Smart Visualization in Medicine

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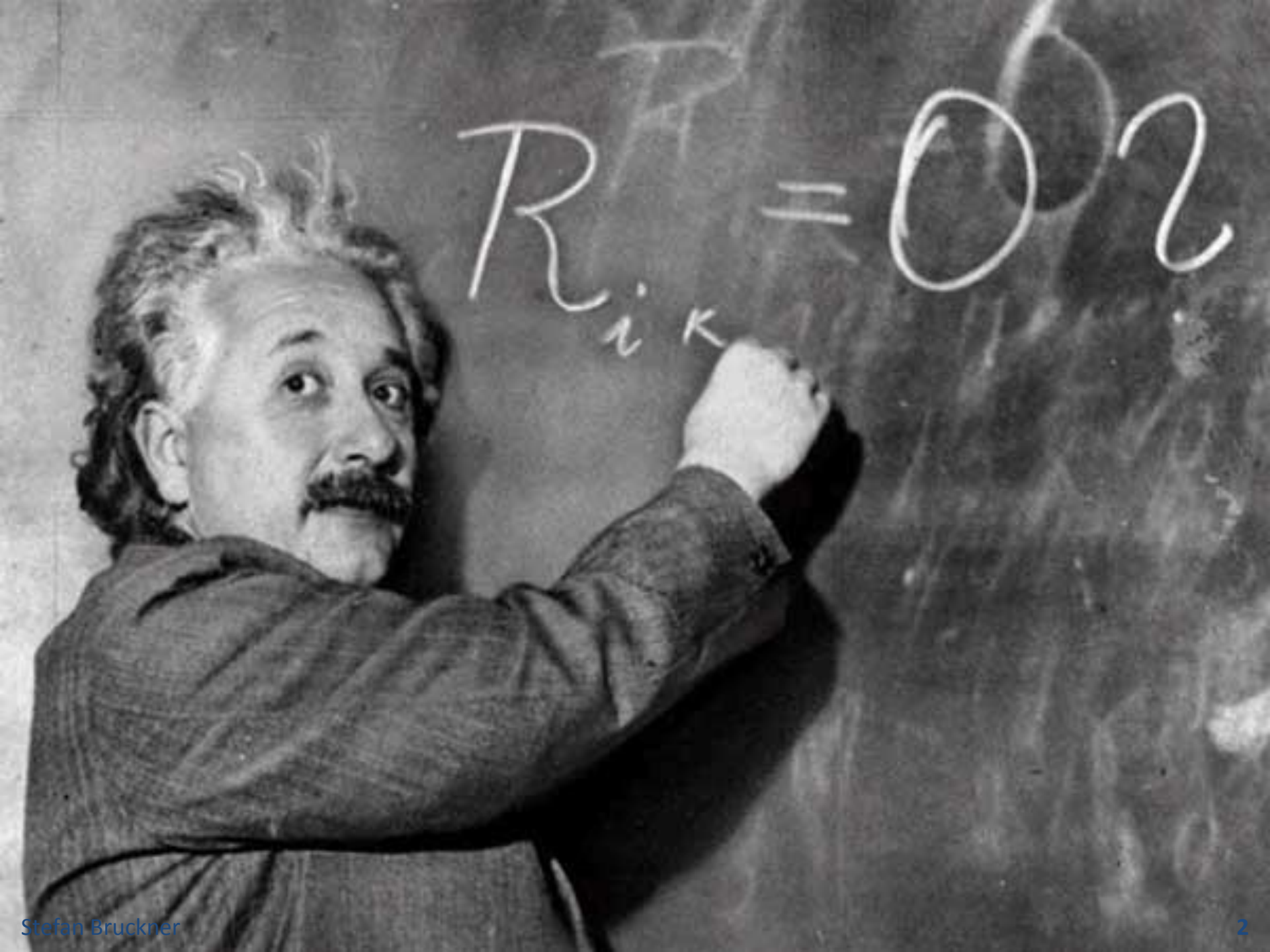

$R_{ik} = 0$

“Smart” Visualization

- Alternative terms: knowledge-assisted, knowledge-based, etc.
- Incorporate domain knowledge into the algorithm design
- Knowledge can be about data, user intent, and algorithm behavior
- “Smartness” comes from the effective use of existing information

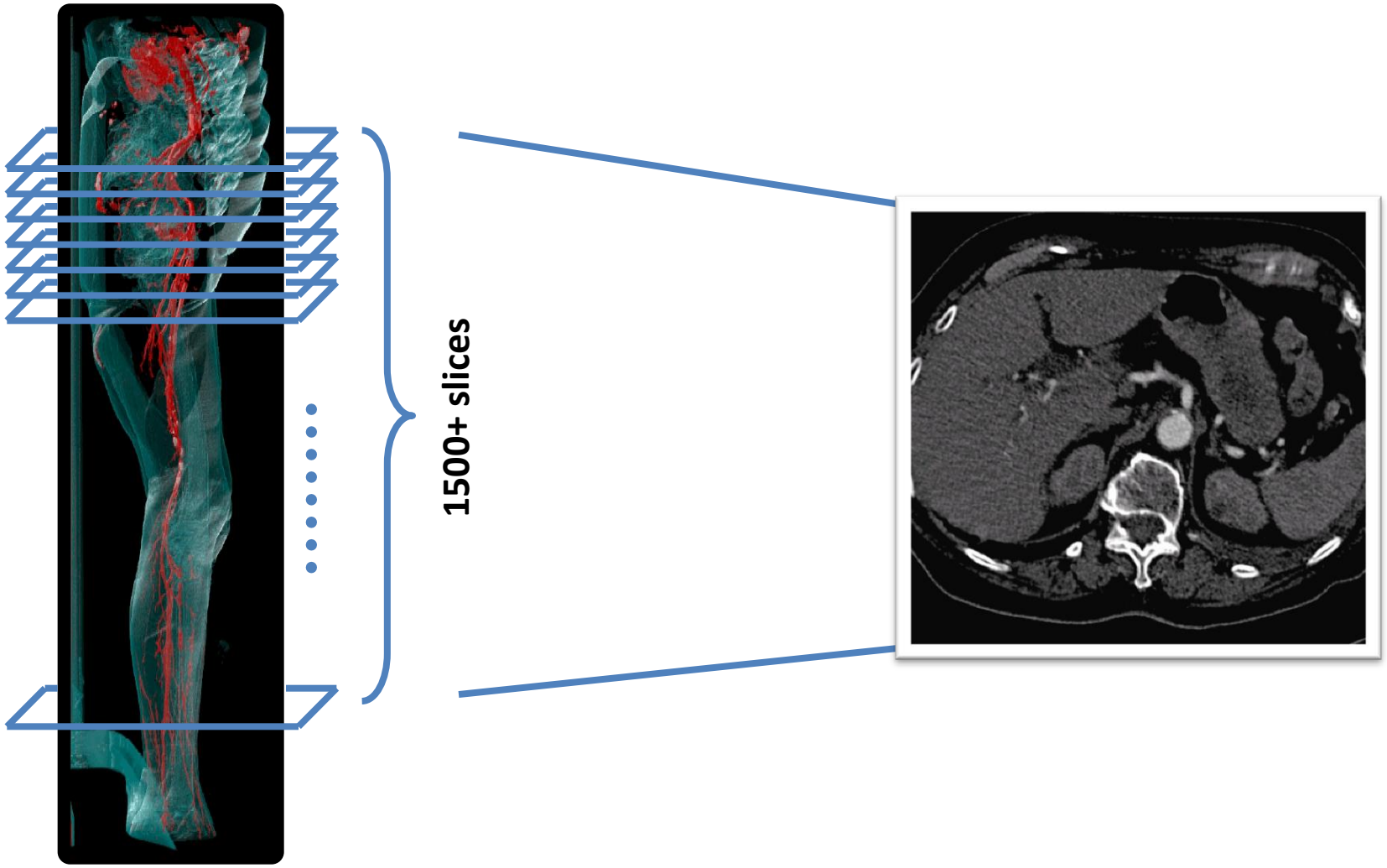
Levels of Smartness

- **Technique level:** consider the fact that the data has been generated for a reason
- **Parameter level:** recognize that not every part of the parameter space is meaningful
- **Interface level:** exploit knowledge about the performance of techniques/parameters

Visualization in Radiology

- Different imaging devices (CT, MRI, …)
- Archival of image data using PACS (Picture Archiving and Communication Systems)
- Imaging devices, output devices, workstations, and PACS are interconnected via the DICOM standard

Vessel Investigation (1)



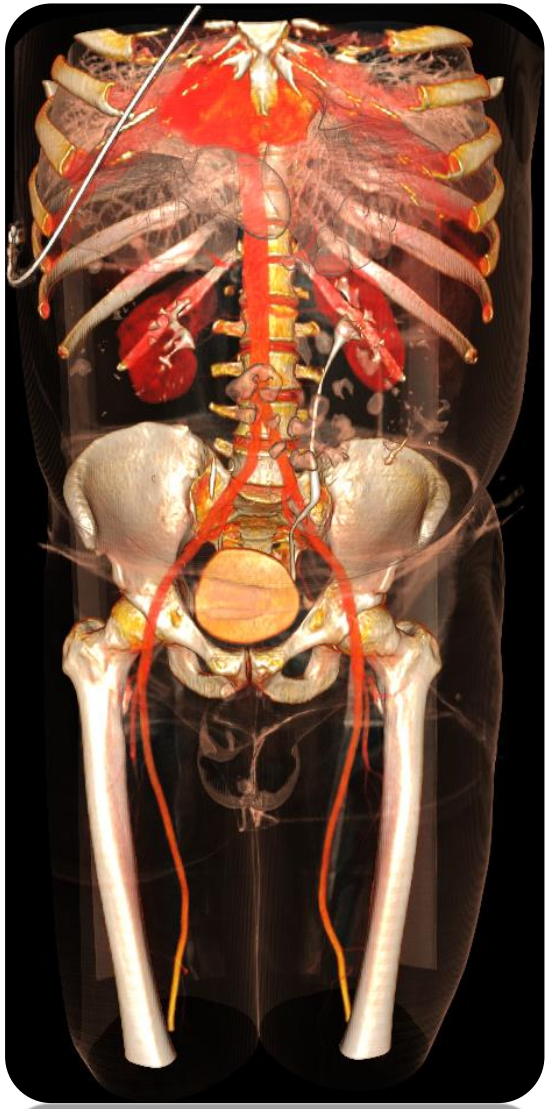
Vessel Investigation (2)

- High-throughput scenario, radiologist has no time to “play around”
- Many slices to inspect: time-consuming and error prone
- Mental reconstruction of the vessel tree can be difficult

Overall goal: make examination as safe and fast as possible

3D Visualization Methods

DVR – Direct Volume Rendering



MIP – Maximum Intensity Projection

DVR vs. MIP (1)

DVR

Direct Volume Rendering

- Physically-based
- Optical model for emission & absorption
- May require complex transfer function
- Visual cues due to accumulation and shading

MIP

Maximum Intensity Projection

- Practically-motivated
- Project maximum value along each viewing ray
- Suffices with window/level setting
- Spatial ambiguities caused by order-independency

DVR vs. MIP (2)

DVR

Direct Volume Rendering

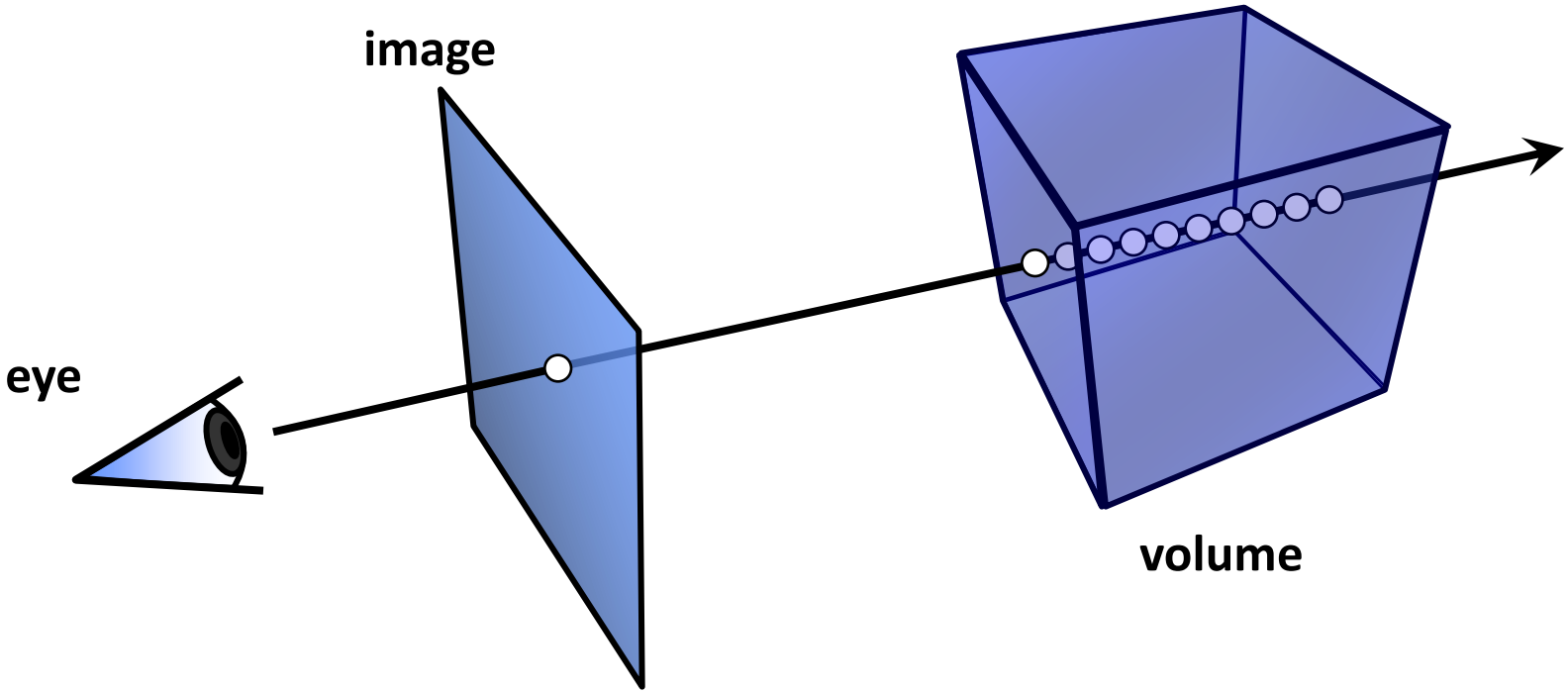
- Physically-based
- Optical model for emission & absorption
- May require complex transfer function
- Visual cues due to accumulation and shading

MIP

Maximum Intensity Projection

- Practically-motivated
- Project maximum value along each viewing ray
- Suffices with window/level setting
- Spatial ambiguities caused by order-independency

