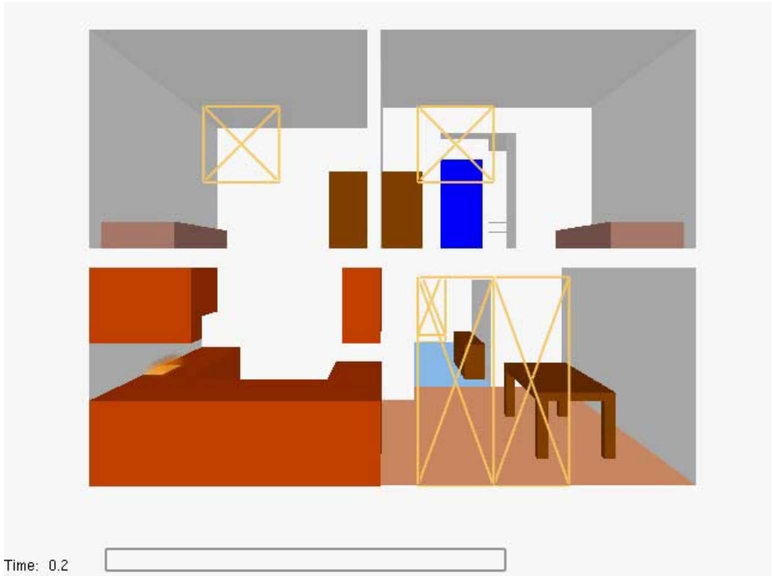
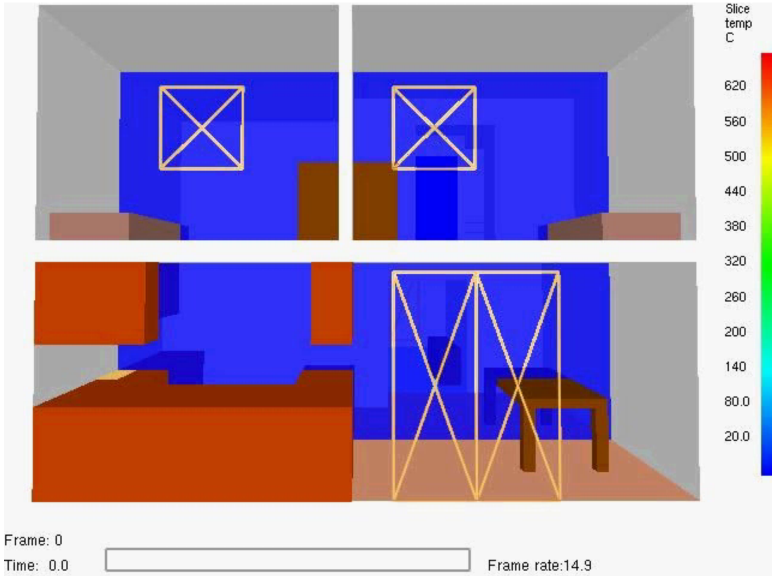
# Modeling And Visualizing Fire Without Getting Burned




MCSD Seminar

June 29, 2005

Glenn P. Forney

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

# Overview

- Fire Models
- Fire modeling applications
- Gaining insight through visualization

# Smokeview Visualization "Team"

**FDS computational model**

Kevin McGrattan
Howard Baum
Ron Rehm

Kuldeep Prasad – multi-mesh
Chuck Bouldin - parallelization

Anthony Hamins – experimental validation
Steve Kerber – forced ventilation
Greg Linteris – fundamental fire Physics

**Smokeview visualization**

Glenn Forney

**Urban-wildland interface problem**

Ruddy Mell
Ron Rehm

**Fire reconstructions**

Dan Madrzykowski
Bob Vettori
Doug Walton

and others…

# The Purpose of Computing is Insight Not Numbers - *R. W. Hamming*

Influence on visualization and Smokeview

# Fire Models

- Can provide insight into complex phenomena within a fire scenario including

| | |
|---|---|
| Flame spread | Gas Conc. |
| Fuel package | Smoke |
| HRR | Ventilation |
| Suppression | Radiation |

- Can provide a tool for understanding
  Fire behavior under various ventilation conditions

# Single Equation Models

Hand (or simple computer) calculations

– Heat release rate
– Flame height
– Minimum Flashover HRR
– T-squared Fire Growth
- Predicting Time to Flashover

# Flame Height

$$L_f = 0.23\dot{Q}^{2/5} - 1.02D$$

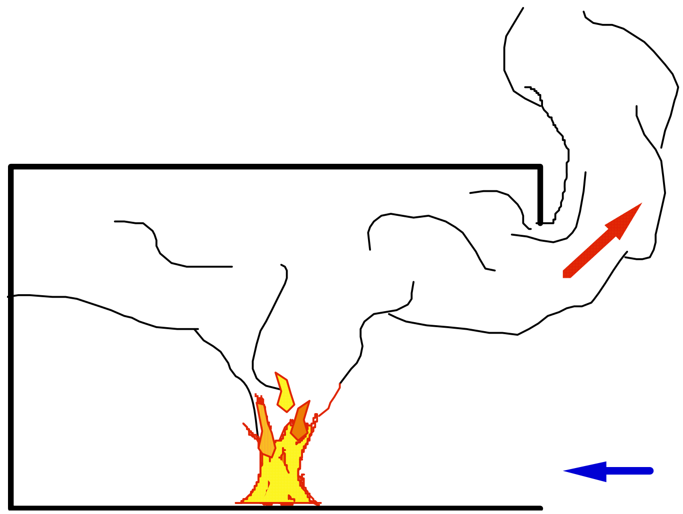
**P 138 JQ**

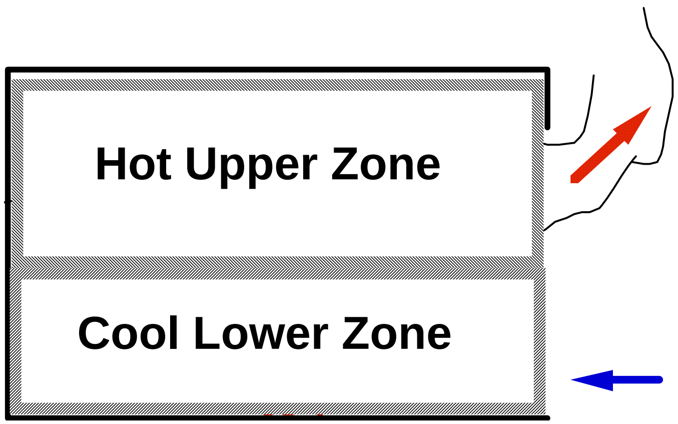
**Trash can HRR = 50 kW**
**Trash can diameter = 0.3 m (1 ft)**
**Estimated Trash Can Flame Height = 0.8 m (2.5 ft)**

# Zone Models

(ODE models)

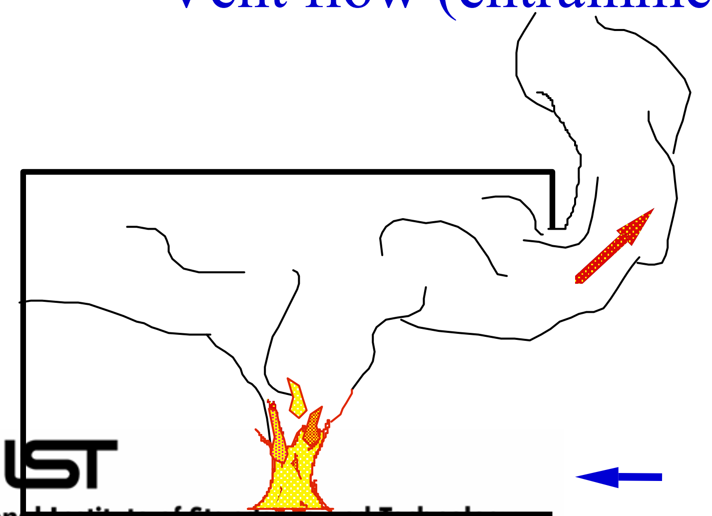
- Divide room into two zones

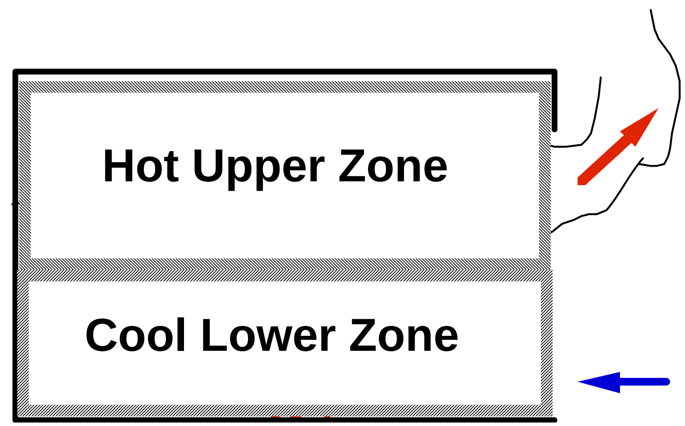




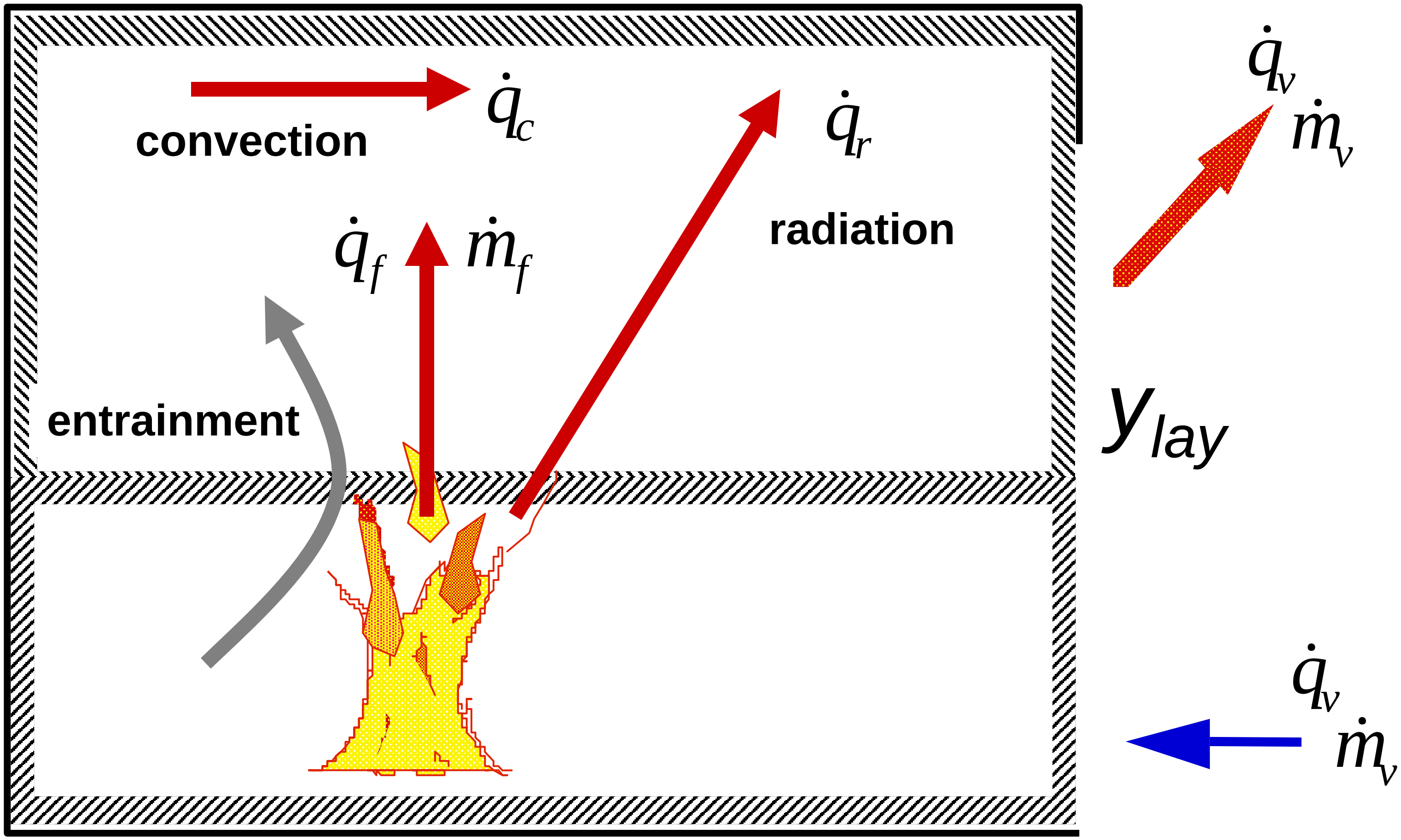
# Zone models

- Two primary control volumes
  - Upper / lower layers
- Conditions assumed uniform in each layer
- Correlations
  - Combustion
  - Plume flow
  - Vent flow (entrainment)



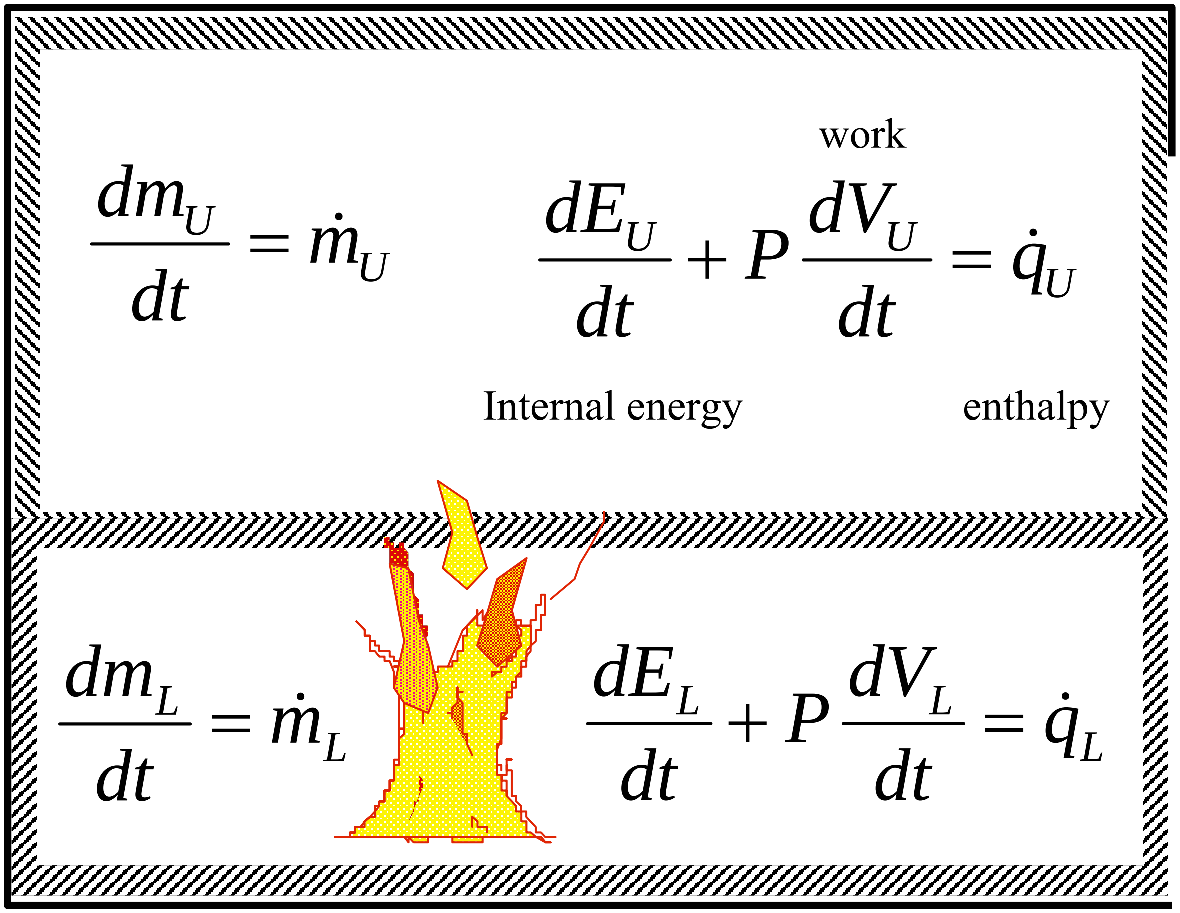


# Zone models


$\dot{q}_c$
convection
$\dot{q}_r$
radiation
$\dot{q}_f$
$\dot{m}_f$
entrainment
$\dot{q}_v$
$\dot{m}_v$
$y_{lay}$
$\dot{q}_v$
$\dot{m}_v$

