Introduction to Scientific Visualization

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Scientific Visualization

"The purpose of computing is insight not numbers."

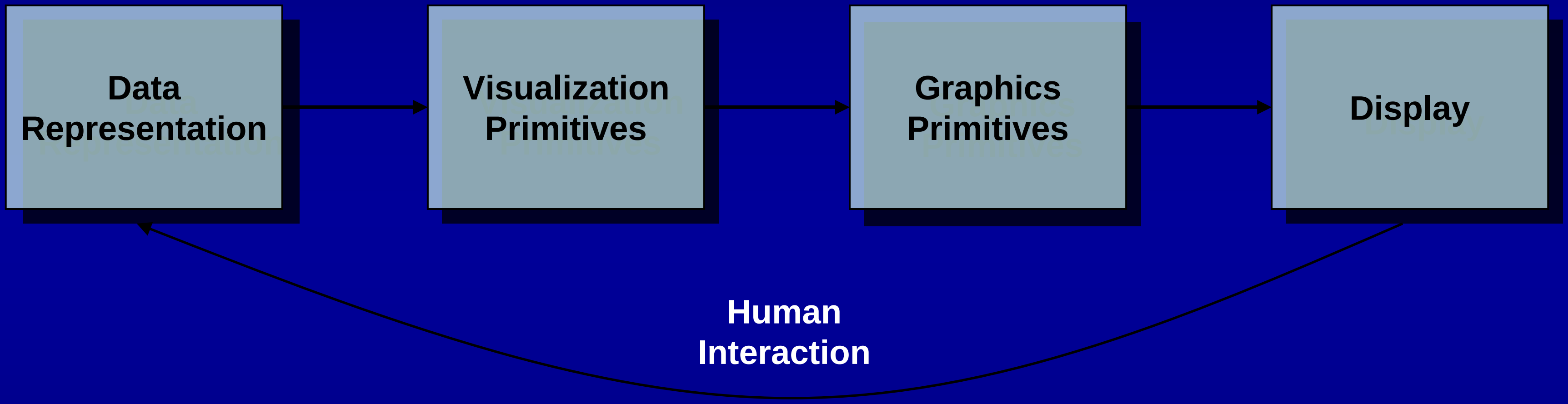
-- R. W. Hamming (1961)

Scientific Visualization

“A useful definition of visualization might be the binding (or mapping) of data to representations that can be perceived. The types of bindings could be visual, auditory, tactile, etc., or a combination of these.”

-- Foley and Ribarsky (1994)

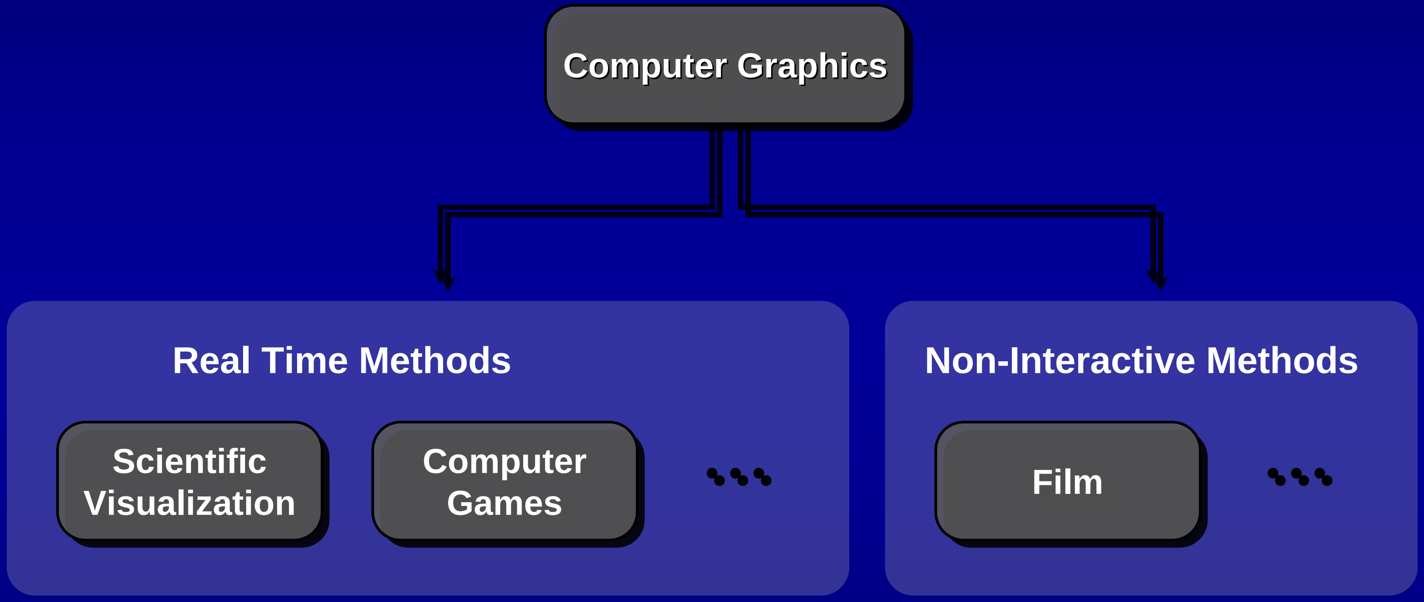
Getting from Data to Insight



Topics

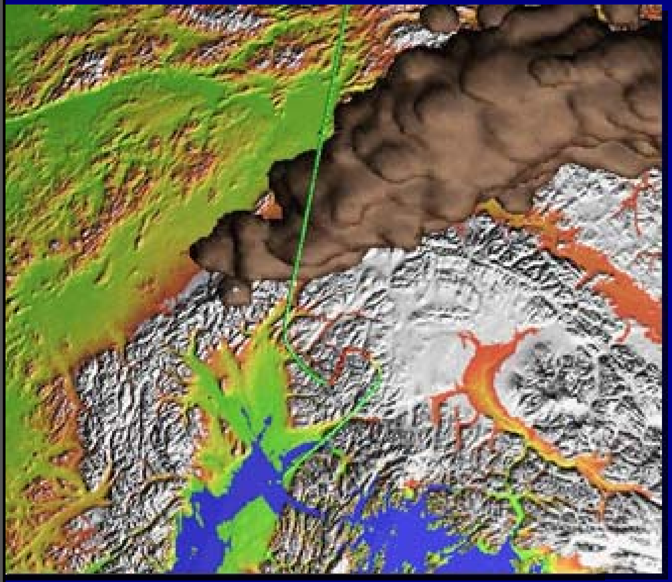
- Computer Graphics
- Scientific Visualization Process
- Scientific Visualization Techniques

Computer Graphics is the mechanism for converting geometry to pixels.

