VisWeek 08
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Perception-Based Transfer Function Design

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Outline

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- Introduction
- Transfer Function Design Based on Editing Direct Volume Rendering Images
- Quality Enhancement of Direct Volume Rendered Images
- Quantitative Effectiveness Metrics for Direct Volume Rendering

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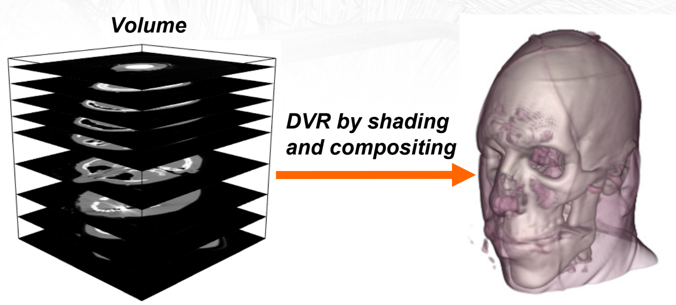
Direct Volume Rendering

- *Direct Volume Rendering* (DVR) is a powerful and flexible volume visualization tool and has been widely used in many fields



Direct Volume Rendered Image (DVRI)

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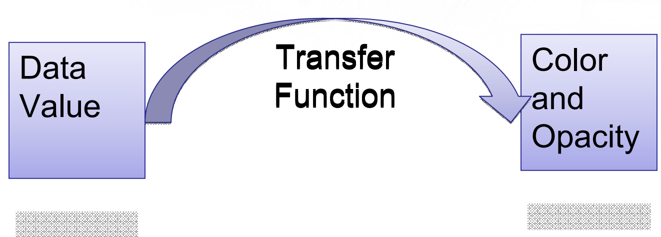
Object-Based Methods V.S. Image-Based Methods

- Direct Volume Rendering (DVR):
  - Object-order DVR (forward mapping)
  - Image-order DVR (backward mapping)

Transfer Functions (1/2)

- *Transfer functions* (TFs) assign opacity and color to the different features in the volume data
  - Emphasize the region of focus
  - Subjugate the unimportant details



Transfer Function(2/2)

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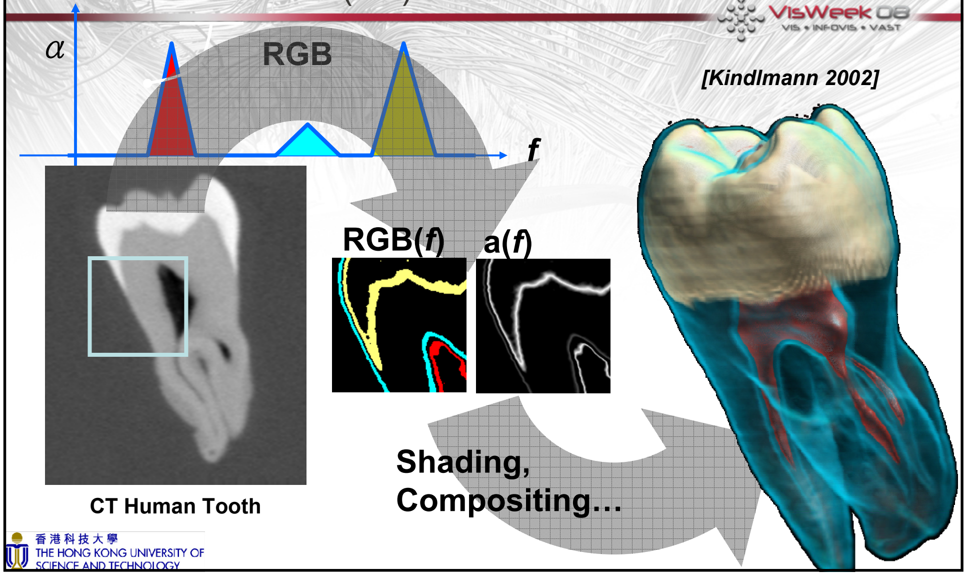

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Perception-Guided Transfer Function Specification

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- The effectiveness of DVR largely depends on the TF used
  - Appropriate TFs allow users to reveal important features in the data
  - Inappropriate ones may obscure these features
- Finding appropriate TFs is difficult in practice
  - One major reason is that the search space for finding TFs is huge even for one dimensional TFs, not to mention multi-dimensional TFs
- We propose a perception-guided volume exploration framework
  - Transfer function design framework based on editing DVRIs and its front-end intuitive interfaces
  - Quality enhancement for the edited DVRIs
  - Quantitative effectiveness evaluation for direct volume rendering

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Motivation

- Physicians usually prefer to directly work on 2D slice images rather than in the TF domain
  - It is more straightforward for them to identify features in 2D slice images
- Some 3D structures can be more easily identified in direct volume rendered images (DVRIs) than in 2D gray-scale slice images
  - Therefore, it is more intuitive and convenient for users to directly work on DVRIs
- Usually, a number of partially good DVRIs can be easily generated by previous volume visualization methods, however, these DVRIs may only partially satisfy users' demands
  - Some context in one image may need to be removed
  - Some features in different image may need to be combined

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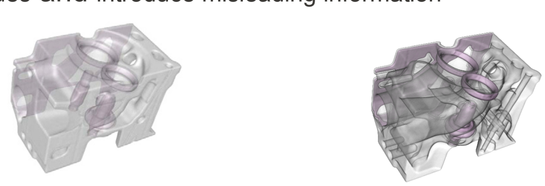
Two Straight Solutions

- Some DVRI editing operations, such as fusing features from different DVRIs, blending two DVRIs, and erasing unwanted features in DVRIs, may be very useful in practice
- There are two straightforward solutions for fusing:
  - Traditional 2D image editing operations
  - Linear combination of several TFs
- They both fail to achieve goals in most cases

Traditional 2D image editing operations

- DVRIs are different from traditional 2D images
  - DVRIs are used to reveal information contained in 3D volume data so multi-layer transparent surfaces are usually displayed
  - Traditional images usually show objects in a real world setting, thus opaque surfaces are often presented
- Alpha Blending is not suitable for DVRIs
  - Lose depth cues and introduce misleading information



