An Octree Based Approach to Multi-Grid B-spline Registration

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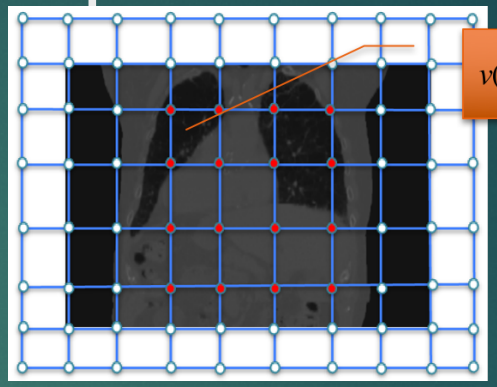
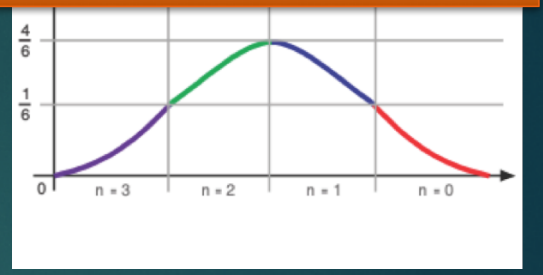
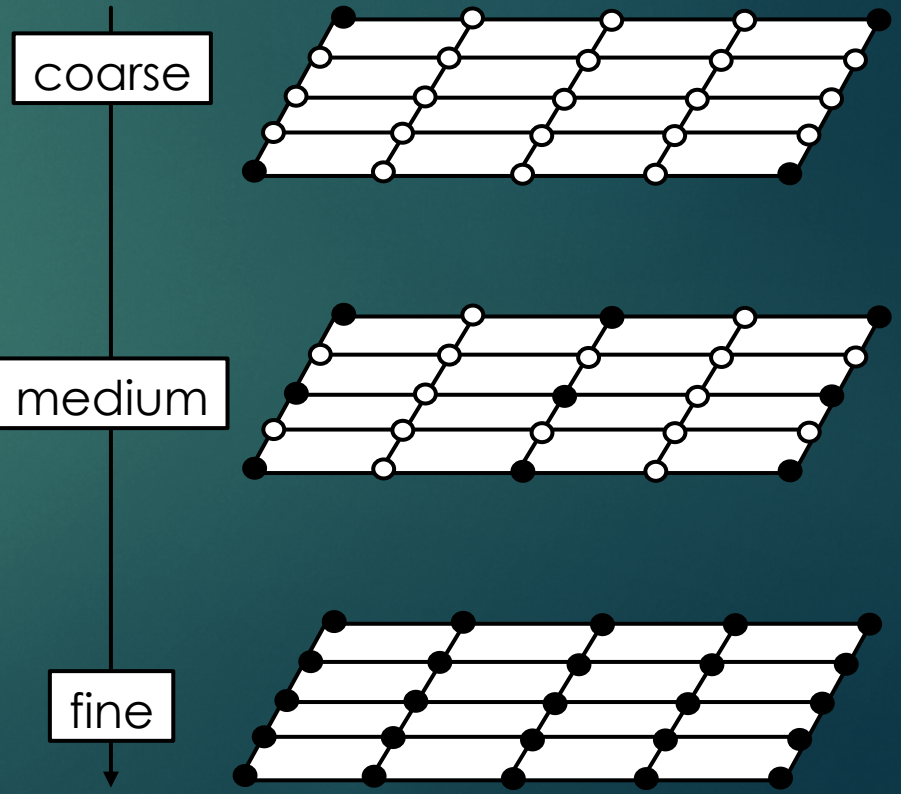
Multi-grid Hierarchical B-spline Registration

- Goal:
  - Recover deformation field that captures both gross and local motion by giving information from coarser layer to finer layer
  - Each layer increases the number of parameterizing control points, allow for increasingly complex deformations
- Limitations:
  - Each layer is optimized independently (only one layer at a time) and forces to apply uniform spacing of control points everywhere
  - Inability to correctly capture discontinuities (e.x. sliding motion) at organ interfaces while maintaining acceptable solutions
  - Difficulty in selecting number of free parameters/number of layers for a particular anatomical site



