Heightmap Segmentation

To accompany Sup240 Final Text

Topics

- Heightmap
- Classic segmentation in DICOM (background information)
- Heightmap segmentation
  - 1D and 2D
  - Notes and clarifications
- Heightmap use in derived En Face Images
  - Changes to Sup 197 En Face IOD

Heightmap definition

(computer graphics) A two-dimensional raster image used to store surface elevations that can later be applied to a three-dimensional object. *https://en.wiktionary.org/wiki/heightmap*

Heightmap in DICOM

Use case: identify surface in a 3D volume

- Restricted to single height (z) at any baseline location (x,y)
- Initial primary use for retinal layer surfaces in ophthalmic tomography (OPT)
- Degenerate case - intersection of surface with single image plane (1D raster for 2D object)

Mechanism: Heightmap Segmentation IOD

- Modeled on Segmentation IOD

Simplified alternative to Surface Segmentation IOD whose complexity allows arbitrary (folded, volume) surfaces

Segmentation (general background)

Important analytic task is identifying the different anatomical features in an image

- Bones, organs, tumors, blood
- Brain areas that are active with stimulus (functional MRI)

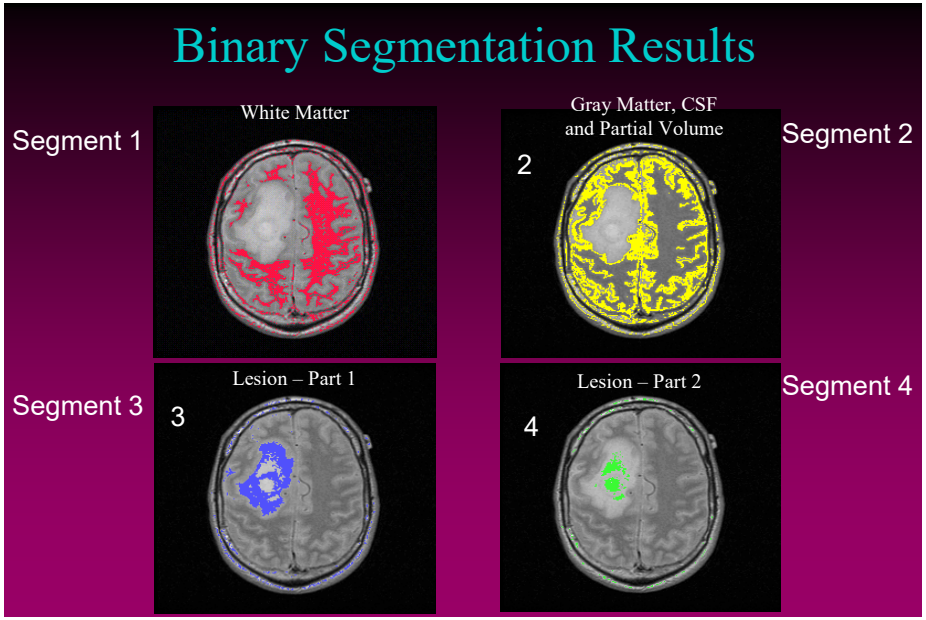
Segmentation classifies areas, volumes, or surfaces in categories

Segments can feed into imaging display pipelines

- As overlay or blending with source image (e.g., with Blending Softcopy Presentation State)
- Virtual removal of background or segmented anatomy from display of source (e.g., with Volumetric Presentation State)

Segments can feed into quantitative measurements

DICOM “classic” (pixel/voxel) segmentation



Modality = “SEG”

Derived image object using enhanced multi-frame image paradigm

Multiple segments per object, each having a property (categorization)

Segments linked to one or more frames, pixels show presence of property at pixel location

Two disparate methods in single SOP Class – planar and volumetric

Planar (pixel) segmentation

For segmentation of projection or other single plane images

- Possibly including each slice in a CT or MR volume (multi-frame, or series of single frames)

Indicated by absence of Frame of Reference UID

Each segmentation frame references its corresponding source single frame

- AKA “derivation image”

Segmentation frame pixels are 1:1 with source

- Same pixel matrix size, spacing

Volumetric (voxel) segmentation

Segmentation object uses same Frame of Reference as source image(s)

Extent of SEG frames may differ from extent of source, may use different spatial resolution, different orientation

