A Comparative Evaluation of Interactive Segmentation Approaches

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TECHNISCHE FAKULTÄT

Outline

Motivation Transcatheter Arterial Chemoembolization

Methods Seeded Segmentation and Metrics

Experiments Seed Placement

Results Segmentation Evaluation

Conclusion and Outlook

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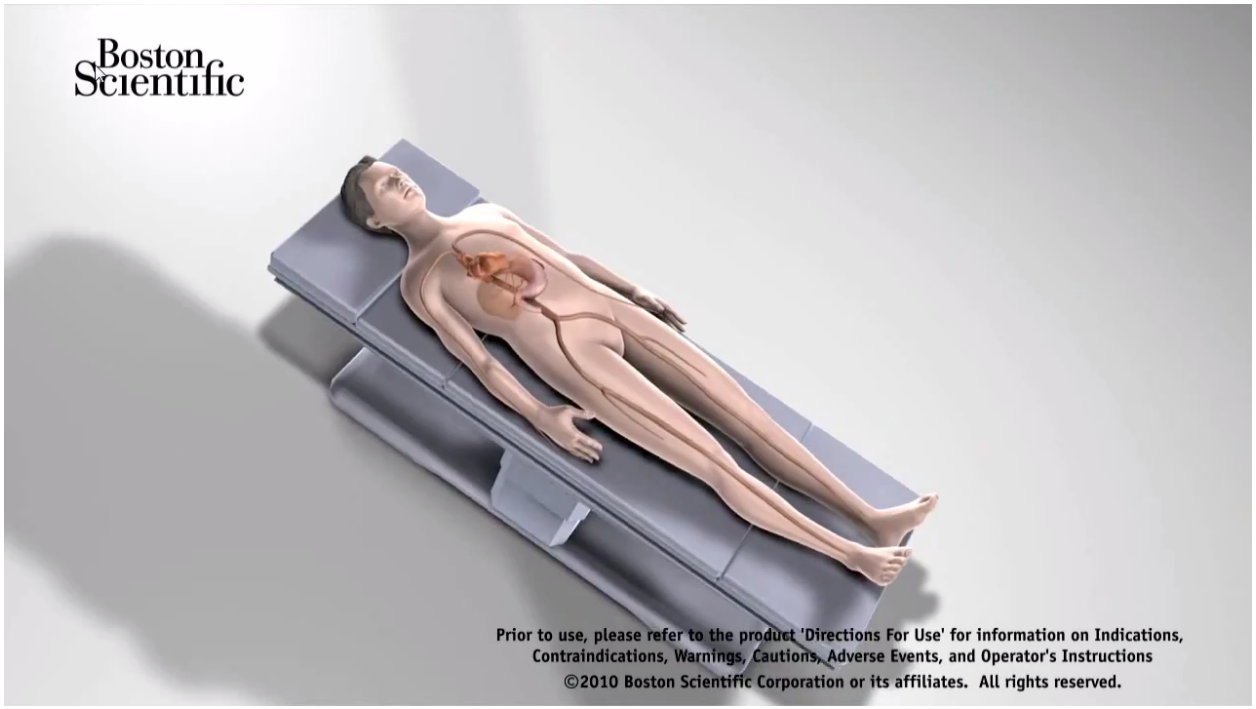
Transcatheter Arterial Chemoembolization (TACE)

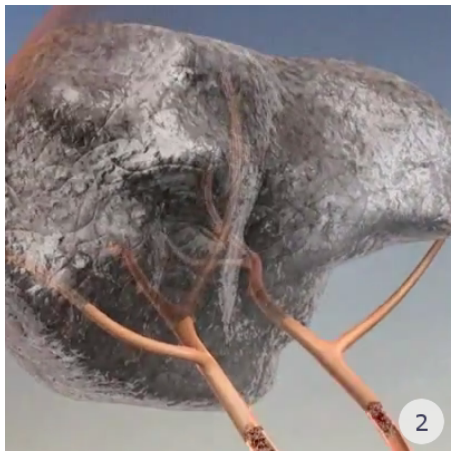


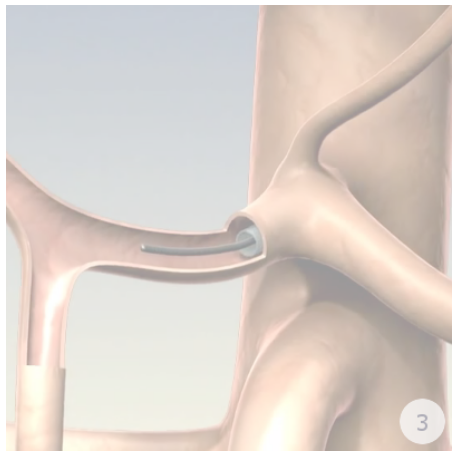
Video: https://www.youtube.com/watch?v=XBSfdDAEJ28

Transcatheter Arterial Chemoembolization

Procedural steps

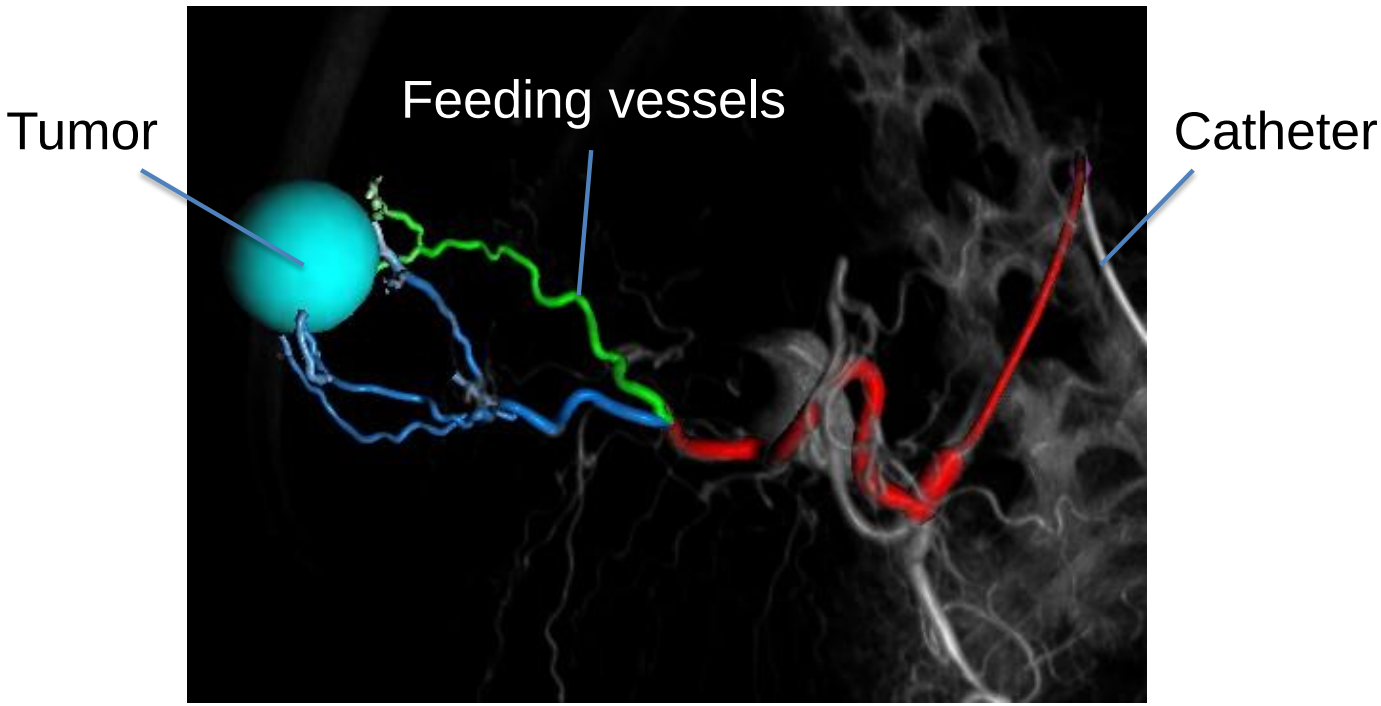
1. C-arm CT imaging and 3-D reconstruction during intervention
2. **accurate and fast lesion segmentation tool**
3. method to extract route from catheter tip to tumor





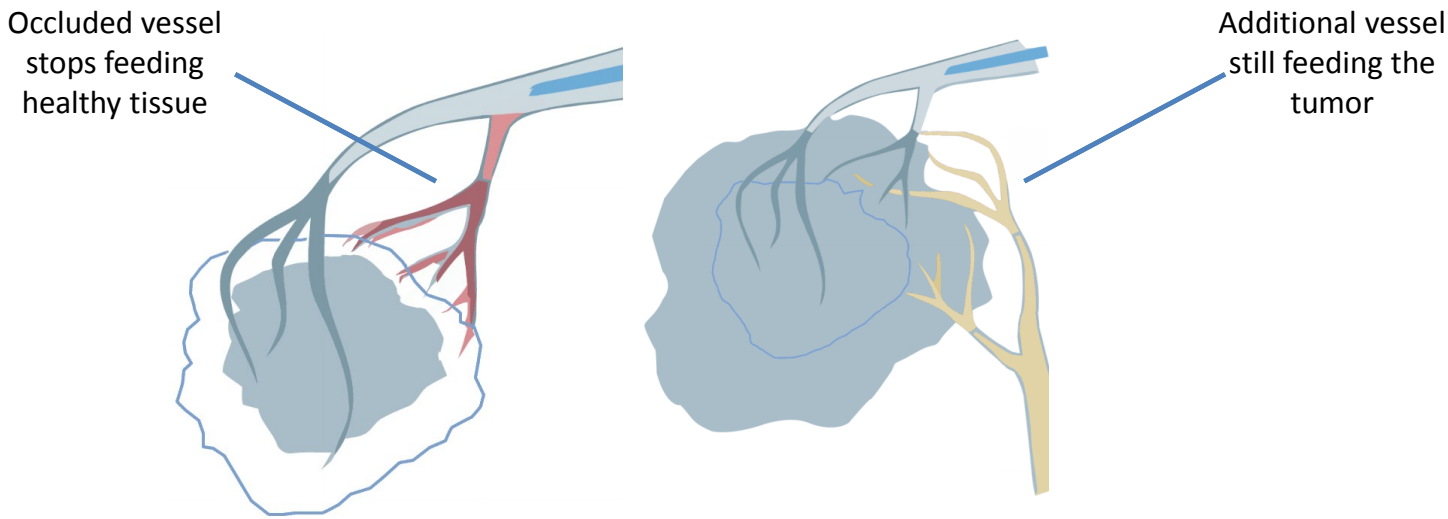
Accuracy – Impact of Segmentation Quality

Why an exact segmentation?



Roughly segmented tumor and subsequently generated vessel tree

Accuracy – Impact of Segmentation Quality

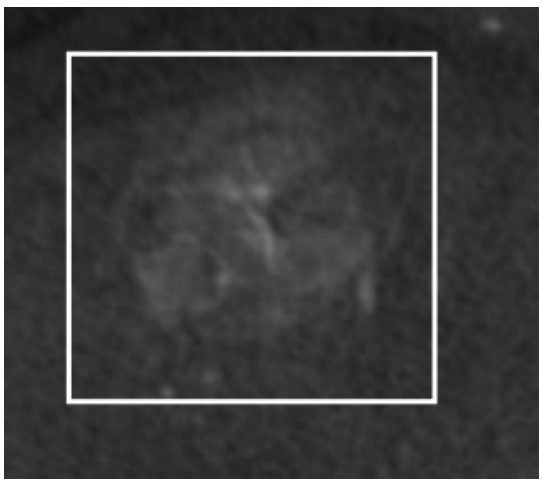
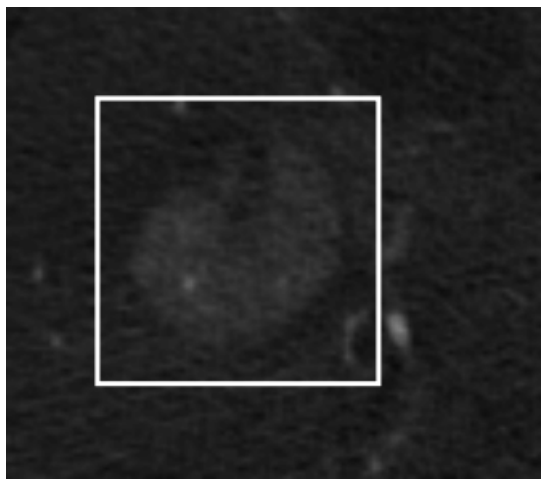
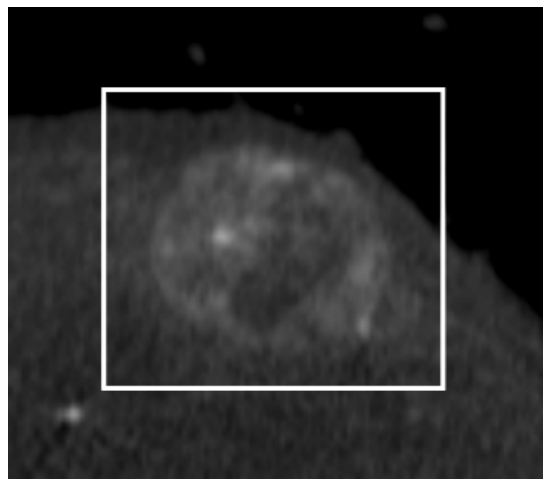


Why an exact segmentation?

- segmented volume too big $\rightarrow$ healthy tissue gets occluded
- segmented volume too small $\rightarrow$ tumor growth unimpeded

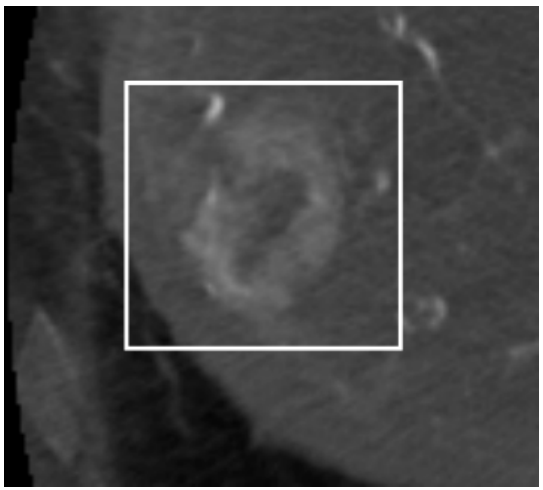
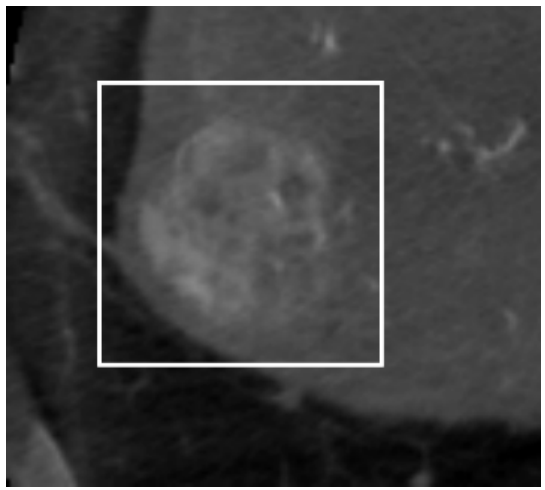
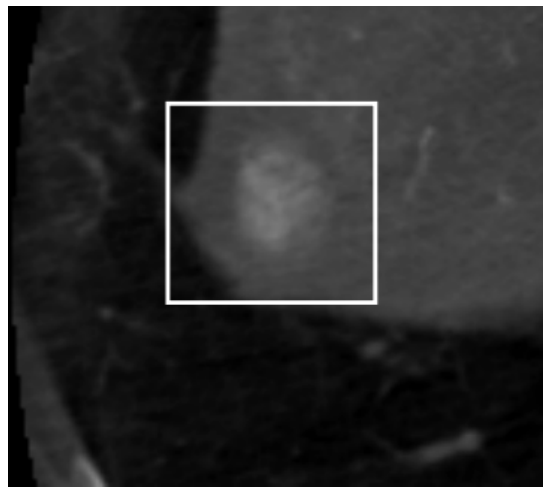
Challenges of Hepatic Lesion Segmentation

- high diversity without a typical shape
- intensity overlaps between tumor and surrounding tissue
- different intensity patches due to necrotic regions

Challenges of Hepatic Lesion Segmentation

- high diversity without a typical shape
- intensity overlaps between tumor and surrounding tissue
- different intensity patches due to necrotic regions
- appearance of a tumor varies within different slices

Interactive Segmentation

- fully manual segmentation takes a lot of time; accurate outcome
- fully automatic segmentation also takes a lot of time to compute; quality correlated with size of ground truth database

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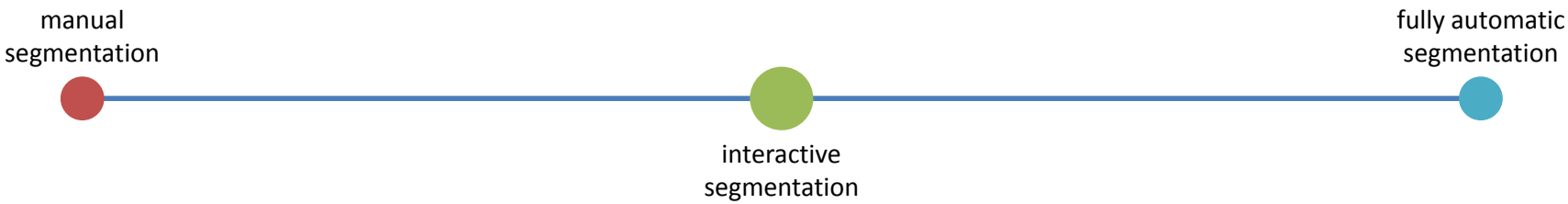
Interactive Segmentation



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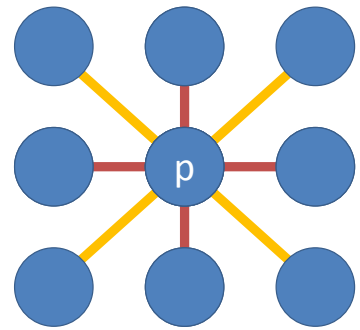
GrowCut Segmentation

Initialization of GC $= (Z^n, S, N, \delta)$

- voxel / cell space Z^n
- state $S \ni S_p = (l_p, \Theta_p, C_p)$, $p \in Z^n$
  - class label l_p
  - cell strength Θ_p
  - feature vector C_p
- neighborhood system N
  - von Neumann $\rightarrow$ 6-voxel neighborhood in 3-D
  - Moore $\rightarrow$ 26-voxel neighborhood in 3-D
- transition rule δ

$$\delta_t\left(S^t\right) = \delta_t\left(I^t, \Theta^t, C^t\right) = \left(I^{t+1}, \Theta^{t+1}, C^t\right) = S^{t+1}$$



GrowCut Segmentation

$I^t_{N(p)}$ $I^{t+1}_{N(p)}$

Conquer cell $q \in N(p)$ if $\mathrm{g}(p,q) \cdot \Theta^t_p > \Theta^t_q$, where

$$\mathrm{g}(p,q) = 1 - \frac{\|C_p - C_q\|}{C_{\max}} \in [0,1]$$

then update cell strength $\Theta^{t+1}_q = \mathrm{g}(p,q) \cdot \Theta^t_p$

Popular Segmentation Quality Metrics

Metrics with an optimum at zero (metric$(x, x) := 0$)

Abbreviation	Range	Goal	Name
ASSD	≥ 0	0	average symmetric surface distance
HD	≥ 0	0	Hausdorff distance
MSE	≥ 0	0	mean squared error
RAVD	$\pm n\%$	0	relative absolute volume difference

Popular Segmentation Quality Metrics (cont'd)

Metrics with an optimum at one (metric$(x, x) := 1$)

Abbreviation	Range	Goal	Name
ARI	$\in [-1, 1]$	1	Rand index adjusted for chance
COMPL	$\in [0, 1]$	1	completeness score (not symmetric $\rightarrow$ homogeneity)
DICE	$\in [0, 1]$	1	Sørensen-Dice coefficient
HOM	$\in [0, 1]$	1	homogeneity score (not symmetric $\rightarrow$ completeness)
MI	$\in [0, 1]$	1	normalized mutual information score
OBJ_TPR	$\in [0, 1]$	1	true positive rate of distinct binary object detection
PRECISION	$\in [0, 1]$	1	precision
RECALL	$\in [0, 1]$	1	recall
ROC_AUC	$\in [0, 1]$	1	area under the receiver operating characteristic curve
V_MEASURE	$\in [0, 1]$	1	harmonic mean of homogeneity and completeness

