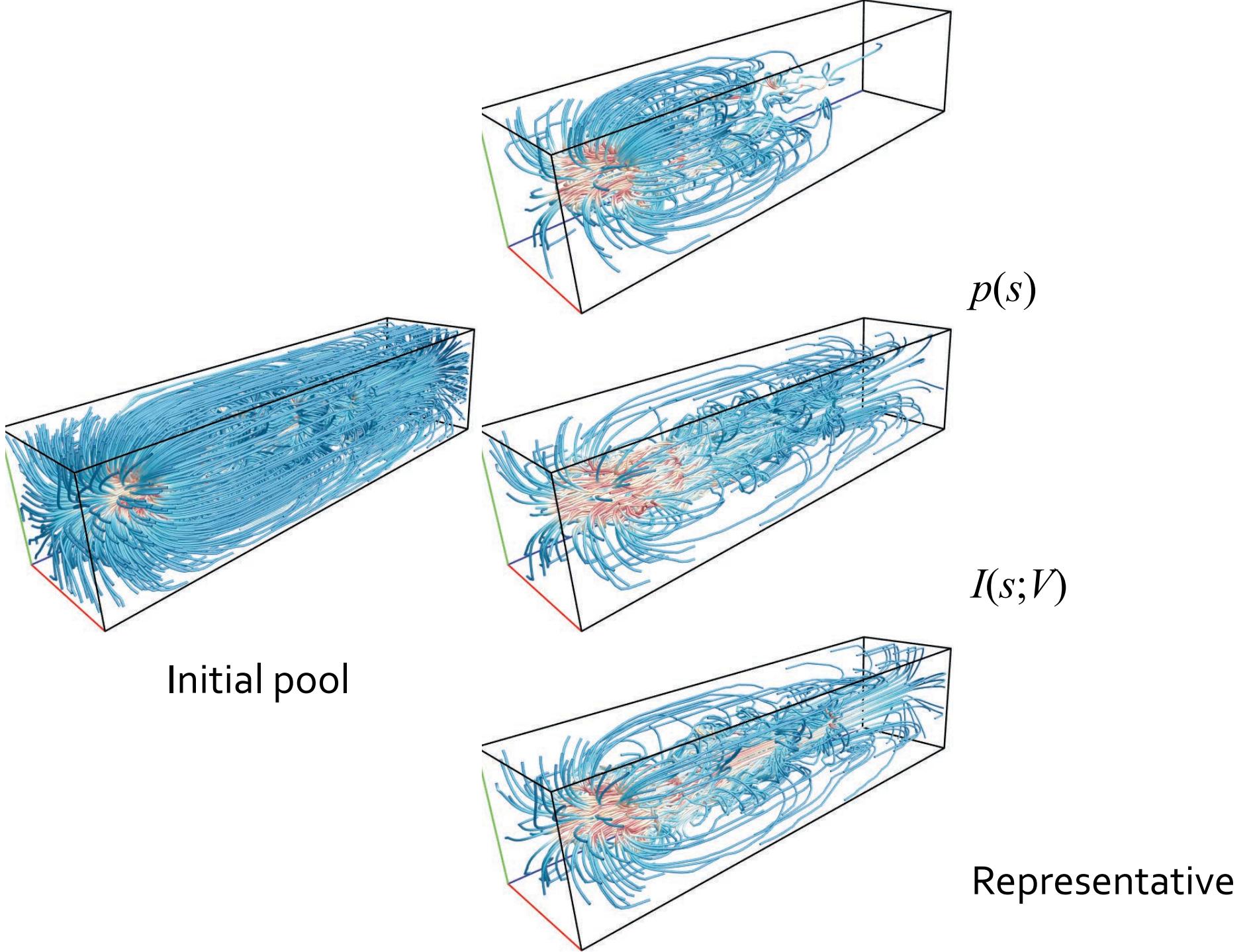
$$p(s)$$

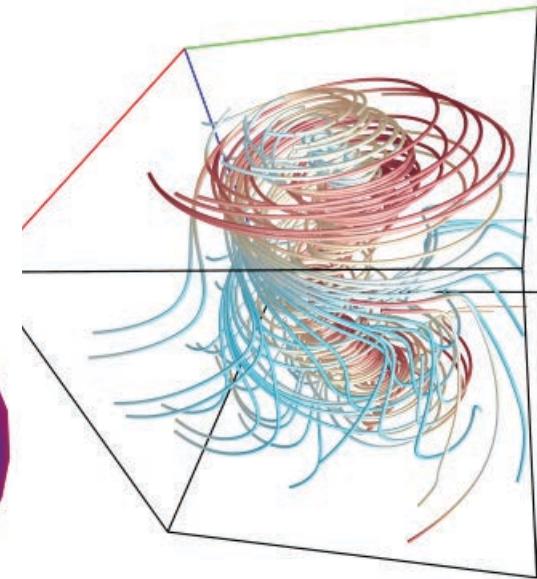
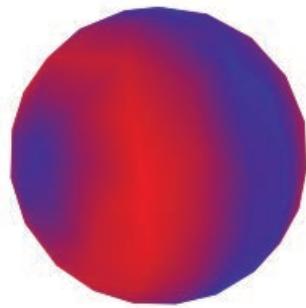


