Vector Field Visualisation

Computer Animation and Visualization
Lecture 14

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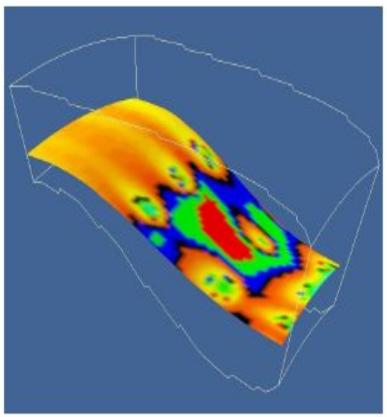
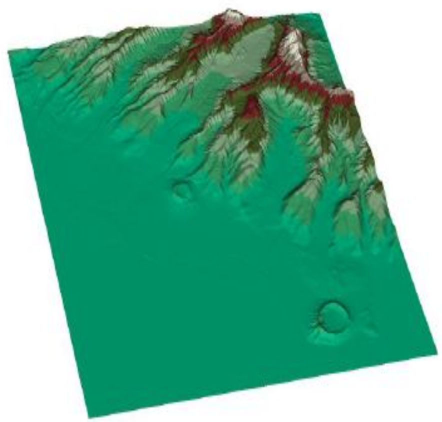
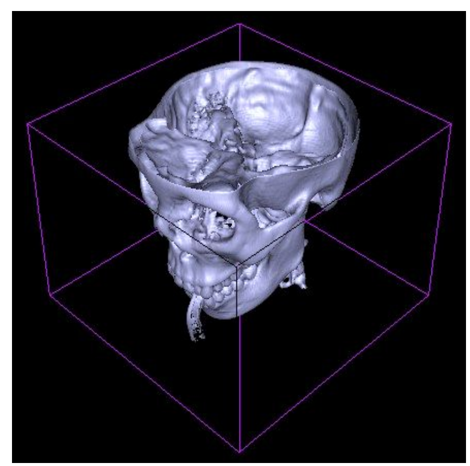
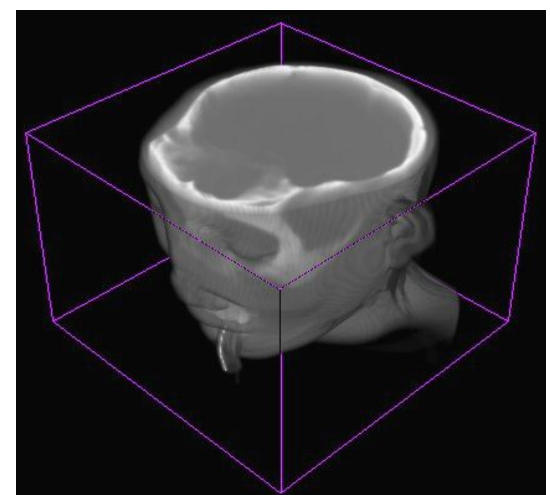
Up-to-now

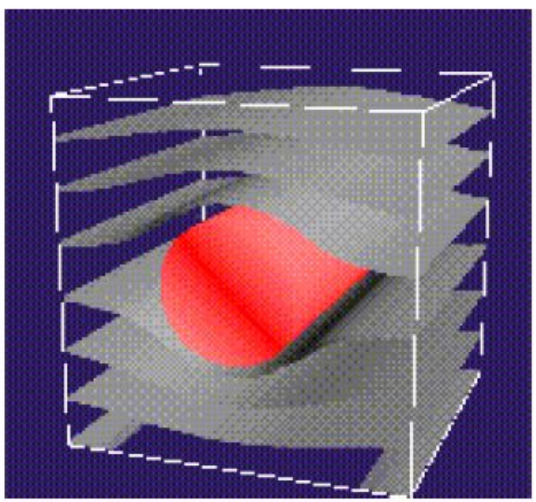
- Visualising scalar fields : 1D attributes at the sample points

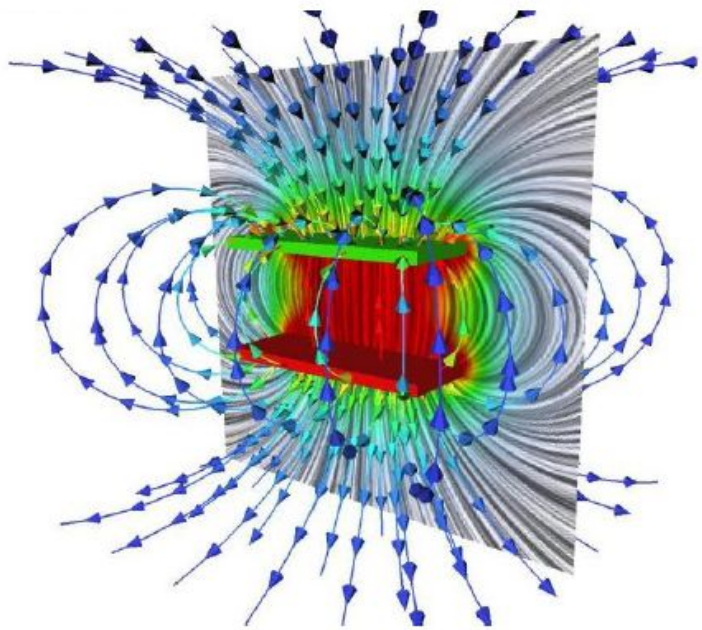
Today: Vector fields

- Visualising vector fields : 2D/3D/nD attributes at the sample points

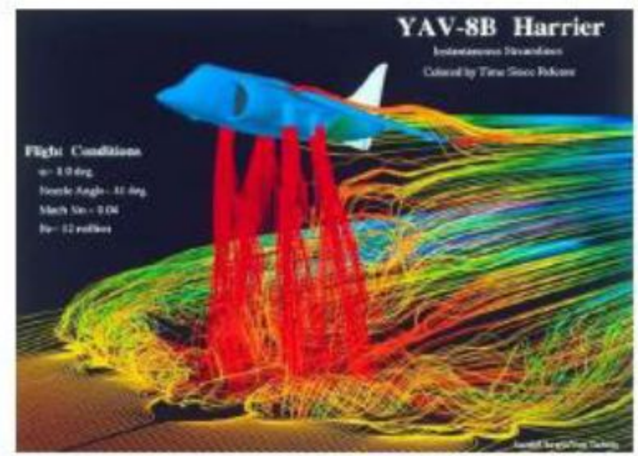
- **Magnitude and direction** at each location
  - 3D triplet of values *(i, j, k)*



Force / Displacement



Magnetic Field

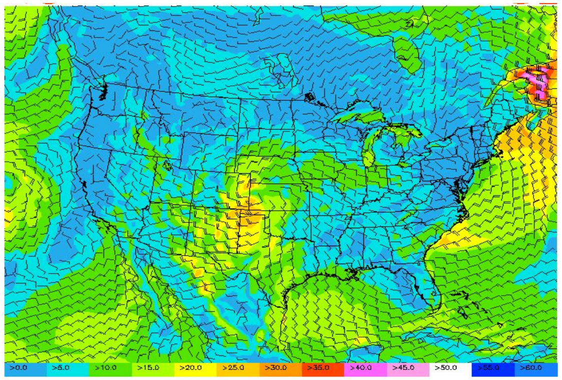


Wind Speed

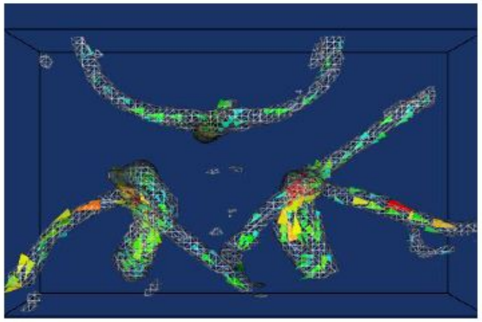
Overview

- **Vector field visualisation**
  - Local View
    - Warping
    - Glyphs
  - Global View
    - Pathline, Streakline, Streamline
    - Integration
    - Stream surface, Stream volume
  - Line Integral Convolution

Visualising Vectors

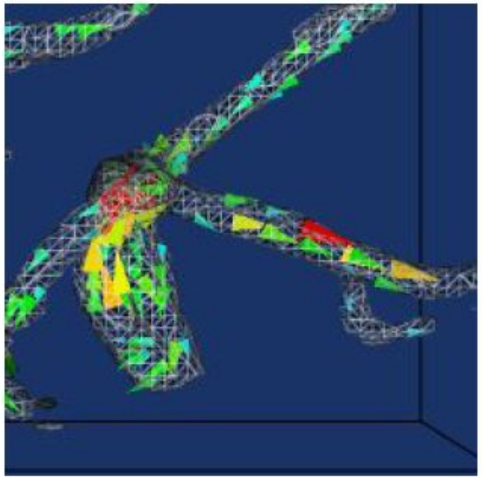


- Examples of vector data:
  - meteorological analyses / simulation
  - medical blood flow measurement
  - Computational simulation of flow over aircraft, ships, submarines etc.
  - Derivatives of a scalar field



- **Why is visualising these difficult ?**
  - **2 or 3 components per data point, temporal aspects of vector flow, vector density**

Two Methods of Flow Visualisation

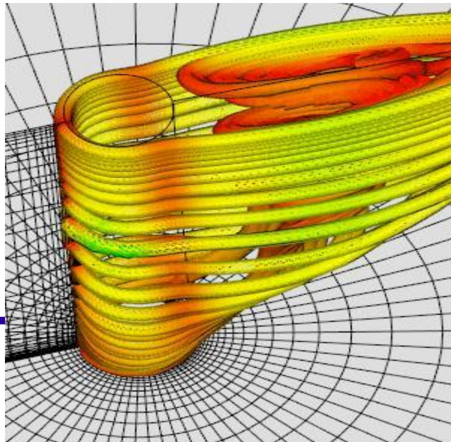


- **Local View** of the vector field
  - Visualise Flow **wrt fixed point**

local direction and magnitude

e.g. for given location, what is the current wind strength and direction

- **Global view of vector field**
  - **Visualise flow as the trajectory of a particles transported by the flow**

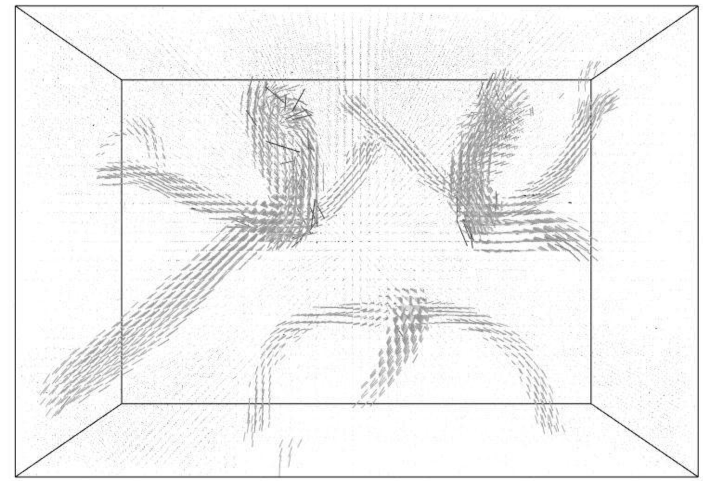


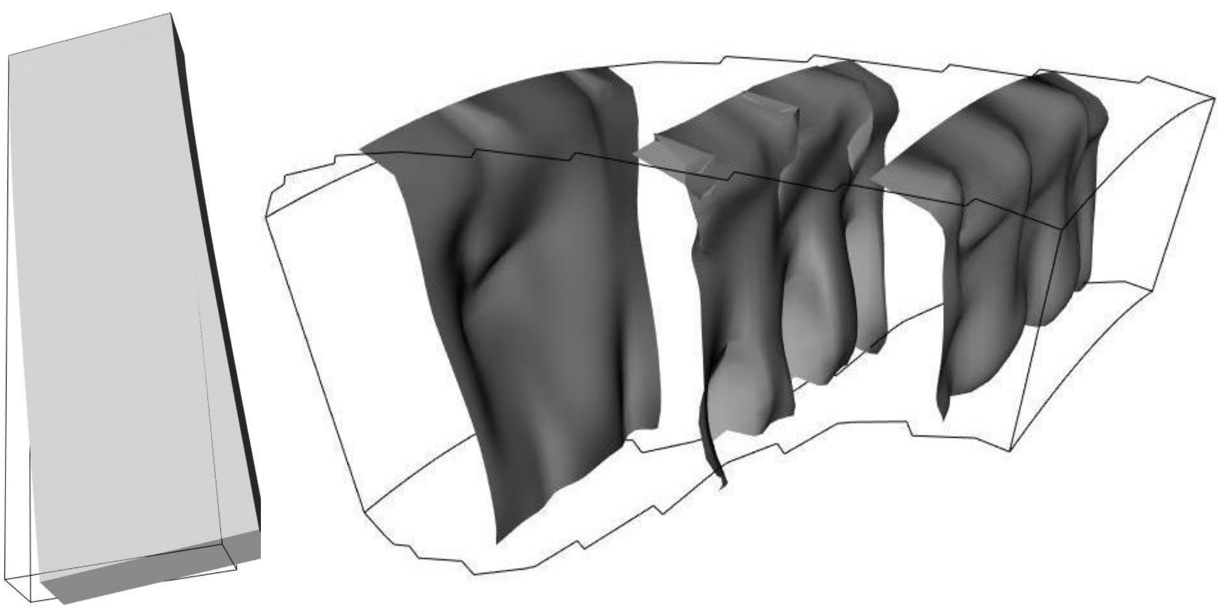
a given location, where has the wind flow come from,

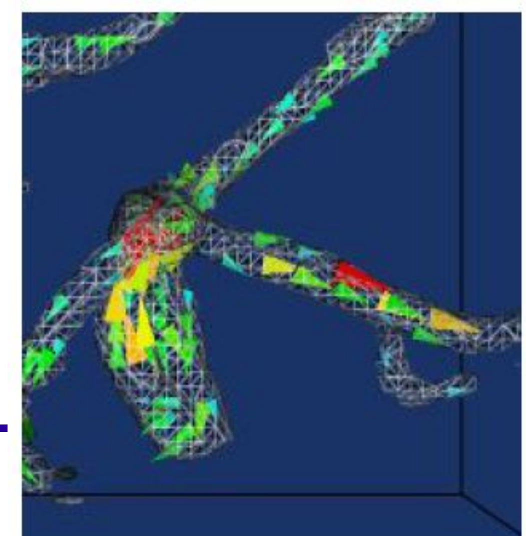
and where will it go to.