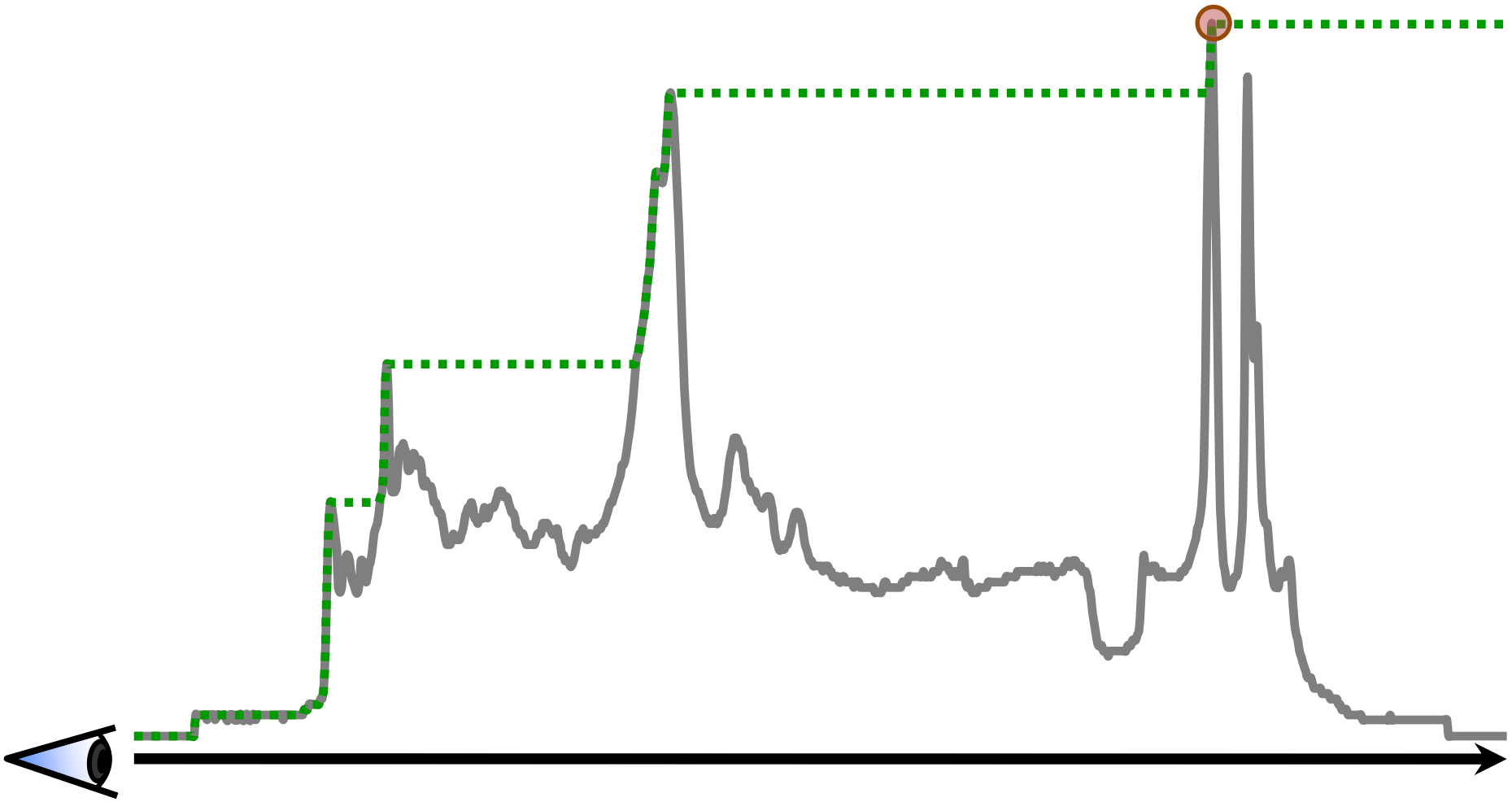
Volume Ray Casting



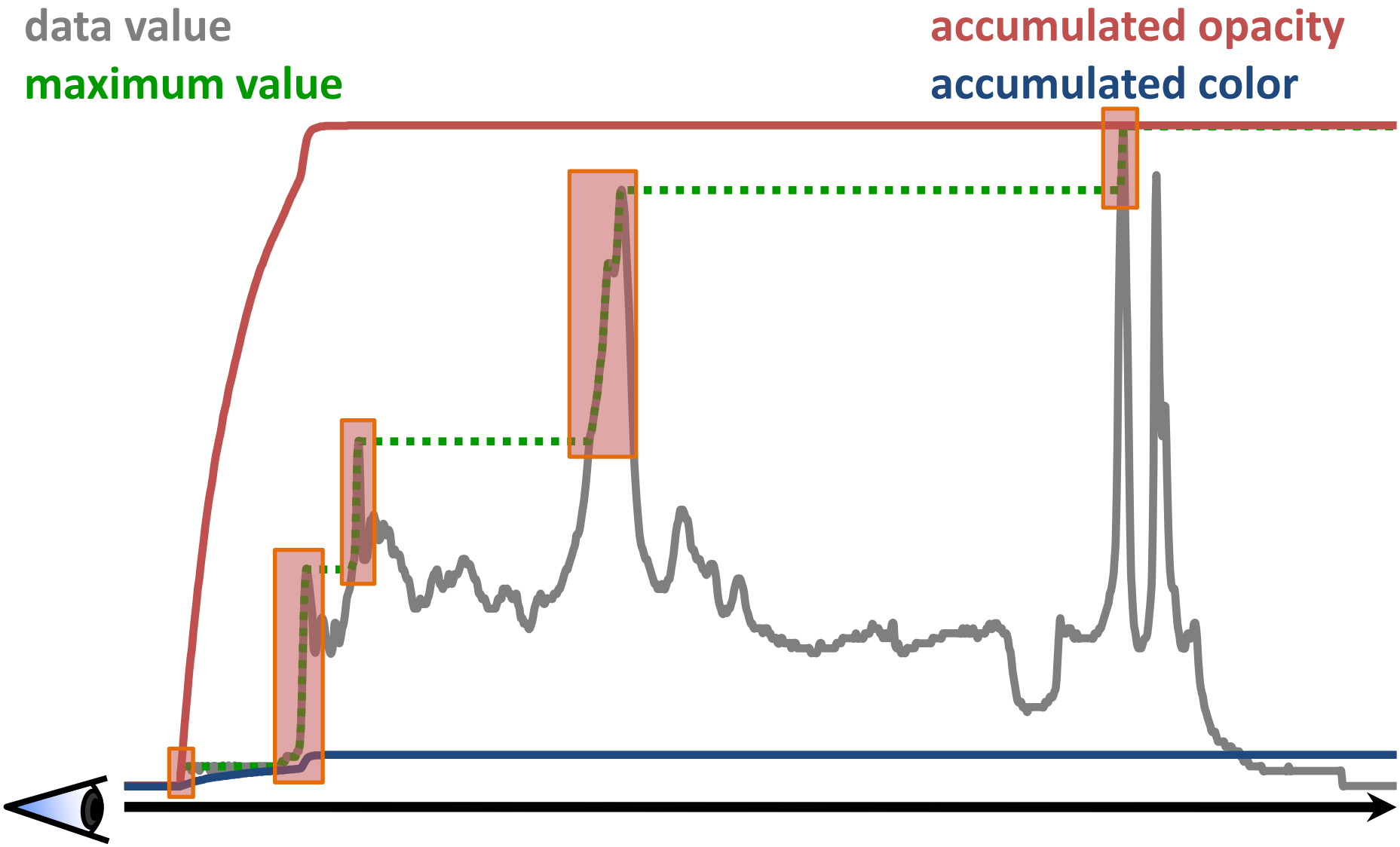
Maximum Intensity Projection

data value

maximum value



Direct Volume Rendering

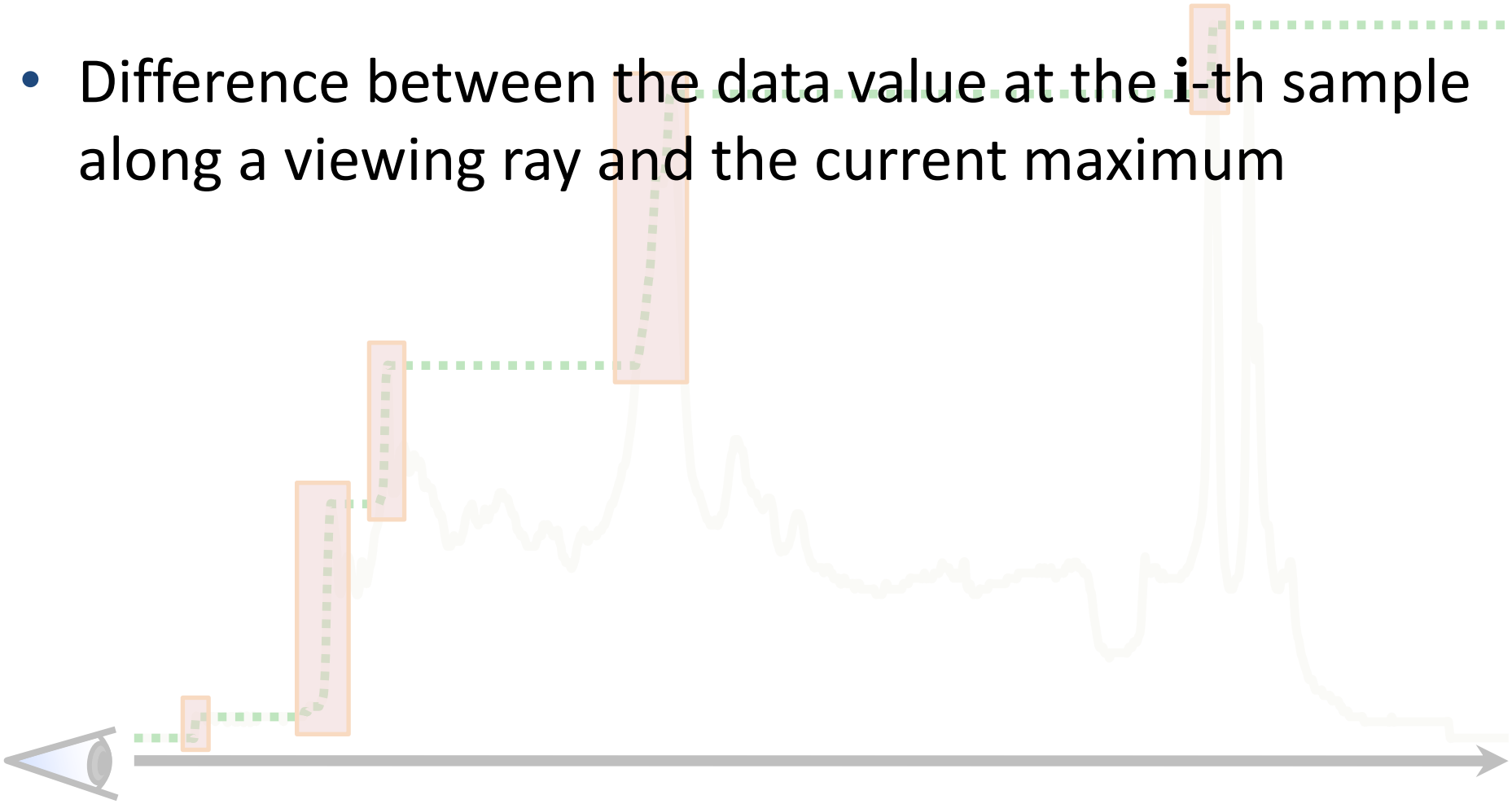


Maximum Intensity Difference

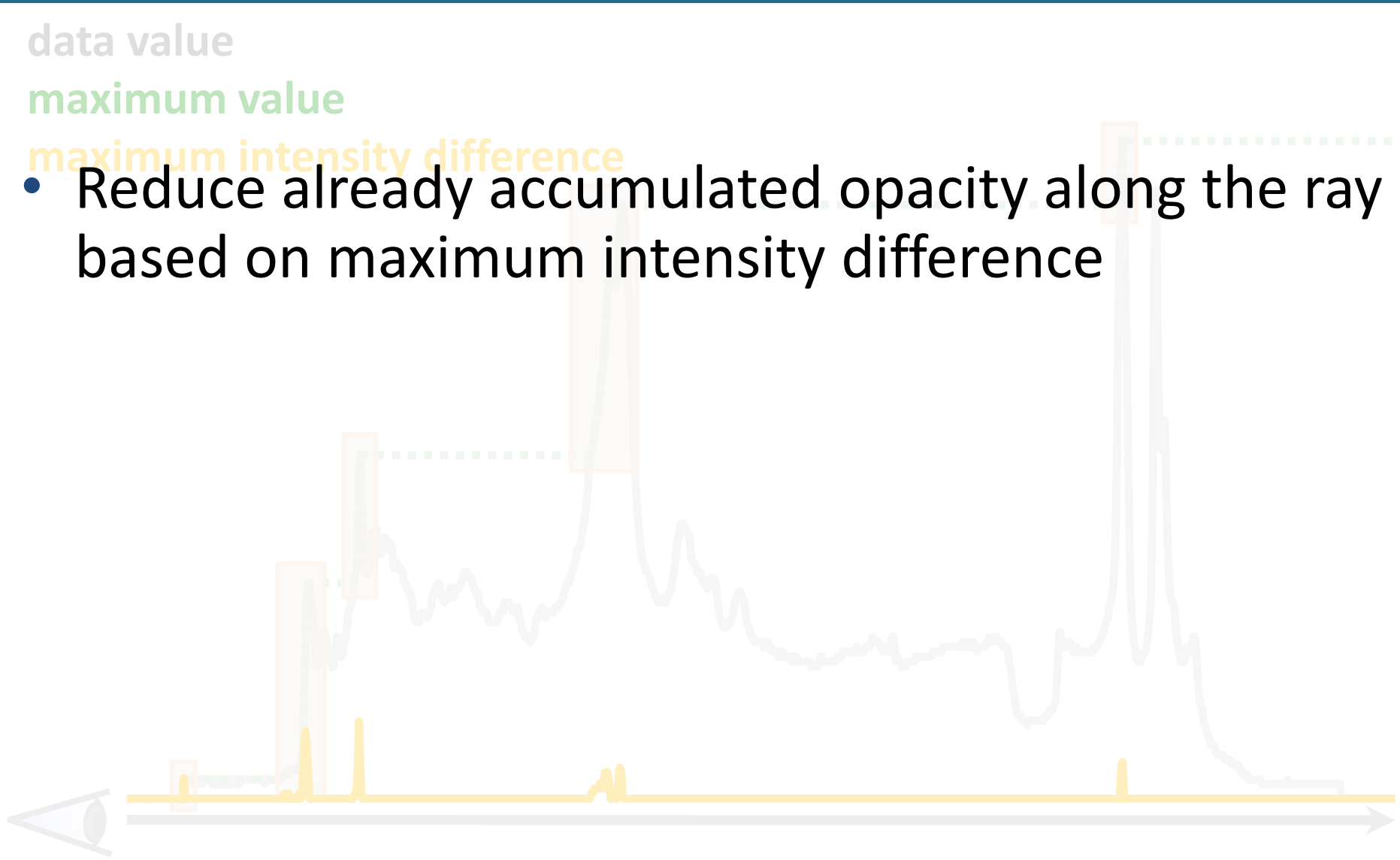
data value

maximum value

- Difference between the data value at the **i**-th sample along a viewing ray and the current maximum

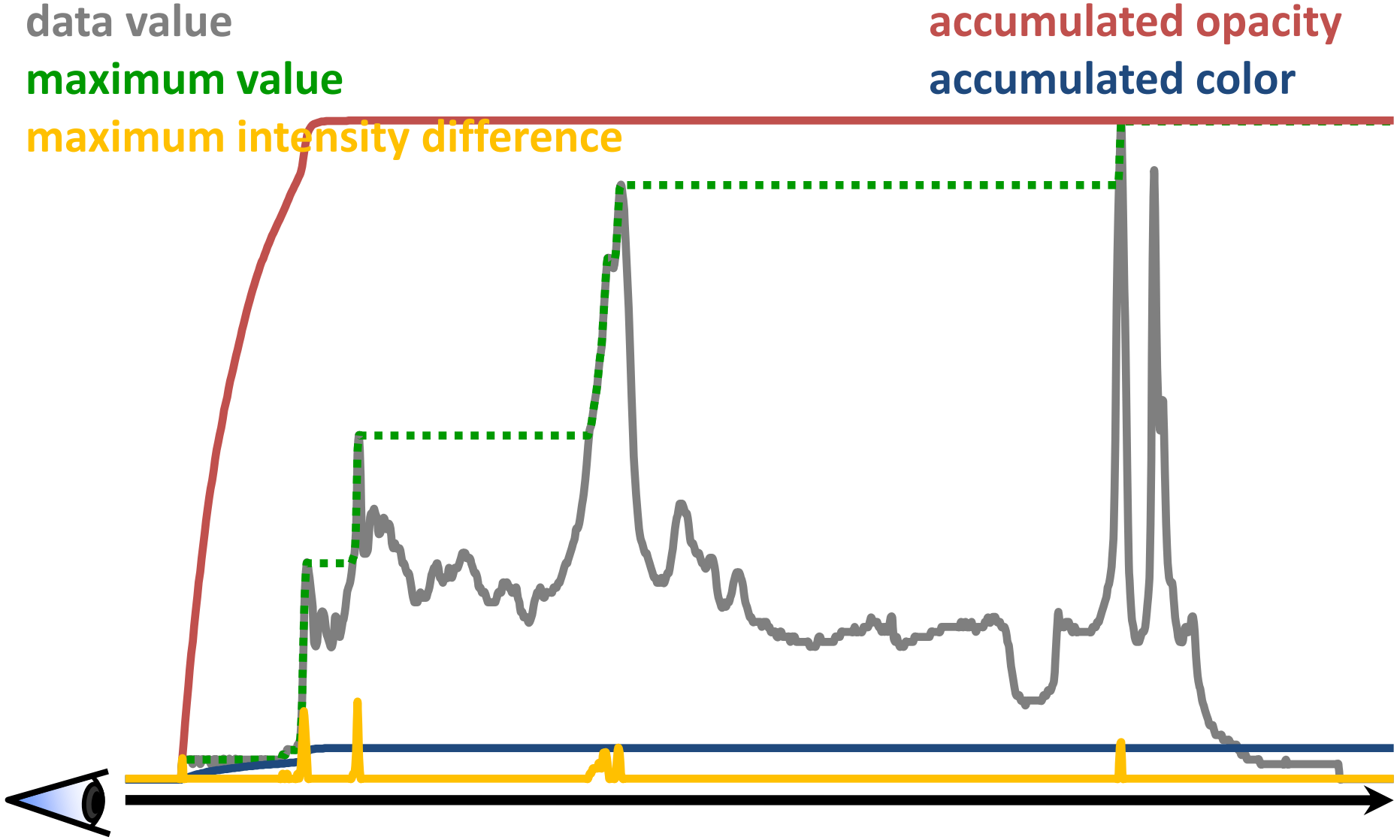


Maximum Intensity Difference

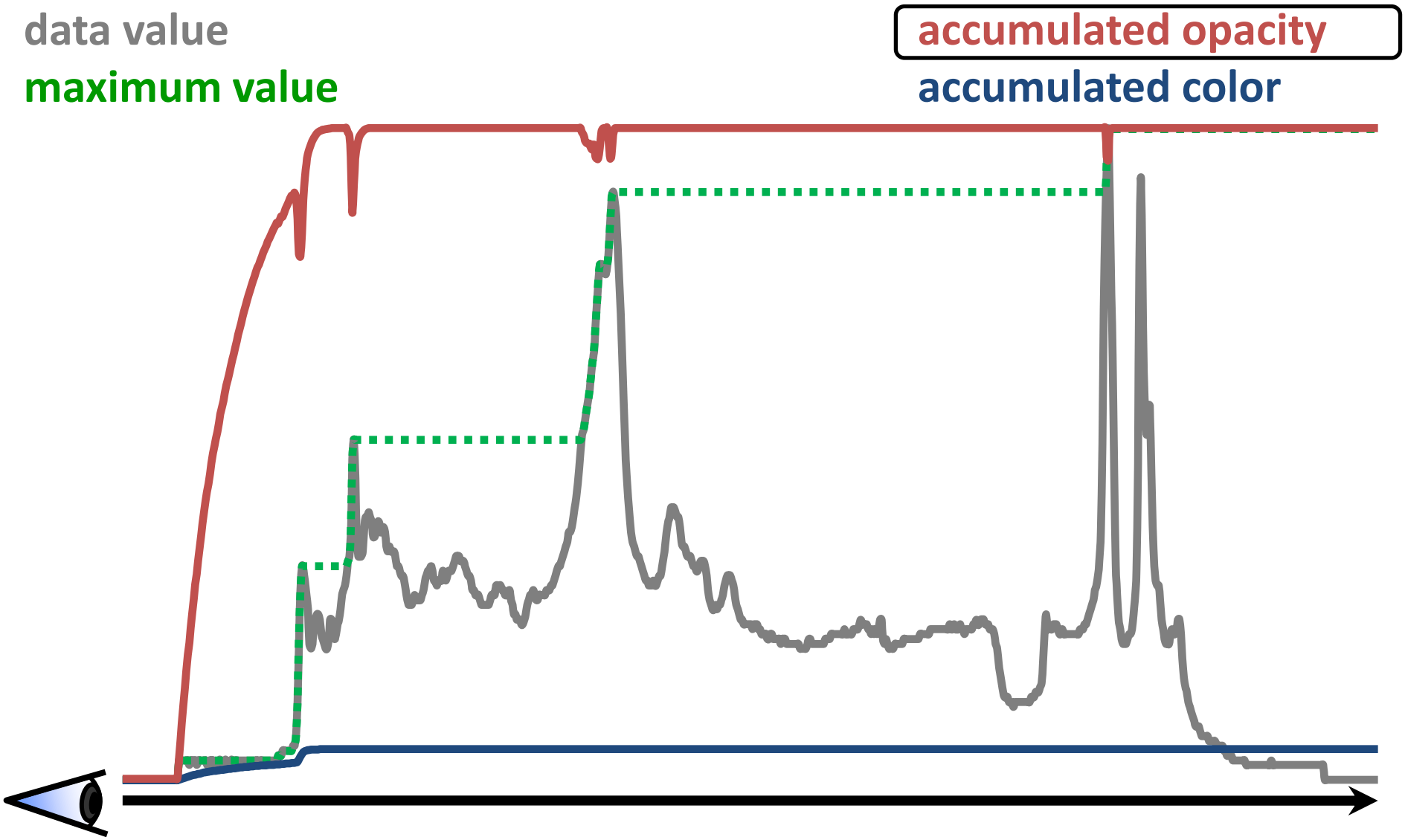


- Reduce already accumulated opacity along the ray based on maximum intensity difference