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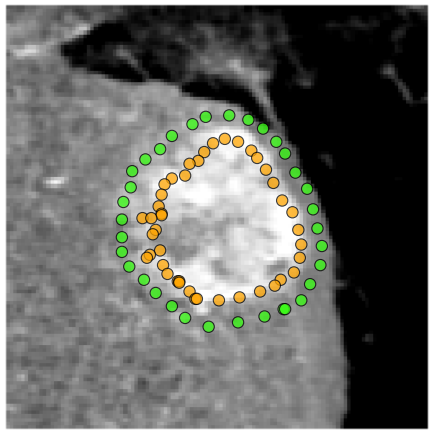
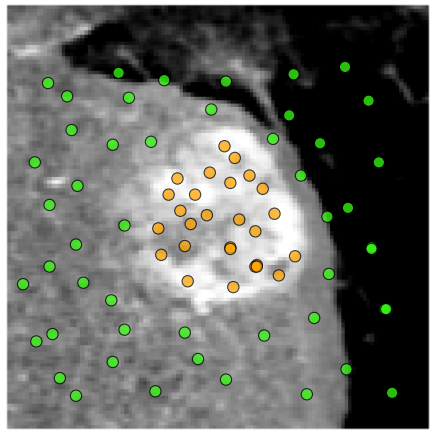
Seed Point Generation

How to place seeds effectively? Moschidis et al. [1]

surface seeds



volume seeds

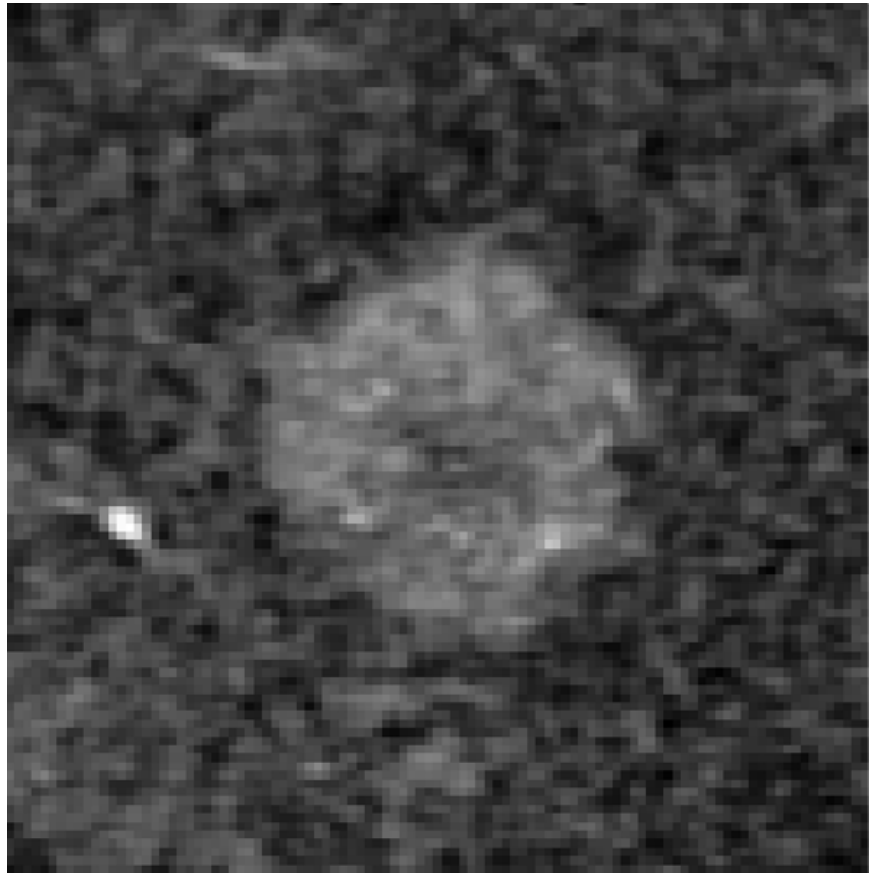


(1) the more seeds the higher the segmentation quality

(2) volume seeds yield better results than surface seeds

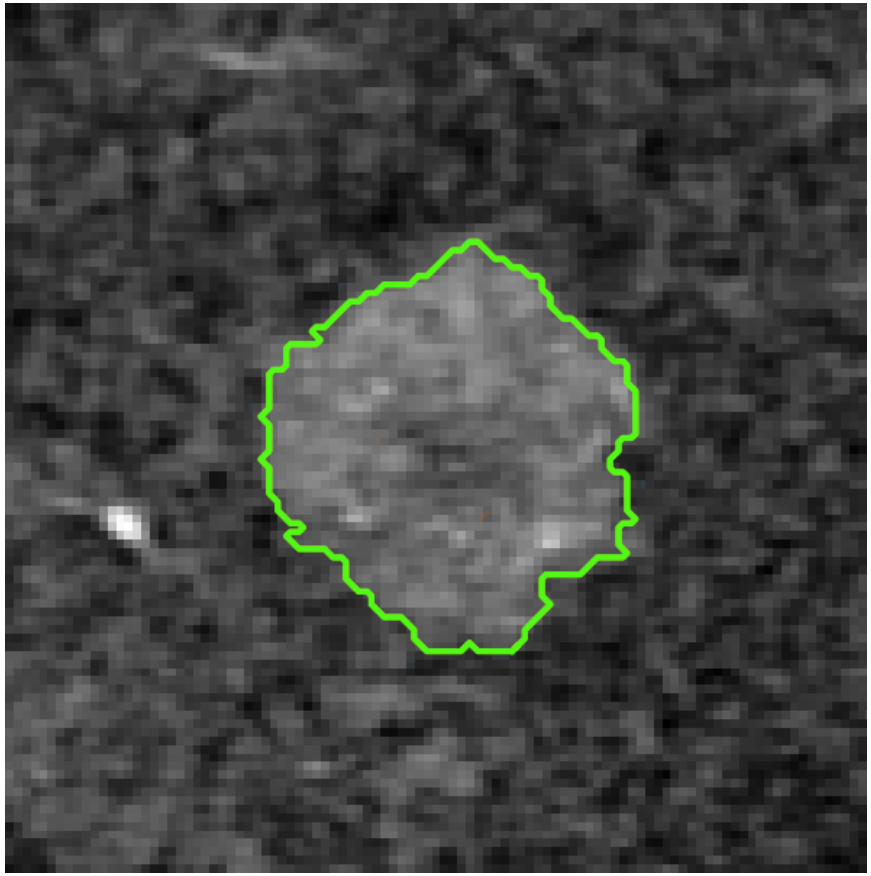
$\Rightarrow$ for an evaluation, place volume seeds based on ground truth

Generate Seed Points Automatically from Ground Truth



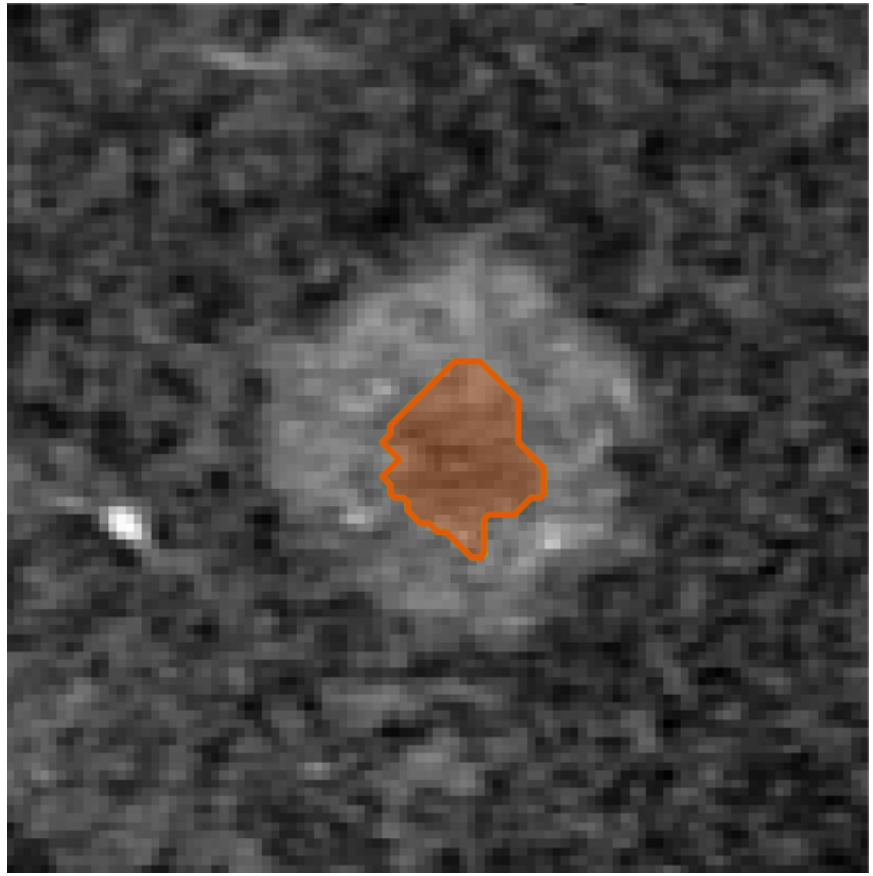
Volume of interest for lesion segmentation

Generate Seed Points Automatically from Ground Truth



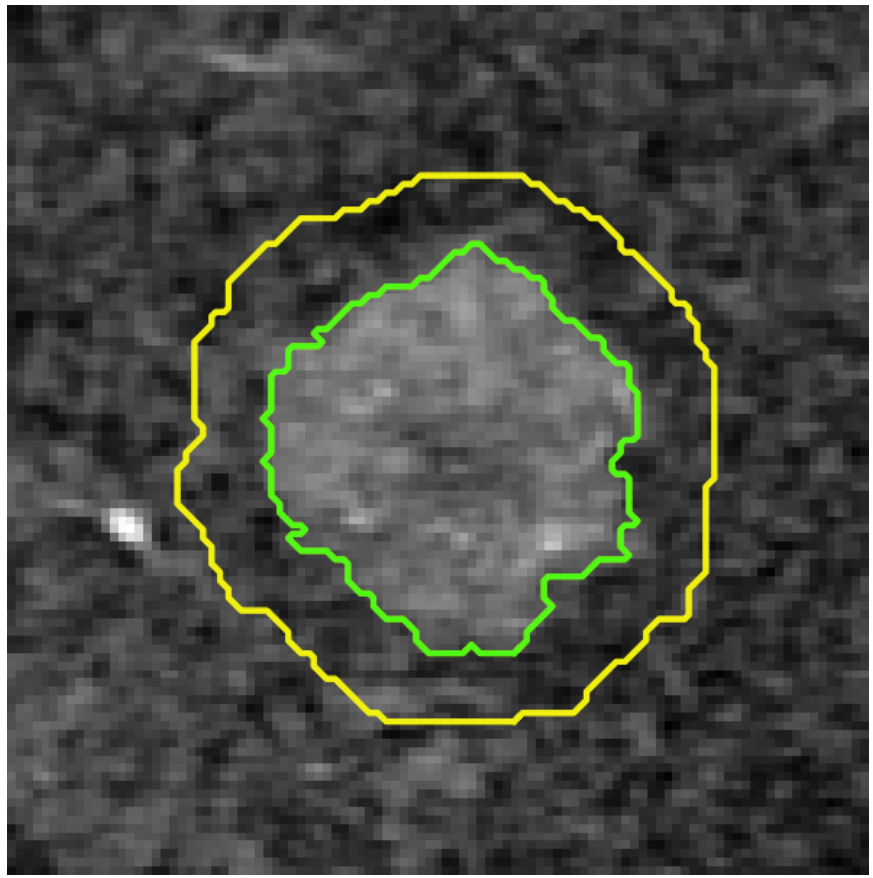
Ground truth (green contour line)

Generate Seed Points Automatically from Ground Truth



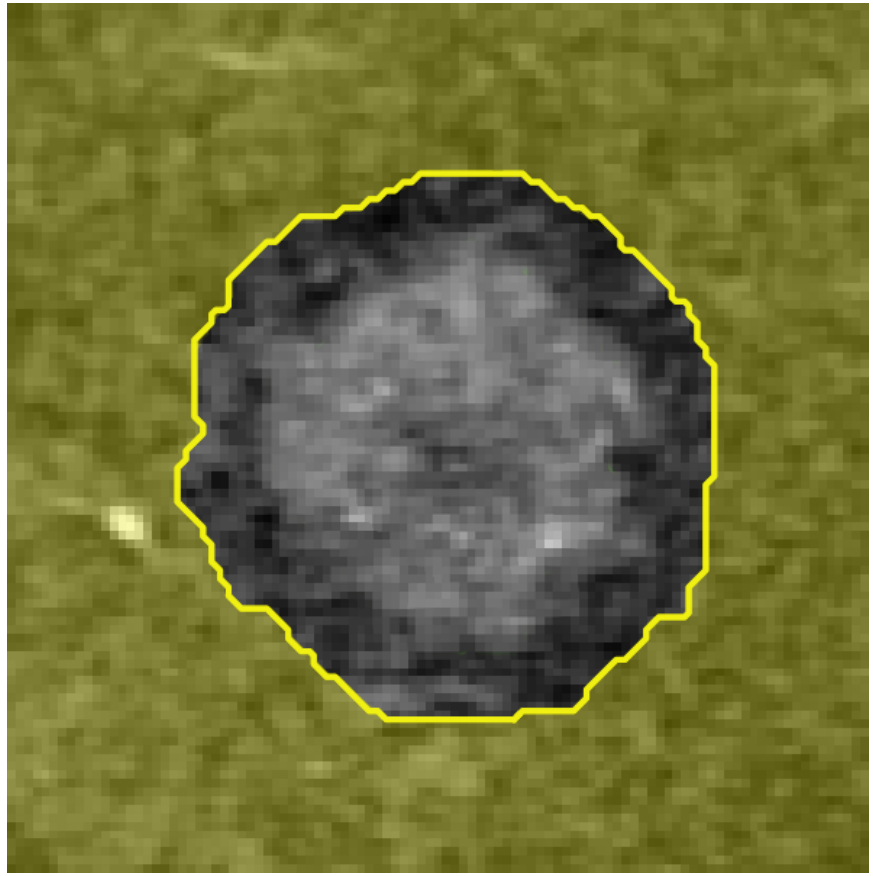
Eroded region utilized for foreground seed placement

Generate Seed Points Automatically from Ground Truth



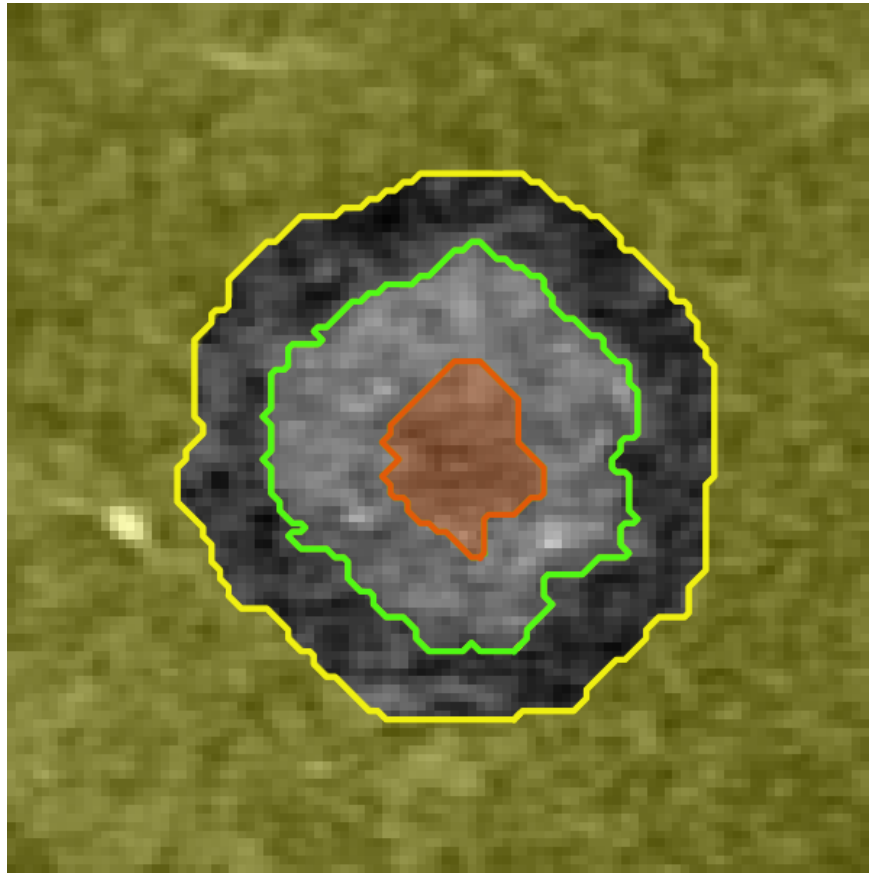
Dilated region (yellow contour line) from ground truth

Generate Seed Points Automatically from Ground Truth



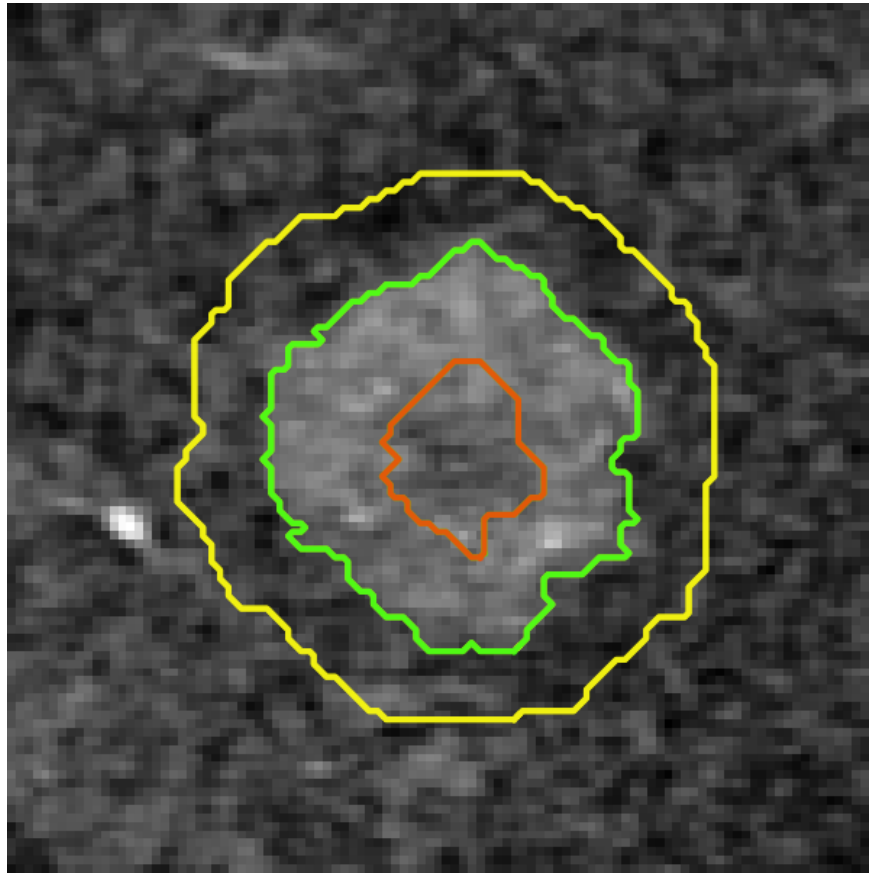
Dilated region utilized for background seed placement

