Evaluation of Features (Vortices)

Ming Jiang
Raghu Machiraju
David Thompson

SimCenter
COMPUTATIONAL
SIMULATION and DESIGN CENTER

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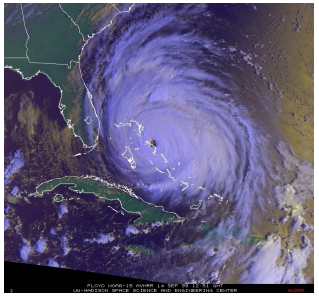
Outline

- Vortex Definitions
- Detection
- Verification
- Application - characterization

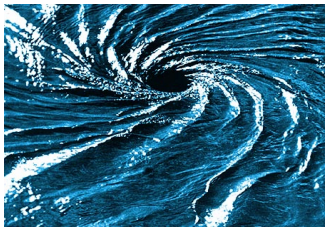
Swirling Features or Vortices

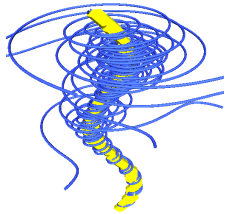


Swirling Features or Vortices

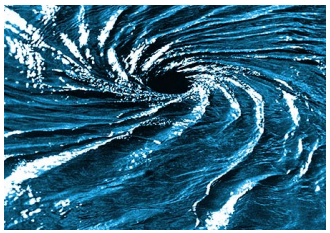
A Vortex?

- Not well defined!
- Vorticity is sufficiently strong – not enough to detect
- [Lugt ‘72]:
  - A vortex is the rotating motion of a multitude of material particles around a common center





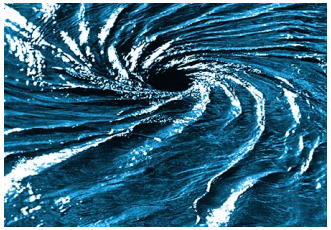
Other Definitions (1)



[Robinson ‘91]:

- A vortex exists when its streamlines, mapped onto a plane normal to its core, exhibit a circular or spiral pattern, under an appropriate reference frame

Other Definitions (2)

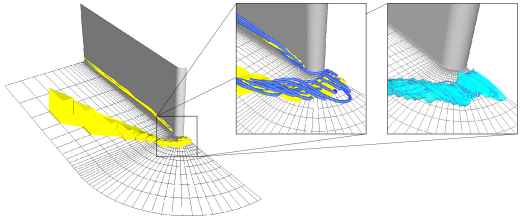


[Portela ‘97]:

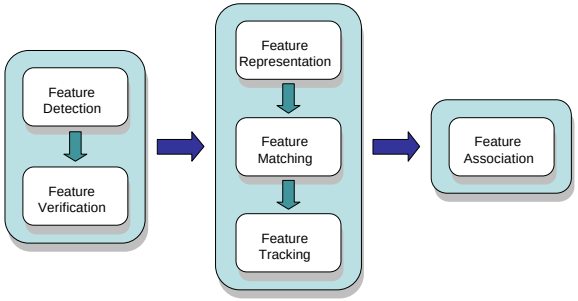
- A vortex is comprised of a central core region surrounded by swirling streamlines

Automatic Analysis

- Feature detection
- Feature verification
- Feature representation



A Full-fledged Solution

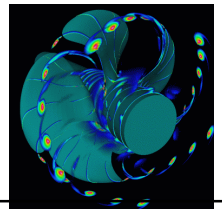


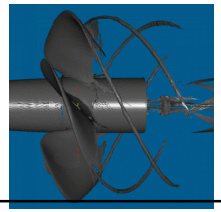
Previous Methods …

- Feature detection but not verification
- Feature tracking but poor representation
- A paucity of work on feature association
- Note:
  - Not every component is necessary for all features
  - But they are there and can be adjusted and refined

Scalar Methods

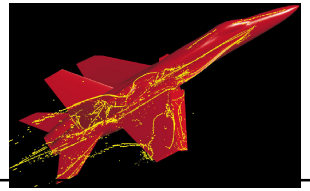
- Isosurfaces of a scalar field
  - Low-pressure region [Robinson et al. 91]
  - Normalized helicity [Levy et al. 90]
  - Swirl parameter [Berdhal and Thompson 93]
  - Lambda2 [Jeong and Hussain 95]
- Disadvantage
  - Difficulty in distinguishing individual vortices