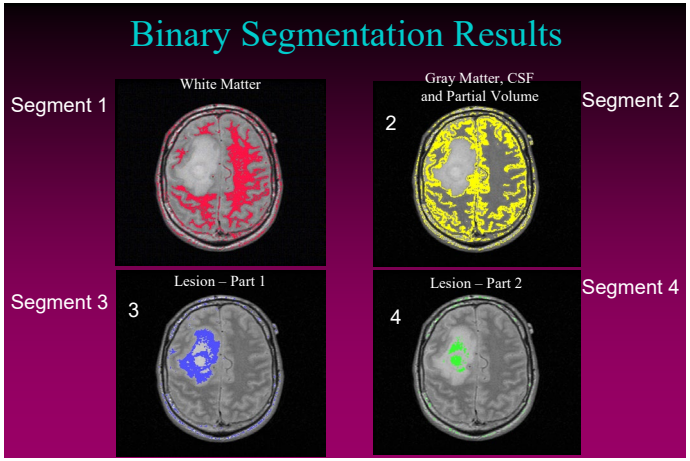
- Frame location in Frame of Reference specified by Pixel Measures, Plane Position (Patient), and Plane Orientation (Patient) functional groups

Segmented volume identified by Frame of Reference UID may correspond to multiple single frame objects in a source series

- E.g., for classical CT or MR SOP Instances
- Single Segmentation object may reference such multiple source images

Note: similar approach NOT used in Heightmap Segmentation

Segmentation data structure



Other attributes

Segment Sequence

Item 1 (Segment 1)
- Segment Number = 1
- Segment Name = White Matter
- Segment Category = Brain
- Segment Type = White Matter

Item 2 (Segment 2)
- Segment Number = 2
- Segment Name = Grey Matter
- Segment Category = Brain
- Segment Type = Grey Matter

Item 3 (Segment 3)
- Segment Number = 3
- Segment Name = Lesion Part 1
- Segment Category = Brain
- Segment Type = Lesion

Shared Functional Groups Sequence

Item 1 (Shared – all frames)
- Derivation Image Sequence
  - Item 1
    - Reference to source image (external object)

Per-frame Functional Groups Sequence

Item 1 (Frame 1)
- Segment Identification Sequence
  - Item 1
    - Referenced Segment Number = 1

Item 2 (Frame 2)
- Segment Identification Sequence
  - Item 1
    - Referenced Segment Number = 2

Item 3 (Frame 3)
- Segment Identification Sequence
  - Item 1
    - Referenced Segment Number = 3

Item 4 (Frame 4)
- Segment Identification Sequence
  - Item 1
    - Referenced Segment Number = 4

Pixel Data
- Frame 1
- Frame 2
- Frame 3
- Frame 4

Segment Sequence: Catalog of properties

Functional Group Sequence: Attributes and classification of each frame

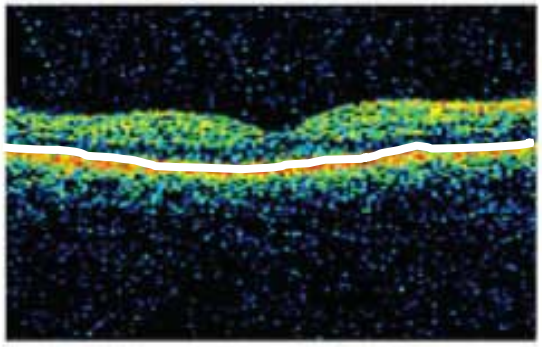
Pixel Data: Stream of multiple frames

Segment Sequence (0062,0002)

Catalog of segmentation properties

- Identifier, label, description
- Algorithm used
- Property category (e.g., anatomy, physical object, functional locus) - CID 7150
- Specific property (e.g., liver, pacemaker, perfusion) – CID 7151
- Preferred display color

Heightmap segmentation



Locates a surface intersecting an image plane or volume by its height (distance) from a baseline

Reuses planar segmentation data mechanism

- Enhanced multi-frame image paradigm
- Multiple segments per object, each having a property
- Each segmentation frame references its corresponding source
- Pixel spacing is 1:1 with source

Derivation (Source) Image

Heightmap is specified in the volumetric space (Frame of Reference) of referenced Derivation Image(s)

Identified in Derivation Image Functional Group

- Derivation Code Sequence (113076, DCM, "Segmentation"); Purpose of Reference (121322, DCM, "Source Image for Image Processing Operation")
- For consistency with Segmentation IOD planar segmentation codes

2D and 1D Heightmaps

Heightmap for a 3D volume is a 2D plane

Heightmap for a 2D plane is a 1D raster (row)