(a) Traditional Image created by blending two images

(b) DVRI

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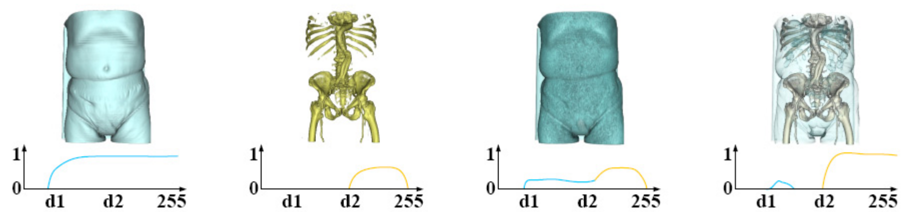
Linear Combination of TFs

- Linear Combination of TFs
  - Nonlinear operations of the integration used in DVR makes it inappropriate for the general fusing problems



(a) (b) (c) (d)

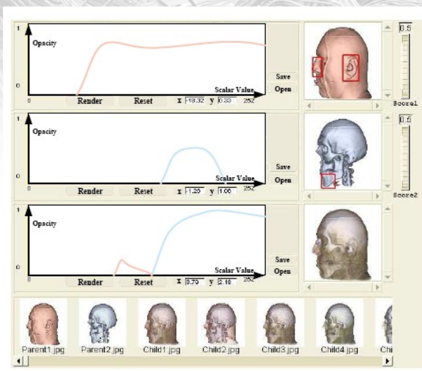
(a)-(b) Source images 1 and 2, and their TFs: TF1 and TF2; (c) DVRI rendered with a linearly combined TF: TF3 = α*TF1+ ß *TF2, where a = 0.3 and ß = 1; (d) DVRI rendered with our method by fusing (a) and (b)

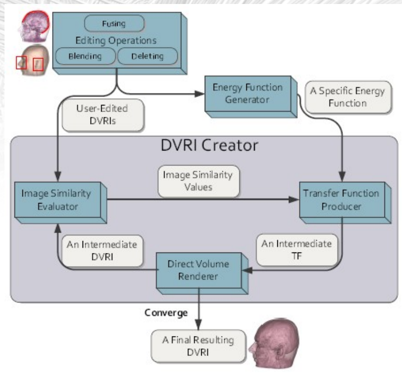
A Robust DVRI Editing Framework

- We introduce a general and robust editing framework to solve the general DVRI editing problem
  - Allows users to directly manipulates features in DVRIs
  - Integrates user knowledge into the optimization process

- The uses of the framework are two-fold:
  - As an image editing tool
    - For users without expertise in TF, our system is a Photoshop-style editing tool for DVRIs while TFs are only used internally and will not be exposed to users.
  - As an interactive TF design method
    - For expert users, our system can show the generated TF, which can be further edited or manually fine-tuned by users. The system allows users to interactively and intuitively design TFs from simple to complex by gradually editing simple DVRIs into comprehensive ones

System Overview





(a) *(b)*

(a) User interface which consists of source DVRIs and their TFs, target DVRI and its TF, and a history region; (b) System architecture which consists of energy function generator, transfer function producer, direct volume renderer, and image similarity evaluator

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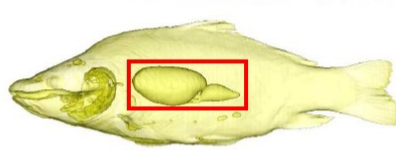
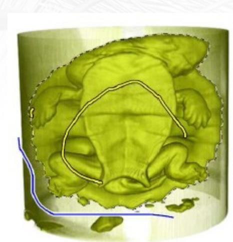
Feature Selection

- Our approach allows users to select desired features in DVRIs to edit using rectangles or semi-automatic feature selection tools





Rectangles ***Lazy Snapping***

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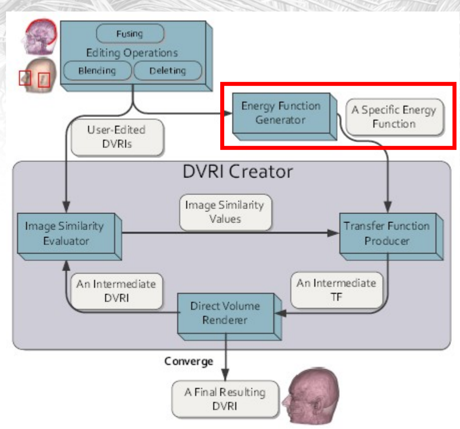
Editing Operations

- Fusing Operation
  - Combines multiple user selected features which appear in different DVRIs into a comprehensive one
- Blending Operation
  - Composites two DVRIs and generate a similar resulting image from alpha blending.
- Deleting Operation
  - Removes extra features from a DVRI

Energy Function Generator



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Energy Function

- An energy function for evaluating the fitness of candidate solutions should be formed after users specify editing operations in DVRIs
- The energy function is based on image similarity and editing operations to objectively evaluate the fitness of intermediate TFs
- It returns the measurement to the Genetic Algorithm (GA) module
  - The values are used to determine which genomes in the current population are more likely to be selected to survive

Fusing Operation

- The energy function: $F_1 = \sum_{k=1}^{n} V_k * |V_k - S_k|$
  - n : number of source images to be fused
  - V_k: the vote (or user expected similarity value) given by users for the features in source image k
  - S_k: the computed image similarity value between the candidate image and source image k

(a) (b) (c) (d) (e) (f) (g)

The fusing operation: (a)-(d) Source DVRIs; (e) Target DVRI generated with V1 = 0.7, V2 = 0.3, V3 = 0.4, and V4 = 0.6; (f) Target DVRI generated with V1 = 0.5, V2 = 0.5, V3 = 0.5, and V4 = 0.6; (g) Target DVRI generated with V1 = 0.3, V2 = 0.7, V3 = 0.6, and V4 = 0.4

Blending Operation

- The energy function: $F_2 = \alpha_1 * |\alpha_1 - S_1| + \alpha_2 * |\alpha_2 - S_2|$
  - α_1 and α_2: the alpha values used for blending
  - S_1 and S_2: the computed image similarity value between the candidate image and the source images to be blended

(a) (b) (c)

The blending operation: (a)-(b) Source images with bone and skin respectively; (c) Target image generated by blending (a) and (b) using our system

