Design of Visualizations for Urban Modeling

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Abstract. Urban planning experts often use computer models to help evaluate alternative land use policies, particularly as they interact with transportation and environmental decisions. The greatly increased data volume provided by new land use models makes their effective use difficult without suitable visualization tools. We present UrbanView, a visualization system for urban modeling, and describe a user study to determine appropriate visualizations for the urban modeling domain.

1 Introduction

Patterns of land use and available transportation systems play a critical role in determining the economic vitality, livability, and sustainability of urban areas. Transportation interacts strongly with land use: different kinds of transportation systems induce different patterns of land use, while at the same time, different kinds of land use induce demands for different kinds of transportation systems. Both land use and transportation have strong environmental effects, in particular on emissions and resource consumption.

Urban planning experts use computer models to simulate and evaluate different land use polices. UrbanSim, an urban modeling system being written by our collaborators at the University of Washington, is several orders of magnitude more complex than existing models. This resulting increase in data volume, coupled with the diverse types of analyses experts must perform makes the use of new visualization techniques essential.

While there has been a large amount of work on geographical information systems (GIS), very little if any rigorous research has been done evaluating the usefulness of other types of visualizations for this domain. Our goal is to examine various visualization types to find the appropriate visual representations for urban modeling tasks.

We first describe our system architecture which includes UrbanSim, our urban modeling system, and UrbanView, our visualization system specialized for urban modeling. Then we discuss a user study we conducted to determine what types of visualizations are useful for urban modeling tasks.

2 Urban Development Project Architecture

Figure 1 shows the system architecture. UrbanSim and UrbanView are described in the following sections.

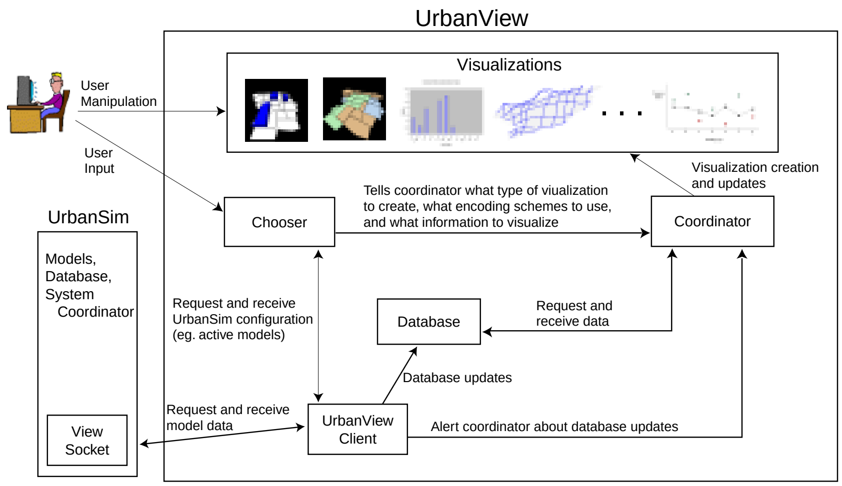


Fig. 1. Urban Development Project Architecture

2.1 UrbanSim

UrbanSim [1, 8] is a land use modeling system designed to model the development of urban areas. In particular, it models the interactions between land use and transportation infrastructure, along with the resulting environmental effects.

In current practice, land use modeling, if done at all, employs a very simplified, aggregate land use model. The unfortunate consequence is that the model is not sensitive to important policy alternatives such as changing zoning, urban growth boundaries, or taxes and incentives. UrbanSim is intended to provide a much more detailed model of land use, which explicitly allows different policy alternatives to be modeled and compared. UrbanSim is composed of an object store and numerous component models that simulate various actors in the urban development process. For example, there are component models that simulate business creation and closure, household and business movement and location choices, and developer decisions such as the character, density, and scale of property development.

A user interacts with UrbanSim to create scenarios that specify alternative packages of policies, economic and demographic forecasts, and other exogenous inputs. The system is then executed for a specified number of years (typically 20), and the results are analyzed.

2.2 UrbanView

UrbanView is the visualization generation system we are building to interface with UrbanSim. With UrbanView a user can create visualizations that represent model execution decisions, resulting land use phenomena and model data output in useful informational form.

