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Multimodal Visualization with Interactive Closeups

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Abstract

Closeups are used in illustrations to provide detailed views on regions of interest. They are integrated into the rendering of the whole structure in order to reveal their spatial context. In this paper we present the concept of interactive closeups for medical reporting. Each closeup is associated with a region of interest and may show a single modality or a desired combination of the available modalities using different visualization styles. Thus it becomes possible to visualize multiple modalities simultaneously and to support doctor-to-doctor communication on the basis of interactive multimodal closeup visualizations. We discuss how to compute a layout for 2D and 3D closeups, and how to edit a closeup configuration to prepare a presentation or a subsequent doctor-to-doctor communication. Furthermore, we introduce a GPU-based rendering algorithm, which allows to render multiple closeups at interactive frame rates. We demonstrate the application of the introduced concepts to multimodal PET/CT data sets additionally co-registered with MRI.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

Recently, multimodal medical scanners have become available to support medical diagnosis. These multimodal scanners, e. g., PET/CT, SPECT/CT or, very recently, also PET/MRI, generate two automatically co-registered modalities of a human subject during a single acquisition procedure. In addition to these modalities, sometimes also other co-registered modalities and/or derived variables are taken into account. The high potential benefit of having multiple different modalities co-registered with each other is unquestioned in medicine as it provides rich information about the patient's anatomy and physiology. While the scanning technology has evolved rapidly over the past years, multimodal visualization techniques for medical applications are still rather basic. Most medical workstations support multimodal visualization only as side by side views, or as a blended image, exploiting alpha compositing. While both techniques constrain the scale of the incorporated visualizations, i. e., the same scale has to be used for all modalities, the alpha compositing also does not support a quantitative visual analysis, since the shown colors are modulated due to the blending. Additionally, contrast between pathology and non-pathology in nuclear medicine and PET-images is often lost by alpha blending with anatomical images. For alpha compositing the number is limited by the fact that it can be interpreted only, if at all, for at most two different colors.

Currently, the communication of diagnostic results is done via a non-standardized reporting system. Thus, even in cases where the surgeon is provided with a detailed text report, sometimes required details about pathologies are not included in the report. In such a case intra-clinical personal exchange provides further details. Alternatively, the surgeon may inspect the patient's screenings available from the PACS data repository. Generation of rapid reports that document findings and provide overview and detail from multiple modalities such as PET/CT/MRI has been our primary motivation for visualization techniques presented in this paper.

To develop technologies, that address the discussed clinical needs, we have borrowed the concept of closeups, a popular expressive technique from hand-crafted technical and medical illustration. They allow the visualization of the same or different data at different scales and/or with differ-

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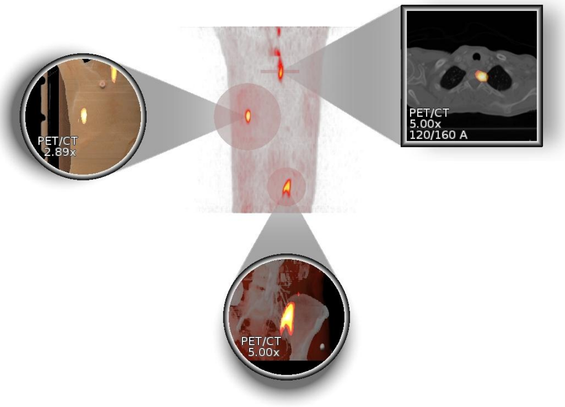

Figure 1: *A closeup layout as generated with our system for a PET/CT data set of a patient suffering from three tumors.*

ent viewing parameters, while they are integrated into an overview rendering in order to reveal their spatial context. Our visualization approach shows an overview of the data by visualizing the *reference modality*, and it generates closeup views which provide the user with a more detailed representation of selected regions of interest (see Figure 1). Each closeup can use its own visualization style to display its contents, and it may either display a single modality or a particular combination of the available modalities. The importance of a closeup's content can be reflected in its screen size. The physician can also modify a closeup's visualization style, viewing direction, size, and position, as well as the shown modalities. To document and include the diagnostic findings, it is possible to annotate the closeups and save the session to capture the results of the medical diagnosis in an interactive way.

