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TECHNICAL REPORT

Caricaturistic Visualization

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TR-TR-186-2-06-01
April 2006

Keywords: illustrative visualization, focus+context techniques, volume visualization, volume manipulation and deformation

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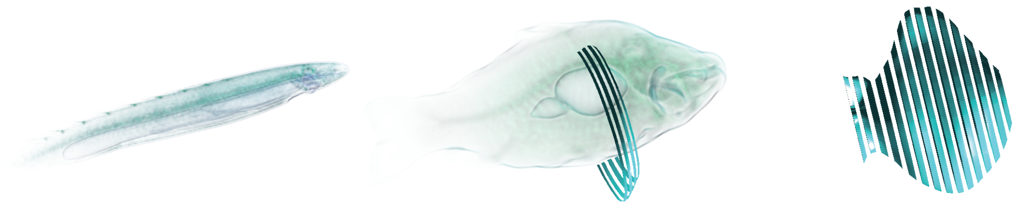

Figure 1: Caricaturistic visualization of a carp. Left: reference model, Middle: direct volume rendering of a specimen augmented with a caricature of the diameter of its gas bladder. Right: caricature of the carp's shape.

Abstract

Caricatures are pieces of art depicting persons or sociological conditions in a non-veridical way. In both cases caricatures are referring to a reference model. The deviations from the reference model are the characteristic features of the depicted subject. Good caricatures exaggerate the characteristics of a subject in order to accent them. The concept of *caricaturistic visualization* is based on the caricature metaphor. The aim of caricaturistic visualization is an illustrative depiction of characteristics of a given dataset by exaggerating deviations from the reference model. We present the general concept of caricaturistic visualization as well as an approach for volumetric data. Our approach investigates different visual representations for the depiction of caricatures. Further we present the caricature matrix, a technique to make differences between datasets easily identifiable.

CR Categories: I.3.3 [Computer Graphics]: Picture/Image Generation—Display algorithms; I.3.3 [Computer Graphics]: Picture/Image Generation—Viewing algorithms;

Keywords: illustrative visualization, focus+context techniques, volume visualization, volume manipulation and deformation

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1 Introduction and Related Work

The high popularity of caricatures indicates the widespread ability of humans to identify outstanding features of faces. In addition to that caricaturists have the ability to exaggerate these features and draw hyperbolized pictures. The exaggeration of features takes place in dependence to a reference model in the caricaturist's brain. A beholder of a caricature can interpret its meaning only if he has a similar reference model in his mind. In Figure 2 an example of a reference model, the subject and the caricature of the subject are shown. The reference model can be seen as an idealized model within the domain of subjects. Each specimen within the domain is characterized by deviations to the reference model. The deviations of the specimen are the features of interest for the caricaturist. The caricature is the outcome of a hyperbolized depiction of the deviating features. It accents the essence of the depicted subject. Caricaturists share many goals with illustrative visualization. Therefore caricatures provide a powerful metaphor. Exaggeration is meant to aid the beholder in recognizing the differences. Caricatures exaggerate but do *not* distort deviations. In Redman [9] the caricaturist is advised to differentiate between exaggeration and distortion: *"Exaggeration is the overemphasis of truth. Distortion is a complete denial of truth"* [9]. In visualization focus+context techniques provide the user with detailed information at the focus of interest while the context is still present. Caricatures usually accent the characteristics and salient details while sparsely sketching the context. The focus of interest in caricatures is on the characteristics of the depicted object. Another aim of illustrative visualization is to communicate content about a given subject. Caricatures are expressive depictions of the essence of a subject. Therefore caricatures are applicable for the communication of visual content. Illustrative visualization often aims to augment a depiction by a sparse but descriptive visual representation. Caricatures are extremely sparse representations of visual content and therefore well suitable for the augmentation of visualizations. Another goal of illustrative and educational visualization is to attract the user's attention to the content of interest. Photorealistic rendering often fails to direct the attention to the focus of relevancy. Caricatures provide intensive cues toward the details of interest. The users attention is steered to the characteristics of the depicted subject. The literature about caricatures mostly focuses on facial caricatures. Computer aided facial caricature generation was addressed in [5, 2, 14, 19, 1]. The perception and recognition of faces in association to caricatures was investigated in [3, 14, 15, 16, 19, 13, 7]. While some works [3, 14, 15, 16] report an advantage in recognition or learning using facial caricatures, other works [13, 7] found no evidence that caricatures of people are better than photographs. Gooch et al. [6] present a more extensive discussion about human facial illustration. For objects in general it was reported [17, 8] that stylized, accentuated drawings are more easily identified. They aid learning more than photographs of the same objects. Wynblatt [20] present visual representations of www documents called caricatures. The caricaturization of web documents allows for fast browsing through a large number of documents. Caricaturistic visualization is based on the illustrative exaggeration of characteristic features of a given data domain. In Figure 3 we illustrate the situation for an educational illustrative visualization system. On the left hand side the system development phase is shown. The system designer chooses appropriate visual representations and designs features that are suitable for use with the data of the given domain. The system designer needs to have domain knowledge to develop a caricaturistic visualization system appropriate for the given domain. On the right hand side the system exploitation phase is shown (in this example) for educational use. A teacher specifies features in the reference model and in datasets showing deviations from the reference model. The student can manipulate the visual representations. The student gains knowledge about the domain by observing deviating datasets. There is a clear distinction between the design of a feature and the specification of a feature. Design of features refers to an appropriate selection of properties that are powerful enough to represent features in a dataset. The design of features is done at the development phase of the caricaturistic visualization system, see Figure 3 (left hand side). In contrast, specification of features refers to the assignment of values to the properties for a specific dataset. Specification is done by the user or semi-automatically when the caricaturistic visualization system is exploited, see Figure 3 (right hand side). Caricaturistic visualization systems are well suitable but not restricted to educational use. In the following we give further ideas for application areas of caricaturistic visualization.