Vectors : local visualisation

- Set of basic methods for showing **local view**:
  - **Warping**
  - **Oriented lines, glyphs**
  - **Can combine with animation**







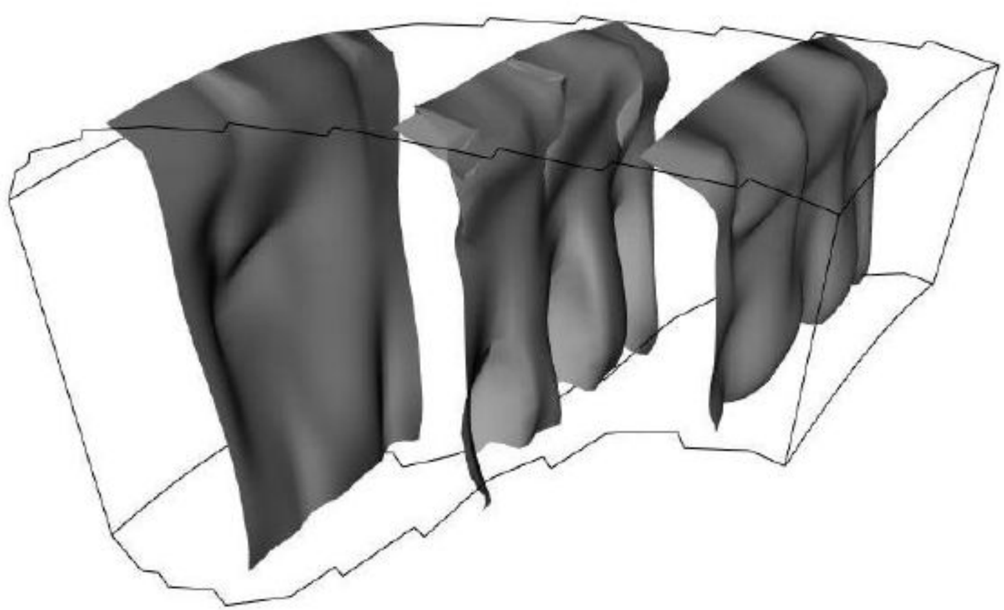
Example : warping

Insert slice planes into the data volume

Displace surface according to flow momentum

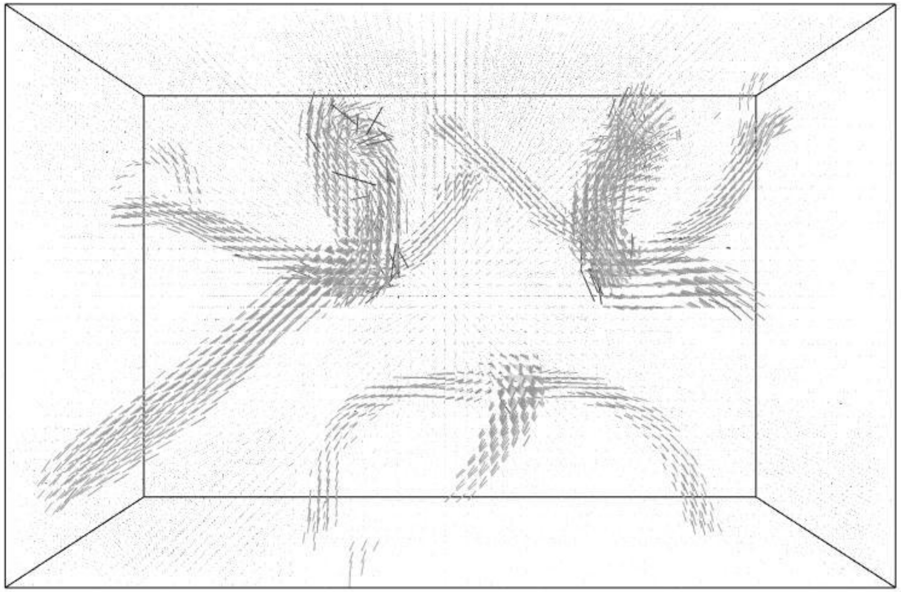
take care with scaling to **avoid excessive geometric distortion**

surfaces may intersect, or even turn inside-out

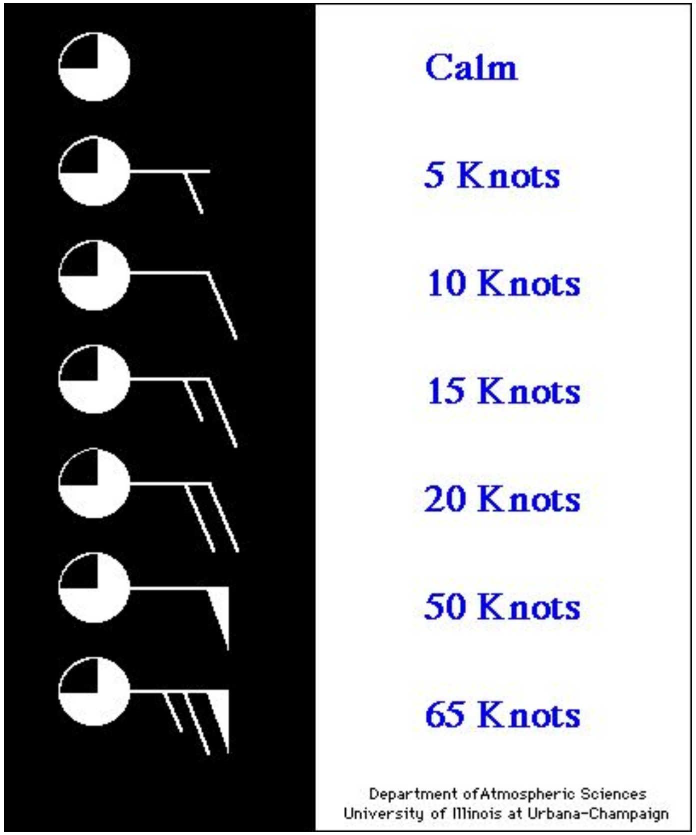


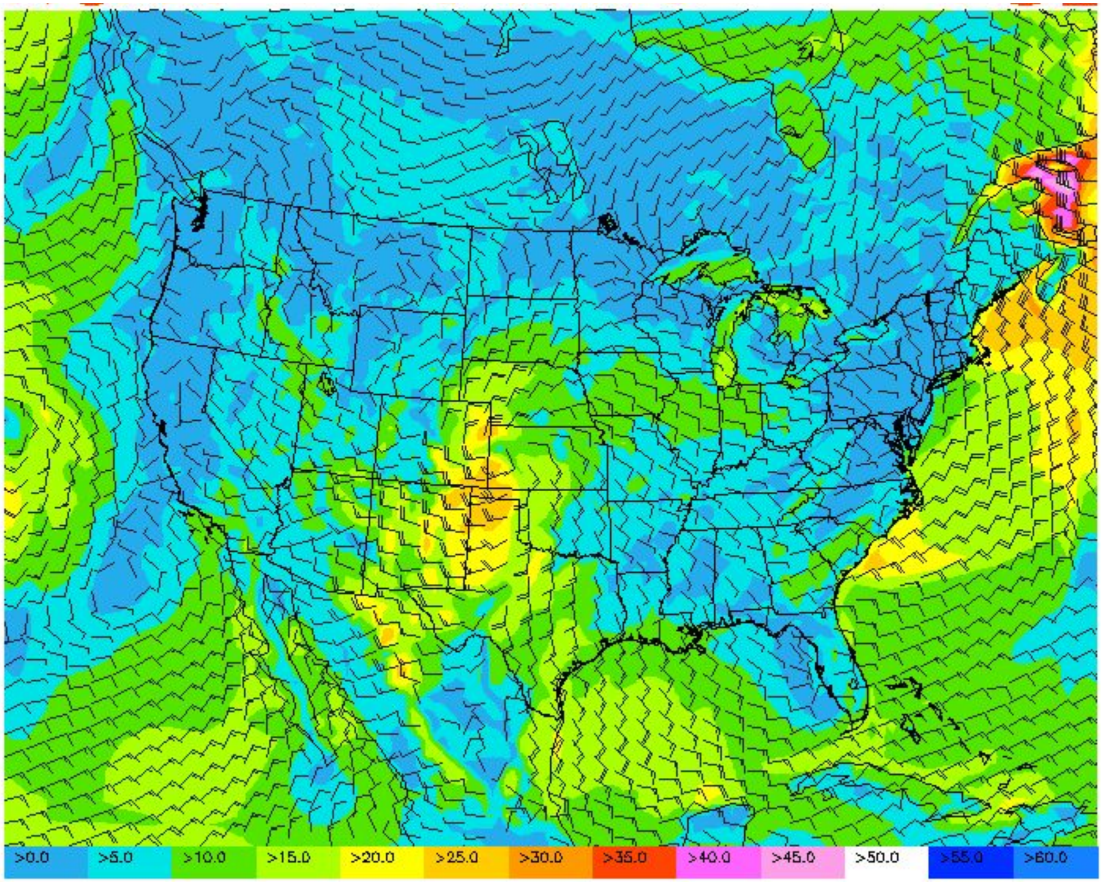
Local vector visualisation : lines

- **Draw line at data point indicating vector direction**
  - scale according to **magnitude**
  - **indicate direction** as vector orientation
- **problems**
  - showing large dynamic range field, e.g. Speed
  - Can result in cluttering
  - Difficult to understand position and orientation in projection to 2D image
- **Option** :
- use colour / barbs to visualise magnitude



Example : meteorology





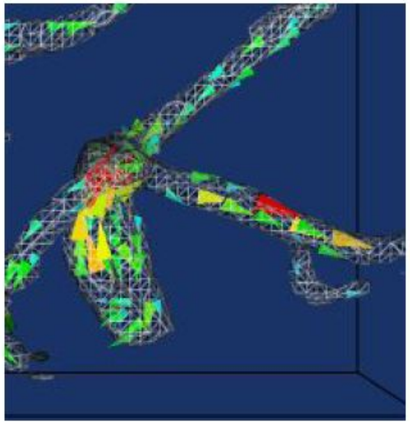
NOAA/FSL

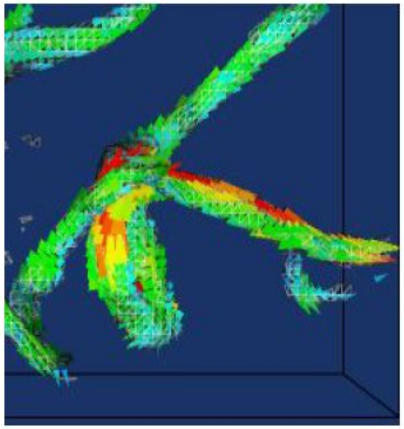
Lines are drawn with constant length, *barbs* indicate wind speed. Also colour mapped scalar field of wind speed.