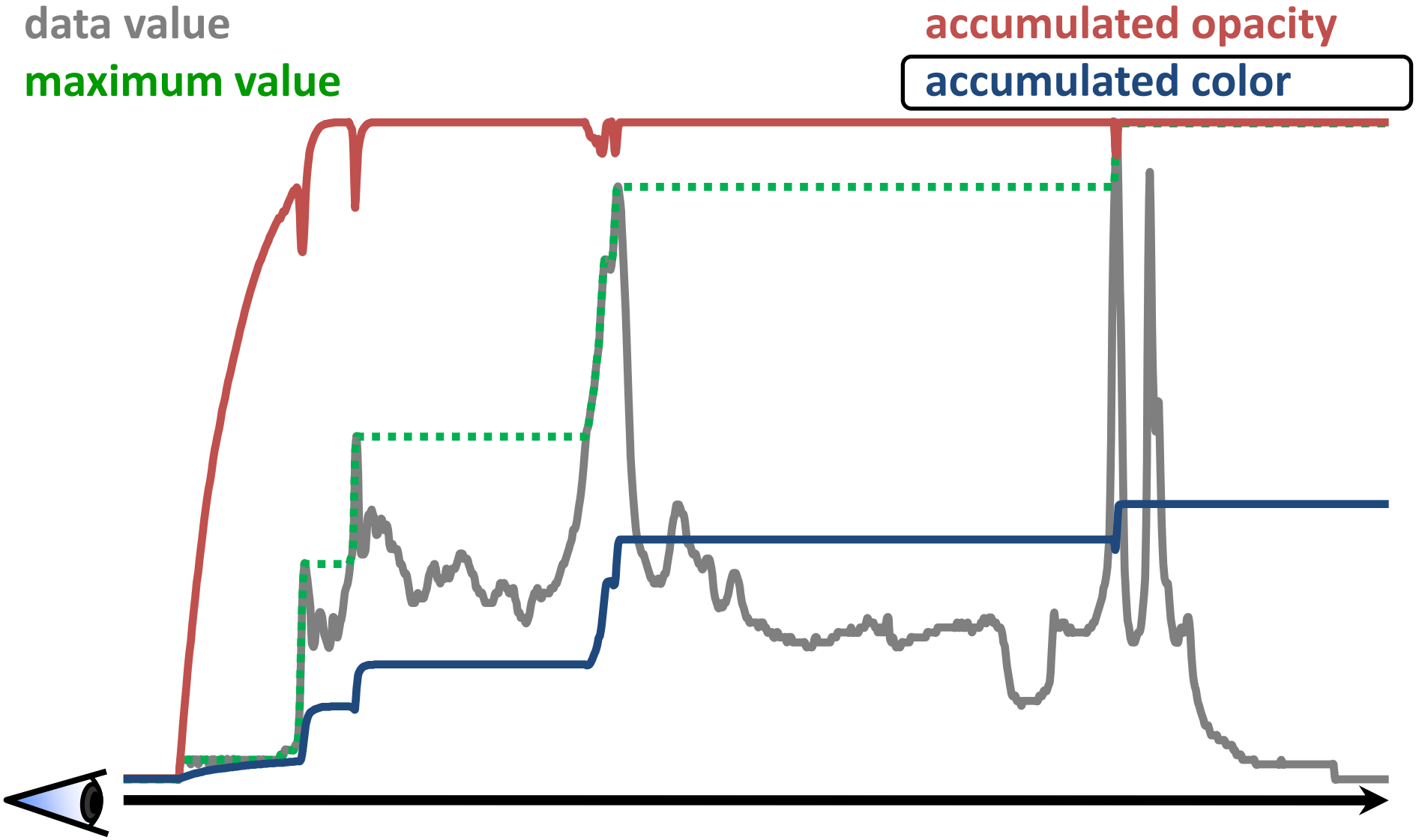
Direct Volume Rendering



Max. Int. Difference Accumulation

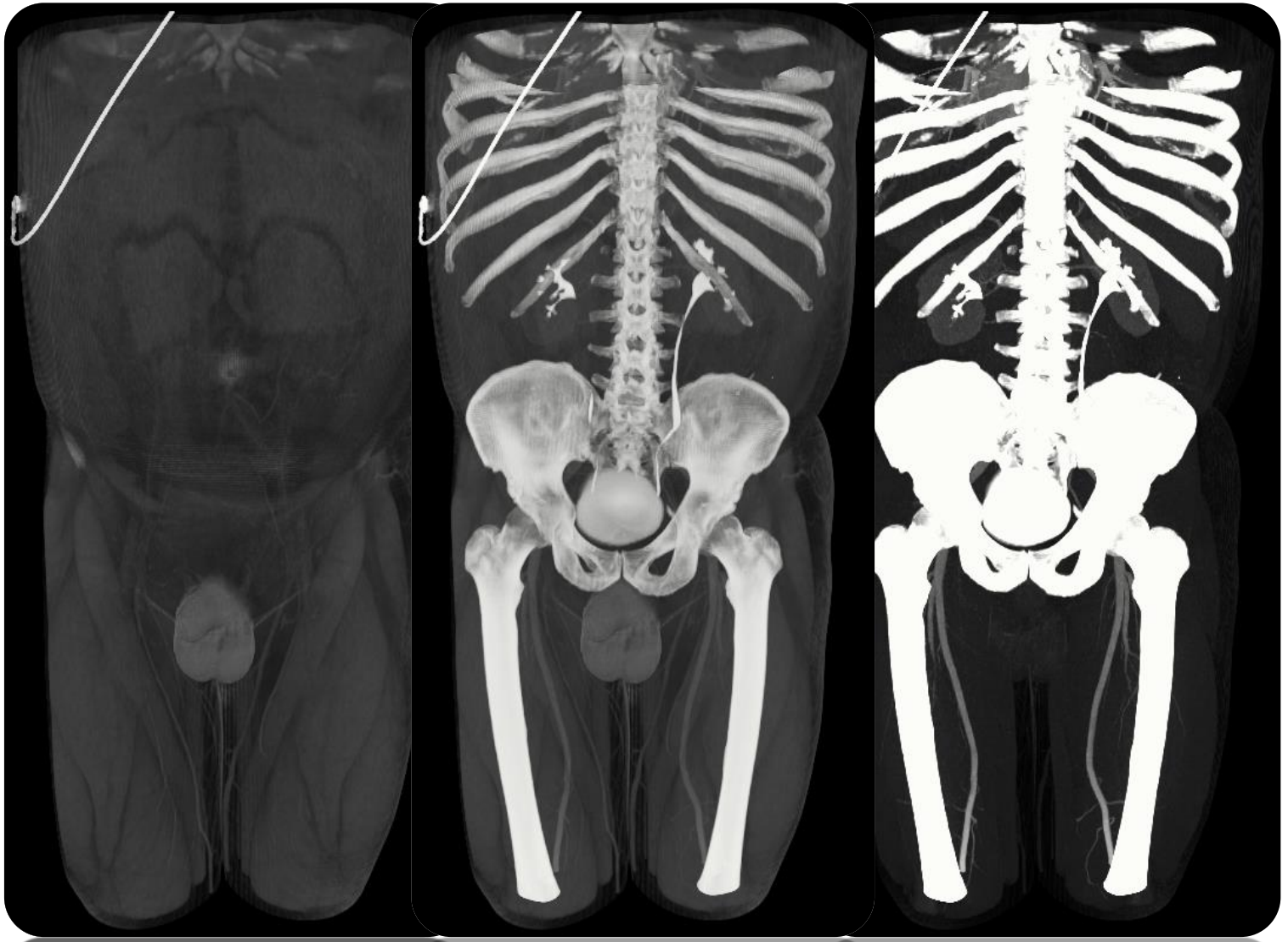


Max. Int. Difference Accumulation



MIDA = DVR + MIP (1)

DVR – Direct Volume Rendering **MIDA** – Maximum Intensity Difference Accumulation **MIP** – Maximum Intensity Projection



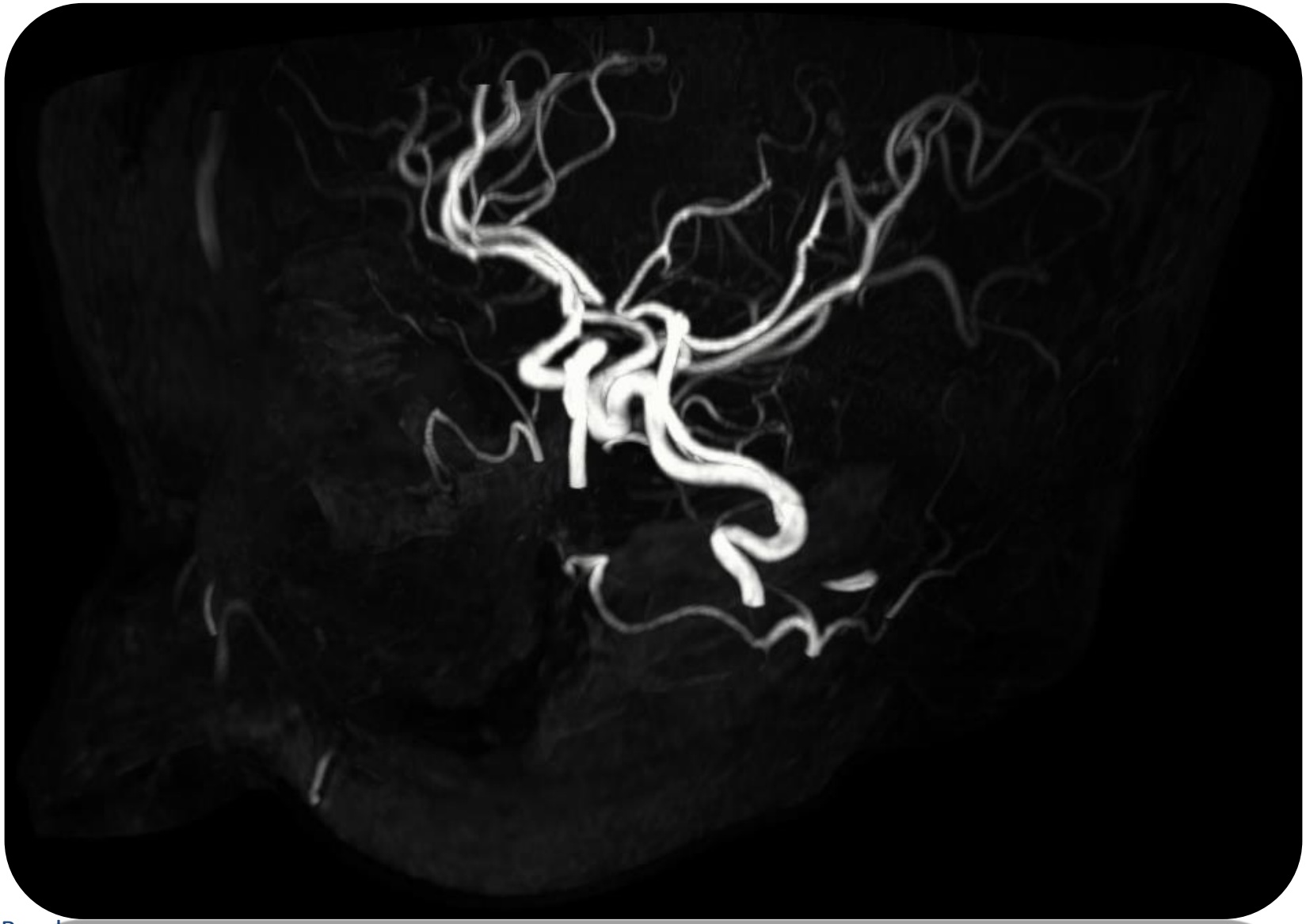
MIDA = DVR + MIP (2)

DVR

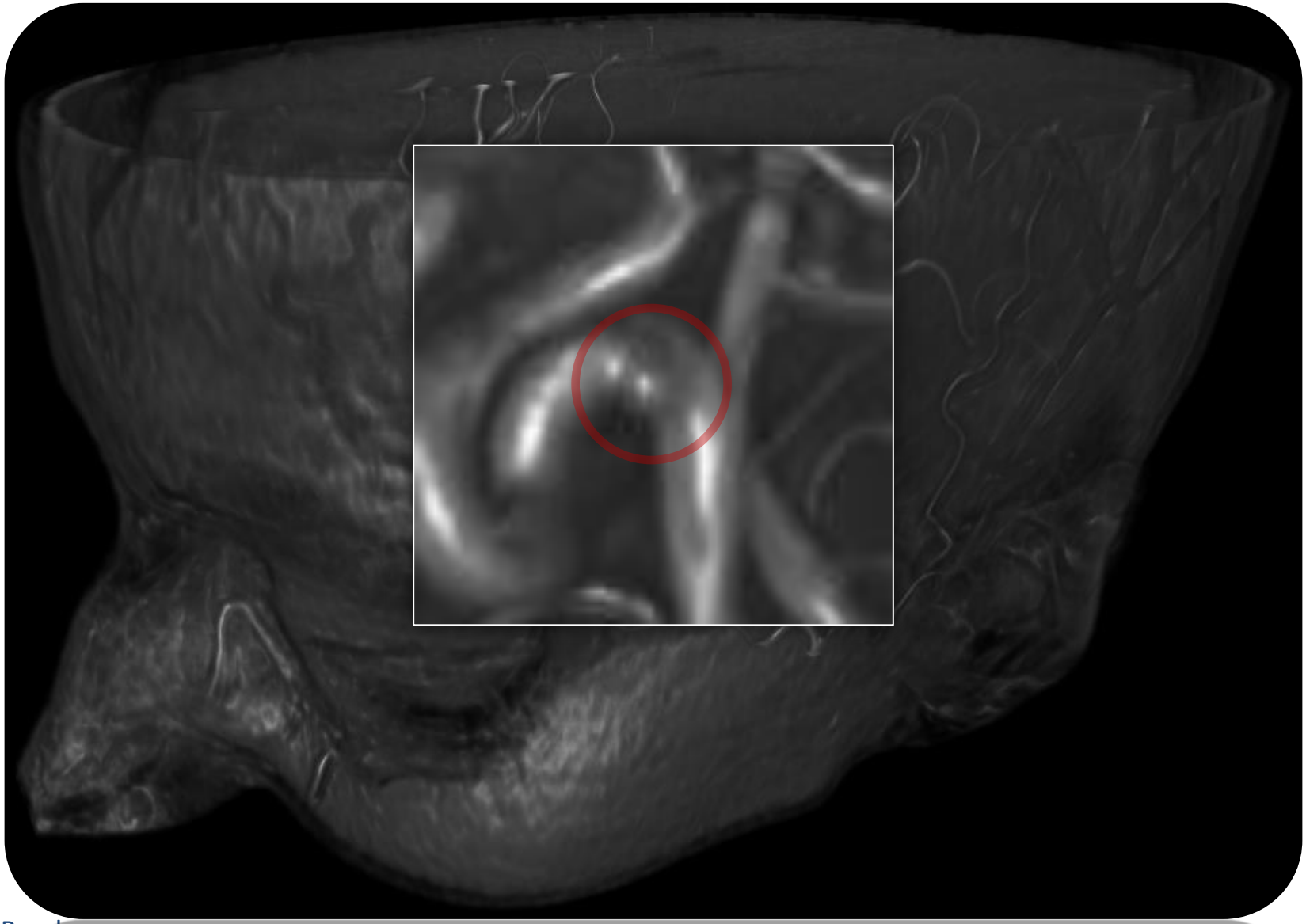
MIDA

MIP

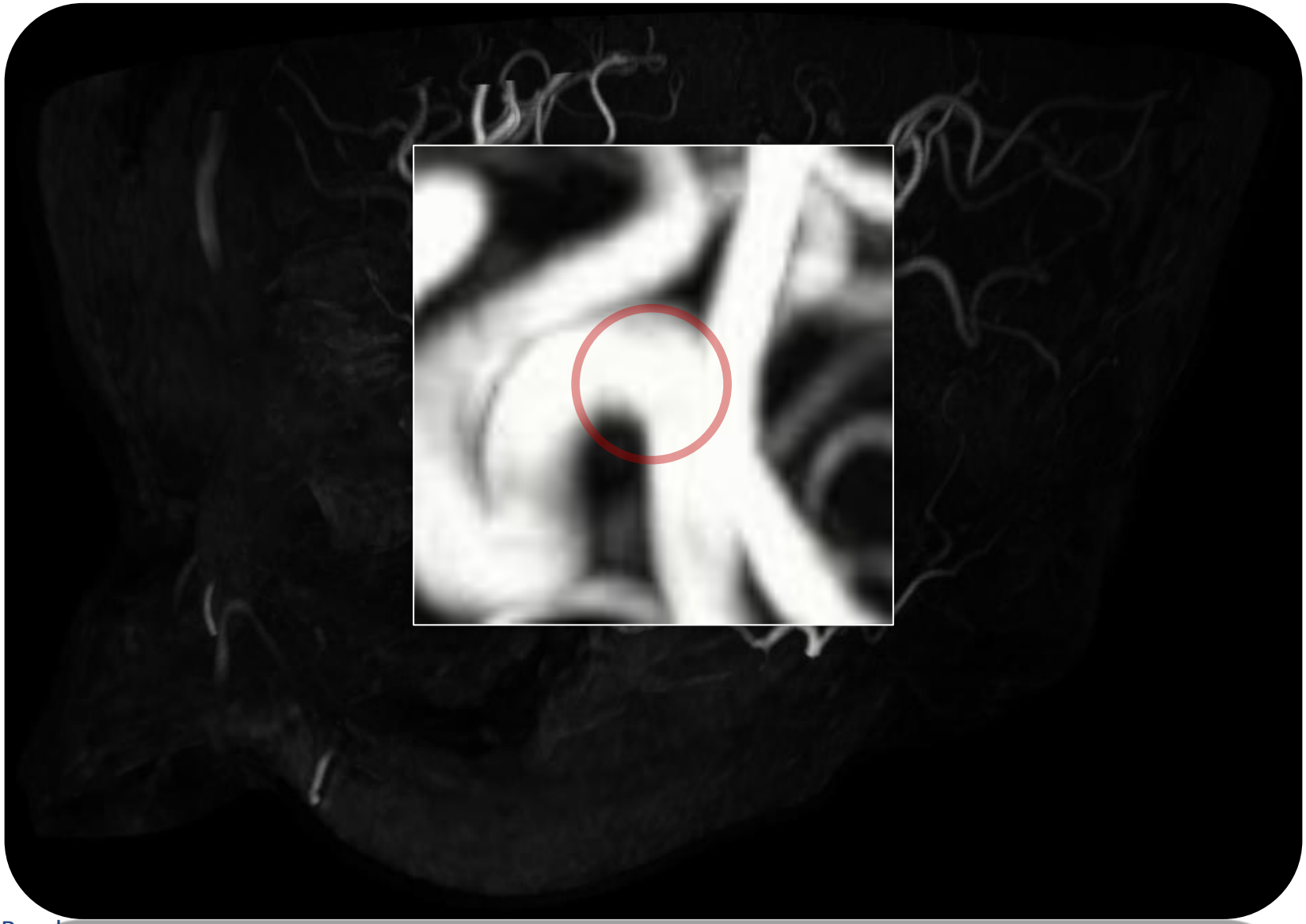
MIP



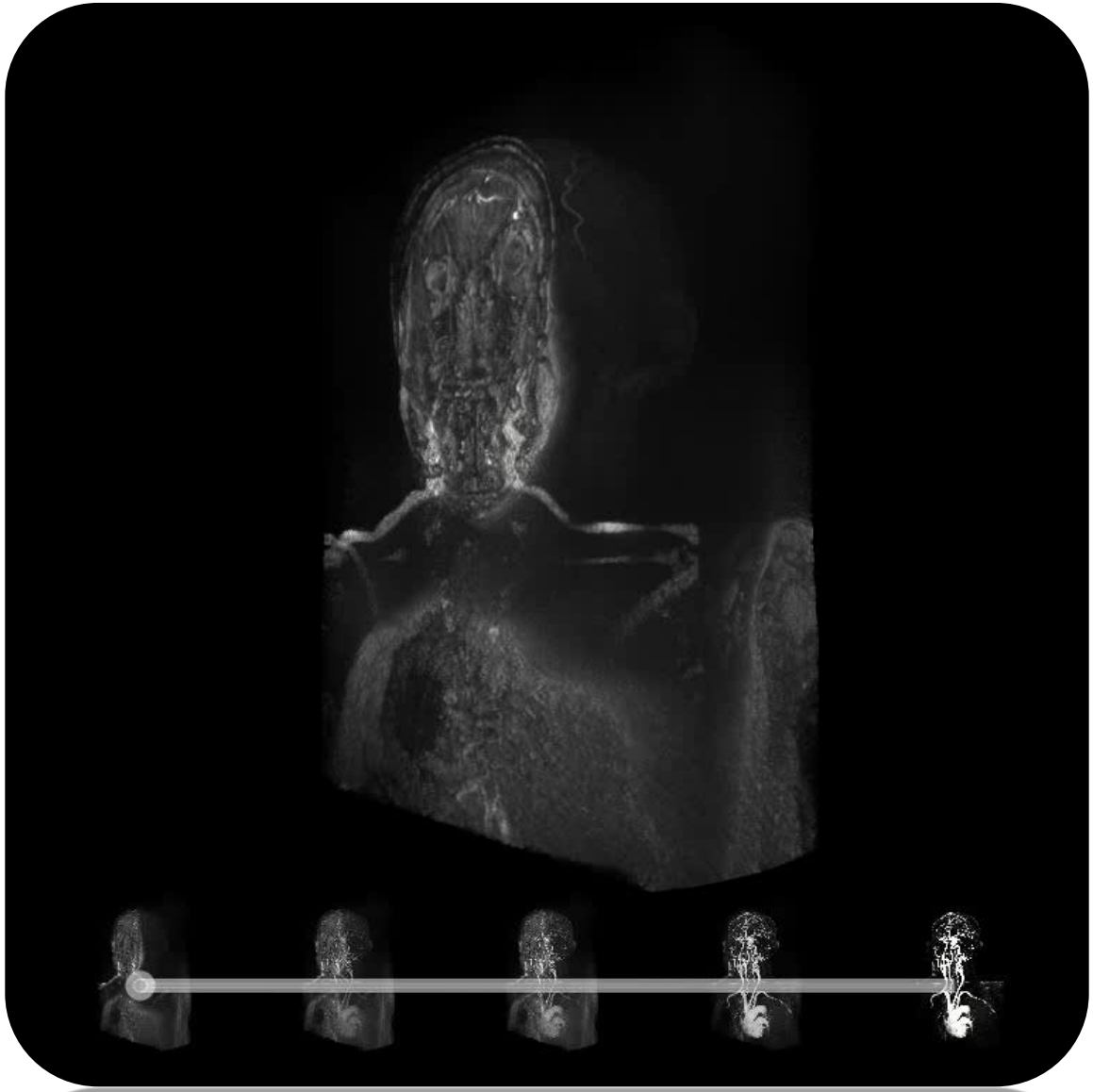
MIDA



MIP



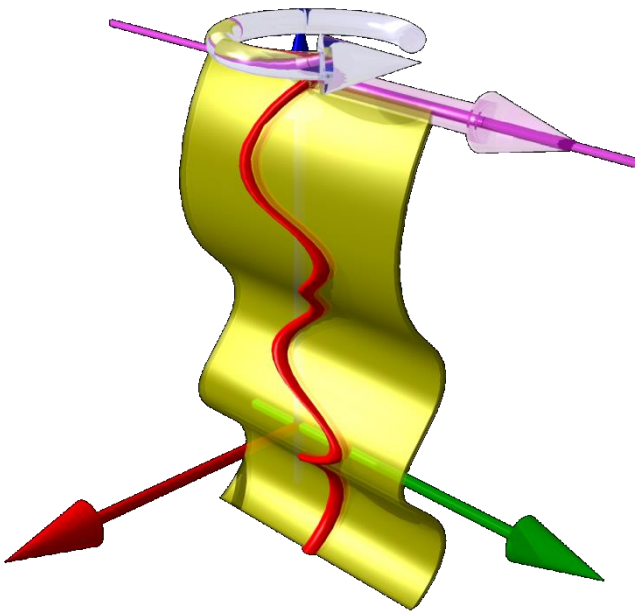
From DVR via MIDA to MIP

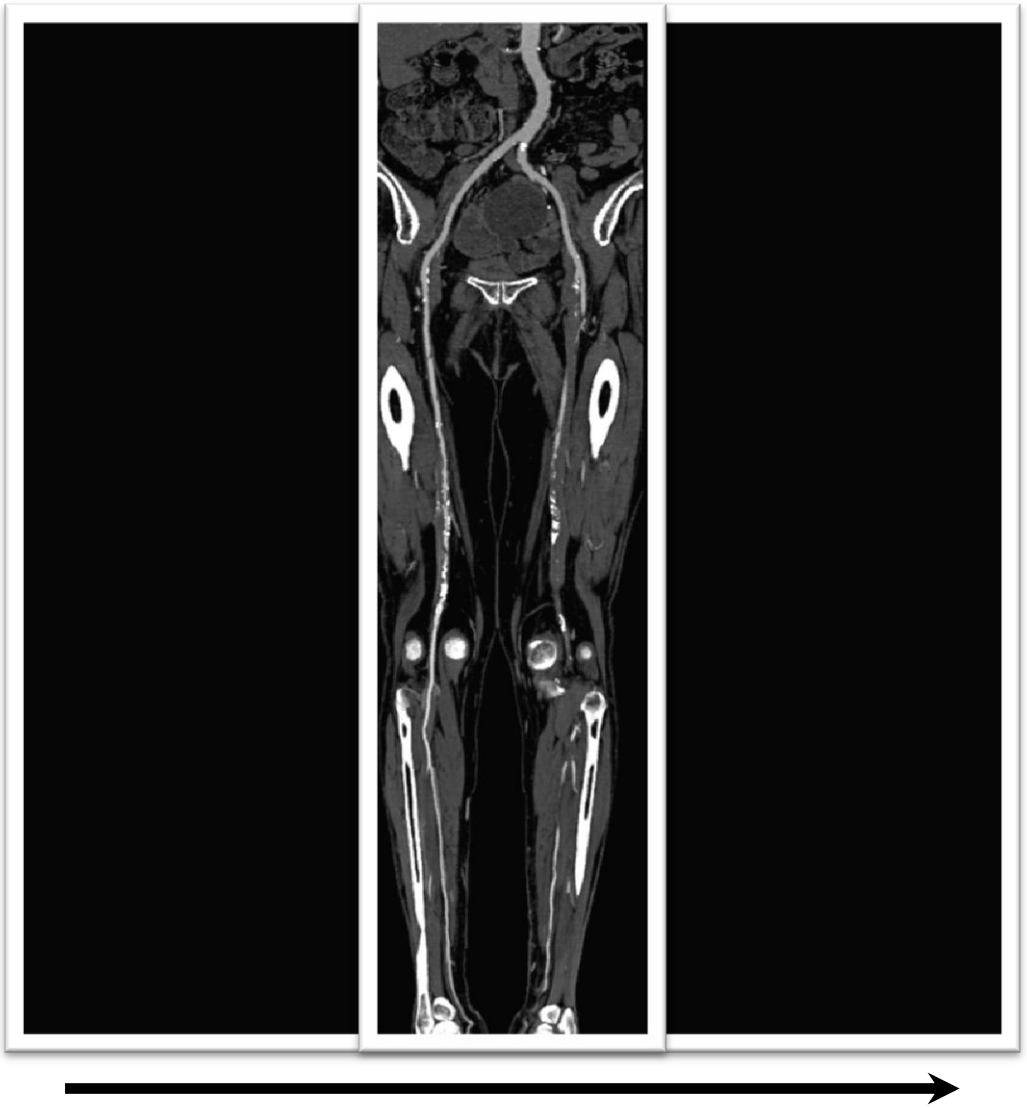


Limitations of 3D Visualizations

- MIP & MIDA only incorporate information about data value semantics
- No knowledge about the geometrical arrangement of the focus object is used
- Detailed assessment of the vessel lumen is difficult