Heightmap Segmentation IOD supports 1D or 2D frames

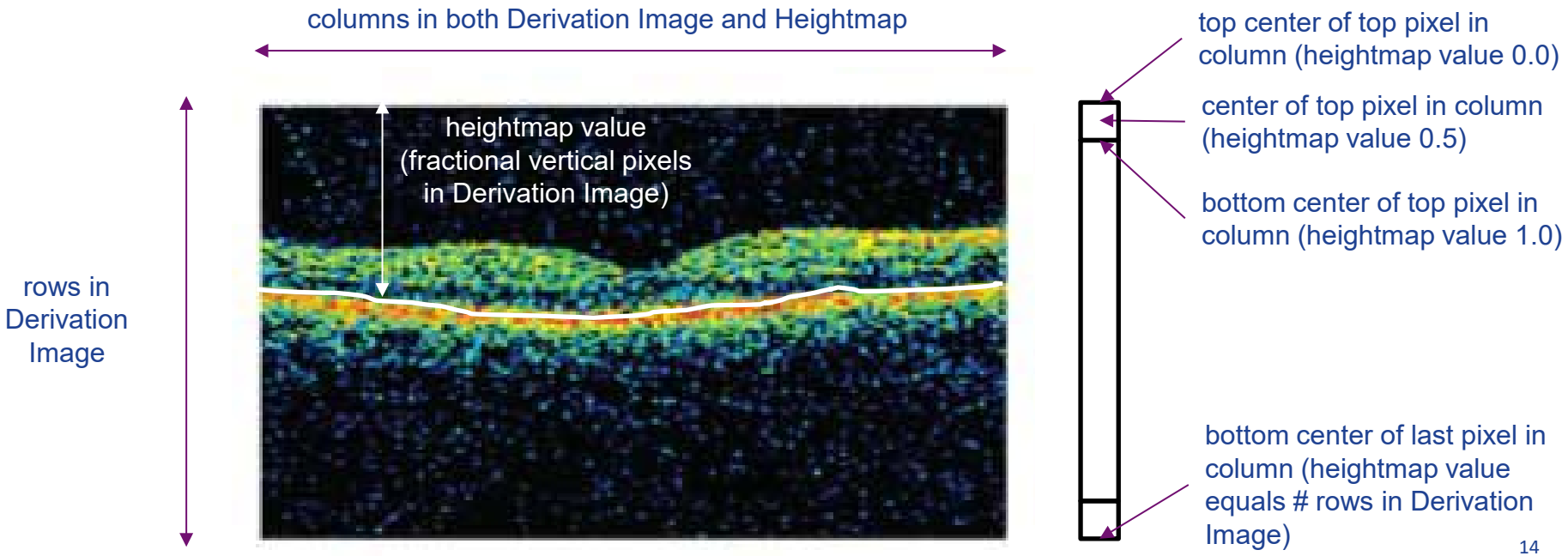
Heightmap follows DICOM convention of measuring pixel offsets from top of frame (TLHC)

Heightmap segmentation 1D frame

Each Heightmap 1D frame is one row with number of columns the same as corresponding source (Derivation Image) frame

Heightmap stored pixel values represent distance from top in source image in units of pixel rows (sub-pixel resolution)