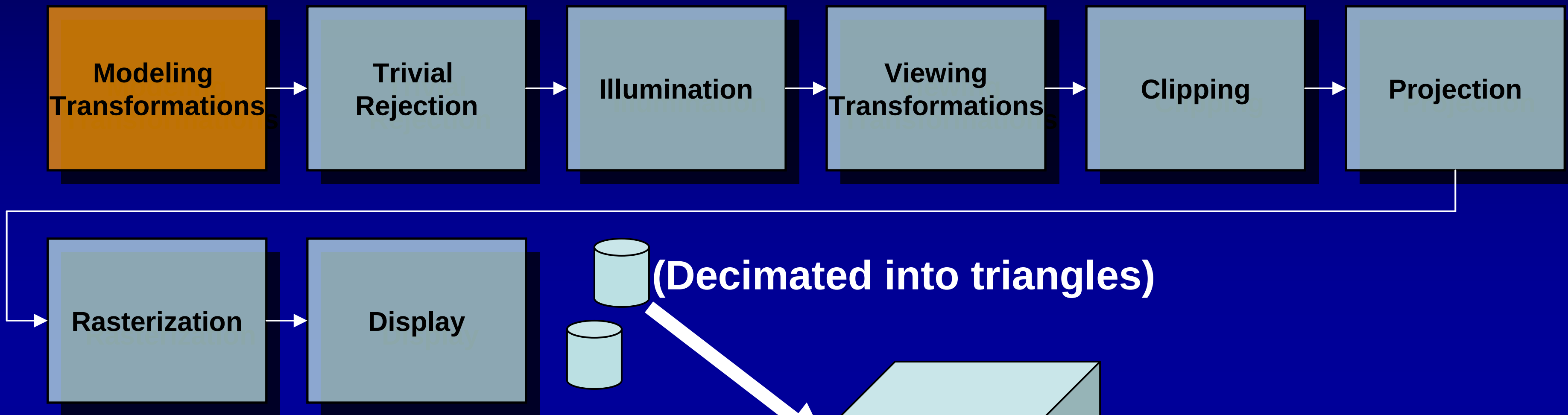


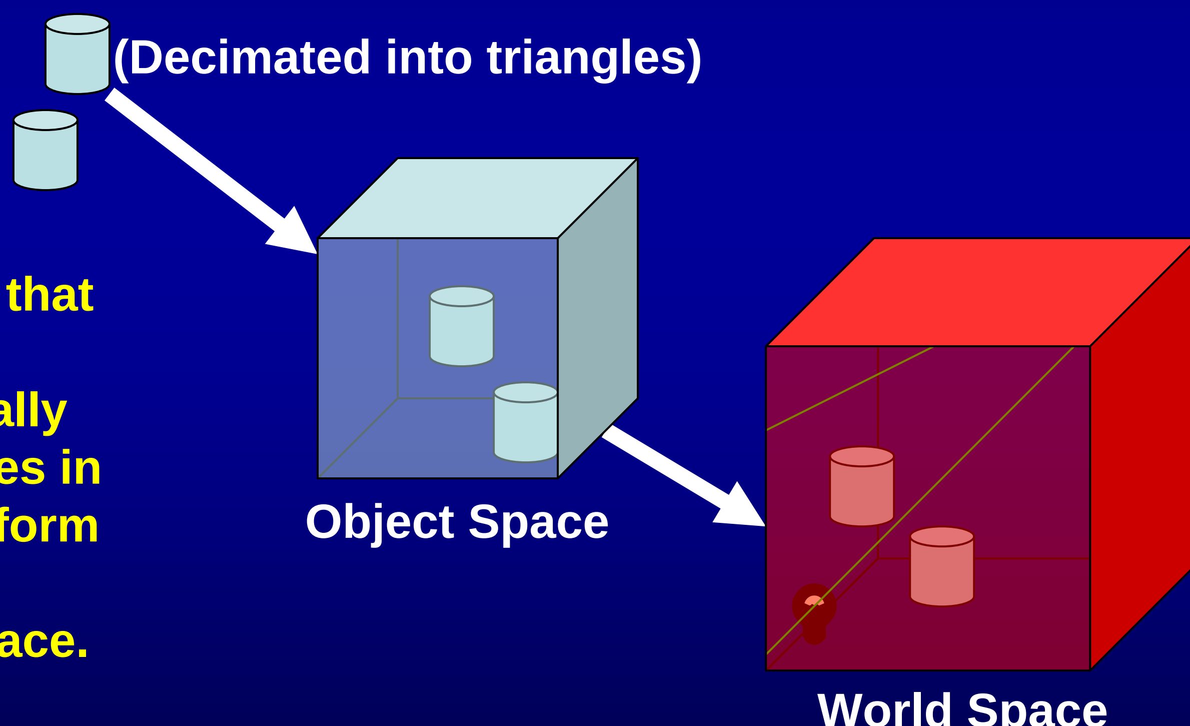
Non-Interactive Methods

... versus Real-Time Methods



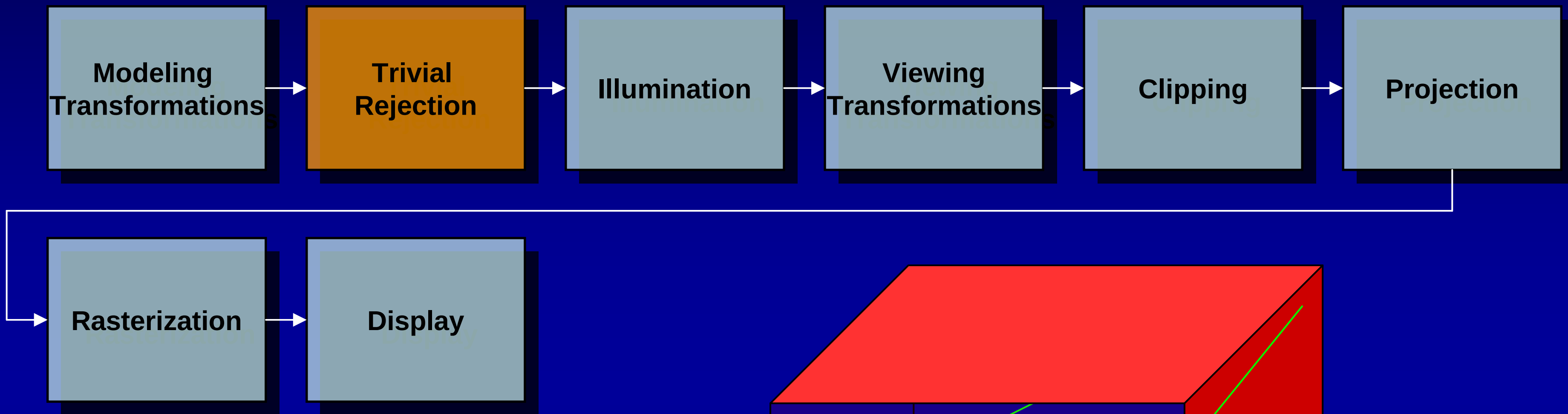
Computer Graphics Pipeline

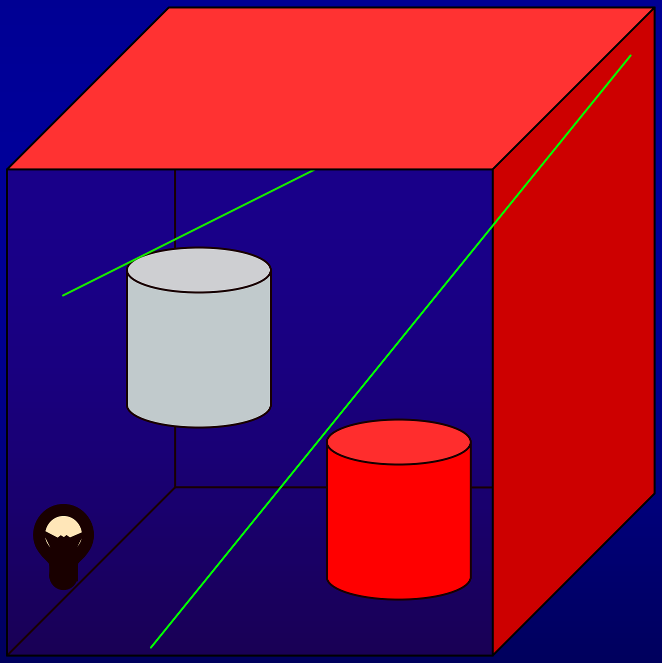




Starts with data or models that are described in (x,y,z) coordinates. The data usually defines solids or boundaries in terms of their skins. Transform from data coordinates to something called world space.

Computer Graphics Pipeline





Attempt to eliminate any objects that can not possibly be seen. Check endpoints of a triangle, line segment or point and store a flag for inside or outside. Perform a logical and of the endpoints to determine whether the entity is wholly in or out of the view.

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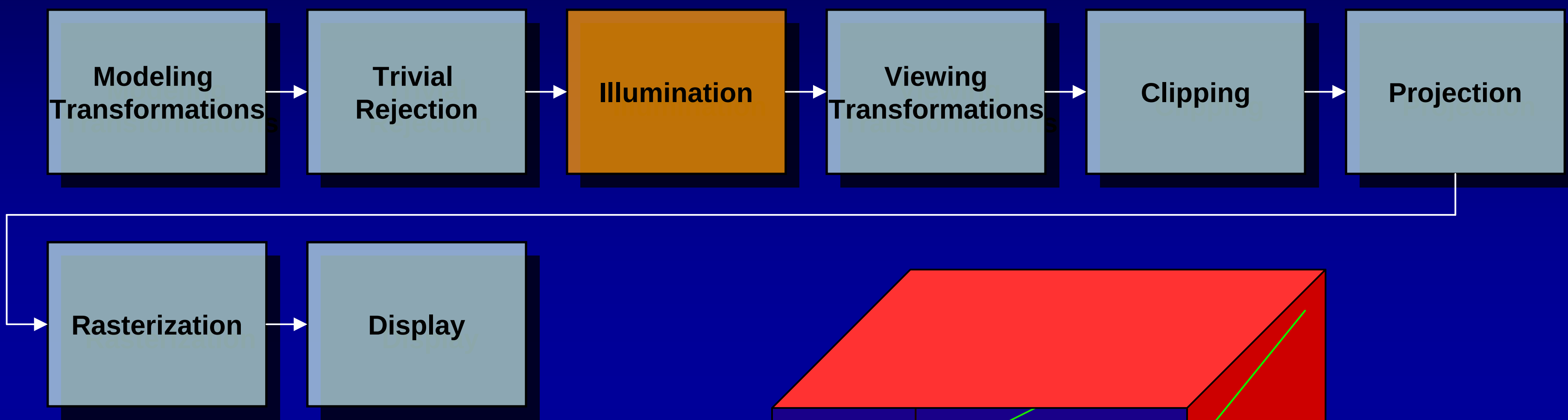
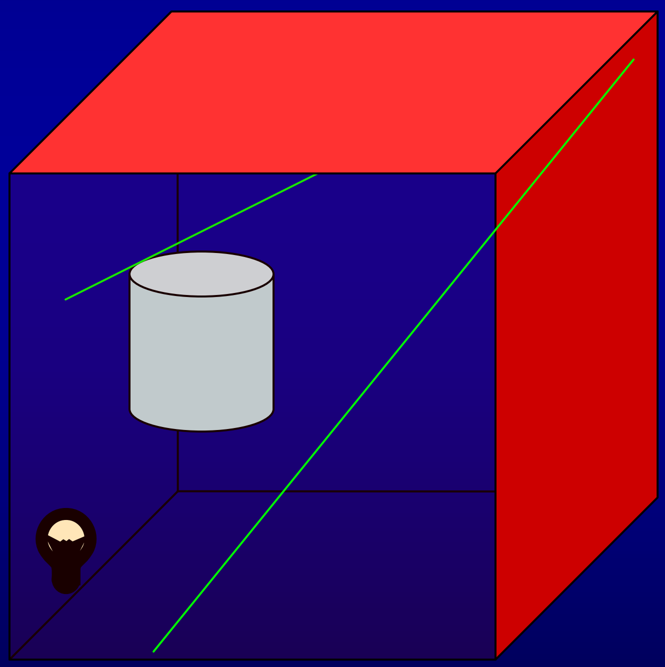
Computer Graphics Pipeline



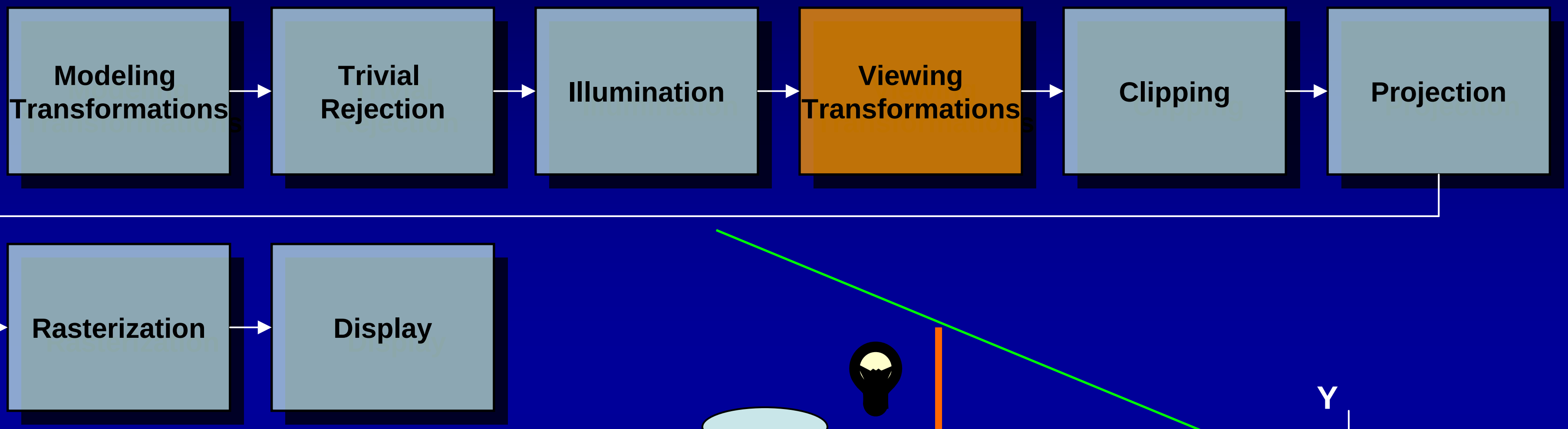
Compute normals at the endpoints for lighting calculation:

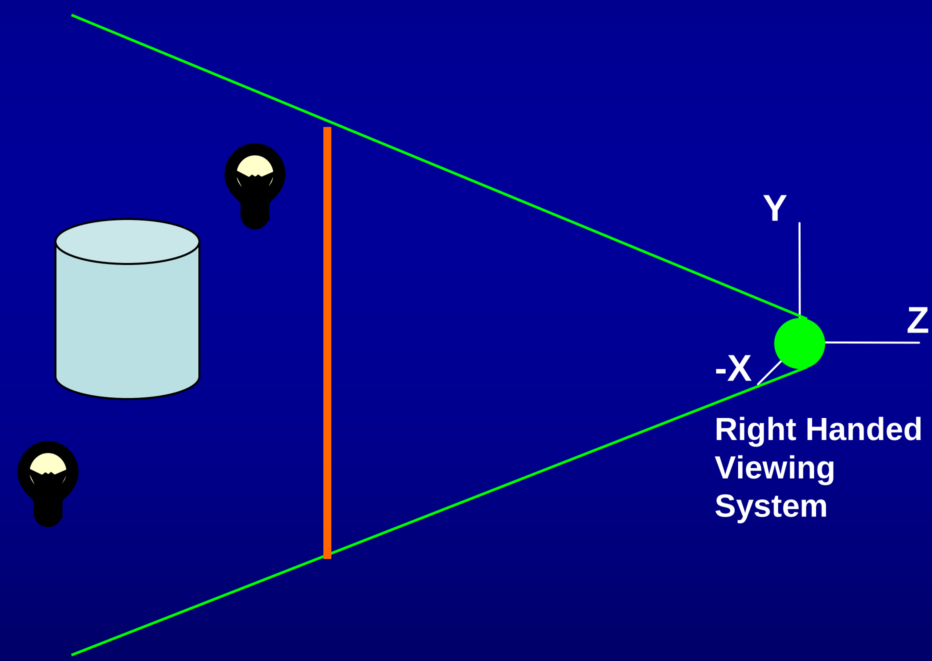
$$I_p = k_a i_a + \sum_{\text{lights}} \left(k_d (L \cdot N) i_d + k_s (R \cdot V)^{\alpha} i_s \right).$$