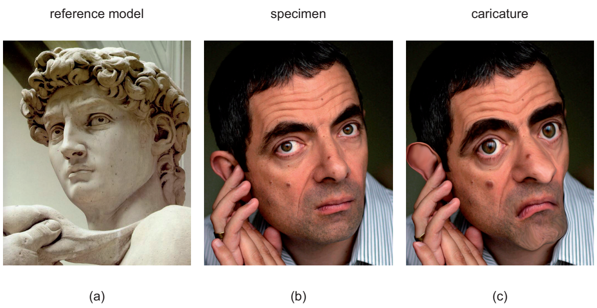

Figure 2: Example of a non automatic caricature drawing: In (a) the head of Michelangelo's David statue is shown as analogy for the reference model. In (b) a photograph of Rowan Atkinson is shown. In (c) the caricature of (b) is shown. The caricature (c) presumes the existence of a reference model (a).

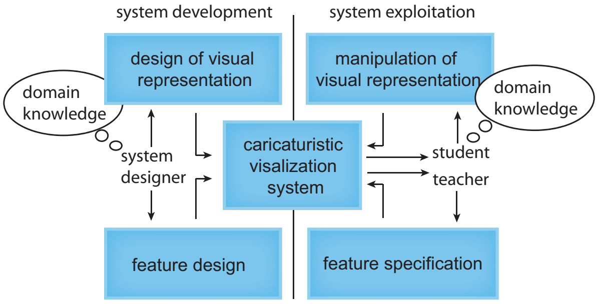

Figure 3: Illustration of a caricaturistic visualization framework for use in education: On the left hand side the development of a caricaturistic visualization system is depicted. The system designer needs to have knowledge about the given domain. On the right hand side the use of the system is illustrated. Teacher and student study the deviating datasets by exaggerating the characteristics of different cases.

Quality control aims to find subtle differences of workpieces to the reference model. Irregularities of surfaces are of immediate interest. The visual exaggeration of such irregularities is subject to caricaturistic visualization.

Dentistry is interested in subtle abnormalities of the teeth. These abnormalities can be visualized in an exaggerated way.

Communication of diagnosis in clinical practice often lacks suitable visualizations. The patient as a layperson often fails to see the abnormalities in the data. Illustrative visualizations accenting the deviations can aid the patient to understand the diagnosis. Caricaturistic visualizations can bridge the gap in communication between medical doctors and patients.

The designer of a caricaturistic visualization system has to have domain knowledge in order to design appropriate features. The design of good features is crucial for caricaturistic visualization. We derive a mathematical formulation of a feature in Section 2 and provide some simple guidelines for the design of features in Section 2.1. In Section 3 we further illustrate the idea of caricaturistic visualization on some examples for simple caricaturistic operations using the provided mathematical framework. In Section 4 we present the *caricature matrix*, a technique for the visualization of divergences of datasets to each other. It is based on the caricaturistic visualization metaphor and exploits the feature based approach of caricaturistic visualization. In Section 5 we describe the implementation of our caricaturistic visualization prototype. We give ideas about feature design and a user interface for feature specification. Further we show examples of visual representations that are suitable for caricaturistic visualization. In Section 6 our work is concluded and ideas for future work are given.

