Karlsruhe Institute of Technology

Towards Negative Cycle Canceling in Wind Farm Cable Layout Optimization

[Gritzbach et al., 2018]

Seminar Energieinformatik · December 11, 2018

Sascha Gritzbach, T. Ueckerdt, D. Wagner, F. Wegner, and M. Wolf

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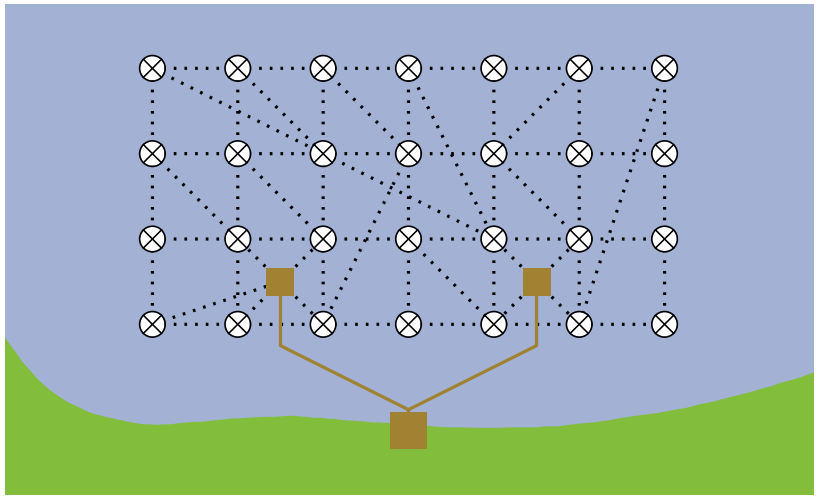

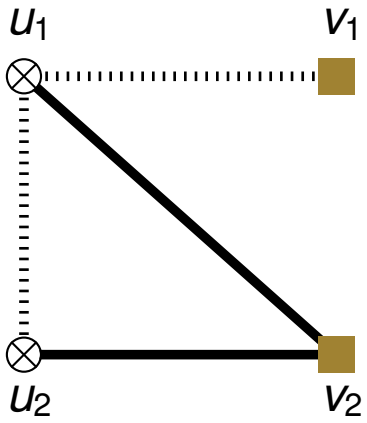

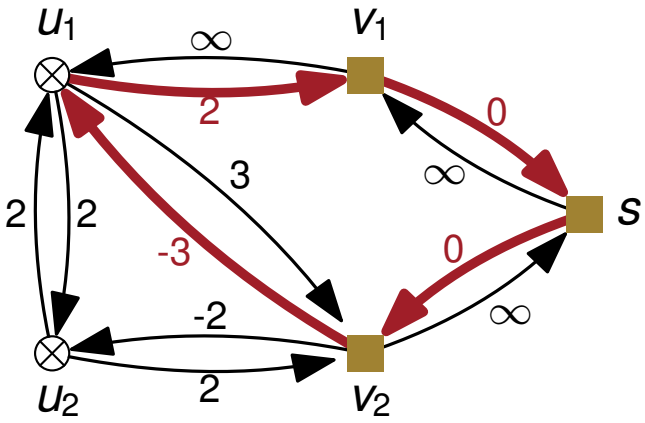

Introduction

- EU28 (2016): 30.2 % of gross electricity generation from renewables, out of which 39.9 % from wind [1]
- Offshore wind farm: 17 % of total planning and building cost for internal cabling [2]

[1] *Energy datasheets: EU28 countries*. European Commission DG ENER Unit A4, 2018.
[2] P. Santos Valverde, A. J. N. A. Sarmento, M. Alves. Offshore wind farm layout optimization – state of the art. *Journal of Ocean and Wind Energy*, 1(1):23–29, 2014.

Introduction

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Our contribution:

- Fast algorithm to find good wind farm cablings

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Outline

- Wind Farm Cabling Problem
- Network Flows and Negative Cycle Canceling
- Our Algorithm
- Evaluation
- Outlook

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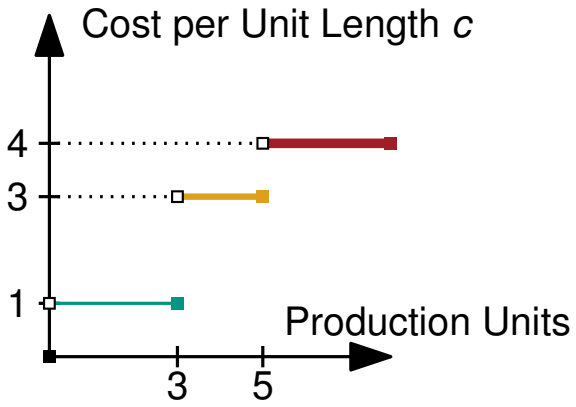
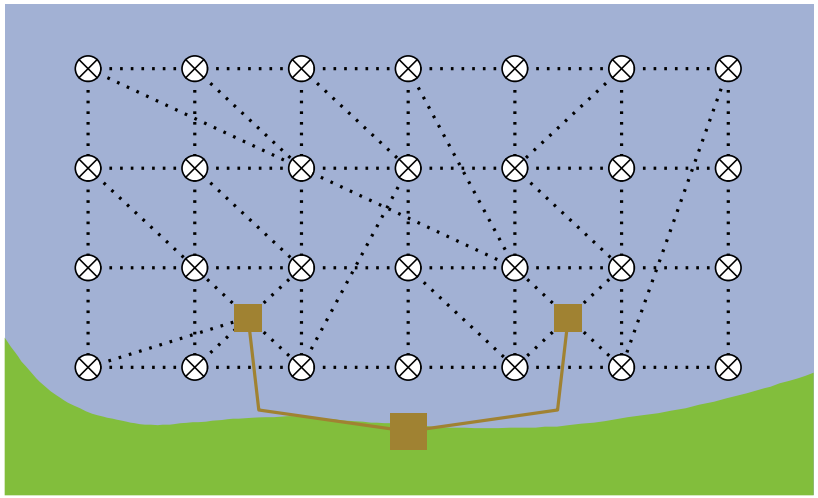
Optimization Problem

Given

- turbines (unit production)
- substations (each with **capacity**)
- edge set: possible connections
- cable types (**cost** and **capacity**)