# Zone Modeling Equations

Conservation of mass and energy




## State Equations

Ideal Gas Law

$$\frac{P}{R} = \rho_L T_L = \rho_U T_U$$

Internal Energy

$$E_L = c_V m_L T_L$$

$$E_U = c_V m_U T_U$$

# Zone models

**Governing Equations:**

**Pressure:**

$$\frac{dP}{dt} = \frac{\gamma - 1}{V}(\dot{q}_L + \dot{q}_U)$$

**Layer interface:**

$$\frac{dy_{lay}}{dt} = \frac{-1}{A_{room}\gamma P_{abs}}(\dot{q}_U - V_U \frac{dP}{dt})$$

**Upper/Lower Layer Temperature:**

$$\frac{dT_X}{dt} = \frac{1}{c_p m_X}((\dot{q}_X - c_p \dot{m}_X T_X) - V_X \frac{dP}{dt})$$

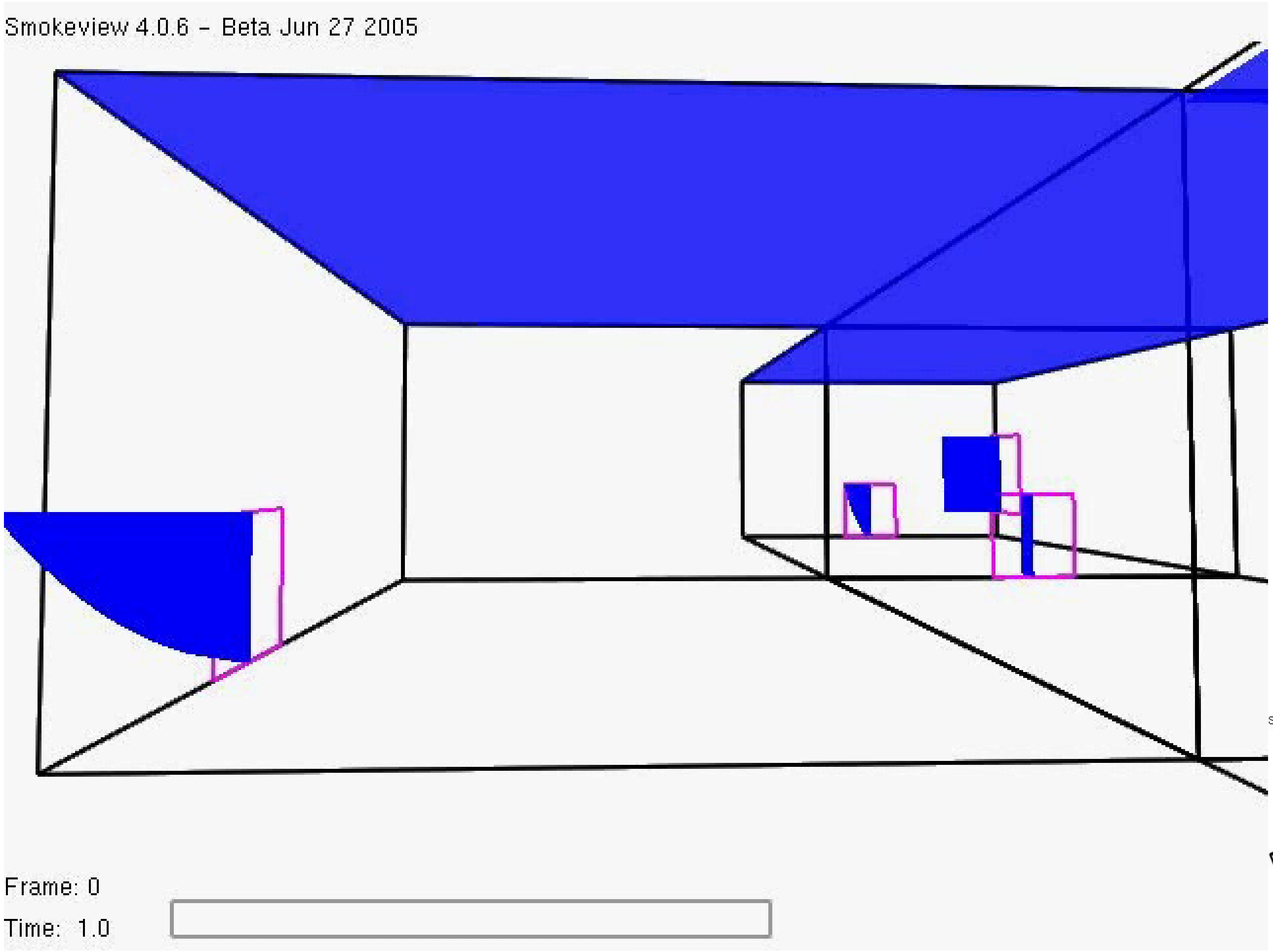
# Zone Modeling Equations

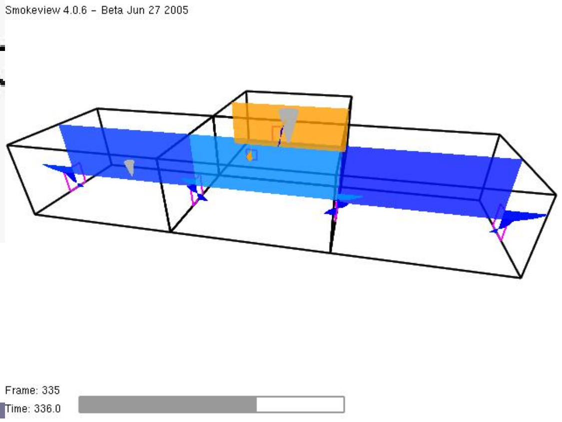
$$x = \begin{pmatrix} P \\ V_U \\ T_L \\ T_U \end{pmatrix} \qquad \frac{dx}{dt} = f(x)$$

"Small" changes in P, $V_U$, $T_L$, $T_U$ → Large changes in dP/dt

Stiff ODE solvers required for solution (use DASSL)

# Zone model visualization

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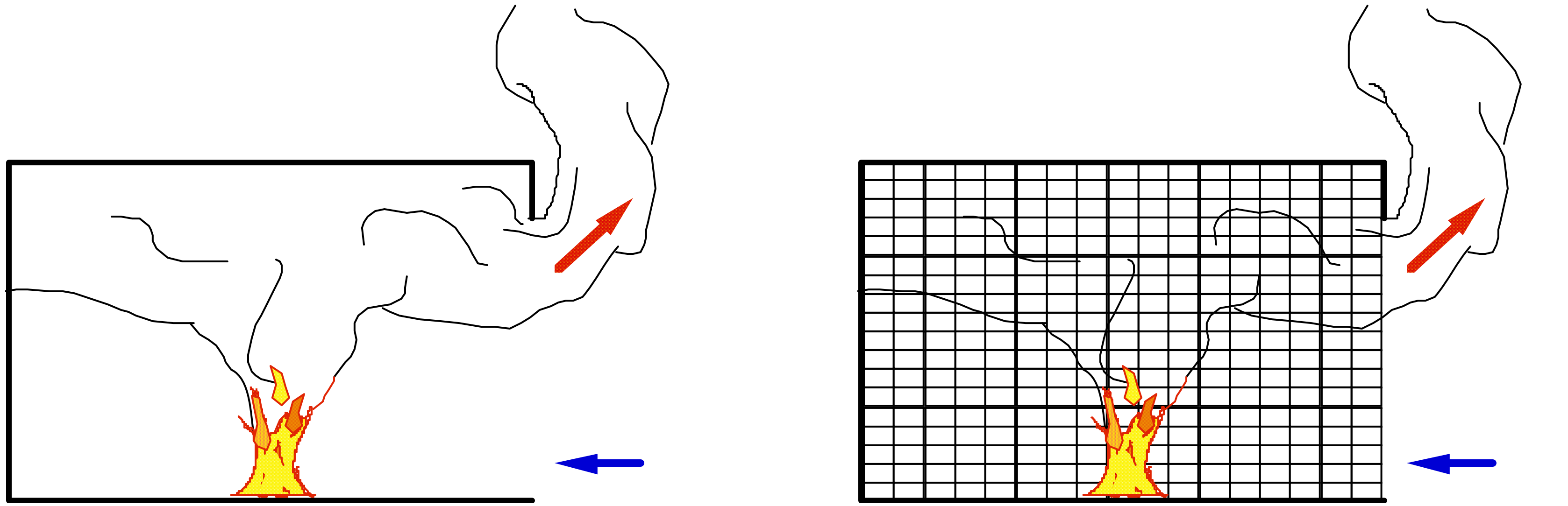
# Zone to Field Models



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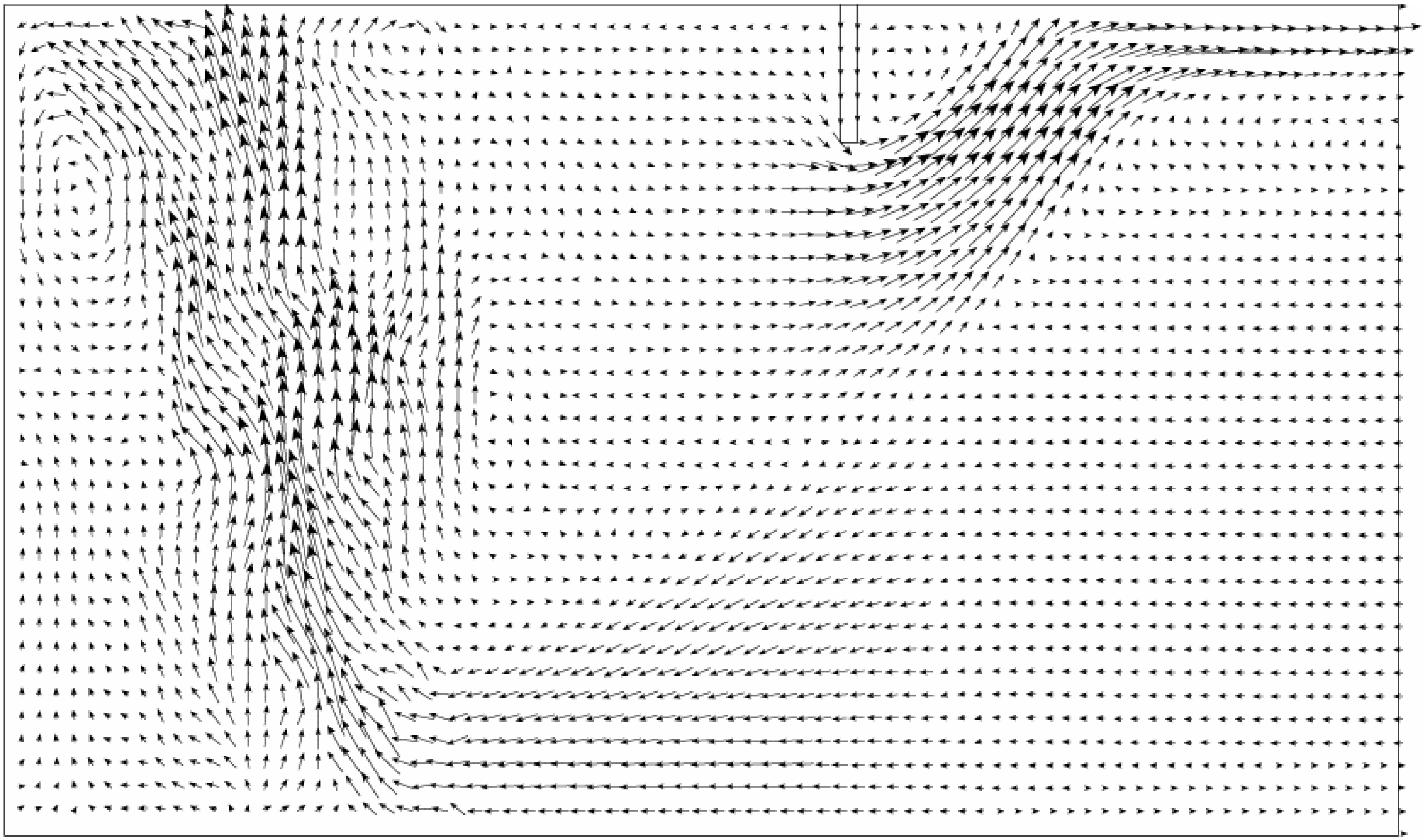
# Field models