- Upper edge of top pixel is 0.0, center of top pixel is 0.5

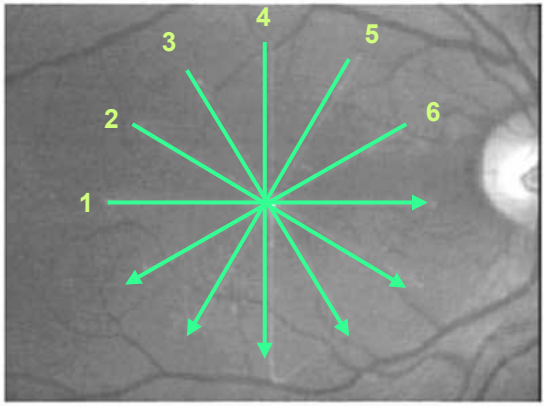


Heightmap 1D frames for various OPT scan patterns

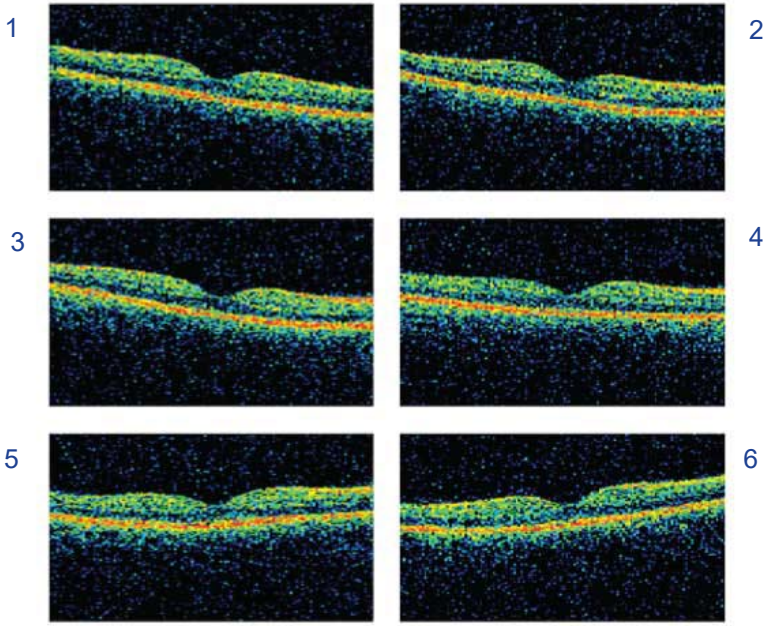
Multi-frame Ophthalmic Tomography (OPT) image may have b-scans at varying plane orientations

- E.g., radial scan pattern, circular scan pattern

One Heightmap 1D frame for each segmented layer in each source b-scan frame



OPT radial scan frame orientations relative to OP retinal image



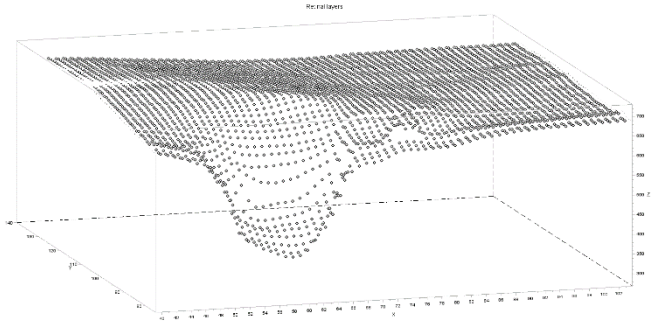
Heightmap 2D frames for volumetric OPT scan patterns

OPT image may have b-scans at constant plane orientation and regular plane spacing

- E.g., cube scan pattern

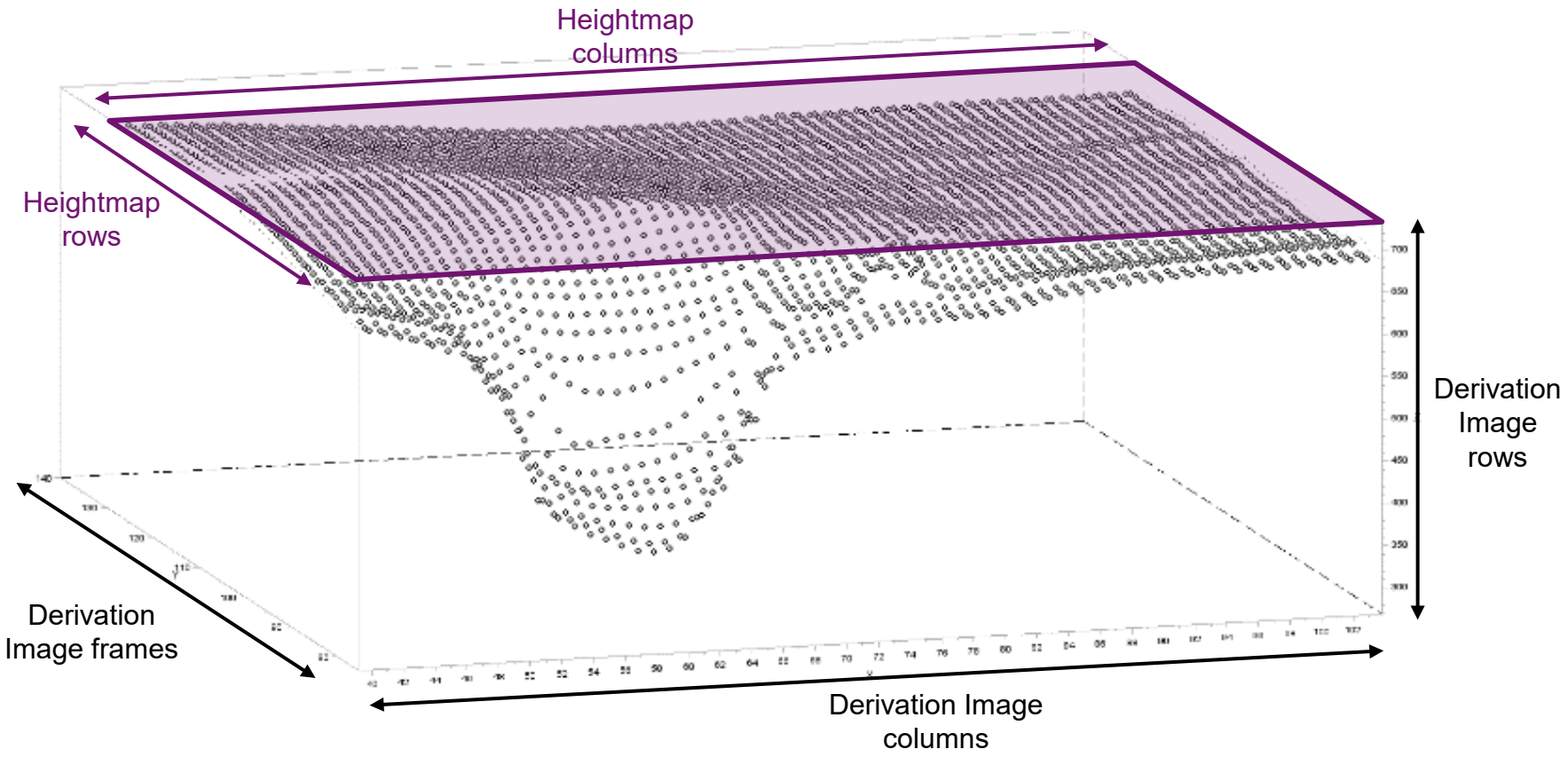
One Heightmap 2D frame for each segmented layer covers all source B-scan frames

