INTEGRATION OF GIS WITH PESTICIDES LOSSES RUNOFF MODEL

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ABSTRACT

Pesticides pollution is derived from agricultural activities on broad and diffuse location. The pollution is often a gradual and subtle hazard and the extent of pollution is affected by uncontrollable events, such as storms as well as geographic and geologic conditions. The development of spatial models incorporating remote sensing data sets and GIS software provides a useful tool. In this paper, an integration approach of GIS and remote sensing with pesticides losses runoff model is proposed. A set of terrain analysis methods is applied to compute the slope, direction flow and contributing area, etc. The DEM generated from aerial photographs is used to compute hydrological parameters for the pesticides model. Cell numbers, cell connectivity, flow directions, land and channel slopes, slope lengths, slope shapes, and upslope contributing areas, are carried out. Although they are only some of results derived from an ongoing project, the results have proved that the feasibility and utility of interfacing terrain analysis technique with existing pesticides losses runoff models. By using the capabilities of terrain analysis in modeling processes directly impacted by terrain characteristics, a more realistic description of these processes is possible. The paper concludes by briefly analyzing the advantages of integration of pesticides pollution model with GIS application.

INTRODUCTION

The use of pesticides is widely accepted as indispensable in most agricultural systems. However, there has been growing concern about the fate of chemicals leaving the field and which are threatening water quality in the past decades. This kind of nonpoint source pollution is often a gradual and subtle hazard to the environment. This is because the chemicals applied as both herbicides and pesticides are long-lived, and can be transported by water. Because of their severe toxicity, most of these compounds have been banned or restricted from extensive uses (Heidi and Jeff, 1994). However, many other pesticides, especially herbicides, remain in use as essential chemicals in modern agriculture, which has spanned a wide range of research efforts on their behavioral and toxicological properties. Among all the herbicides, alachlor, atrazine, cyanazine and metolachlor account for about 73% of the pesticides applied (Giannocci and Puffer, 1991). As water runoff moves over the land, pesticides resulting from agricultural activity are picked up and deposited into rivers, lakes, and other bodies of water. Pollutants dissolved in the runoff are generally more biologically available in water bodies than sediment-based fractions and can be potentially more harmful (DEC, 1990). It affects human health, quality of life, economic smooth activities, and recreation, as well as the survival of fish and wildlife and ecosystems integral to natural resource preservation (Floyd et al., 1998). For example, Lowe et al. (1991) reported that, nationally, 5% of fish kills were caused by pesticides in USA.

Pesticides pollution are derived from agricultural activities on broad and diffuse location; the pollution sources are difficult to identify. The discharges from them enter surface waters in a diffuse manner and at intermittent intervals and travel over land before reaching surface waters. The extent of the pollution is affected by uncontrollable events, such as storms as well as geographic, geologic and hydrological conditions, and may differ greatly from place to place and year to year. The governments of many countries have targeted the identification and control of pesticides losses as a major goal for pollution abatement. In order to develop plans to assess, manage, and reduce pesticides remains in waters where water quality problems have been identified. Remote sensing and geographic information system (GIS) can aid in rapid inventory and assessment of regions for potential pesticides pollution problems. Because surface runoff in agricultural areas contributes heavily to pesticides pollution, one way to implement such a management program is to focus on the characteristics and conditions of surface runoff. But, to control and monitor these problems, it is necessary to know what the current areas of concern, often at the parcel level (Floyd et al., 1998).

The development of spatial models incorporating remote sensing data sets and GIS software provides a useful tool, not only for depiction of past and current pesticides losses, but also
for the identification and location of areas at high risk of change and subsequent increase in pesticides pollution (Stephen and Kyehyun, 1993; Vassilis et al., 1997). High-resolution digital remote sensing data have several characteristics that make them well suited for contributing to pesticides pollution assessment studies: Computer analysis of multispectral data allows rapid mapping and monitoring of land cover types and conditions; Terrain analysis helps to show the hydrological characteristics of study areas. The regional coverage of satellite data provides a cost-effective method of rapidly inventorying extensive areas; Additionally, the digital maps produced can be readily integrated with other information in a GIS or used to derive input parameters for mathematical models that predict the pesticides pollution potential (Mark et al., 1992; Hanadi et al. 1993; Kurt and Robert, 1993; Mark et al., 1994; Adams and Bergman, 1995; Nuckols et al., 1996).