Generate Seed Points Automatically from Ground Truth



Regions utilized for foreground and background seed placement

Generate Seed Points Automatically from Ground Truth



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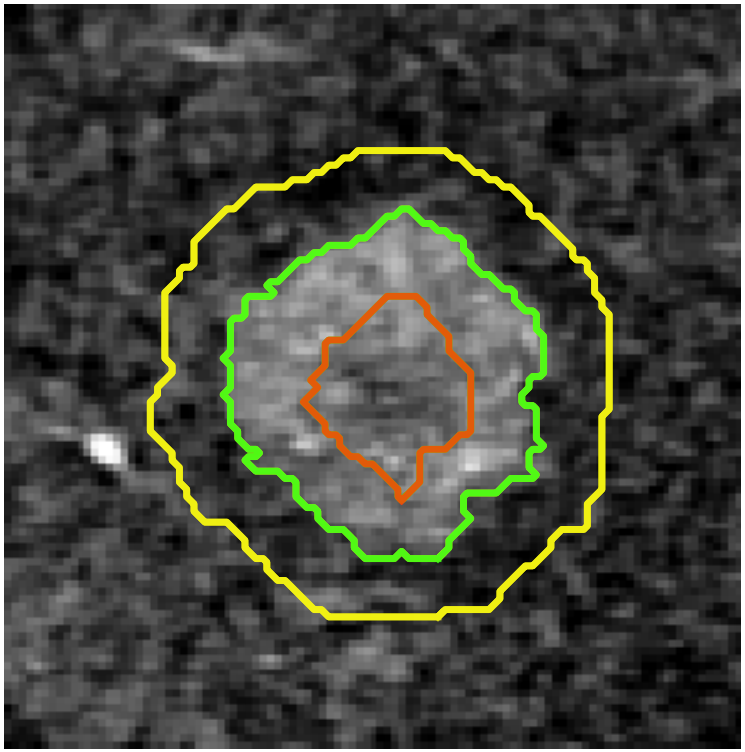
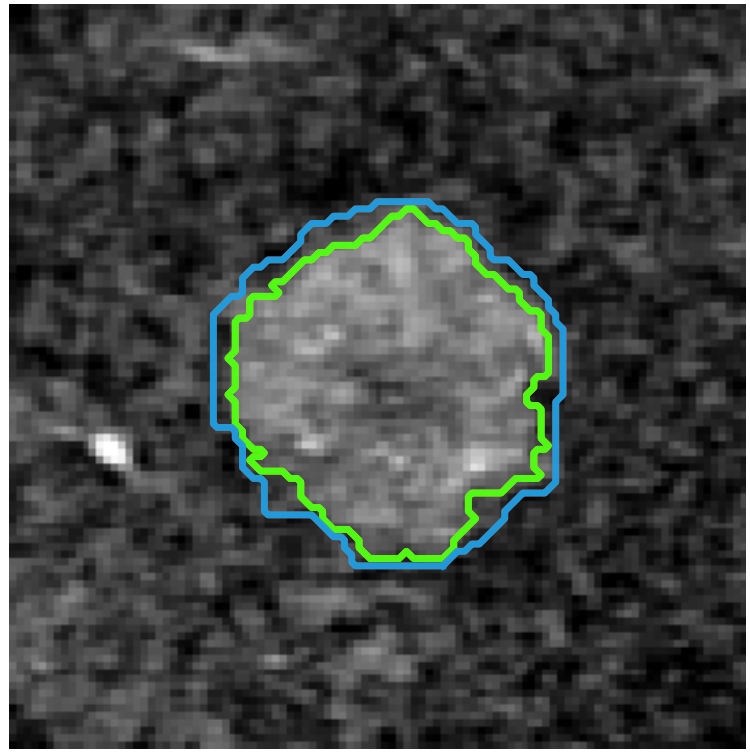
GT and Seeds



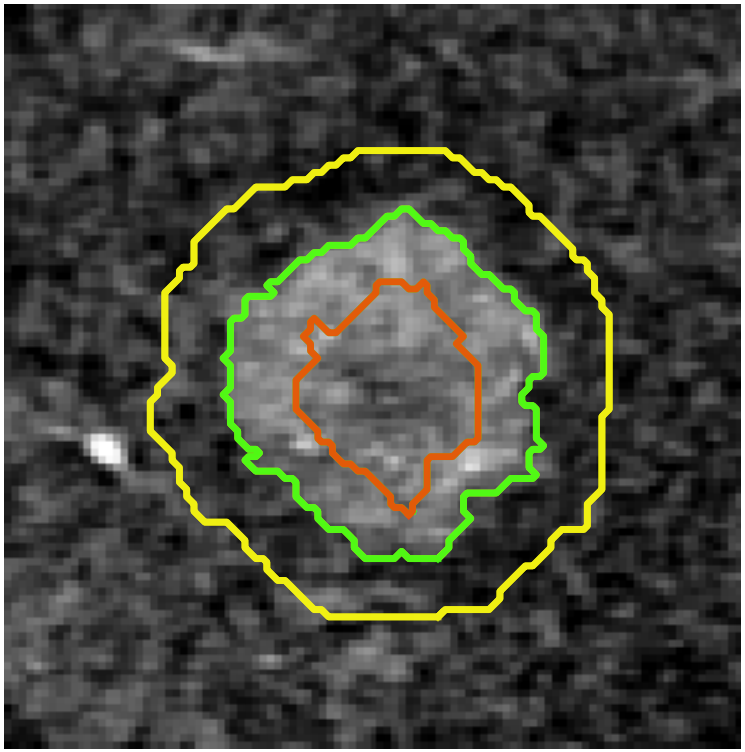
GT and Segmentation



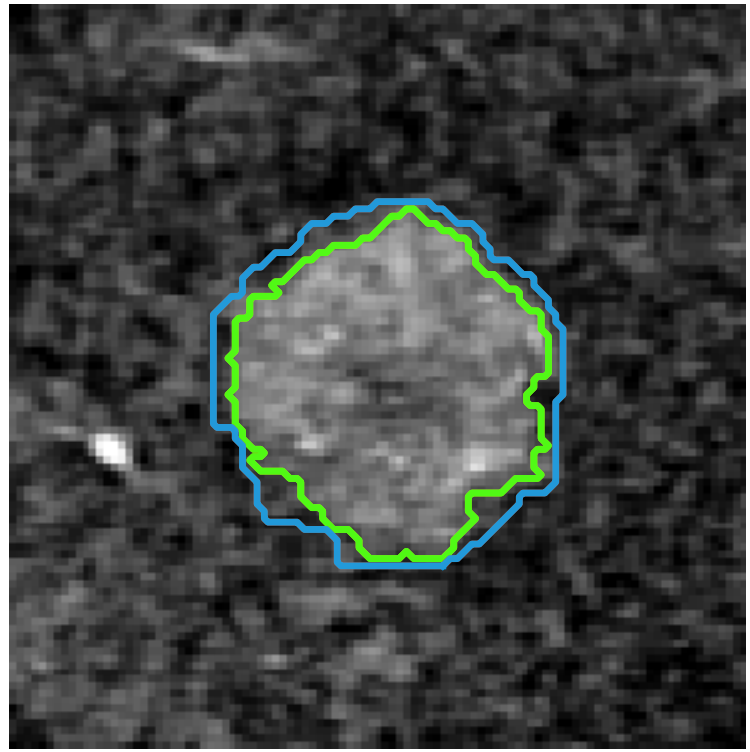
ARI .793, ASSD 2.213, COMPL .599, DICE .819, HD 8.062, HOM .786,
MI .686, MSE .018, OBJ_TPR .167, PRECISION .694, RAVD .441,
RECALL .999, ROC_AUC .990, V_MEASURE .680

GrowCut – BG Seeds 200%, FG Seeds 30%

GT and Seeds



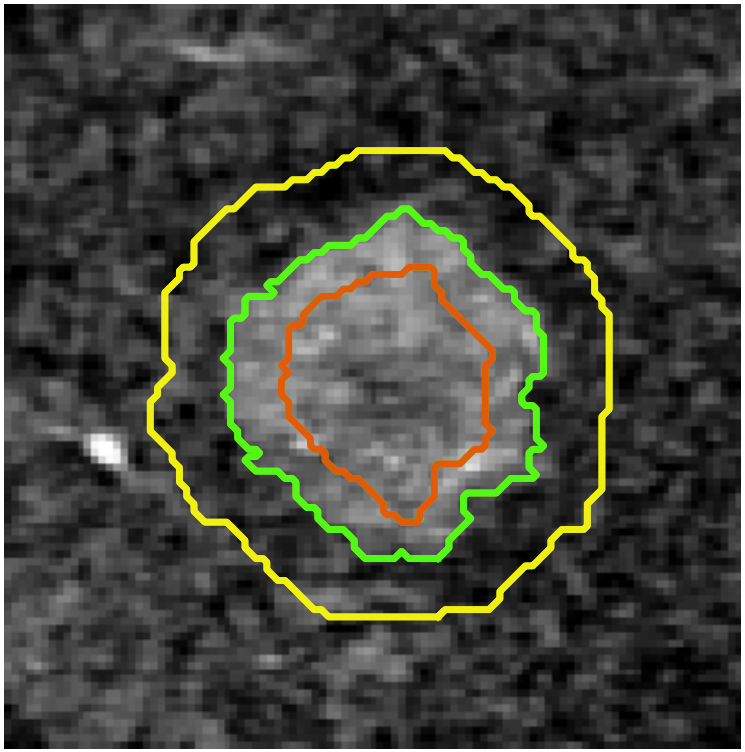
GT and Segmentation



ARI .785, ASSD 2.321, COMPL .587, DICE .811, HD 8.485, HOM .780,
MI .677, MSE .019, OBJ_TPR .167, PRECISION .683, RAVD .465,
RECALL 1.000, ROC_AUC .990, V_MEASURE .670

GrowCut – BG Seeds 200%, FG Seeds 40%

GT and Seeds



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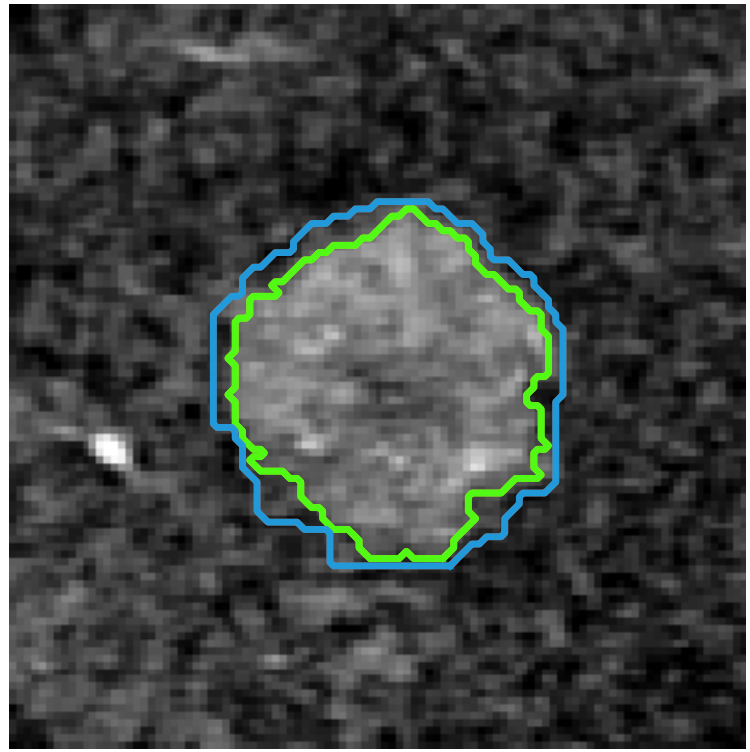
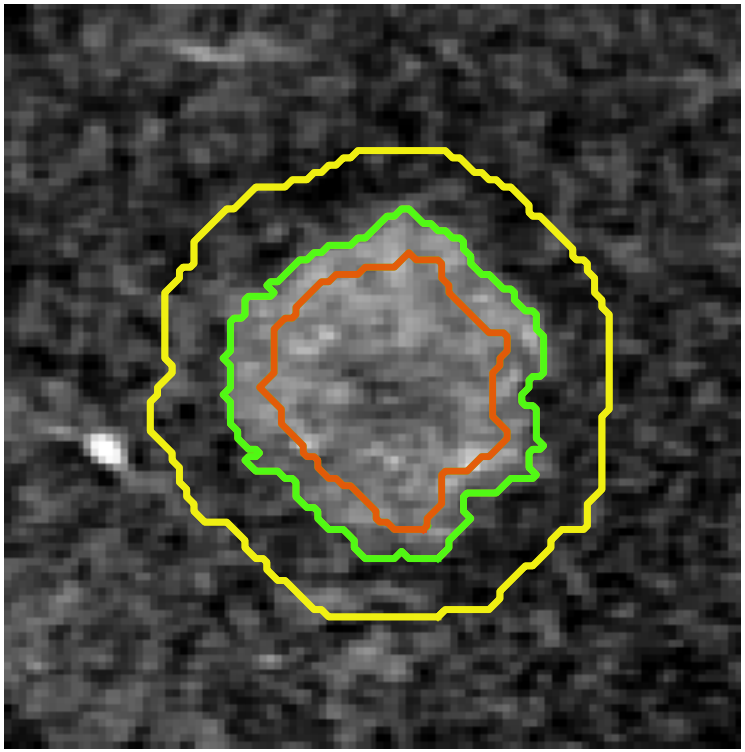


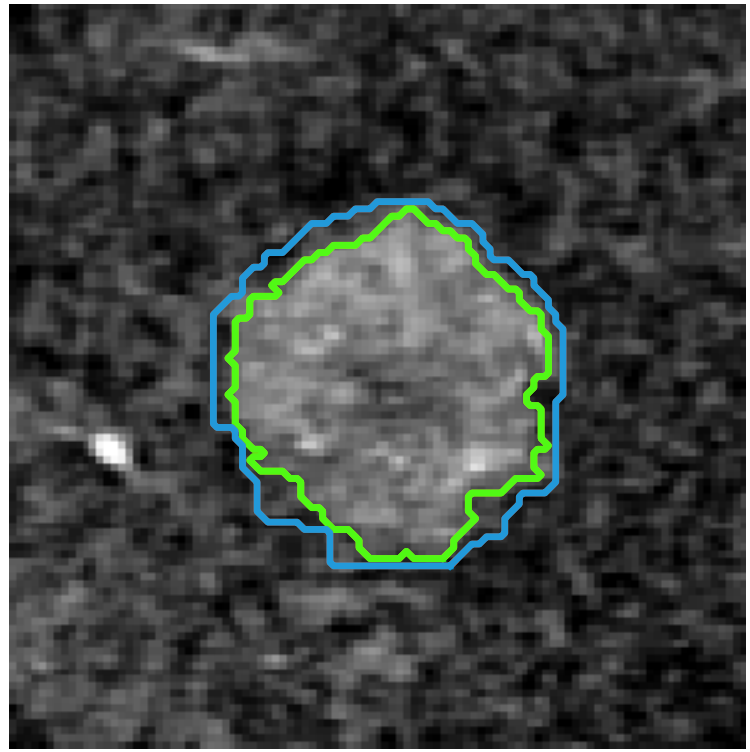
ARI .770, ASSD 2.516, COMPL .569, DICE .799, HD 1.000, HOM .769,
MI .661, MSE .021, OBJ_TPR .167, PRECISION .665, RAVD .504,
RECALL 1.000, ROC_AUC .989, V_MEASURE .654

GrowCut – BG Seeds 200%, FG Seeds 50%

GT and Seeds



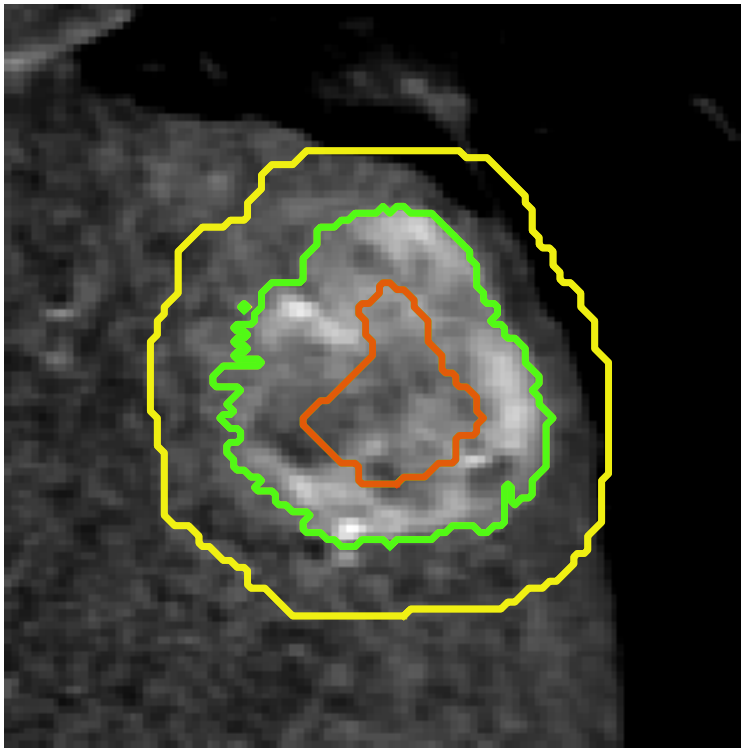
GT and Segmentation



ARI .753, ASSD 2.722, COMPL .547, DICE .784, HD 11.662, HOM .757,
MI .644, MSE .023, OBJ_TPR .167, PRECISION .644, RAVD .552,
RECALL 1.000, ROC_AUC .988, V_MEASURE .635

GrowCut – BG Seeds 200%, FG Seeds 20%

GT and Seeds



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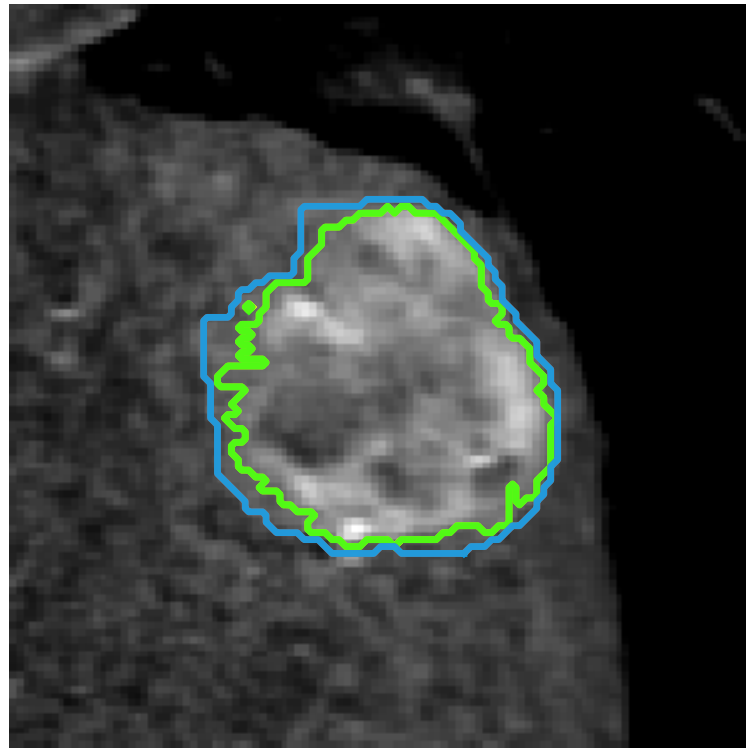
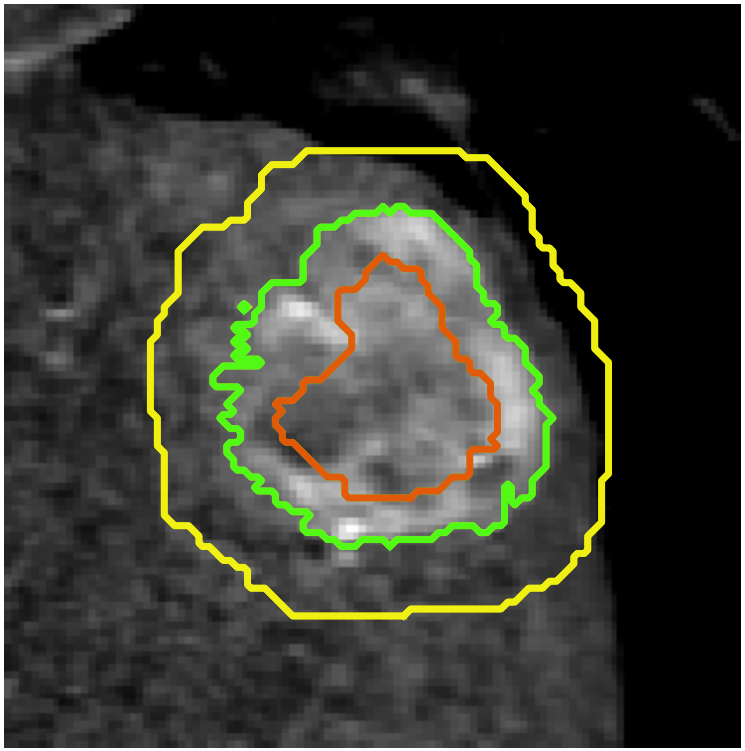