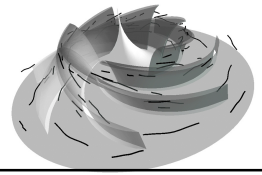




Line-Based Methods

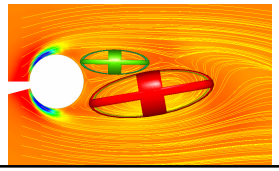
- Vorticity lines [Banks and Singer 95]
- Eigenvector method [Sujudi and Haimes 94]
- Parallel vectors method [Roth and Peikert 98]
- Disadvantage
  - Memory intensive and computationally expensive

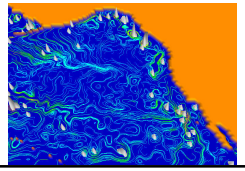




Geometry-based Methods

- 2D winding angle [Sadarjoen et al. 98]
- Curvature center density [Pagendarm et al. 99]
- Flow directional winding angle of streamlines [Portela97]
- Disadvantage
  - Inherently limited to 2D





Core Detection Algorithm

- Jiang et al., Vissym 02, Barcelona
- Local, aggregate approach based on ideas from combinatorial topology
- Its qualities are:
  - Extract individual vortex core regions
  - Simple, fast, and effective
- However, it is only heuristic and can produce false positives
- On the other hand so can almost every other method !

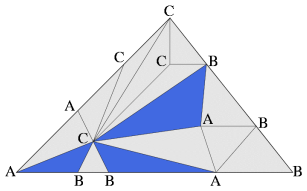
Core Detection (2)

- Really simple and very efficient!
- Point-based approach using ideas from combinatorial topology
- Sperner's Lemma:

  Every properly labeled subdivision of a simplex has an odd number of distinguished simplices
- Brouwer's Fixed Point Theorem:

  Every continuous mapping has a fixed point

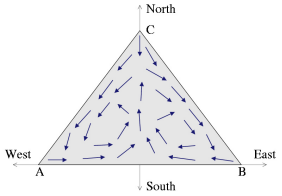
Sperner's Lemma

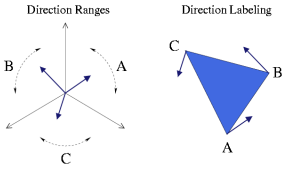


- Every Sperner labeled triangulation has an odd number of fully labeled subtriangles.
  - At least one subtriangle has all three labels: {A, B, C}
- Provided a simple and elegant proof to Brouwer's Fixed Point Theorem:
  - Every continuous mapping of a compact domain onto itself has a fixed point.

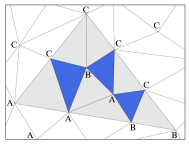
Vector Field Labeling

- Vectors can be labeled according to their directions
  - A label corresponds to a direction range
- Fully labeled subtriangle → direction spanning property
- An odd number of critical points exist in a vector field if the direction spanning property is satisfied.

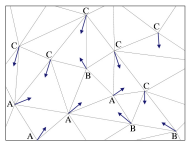




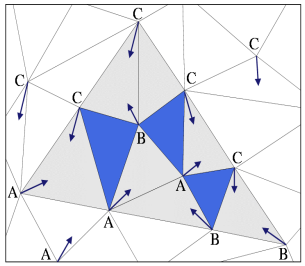
Labeling Duality



Sperner labeling of a triangulation

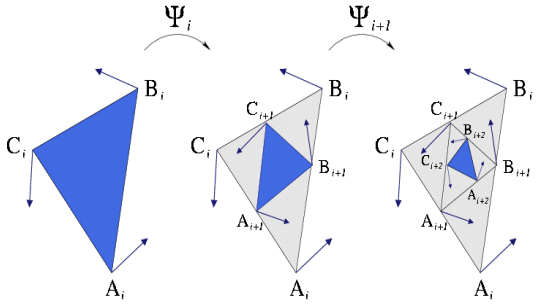


Vector labeling of an unstructured grid



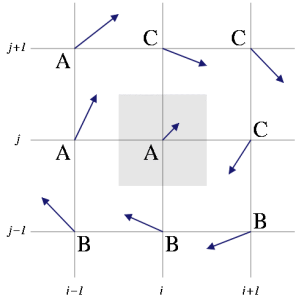
Dual labeling of the same region

Why Does It Work ?



