



# **CS 247 – Scientific Visualization**

## **Lecture 19: Vector Field / Flow Visualization, Pt.1**

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# Reading Assignment #10 (until Apr 19)



## Read (required):

- Real-Time Volume Graphics, Chapter 10  
(Transfer Functions Reloaded)
- Paper:  
*Joe Kniss, Gordon Kindlmann, Charles Hansen,*  
Multidimensional Transfer Functions for Interactive Volume Rendering, *IEEE Transactions on Visualization and Comp. Graph. (TVCG) 2002*  
<https://ieeexplore.ieee.org/document/1021579>

## Read (optional):

- Real-Time Volume Graphics, Chapter 14  
(Non-Photorealistic and Illustrative Techniques)

# Quiz #2: Apr 19



## Organization

- First 30 min of lecture
- No material (book, notes, ...) allowed

## Content of questions

- Lectures (both actual lectures and slides)
- Reading assignments (except optional ones)
- Programming assignments (algorithms, methods)
- Solve short practical examples

# Vector / Flow Visualization

# Online Demos and Info



Numerical ODE integration methods (Euler vs. Runge Kutta, etc.)

[https://demonstrations.wolfram.com/  
NumericalMethodsForDifferentialEquations/](https://demonstrations.wolfram.com/NumericalMethodsForDifferentialEquations/)

Flow visualization concepts

<https://www3.nd.edu/~cwang11/flowvis.html>

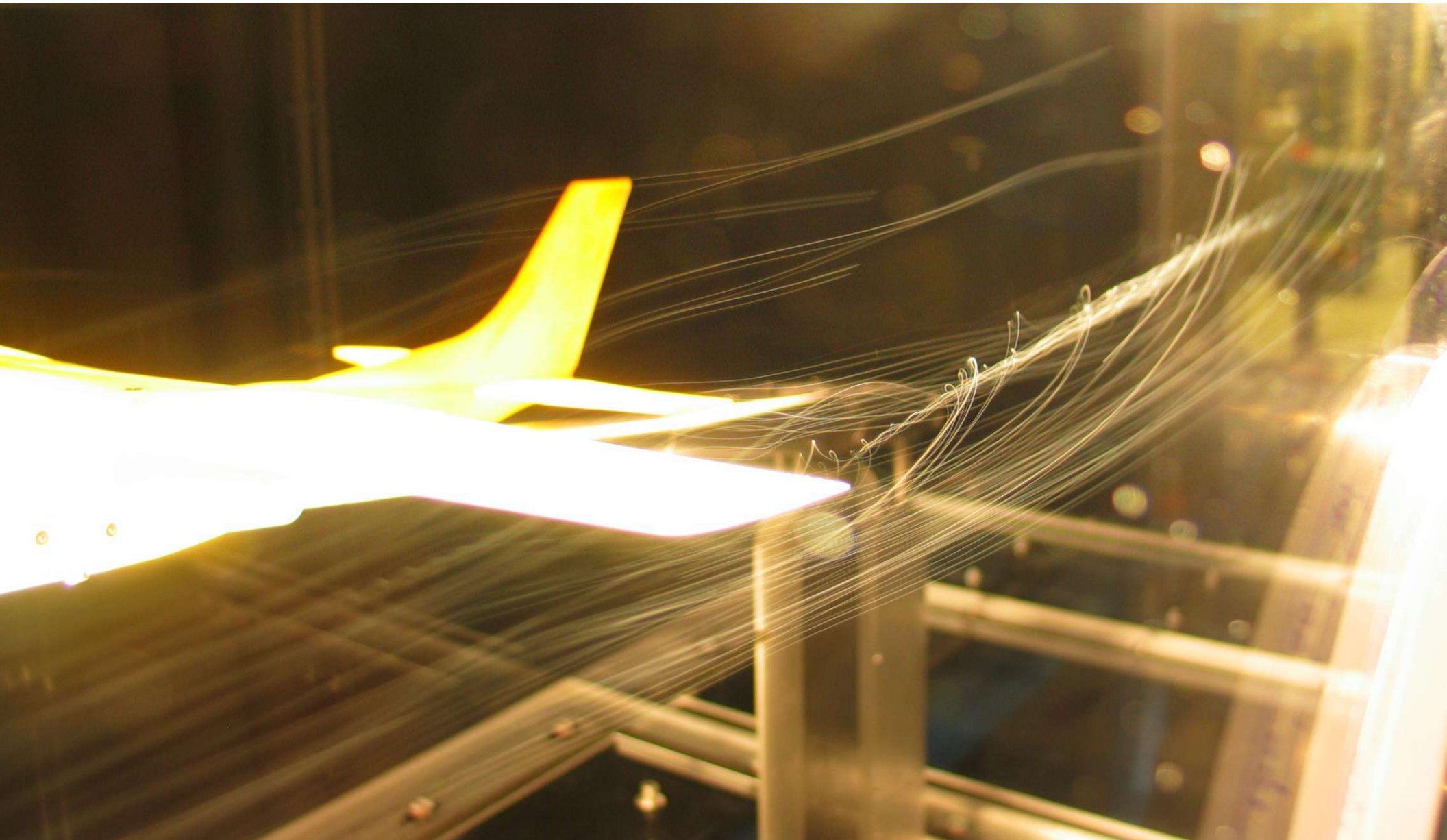
# Vector Fields: Motivation



### **Smoke angel**

A C-17 Globemaster III from the 14th Airlift Squadron, Charleston Air Force Base, S.C. flies off after releasing flares over the Atlantic Ocean near Charleston, S.C., during a training mission on Tuesday, May 16, 2006. The "smoke angel" is caused by the vortex from the engines.