- Pixel Data same as stream of 1D Heightmap rows for each source frame
- Column spacing same as source column spacing, row spacing same as source frame spacing

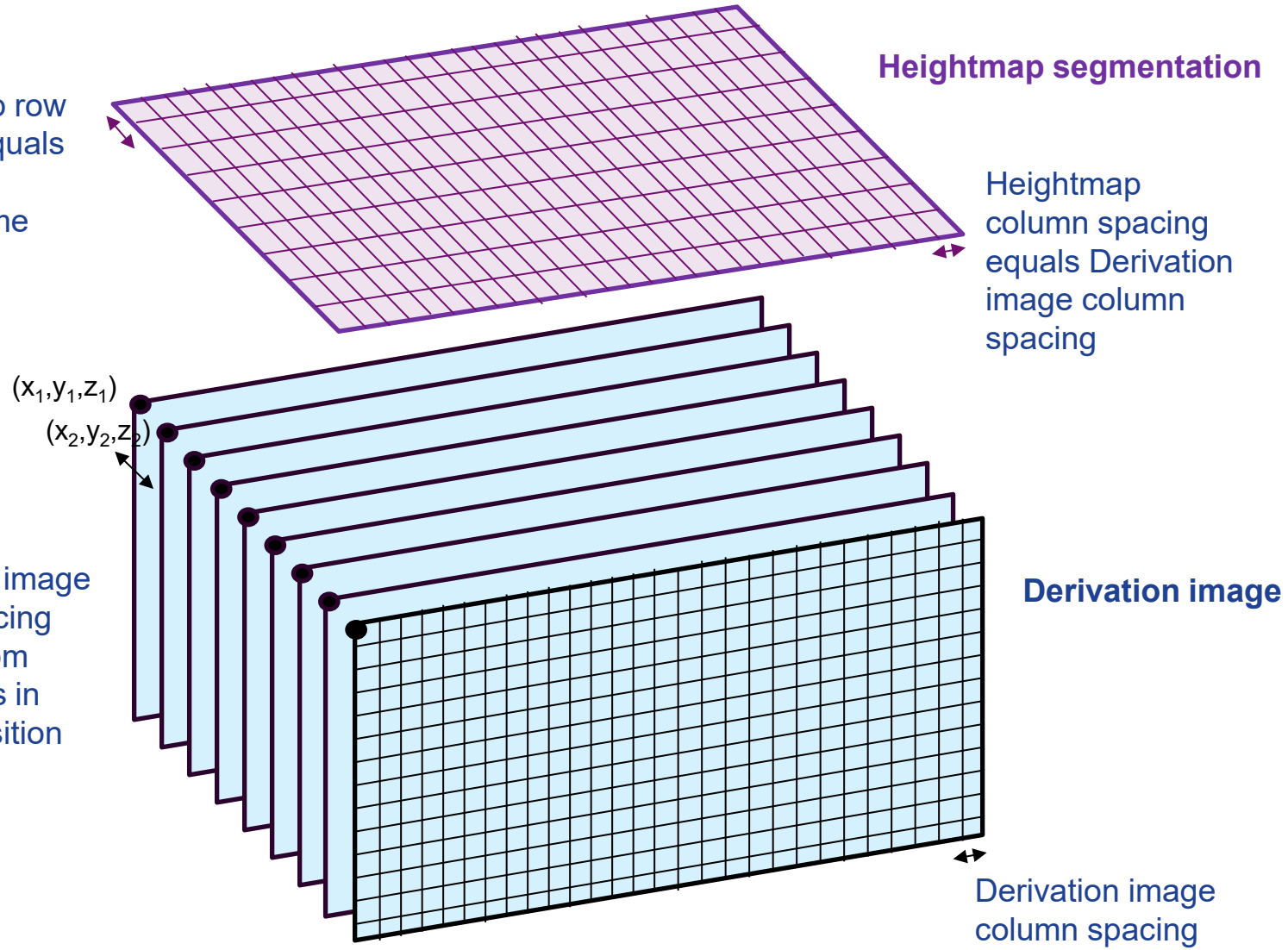


heightmap 2D frame values rendered as offsets into a 3D volume

Heightmap 2D frame pixel values rendered as offsets into a Derivation Image 3D volume



