Multi-Scale Rigid Registration of Ultrasound and CT Based on Similarity Measures

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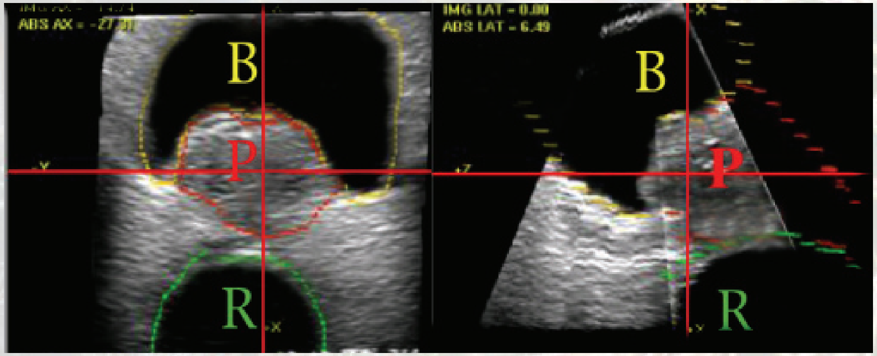
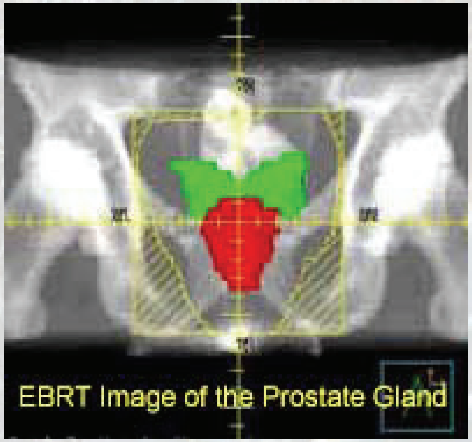
Outline

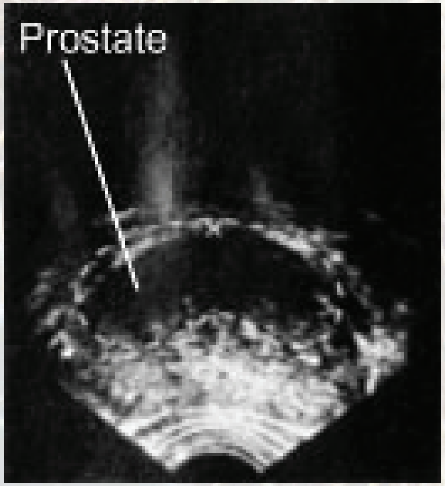
- Registration problem
- Similarity Metrics
- Multi-Resolution
- Optimizer / search engine
- Testing and verification
- Conclusion

Registration Problem

- Why?
  - Alignment in Radiation Therapy

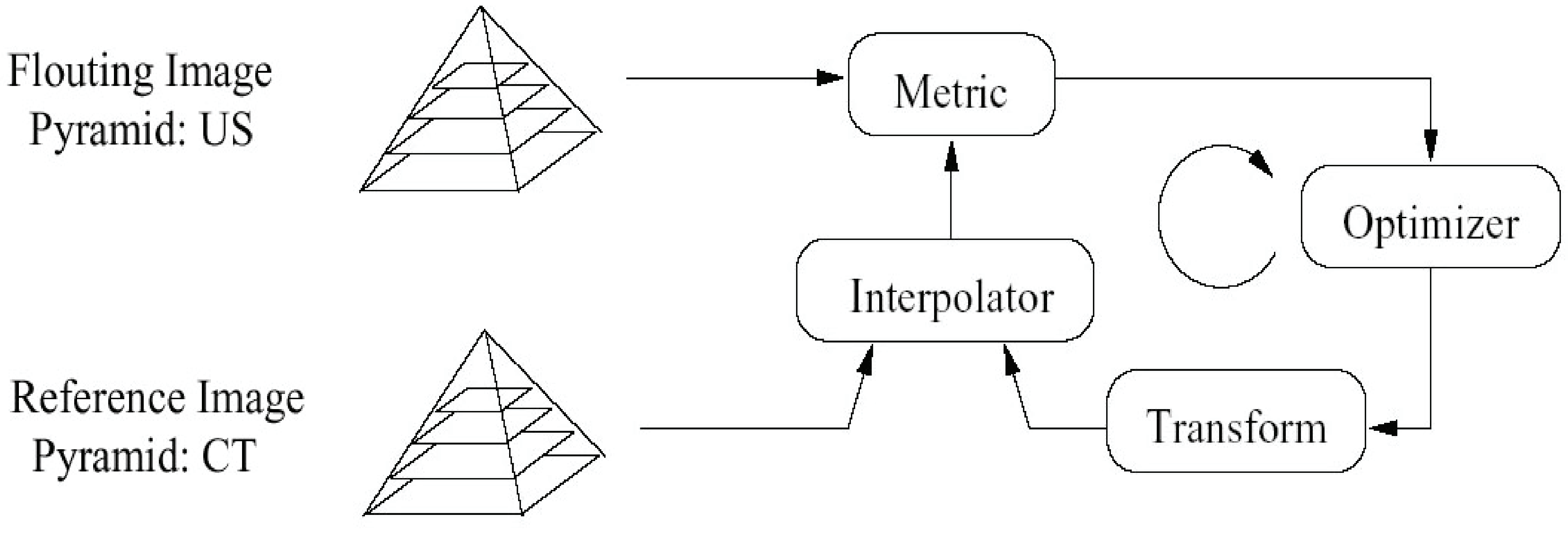






- Outline
  - **problem**
  - Metrics
  - Multi-Scale
  - Optimizer
  - Testing
  - Conclusion

Rigid Registration Process

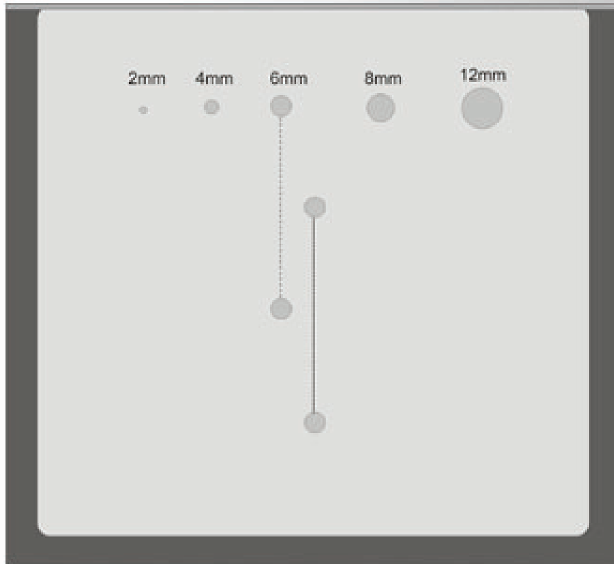


Frame work for multi-scale rigid registraion process

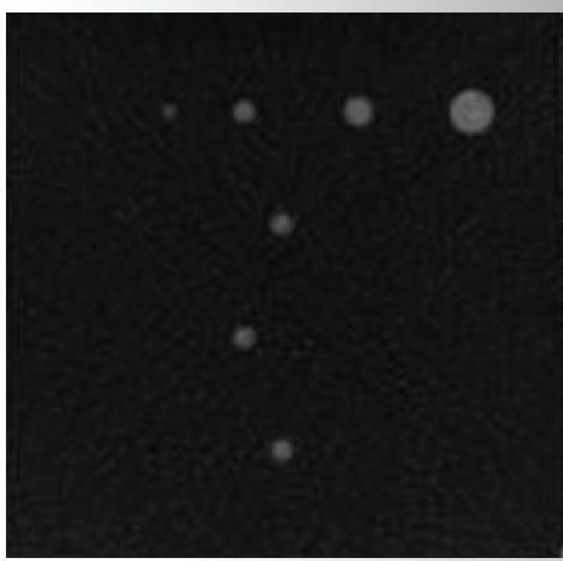
Phantom

- Constructed with well known dimensions
- 3D-US:
  - mechanical translation
  - Obj/bg = 2x
- CT
  - Obj/Bg = 4-5x
  - 16bit->8bit
  - Obj/Bg = 3-4x