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Deleting Operation

- The energy function: $F_3 = S_1 + (1 - S_2)$
  - S_1 is the computed image similarity value between the candidate image and the source image within region A where a selected feature is to be removed, and S_2 is defined the same as S_1 but outside A

(a) (b) (c)

The deleting operation: (a) A DVRI where the skin is to be removed; (b) Mask created from (a) using lazy snapping; (c) Resulting DVRI after executing the deleting operation

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Mix Multiple Editing Operations

- Our system enables users to mix different basic operations together
  - Users can fuse multiple features in distinct DVRIs together and can meanwhile remove certain features from some DVRIs
- The energy function:

$$F = F_1 + F_2 + F_3$$

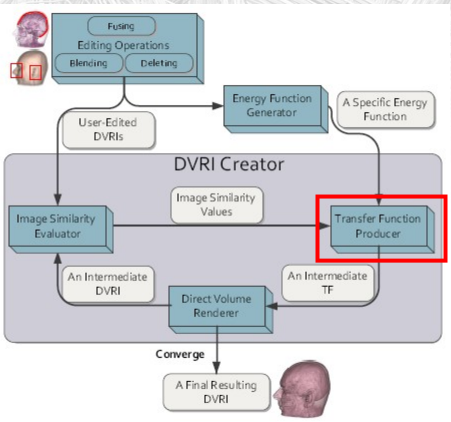
Editing Features from Different Viewpoints

- Given *n* viewpoints and their corresponding DVRIs
  - Select a common good viewpoint
  - Re-render the user selected features from this viewpoint
  - Apply the basic DVRI editing operations to these new DVRIs

(a) *(b)* *(c)*

The editing operation on DVRIs generated from different viewpoints: (a)-(b) Source images generated from different viewpoints; (c) Resulting image generated by blending the (a) and (b)

Transfer Function Producer



Genetic Algorithm

- A *Genetic Algorithm* (GA) is a search algorithm imitating the process of natural evolution
- It is particularly useful for searching solutions to optimization problems, especially when the search space is huge and unknown

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Solution Encoder/Decoder

- The solution encoder/decoder specifies the genome representation by analyzing the source TFs
  - 1D array of floating numbers
- The process:
  - Smoothens the source TFs
  - Samples TFs adaptively above the Nyquist frequency

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Genome Representation

- The samples are then used to specify the genome representation
  - They can be used to restrict the search space to improve the GA performance
  - The yellow points below are the genome representation

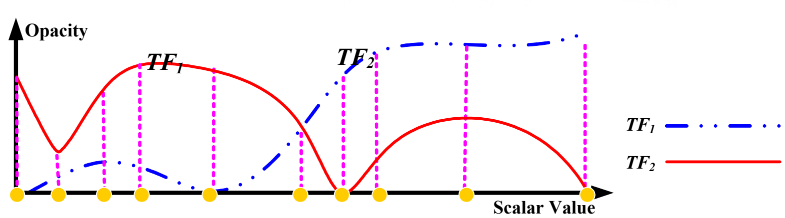

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Image Similarity Evaluator

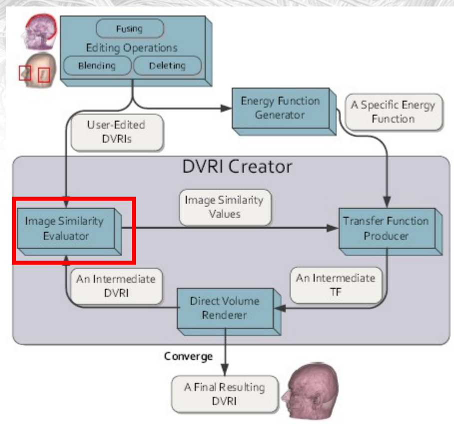


Image Similarity Metric

- A contour-based similarity metric is developed to compare two DVRIs
- The preprocessing:
  - Converts DVRIs into grey-scale images
  - Detects the edge images from the grey-scale images with *Canny edge detector*
  - Smoothes the edge images with a Gaussian filter

How to Compute Image Similarity

- The image similarity value S_k is:

$$
\begin{aligned}
S_k &= \frac{\sum_{y=1}^{height} \sum_{x=1}^{width} Q(x,y)}{N_{source}} \\
Q(x,y) &= \begin{cases} 1 & \text{if} \quad P(x,y) < threshold \\ 0 & \quad Otherwise \end{cases} \\
P(x,y) &= |K_{(x,y)} - K'_{(x,y)}|
\end{aligned}
$$

  - N_{source} : the number of all pixels on the edges of the source k's edge image
  - K and K' :are the Gaussian filtered target and source edge images with resolution (*width*, *height*)

Supplement to Image Similarity

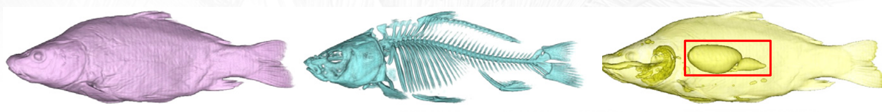
- Notice that we consider only the pixels on the source edge image k for S_k
  - S_k is only computed if $K'_{(x,y)}$ *!=0*

$$
\begin{aligned}
S_k &= \frac{\sum_{y=1}^{height} \sum_{x=1}^{width} Q(x,y)}{N_{source}} \\
Q(x,y) &= \begin{cases} 1 & \text{if} \quad P(x,y) < threshold \\ 0 & \quad Otherwise \end{cases} \\
P(x,y) &= |K_{(x,y)} - K'_{(x,y)}|
\end{aligned}
$$

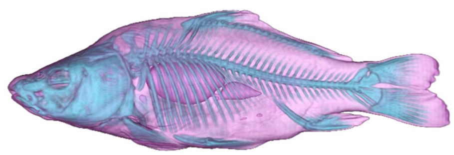
- If there are user-selected features in the DVRIs which are to be compared, our system considers only the pixels within these features
  - N_{source} becomes the number of pixels within the features on the edges of the source edge image

Results for The Basic Editing Operations (Fusing)

- Create a new DVRI (d) by fusing the features in multiple DVRIs (a), (b), and (c) into a comprehensive one (d) with V_1=0.3, V_2=0.4, and V_3=0.3