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Optimization Problem

Given
- ⊗ turbines (unit production)
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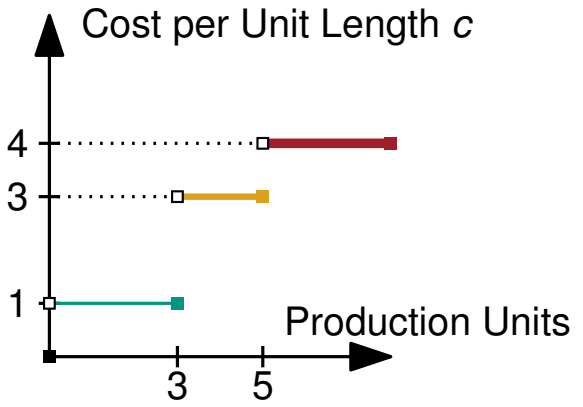
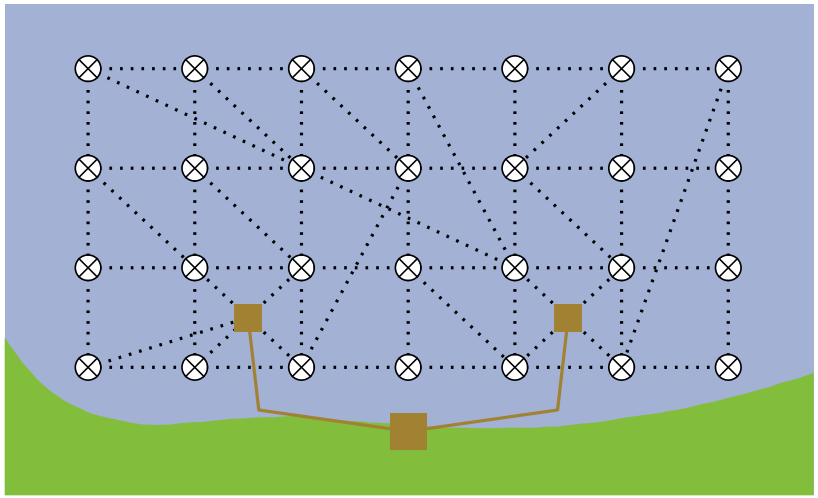
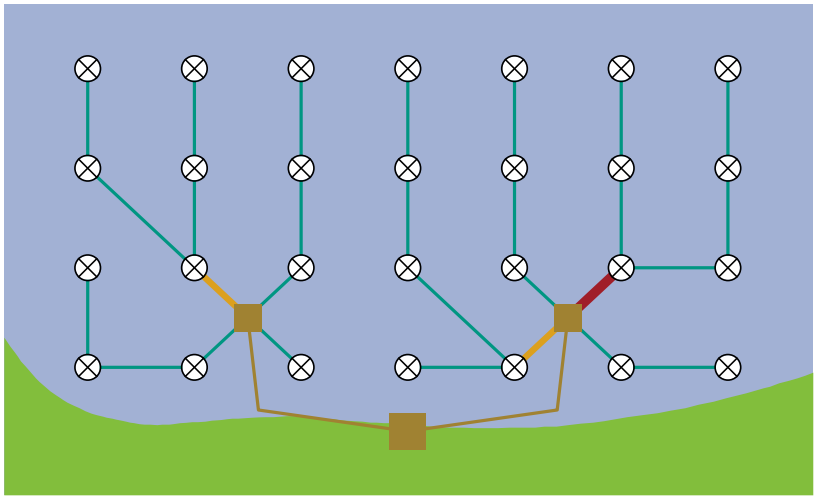
find — for each edge: the **cable type**

minimizing — **total cable cost**



$$\sum_{e\text{: edge}} c(e) \cdot \text{length}(e)$$





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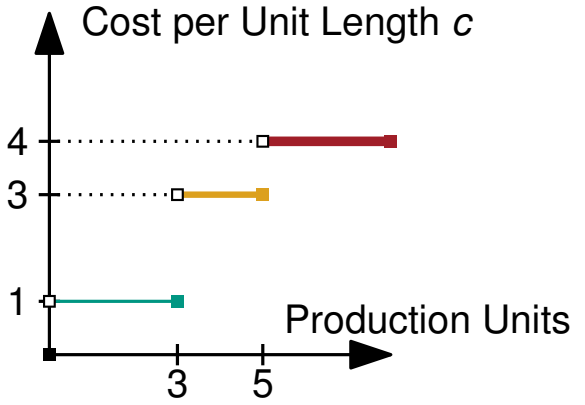
Optimization Problem

Given	⊗	turbines (unit production)
	■	substations (each with **capacity**)
	·····	edge set: possible connections
	═	cable types (**cost** and **capacity**)
find		for each edge: the **cable type**
minimizing		**total cable cost**
subject to		cable capacity constraints
		substation capacity constraints
		flow conservation constraints



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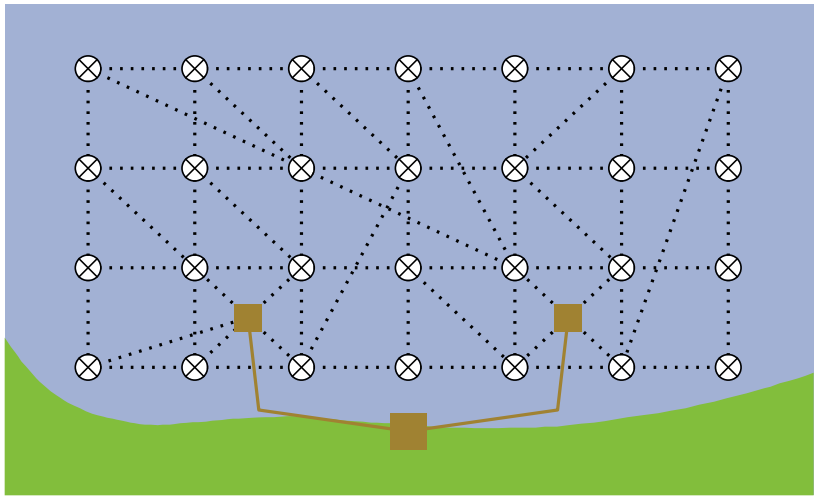

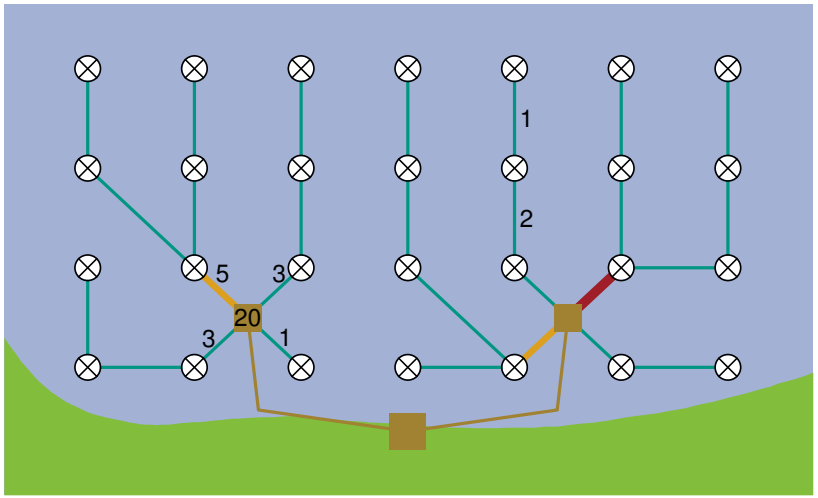

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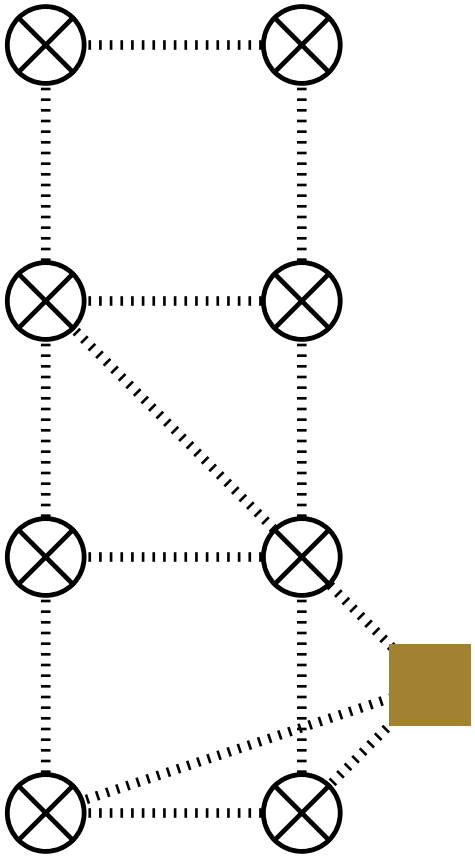
Network Flows and Wind Farm Cabling



