Implementing a patient-based orientation system within STIR

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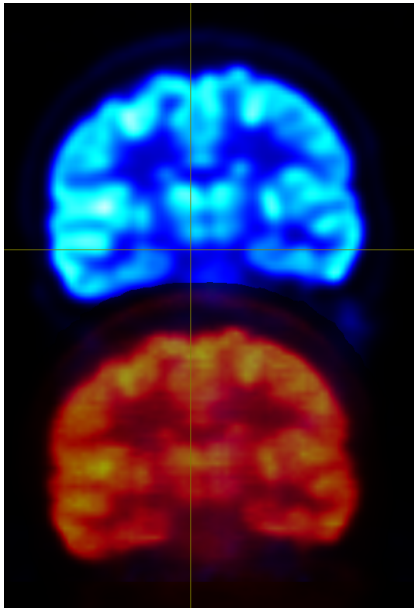
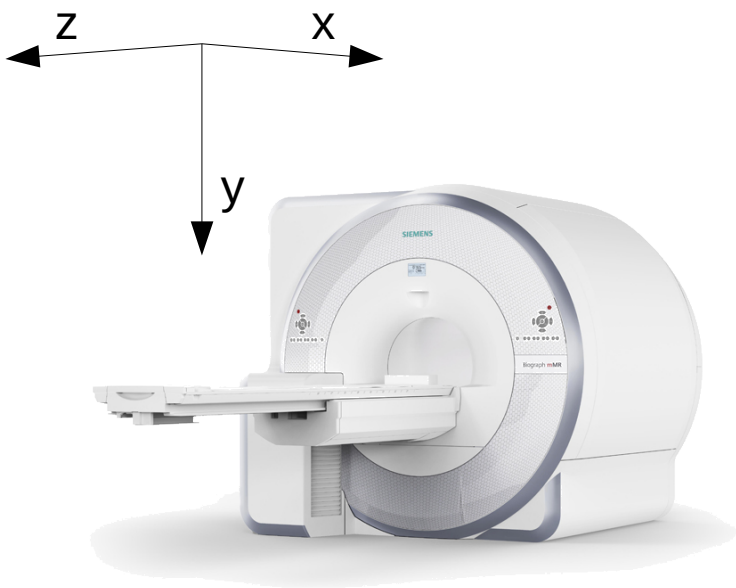
Motivation

- Currently, SIRF's output images aren't aligned with vendor reconstructions.
- This can make it difficult to align vendor images, e.g. for:
  - Attenuation correction using CT or MRAC.
  - Comparing STIR reconstructions with vendor reconstructions.
  - Using anatomical prior images.
  - Potentially simplifies use of STIR in clinical studies.



Coordinate Systems

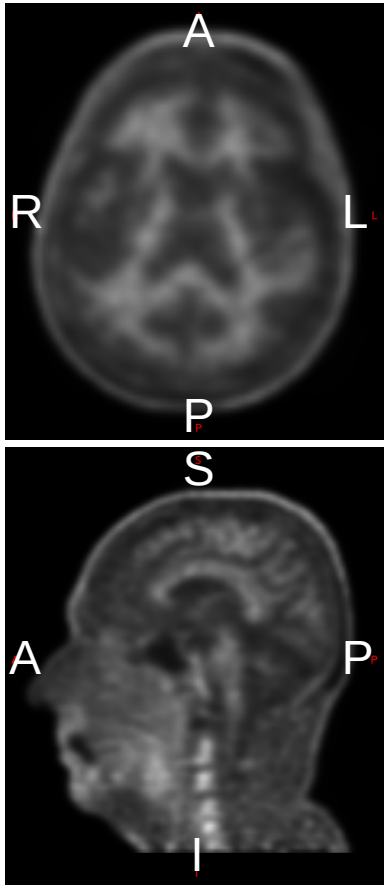
- STIR Uses a gantry-based coordinate system.
- From the STIR Developers' overview:
  - X-axis : horizontal axis, pointing right when looking from the bed into the gantry
  - Y-axis : vertical axis, pointing downwards
  - Z-axis : the scanner axis, pointing from the gantry towards the bed



Demonstration of STIR axes conventions

Coordinate Systems Cont.