UrbanView is composed of an object store, a visualization coordinator, a visualization chooser, and individual visualization components. As illustrated

1. Where is the development of different types of land occurring?
2. How much of the development of each type is Greenfield vs. redevelopment?
3. How much and what types of land are being redeveloped? From what use into what use? Where?
4. What is the distribution of density of new development?
5. How much development is occurring in desired locations?
6. How many acres of agricultural and forest land are being consumed by development? How fast?
7. Why is the model building/developing the parcels/buildings it is?
8. Where are households of each type generally locating?
9. Where are the biggest population gains and losses?
10. How much is employment decentralizing?

Fig. 2. User Tasks

in Figure 1, this modular architecture allows us to easily modify each component in the system. Most importantly, it allows us to experiment with different visualization chooser modules during user testing.

There are a wide range of possibilities for user interaction with the chooser module, from complete user control over the creation of visualizations to an autonomous visualization generator based on user task input. The results from this user study and future user studies will determine where on this continuum of user interaction the chooser should be placed to optimally support users.

The coordinator creates the individual visualizations from visualization specifications, keeps track of each of the visual displays, and notifies the visualizations of data updates. The individual visualization components then request their data directly from the object store.

UrbanView will dynamically interact with the UrbanSim component models as they are executing, as well as create static visualizations of model results. We are currently in the process of linking UrbanView and UrbanSim which will allow us to present users with interactive visualizations in addition to the existing static ones.

3 User Study

It seems clear that certain visualizations are extremely useful and much more effective than textual descriptions for specific contexts. However, there is not one perfect visualizations for an urban modeling data set. Different visualizations are often necessary for each different user task. We present an analysis of visualization types that provides some initial results for understanding what makes visualizations useful and how to create them for the urban planning domain.

For the study, all of the two- and three-dimensional map visualizations were generated using UrbanView. At the time of the tests we were still implementing the other visualization types, which we have now completed.

3.1 Study Method

Five participants, two graduate students and three professors, all from the Department of Urban Design and Planning at the University of Washington, took

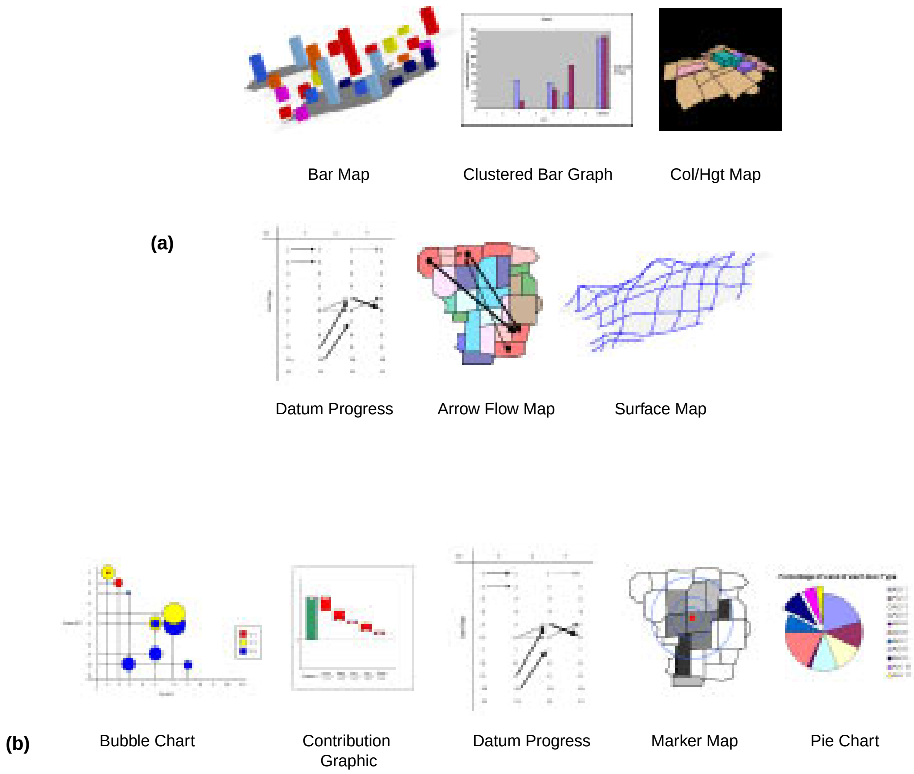


Fig. 3. Sample visualization layouts for (a) comparison processing activities and (b) quantitative processing activities

part in the user study. Each participant was given a series of tasks, enumerated in Figure 2, that could be answered using the information provided by UrbanSim model output. These tasks were selected by an urban land use expert and intended to be representative of the questions an analyst asks while using a system such as UrbanSim.

