MADALGO

CENTER FOR MASSIVE DATA ALGORITHMICS

PhD Defence

Jakob Truelsen

Danmarks
Grundforskningsfond
Danish National
Research Foundation

AARHUS
UNIVERSITY

Welcome

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Theoretical Computer Science

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Large Datasets

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- Decomposition Simplification

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- Multiresolution rasters

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- Implicite Structures

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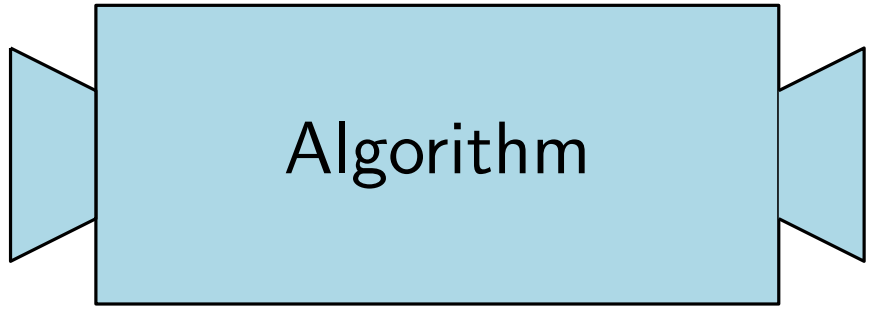
Theoretical Computer Science

Theoretical Computer Science



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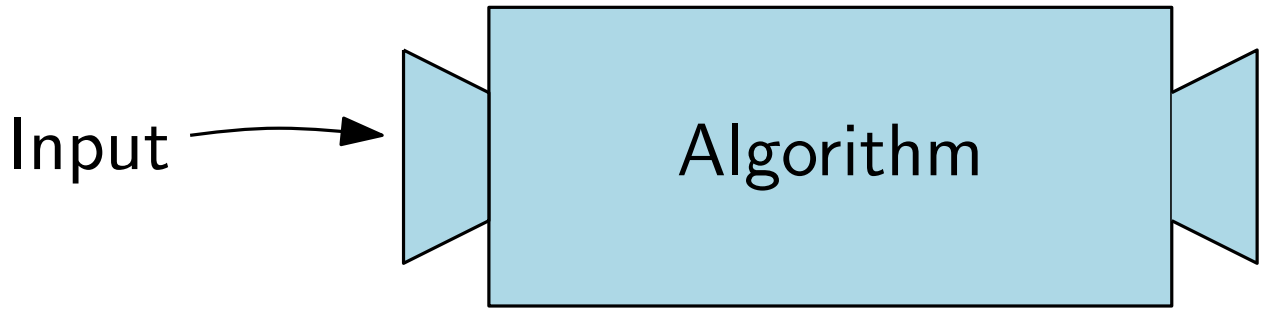

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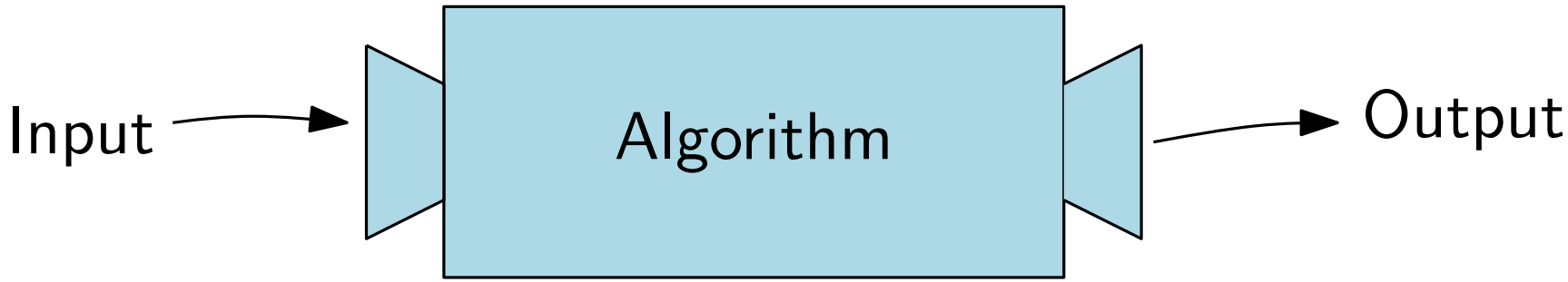

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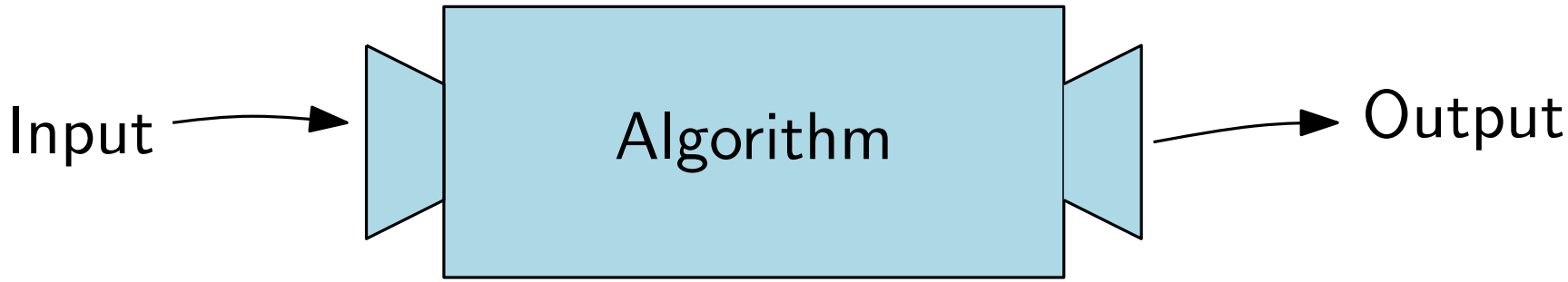

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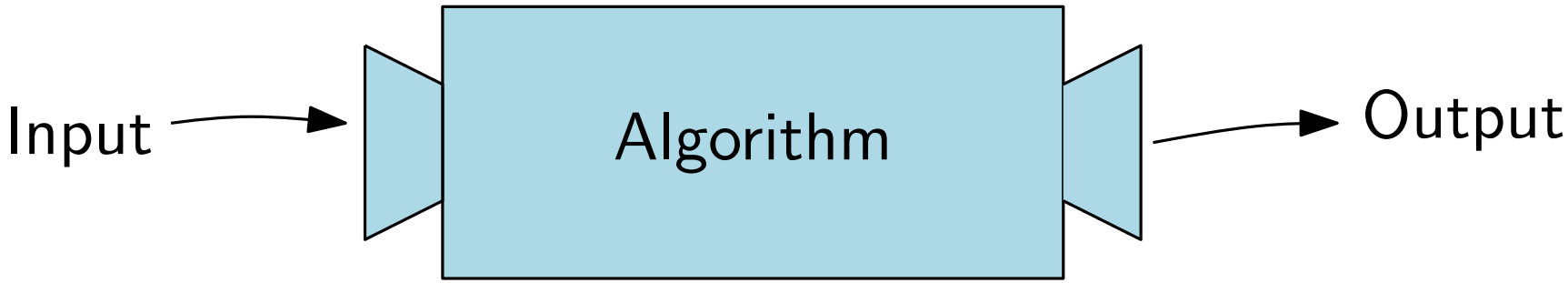
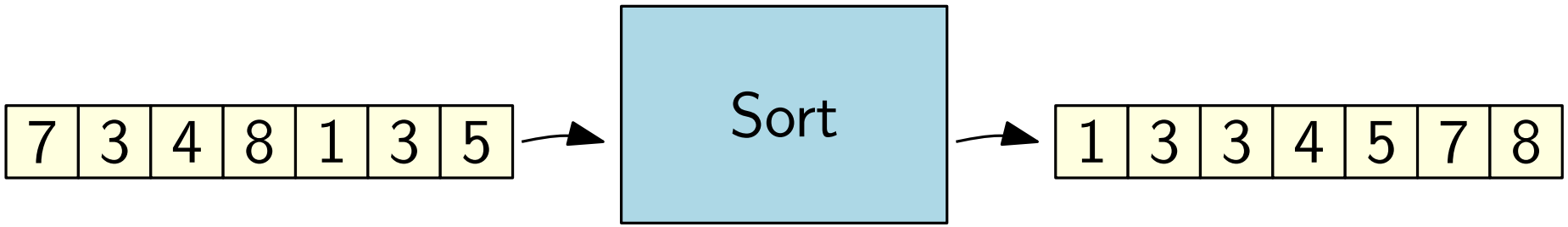
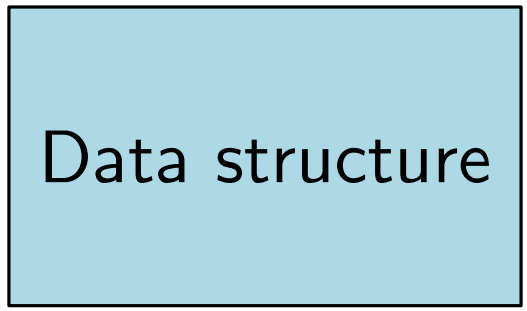
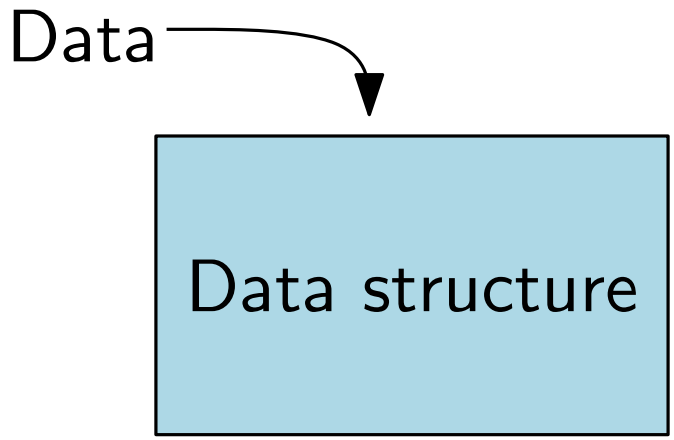
Theoretical Computer Science






Data structure

Theoretical Computer Science



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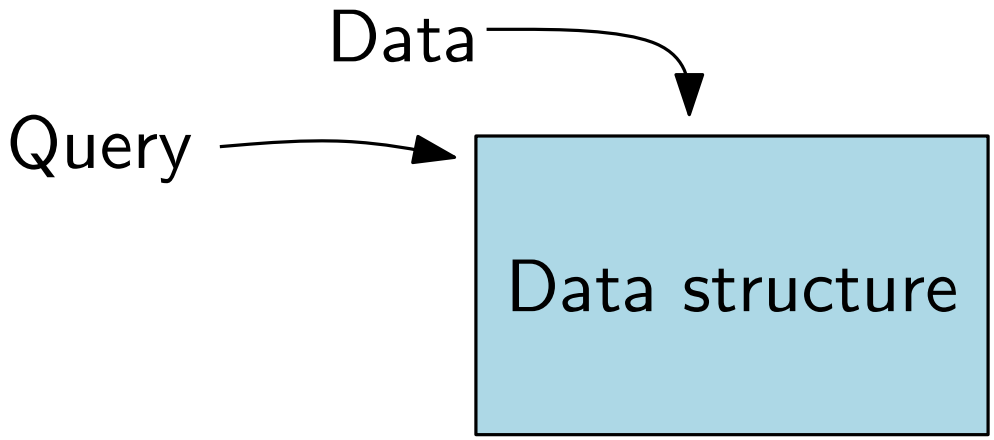

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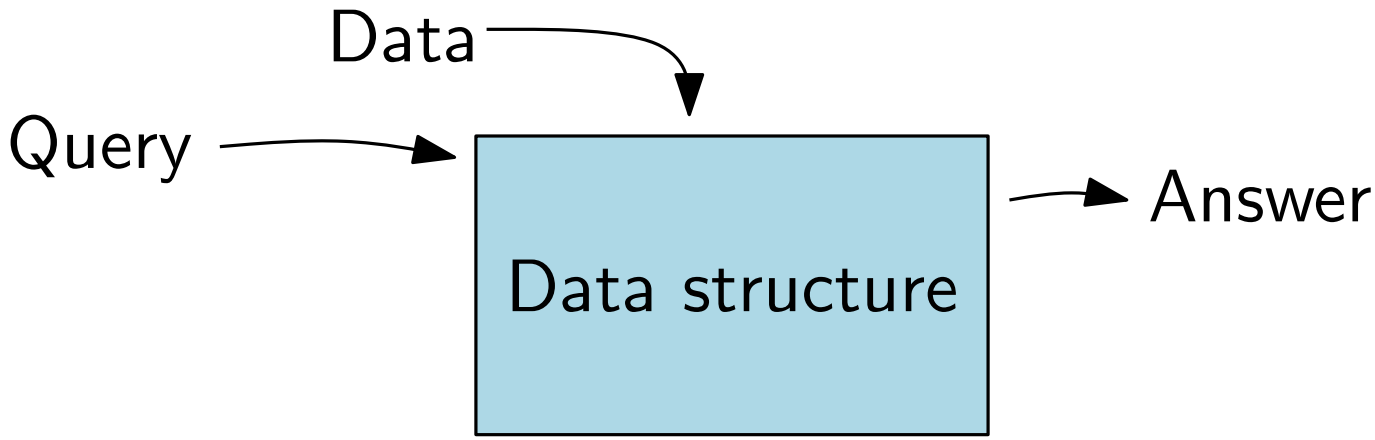

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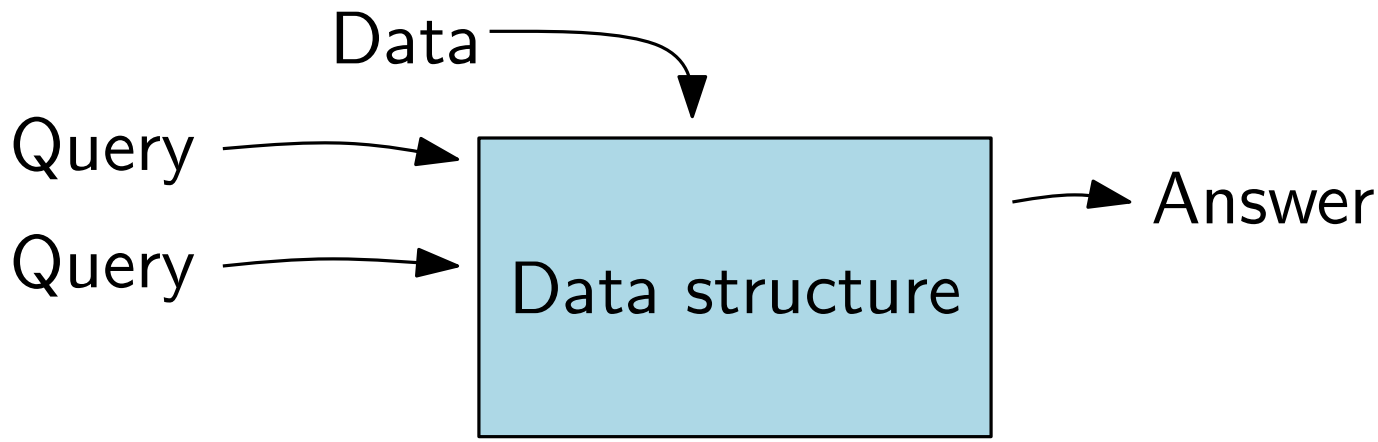

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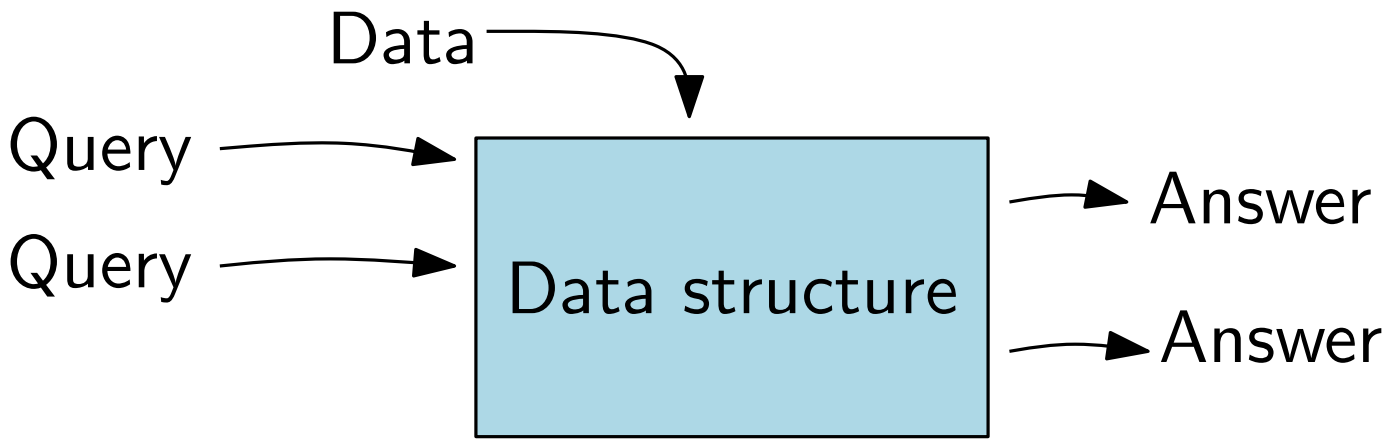

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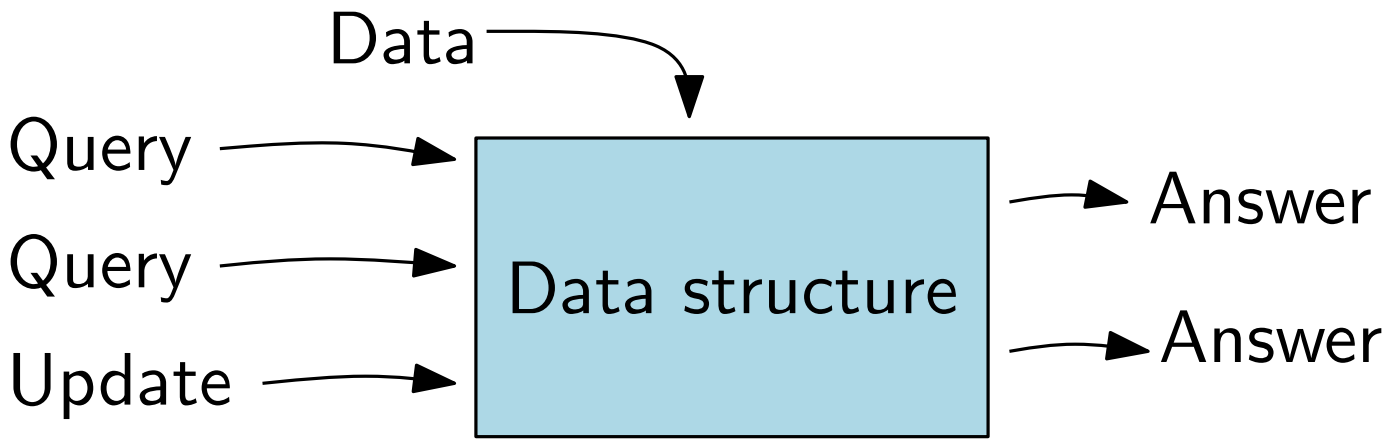

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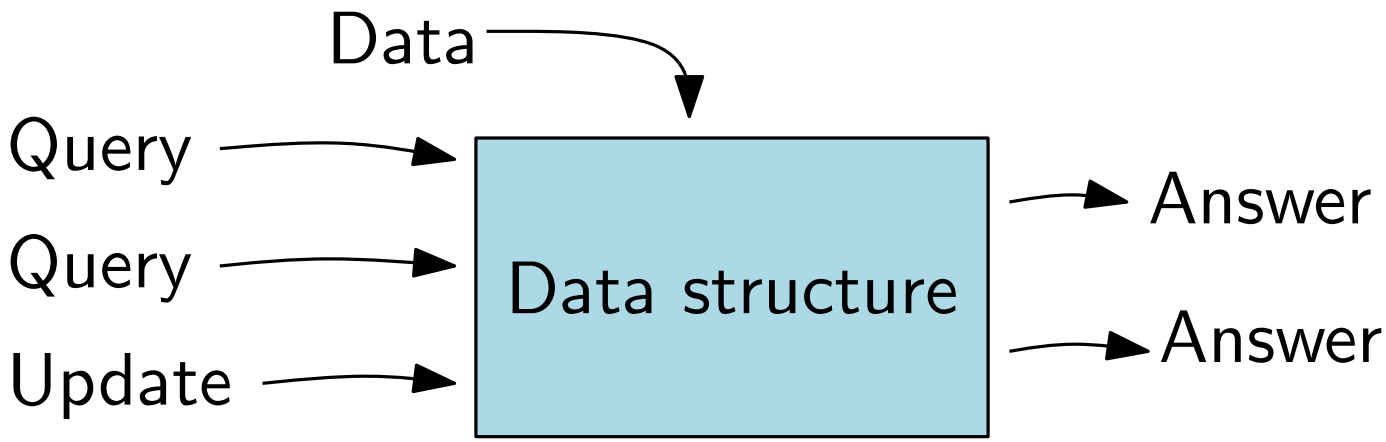
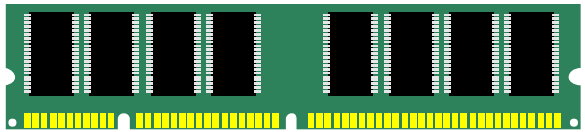


Alice	1324
Bob	4315
Carlos	6875
Eve	3542

Large Datasets



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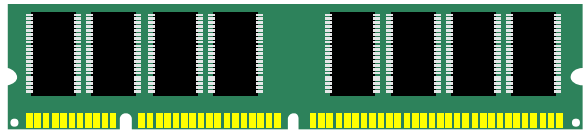

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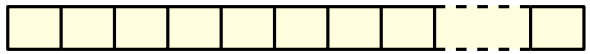

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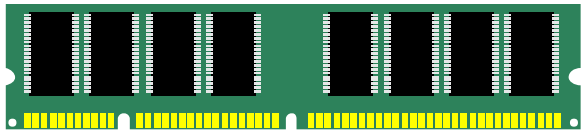