Ambient **Diffuse** **Specular**



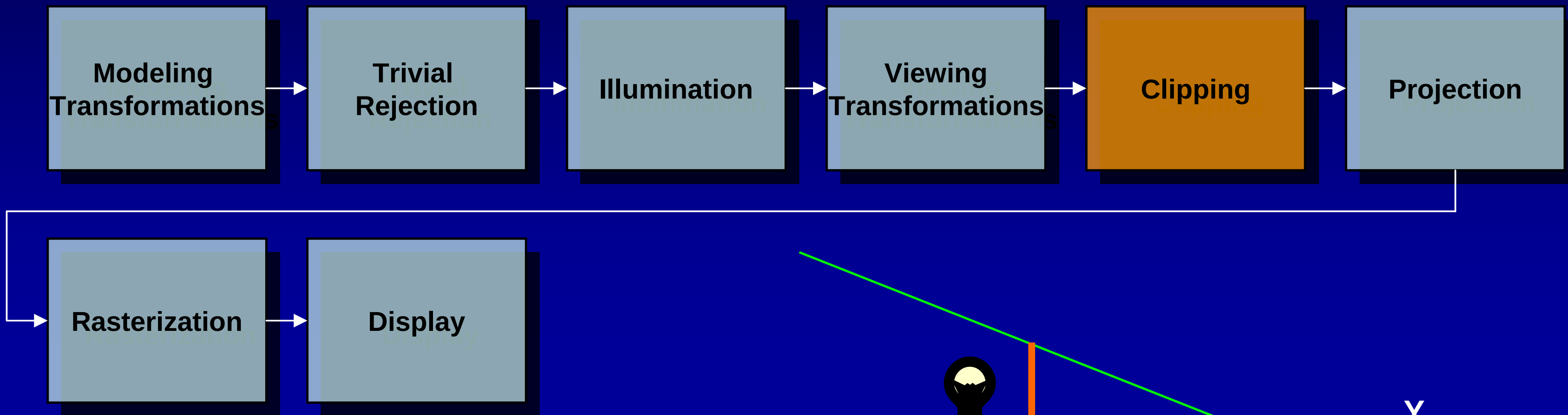
Computer Graphics Pipeline

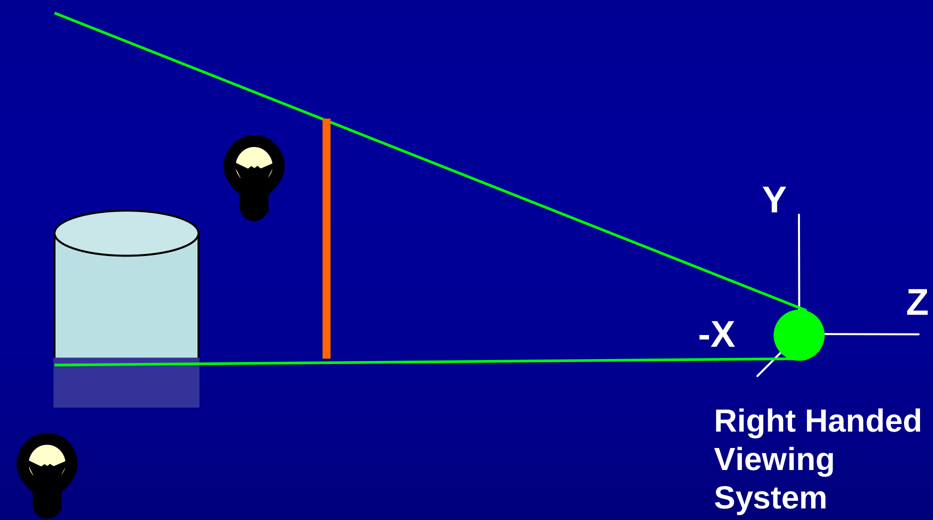




Change coordinate systems such that the eye sits at the origin and the viewing plane is defined. This is called eye space.

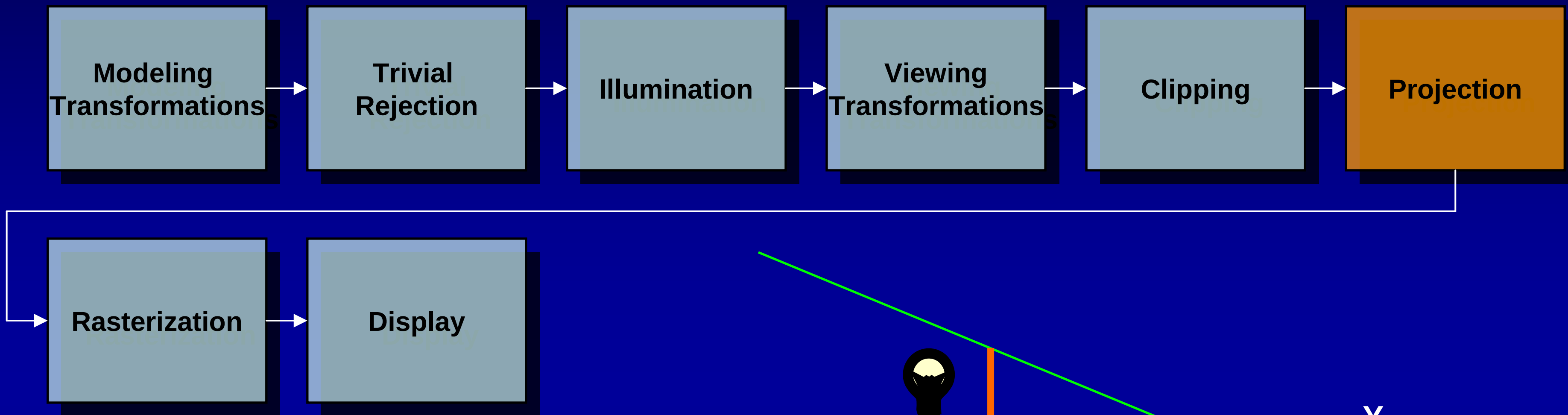
Computer Graphics Pipeline



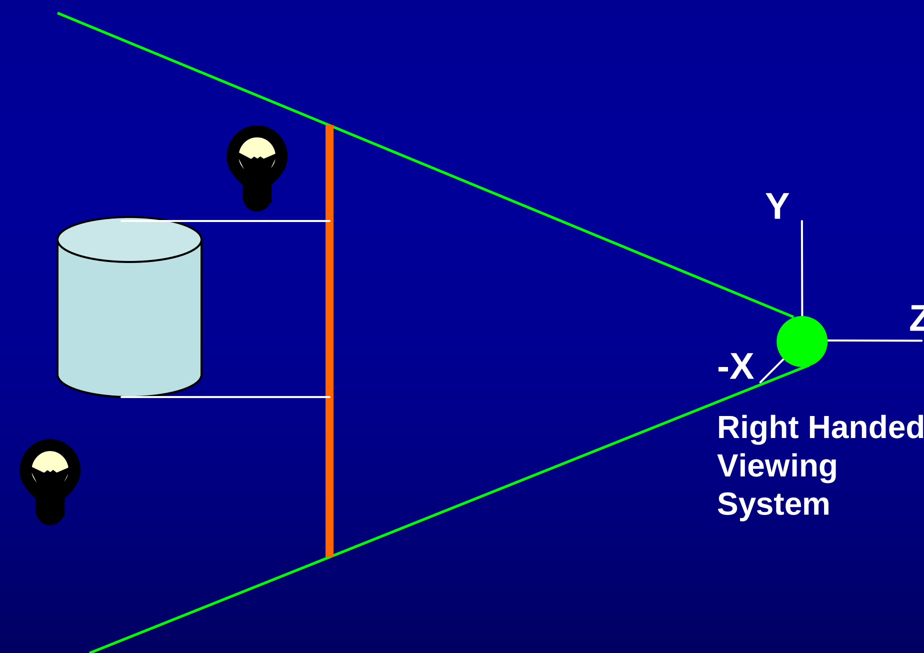


Eliminate any triangles or points that are not within the view frustum (outside the scene) so that we don't have to draw them.

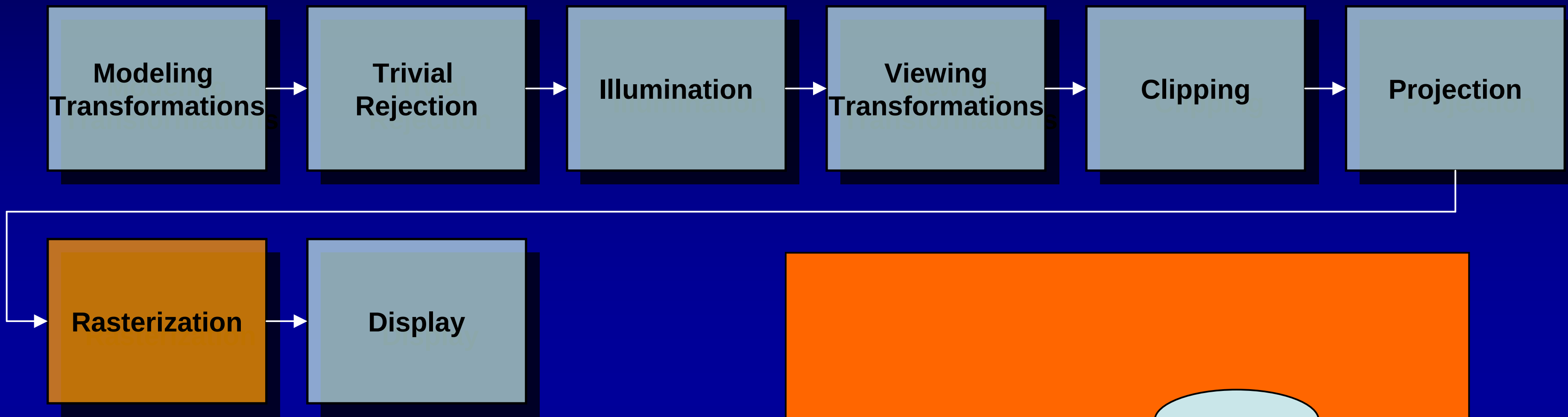
Computer Graphics Pipeline

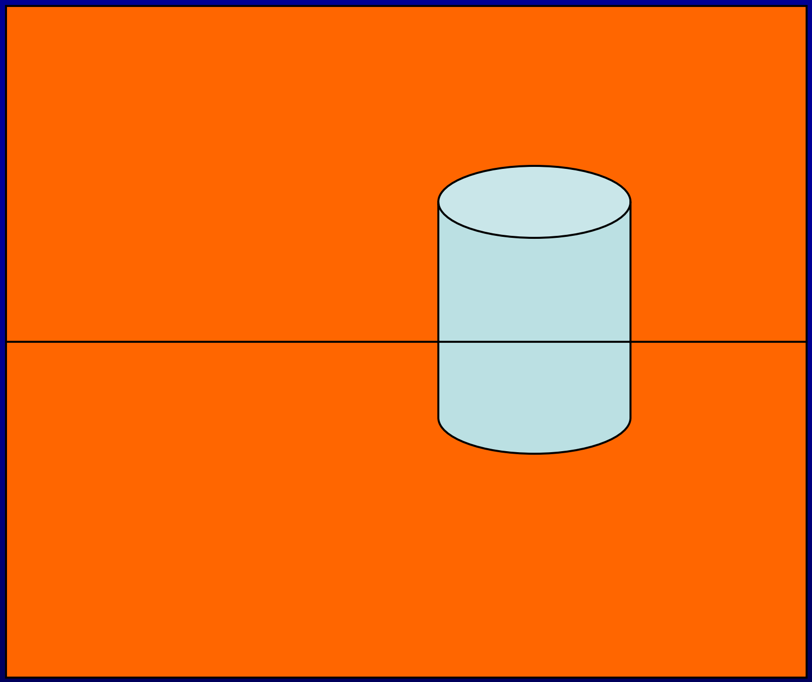


Project 3D objects to 2D Viewing plane. This is a projection from eye space to screen space.