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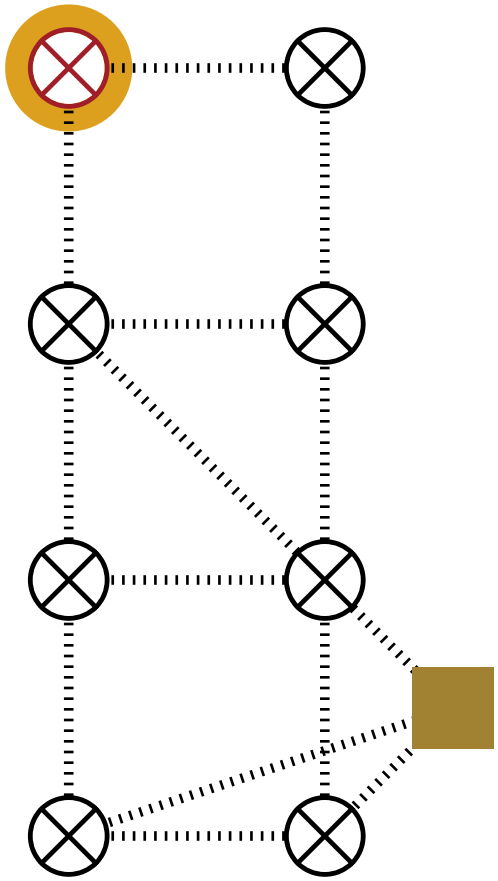

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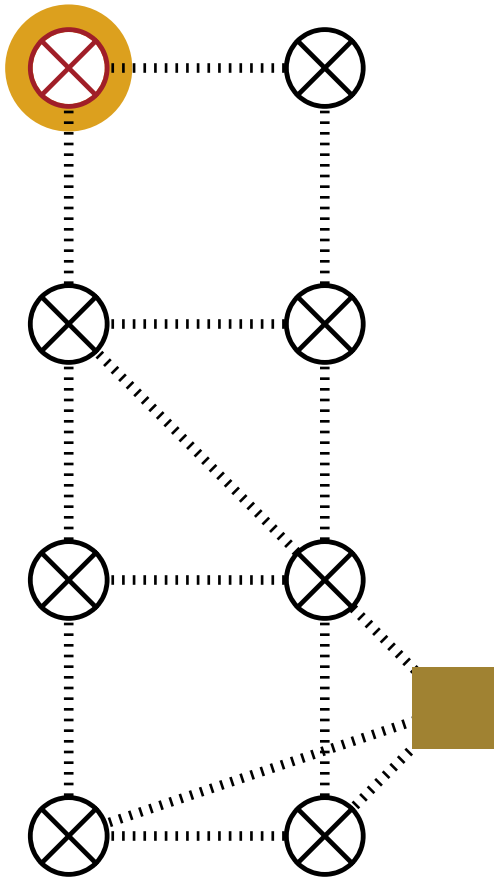

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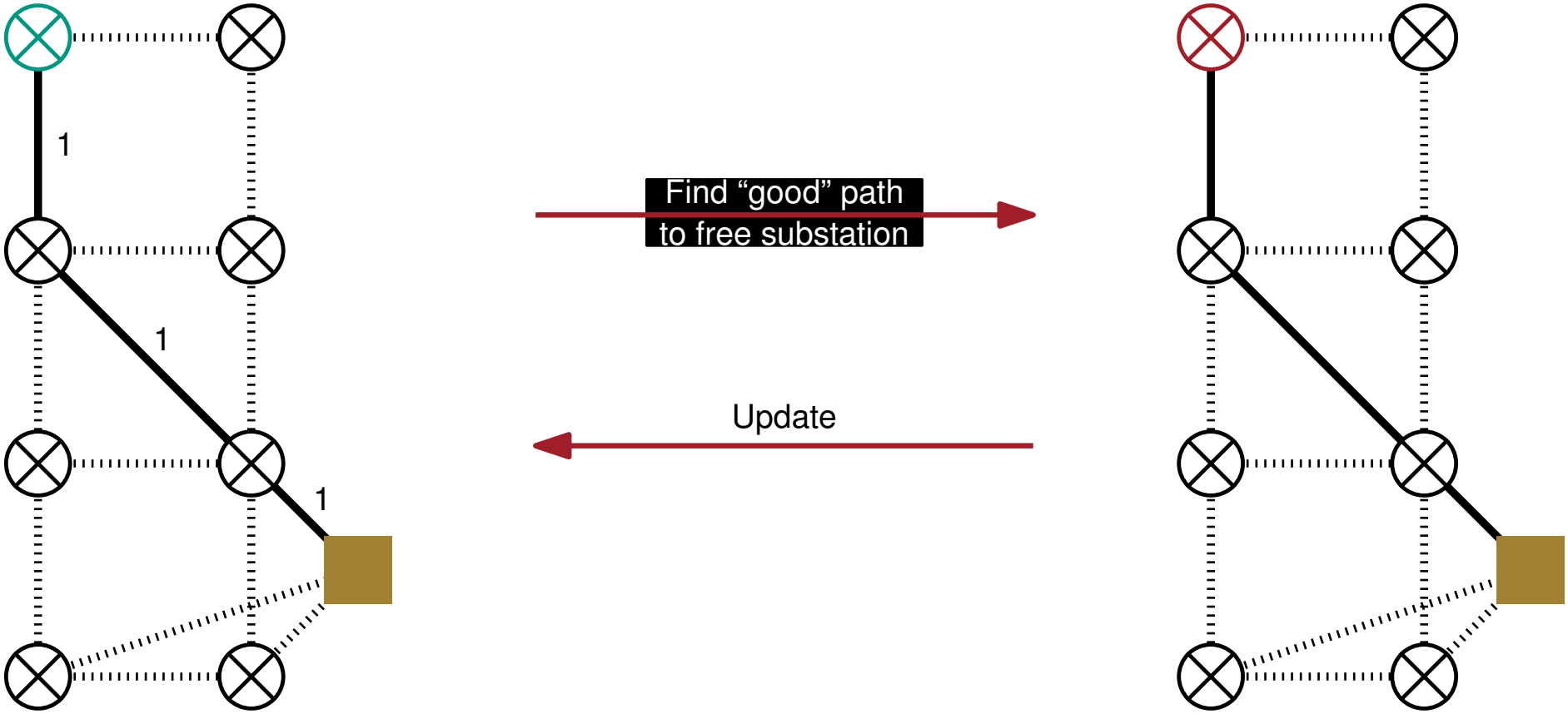