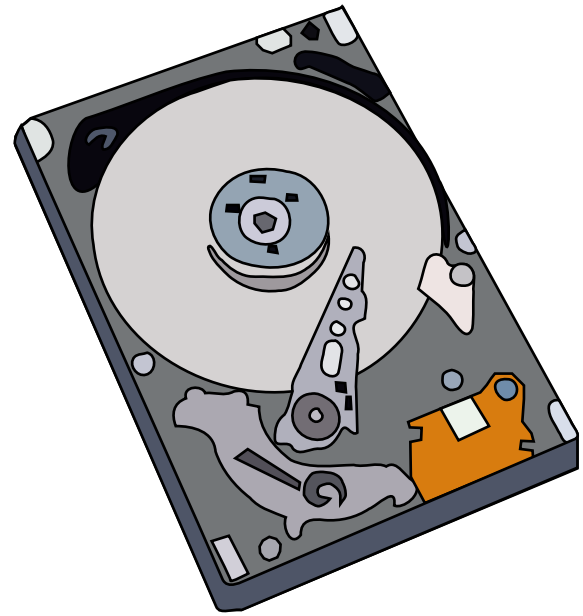

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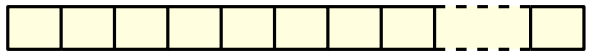

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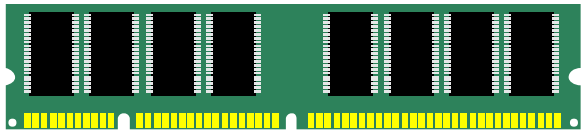
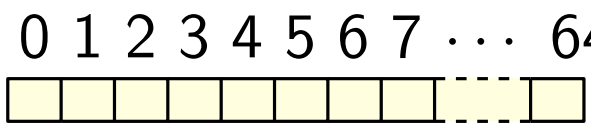
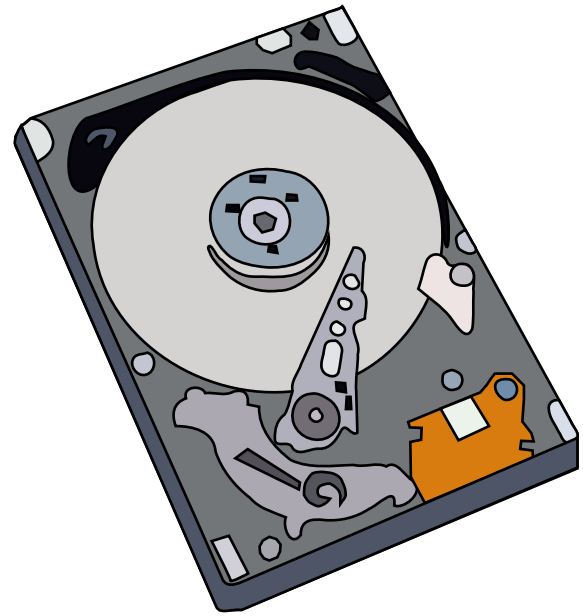
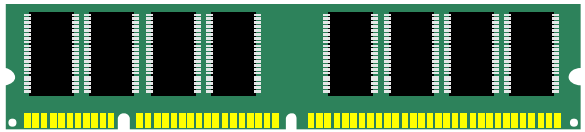


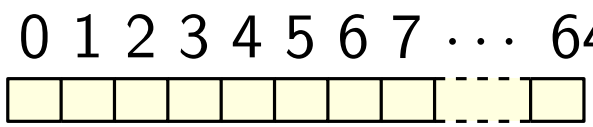


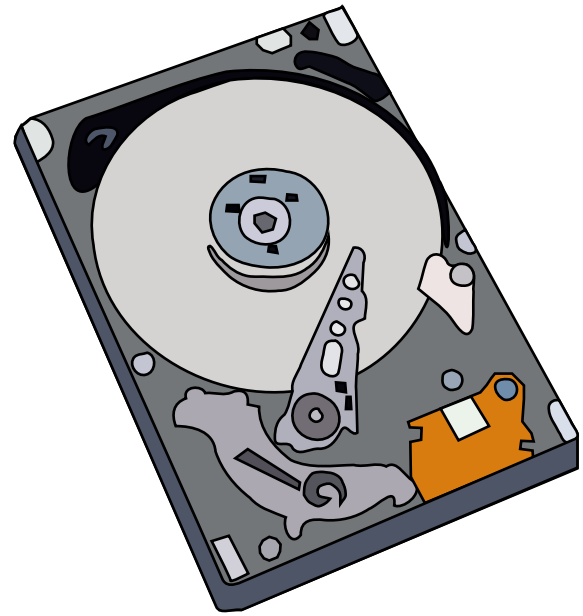


Size:	48 GiB	21 TiB	($\times$ 500)

Large Datasets

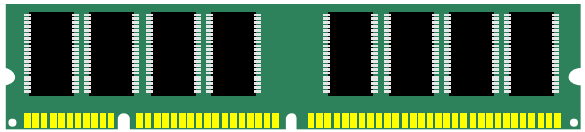


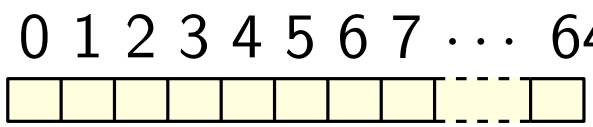


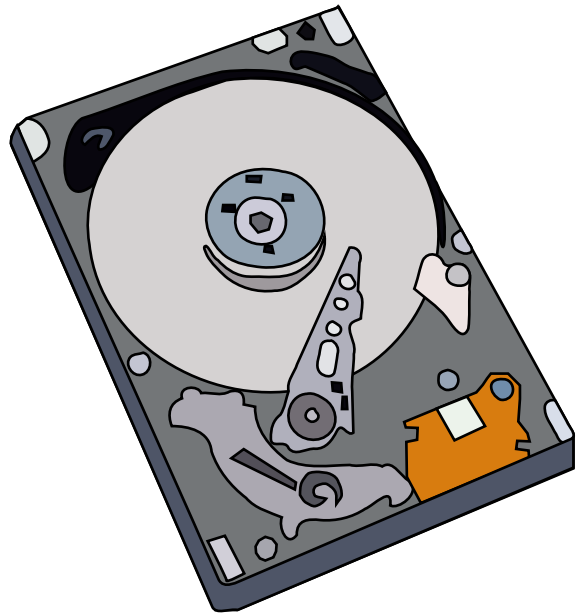


Size:	48 GiB	21 TiB	($\times$ 500)
Access Time:	9 ns	9 ms	($\times$ 1000000)

Large Datasets



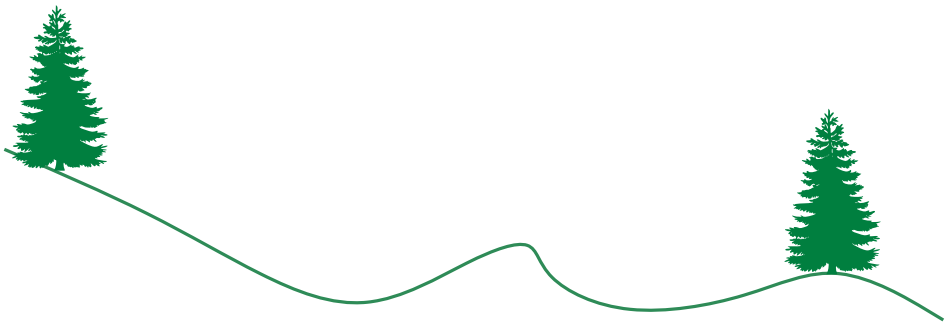




Size:	48 GiB	21 TiB	($\times$ 500)
Access Time:	9 ns	9 ms	($\times$ 1000000)
Throughput:	8 GiB/s	450 MiB/s	($\div$ 18)

Large Datasets

Large Datasets



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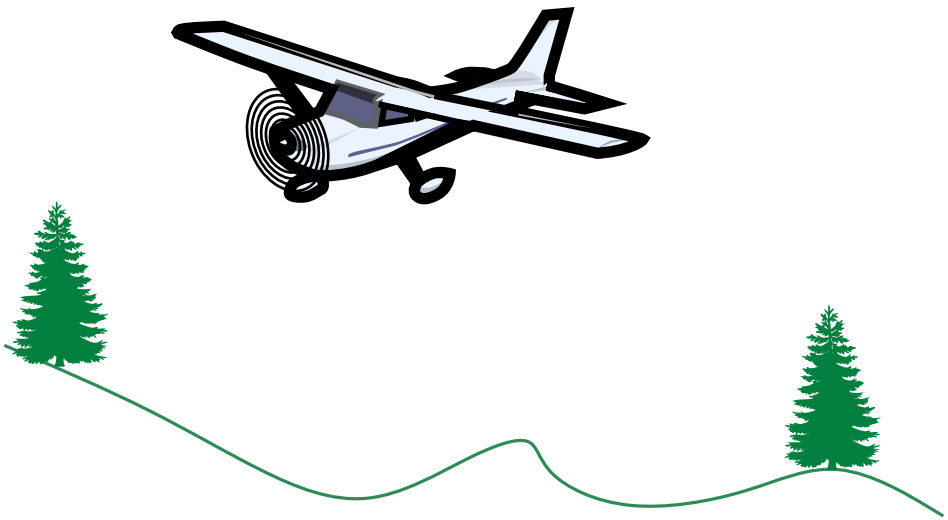

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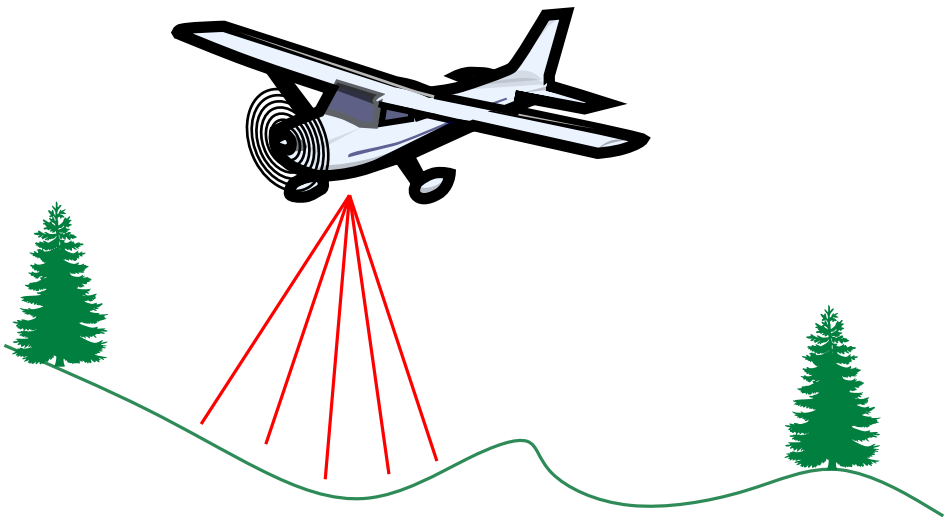

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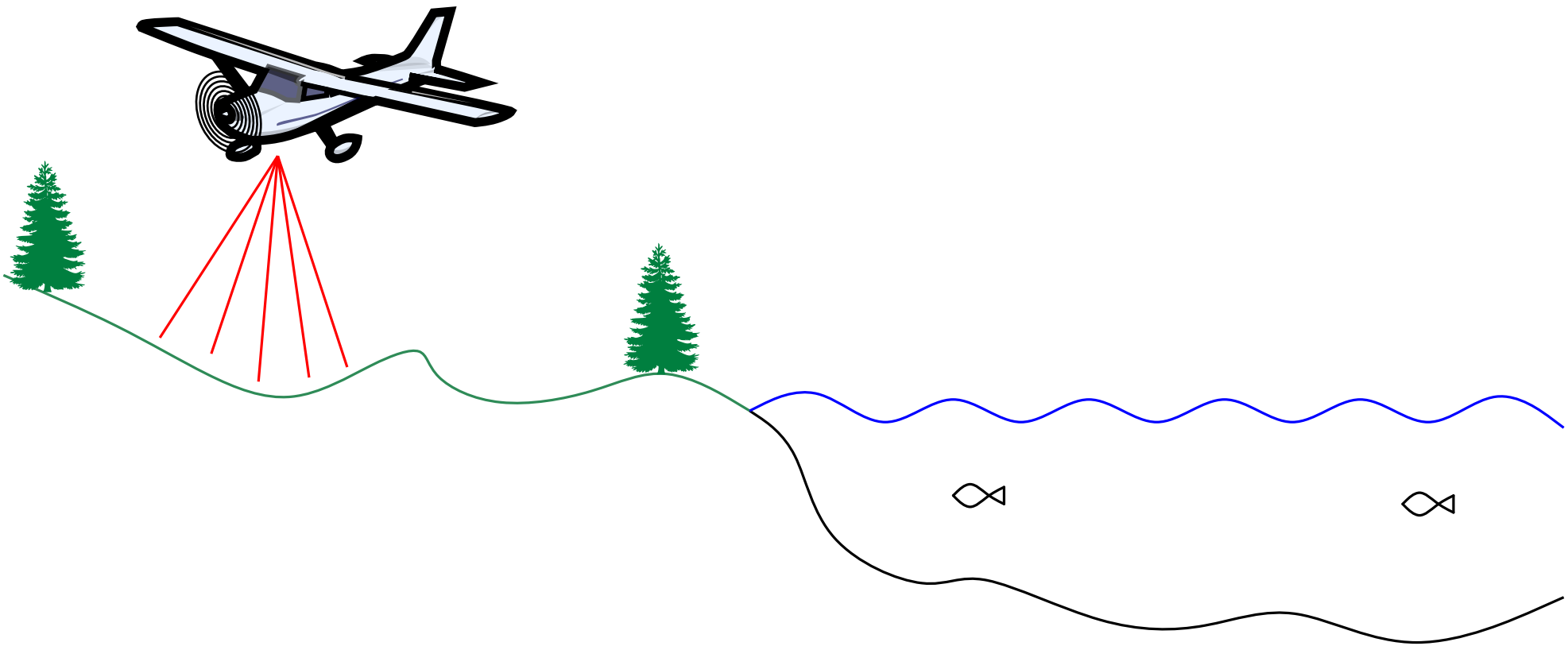

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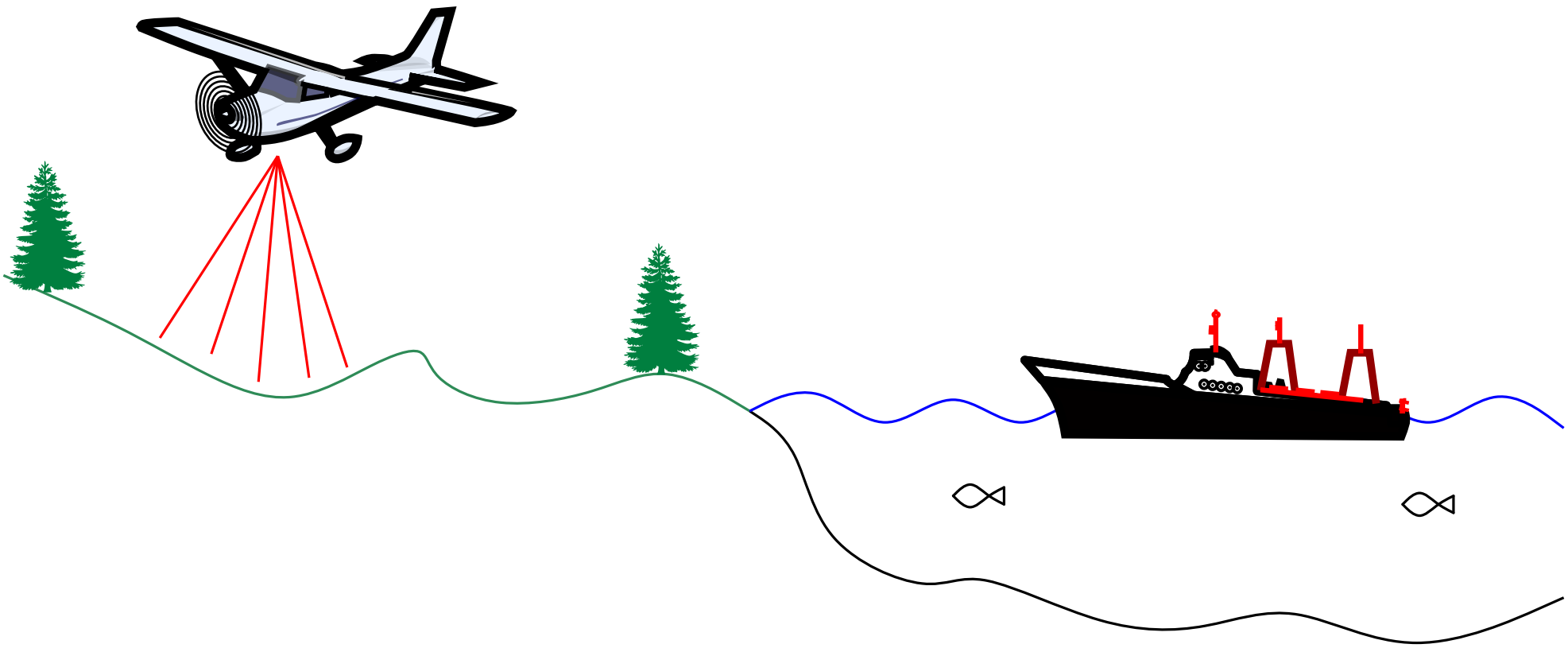

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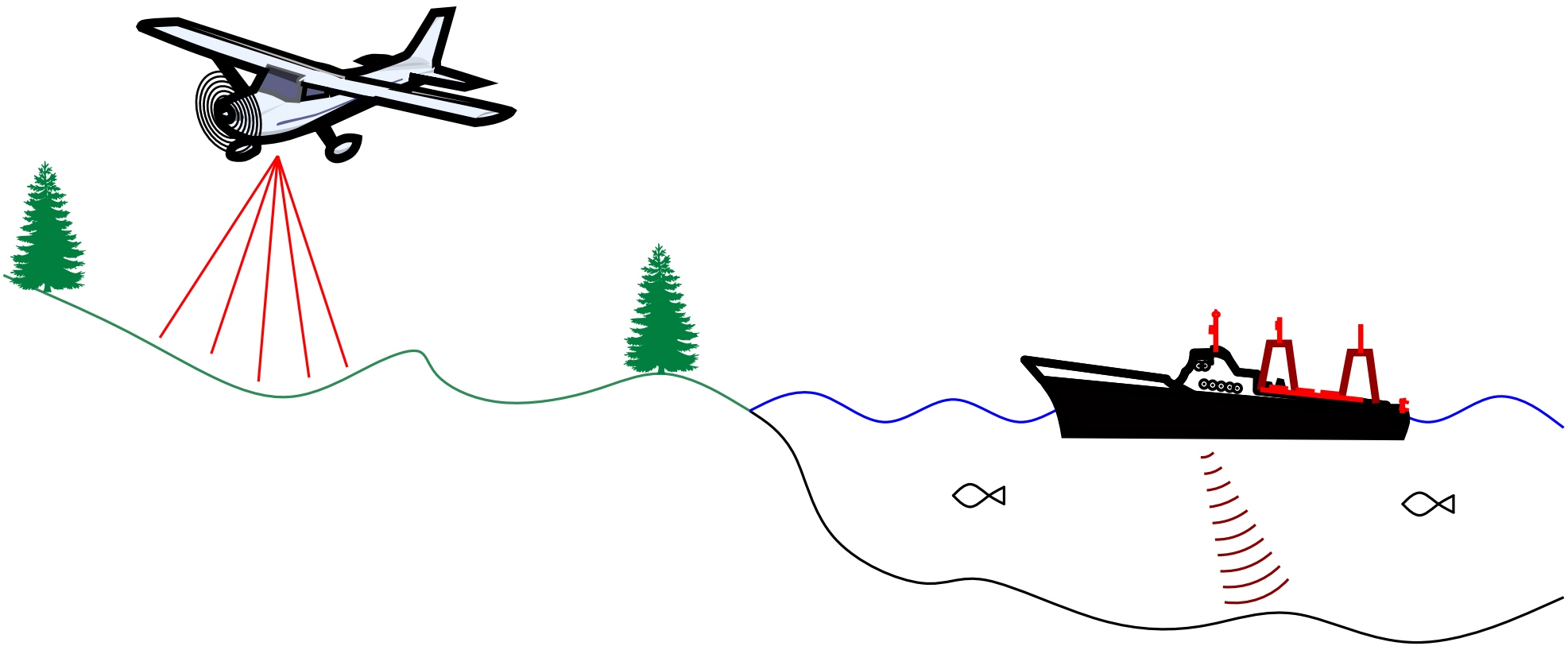

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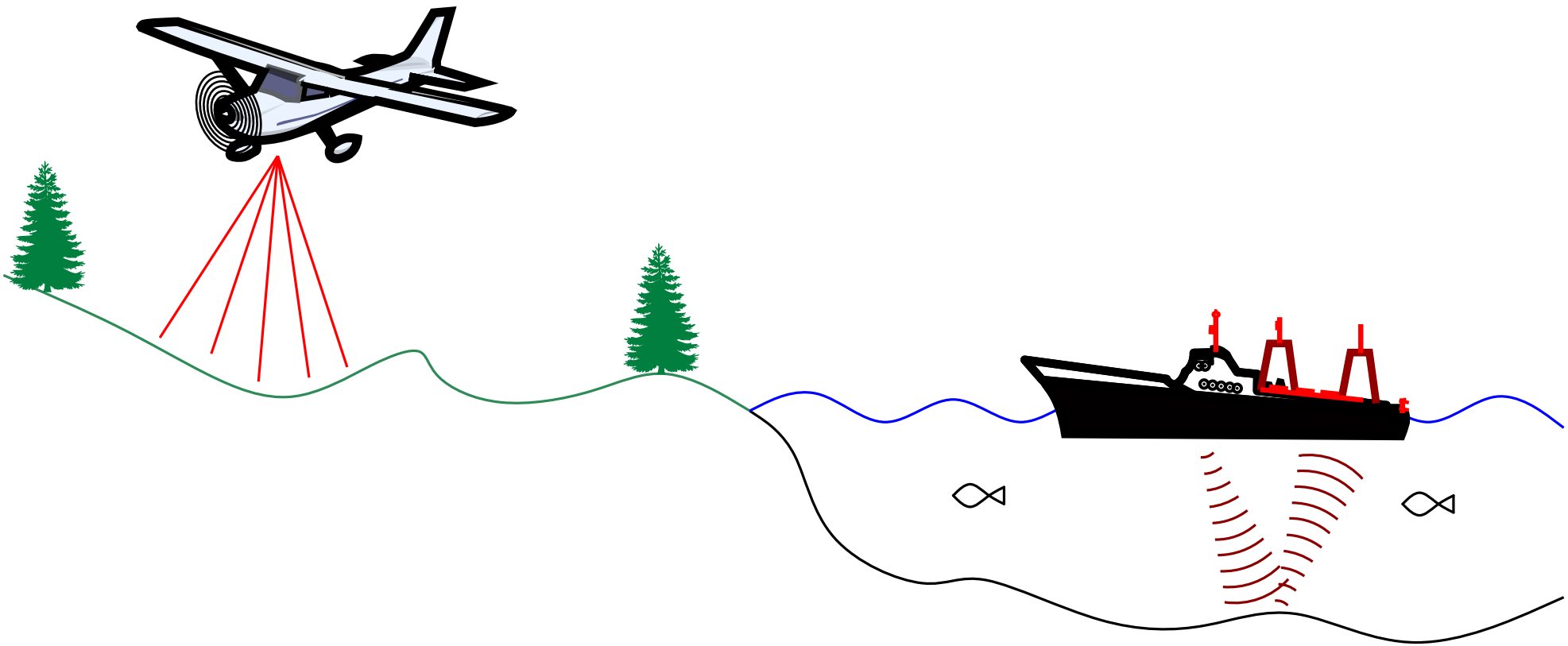