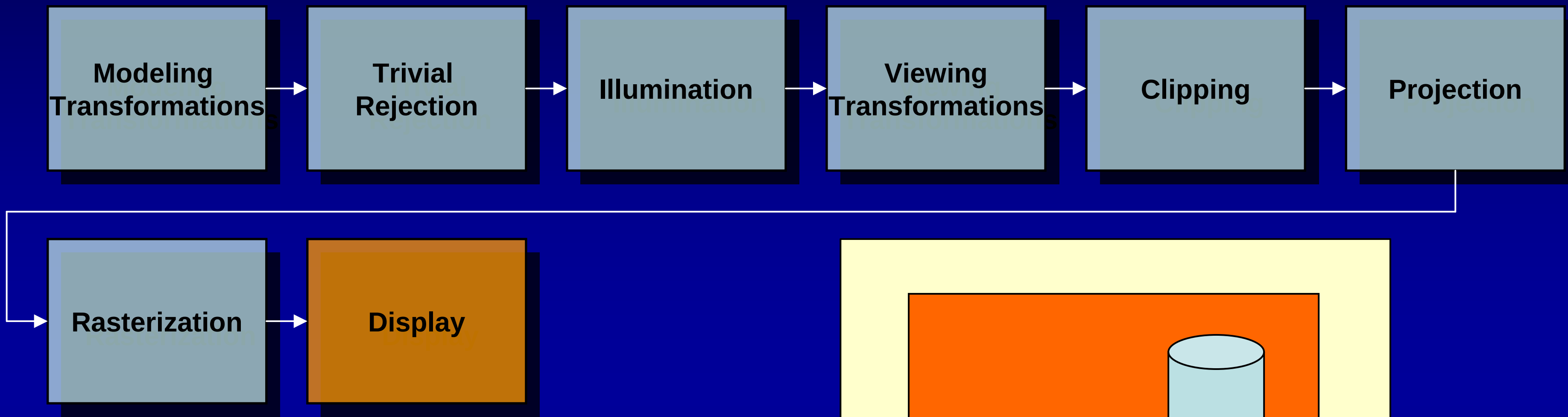
Computer Graphics Pipeline





Convert the object into pixels using some sort of interpolation (usually linear).

Computer Graphics Pipeline



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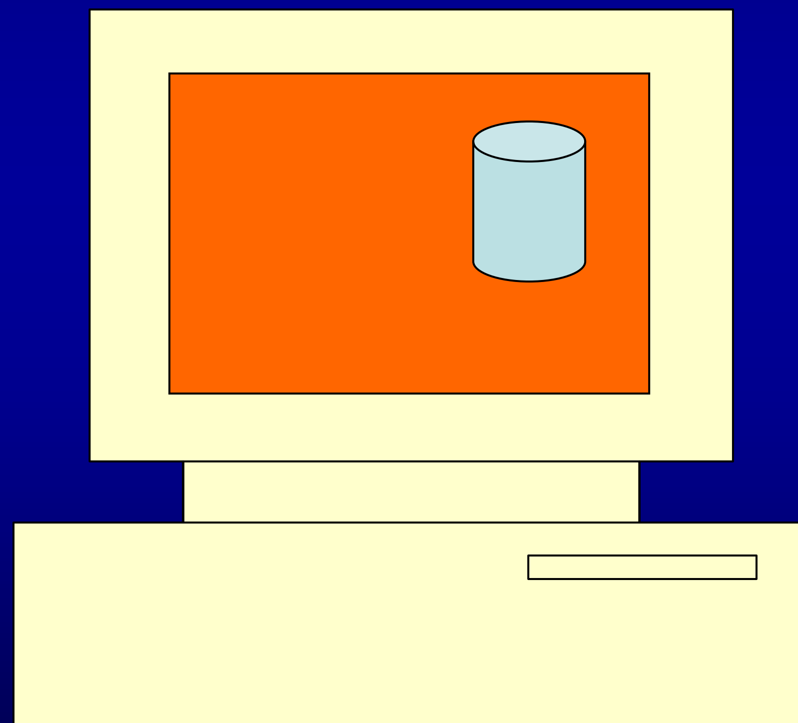
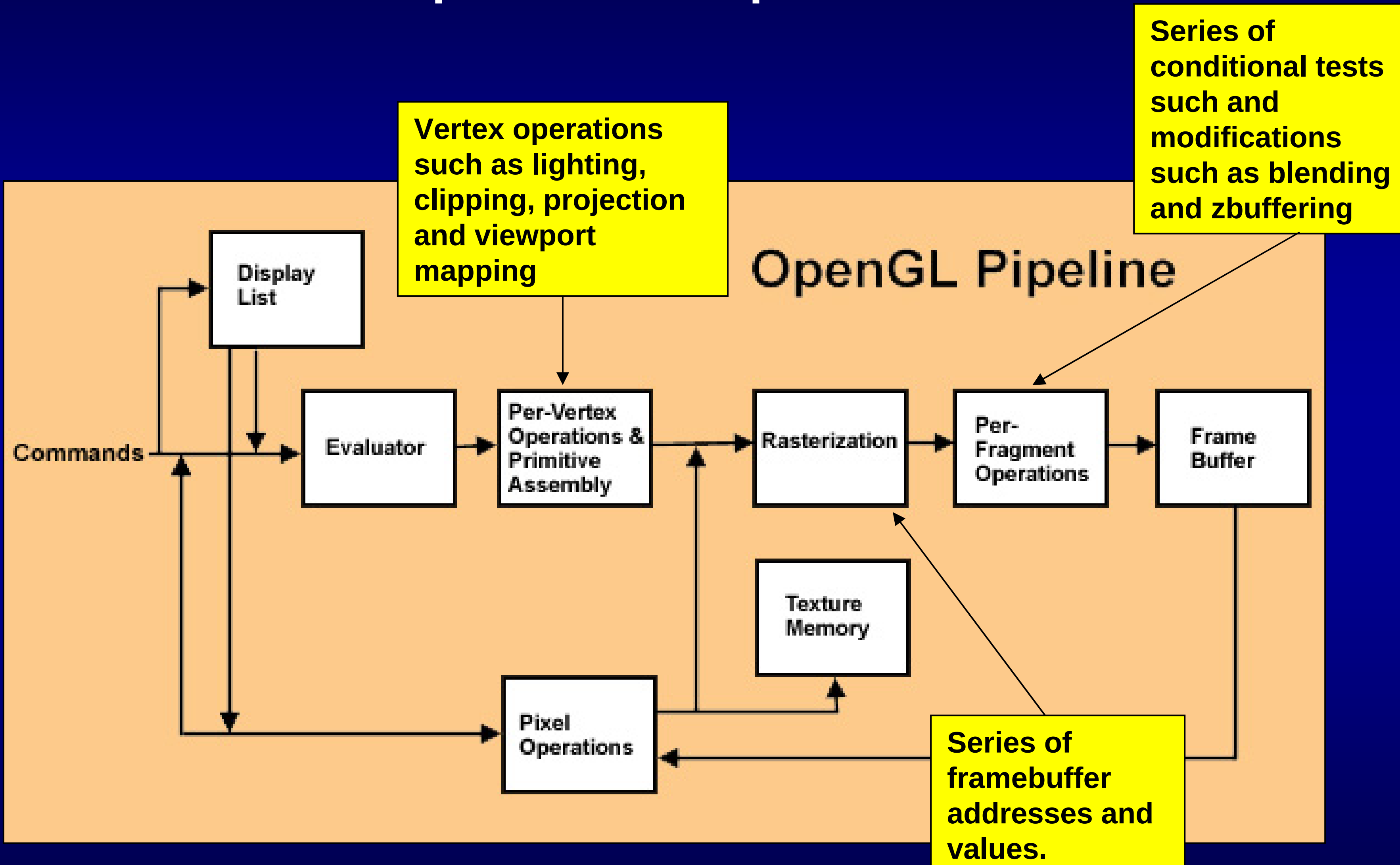


OpenGL Pipeline

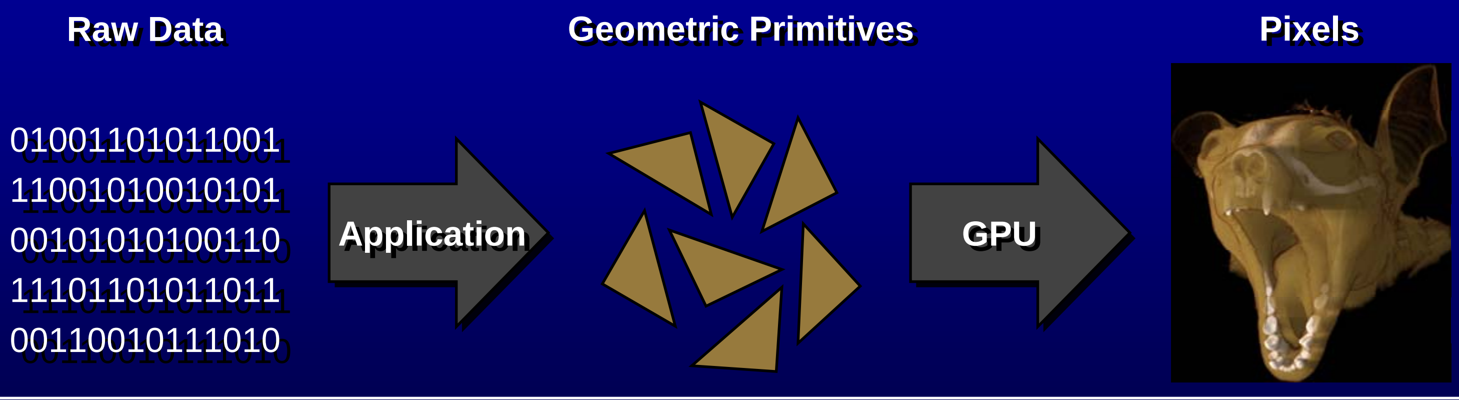


Topics

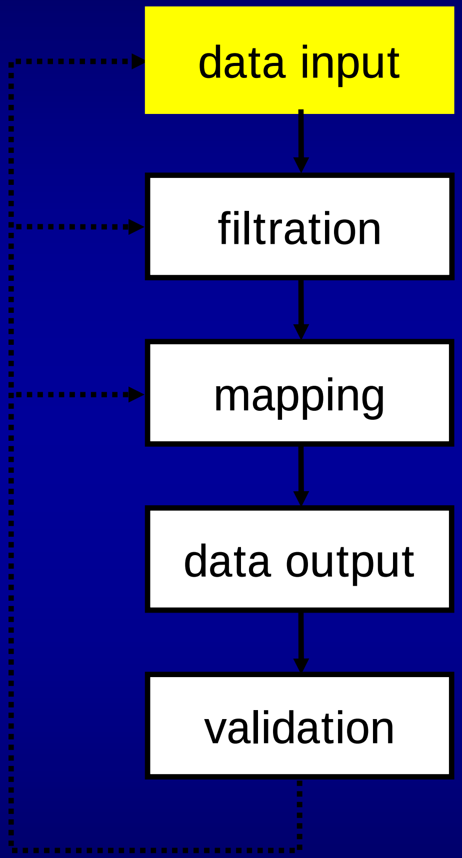
- Computer Graphics Pipeline
- Scientific Visualization Process
- Scientific Visualization Techniques

Scientific Visualization Process

- the primary goal of visualization is *insight*
- a picture really is worth 1000 words or (potentially) tera/peta-bytes of data
- as dataset sizes increase so does the need for scientific visualization



