Understanding geographic information is critical if we are to build and maintain livable communities. Since computing has become almost ubiquitous in planning and managing our communities, it is probable that advances in geographic information science will play a founding role in smarter decision making, available to all. We examine the challenges that occur between humans and their environment under conditions thought to be hazardous to life and habitat.

Unfortunately becoming a familiar sight

Los Alamos Wildfire

The cost

And not just limited to fire
"Mission control ... We have problems..."

"...some big problems."

...the list is impressive

- **Natural Hazards**: Earthquakes, Volcanoes, Tsunami, Landslides, Fire, Floods, Tornadoes, and Hurricanes.
- **Human Induced Hazards**: Health Related Epidemics, Social Unrest - War, Toxic Spills, Explosions and Fires (accident or otherwise).

What about the *information age*...

- What are the challenges for emergency preparedness and response?
- What technologies in the information age will aid us in reducing and possibly eliminating these disasters?

Is the World Wide Web... the solution? ...Not.

- The revolution is yet to come...
- The rapid deployment and acceptance of the Internet (affectionately known as the Web) has changed the way we communicate, but most of us still exchange the same old data and information... just a new medium.
- Like the telephone before it we use this communication device to exchange, for the most part, known information.
- This is good, but the Web and communication alone will not solve the big problems.

Planet Earth... we have some *big problems*.

- So we can now access data and information like never before, **voluminous amounts at unprecedented speeds**.
- One of our *big problems* is too much data... and our only solution appears to be intelligent **data mining**.
- The solutions to help us sift through and extract the relevant information for the known pool of information already assembled on this planet is also the key to building the information that is not currently known... and the road to solving our *big problems*. 
Hopefully I will convince you that our minds alone are not robust enough to accept the guardianship of mother earth...and that working along side computers, it looks almost possible.

To boldly go where no human has gone before.

- We seek to transform:
  - Data → Information → Knowledge
- Only then can we hope to solve the problems we face on planet earth.

Systematic transformation of data into information

- Geographic Information Science is proving to be a very powerful agent for processing complex data and extracting information.
- The University Consortium for Geographic Information Science (UCGIS) is formed in 1996.

UCGIS formalizes challenges

- The UCGIS formalizes the challenges for Emergency Preparedness and Response during 1999-2000, and publishes its findings:

Before we proceed...

Before we discuss the research challenges and priorities, we must:
- define for this audience what is meant by the term GI Science,
- work through an example of how GI technologies help in Emergency Preparedness and Response.

Geographic Information Science

Powerful new technologies have emerged in recent years that greatly improve our ability to collect, store, manage, analyze, and use geographic information, about features and activities on the Earth’s surface. These new technologies include geographic information systems (GIS), the global positioning system (GPS), and satellite-based remote sensing. They now penetrate every aspect of our lives, from digital maps in rental and delivery vehicles to management and maintenance of city infrastructure, forests and agriculture.
The obvious need for geographic information and resultant technologies raises fundamental research questions. The term "geographic information science" has been coined to describe this research field. Because geographic information science is fundamentally multidisciplinary, coordination and collaboration must work across the traditional barriers between disciplines.

The spatial relate advantage

Where we once could only relate variables from different data sources based on a common field, the inclusion of spatial data accommodates relating phenomena using location.

GI technologies in Emergency Preparedness and Response: an example

Model and assess the risk of a class of uncontrollable fires, Firestorms, in the East Bay hills.

Two models:
- BEHAVE (a Wildland Fire Model)
- RFHAM (a Residential Fire Hazard Assessment Model)

The Science of WildFires

Oakland Hills firestorm

- October 21, 1991 Fire in the East Bay Hills
  - Damage:
    - 1580 acres burned,
    - over 2700 structures destroyed,
    - 25 lives lost
  - The damage to infrastructure and dwellings exceeds $1.68 billion.