2 Mathematical Framework

Caricaturists identify features and exaggerate certain properties of these features such as extend, displacement, or angularity. As we want to exaggerate the deviations of a specimen from the corresponding reference model we measure the difference between the model and the specimen for each property. In case of a facial caricature the displacement of the ear is an example for such a property. For each property we define a difference function over the domain of the property. The domain of property i is denoted as P_i and the difference function is denoted as $\ominus_i$. In a facial caricature a typical property is the angular offset of the ear to the reference model. Jug ears have a high value for the angular offset property while tight-fitting ears have the value zero. The defined domain of the angular offset of the ears could for example be $P_i = \{x \| x \in (0, \frac{\Pi}{2})\}$. The difference operation for two values of P_i is the difference between the two angles. Another example for a property is the three dimensional position of the ear. The domain of this property is some subspace of the three dimensional space $P_i \subset \Re^3$. The distance measure for the position of the ear is simply the euclidean distance. A feature describes a characteristic of the model respectively of the specimen. A feature is therefore defined as a property vector. The property vector space is defined as

$$P = P_1 \times P_2 \times \ldots \times P_{n-1} \times P_n \tag{1}$$

In analogy to a facial caricature a possible feature would be the ear given by its position, angular offset and extend along its major axis. We define an exaggeration function for each property of the feature which describes the behavior of a feature as its properties are exaggerated. It is desirable, that the deviating properties of the feature are even further deviated. In terms of facial caricatures the displacement of the ears would lead to even further displacement. We call this kind of exaggeration of a property *intra property exaggeration*. In contrast to that an *inter property exaggeration* is the exaggeration of a property caused by the deviation of another property. In the above example the inter property exaggeration of the displacement of the ears would also lead to an exaggeration of the scaling of the ears (i.e., the increase of the extend of the major axis). We therefore define the exaggeration function for the property i as:

$$e_i(x_i, \delta) = x_i + (c_{i1} d_1(x_1, \widetilde{x_1}) + \ldots + c_{in} d_n(x_n, \widetilde{x_n})) \, |x_i \ominus \widetilde{x_i}| \, \delta \tag{2}$$

where δ is the exaggeration parameter, d_i is the distance function for property i, $\widetilde{x_j}$ is the value of the reference model for the property j, $c_{ij} \in \Re^+$ for $i, j = 1 \ldots n$ are the coefficients describing the inter and intra property exaggeration, and $|x_i \ominus \widetilde{x_i}|$ is given by

$$|x_i \ominus \widetilde{x_i}| = x_i \ominus \widetilde{x_i} \frac{1}{d_i(x_i, \widetilde{x_i})} \tag{3}$$

The coefficient c_{ij} determines the influence of the distance of property j on the exaggeration of property i. Intra and inter property exaggerations can be observed in real caricatures. In our approach we concentrated on intra property exaggerations. We therefore set all coefficients $c_{ij} = 0$ for $i \neq j$.

2.1 Guidelines for Features

Each feature consists of a set of properties. Simple features may only consist of few properties like position, orientation and extend. More complicated features may consist of hundreds of properties or even of infinitely many describing the shape of the feature. Designing appropriate features is crucial for caricaturistic visualization. We designed our features to meet the following constraints:

Flexibility The set of properties is able to describe a wide variety of concrete features.

Simplicity Each property is easy and fast to specify. The specification of features is a semi-automatic process. Features which are complicated to specify may distract the user. Note that following the constraint of simplicity is not a restriction to the complexity of the shape. The automatically generated shape may be complicated while the user only specified few settings.

Measurability Each property is measurable and induces a distance function. A pair of corresponding features differs only in the specified values of the properties. The distance of those values must be measurable.

While the first two constraints are guidelines to design good features the third constraint is a technical prerequisite to caricaturize features. The flexibility- and simplicity constraint seem at first glance to result in a tradeoff. On one hand the features should have the flexibility to describe the subject of caricaturization on the other hand it should not be too complicated for the user to specify it. To meet both constraints we propose to use a semi-automatic approach. A few properties are specified by the user while the more complex properties are automatically derived. In Section 5 the semi-automatic approach we investigated is described in more detail.

3 Caricaturistic Operations

Based on the above derived mathematical framework we illustrate the idea of caricaturistic visualization. For the purpose of demonstration we define a three dimensional superquadric which is given by the implicit function

$$f(x,y,z) = (\frac{x}{s_x})^{\frac{2}{\gamma}} + y^{\frac{2}{\gamma}} + z^{\frac{2}{\gamma}} \quad (4)$$

We define $\gamma, s_x \in \Re^+$ to be the properties of the implicit function. The property vector space of the implicit function is therefore defined as $\Re^+ \times \Re^+$. As a reference model we choose the superquadric with the property vector (1,1) which is a sphere. We define eight deviating objects with all combinations of the properties $s_x = 0.8, 1.0, 1.2$ and $\gamma = 0.6, 1.0, 2.5$. As visual representation for the implicitly defined function $f(x,y,z)$ we choose the iso-surface of the function

$$g(x,y,z) = \frac{1}{f(x,y,z)^2} \quad (5)$$

at an iso-value of 0.5.