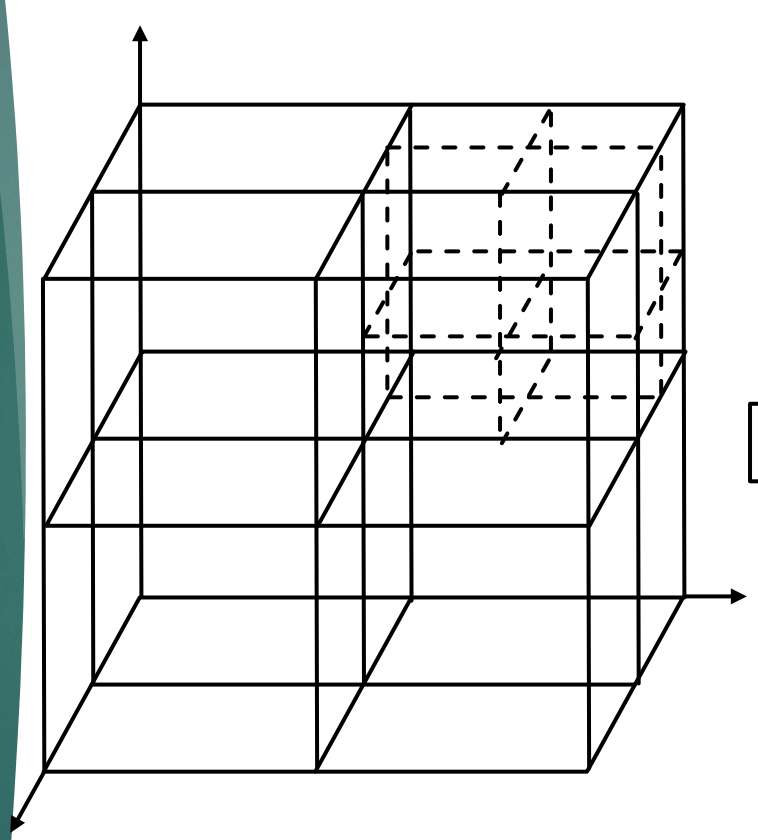
$$v(x) = \sum_{l=0}^{3} \sum_{m=0}^{3} \sum_{n=0}^{3} B_l(u) B_m(v) B_n(w) P_{i+l,\, j+m,\, k+n}$$

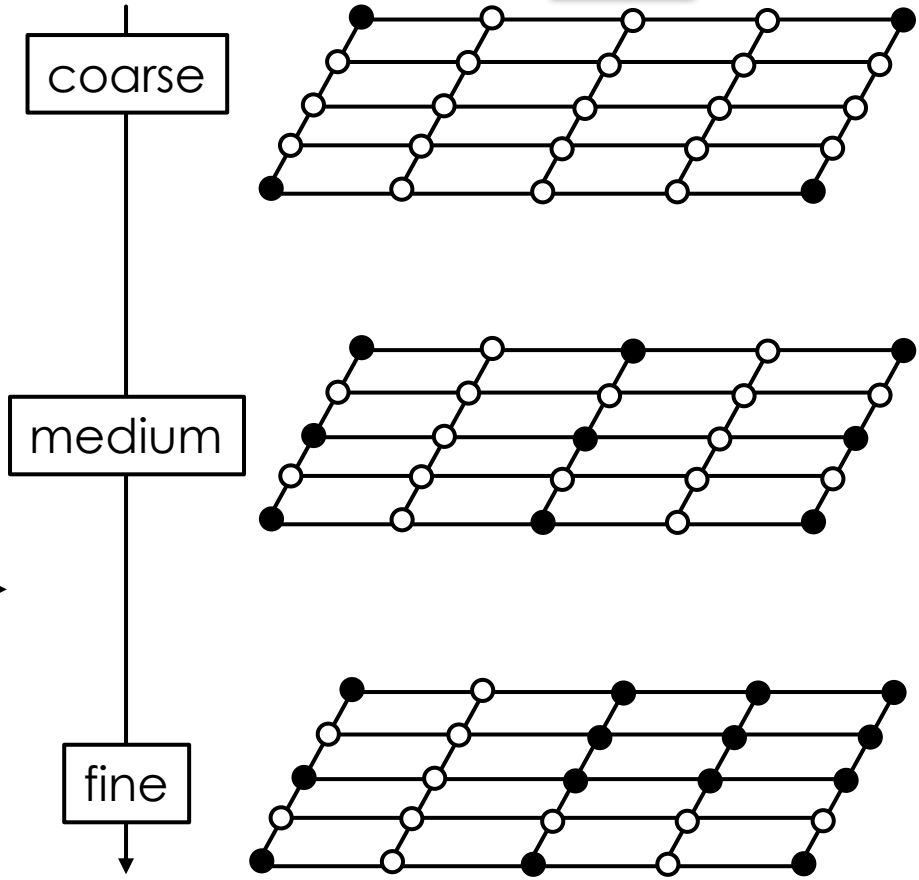




Hierarchical Octree B-spline

- Constructed from multiple levels with different grid spacing and optimized simultaneously
- Different regions are managed by different control point grid spacing
- Recursively subdivide support regions of coarser grid levels into 8 finer support regions and it's not applied uniformly to all regions
- How to figure out which regions need to be subdivided?