2. Related Work

Our work fits into the category of focus+context visualization techniques [Hau05] and linking through views [Rob07]. Both concepts are extensively researched in information visualization for non-spatial abstract data. In volume visualization a related focus+context technique is the magic volume lens [WZMK05] which differs from closeups by keeping the original spatial location of the focus region.

The concept of closeup illustration has been frequently used throughout modern hand-crafted illustration. The strength of this illustration technique is in multiscale integration, for example it allows to show the cell level in the context of the entire human anatomy. In scientific visualization there are few works that directly use the closeup concept for focus of attention. The first appearance of closeups for volume data was in the VolumeShop framework [BG05]. In this framework closeups were denoted as *fanning* and have been part of the illustrator's toolbox. They could be combined for example with interactive focus brushing and object's labeling. The closeup was combined either with a *fan* or an arrow depicting its original spatial location in the context volume. The second appearance of closeups in the scientific literature for medical visualization has been focusing on the application of higher-order reconstruction kernels at interactive frame rates [TSS*06]. The aim was to provide super resolution visual appearance in the closeup region. Both of the previous works on closeups have been primarily targeting on using a *single closeup + context* visualization scenario using one modality only. In contrast to our work they were not addressing any multimodal, multiscale, or multifocal aspects.

Integration of multiple modalities, possibly of different scales, through the visual closeup metaphor is the main focus of our work. Although the advanced imaging technologies are capable of combining several different modalities, there are only few visualization concepts for multimodal medical visualization. Typical visualization of two co-registered modalities is overlaying one modality with another. This type of multimodal integration for PET/CT is already implemented in most dedicated medical workstations [KCF05]. One of the early more advanced multimodal visualization approaches for MRI + fMRI integration used the magic mirror metaphor [KDG99]. The anatomical data shown in the center has been combined with visualization in *mirrors* showing the functional modality as linked mirror *reflection*. This approach has linked views with closeups in common, however it suggests the spatial location of the *functional reflection* by mirror projections, whereas we use explicit helper *fanning* graphics. Moreover the number of mirrors is conceptually limited to three, whereas our technique is not limited to any specific number of closeup views. In some sense our technique exhibits similarity to the profile flags visual metaphor for MRI T1-T2 visualization of cartilage pathologies or breast DCE-MRI [Mle06]. In contrast to the anatomical closeups, profile flags are small flag-like views placed on an iso-surface visualization of a T1 scan showing several non-spatial profile curves of T2 values over the cartilage tissue or perfusion values in breast tissue. They have not been used for integration of spatial data which is our aim. Recently, the cutaway approach has been borrowed from illustrative visualization techniques for integration of a co-registered pre-operative modality with an interventional ultrasound modality [BHW*07]. This visualization technique provides a clear view on the ultrasound plane in context of the rest of the anatomy obtained from the tomography data. Another technique is utilizing various cutting tools for neurosurgery planning [MFOF02]. Both works focus on guiding the intervention or exploration, whereas our visualization technique aims at assisting the doctor-to-doctor communication.

Supporting intraclinical doctor-to-doctor or doctor-to-patient communication has been recognized as an area where visual means of interactive visualization has the potential to be used as a very effective communication platform. There