ARI .844, ASSD 1.896, COMPL .671, DICE .865, HD 8.544, HOM .818,
MI .741, MSE .014, OBJ_TPR .167, PRECISION .763, RAVD .308,
RECALL .998, ROC_AUC .991, V_MEASURE .737

GrowCut – BG Seeds 200%, FG Seeds 30%

GT and Seeds



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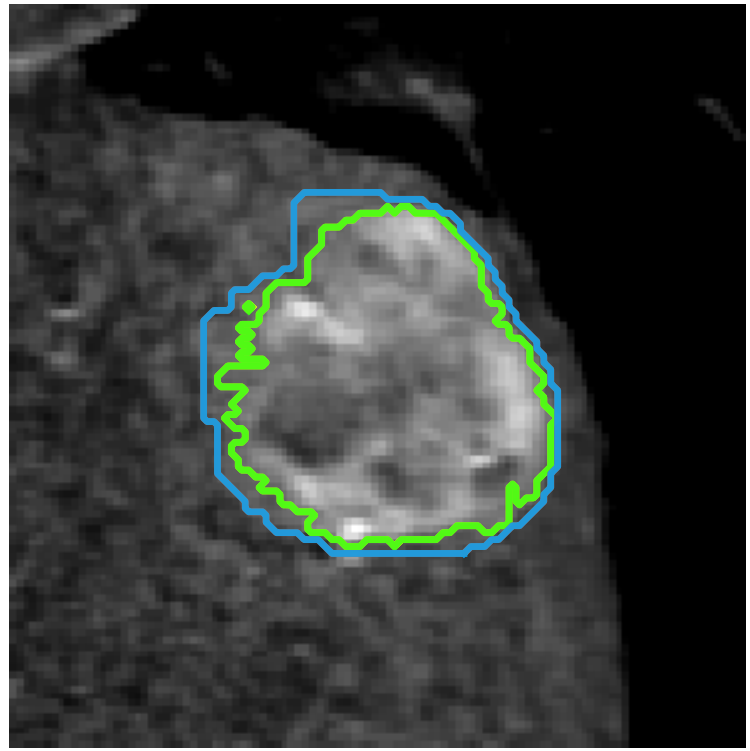
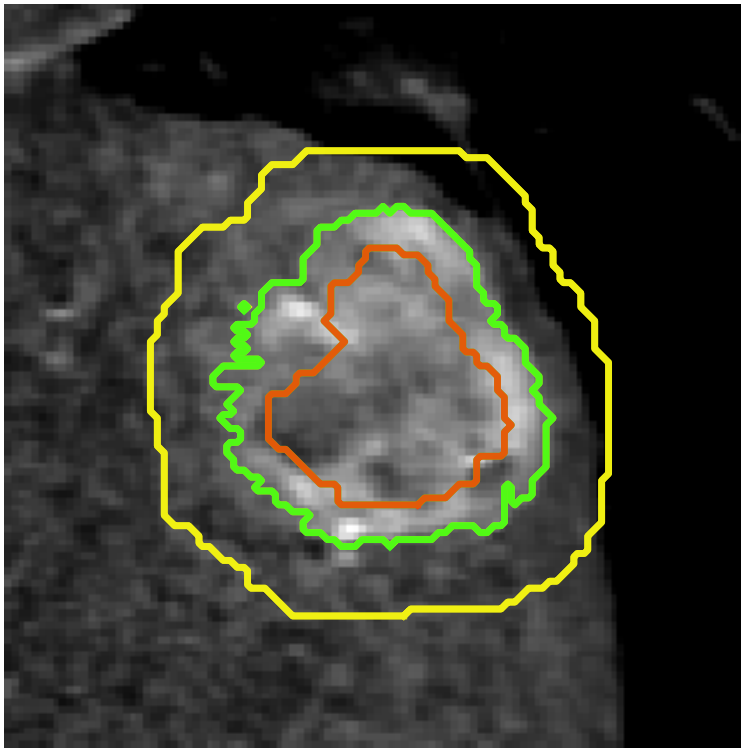


ARI .831, ASSD 2.051, COMPL .653, DICE .854, HD 8.544, HOM .810,
MI .727, MSE .016, OBJ_TPR .167, PRECISION .746, RAVD .338,
RECALL .999, ROC_AUC .991, V_MEASURE .723

GrowCut – BG Seeds 200%, FG Seeds 40%

GT and Seeds



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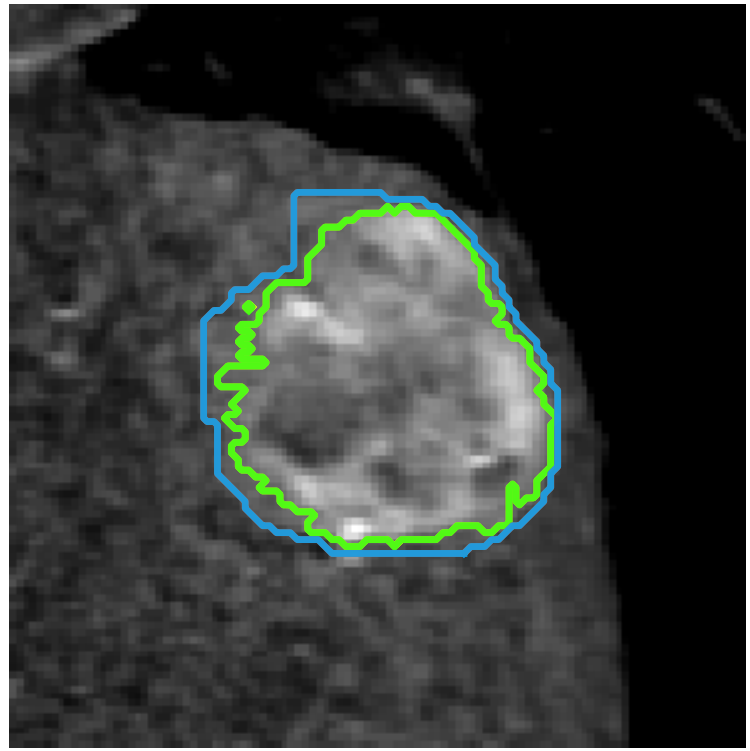
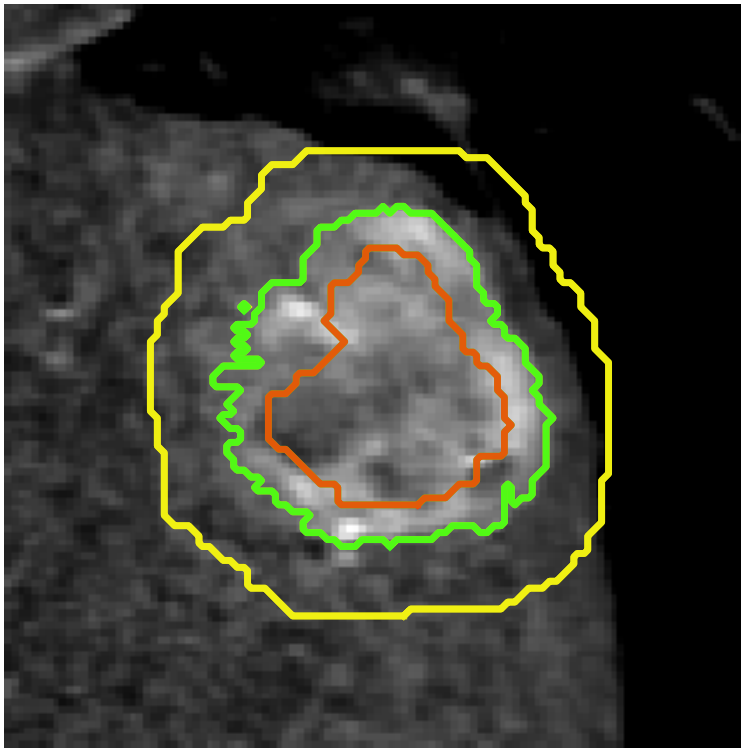


ARI .823, ASSD 2.150, COMPL .642, DICE .847, HD 8.544, HOM .804,
MI .718, MSE .017, OBJ_TPR .167, PRECISION .735, RAVD .359,
RECALL .999, ROC_AUC .991, V_MEASURE .714

GrowCut – BG Seeds 200%, FG Seeds 50%

GT and Seeds



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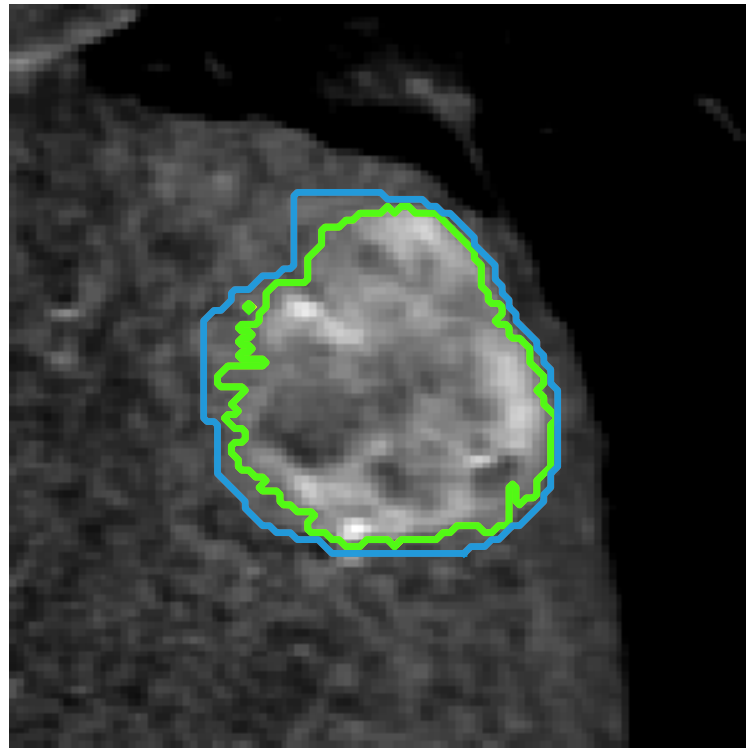

ARI .823, ASSD 2.150, COMPL .642, DICE .847, HD 8.544, HOM .804,
MI .718, MSE .017, OBJ_TPR .167, PRECISION .735, RAVD .359,
RECALL .999, ROC_AUC .991, V_MEASURE .714

GrowCut – BG Seeds 200%, FG Seeds 20%

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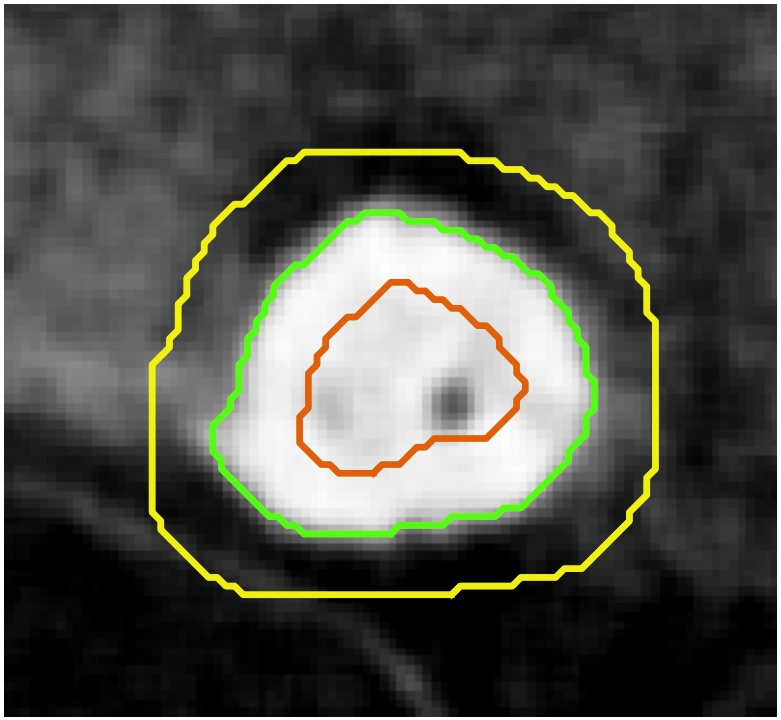

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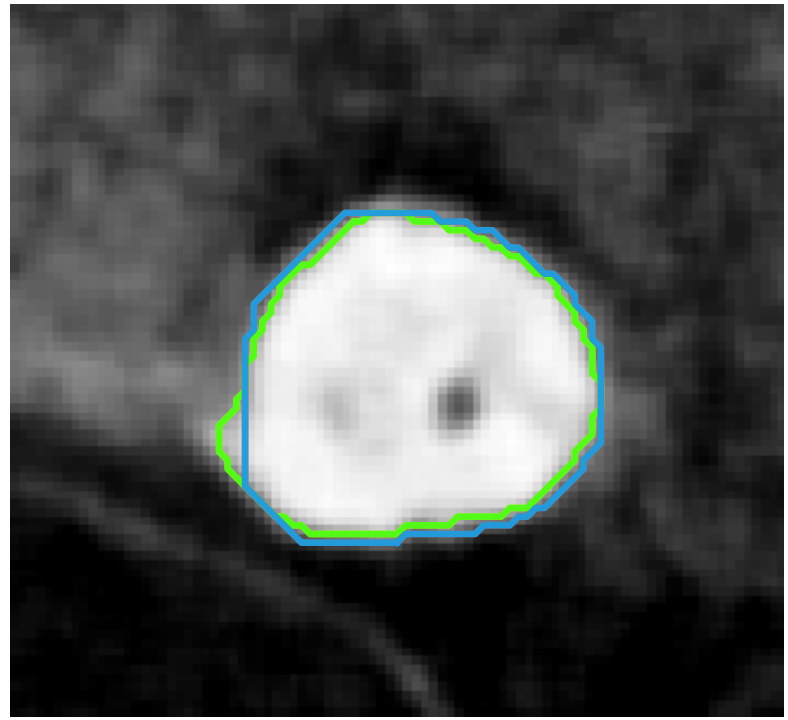

ARI .878, ASSD 1.259, COMPL .724, DICE .894, HD 4.123, HOM .835, MI .777, MSE .011, OBJ_TPR 1.000, PRECISION .816, RAVD .213, RECALL .989, ROC_AUC .989, V_MEASURE .775

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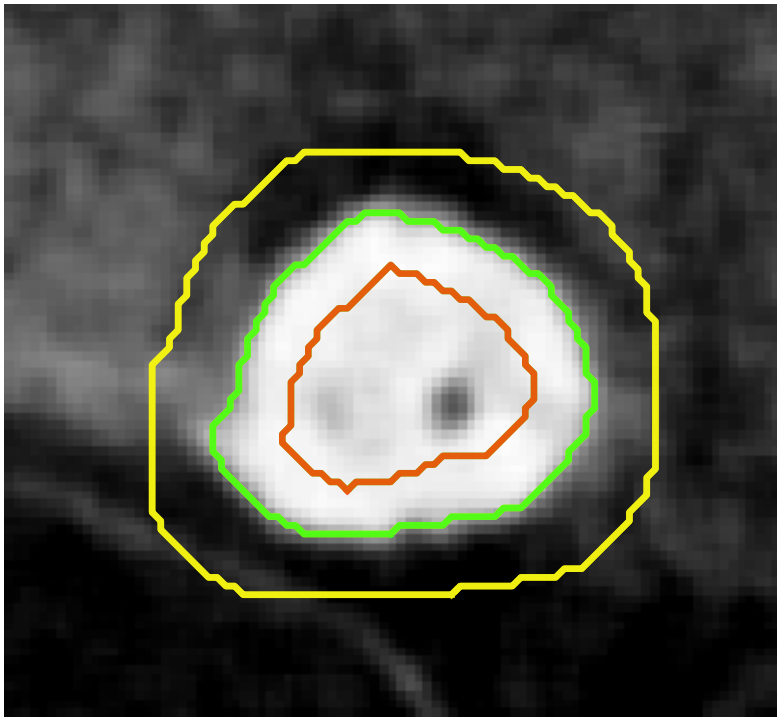
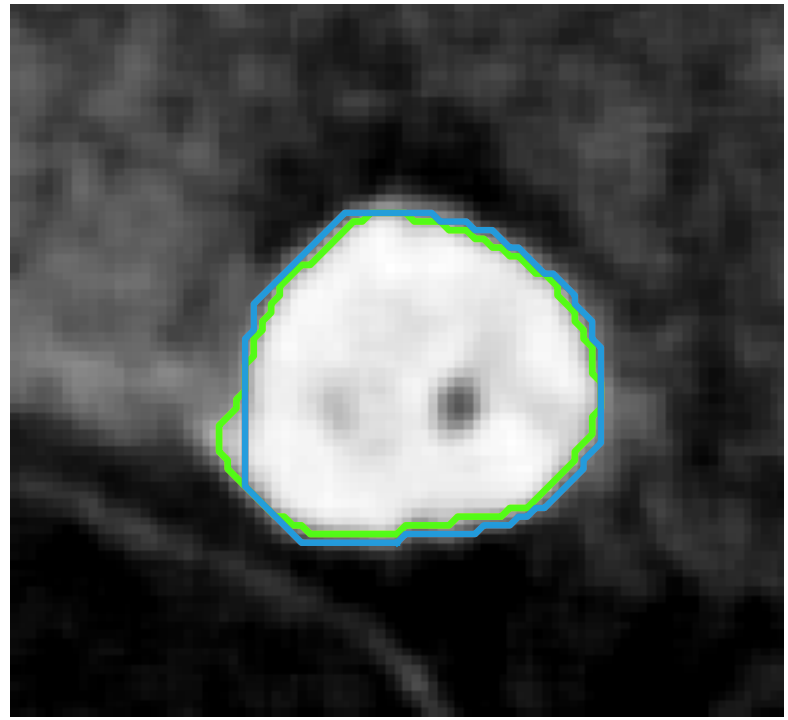
GT and Seeds