Local vector visualisation : Glyphs

- **2D or 3D objects**
  - inserted at data point, oriented with vector flow

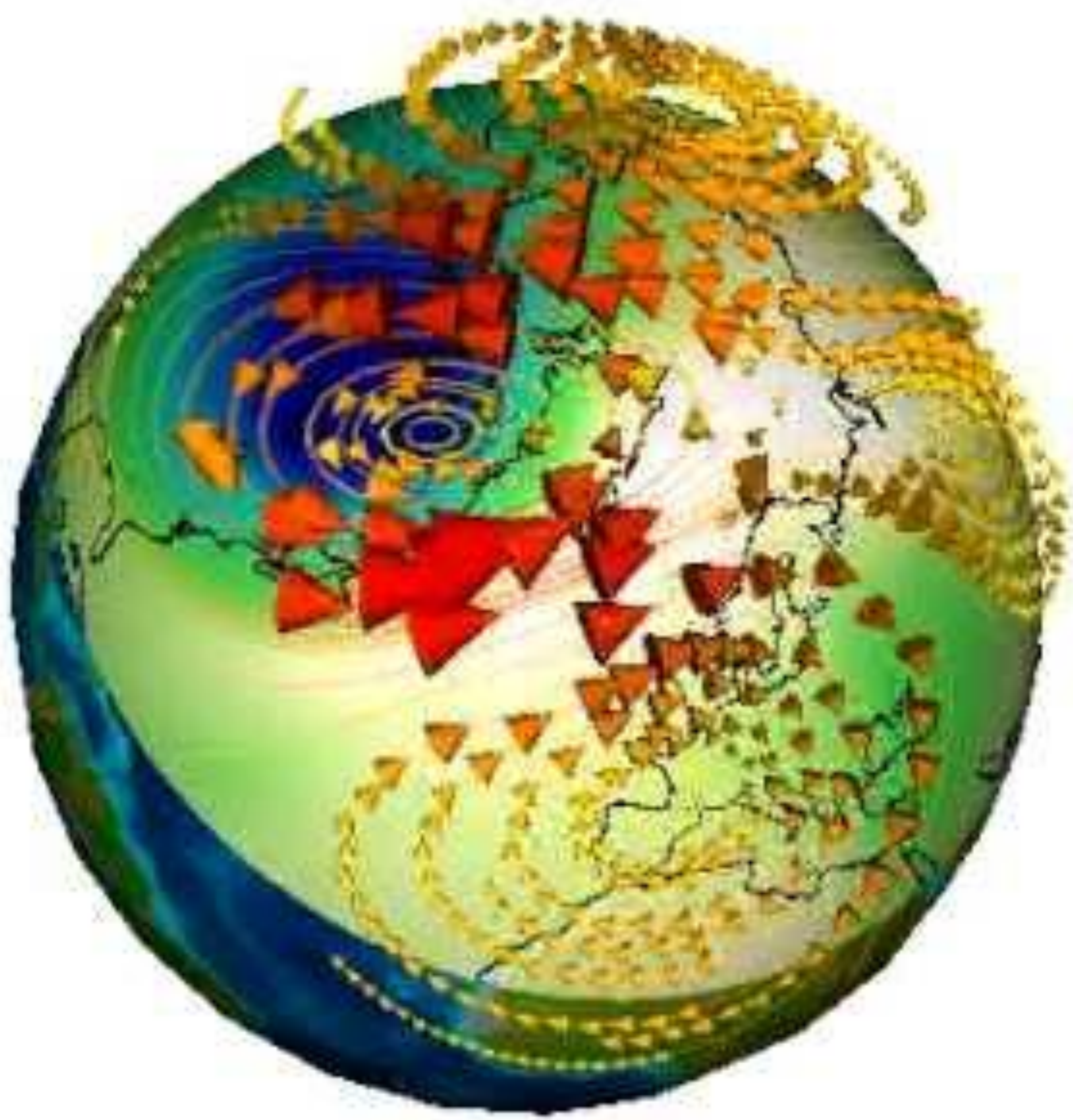
Need to scale and sample at the appropriate rate otherwise clutter





- e.g. blood flow (reduced data)
  - colourmap shows magnitude in addition to glyph scale

http://www.youtube.com/watch?v=KpURSH_HGB4&feature=related



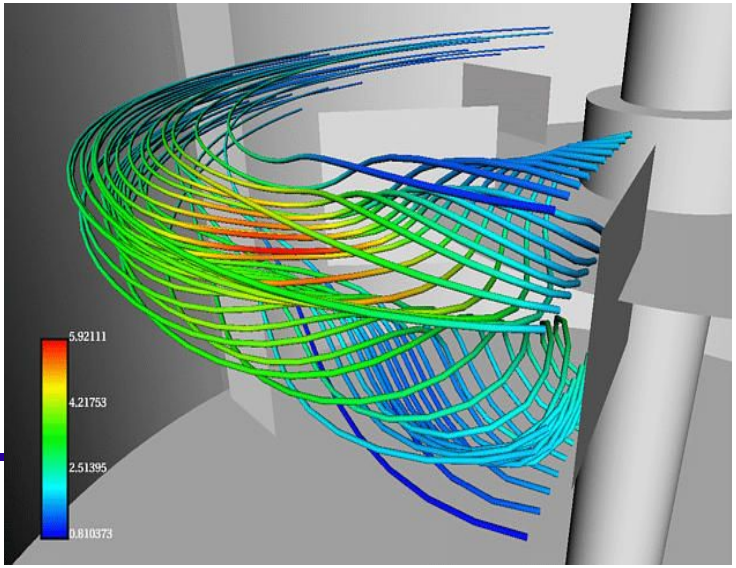
Wind streamlines (red = strong winds)

Overview

- **Vector field visualisation**
  - Local View
    - Warping
    - Glyphs
  - **Global View**
    - Pathline, Streakline, Streamline
    - Integration
    - Stream surface, Stream volume
  - Line Integral Convolution

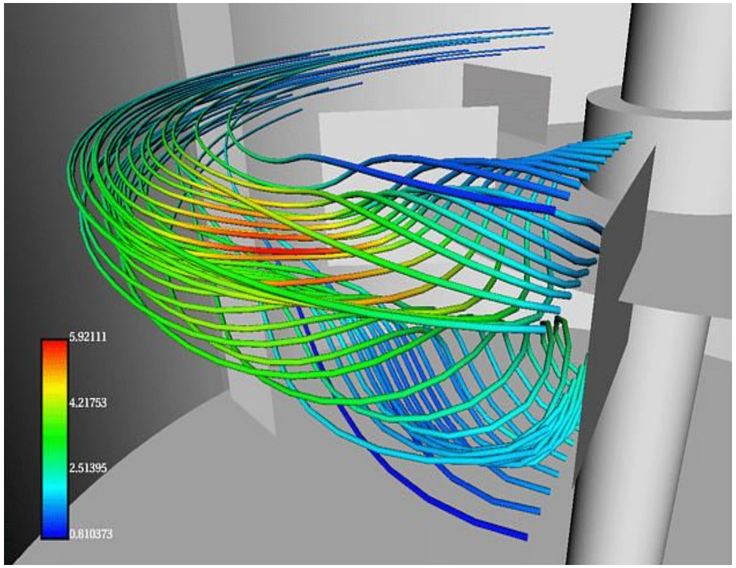
• The Global views of vector fields

- Visualise where the flow comes from and where it will go
- Visualise flow as the trajectory of a particles transported by the flow
- Pathline, Streamline, Streakline



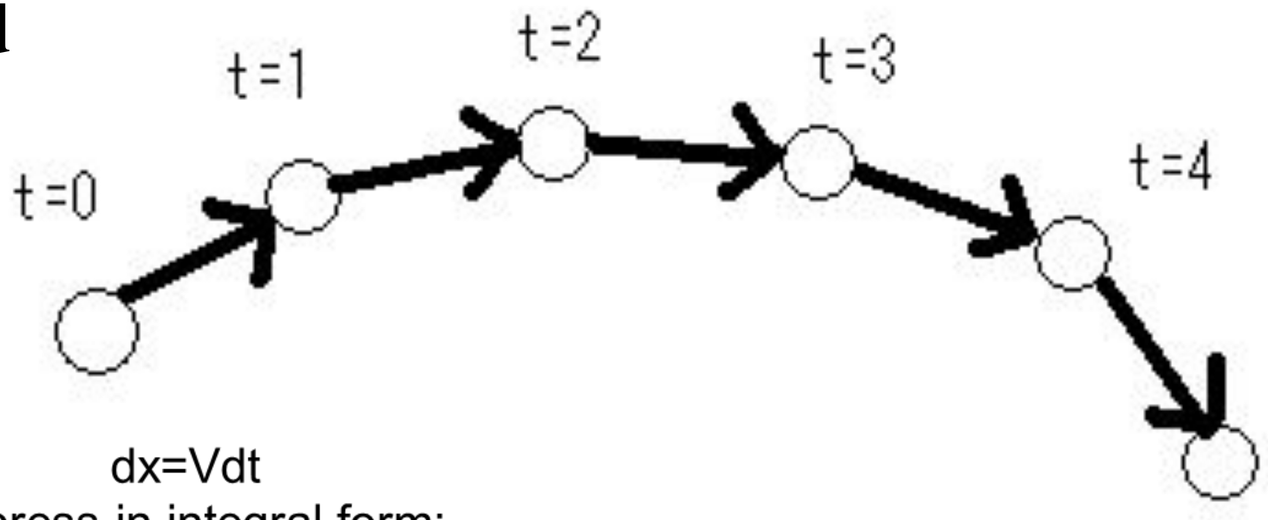
The Global views of vector fields (2)

- Shows flow features such as **vortices in flow**
- Easily possible to backtrace where the information was coming from
- Visibility can be depending on viewing angle.
- Occlusion can happen, and high intersection may cause problems.
- Combining with coloring helps.



Pathline

- **Particle trace : the path over time of a massless fluid particle transported by the vector field**
- **The particle's velocity is always determined by the vector field**



dx=Vdt

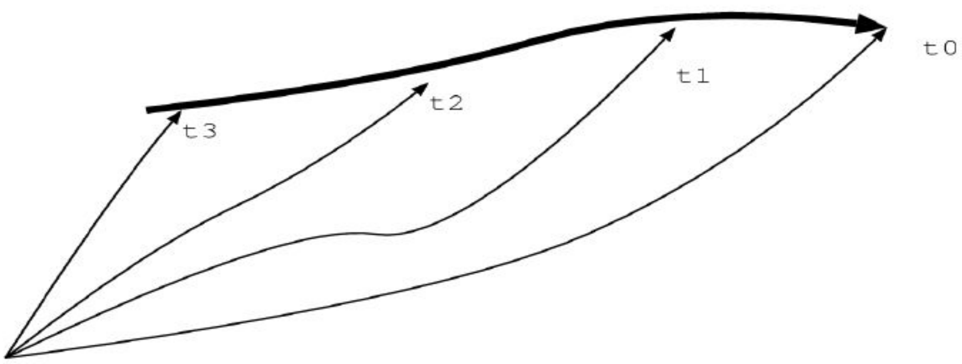
Express in integral form:

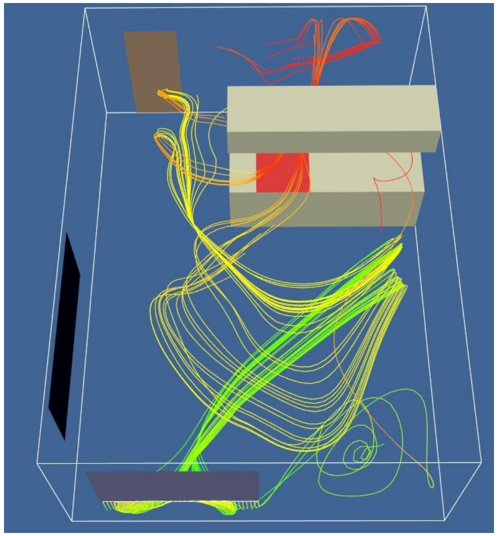
$$x=\int_{t0}^{tf} V dt$$

Solve using numerical integration

Streakline

- The set of points at a particular time that have previously passed through a specific point
  - Path of the particles that were released from a point x_0 at times $t_0 < t < t_f$
  - Dye steadily injected into the fluid at a fixed point

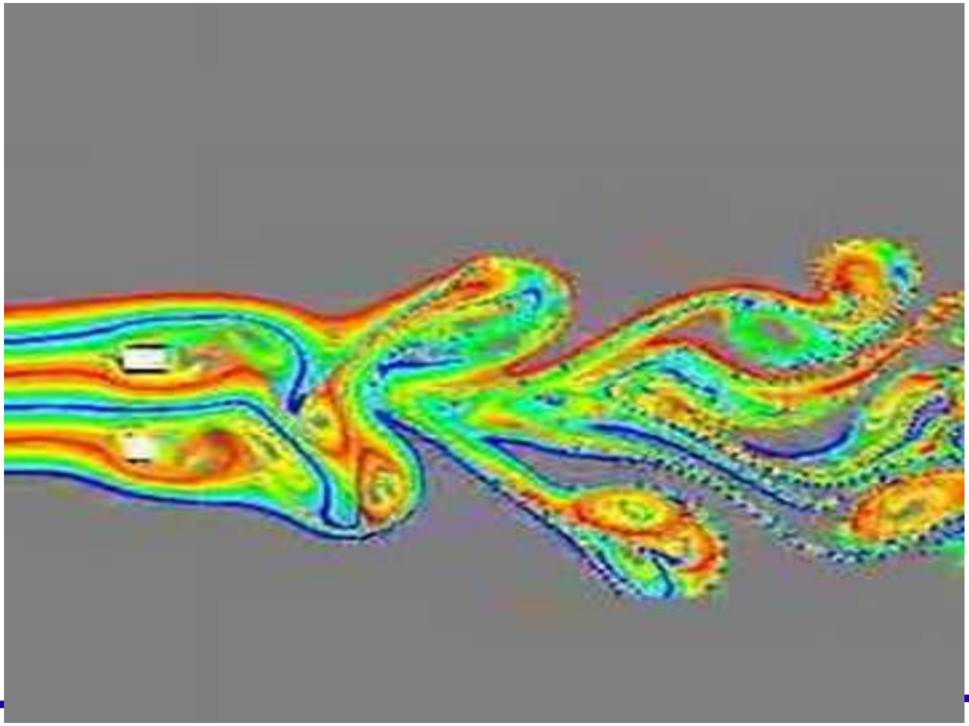




http://www-mdp.eng.cam.ac.uk/web/library/enginfo/aerothermal_dvd_only/aero/fprops/cvanalysis/node8.html