$$I(s;V)$$

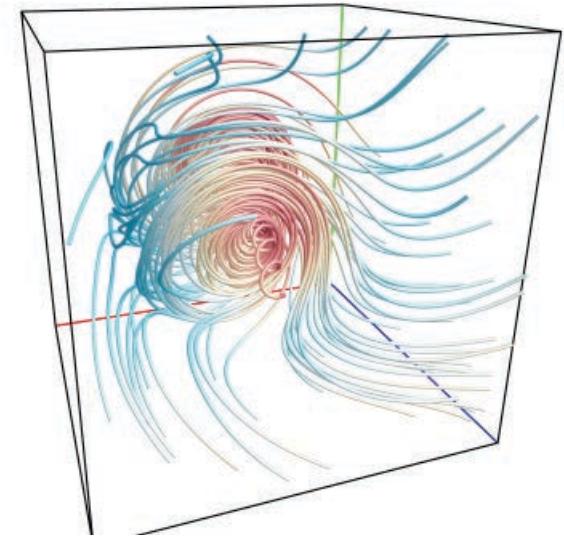
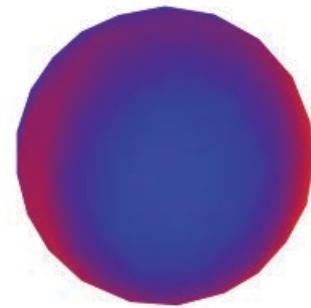


Representative

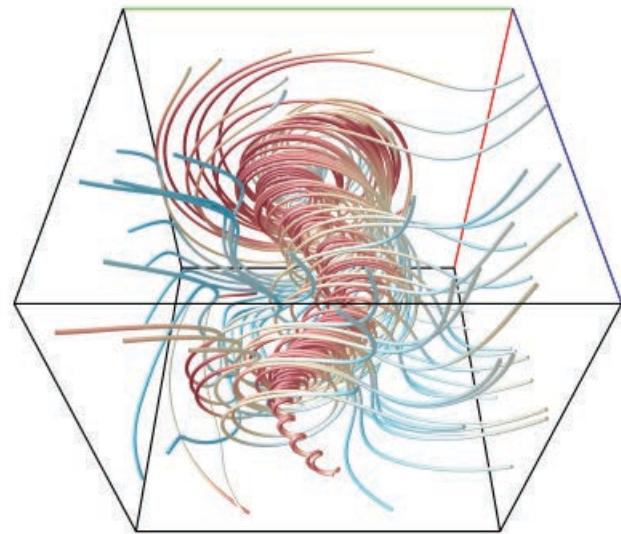
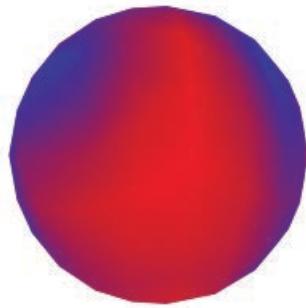




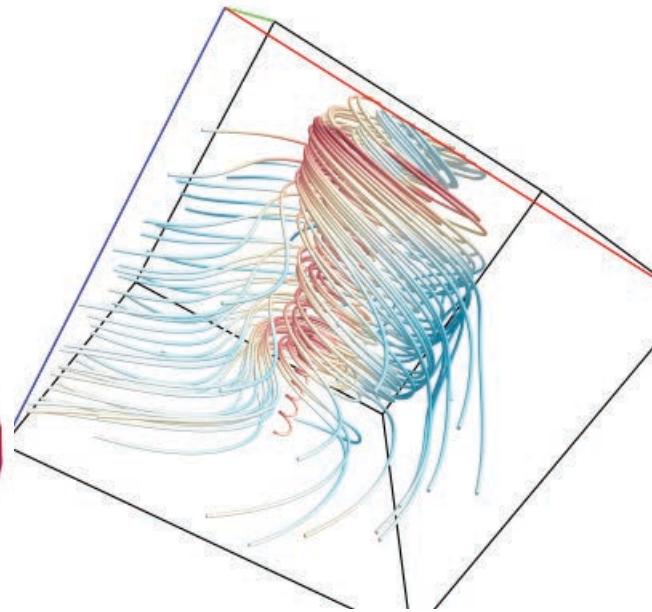
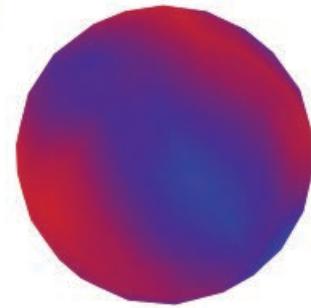
Best viewpoint $p(v)$



