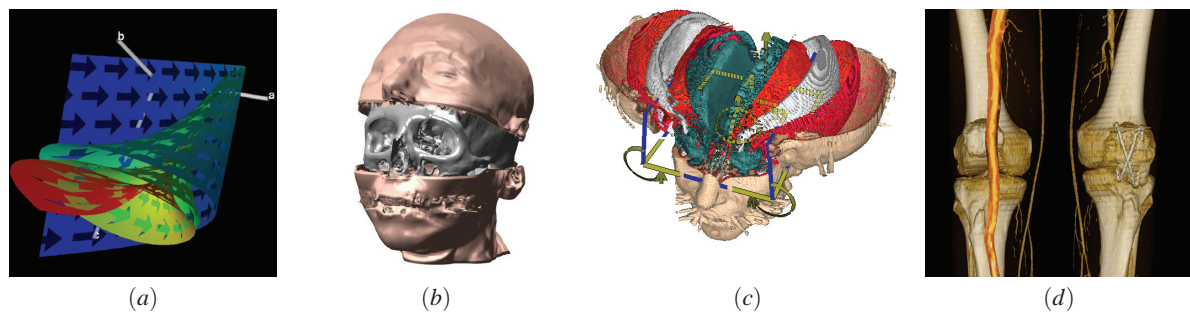


# Smart Visibility in Visualization

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**Figure 1:** Examples of smart visibility visualizations: cut-away view of a complex dynamical system [LMG97] (a), volumetric splitting [IDSC04] (b), feature browsing by leaflet deformation [MTB03] (c), and cut-away view of peripheral arteries [SvC\*04] (d).

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## Abstract

*In this paper we discuss expressive visualization techniques that smartly uncover the most important information in order to maximize the visual information in the resulting images. This is achieved through dynamic changes in visual representations, through deformations, or through spatial modifications of parts of the data. Such techniques originate from technical illustration and are called cut-away views, ghosted views, and exploded views. These illustrative techniques unveil the most important visual information by employing high levels of abstraction. The change in visual representation or spatial position is done easily perceivable and the overall visual harmony is preserved.*

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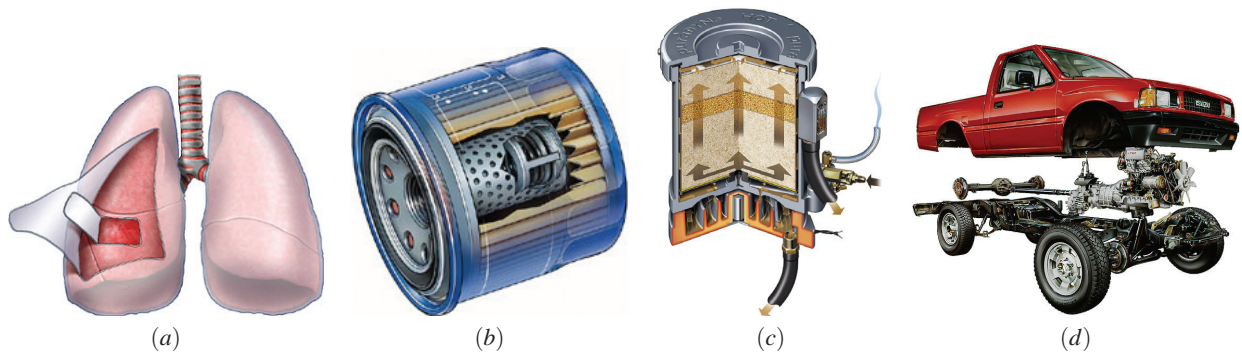
## 1. Introduction

Illustration has always been an important visual communication medium for humans. The origin of illustration can be found in the Paleolithic period (30000 B.C. to 10000 B.C.) The cave paintings from this period display mostly large wild animals and tracings of human hands. Drawings of humans are rare and are usually schematic rather than the more naturalistic drawings of animals.