Examples

- Streaklines for 2 square obstruction
- http://www.youtube.com/watch?v=ucetWHDXjAA
- Streaklines exiting from a channel
- http://www.youtube.com/watch?v=tdZ1QafL6MM&feature=channel



Streamline

- **Streamline : integral curves along a curve *s* satisfying:**

$$s = \int_{t0}^{tf} V \, ds, \text{ with } s = s(x,t)$$

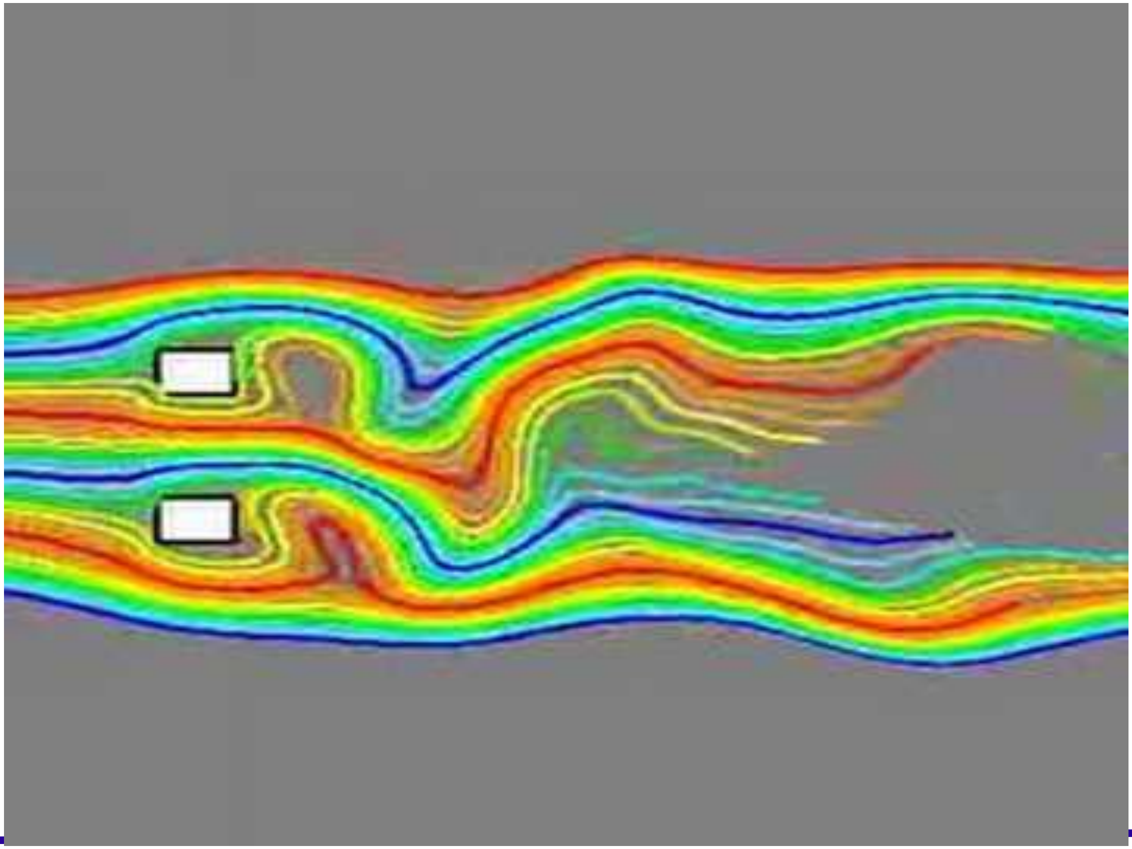
at a fixed time t

  - **Integral in the vector field while keeping the time constant**

Example

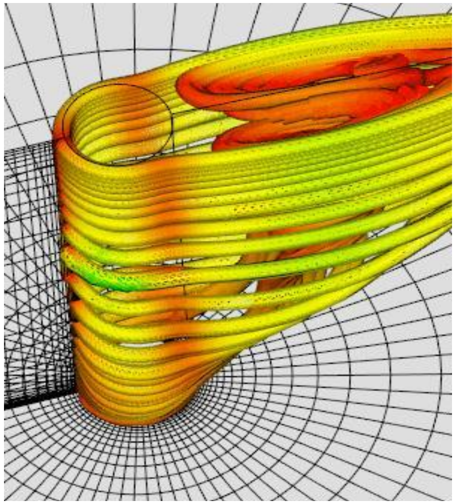
- Streamlines for 2 square obstruction

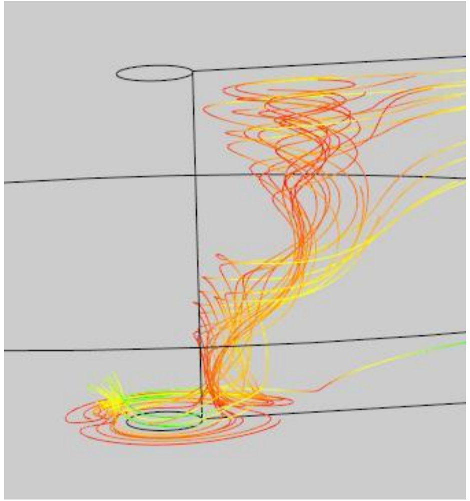
http://www.youtube.com/watch?v=-njBmpInmcU&feature=channel



State of Flow : Steady / Unsteady

- **Steady flow**
  - remains **constant** over time
  - state of **equilibrium** or snapshot
  - **Streamlines==Streaklines**
- **Unsteady flow**
  - **varies** with time
  - streamlines always change the entire shape
  - **Streaklines are more suitable**





Overview

- **Vector field visualisation**
  - Local View
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  - **Global View**
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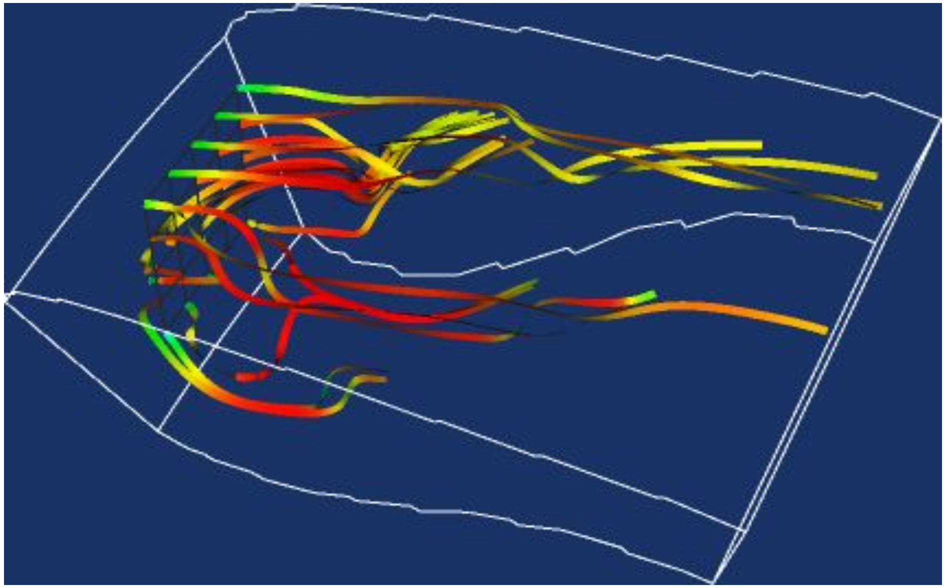
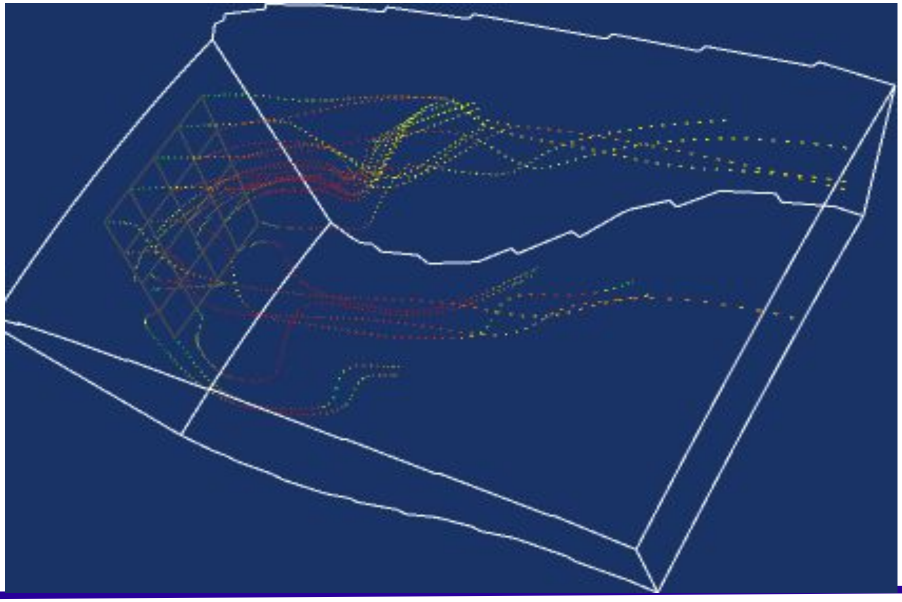
    - **Stream surface, Stream volume**
  - Line Integral Convolution

Stream Ribbons

Streamribbon : initialise two streamlines together

- **flow rotation**: lines will rotate around each other : can visualize vorticity
- **flow convergence/divergence**: relative distance between lines
- *both not visible with regular separate streamlines*
    - ***Problem if streamlines diverge significantly***



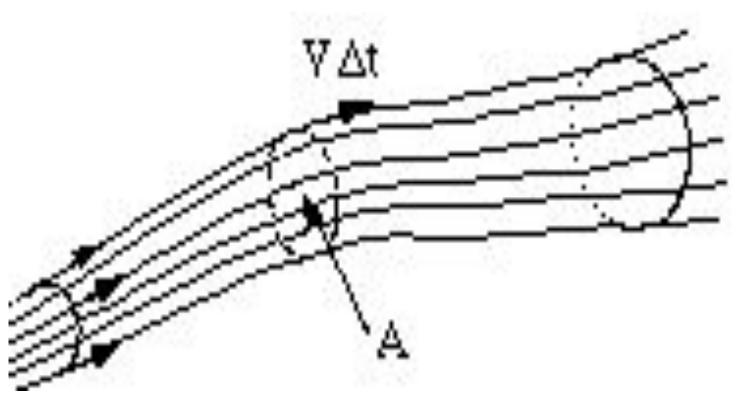


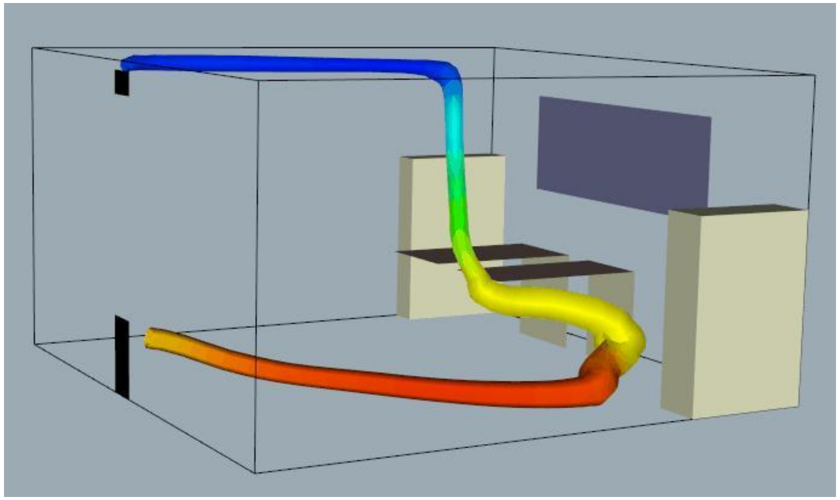
Streamsurface, Streamtube

Initialise multiple streamlines along a base curve or line rake and connect with polygons