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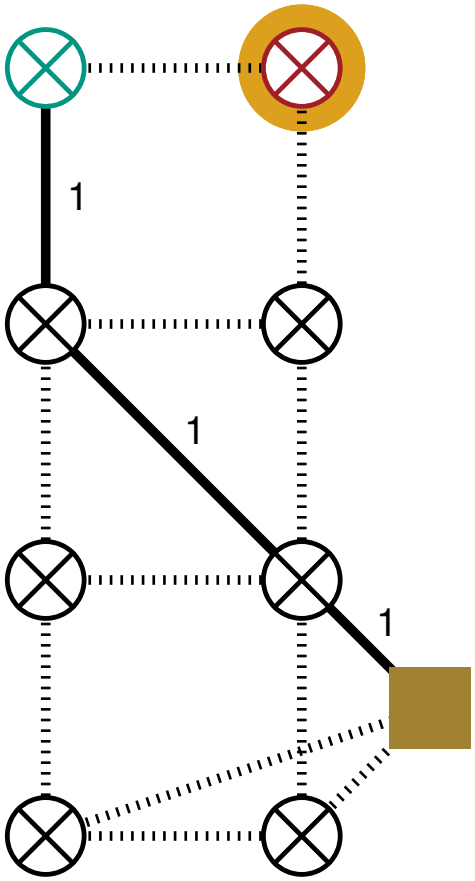
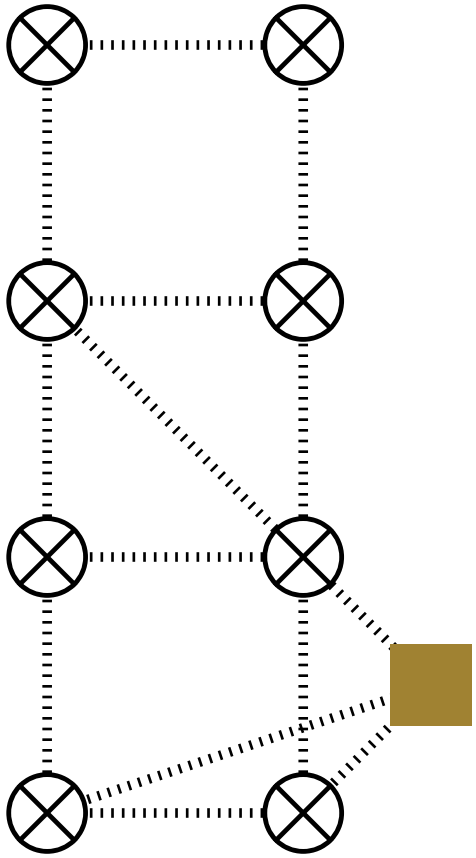


Find “good” path
to free substation

Update



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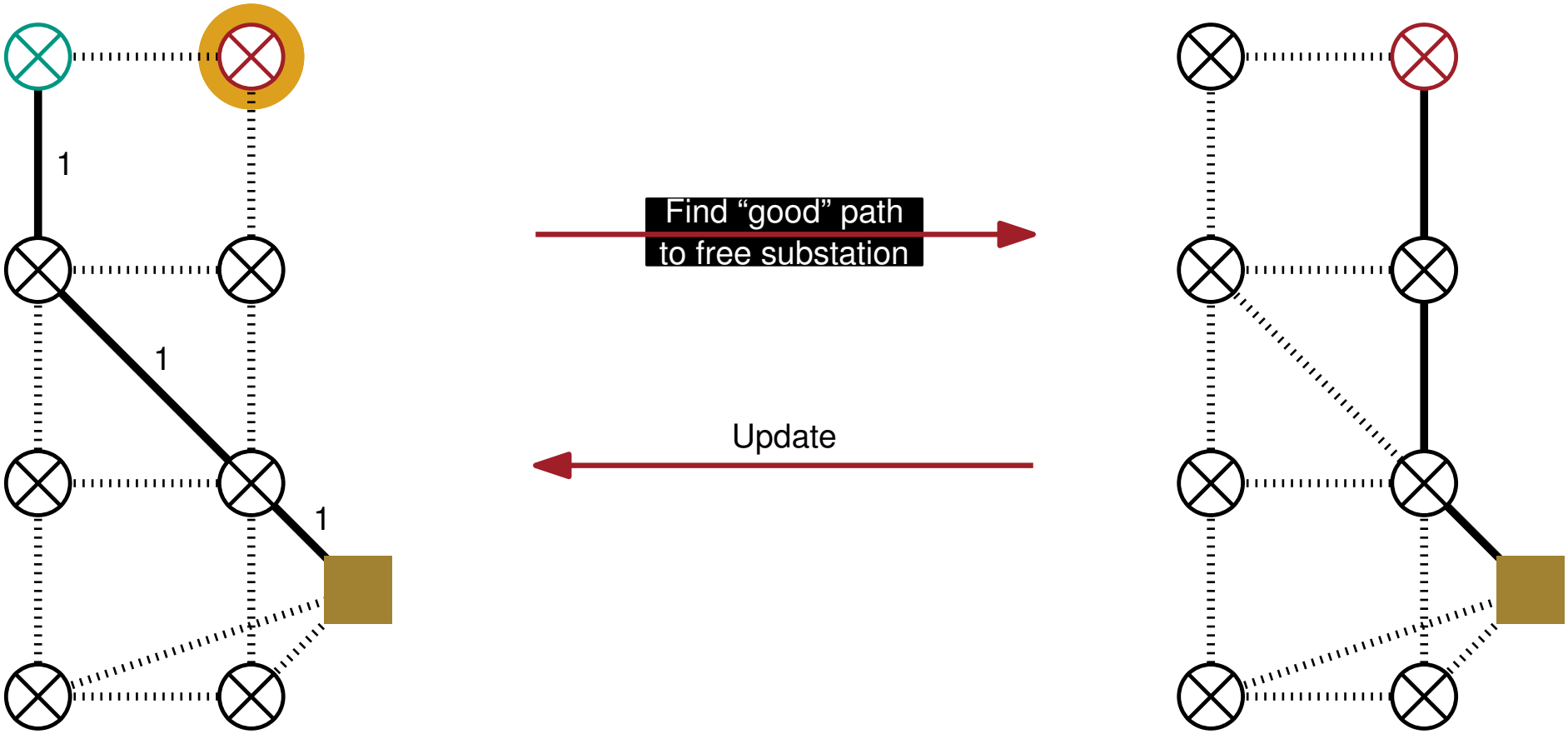