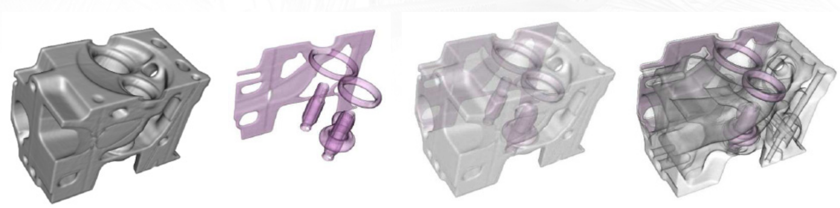
(a) *(b)* *(c)*



(d)

Results for The Basic Editing Operations (Blending)

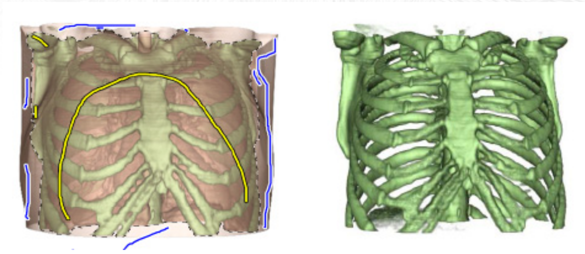
- Generate a new DVRI (c) by blending DVRIs (a) and (b)
  - (c) Obtained by traditional alpha-bending
  - (d) Created by our approach (better details)



(a) *(b)* *(c)* *(c)*

Results for The Basic Editing Operations (Deleting)

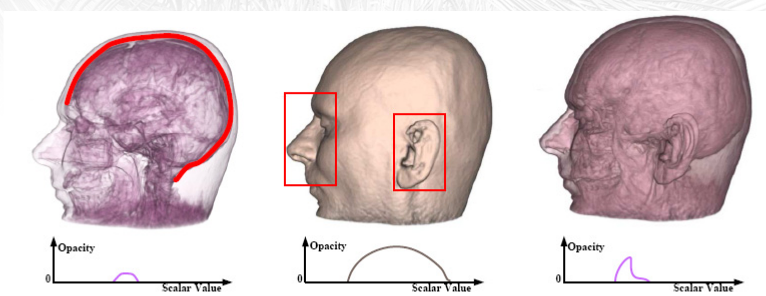
- Generate a new DVRI (b) by deleting feature (a) indicated by blue strokes while retaining the feature selected by yellow strokes



(a) *(b)*

Examples for TF Design (1/2)

- Creating a DVRI of better quality (*i.e.*, clearer contours) by fusing the selected features in (a) and (b)



(a) *(b)* *(c)*

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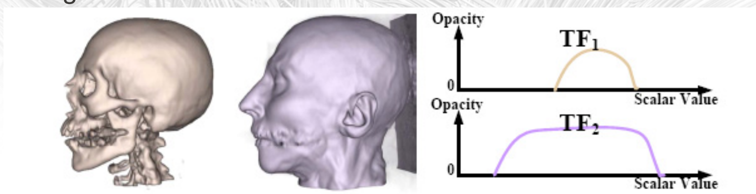
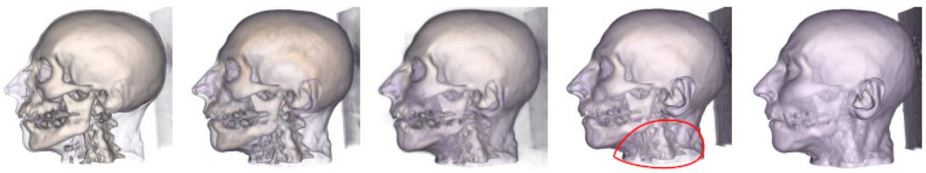
Examples for Generating Animations

- Generating intermediate frames for animations



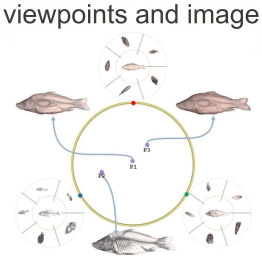
(a) keyframe1 *(b) keyframe2*



Intermediate frames created by the blending operation

Palette-Style Interface and Radial Graph Interface

- A palette style intuitive interface is further developed to server as the front-end of the editing framework
- A radial graph interface arranges the resulting images based on viewpoints and image quality for detailed exploration

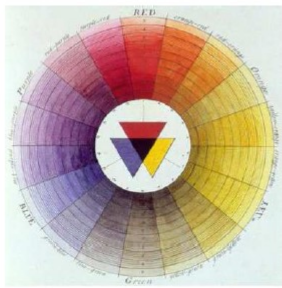


Palette-Style Volume Exploration Interface

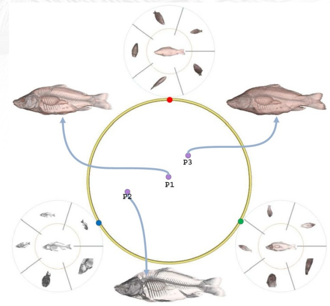
Radial Graph

Palette-Style Interface

- A palette-style interface motivated by the color palette is proposed for intuitive DVRI generation to increase exploration intuitiveness, reduce exploration redundancy, and save and share exploration results



Moses Harris: the first color wheel to classify red, blue and yellow as the three primary colors



Palette-Style Volume Exploration Interface

Visualization Process with The Interface

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1. Primary opacity TFs and DVRIs (analogy of the primary color in the color palette) are created automatically or semi-automatically
2. More DVRIs of different opacity TFs can be created by fusing the primary DVRIs in the DVRI wheel
3. The system enables users to further explore the data using the created opacity TF with different parameters in a separate radial graph

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Primary DVRI Generation

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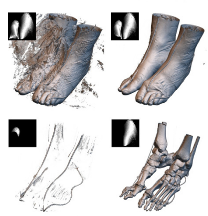
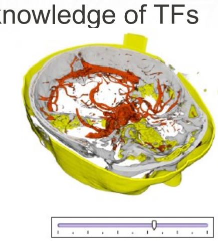
- Primary DVRIs (analogy of primary colors in the color palettes) can be created by experts manually or semi-automatically which makes boundaries of structures in volumetric data visible
- For non-expert users, other high-level methods can be adopted for primary DVRI generation without the knowledge of TFs



Kindlmann and Durkin 1998



Salama et al. 2006

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Editing Operations on The DVRI Wheel