(U.S. Air Force photo/Tech. Sgt. Russell E. Cooley IV)



A wind tunnel model of a Cessna 182 showing a wingtip vortex.  
Tested in the RPI (Rensselaer Polytechnic Institute) Subsonic Wind Tunnel.  
By Ben FrantzDale (2007).



wool tufts





smoke injection



[http://autospeed.com/cms/A\\_108677/article.html](http://autospeed.com/cms/A_108677/article.html)

smoke nozzles



[NASA, J. Exp. Biol.]



[http://autospeed.com/cms/A\\_108677/article.html](http://autospeed.com/cms/A_108677/article.html)

smoke nozzles

## Smoke injection

A. L. R. Thomas, G. K. Taylor, R. B. Srygley, R. L. Nudds, and R. J. Bomphrey. Dragonfly flight: free-flight and tethered flow visualizations reveal a diverse array of unsteady lift-generating mechanisms, controlled primarily via angle of attack. *J Exp Biol*, 207(24):4299–4323, 2004.



[http://de.wikipedia.org/wiki/Bild:Airplane\\_vortex\\_edit.jpg](http://de.wikipedia.org/wiki/Bild:Airplane_vortex_edit.jpg)

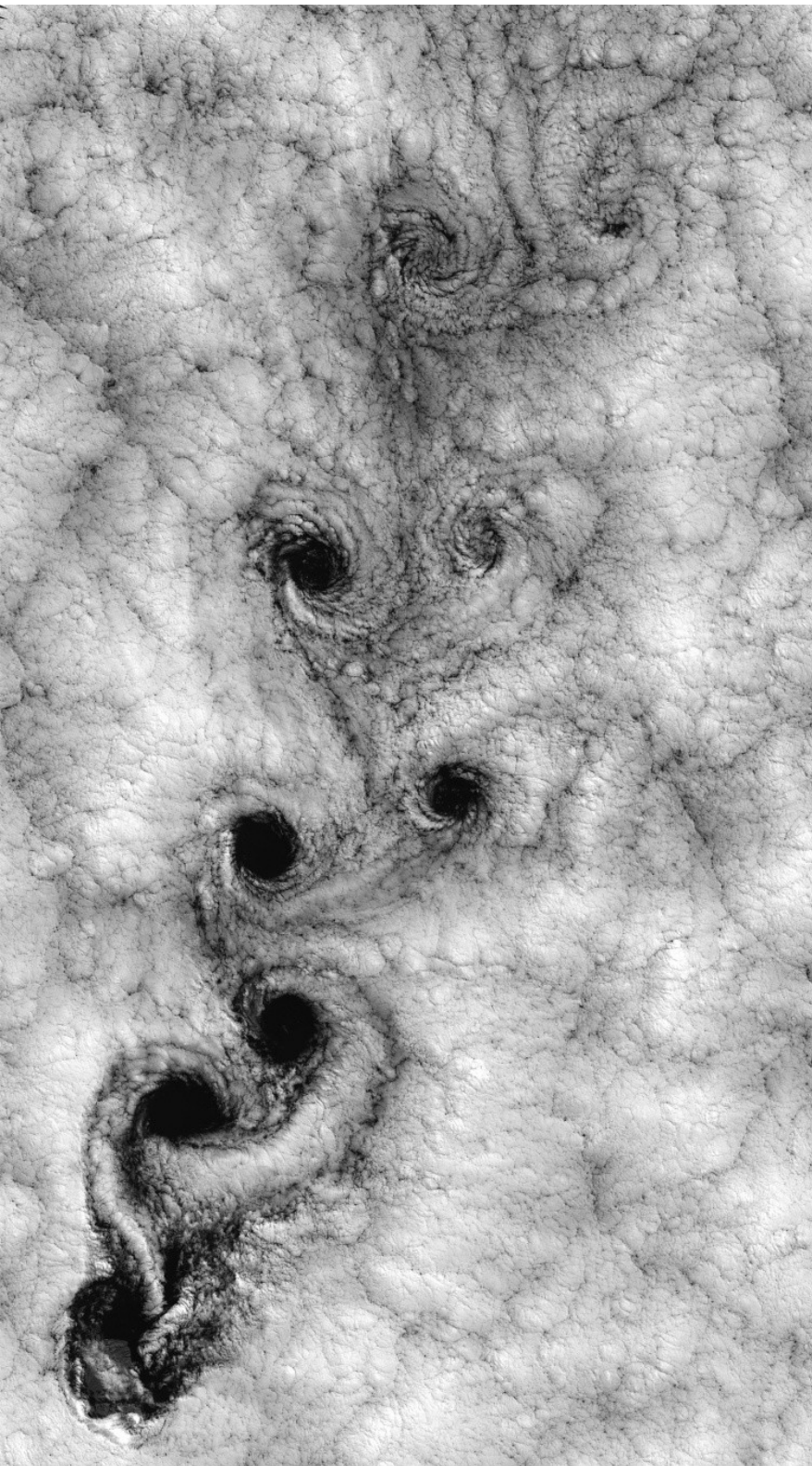
*Flow Visualization: Problems and Concepts*