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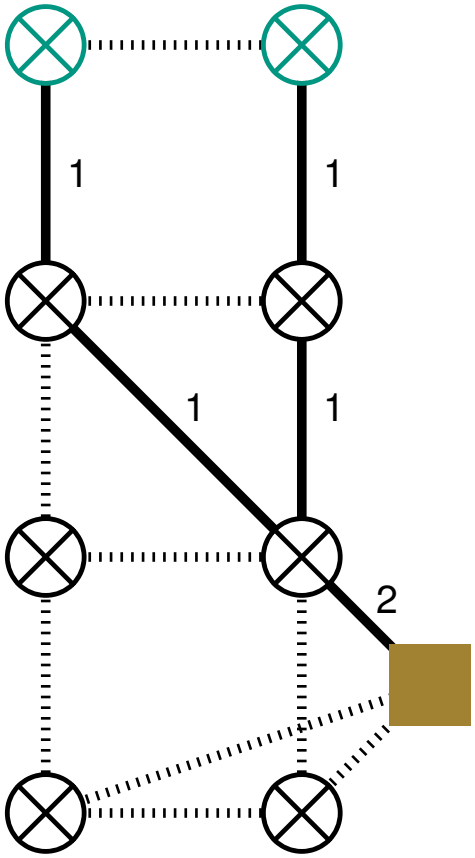

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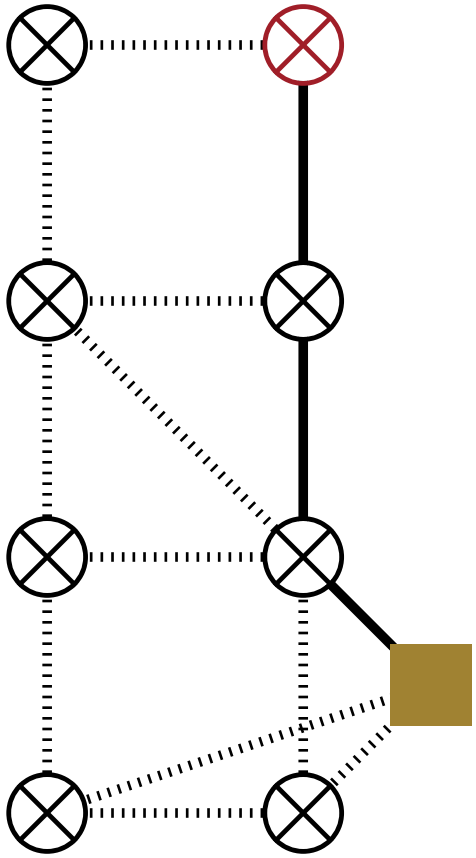

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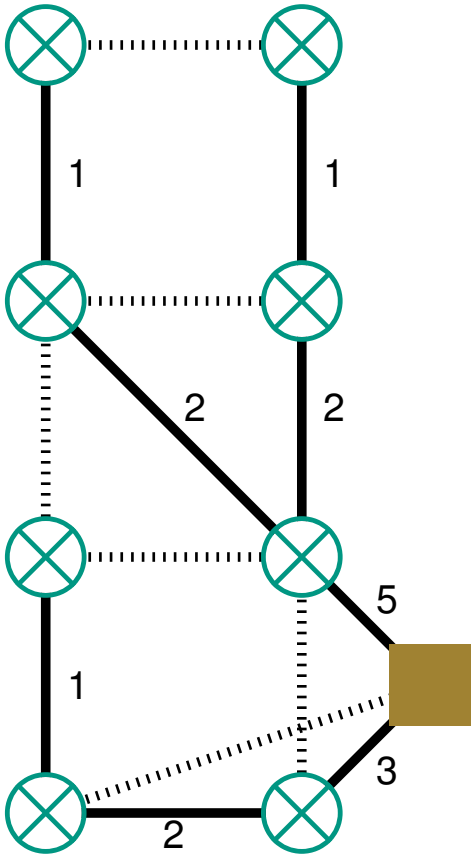

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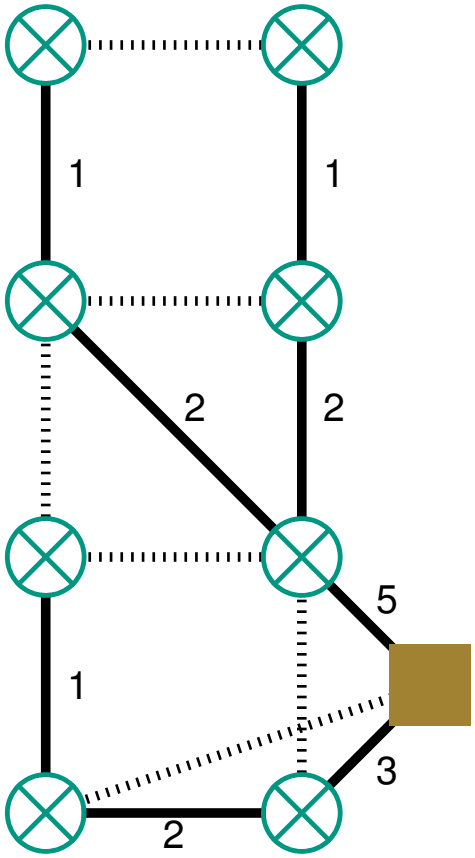