The right conditions for a firestorm

- Heterogeneous landscape - an intermix of urban residential and wildland landscape
- Mediterranean climate
- Rugged topography
- The practice of fire suppression in recent history
- Fire is not a new phenomenon in the East Bay Hills. Over the past hundred years dozens of similar fires in the East Bay Hills have been documented
A changing landscape: 1920 to 1990

Study Site

54.3 square miles

Project FlowChart

Observations and data collection - Focus on Fuels

Data Sources:

- **Ancillary data**: Local, state and Federal government sources.
- **Current fuel conditions**: Remotely Sensed imagery (NASA) along with ground truth (ground observation) and ground control (Differential GPS) of Vegetation and Structure conditions (Classified for Fire conditions)

NS001 Images

Overlay: Eastbay Study Area boundary on true-color image

Overlay: Eastbay Study Area boundary on false-color image
Fire behavior - the Rothermel Model

Early work on fire spread developed relationships between burning conditions and obvious variables such as:
- Fuel moisture
- Fuel loading
- Wind velocity
- Relative humidity
- Slope
- And solar aspect


Flame Spread Theory

- W.R. Fons (1946) was the first to attempt to describe fire spread using a mathematical model.
- Tarifa and Torralbo confirmed Fons' theory of heating fuel ahead of the flame is the most essential process of flame propagation. Therefore it is important to know the flame propagation mechanism and the fuel heating process.
- Rothermel considers fire as a series of ignitions and breaks the problem down into heat supplied from the fire to potential fuel raises the temperature until the flame begins to release combustible gases and ignites.
- What are those temperatures just ahead of the fire and how quickly are they changing...no system exists to do this in real time.
The Rothermel Fire Model has become the basis for most modern day fire models due to its robust prediction of the rate of fire spread through a uniform fuel array in the absence of wind and topography. It has evolved to include the effects of Topography and Weather.

**Assumptions of the Rothermel Fire Model**

- Continuous homogeneous fuel bed
- Dead fuels (litter or grass)
- Surface fire only (crown fire and spotting not modeled)
- Fire has stabilized into a quasi-steady spread condition

**Input / Output of the Rothermel Fire Model**

- **Inputs**
  - Fuel loading, depth, surface to volume ratio, heat content, moisture and mineral content, extinction moisture content
  - Environment mean wind velocity, slope of terrain
- **Outputs**
  - Initial outputs - Rate of spread, intensity.
  - Later modifications to the model return other outputs - heat per unit area, flame length, direction of maximum spread.

**How fire spreads**

- Fire as a series of ignitions
- Spread rate is controlled primarily by the ignition time and the distance between particles
  - W. R. Fons (1946)
  - Tarifa and Torralbo (1967)
  - McAlevy, etc. (1967)
  - Frandsen (1971)

**Fire spread rate**

\[
R = \frac{I_{ig} - \int \left( \frac{Q}{\rho c} \right) dx}{\rho c \alpha}
\]

Frandsen (1971)

The equation shows the rate of spread during the quasi-steady state is a ratio between the heat flux received from the source in the numerator and the heat required for ignition by the potential fuel in the denominator. To solve the equation Frandsen examined each term and determined experimental and analytical methods of evaluation. This lead to an approximate solution to the equation.
Numerator – heat source

\[ I_p = I_{\text{no}} + \int_{-\infty}^{0} \left( \frac{\partial I_p}{\partial x} \right) dx = I_{p0}(1 + \phi_x + \phi_s) \]

- \( I_{p0} \) – No-wind propagating heat flux depends on reaction intensity, which is in turn dependent on fuel parameters (particle size, bulk density, moisture, chemical composition, etc.)
- \( \phi_x, \phi_s \) – Wind and slope effect coefficients

Denominator – heat sink

\[ I_p = I_{\text{no}} + \int_{0}^{\infty} \left( \frac{\partial I_p}{\partial x} \right) dx = I_{p0}(1 + \phi_x + \phi_s) \]

- \( I_{p0} \) – No-wind propagating heat flux depends on reaction intensity, which is in turn dependent on fuel parameters (particle size, bulk density, moisture, chemical composition, etc.)
- \( \phi_x, \phi_s \) – Wind and slope effect coefficients

Input parameters summary

- Oven dry fuel loading
- Fuel depth
- Fuel particle surface-area-to-volume ratio
- Oven dry particle density
- Fuel particle moisture content
- Fuel particle total mineral content
- Fuel particle effective mineral content
- Wind velocity at mid-flame height
- Slope
- Moisture content of extinction

Summary of the Basic Fire Spread Equations

\[ a = \frac{4.01 \times 10^{-4} \times 10^{-4}}{0.0001} \]

- Rate of spread, ft/min
- Net heat release, Btu/hr
- Maximum reaction velocity, ft/min
- Maximum reaction velocity, ft/min
- Maximum reaction velocity, ft/min

- Heat of pre-ignition
- Heat of post-ignition

BEHAVE (a Wildland Fire Model)
BEHAVE (a Wildland Fire Behavior Prediction and Fuel Modeling System)

This Rothermel Fire model lead to the development of the BEHAVE model (1984) and eventually the BEHAVE Plus model. The BEHAVE model (developed by the U.S. Forest Service Rocky Mountain Experiment Station) uses site-specific input data to predict fire behavior for a single point in time and space...the space could be represented by a grid cell or a polygon.