## Smoke injection

<http://www-me.cuny.cuny.edu/research/aerolab/facilities/images/wt2.jpg>



Clouds (satellite image)

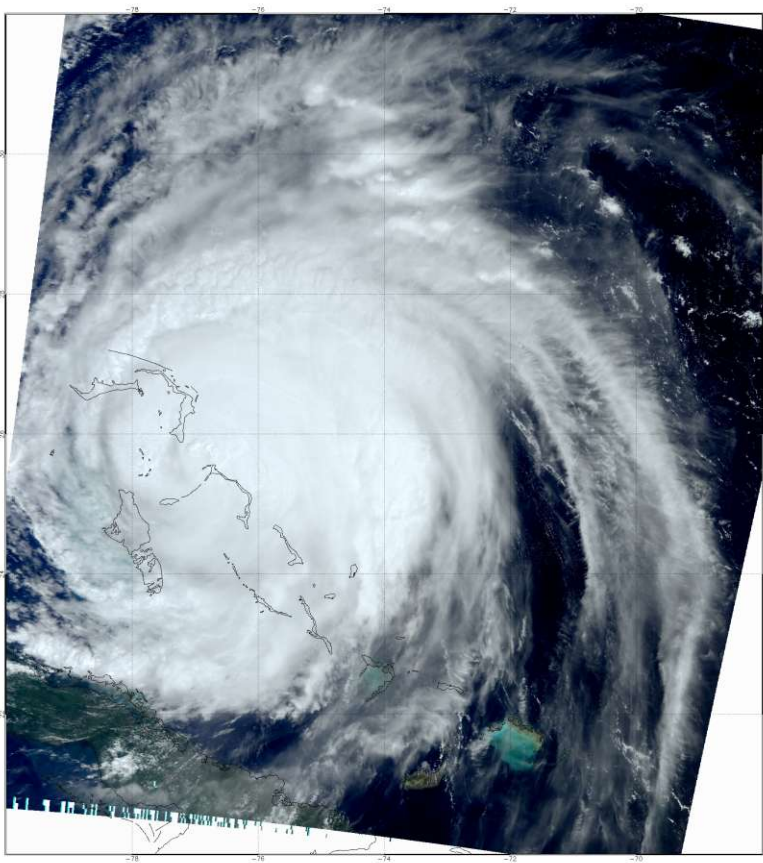
*Juan Fernandez Islands*

<http://de.wikipedia.org/wiki/Bild:Vortex-street-1.jpg>

*d University, Winter 2011/12*

## Clouds (satellite image)

<http://daac.gsfc.nasa.gov/gallery/frances/>



- **Vortex/ Vortex core lines**
  - There is no exact definition of vortices
  - capturing some swirling behavior



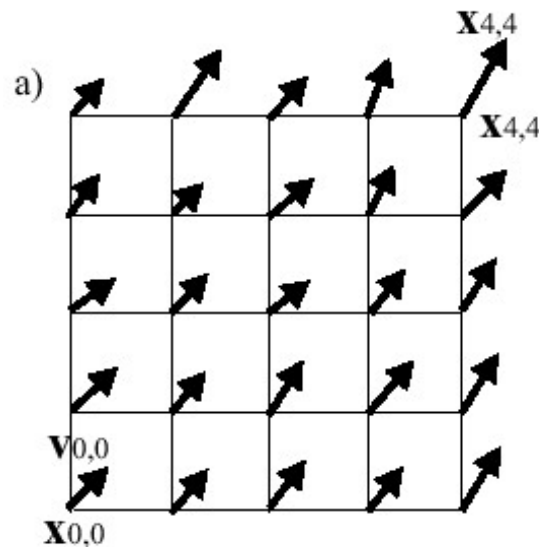
# Vector Fields



Each vector is usually thought of as a velocity vector

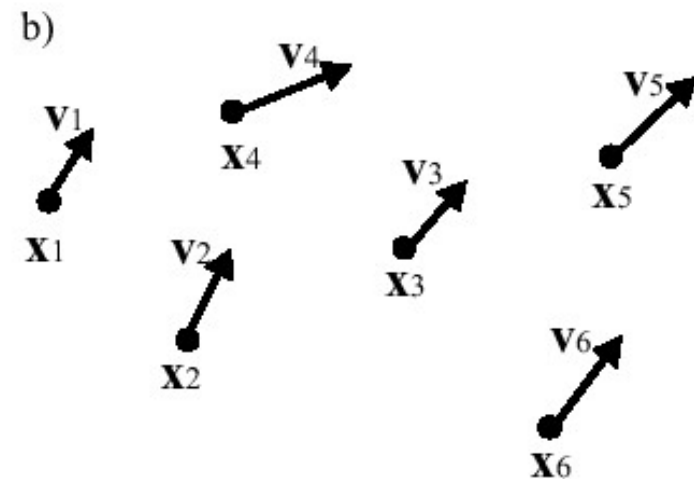
- Example for actual velocity: fluid flow
- But also force fields, etc. (e.g., electrostatic field)