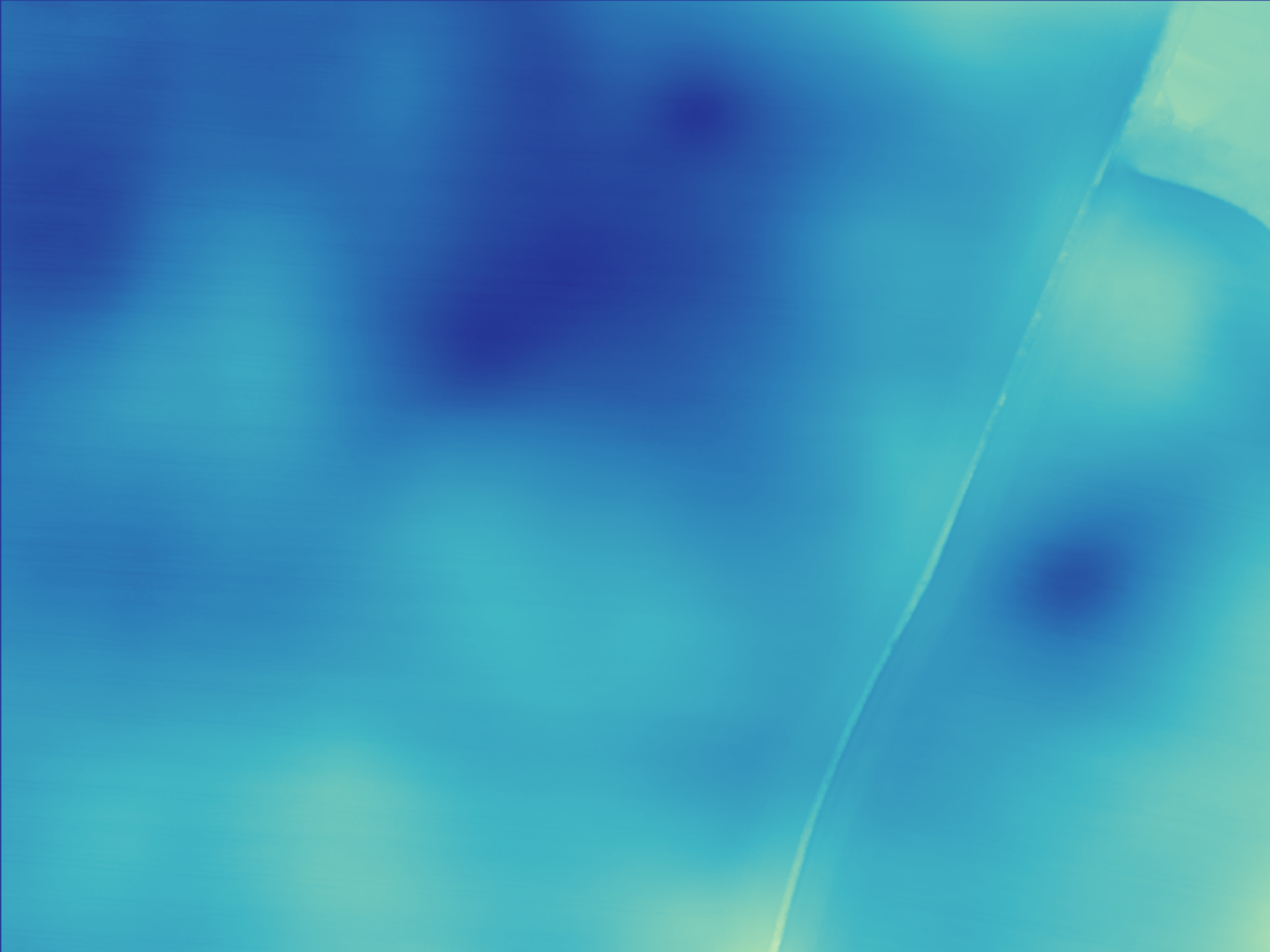

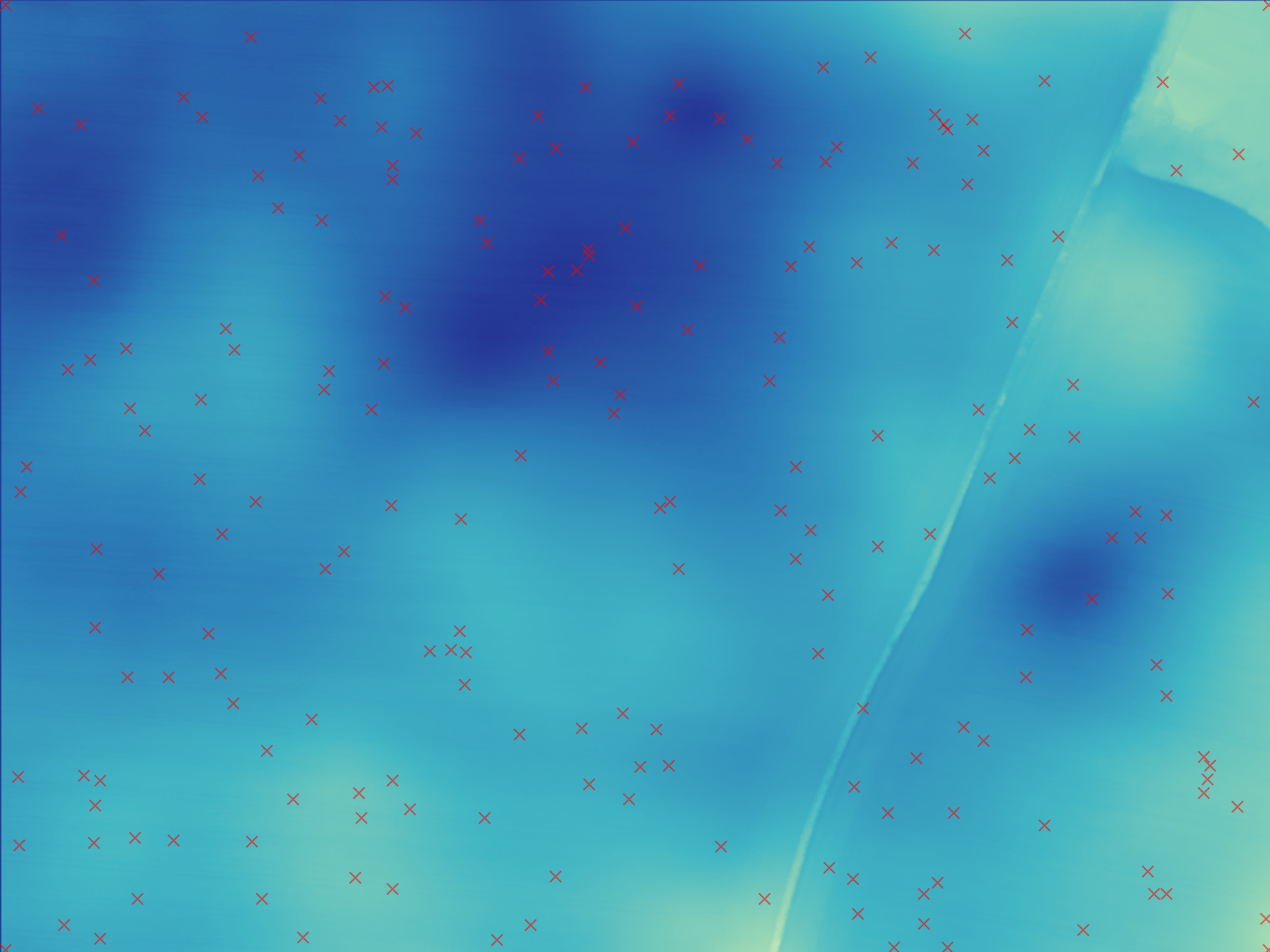

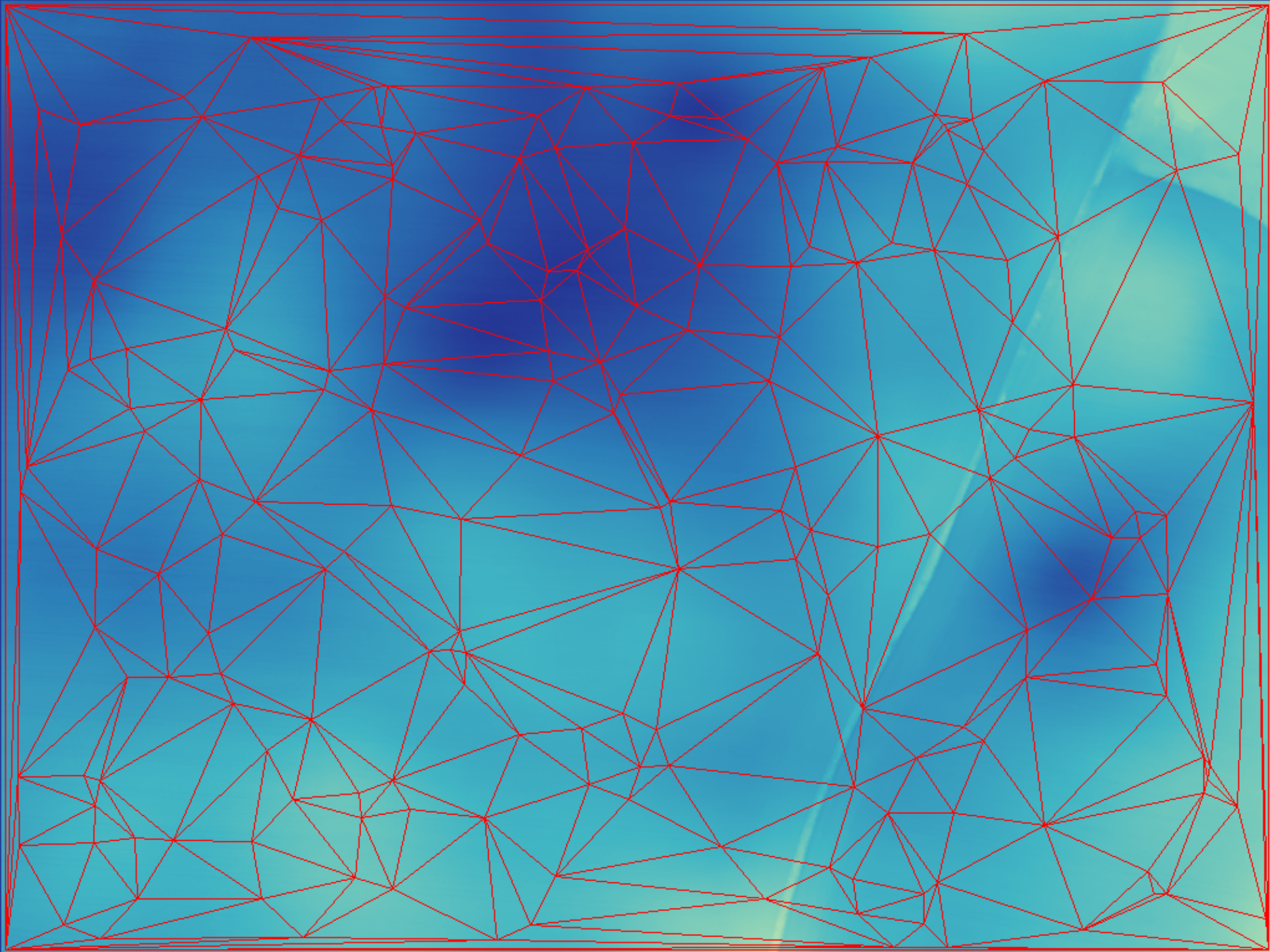

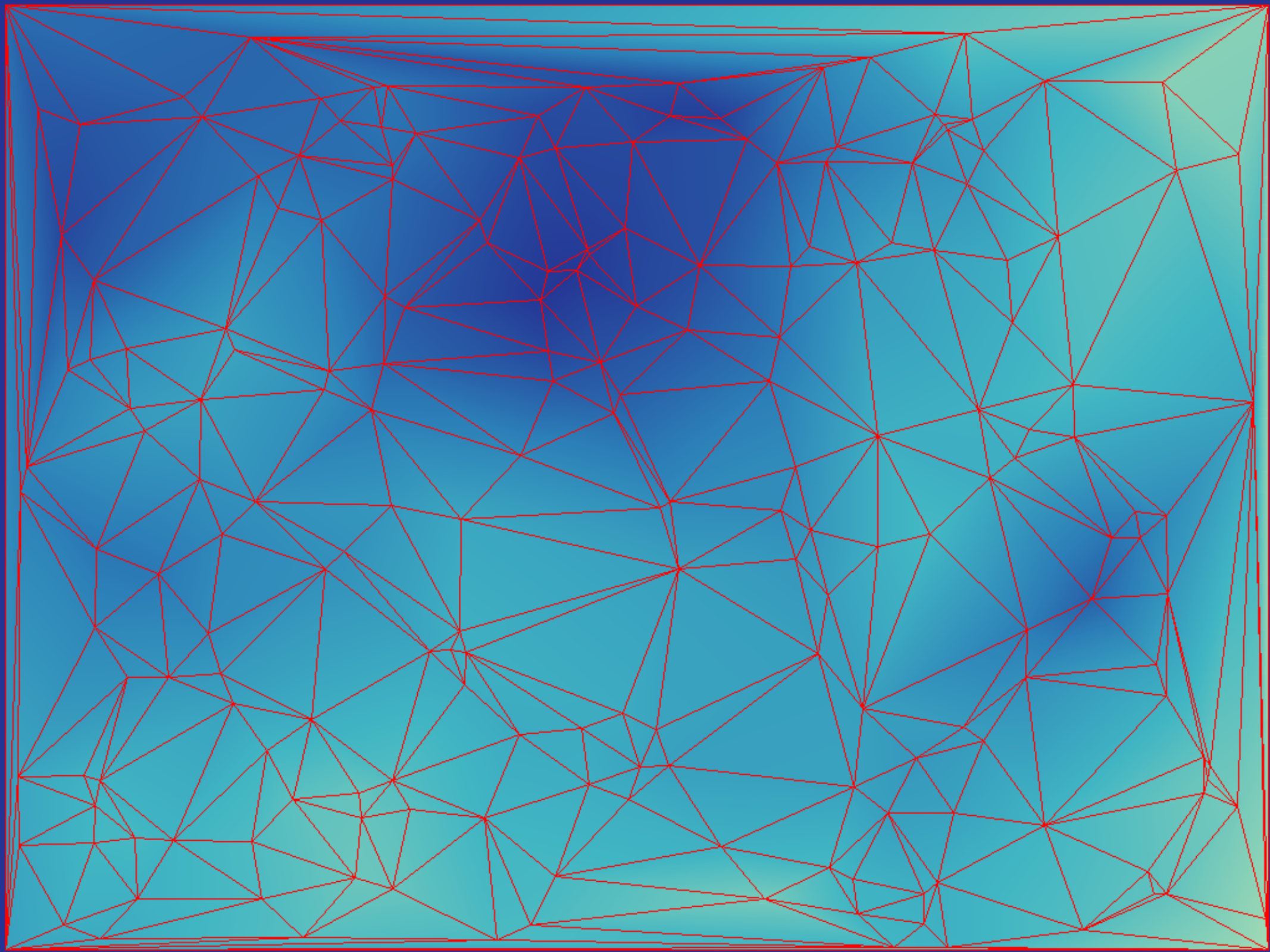

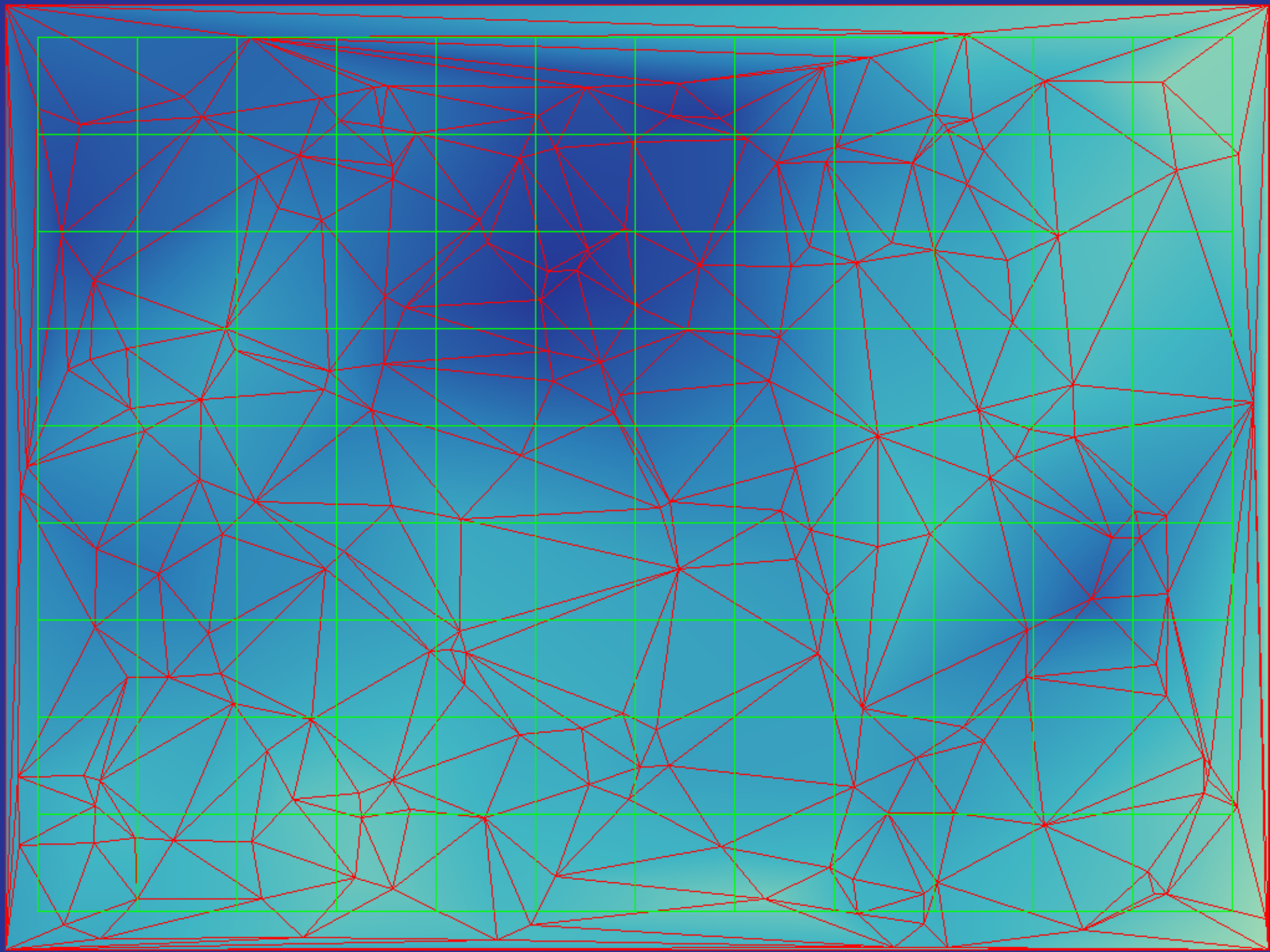

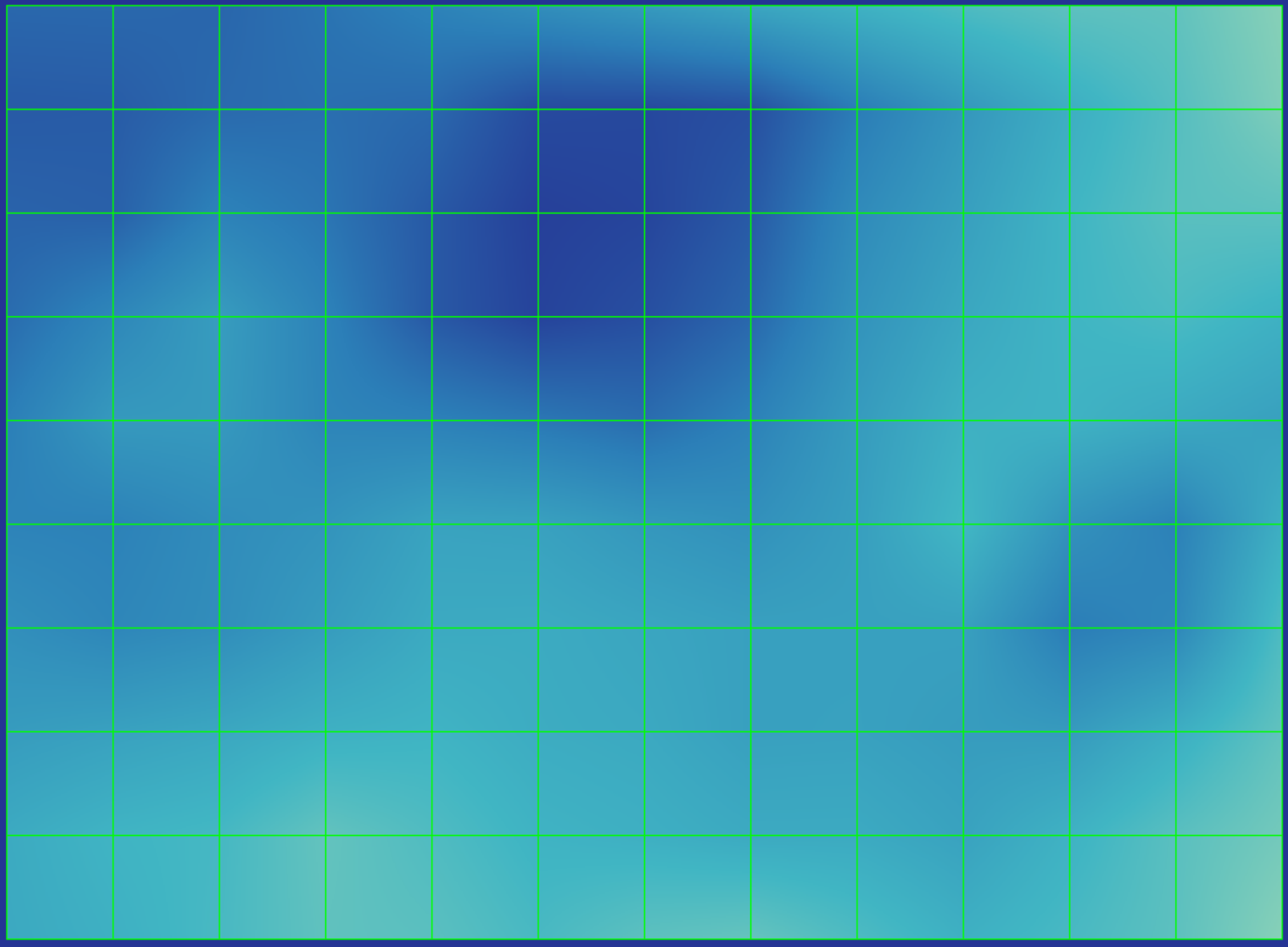

Decomposition Simplification

Simplifying Massive Contour Maps
Lars Arge, Lasse Deleuran, Thomas Mølhave, Morten Revsbæk
ESA 2012