- **Streamtube: A closed stream surface**

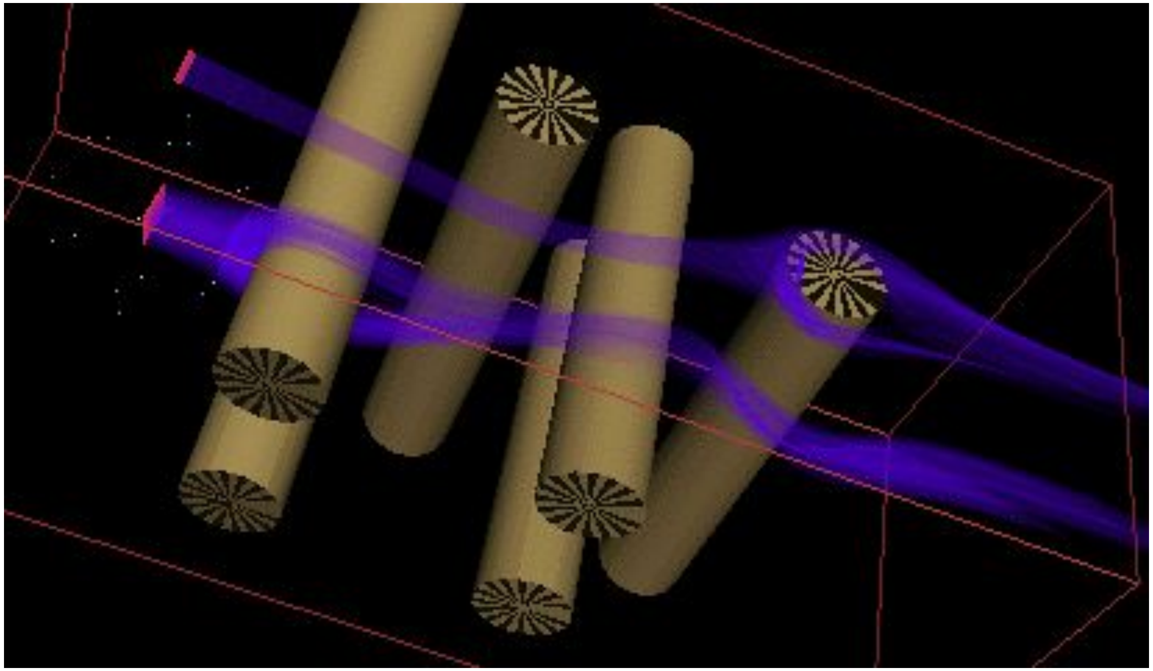
- Properties:
  - surface **orientation at any point on surface tangent to vector field**
  - The amount of substance inside the tube is fixed

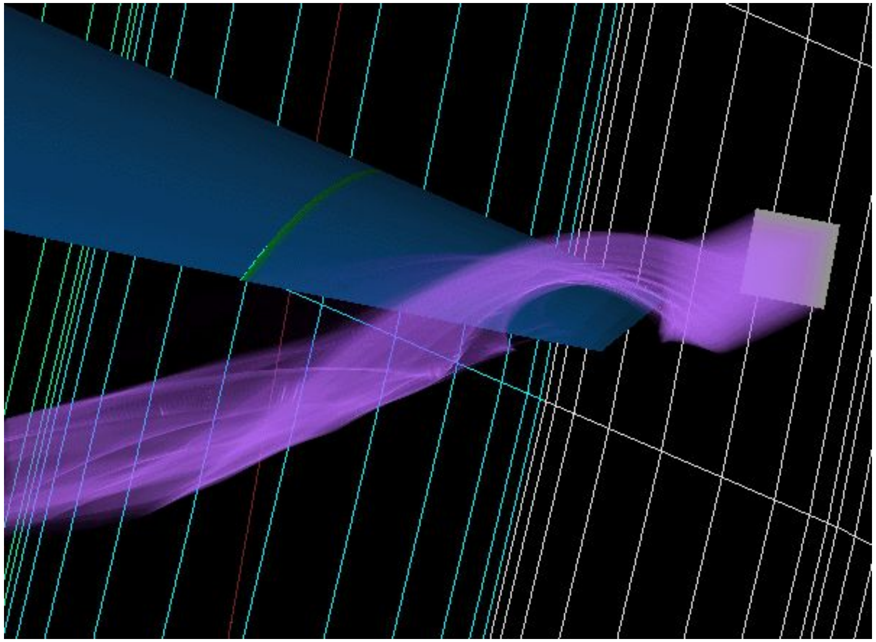




Flow Volumes : simulated smoke

- initialise with a seed polygon – the rake
- calculate streamlines at the vertices.
- split the edges if the points diverge.





Overview

- Data representation and structure
- **Vector field visualisation**
  - Local View
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  - Global View
    - Pathline, Streakline, Streamline
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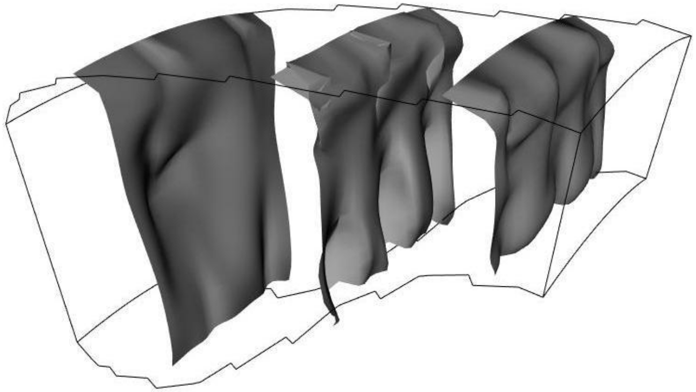
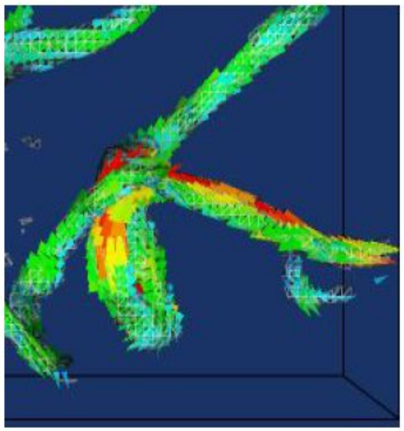
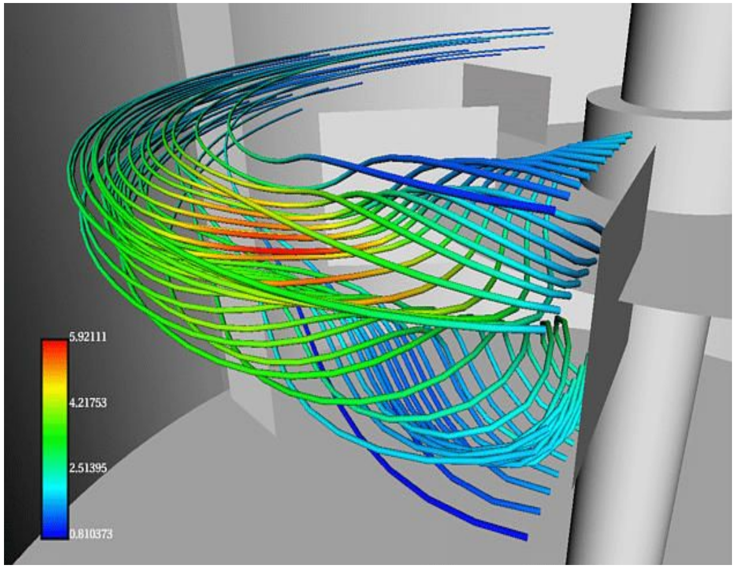
  - **Line Integral Convolution**

Flow Visualisation Ideals - ?

- **High Density Data** – ability to visualise dense vector fields
- **Effective Space Utilisation** – each output pixel (in rendering) should contain useful information
- **Visually Intuitive** – understandable

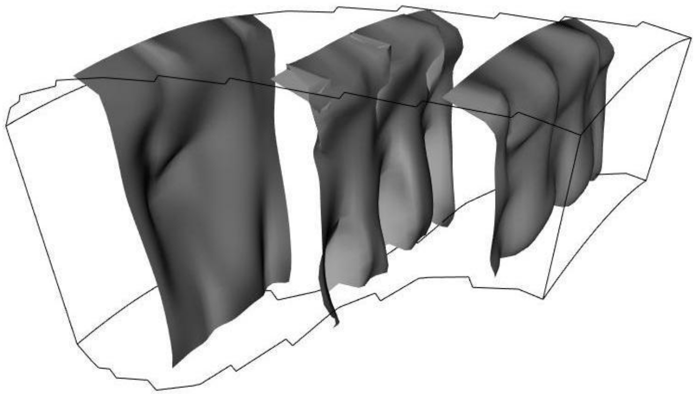


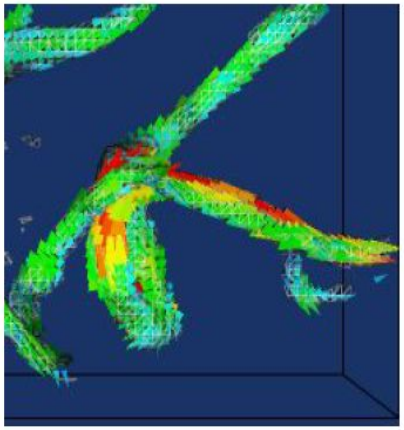


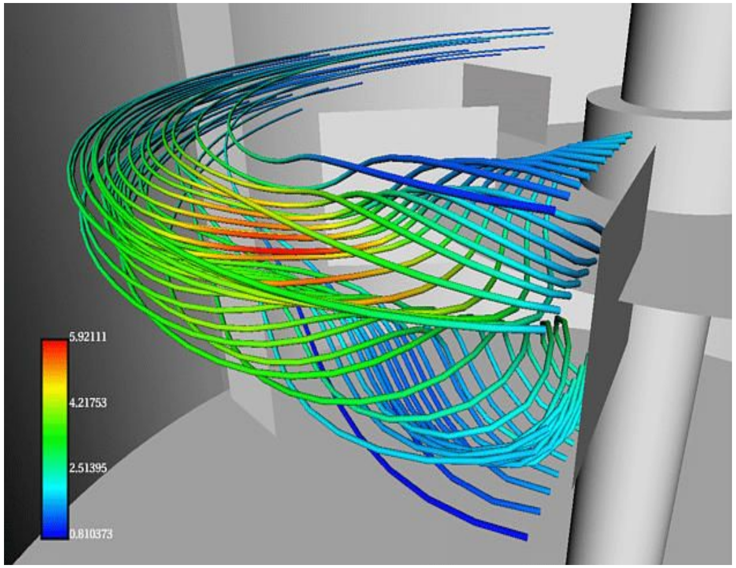


Flow Visualisation Ideals - ? (2)

- **Geometry independent** – not requiring user or algorithmic sampling decisions that can miss data
- **Efficient** – for large data sets, real-time interaction
- **Dimensional Generality** – handle at least 2D & 3D data

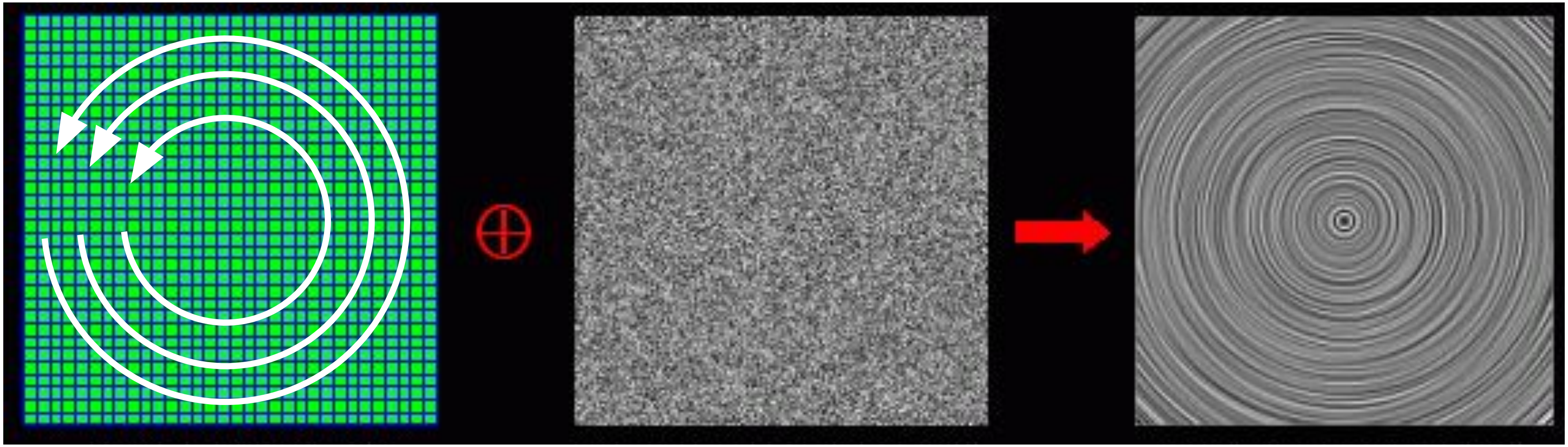






Direct Image Synthesis

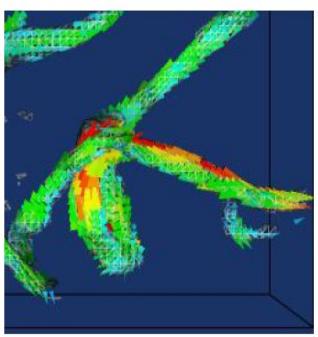
- **Line Integral Convolution (LIC)**
  - **image operator = convolution**