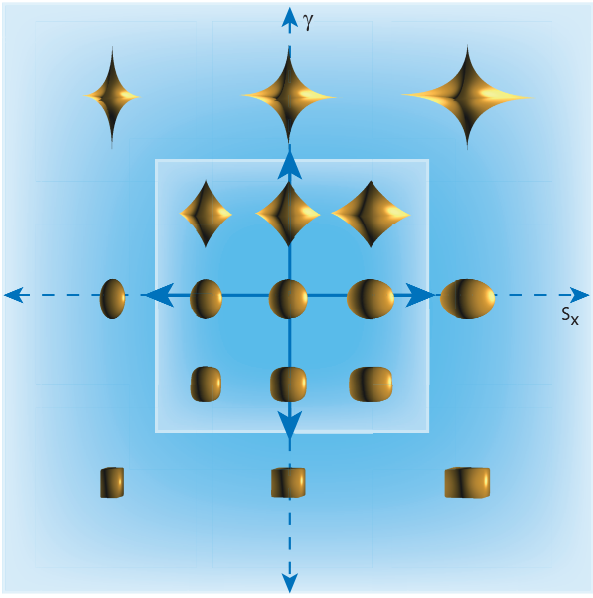

Figure 4: Examples for caricaturistic operations. In the center of the inner square the reference model is depicted. The remaining eight objects in the inner square are examples for deviating specimen. The vertical axis corresponds to the property γ which describes the actual shape of the iso-surface of the implicit function. The horizontal axis corresponds to the parameter s_x which describes the extend of the iso-surface in x-direction. The outer square shows the caricatures of the corresponding inner square's objects.

In the inner square of Figure 4 the eight deviating objects (i.e., the specimen) are depicted. In the middle of the square the reference model is shown. The vertical axis corresponds to the property γ which describes the actual shape of the iso-surface of the implicit function. The horizontal axis corresponds to the parameter s_x which describes the extend of the iso-surface in x-direction. The object in the lower left corner of the inner square for example has the property values $s_x = 0.8$ and $\gamma = 0.6$. The properties s_x and γ form the property vector space. All example objects lie in a subspace of the property vector space (i.e., the inner square in our example). The outer square in Figure 4 is the space of caricatures. In caricature space the properties are exaggerated resulting in more distinctive visual representations. The object in the lower left corner differs in both parameters from the reference model. Its visual representation is still close to the visual representation of the reference model. The caricature makes use of the whole property space therefore resulting in a more deviated visual representation.

The objects in the upper row of the inner square are visually similar. The corresponding caricatures of these objects are shown in the upper row of the outer square. Due to the exaggeration of their descriptive properties they are visually more distinctive. The exaggeration of properties in order to make datasets more distinctive from each other is described in more detail in Section 4.

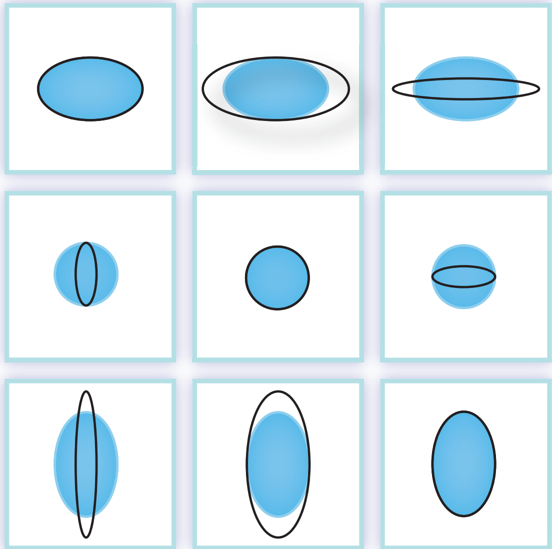

Figure 5: Illustration of the caricature matrix. In the main diagonal the actual objects are shown in dark green. Caricatures of the objects are drawn as black outlines. The rows of the matrix can be read as the caricatures of the object using the remaining objects as reference models.

4 The Caricature Matrix

While artists drawing caricatures do not explicitly make use of a reference model (as illustrated in Figure 2a), for visualization an explicit reference model is of inherent relevance. The definition of the difference function assumes the existence of a reference model and the exaggeration function assumes the definition of a difference function. Therefore caricaturistic visualization fails without a reference model. Pools of datasets about a given subject often lack the explicit existence of a reference model. In some cases this might be compensated by deriving the average of the available datasets. The average can than be used as reference model.