The Rothermel Fire model is still the base for predicting fire behavior in most of the contemporary Fire Spread Models.

**B+ Spreadsheet based Worksheets**

- **SurfaceBasic.bpw**: Basic surface fire spread worksheet. Like DIRECT from the old BEHAVE. Direction of the wind vector is input. The direction the wind is pushing the fire.

**B+ Modules**

- **SURFACE** – Surface Fire Spread
- **SIZE** – Size of a Pt Source Fire
- **SPOT** – Spotting Distance
- **SCORCH** – Crown Scorch
- **MORTALITY** – Tree Mortality
- **IGNITE** – Probability of Ignition
- **RH** – Relative Humidity

**SURFACE Input**

**MODULES**: Surface

**FUEL/ VEGETATION**

**Fuel Model**

1. Short grass
2. Timber with grass and understory
3. Tall grass
4. Chaparral
5. bushes
6. Dominant brush, hardwood, and conifer
7. Southern rough
8. Closed tufted litter
9. Hardwood litter
10. Timber with litter and understory
11. Light logging slash
12. Medium logging slash
13. Heavy logging slash

A fuel model is a set of numerical values that describe the fuel inputs for a mathematical model that predicts spread rate and intensity. There are 13 standard fire behavior fuel models (Anderson 1982).
**Custom Fuel Model**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-h Fuel Load</td>
<td>0.74</td>
</tr>
<tr>
<td>10-h Fuel Load</td>
<td>0.00</td>
</tr>
<tr>
<td>100-h Fuel Load</td>
<td>0.00</td>
</tr>
<tr>
<td>Live Herbaceous Fuel Load</td>
<td>0.00</td>
</tr>
<tr>
<td>Live Woody Fuel Load</td>
<td>0.00</td>
</tr>
<tr>
<td>1-h Surface Area/Volume Ratio</td>
<td>0.22</td>
</tr>
<tr>
<td>Live Herb Surface Area/Volume Ratio</td>
<td>0.02</td>
</tr>
<tr>
<td>Live Woody Surface Area/Volume Ratio</td>
<td>0.25</td>
</tr>
<tr>
<td>Fuel Bed Depth</td>
<td>1.00</td>
</tr>
<tr>
<td>Dead Fuel Moisture of Extinction (%)</td>
<td>12</td>
</tr>
<tr>
<td>Dead Fuel Heat Content</td>
<td>0.00</td>
</tr>
<tr>
<td>Live Fuel Heat Content</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*Parameter values shown above are for fuel model 1 (short grass)*

---

**SURFACE Input 2 – Wind**

- Wind Speed
- Wind & Fire Direction
- Wind & Height
- 20-m wind and wind adjustment factor
- 10-m wind and wind adjustment factor

---

**SURFACE Input 3 – Slope**

- Slope is specified as:
  - degrees
- Slope steepness is:
  - specified on the worksheet
  - calculated from map measurements

---

**SURFACE Output Sample**

- Rate of Spread (maximum): 69.4 ft/h
- Heat per Unit Area: 1000 Btu/
- Fireline Intensity: 1281 Btu/s
- Flame Length: 12.1 ft
- Direction of Maximum Spread (from upslope): 0 deg
- Maximum Wind Exceeded: No

---

**SIZE Output**

- Area
- Perimeter
- Length-to-Width Ratio
- Forward Spread Distance
- Backing Spread Distance
- Fire Length
- Maximum Width of Fire
Behave Plus Predicts

- Fire spread rate,
- Intensity, and
- Flame length in any direction.

From BehavePlus to Two-Dimensional Models of Fire Growth

Predictions of wildland fire behavior are still made at one point in space and time given simple user defined fuel, weather, and topography. BehavePlus inputs can be determined easily in the field while other Two-Dimensional models (such as FARSITE) require extensive GIS support and map theme development.