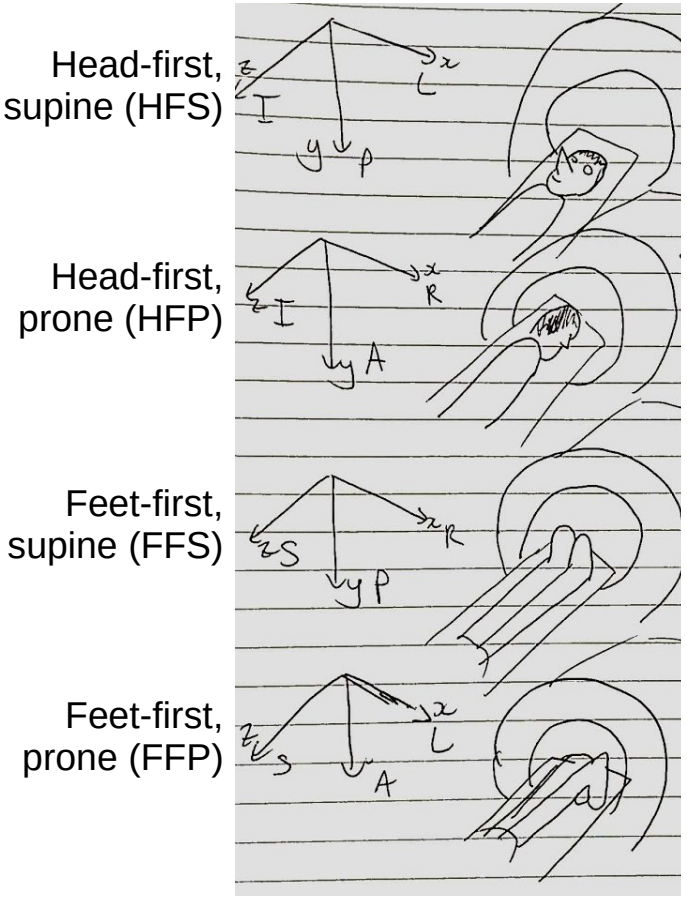
- Many common medical technologies (e.g., DICOM, NifTI) use a patient-based coordinate system, which is define w.r.t. patient anatomy.
  - In DICOM, axes directions are defined with respect to patient's Left, Posterior, Supine (LPS).
  - NIfTI orientation is defined by an affine transform of axes with respect to Right, Anterior, Supine (RAS).
- This system is useful in analysis as it allows rapid approximate alignment of anatomy.



Demonstration of Patient-based axes conventions

Mapping the Coordinate Directions

- In order to convert between these orientation systems, the patient orientation need to be known. Then a mapping is straightforward.



Demonstration of axes mapping for various patient positions

Mapping the Coordinate Directions Cont.