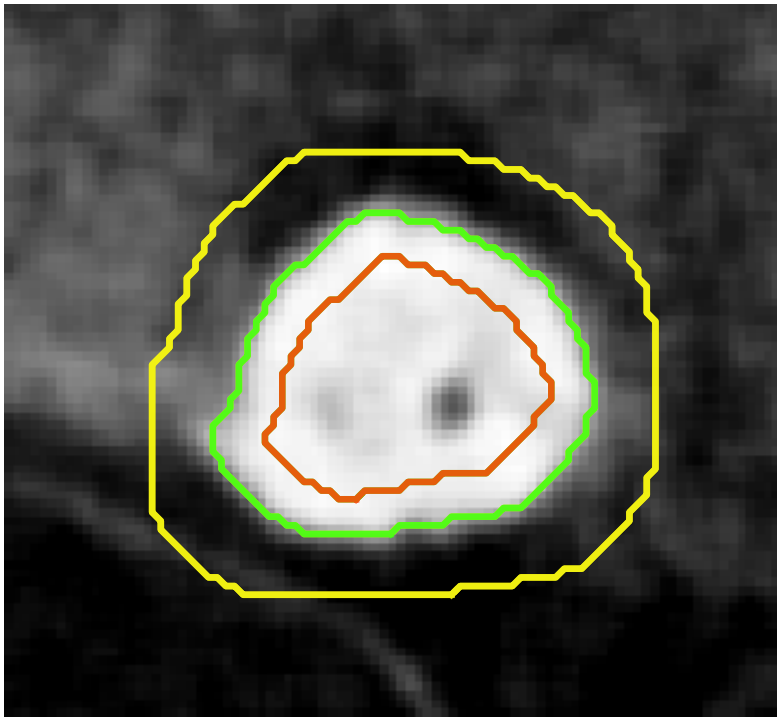
GT and Segmentation



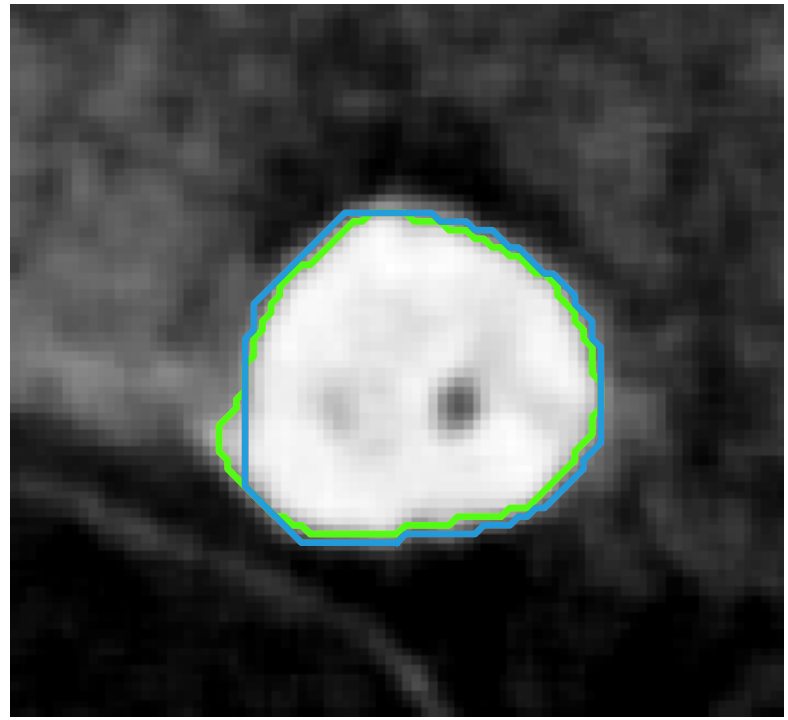
ARI .878, ASSD 1.261, COMPL .724, DICE .894, HD 4.123, HOM .835, MI .777, MSE .011, OBJ_TPR 1.000, PRECISION .816, RAVD .213, RECALL .989, ROC_AUC .989, V_MEASURE .775

GrowCut – BG Seeds 200%, FG Seeds 40%

GT and Seeds



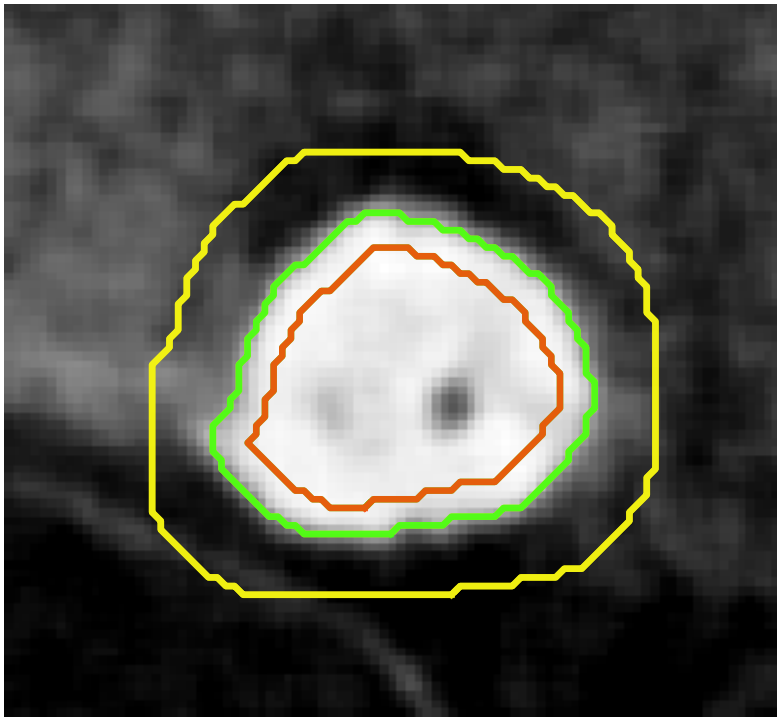
GT and Segmentation



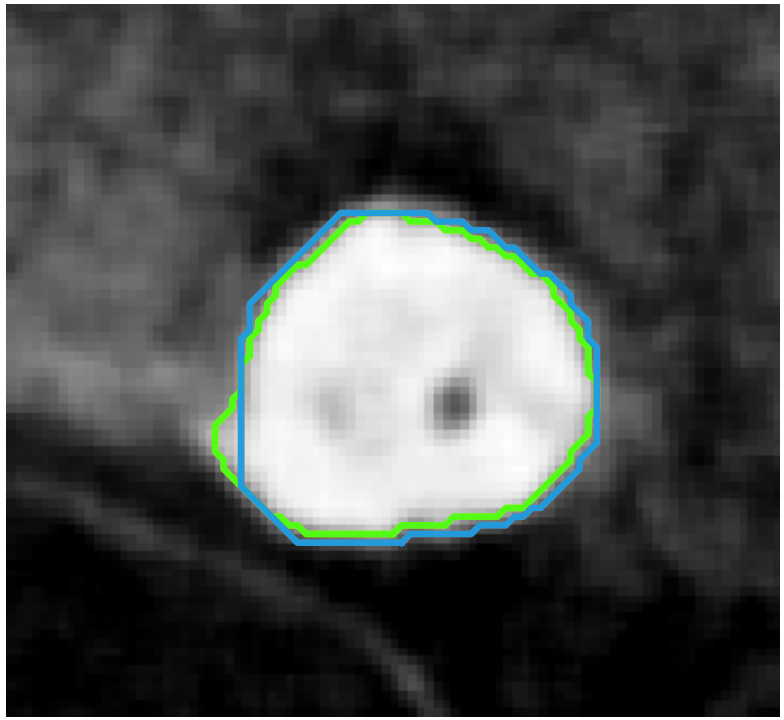
ARI .876, ASSD 1.277, COMPL .721, DICE .893, HD 4.123, HOM .834, MI .775, MSE .011, OBJ_TPR 1.000, PRECISION .813, RAVD .217, RECALL .990, ROC_AUC .989, V_MEASURE .773

GrowCut – BG Seeds 200%, FG Seeds 50%

GT and Seeds



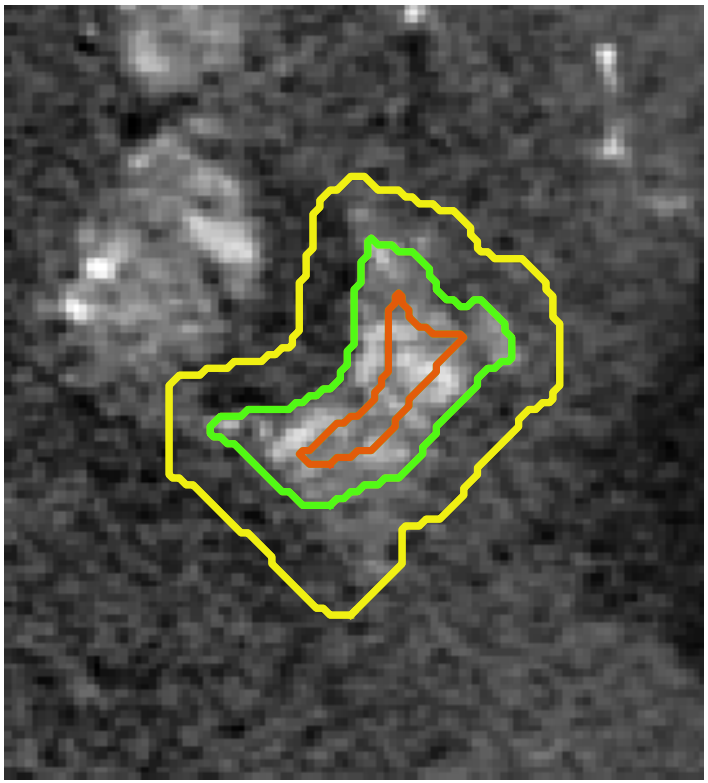
GT and Segmentation



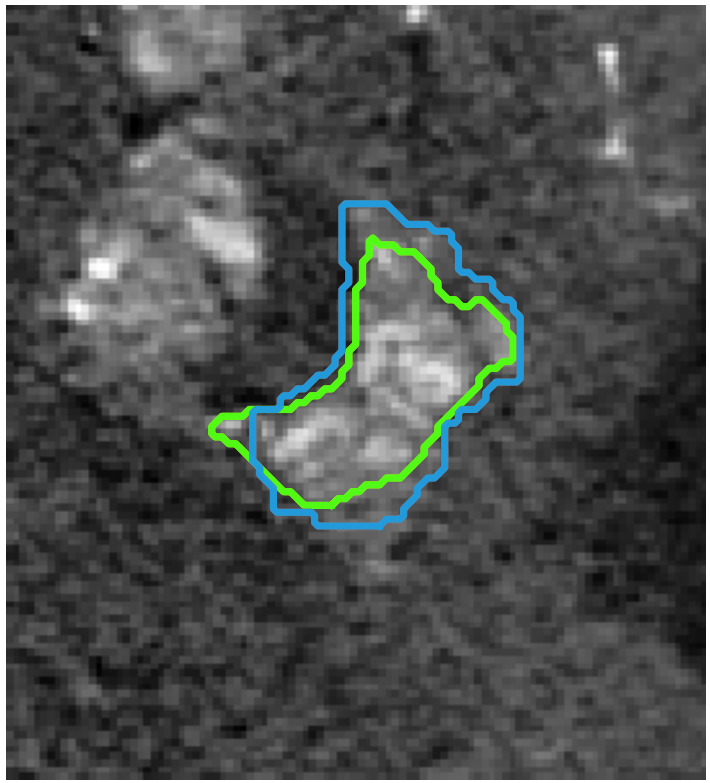
ARI .874, ASSD 1.297, COMPL .718, DICE .891, HD 4.123, HOM .833, MI .773, MSE .011, OBJ_TPR 1.000, PRECISION .810, RAVD .223, RECALL .991, ROC_AUC .990, V_MEASURE .771

GrowCut – BG Seeds 200%, FG Seeds 20%

GT and Seeds



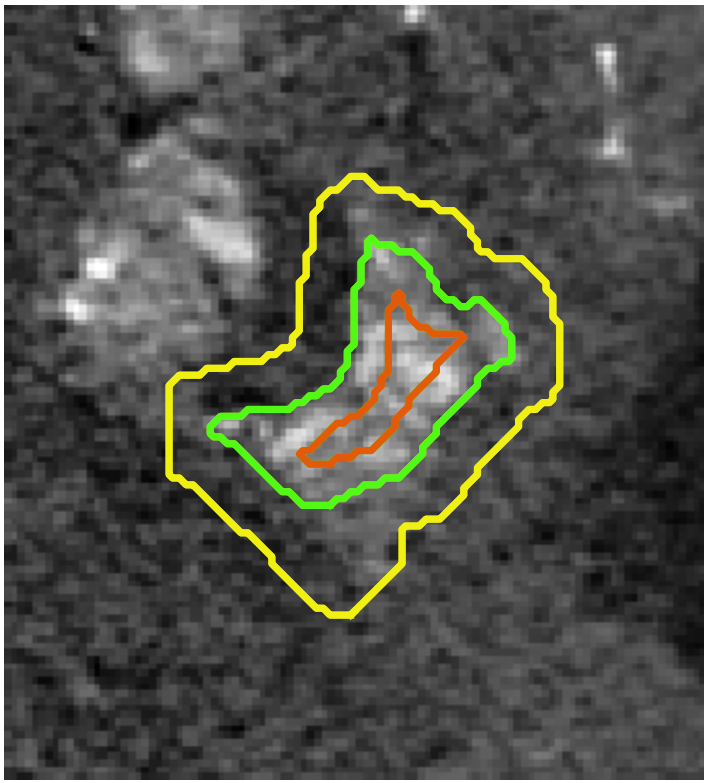
GT and Segmentation



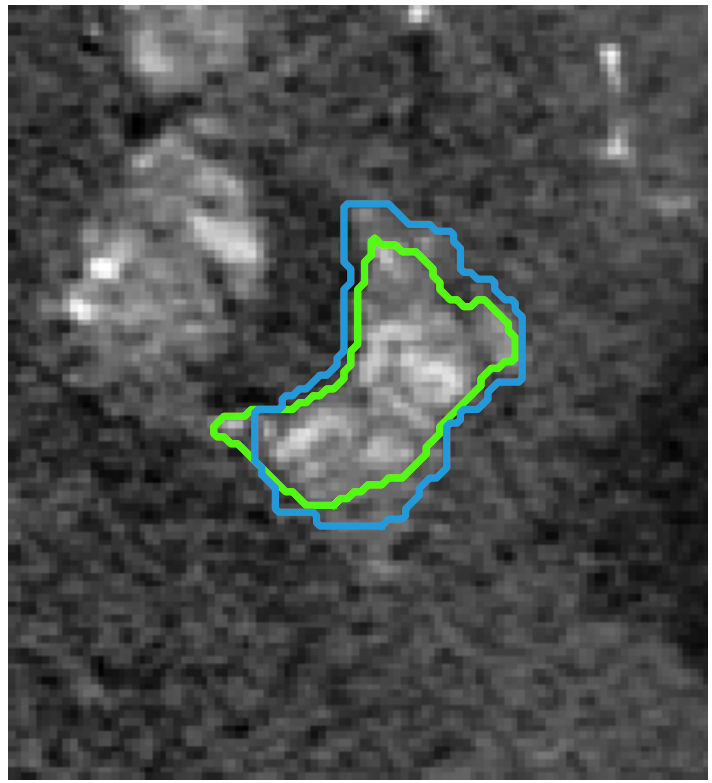
ARI .783, ASSD 1.873, COMPL .577, DICE .798, HD 6.325, HOM .782,
MI .672, MSE .012, OBJ_TPR 1.000, PRECISION .669, RAVD .478,
RECALL .989, ROC_AUC .989, V_MEASURE .664

GrowCut – BG Seeds 200%, FG Seeds 30%

GT and Seeds



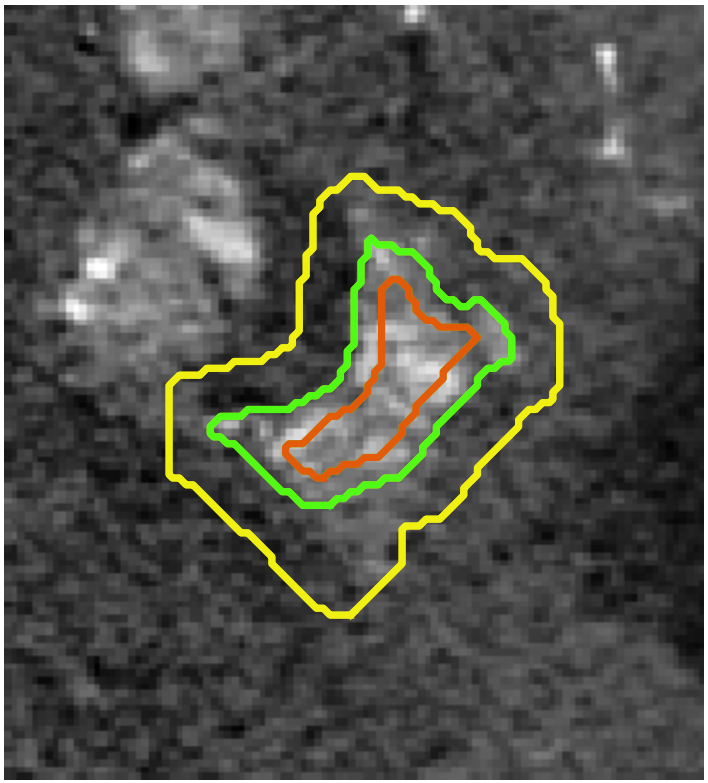
GT and Segmentation



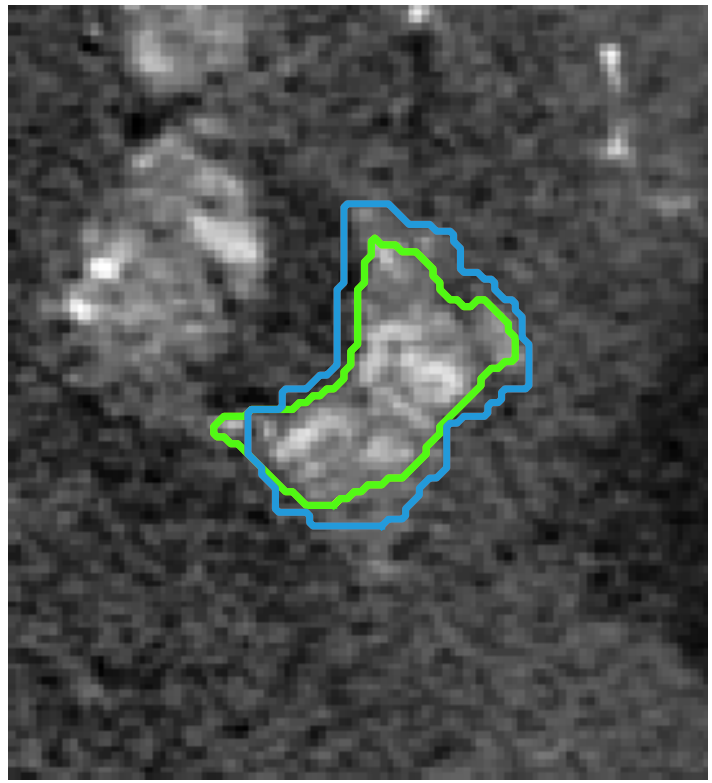
ARI .783, ASSD 1.873, COMPL .577, DICE .798, HD 6.325, HOM .782,
MI .672, MSE .012, OBJ_TPR 1.000, PRECISION .669, RAVD .478,
RECALL .989, ROC_AUC .989, V_MEASURE .664

GrowCut – BG Seeds 200%, FG Seeds 40%

GT and Seeds



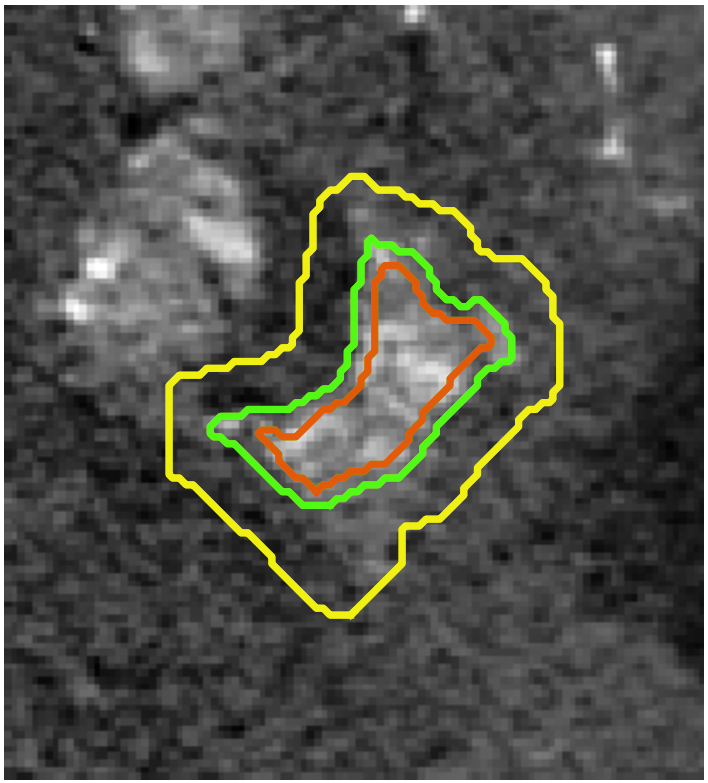
GT and Segmentation



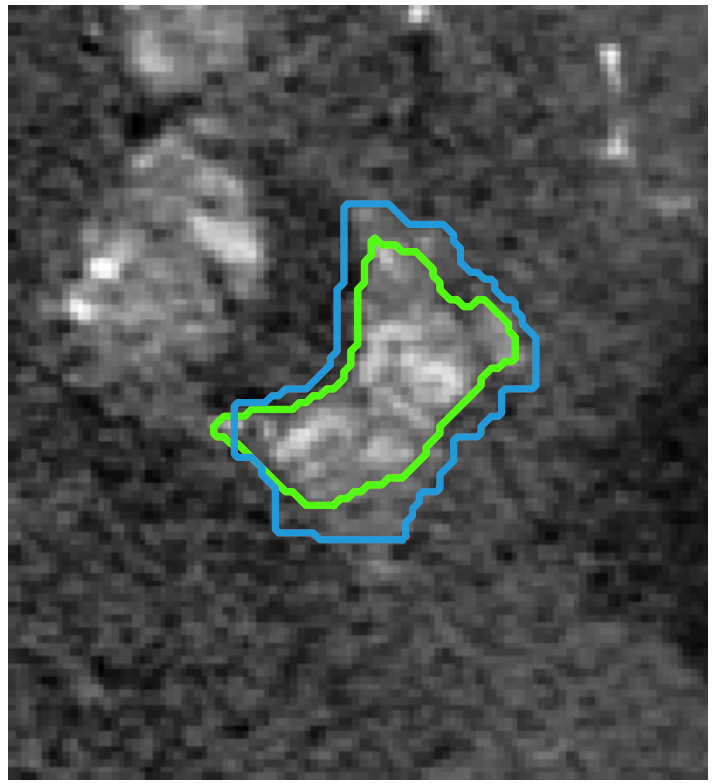
ARI .736, ASSD 2.328, COMPL .519, DICE .755, HD 7.071, HOM .759,
MI .627, MSE .015, OBJ_TPR 1.000, PRECISION .609, RAVD .634,
RECALL .995, ROC_AUC .990, V_MEASURE .616