# Fire Dynamics Simulator and Smokeview

Version 1 release, February 2000
Version 4 release, November 2004

**http://fire.nist.gov/fds**

## NIST Fire Dynamics Simulator (FDS) and Smokeview

### Overview

FDS is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. Smokeview is a visualization program that is used to display the results of an FDS simulation.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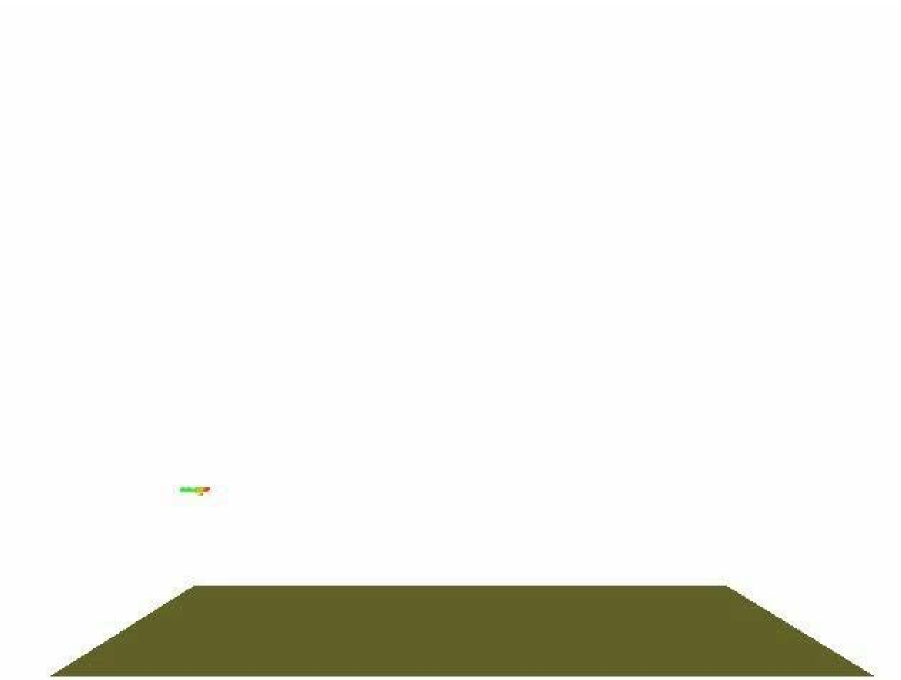
# Fire Modeling Applications

# Fuel Spray (Walton, Floyd)



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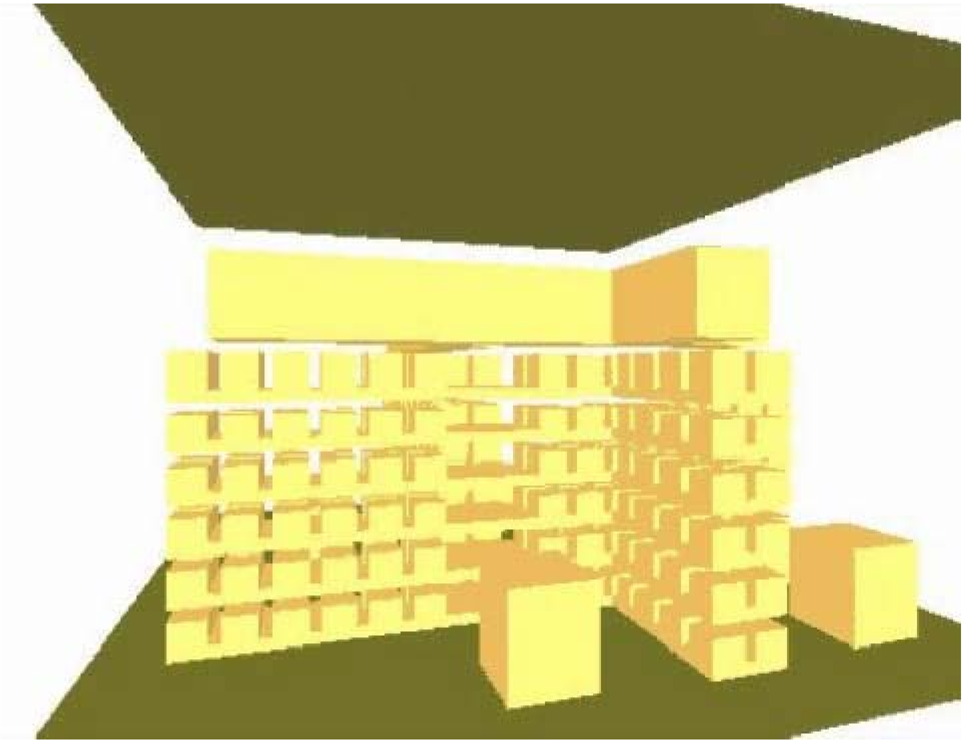

# Rack Storage Fire

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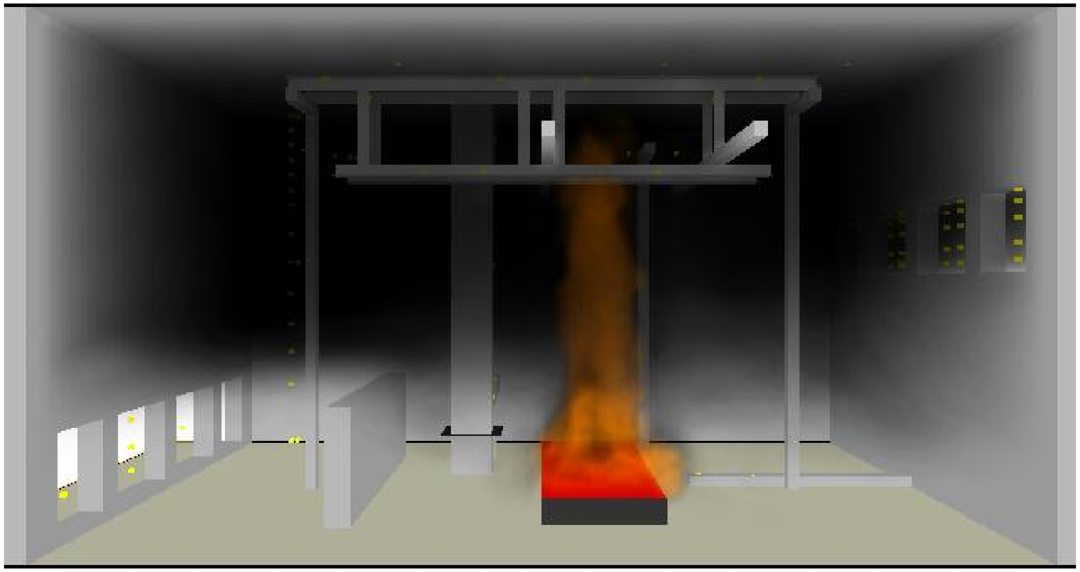
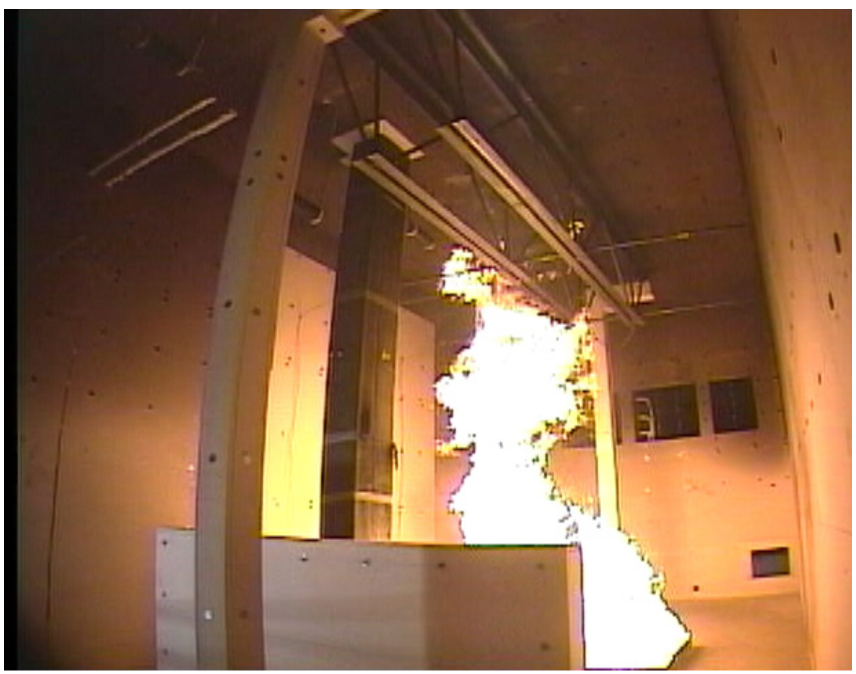
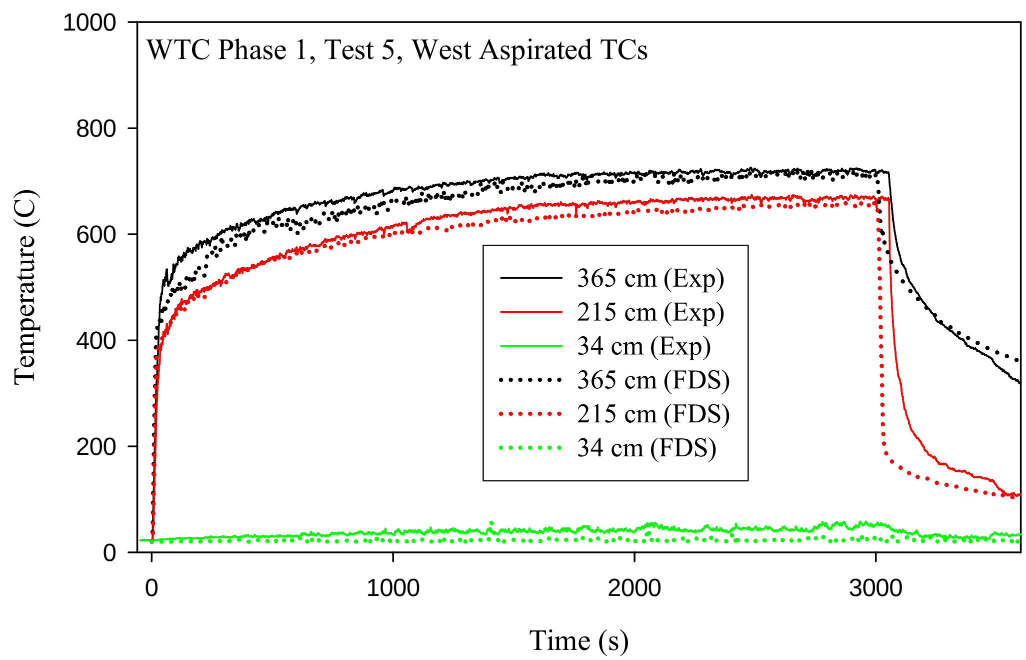
NIST Smokeview 4.0 Alpha - Apr 17 2003



# FDS Validation Experiment

# 3 MW Fire, 23’x12’x12’ Compartment, 1 hour burn





# Visualizing Fire Data

Fire Dynammics Simulator (FDS) - Modeling Fire Data

# Software Used With Smokeview

- OpenGL – 3D low level graphics API
- GLUT – **g**raphics **l**ibrary **u**tility **t**oolkit
- GLUI – user interface toolkit implementing dialog boxes using GLUT and OpenGL
- C
- Fortran 90

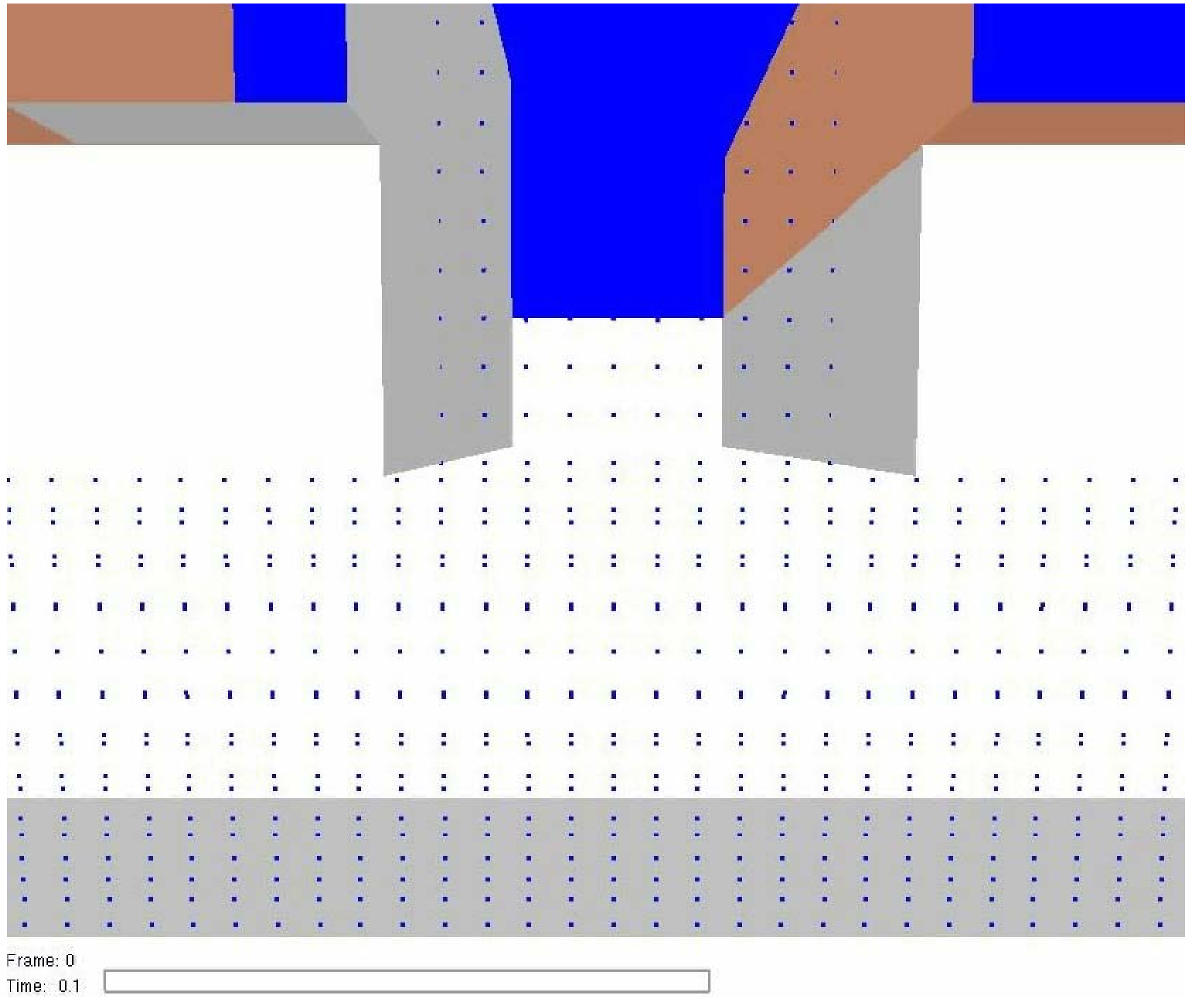
# Software Used With Smokeview (Cont)

- GD – image library
- Pnglib – image library
- Zlib – compression library
- Jpeglib – image library