Scientific Visualization Process



- step 1: read the raw data into the tool
- easy if your data is stored in a standard file format such as netCDF, HDF, etc.
- most tools also provide a format-description mechanism to detail the organization of data elements within a "non-standard" file

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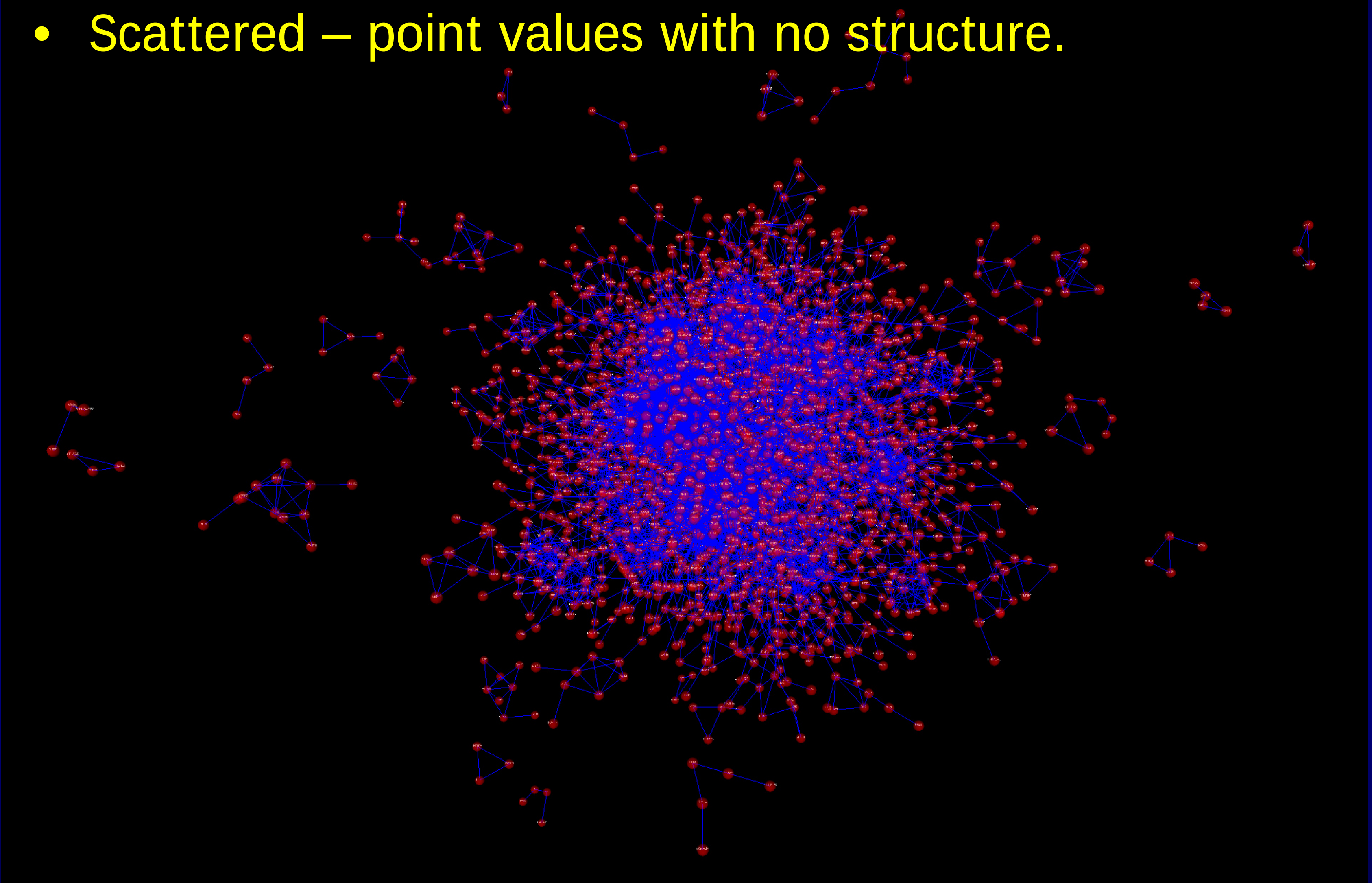
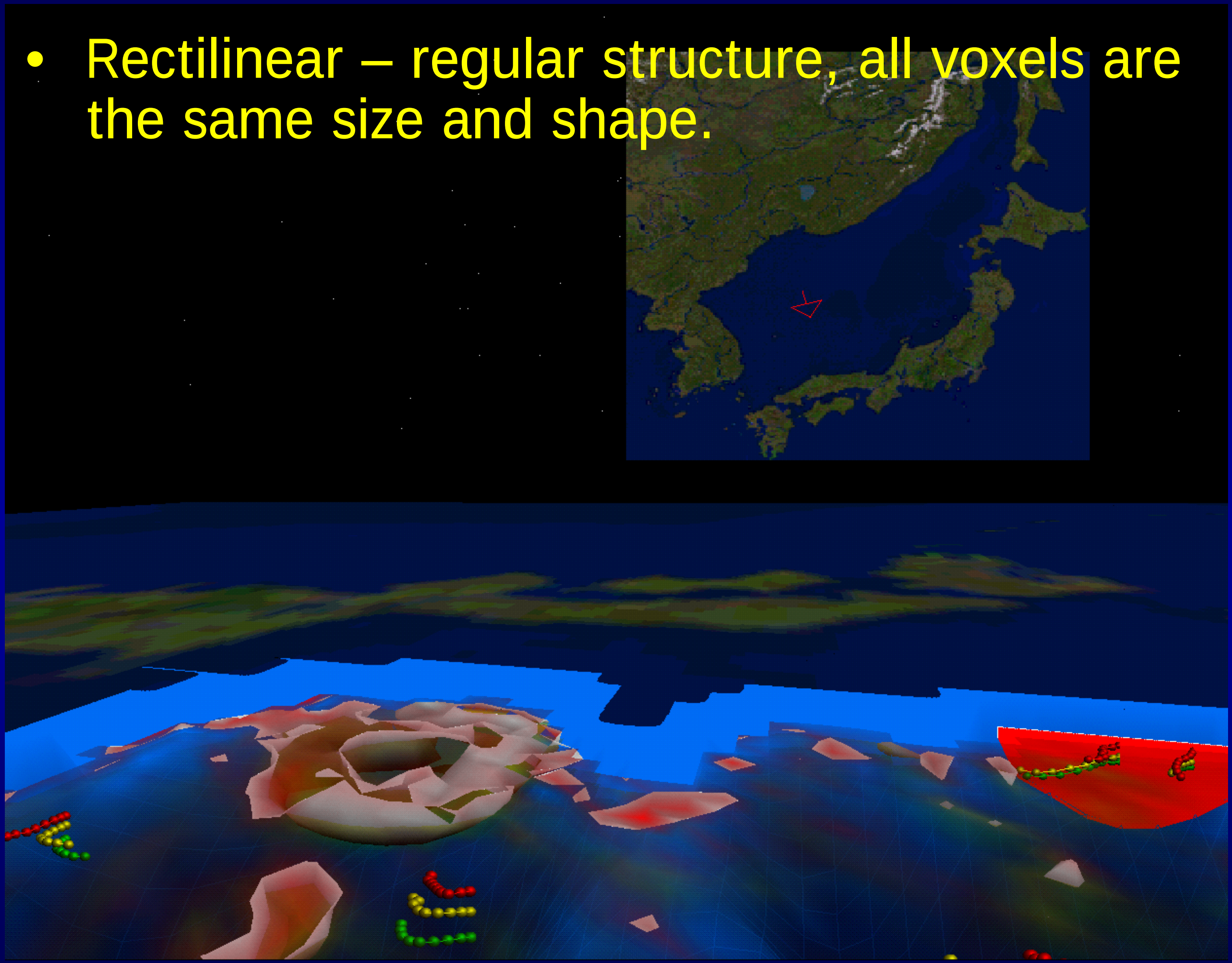
Input Data Types

- Scattered – point values with no structure.



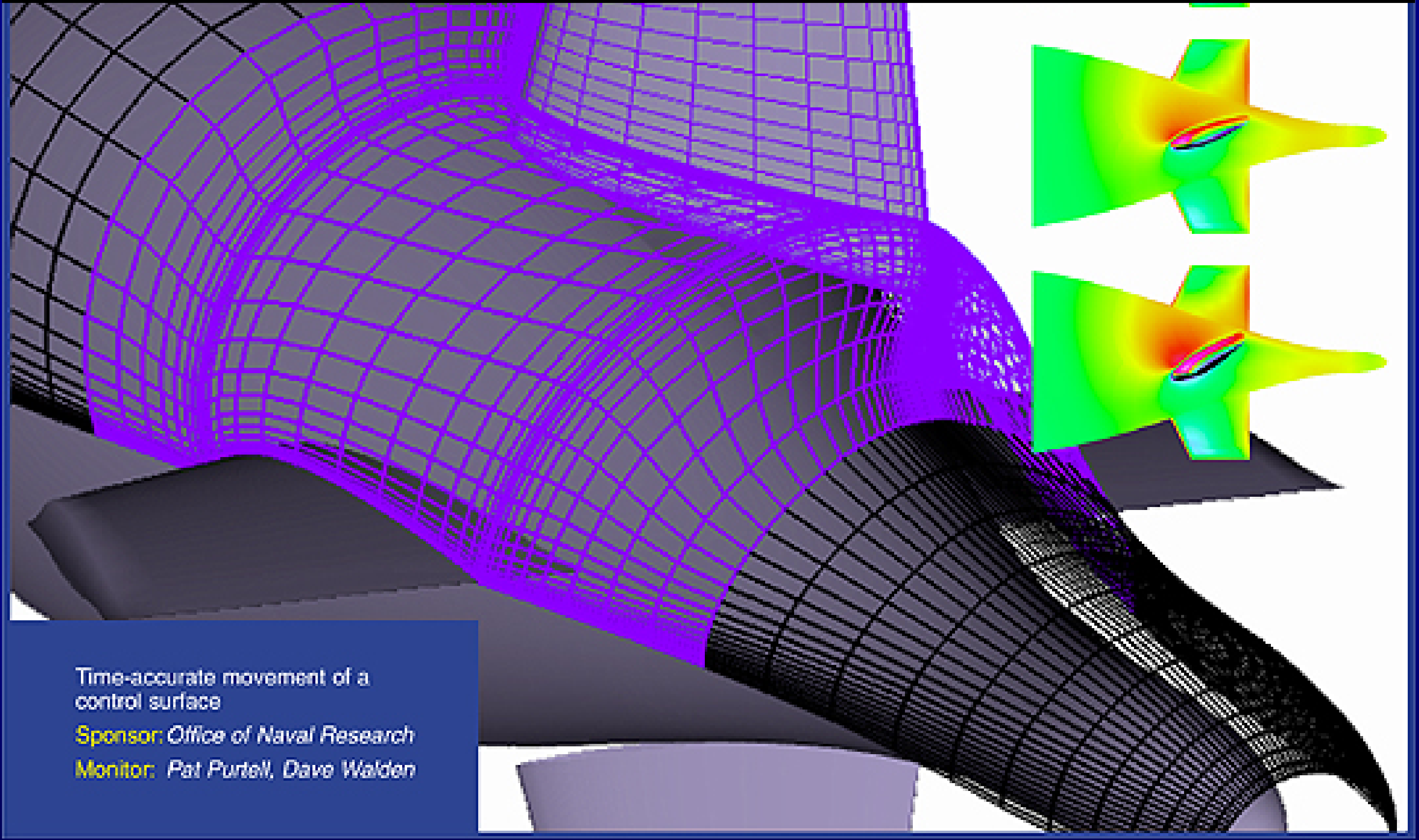
Input Data Types

- Rectilinear – regular structure, all voxels are the same size and shape.