GrowCut – BG Seeds 200%, FG Seeds 50%

GT and Seeds



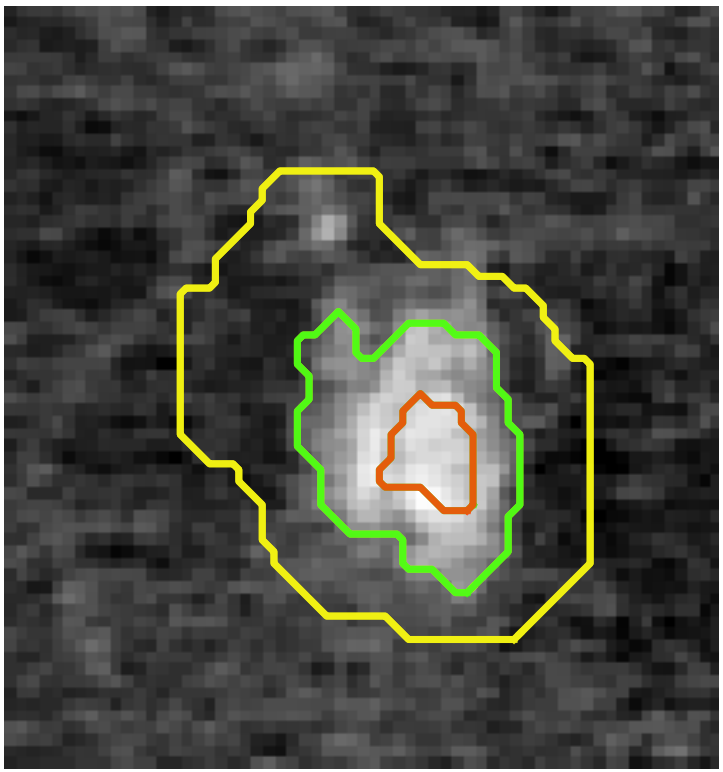
GT and Segmentation



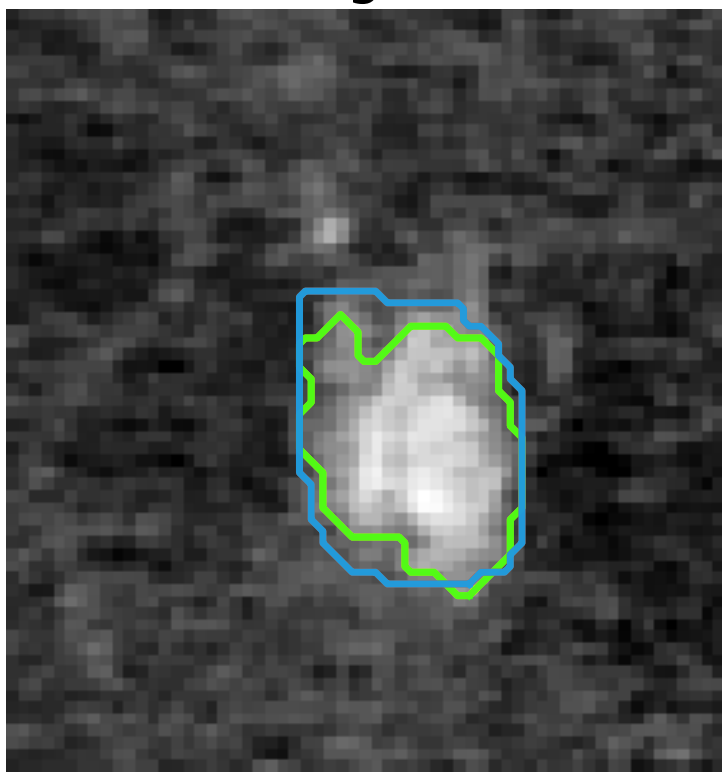
ARI .686, ASSD 2.871, COMPL .463, DICE .709, HD 8.485, HOM .734, MI .583, MSE .019, OBJ_TPR 1.000, PRECISION .550, RAVD .816, RECALL .999, ROC_AUC .990, V_MEASURE .568

GrowCut – BG Seeds 200%, FG Seeds 20%

GT and Seeds



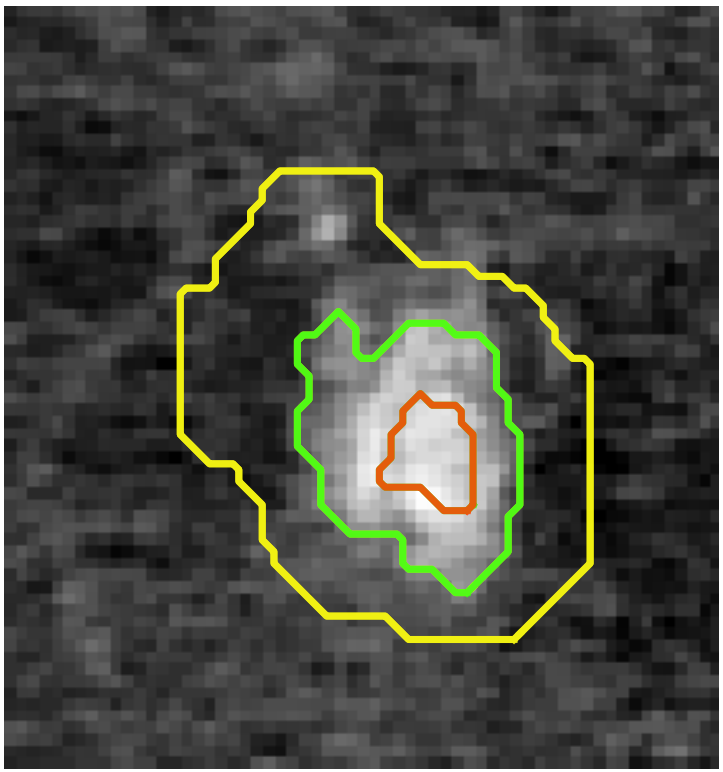
GT and Segmentation



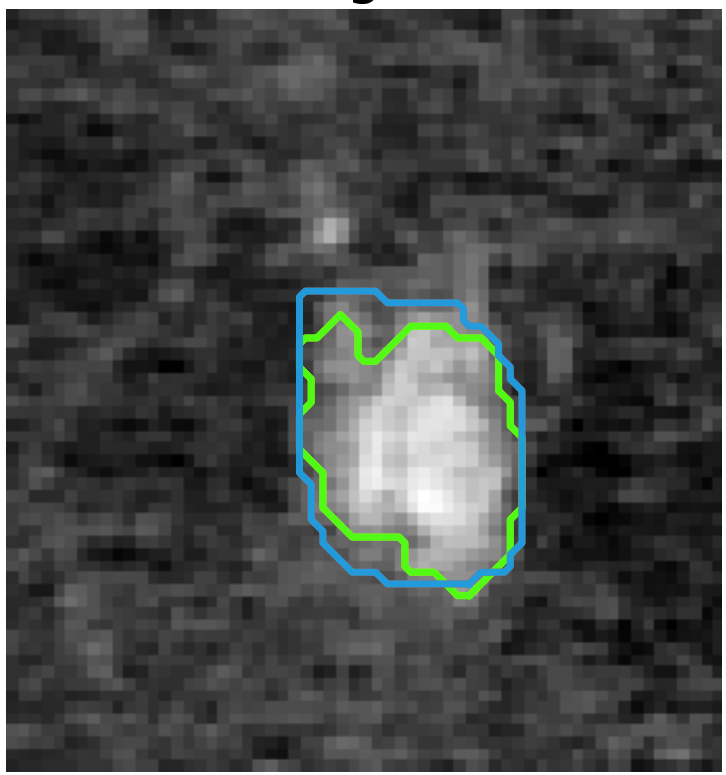
ARI .790, ASSD 1.314, COMPL .587, DICE .807, HD 7.071, HOM .703,
MI .642, MSE .012, OBJ_TPR 1.000, PRECISION .724, RAVD .262,
RECALL .913, ROC_AUC .951, V_MEASURE .640

GrowCut – BG Seeds 200%, FG Seeds 30%

GT and Seeds



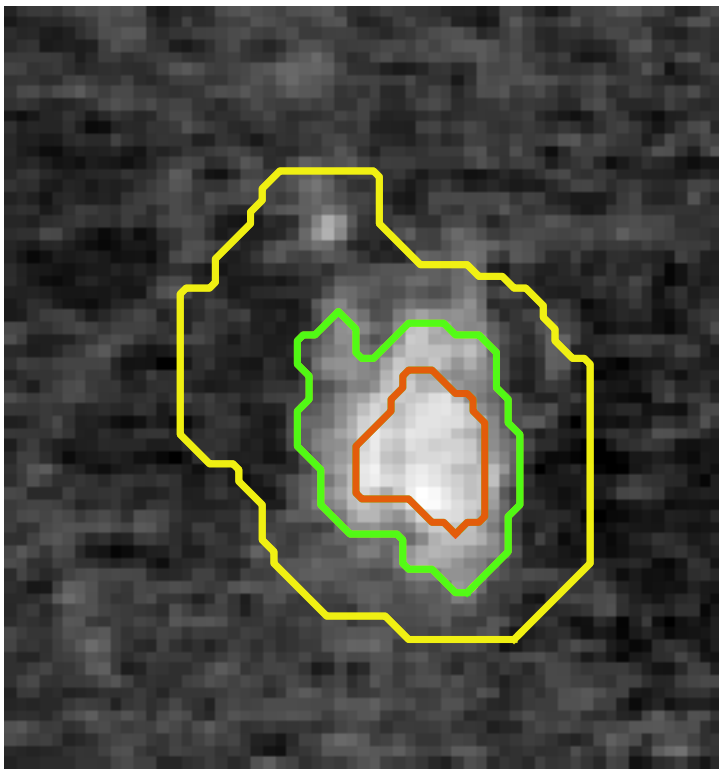
GT and Segmentation



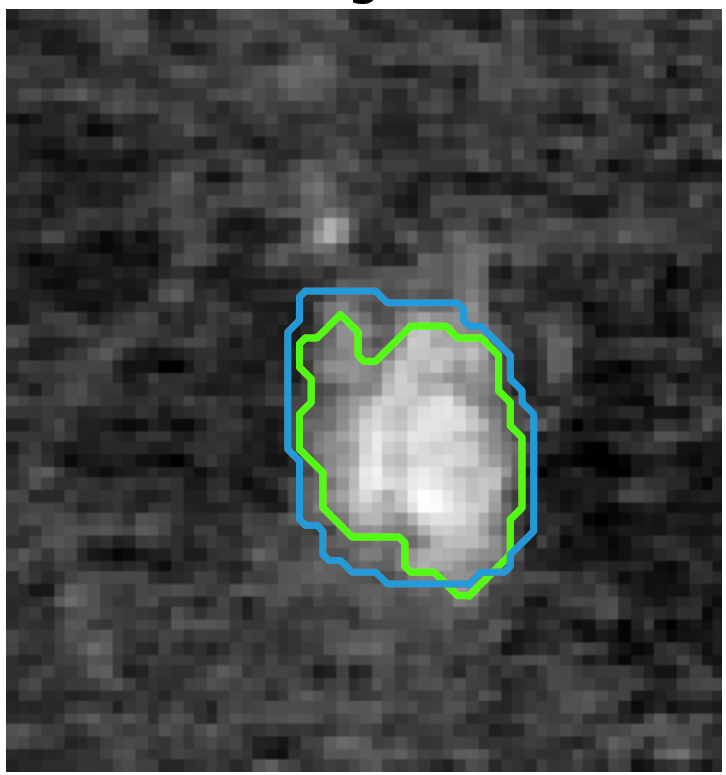
ARI .790, ASSD 1.314, COMPL .587, DICE .807, HD 7.071, HOM .703,
MI .642, MSE .012, OBJ_TPR 1.000, PRECISION .724, RAVD .262,
RECALL .913, ROC_AUC .951, V_MEASURE .640

GrowCut – BG Seeds 200%, FG Seeds 40%

GT and Seeds



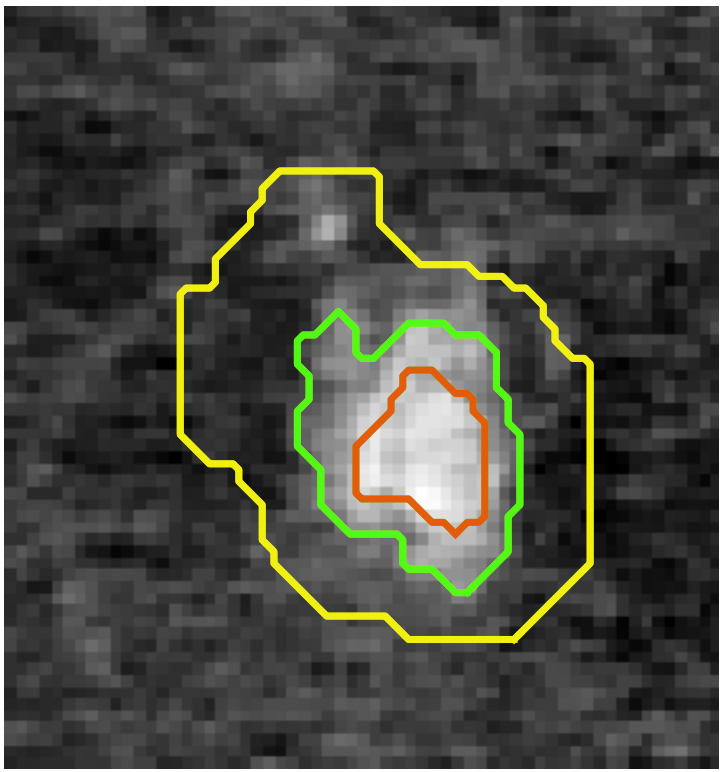
GT and Segmentation



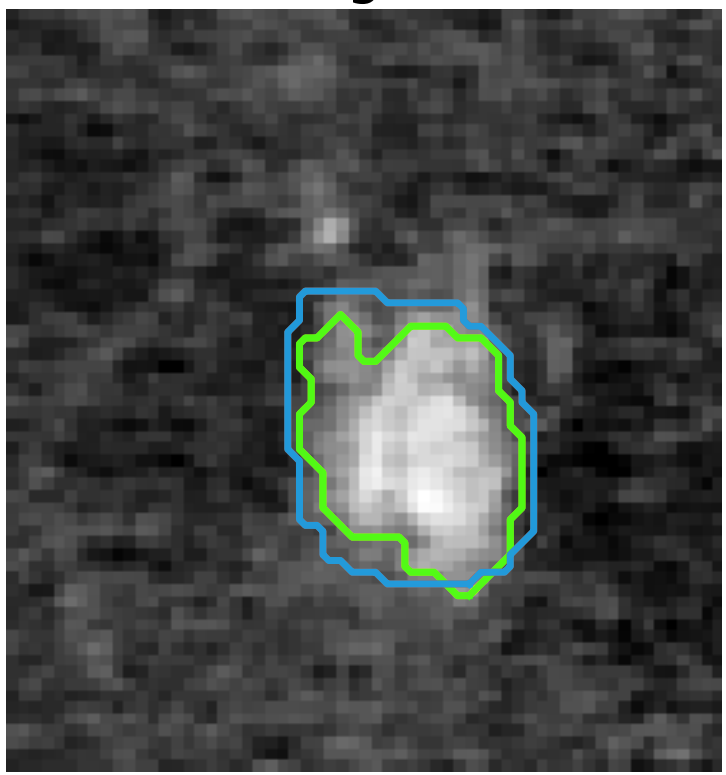
ARI .784, ASSD 1.327, COMPL .580, DICE .803, HD 5.099, HOM .776,
MI .671, MSE .014, OBJ_TPR 1.000, PRECISION .676, RAVD .464,
RECALL .990, ROC_AUC .988, V_MEASURE .664

GrowCut – BG Seeds 200%, FG Seeds 50%

GT and Seeds



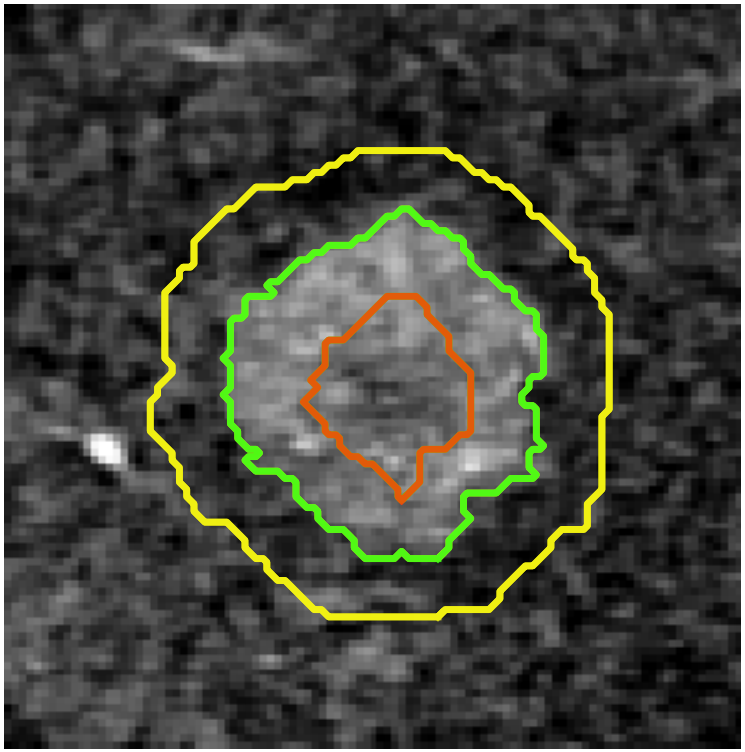
GT and Segmentation



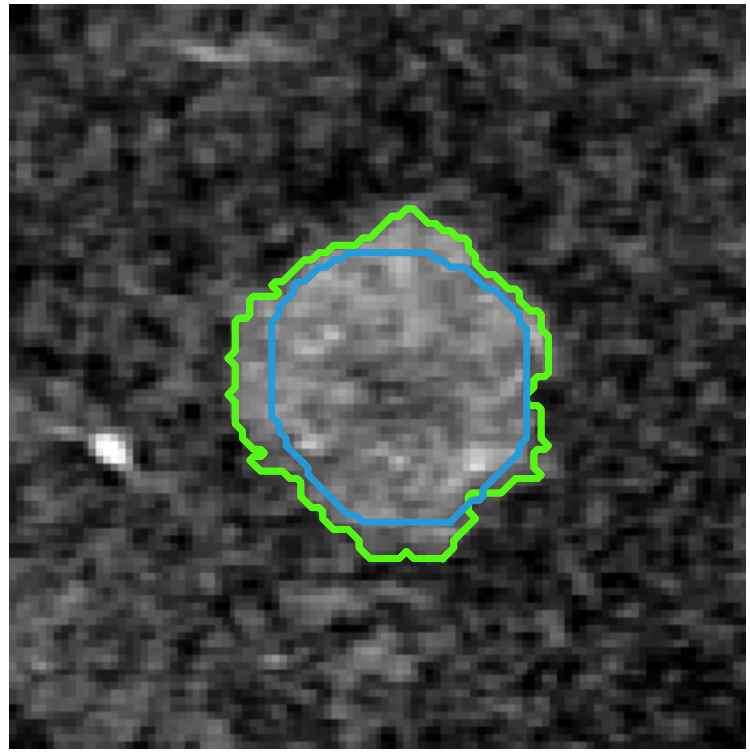
ARI .784, ASSD 1.327, COMPL .580, DICE .803, HD 5.099, HOM .776,
MI .671, MSE .014, OBJ_TPR 1.000, PRECISION .676, RAVD .464,
RECALL .990, ROC_AUC .988, V_MEASURE .664