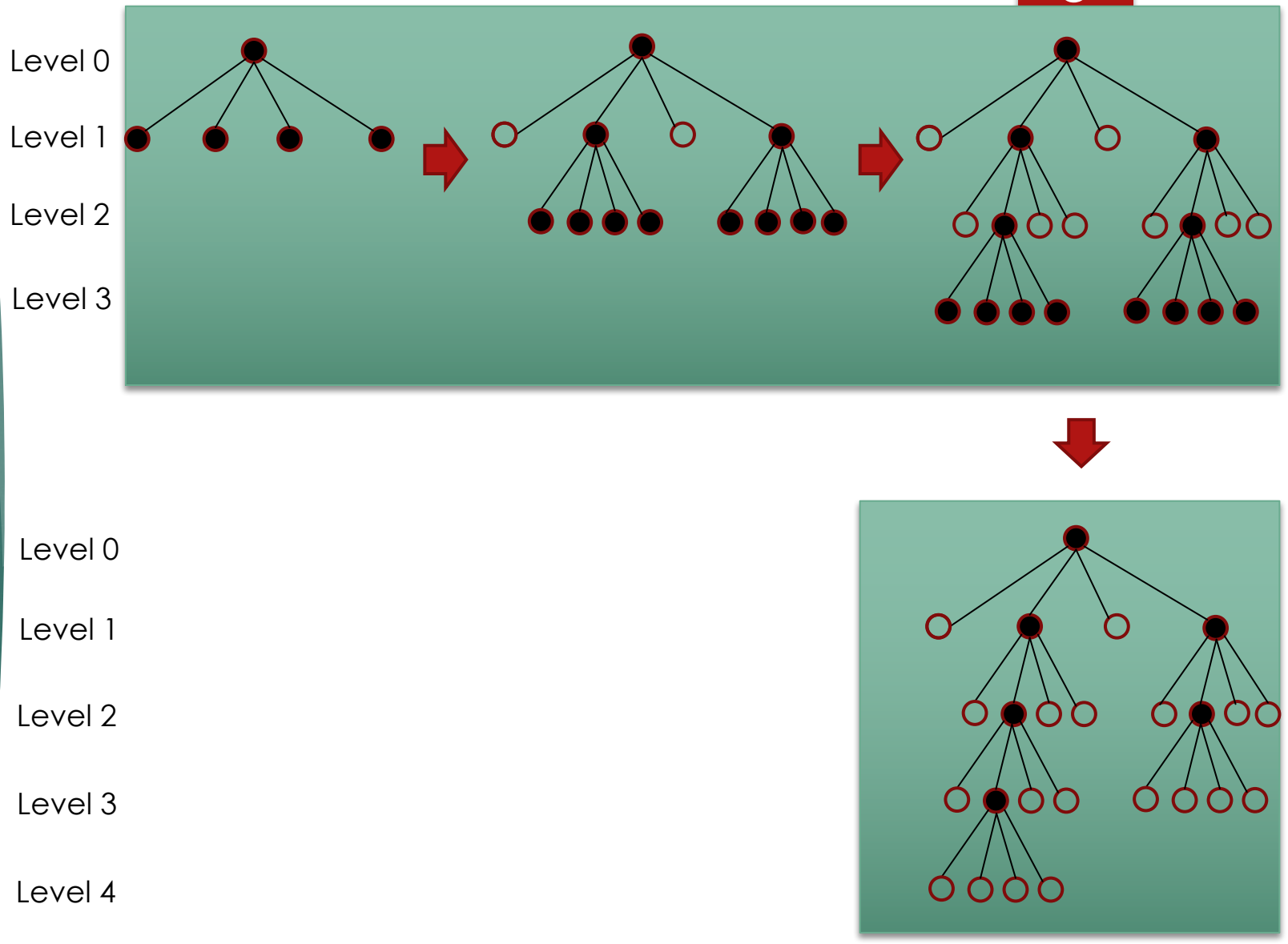




Octree Construction Process

- Each node represents an image region
- Goal: distinguish complex deformation regions V.S. less complex deformation regions
  - Stage 1: build an initial complete octree on frequency power spectrum

Last level (finest level) is designed to decouple the sliding motion vectors (different grid spacing for adjacent regions)



