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Low-Level Track Finding and Completion using Random Fields

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Sandia National Laboratories

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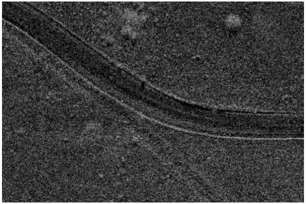
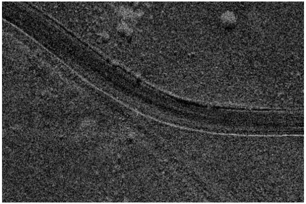
Coherent Change Detection (CCD) Image

Morning



Afternoon



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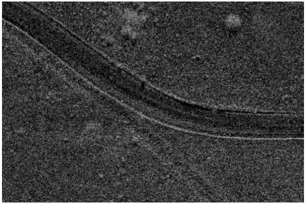

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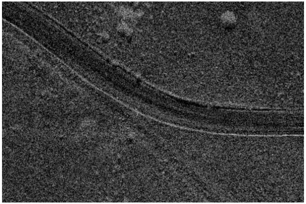
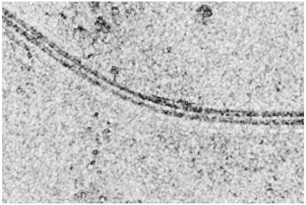


$\Downarrow$



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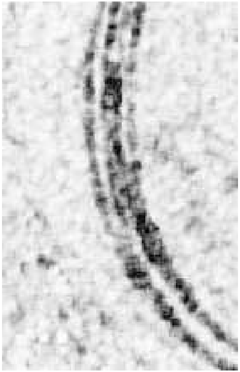
4. Form CDT graph using obtained tracks as *constrained* edges
5. Optimize energy function:

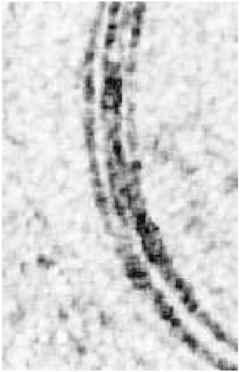
$$\sum_{i \in E} f_i(x_i) + \sum_{i,j \in N} [x_i \neq x_j][i \in E_C \vee j \in E_C] g_{ij}(x_i, x_j)$$

Forming Initial Binary Image



Input CCD Image

Forming Initial Binary Image



Input CCD Image

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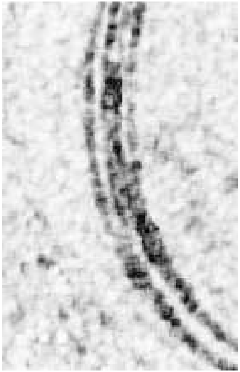
Forming Initial Binary Image

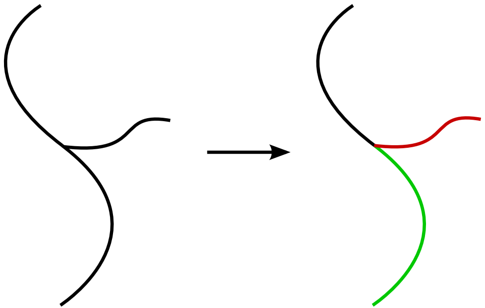


Input CCD Image

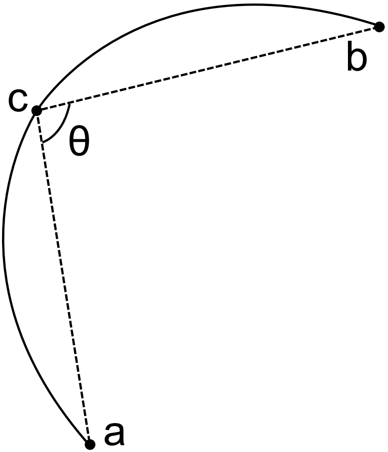
Ridge Feature

Thresholded Image

Branching



Linearization



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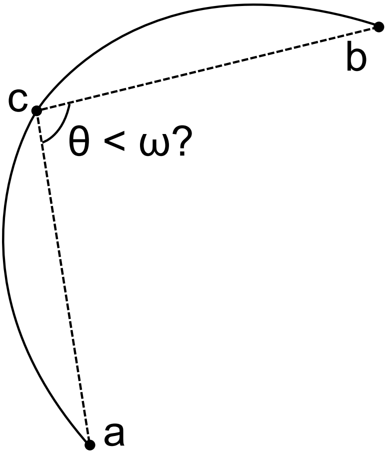