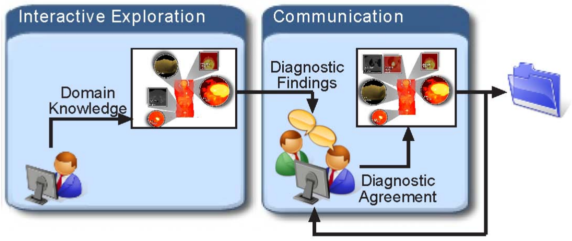

Figure 2: *The successive phases of a medical diagnosis: the physician explores the data and documents and includes the findings; the diagnostic findings are discussed in a doctor-to-doctor communication.*

are first works that are targeting at the communication support. Viewpoint guidance for inspection of specific structures for medical intervention planning is one of these approaches [MNTP07]. In our approach the communication can be assisted by both non-interactive as well as interactive visualization means and allows to focus on several different structures at once. We believe that our closeups can be utilized in combination with another work for visual communication, i. e., in volumetric storytelling [WH07]. In this work several interaction patterns have been discussed from fully passive story telling to a more interactive approach where the user can change attributes of the story. As described in Subsection 3.3, our technique can be used in combination with several of these different interaction patterns.

The concept of multiple views on the same data has also proven its potential in other domains. For instance, Butkiewicz et al. describe an interface for geospatial visualization, where coordinated visualizations are integrated into so-called probe interfaces [BDW*08]. These probes are similar to the closeups described in this paper, since they depict the local data in user-defined regions-of-interest.

3. Interactive Closeups

Medical diagnoses have to be performed on a daily basis, usually under time pressure. Since medical scanners produce data sets with increasing resolutions, the time required for exploring a single data set is rising. Although automatic systems can be exploited to accelerate this exploration, they cannot substitute the physician, and thus can only provide a computer-generated guess, while the physician must have the possibility to intervene at all times.

The process of a medical diagnosis as performed in our radiology department can be seen as a sequence of events (see Figure 2). First, a study is explored. Based on this exploration hypotheses are generated that are checked against other domains, which included other imaging modalities, samples from body tissues as well as the patient's medical history. Often this involves discussions with other domain experts. If there is agreement between a sufficient number of domains, a diagnosis is established. This diagnosis then needs to be communicated with other physicians, e. g. a surgeon performing an intervention or a radiooncologist planning radiotherapy. In the following subsections we explain how closeups can facilitate this process. We describe how 2D as well as 3D closeups are defined, how a closeup layout is computed, and how a physician can interact with a closeup visualization.

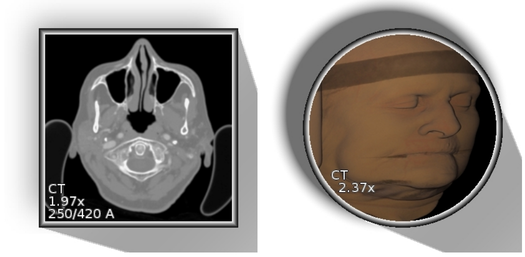

Figure 3: *A 2D closeup shows a single slice and is represented by a rectangular shape (left). A 3D closeup shows a 3D visualization of its volume domain and is represented by a circle (right). Both types of closeups are integrated into the spatial context by exploiting a fan geometry, and they allow to change the used visualization style interactively.*

3.1. Closeup Parameters

When using closeups, the preferences of the viewer may vary, i. e., different domain experts may prefer different visualization styles for the same closeup. To support these preferences, we distinguish between two main categories of closeups which can be used with varying visualization styles. While 2D closeups mimic a conventional 2D medical viewer and show their content slice by slice, 3D closeups visualize their content as a 3D representation. For both types of closeups we distinguish between a closeup's volume domain and its screen domain. While a closeup's volume domain specifies what parts of the volume data set should be visualized, a closeup's screen domain specifies where to visualize this data, i. e., where the closeup is positioned. To allow a close as possible match between a closeup's volume domain and the shape of its screen domain, we have chosen to represent 2D closeups by a rectangle, while 3D closeups are represented by a circle. Thus, we can also ensure that 2D and 3D closeups can be distinguished pre-attentively. Two examples, one for a 2D closeup and one for a 3D closeup, are shown in Figure 3.