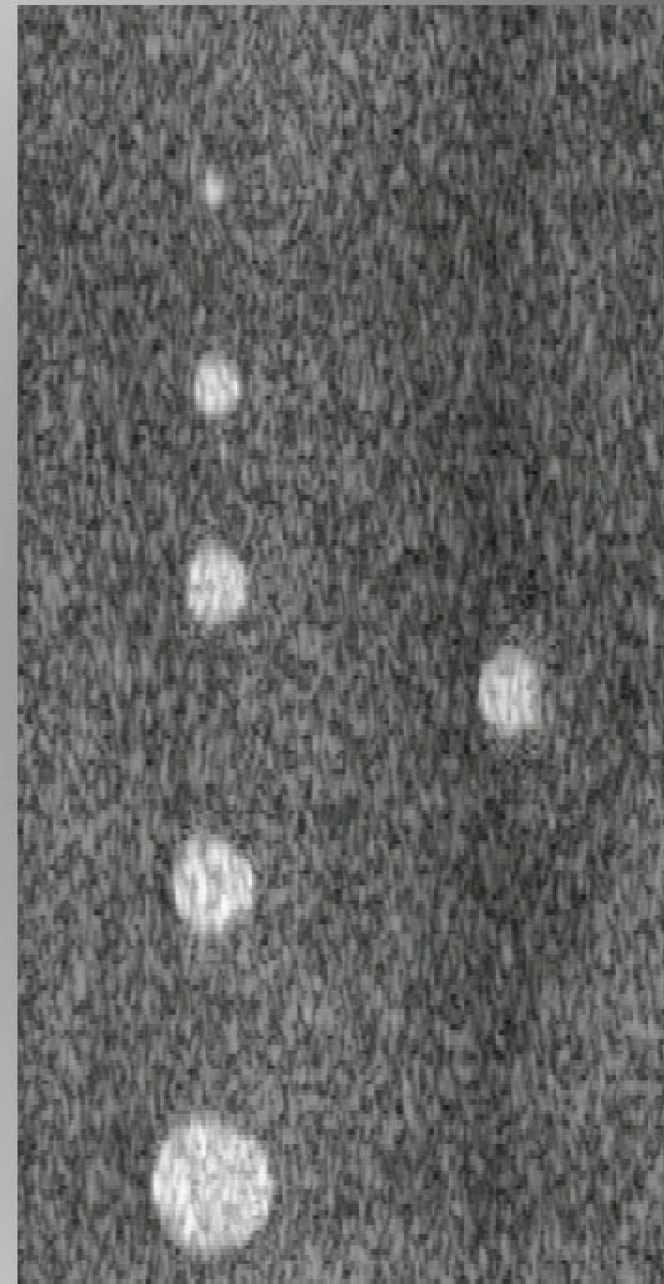
Phantom Schematic

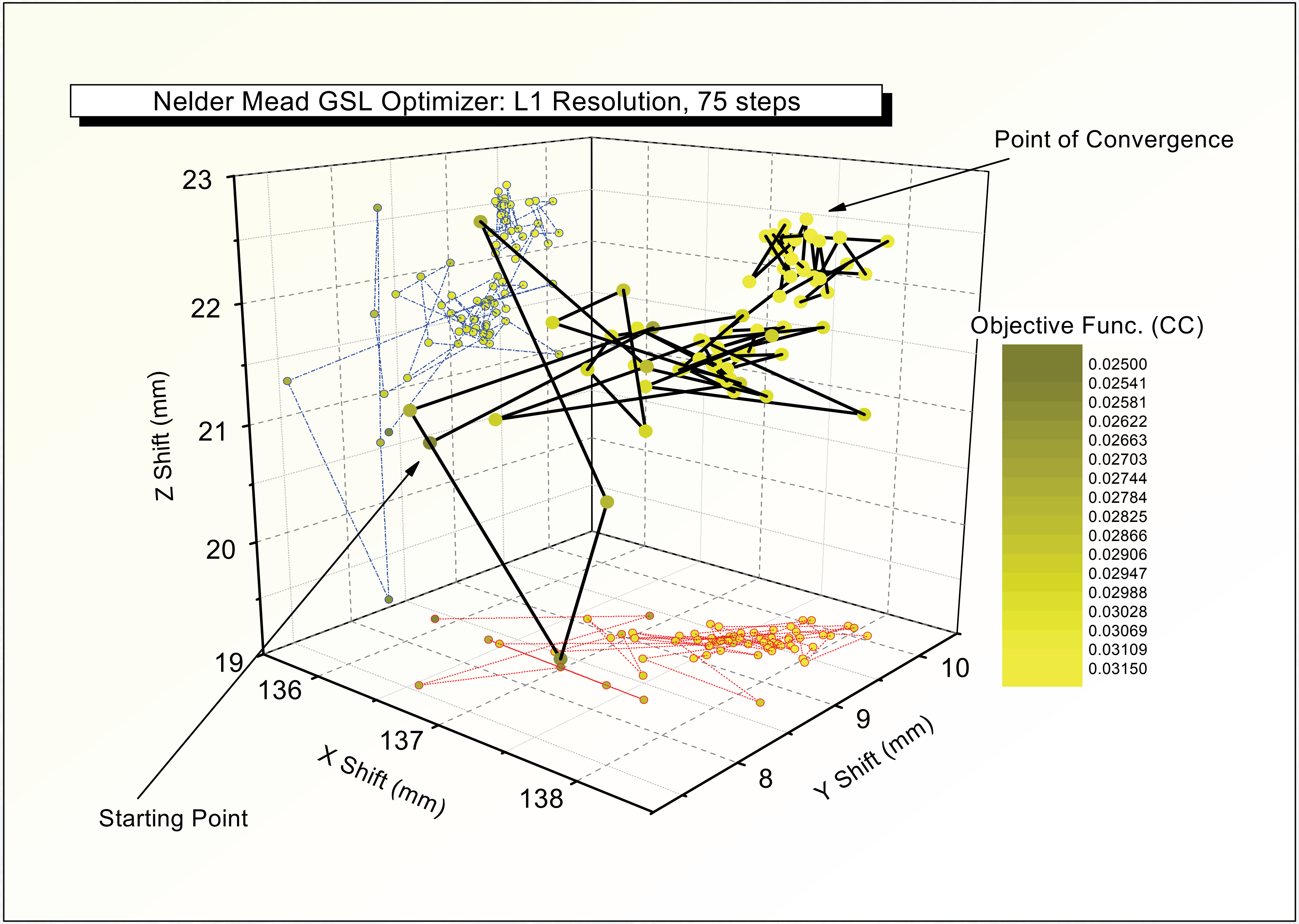


CT Image



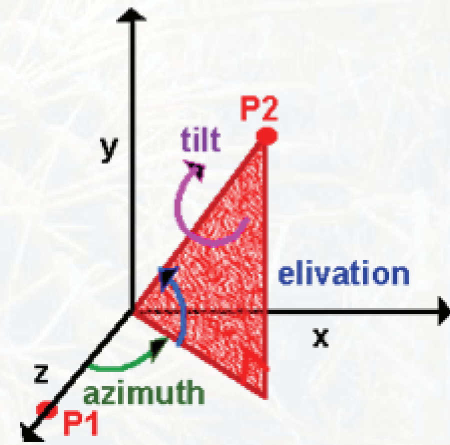
US image



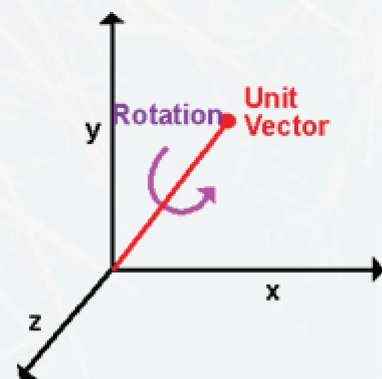

Nelder Mead GSL Optimizer: L1 Resolution, 75 steps
Point of Convergence
Starting Point
Objective Func. (CC)
0.02500
0.02541
0.02581
0.02622
0.02663
0.02703
0.02744
0.02784
0.02825
0.02866
0.02906
0.02947
0.02988
0.03028
0.03069
0.03109
0.03150
Z Shift (mm)
23
22
21
20
19
X Shift (mm)
136
137
138
Y Shift (mm)
8
9
10

Rigid Transformation

- 6DOF: 3 translations & 3 rotations



- Rotations
  - Euler (12 combinations)
  - angle/axis,
- We used:
  - rotations about x then y then z
  - an effective angle about a unit vector
  - Angles Coupled not independent



Metrics / Measures of “Similarity”

- ideal similarity

- testing

- **What is ideal "similarity" for two images:*gray1 & gray2***
  - SAD: gray1 ≅ gray2 Σ (gray1 – gray2)
  - SSD: gray1 ≅ gray2 Σ (gray1 – gray2)^2
  - CC: gray1 ≅ factor * gray2

$$r = \frac{\sum_i [(x(i) - mx) * (y(i-d) - my)]}{\sqrt{\sum_i (x(i) - mx)^2}\sqrt{\sum_i (y(i-d) - my)^2}}$$

  - MI: gray1 ≅ function(gray2)
    - Pairs of values should repeat consistently
    - Operates on joint histogram/ histograms
    - Some intensity operation does not change MI (e.g.: invert)

$$I(A,B) = \sum_a \sum_b p(a,b) \cdot \log\left(\frac{p(a,b)}{p(a)\,p(b)}\right)$$

Further notes

- "*equal sampling*" Assumption
  - CT and US are unequally sampled
  - *Multi-resolution* is naturally placed
- Summation over space is *homogenous*:
  - *Bias /weighting* may be applied in certain ROI

Metrics Testing Methods/ feasibility

- ***Offsetting*** images from a “good” known position (1D or 2D)

- Possible test of *several* things:
  - Similarity metrics
  - How much you can degrade/lower Resolution to gain speed?
  - Image filtering effects