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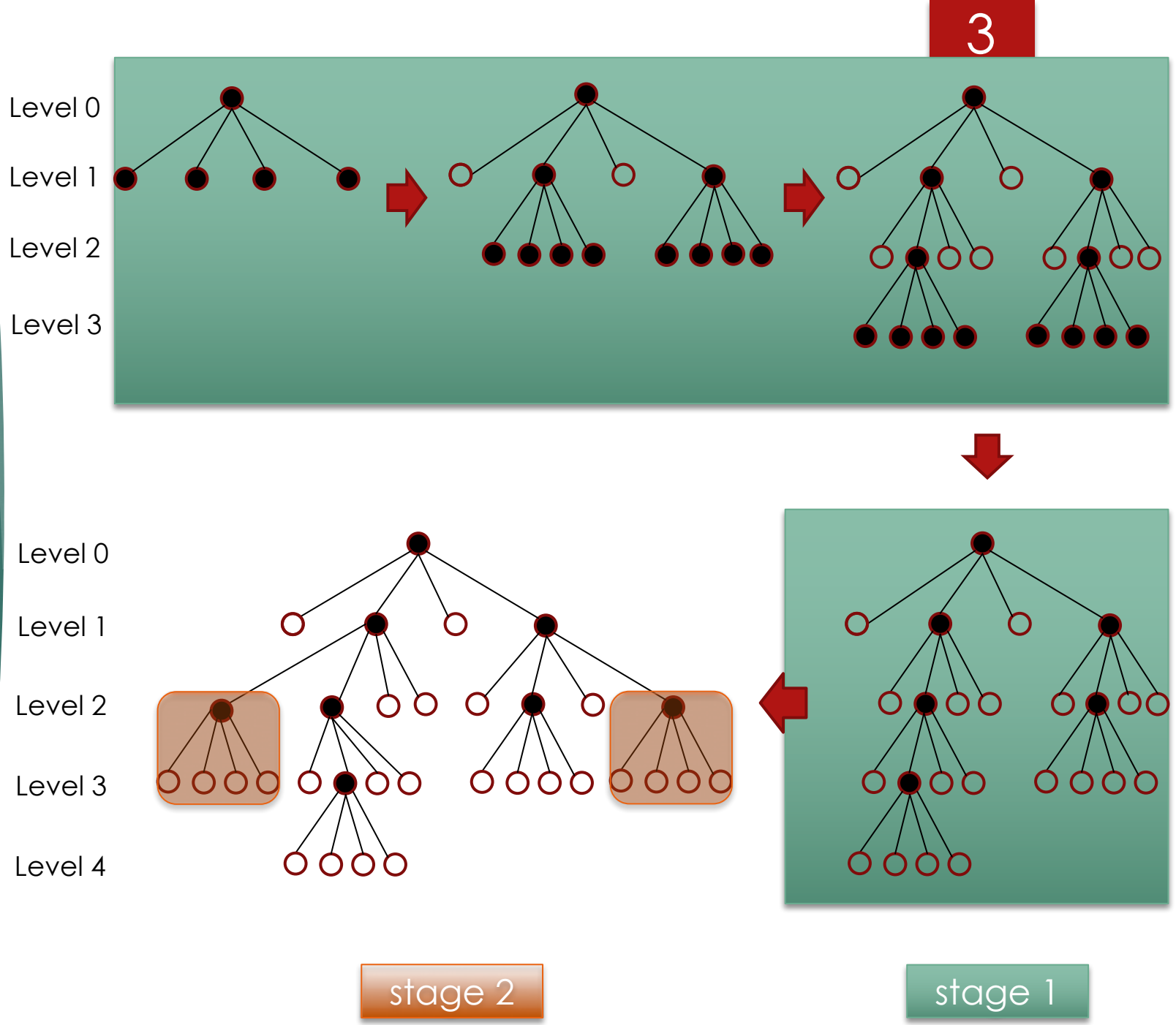