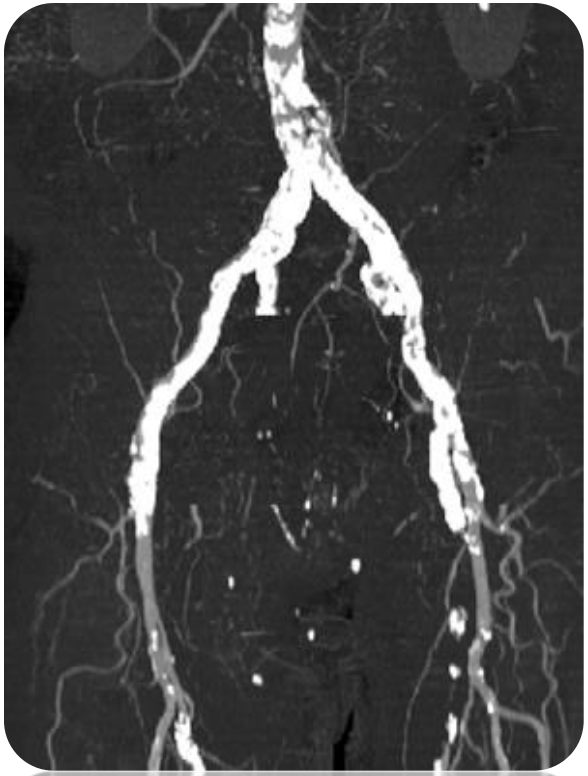
Curved Planar Reformation (CPR)



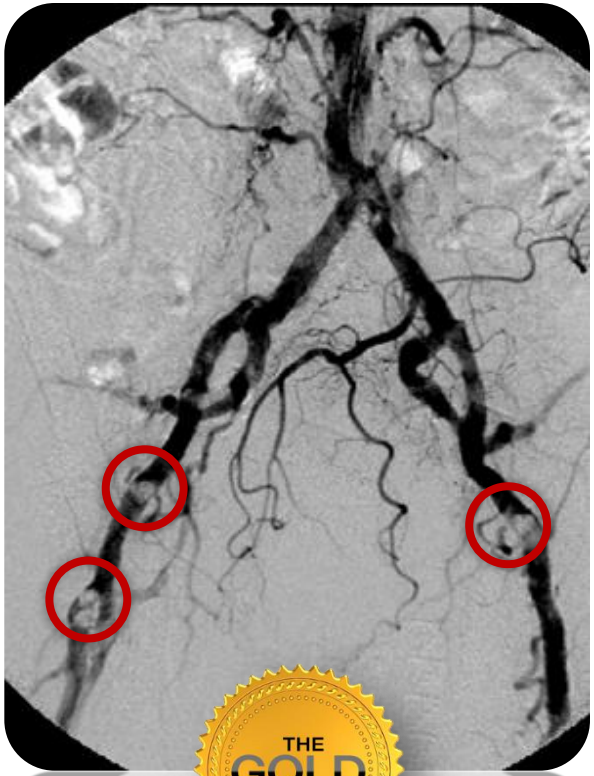


Advantages of CPR

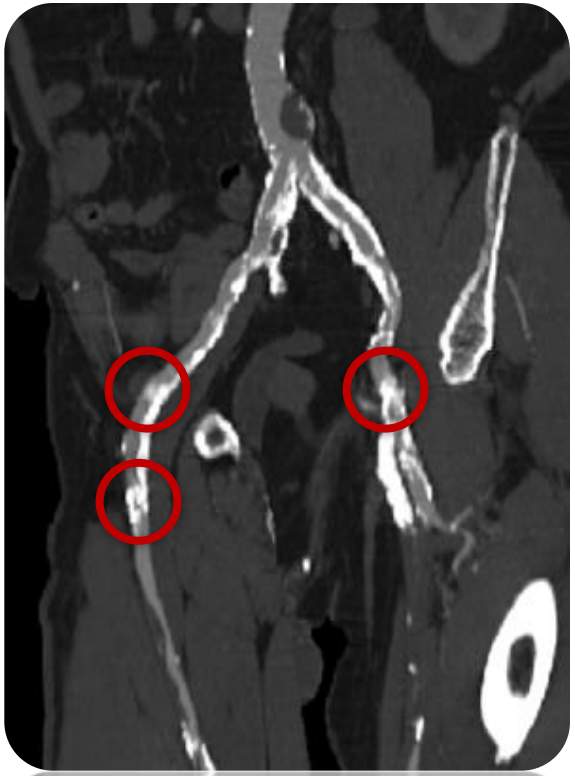
MIP
Maximum Intensity Projection



DSA
Digital Subtraction Angiography



CPR
Curved Planar Reformation

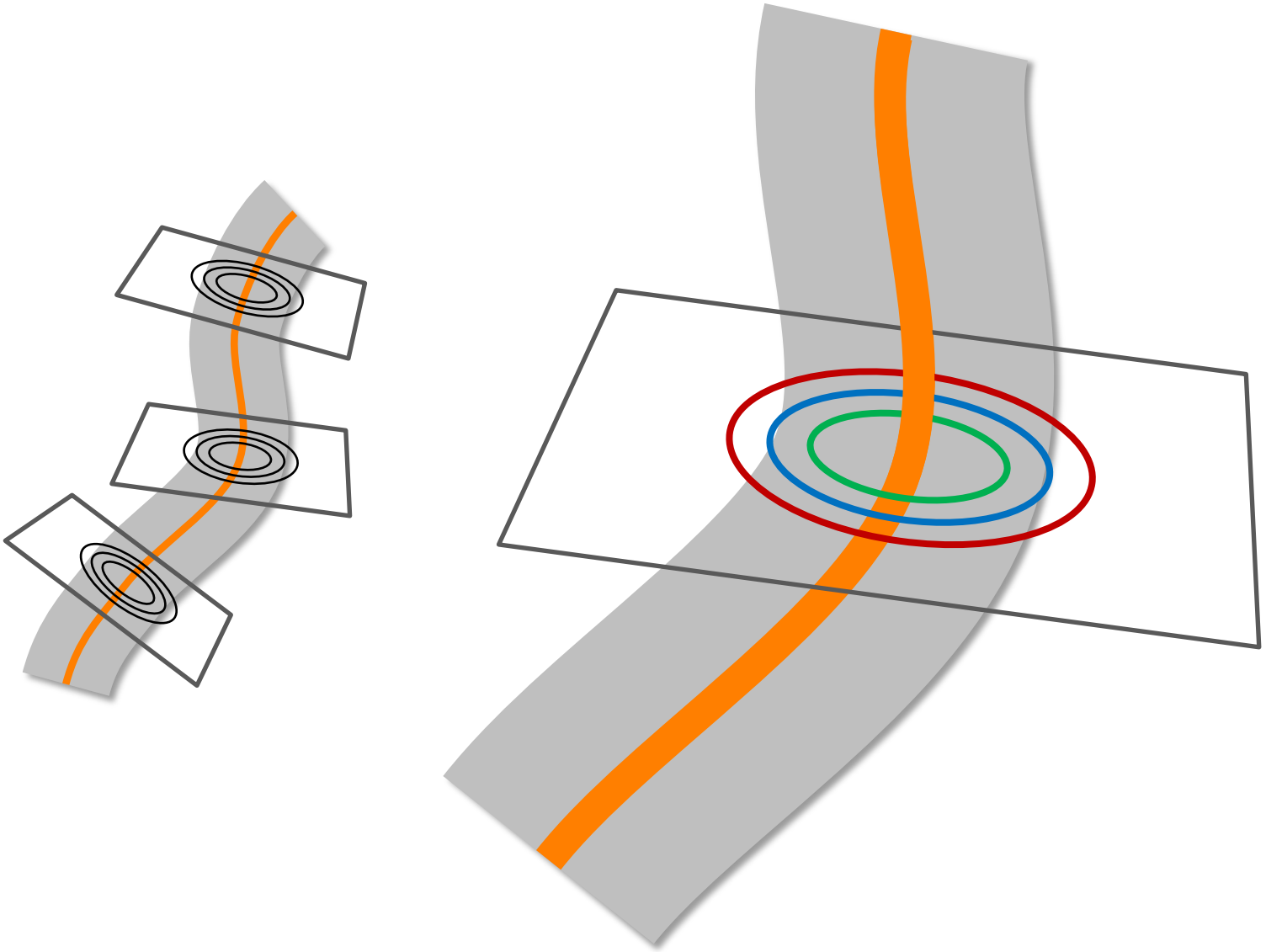


Beyond CPR

- Drawbacks of CPR
  - Many images from various viewing angles
  - Extensive browsing through images
  - Cumbersome to memorize particular regions

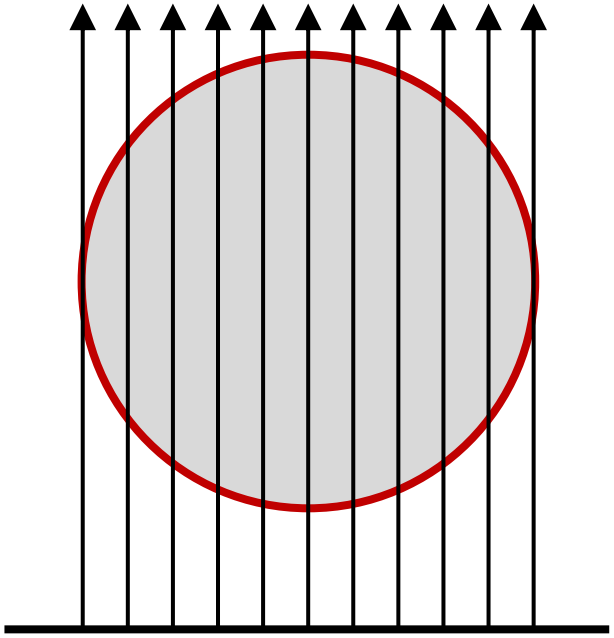
Solution: aggregate rotations into a single image

Curvicircular Feature Aggregation



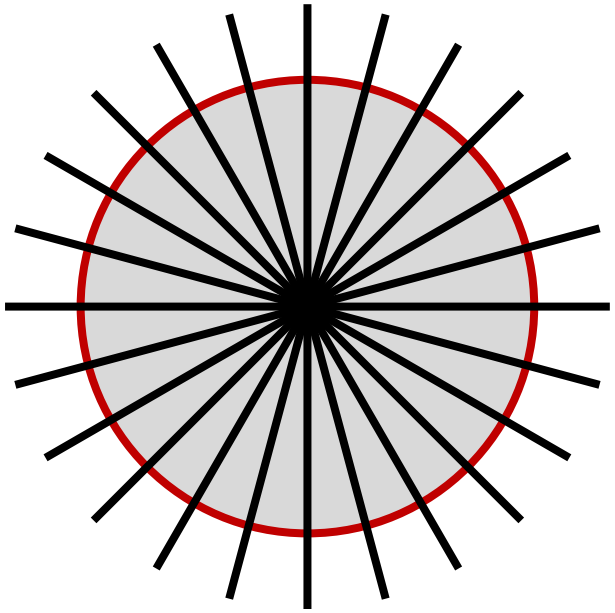
3D vs. CPR vs. CFA

3D Visualization



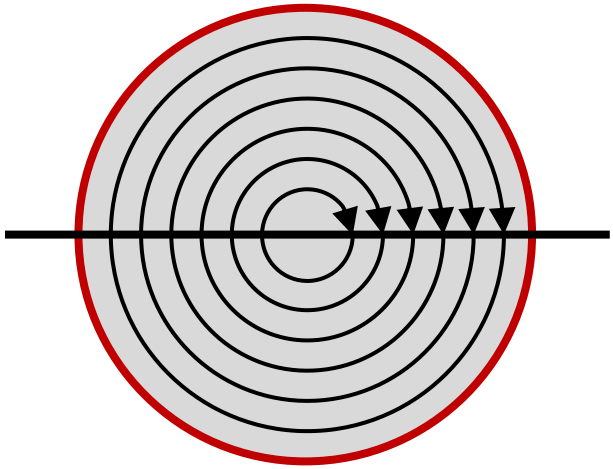
straight rays

Curved Planar Reformation (CPR)



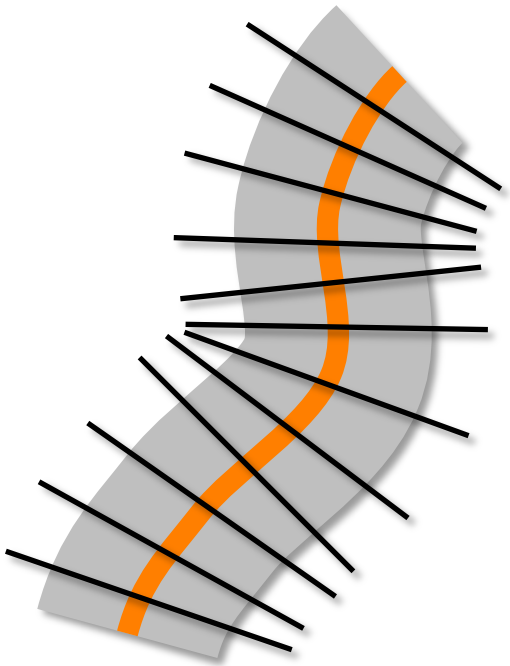
cut through vessel

Curvicircular Feature Aggregation (CFA)

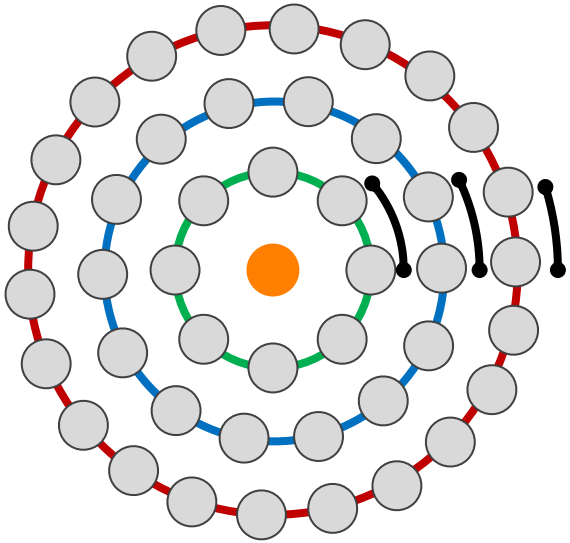


curved rays

Traversal

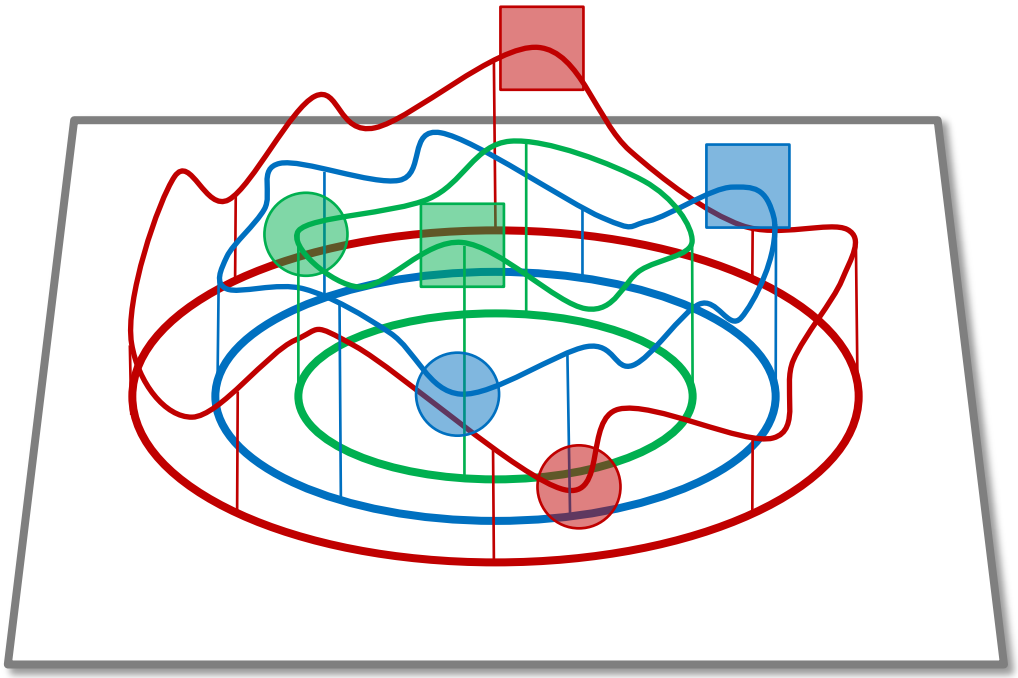


Sampling



Aggregation

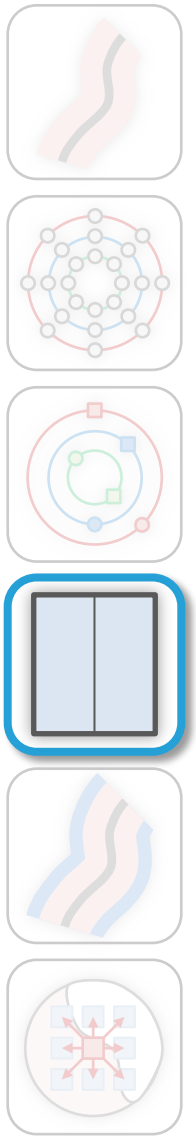
Various methods possible:
maximum (MIP), minimum (MINIP),
MIDA, DVR, etc.