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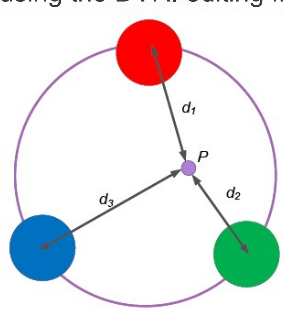
- After creating primary DVRIs, our system allows users to generate more DVRIs from the primary ones intuitively
- Users just need to select a point on the DVRI wheel and indicate how to fuse the DVRIs using the DVRI editing framework



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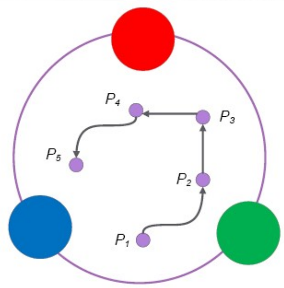
Animation Generation

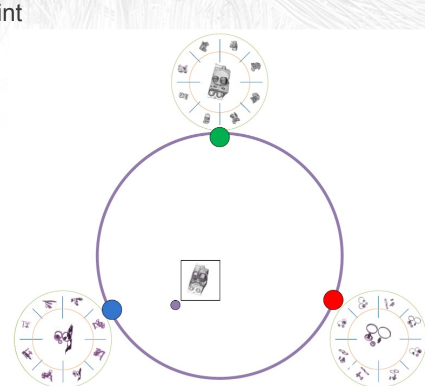
- Animation can be used to reveal 3D relationships between the different structures more effectively than a still image
- Users can create an animation for volume visualization using the DVRI wheel intuitively based on the fusing operation



Animation operation

Support for Multiple Viewpoints

- Primary DVRIs can be generated from different viewpoints
  - However, image similarity can be computed only for DVRIs rendered from the same viewpoint



Radial Graph for Detailed Exploration

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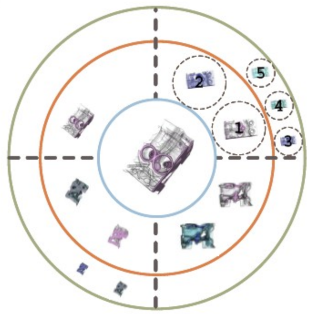
- Users may need to further explore the volume using the opacity TF with different lighting parameters, color TFs, and viewpoints
- A new radial graph style interface was proposed to arrange the resulting images based on viewpoints and image quality



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Graph Layout

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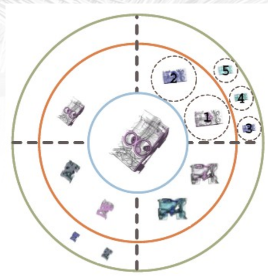
- The graph layout consists of multiple concentric circles, and the radii for these concentric circles are $r_1 \ldots r_n$ from inside to outside and defined as

$$r_i = r_{i-1} + \frac{(r_{i-1} - r_{i-2})}{2}$$

  - where i >=3 and $r_2 = 2r_1$, and $r_1 = C$, *and* C is determined by users



A radial graph for detailed volume exploration with the same opacity TF

- The graph is further divided into multiple sectors for storing the DVRIs created from different viewpoints

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Image Quality Evaluation

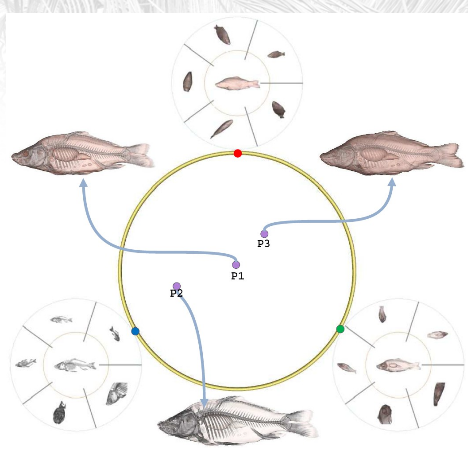
- In each sector, the DVRIs are sorted in terms of image quality so that better DVRIs have larger sizes and are closer to the center
- The features and details in an image with a higher contrast are always better perceived by viewers
  - Contrast can be interpreted as the standard deviation of the pixel values in the image:

$$\sigma = \sqrt{\frac{1}{|\Omega|}\sum_{\Omega}(v(i)-\mu)^2}$$

where Ω is the image and $v(i)$ is the intensity of pixel i, and μ is the mean value of all pixels in the image

Volume Exploration (1)

- Intuitive Volume Exploration



Volume Exploration (2)

- A palette-style DVRI wheel for creating animation
  - An animation was generated along the user selected path P1→P2→P3

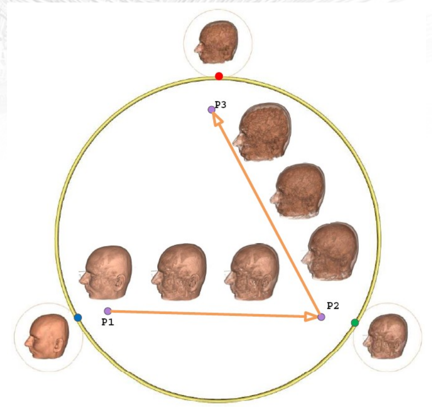
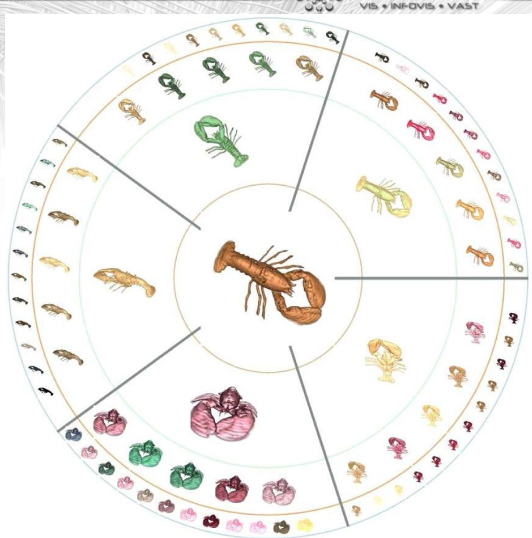


Image Quality Evaluation

- A radial graph for detailed volume exploration
  - The radial graph was divided into multiple sectors for different viewpoints, and the DVRIs in each sector were sorted according to the image quality such that DVRIs with higher image quality lie closer to the center