At present, the efficient cooperation of nonpoint source (Nitrogen, Phosphorous, etc.) pollution model and GIS model is main research trend (Heidke and Auer, 1993). Several studies have illustrated the role of GIS in supplying data and information for assessing nonpoint source pollution attributes and formulating land resource planning and management strategies. For instance, Newell et al. (1992) created a ranking of nonpoint source water pollution loads in Galveston Bay, Texas, using eight land-use categories derived from Landsat TM data incorporated with soil run-off models rainfall amounts, and water quality parameters. Subra and Waters (1993) examined an area of southwestern Louisiana to develop a prototype nonpoint source pollution model using 15 land-cover types mapped from TM imagery, watershed, hydrography, slope, and soil type data. A Connecticut watershed was the focus of research by Nelson and Arnold (1996). Six categories of land-cover were extracted from TM imagery and weighted by their percent of impervious areas to produce current and future runoff values. Floyd et al. (1998) examined the positive potential of an existing satellite-based (TM) land-cover data set (Coastal Change Analysis Program) in a rapidly developing coastal area for nonpoint source water pollution controlling and management.

However, few successful studies are found in the integration of pesticides pollution model with GIS and remote sensing. Especially, real landscapes are three-dimensional and this three-dimensionality has a major impact on the hydrologic and erosional processes occurring on the landscape. Few models with GIS and remote sensing applications are capable of accounting for this kind of three-dimensionality (John, 1991). The objective of this paper is to demonstrate how terrain analysis methods could be applied in pesticides pollution control model to improve their prediction capabilities and decrease the time and effort required to assemble the input data sets. A Pesticides Surface Runoff model was used to integrate with GIS and remote sensing techniques. The terrain analysis approach was used to resolve the runoff flow direction based on Digital Elevation Model (DEM) photographically derived from aerial photograph. The flow direction as an important parameter was then input into the pesticides runoff model to simulate the pesticides losses.

**METHODOLOGY**

**STUDY AREA**

The study area is the Kintore Creek watershed (Latitude: 43°.189 – 43°.145, Longitude: -81°.075 – -80°.995), which has two adjacent sub-watersheds, in south Ontario, Canada (Fig.1). The total area of the watershed is 1,288 ha. The sub-watersheds have nearly equal size, similar highly erodible landscapes, and cropping patterns. Detailed Kintore Creek sub-watershed characteristics are listed in Table 1. Both sub-watersheds are located in agricultural land, which makes it a heavily used land. The sub-watersheds have year round soils. The area is under sub-watersheds in other agricultural areas. The area is under sub-watersheds in southern Ontario, before the heavy used land. The area is under sub-watersheds in northern Ontario, before the heavy used land. The area is under sub-watersheds in eastern Ontario, before the heavy used land.

**Table 1. Kintore Creek sub-watershed characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of sub-watershed</td>
<td>645 ha</td>
</tr>
<tr>
<td>Soil types</td>
<td>645 ha</td>
</tr>
<tr>
<td>Soil erosion profile</td>
<td>645 ha</td>
</tr>
<tr>
<td>Area under study</td>
<td>645 ha</td>
</tr>
<tr>
<td>Area tile drainage</td>
<td>645 ha</td>
</tr>
<tr>
<td>Total forest cover</td>
<td>645 ha</td>
</tr>
<tr>
<td>Total crop area</td>
<td>645 ha</td>
</tr>
</tbody>
</table>

In the western part of the watershed, the area is under sub-watershed in southern Ontario, before the heavy used land. The area is under sub-watershed in northern Ontario, before the heavy used land. The area is under sub-watershed in eastern Ontario, before the heavy used land. The area is under sub-watershed in southern Ontario, before the heavy used land. The area is under sub-watershed in northern Ontario, before the heavy used land. The area is under sub-watershed in eastern Ontario, before the heavy used land.
sub-watersheds originate in swampy headlands that provide a year round source of water. Kintore Creek flows into the Middle Branch of the Thames River, which drains the corn belt of Ontario, before discharging into Lake St. Clair. It is one of most heavily used pesticides in the Great Lakes area.