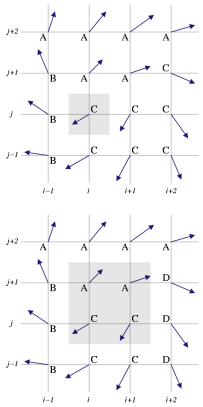
2D Algorithm

- For each grid point, examine its immediate neighbors for direction spanning property
- Possible flow types captured:
  - Switching flows
  - Swirling flows
- Topological cleanup of non-swirling regions



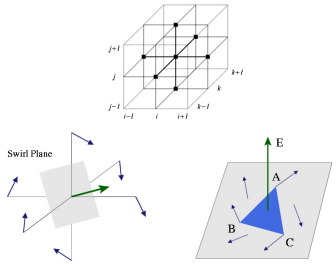
Direction Quantization

- Three direction ranges may not be sufficient!
- For N direction ranges, $\exists\ {}_N C_k$ possible direction spanning properties:
  $0 = K = N$
- Precision vs. efficiency
  - ***Not*** accuracy vs. efficiency
- Accommodates for the discrete nature of the datasets



3D Algorithm

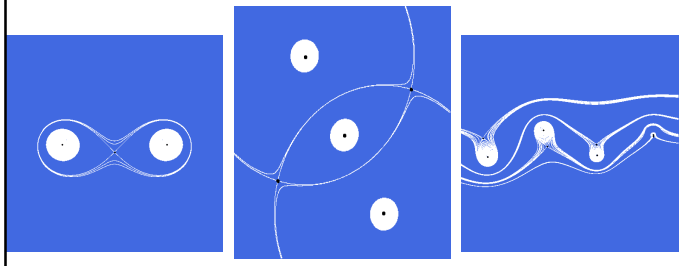
- Must compute the core direction *a priori*
  - Vorticity vector (cheap)
  - Real eigenvector (expensive)
- Combinatorially, check for fully labeled tetrahedrons
  - Project immediate neighbors onto the swirl plane
- Direction quantization → robustness to variations in core direction



Algorithm Outline

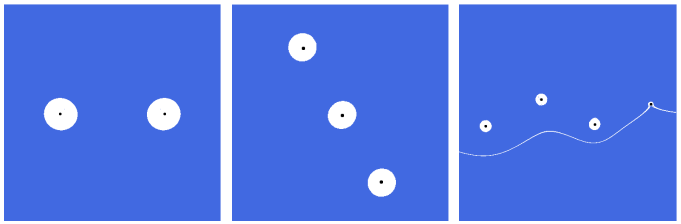
```
1: for all grid cells do
2:    compute swirl plane normal n at cell center
3:    project v from surrounding nodes
4:    for all v_p in swirl plane do
5:       compute its angle α from local x-axis
6:       label direction range for α
7:    end for
8:    if all direction ranges are labeled then
9:       mark grid cell as vortex core
10:   end if
11: end for
```

2D Results



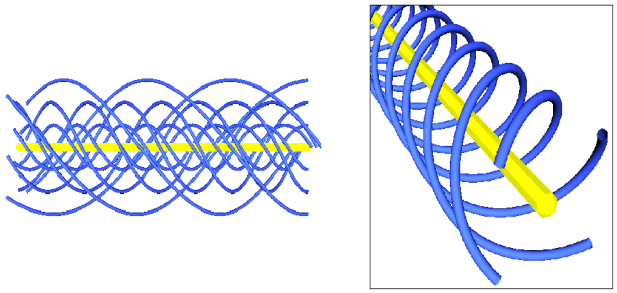
Rankine vortices | LIC dataset | Wake simulation

2D Topological Cleanup



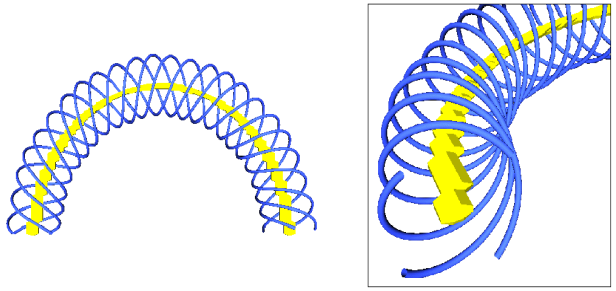
Rankine vortices | LIC dataset | Wake simulation

