# Visual Abstractions and Interaction Metaphors for Knowledge Assisted Volume Visualization


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## 1 SEMANTICS AS KNOWLEDGE DESCRIPTORS

The term knowledge assisted visualization specifies systems that explicitly integrate domain knowledge to control visualization settings. The knowledge is given either by users or by simulated cognitive processes (e.g., neural networks) [3]. Assisted knowledge is related to the data and to the domain or even focused on a specific procedure which the visualization is part of. The information and knowledge is represented by data and domain semantics. Semantics closer to raw data are low-level semantics. Abstracting from the raw data towards notions of the domain leads to higher-level semantics. Our basic categorization of different levels of semantics and the corresponding approaches to achieve them is illustrated in Figure 1.

The visualization pipeline usually starts with data acquisition. Conceptually the *raw data* has no additional information available apart from the measured or simulated values. A typical representative in volume visualization is the scalar volumetric data obtained from computed tomography (CT), where each voxel defines a tissue density value. This represents the lowest abstraction level, where no semantics are present.
The CT density values reflect the absorption of X-ray radiation. Setting up a simple threshold allows to roughly differentiate between soft and hard tissue. To define gradient or curvature information various image processing filters for smoothing and noise-reduction or other local operators can be applied. If another scan from the same spatial region is available from a different modality the data sets can be related using registration. All these enhancements give a little more insights about the underlying raw data. We refer to these data-near semantics as *markups*. As low-level semantics, data markups are not bound to any specific application domain.

On the next level domain specific semantics are introduced. Acoustic echo measurements are a powerful exploration technique for seismic exploration as well as in the medical domain. Performing filtering and shape analysis on two acoustic echo data sets (from different domains) results in the same markups. However, for each domain these markups have a distinct meaning. Markups in the seismic domain identify geologic layers and faults, whereas in the medical domain the same markups identify vascular structures or organ boundaries. Faults, seismic layers, organs, or vessels are all domain-specific *objects* and define higher-level semantics. Objects, unlike markups are elements bound to a domain and their names are coined terms in the respective domain. Object semantics can be derived with model- or atlas-based segmentation methods, or they are defined through a combination of markups that identify unique object in a given domain.

Despite the fact that raw data does not contain any semantic information, the data acquisition is motivated by a specific need of the respective domain. Medical imaging is carried out to perform diagnosis or to identify the best treatment method. Each procedure looks for specific features and for relations to other features. For example, when planning tumor removal from the neck, the muscle also has to be dissected if the tumor tissue or metastatic lymph nodes are too close to a muscle. Vascular structures, however, must not be dissected. From such procedure descriptions, information about the importance of features from a neck CT scan is extracted. A *degree of interest* (DOI) describes the relevance of objects, markups, or raw data.

The DOI function, as a high-level semantics, can be defined as abstractions of particular domain procedures and gives information about structures the analyst wants to investigate in order to draw conclusions. *Findings* are the outcome or the gained knowledge of the visual analysis procedure. For the aims of the new knowledge dissemination, findings are seen as the highest semantic level that assists visual communication.


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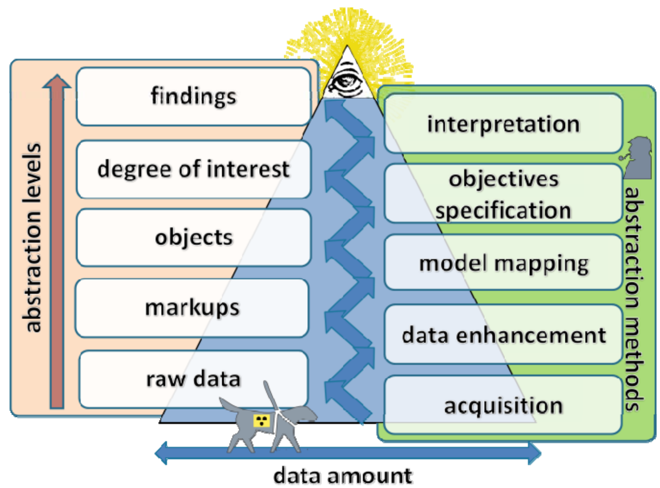


Figure 1. From data to findings via different levels of abstraction and abstraction methods.