Table 1. Kintore Creek sub-watersheds characteristics

<table>
<thead>
<tr>
<th></th>
<th>Conventional tillage (West)</th>
<th>Conservation tillage (East)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of sub watershed</td>
<td>6.61 sq. km</td>
<td>6.42 sq. km</td>
</tr>
<tr>
<td>Soil type</td>
<td>silt loam</td>
<td>silt loam &amp; muck</td>
</tr>
<tr>
<td>Soil erosion potential</td>
<td>medium to high</td>
<td>high</td>
</tr>
<tr>
<td>Area under study</td>
<td>653 ha</td>
<td>635 ha</td>
</tr>
<tr>
<td>Area tile drained</td>
<td>56</td>
<td>36</td>
</tr>
<tr>
<td>Total forest cover</td>
<td>78 ha</td>
<td>175 ha</td>
</tr>
<tr>
<td>Total crop area</td>
<td>473 ha</td>
<td>333 ha</td>
</tr>
</tbody>
</table>

In the western sub-watershed, landowners employed conservation techniques, which included the mulch-finishing of row crops, the planting of forage and cover crops, no-till and reduced till practices, the installation of sediment control basins, slope stabilization along stream banks, and tree planting. In the eastern sub-watershed, landowners used the conventional tillage practice of fall moldboard ploughing of a corn-wheat-alalfa rotation.

DATA DEVELOPMENT

In this paper, color infrared airphotos purchased from the Information Center of Natural Resources Ontario, were used to generate a mosaic of color orthoimages and a DEM. The grid-DEM created in this study was used to provide basic input data for the pesticides losses runoff model. The several input parameters of pesticides model were derived by using desktop ArcView 3.1 GIS. A grid of flow accumulation was produced. Slope and aspect grids were also computed from DEM based on the terrain analysis and relative hydrological parameter determination methods (Ballard et. al., 1998, 2000).

For the study of a paired watershed of Kintore Creek to examine the effects of farm conservation practices on pesticides transport to surface water was carried out by Environment Canada and the Upper Thames River Conservation Authority, some relative meteorology, agriculture and pesticides data were also obtained.

Table 2. Parameters of the pesticides losses runoff model

<table>
<thead>
<tr>
<th>SCS curve number</th>
<th>Surface condition constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land slope</td>
<td>Aspect</td>
</tr>
<tr>
<td>Slope shape factor</td>
<td>Soil texture</td>
</tr>
<tr>
<td>Field slope length</td>
<td>Gully source indicator</td>
</tr>
<tr>
<td>Channel slope</td>
<td>Channel indicator</td>
</tr>
<tr>
<td>Channel slippage</td>
<td>Soil erodibility factor</td>
</tr>
<tr>
<td>Roughness coefficient</td>
<td>Practice factor</td>
</tr>
</tbody>
</table>

These data are helpful to accompany with the derived parameters to input the pesticides losses runoff model for assessing the reliability and efficiency of the methods proposed in this paper. The pesticides losses runoff model used in this paper was developed for concerning the potential effects of pesticides pollution on surface water quality and quantitatively examining these effects. This model used a square grid cell system, which has 320 grid cells and each 280m by 400m (0.043 mi²), to represent the spatial variability of catchment properties. About one-third of the input parameters required by the model are terrain-based and could be obtained directly or indirectly from remote sensing data (Table 2). In this paper, only some of these parameters, including cell numbers, cell connectivities, aspects (flow directions), land and channel slopes, slope lengths, slope shapes, and upslope contributing areas, were carried out by the terrain analysis for this project is an undergoing. For the conventional nonpoint sources pollution model, all terrain input data must be entered into the input file by hand, along with the other soil and land use data, which is a time consuming process. While, the advantage of GIS, here is the terrain analysis, are appeared. Therefore, some terrain analysis techniques were applied to obtain the important input parameters for the runoff model.

Flow directions based on digital elevation models are needed in hydrology to determine the paths of water and pesticides residues movement. Two important distributed quantities that depend on flow directions are the upslope area and specific catchment area. Upslope area, A, is defined as the total catchment area above a point or short length of contour. The specific catchment area, a, is defined as the upslope area per unit width of contour. (a = A/L) (Moore et. al., 1991) and is a distributed quantity that has important hydrological, geomorphological and geological significance (Tarboton, 1997).