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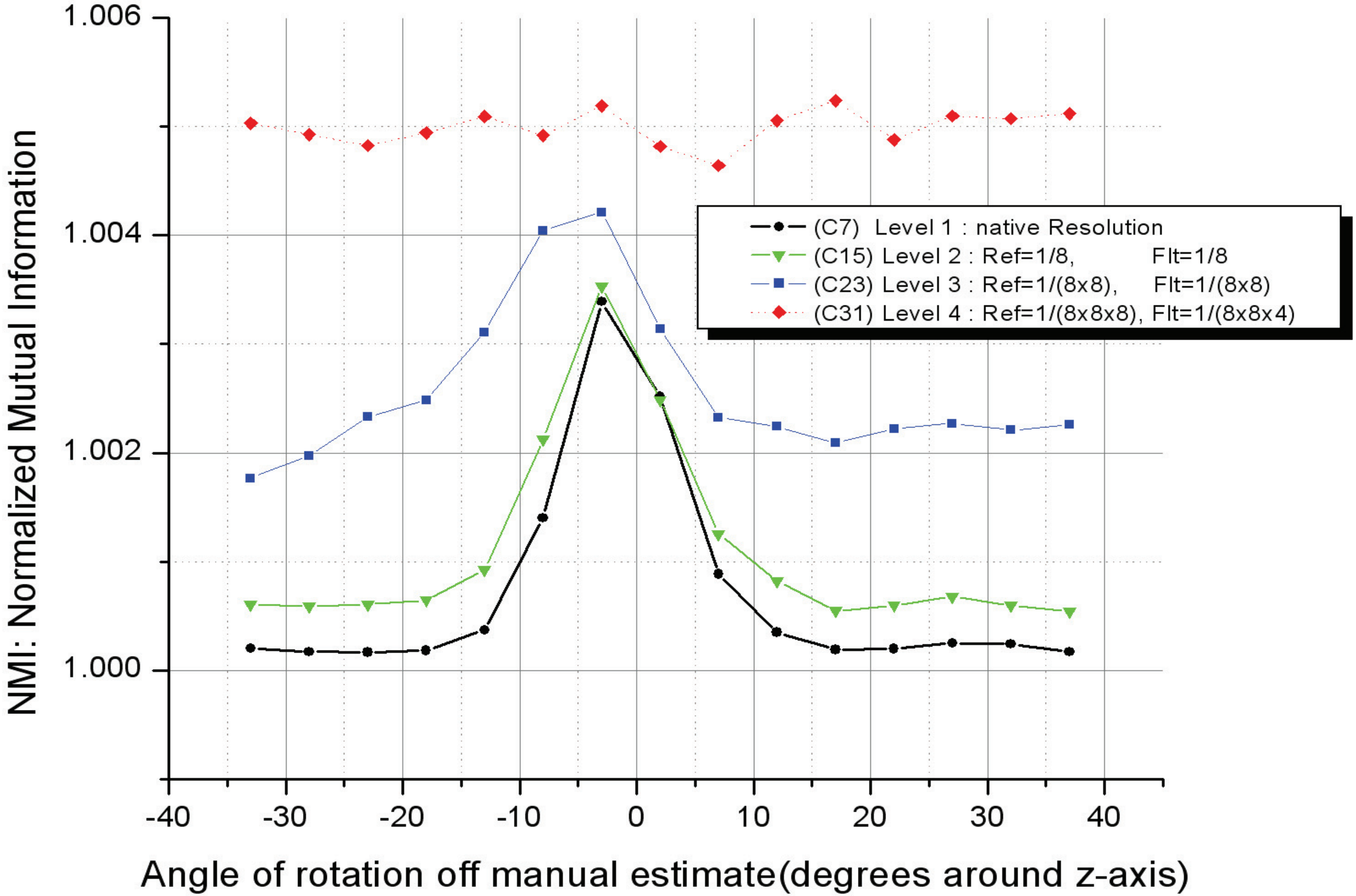