maximum intensity

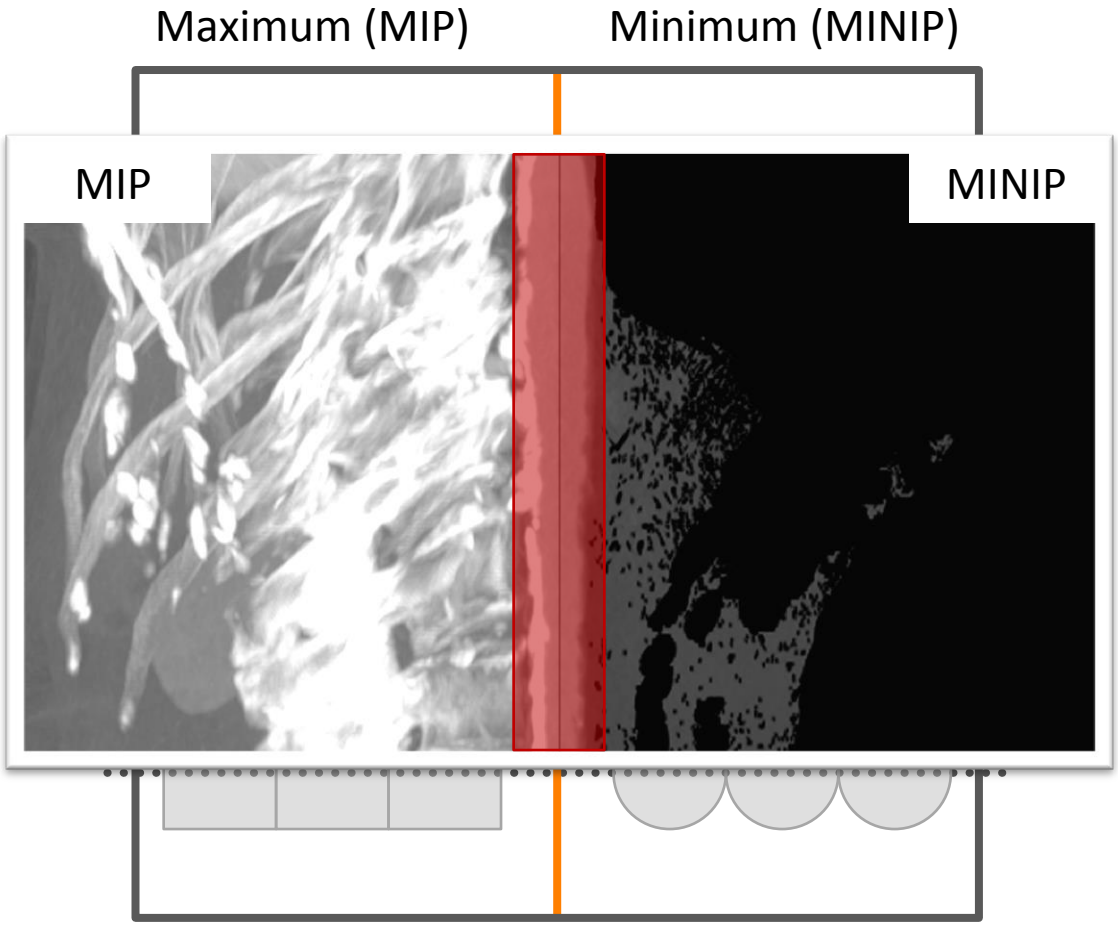
minimum intensity

Display



Complete vessel aggregated & straightened

Image split into two parts along centerline



Rows are sampling planes

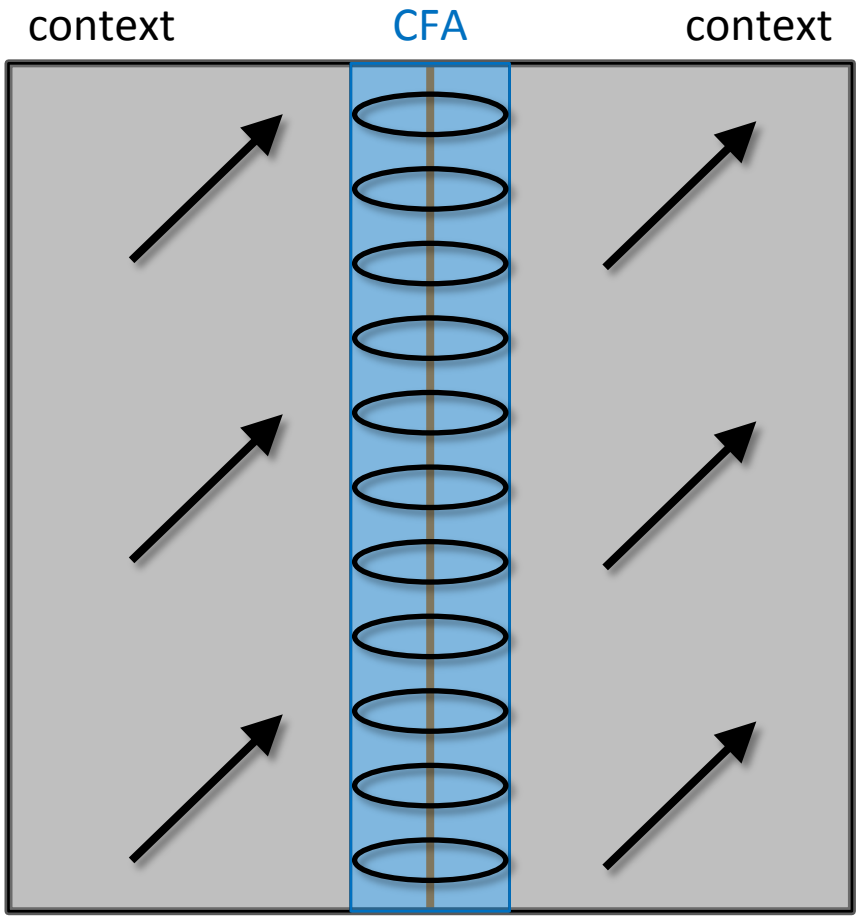
Columns are circular rays

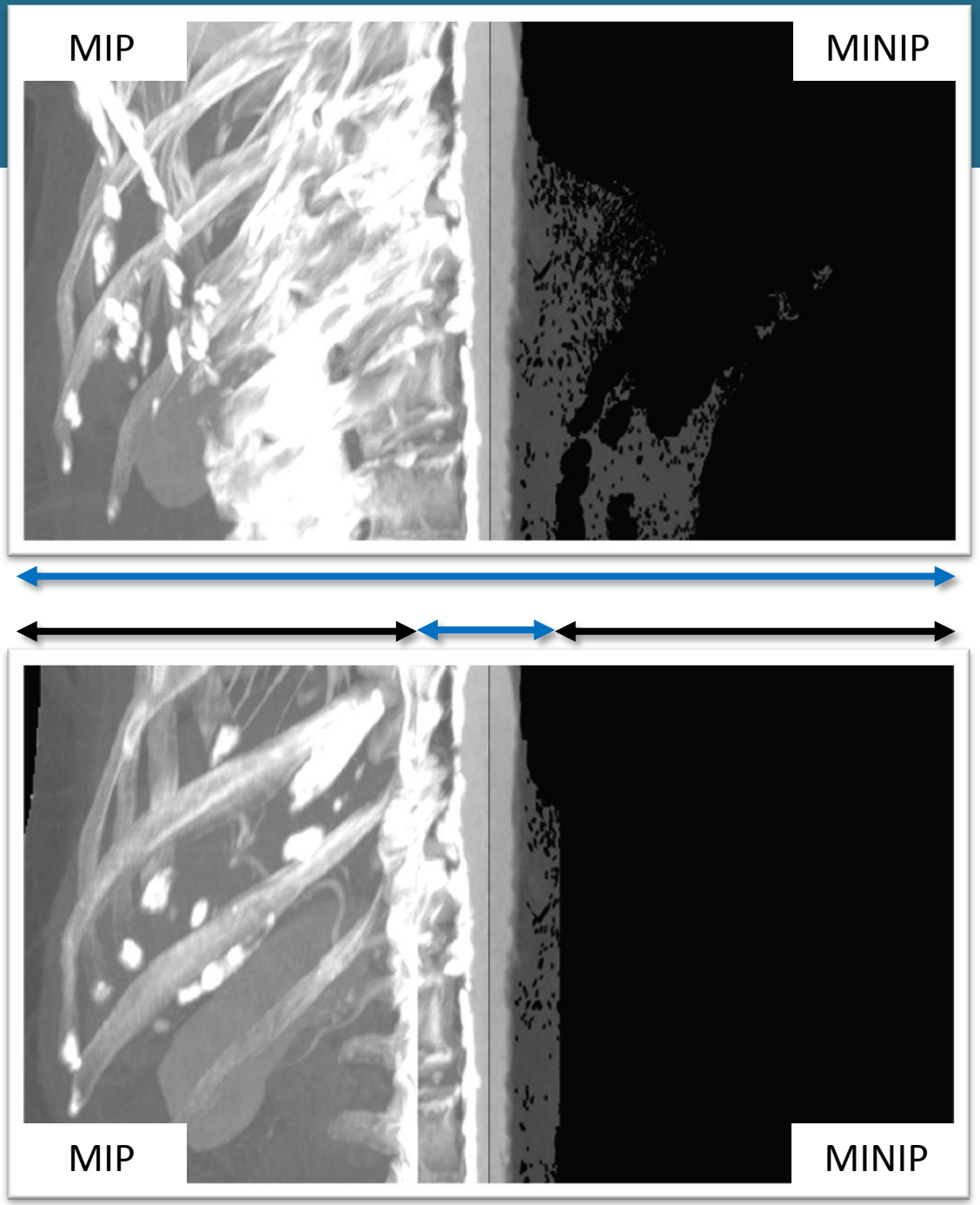
Min / max for every pixel of the image

Context

Requires vessel radius information

Cast straight rays outside the vessel lumen

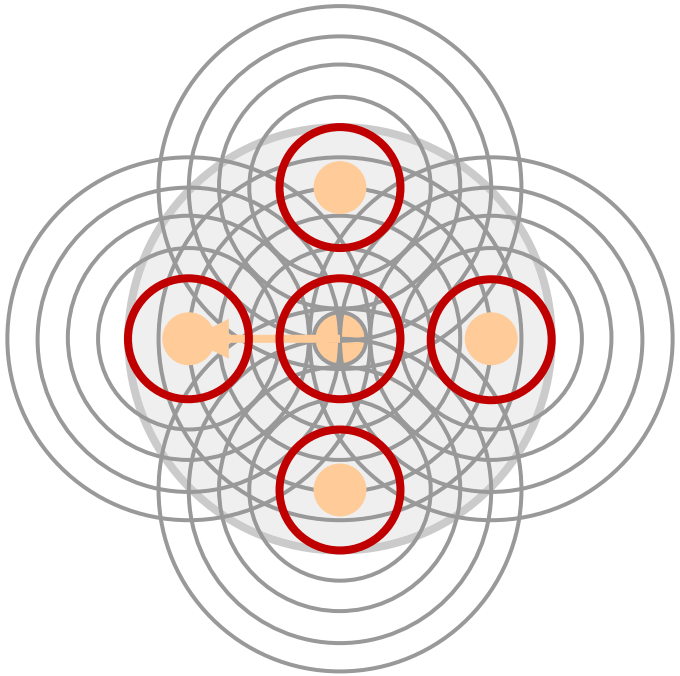



MIP
MINIP
CFA
CFA + context
MIP
MINIP

Stability

Centerline only has limited accuracy

Investigate changes caused by small variations



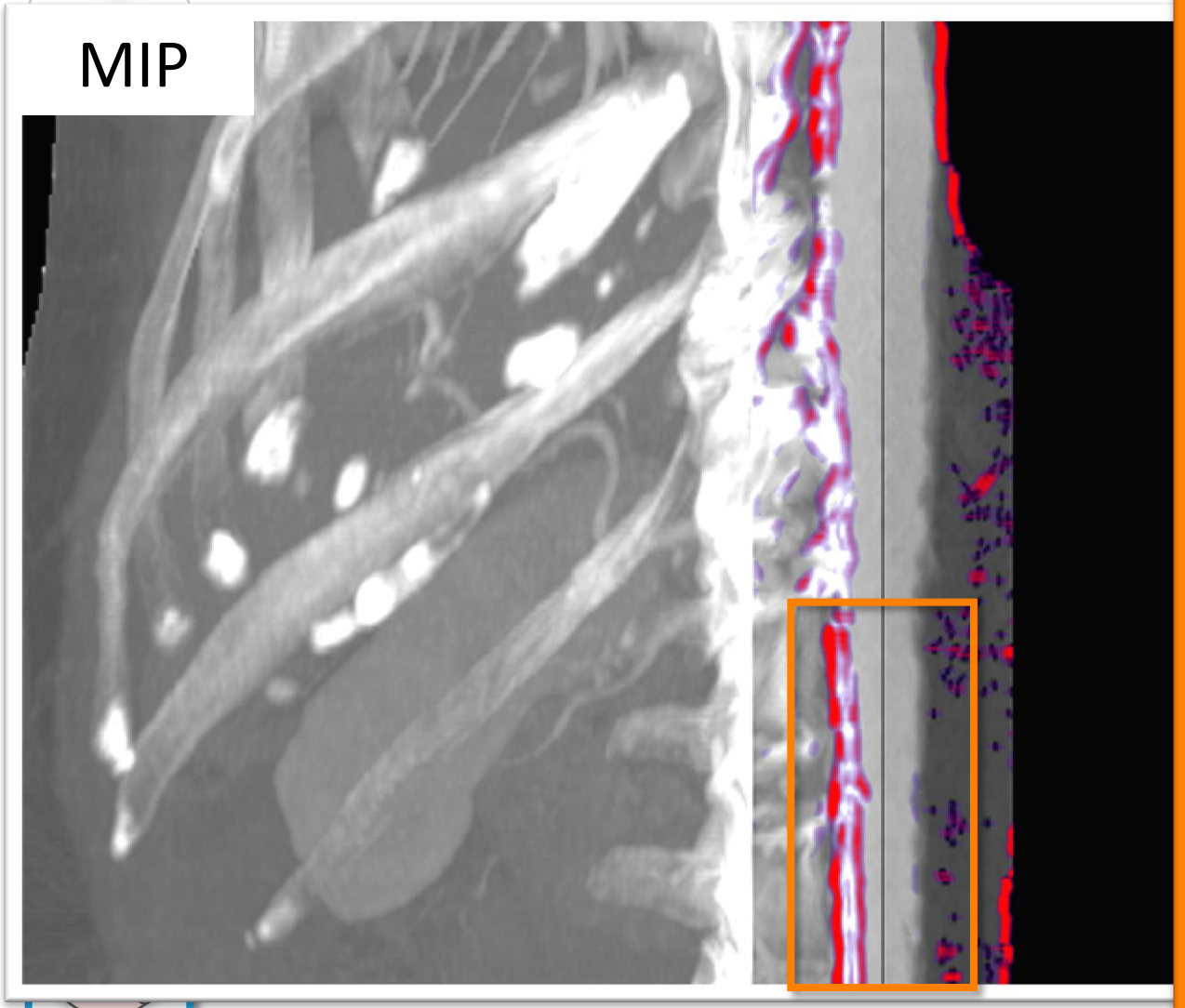
One aggregated value for every circular ray