The specific catchment area contributing to flow at any particular location is useful for determining relative saturation and generation of runoff from saturation excess in models such as Topmodel. Specific catchment area together with other topographical parameters has also been used in the analysis of processes such as erosion and landslides. Upslope area is commonly used for the automatic demarcation of channels relying on the notion of a critical support area. From the number of recent papers there is considerable hydrologic interest in the effect of grid scale and procedures for computation of specific catchment areas. It is therefore important that flow directions and specific catchment areas be accurately determined free from grid artifacts.

- Slope/Aspect

The computation of slope/aspect for each surface cell was made from some number of neighboring elevation values in four or nine adjacent windows but was used as if it represents the surface angles for only the central cell. It is often assumed that the computed surface angles actually represent a cell size twice as large as the original grid cell (Hodgson, 1995). The most common algorithms use either four or eight of the neighbors in a three by three window centered on the cell in question (Fig. 2). When using all eight neighbors, variations in...
algorithms use different weights for the diagonal neighbors. This study used a modified version of Shapack and Akin’s method using unequal weights for the closer elevation values (Horn, 1998) as follows:

\[
\text{Slope}_a = \frac{(e_1 + 2e_2 + e_3) - (e_1 + 2e_2 + e_4)}{8 \times \text{cell size}}
\]

\[
\text{Slope}_w = \frac{(e_1 + 2e_2 + e_3) - (e_1 + 2e_2 + e_4)}{8 \times \text{cell size}}
\]

- Flow direction

Topographic analysis required to define the hydrologic system is based on the DEM. According to the process showed in Fig. 3, a single downstream cell -- in the direction of the steepest descent -- was defined for each terrain cell, so that a unique path from each cell to the basin outlet is determined. This process produced a cell-network, with the shape of a spanning tree, which represents the paths of the watershed flow system. However, because a flow direction cannot be determined for cells that are lower than their surrounding neighbor cells, a process of filling the spurious terrain pits is necessary before the flow direction determination.

Fig. 3 Grid functions for terrain analysis for hydrologic purposes (Francisco and David, 1999)

Pits in digital elevation data are defined as grid elements or sets of grid elements surrounded by higher terrain that, in terms of the DEM, do not drain. These are rare in natural topography and generally assumed to be artifacts arising due to the discrete nature and data errors in the preparation of the DEM. They were eliminated here using a ‘flooding’ approach. This raised the elevation of each pit grid cell within the DEM to the elevation of the lowest point on the perimeter of the pit (Jenson and Dorninge, 1988).

In most cases, the existence of pits in the DEM is explained by numerical errors introduced in the process of interpolation of observed values to estimate values for each grid cell. Filling the DEM pits consists of increasing the value of the pit cells to the level of the surrounding terrain, so that water is able to flow out of the area. Once the pits have been filled and the flow directions are known, the drainage area (in units of cells) is calculated counting the number of cells located upstream of each cell (the cell itself is not included) and, if multiplied by the cell area, equals the drainage area.

- Contributing Area

Upland area (counted in terms of the number of grid cells) was calculated for both single and multiple flow directions using a recursive procedure that is an extension of the very efficient recursive algorithm for single directions (Mark, 1988). The upland area of each grid cell is taken as its own area (one) plus the area from upland neighbors that have some fraction draining to it. The flow from each cell either all drains to one neighbor, if the angle falls along a cardinal (0, π/2, π, 3π/2) direction or diagonal (π/4, 3π/4, π/2, 5π/4) direction, or is on an angle falling between the direct angle to two adjacent neighbors. In the latter case the flow is proportioned between these two neighbor pixels according to how close the flow direction angle is to the direct angle to those pixels, as illustrated in Fig. 4. Specific catchment area, is then upland area per unit contour length, taken here as the number of cells times grid cell size (cell area divided by cell size). This assumes that grid cell size is the effective contour length, in the definition of specific catchment area (Fig. 4) and does not distinguish any difference in contour length dependent upon the flow direction. For shallower lateral subsurface flow follows topographic gradients, this implies that the contributing area to flow at any point is given by the specific catchment area defined from the surface topography.