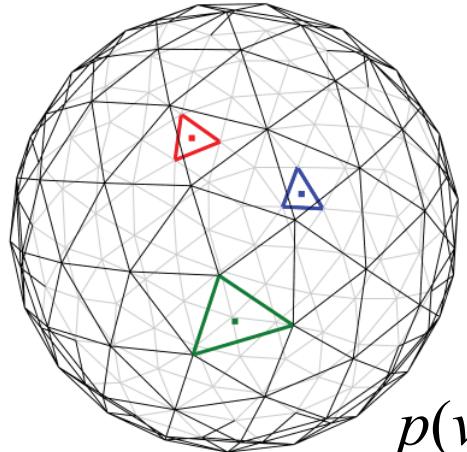
Worst viewpoint $p(v)$



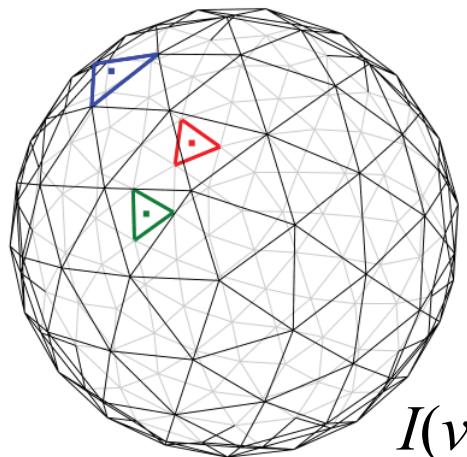
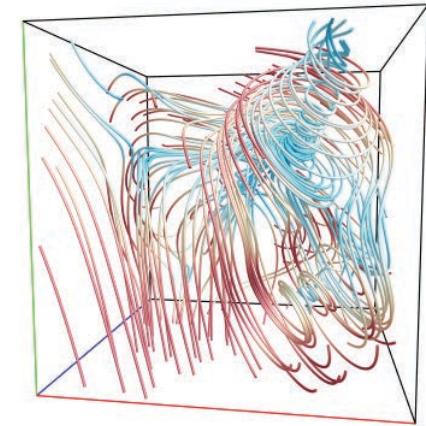
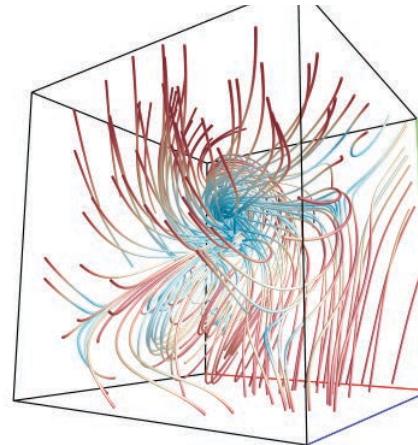
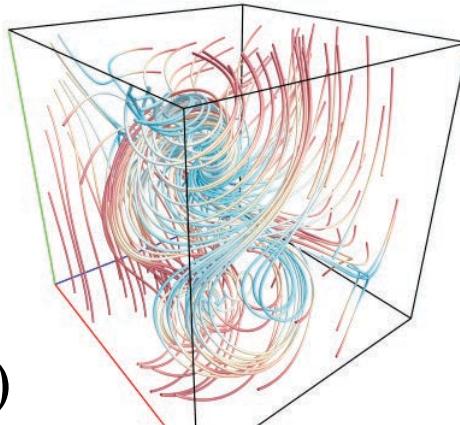
Best viewpoint $I(v; S)$



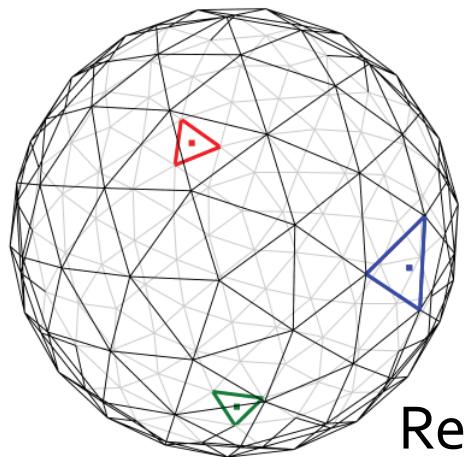
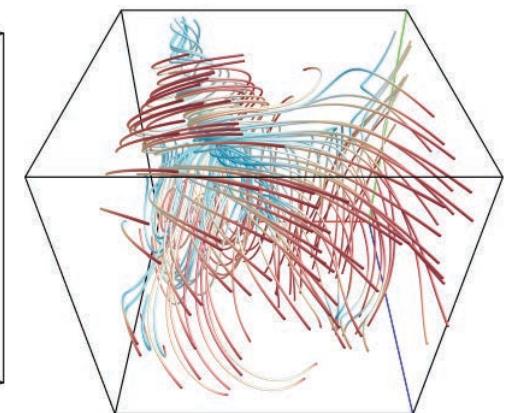
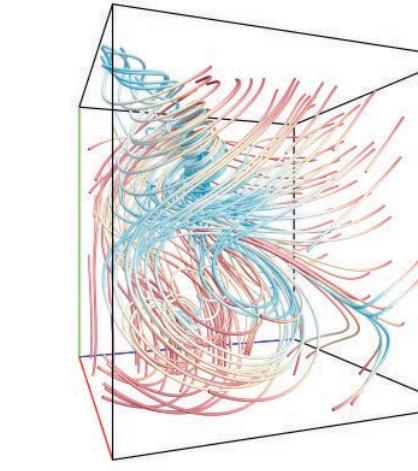
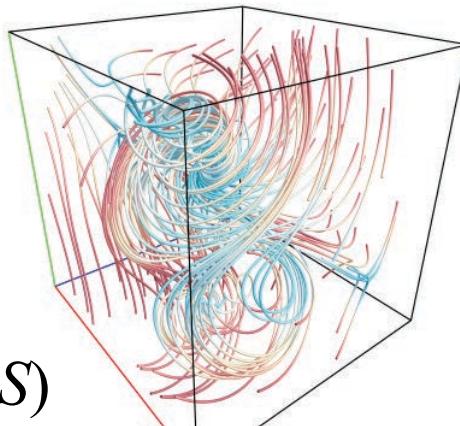
Worst viewpoint $I(v; S)$