3D Results



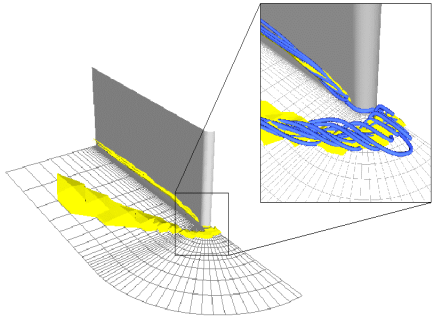
3D Rankine vortex

3D Results



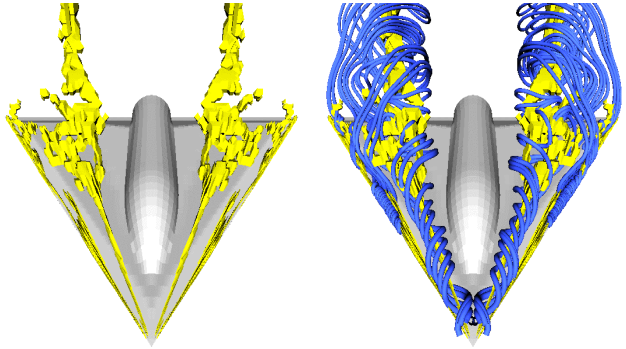
Bent helical vortex

Blunt Fin Dataset



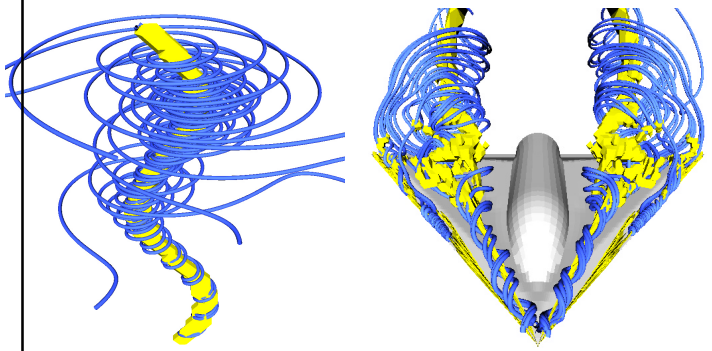
Blunt fin on flat plate

Delta Wing Dataset



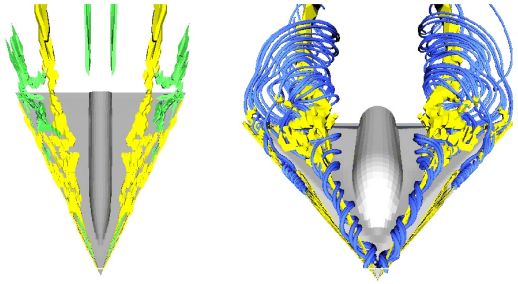
Delta wing from NASA

Verification - Visual Inspection



Did I get the correct ones ?

False Positives



Yellow: Good, Green:Bad

Yellow ones really swirl !

Green ones do not !

Feature Verification

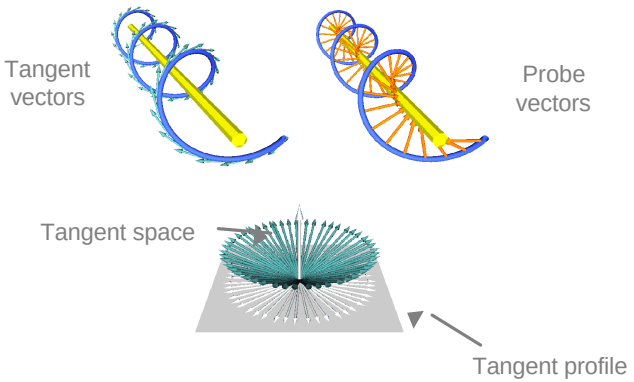
No formal definition → No formal verification

- Human visual inspection
  - Swirling streamlines
  - Contrary to automatic detection
  - Infeasible for large-scale datasets