**Eulerian** specification:



vectors given at grid points  
(grid points **do not** move)

**Lagrangian** specification:



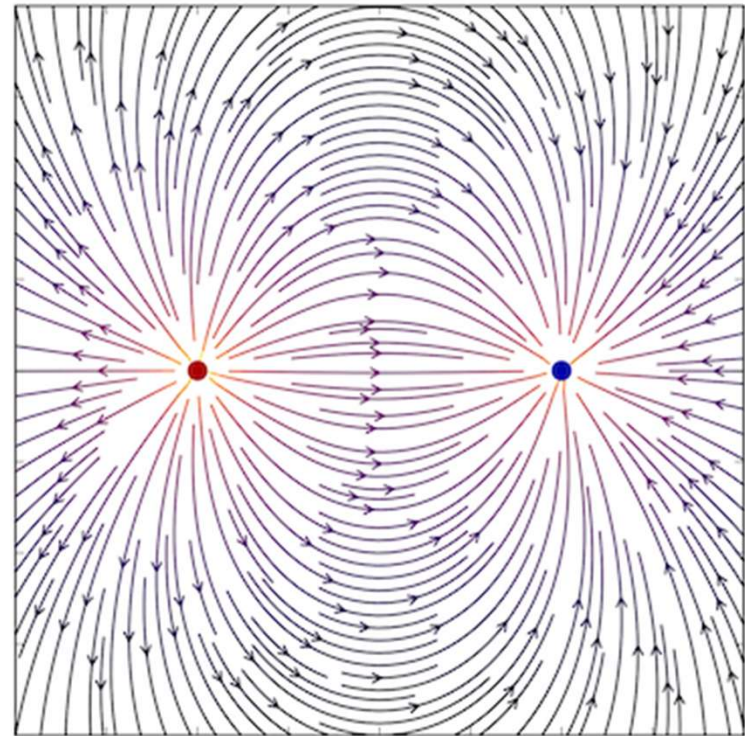
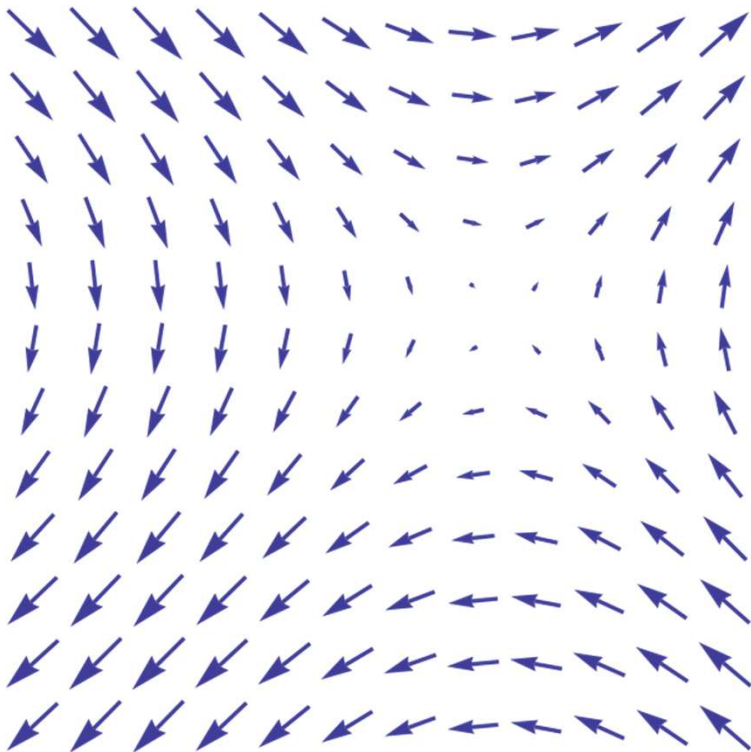
vectors given at particle positions  
(particle positions **do** move)

# Vector Fields



Each vector is usually thought of as a velocity vector

- Example for actual velocity: fluid flow
- But also force fields, etc. (e.g., electrostatic field)