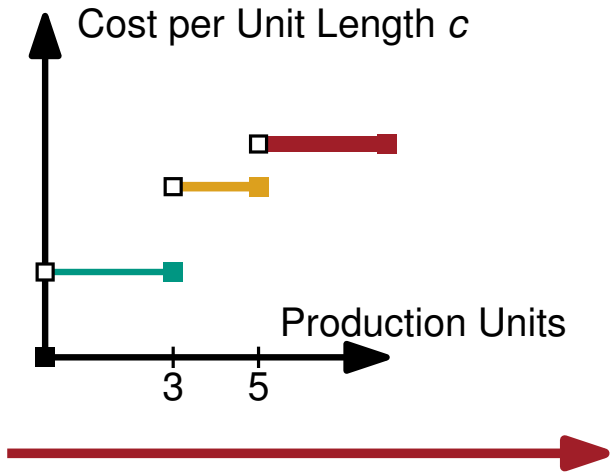

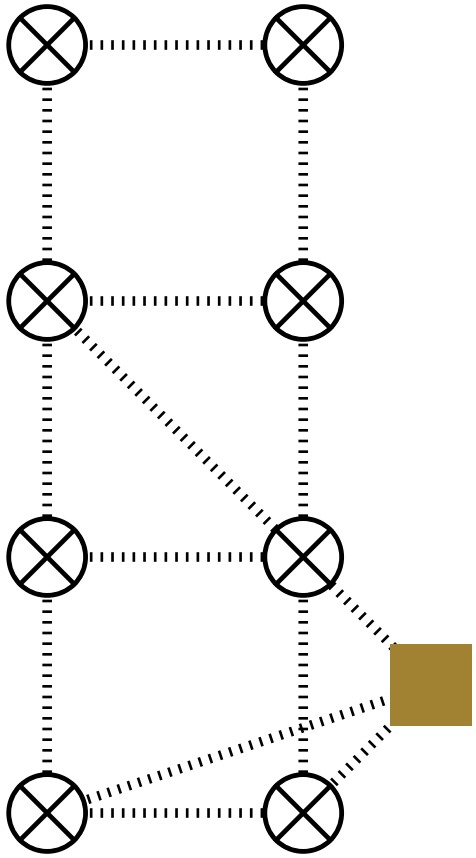

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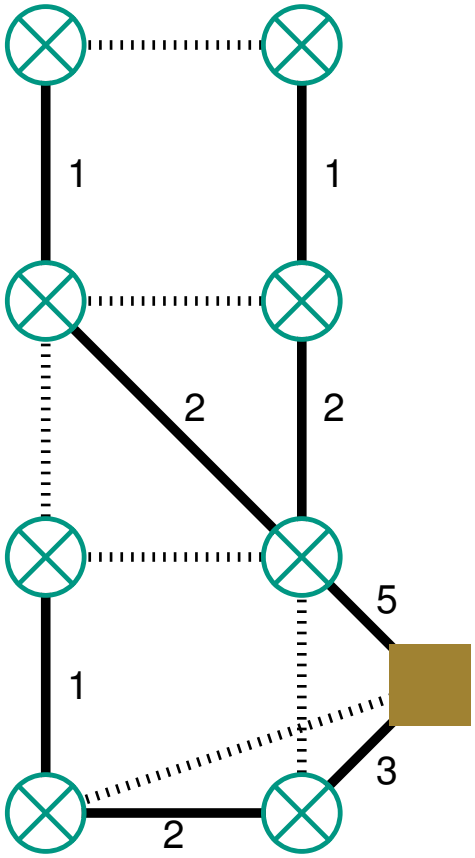

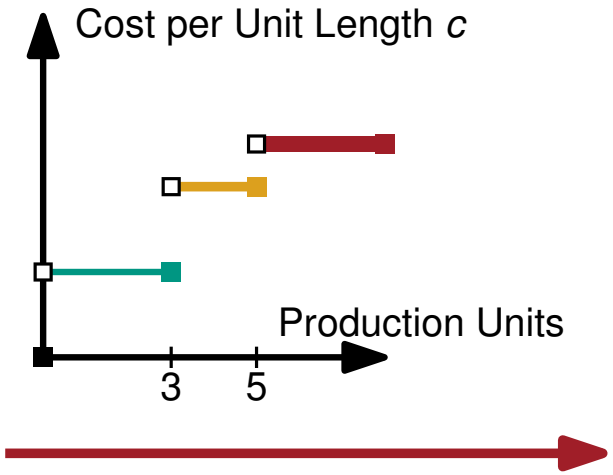

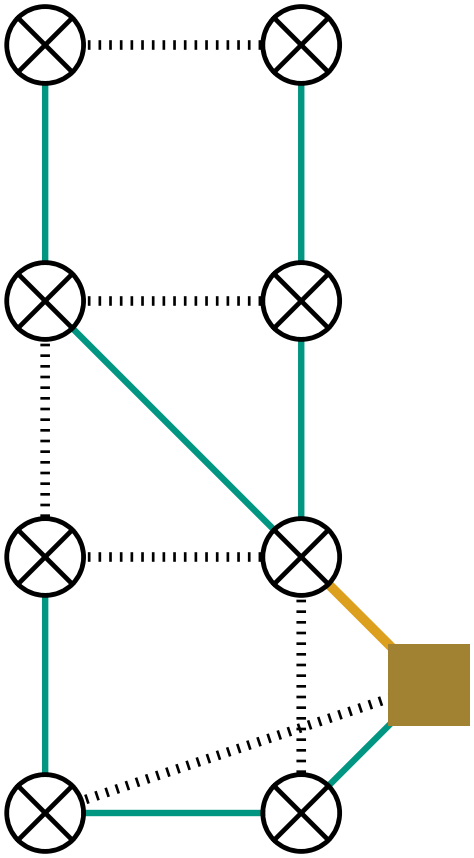

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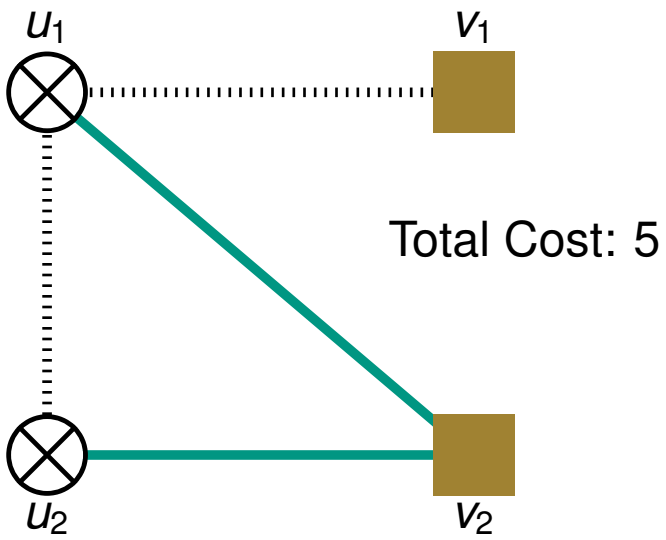
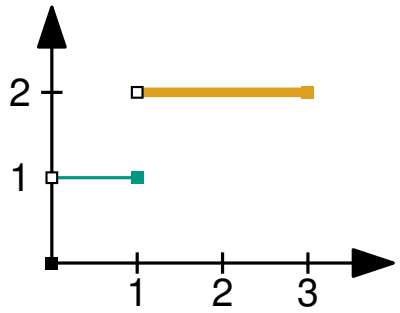
Negative Cycle Canceling



- Substation capacity: 2
- Edge lengths: 2 (edge $u_1 v_2$: 3)
- Cable types:



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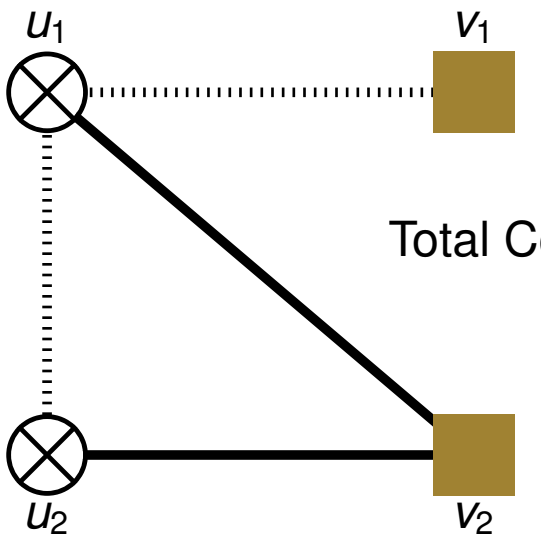
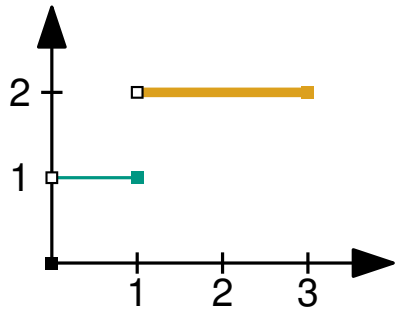
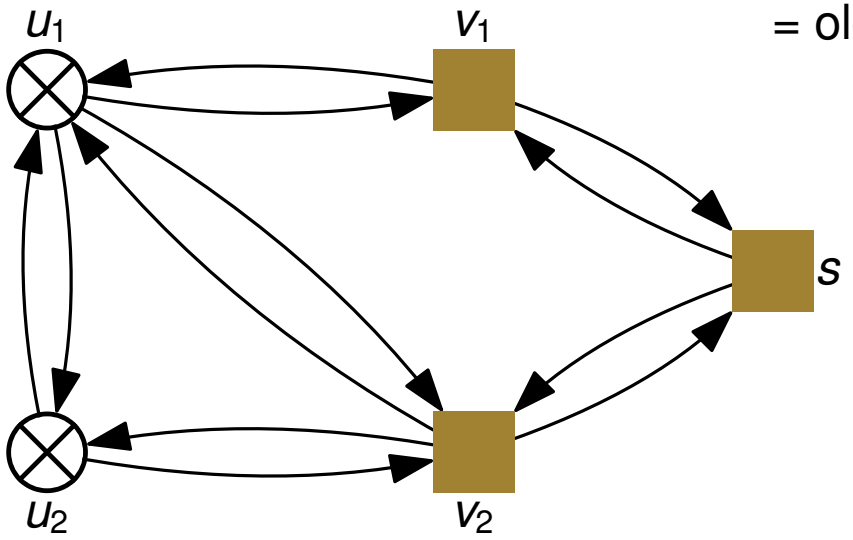


Total Cost: 5

- Substation capacity: 2
- Edge lengths: 2 (edge $u_1 v_2$: 3)
- Cable types:



Find edge weights for change of flow $\Delta = 1$
= old cost - new cost



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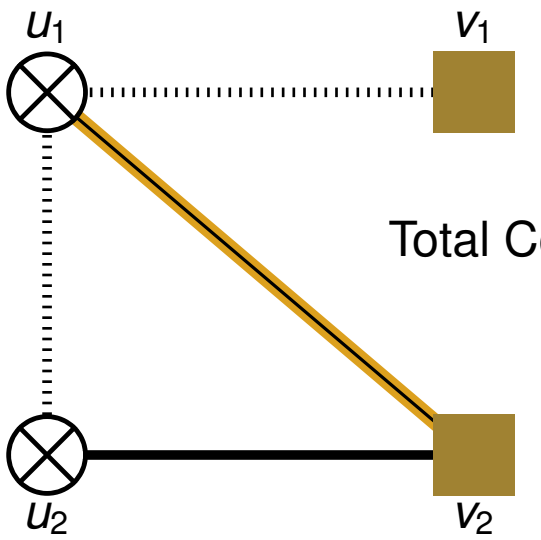

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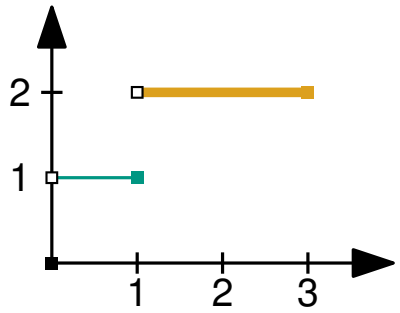

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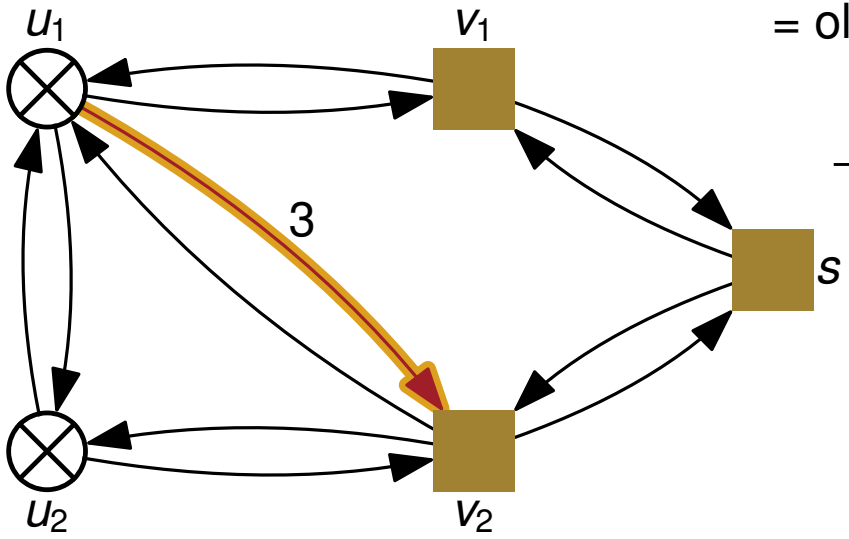

old flow	old cost
1	3

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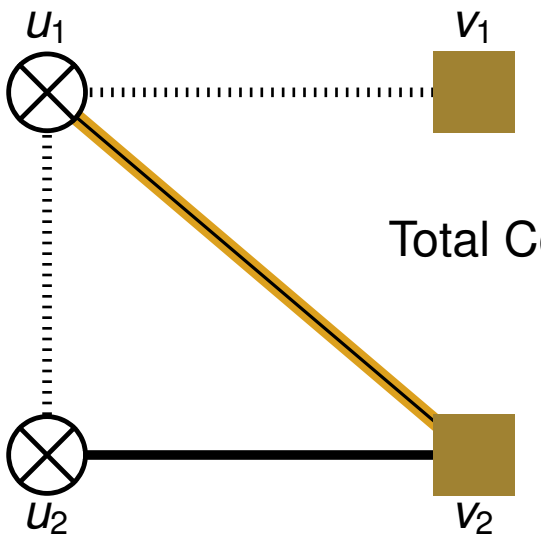
Negative Cycle Canceling



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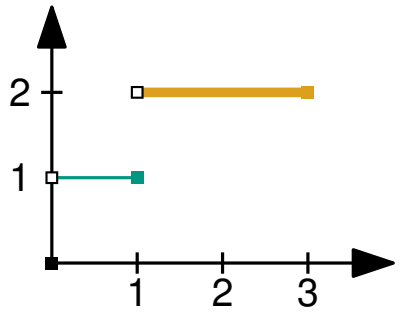