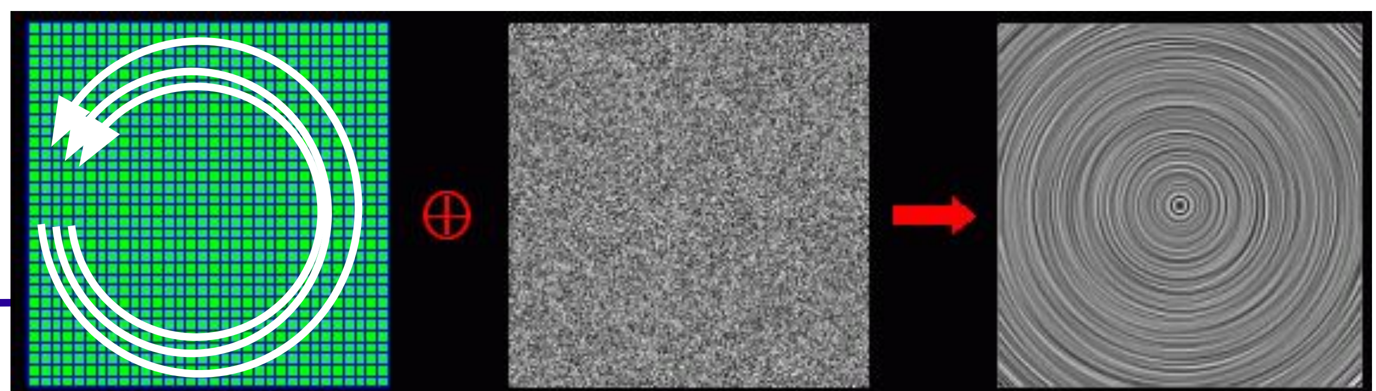


Vector Field   White Noise Image   LIC Image

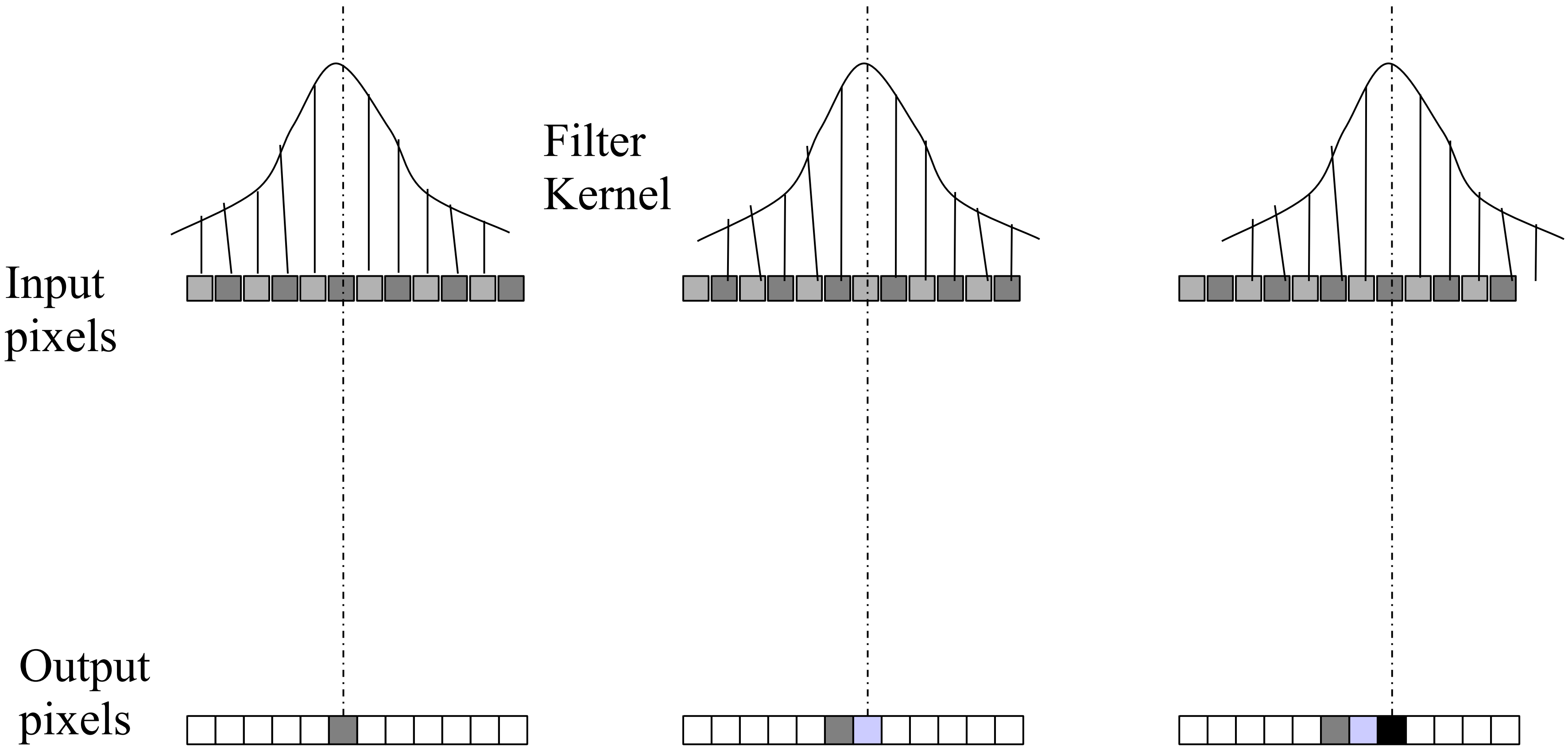
Line Integral Convolution (LIC)

- **Concept** : modify an image directly with reference to the vector flow field
  - **alternative to graphics primitives**
  - ***modified image allows visualisation of flow***
- ***Practice :***
  - ***use image operator to modify image***
  - ***modify operator based on local value of vector field***
  - ***use initial image with no structure***
    - ***e.g. white noise (then modified by operator to create structure)***



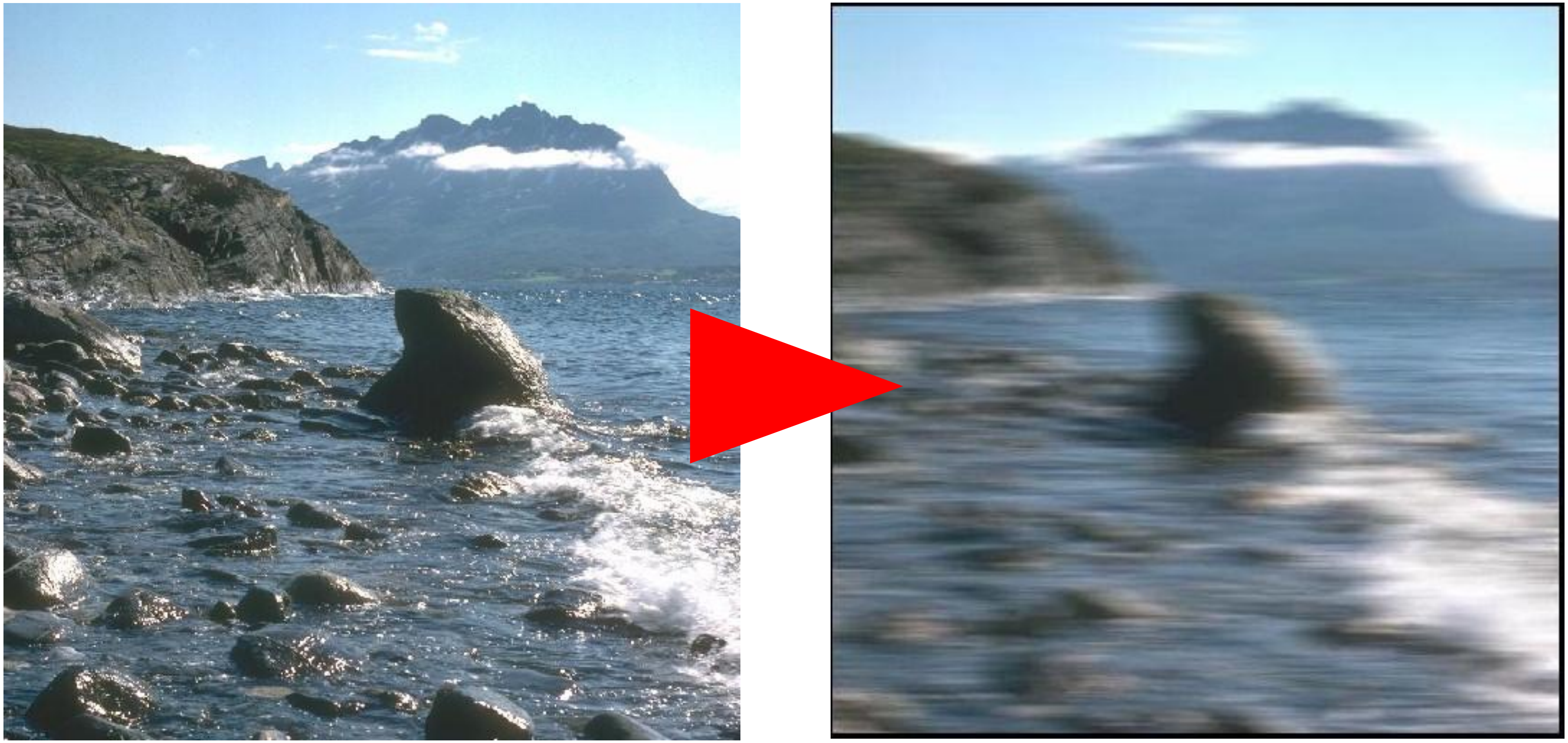


How ? - image convolution



- Each **output pixel p' is computed as a weighted sum of pixel neighbourhood of corresponding input pixel p**
  - weighting / size of neighbourhood defined by kernel filter

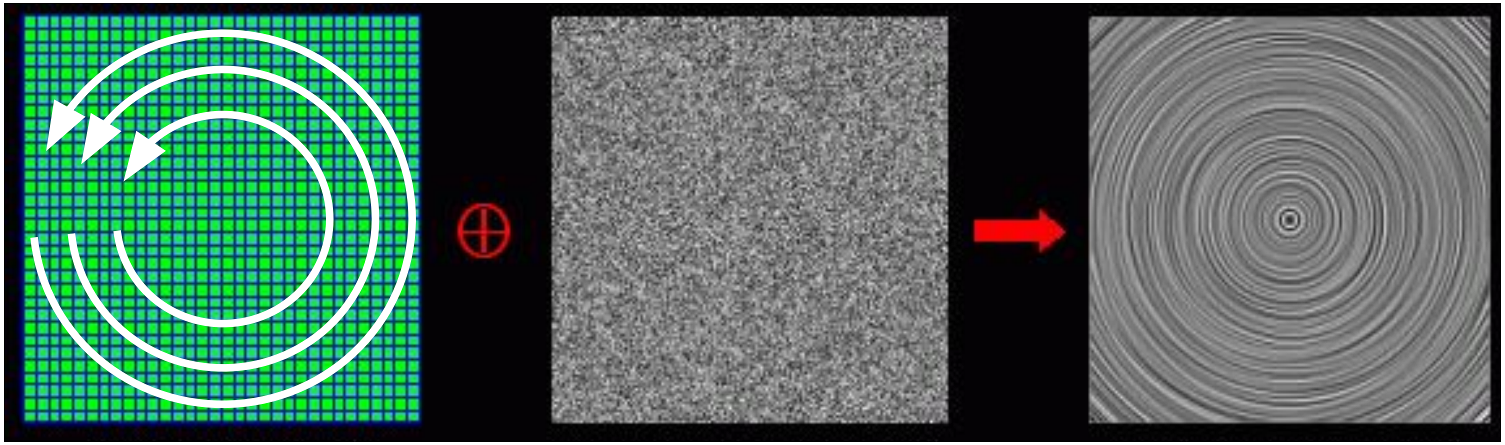
Example : image convolution



- Linear convolution applied to an image
  - linear kernel (causes blurring)

Convolution Along the Vector Field

- Perform **convolution in the direction of the vector field**
  - use vector field to define (and modify) convolution kernel
  - produce the effect of **motion blur in direction of vector field**

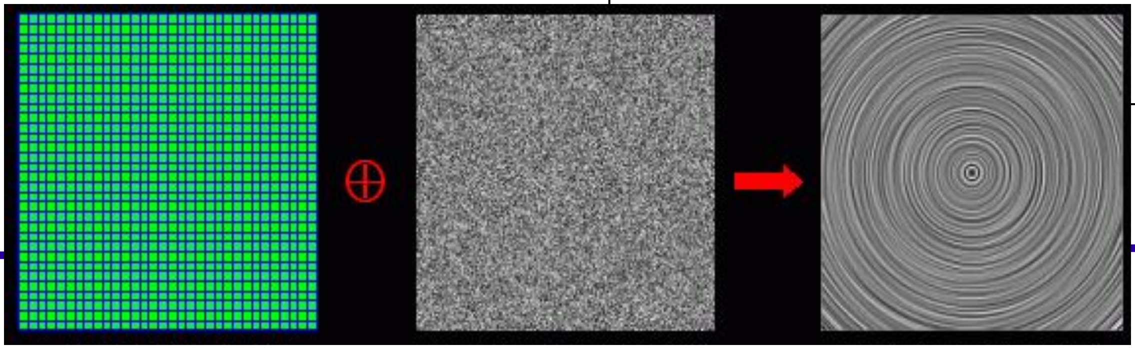


LIC : stated formally

$$F'(p) = \frac{\int_{-L}^{L} F(P(s))\ k(s)\ ds}{\int_{-L}^{L} k(s)\, ds}$$

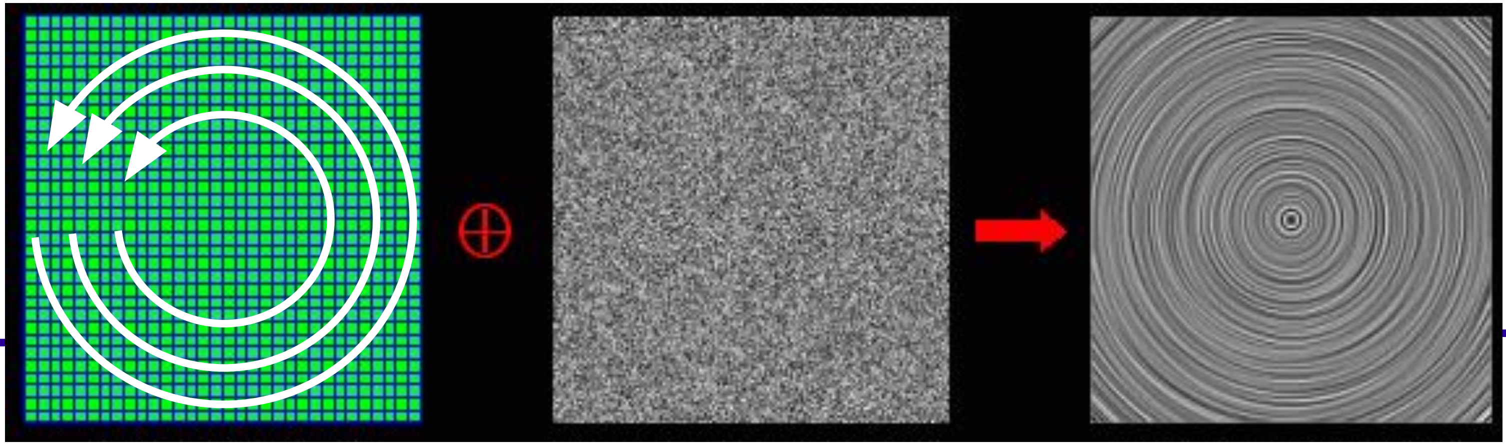
p is the **image domain**
s is the **parameter along the streamline,** *L* is streamline length
F(p) is the **input image**
F'(p) is the **output LIC image**
P(s) is the **position in the image of a point on the streamline**
k(s) is **convolution kernel**

