Multilevel Interaction Model For Hierarchical Tasks In Information Visualization

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ABSTRACT
Infovis (Information visualization) task taxonomy plays an essential role in guiding Infovis design and implementation. Infovis users with various roles in Infovis usually have different requirements for Infovis task modeling. Actually, Infovis research need a consistent taxonomy covering the tasks at different levels, or an interaction model that can facilitate Infovis system development with formal descriptions. But in fact, finding such a unified model is challenging. In this paper we propose a multilevel interaction model (MIM) for hierarchical tasks in Infovis systems. In MIM we define goal model, behavior model, and operation model that can model multilevel tasks in Infovis. In addition, we establish mapping models among MIM components, which can support Infovis systems design, development, application, and evaluation. Finally, we present a domain-specific Infovis application modeled by MIM. Application examples shows that MIM can effectively model multilevel tasks in Infovis and has potential to provide a framework enabling rapid prototyping of Infovis systems.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces - Graphical user interfaces (GUI).

General Terms
Design, Experimentation, Human Factors.

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Keywords
Information Visualization, Task Taxonomy, Human-Computer Interaction, Interaction Model, Visual Analytics

1. INTRODUCTION
Information visualization (Infovis) leverages interactive visual representations to enhance human cognition on large volume of information [1]. Infovis systems have become essential tools that can support getting insights intuitively in various domains such as complex social networks, business intelligence, and military command systems. The design and implementation of domain-specific Infovis systems usually relies on the guidance of Infovis task taxonomies. A clear Infovis task taxonomy, e.g., shneiderman's taxonomy [2], can specify the behaviors a user may perform in an infovis system and, hence, lay the foundation for the system design, development, application, and evaluation.

However, various users with different roles in a life circle of an Infovis system usually have different requirements for Infovis task taxonomies. From an end-user point of view, Infovis tasks mean the end-user's particular requirements in his specific field. This kind of tasks, e.g., market development trend analysis, often represent an end-user's high-level intentions that are usually abstract and vague. From the perspective of an Infovis system designer, Infovis tasks refer to interaction behaviors a user may perform to support the process of analytics. The purpose of interaction tasks design is to provide a set of Infovis actions (e.g., overview, zoom, and filter) for end-users to utilize them to realized their analytic goals. These low-level actions can adopted and combined by users flexibly. From the angle of an Infovis software developer, Infovis tasks are system operations implementing the dialogs in the process of Human-Computer Interaction (HCI) [3]. These system-level tasks (e.g., click and drag) are related to the control artifacts and the visual representations on an interface. The components of Infovis tasks at this level eventually consist of an Infovis software system. In addition, a researcher of Infovis application usability study need the tasks definitions at all different levels above, guiding the design and implementation of evaluation experiments.

Actually, Infovis research is always associated with the multilevel tasks mentioned above as a novel visualization is created, designed, implemented, and applied to solve a problem in a given domain. An Infovis researcher need a consistent taxonomy covering the hierarchical tasks at different levels, as well as an interaction model that can facilitate Infovis system development with formal descriptions.

But in fact, it seems challenging to find a unified model that can describe the multilevel tasks in Infovis. Most of current research related to Infovis task taxonomy focus only on one level. For example, [4] and [5] presented low-level analytic tasks in Infovis, while [6] and [7] discussed system-level operational tasks. These taxonomies are certainly useful for some Infovis systems, e.g., graph visualization design [8], but they still lack comprehensive guidance for a life circle of Infovis systems.

To address this issue, we present a multilevel interaction model (MIM) for hierarchical tasks in Infovis systems. In MIM we define end-user's goals, behaviors, and operations that describe multilevel tasks in Infovis. In addition, we establish mapping models among the task elements, which can support Infovis systems design, development, application, and evaluation. To evaluate the modeling ability of MIM, we use MIM to model a domain-specific Infovis application. Application examples show the effectiveness of MIM.