# Who is Using FDS and Smokeview?

## 1) Developers

Diagnose problems with Physics and Numerics of FDS

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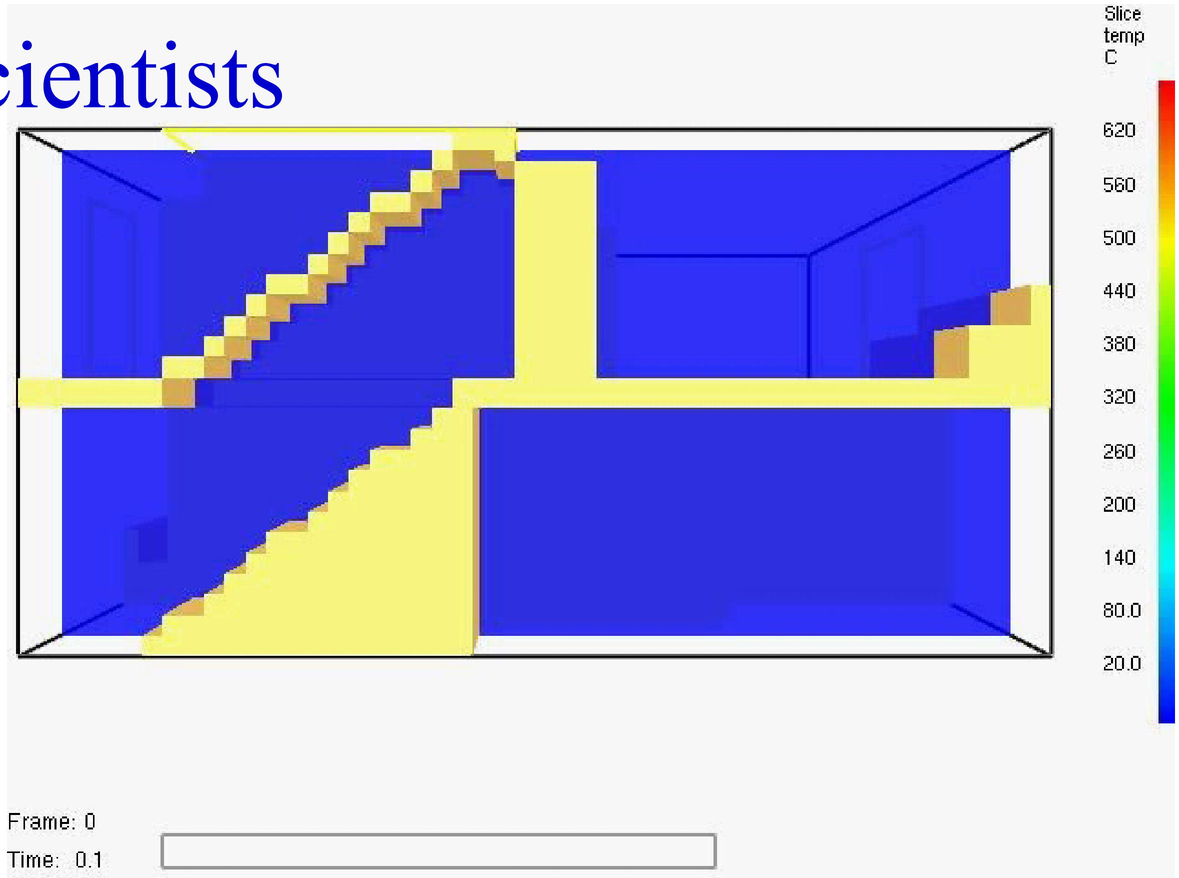
# Who is Using FDS and Smokeview?

## 2) Engineers/Scientists

Study effects of fire dynamics

Cherry Road LODD Incident December 1999

Litigation, Forensic studies, Fire Protection Engineers, Architects, Regulatory agencies NRC, DOE, …

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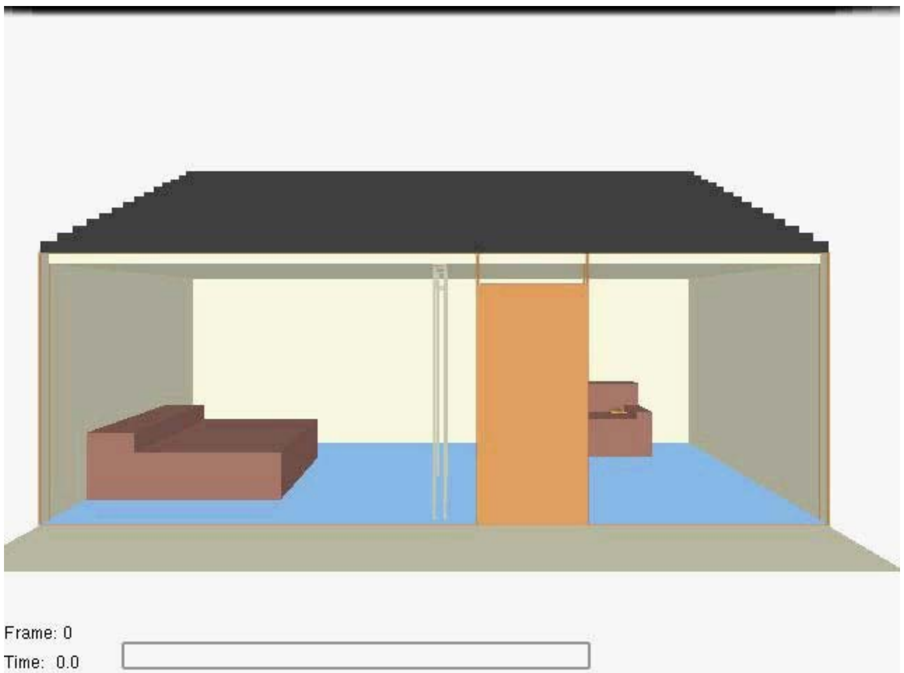
# Who is Using FDS and Smokeview?

## 3) Fire Fighters (trainees)

Fight fire "on the computer"





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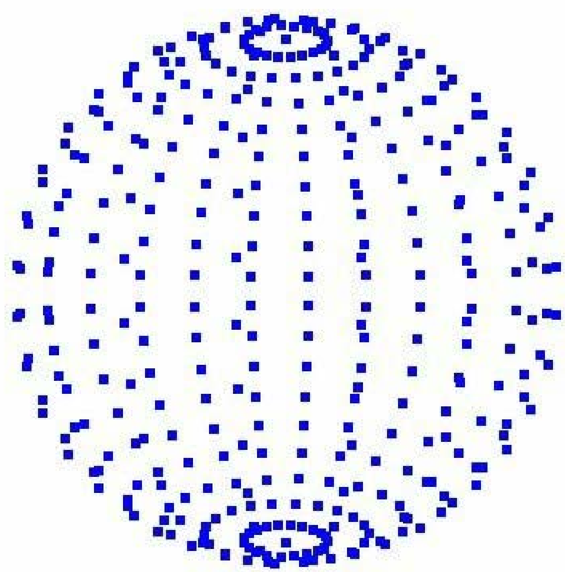
# Visualization Overview

- load data
- specify geometry
- Light scene
- move, translate and scale geometry

$$\mathbf{M_1 \cdots M_n x}$$

$\mathbf{M_i}$ – rotation, translation or scaling matrix transformations

$\mathbf{x}$ – position vector

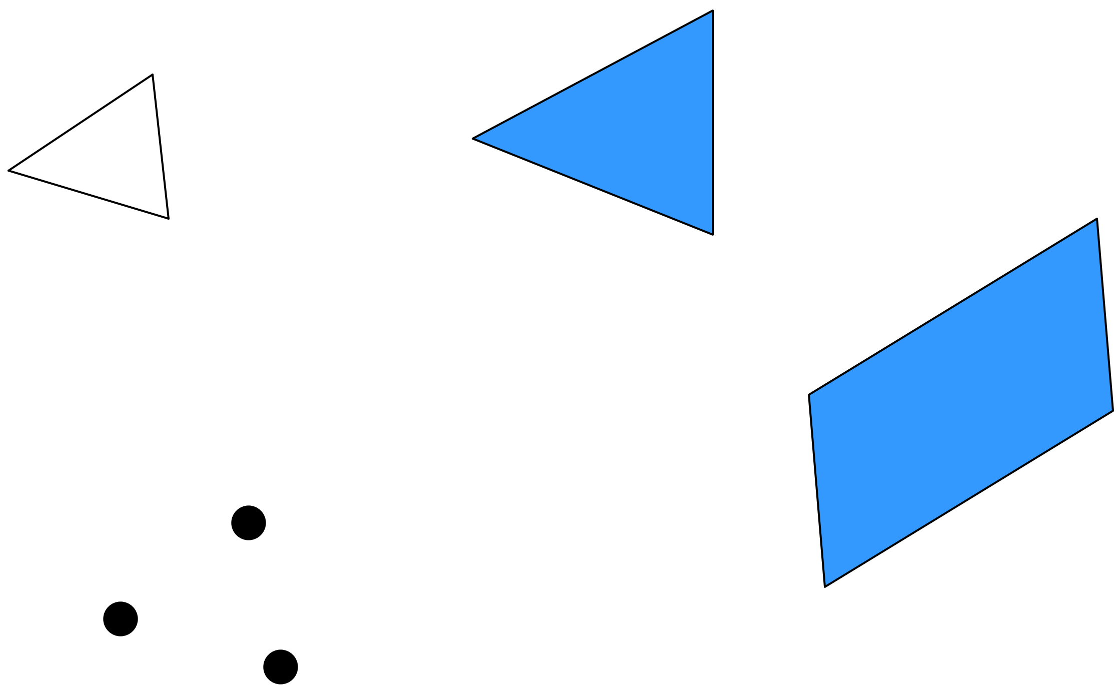


Motion
Color
Structure

# Drawing

- Specify vertices
- Draw objects (connect vertices)
- Move objects
- Project objects onto 2D plane
- Transfer 2D plane onto a portion of the computer screen

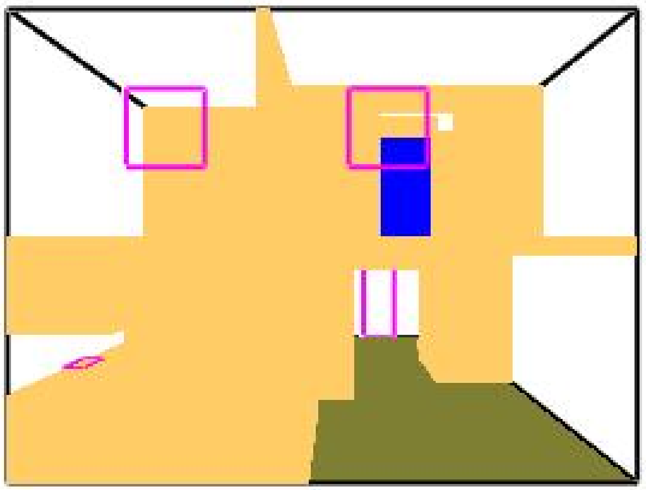
# Drawing Shapes



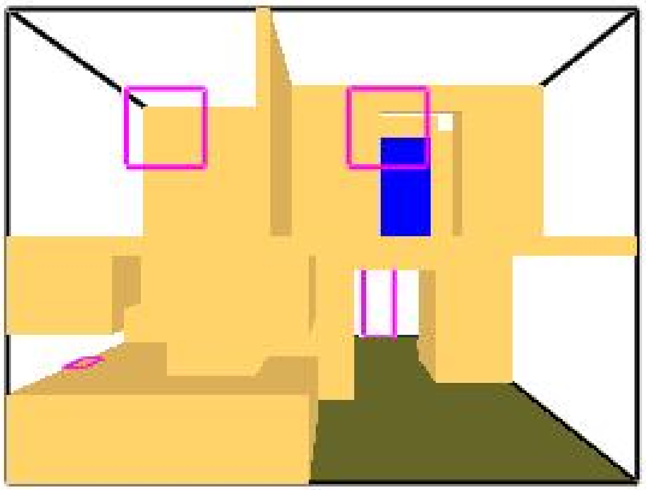
# Lighting

# Smokeview Shading Example

Unshaded



Shaded



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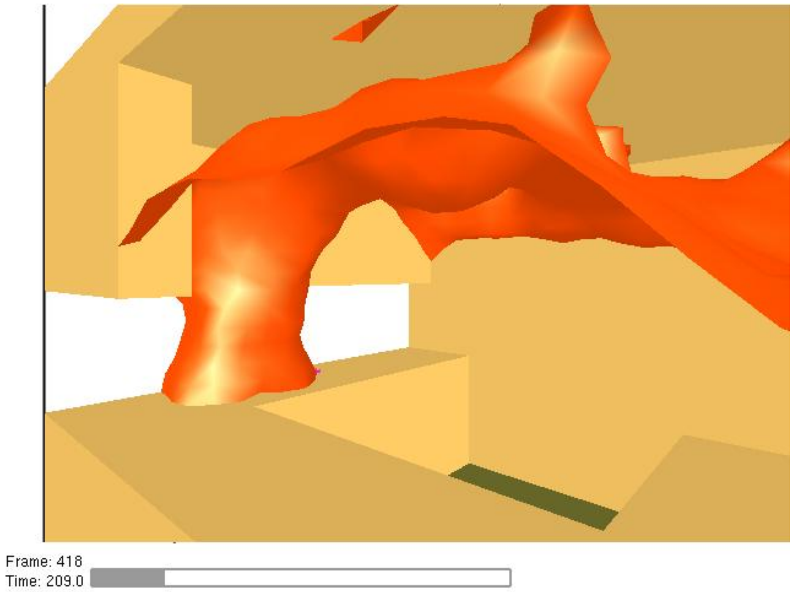
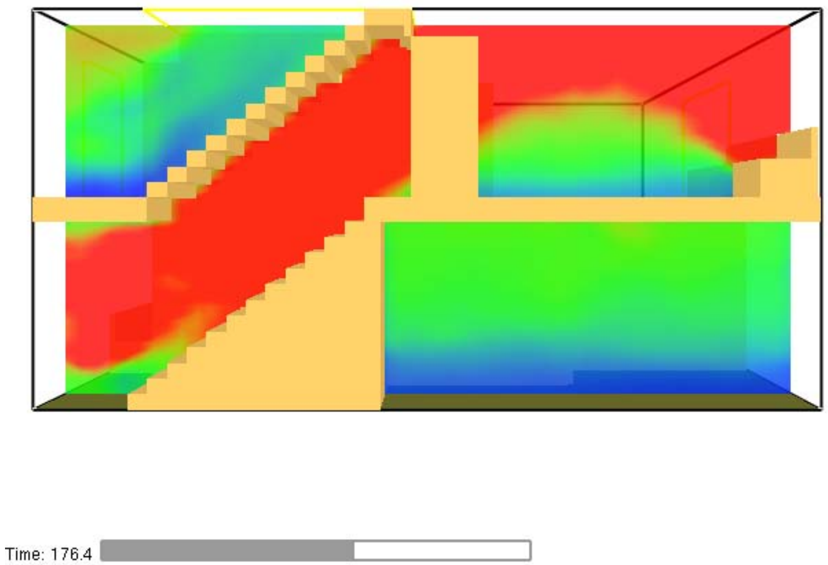
# Smokeview Shading Example