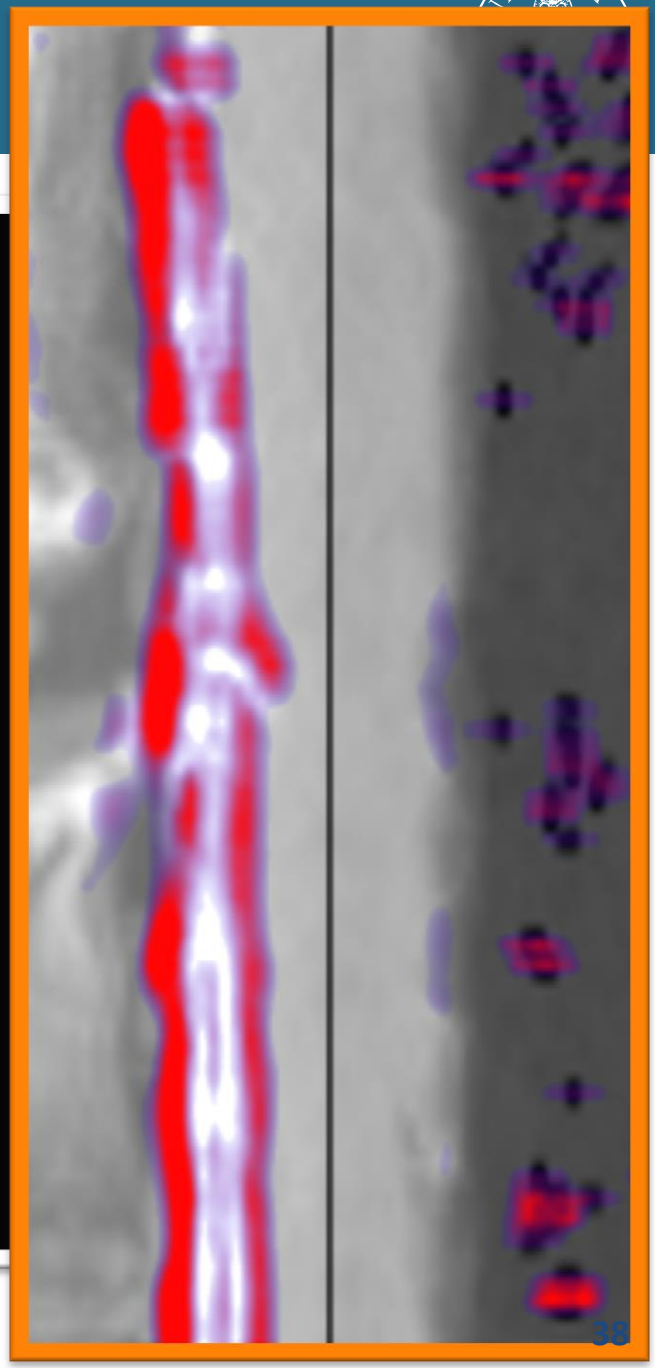
Variance defines stability

Indicator of centerline centeredness

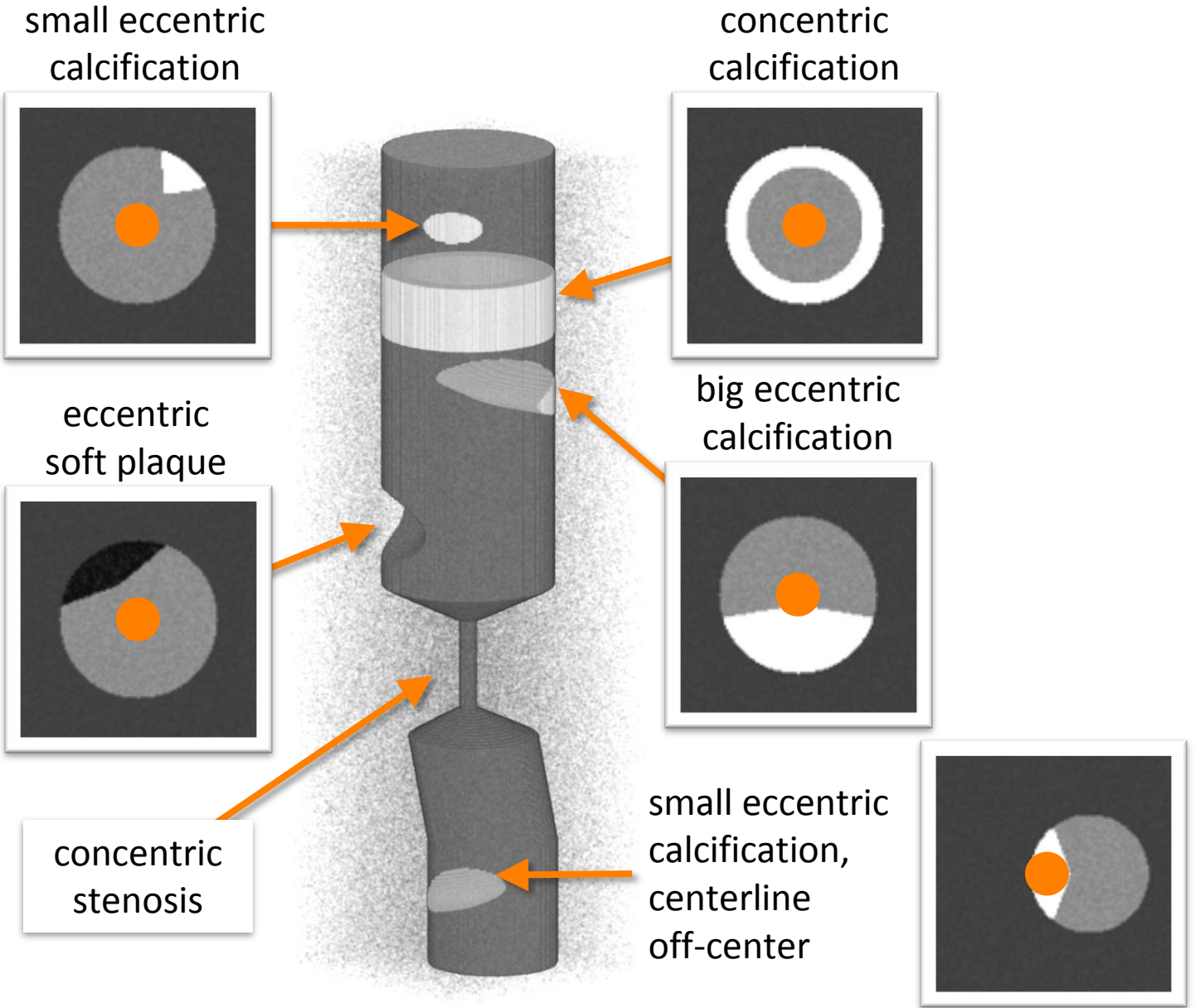
Overlaid for visual guidance

Stability

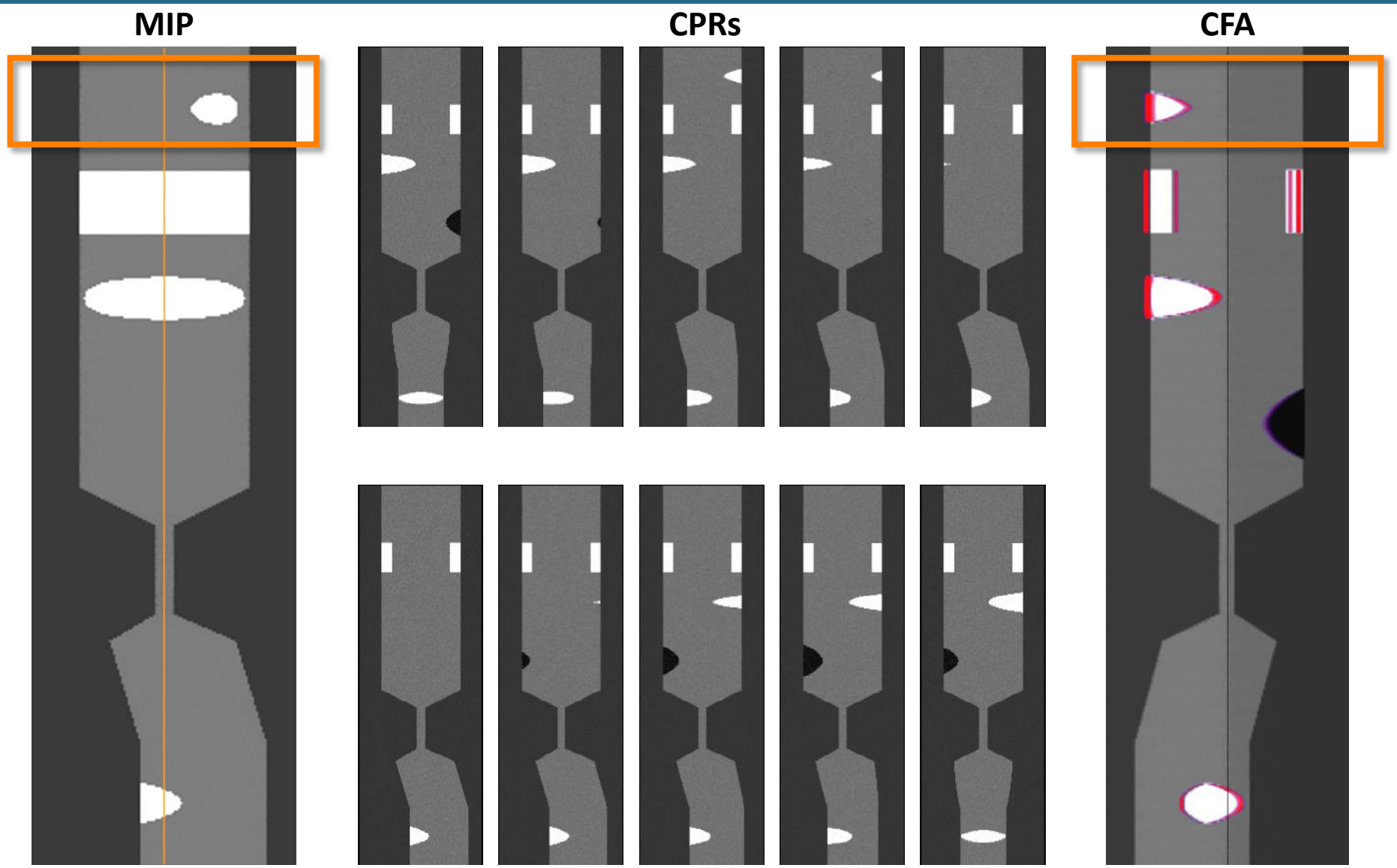




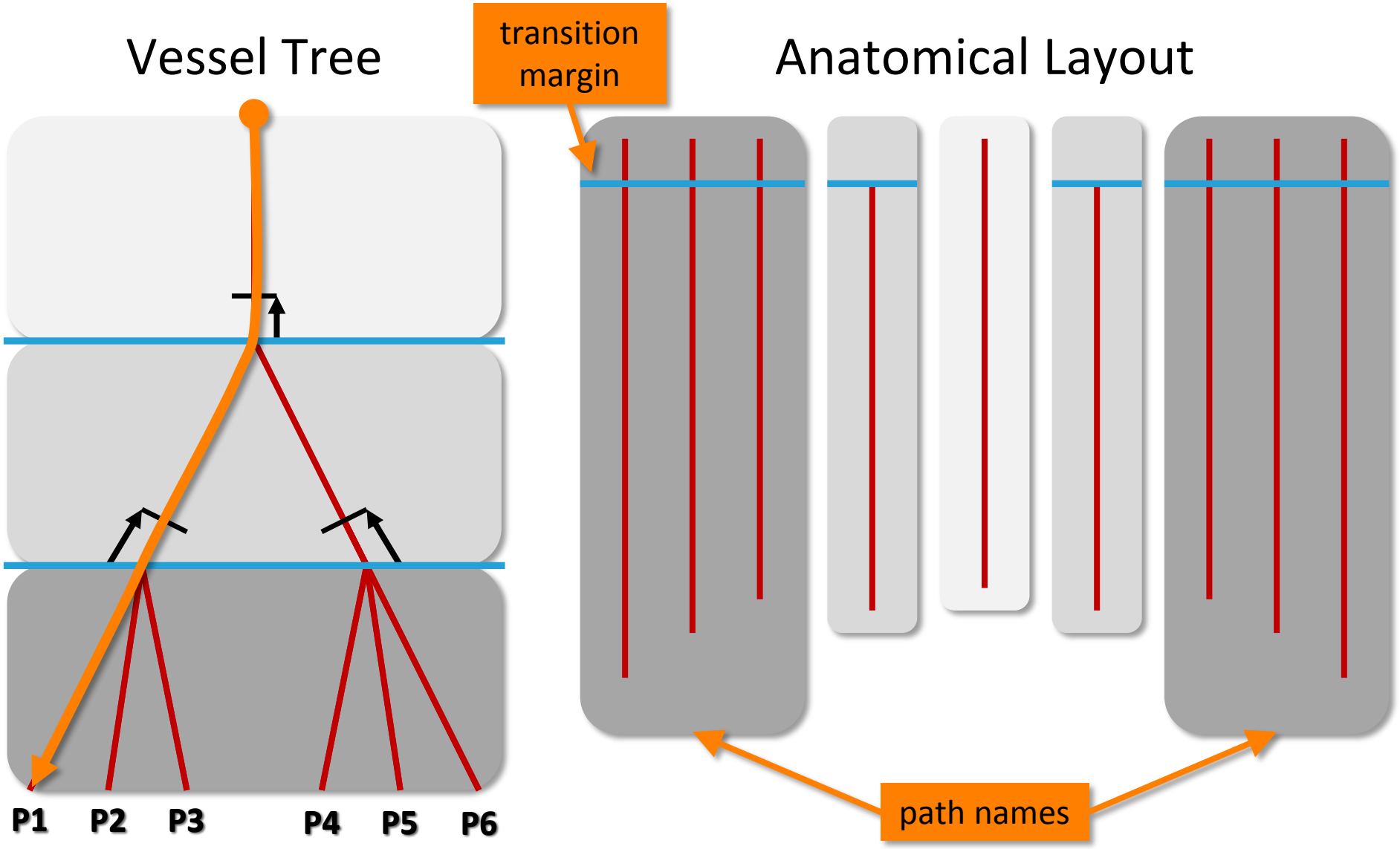
Phantom Data Set (1)



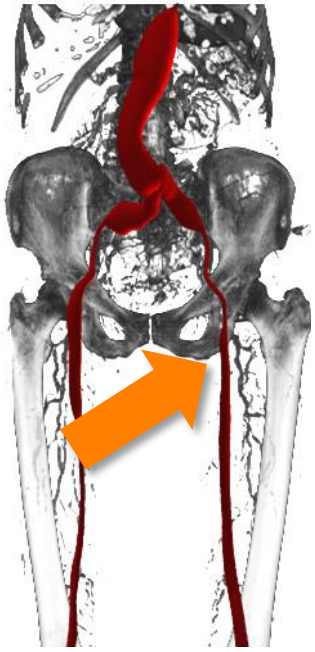
Phantom Data Set (2)

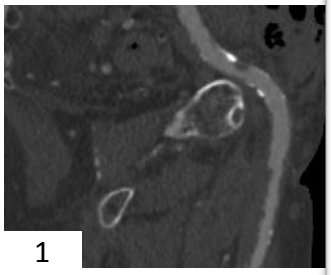


Presentation



Vessel Stenosis





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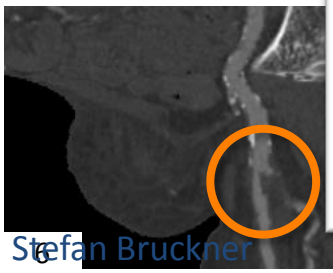
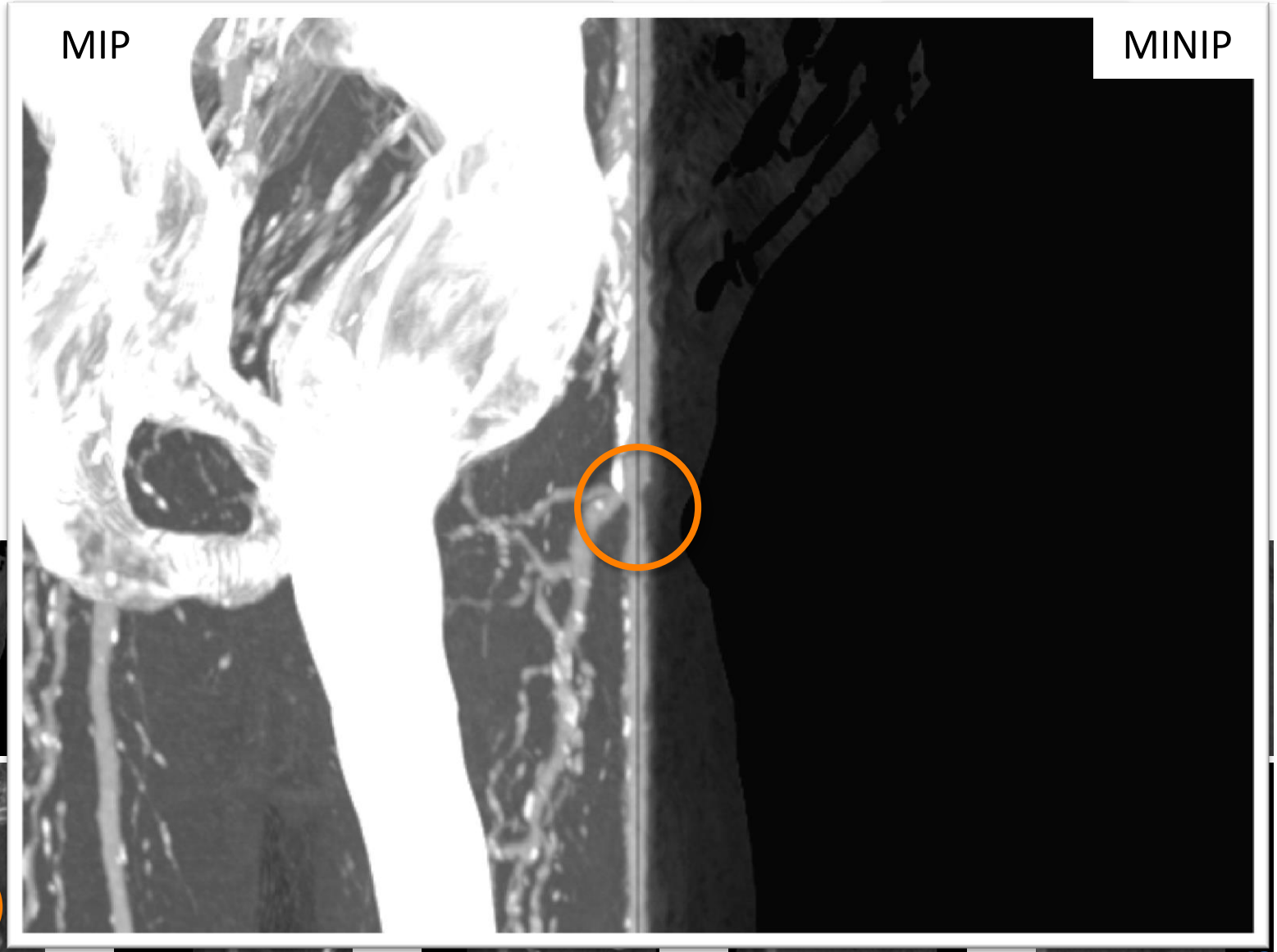
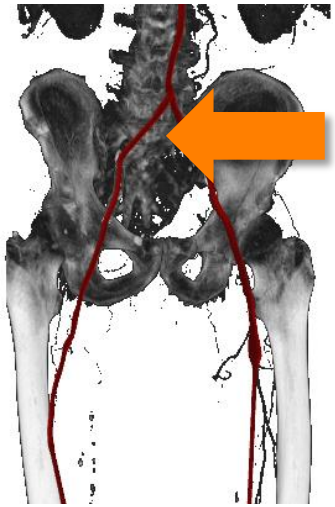
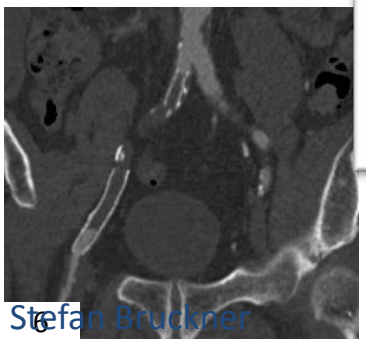
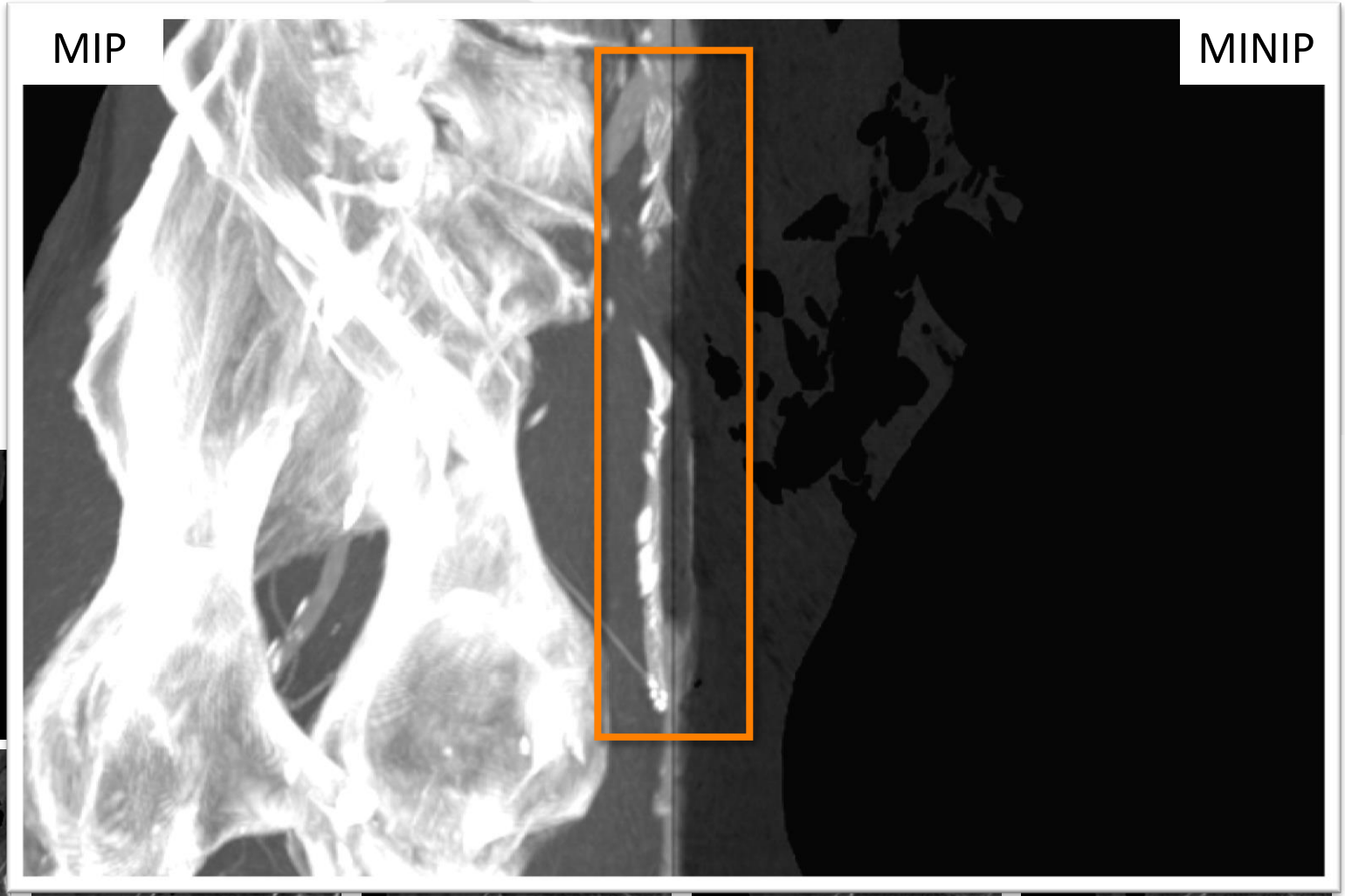