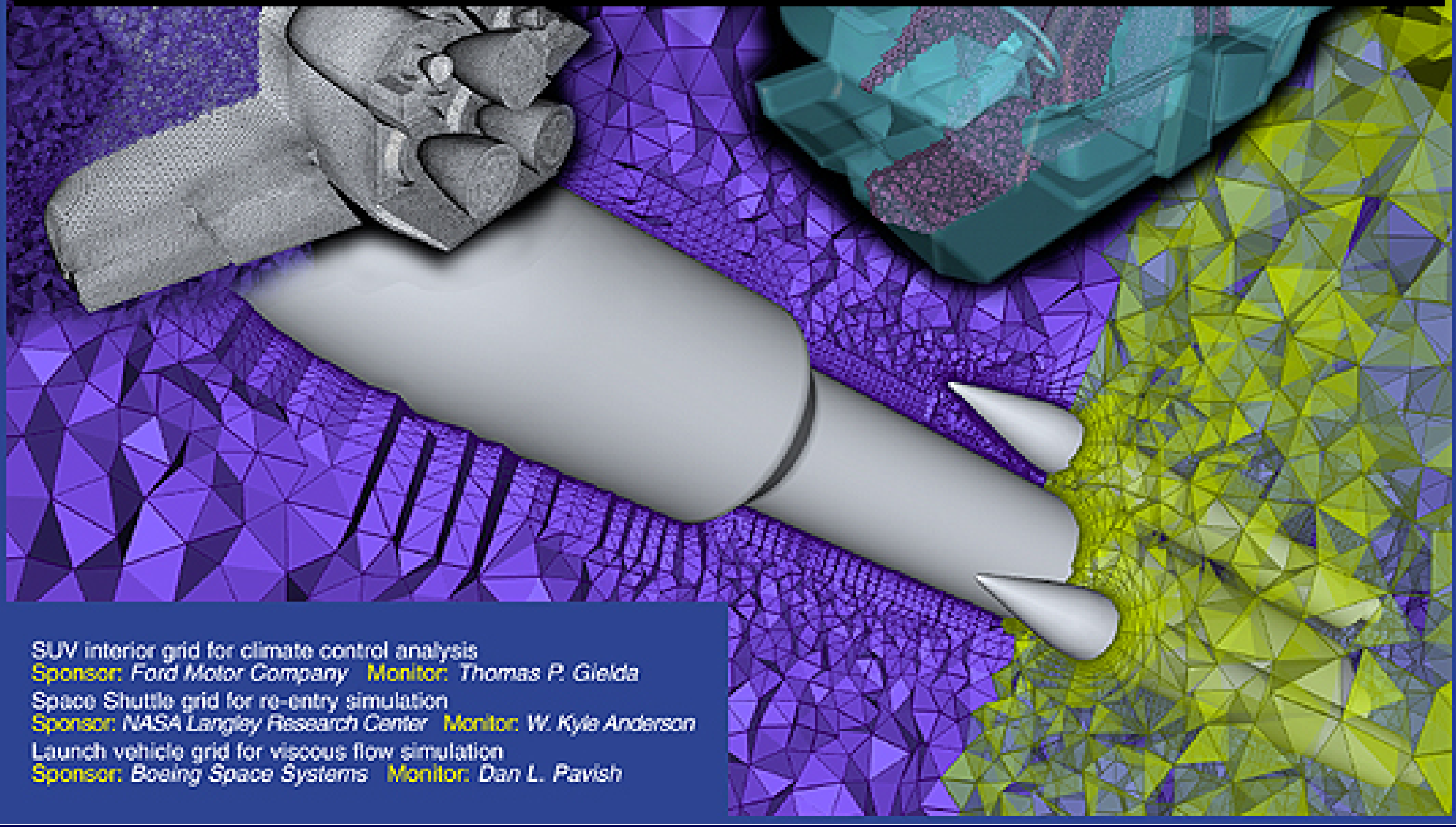
Input Data Types

- Curvilinear – implied adjacency structure with nonlinear shape function applied to cell structure.



Input Data Types

- Unstructured – no implied adjacency in structure typically composed of tetrahedral, prisms, pyramids, and hexahedra.

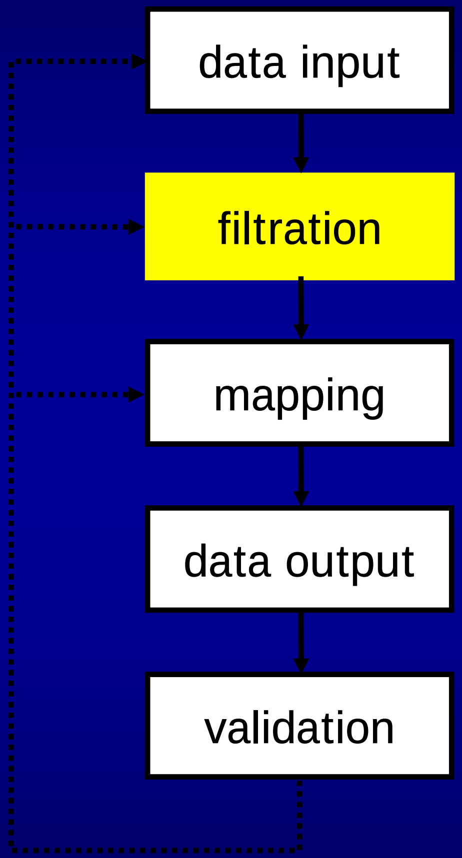


SUV interior grid for climate control analysis
Sponsor: *Ford Motor Company* Monitor: *Thomas P. Gielda*
Space Shuttle grid for re-entry simulation
Sponsor: *NASA Langley Research Center* Monitor: *W. Kyle Anderson*
Launch vehicle grid for viscous flow simulation
Sponsor: *Boeing Space Systems* Monitor: *Dan L. Pavish*

Types of Values Present in Input Data

- Scalar – single value at either the node or center of the cell.
- Vector – 3-tuple typically indicating both magnitude and direction at either the node or center of the cell.
- Tensor – system of equations that can be solved to find various physical components.

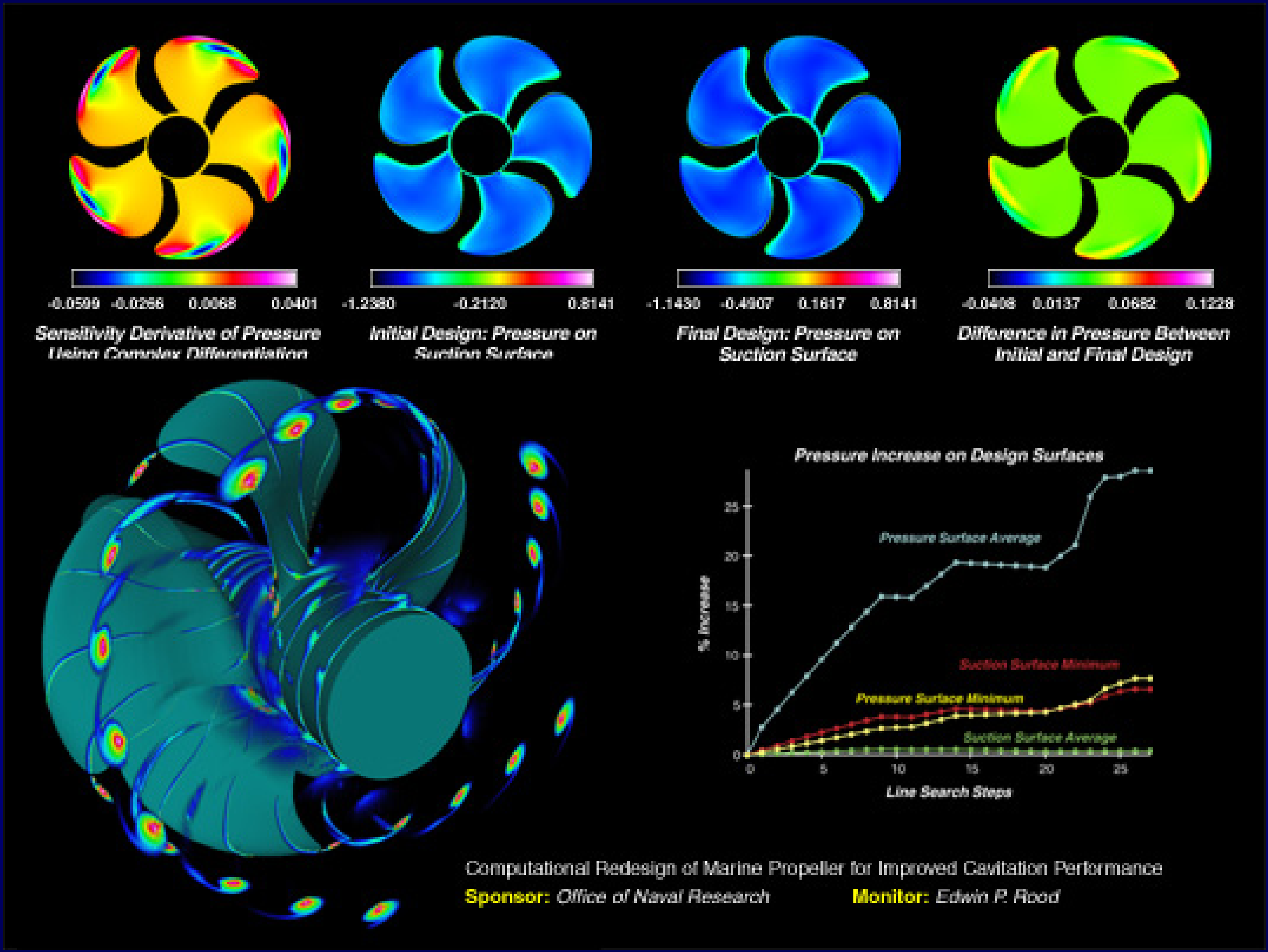
Scientific Visualization Process



- step 2: pre-process the raw data to extract the region or resolution of interest