Outline

- Introduction
- Transfer Function Design Based on Editing Direct Volume Rendering Images
- Quality Enhancement of Direct Volume Rendered Images
- Quantitative Effectiveness Metrics for Direct Volume Rendering

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Introduction (1/3)

- Direct volume rendering for scientific visualization
  - Revealing different structures by specifying proper transfer functions
  - Allowing visual analysis on the volumetric data
- Quality of the DVRIs is an important issue
  - Ensuring features are clearly shown (enhanced features)
  - Preserving the information in the volume
  - Delivering a pleasing result (better contrast)

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Introduction (2/3)

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- Quality enhancement in image domain
  - Commonly used image processing approaches, *e.g.,* contrast and feature enhancement
  - Formation of a new image with certain mapping of pixel values
  - Objective: easy interpretation of image information
  - Drawbacks: information may be missing in the image and cannot be restored

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Introduction (3/3)

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- Our approach: working in transfer function and volume domains
  - Image measurement: evaluating the effectiveness of the image in conveying the volume information
  - Parameter refinement: adjusting the rendering parameters for better image quality
- Restoring the missing information due to poor lighting and rendering settings
- Revealing the information in the volume by analyzing the composition of the rays in the rendering process

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Limitations of Image-Based Approaches

- Limitations of image-based approaches
  - Cannot recover the missing details due to poor lighting
  - Cannot enhance the structure with respect to the topology and shape in the volumetric data
- Our method:
  - Taking the volume into consideration to preserve the details

Typical Problems in DVRIs (1/2)

- Structures are not clearly shown due to poor lighting and rendering parameter settings
- Pixels in the DVRIs cannot give any implication on the existence of structure
  - Homogenous regions in DVRI may represent some fine features
  - They should demonstrate certain variations in the image to convey the information of the structures

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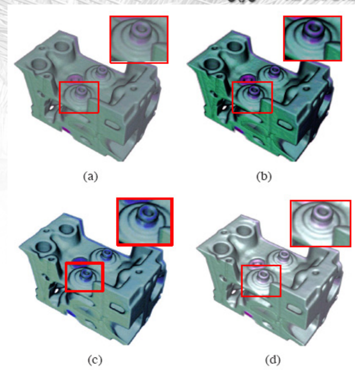
Typical Problems in DVRIs (2/2)

An example using the CT engine dataset: (a) shows the original image with a poor contrast; (b) and (c) are the images enhanced by Photoshop and manual adjustment using various image filters; (d) is the result generated by adjusting the rendering parameters.



- Idea: with the help of the volumetric data and the knowledge of the rendering process of DVRIs, we can
  - Further improve the image quality accordingly
  - Reinforce the hidden details about the volume in the image

Image Quality Measurement

- The quality of DVRIs is defined as the effectiveness of the rendered images in presenting the information in the volumetric data
  - Determine whether the image can show a significant variation in regions where the rays carry different information
- To quantitatively analyze a DVRI, we establish several measurements for both image and volume data information

Image Measure

- Variations / information in an image are interpreted as contrast
- Homogeneity measurement [Cheng et al. 03']
- Image standard deviation σ as $\sigma(x) = \sqrt{\frac{1}{|\omega|}\sum_{\omega}(v(i) - \mu_x)^2}$
- Image entropy h as $h(x) = -\frac{1}{log|\omega|}\sum_i p_i log p_i$
- Estimate the visual information in the image
- Final image measure: $M_I(x) = \sigma(x) \times h(x)$

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Ray Measure

- Each sample point contributes to the final image in different degrees and their contribution can be estimated by

$$\alpha(1 - \alpha_{accum})$$

- We estimate the information carried by the rays and their variations by considering those visible sample points along the rays
- Ray measure can be represented as

$$M_R(R) = -\sum_i p_i \sum_j p_i(j) log p_i(j)$$

  - Entropy term on the composition of the rays
  - Signifying the information variation among rays

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Composite Measure

- Compositing measure on the quality of an image

$$M_C = (1 + exp(-\frac{-M_I + M_R}{s}))^{-1}$$

- Indicating the deviation between the image and ray information at each pixel in the image
- Minimizing the overall information deviation - preserving the information of the volume in the image domain.

Parameter Refinement

- Adjusting different rendering parameters for better results
  - Manual adjustment
    - Tedious and non-trivial task
  - Optimization of the parameters using a genetic algorithm
    - Image quality measure as the fitness measure
    - Parameters involved:
      - Reflection / illumination model
        - » Ambient, diffuse and specular coefficients
      - Transfer function
        - » HSV (brightness and saturation)
        - » YIQ (luma information)
        - » Only “safe” channels are modified to preserve the original color

Genetic Algorithm

- Combinatorial optimization of parameters
- Efficient search of an optimal solution in the parameter space through the evolution process
- Process driven by the image quality measure to obtain a better result
- Advantages:
  - stochastic search - avoiding local optima
  - efficient

Adaptive Enhancement and User Interaction

- Adaptive enhancement
  - Preserve the under-enhanced details missing in the global configuration
  - Enhance and refine on certain parts of the DVRI
- User interaction
  - Highlight regions in the image
  - Select Structure in volume / intensity domain
  - Process on the selected regions and the corresponding rays

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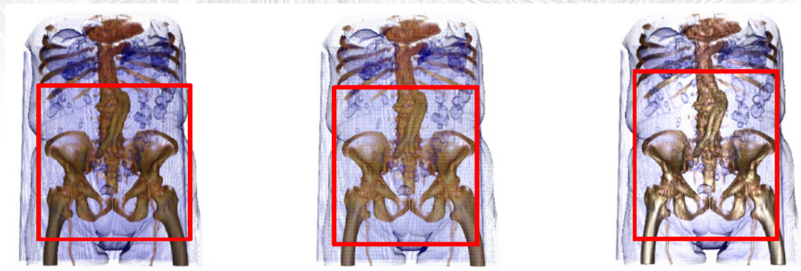
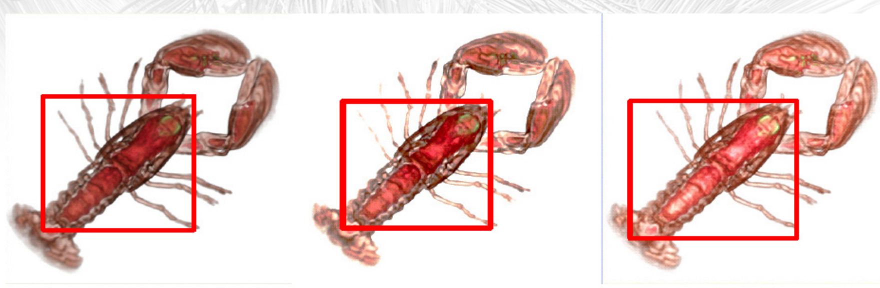
Experimental Results