Heightmap pixel matrix spacing based on Derivation Image spacing



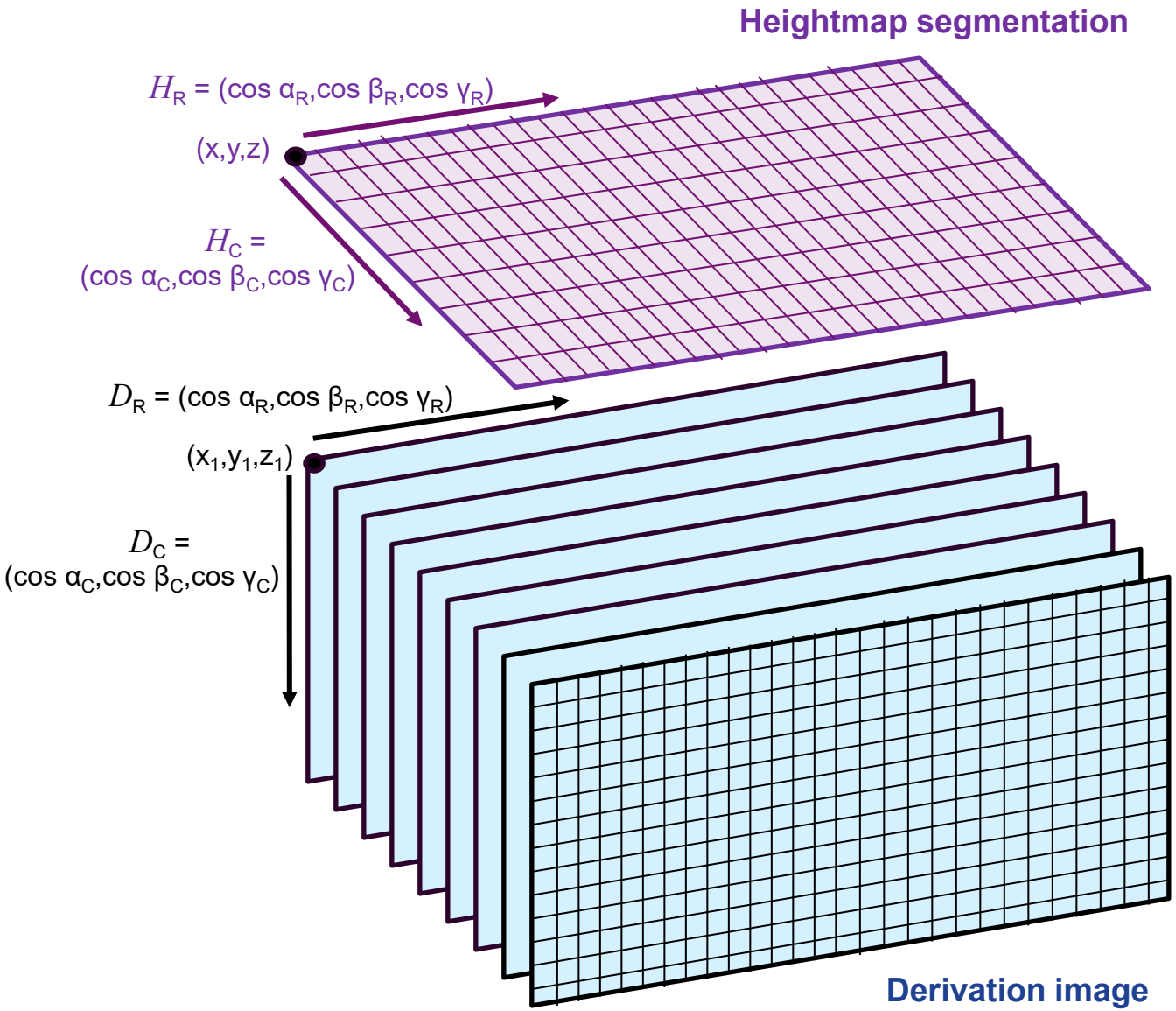
2D Heightmap Frame Row Spacing

Equal to slice spacing in referenced derivation image

- Spacing Between Slices (0018,0088) might not be present in OPT images
- Slice Thickness (0018,0050) is technically an ***incorrect*** substitute – even though it is commonly used (as it is a required attribute)

Correctly should be computed from differences in Image Position (Patient) (0020,0032) in referenced Derivation Image

Heightmap position and orientation based on Derivation Image



Heightmap plane position (x,y,z) equals Derivation image 1st plane position (x_1,y_1,z_1)

Heightmap plane row orientation H_R equals Derivation image plane row orientation D_R

Heightmap plane column orientation H_C equals cross product of Derivation image plane column orientation and row orientation D_C X D_R

Referenced images

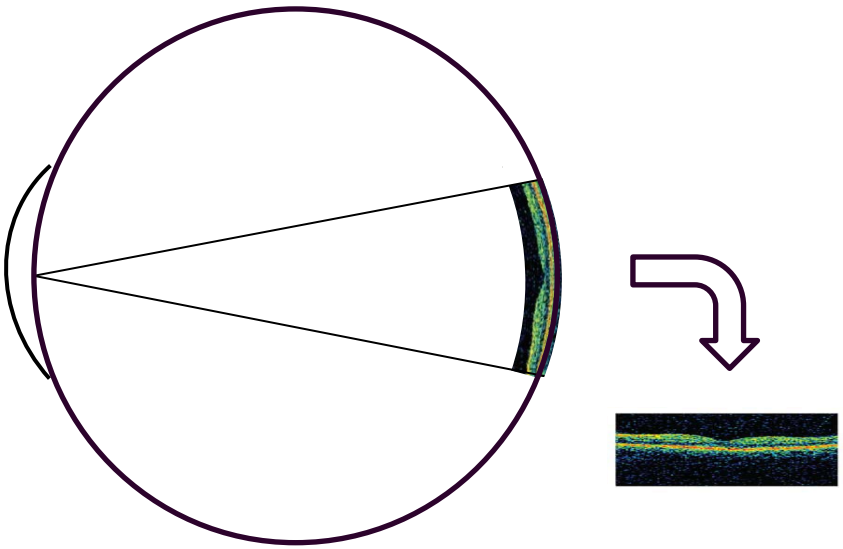
Heightmap is specified in the volumetric space (Frame of Reference) of a referenced Derivation Image

- Identified in Derivation Image Functional Group
- Frame of Reference Coordinate System may be deformed – see CP2347 “Clarify OPT Frame of Reference Coordinate System” [included in DICOM 2024d release]

Heightmap may be computed from a different object (e.g., Raw Data) identified in Referenced Image Functional Group