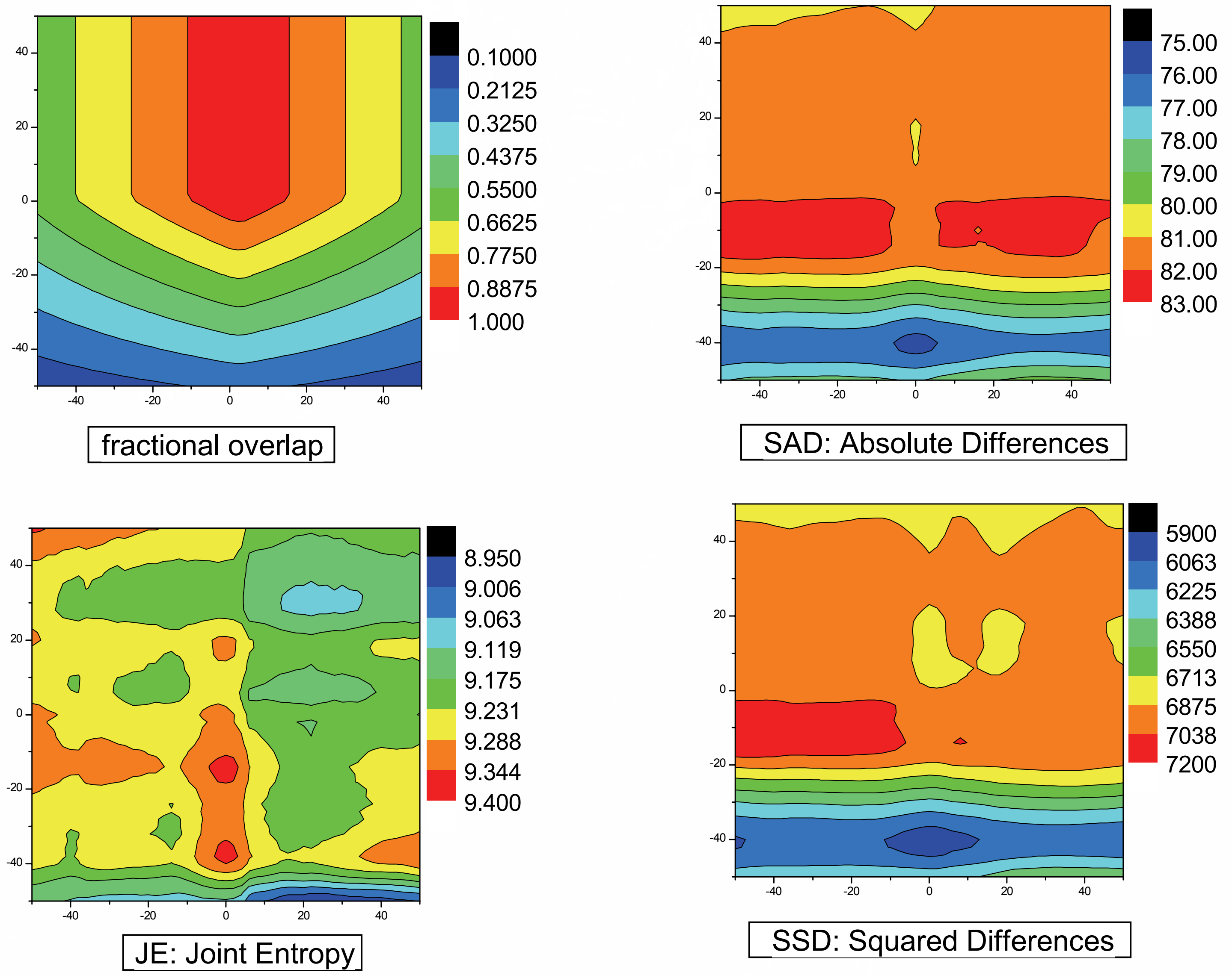
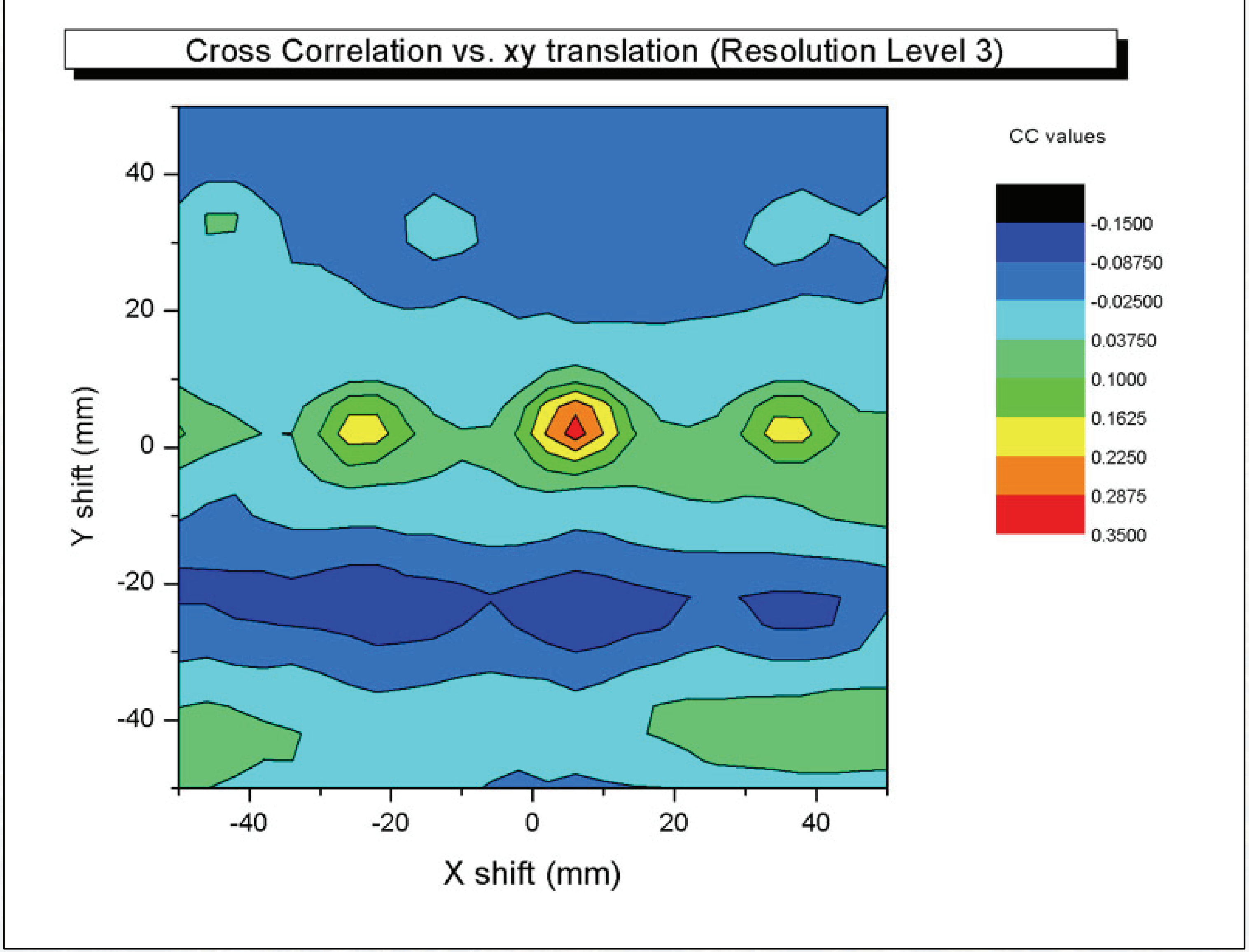
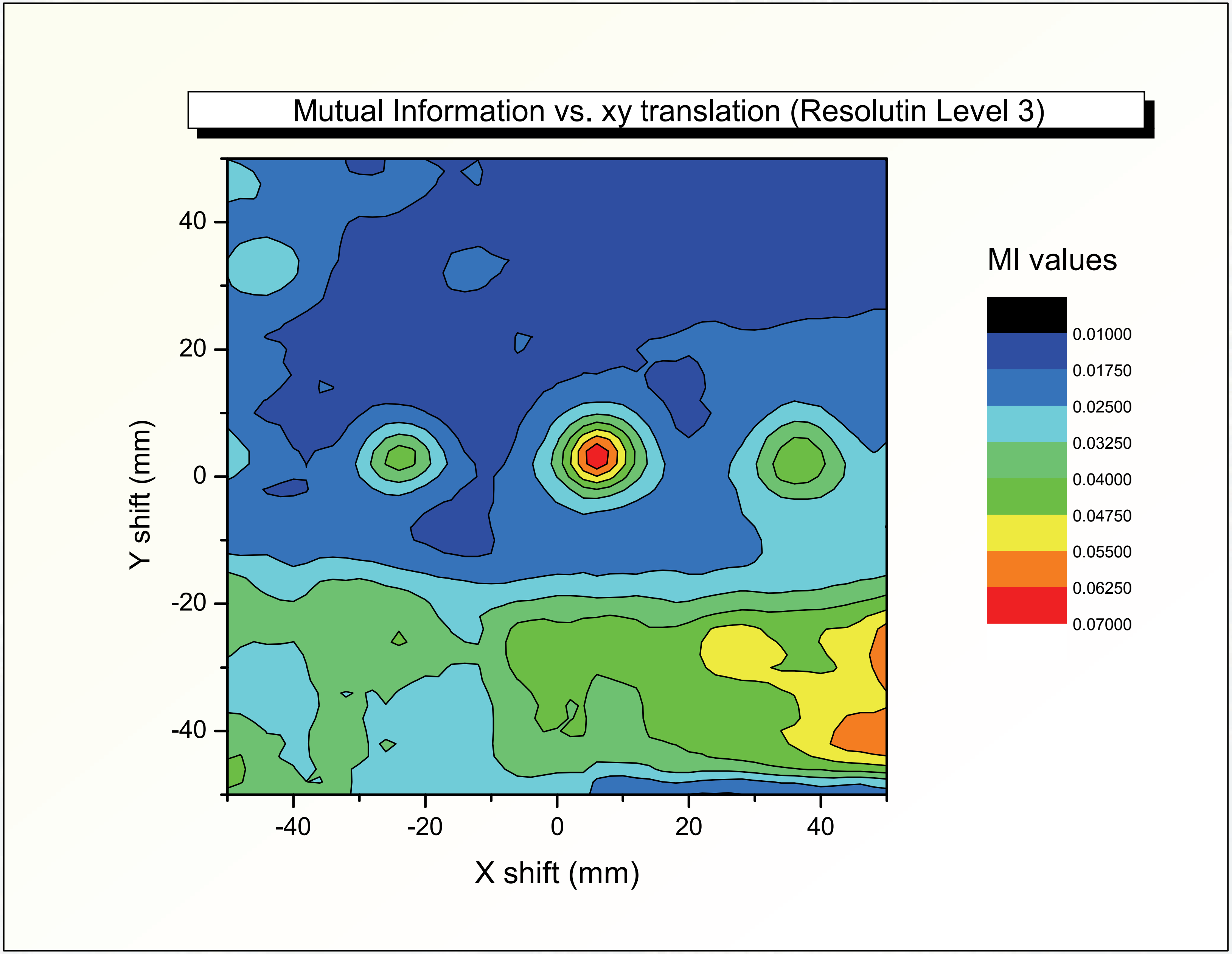