Hieroglyphs as the visual language developed in ancient Egypt (3200 B.C. to 30 B.C.), depicted religious, political, and daily life. The line is the most important element

in Egyptian paintings. All visual elements are delimited by black lines. It is generally accepted that Egyptians did not use perspective. They just used hierarchic perspective in their early profile drawings. Through overlapping they tried to convey the idea of depth. Some scenes with sets of overlapping people depict workers involved in the seeding of the fields.

Like the drawings of the ancient Egyptians, the architectural drawings of the early Greeks (1100 B.C. to 100 B.C.) also lacked perspective. To imitate this kind of art in architecture, the ancient Greek architects even designed their buildings to visually counterbalance the viewer's in-



**Figure 2:** Different types of hand crafted expressive illustrations: cut-away view (a), ghosted view (b), section view (c), and exploded view (d). Technical illustrations are courtesy of Kevin Hulsey Illustration, Inc [Hul05].

tuitive understanding of perspective. A typical example is the Parthenon in Athens, which was situated at the top of the Acropolis compound. The Parthenon could only be approached from one access point. The rear of the structure is bigger and wider than the front, and the side columns increase in mass from front to rear. This construction technique gave the Parthenon an appearance through which it approximated the flat or axonometric views the Greeks were used to see in their art.

The principle of perspective was defined in the year 1000 A.D. by the Arabian mathematician and philosopher Al-hazen [Oma77]. He explained in his work that light projects conically into the eye. A method for perspectively projecting a scene onto an image was developed approximately 300 years later during the Renaissance period. In this period the beginning of descriptive technical illustrations took place through the work of artists such as Leonardo da Vinci (1452-1519). In da Vinci's personality artistic abilities were combined with a scientific mind, which enabled a merging of visual art with invention. The creation of spatial illusions was another major achievement of this period. The evolution of what is called illusionistic perspective happened at that time.

The flourishing of technical illustrations was a direct result of the industrial revolution. Mass production and outsourcing created the need to adopt conventions and standards in technical illustrations that were universally understood. By the mid 1900s both artistic and technical illustrators had a predictable methodology available for illustrating objects and environments more realistically. Illustrative techniques are often designed in a way that even a person with no technical understanding clearly understands the piece of art. The use of varying line widths to emphasize mass, proximity, and scale helped to make a simple line drawing more understandable to the lay person. Cross hatching, stippling, and other low abstraction techniques gave greater depth and dimension to the subject matter. Technical illustrations were further ad-

vanced during the photorealistic art movement around 1960. Photorealists were often working with photographic slide projections onto canvases. The style is very accurate, with an emphasis on details and it often simulates glossy effects such as reflections in specular surfaces.

By merging technical illustration and photorealism, the technical illustrator could now convey highly complex technical information to someone with little understanding of mechanics or drafting. To further increase the expressivity of illustrations, high level abstraction techniques such as cut-away views or exploded views have been established.

The aim of illustration is to generate expressive images that effectively convey certain information via the visual channel to the human observer. Additionally, illustrators and visual artists in general create images that follow principles of visual harmony such as color combinations, scene composition, contrast, dynamics or other *aesthetical* aspects. Breaking some of these principles may evoke misunderstanding and confusion. Thus, not only expressivity but also the overall visual harmony and aesthetics play a very important role in illustrations. In the next sections we will address high level abstraction techniques and expressive visualization techniques in more detail.

## 2. Smart Visibility

A typical problem in the visualization of three-dimensional or higher-dimensional data is that the most interesting features are not easily perceivable, because they are occluded by other, less important features. Traditional visualization techniques classify the visual representation of features independently from the viewpoint. The global setting limits viewpoint positions and viewing angles to a range, where the important structures are not occluded by other objects.

An effective way to visualize three-dimensional data and resolve the occlusion of the most prominent information

is to take approaches used in technical and medical illustrations [GMS\*02, Hod03]. Illustration challenges are very similar in these cases. Illustration techniques such as cut-away views, ghosted views, or exploded views effectively uncover the most important information. This is achieved by changing the level of visual abstraction or modifying the spatial arrangement of features. Figure 2 shows examples of expressive illustrations that enable to see interesting structures. Further excellent illustrations featuring expressive techniques can be found on the referenced websites [How05, Hul05].