- Not necessarily directly derived from “Derivation Image”

OPT Acquisition and Display
Frame of Reference Coordinate System



Typical 6x6mm scan area

Deformation is small, and measurements in image are often corrected by (proprietary) algorithms

CP2347 clarifies that it is *nominally* in the Patient-based Coordinate System, with caveat for possible deformation

Heightmap follows OPT frame location in space and coordinate system, including for circular or other non-linear scans

N::M Relationship between OPT and SEG Instances

Heightmap SOP Instance can record multiple layers (segments)

One Heightmap SOP Instance can be applied to multiple OPT SOP Instances (e.g., if OPTs are one frame per instance)

- All OPTs (and Heightmap) must have same Frame of Reference UID

Multiple Heightmap SOP Instances can be applied to single OPT SOP Instances (e.g., one layer per Heightmap instance)

Pixel Values

Heightmap pixel data values use 32-bit floating point VR for sub-pixel resolution of position in anatomic image

Absence of segment in a column indicated by value in range specified by Float Pixel Padding Value (0028,0122) and Float Pixel Padding Range Limit (0028,0124)

IEEE 754 NaN (Not a Number) values are legal for padding

Heightmap in En Face Image

Ophthalmic OCT En Face Image presents a cross-sectional slab of OPT or OPT Volume Analysis multi-frame image as a planar image