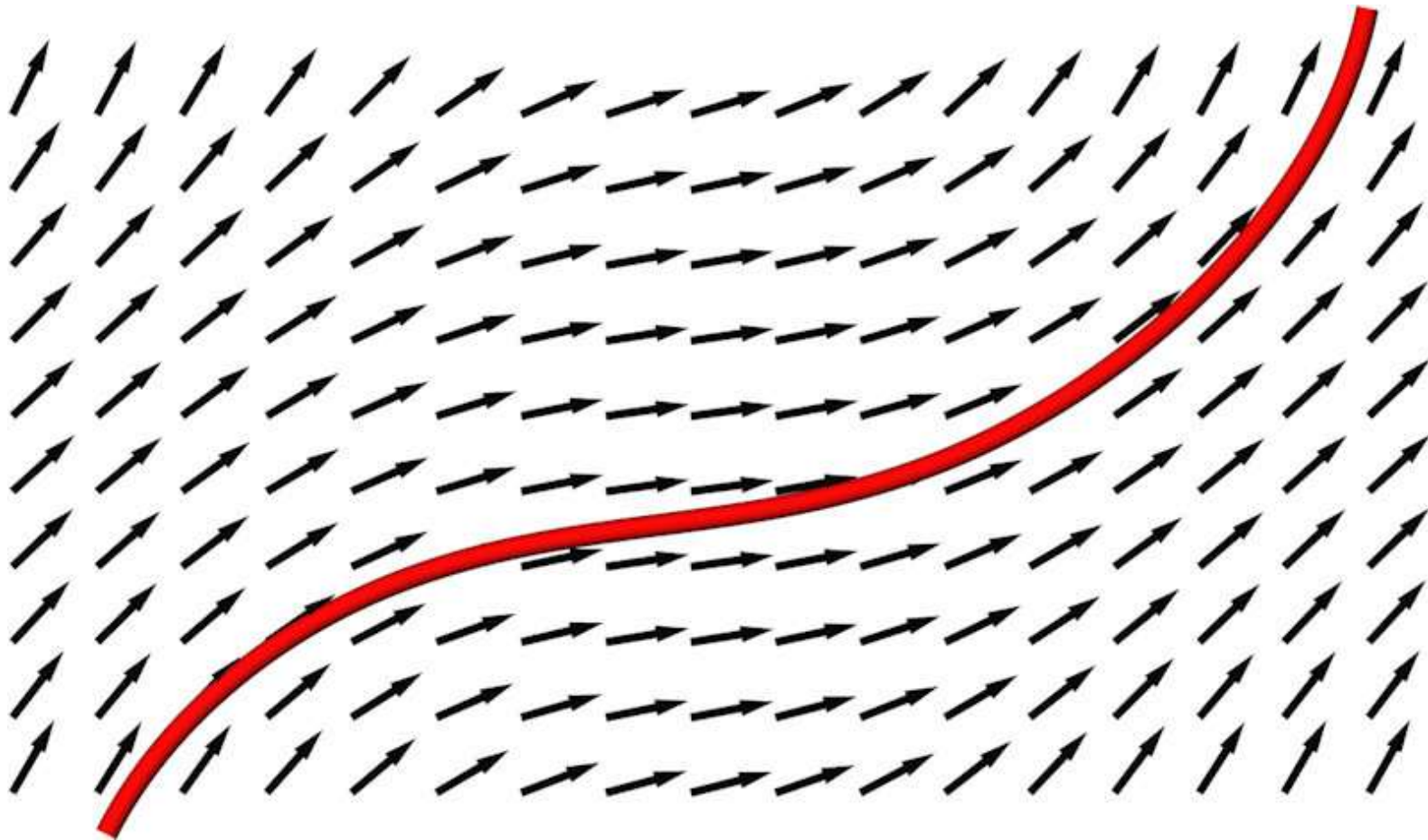


images from wikipedia

# Integral Curves / Stream Objects



Integrating velocity over time yields spatial motion



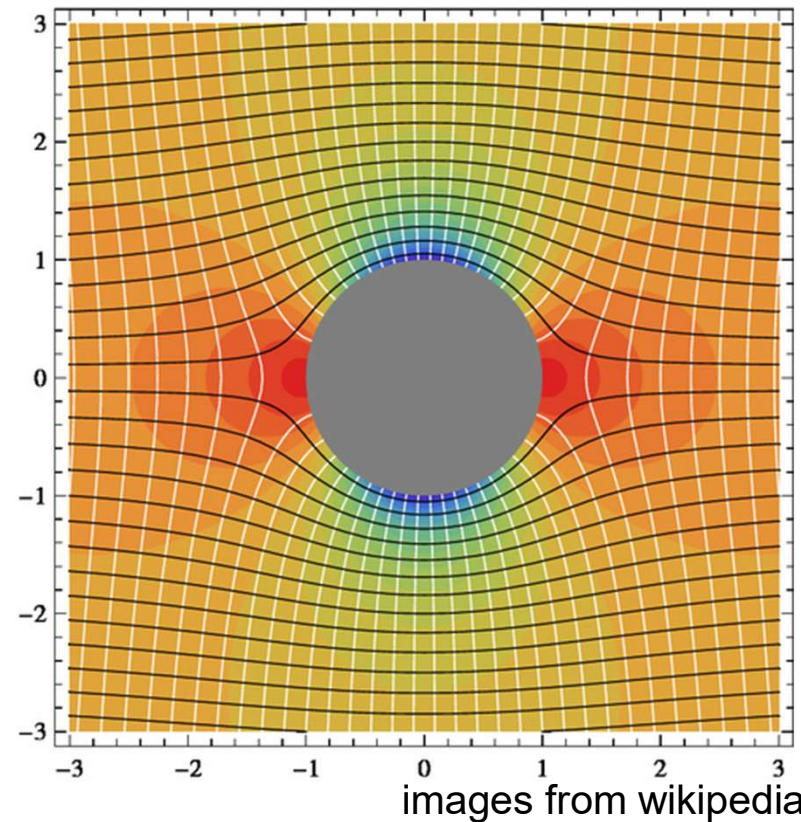
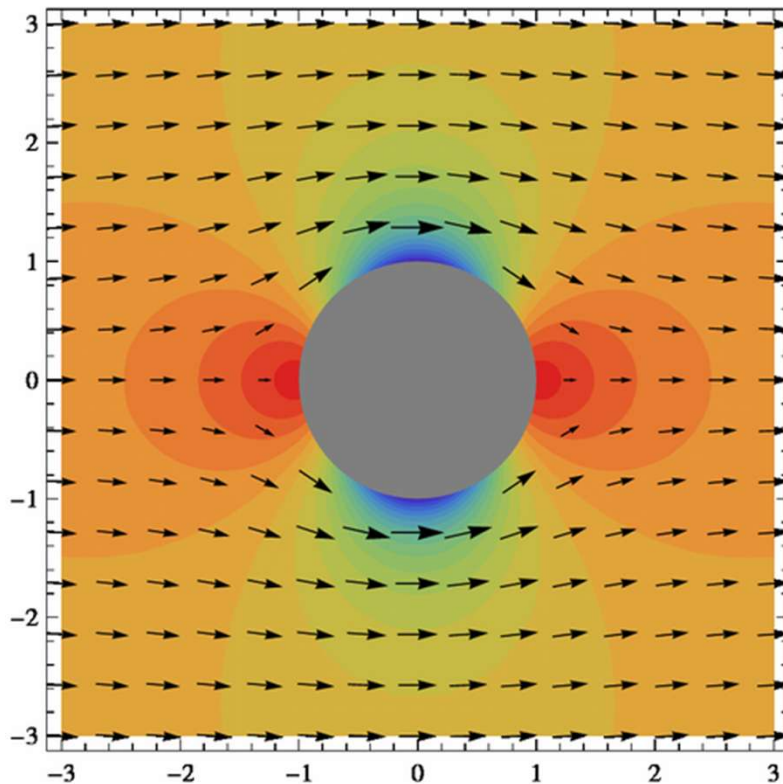
# Flow Field Example (1)



## Potential flow around a circular cylinder

[https://en.wikipedia.org/wiki/Potential\\_flow\\_around