2. TAXONOMY OF TASK AND INTERACTION IN INFOVIS

It seems quite necessary to review the taxonomies of task and interaction techniques in Infovis. Shneiderman [2] proposed the first Infovis task taxonomy, that is, overview, zoom, filter, details-on-demand, relate, history, and extract. After that, many researchers presented a variety of Infovis task taxonomies for different purposes.

Some research related to task taxonomies discussed the high-level goals of users in Infovis. Card *et al*. [9] presented a sensemaking circle model that depicts the various phases of the sensemaking process, mainly consisting of forage for data, search for schema, instantiate schema, problem-solve, and author, decide, or act. Liu and Stasko [10] discussed mental models, visual reasoning and interaction in information visualization from a top-down perspective. They viewed reasoning as mental model construction and simulation, and considered interaction has three functions, i.e., external anchoring, information foraging, and cognitive offloading. North *et al*. [11] studied user's reasoning process, i.e., analytic provenance, through the interactions in Infovis. They proposed five interrelated stages of analytic provenance, that is, perceive, capture, encode, recover, and reuse. Pike *et al*. [12] discussed the interaction science in Infovis, and presented analytic discourse involving high-level user goals such as explore, analyze, browse, assimilate, triage, assess, understand, and compare. These research tried to uncover human cognition activities and mechanisms in the process of information visualization.

Another group of research fruits of task taxonomies focused on user behaviors or actions in the process of information visualization. The famous Shneiderman's mantra [2] can be viewed as the beginning. Keim [13] proposed a classification of interaction tasks, including interactive projection, interactive filtering, interactive zooming, interactive distortion, and interactive linking and brushing. Amar *et al*. [14] presented the low-level components of analytic activities in information visualization, i.e., retrieve value, filter, computer derived value, find extremum, sort, determine range, characterize distribution, find anomalies, cluster, and correlate. Wilkinson [15] viewed the interaction tasks as filtering, navigating, manipulating, brushing and linking, animating, rotating, and transforming. Yi *et al*. [5] indicated the importance of interaction in Infovis, and proposed seven general categories of interaction techniques widely used in Infovis, i.e., select, explore, reconfigure, encode, abstract or elaborate, filter, and connect. These taxonomies aims at defining a classification of low-level activities broadly adopted in Infovis, especially as a user interacts with the visual representations on the screen.

To realize the high-level goals and low-level behaviors, some Infovis researchers put emphasis on software system-level interaction taxonomy. Chuah and Roth [17] proposed a hierarchical framework for classifying visualization interactions, mainly involving three categories: graphical operations, set operations, and data operations. Ward and Yang [6] identified a list of spaces within which interactive operations can occur in information visualization. It's composed of interaction operators, interaction operands and spaces, and interaction parameters. Heer and Agrawala [16] discussed software frameworks that can simplify Infovis system development, and presented a package of software design patterns frequently used in Infovis in the form of class diagrams. The research work above mainly focuses on defining the software system operations in Infovis, facilitating the development of Infovis application systems.

Table 1. Taxonomy of task and interaction in Infovis

Perspective	Publications	Taxonomy
High-level goals, user intent-centric	Card *et al*. [9]	Forage for data, search for schema, instantiate schema, problem-solve, and author, decide, or act
	Liu and Stasko [10]	Mental model construction and simulation. External anchoring, information foraging, and cognitive offloading
	North *et al*. [11]	Perceive, capture, encode, recover, and reuse
	Pike *et al*. [12]	Explore, analyze, browse, assimilate, triage, assess, understand, and compare
Low-level activities, user behavior-centric	Shneiderman [2]	Overview, zoom, filter, details-on-demand, relate, history, and extract
	Keim [13]	Interactive projection, interactive filtering, interactive zooming, interactive distortion, and interactive linking and brushing
	Amar *et al*. [14]	Retrieve value, filter, computer derived value, find extremum, sort, determine range, characterize distribution, find anomalies, cluster, and correlate
	Wilkinson [15]	Filtering, navigating, manipulating, brushing and linking, animating, rotating, and

		transforming
	Yi *et al*. [5]	Select, explore, reconfigure, encode, abstract or elaborate, filter, and connect
System-level, software operation-centric	Chuah and Roth [17]	Graphical operations, set operations, and data operations
	Ward and Yang [6]	Interaction operators, interaction operands and spaces, and interaction parameters
	Heer and Agrawala [16]	A package of software design patterns frequently used in Infovis in the form of class diagrams