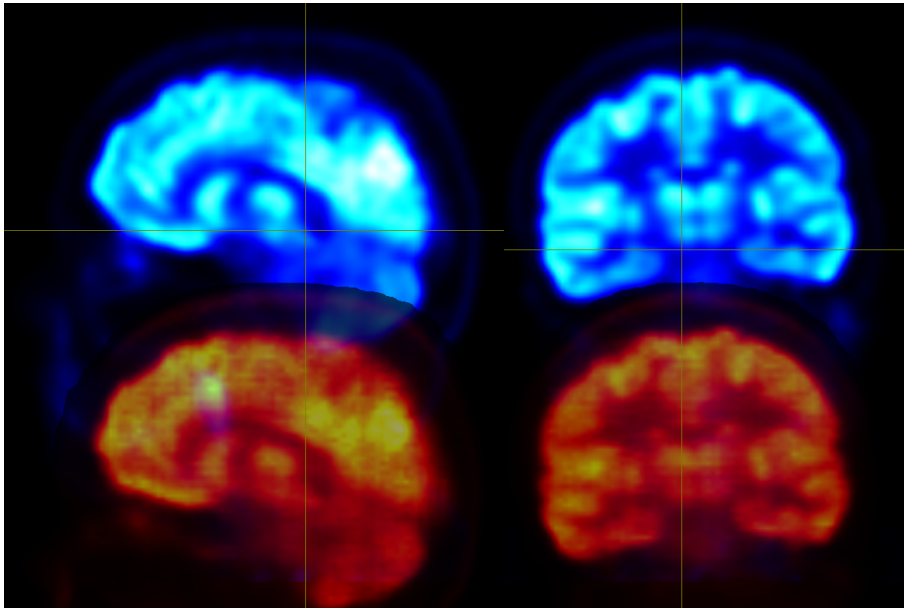
- Implemented in STIR Pull Request #248
- Adds `get_LPS_coordinates_for_indices()` and friends to `DiscretisedDensity`

```
switch (patient_position.get_position())
  {
  case PatientPosition::unknown_position: // If unknown, assume HFS
  case PatientPosition::HFS:              // HFS means currently in patient LPI
    flip_coords.z() *= -1;
    break;

  case PatientPosition::HFP:              // HFP means currently in patient RAI
    flip_coords.x() *= -1;
    flip_coords.y() *= -1;
    flip_coords.z() *= -1;
    break;

  case PatientPosition::FFS:              // FFS means currently in patient RPS
    flip_coords.x() *= -1;
    break;

  case PatientPosition::FFP:              // FFP means currently in patient LAS
    flip_coords.y() *= -1;
    break;
```

```
+   //! Translation from LPS coordinates to continuous indices.
+   inline BasicCoordinate<num_dimensions, float>
+   get_index_coordinates_for_LPS_coordinates(const CartesianCoordinate3D<float>& coords) const;
+
+   //! Translation from physical to LPS coordinates.
+   inline CartesianCoordinate3D<float>
+   get_LPS_coordinates_for_physical_coordinates(const CartesianCoordinate3D<float>& indices) const;
+
+   //! Translation from indices to LPS coordinates.
+   inline CartesianCoordinate3D<float>
+   get_LPS_coordinates_for_indices(const BasicCoordinate<num_dimensions,int>& indices) const;
+
+   //! Translation from continuous indices to LPS coordinates.
+   inline CartesianCoordinate3D<float>
+   get_LPS_coordinates_for_indices(const BasicCoordinate<num_dimensions,float>& indices) const;
+
+   //! Translation from LPS coordinates to physical coordinates.
+   inline CartesianCoordinate3D<float>
+   get_physical_coordinates_for_LPS_coordinates(const CartesianCoordinate3D<float>& coords) const;
+
+   //! Translation from LPS coordinates to indices.
+   inline BasicCoordinate<num_dimensions,int>
+   get_indices_closest_to_LPS_coordinates(const CartesianCoordinate3D<float>& coords) const;
```

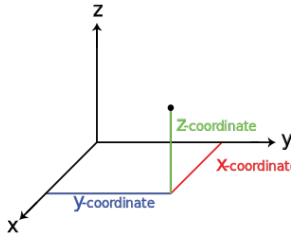
Using new directions with ITK IO

- With Pull Request #257, ITK I/O is LPS compatible.
- When saving, the image will be correctly oriented.
- When reading, only DICOM images store patient orientation and will be correctly oriented.
- NIfTI images will be read as “unknown_orientation”, treated internally as Head-first, supine.



Vendor reconstruction (blue, DICOM) and STIR reconstruction (red, NIfTI), in the same, patient-based orientation system.