fractional overlap
0.1000
0.2125
0.3250
0.4375
0.5500
0.6625
0.7750
0.8875
1.000
SAD: Absolute Differences
75.00
76.00
77.00
78.00
79.00
80.00
81.00
82.00
83.00
JE: Joint Entropy
8.950
9.006
9.063
9.119
9.175
9.231
9.288
9.344
9.400
SSD: Squared Differences
5900
6063
6225
6388
6550
6713
6875
7038
7200
-40
-20
0
20
40



- *It works but this phantom is with two materials: object +background*
- *linear function is possible between CT and US*



Mutual Information vs. xy translation (Resolutin Level 3)
40
20
0
-20
-40
Y shift (mm)
-40
-20
0
20
40
X shift (mm)
MI values
0.01000
0.01750
0.02500
0.03250
0.04000
0.04750
0.05500
0.06250
0.07000

Multi-Resolution Pyramid

- Sampling → Pyramid
- Sampling → Maximum accuracy
- Step Size for the optimizer

- Outline
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  - **Multi-Scale**
  - Optimizer
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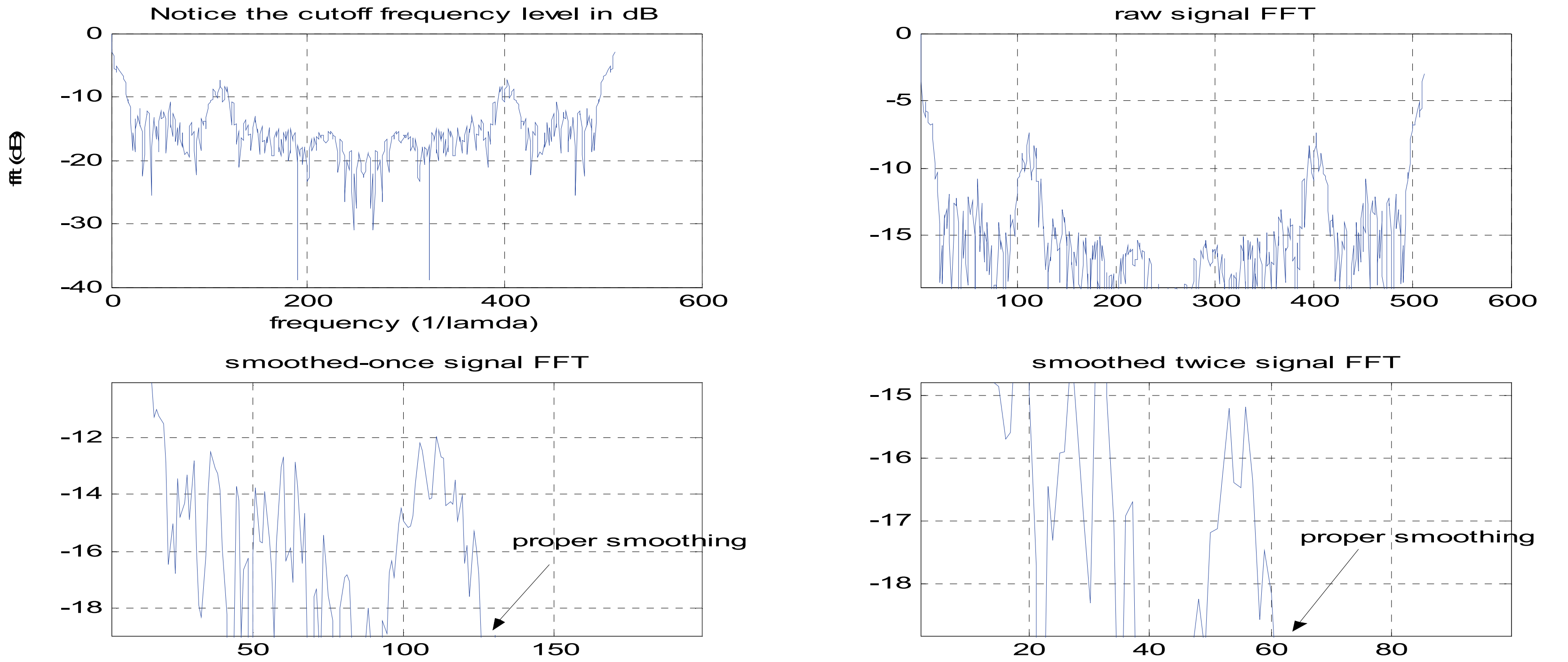
Smoothing filter width