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ESA 2012

Simplifying massive planar decompositions
Lars Arge and Jungwoo Yang
Alenex 14

Decomposition Simplification

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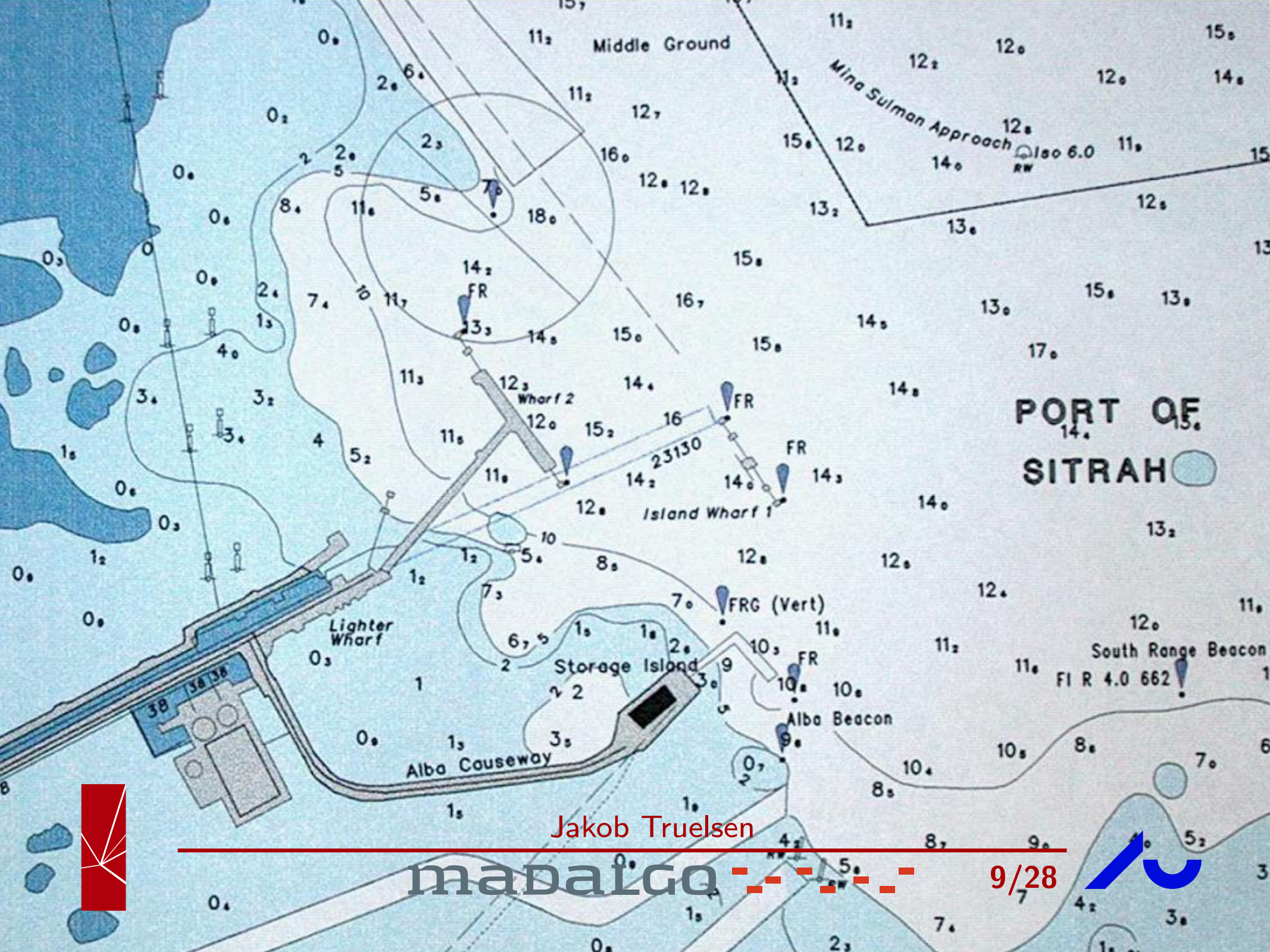
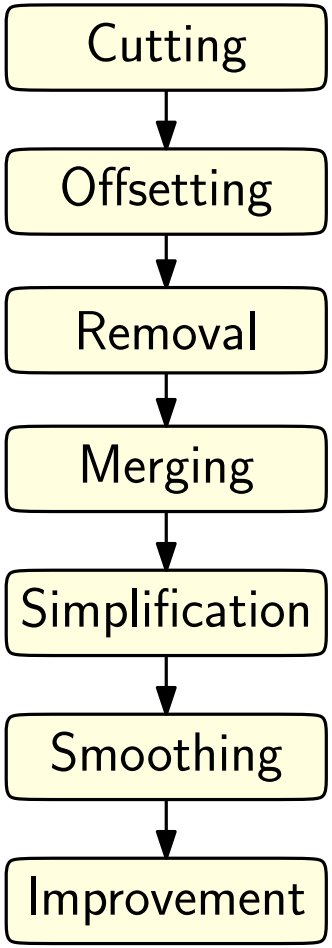
ESA 2012

Simplifying massive planar decompositions
Lars Arge and Jungwoo Yang
Alenex 14

Ongoing work with SCALGO and GST


Middle Ground
Mina Sulman Approach
Iso 6.0
PORT OF
SITRAH
Wharf 2
Island Wharf 1
FR
FRG (Vert)
23130
Lighter
Wharf
Storage Island
Alba Causeway
Alba Beacon
South Range Beacon
Fl R 4.0 662
38

Decomposition Simplification



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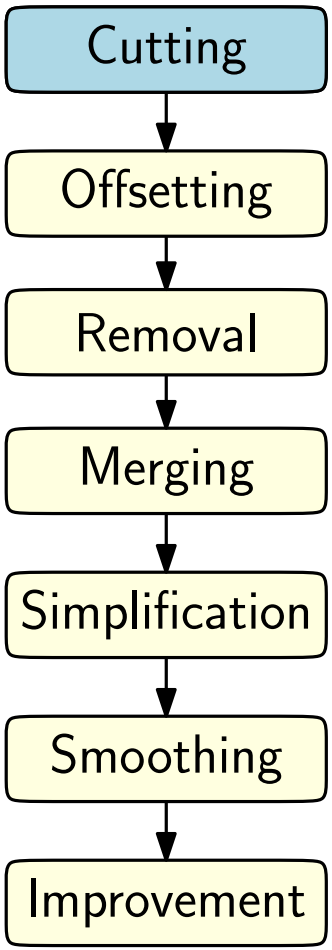

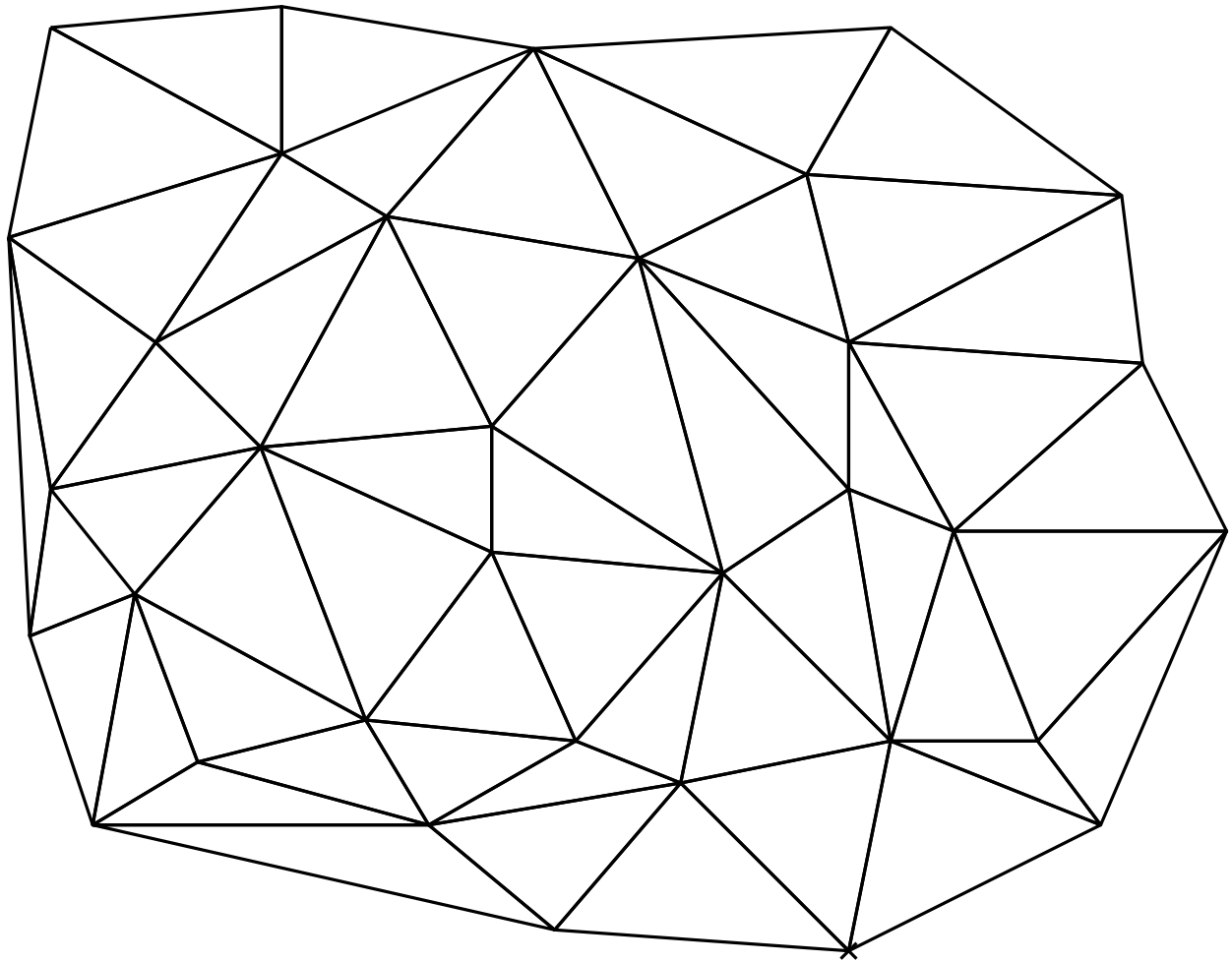

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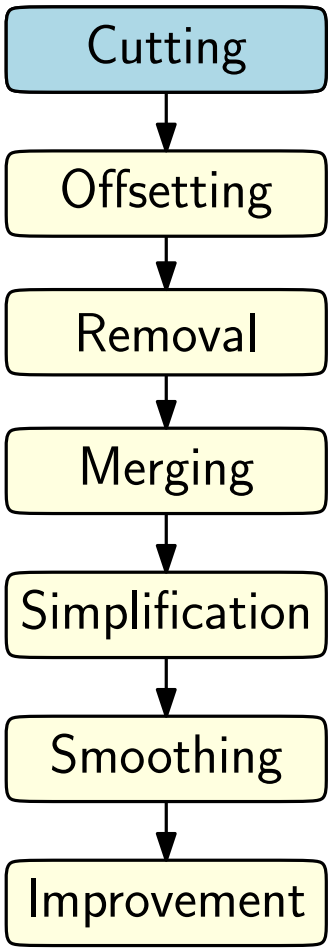

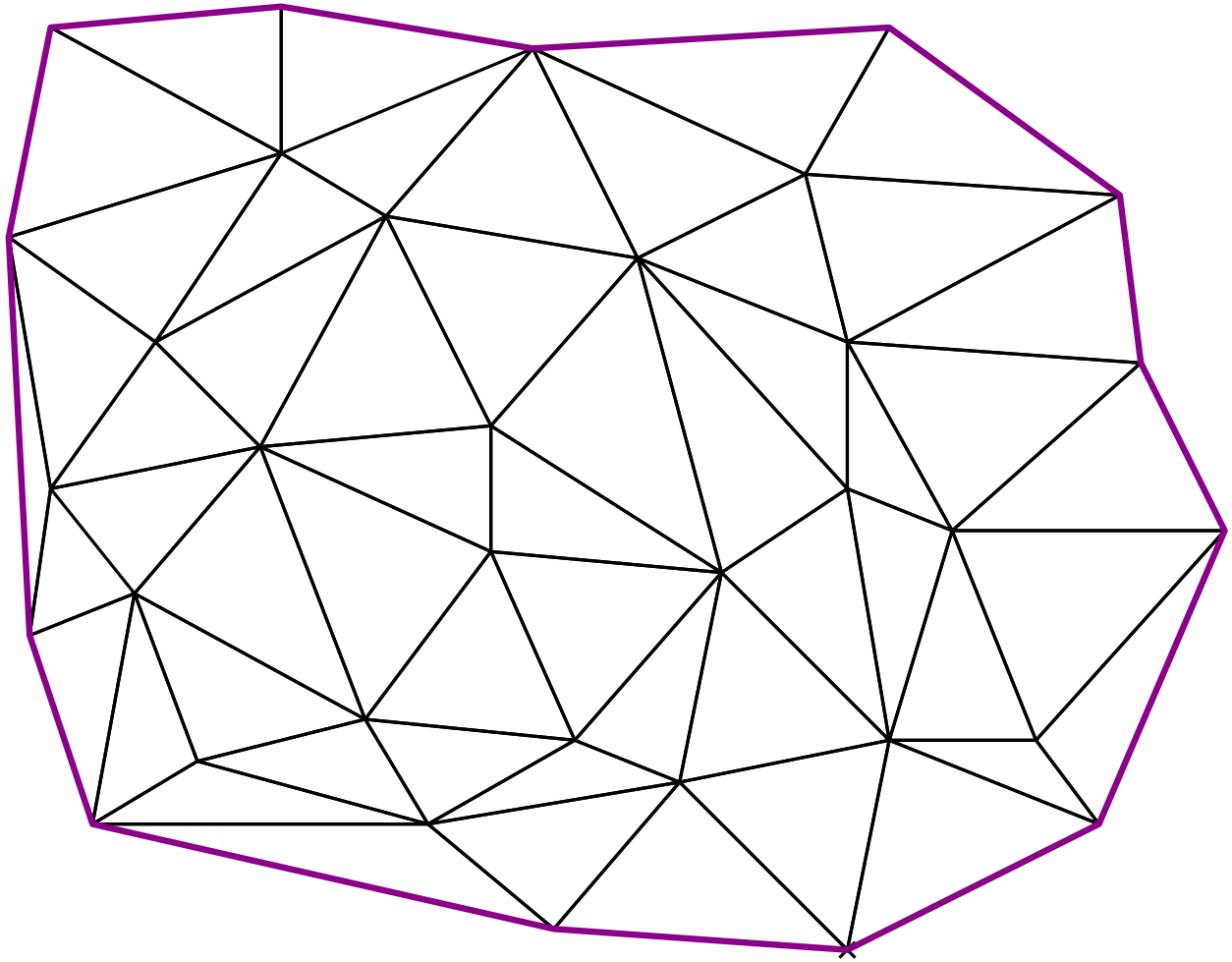

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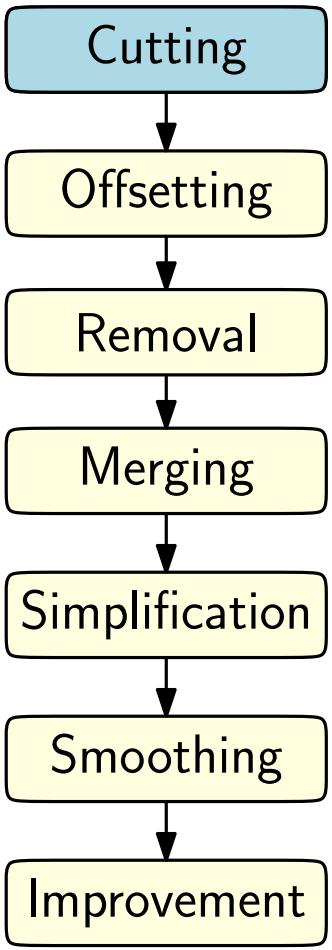