## 2 VISUALIZATION AND INTERACTION CATEGORIZATION

Abstractions enrich the underlying raw data and allow for broader set of data visualizations and interaction methods. Based on the described semantics we categorize visualization and interaction techniques for each level and provide examples to each category (see Figure 2).

On the bottom of Figure 2 common visualization scenarios (i.e., exploration, analysis, and dissemination) are shown. In the exploration phase the user examines the raw data without any further information. The visualization system offers basic visual abstractions such as maximum intensity projection (MIP), or slicing. The user interaction in this stage is limited to simple metaphors like camera manipulations and slice placement. In the exploration phase the user typically aims at gaining knowledge about the data range and features that are present in the data, but is not interested in details about the features. Transfer functions are a common interaction tool allowing the highlighting of a specific data range. Direct volume rendering is commonly used to visualize data markups such as those defined through transfer functions. Another more recent approach for visual abstractions in the exploration phase is opacity peeling [7], for example. With opacity peeling the dataset is split into view-aligned layers. Layers are peeled away when they reach full opacity during raycasting. The result is a set of multiple images that show the individual layers.

Once the structures of interest in the dataset are identified the user gradually moves from pure exploration towards analysis. In the exploration phase the user generates hypotheses and tries to validate or reject them in the analysis phase. The exploration and analysis phase are usually iterated until the user is satisfied with the results. Transfer functions (also in higher dimensions) [4] play an important role in this phase since they are flexible enough to reveal details of the features of interest. Objects are more clearly identified and names and specific properties are assigned to them. The objects and the properties are very much domain dependent. Typically at this stage domain semantics are introduced to describe the properties that are of interest for certain objects. For example in the case of coronary artery examination the properties of the arteries and of their surrounding tissue need to be modeled. Another example is the exact localization of a tumor and its spatial relation to structures at risk. Further the quantification of object properties such as volume, surface area, etc. are analyzed in this