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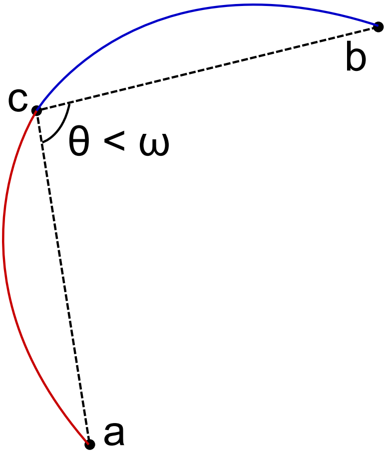

Constrained Delaunay Triangulation (CDT) Graph

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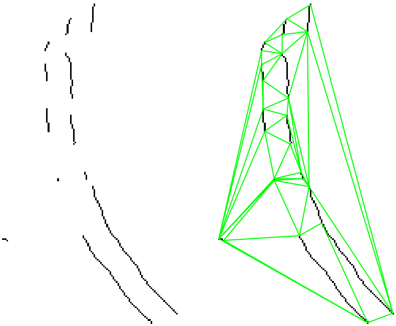

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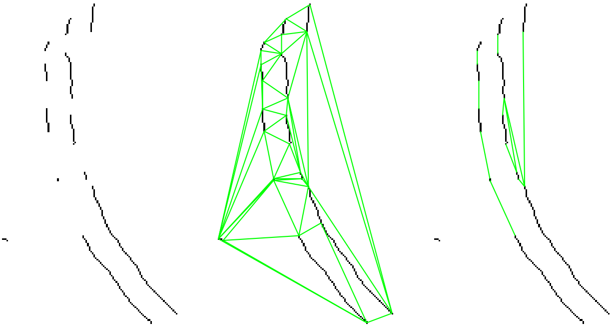

Optimization

E: edges of CDT graph

$E_C \subset E$: constrained edges

$N \subset E \times E$: neighborhood system

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$E_C \subset E$: constrained edges

$N \subset E \times E$: neighborhood system

Minimize binary energy function ($x_i \in \{0, 1\}$):

$$\sum_{i \in E} \underbrace{f_i(x_i)}_{Unary} + \sum_{i,j \in N} \underbrace{[x_i \neq x_j][i \in E_C \vee j \in E_C]g(i,j)}_{Pairwise}$$

Unary Cost

$\mathcal{P}(i)$: set of pixels corresponding to edge i

$\lambda^i = \frac{1}{|\mathcal{P}(i)|} \sum_{j \in \mathcal{P}(i)} \lambda_j$: average ridge feature along edge i

$$f_i(x_i) = -\log p(\lambda^i | x_i)$$

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$$f_i(x_i) = -\log p(\lambda^i | x_i)$$

By central limit theorem,

$$p(\lambda^i | x_i = 0) \approx \mathcal{N}(\mu_0, \sigma_0 / \sqrt{|\mathcal{P}(i)|}),$$

$$p(\lambda^i | x_i = 1) \approx \mathcal{N}(\mu_1, \sigma_1 / \sqrt{|\mathcal{P}(i)|}),$$

u_0 and σ_0: mean and standard deviation of background ridge feature

u_1 and σ_1: mean and standard deviation of track ridge feature

Pairwise Cost

θ_{ij}: angle formed by edges i and j

$$g(i,j) = \frac{\alpha}{1 + \exp(-\beta(\theta_{ij} - \theta_0))}$$

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Edges with large angles should have the same class

Sub-Modular Energy Function

Minimize binary energy function:

$$\sum_{i \in E} f_i(x_i) + \sum_{i,j \in N} [x_i \neq x_j][i \in E_C \vee j \in E_C] g(i,j)$$

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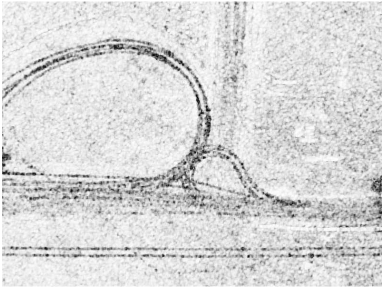
Pairwise cost is sub-modular $\rightarrow$ global solution obtained via graph cut

Sub-modular: $\psi(0,0) + \psi(1,1) \leq \psi(0,1) + \psi(1,0)$

Kolmogorov, V., Zabih, R., "What Energy Functions Can Be Minimized via Graph Cuts," *IEEE Trans. Pattern Anal. Mach. Intell.*, 2004.