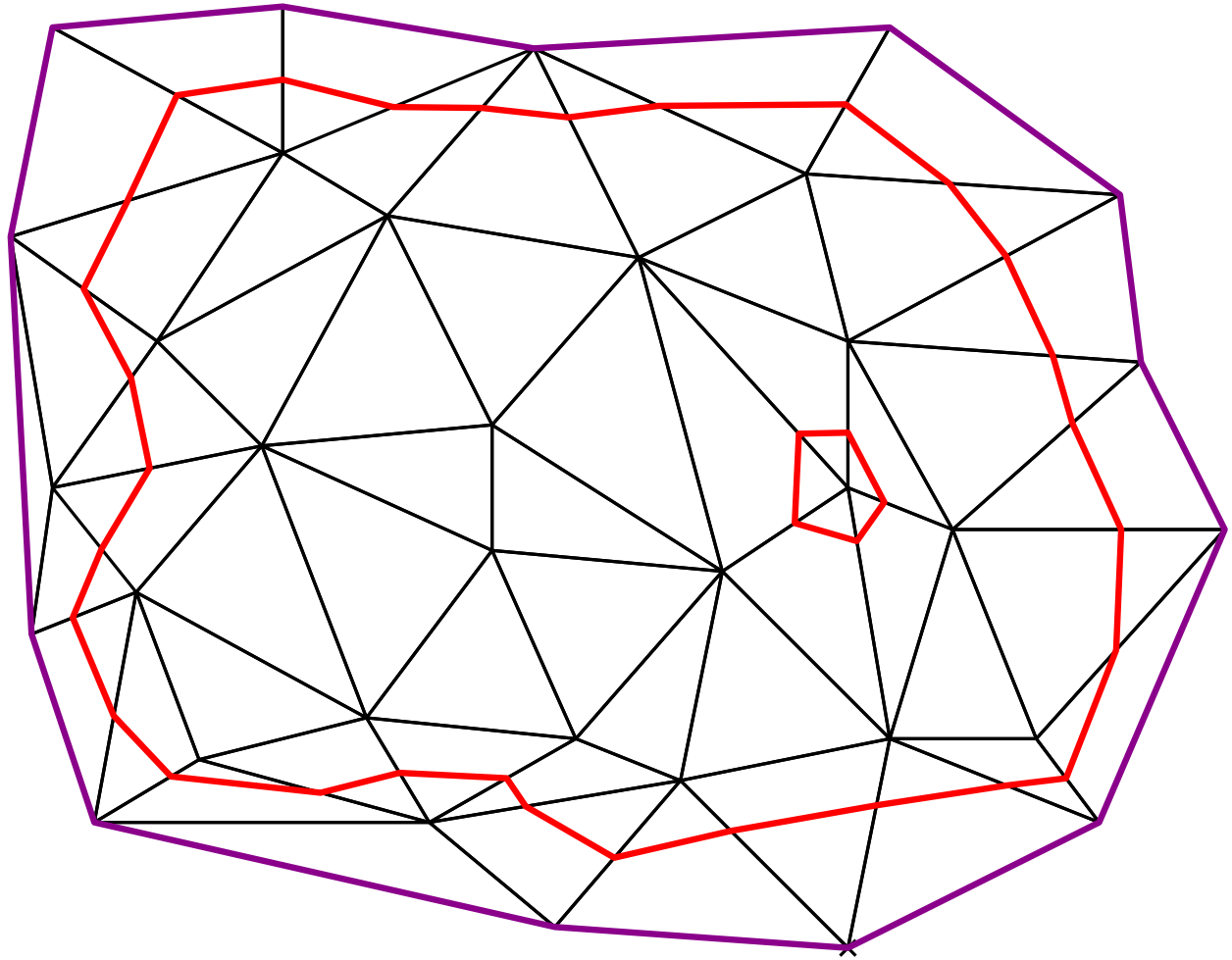

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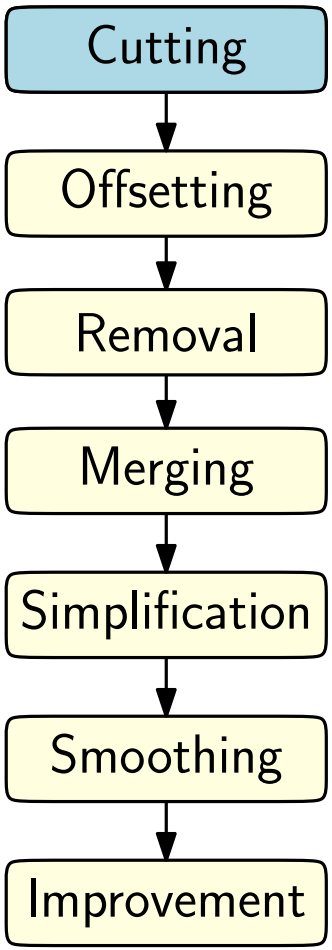
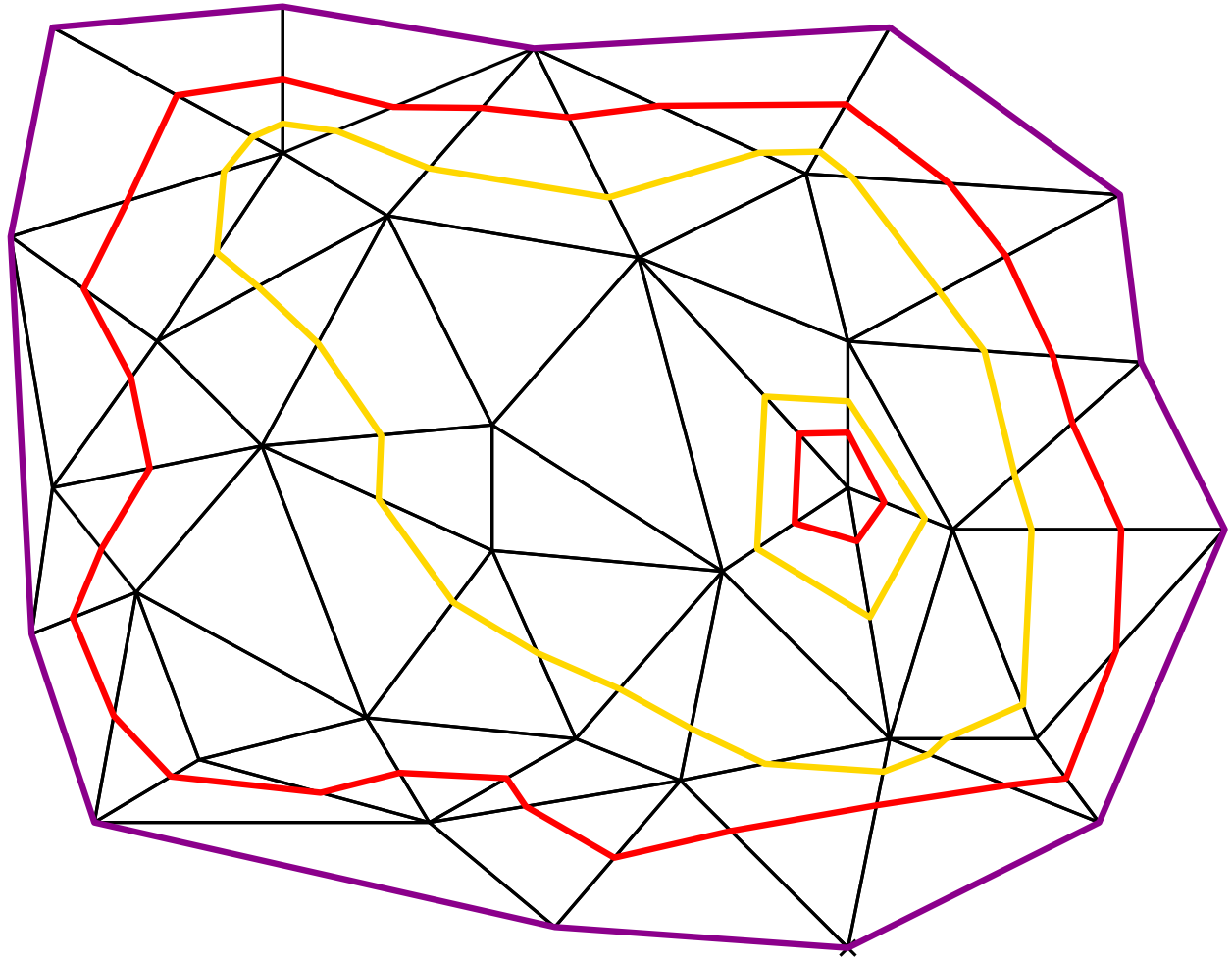
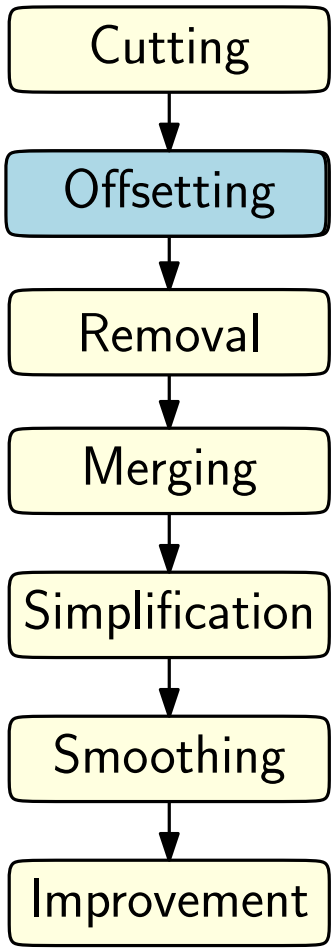
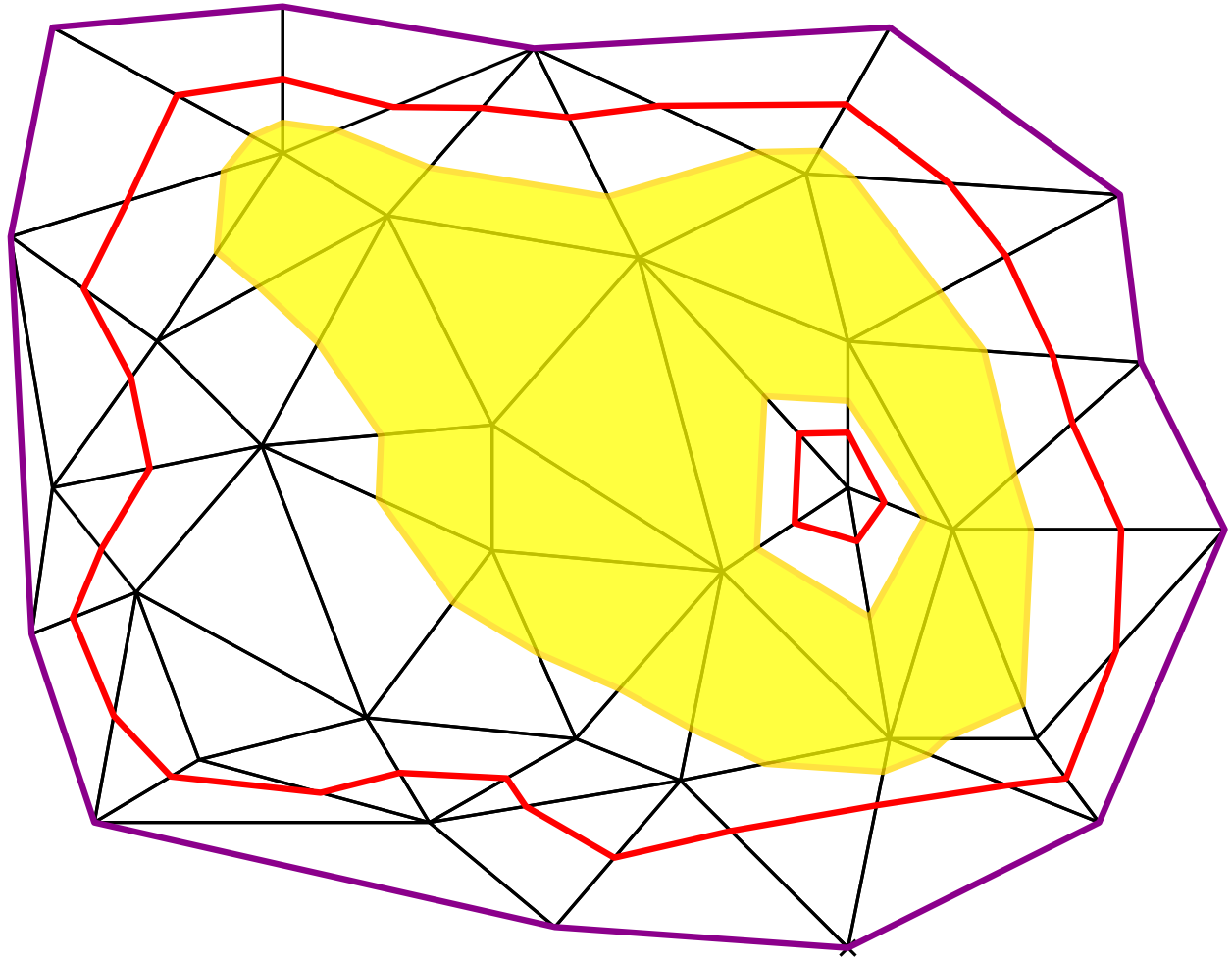




Decomposition Simplification





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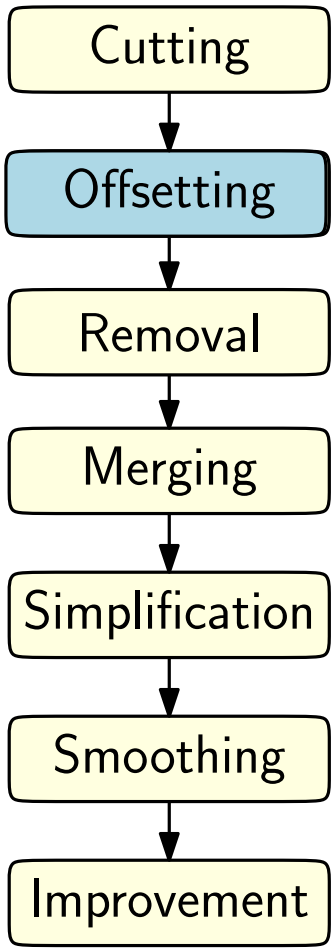

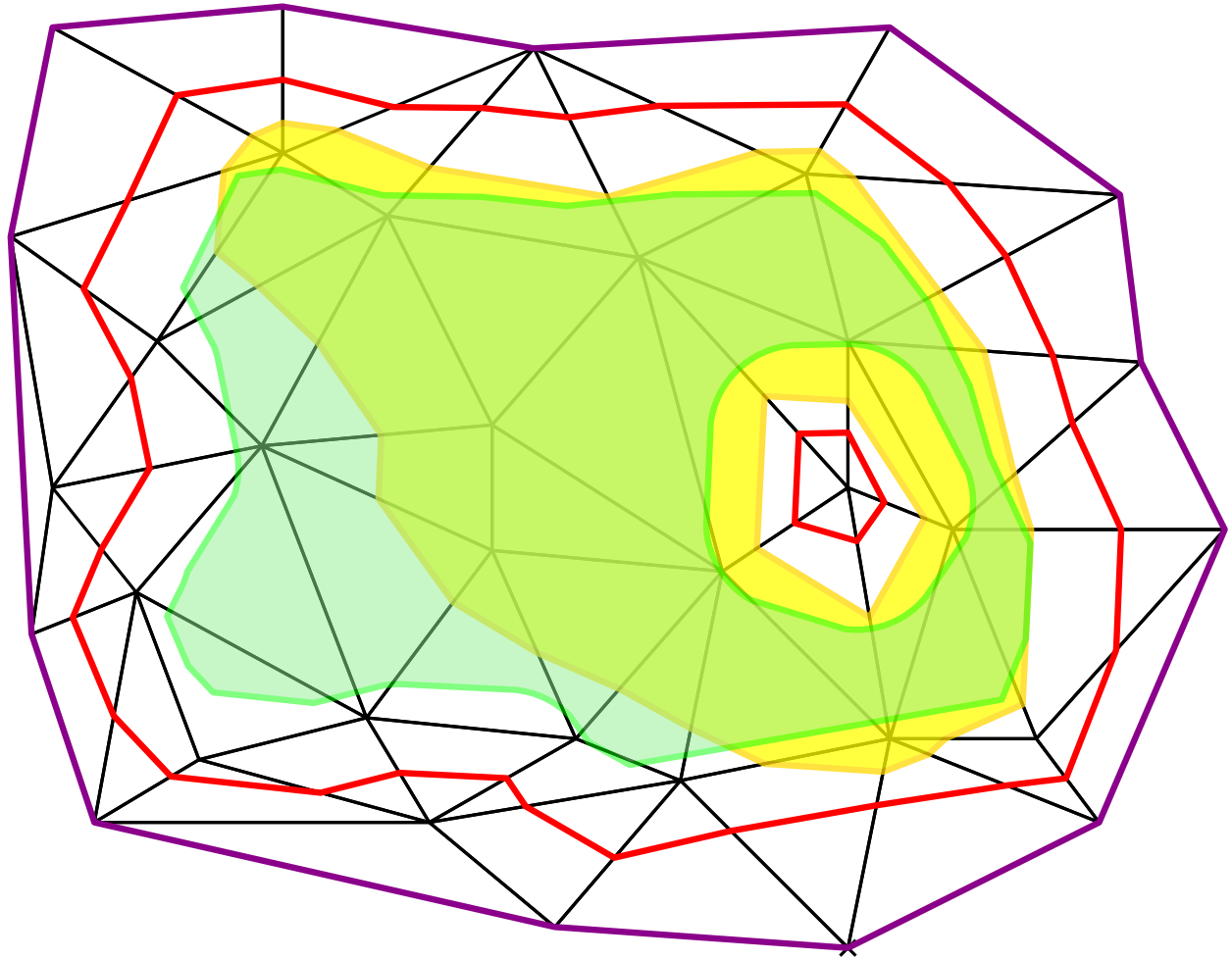

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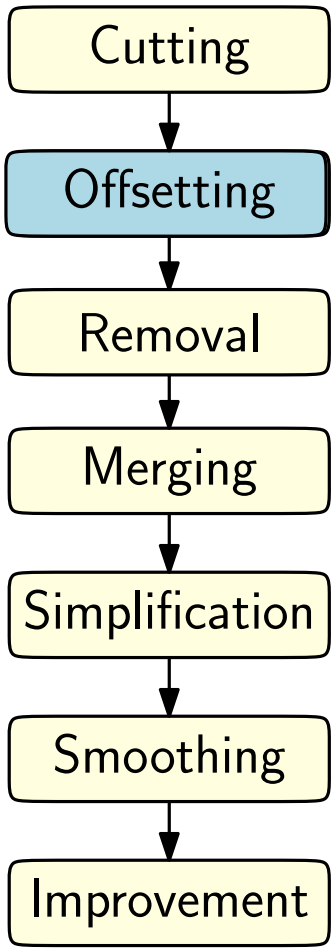

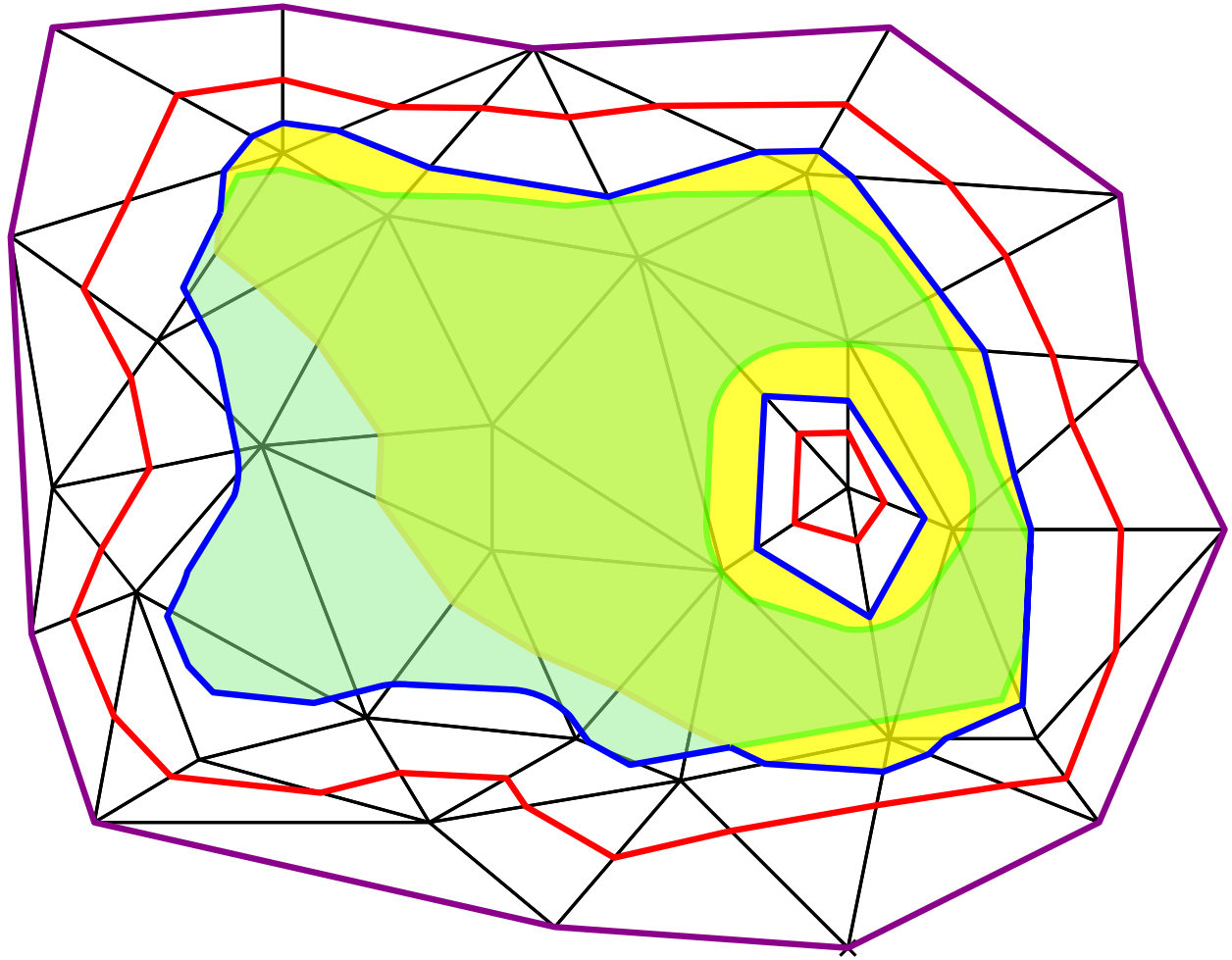

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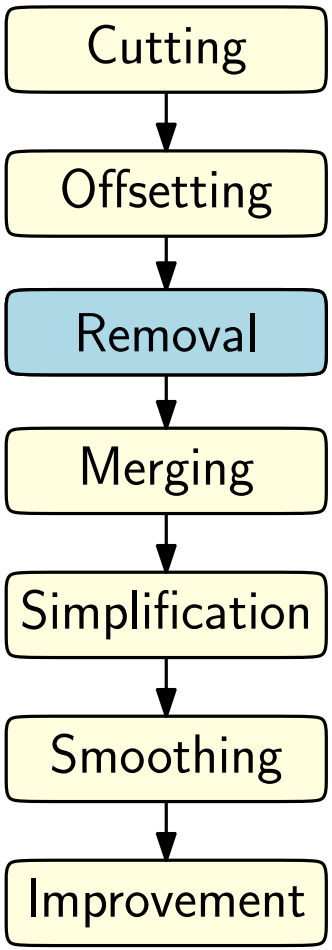

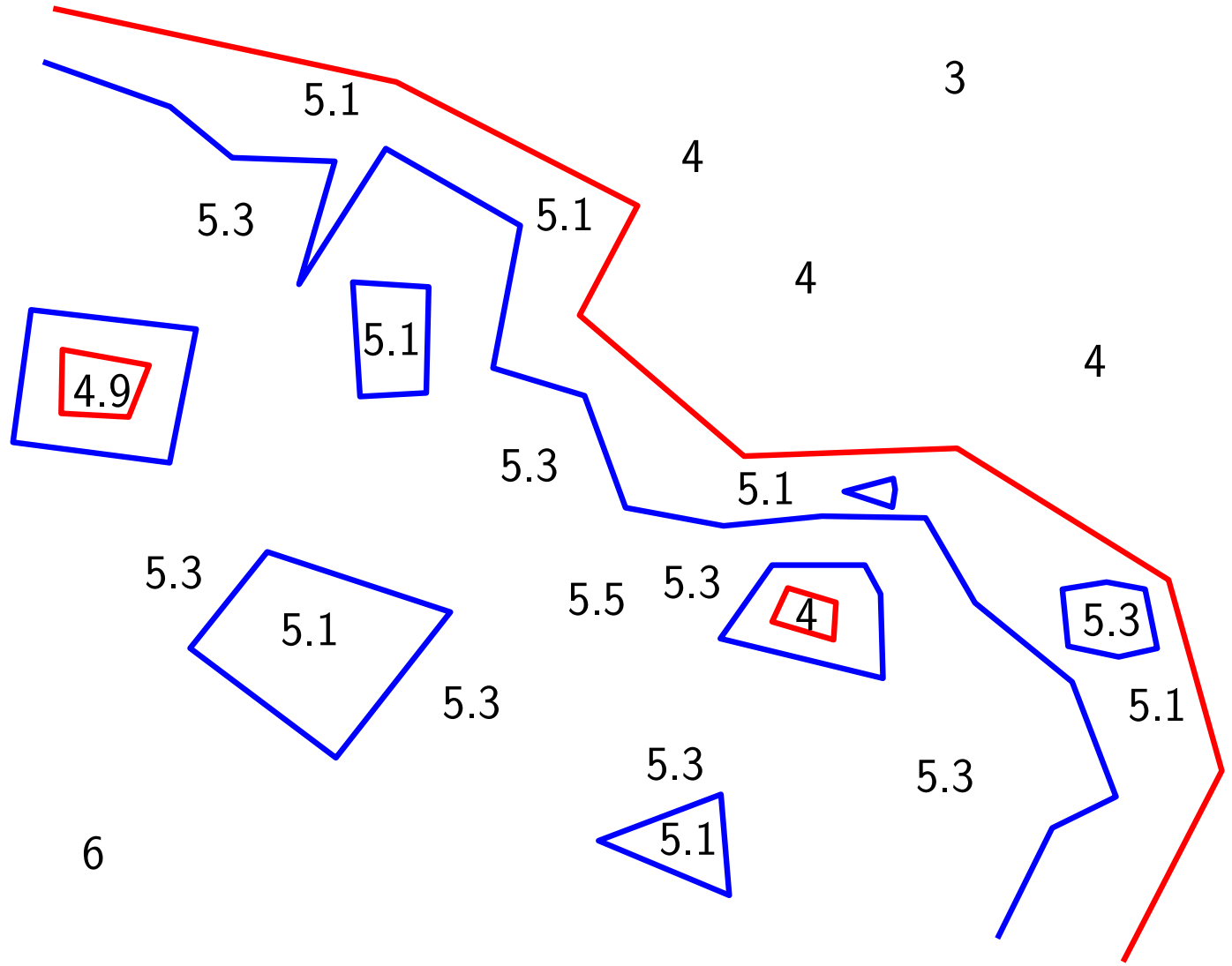

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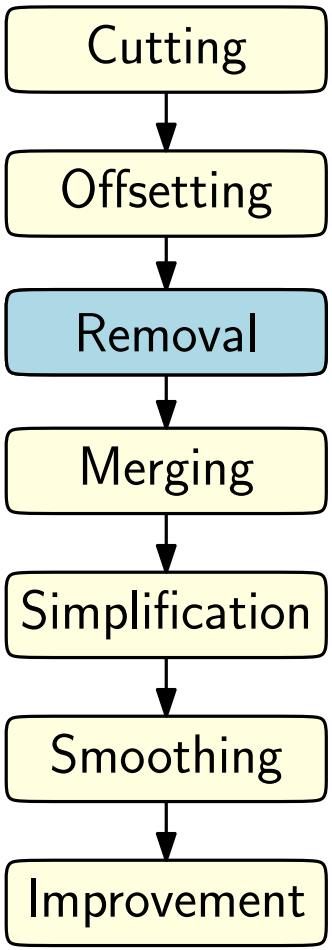