Illustration techniques such as cut-aways or exploded views are realized in scientific visualization through *Smart Visibility Techniques*. As done in illustrations, Smart Visibility Techniques use high-level abstractions to capitalize on characteristics of the human cognition. Approaches include local modifications of visual representations (e.g., artificial cuts) or changes in spatial arrangements (e.g., deformations) in order to emphasize the most relevant data. We utilize the term Smart Visibility in two meanings:

- Smart Visibility goes beyond simple visibility calculation. Typically visibility is determined due to the light propagation in a scene. Depending on the spatial arrangement of objects with respect to the viewer the light reflected from certain objects might be (partially) prevented from reaching the viewer. Some of the objects are occluded. Smart Visibility considers more than just light propagation. For example also the relevance of the individual objects is taken into account. An important object might shine through an otherwise occluding object closer to the viewer. In this sense the augmented visibility determination can be called "smart".
- Smart Visibility exploits the expertise of the human observer. Let us assume that the viewer already has a pre-knowledge on the shape of an object. In this case part of the shape can be left away to reveal more interesting inner structures. Due to the viewer's prior experience with the object he still can mentally complete the object from the partial information he is shown. A prominent example are cut-aways along symmetry axes of highly symmetrical objects. The viewer can easily perceive the entire object by actually just seeing parts of it. In this sense Smart Visibility makes use of the present mental models in "smart" viewers.

### 3. Cut-Away Views, Section Views, and Ghosted Views

The popularity of cut-away and ghosted views is demonstrated by the fact that they can be found in all books on technical or medical illustrations [GMS\*02, Hod03]. An automatic generation of cut-away and ghosted views for polygonal data was introduced by Feiner and Seligmann [FS92]. They propose a family of algorithms that automatically identify potentially obscuring objects and display them in a ghosted or cut-away view. The proposed algorithms exploit

z-buffer rendering. They are suitable for real-time interaction achieved by hardware acceleration. Interactive semi-transparent views, section views, and cut-away views for polygonal data have been recently revised by Diepstraten et al. [DWE02, DWE03]. Semi-transparent views unveil interesting objects obscured by context information through increasing the transparency of the context. Diepstraten et al. propose to adhere to an effective set of rules for the automatic generation of the discussed illustrative techniques. For semi-transparent illustrative views the following three rules should be taken into consideration:

- faces of transparent objects never shine through
- objects occluded by two transparent objects do not shine through
- transparency falls-off close to the edges of transparent objects

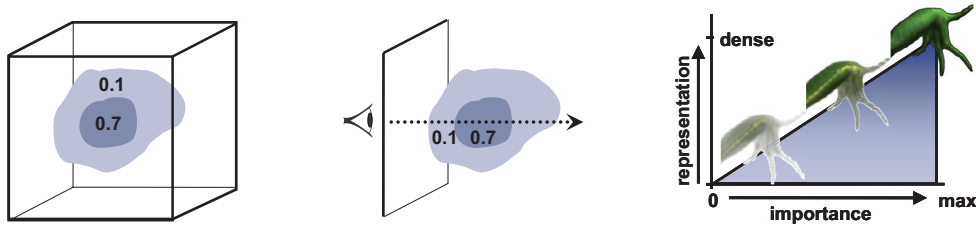
For section views and cut-away views they propose to follow seven other rules:

- inside and outside objects have to be distinguished from each other
- a section view is represented by the intersection of two half spaces
- the cut-out of a section view is aligned to the main axis of the outside object
- an optional jittering mechanism is useful for cut-outs
- a mechanism to make the walls visible is needed
- cut-outs consist of a single hole in the outside object
- interior objects should be visible from any given viewing angle