3. MIM: MULTILEVEL INTERACTION MODEL IN INFOVIS

3.1 MIM Structure

Figure 1 shows the structure of multilevel interaction model (MIM) in Infovis. MIM covers three levels of the Infovis task requirements, that is, high-level, low-level, and system-level tasks. Three main subsidiary models, goal model, behavior model, and operation model, compose a MIM.

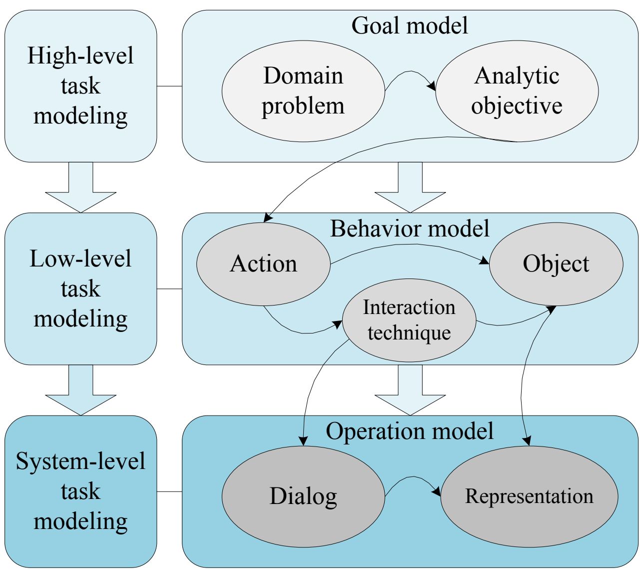


Figure 1. Multilevel interaction model in Infovis.

The goal model is used to describe user's analytic requirements in a given domain. Generally, the analytic demands are relevant to the specific domain problems. So the domain problems should be described before the analytic objectives are specified.

Formally, we define a goal model as follows.

GM = < *DomainProblem*, *AnalyticObjective* >, where *DomainProblem* is the description of a given domain problem, and *AnalyticObjective* is an analytic objective an end-user intends to achieve by using Infovis.

The behavior model defines interaction actions that might be used by users to assist their analytic process. Typically, these actions may have corresponding interaction techniques. Hence these techniques also need be pointed out in this model. In addition, each interaction action, or technique, need bind the action with some objects whether data objects or visual objects. Therefore, interaction actions, techniques, and objects compose the behavior model.

Formally, a behavior model *BM* = < *InteractionAction*, *InteractionTech*, *InteractionObj* >, where *InteractionAction* is an interaction action, *InteractionTech* is an interaction technique in Infovis, and *InteractionObj* is an interactive object.

The operation model is responsible for specifying system-level interaction components of Infovis software. This model depicts the dialogs between a user and the Infovis system. A dialog involves the messages sent by use's actions, the system events caused by the messages, and the system feedbacks triggered by the events. Visual representations play a role of intermediary carrier in the circle of a dialog, so the operation model need specify the representations related to each dialog.

Formally, a operation model *OM* = < *Dialog*, *VisualRepresentation* >, where *Dialog* is a dialog in an interaction circle, and *VisualRepresentation* is an visual representation in the dialog.

3.2 Mappings In MIM

The elements in each subsidiary model of MIM are interrelated, and the relationships can be specified by defining internal mappings.

In goal model, we define the mapping from *DomainProblem* to *AnalyticObjective* as *D-A-Mapping* = < *DomainProblemID*, *AnalyticObjectiveSet* > where *DomainProblemID* is the identification of a *DomainProblem*, and *AnalyticObjectiveSet* is a set of *AnalyticObjectives*.