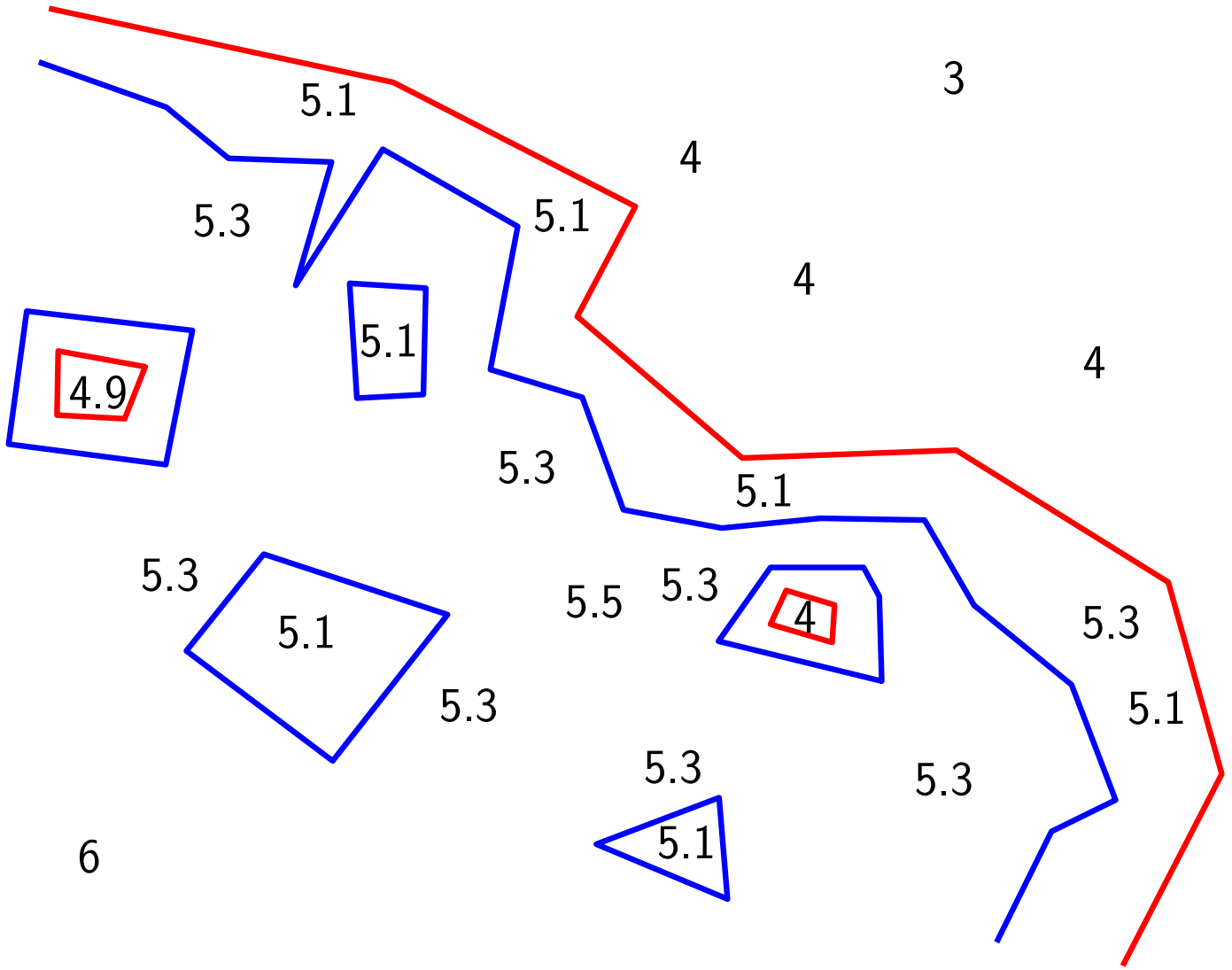

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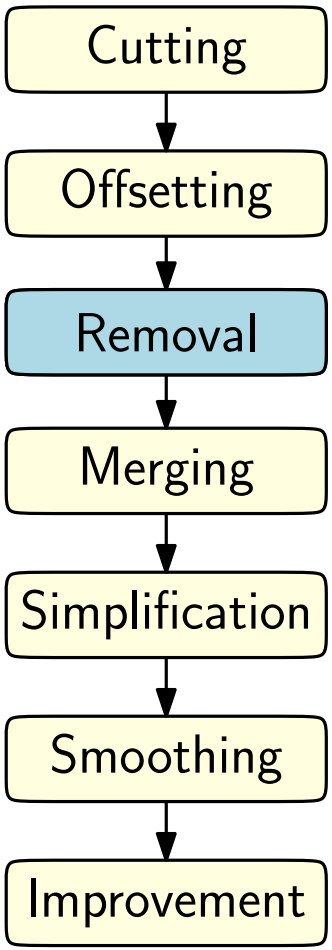

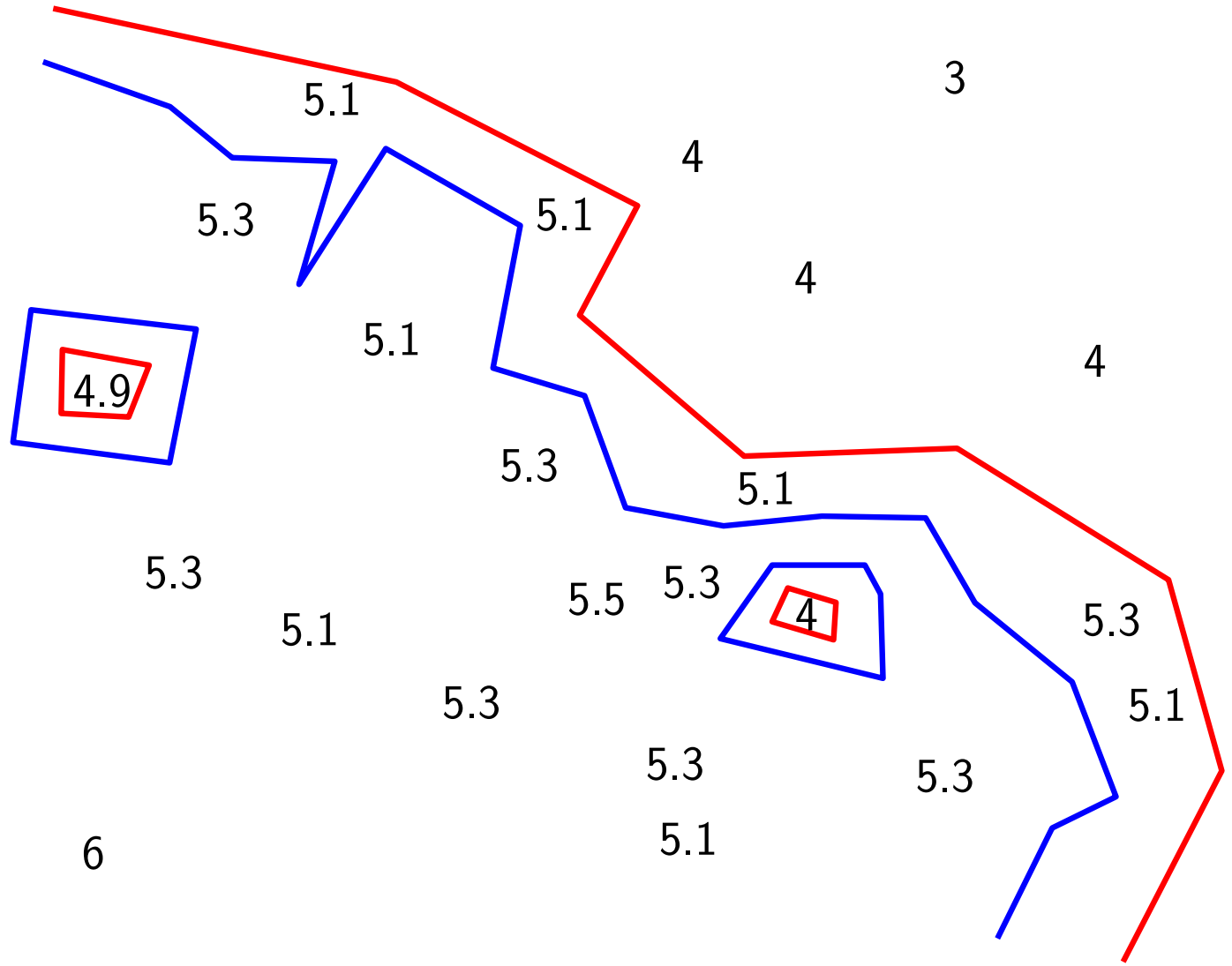

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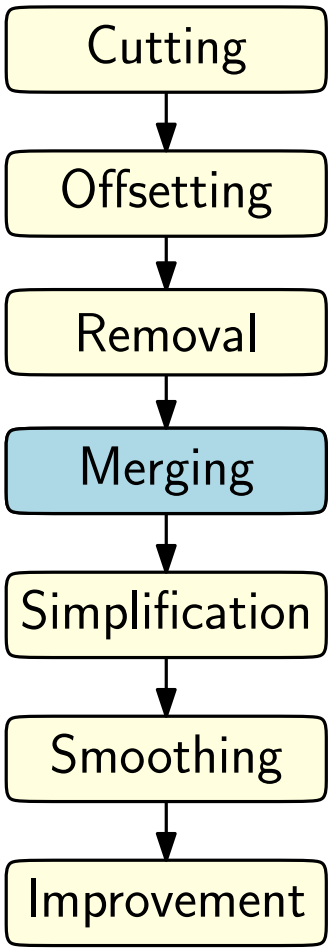

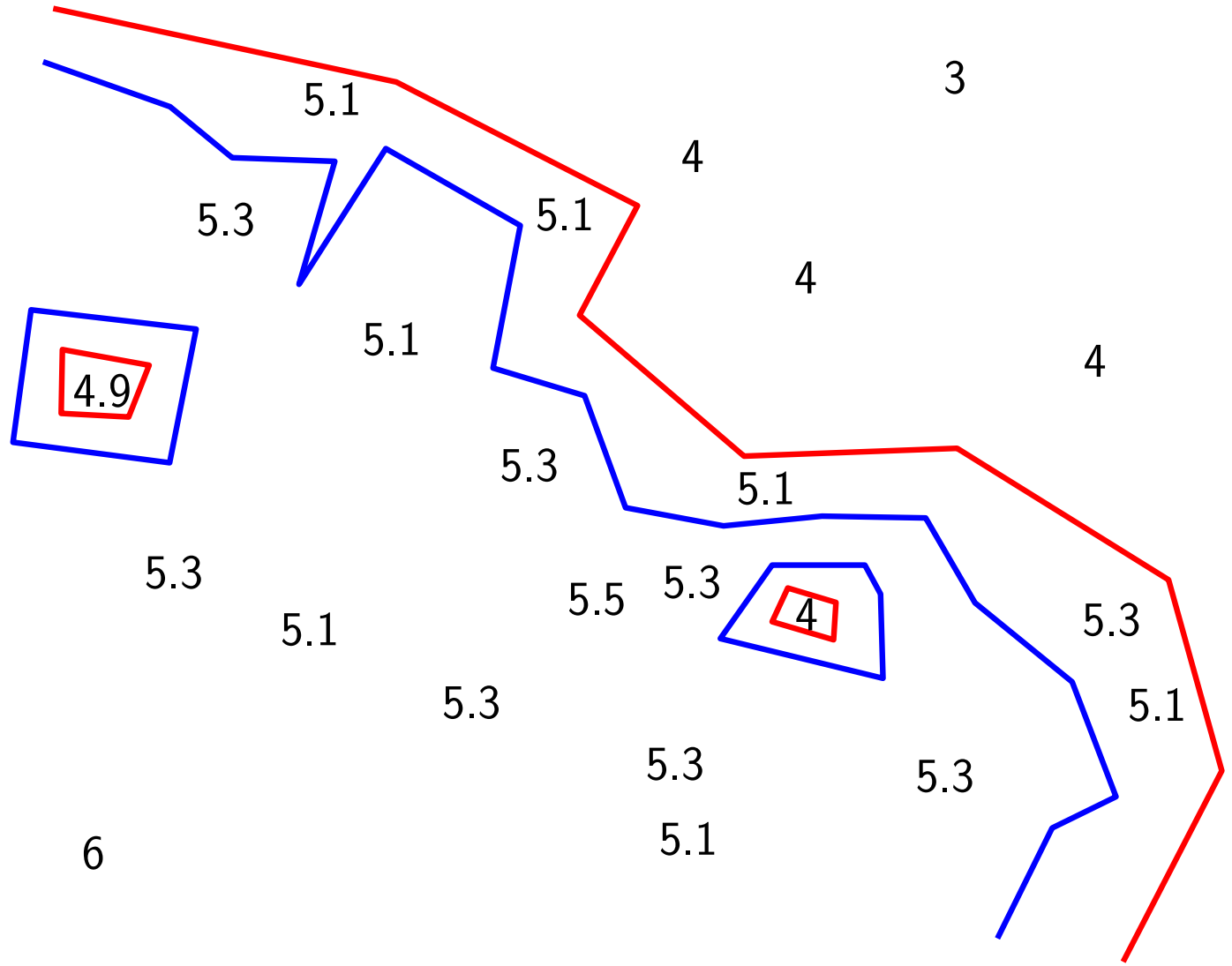

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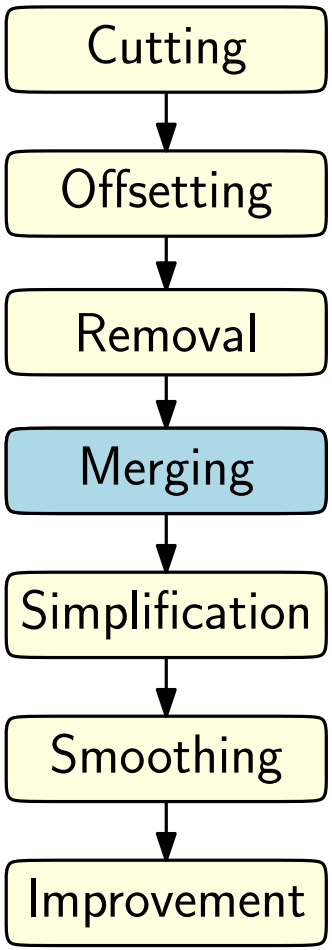

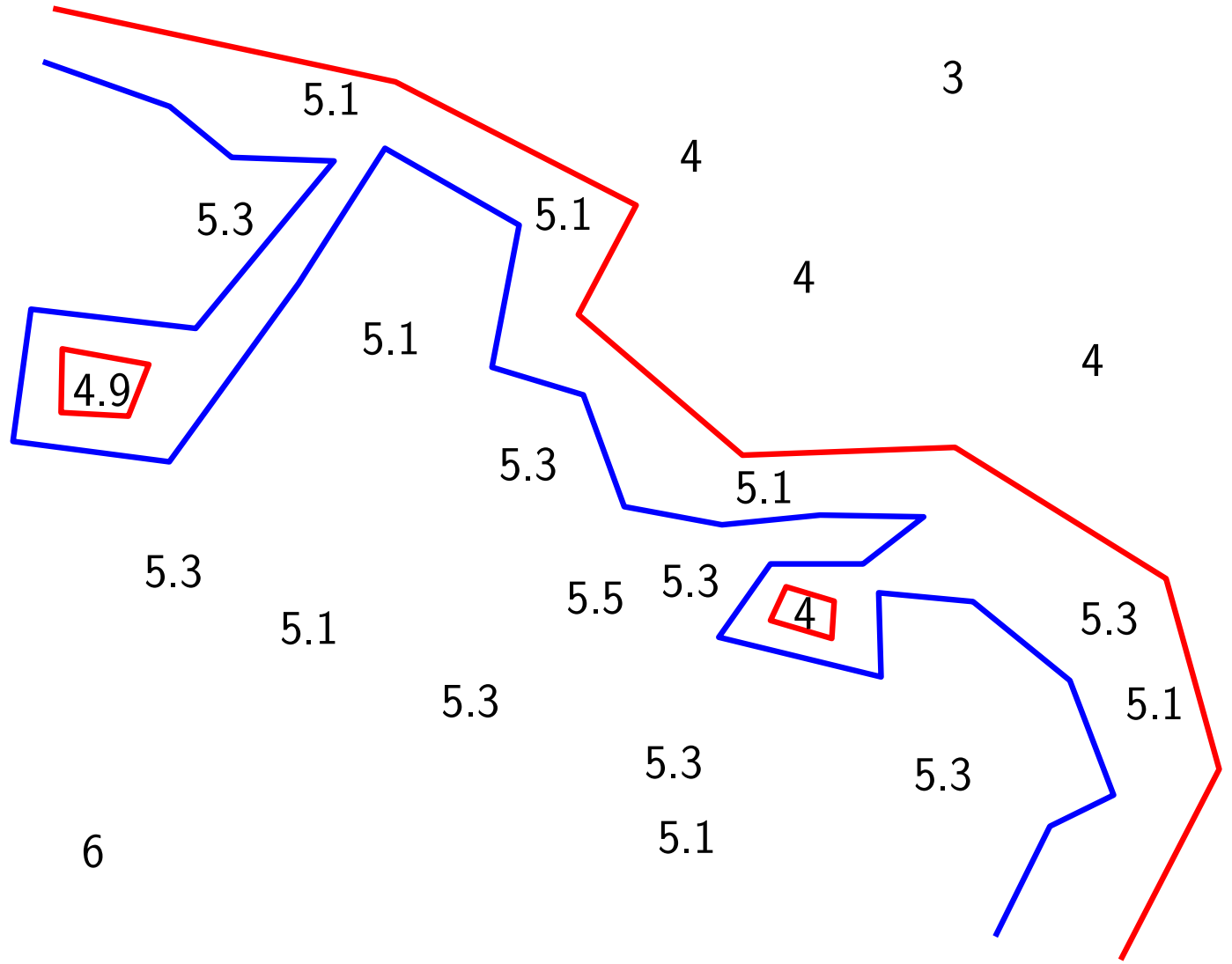

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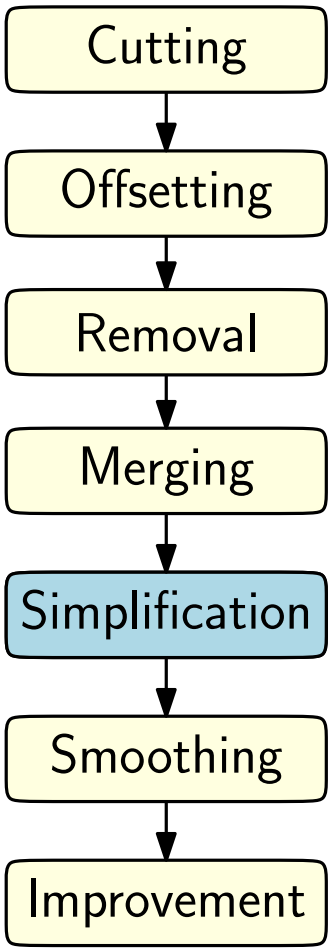