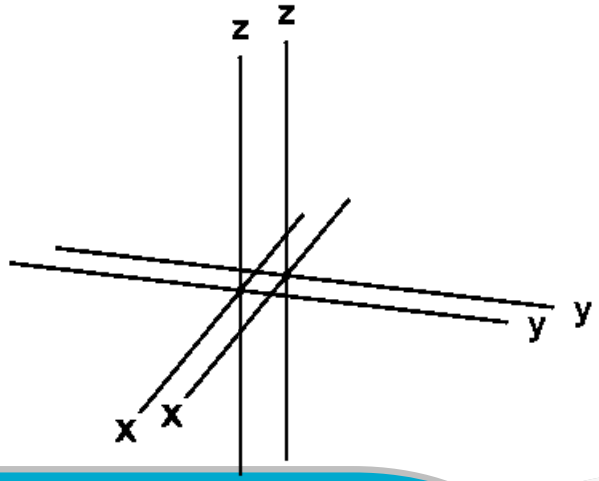
Difference between vendor and STIR FoR



- STIR and vendor images have different Frame-of-References (FoR, [0, 0, 0] points)
- From the STIR Developers' overview:
  - The origin of the X and Y axes are located on the central axis of the PET scanner and the Z origin (z=0) is located in the middle of the first ring (i.e., at the opposite side of the bed).
- DICOM only guarantees that images with the same Frame of Reference Unique Identifier are self-consistent.
  - Since it is patient based, the FoR moves with the bed.

Difference between vendor and STIR FoR

- Testing on the Siemens mMR at HIRF, Brisbane and at UCL, London, indicate the DICOM FoR is, at least approximately, the center of the PET gantry.
  - NB: More likely the MR isocentre, and the PET gantry center happens to be approximately the same.



Experiment – changing the LPS origin

- To test, I created a temporary new origin, called the vendor origin.
  - It is set to:
    STIR-origin + vector-to-centre + bed-position-vector
- LPS uses this, and therefore ITK IO

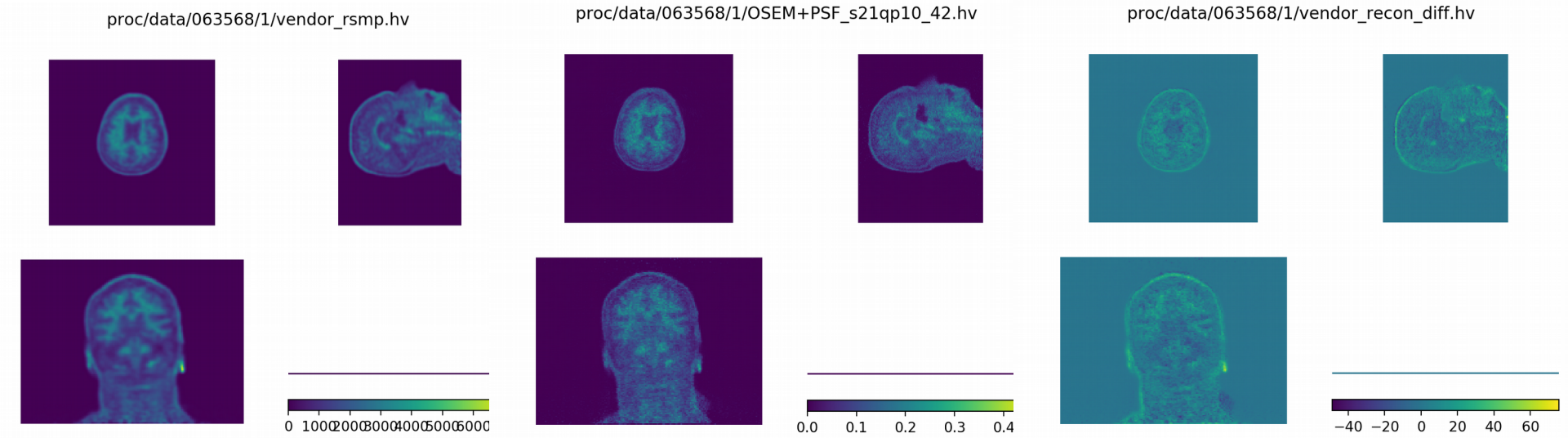
```
const CartesianCoordinate3D<float>
ProjDataInfo::
get_location_of_vendor_frame_of_reference_in_physical_coordinates() const {
  return
    //vendor FoR is from the centre of the gantry, STIR is from first ring
    get_vector_centre_of_first_ring_to_centre_of_gantry()
    //vendor FoR is bed-based
    + get_bed_position();
}
```

```
template<class elemT>
void
VoxelsOnCartesianGrid<elemT>::
init_from_proj_data_info(const ProjDataInfo& proj_data_info,
                         const float zoom,
                         const CartesianCoordinate3D<float>& origin,
                         const CartesianCoordinate3D<int>& sizes)
{
  ... //omitted

  this->set_origin(origin);
  this->set_vendor_origin
    (origin
     - (proj_data_info
        .get_location_of_vendor_frame_of_reference_in_physical_coordinates()));

  ... //omitted
}
```

```
template<int num_dimensions, typename elemT>
CartesianCoordinate3D<float>
DiscretisedDensity<num_dimensions, elemT>::
get_LPS_coordinates_for_indices
(const BasicCoordinate<num_dimensions, float>& indices) const
{
  return swap_axes_based_on_orientation
    (get_relative_coordinates_for_indices(indices) + get_vendor_origin(),
     get_exam_info().patient_position);
}
```