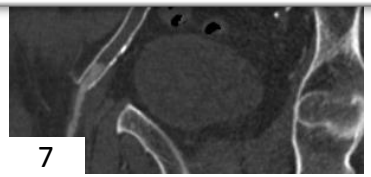


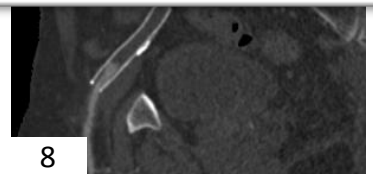
Vessel Occlusion

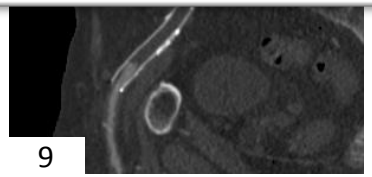


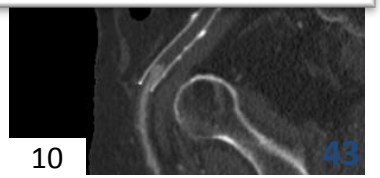




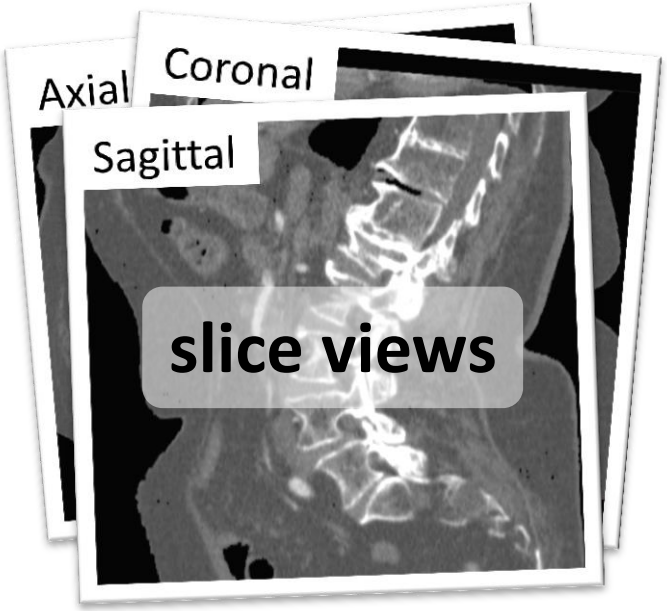


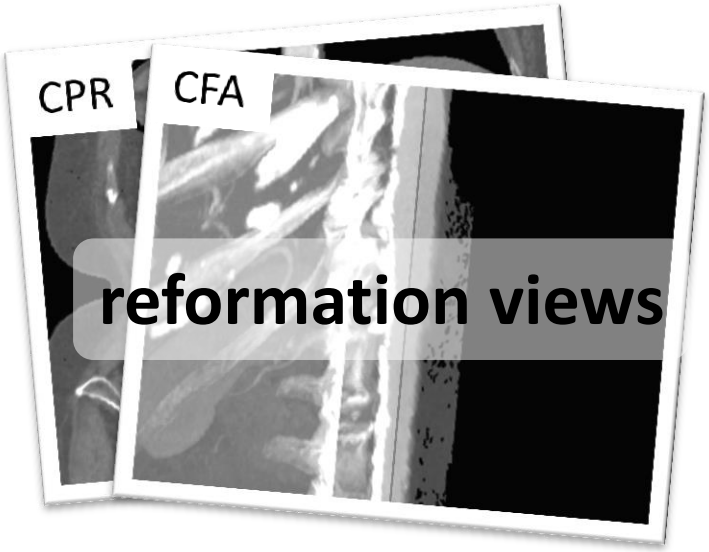


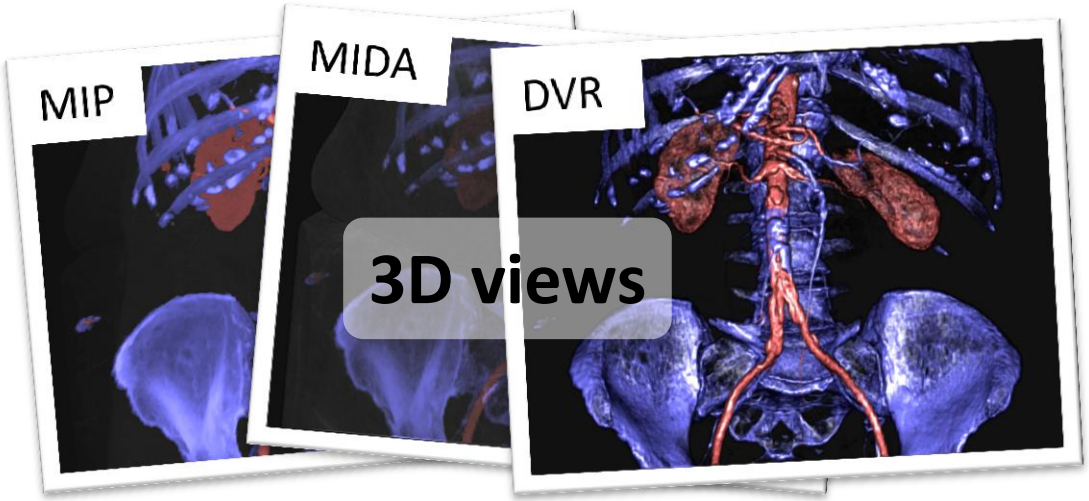




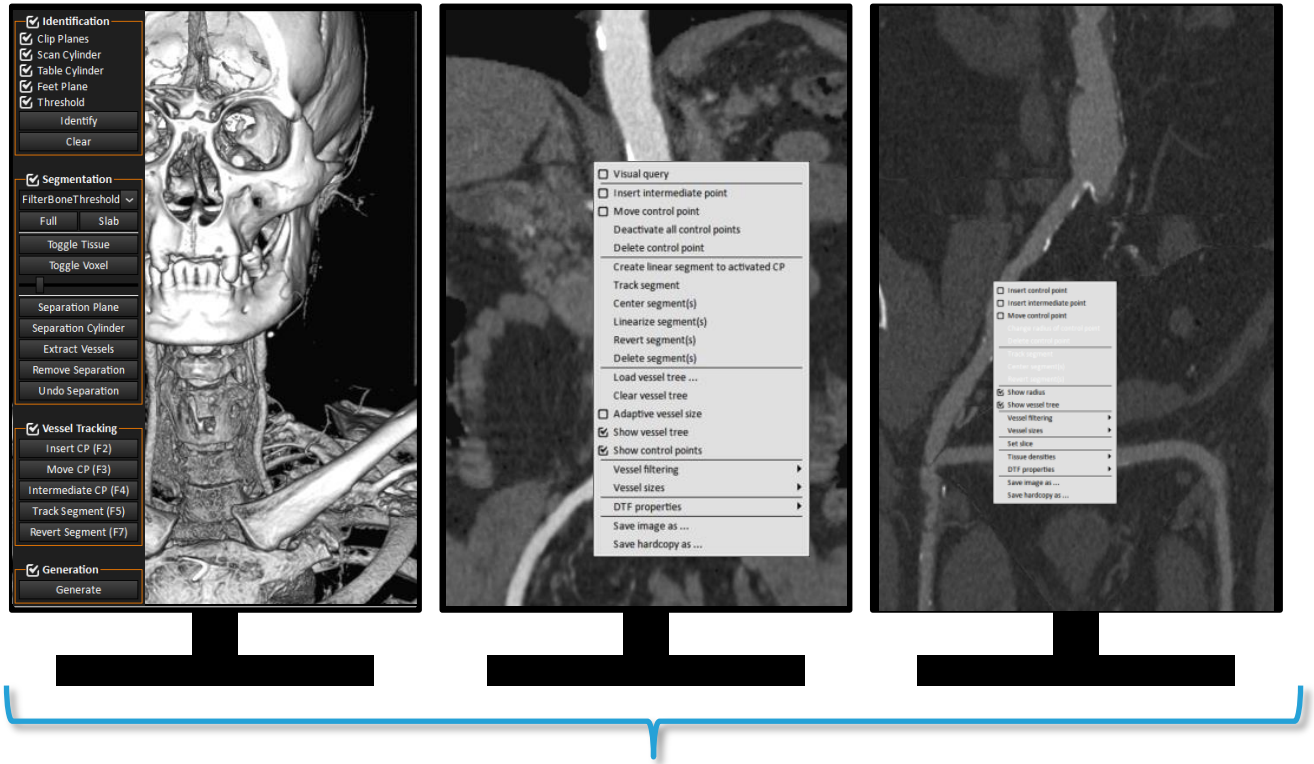
Demonstration


Axial
Coronal
Sagittal
slice views


CPR
CFA
reformation views


MIP
MIDA
DVR
3D views

Medical Workstations



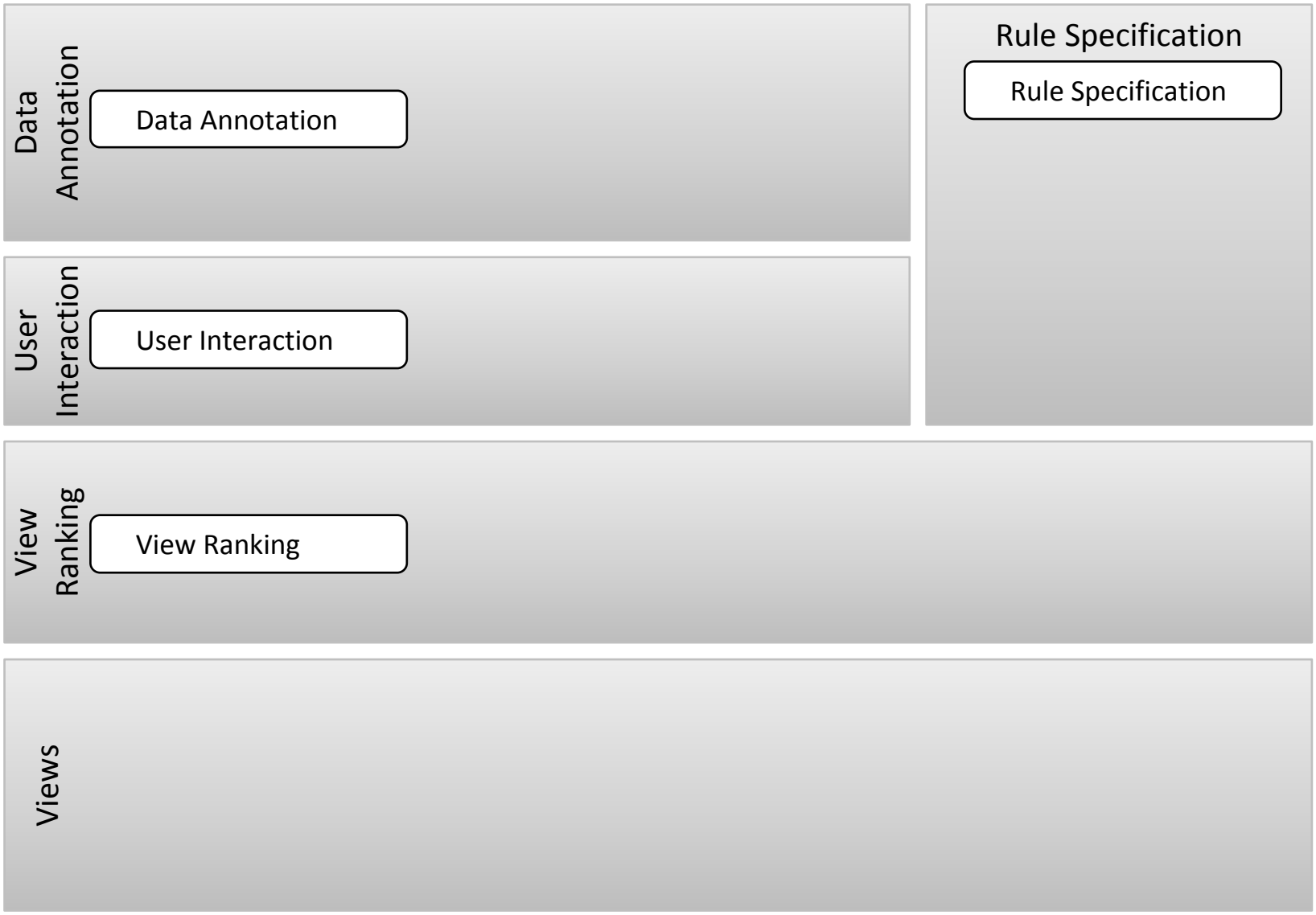
- Multiple high-resolution diagnostic monitors
- Many different views (identified by weird acronyms)
- Parameters, options, and settings gallore

Smart View Concept

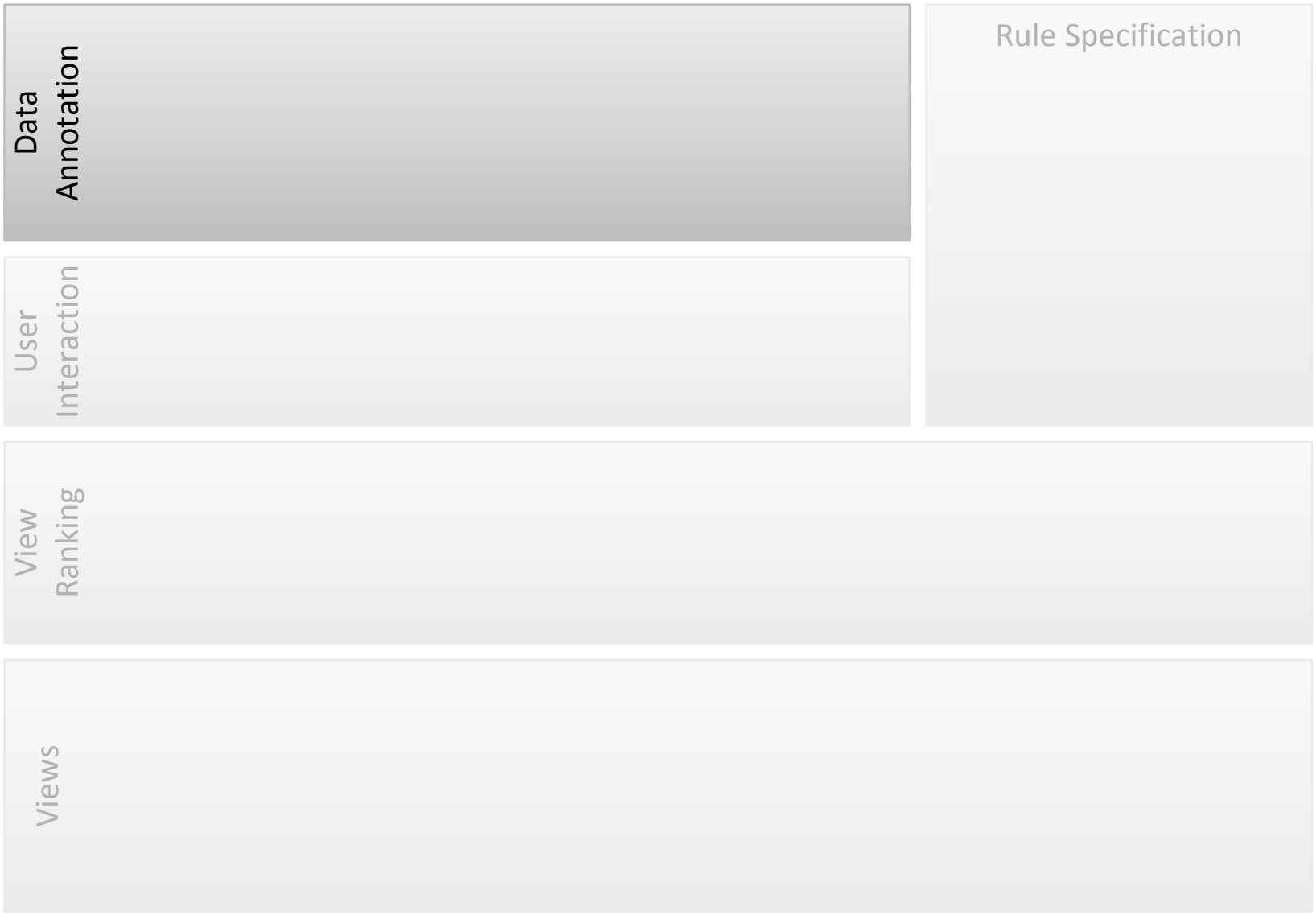
- Menues, panels, and toolbars are artificial and unfamilar constructs (a lightbox has no menu)
- Images should be central, radialogists know how to interpret them
- Usefulness of individual views depends on the context

Approach: avoid additional scaffolding – the image itself becomes the user interface

Smart Views (1)



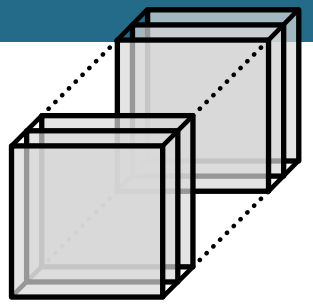
Smart Views (2)



Data Annotation (1)

CTA

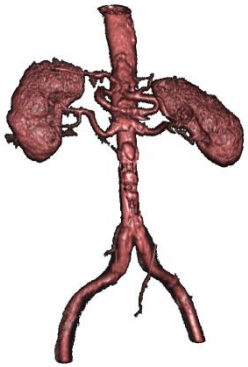
- Computed Tomography Angiography
- Contrast agent for vessel enhancement
- Data set consists of slice images

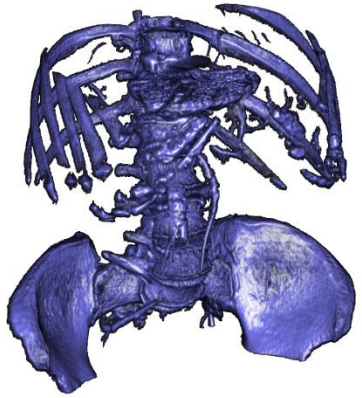


512 x 512 x 1500

Mask Information

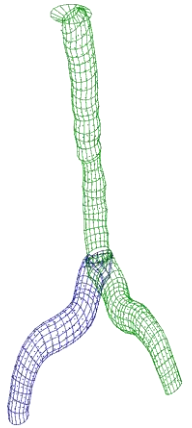
- Vessel & bone masks
- Defined by radiological assistants



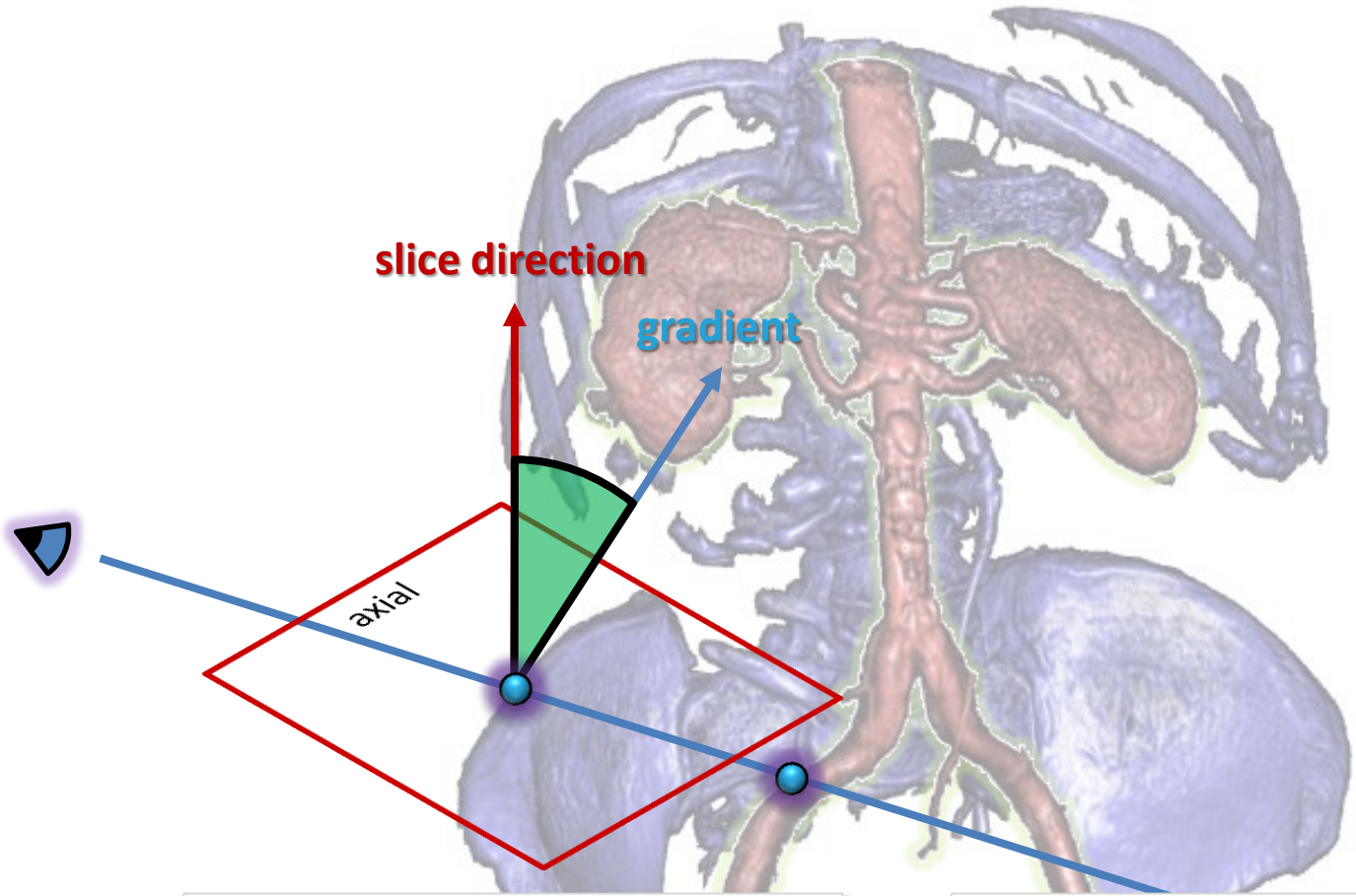


Vessel Tree Information

- Acyclic graph
- Edges are segments between branchings
- Segments can be selected
- Defined by radiological assistants



Data Annotation (2)



if dot(gradient,direction) = 0
⇒ gradient lies in slice plane
⇒ slice is highly relevant

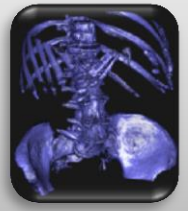
Store depth of first hit with masks
⇒ vessel mask depth layer
⇒ bone mask depth layer

Smart Views (3)