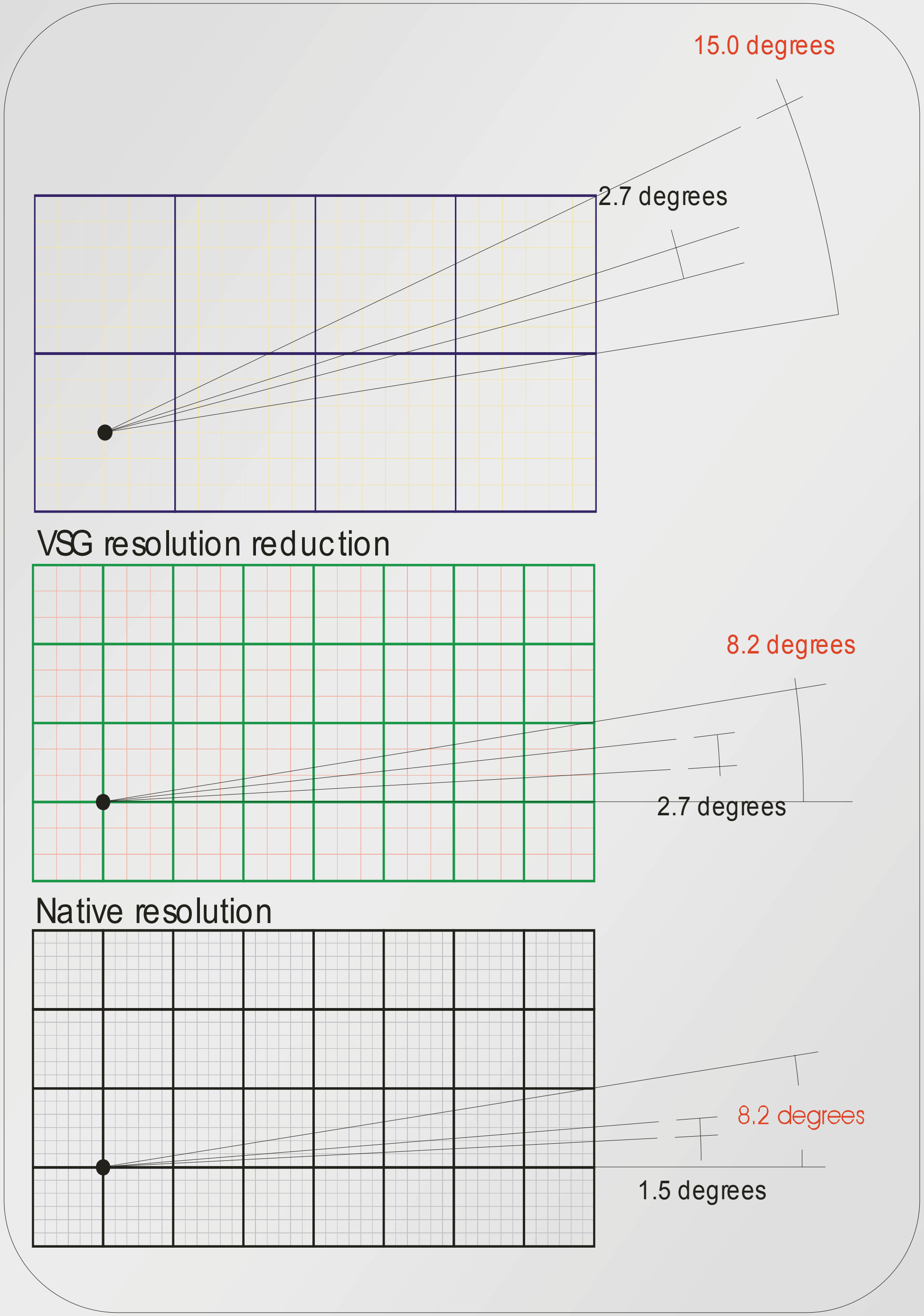
- 3 points — 5points — 7points
- under-smooth — proper — over-smooth

- Sub-sampling by 2 → 5 point binomial filter [1 4 6 4 1]/16



Resolution Pyramid

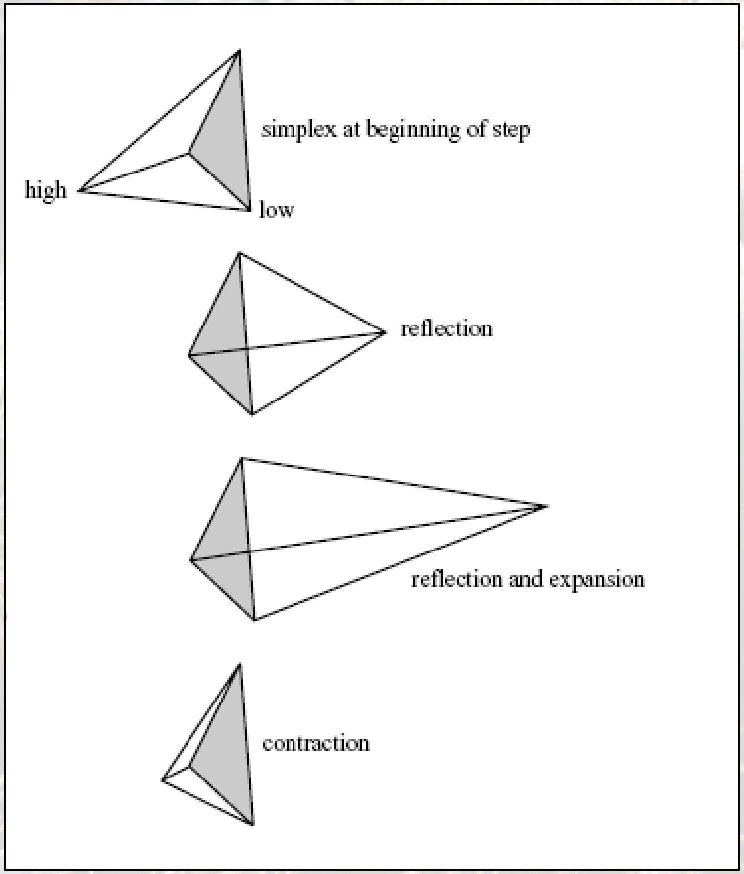
- US-sampling > CT (in-plane)
- Treat each dimension separately
- Voxel-Size Guided pyramid: ***VSG-Pyramid***
  - Degrade US toward CT in each dimension
  - Then, both toward cubic voxel
  - Then, move degradation together



- Which image determines *<u>accuracy of rotation /translation</u>*:
  - Higher resolution image (NO)
  - Lower resolution image **(yes)**
- Translation:
  - Half CT voxel of steps
- Re-compute for each resolution level

Optimizer: Simplex

- simple
- slow
  - –Many evaluations
- assume independent parameters



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  - –Multi-Scale
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angle coupling problem really slow it down