The entire user test consisted of ten questions, each having between three and seven corresponding visualizations, for a total of 55 different visualizations. Each visualization contained all the information necessary to complete the task. The participants were asked to evaluate, for each task, the usefulness of each of the visualizations presented on a scale of one (most useful) to five (least useful), and then to rank the visualizations in order of preference.

Our visualization designs focused on the understanding and explanation of land use as simulated by the UrbanSim system. Visualizations such as the ones presented to participants in this study would be used by analysts while they are studying the system's output and behavior. To choose the sample visualizations for each task, we examined the current GIS visualizations prevalent in the urban planning domain and designed visualizations based on previous research.

Figure 3 shows some of the different visualization types presented for Comparison and Quantitative processing activities as described in Section 4.1. Many

	Encodings												
Types	Color Intensity	Distinct Colors	Color Scale	Bars	Stacked Bars	Cluster Bars	Lines	Area Height	Terrain/ Surface	Arrows	Num./ Values	Marker Size	Marker Shape
Graphs		x		x	x	x	x						
Pie Chart		x											
2D Map	x	x	x							x	x	x	
3D Map	x	x	x	x	x			x	x	x			
Symbol Chart													x
Bubble Chart		x										x	
Progression										x	x	x	
Contribution		x		x					x	x			
Table		x								x			

Fig. 4. Types of visualizations cross-referenced by the encodings they can utilize effectively.

of our test visualizations were map type visualizations due to the spatial nature of the urban planning domain. However, in order to verify our belief that map type visualizations are the most useful for urban planning and analysis we included at least two alternative graphic layouts for each task.

To limit our user study we focused on two of the component models within the UrbanSim system: Household Location and Choice, and the Developer/Redeveloper. These models were chosen because our urban planning experts believe these to be two of the most critical component models within the system. In addition, these component models use different types of analyses, thus providing us with a larger task base.

The Household Location and Choice sub-model simulates the decisions made by households. It determines whether or not each household relocates, and if relocating, determines the relocation site. The Developer/Redeveloper sub-model simulates the decisions made by builders as to whether or not to develop or redevelop property, and if so, where, what, and how much to build.

4 Data Analysis

We analyzed the data collected during our user tests to determine favored visualization types and encoding methods. We believe the most promising approach to generating visualizations for analysis and understanding of the urban modeling domain is to design them based on user tasks and their corresponding cognitive processing requirements.

Observation of visualizations show that the makeup of a visualization is more complex than the simple classification scheme used by Lohse et al. [5]. In addition to the overall schematic layout and base look of visualizations, visualizations represent data using information encoding schemes. Thus, rather than using a single type classification of visualizations, we break visualizations down into base type (map, bar chart, line graph) and encoding method(color, marker, arrows, height). Classifying the test visualizations by type and encoding methods resulted in thirty-two distinct visualization type variations as shown in Figure 4. Color examples of these visualization type variations can be found in our technical report [7].

Our analyses focused on matching visualization base types and visualization encoding methods to both specific cognitive processing activities and complete tasks. Given the spatial nature of the urban planning domain, we expect that

	Spatial	Comparison	Alternatives	Options	Trends	Relations	Aggregation	Qualitative	Quantitative	Description
Task 1	x	x			x			x		
Task 2		x							x	
Task 3	**x**				**x**	**x**			**x**	
Task 4					x	x	x	x		
Task 5	x		x			x			x	
Task 6							x		x	
Task 7			x			x		x		x
Task 8	x	x			x			x		
Task 9	x	x		x			x	x		
Task 10					x	x	x		x	

Fig. 5. Breakdown of tasks into human cognitive processing activity requirements. We describe the breakdown of Task 3 into the required cognitive processing activities in the text.

map type visualizations will be the most widely preferred type of visualization. For those activities and tasks where map visualizations were favored, we explored the relationship between map encoding schemes and processing activities and user tasks. We also looked at processing activities and user tasks where map based visualizations were not preferred even though the domain is spatially oriented.

4.1 Cognitive Processing Based Analysis

Previous research [2–4, 6] has shown that effective visualizations allow users to substitute quick perceptual inferences for more difficult logic inferences. Thus the display of information is dependent upon the cognitive processing required by a user's task.