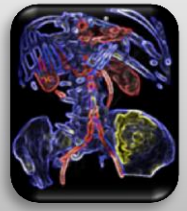
Data Annotation

Vessel Layer

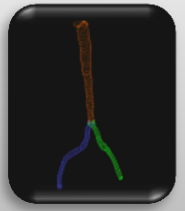
Bone Layer



Slice Layer



Vessel Tree Layer



Rule Specification

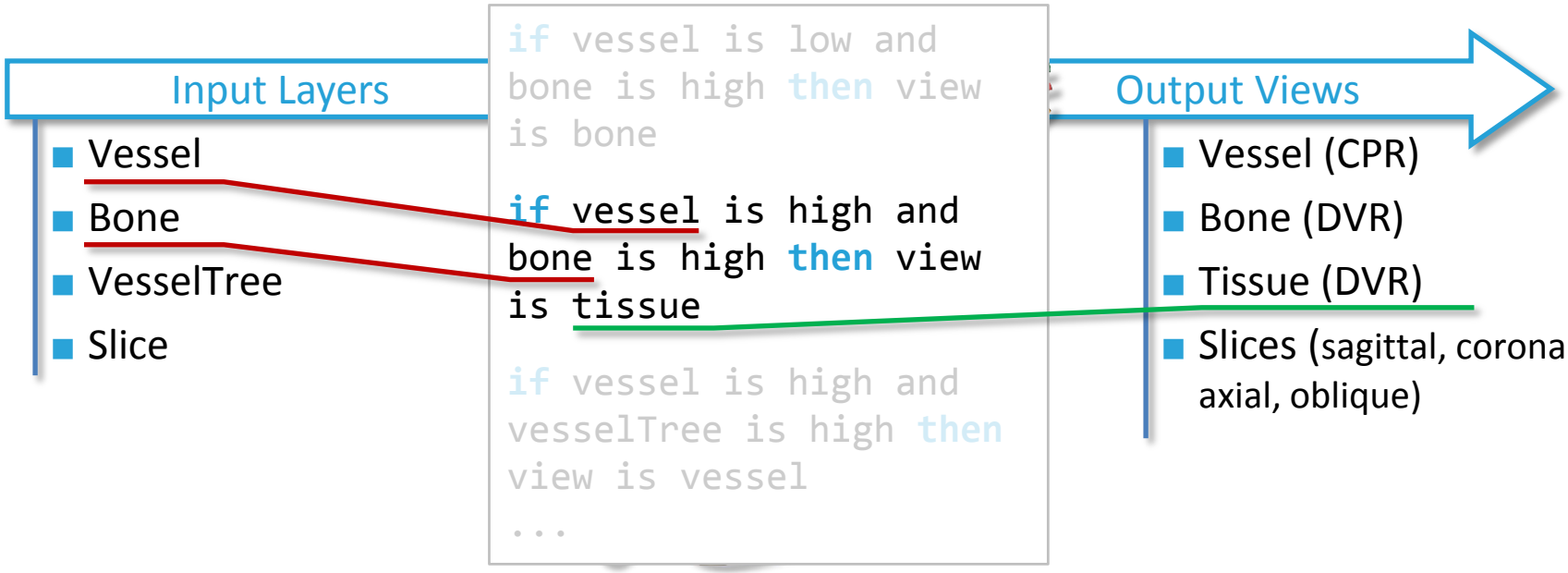
User Interaction

View Ranking

Views

Rule Specification (1)

- Relations between input and output
- User-defined rules
- If-then clauses



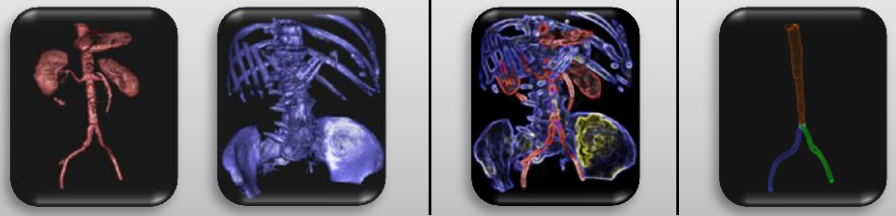
Rule Specification (2)

- Rules stored in an external file
- Adapted to specific demands of users
- Defined by domain experts
- Flexible extension by adding new rules
- Human readable form

Smart Views (4)

Data Annotation

Vessel Layer | Bone Layer | Slice Layer | Vessel Tree Layer



Rule Specification

If bone then use DVR
If vessel then use CPR
If tissue then use DVR

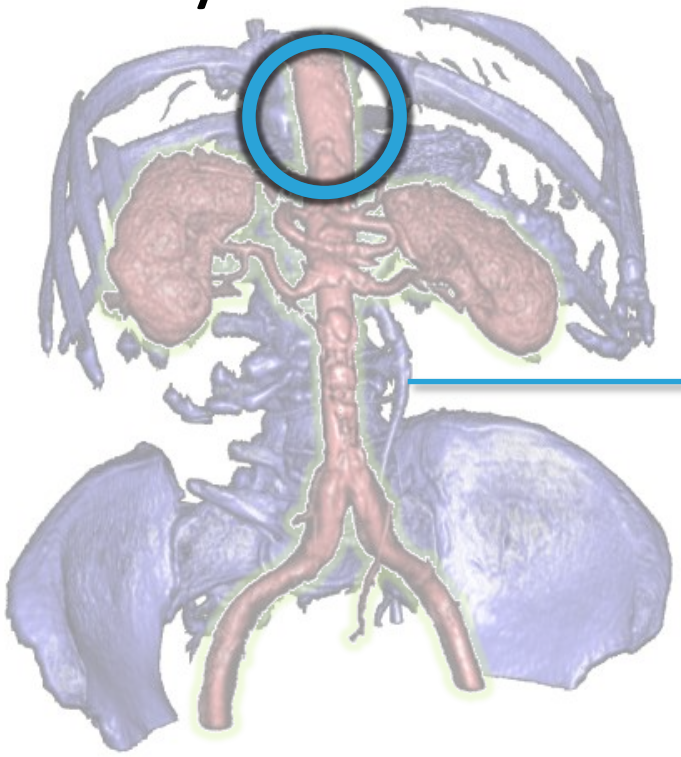
User Interaction

View Ranking

Views

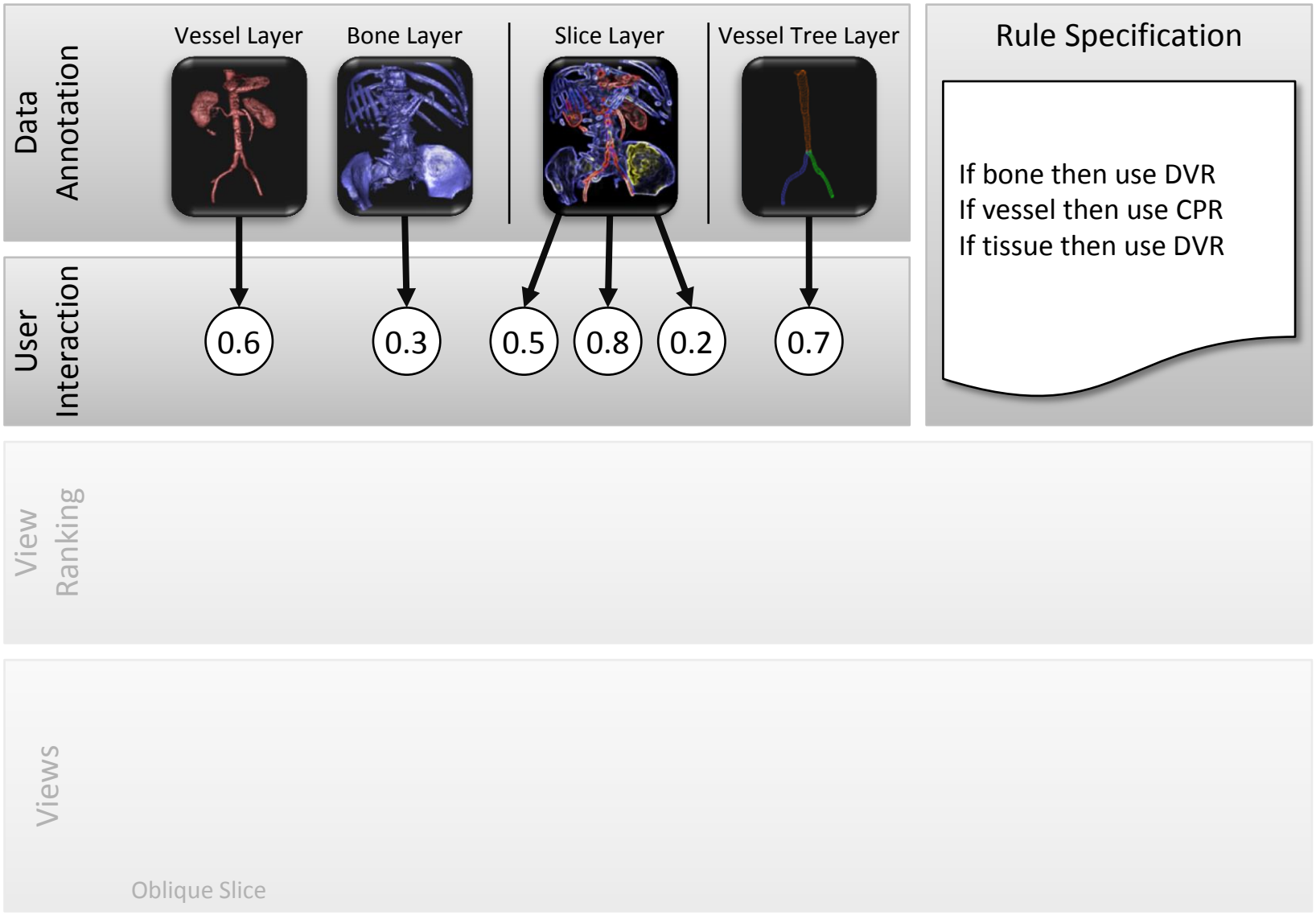
User Interaction

- User defines a ROI by moving the mouse
- Compute input values for all variables
- Layers are used inside the ROI



- One value for every input variable
- Sum over all pixels inside the ROI
- Pixels weighted with distance to center
- Specific layers for input variables

Smart Views (5)

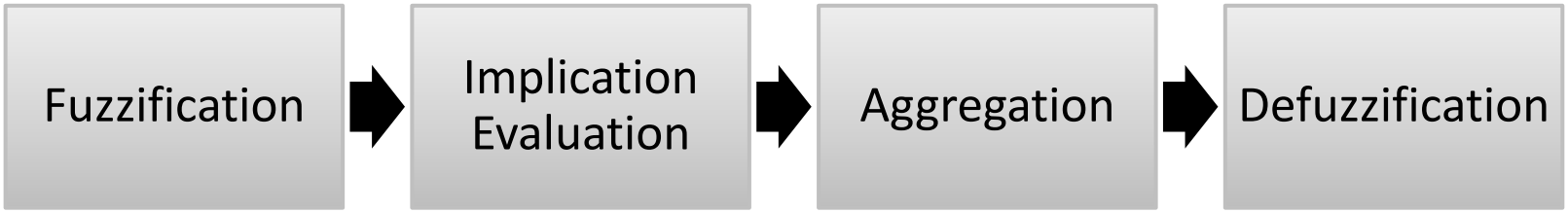


View Ranking

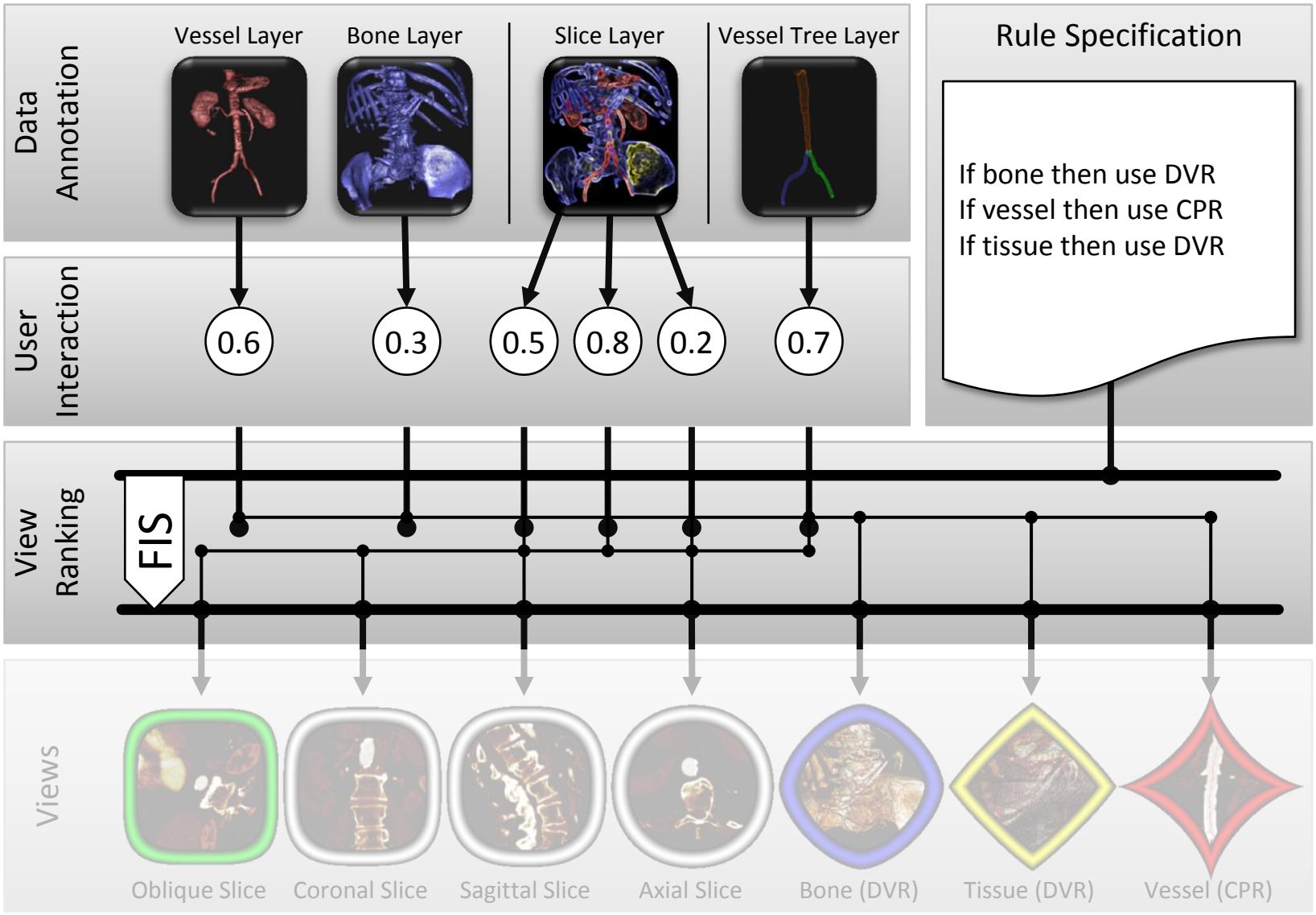
- Fuzzy logic for the inference system

$\Rightarrow$Fuzzy Inference System

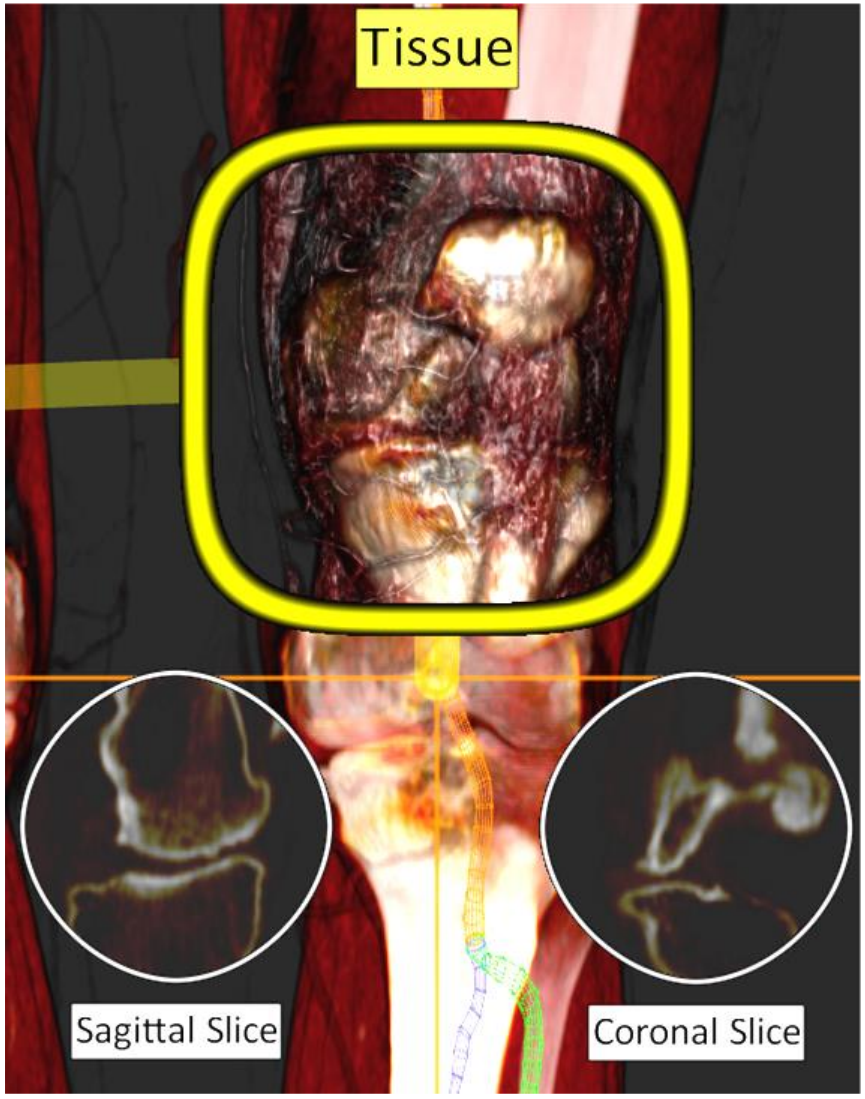
$\Rightarrow$Fuzzy rules specified by domain experts



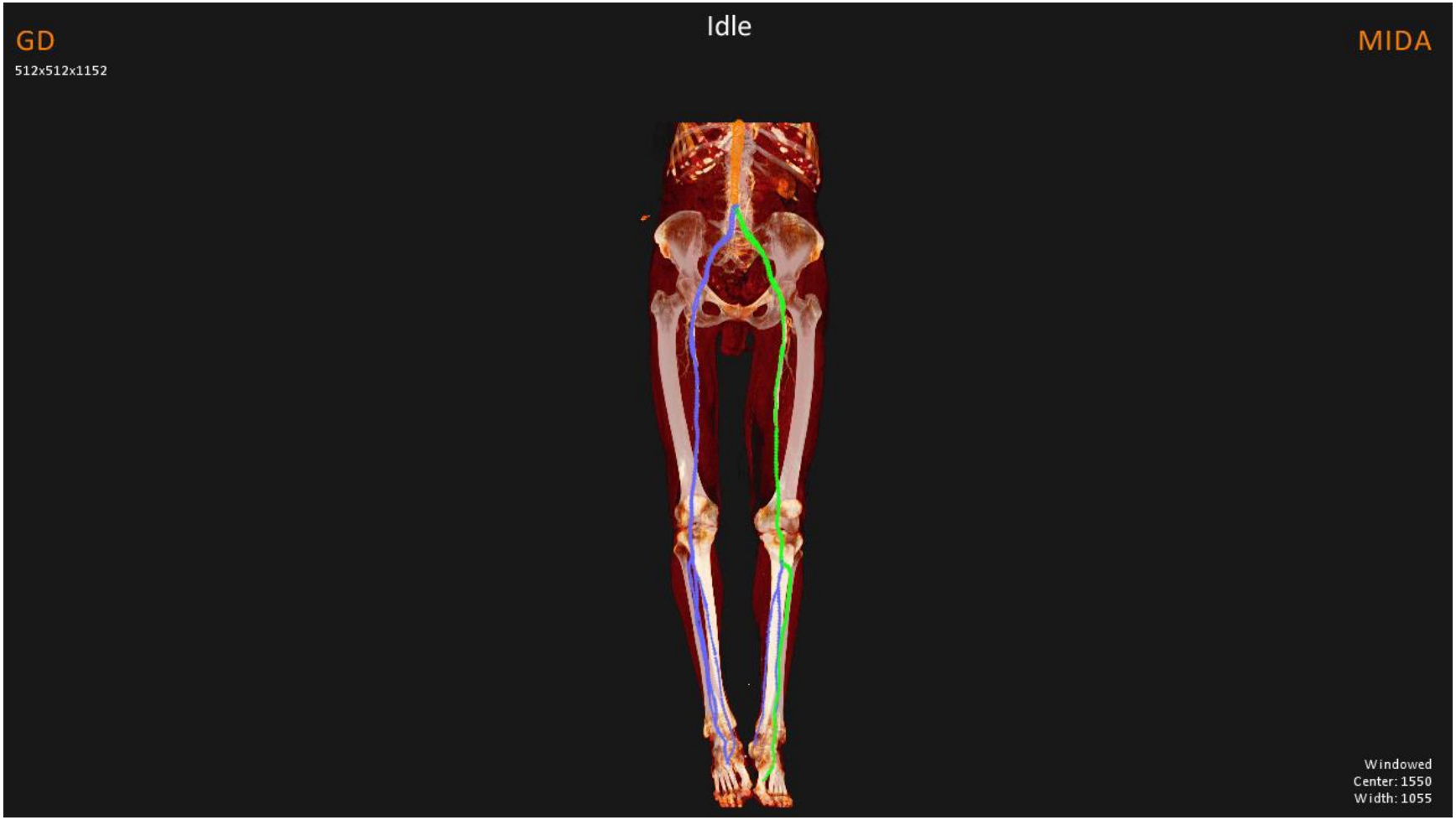
Smart Views (6)



Integrated Smart Views



Demostration



What's Next?

- Adaptive rule base: smart systems should become smarter over time
- Incorporate mechanisms to capture data about the success and failure of an operation
- Employ machine learning methods to improve the system based on user actions
- Use acquired information for goal-directed exploration of the algorithm space

Conclusion

- Smart visualization means using the right tool (algorithm) for the job (task)
- Knowledge about both task and algorithm behavior is essential

Challenge: acquire and use this knowledge in a systematic manner

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Smart Visualization in Medicine

THANK YOU FOR YOUR ATTENTION