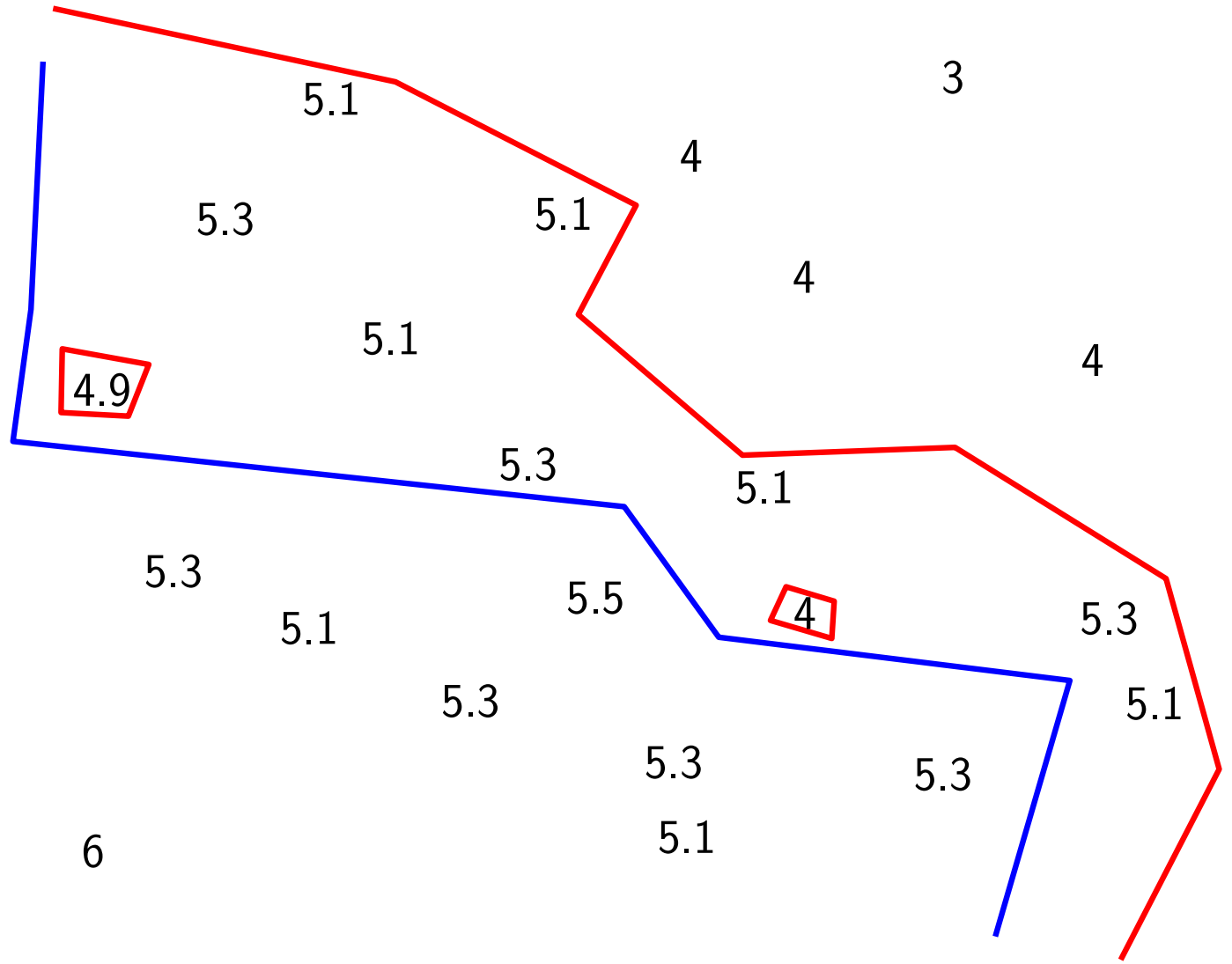

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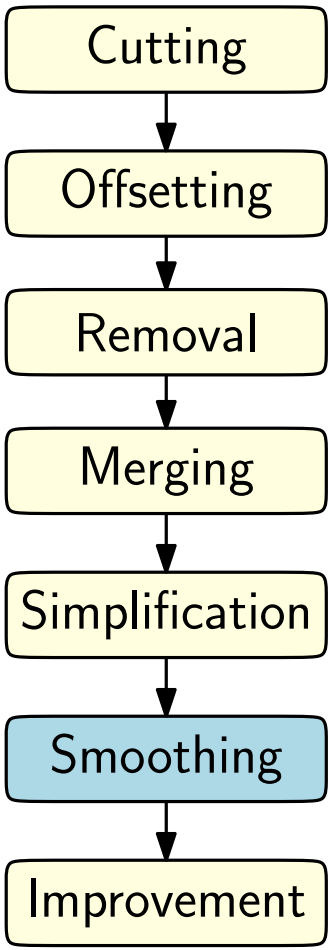

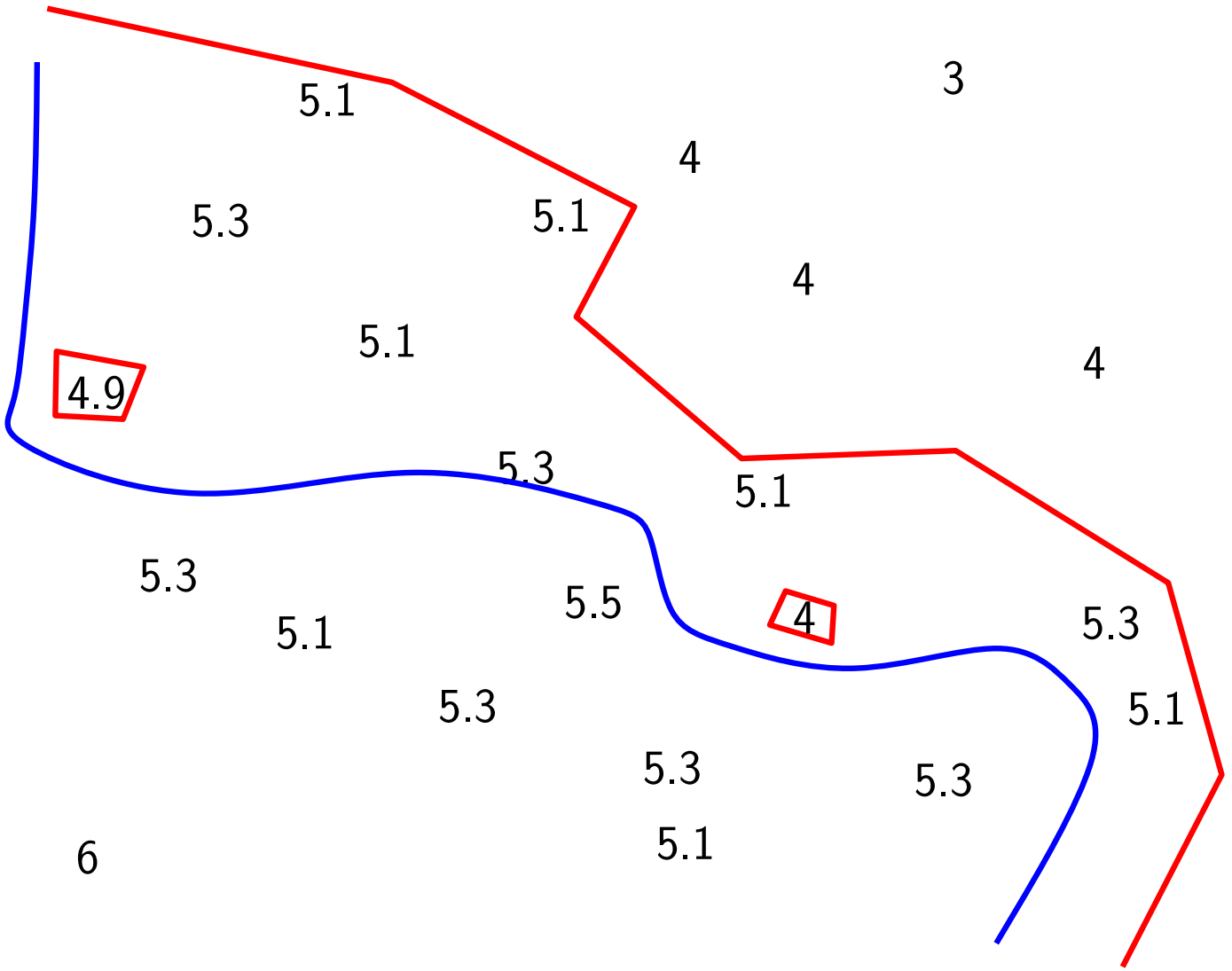

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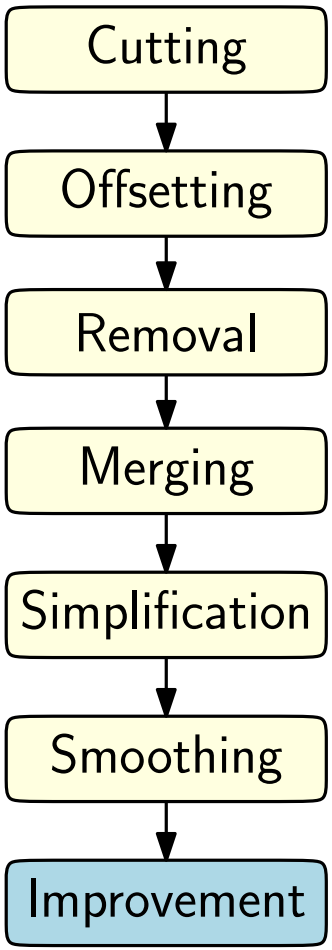

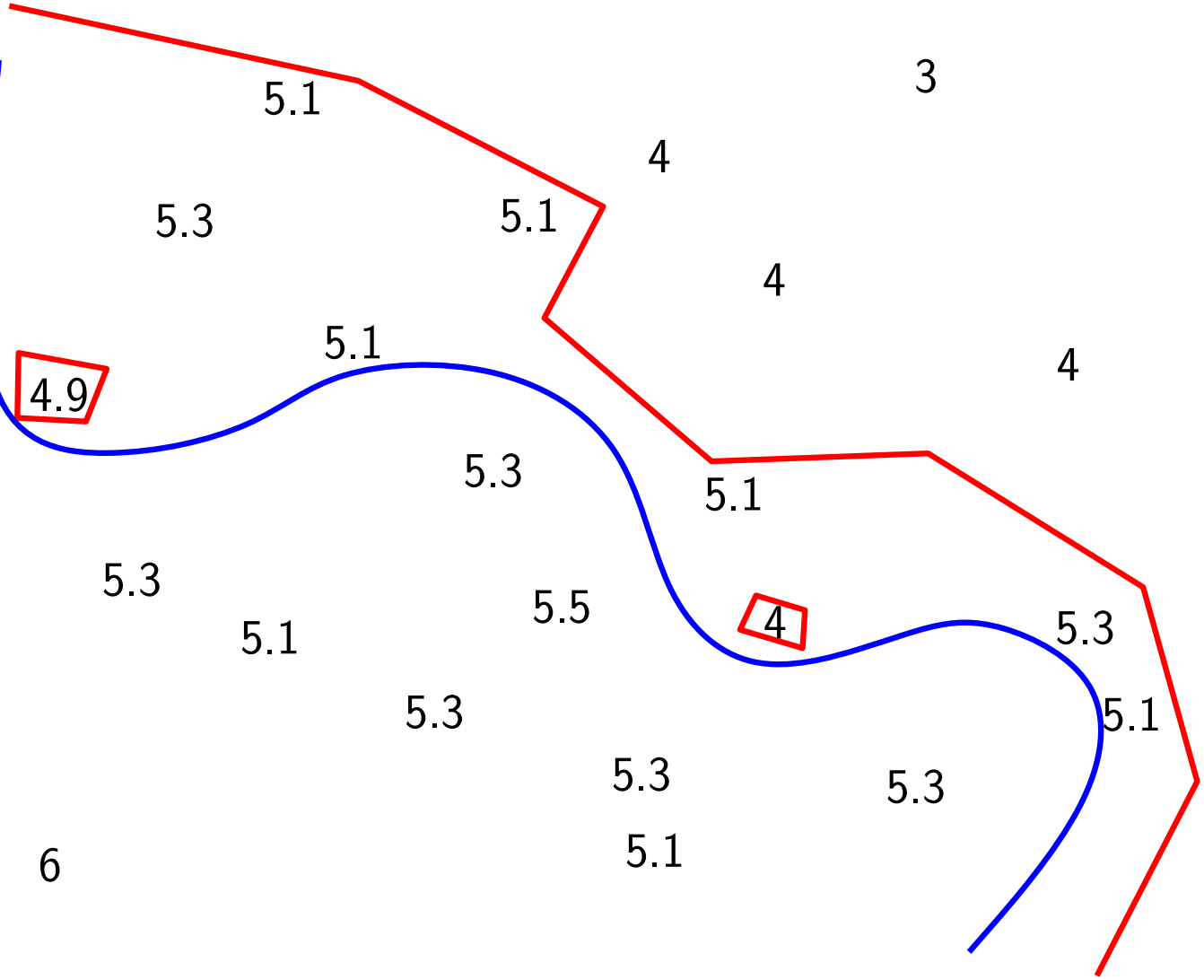

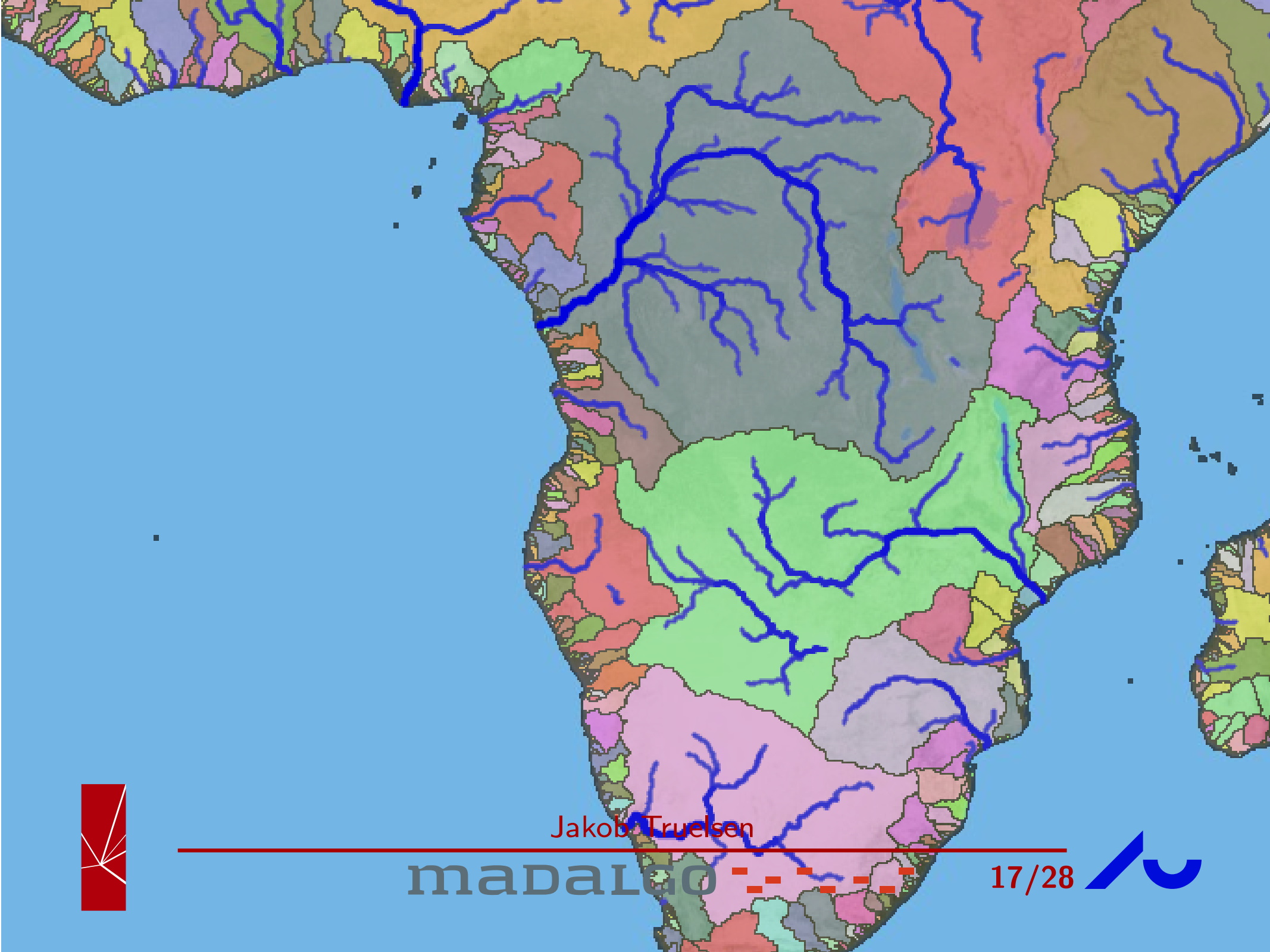

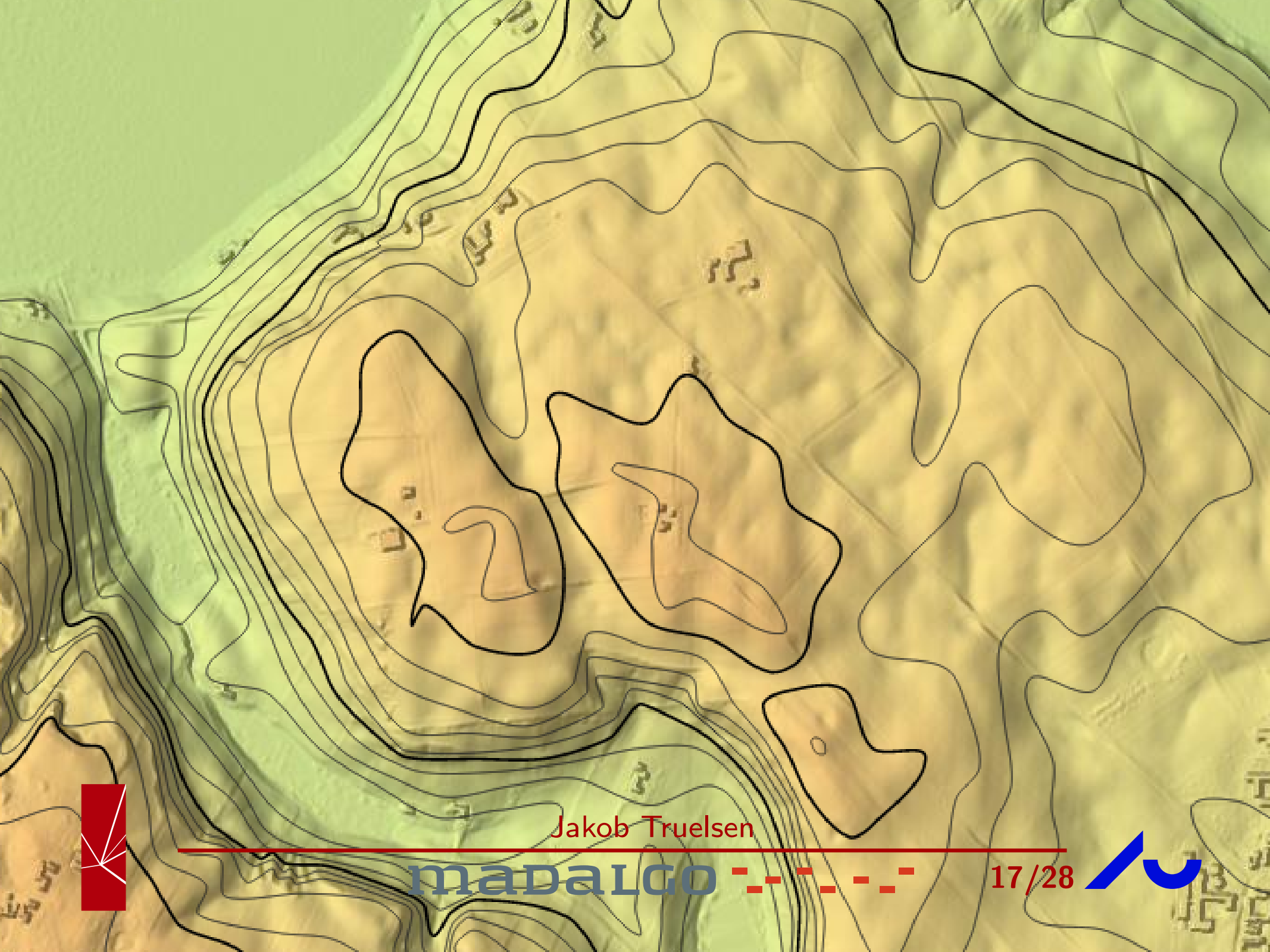

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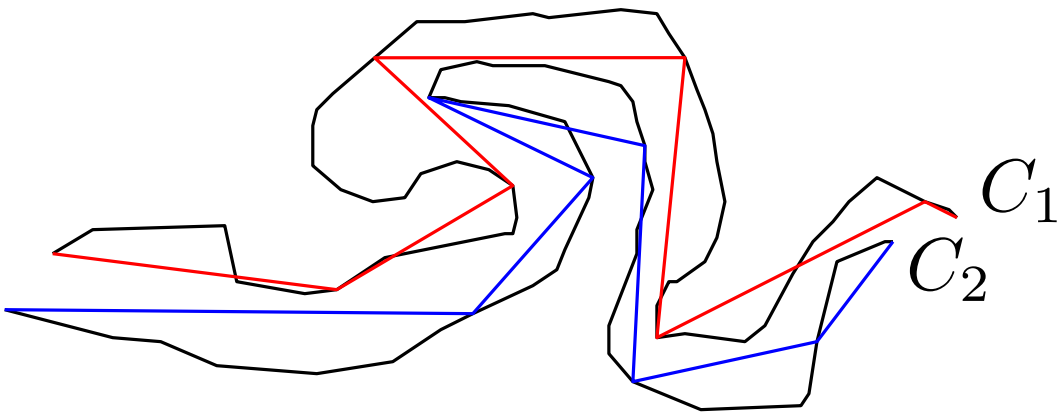

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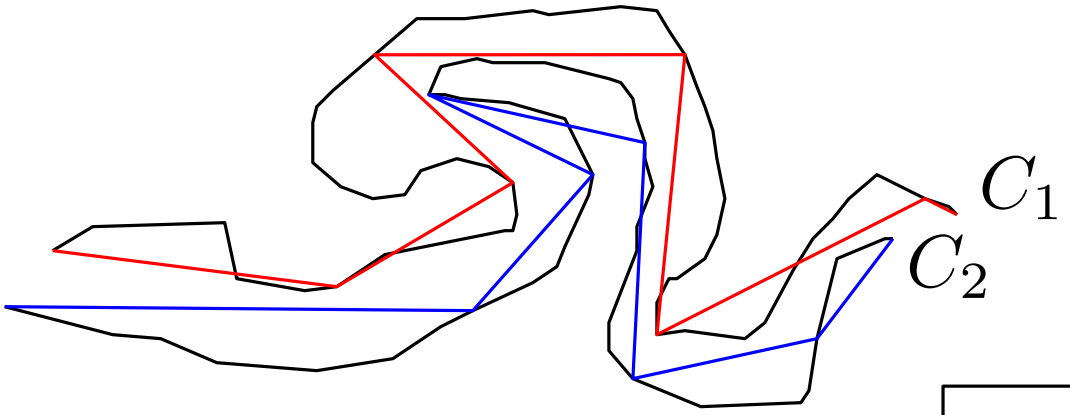
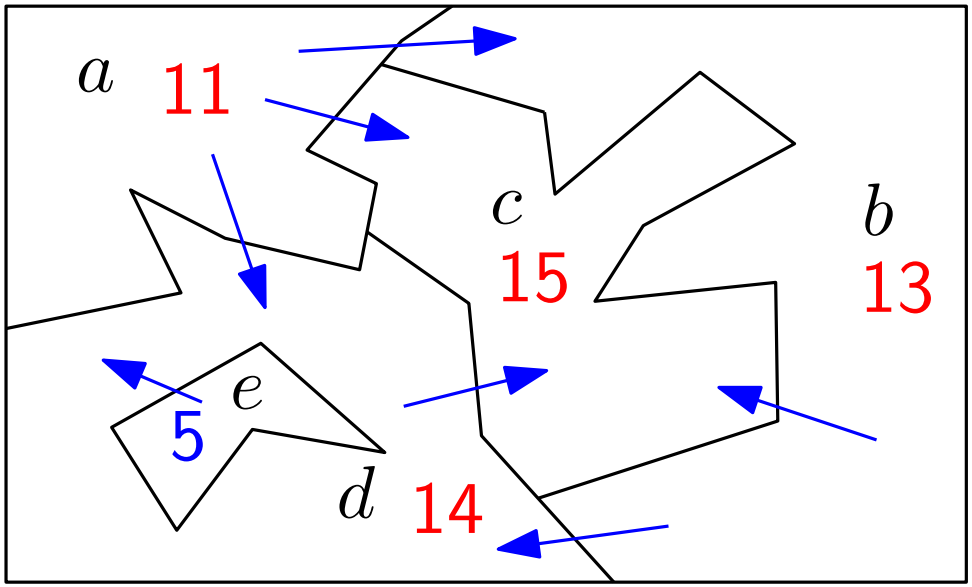


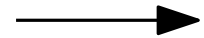


Multiresolution Rasters

1	2	3	4	5	6	7	8	9
2	3	4	5	6	7	8	8	8
3	4	5	6	7	8	9	8	7
4	5	6	7	8	9	8	7	6
5	6	7	8	8	8	7	6	5
6	7	8	9	8	7	6	5	4
7	8	9	8	7	6	5	4	3
8	8	8	7	6	5	4	3	2
9	8	7	6	5	4	3	2	1

Multiresolution Rasters

1	2	3	4	5	6	7	8	9
2	3	4	5	6	7	8	8	8
3	4	5	6	7	8	9	8	7
4	5	6	7	8	9	8	7	6
5	6	7	8	8	8	7	6	5
6	7	8	9	8	7	6	5	4
7	8	9	8	7	6	5	4	3
8	8	8	7	6	5	4	3	2
9	8	7	6	5	4	3	2	1

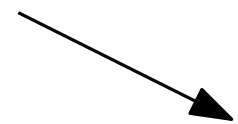


3	6	8
6	8	6
8	6	3

Multiresolution Rasters

1	2	3	4	5	6	7	8	9
2	3	4	5	6	7	8	8	8
3	4	5	6	7	8	9	8	7
4	5	6	7	8	9	8	7	6
5	6	7	8	8	8	7	6	5
6	7	8	9	8	7	6	5	4
7	8	9	8	7	6	5	4	3
8	8	8	7	6	5	4	3	2
9	8	7	6	5	4	3	2	1

3	6	8
6	8	6
8	6	3



2	4	6	$7\frac{3}{4}$
4	6	8	8
6	8	$7\frac{3}{4}$	6
$7\frac{3}{4}$	8	6	4

Multiresolution Rasters

"An Optimal and Practical Cache-Oblivious Algorithm for Computing Multiresolution Rasters"
Lars Arge, Gerth Stølting Brodal and Constantinos Tsirogiannis.
Constantinos at ESA 2013

Multiresolution Rasters

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$\mathcal{O}(\text{scan}(N))$ IO's cache oblivious.