Qualitative Results



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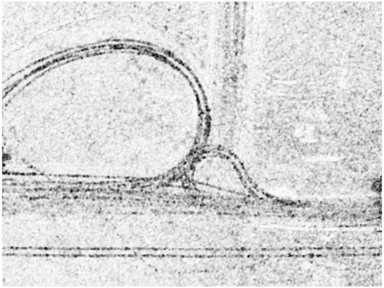

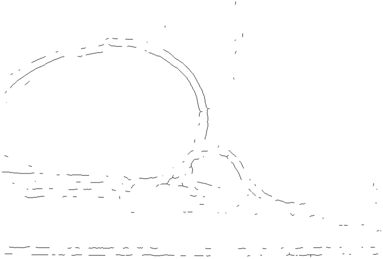

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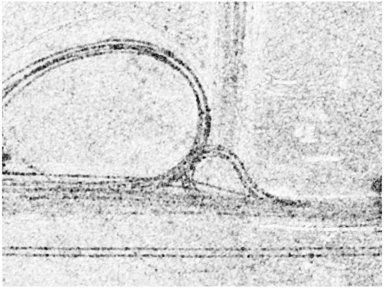

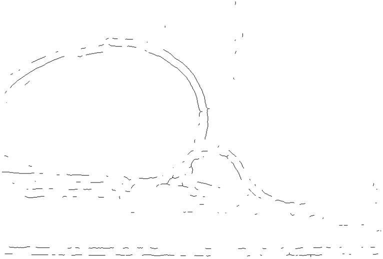

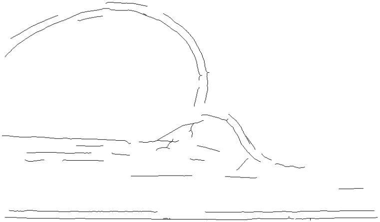

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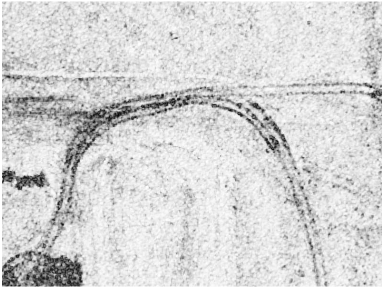

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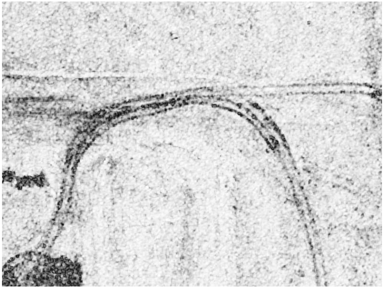

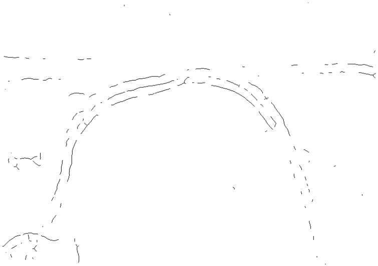

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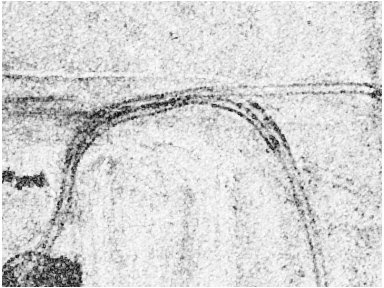
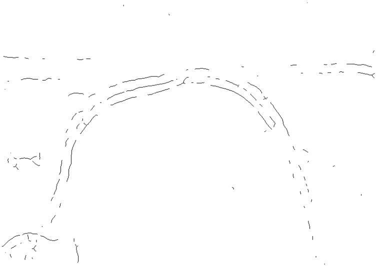
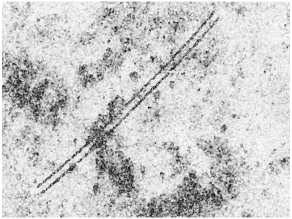
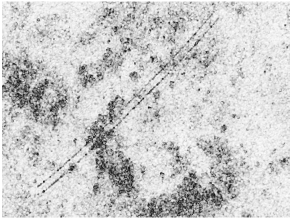




Quantitative Results

Data sets:


Dark


Medium

Accuracy:

$$\frac{TP}{GT + FA}$$

Quantitative Results

	Model-Based[1]	Current
dark	0.9767	**0.9941**
medium	0.8429	**0.9822**

[1]Quach et al., "A Model-Based Approach to Finding Tracks in SAR CCD Images," *IEEE CVPR Workshops*, 2015.

Conclusion

- Track completion via CDT + random field is useful in completing tracks
- Approach is fast: less than 1 second on 600-by-800 image
- Future work: leverage parallel nature of tracks

Thank You

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