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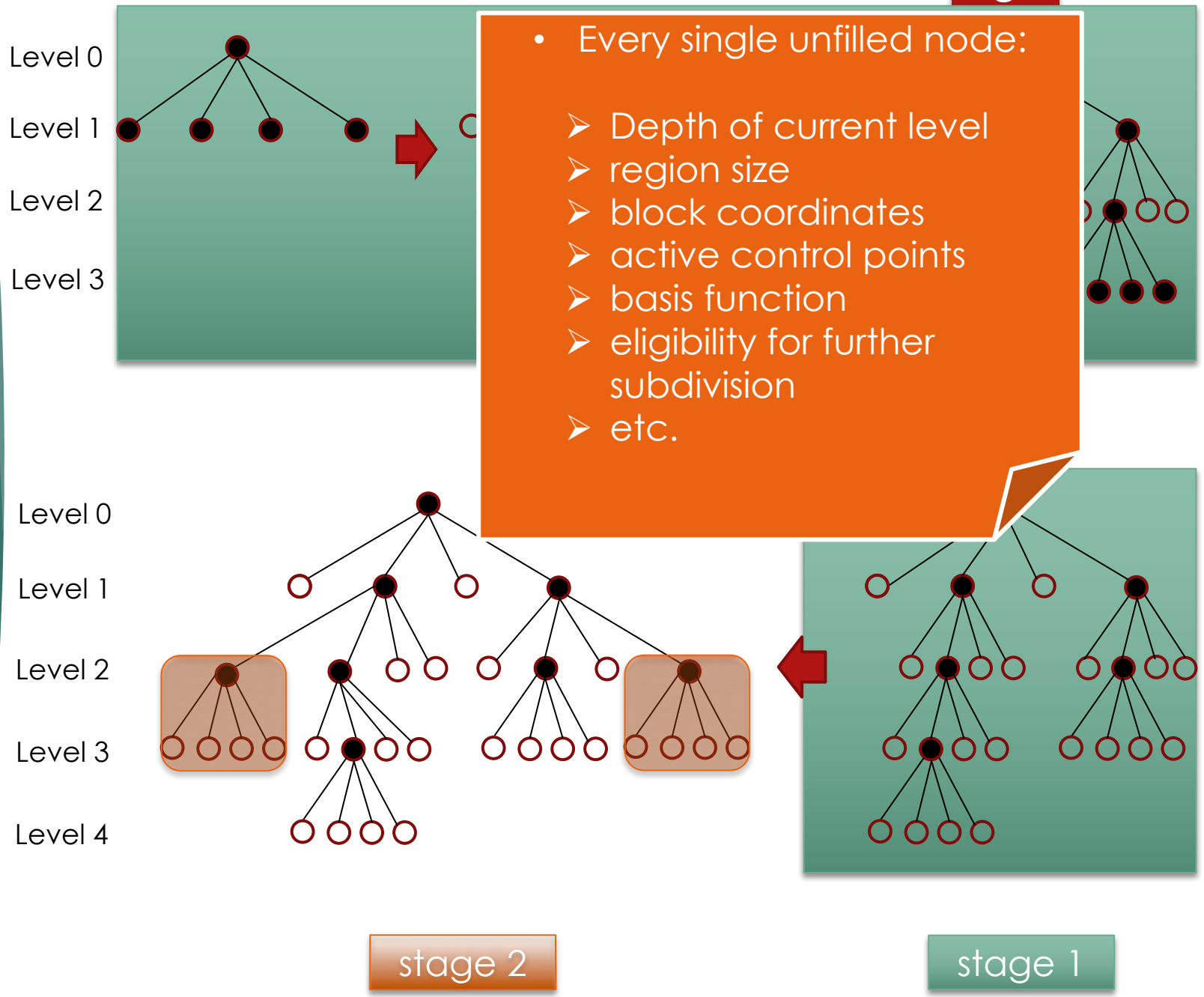

Subdivision strategy

$$S_{final} = \begin{cases} S_{freq} \cup S_{second}, & ROIs\ (e.x.\ in-lung\ region) \\ S_{freq}, & otherwise \end{cases}$$

- Two stages:
  - stage 1: S_{freq} frequency power spectrum based, extract high frequency image content for potential discontinuous regions

$$S_{freq} = \begin{cases} 1, & \sum_{z=0}^{N_z}\sum_{y=0}^{N_y}\sum_{x=0}^{N_x} I_{freq}(x,y,z) > T \\ 0, & otherwise \end{cases}$$

I_{freq}: high-pass filtered support region

T: threshold determined by ranking image power for all regions

N_x, N_y, N_z: region dimensions

  - stage 2: S_{second} heuristic methods

    (*S_{freq} is conservative. Stage 2 finds overlooked regions to be subdivided*)
    - MSE/NMSE
    - Dominant flow direction
    - Motion Bifurcation

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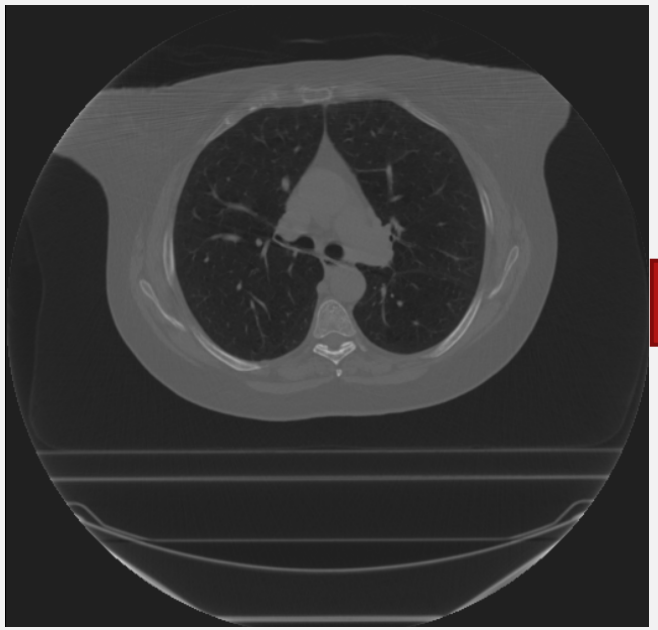
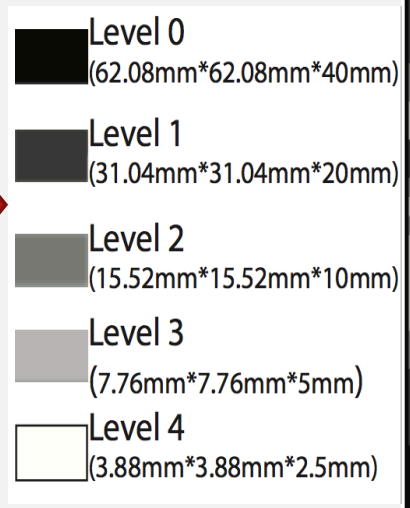