\\_a\\_circular\\_cylinder](https://en.wikipedia.org/wiki/Potential_flow_around_a_circular_cylinder)

Inviscid, incompressible flow that is irrotational (curl-free) and can be modeled as the gradient of a scalar function called the (scalar) velocity potential



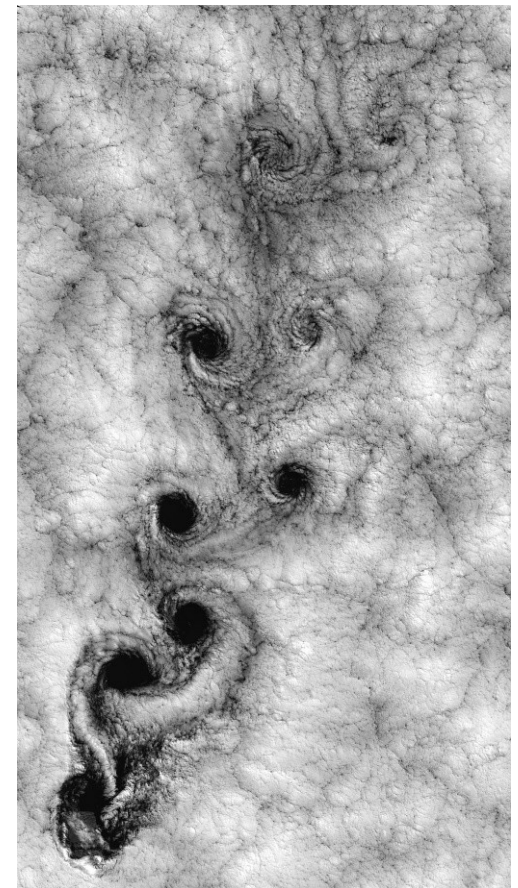
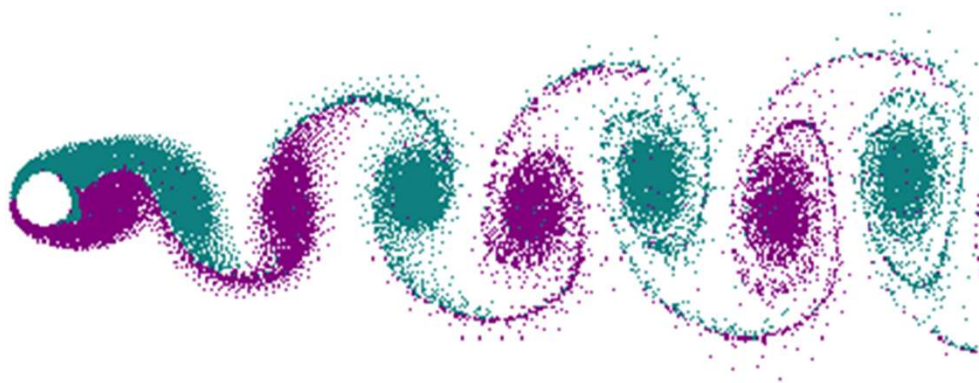
# Flow Field Example (2)