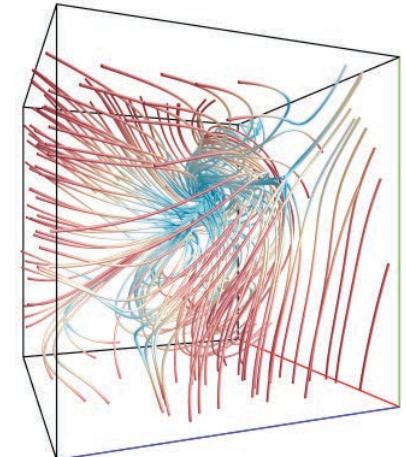
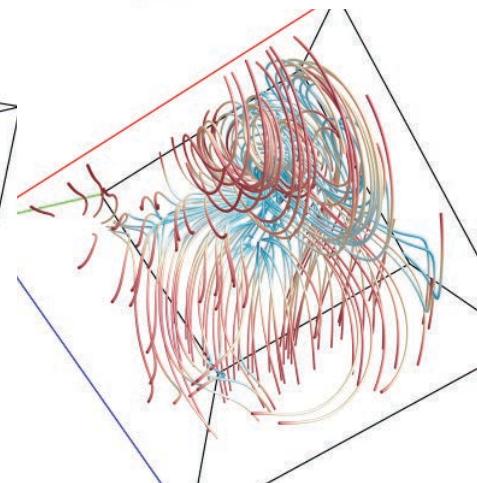
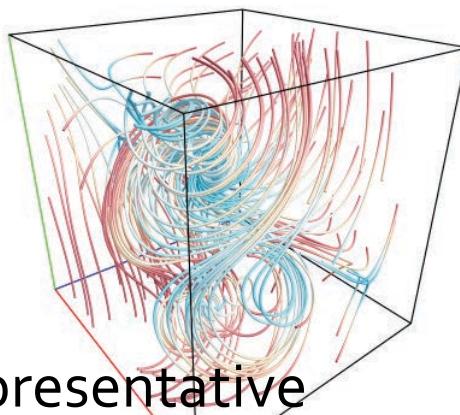
$p(v)$



$I(v; S)$



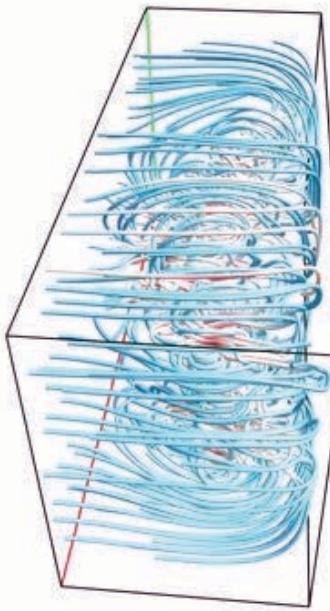
Representative



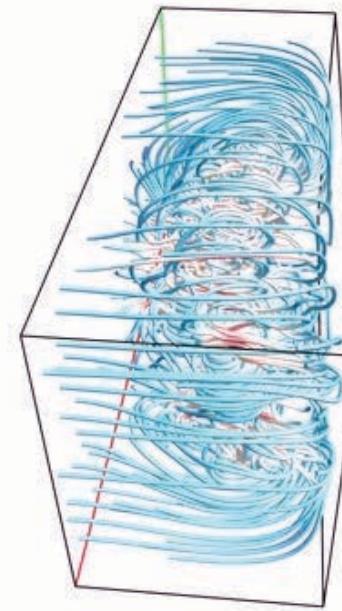
View-dependent streamline selection

Objectives

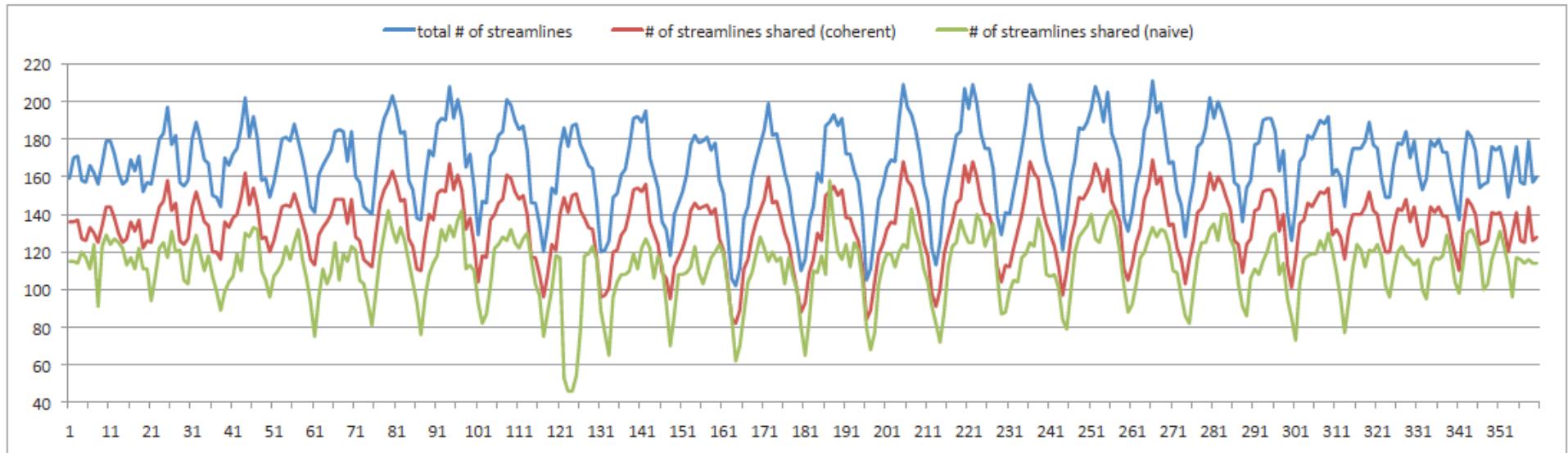
- View-dependent streamline selection
- Smooth streamline update when viewpoints change gradually