Types of fire Two-Dimensional models

Two types of 2D fire models:
- Vector models
- Cellular Automata (CA) models

Vector Models

✓ Assume:
  ✓ Fires spread according to a growth law
  ✓ Fires take a standard geometrical shape
  ❗ Ellipsoidal under uniform conditions (Van Wagner, 1969)

✓ Examples:
  ✓ FARSITE (Finney 1990, 1994)
  ✓ FIRE! (Green et al. 1995)

FARSITE: Fire Area Simulator-Model

✓ FARSITE is a two dimensional deterministic fire growth model
✓ This simulator incorporates existing fire behavior models of surface spread, crown fire spread, spotting, point-source fire acceleration, and fuel moisture.
✓ It demonstrates the linkages between existing fire behavior models and the consequences to spatial patterns of fire growth and behavior.
✓ Here the fire front is propagated as a continuously expanding fire polygon at specified time steps.
✓ The fire polygon is defined by a series of two-dimensional vertices (points with X, Y coordinates).
✓ The number of vertices increases as the fire grows over time (polygon expands).
FARSITE

- Rate of only the heading portion of a fire is predicted by the present fire spread model.
- Fire spread in all other directions is inferred from the forward spread rate using the mathematical properties of an ellipse.

Richard's Fire Growth Model is incorporated in FARSITE

- Fire growth model, (Richard, 1990)
  - computes the orthogonal spread rate differentials $X_t$ and $Y_t$ for a given vertex
    $$
    X_t = \frac{a^2}{b^2} \frac{x}{a^4} \sin \theta + \frac{y}{a^2} \cos \theta - \frac{b^2}{a^2} \frac{x}{b^4} \cos \theta + \frac{y}{b^2} \sin \theta
    $$
    $$
    Y_t = \frac{a^2}{b^2} \frac{x}{a^4} \cos \theta + \frac{y}{a^2} \sin \theta - \frac{b^2}{a^2} \frac{x}{b^4} \sin \theta + \frac{y}{b^2} \cos \theta
    $$

Richard's Fire Growth Model continued

- $x_s, y_s$: the orientation of the vertex on the fire front in terms of component differentials
- $\theta$: the direction of maximum fire spread rate (the resultant wind-slope vector, radians azimuth)
- $a, b, c$: the shape of an elliptical fire determined from the conditions local to that vertex in terms of dimensions

Topography Effect

- $x_s$ and $y_s$ are transformed from their original horizontal values by adding or subtracting a slope correction $D_i$ (m) depending on the aspect $\phi_i$ (radians) of the $i$th vertex:
- Formula Mistyped in PDF file – currently searching for correct one
  $$
  x_t = (x_s - x_{st}) \cdot D_i
  $$
  $$
  y_t = (y_s - y_{st}) \cdot D_i
  $$

Wind-Slope

- $\theta$: calculated for surface fires from mid-flame wind vector $F_{w}$ and slope $F_{s}$ (Rothermel, 1972)
  $$
  \theta = \frac{5.275 \delta^{0.3}}{\tan \theta}
  $$
  $$
  \theta = \frac{C(3.2814)^{k} \delta^{0.3}}{\tan \theta}
  $$

- formula mistyped in original PDF

FARSITE – wind, slope and fuels affect fire shapes

- Huygens’ principle (wave or vector approach)
  - The fire front is propagated as a continuously expanding fire polygon
  - assumes that each vertex can serve as the source of an independent elliptical expansion.
  - fire environment at each vertex on the fire perimeter to dimension and orient an elliptical wavelet at each time step
  - calculations at each vertex of the fire front are assumed independent of the others.
  - shape and direction of the ellipse are determined by wind-slope vector
  - the size of the ellipse is determined by the length of the time step.
**Inputs – Landscape**

<table>
<thead>
<tr>
<th>File Theme</th>
<th>Required</th>
<th>Default Units</th>
<th>Alternate Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>elevation</td>
<td>yes</td>
<td>meters</td>
<td>feet</td>
</tr>
<tr>
<td>slope</td>
<td>yes</td>
<td>degrees</td>
<td>percent</td>
</tr>
<tr>
<td>aspect</td>
<td>yes</td>
<td>categories 1-25</td>
<td>degrees</td>
</tr>
<tr>
<td>fuel model</td>
<td>yes</td>
<td>13 NFFL models</td>
<td>custom or converted models</td>
</tr>
<tr>
<td>canopy cover</td>
<td>yes</td>
<td>categories 1-4</td>
<td>percent</td>
</tr>
<tr>
<td>tree height</td>
<td>no</td>
<td>meters*10</td>
<td>meters, feet, feet*10</td>
</tr>
<tr>
<td>crown base height</td>
<td>no</td>
<td>meters*10</td>
<td>meters, feet, feet*10</td>
</tr>
<tr>
<td>crown bulk density</td>
<td>no</td>
<td>kg/m3*100</td>
<td>kg/m3, lbs/ft3, lbs/ft3*100</td>
</tr>
<tr>
<td>duff loading</td>
<td>no</td>
<td>Mg/ha</td>
<td>tons/acre</td>
</tr>
<tr>
<td>coarse woody</td>
<td>no</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Inputs – Weather Stream**