The mentioned algorithms and rules for cut-away views, section views, and ghosted views have been applied to polygonal data and are generally applicable in computer graphics. For an arbitrary clipping of volumetric data Weiskopf et al. [WEE03] propose a number of effective techniques to increase performance and visual quality. The implementation of clipping operations is mapped to commodity graphics hardware to achieve interactive framerates. Additionally to clipping all rendering computations are performed on the graphics hardware. Per-fragment operations estimate on-the-fly the visibility according to the clipping geometry and adjust the shading in areas where clipping occurs. In the following Sections 3.1 and 3.2 we focus more on visualization related tasks. First we will discuss an approach for automatic cut-away and ghosted views from volumetric data [VKG05]. This technique employs additional information about the importance of a particular feature. Afterwards we will show the potential of such expressive views with a set of applications.

#### 3.1. Importance-Driven Feature Enhancement

Traditionally features within a volume dataset are classified by optical properties like color and opacity. With

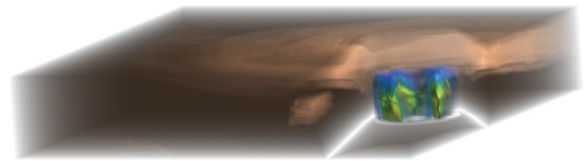


**Figure 3:** Stages in the pipeline of importance-driven volume rendering: Volumetric features are assigned importance values (left image). The volume is traversed (center) in the importance compositing stage to estimate levels of sparseness (right). These levels are used to enhance or suppress particular parts of the volume. The resulting images then emphasize important features.

importance-driven feature enhancement we additionally assign one more dimension to features, which describes their importance. Importance encodes which features are the most interesting ones and have the highest priority to be clearly visible. Prior to the final image synthesis, the visibility of important features is estimated. If less important objects are occluding features that are more interesting, the less important ones are rendered more sparsely, e.g., more transparently. If the same object does not cause any unwanted occlusions in other regions of the image, it is rendered more densely, e.g., opaque, in order to see its features more clearly. This allows to see all interesting structures irrespective if they are interior or not, and the less important parts are still visible as much as possible. Instead of using constant optical characteristics, which are independent from the viewpoint, we use several levels of sparseness for each feature. Levels of sparseness correspond to levels of abstraction. We do not assign a single optical characteristic, but several characteristics with smooth transitions in between. These multiple levels of sparseness allow the object to continuously change its visual appearance from a very dense representation to a very sparse one. Which level of sparseness will be chosen, is dependent on the importance of the particular object and the importance of objects in front and behind. The level of sparseness thus may continuously vary within a single feature. For different viewpoints the same part of a feature may be represented with different levels of sparseness. To determine the sparseness level for each object or parts thereof the rendering pipeline requires an additional step, which we call importance compositing. This step evaluates the occlusion according to the viewpoint settings, takes the importance factor of each feature into account and assigns to each feature a particular level of sparseness. The final synthesis results in images with maximal visual information with respect to the predefined object importance. The interrelationship between object importance, importance compositing, and levels of sparseness is depicted in Figure 3. Importance compositing traverses the whole volume to identify object occlusions and assigns the corresponding level of sparseness to each object. Object importance translates to object visibility in the result image. This causes different rendering settings for the context object (with importance  $0.1$ ) in the area of

the image which is covered by the focus object (importance  $0.7$ ).

Figure 4 shows a cut-away view of the multi-dimensional volumetric data of hurricane Isabel using importance-driven feature enhancement. The important feature was the hurricane eye selected through a cylindrical proxy geometry. Inside the cylinder the total precipitation mixing ratio is visualized. Thanks to the cut-away view it is possible to have a clear view at this property close to the eye of the hurricane. Outside the cylinder is the context area where the total cloud moisture is visualized.



**Figure 4:** Cut-away visualization of a multidimensional volumetric data of hurricane Isabel.

Figure 5 illustrates a ghosted view of the scalar volumetric data of a Leopard gecko. The small internal structure (in yellow) of the Leopard gecko dataset is the most interesting information and has been pre-segmented. The body is considered as context information. In the area of occlusion the visual representation of the gecko body is reduced to contours to have a clear view on the interesting internal organ.