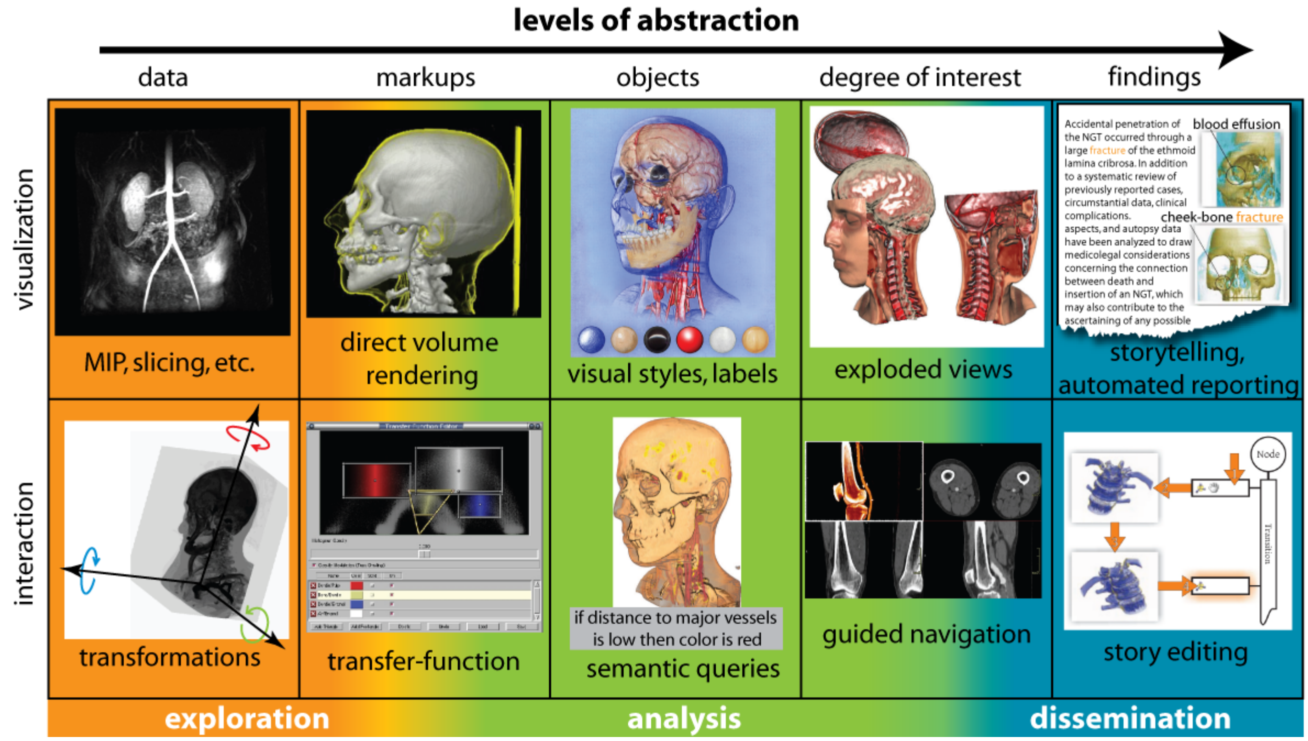


Figure 2. Examples of visualization methods and interaction metaphors for increasing levels of abstraction. At the bottom the phases of exploration, analysis and dissemination are shown in relation to the levels of abstraction.

phase. With the identification and quantification of objects and their properties as well as with the introduction of domain semantics, more expressive visual abstractions and more elaborate interaction metaphors are possible.

Domain specific terms are used to identify structures and to name the characteristics of the particular objects that are represented by the data. Examples for visual abstractions that make use of domain specific terms are labels and illustrative styles [1]. Labels are placed close to or directly on the identified structures. Visual styles that are designed by illustrators for specific classes of objects (e.g., bone style) can be applied to the respective objects. Interactions metaphors that are used with this level of abstraction include property based highlighting. The user specifies a range of property values that are of interest for the current use case. The areas of interest are highlighted and guide the user attention to regions that might be of interest and need further analysis. Semantic querying is an example where domain specific properties are used [6]. Figure 2 shows an example where low distances to the major vessels are queried and are colored in red as a result. The major vessels are objects that are defined according to the domain knowledge and also “low distance” has a meaning that is only valid in this domain. Semantic queries can be used to analyze certain properties and can also be used to define specific domain questions.

To find adequate representations for the objects and their relations, the user needs to define her goals. A visualization system that models the user intent can derive a degree of interest function for objects and their relations. Visual abstractions that make use of information concerning the user intent can be found in traditional illustration. Cutaways, ghosting, exploded views and other focus+context techniques incorporate the information about degree of interest for specific objects. Typically these techniques are not limited to only reflect spatial relations but can also unveil occluded objects of higher importance. Ghosting simply modulates the opacity of objects that occlude objects that are more interesting for a given user intent. Cutaways are used to cut open structures in an intuitive way and to remove parts that are of less interest. Exploded views [2] break objects apart and reposition the parts to show inner structures and the spatial relations between them. This is especially meaningful for understanding how structures fit into each other. Guided navigation is an example of high-level interaction metaphor making use of an explicit degree of interest specification by the user. In Figure 2 an example of the LiveSync system [5] is shown. The user interacts with the 2D slices and specifies a high degree of interest to structures under examination. The system automatically generates a corresponding 3D view that shows the structure of interest taking the orientation of the structure as well as user preferences into account.

Although, dissemination is typically done using results already acquired in the exploration and analysis phase, it is often necessary to prepare additional material to communicate interesting findings to audience lacking domain expertise. Findings are often documented with reports containing text and imagery. A textual report is a very abstract representation of the underlying data. A visualization system can be used to relate text and imagery and to allow editing of stories that describe the examined case. Story telling is used to describe findings and make the process of abstraction and knowledge gain more comprehensible [8]. Interaction metaphors like links between text and the renderings are commonly used for student education. The renderings are not only images but allow interaction methods of prior stages like simple transformations or changes of domain specific properties and degree of interest definitions.

## 3 Conclusion

This article has proposed a separation of semantics into different levels of abstraction and a basic categorization of visualization and interaction techniques according to these semantic levels. Low, data-near semantics allow direct data visualization and explicit interaction suitable especially for data exploration. Higher, domain-near semantics are useful for visual overload reduction and communication of the acquired findings from the visual analysis procedure.

## 4 References


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