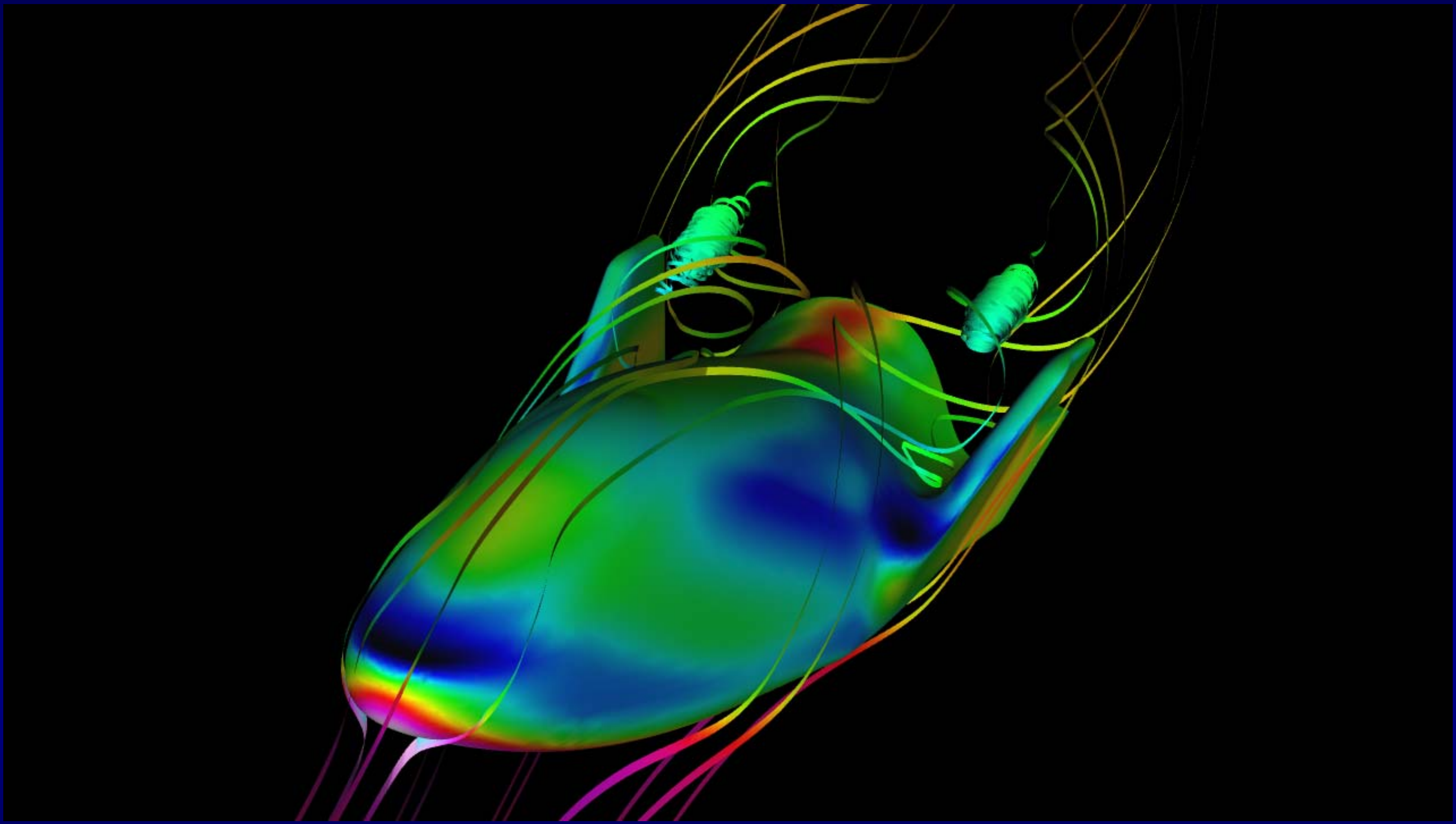
- crop, downsample, convolve, histogram-equalization, grid-fitting, are examples of common operations

Extract Tip Vortices



Propellor, Mike Remotigue, Kelly Gaither

Extract Vortex Cores



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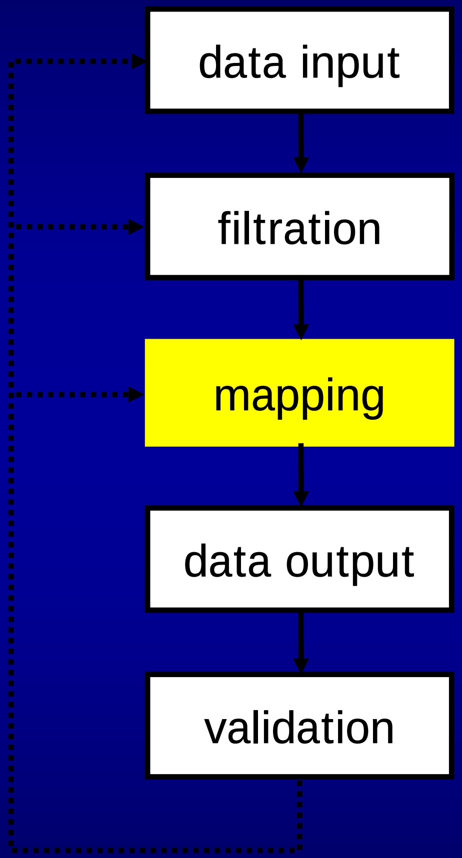
Scientific Visualization Process

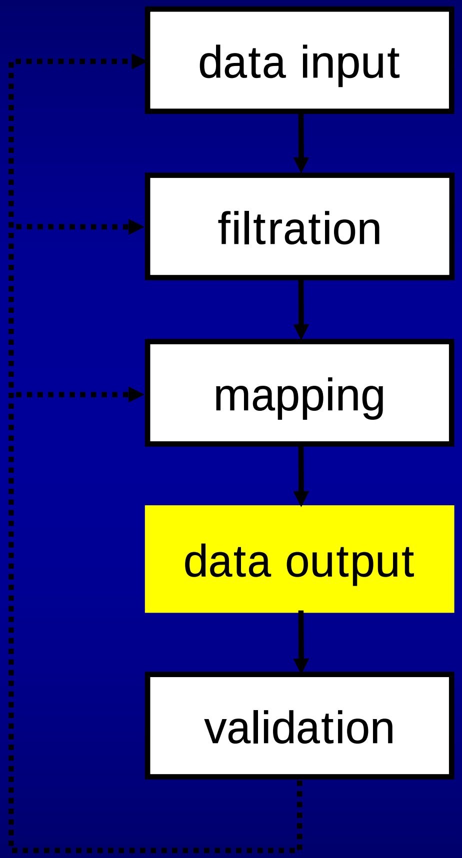


- step 3: map the data to graphical elements
- elements can include geometric primitives like polygons, spheres, arrows, streamlines, etc. or color, texture, lighting, and opacity
- components of multi-variate data may map to distinct graphical elements (one variable may be represented by a polygonal surface, while another variable is used to color the surface)

Classes of Visualization Techniques

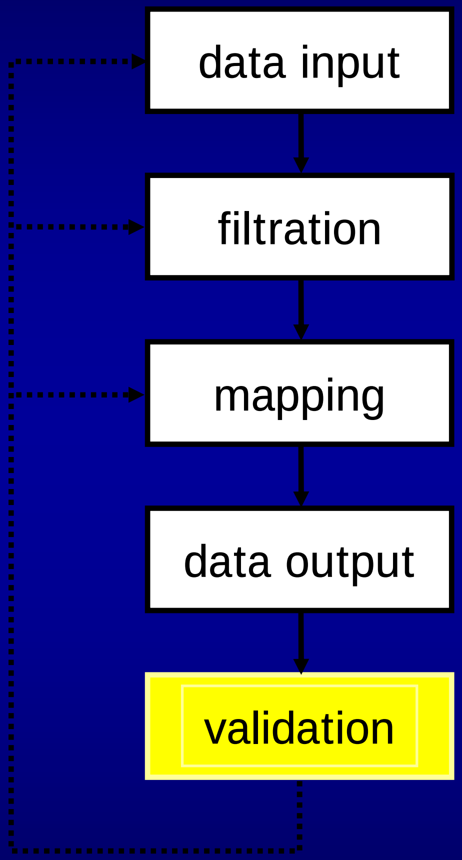
- Glyph techniques – use symbols to represent values or states within a field of information.
- Surface Methods – extracts polygonal versions of calculated components.
- Direct Volume Rendering – generates a rendered image of the volume where volume elements are projected directly onto the image plane.

Scientific Visualization Process



- step 4: output the visualization product
- may include viewing an image of the result in a window, saving the image to a file, creating a movie, a 3D VRML file, or a stereo pair, etc.
- not all output media are appropriate for all mapping algorithms (example: VRML files cannot be output from visualization methods which do not produce geometric primitives)

Scientific Visualization Process



- step 5: verify that the visualization product is a reasonable approximation of the raw data
- errors may result from how the data is read and manipulated by the visualization tool, bugs in the tool, or problems in the data itself
- most tools today do not include a mechanism to automatically tell you if there is a problem

Topics

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- Scientific Visualization Process
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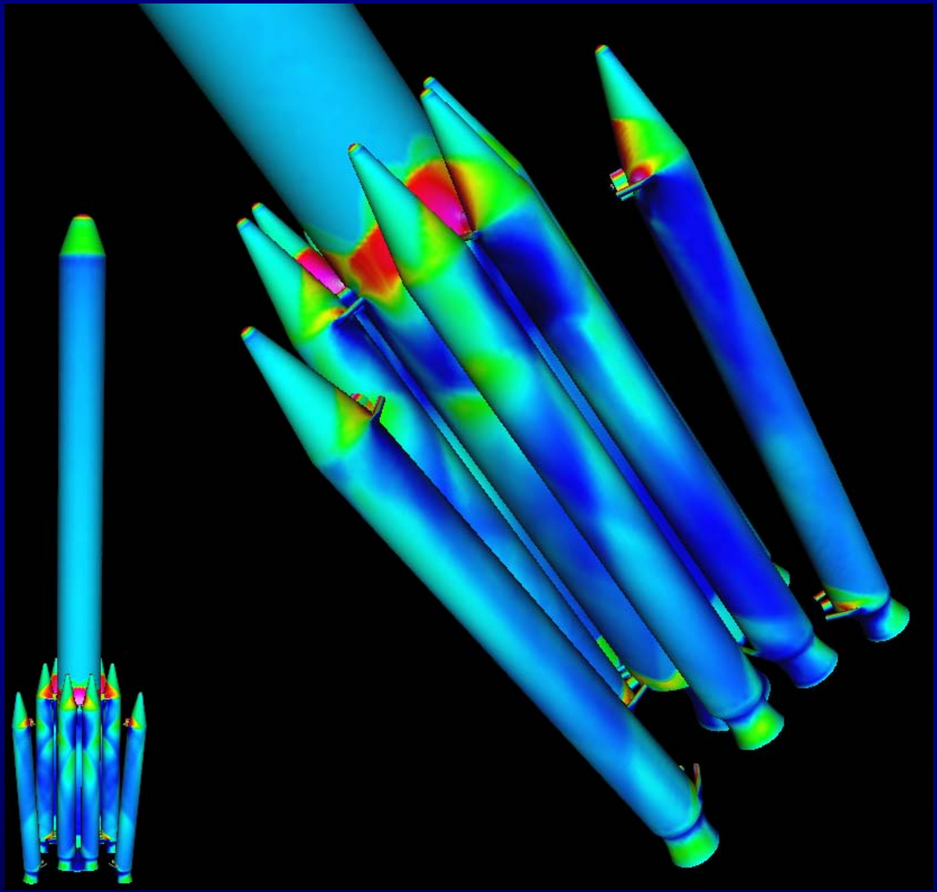
Contours

Given a scalar value and a color map, find the corresponding (r,g,b,a) for that scalar value.