### 3.2. Applications of Expressive Visualizations

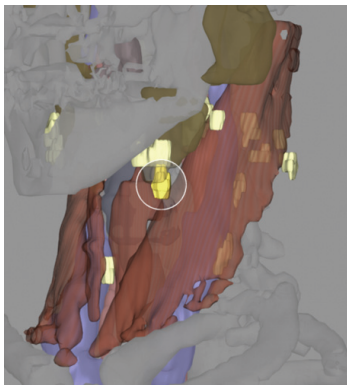
Expressive visualizations inspired by illustration techniques are useful for various visualization tasks. Straka et al. [SvC\*04] are applying a cut-away technique for CT-angiography of peripheral arteries in human legs. The goal is to have a clear view on the vessels, which are partially segmented by their centerline. For a clear understanding of the spatial arrangement it is necessary to visualize also bones and skin contours. To have an unobstructed view on the vessel for each viewpoint it is sometimes necessary to perform



**Figure 5:** Ghosted visualization using contours in a CT scan of a Leopard gecko.

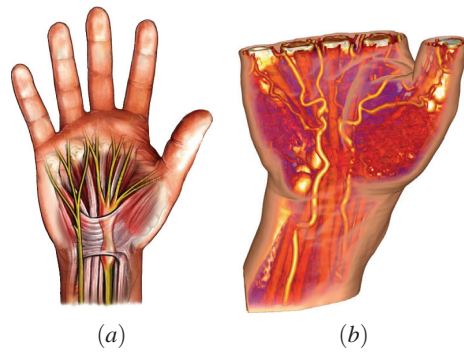
a cut in the bone. To avoid potential misinterpretations, the cut is clearly depicted as an artificial and sharp change in the data. This is illustrated in Figure 1 (d).

Krueger et al. [KTH\*05] incorporate smart visibility to improve the spatial perception of feature arrangement for surgical planning. They present a system for neck dissection planning, where the lymph nodes are emphasized using ghosted views to easily convey their spatial position. Other features such as muscles or bones are suppressed either locally or globally. They are represented in a sparse way to support the understanding of the feature arrangement. The neck dissection planning system is designed for interactive path-planning in minimal invasive interventions. Figure 6 clearly shows all lymph nodes in the neck to enable optimal path planning for the neck dissection.



**Figure 6:** Smart visibility of lymph nodes in the neck. All lymph nodes are clearly visible, the currently analyzed one is additionally emphasized by a circle around it.

An extension to direct volume rendering that focuses on implicitly increasing the visibility of features has been proposed by Bruckner et al. [BGKG05]. This technique is known as illustrative context-preserving volume rendering. The approach maps transparency to the strength of specular highlights. This allows to see *inside* the volume in the areas

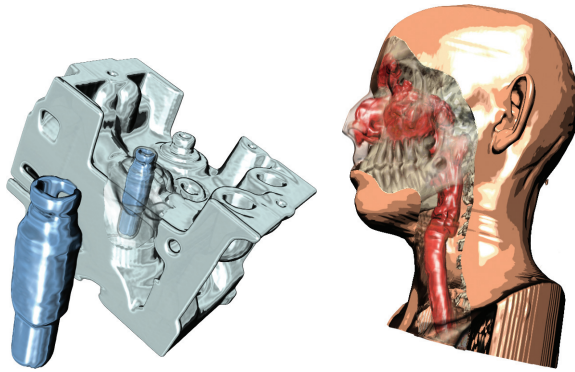


**Figure 7:** Medical illustration of a human hand (a) compared to the visualization of a human hand using a dynamic opacity approach as a function of the specular highlight [BGKG05] (b).

of highlights. The human visual system can easily complete the shape of partially transparent parts and therefore additional information can be shown there. One parameter tunes the ratio between specularity and transparency. A depth parameter determines how far one can look inside a volumetric object (fuzzy clipping). Certain data-value ranges can be excluded from the transparency modulation to allow a clear view on specific (inner) structures. In Figure 7 Their approach is compared to a medical illustration of a human hand.