2D and 3D Closeups. A 2D Closeup is specified by a center and a normal (in volume coordinates) which determine the location and the orientation of the slice to be visualized, i. e., a 2D closeup's volume domain. A 2D closeup's screen domain is specified by its center in image space as well as its size. A 3D Closeup is specified by a center and a viewing direction (in volume coordinates) which determine how the local camera associated with the closeup is oriented. Besides its actual content, a closeup display also incorporates a text overlay as well as a fan geometry. The fan geometry supports an easy registration within the spatial context by pointing towards the center of the associated volume domain within the overview rendering. The text overlay supports an easy interpretation of the individual closeups by depicting the shown modalities as well as the degree of magnification used for the volume domain.

Depth Awareness. While the fan geometry gives an appropriate cue about the projected position of the anchor point within the overview rendering, it does not provide any depth cues. However, especially when the projections of multiple anchor points overlap each other, at least a relative depth order has to be perceivable to support spatial comprehension. Shadows are known to improve spatial cognition by introducing additional depth cues [SSMK05]. Therefore, we have chosen to incorporate shadows into our closeup visualization with the goal to provide some extra depth information for the anchor point. For each closeup we introduce a shadow whose appearance is proportional to the depth value of the closeup's anchor point with respect to the current overview orientation. For closeups being far away, we want to generate a shadow suggesting that the closeup is close to the image plane, while for closeups being close to the viewer, we want to generate a shadow which gives the impression that the closeup hovers at a certain distance over the image plane. Therefore we set the translation of the shadow, i. e., the distance between the closeup's center and the associated shadow's center, as well as its size inversely proportional to the closeup's depth value. This results in the impression that closeups lying further back and having smaller shadows are perceived as being closer to the image plane than closeups being closer to the viewer, which have a greater shadow translation. To avoid overlap between a closeup's fan and its shadow, we assume that the shadow generating light source is located in the closeup's anchor point.

3.2. Closeup Layout

Multiple closeups as handled by our system need to be arranged in order to generate an adequate layout. For this layout process we adhere to three simple guidelines potentially leading to a more sophisticated arrangement. The first layout guideline addresses optimal visibility of all closeups and therefore forbids closeups overlapping each other. The second guideline aims at improved readability of the closeup visualization, which we try to achieve by placing each closeup as close to its anchor point as possible. Finally, in order to support visual tracing of closeups in different layouts of the same visualization, we aim at a coherent layout, where adding of closeups results in minor changes only. During the whole layout process, we consider the importance of each

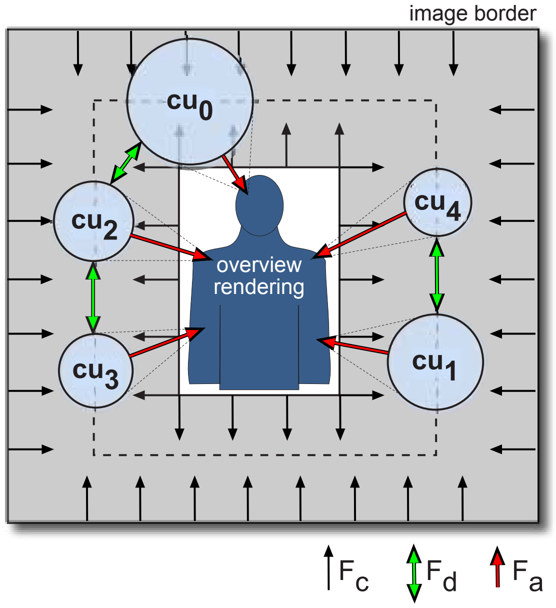

Figure 4: *To compute the position for the closeups, we exploit a force model. The centering force F_c allows to position closeups centered between the image border and the overview rendering, while the distribution force F_d avoids closeup clustering. To position closeups close to their anchor points, we apply the anchor force F_a.*

closeup in such a way that closeups having a higher importance more likely meet the layout guidelines in cases where not all closeups can conform to the guidelines. Since more important closeups should be visually emphasized, we have decided to provide them more screen space and therefore have mapped the importance directly to a closeup's size.