In behavior model, we define the mapping from *InteractionAction* to *InteractionObj* as *A-O-Mapping* = < *InteractionActionID*, *InteractionObjSet* > where *InteractionActionID* is the identification of an *InteractionAction*, and *InteractionObjSet* is a set of *InteractionObj*. The mapping from *InteractionAction* to *InteractionTech* is defined as *A-T-Mapping* = < *InteractionActionID*, *InteractionTechID* > where *InteractionActionID* is the identification of an *InteractionAction*, and *InteractionTechID* is the identification of an *InteractionTech*. The mapping from *InteractionTech* to *InteractionObj* is defined as *T-O-Mapping* =< *InteractionTechID*, *InteractionObjSet* > where *InteractionTechID* is the identification of a *InteractionTech*, and *InteractionObjSet* is a set of *InteractionObjs*.

In operation model, we define the mapping from *Dialog* to *VisualRepresentation* as *D-R-Mapping* = < *DialogID*, *VisualRepresentationSet* > where *DialogID* is the identification of a *Dialog*, and *VisualRepresentationSet* is a set of *VisualRepresentations*.

The relationships among multiple levels of MIM can be described by modeling top-down mappings.

The mapping from *GM* to *BM* is defined as *Goal-Behav-Mapping* = < *AnalyticObjectiveID*, *InteractionActionSet* > where *AnalyticObjectiveID* is the identification of an *AnalyticObjective*.

The mapping from *BM* to *OM* is defined as *Behav-Operation-Mapping* = < *T-D-Mapping*, *O-R-Mapping* > where *T-D-Mapping* is the mapping from *InteractionTech* to *Dialog*, and *O-R-Mapping* is the mapping from *InteractionObj* to *VisualRepresentation*. *T-D-Mapping* = < *InteractionTechID*, *DialogID* > where *InteractionTechID* is the identification of an *InteractionTech* and

DialogID is the identification of a *Dialog*. *O-R-Mapping* = < *InteractionObjID*, *VisualRepresentationID* > where *InteractionObjID* is the identification of an *InteractionObj* and *VisualRepresentationID* is the identification of a *VisualRepresentation*.

Through modeling the mappings above, the bindings within MIM can be established to describe the relationships among multilevel tasks of an Infovis system.

4. APPLICATION EXAMPLE

In this section we present a simple application example that uses MIM to construct the model of an Infovis system.