The direct visualization of differences between the datasets is a more expressive option. Each dataset from a given pool can be used as the reference model for all remaining datasets. A pool of n datasets leads to n^2 caricaturistic visualizations. We call the set of images the *caricature matrix*. In Figure 5 we illustrate the structure of the caricature matrix. The main diagonal is depicting the actual objects. Row i of the matrix shows all caricatures of the object i using the remaining objects as reference models. Column j of the matrix shows all caricatures using object j as the reference model. Element (i, j) of the matrix shows the caricature of the object i using the object j as the reference model. The caricature matrix is not necessarily meant to be completely shown to the user at once. It is a concept requiring further visualization and exploration techniques. While the average of datasets is distorted by outliers the caricature matrix depicts the direct comparison of all datasets to each other. Therefore we expect the caricature matrix to be more robust.

5 Caricaturistic Visualization System

For a proof of concept we implemented a caricaturistic visualization system for volumetric data. The aim of the implementation was to explore the abilities of caricaturistic visualization. As shown in Figure 3 the system must have well designed features to meet the requirements of the data and the visualization. The design of the features used in our system is described in Section 5.1. Further the caricaturistic visualization system must provide the user with an interface for feature specification. The user has to specify corresponding features in the reference model and in the datasets respectively. We investigated a semi-automatic feature specification approach described in Section 5.2. The specified features must be mapped to a visual representation. We investigated two different approaches. The first approach is a direct volume rendering approach based on the exaggerated deformation of the volumetric data. The second approach utilizes a more sparse representation of the caricature based on Nurbs curves and surfaces. Both approaches are described in Section 5.3.

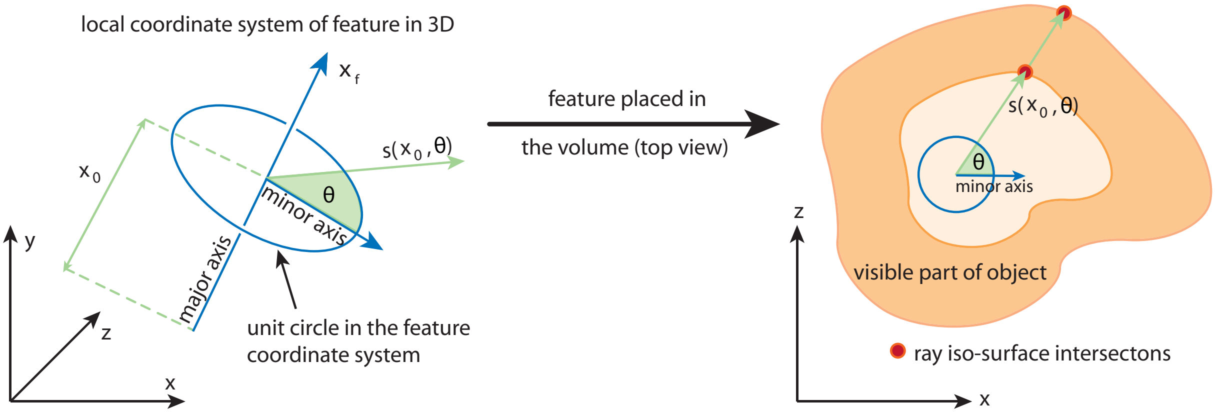

Figure 6: Illustration of the feature local coordinate system. On the left hand side the feature is shown in 3D. The direction and extend of the major and minor axis has to be specified by the user. The blue circle depicts a unit circle in the plane perpendicular to the major axis. The parameter x_f determines the position of the plane along the major axis. In the figure the parameter is set to x_0. $s(x_0, \theta)$ is the distance of x_0 to the intersection point with the iso-surface in the direction θ. Where θ is the angular offset of the ray to the minor axis. $s(x_f, \theta)$ corresponds therefore to the normal distance of the iso-surface to the major axis. On the right hand side the feature is shown as its local coordinate system is defined in the volume. From point x_0 a ray is cast in the direction of a vector specified by the angular offset θ. The distance $s(x_0, \theta)$ of the iso-surface intersection is computed and stored.

5.1 Feature Design

Our feature consists of the following properties: the position, a major axis and a minor axis. These properties implicitly define a right-handed local feature coordinate system. Further the feature is defined by the extend in the directions of the axes of the local coordinate system. These properties are specified and manipulated directly by the user. Additionally we define a property that is derived automatically once the user has specified the other properties. This property describes the normal distance of an iso-surface of the object to the features major axis. On the left side of Figure 6 the local coordinate system of the feature is shown. On the left hand side the feature is shown in 3D. The blue circle in Figure 6 is the unit circle in the plane perpendicular to the major axis going through the point x_f. x_f is a parameter varying over the major axis of the local coordinate system. In the example in Figure 6 it is set to x_0. $s(x_f, \theta)$ is the distance of the point x_f on the major axis to the intersection point with the iso-surface in the direction θ. θ is the angular offset of the ray to the minor axis. $s(x_f, \theta)$ therefore corresponds to the normal distance of the iso-surface to the major axis. In fact x_f, θ are a parametrization of the feature coordinate system. We descretize the parameters x_f and θ in order to precompute the normal distance of the iso-surface to the major axis. The granularity of the discretization can be adjusted by the user. On the right hand side of Figure 6 the feature is shown in the volume. For each point x_f a ray is cast in the direction of a vector specified by the angular offset θ. The distance $s(x_f, \theta)$ of the iso-surface intersection is computed and stored. The casted ray in general intersects many iso-surfaces. In our current prototype implementation the user can choose to either store the distance to the first or to store the distance to the last intersection point.