C = min_color_index + (value-minvalue)/(maxvalue-minvalue)*(max_color_index-min_color_index)

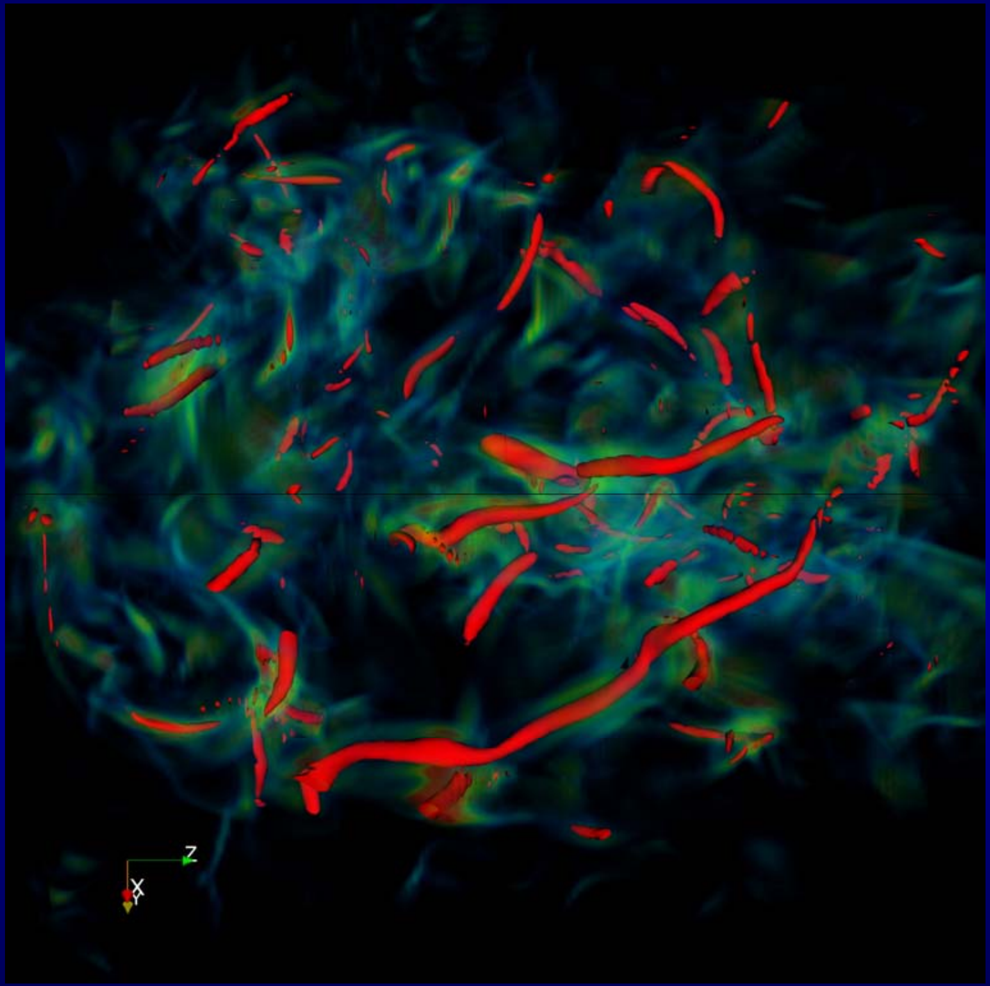


Isosurfaces

Plot the surface for a given scalar value.

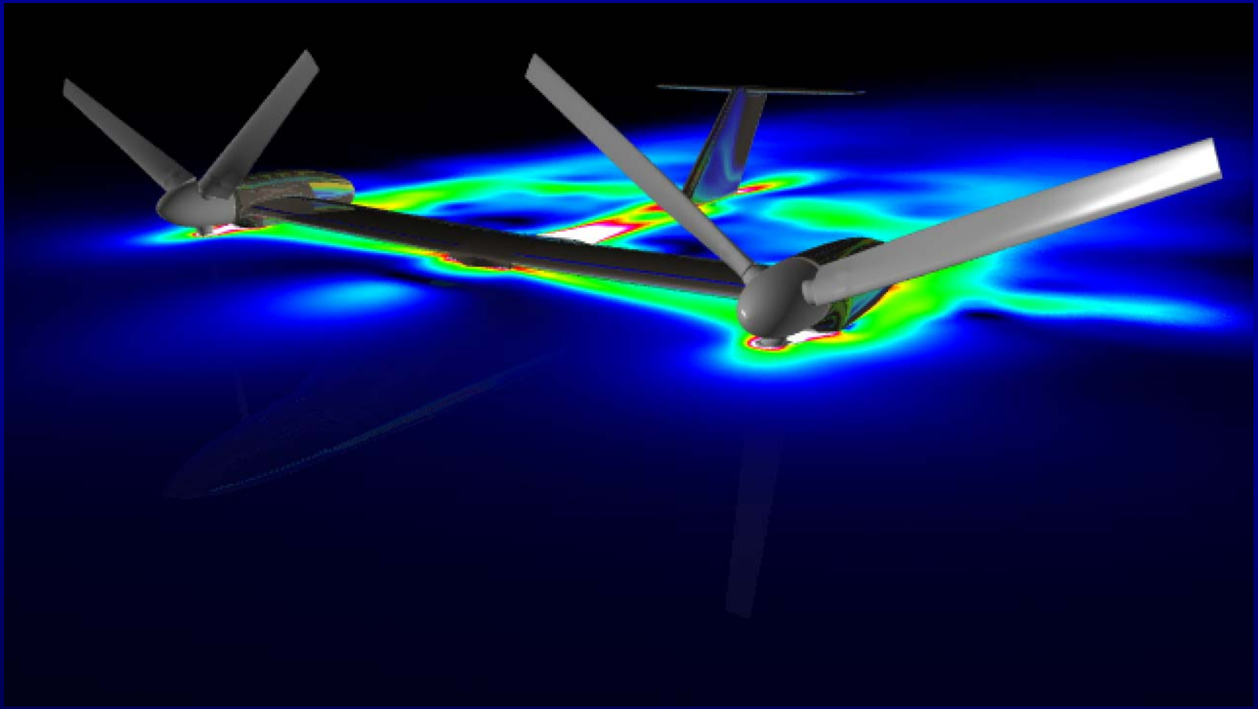
F(x) = y

Most common packages use marching cubes or some variation.



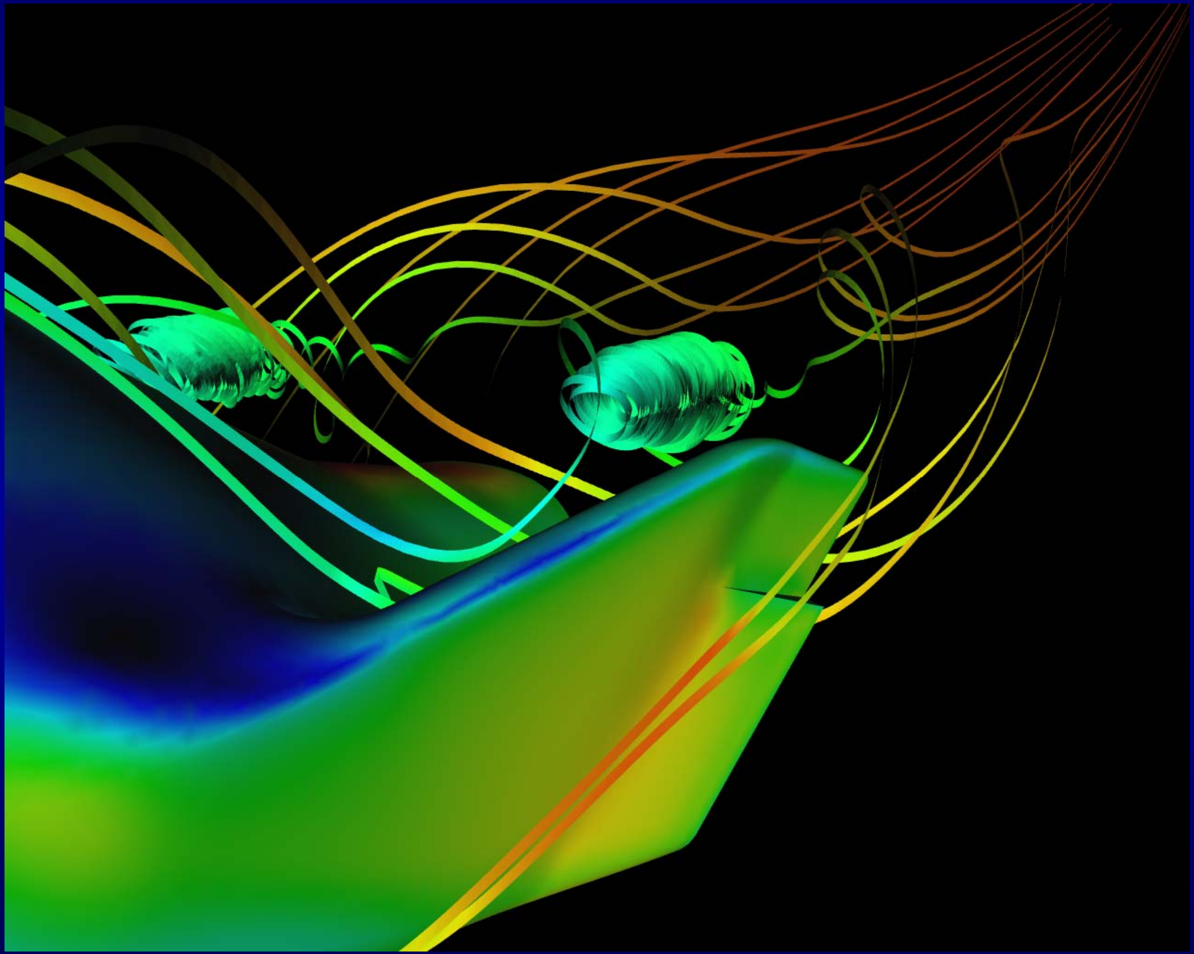
Cutting Planes

Extract a plane from the volume. All packages have axis aligned cutting plane. Many of them have arbitrary cutting plane capabilities.



Particle Traces

Given a vector field, extract a trace that follows that trajectory defined by the vector.



$P_{new} = P_{current} + V_P\Delta t$

Streamlines – trace in space

Pathlines – trace in time

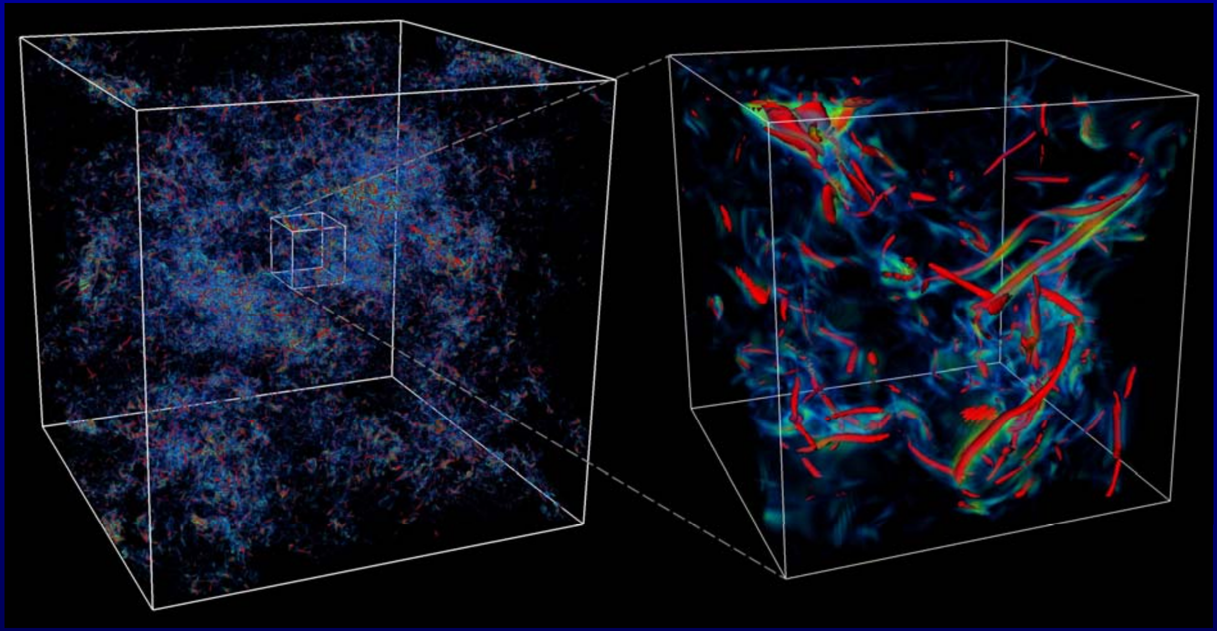
Volume Rendering

Volume rendering captures how particles in space interact with the light.

Volume Rendering Equation:

$$C = \sum_{i=1}^{n} C_i \prod_{j=1}^{i-1} \left(1 - A_j\right)$$

$$A = 1 - \prod_{j=1}^{n} \left(1 - A_j\right)$$



Questions?