(a) (b) (c)

Experimental Results



(d) (e) (f)

Outline

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Visualization Tasks and Features of Interest

- The effectiveness of a visualization highly depends on the tasks that can be classified into two categories
  - Routine tasks
    - Users usually have prior knowledge of the features that they intend to visualize
  - Exploration tasks
    - Features of interest are unknown
      - Use other visualization techniques to explore the volume and gain some knowledge
      - Use our system in a divide-and-conquer manner
      - Estimate the useful information in the data automatically

- In summary, features of interest (or desired features) can be either specified by users or predicted by the system

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Effectiveness Metrics (1/3)

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- It is very difficult to design an ideal visualization system which can automatically reveal desired features to users
  - Huge parameter space (e.g., transfer function, viewpoint, lighting)
- Merely displaying these desired features one by one is not enough
  - Users want to know context and spatial relations between the features
- Even if only one feature needs to be displayed, self occlusion may become an issue.
- Artifacts and illusions may be introduced because of inappropriate lighting or view angles

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Effectiveness Metrics (2/3)

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- User interactions such as changing viewpoints and specifying transfer functions are needed
  - Routine tasks and exploration tasks
- Even if we know what users want, we may not have a perfect solution to present the information to users automatically so user interactions are still needed
- The interactions by non-expert users are often error prone and may introduce misleading information leading to unreliable conclusions
- A scheme is needed to let users know whether their fine tuned transfer functions or view angles are effective or not

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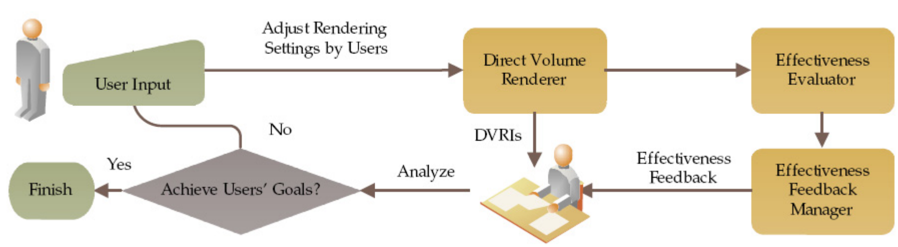
Effectiveness Metrics (3/3)

- There are two sets of effectiveness metrics
  - Adequate effectiveness metrics
    - If these metrics are satisfied then the visualizations tasks can be achieved
    - They are the holy grail of volume visualization and may not be possible for many applications in the near future
  - Necessary effectiveness metrics
    - If these metrics are not satisfied then visualization tasks cannot be achieved. However, even if these necessary metrics are satisfied, there is still no guarantee that the visualization tasks can be achieved
    - They are more practical and what we want to deal with

New Visualization Pipeline

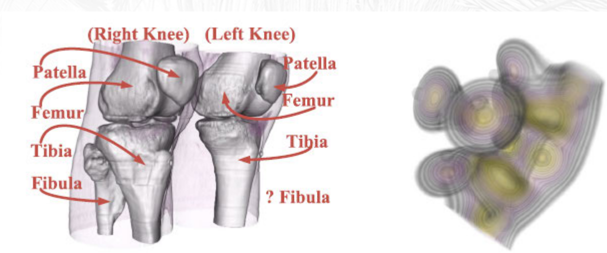


Effectiveness Evaluator

- The effectiveness evaluator is used to quantitatively and objectively assess the effectiveness of a DVRI or a whole visualization process based on three effectiveness metrics
  - Visibility metric
  - Distinguishability metric
  - Contour Clarity metric

Visibility Metric (1/2)

- The visibility metric measures the visibility of an important feature in a volume by counting the visible voxels of the feature



Two common cases where the visibility metric is needed: (a) DVRI of the CT Knee where the fibula of the left knee is invisible; (b) DVRI of the simulated Neghip having large variance of the intensity values

Visibility Metric (2/2)

- The visibility of voxels can be estimated in the process of full image-order volume rendering
  - Estimate visibility values for the sampling points along each ray

Visibility value V_i for sampling point *i*

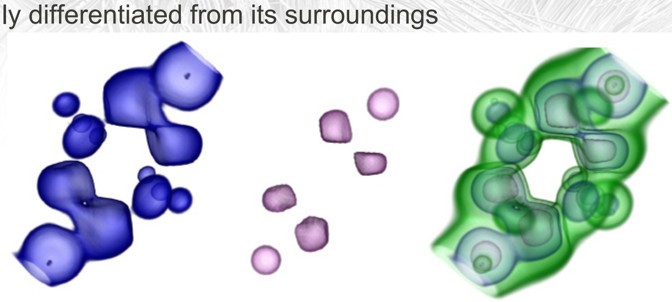
$$
\begin{aligned}
C &= \boxed{(1-\alpha) * \alpha_i * C_i} + C && (1)\\
\alpha &= \alpha_i * (1-\alpha) + \alpha && (2)
\end{aligned}
$$

  - V_i would be distributed to the neighboring voxels based on the corresponding weights used in the interpolation

- The visibility value of a DVRI can then be estimate as $E = n_i / n$
  - n_i and n are the number of visible voxels and the number of all voxels inside the important feature, respectively

Distinguishability Metric (1/2)

- The distinguishability metric evaluates how well a feature can be visually differentiated from its surroundings



(a) (b) (c)

(a) Structure A in blue; (b) Structure B in purple; (c) Blending A and B as well as a green structure C into a new DVRI where A and B are indistinguishable

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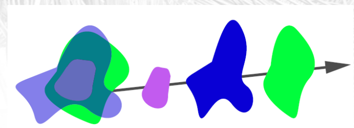
Distinguishability Metric (2/2)