5.2 Feature Specification

For the specification of a feature in volumetric space the user has to specify values for properties like position and extend of the major axis. Therefore it is necessary to provide a method for the specification of a position in three dimensional space. We implemented a user interface which allows the user to specify a ray being cast from the image plane in the viewing direction by clicking on the image plane. The ray is intersected with the iso-surfaces of the volumetric object. In Figure 7 the casted ray is shown intersecting the iso-surfaces of the object at several positions. The user decides if the chosen ray specifies a point at the hit iso-surface, or a point in the middle between two consecutive iso-surface intersections. This approach allows to place a feature in the middle of a homogenous region or directly on the iso-surface. The spacial positioning of a point enables a wide variety of feature specification methods. In our approach the user can set the position of the feature as

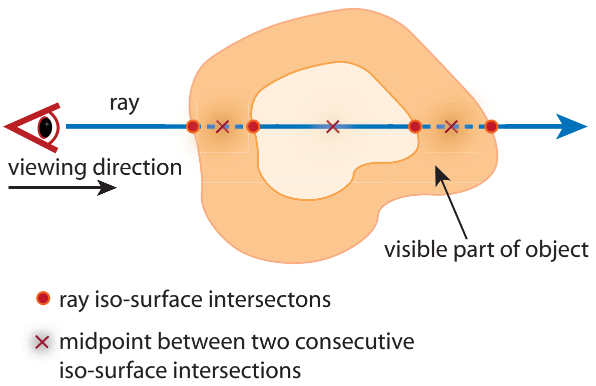

Figure 7: Specification of a position in volumetric space. A ray is cast in the viewing direction intersecting the iso-surfaces of the volumetric object. Regions of homogeneous color in the figure correspond to regions of homogeneous visibility in volumetric space. The ray iso-surface intersections and the midpoints between two consecutive intersection points are possible candidates for the specified position in the volumetric space.

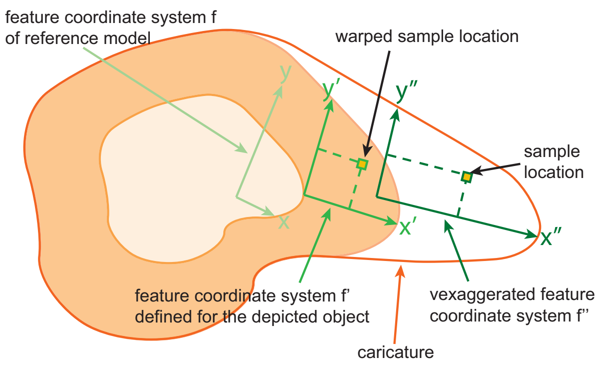

Figure 8: Warping of the sample location. The feature coordinate system of the specimen dataset f' is exaggerated according to the feature coordinate system of the reference model f resulting in the exaggerated coordinate system f''. Each sample is warped from f'' to f'. The density value is derived by transforming the warped sample into volume space.

well as the direction and the extend of the major axis by two consecutive mouse-clicks. Where the first click specifies the position and the second click the remaining properties. The extend of the two remaining axis as well as the direction can be immediately manipulated by the user. When the local feature coordinate system is specified the normal distance to the major axis is derived automatically.

5.3 Visual Representations

To achieve a caricaturistic visualization the user has to specify a certain number of features in the reference model and corresponding features in the datasets of interest. Once the corresponding feature pairs are specified in the reference model and in the specimen, the exaggeration function provides a feature vector for each value of the exaggeration parameter δ. This exaggerated feature vector has to be mapped to a visual representation. Caricaturistic visualization is not restricted to a specific visual representation. The exaggeration of features can be mapped to sparse representations such as contours, iso-lines, hatched surfaces, etc., or to dense representations such as polygonal surfaces or iso-surfaces. The possible visual representations also vary in the degree of abstraction and range from very tangible representations like iso-surfaces to high-level abstractions such as explanatory glyphs or automatically placed captions. In our system we implemented two different visualization approaches described in the following.