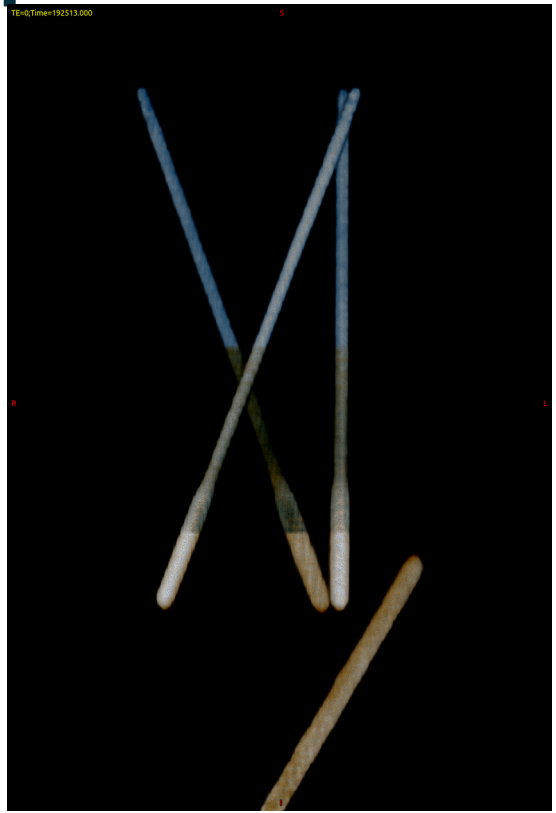
Results – changing the LPS origin

- Here we have the vendor resampled into STIR recon space (but no physical transform), a STIR recon, and the difference.



Results – changing the LPS origin

- Here we have a volume render of a Rod Phantom, acquired on the UCL mMR. 2 Bed positions were acquired with 50% overlap.
- In white, the vendor reconstruction, 2 bed positions composed.
- Overlay in red and blue are STIR reconstructions of each of the bed positions.



TODO: Implementation

- Second origin isn't an elegant solution.
- How to encode the gantry-image offset?
- Image data could encode gantry center position
  - DICOM[1]: Isocenter Position (300A,012C)
    - Isocenter coordinates (x,y,z), in mm. Specifies the location of the machine isocenter in the Patient-Based Coordinate System associated with the Frame of Reference. It allows transformation from the Equipment-Based Coordinate System to the Patient-Based Coordinate System.
  - New Interfile "vendor origin (mm) [X]"?
- ProjDataInfo has Bed Position and Gantry Information

[1] http://dicom.nema.org/MEDICAL/DICOM/current/output/chtml/part03/sect_C.8.9.4.html

TODO: Long Term

- Original plan was to have STIR's origin be consistent with the Vendor FoR.
  - This gets difficult when there is an offset – It means STIR origin is no longer the same every time. Each image would have to be paired with a specific Projection Data to have all the information.
- PET – MR gantry offset.
  - For this scanner, seems to only be in the Raw Data DICOMs – public info?

Conclusion

- ITK Input reading DICOM images will be correctly orientated.
- ITK Input reading NIfTI images will only be correctly orientated if HFS.
- ITK Output NIfTI/DICOM images spatially consistent with vendor DICOMs (soon), including for varying bed position.
- I will be using this facility for attenuation correction, comparisons with vendor reconstructions, using priors in PET reconstruction, and replacing portions of an existing clinical research study.

It takes a village…

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