- The distinguishability metric aims at detecting the ambiguity caused by the blending effect

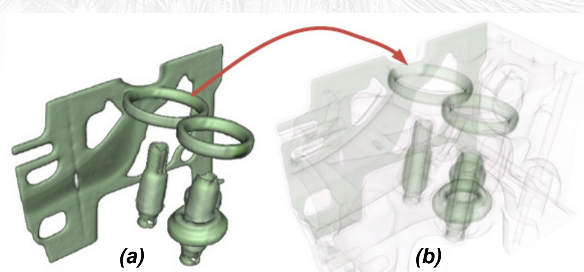


1. Segment a given DVRI into a number of fragments
2. Classify the fragments into two classes - fragments with the desired feature and fragments without the desired feature
3. If the fragment with the desired feature has color similar to any fragments without the feature, the metric will record the feature’s voxels that contribute to the fragment as indistinguishable voxels

- The distinguishability value of a DVRI can then be estimated as the ratio of the distinguishable voxels to indistinguishable voxels

Contour Clarity Metric (1/2)

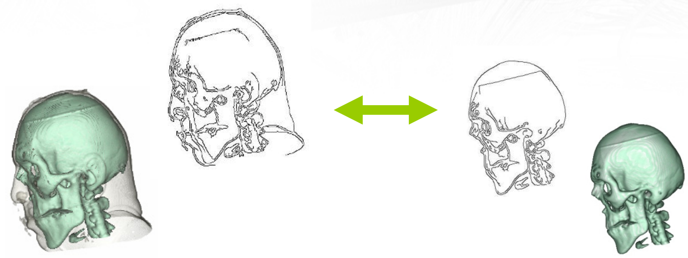
- The contour clarity metric measures how clear the contours of a desired feature are presented in a DVRI



A common scenario in volume rendering where the contour clarity metric is needed: the contours of an important feature as shown in (a) are fuzzy and unclear in (b) although the feature is visible and distinguishable

Contour Clarity Metric (2/2)

- The metric measures the contour clarity by estimating the similarity between the DVRI and the iso-surface of the salient feature
  1. Derive the edge images of both DVRI and the iso-surface
  2. Estimate the similarity between the two edge images



A given DVRI ***Salient iso-surface***

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Effectiveness for A Whole Visualization Process

- For the visibility and distinguishability metrics, we accumulate each voxel's effectiveness values at each DVRI in the visualization process
  - The overall effectiveness values can then be measured as the percentage of the visible and distinguishable voxels after the accumulation to all voxels, respectively.
- For each of other metrics,
  - Collect all explored viewpoints in the visualization process
    - Each viewpoint stores a highest effectiveness value for the metric and treat it as the metric value at this viewpoint for the whole process
  - Select the lowest effectiveness value among all explored viewpoints as the metric's effectiveness value of the process

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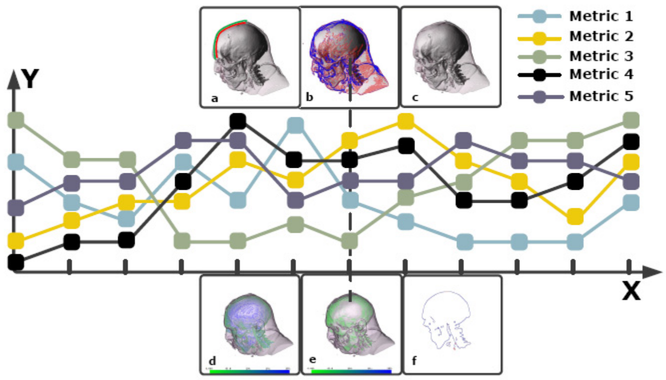
Effectiveness Feedback Manager

- It organizes and presents the effectiveness values to the end-users in an intuitive manner



Conclusions

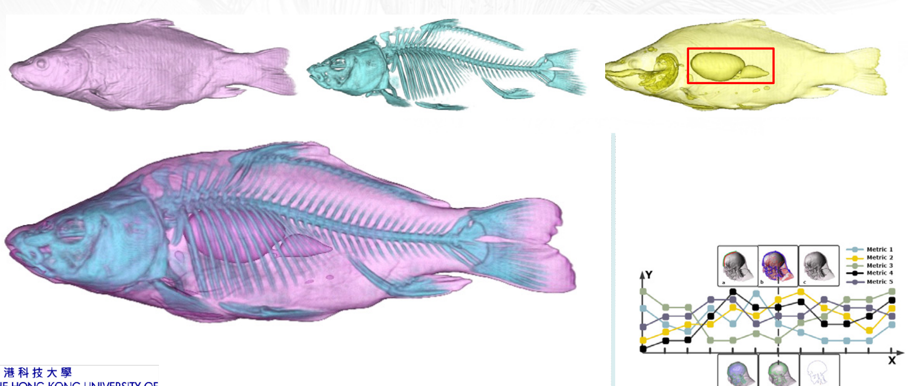
- Perception-based transfer function design and evaluation
- Transfer function design based on editing DVRIs
- Quality enhancement of DVRIs
- Effectiveness assessment of DVRIs

References

- Yingcai Wu, Huamin Qu. “Interactive Transfer Function Design Based on Editing Direct Volume Rendered Images", IEEE Transactions on Visualization and Computer Graphics (TVCG), Vol. 13, No.5, pp. 1027--1040, 2007
- Ming-Yuen Chan, Yingcai Wu, and Huamin Qu. "Quality Enhancement of Direct Volume Rendered Images", 6th IEEE/EG International Symposium on Volume Graphics (VG'07), pp. 25 - 32, 2007. (Cover Image)
- Yingcai Wu, Anbang Xu, Ming-Yuen Chan, Huamin Qu, and Ping Guo. "Palette-Style Volume Visualization", to appear in 6th IEEE/EG International Symposium on Volume Graphics (VG'07), pp. 33 - 40, 2007.
- Yingcai Wu, Huamin Qu, Ka-Kei Chung, Wai-Ho Mak, Anbang Xu. "Quantitative Effectiveness Metrics for Direct Volume Rendering". Poster, in the poster session of IEEE Visualization 2007 (Best Poster Candidate).

Q & A

- Thank you for your attention!



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