Shaded isosurface




Unshaded slice

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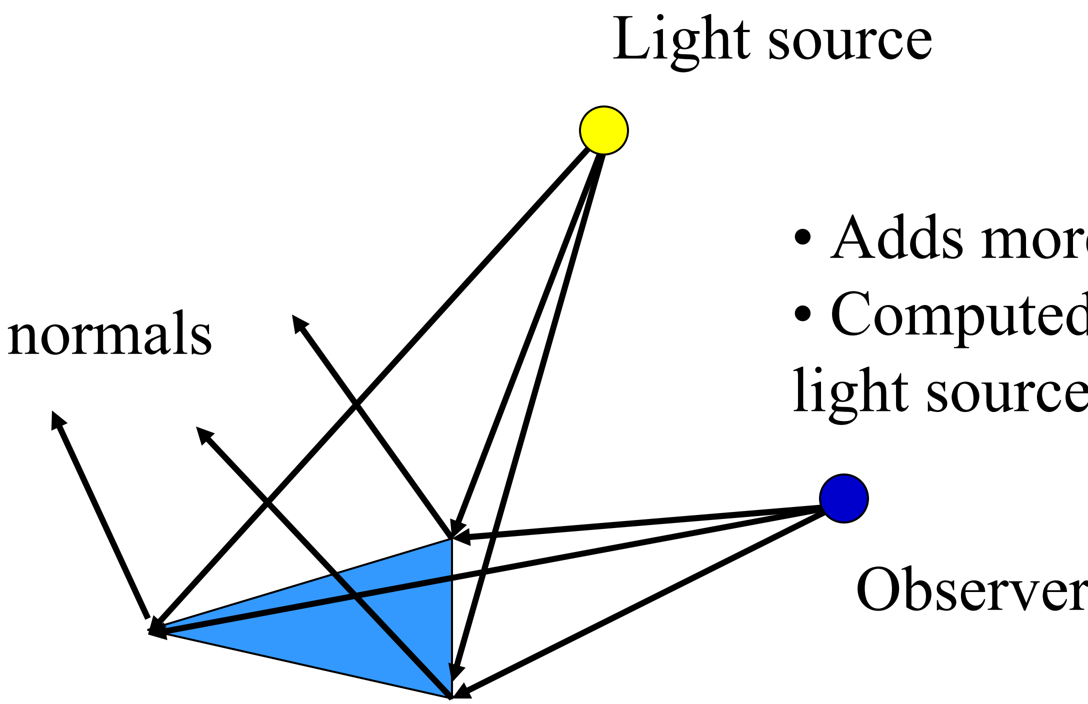
# Lighting/Shading



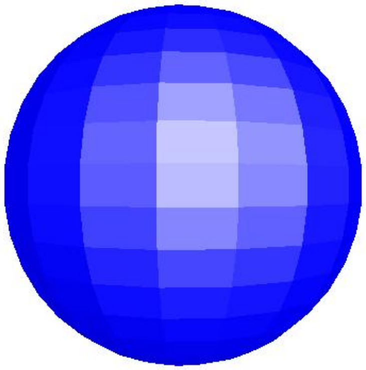

## Lighting

• Adds more realism to 3D scenes
• Computed using normal vectors
light source direction vectors

# Specifying Normals
## (Perpendiculars)

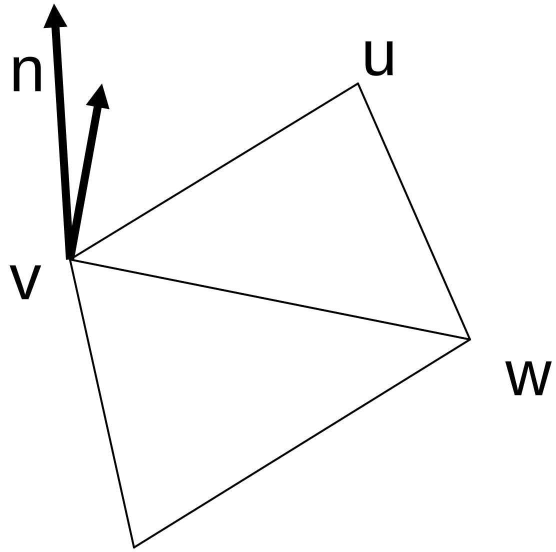
One normal
per triangle

```
glNormal3f(nx,ny,nz);
glVertex3f(ux,uy,uz);
glVertex3f(vx,vy,vz);
glVertex3f(wx,wy,wz);
```



(facet shape)

n = (u-v) x (w-v)

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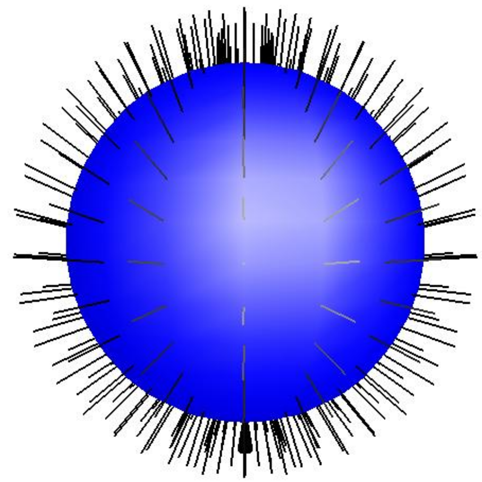
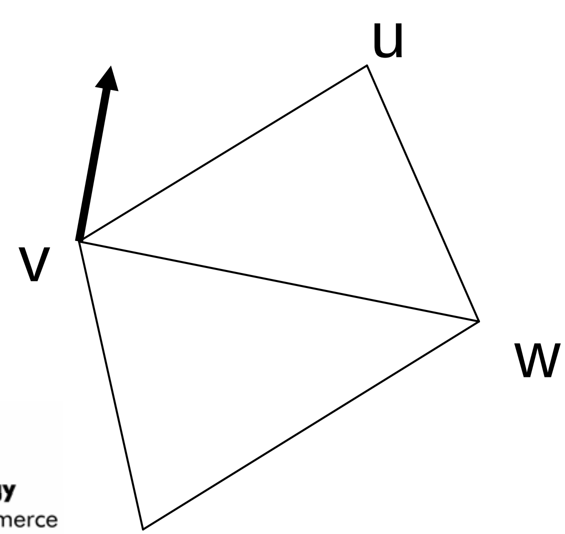
# Specifying Normals (Cont)
## (Perpendiculars)

One normal per vertex

```
glNormal3f(nx1,ny1,nz1);
glVertex3f(x1,y1,z1);
glNormal3f(nx2,ny2,nz2);
glVertex3f(x2,y2,z2);
glNormal3f(nx3,ny3,nz3);
glVertex3f(x3,y3,z3);
```



(smooth shape)

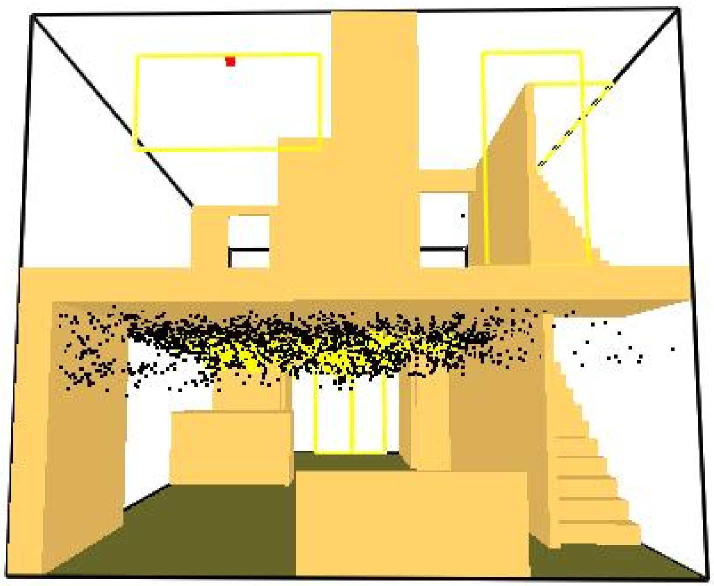


# Drawing a Smokeview Scene

- Particles
- Shaded contours (slice files)
- 3D contours (isosurface files)
- 3D Smoke

# Particles

```
glPointSize(partpointsize);
 glBegin(GL_POINTS);
 for (n = 0; n < nsmokepoints; n++) {
   glColor4fv(rgb[itpoint[n]]);
   glVertex3f(xplts[xpoints[n]],
              yplts[ypoints[n]],zplts[zpoints[n]]);
 }
 glEnd();
```



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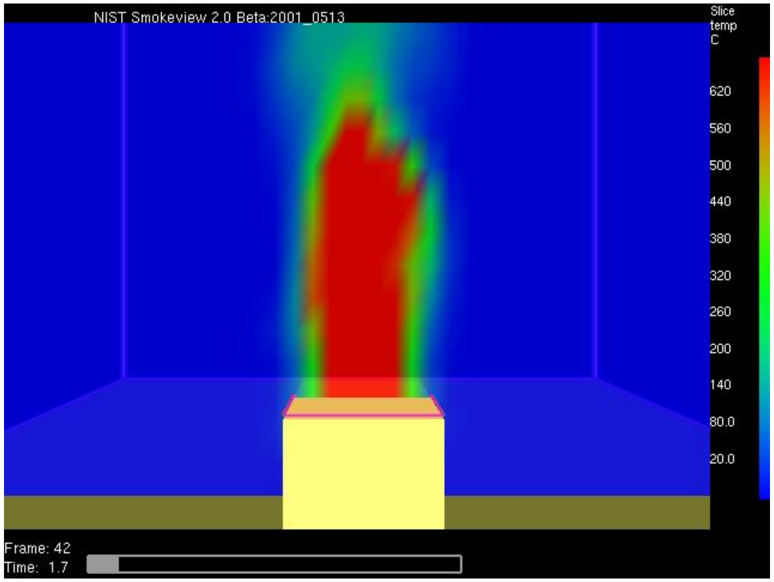
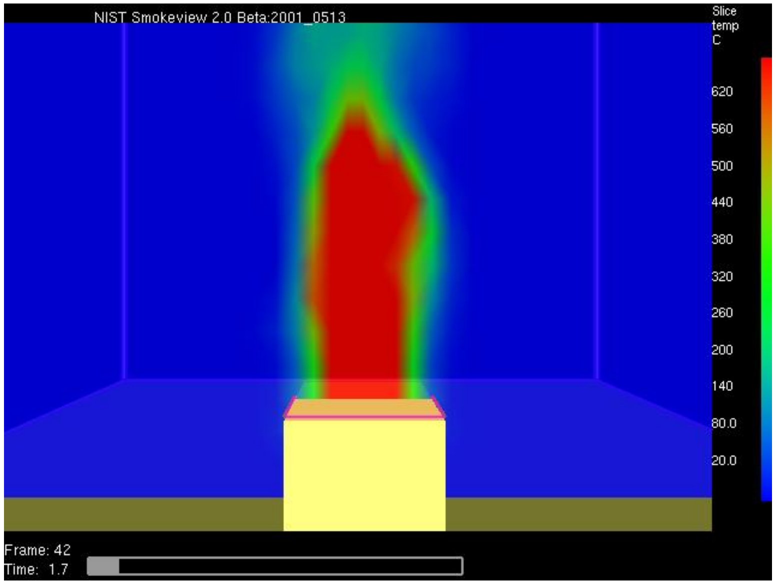
# Slices - 2D Contours

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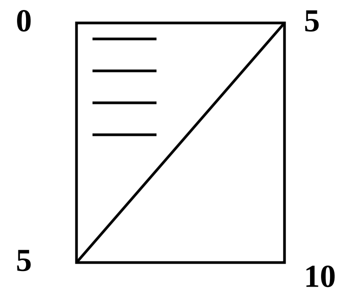
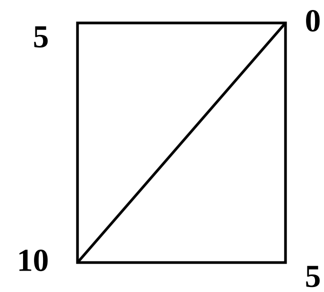
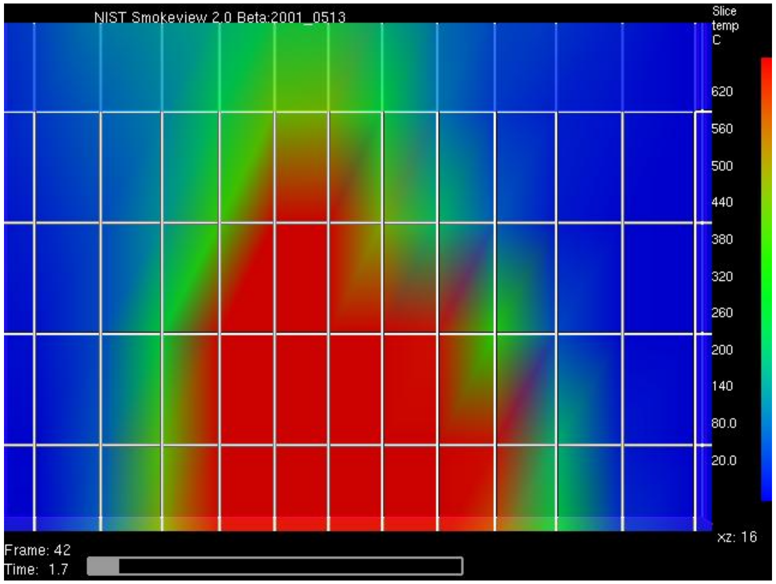
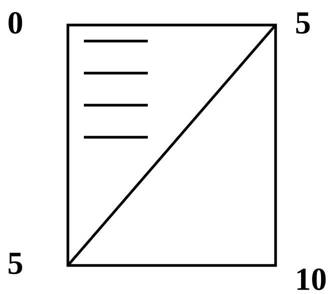
# 2D Contours (Cont)