Our view-dependent algorithm

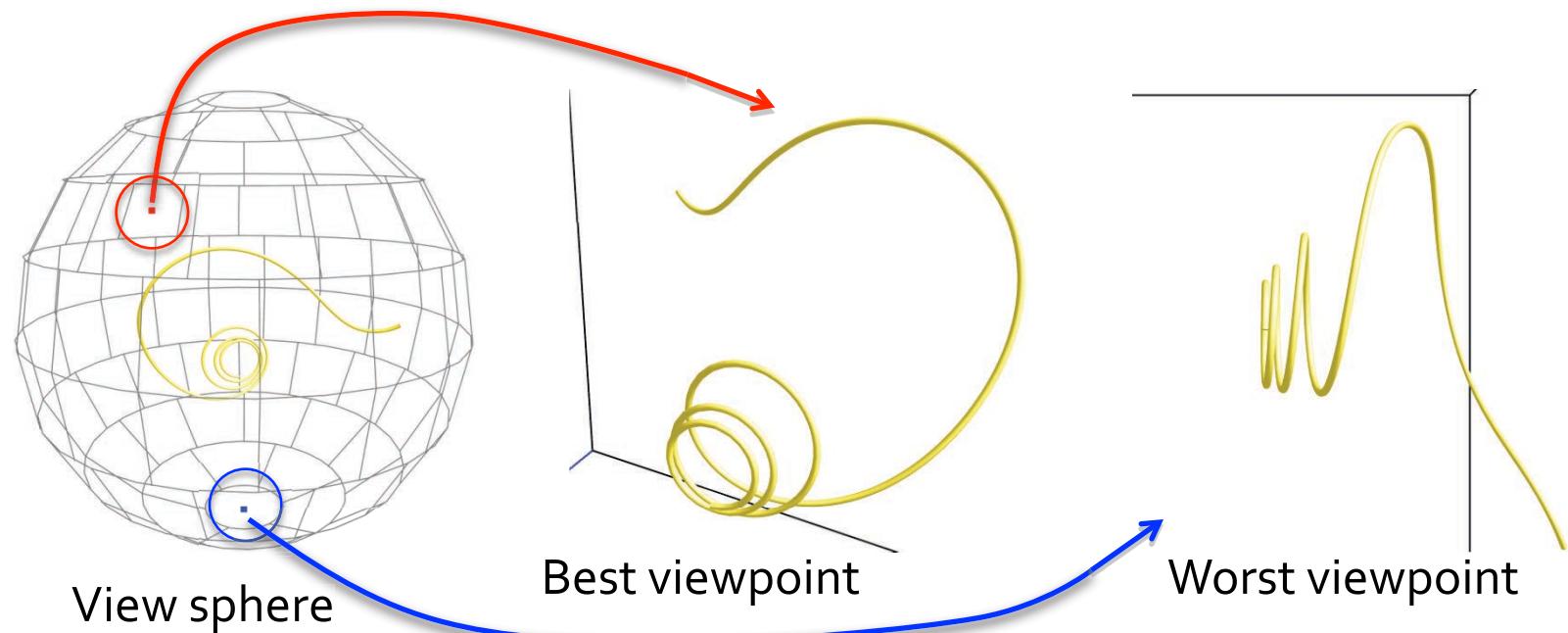


The naïve algorithm



Streamline importance evaluation

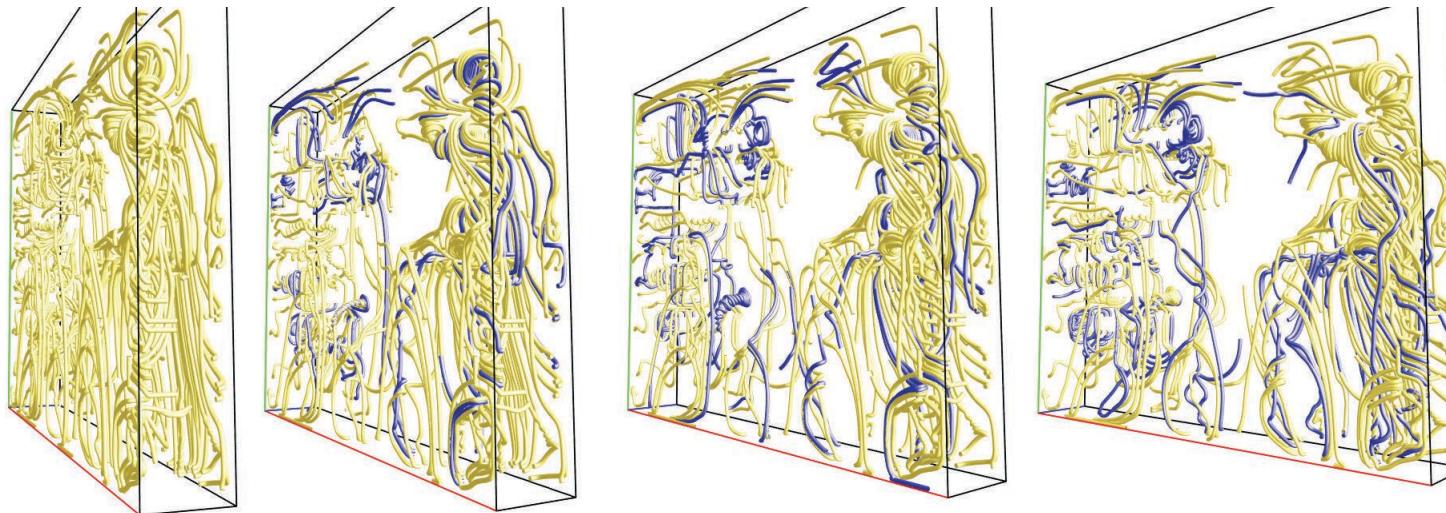
- View-dependent streamline importance
- Combination of mutual information and shape characteristic of a streamline s under a given viewpoint v