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Height model of Denmark:

Naive $\mathcal{O}(\text{sort}(N))$ IO algorithm: $13\frac{1}{4}$ Hours.

Multiresolution Rasters

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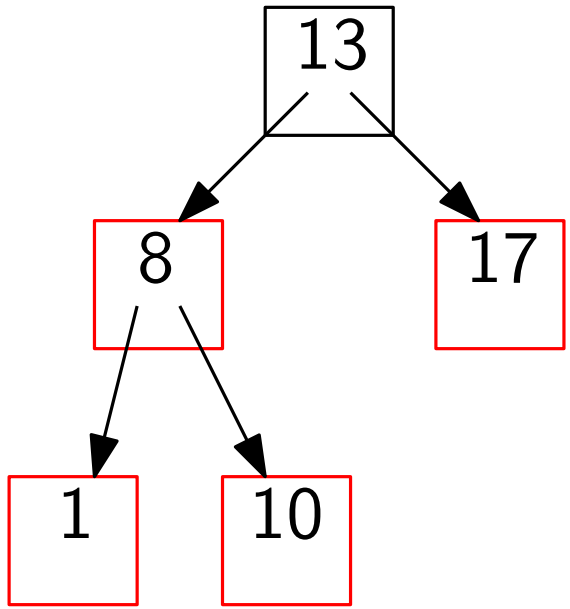
$\mathcal{O}(\text{scan}(N))$ IO's cache oblivious.

Height model of Denmark:

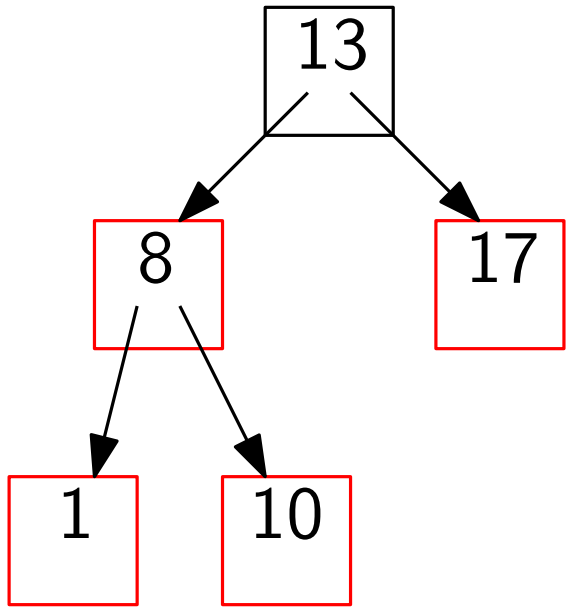
Naive $\mathcal{O}(\text{sort}(N))$ IO algorithm: $13\frac{1}{4}$ Hours.

Our algorithm: $2\frac{1}{4}$ Hours.

Implicite Structures

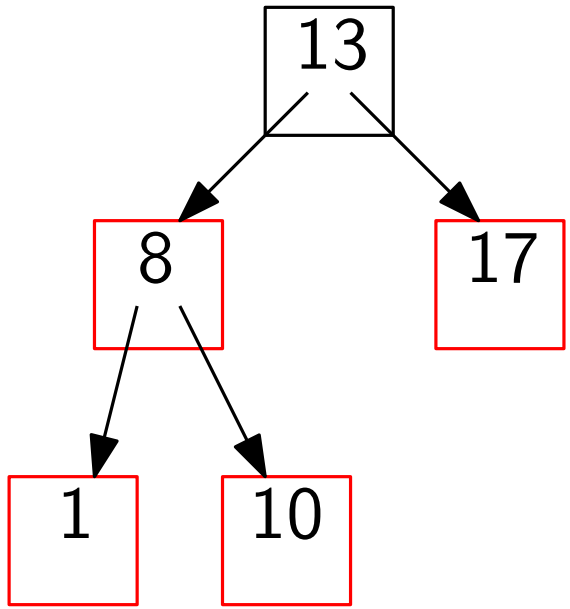


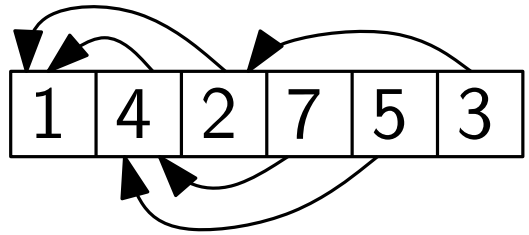
Implicite Structures



1	4	2	7	5	3

Implicite Structures





Workingset Structure

1	4	22	24	25	30	37	42	45	55	56	57	60	63	69	74	88	97	99

Workingset Structure

1	4	22	24	25	30	37	42	45	55	56	57	60	63	69	74	88	97	99

	Find	Predecessor	Update
Our	$\mathcal{O}(\log \ell)$	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$

A Cache-Oblivious Implicit Dictionary with the Working Set Property
Gerth Stølting Brodal, Casper Kejlberg-Rasmussen
ISAAC 2010

Workingset Structure

1	4	22	24	25	30	37	42	45	55	56	57	60	63	69	74	88	97	99

	Find	Predecessor	Update
Our	$\mathcal{O}(\log \ell)$	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$
Better	$\mathcal{O}(\log \ell)$	$\mathcal{O}(\log \ell)$	$\mathcal{O}(\log n)$

A Cache-Oblivious Implicit Dictionary with the Working Set Property
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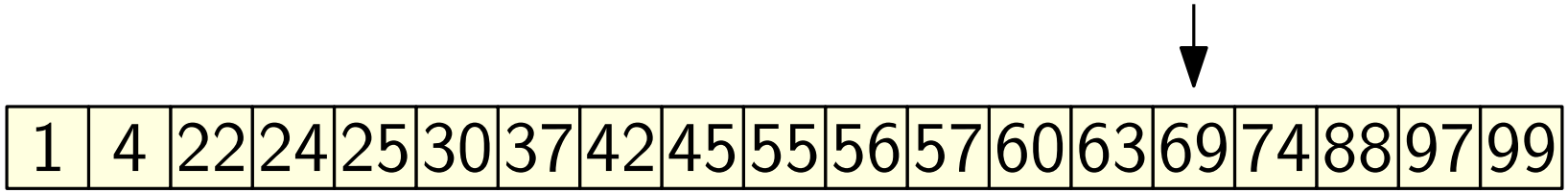
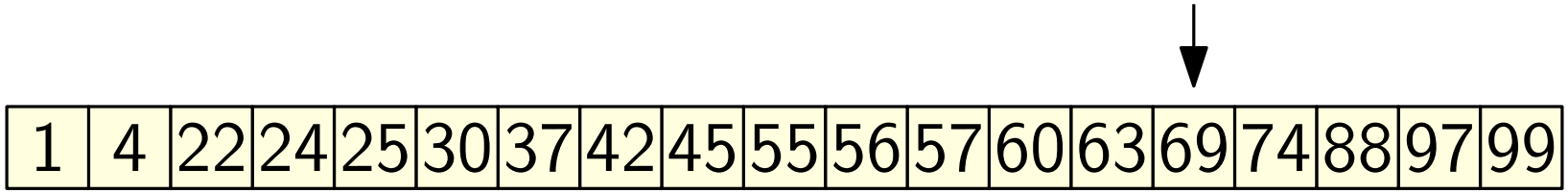
Fingersearch structure

1	4	22	24	25	30	37	42	45	55	56	57	60	63	69	74	88	97	99

Fingersearch structure

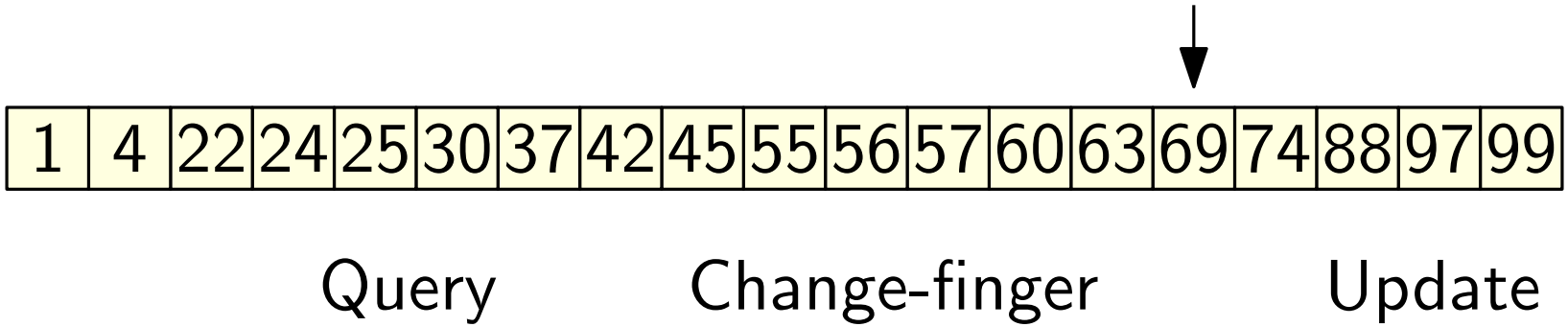


Fingersearch structure



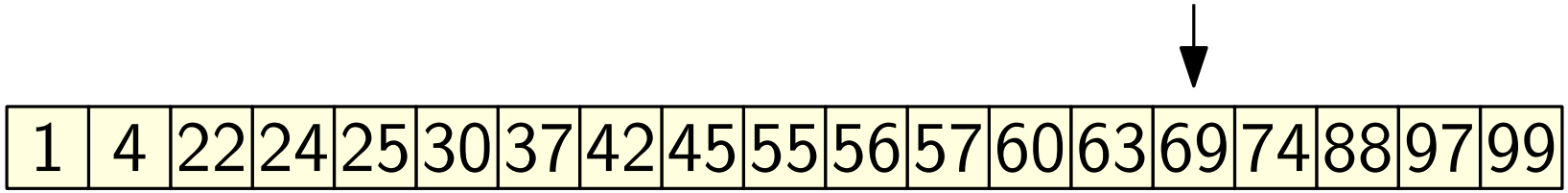
Query Change-finger Update

Fingersearch structure



Finger Search in the Implicit Model
Gerth Stølting Brodal and Jesper Sindahl Nielsen
IAAAC 2012

Fingersearch structure



	Query	Change-finger	Update
Static	$\mathcal{O}(q(t))$	$\mathcal{O}(q^{-1}(\log n))$	

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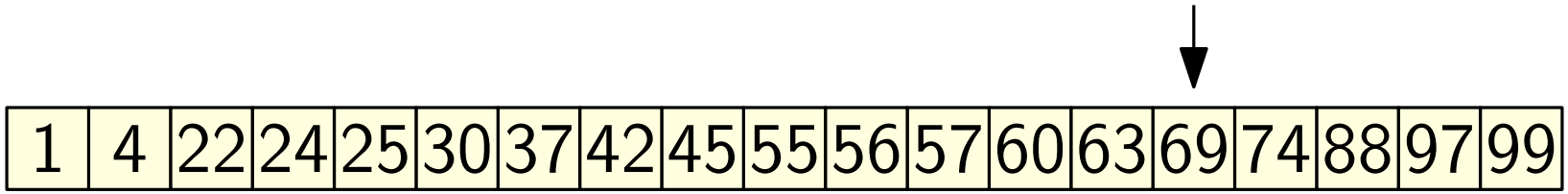
Fingersearch structure



	Query	Change-finger	Update
Static	$\mathcal{O}(q(t))$	$\mathcal{O}(q^{-1}(\log n))$	
Dynamic	$\mathcal{O}(q(t))$	$\mathcal{O}(q^{-1}(\log n) \log n)$	$\mathcal{O}(\log n)$

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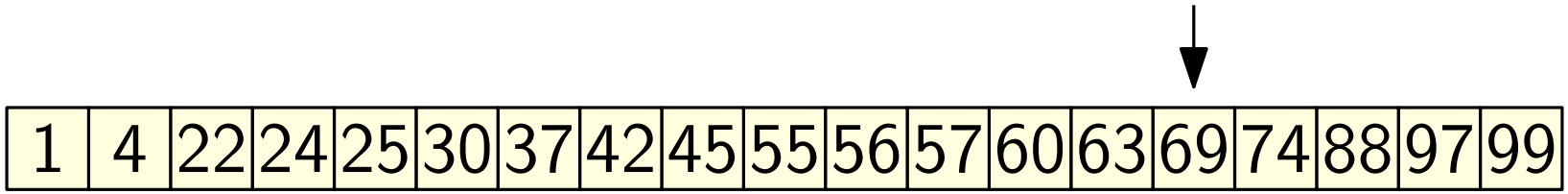
Fingersearch structure



	Query	Change-finger	Update
Static	$\mathcal{O}(q(t))$	$\mathcal{O}(q^{-1}(\log n))$	
Dynamic	$\mathcal{O}(q(t))$	$\mathcal{O}(q^{-1}(\log n)\log n)$	$\mathcal{O}(\log n)$
	$\mathcal{O}(\log t)$	$\mathcal{O}(n^{\varepsilon})$	$\mathcal{O}(\log n)$

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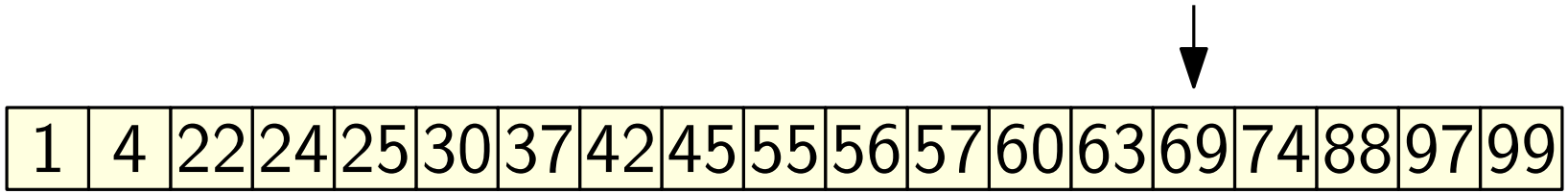
Fingersearch structure



	Query	Change-finger	Update
Static	$\mathcal{O}(q(t))^*$	$\mathcal{O}(q^{-1}(\log n))^*$	
Dynamic	$\mathcal{O}(q(t))$	$\mathcal{O}(q^{-1}(\log n)\log n)$	$\mathcal{O}(\log n)$
	$\mathcal{O}(\log t)$	$\mathcal{O}(n^\varepsilon)$	$\mathcal{O}(\log n)$

Finger Search in the Implicit Model
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IAAAC 2012

Priority Queues

Insert(v) ExtractMin()

Priority Queues

	Insert(v)	ExtractMin()
Williams	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$

Priority Queues

	Insert(v)	ExtractMin()
Williams	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$

Strictly Implicit Priority Queues: On the Number of Moves and Worst-Case Time
Gerth Stølting Brodal And Jesper Sindahl Nielsen
WADS 2015

Priority Queues

	Insert(v)	ExtractMin()
Williams	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$
	$\mathcal{O}(1)^*$	$\mathcal{O}(\log n)^*$

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Priority Queues

	Insert(v)	ExtractMin()
Williams	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$
	$\mathcal{O}(1)^*$	$\mathcal{O}(\log n)^*$
	$\mathcal{O}(1)$	$\mathcal{O}(\log n)$

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Priority Queues

	Insert(v)	ExtractMin()	Moves
Williams	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$
	$\mathcal{O}(1)^*$	$\mathcal{O}(\log n)^*$	$\mathcal{O}(1)^*$
	$\mathcal{O}(1)$	$\mathcal{O}(\log n)$	$\mathcal{O}(\log n)$

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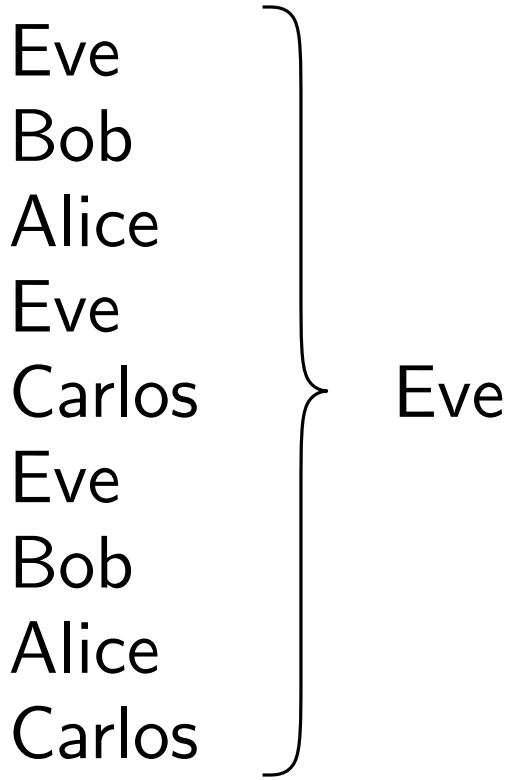
WADS 2015

Range Mode

Eve
Bob
Alice
Eve
Carlos
Eve
Bob
Alice
Carlos

Range Mode



Range Mode

Eve
Bob
Alice
Eve
Carlos
Eve
Bob
Alice
Carlos

} Carlos

Range Mode

Eve
Bob
Alice } Bob
Eve
Carlos
Eve
Bob
Alice
Carlos

Range Mode

Cell Probe Lower Bounds and Approximations for Range Mode
Mark Greve, Allan G. Jørgensen and Kasper G. Larsen
ICALP 2010

Range Mode

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	Query	Space
3-approximation	$\mathcal{O}(1)$	$\mathcal{O}(n)$

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$(1+\varepsilon)$-approximation	$\mathcal{O}(\log \frac{1}{\varepsilon})$	$\mathcal{O}(\frac{n}{\varepsilon})$

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Lowerbound $\Omega\left(\frac{\log n}{\log(Sw/n)}\right)$

Summary

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Theory

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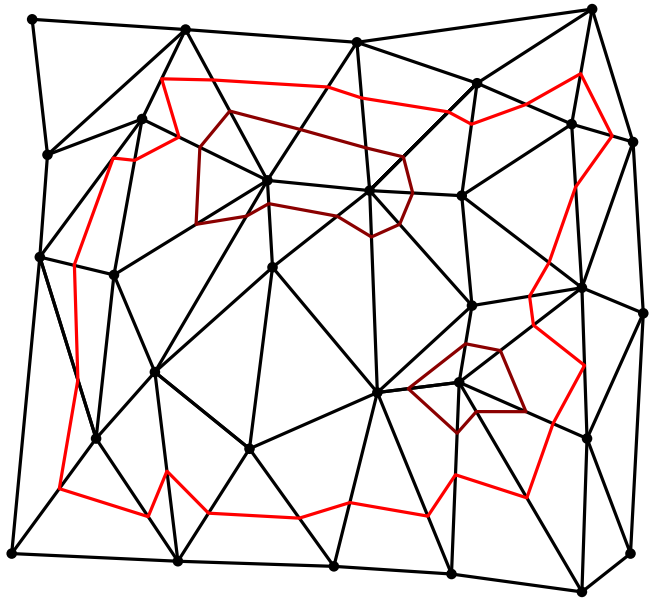
Simplifying massive planar decompositions
Alenex 2014 Lars Arge, Jakob Truelsen, Jungwoo Yang

Thank You!

Decomposition Simplification

Decomposition Simplification



Lower Bounds

Let A be an operation running in time τ worst case. Then there exists a set $\mathcal{X}$ of size 2^τ, such that executing A will touch only cells from $\mathcal{X}$.

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Fingersearch
Quiry time $q(t) \Rightarrow$ change-finger time $\Omega(q^{-1}(\log n))$.