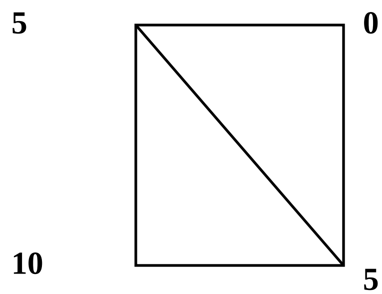


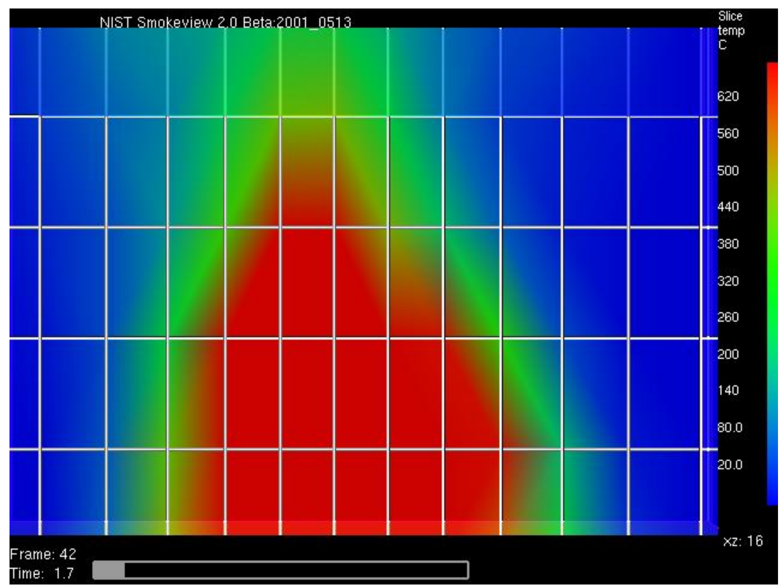



# 2D Contours (Cont)

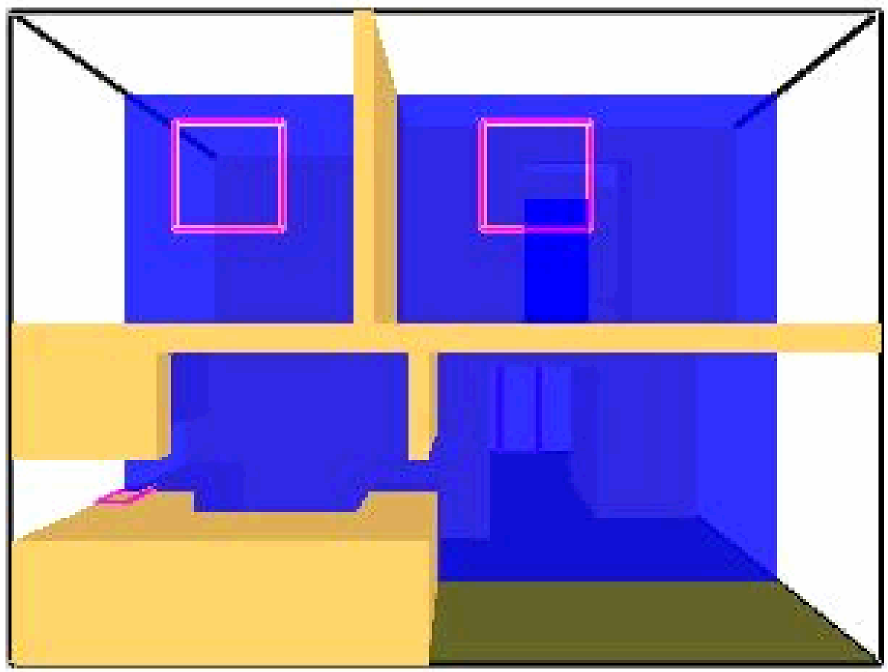



Triangulate so that all hypotenuses follow level curves



# Slices 2D Contours - Example



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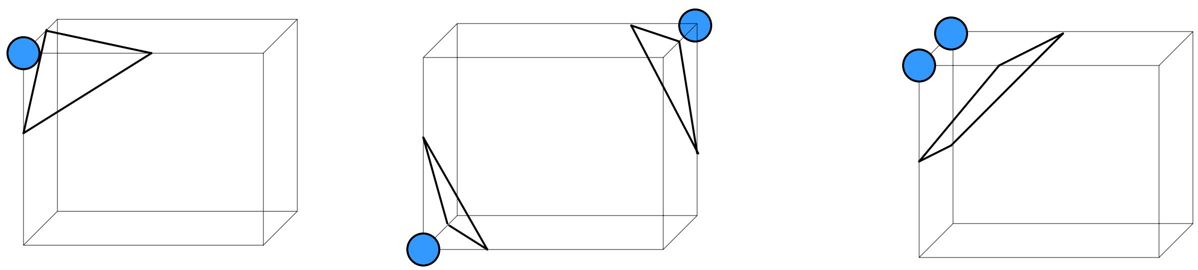
# Computing 3D Contours (isosurfaces)

Marching Cube Algorithm

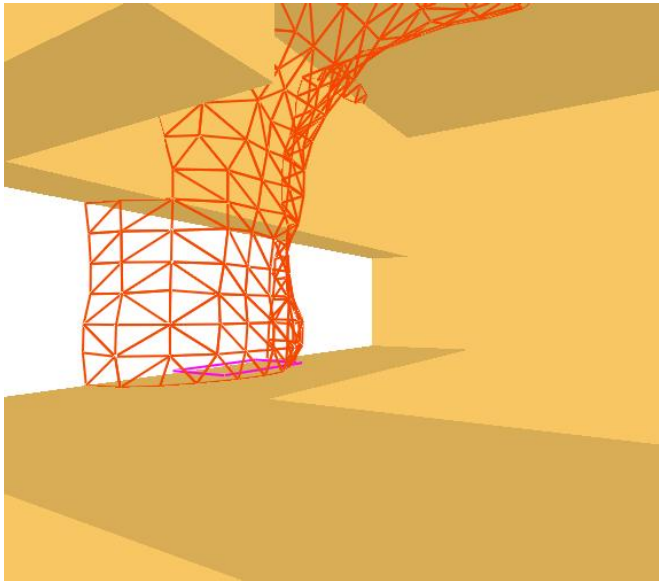
- Divide domain into a number of cubes
- For each cube determine where isosurface crosses cube
- At each corner of cube data is either above or below isosurface level – 256 cases