Fig. 4 Definition of Specific Catchment Area

- Network

The stream network was derived from the DEM using a user-defined network conformed to the largest flow direction, a user-defined network which is a network of adjoining grid cells connected in the order of descending grid cell size.

To include the network it can be necessary to define a basin network. Sub-basin network is a set of all cells in a catchment at a junction of a stream to an outlet. The area associated with each sub-basin code is the area of the headwater basin.

- Length

A minimum flow direction represents length-slope (USLE), USLE erosion in the USLE soil loss equation in the US. The USLE represent a set of length-slope, units for erosion:

\[
LS = \frac{A}{12}
\]

Where \(A\) is the upslope contributing area, \(m=1.3\). These cells contain cell value of zero.
• Network definition

The stream and watershed network was determined so that there was a single stream segment for each watershed that had been modeled. The DEM cells that form the streams are defined as the union of two sets of grid cells. The first set consists of all cells whose flow accumulation is greater than a user-defined threshold value. This set identifies the streams with the largest drainage area, but not necessarily with the largest flow because flow depends on other variables that are not related exclusively to topography. The second set is defined interactively by the user by clicking a certain point on the map, which results in an automatic selection of all downstream cells. To include these streams using the threshold criterion, it would be necessary to lower the threshold value for the entire system, thus defining unnecessarily a much more dense stream network.

Sub-basin outlets were also defined as the union of two sets of grid cells. The first set, based on the stream network, consists of all cells located just upstream of the junctions. Consequently, at a junction, two outlet cells are identified, one for each of the upstream branches. The system outlet is also identified as an outlet. The second set is defined interactively by the user by clicking on any cell on the stream network such as those associated with gages or other water control points. After the sub-basin outlets have been defined, a unique identification code is assigned to each stream segment connecting a headwater cell with a sub-basin outlet or, in some cases, to sub-basin outlets.

• Length-slope factor

A minimum cell area of 280 m² has been applied with Pesticides Losses Runoff Model in this paper to allow a representative field slope length to be used in estimating the length-slope factor (LS) in the Universal Soil Loss Equation (USLE). The USLE is used to calculate the sheet and rill erosion in each cell. A theoretical equation derived from unit stream power theory is used to estimate the length-slope factor in the USLE (Cazella et al. 1997). This equation also better represents the effects of flow convergence and divergence on erosion:

\[ LS = \frac{A_s}{22.13} \times 0.0896 \times \sin \beta_s \]

Where \( A_s \) is the specific catchment area (\( \text{m}^2 \)), \( \beta_s \) is the slope gradient in degrees, \( n=0.4 \) and \( m=1.3 \). The within-cell sheet and rill erosion is then estimated using an approach similar to that proposed by Foster and Wischmeier:

\[ Y = EI_s K_s C_s R_s S_i \left( \frac{A_{(A_s/22.13)} - A_j(A_{A_s/22.13})}{A_j - A_{j-1}} \right) \]

Where \( Y, K_s, C_s, P_s \) and \( S_i \) are the sheet and rill erosion, soil erodibility factor, cover and management factor, practice factor and slope factor, respectively, in the \( j \)th cell and \( A_s \) and \( A_j \) are the upslope contributing areas where flow exits and enters each cell, respectively. \( E \) is the rainfall intensity.

The LS factor derived from unit stream power theory used with GIS enhanced pesticides model appeared to perform satisfactorily. It has an advantage over the traditional method in that the inputs to the relationship are derived easily from the terrain analysis and physically can better account for the effects of flow convergence and divergence on erosion.

RESULTS AND DISCUSSION

For this paper is based on an ongoing project, there are little results that can be showed here. Through the application of the methods mentioned in previous section, the slope and flow direction of the study basin were carried out (Fig 5 and Fig 6). To evaluate the reliability of terrain analysis, the results generated by the integration of GIS and remote sensing and the field measured slope and direction were compared. It was showed there were some disagreement though satisfying in general.

Two reasons have been identified for the mismatch between true topographic surface form, and its representation as a DEM within a GIS. Firstly, the methods themselves provide some conceptual limitations. It is not possible to represent fully, a continuous, undifferentiatable surface with a discrete, finite resolution elevation model. Secondly, the process of elevation interpolation required for DEM generation can lead to model error (Garnbrecht and Stark, 1995; Gong et al., 2000).