Depending on Reynolds number, turbulence will develop

Example: von Kármán vortex street: vortex shedding

[https://en.wikipedia.org/wiki/Karman\\_vortex\\_street](https://en.wikipedia.org/wiki/Karman_vortex_street)



images from wikipedia

# Vector Fields



Each vector is usually thought of as a velocity vector

- Example for actual velocity: fluid flow
- But also force fields, etc. (e.g., electrostatic field)

Each vector in a vector field lives in the **tangent space** of the manifold at that point:

Each vector is a **tangent vector**

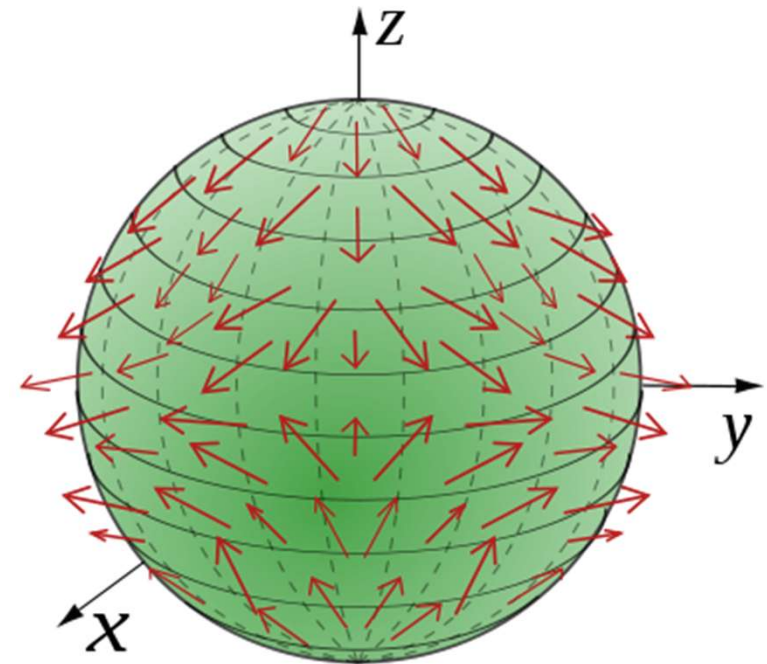
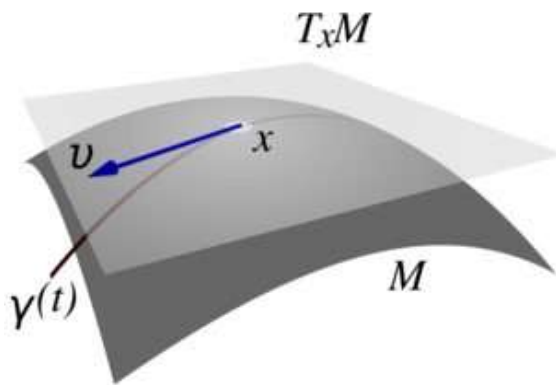


image from wikipedia

# Vector Fields



Vector fields on general manifolds  $M$  (not just Euclidean space)

*Tangent space* at a point  $x \in M$ :

$$T_x M$$

*Tangent bundle*: Manifold of all tangent spaces over base manifold

$$\pi: TM \rightarrow M$$

Vector field: *Section* of tangent bundle

$$s: M \rightarrow TM,$$

$$x \mapsto s(x).$$

$$\pi(s(x)) = x$$

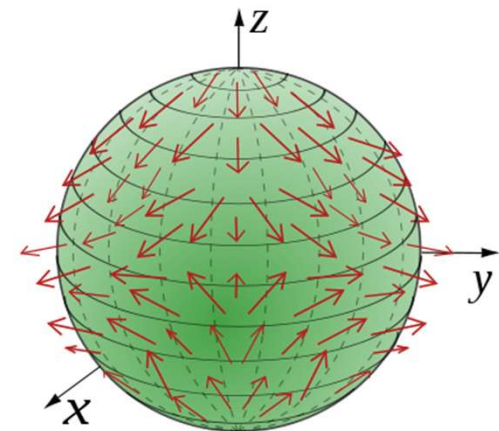
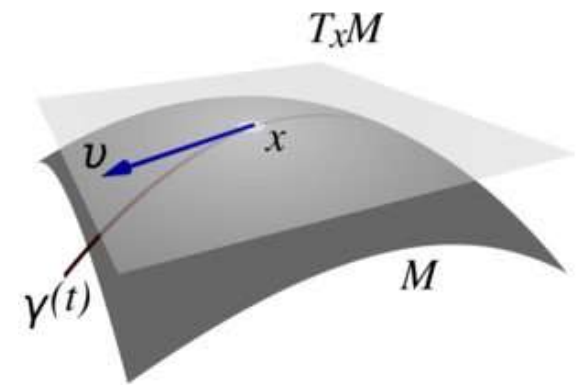