To support the coherent layout as well as to avoid closeups overlapping each other, we make use of a physics engine introducing a simple force model. The idea of using a physics engine to arrange the components of a visualization has already been proposed in [BG06], where the layout of the 3D components of an exploded view is computed. Since in our case we have to deal with 2D objects only, namely rectangles and circles, using 2D physics is sufficient. Therefore we have chosen the Box2D physics engine†, which can handle arbitrary convex 2D objects. By exploiting its physics capabilities, we can easily compute an initial layout for each closeup and are also able to avoid closeup overlaps during the interaction process when moving or resizing closeups (see Subsection 3.3). The initial layout is computed by exploiting the following forces, which affect the positioning of the closeups. The centering force $F_c = c_c \cdot N$ emanating

† www.box2d.org

(a) (b) (c)

Figure 5: *A sequence of images showing the same 3D closeup after successive interactions have been performed: the intial closeup (a), after shrinking its volume domain (b) and after increasing its importance and changing the camera orientation (c).*

from the image border and the border of the overview rendering effects that closeups are positioned halfway between the image border and the overview rendering. c_c is a global constant influencing the centering force, and N is the normal of the image border resp. the overview rendering. Since the image border and the overview rendering are treated alike, a centering effect between both is achieved (see Figure 4). In order to reduce clustering of closeups we ensure that they are distributed within the available image space by applying a repulsive force $F_d(cu_k, cu_j) = c_d \cdot i_k \cdot \frac{V_{kj}}{||V_{kj}||}$, which emanates from a closeup cu_k and acts on an adjacent closeup cu_j. V_{kj} is the unique vector $p_j - p_k$ determined by any pair of points p_k on the border of cu_k and p_j on the border of cu_j which realize the minimal distance between cu_k and cu_j. The normalized vector given by the fraction is modulated with the global constant c_d and the importance i_k of the closeup cu_k. Thus we can ensure that closeups having a higher importance are positioned with more spacing to other closeups. To allow the closeups to stay close to their anchor points, we introduce an anchor force $F_a(cu_k) = c_a \cdot i_k \cdot \frac{anchor_k - center_k}{||anchor_k - center_k||}$ attracting closeup cu_k to its anchor point. c_a is the global anchor distance constant which is proportional to the available image space, i_k again represents the importance of closeup cu_k, $anchor_k$ the position of its anchor point and $center_k$ its position in image space. By incorporating i_k we force more important closeups to stay closer to their anchor point than less important closeups in cases of collision.

3.3. Closeup Interaction

To support interactive reporting, we introduce a set of interaction metaphors, which enable the physician to change the subset of visualized closeups, their layout as well as their used visualization style.

3D Closeup Interaction. To configure the views presented in the individual 3D closeups, the user can also change the viewing parameters. Therefore, in addition to a set of variables capturing the individual visualization style, a quaternion is associated with each 3D closeup which specifies the orientation of the closeup's camera. This rotation can be changed by using a trackball metaphor. Furthermore a rotation can be transferred from one closeup to another one. The latter can be especially helpful when multiple closeups show different modalities for the same volume domain. Besides modifying the camera orientation of a 3D closeup also its volume center can be changed interactively. This can be done either directly, by dragging the closeup's anchor point, or indirectly by changing the volume center within the closeup. When changing the volume center indirectly the anchor point displayed on top of the overview rendering is updated automatically. To magnify the content of a 3D closeup the size of its volume domain can be changed. When shrinking the volume domain, less volume data is shown within a closeup of the same size in image space, which results in a higher degree of magnification. Figure 5 shows a sequence of images with the same 3D closeup after successive interactions have been performed. In Figure 5(a) the initial closeup is shown. The volume domain has been shrunk in Figure 5(b). Finally, in Figure 5(c) the importance has been increased and the camera orientation has been changed.

2D Closeup Interaction. The interaction techniques for the 2D closeups are very similar to those used in medical slice viewers. The domain expert may change the visualization style, the shown slice, its thickness as well as the shown section. Furthermore, the alignment of the shown slice may be changed between axial, sagittal and coronal.