To analyze the data collected during our user study we classified the ten tasks based on the cognitive processing activities required for each task. Consider for example Task 3 from Figure 2, one of the more complex tasks in the study. This multi-step task poses the questions, How much and what types of land are being redeveloped? From what use into what use? Where? First the participants must determine the amount of land and the type of land being developed (quantitative judgments), then they must determine the change in land type over time (determining trends and looking at relations on the land type attribute), and last they need to determine relative locations of redevelopment (spatial determinations). Figure 5 shows the breakdown of all the tasks into their information processing requirements.

Map Based Visualizations Discussions with the participants during and after the tests revealed that location of urban activity is extremely important for urban policy decisions. Figure 6 shows that visualizations with a map base type were preferred for the majority of tasks and processing activities. Because the map layout implicitly encodes important geographic location information and is the common display currently used by experts in urban planning, this was the expected result.

Processing Activity	Spatial	Comparison	Alternatives	Optima	Trends
Preferred Visualizations	2D Color Map Datum Progress 3D Col/Hgt Map 3D Col/Hgt Map 2D Intensity Map	2D Color Map Clustered Bar 3D Col/Hgt Map 3D Col/Hgt Map 2D Intensity Map	Clustered Bar 3D Col/Hgt Map 2D Intensity Map	3D Height Map	2D Color Map Datum Progress 3D Height 3D Col/Hgt Map 2D Marker Map
Favored Base Type	Map	Map	Map	*inconclusive*	Map
Favored Encoding Method	*N/A*	Distinct Color	*inconclusive*	*inconclusive*	Area Height/ Color

Processing Activity	Relations	Aggregation	Qualitative	Quantitative	Description
Preferred Visualizations	Datum Progress 3D Height 3D Col/Hgt Map 2D Intensity Map 2D Marker Map	3D Height Stacked Bar 2D Intensity Map 2D Marker Map	2D Color Map 3D Height 2D Intensity Map 3D Col/Hgt Map 2D Intensity Map	Clustered Bar Datum Progress Contribution Gr. Stacked Bar 2D Marker Map	2D Intensity Contribution Gr.
Favored Base Type	Map	Map	Map	Bar	*inconclusive*
Favored Encoding Method	Color to Area Height	Color	Intensity/ Area Height	Bar Size	*inconclusive*

Fig. 6. The preferred visualizations and the favored base type and encoding methods for each task that requires the corresponding processing activity.

We analyzed the activities where maps were the preferred base type to determine if there was a correlation between cognitive activity and preference for map encoding schemes. We determined that color distinctions and area height are the two most commonly preferred encoding methods for the processing activities. Due to the geographical nature of urban planning, the combination of color to distinguish values and map placement to determine relative locations was considered the most useful encoding for comparison, trend, and qualitative processing activities. The Favorite Encoding Method rows of Figure 6 show the results of this analysis.

There were three processing activities, Alternatives, Optima, and Description, for which there was no clearly preferred encoding method. Two of these also showed no significant base type preference. We attribute the lack of significant results for these three activities to the scarcity of tasks requiring them. Future tests will encompass the entire domain of activities that UrbanSim simulates, thus giving us a broader task base.

2D versus 3D Map Types Whether or not 3D is better than 2D is an open and very controversial question in information visualization. We designed our tests so that we could evaluate the differences between two- and three-dimensional map visualizations for this domain. For our analysis we considered two- and three-dimensional maps as separate visualization types rather than different encodings, because we believe there are fundamental differences in the expressive styles and capacities of two- and three-dimensional map visualizations. However, analysis shows that while there is a slight preference for two-dimensional maps for almost all of the processing activities, tasks that require the same processing activity show no bias to either two- or three-dimensional maps. This was a surprising result and is a further area of study that we plan to pursue.

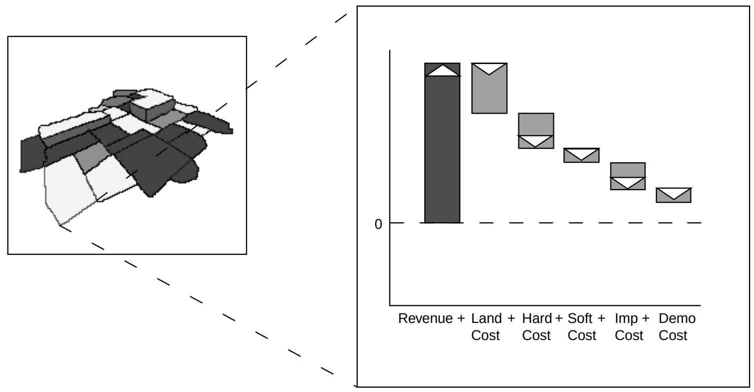


Fig. 7. Example contribution graphic from the user study. The large graphic shows why a particular land parcel was not developed due to the low total expected profit.