RandomWalker – BG Seeds 200%, FG Seeds 20%, β 190, tol 1e−03

GT and Seeds



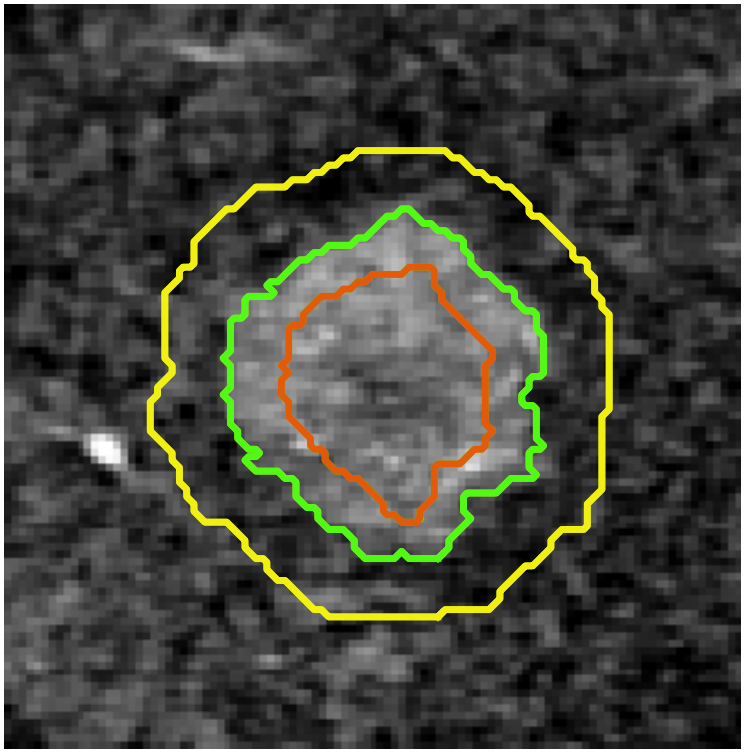
GT and Segmentation



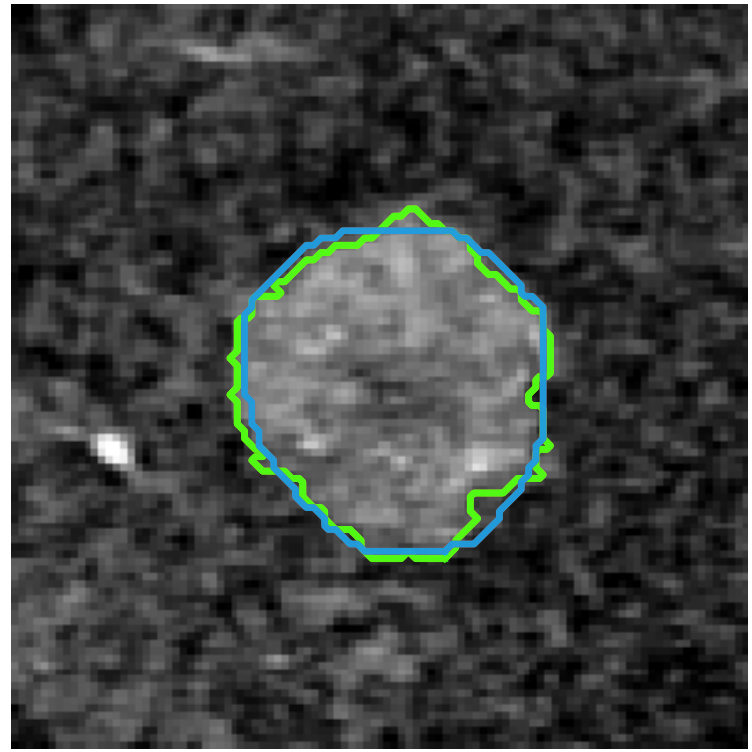
ARI .719, ASSD 2.859, COMPL .750, DICE .741, HD 12.649, HOM .500,
MI .612, MSE .017, OBJ_TPR .167, PRECISION .997, RAVD −.409,
RECALL .589, ROC_AUC .794, V_MEASURE .600

RandomWalker – BG Seeds 200%, FG Seeds 40%, β 190, tol 1e−03

GT and Seeds



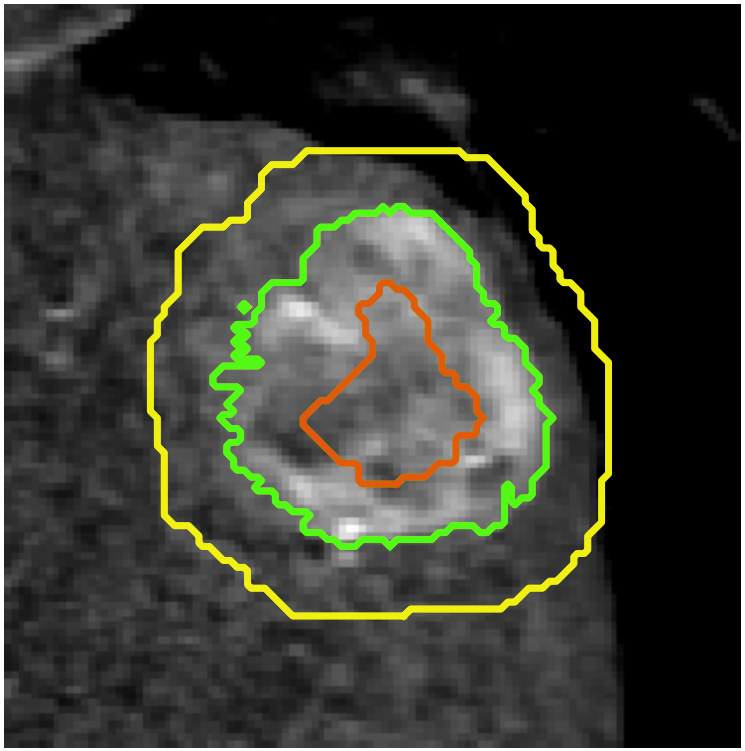
GT and Segmentation



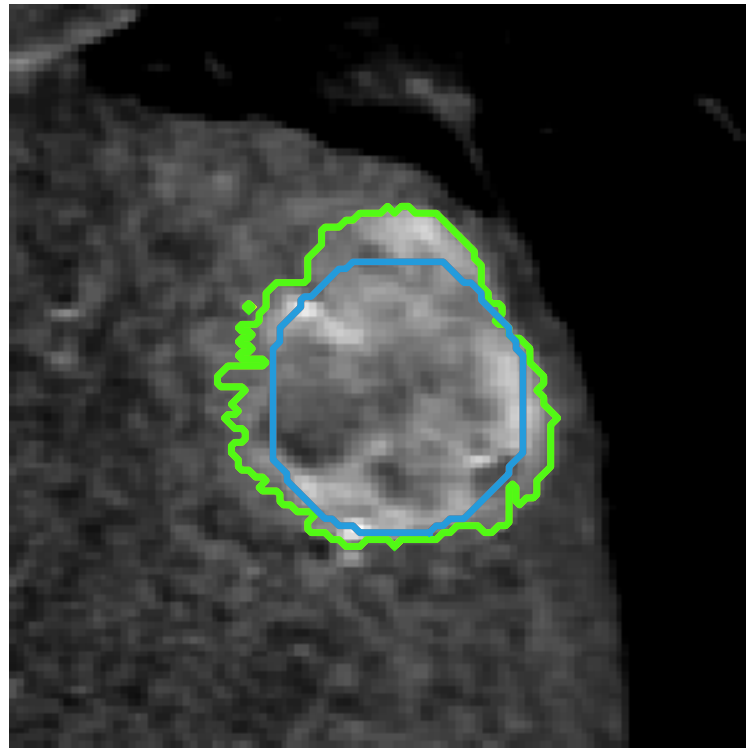
ARI .893, ASSD 1.177, COMPL .779, DICE .905, HD 7.280, HOM .774,
MI .776, MSE .008, OBJ_TPR .167, PRECISION .909, RAVD −.008,
RECALL .901, ROC_AUC .949, V_MEASURE .776

RandomWalker – BG Seeds 200%, FG Seeds 20%, β 190, tol 1e−03

GT and Seeds



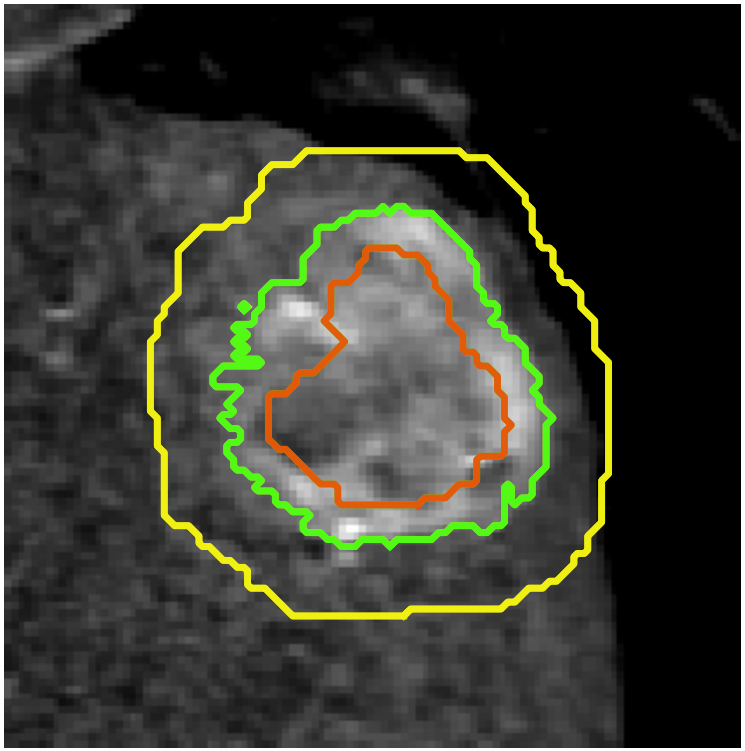
GT and Segmentation



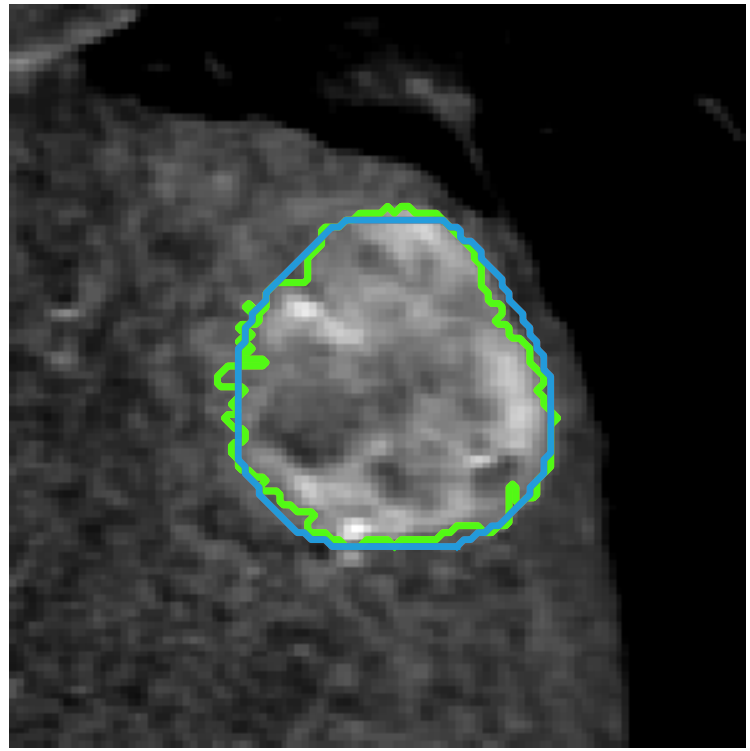
ARI .748, ASSD 2.890, COMPL .761, DICE .770, HD 9.000, HOM .535,
MI .638, MSE .017, OBJ_TPR .167, PRECISION .996, RAVD −.370,
RECALL .628, ROC_AUC .814, V_MEASURE .628

RandomWalker – BG Seeds 200%, FG Seeds 40%, β 190, tol 1e−03

GT and Seeds



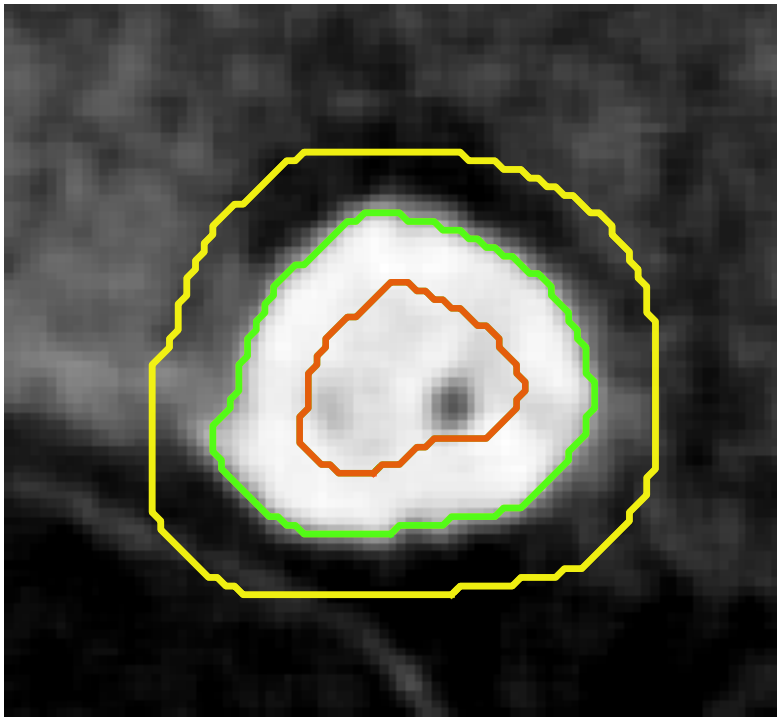
GT and Segmentation



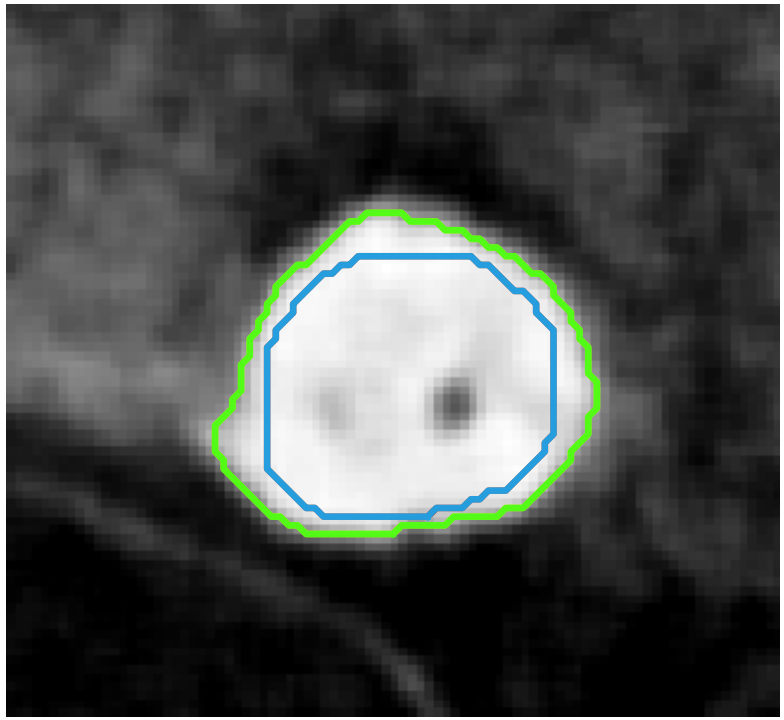
ARI .905, ASSD 1.206, COMPL .773, DICE .917, HD 8.775, HOM .841,
MI .806, MSE .008, OBJ_TPR .167, PRECISION .868, RAVD .121,
RECALL .973, ROC_AUC .983, V_MEASURE .806

RandomWalker – BG Seeds 200%, FG Seeds 20%, β 190, tol 1e−03

GT and Seeds



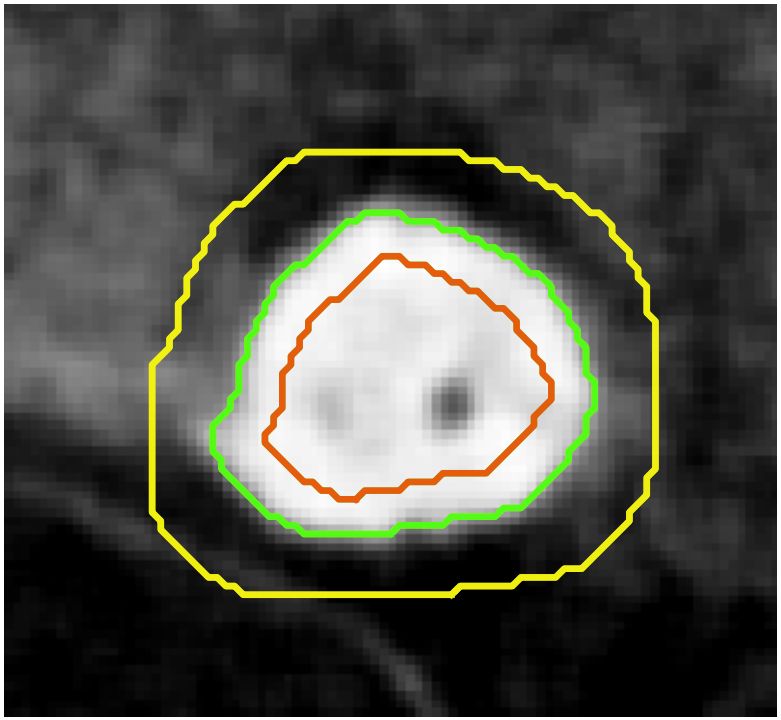
GT and Segmentation



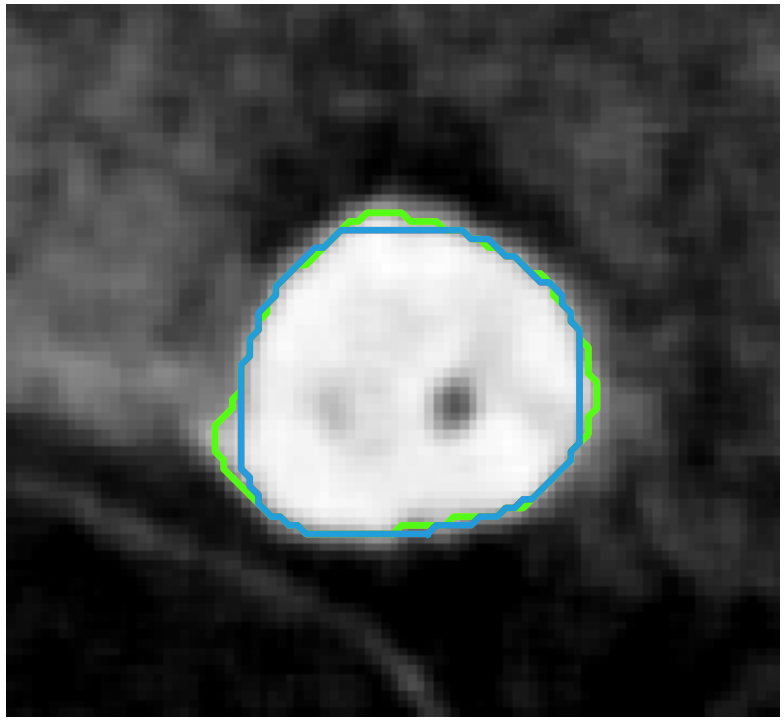
ARI .782, ASSD 2.264, COMPL .787, DICE .803, HD 6.000, HOM .581, MI .676, MSE .015, OBJ_TPR 1.000, PRECISION 1.000, RAVD −.329, RECALL .671, ROC_AUC .835, V_MEASURE .668