4. Rendering of Multiple Closeups

When using closeups in an interactive visualization, it is essential to be able to render at interactive frame rates. To achieve high quality rendering we exploit GPU-based ray casting [KW03] for both the overview rendering as well as the 3D closeups. Our C++-implementation uses the OpenGL library together with GLSL for the image generation. The closeup visualization algorithm proceeds in two consecutive stages: overview generation and closeup rendering. When generating the overview rendering, arbitrary rendering styles can be chosen. For creation of the overview rendering, we initially construct the proxy-geometry and render the entry and exit parameters into 2D textures, which are used during the actual ray casting. The ray casting produces an RGBA texture containing the final rendering, in our case a MIP, as well as the associated alpha values. To enable a user to manually add closeups by double-clicking onto the overview rendering, we generate an additional texture, which contains appropriate volume coordinates. For performance enhancement we exploit the OpenGL multiple render target extension and generate the overview rendering as well as the volume coordinates in a single rendering pass. While in most cases the volume coordinates would be given by the coordinates of the first point hit by a ray, for a MIP we store the volume coordinates of the sample having the maximum intensity along each ray.

Since several closeups may be rendered simultaneously, it is important to minimize the used memory resources as well as to reduce the number of context switches, which deteriorate rendering performance. However, we still have to support different visualization styles for the contents of different closeups. In order to address the context switch issue, before rendering we sort the closeups lexicographically according to the following three keys: (1) type of closeup, i. e., 2D or 3D, (2) displayed modality, e. g., CT, MRI or PET, and (3) type of visualization, e. g., direct volume rendering (DVR), MIP or surface rendering. Thus *similar* closeups are rendered successively, and the number of context switches is reduced. While the rendering of 2D closeups consists of rendering appropriately sized quads with suitable texture coordinates, efficient rendering of 3D closeups requires some extra effort. A straightforward approach to rendering 3D closeups would be to generate a pair of 2D entry and exit parameter textures representing the volume domain of each 3D closeup. While this would allow an easy integration of different visualization styles, the amount of used resources - in terms of texture memory as well as the number of context switches needed for binding these textures prior to ray casting - is too high and does not allow interactive rendering. Therefore, we propose a rendering technique for multiple closeups, which exploits a single screen-sized texture only, introduces no additional overhead in terms of context switches, and still allows to use different visualization styles for the content of different closeups. In a pre-pass, we construct a 2D texture which contains the exit parameters of all 3D closeups. During this pre-pass we render for each 3D closeup a sphere with radius equal to the image space radius of the 3D closeup. The mapping of the volume coordinates specified by the closeup's volume domain to color-coded coordinates as used during the ray casting is done as follows:

$$RBG = cu_{volumePos} + vert_{cur} * (cu_{volumeSize}/cu_{screenSize}), \tag{1}$$

where $cu_{volumePos}$ is the center in volume coordinates for the current closeup, $cu_{volumeSize}$ is the size of its volume domain and $cu_{screenSize}$ is its screen radius. $vert_{cur}$ is the currently processed vertex as it is not transformed by the modelview matrix, i. e., the sphere is specified as centered in the origin. Notice that we apply swizzling by assigning the value to *RBG* in order to deal with the different coordinate axis alignment used in volume and model space. After processing all 3D closeups in this way, we have a single 2D texture containing all exit parameters. During the successive rendering pass, the generated 2D texture is bound and the 3D closeups are rendered in their previously defined order. Therefore, we enable front face culling and render the spheres using the same mapping between volume coordinates and color as defined in Equation 1. By also binding the volume data sets representing the used modalities as well as enabling the appropriate shader programs, the GPU-based ray casting of the 3D closeups can be performed. The result of this closeup rendering pass is stored in a closeup buffer, which is composited with the overview rendering to obtain the final rendering. To allow easy picking of the closeups we again exploit multiple render targets to render a unique ID for each closeup into an ID buffer during the pre-pass.