After stage 1

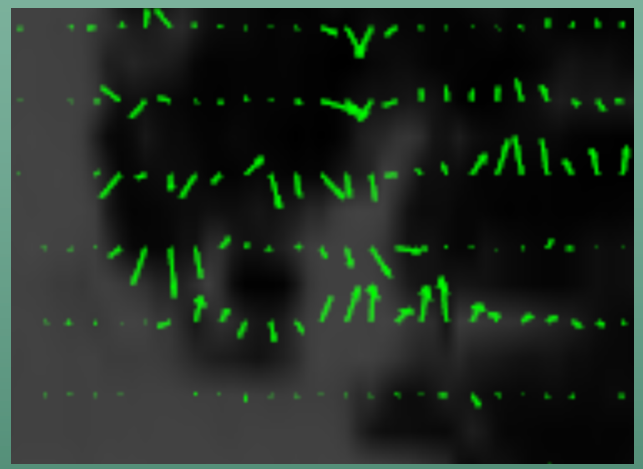
After stage 2

Stage 2 Heuristics

- MSE/NMSE
  - Quantifies similarity of two corresponding regions
  - Increases the degree of freedom for regions not well aligned yet

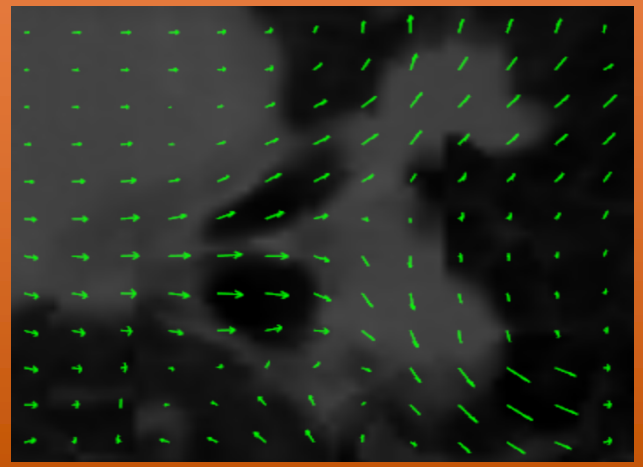
OR

- Dominant Flow Direction
  - Good basis for estimating discontinuous motion vectors
  - Detects the presence of multiple optical flow directions



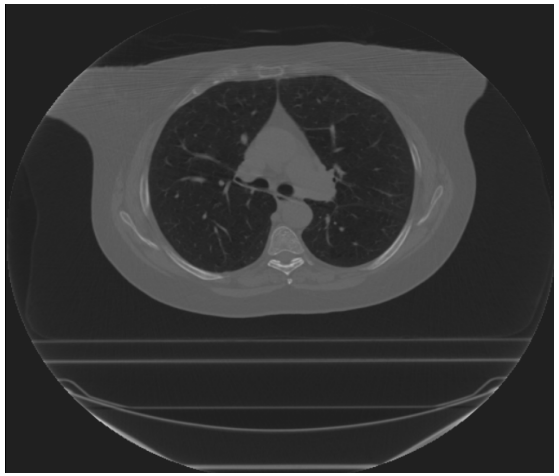
OR

- Motion Bifurcation
  - Strong indicator of sliding motion between organs moving in different directions
  - Analyzes displacement field by using incomplete octree grid



Results

- **DIR-Lab** data: 10 thoracic 4DCT image volumes with 10 respiratory phases each
- 300 in-lung reference landmarks and 20 additional landmarks in spinal column on the extreme phase images
- Each testing image has 512 * 512 * 128 voxel dimension with 0.97mm * 0.97mm * 2.5mm physical spacing
- Begin with 8 * 8 * 8 nodes at coarsest level (uniformly spaced) , to 128 * 128 * 128 finest level (non-uniform, depend on different regions)



Level index	Control point spacing(mm)	Number of regions	
0	62.08 * 62.08 * 40	8 * 8 * 8	
1	31.04 * 31.04 * 20	16 * 16 * 16	
2	15.52 * 15.52 * 10	32 * 32 * 32	
3	7.76 * 7.76 * 5	64 * 64 * 64	For ROIs
4	3.88 * 3.88 * 2.5	128 * 128 * 128	For Decoupling