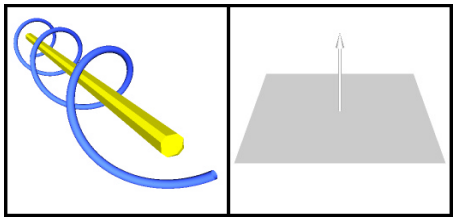
Automatic Verification

- Automate visual inspection process
  - Identify swirling streamlines
  - Eliminate false positives
- [Portela 97 and Sadarjoen 98] approach:
  - 2π swirling criterion
  - Sufficient for 2D vortices
  - Incomplete for 3D vortices
- 3D verification – Jiang et al. Vis02

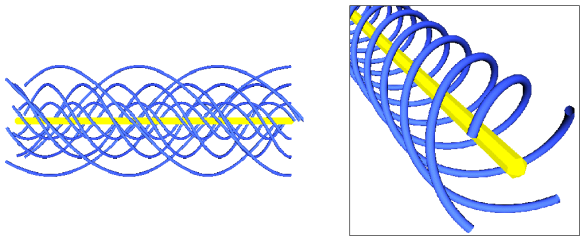
Verification Process



2π Swirling Criterion

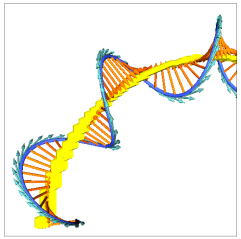


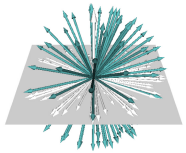
3D Rankine Vortex



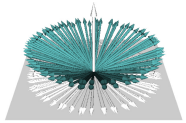
- Concentrated vorticity in its core region
- Decay of circumferential velocity

Tangential Alignment





No alignment

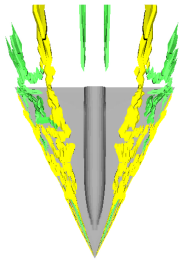


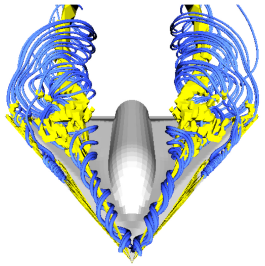
With alignment

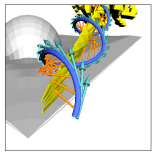
Verification Algorithm

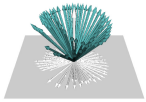
```
1: uniformly distribute seed points at start position
2: for all seed points do
3:   for i = 0 to N do
4:     trace next streampoint
5:     compute tangent vector t and probe vector
6:     probe vortex core for swirl plane normal n
7:     align n to z-axis and save transformation
8:     apply transformation to t → t_a
9:     project t_a on (x,y)-plane → t_p
10:    if ∠(t_p^0, t_p^i) ≥ 2π then
11:      accept candidate vortex core
12:    end if
13:  end for
14: end for
```