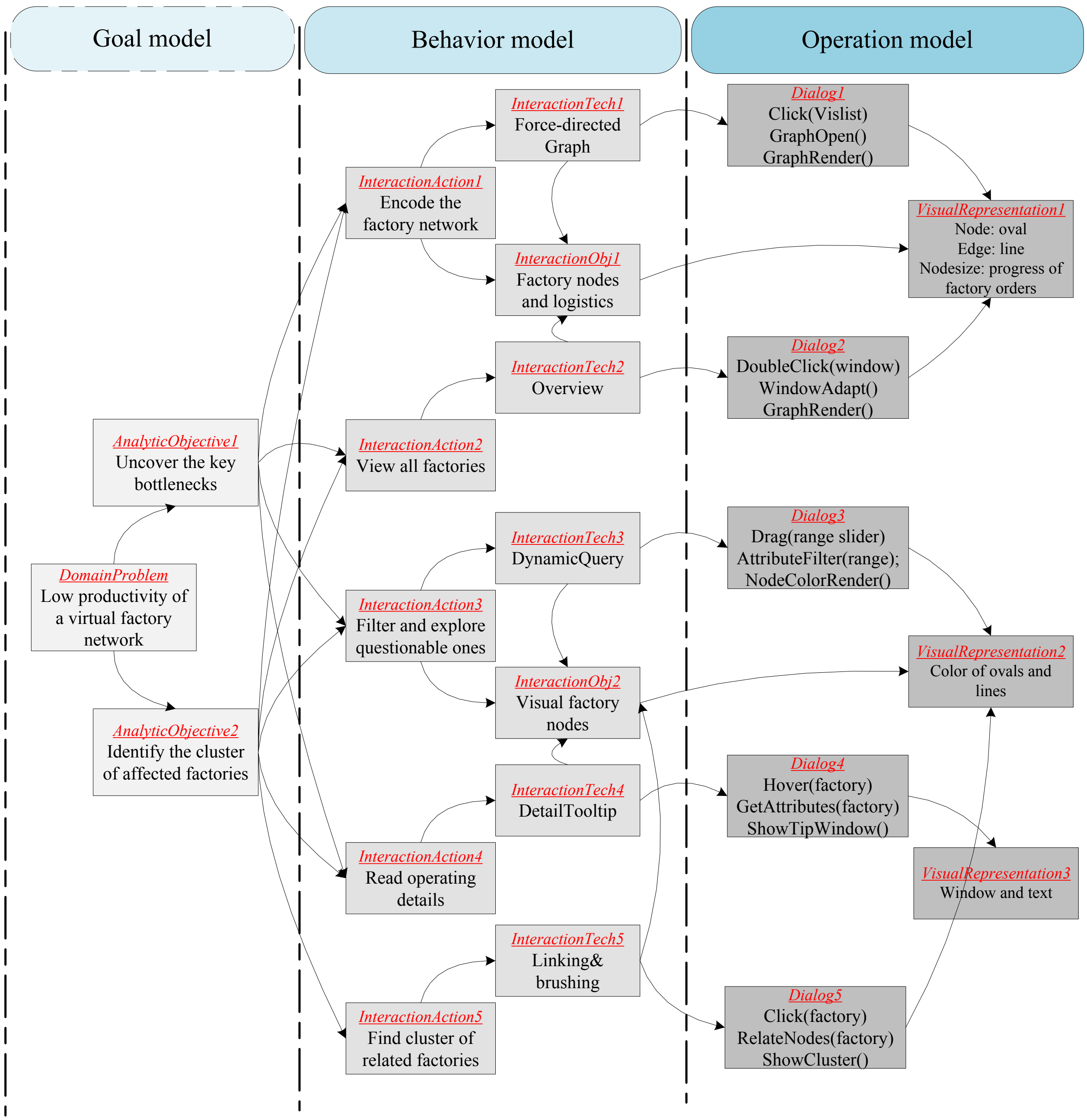


Figure 2. An Infovis application example modeled by MIM.

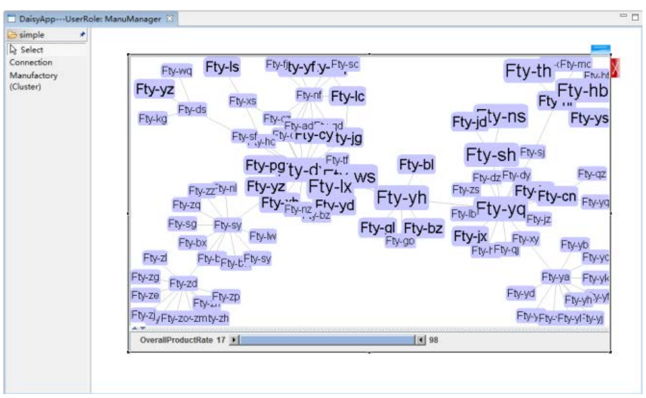
Figure 2 illustrates the model definitions as well as mappings of MIM in the Infovis application. The end-user's requirement is to analyze why the productivity of a virtual factory network is lower than expected. This is the domain-specific problem, which is further decomposed into two analytic objectives. One is to uncover the key bottlenecks, and the other is to identify the cluster of affected factories.

To support analytic process of the objectives, five low-level tasks are provided for users: encode the factory network, view all factories, filter and explore questionable ones, read operating details, and find cluster of related factories. These actions adopt various Infovis interaction techniques such as force-directed graph [17], overview, dynamic query, detail tooltip, linking and brushing.