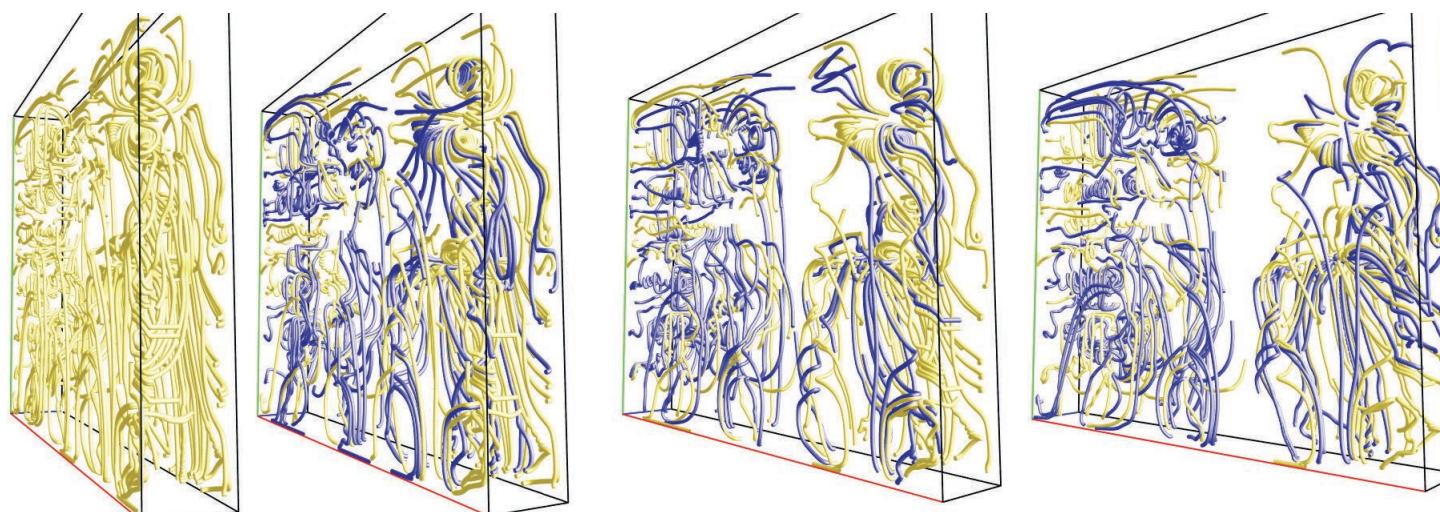
View-dependent streamline selection

- Consider three streamline sets
 - *View-independent streamline set*: top ranked streamlines based on the average importance values under all sample viewpoints
 - *Streamline set of the current viewpoint*: top ranked streamlines based on the importance values under the current viewpoint
 - *Streamline set of the previous neighboring viewpoint*: streamlines displayed in the previous neighboring viewpoint