After the contents of the closeups have been rendered, we have to overlay the image space elements as closeup borders, shadows and the fans which are used to associate a closeup with the corresponding position in the overview rendering. The shadows are generated by rendering a disc resp. quad with the desired shadow size. This shadow proxy is translated with respect to the depth of the closeup, i. e., for closeups being further away the translation is smaller, which makes the closeup appear to lie closer to the image plane. We improve rendering performance by adding approximated soft shadows only. This is done by linearly interpolating from $\alpha = 0$ to $\alpha = 1$ along the visible part of the shadow geometry. As it can be seen in Figure 1 and Figure 6 (b) we are thus able to generate plausible shadows, which allow an improved depth separation. Furthermore, for rendering the fan geometry, we have to compute the attachment points on the closeups. While we choose the extremal points for rectangular 2D closeups, we have to compute the two tangential points for the circular 3D closeups. Assuming that the center of the closeup lies in the origin this calculation can be performed as follows:

$$x_t = \frac{cu_{ap_x} \cdot cu_{ss}^2 \pm cu_{ap_y} \cdot cu_{ss} \cdot \sqrt{cu_{ap_x}^2 + cu_{ap_y}^2 - cu_{ss}^2}}{cu_{ap_x}^2 + cu_{ap_y}^2}, \tag{2}$$

where x_t denotes the x-coordinate of the tangential point, cu_{ap} is the position of the corresponding anchor point and cu_{ss} is the image space radius of the closeup. The respective values for y_t can be computed by evaluating the circle function for the two computed x_t values.

We have analyzed the performance of our algorithm by rendering a multimodal PET/CT data set. While the CT data set has a resolution of $512 \times 512 \times 162$ voxel, the PET data set has a resolution of $128 \times 128 \times 162$ voxel. The tests have been performed on a standard desktop system, having an Intel Core2 CPU 6600 running at 2.40 GHz, 2 GB of main memory, and an nVidia GeForce 8800GTX graphics board. We have rendered the multimodal data set at a resolution of 1024×1024 pixels with a varying number of 3D closeups having the maximal possible screen size. The results of our performance tests are shown in Table 1 and emphasize the expected linear scaling. As it can be seen, our technique still allows interactive frame rates and thus supports user interaction as described in Subsection 3.3.

5. Closeups for PET/CT Visualization

While the concept of interactive closeups can also be applied to other multimodal application scenarios, PET/CT is a good example which provides a high quality spatial context given by the CT data set as well as metabolism activity patterns specified by the PET data set. Often PET/CT scans are used

	fps
1 closeup	33
2 closeups	29
4 closeups	27
8 closeups	18
16 closeups	11

Table 1: *Average frame rates for a varying number of 3D closeups captured on a desktop system with a GeForce 8800GTX graphics board.*

for detecting pathological cell growth, as it occurs in cancer affected regions. During this medical diagnosis, the physician scans usually through the PET data set slice by slice to visually examine the PET uptake. In regions where an abnormal PET uptake is present, the physician examines the data sets in more detail. The CT data set is consulted in order to identify a corresponding pathological lesion in the morphological domain or to identify structures (such as the ureter) that have confounding physiological uptake. In addition to the CT data set also a 3D visualization of the PET data set can be helpful. When examining the urinary bladder, small activity spots may be close to the urinary bladder, which has a high uptake. In some cases these potentially abnormal uptakes cannot be spatially distinguished from the urinary bladder in a slice visualization. Thus physicians consult a 3D PET visualization or even a multimodal fusion visualization. Besides the standard fusion, we provide a CT visualization, in which the opacity is modulated by the intensity of the PET. Thus, we can ensure, that potentially interesting areas with a high PET uptake are clearly visible.

To support nuclear radiologists during the inspection of PET/CT data sets when scanning for abnormal cancer activity, we provide a MIP of the PET data set, which serves as the overview rendering. Providing this overview rendering fits with the medical diagnosis workflow, where the PET data set is observed slice by slice. By applying a desired color lookup table, areas of high uptake can be visually emphasized. By exploiting the interaction metaphors introduced in Subsection 3.3, the domain expert can add, modify and remove closeups. The application of our technique to PET/CT is shown in Figure 1. The patient suffers from three tumors, one in the throat, one in the chest and one in the abdomen. The three closeups all show a PET/CT visualization, whereas in the 3D closeups ghosting is exploited to make the areas with high PET uptake visible.