● - Above isosurface level

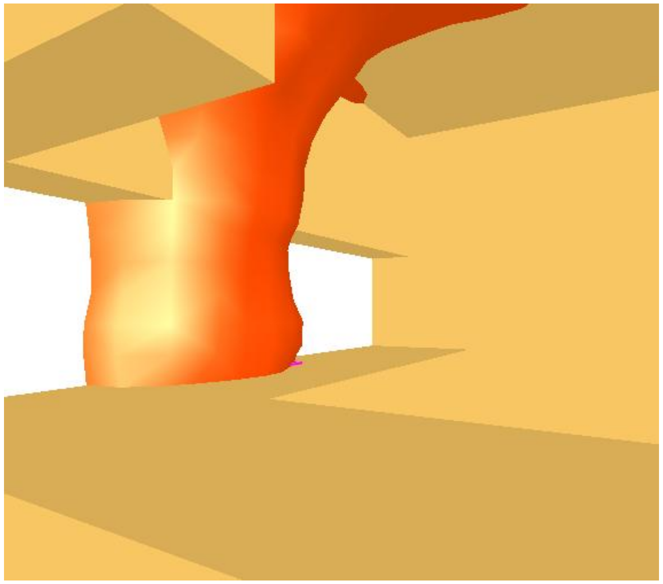
3 of 15 cases



# 3D Contours - Example

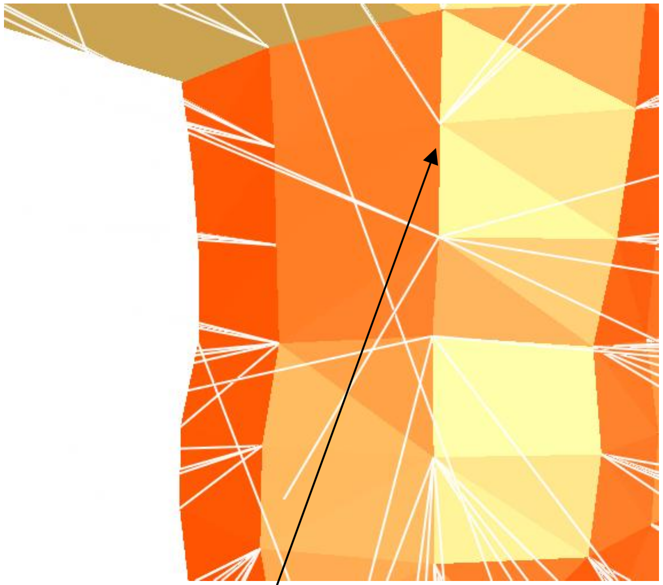


Outline

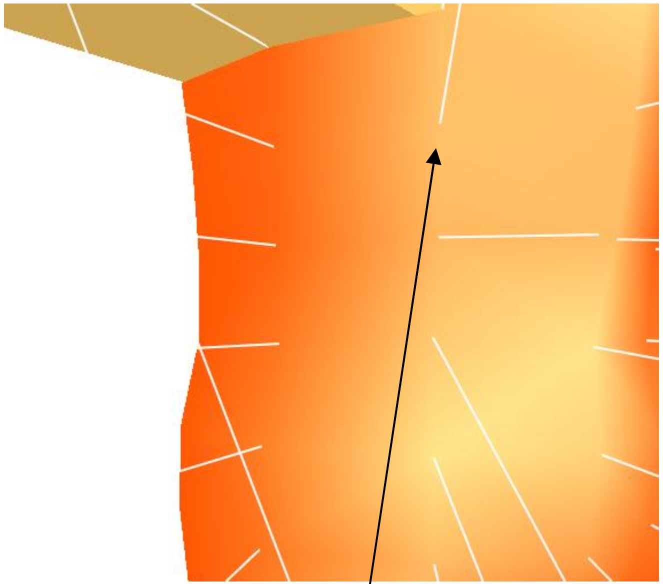


Solid

# 3D Contours - Example



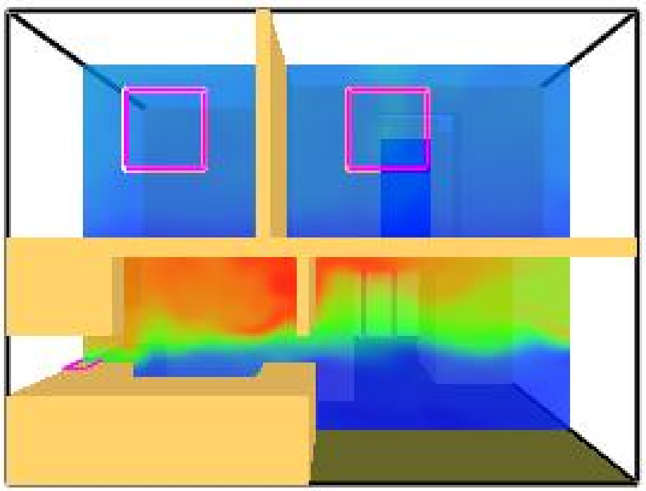
Multiple normals for each vertex



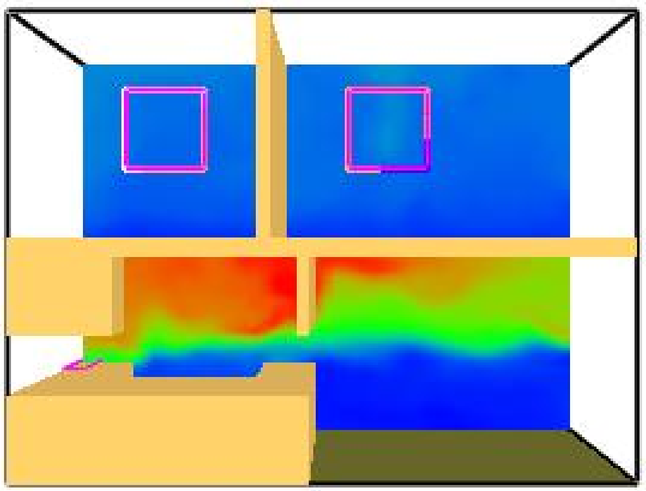
Single normal for each vertex

# Transparency - Example

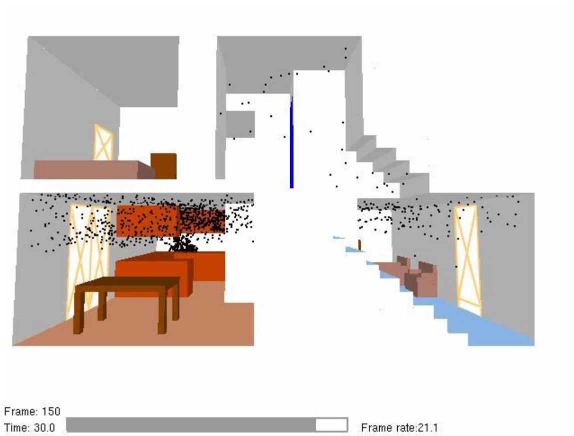
Transparent



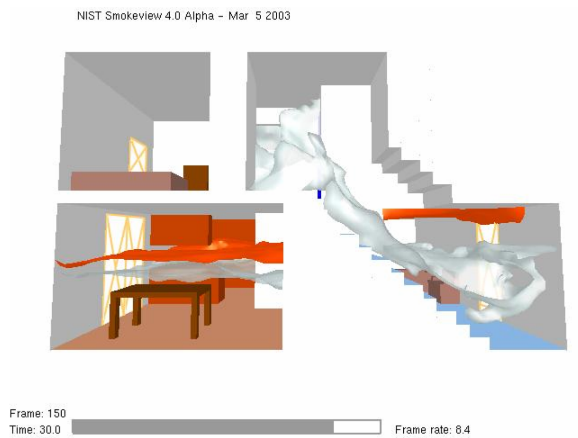
Solid



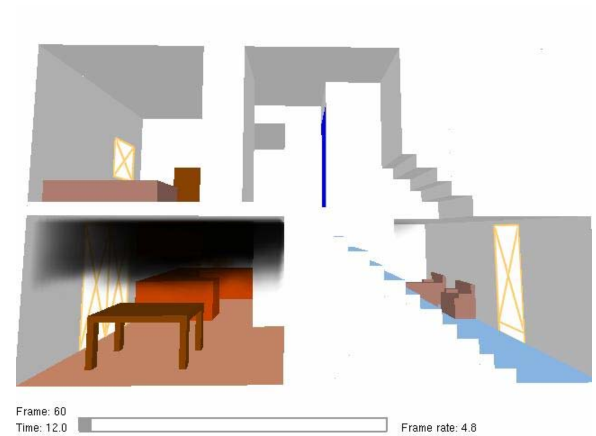
# Visualizing Smoke




tracer particles




3d contours



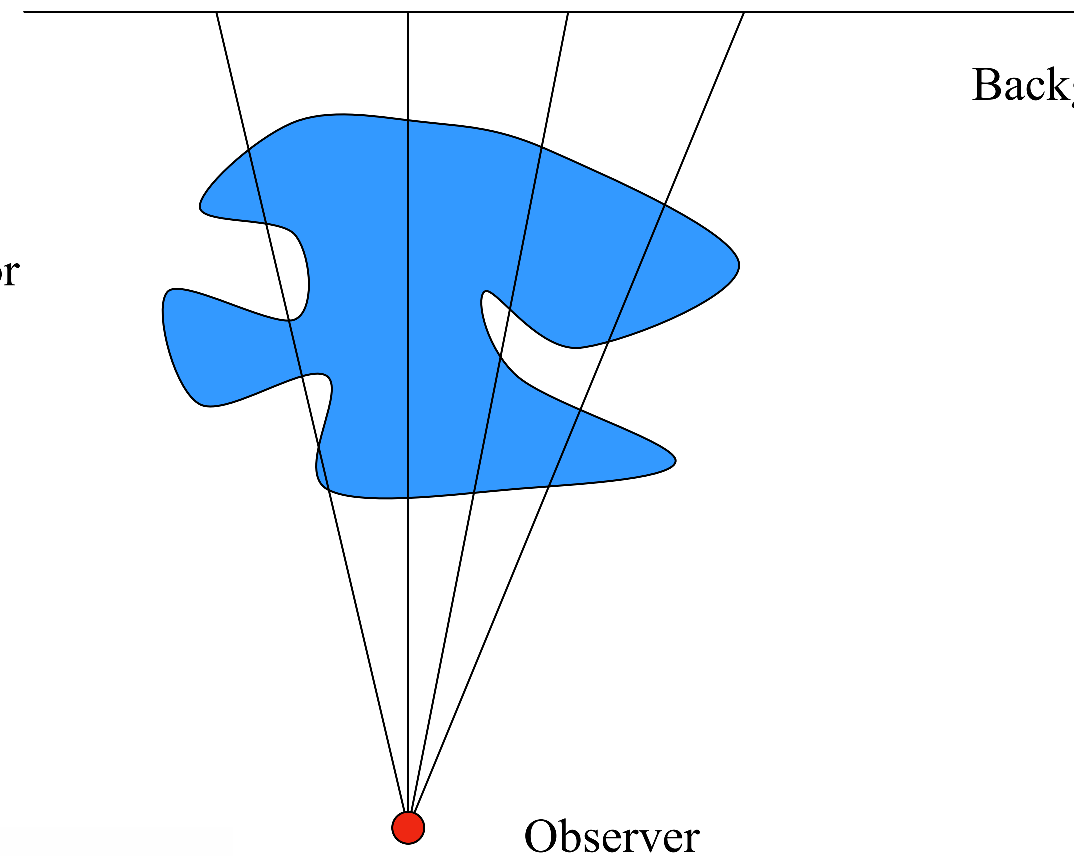

realistic/3D smoke

# Simple Smoke Visualization Strategy

Assume “ambient” light source behind smoke

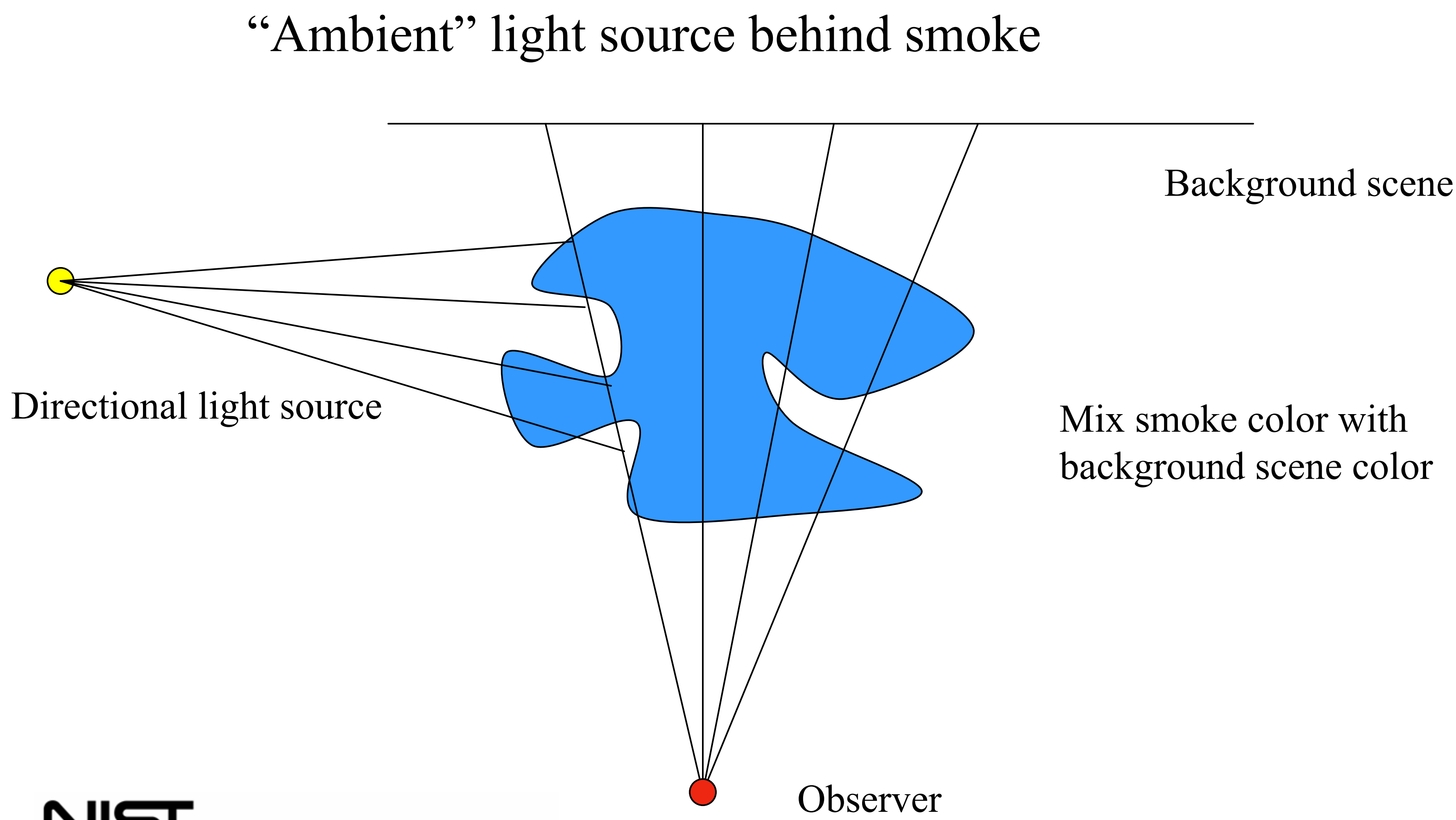
Background scene

Mix smoke color with
background scene color



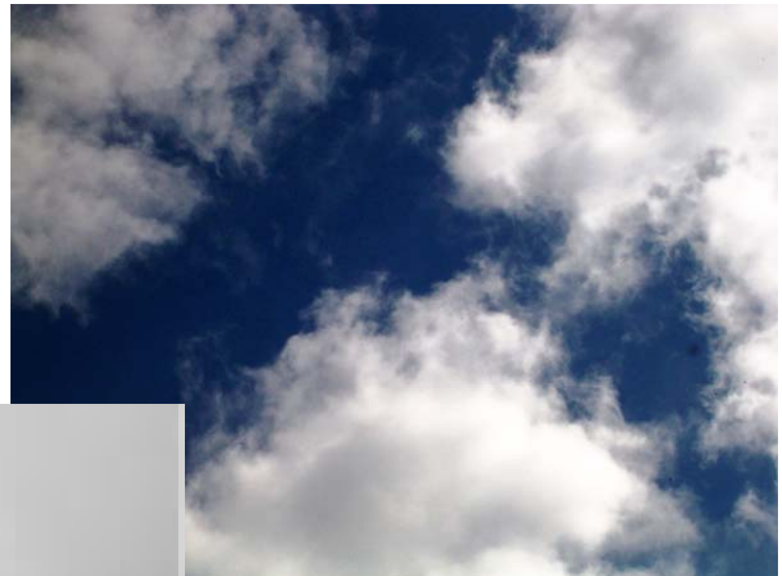
Observer

# Advanced Smoke Visualization Strategy



# Examples

Sun above clouds



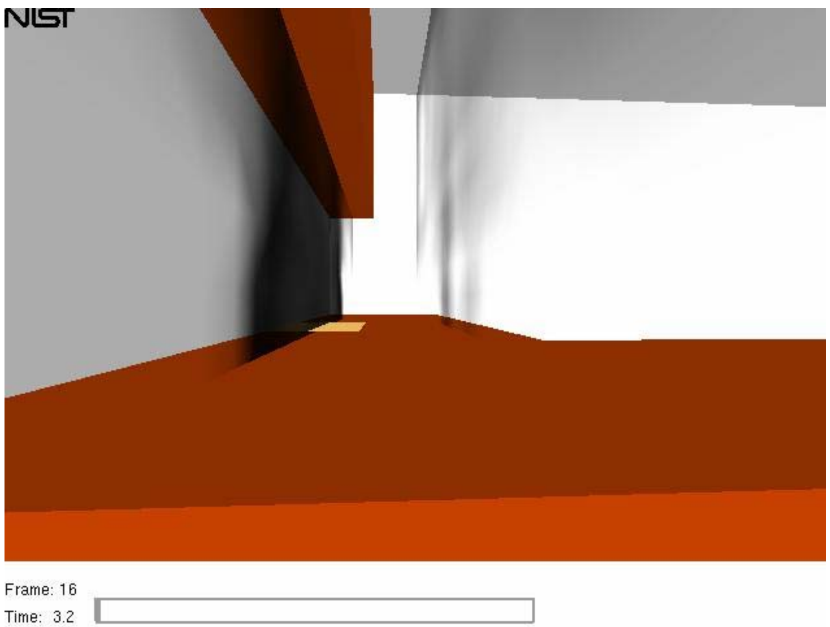
Sun behind clouds

Diffuse/Ambient Light

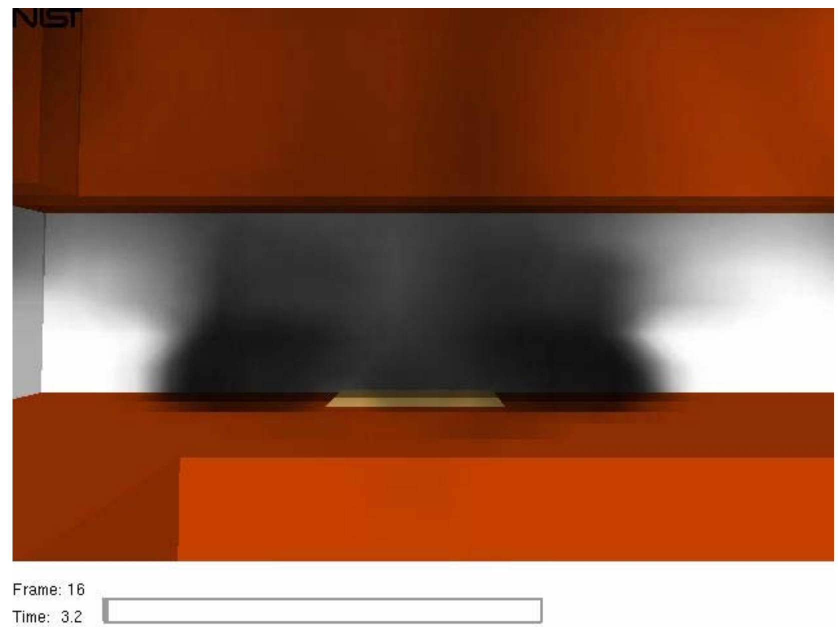
# 3D Smoke

Using Transparency to Visualize Smoke

*Physics-based computation of smoke transparency*




Side View




Front View

# 3D Smoke

Using Transparency to Visualize Smoke

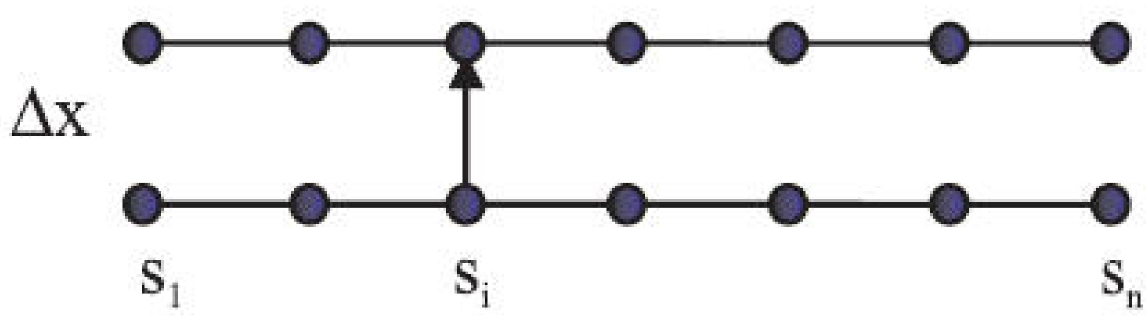
*Physics-based computation of smoke transparency*

$\alpha$ – obscuration

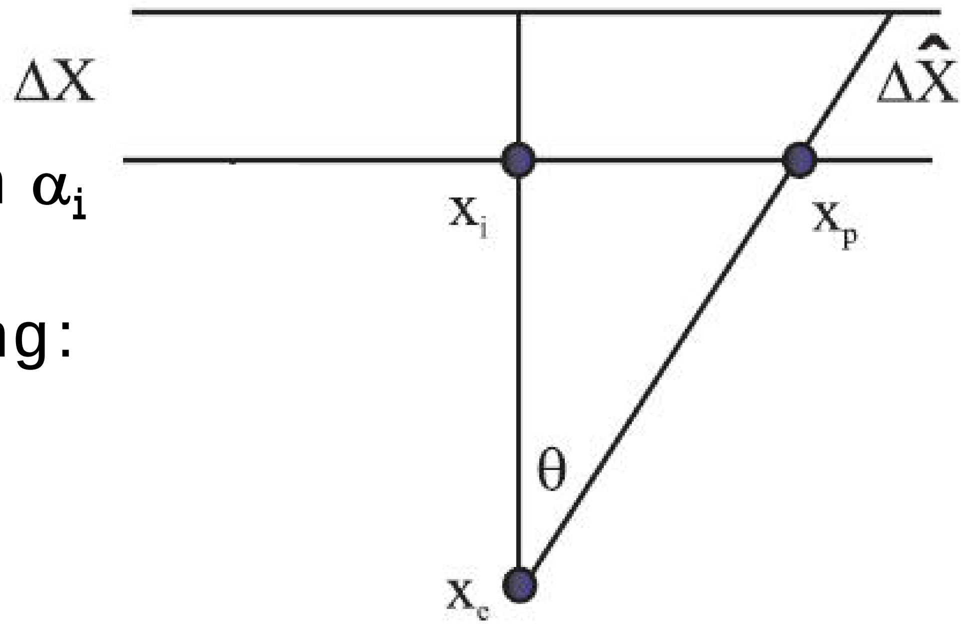
$\Delta x$ - distance between adjacent grid planes