An interactive tool for cut-away and ghosting visualizations has been recently proposed by Bruckner et al. [BG05]. The tool denoted as VolumeShop is an interactive system which features advanced manipulation techniques and illustrative rendering techniques to generate interactive illustrations directly from volumetric data. The system is using latest-generation texture-mapping hardware to perform interactive rendering applying various kinds of rendering styles. It implements a multi-volume concept to enable individual manipulations of each volume part. The segmentation of the volumetric objects can be done directly via 3D painting. Apart from importance-driven visualization resulting into cut-away and ghosted views, VolumeShop includes a label management to introduce basic descriptions for the visualized data. To focus on a particular feature, it can be moved from its original spatial position. To indicate its original spatial position it is possible to display a *ghost* there, or add additional markers such as *fanning* or arrows. Some ghosted visualizations generated using VolumeShop are shown in Figure 8.

Previous applications of cut-away views are viewpoint-dependent, i.e., the shape and location of the cut is directly dependent on the viewpoint information. Volume cutting is another medical visualization technique that is related to cut-away views, but the cut shape is not influenced by viewpoint settings. Pflesser et al. [PPT\*02] present an interac-



**Figure 8:** Interactive ghosted visualizations of the engine block and human head datasets [BG05].

tive drill-like tool for surgical training, which is based on a multi-volume concept. Owada et al. [ONOI04] extend volume cutting by incorporating two-dimensional textures that are mapped on the cut surface. This enhances the visualization with additional information of the internal arrangement of bones or muscles. Such a concept can be very useful for anatomy education for example. Both volume cutting techniques are illustrated in Figure 9.

Visualization of complex dynamical systems can also be enhanced by applying cuts to stream surfaces. Streamarrows proposed by Löffelmann et al. [LMG97] exploit cutting for enhancing the visual information. They use arrows as a basic element for cutting away part of the stream surface. This allows to see through the surface and perceive other surfaces or structures behind. Animating streamarrows along the stream surface enables to see beyond the front stream surfaces and



**Figure 9:** Volume cutting featuring two-dimensional textures for anatomy education [ONOI04] (left) and volume cutting with a drill-like tool for surgical education [PPT\*02] (right).

perceive the flow direction. Streamarrows belong to the category of view-point independent cut-away techniques and are shown in Figure 1 (a).

#### 4. Exploded Views and Deformations

Exploded views and deformations modify the spatial arrangement of features to uncover the most prominent ones. It is also a very effective way to present assembly instructions. Exploded views enable a clear view on individual features and convey the information about the original spatial location by helpers such as lines or arrows. Agrawala et al. [APH\*03] proposed design principles for creating effective assembly instructions based on exploded views. They additionally present a system for the automatic design of assembly instructions and a system that semi-automatically generates exploded views from two-dimensional images [LAS04]. The rules for assembly instructions are based on cognitive psychology and experiments:

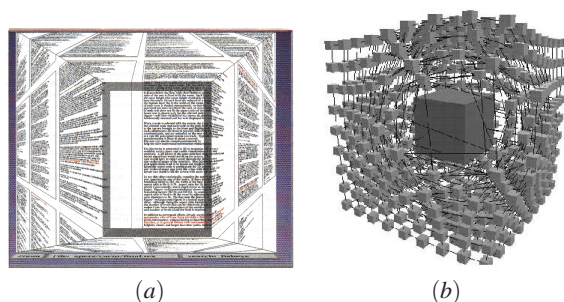
- assembling is decomposed into a hierarchy of operations and parts
- parts in the same hierarchy (e.g., legs of a chair) have to be added at the same time-step, or in sequence one after another
- step-by-step instructions are better understandable than a single diagram showing all the operations
- diagrams presenting the final assembly are necessary to understand the step-by-step action diagrams
- parts added in the current assembly step must be clearly visible
- objects have to be presented in their clearest orientation

Smart-visibility visualizations are using some of the above mentioned rules for other tasks than assembly instructions. In the following visualization approaches are presented that have been inspired by the exploded views concept. They implicitly use some of the rules for assembly instructions.