<table>
<thead>
<tr>
<th>Month</th>
<th>Day</th>
<th>Precip</th>
<th>Hour1</th>
<th>Hour2</th>
<th>Temp1</th>
<th>Temp2</th>
<th>Humid1</th>
<th>Humid2</th>
<th>Elevation</th>
<th>r1</th>
<th>r2</th>
</tr>
</thead>
</table>

r1-r2: Precipitation Duration

**Inputs – Adjustment – fudge-factor**

Rate of spread adjustment factors allow the user to use experienced judgment or local data to tune the simulation to observed or actual fire spread patterns (see spread patterns [Lattanzio and Associates]). These factors have the same purpose as adjustments for BEHAVE predictions (Rothermel and Rinehart 1983). Factors are fuel model specific and are multiplied by the rate of spread to achieve the specified adjustment.

**Inputs – Initial Fuel Moisture**

The fuel moistures at the beginning of the simulation must be set for each fuel type. Those fuel moistures are required to begin the process of calculating site-specific fuel moisture throughout the simulation.
**RFHAM** (a Residential Fire Hazard Assessment Model)

We made observations in residential areas logging both vegetation conditions and building structures. The observation points were the basis for the Voronoi Diagram and eight classification categories (that contained the attribute data), made up the data dictionary for the Residential Fire Hazard Assessment Model (RFHAM).

Observed Structural Fuel Characteristics

- **Combustible roof materials**
- **Siding, decking and fencing**

**Roof Structure**

**Side Conditions**
Observed Vegetation Fuel Characteristics

Surface Fuel Density

Aerial Fuel Density

Vertical Continuity

Surface Fuel Density

Aerial Fuel Density

Vertical Continuity

Observed Vegetation Fuel Characteristics

Tree Height

Flammability

Fuel Clearance

Tree Height
From this example we can see how advances in technology helped us gather and position data, aided in the processing and modeling of that data to generate information and knowledge about existing fire conditions. From here, informed planners and policy makers can produce a safer strategy, a safer environment with reduced problems.

Have I convinced you?

Hopefully through this very brief description I have convinced you that GI Science is critical to tackling and solving Emergency Preparedness and Response problems ... big problems.

What we discovered

We need to:
✓ build early warning systems,
✓ educate and change land use and life style,
✓ construct large databases that contain information on humans, their activities, and their habitat,
✓ insure that these data are accessible to assess risk, prepare to engage disaster, and aid in effective response and settlement,
✓ insure these databases are engineered to effectively assist emergency workers,
✓ insure the privacy of the individual so that exploitation cannot occur.
Policy Implications

Both natural and human-generated hazards usually transcend political boundaries that are effective for defining regions used to successfully mitigate against disaster, manage rescue and response operations, or to organize and deliver relief. Since policy is most often generated and administered within politically defined boundaries, we must develop new policies that emulate hazards rather than human administrative structures. As illustrated in the firestorm example, advances in GI Science can accommodate this.

More on Policy

Policy and regulation are commonly applied on the landscape as a function of form. For example, brush must be cleared to create a specific size protective buffer zone around homes in an urban-wildland intermix region. Although the specific buffer zone, represented here as a form, can easily be complied to and administered, it is naive and unrealistic to assume that the impact of this buffer zone will be uniform over space. Advances in GIScience will bring about a shift where policy and regulation can become a function of the underlying process rather than relying on an easily administered but limited form-based policy.

One last statement on Policy

The greater our confidence in data and models, the more likely that policy will be process-based rather than form-based.

Conclusions

- Hopefully I have managed to convince you that GI Science will play an important role in processing data into information and knowledge.
- Research and education in emergency preparedness and response are crucial as we search for conditions thought to be hazardous to life and habitat, undertake mitigation efforts, respond during emergencies to reduce loss of life and property, and settle and restore a damaged environment.

More Conclusions

- We discovered that interaction between humans and their environment under conditions thought to be hazardous to life and habitat can be facilitated through advances in GIScience.
- GI Science can help us mine, analyze, synthesize, and extract the relevant information from seemingly complex data sets. It is clearly on the road to solving our big problems and helping us honor the guardianship of planet earth.