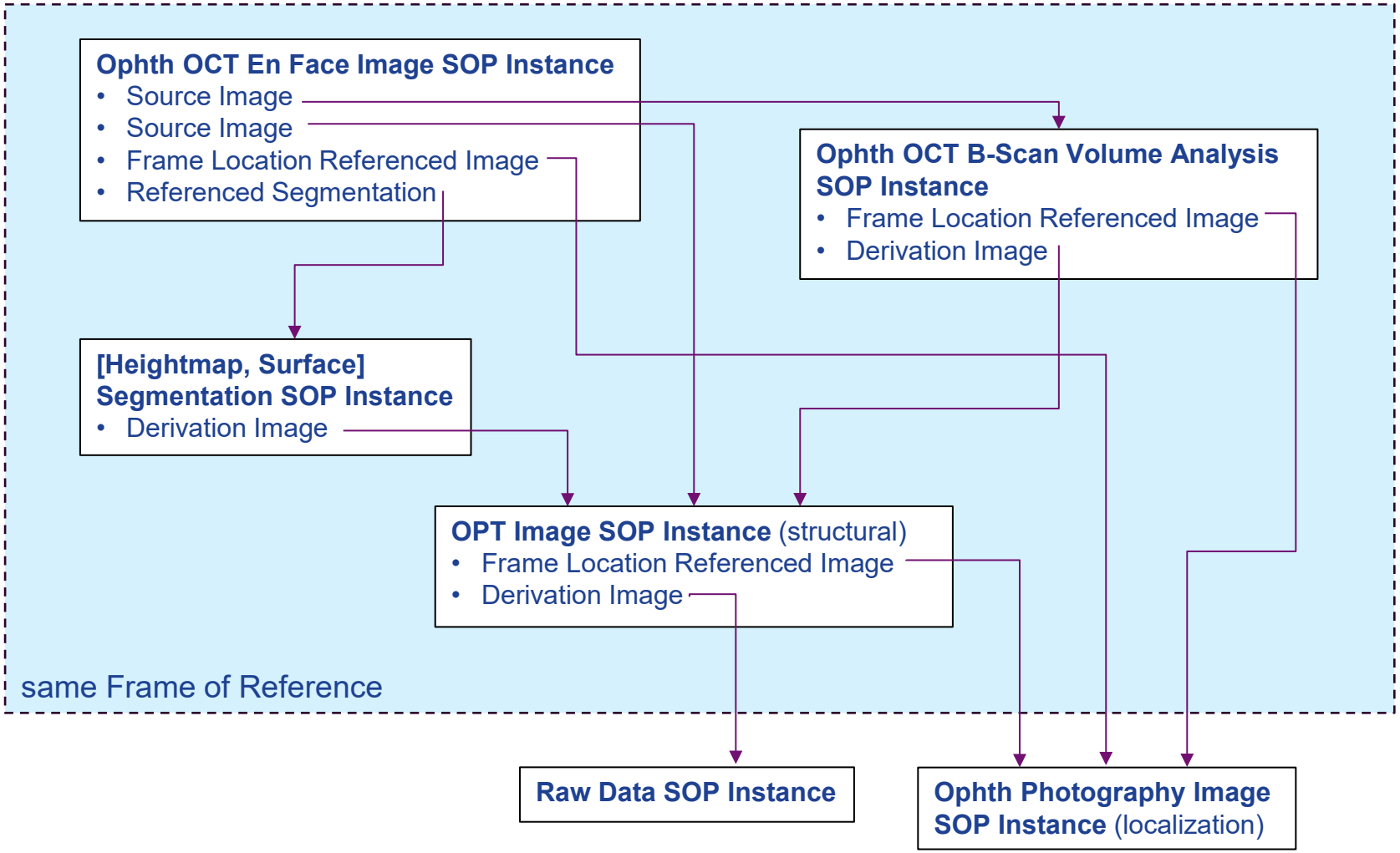
A surface of the slab may be specified using one segmented surface, or an interpolation of two segmented surfaces, or a fixed offset above/below a segmented surface

Revision of En Face IOD allows segmented surface to be Heightmap, Surface Segmentation, or any other SOP Class

- Previously, En Face IOD allowed only Surface Segmentation

Purpose is to show traceability, not to enable receiving app to reproduce slab

Relationship of OCT-A related SOP Instances



Non-Backward Compatible Changes to Sup 197 (2017) En Face Image IOD

Referencing the en face slab surface segmentations changes Type 1 attributes

- Allows more robust specification of anterior and posterior surfaces
- Required reference to Surface Segmentation SOP Instances revised to allow any type of segmentation

Added required reference to a localizer image (en face image location on fundus image)

Changes do not affect any attributes used in an image rendering pipeline, only in the metadata describing the image derivation process