Denominator normalises the output pixel (i.e. maps it back into correct value range to be an output pixel)

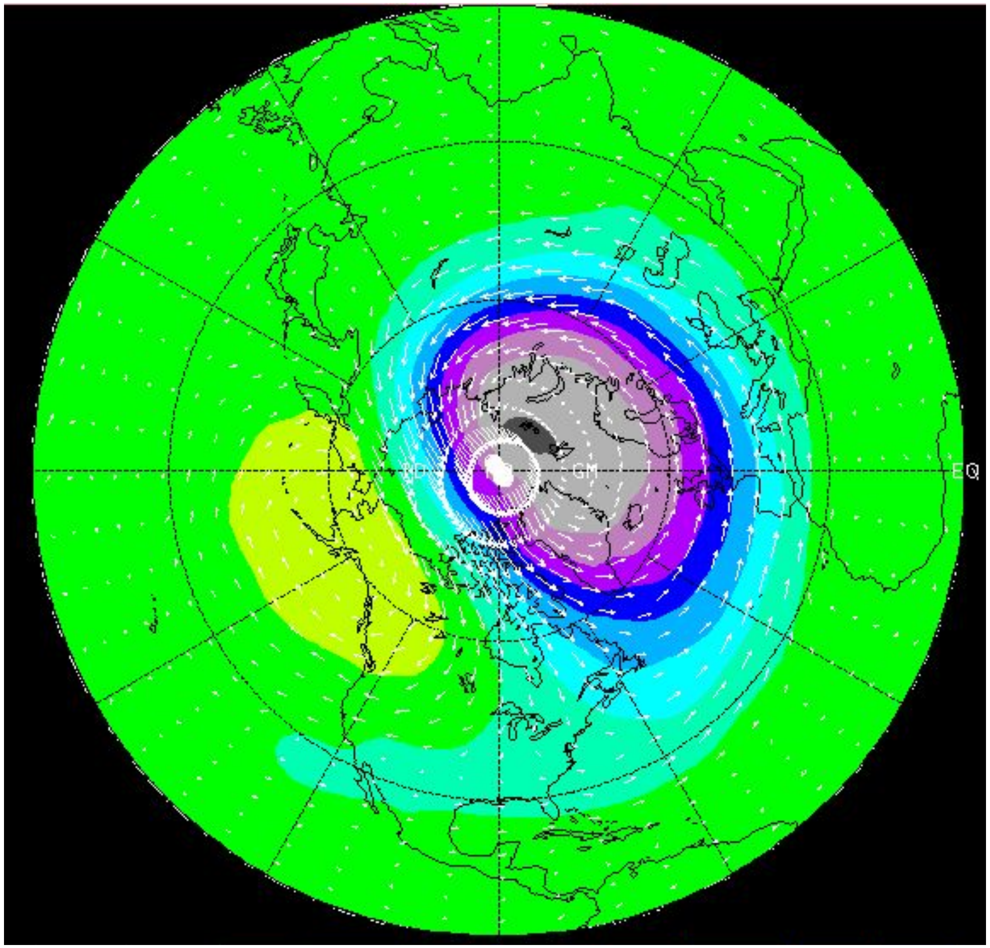


Effects of Convolution

- **Convolution 'blurs' the pixels together**
  - amount and direction of blurring defined by kernel
- For **white noise input** image, convolved output image will exhibit
  - **strong correlation along the vector field streamlines** and
  - **no correlation across the streamlines.**



Example : wind flow using LIC

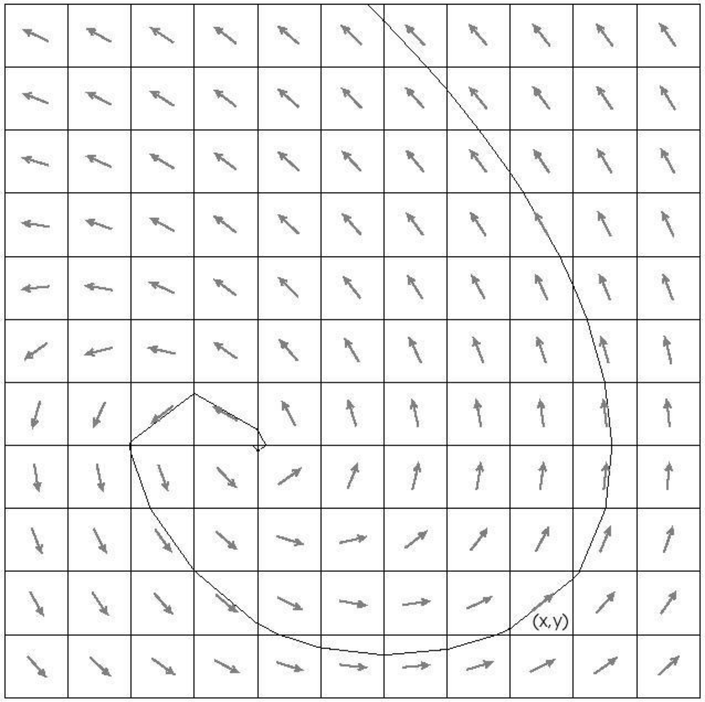


Colour-mapped

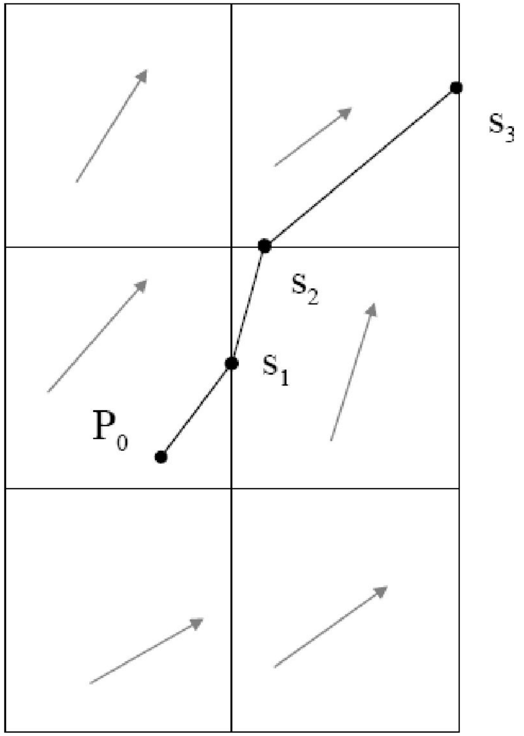
LIC

Data: atmospheric wind data from UK Met. Office Visualisation : G. Watson (UoE)

Streamline Calculation



$$h_i = \int_{s_i}^{s_i+1} k(s)\,ds$$

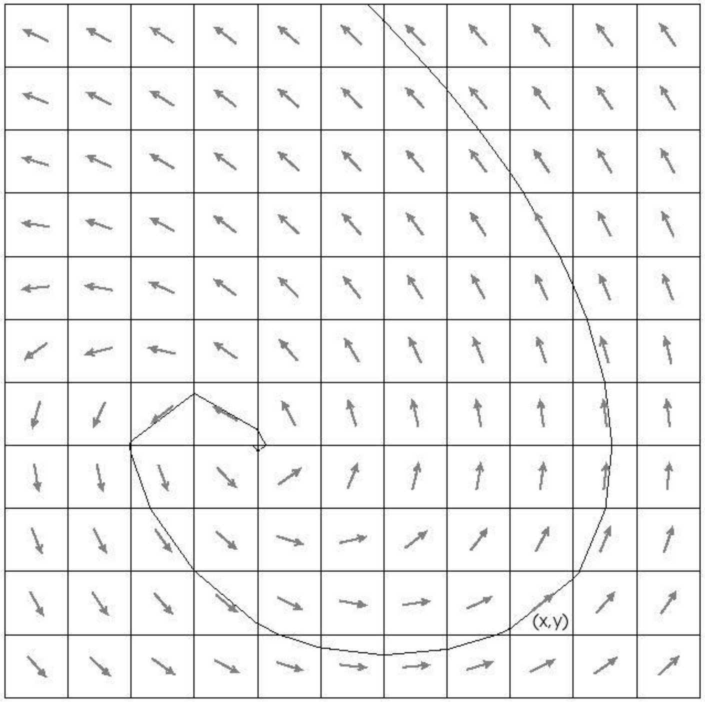


- Constrain the image **pixels to the vector field cells**
  - for each vector field cell, the input white noise image has a corresponding pixel

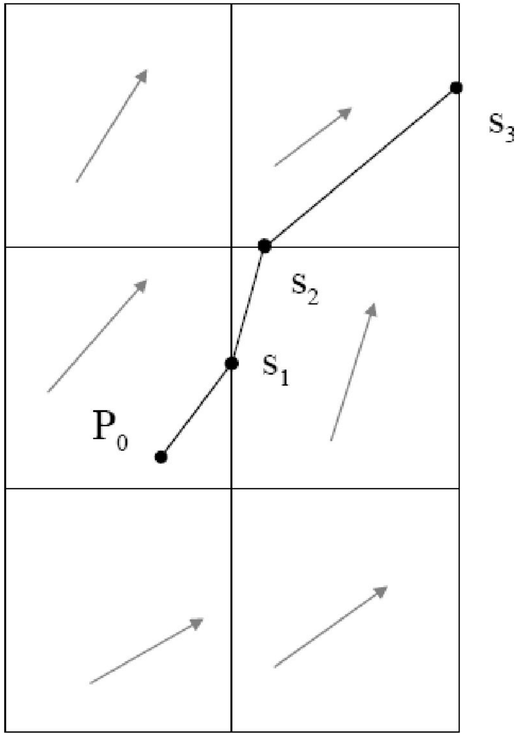
Compute the streamline forwards and backwards in the vector field using **variable-step Euler method.**

- **Compute the parametric endpoints** of each line streamline segment that intersects a cell.

Variable step Euler method



$$h_i = \int_{s_i}^{s_i+1} k(s)\,ds$$



In 2D (lines through cells)

Assume vector is constant across cell.

Calculate closest intersection of cell edge with ray parallel to vector direction using ray-ray intersection.

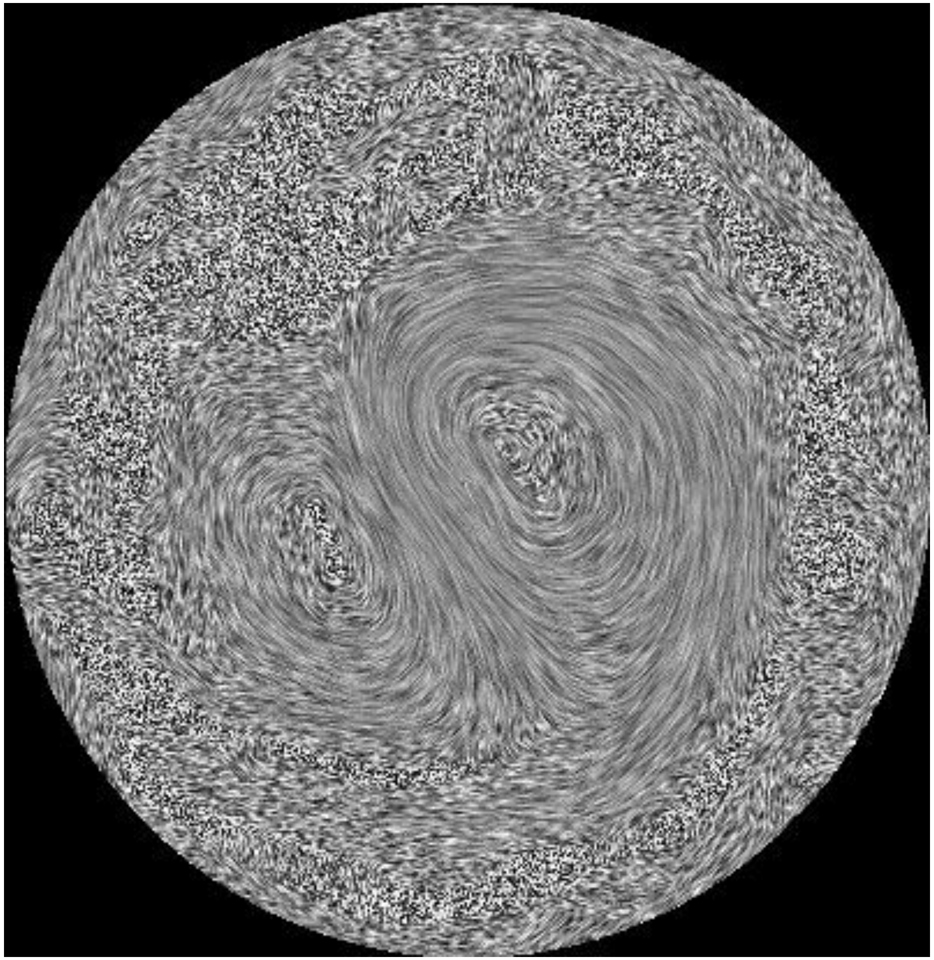
Iterate for next cell position.