6. Case Study

We have also evaluated the proposed concepts on the case of a 58 years old patient who was diagnosed using F-18-FDG-PET-CT. Preparing a structured report about the diagnosis, though it is very helpful, is a quite lengthy process and can take more than an hour. During the evaluation, we have regenerated the medical report shown in Figure 6 (a)[‡]. The report can now be generated with only a few mouse clicks. As shown in Figure 6, the resulting closeup visualization provides a good overview to support the localization of pathologies, as well as a detailed view of them. Textual functionality allows to write annotations directly next to the images, so that several examiners can include their comments (see Figure 6 (b)).

A feature which makes the proposed solution distinguishable from all available commercial software, is the possibility of interactive reporting. Instead of generating a static report, we generate a project file, that describes parameters of the entire closeup visualization, including closeup positions, viewpoints and visual representations. Using this report the surgeon can interact with it, and has the opportunity to seek for information that is not included in the report.

7. Conclusions and Future Work

In this paper we have introduced the concept of interactive closeups for multimodal visualization. Closeup visualizations introduce a new quality into the communication of medical findings. They facilitate the diagnostic process by emphasizing potentially relevant regions. Furthermore, they reduce interaction time by supporting intuitive interaction and layout concepts. Theoretically, an unlimited number of modalities as well as scales can be visualized by using interactive closeups. Interactive closeups support doctor-to-doctor communication by allowing physicians to perform an interactive exploration and to save and communicate their insights in an intuitive way. We believe, that our systems allows to generate interactive reports more efficient, in comparison to current medical workstations. Thus, discussion, presentation as well as reporting of diagnostic findings can be performed more efficiently. Since interactive closeups do not constrain the number of incorporated modalities or the difference in data scale, they can be widely used for different application cases.

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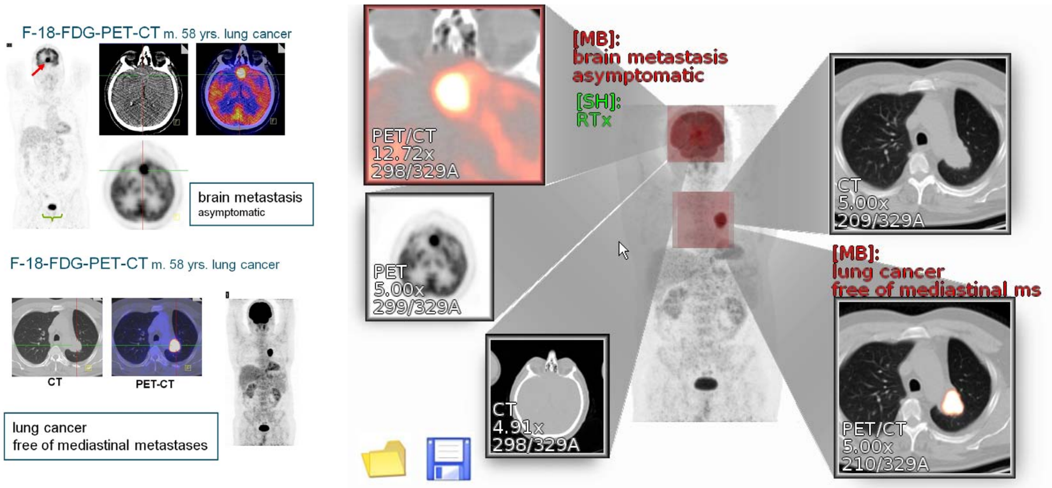
‡ The setup process is shown in the accompanying video



(a) (b)

Figure 6: *(a) A report generated to communicate a medical case. The generation took more than an hour. (b) An interactive closeup report could be generated in a couple of minutes with the concepts proposed in this paper.*

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