We investigated an approach based on the deformation of the volume during ray casting. Our approach is similar to the approach of Lerios et al. [10]. While in [10] an approach for interpolation of two volumetric models is described, we use a similar approach to extrapolate from the volumetric model according to the exaggeration of the feature coordinate system. This results in a volume deformation driven by the characteristics of the volume dataset. We describe the approach first for one feature and later extend it to an arbitrary number of features. A feature is defined by its local coordinate system as described in Section 5.1. We warp the exaggerated feature coordinate system during ray casting back to the original position of the features local coordinate system. The idea is sketched in Figure 8. The volume deformation is determined by the feature coordinate system of the reference model and by the feature coordinate system of the specimens dataset. First the exaggerated feature coordinate system is computed according to Equation 3. In Figure 8 the three different feature coordinate systems are shown from left to right. We implemented a ray tracing approach where each sample position is transformed into the feature coordinates of the exaggerated feature coordinate system, denoted as f'' in Figure 8. The coordinates of the sample in the exaggerated feature coordinate system are then warped into the feature coordinate system of the original feature, denoted as f' in Figure 8. The warped sample coordinates are then transformed back into volume space in order to derive

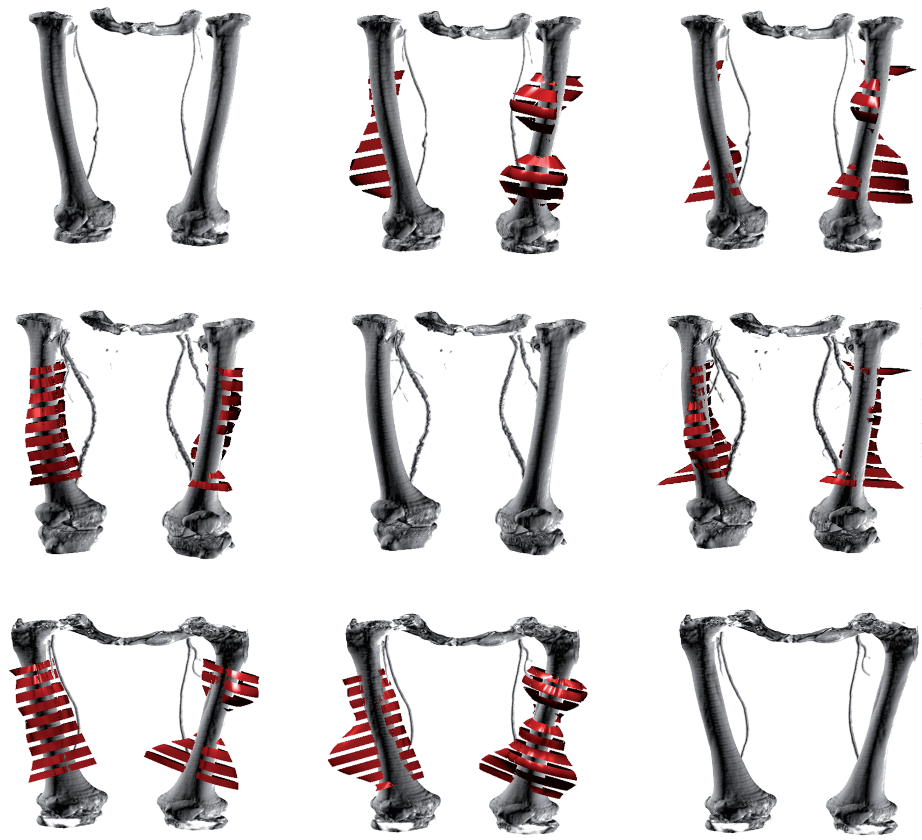

Figure 10: The caricature matrix for three datasets of the human femur are shown. The features are specified to describe the frontal part of the substantia compacta of the os femoris. The main diagonal shows the three different datasets. Each row shows the caricatures of the object in the main diagonal. The columns show the caricatures of all objects using the object in the main diagonal as reference model.

the density value needed for ray-casting. The resulting caricature of the object is illustrated as an orange outline in Figure 8. Following the approach described in [10], we extend our approach to more features by defining a weighting function for each feature which falls off with the square of the reciprocal distance between the sample position and the position of the exaggerated feature. This allows for local control over the volume deformation specified by each feature. The above described calculation is done for each feature. The final density value for an arbitrary sample is then computed as the weighted sum of all resulting density values. In Figure 9 an example of a caricaturistic volume deformation specified by two feature pairs is shown. The features are specified to describe the extent and rotation of the nose and the right ear. The two depicted datasets where used as reference models for each other. The second caricaturistic visualization approach we investigated was motivated by an illustrative augmentation of the datasets. We therefore chose a visual representation that is adjustable in the level of sparseness. We represent the caricature by Nurbs curves and Nurbs patches that are displaced from each other. We use the above described property of the normal distance of the iso-surface to the major axis of the feature coordinate system. First we exaggerate the feature according to equation 3. The exaggerated distances are used to compute a set of control points. The control points are used to define Nurbs patches and Nurbs curves. The described visual representation was used to produce the images for the caricature matrix of three datasets of the human femur shown in Figure 10. The human os femoris is a compact sub-