The lack of agreement implies further refinement of the terrain analysis methodology may provide more insight into the pesticides losses runoff modeling. It suggests that GIS data, no matter what specific methodology is employed, may need to be augmented with site-specific sampling data to facilitate pesticides control decision making. However, the important point should be confirmed is the GIS and remote sensing integrated modeling is a useful tool for the pesticides losses control and the results are receivable.
Our study demonstrates the feasibility and utility of interfacing terrain-analysis technique with existing pesticides losses runoff models. By using the capabilities of terrain analysis in modeling processes directly impacted by terrain characteristics, a more realistic description of these processes is possible. When working with processes that must consider such properties as flow direction and contributing area, as is the case with hydrologic and soil erosion models, quick, accurate representation of the terrain is especially important. As computer capabilities continue to improve, terrain analysis undoubtedly will play an increasing role in hydrologic and water quality modeling for pesticides losses control.

At present, we are working on the further analysis of hydrologic characteristics by the GIS and remote sensing techniques. New 4m spatial resolution IKONOS multispectral images will be used to extract thematic information, while 1m resolution IKONOS panchromatic images to generated DEMs. Particularly, some index or parameters of the soil used in the pesticides losses runoff model can be derived by automated classification of IKONOS multispectral imagery. Future investigations in this project include:

- Adding vegetation analysis, such as crops and forests, to the pesticides model for considering the canopy effects on the pesticides losses;
- Developing new algorithm for high accuracy of DEM interpolation, or modify the existed algorithm to well suit for the pesticides control system;
- Data connection with the pesticides losses runoff model and terrain analysis of the GIS and remote sensing;
- Enhancing the display function of the GIS and remote sensing.

Fig. 5 Slope of the study area
Fig. 6 Flow direction of the study area

CONCLUSIONS

This paper has demonstrated new analysis method for pesticide losses runoff model. The flow direction, land use, and area, and input data must take advantage of integrated analysis. The advantages of this approach are:

For the practical application of the proposed model, high resolution data are required. However, through the additional input data, the model’s potential accuracy and efficiency may be increased. The efficiency may be increased through the convergence analysis on the acquisition algorithms and the acquisition of run-off model to control system.

From the analysis of the initial conclusions, the following results are obtained:

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sensing integrated model with real 3-dimensions for showing the pesticides pollution distribution with relative multi-layers geographic information and providing dynamic decision support for the environmental quality managers.

CONCLUSIONS

This paper has described the use of a set of DEM-based analysis method to compute hydrological parameters for the pesticides losses runoff model. Cell numbers, cell connectivities, flow direction, land and channel slopes, slope lengths, slope shapes, and upstroke contributing areas, were carried out. Comparing with the conventional model, in which all terrain input data must be entered into the input file by hand, the advantage of integration with GIS techniques, here is the terrain analysis, are appeared obviously.

For the project is just in operation now, the results showed in this paper are only a small portion of total anticipated output. However, through the comparison of results generated by the integration of GIS with the field measured slope and direction, there are only little disagreement. It is shown that it is feasible to use terrain analysis methods to restructure existing hydrologic and soil erosion models to improve their usefulness and potential accuracy in the pesticides losses simulation. Though the efficiency may be limited by the relative simplicity of the model algorithms and better account for the effects of flow convergence and divergence in natural landscapes. It makes the acquisition and input of the terrain-based parameters into runoff model to access a DEM databases.

From the analyzing and proving of this study, we can draw an initial conclusion that the incorporation of GIS with the pesticides losses runoff model provides a powerful tool for pesticides load simulation and pollution control management. Further studies are underway as part of this project to further explore some of issues presented, including investigations on the use of thematic information and DEMs derived from high-resolution IKONOS images for generating some of input parameters of the pesticides losses runoff model.

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Environmental Assessment Division, ORCA/NOS/NOAA, Rockville, MD


KEY WORDS: 3D Reality Modeling Language (HTML) and geographical data, the 3D objects, technique and software, estate management. Internet, as well as Graphics User Interfaces (GUI) In order to visually provide the Internet, building many approaches semi-reconstructed For example: CCA-CC includes vector and...