RandomWalker – BG Seeds 200%, FG Seeds 40%, β 190, tol 1e−03

GT and Seeds



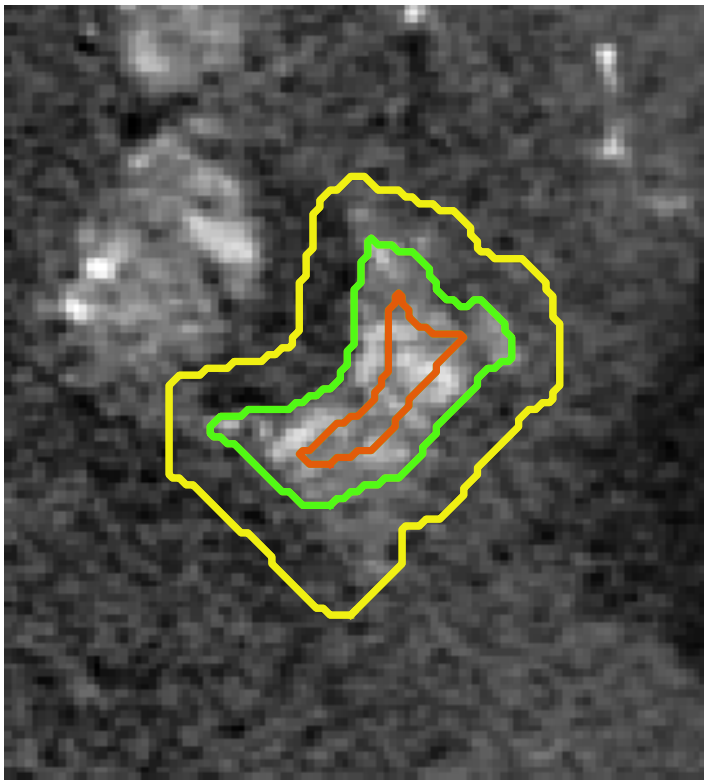
GT and Segmentation



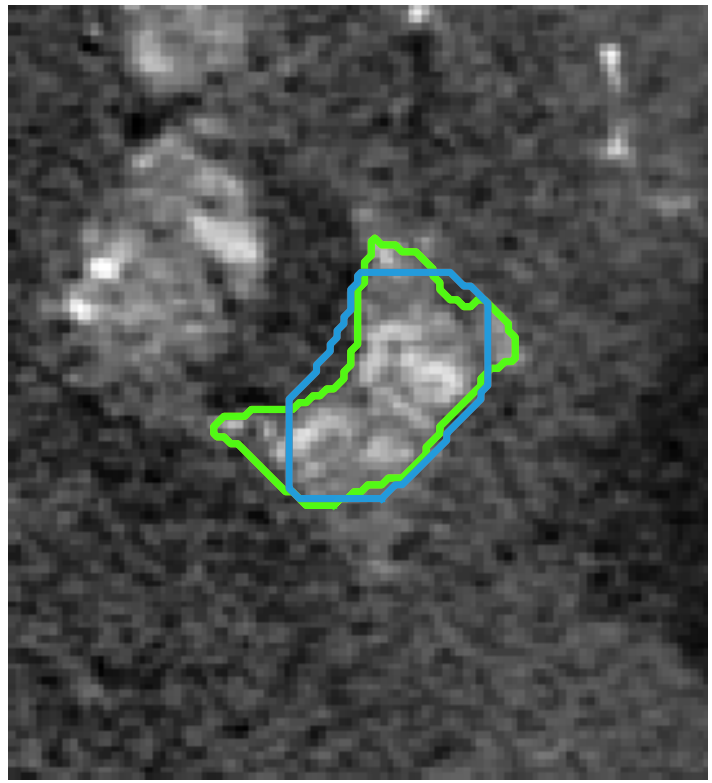
ARI .932, ASSD .753, COMPL .829, DICE .941, HD 3.000, HOM .866,
MI .847, MSE .006, OBJ_TPR 1.000, PRECISION .914, RAVD .060,
RECALL .969, ROC_AUC .982, V_MEASURE .847

RandomWalker – BG Seeds 200%, FG Seeds 20%, β 190, tol 1e−03

GT and Seeds



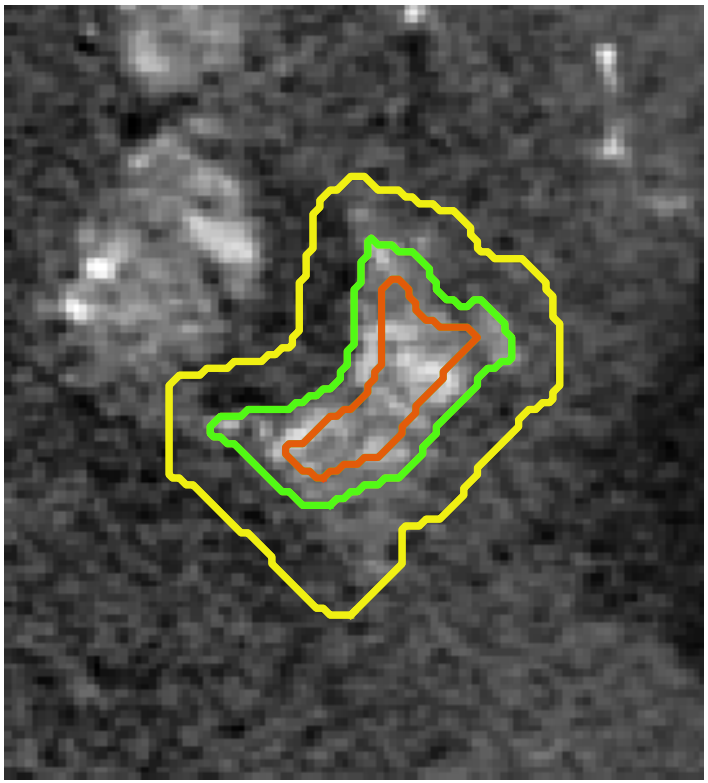
GT and Segmentation



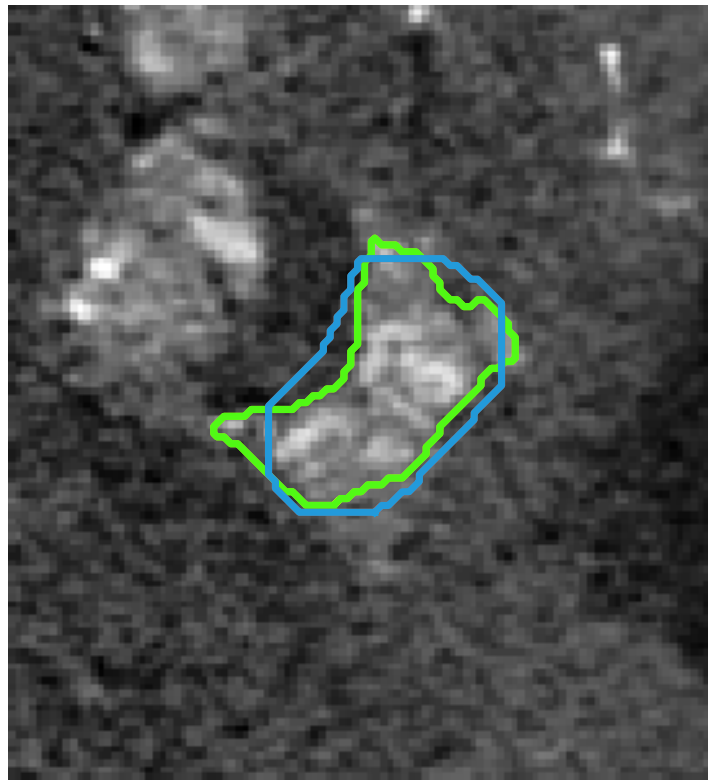
ARI .759, ASSD 2.233, COMPL .681, DICE .771, HD 13.153, HOM .548, MI .611, MSE .009, OBJ_TPR 1.000, PRECISION .893, RAVD −.241, RECALL .678, ROC_AUC .838, V_MEASURE .607

RandomWalker – BG Seeds 200%, FG Seeds 40%, β 190, tol 1e−03

GT and Seeds



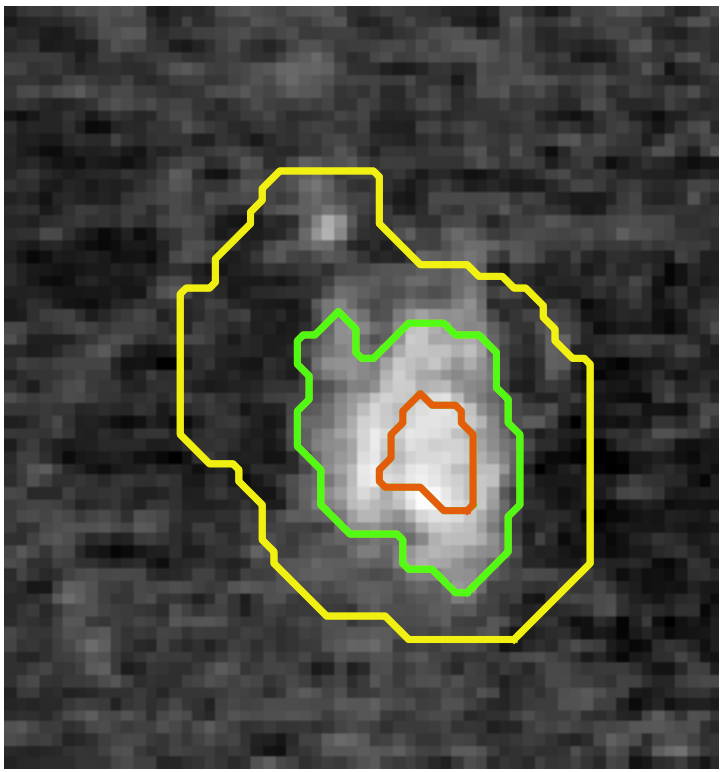
GT and Segmentation



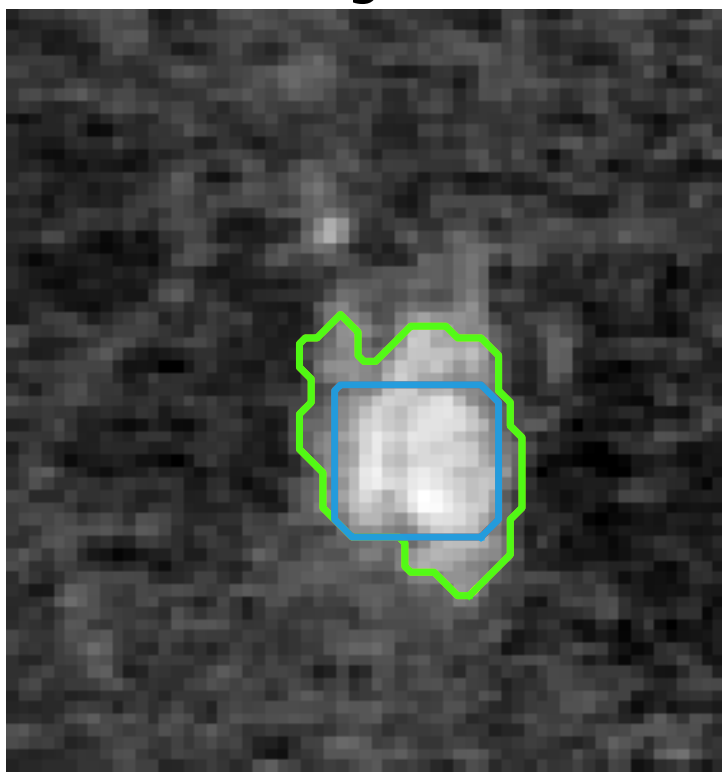
ARI .821, ASSD 1.655, COMPL .651, DICE .832, HD 8.062, HOM .701,
MI .675, MSE .008, OBJ_TPR 1.000, PRECISION .795, RAVD .099,
RECALL .873, ROC_AUC .934, V_MEASURE .675

RandomWalker – BG Seeds 200%, FG Seeds 20%, β 190, tol 1e−03

GT and Seeds



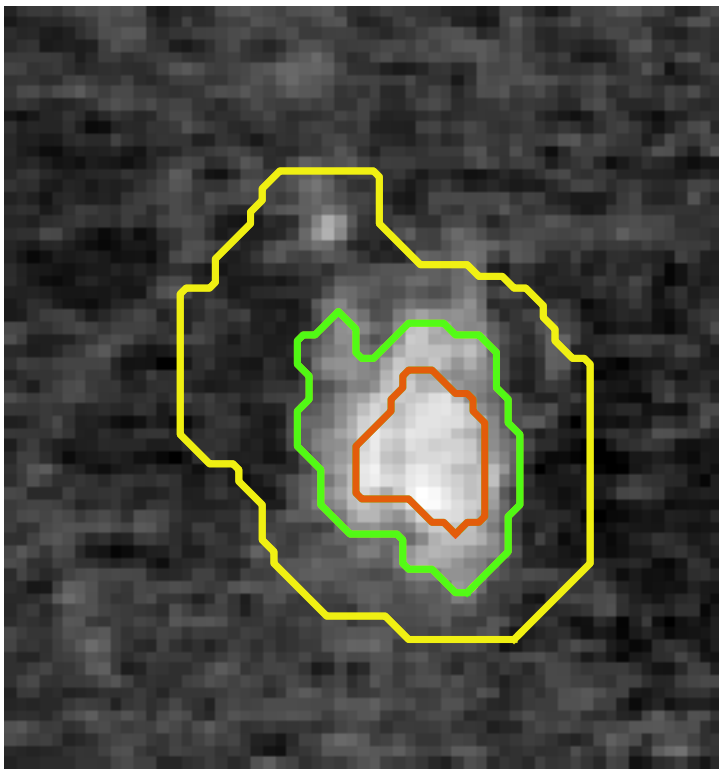
GT and Segmentation



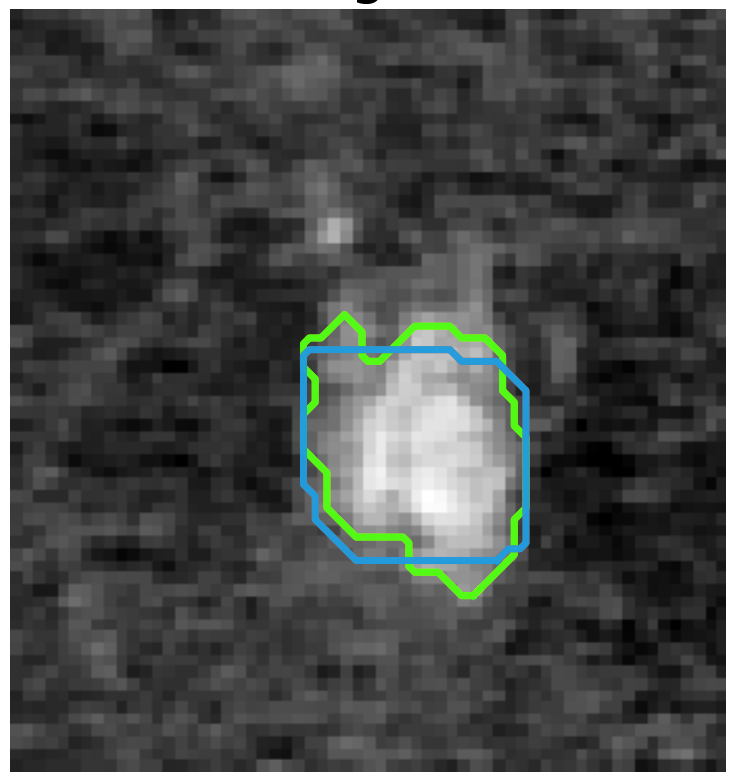
ARI .507, ASSD 2.968, COMPL .661, DICE .525, HD 14.036, HOM .291,
MI .439, MSE .018, OBJ_TPR 1.000, PRECISION .993, RAVD −.641,
RECALL .356, ROC_AUC .678, V_MEASURE .404

RandomWalker – BG Seeds 200%, FG Seeds 40%, β 190, tol 1e−03

GT and Seeds



GT and Segmentation



ARI .789, ASSD 1.352, COMPL .666, DICE .803, HD 11.000, HOM .600,
MI .632, MSE .011, OBJ_TPR 1.000, PRECISION .861, RAVD −.126,
RECALL .753, ROC_AUC .874, V_MEASURE .631

Quantitative Evaluation

- evaluation from automatically drawn seed points
- ground truth from manual annotation by a clinical expert

Segmentation algorithm	ARI (%)	DC (%)	MI (%)	RAVD (%)
GrowCut	**72.96**	**78.46**	**63.00**	**-0.26**
Random Walker	51.12	57.34	45.46	-0.52
Seeded Watershed	53.28	59.44	47.04	-0.46

Table: Averaged segmentation results for all data sets

Outline

Conclusion

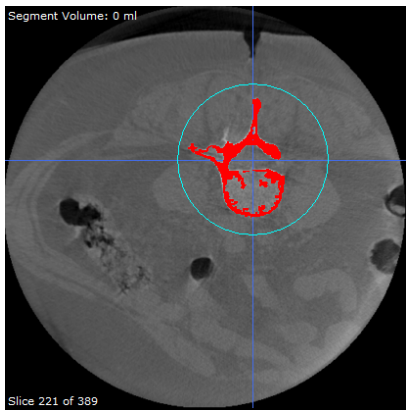
Fast and reliable tumor segmentation is important for

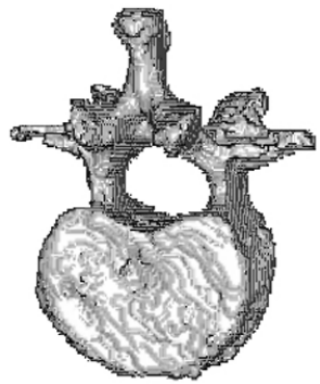
- quantitative therapy monitoring, e.g. during TACE
- efficient planing of follow-up treatments

The cellular automaton based GrowCut method

- has a good trade-off between accuracy and level of automation
- is a reliable semi-automatic tool for medical image segmentation

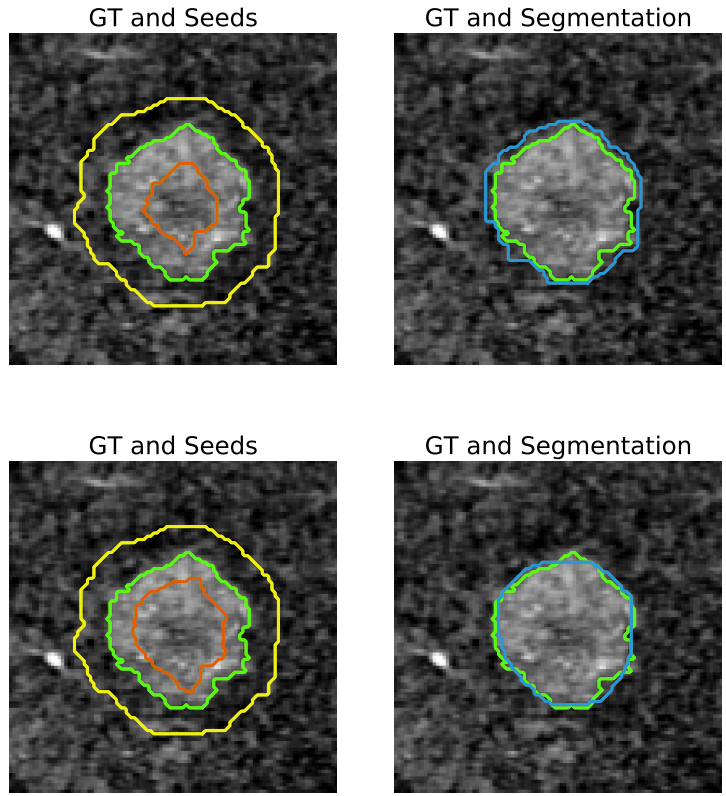
Outlook





- segmentation of different medically relevant body parts
- investigation of sensitivity to user interaction w.r.t. the VOI
- evaluation on a larger ground truth database

Thank you for your attention!



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