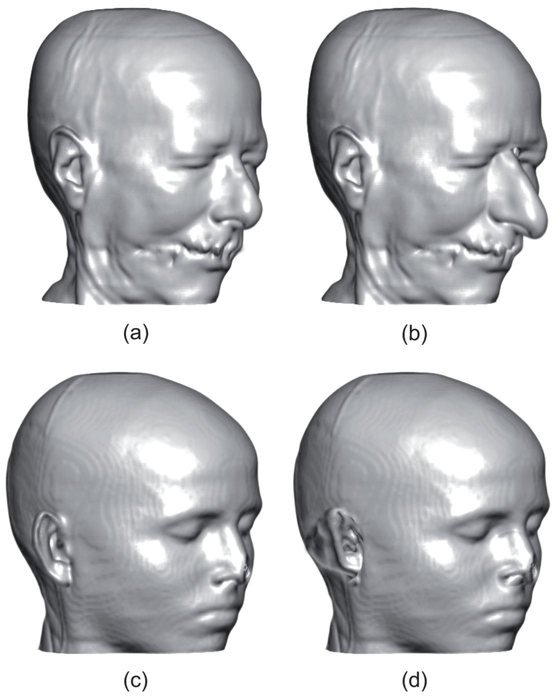

Figure 9: A caricaturistic volume deformation based on the exaggeration of two features. In (a) and (c) iso-surface renderings of the two actual datasets are shown. Two features where specified for each dataset and used to produce the caricaturistic visualizations shown in (b) and (d). In (b) a caricaturistic iso-surface rendering of (a) is shown. The features of the dataset shown in (c) were used as reference model. In (d) a caricaturistic iso-surface rendering of (c) is shown. The features of the dataset shown in (a) were used as a reference model.

stance containing soft tissue in the middle. The subject of caricature in Figure 10 is the thickness of the frontal compact substance. We use the feature described in Section 5.1 that measures the extend of the surrounding tissue in the plane perpendicular to the major axis of the feature. One feature is placed for each left and right bone resulting in a total of six features for the three datasets. The matrix in Figure 10 is read as described in Section 4. Row i shows all caricatures of dataset i and the dataset itself. The dataset is shown in the main diagonal. Colum j shows all caricatures using the dataset j as reference model $j = 1 \ldots 3$. The left column shows the two caricatures using the object in the upper left corner as reference model. The exaggeration parameter δ is set to 4. This means that the difference of the thickness of the bone front compact substance between a dataset and the reference model is multiplied by 4 resulting in an even larger offset. The caricatures of the left bone in the left column indicate that the frontal compact substance of the reference model is thinner. While this example indicates that the concept of caricaturistic visualization is useful to emphasize small deviations the bumpy structure of the caricatures in the middle column are artifacts of the insufficient feature specification. In fact the frontal compact substance of the os femura can only be insufficiently described by a single line. Due to the curved structure of the bone the major axis of the feature describing the structure of the right bone intersects the containing soft tissue in dataset 2. At these parts the feature measures the extend of the soft tissue resulting in artifacts when used for caricature. In Section 6 we give further ideas for the design of advanced features.

6 Conclusion and Future Work

Caricatures exaggerate deviations of features of specimen. These deviations are the characteristics of a specimen. Therefor caricatures depict the essence of a subject of interest. The caricature metaphor is well suitable for visualization since caricatures have many goals in common with visualization. A caricatures as well as illustrative visualization is an approach to communicate the essence of a subject in a non-veridical way. We presented a mathematical framework for caricaturistic visualization suitable for a wide variety of applications. Further we introduced the caricature matrix, a technique based on the caricature metaphor. It is suitable to make subtle differences between datasets visible without the need of an explicit reference model. The design of features that accurately describe the object with minimal need of user interaction during feature specification is an obvious goal for the future. We will investigate different approaches for feature design including features that describe the shape of non-linear curves (such as bones), surfaces and volume elements. Further we will analyze the usefulness of inter property exaggerations for visualization.

7 Acknowledgments

The work presented in this publication is carried out as part of the ex**vis**ation project (`www.cg.tuwien.ac.at/research/vis/exvisation`) supported by the Austrian Science Fund (FWF) grant no. P18322. The caricaturistic system prototype was implementation using volumeshop [4], a system for illustrative visualization.

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