##### 4.1. Applications of Expressive Visualization

Information visualization is a field where deformations in visual data representation are rather wide spread. Information visualization is often concerned with the display of large, multi-dimensional, abstract data. In this area focus+context techniques are crucial to emphasize the small amount of relevant information among the typically very large overall data with multiple dimensions.

There are a lot of techniques that incorporate a kind of distortion for important feature emphasis. Typical representatives are magic lenses, fish-eye views, or perspective wall displays. These techniques allow to zoom into the data and to discriminate the focus data from the context data. An example of a magic lens applied to a document is shown in Figure 10 (a).



**Figure 10:** Information visualization examples using the smart visibility concept: lens metaphor for easier document browsing [RM93] (a) and viewpoint-dependent distortions of three-dimensional graphs [CCF96] (b).

One technique that relates especially to smart visibility performs viewpoint-dependent distortion of three-dimensional data. This technique highlights data by dedicating more display space to it [CCF96]. Distortions are applied to abstract graphs in order to clearly see interesting graph nodes. All nodes originally occluding the focus node are moved away to uncover the most relevant information as shown in Figure 10 (b). Similar concept has also been recently proposed for exploration of scalar volumetric data [WZMK05].

Volume splitting is a scientific visualization technique that is closely related to exploded views [IDSC04, GBKG04]. This technique is intended for displaying multiple enclosed iso-surfaces within the volumetric data. Each iso-surface, except the innermost one, is split into two parts and moved apart. Such splitting is denoted as logical splitting. Another type is geometrical splitting which moves apart the two halves of the entire volume. Logical splitting is illustrated in Figure 1 (b).

McGuffin et al. [MTB03] propose an elaborate framework with a set of advanced deformations for an understandable visual presentation of complex three-dimensional information. Browsing is investigated as the operation for investigating the interior of a volume. Browsing is realized on pre-segmented data decomposed into several semantic layers (e.g., skin, muscle, skull, brain). The user can cut into and open up, spread apart, or peel away parts of the volume in real time. This makes the interior visible while still retaining surrounding context. Additionally they present a set of interaction techniques based on various metaphors. Interaction techniques are controlled by pop-up menus and three-dimensional widgets. The interaction technique using leafing deformation is shown in Figure 1 (c).

Another interesting visualization technique inspired by exploded views is called fanning in time [GBKG04]. It is a temporal exploded view analogous to temporal exploded

views from illustration or multiple exposure photographs. In photography and digital image processing this technique is known as computer enhanced multiple exposure numerical technique (CEMENT). It is useful for the visualization of time-series with a relatively small number of time-steps. The main goal is to show all time-steps in one image similar to illustrative photographs of for example a skateboarder performing a certain motion sequence. Figure 11 illustrates the idea of fanning in time and the correspondence to illustrative photography.



**Figure 11:** Illustrative photography of a snowboarder performing a jump (top). Photography expressively displays the principle of a particular motion sequence (Image is courtesy of snowboarder Matúš Hubka). Fanning in time (bottom) shows all time steps of a time-varying dataset of a beating heard [GBKG04].

## 5. Conclusions

In this paper we have presented smart visibility visualization techniques inspired by strategies from high level abstraction approaches in traditional illustration. We have shown that many challenging visualization tasks can be solved by adopting existing techniques from visual arts. Computer generated visualization still needs improvement to compete with hand crafted illustrations in terms of expressivity, harmony, or aesthetics. Therefore the aesthetical aspect of scientific visualizations will be an intensively researched area in the scope of illustrative visualization in the future.

A considerable advantage of scientific visualization as compared to traditional illustration is the possibility of real-time interaction and manipulation. The effective combination of expressive visualization techniques with appropriate

interaction tools conveys the information from complex scientific data much better than a static image.

## 6. Acknowledgments

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