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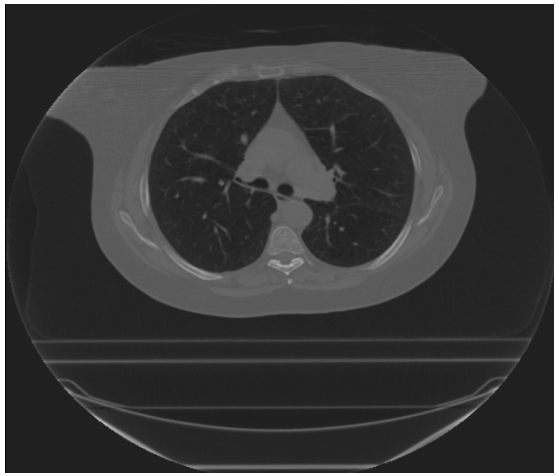
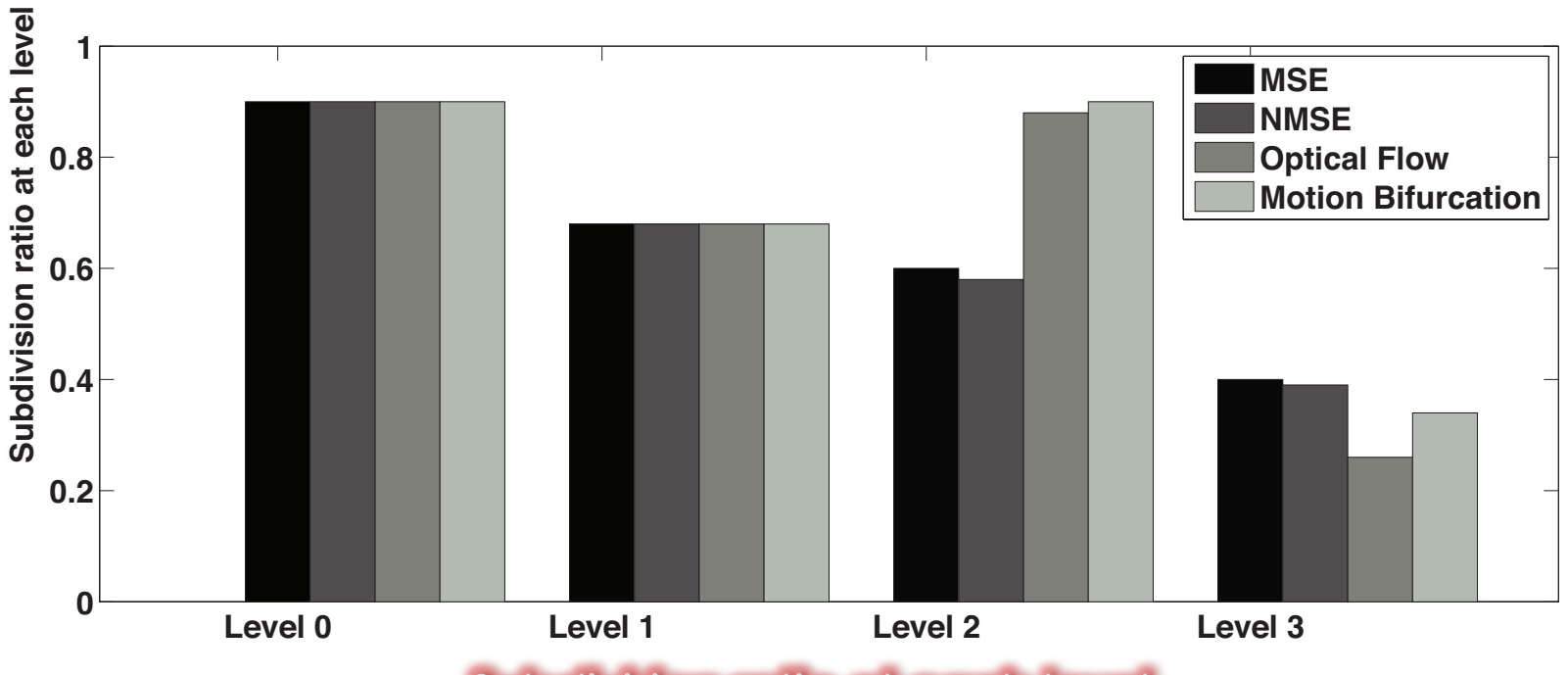
- Begin with 8 * 8 * 8 nodes at coarsest level (uniformly spaced) , to 128 * 128 * 128 finest level (ununiformed, depend on different regions)
- Level 0 and level 1 completely generated from frequency power spectrum and subdivision ratio are the same
- Level 2 ratio differs, MSE and NMSE are around 60%. Optical flow and motion bifurcation are around 87%