$s_i$- soot density

$\alpha_i = 1 - \exp(-ks_i\Delta x)$ - Beer's law



# 3D Smoke



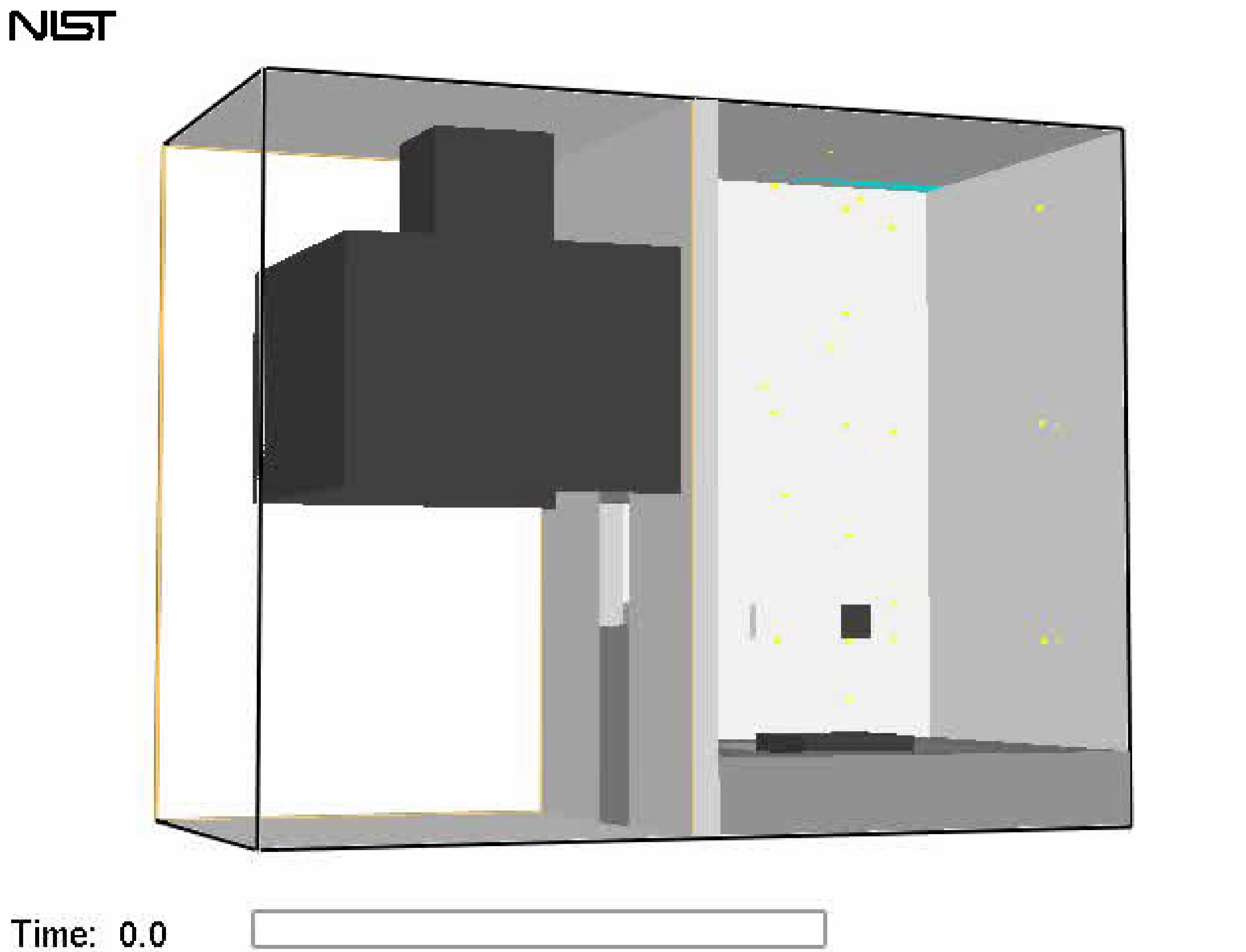

- Smokeview adjusts each $\alpha_i$ in real time for non-axis aligned view distances using:

$$\hat{\alpha} = 1 - (1 - \alpha)^{\Delta\hat{x}/\Delta x}$$

- Smoke may be drawn faster by skipping planes (need to adjust $\alpha$'s for planes that remain)

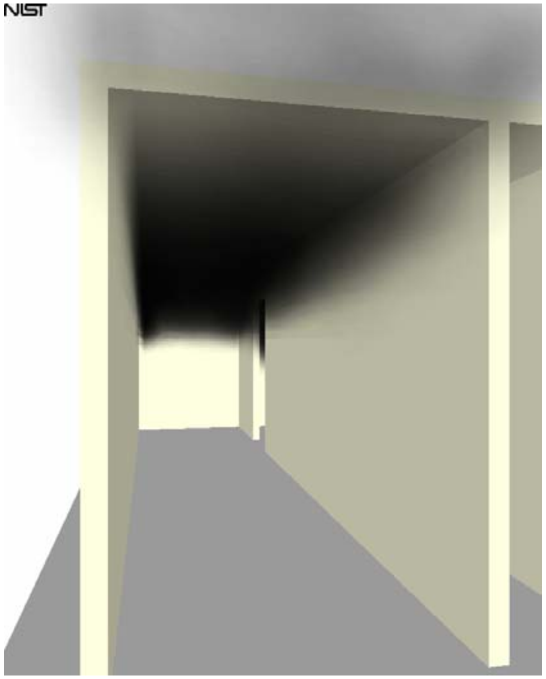
$$\Delta\hat{X} / \Delta X = 2 \quad \Longrightarrow \quad \hat{\alpha} = 1 - (1 - \alpha)^2 = 2\alpha - \alpha^2$$

# Benchmark Exercise: Under-ventilated Compartment



# 3D Smoke

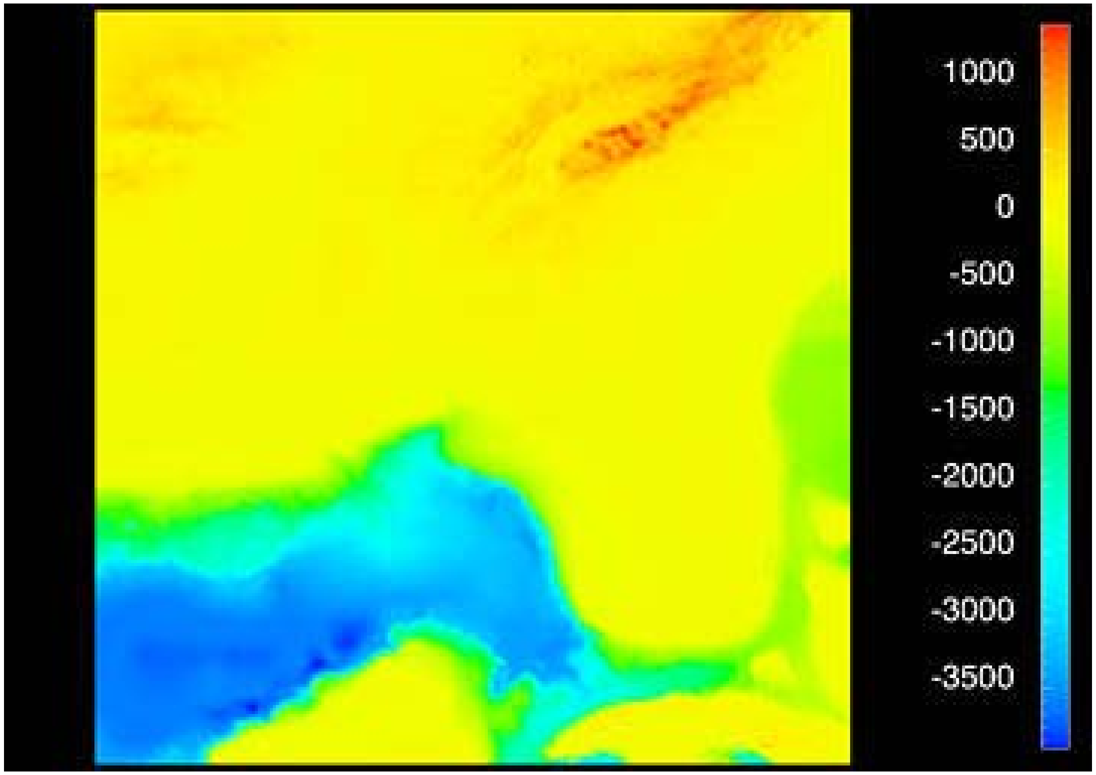
Reality Check



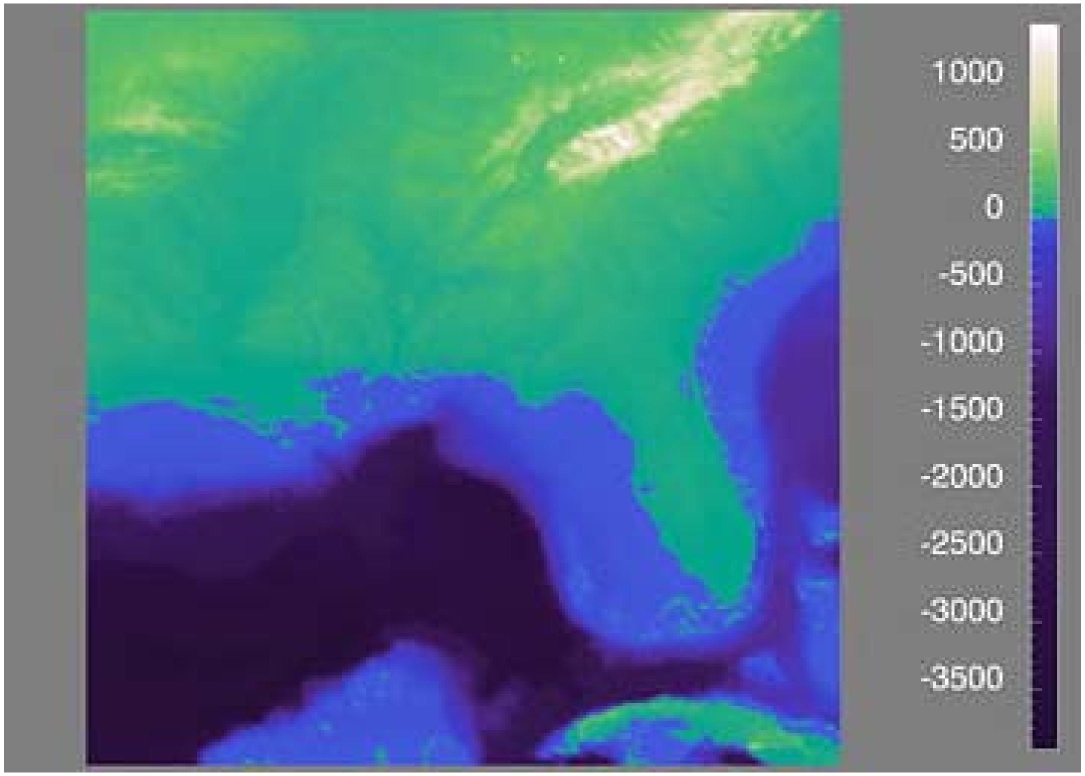
# Future Work

Possible future directions for Smokeview

# Representing Data With Color

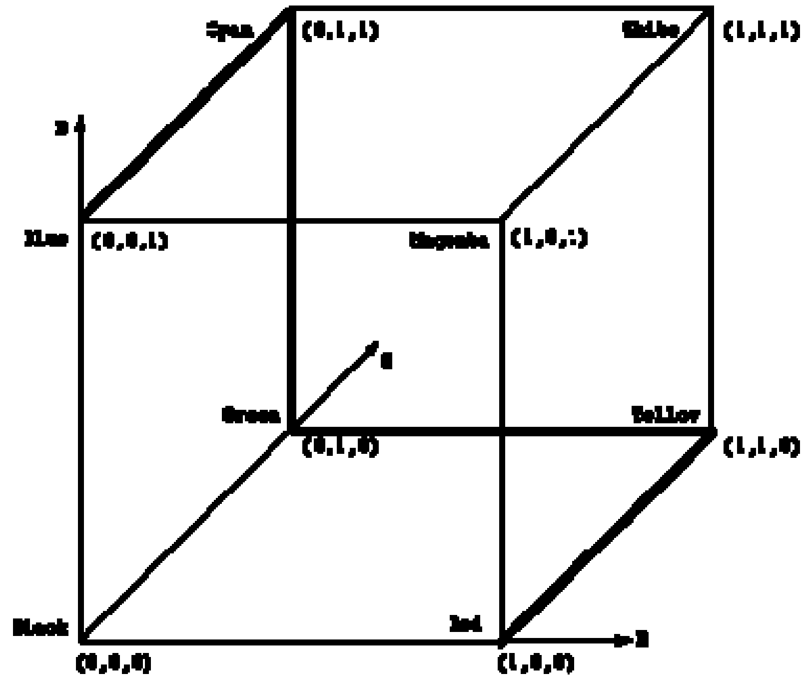


# Representing Data With Color



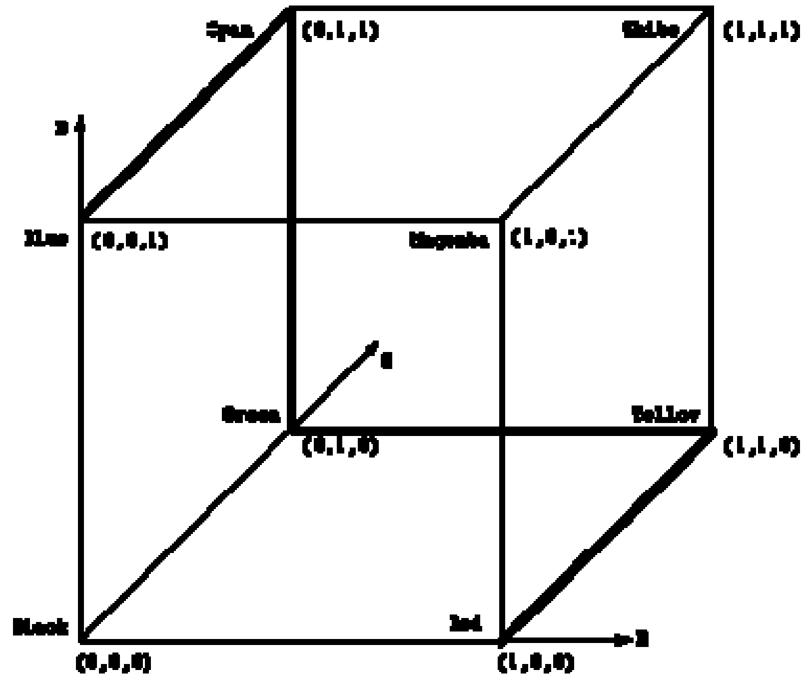
# Representing Data With Color

3D color “space”

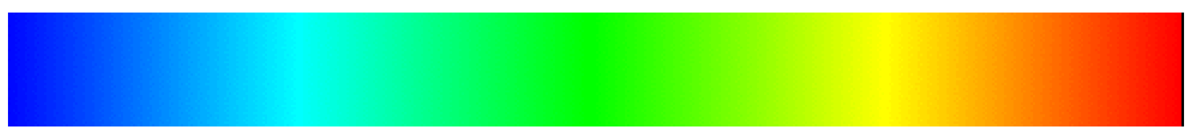


# Representing Data With Color

3D color “space”




“rainbow colorbar”



NIST

**National Institute of Standards and Technology**
Technology Administration, U.S. Department of Commerce

# Simulating Thermal Imagers

Determine colorbar appropriate for use with a thermal imager

How does a thermal imager respond to
- temperature,
- gas composition


NIST
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# Exploiting Texture Mapping and Tours

# Beyond the CPU

## Programming the GPU

Use the video card (**GPU**) to perform scientific computations

Why?

Pseudo code for 3D smoke visualization

```
for(i=0;i<ni;i++){
        for(j=0;j<nj;j++){
                correct α at each grid node
        {
}
```

**CPU - serial**

**GPU - parallel**

# Summary

•Not enough to run a fire model (or any model)

•Visualization is a useful tool for analyzing data and gaining insight into the phenomena being studid

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