image from wikipedia

# Vector Fields



Vector fields on general manifolds  $M$  (not just Euclidean space)

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*Tangent bundle*: Manifold of all tangent spaces over base manifold

$$\pi: TM \rightarrow M$$

Vector field: *Section* of tangent bundle

$$\begin{aligned} \mathbf{v}: M &\rightarrow TM, \\ x &\mapsto \mathbf{v}(x). \end{aligned} \quad \mathbf{v}(x) \in T_x M$$

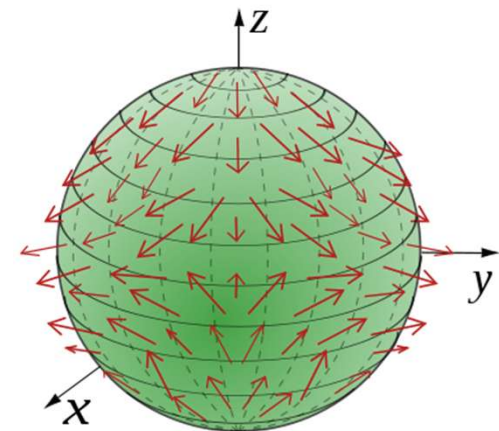
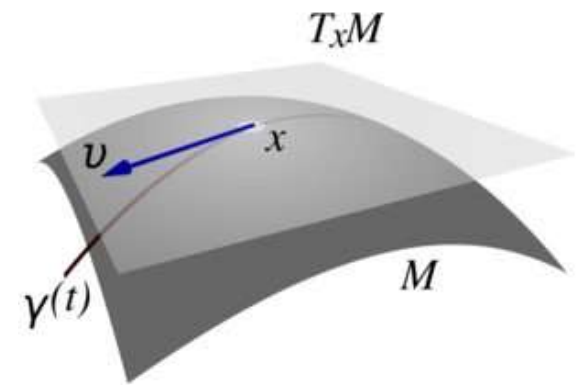


image from wikipedia

## Vector fields

A **static vector field**  $\mathbf{v}(\mathbf{x})$  is a vector-valued function of space.

A **time-dependent vector field**  $\mathbf{v}(\mathbf{x}, t)$  depends also on time.

In the case of **velocity** fields, the terms **steady** and **unsteady flow** are used.

The dimensions of  $\mathbf{x}$  and  $\mathbf{v}$  are equal, often 2 or 3, and we denote components by  $x, y, z$  and  $u, v, w$ :

$$\mathbf{x} = (x, y, z), \quad \mathbf{v} = (u, v, w)$$

Sometimes a vector field is defined on a surface  $\mathbf{x}(i, j)$ . The vector field is then a function of parameters and time:

$$\mathbf{v}(i, j, t)$$

# Steady vs. Unsteady Flow



- Steady flow: time-independent

- Flow itself is static over time:

$$\mathbf{v}(\mathbf{x})$$

$$\mathbf{v}: \mathbb{R}^n \rightarrow \mathbb{R}^n,$$

- Example: laminar flows

$$x \mapsto \mathbf{v}(x).$$

- Unsteady flow: time-dependent

- Flow itself changes over time:

$$\mathbf{v}(\mathbf{x}, t)$$

$$\mathbf{v}: \mathbb{R}^n \times \mathbb{R} \rightarrow \mathbb{R}^n,$$

- Example: turbulent flows

$$(x, t) \mapsto \mathbf{v}(x, t).$$

(here just for Euclidean domain; analogous on general manifolds)

# Steady vs. Unsteady Flow



- Steady flow: time-independent

- Flow itself is static over time:

$$\mathbf{v}(\mathbf{x})$$

$$\mathbf{v}: M \rightarrow \mathbb{R}^n,$$

- Example: laminar flows

$$x \mapsto \mathbf{v}(x).$$

- Unsteady flow: time-dependent

- Flow itself changes over time:

$$\mathbf{v}(\mathbf{x}, t)$$

$$\mathbf{v}: M \times \mathbb{R} \rightarrow \mathbb{R}^n,$$

- Example: turbulent flows

$$(x, t) \mapsto \mathbf{v}(x, t).$$

(here now for general manifolds)

# Thank you.

## Thanks for material

- Helwig Hauser
- Eduard Gröller
- Daniel Weiskopf
- Torsten Möller
- Ronny Peikert
- Philipp Muigg
- Christof Rezk-Salama