Testing / Verification

1. Visual

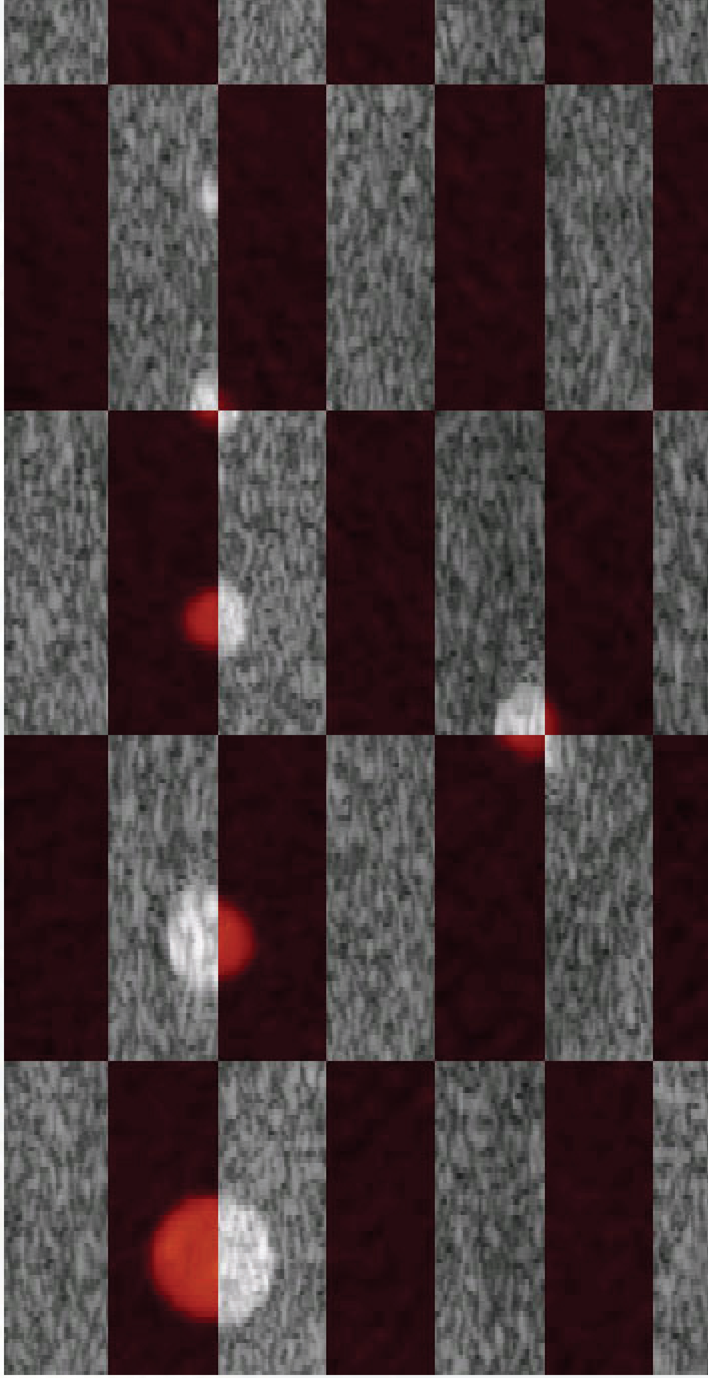
2. Convergence

1) Visual Assessment

- Manual/ subjective
- Statistics only with few observer

- US broadening in lateral/elevational directions

- CT barely see the smallest sphere

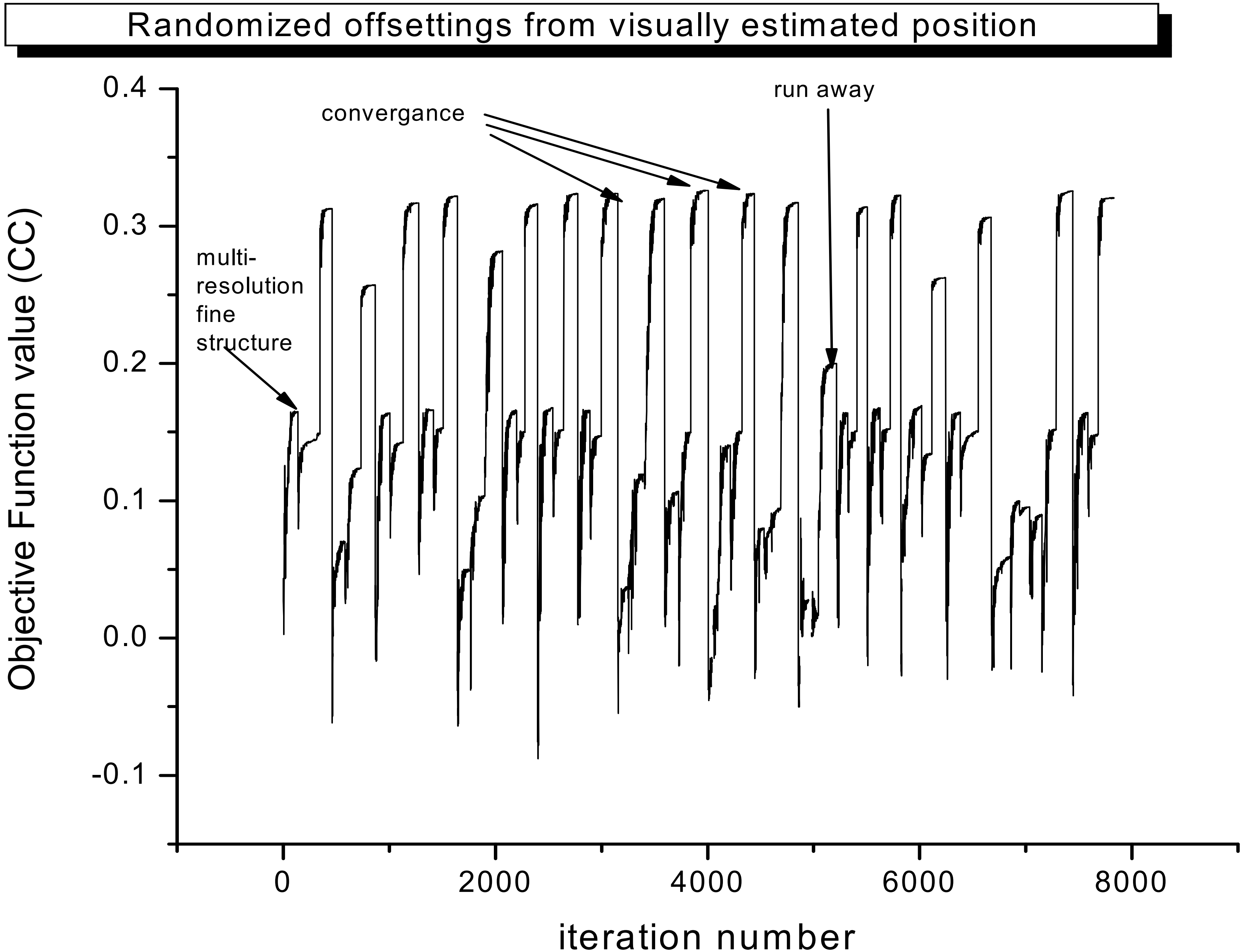


2) Convergence study

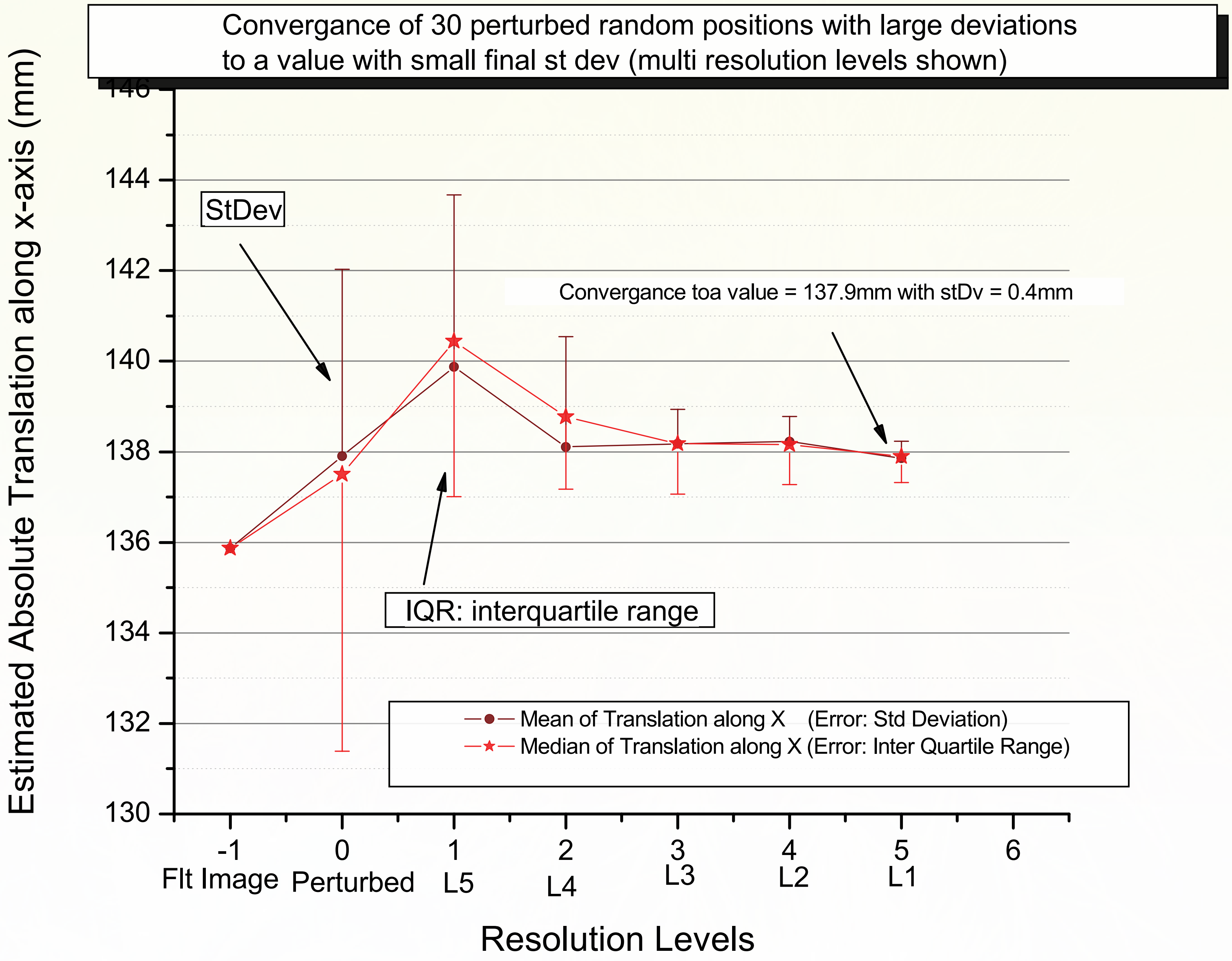
- ***Randomize*** starting position with clinically relevant starting position:
  - Rotational Angles in [-5,+5] degrees range
  - Translational shifts with [-10,10] mm

- Effective registration should *converge* these position back to the "true" position

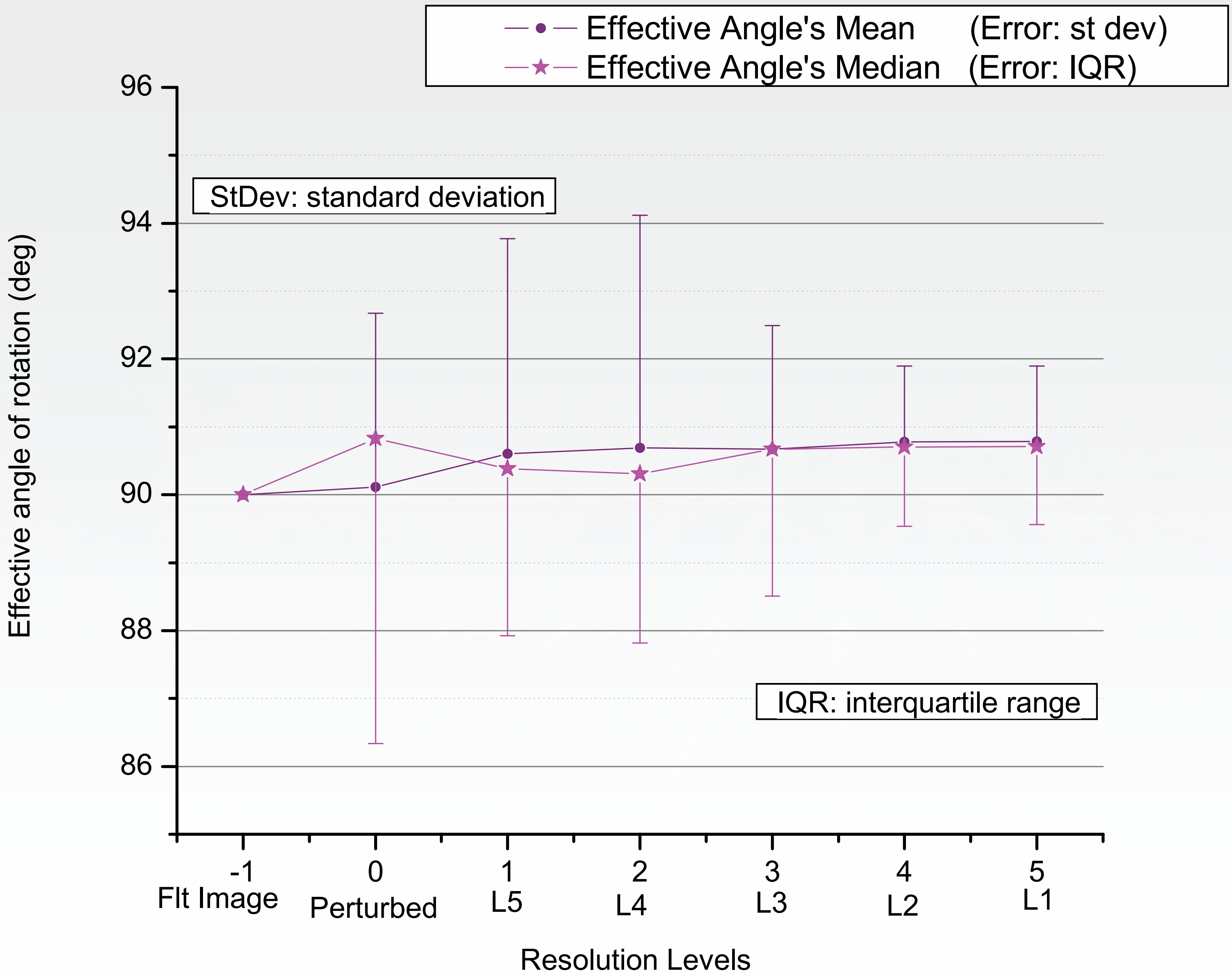
- Statistics of "final parameters" values for different trial



Randomized offsettings from visually estimated position
Objective Function value (CC)
iteration number
convergance
run away
multi-
resolution
fine
structure
0.4
0.3
0.2
0.1
0.0
-0.1
0
2000
4000
6000
8000



Convergance of 30 perturbed random positions with large deviations
to a value with small final st dev (multi resolution levels shown)
Estimated Absolute Translation along x-axis (mm)
146
144
142
140
138
136
134
132
130
StDev
Convergance toa value = 137.9mm with stDv = 0.4mm
IQR: interquartile range
Mean of Translation along X (Error: Std Deviation)
Median of Translation along X (Error: Inter Quartile Range)
-1
Flt Image
0
Perturbed
1
L5
2
L4
3
L3
4
L2
5
L1
6
Resolution Levels



Effective Angle's Mean (Error: st dev)
Effective Angle's Median (Error: IQR)
StDev: standard deviation
IQR: interquartile range
Effective angle of rotation (deg)
96
94
92
90
88
86
-1
Flt Image
0
Perturbed
1
L5
2
L4
3
L3
4
L2
5
L1
Resolution Levels

Conclusions

- Similarity based registration is *feasible*

- More work on:
  - avoidance tactic to low overlap run away cases
  - Angle coupling problem

- Future work
  - More robust optimizer
  - Effect of image filtering on convergence speed
  - Bias weighting: emphasize certain ROI


Thank you