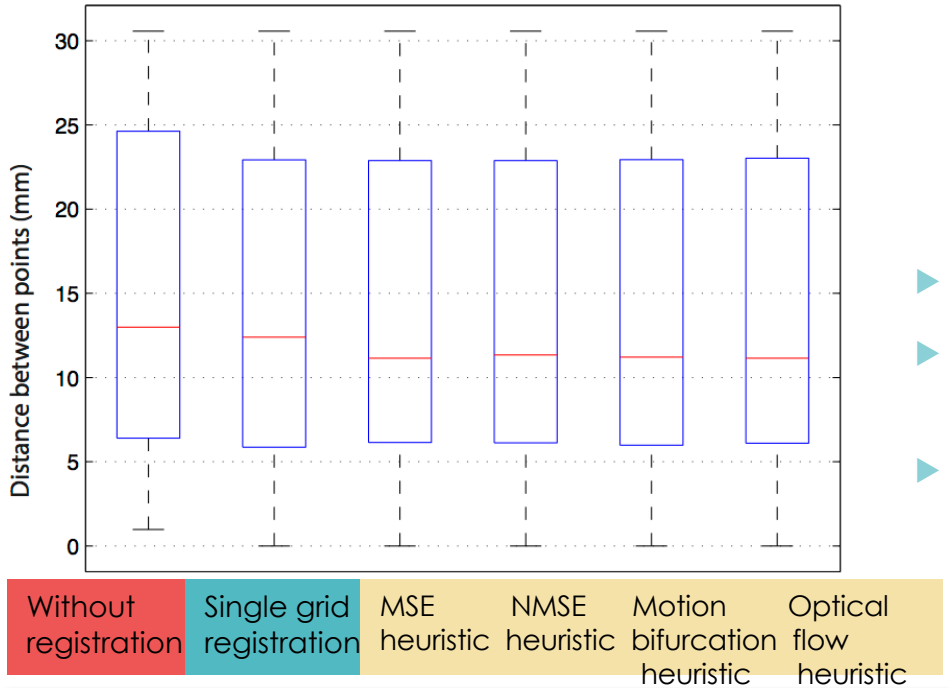




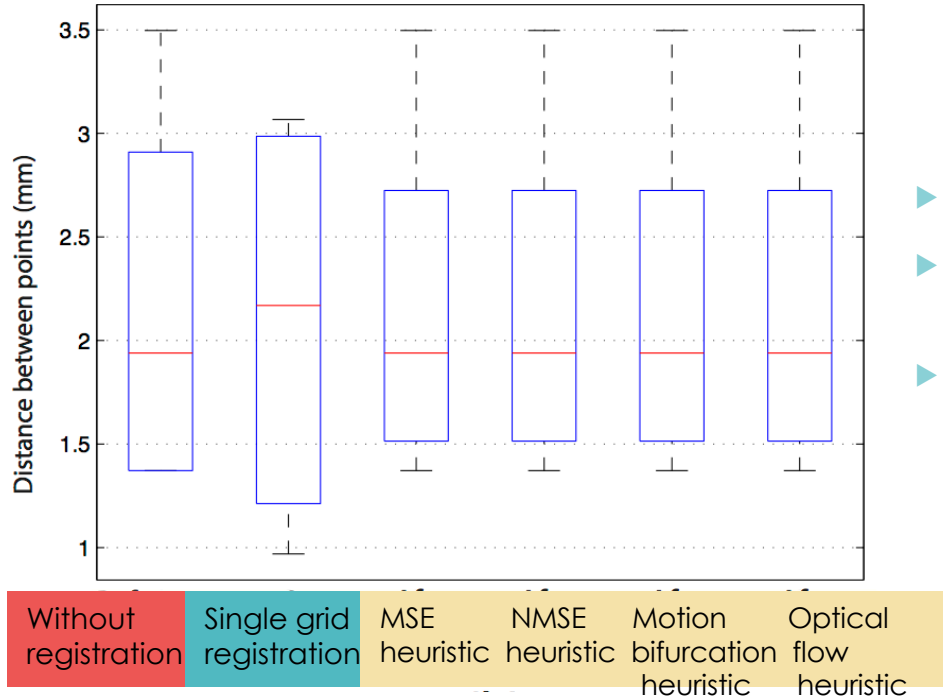
Subdivision ratio at each level

Results

- Proposed octree B-spline compared with a traditional single grid uniform B-spline according to distance of representative landmarks before and after registration



- **300 landmark points in-lung**
- similar outlier statistics as traditional single grid B-spline
- improved median landmark error of approximately 18%



- **20 landmark points in spinal column**
- notably outperforms the traditional single grid B-spline
- exhibits improved decoupling of the in-lung and in spinal column regions for all four heuristic subdivision strategies

Thank you

Questions?