Result: coherent update



Our view-dependent algorithm



The naïve algorithm

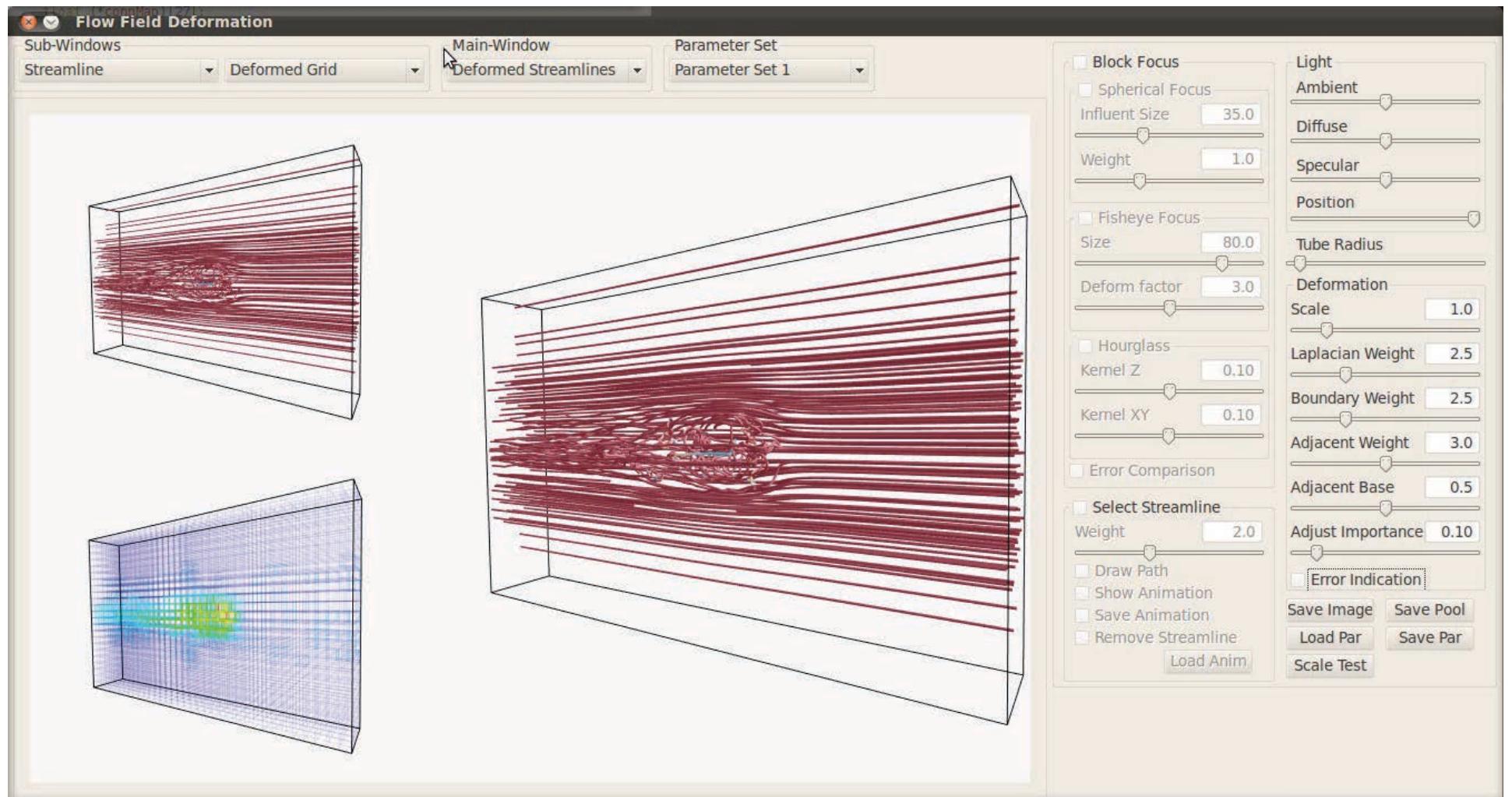
Streamline repositioning

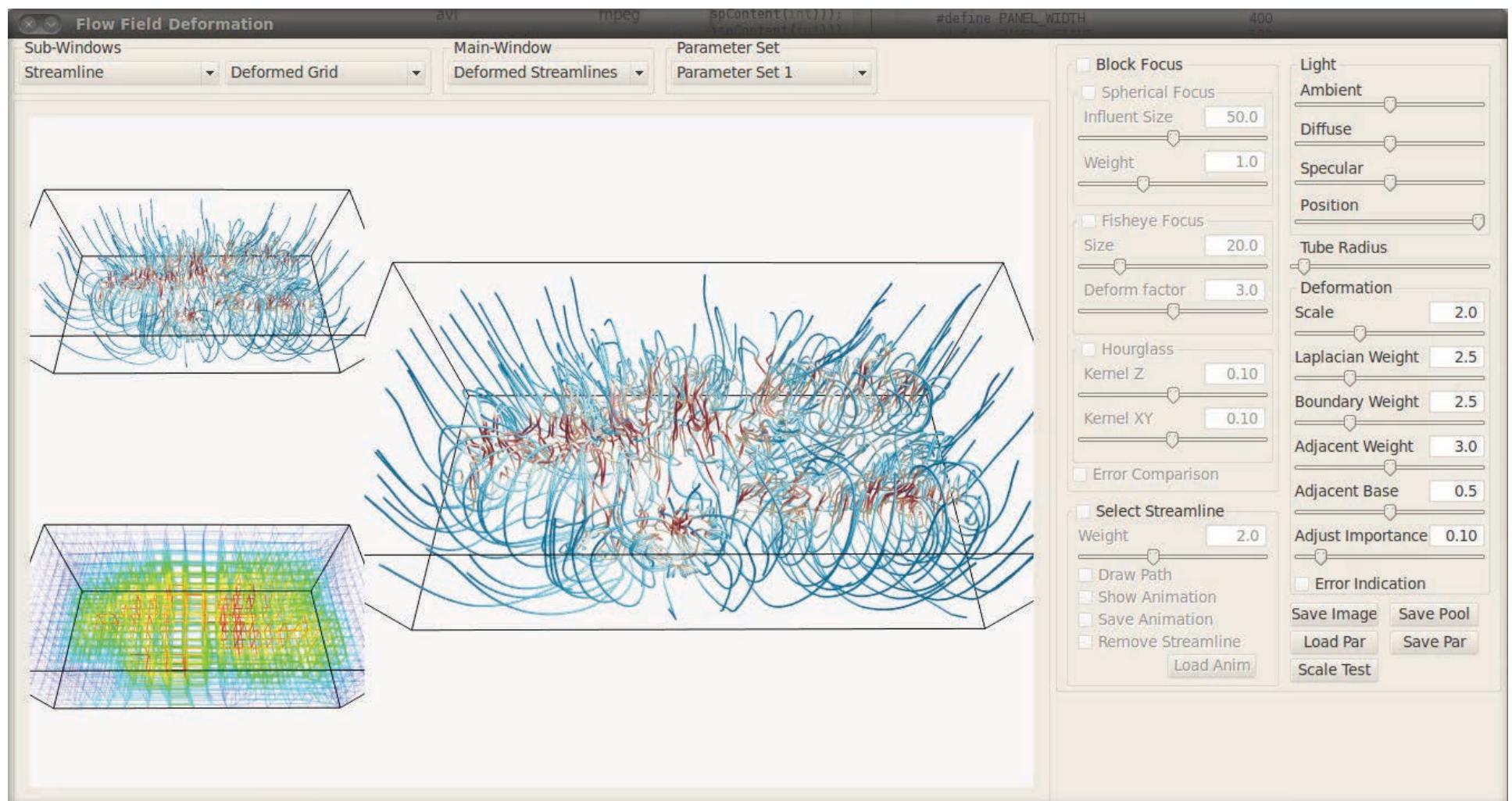
Objectives

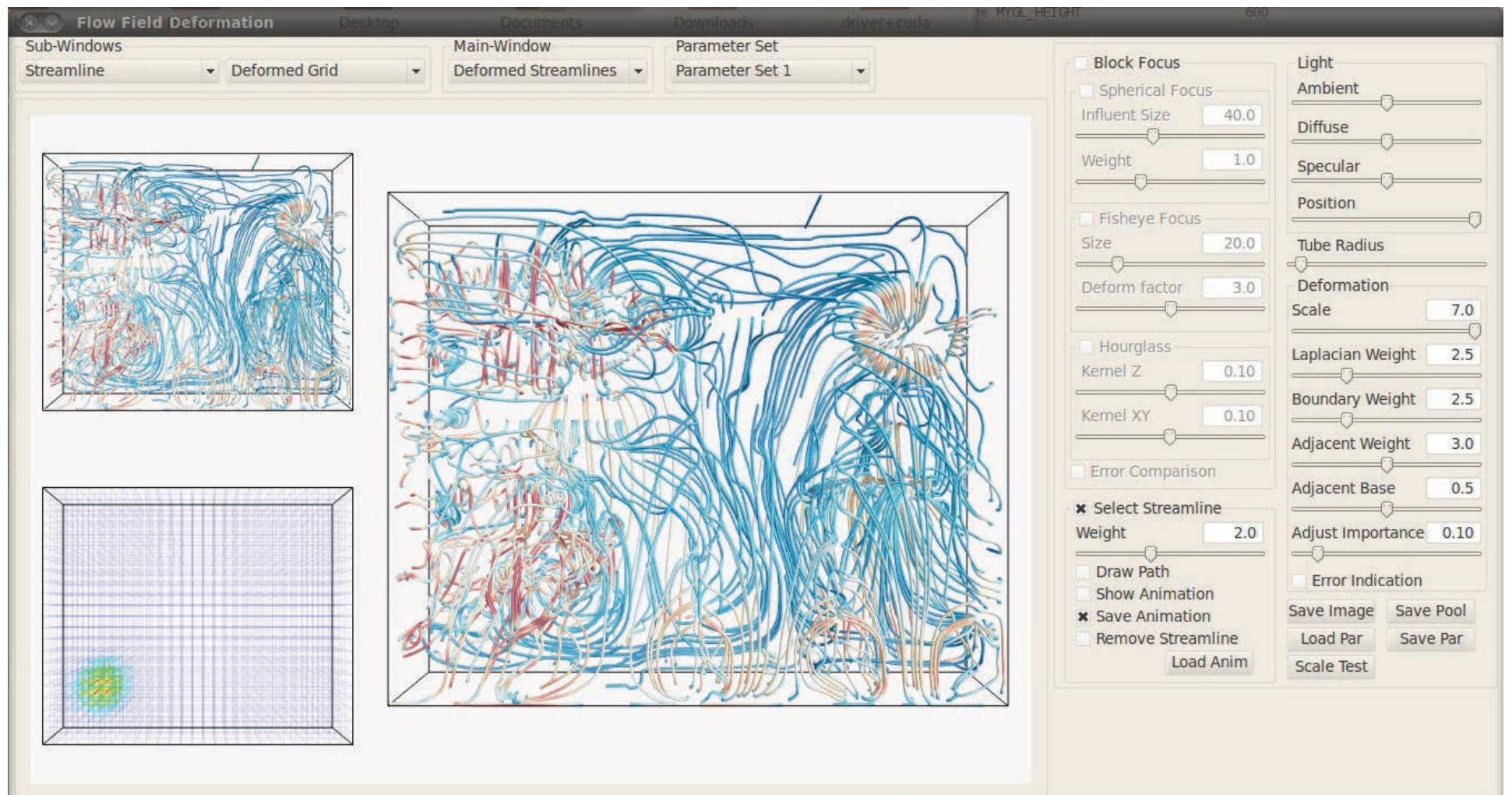
- Focus+context visualization of flow fields
- Reduce occlusion and clutter around features of interest
- Minimize the distortion around the regions of focus
- Do not vary streamline *density* but manipulate streamline *position*

Solution

- Partitioning the flow field's volume space into blocks
- Formulating block expansion and block smoothing into energy terms
- Solving for a deformed grid that minimizes the objective function
- Using the deformed blocks to guide streamline repositioning
- Leveraging a GPU linear system solver to achieve interactivity







Summary

- Changing the mind
 - Selecting *good seeds*: every streamline placed is displayed, careful seeding is the key
 - Selecting *good streamlines*: only important streamlines from a pool are selected for display, careful selection is the key
- Alternative techniques to seed placement
 - Bundling, filtering, and repositioning
 - Opacity optimization (not covered in this talk)

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