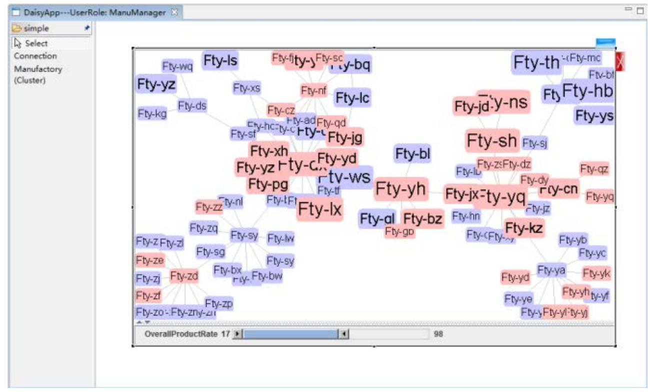
To realize the low-level tasks, the related dialogs and visual representations are defined accordingly. The input messages mainly are conveyed by mouse events, such as click, double click, or drag. The system feedbacks are specified in the form of some functions with parameters. The visual representations employ ovals and lines, as well as different sizes and colors, to represent factories and logistics.

Figure 3 shows some screenshots of the corresponding Infovis system modeled by MIM above. Figure (a) shows the force-directed graph of the factory network as the end-user performs *InteractionAction1* encoding and *InteractionAction2* overview. Figure (b) depicts *InteractionAction3,* that is, the end-user is exploring some bottleneck factories by using the dynamic query slider. In Figure (c), as leveraging *InteractionAction4* and *InteractionAction5*, the end-user is reading the operating details of questionable ones, and the factory cluster affected by the key bottlenecks are also highlighted in yellow color.

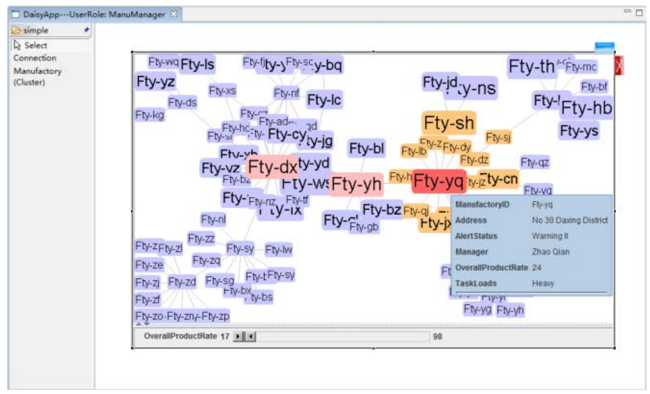
From this application example we can see that the multilevel tasks of an Infovis system, as well as their semantic relationships, can be effectively modeled by using MIM. In addition, it can be easily seen that the mapping correlations between the model (Figure 2) and the Infovis system (Figure 3) are quite clear, so that MIM has potential to provide a framework enabling automatic generation of Infovis systems.



(a) *InteractionAction1* encoding and *InteractionAction2* overview



(b) *InteractionAction3* filter and explore



(c) *InteractionAction4* read details and *InteractionAction5* find cluster

Figure 3. The Infovis system modeled by MIM.

5. CONCLUSION

Infovis task taxonomy plays an essential role in guiding Infovis design and implementation. Different users of different phases in a life circle of Infovis have diverse requirements for task models. Current Infovis task taxonomies lack a unified model that enables modeling tasks at high-level, low-level, and system-level. In this paper we review the taxonomies of task and interaction in Infovis, and propose MIM, a multilevel interaction model for hierarchical tasks in Infovis systems. We define MIM subsidiary models, goal model, behavior model, and operation model. In addition, we establish the mapping models among the components in MIM. To show the modeling capability of MIM, we leverage MIM to model a domain-specific Infovis application. Application examples shows that MIM can effectively model multilevel tasks in Infovis, and it might be extended to a unified framework supporting rapid prototyping in visual analytics. This is also in our plan of future research work.

6. ACKNOWLEDGMENTS

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