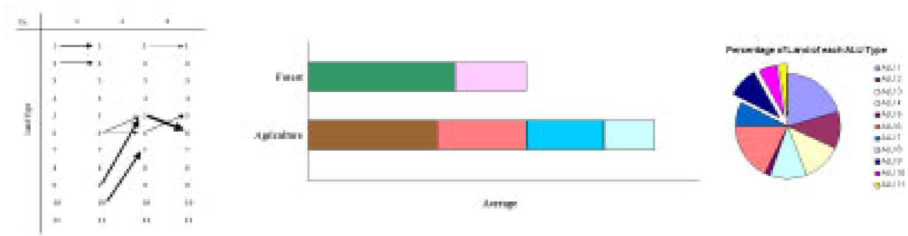
Companion Graphics Participant comments during the user tests revealed that in many cases one all-encompassing graphic is not sufficient. Participants liked the bar charts as companion and summary graphics for making quantity judgments and comparisons between planning attributes. For describing the internal logic of component models within a simulation system, the participants preferred a visualization that presented an overview of the actual process, such as the contribution graphic in Figure 7.

Other Preferred Visualization Types The one processing activity that revealed itself to be better represented by non-map visualizations involved tasks that required them to make quantitative judgments. For quantitative judgments, Figure 6 shows that even when presented with a majority of map type visualizations, participants preferred bar type graphics.

4.2 Task Based Analysis

We also performed an analysis based on the entire tasks rather than on the individual processing activities required by the tasks. The major result of this analysis was that map based visualizations were not considered useful for tasks that included a time dimension. In Tasks 3 and 6, described in Figure 2, users were asked to make judgments about the change in variable values over a time span. The preferred visualization types, shown in Figure 8, were datum progress visualizations, stacked bar graphs, and pie charts.

Initially we attributed a dislike of map based visualizations solely to the presence of quantitative reasoning required by both tasks. As discussed previously, when we broke tasks down into processing activities, we found map based visualizations were not the most preferred visualization type for quantitative processing activities. This alternate analysis based on entire user tasks suggests that it is really the time dimension in Tasks 3 and 6 that cause users to eliminate map based visualizations as a useful information display. To verify this hypothesis we plan to look at tasks that include a time dimension but do not



(a) Datum Progress (b) Stacked Bar Charts (c) Pie Charts

Fig. 8. Favored visualization types for tasks with quantitative processing activities.

require quantitative judgments. For example, we can extend Tasks 8 and 9 to include a time component and retest to see if users no longer prefer map based visualizations.

5 Conclusions

We found that for urban planning and analysis, map type visualizations provide the geographical information that plays a critical role in analysis of systems like UrbanSim. At the same time, we learned that for quantitative tasks bar charts and summaries better present the needed information. Of the encoding methods, analysts tended to like color and size encoding schemes.

User testing showed that there is great variance in which visualizations users consider effective. However, while there may not be one perfect way to design useful visualizations, we learned from this study that there are certain characteristics of visualization types that appear to be better for presenting the information necessary to help solve different types of tasks. This suggests that the visualization chooser can and should automatically present users with useful default visualizations based on their tasks. Our strategy is to provide a configurable but directed visualization system that integrates and facilitates the display of simulation information using many different types and styles of visualizations.

6 Future Work

There remain several problems for future research. Currently, UrbanView does not automatically choose visualization presentations; rather, the user specifies the visualization type and encoding methods and data to be viewed. Our research goal is the automatic generation of default visualizations. We hope to create a user interface where users indicate their task to the system and then are presented with default graphics.

Additional user studies include further investigation of the classification of user tasks by cognitive processing activities, increasing the variety of visualizations included in user studies, and expanding the domains of study beyond the visualization of the urban planning domain. We will also be performing user studies to determine the applicability of our exploratory results in static visualization to interactive model visualizations.

Finally, the focus of this paper has been the identification of useful visualizations for aiding urban planning professionals; but in the longer term we also want to aid citizens' groups and elected officials in understanding the component models and their outputs, thus opening the traditional black-box model to support informed civic deliberation and debate on issues of land use, growth, sprawl, and transportation choices [1].

7 Acknowledgments

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