Delta Wing Dataset

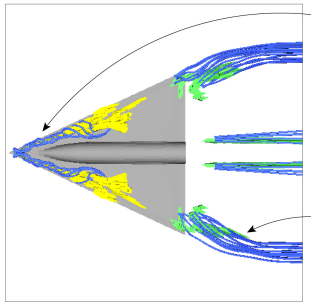


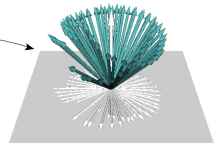




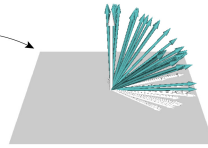


Eliminating False Positives



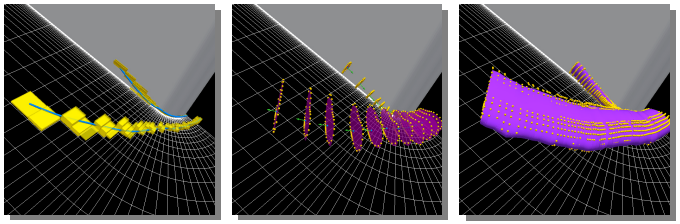


2π



0.5π

Application: Characterization

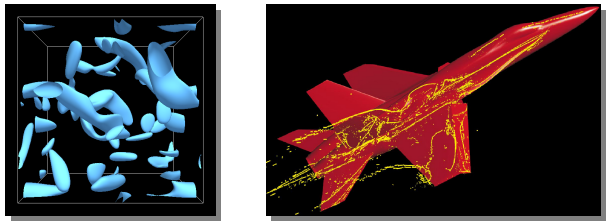


Step 1
Hybrid Framework
Core Path Extraction

Step 2
Radial Marching
Max. Tangential Velocity

Step 3
Ellipse Fitting
Attribute Computation

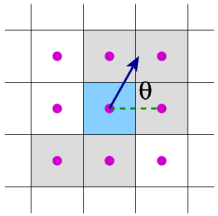
Core Line Extraction



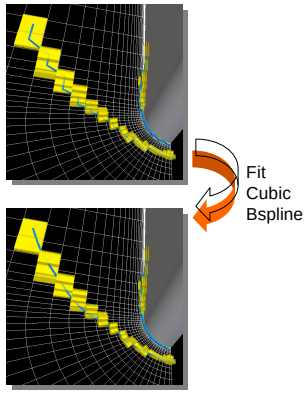
Region-based approach:
Contiguous
No sense of direction

Line-based approach:
Sense of direction
Not contiguous

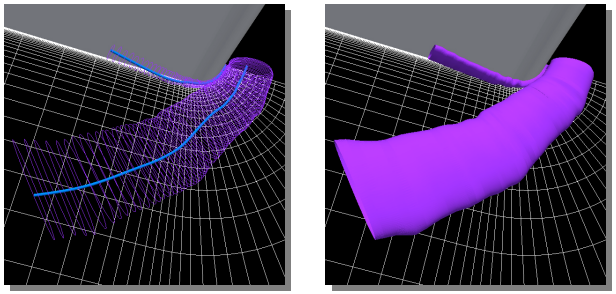
Hybrid Framework



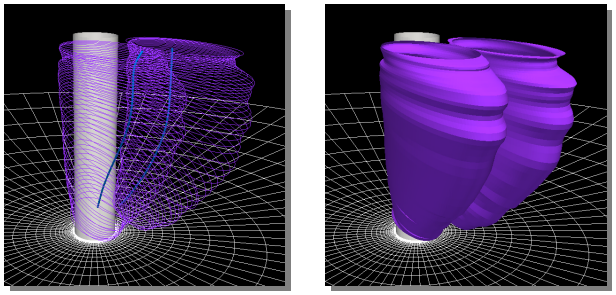
Extraction Algorithm:
For N iterations
Start with seed point
Trace both directions
Search more neighbors



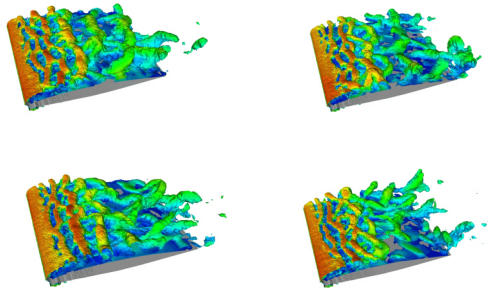
Surface Generation



Oxygen Post Dataset

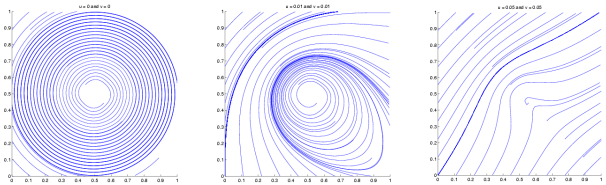


Work Not Done – Unsteady Flows



More Work is Needed …

- Modify detection algorithm
  - Require Galilean invariance
  - Properly handle unsteady flow fields



Research Directions

- Verification
  - Seeding and continuation strategies
  - Include dynamics
  - Unsteady flows
  - Apply it more detection algorithms
- Characterization
  - Robust extraction
  - Use of dynamical characteristics
- Develop feature matching algorithm
  - Efficiency is the key to feature tracking
  - Build on top of shape-based representation
  - Use parameter space matching
- Develop feature association mining
  - Gain new insights into evolutionary phenomena
  - Analyze feature-to-feature interactions
  - Discover physical laws governing such behavior
  - Mine frequent patterns in time-varying datasets

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Thank You