Kernel Length constant vs. variable

- **Constant length convolution kernel**
  - small scale flow features very clear
  - no visualisation of velocity magnitude from vectors
    - can use colour-mapping instead
- **Kernel length proportional to velocity magnitude**
  - large scale flow features are clearer
  - poor visualisation of small scale features

LIC : 2D results

Variable length Kernel

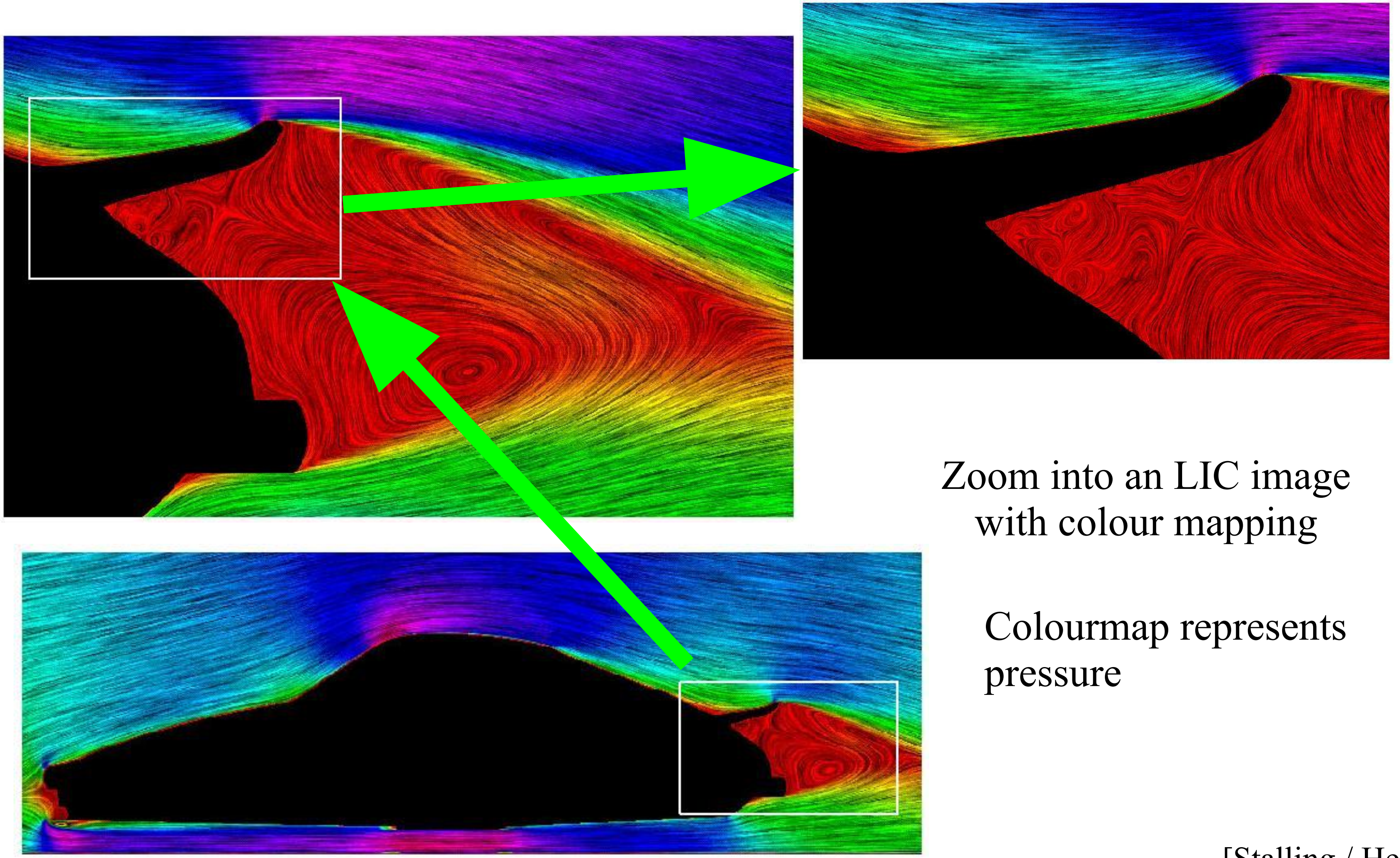


Fixed length Kernel

- Same trade off as with glyph size

images : G. Watson (UoE)

Example : colour-mapped LIC



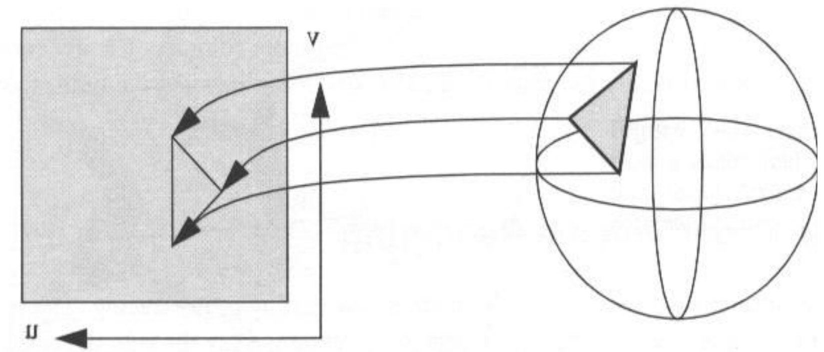
Zoom into an LIC image with colour mapping

Colourmap represents pressure

[Stalling / Hege]

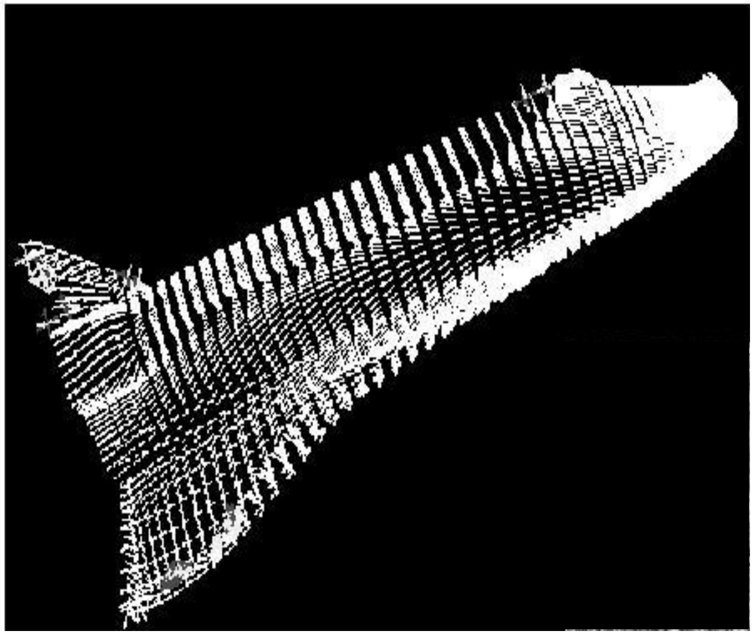
LIC : extension to 3D

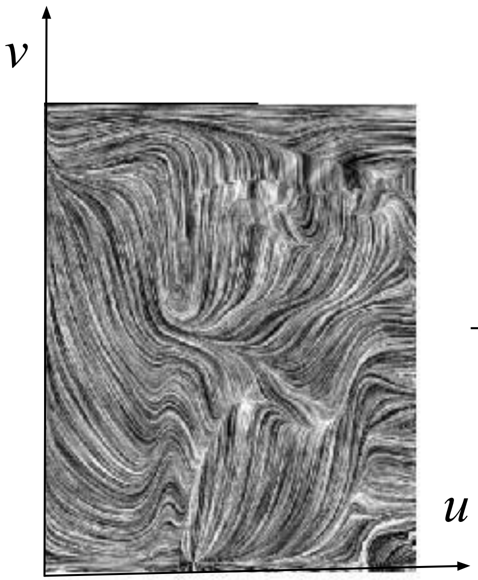
- LIC on *uv* parametric surfaces



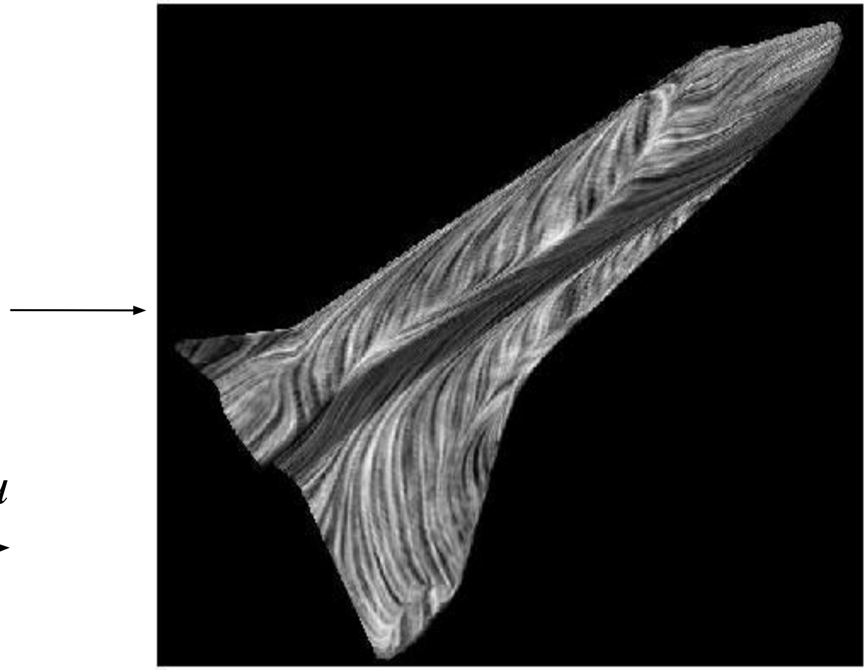
uv coordinates are the same as used in texture coordinates

Vector field on surface to be visualised





Perform LIC in *uv* space



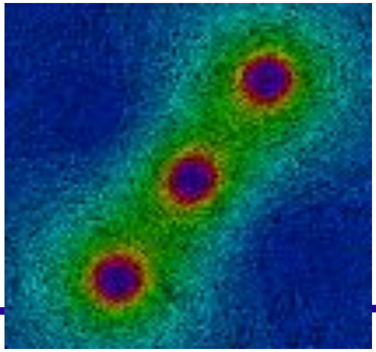
LIC : steady / unsteady flow

- **LIC : Steady Flow** only (i.e. **streamlines**)
  - animate : shift phase of a periodic convolution kernel

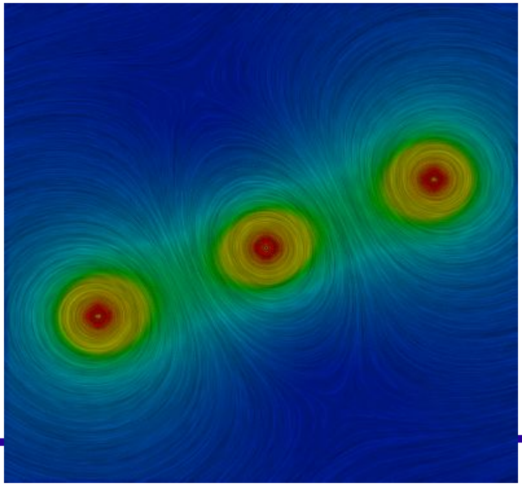
[Cabral/Leedom '93]

- **UFLIC : Unsteady Flow**
  - **Streaklines** are calculated rather than streamlines
  - convolution takes time into account.

[Kao/Shen '97]



[Zhanping Liu]



Summary

- **Local and Global View** of Vector Fields
  - **Local View**
    - **Glyphs, warping, animation**
  - **Global View**
    - visualising **transport**
    - requires **numerical integration**
      - Euler's method
      - Runge-Kutta

    Stream **ribbons and surfaces**:
- **LIC**
  - **steady flow visualisation using direct image synthessis**
  - **convolution with kernel function**
  - **3D & unsteady flow extensions**