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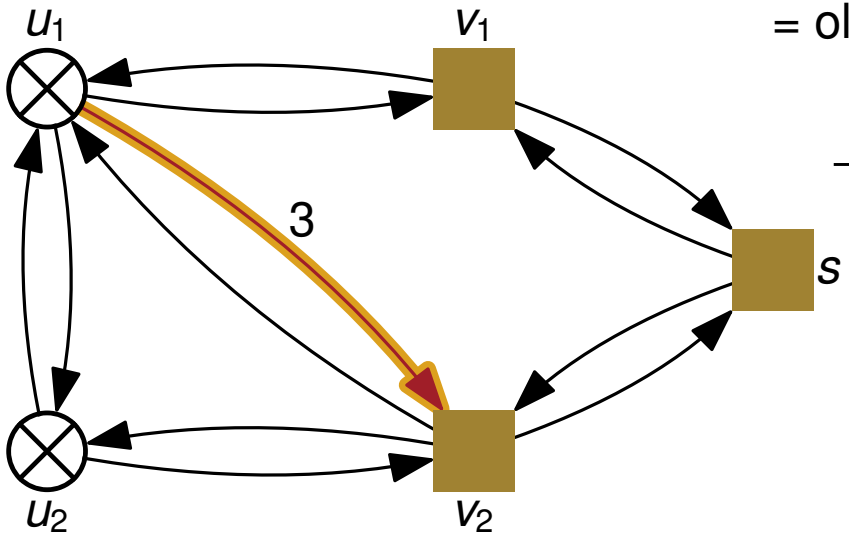

old flow	old cost	new flow	new cost
1	3	2	6

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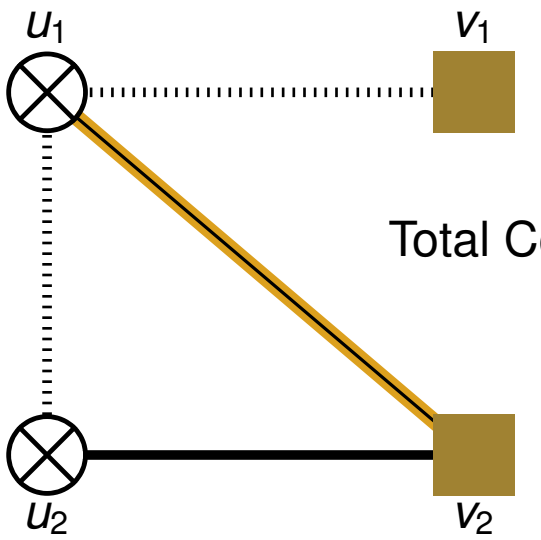
Negative Cycle Canceling



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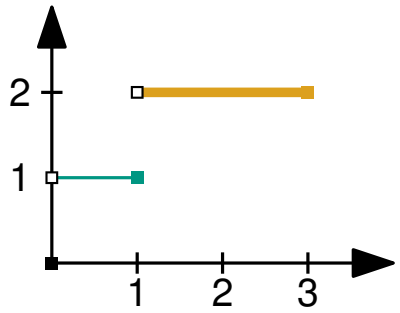

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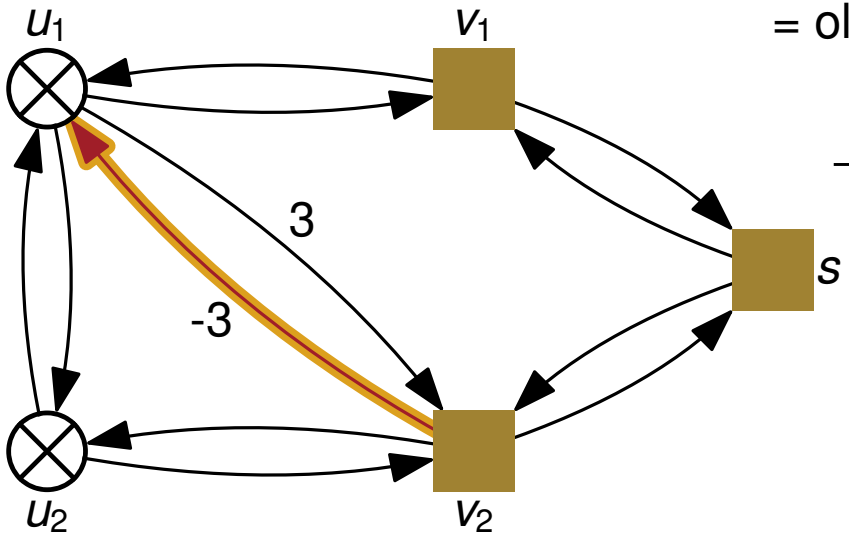

old flow	old cost	new flow	new cost
1	3	2	6
1	3	0	0

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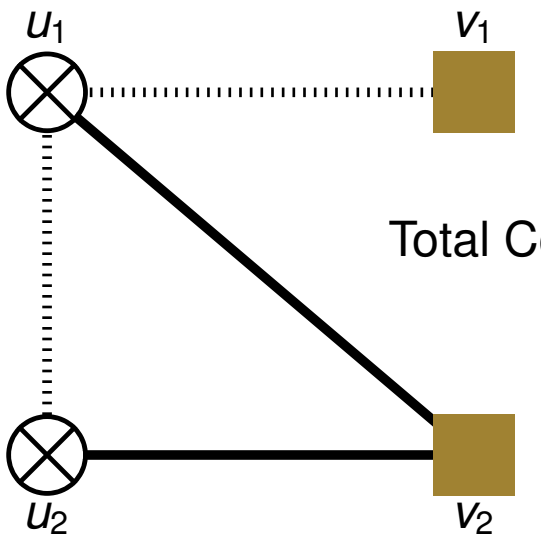

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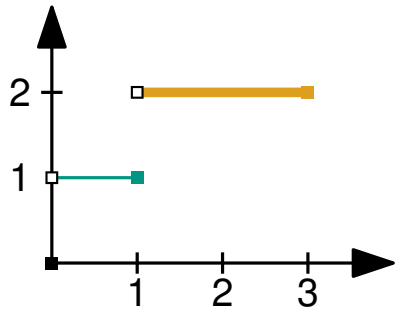

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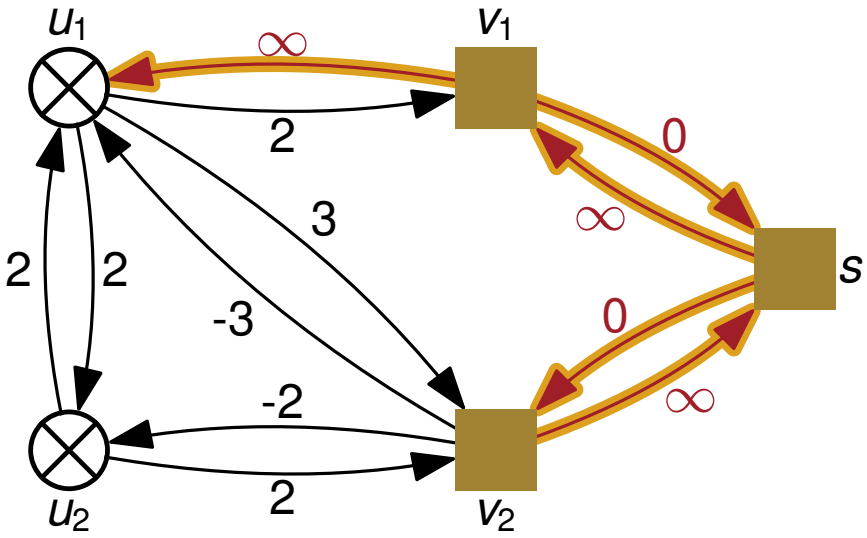

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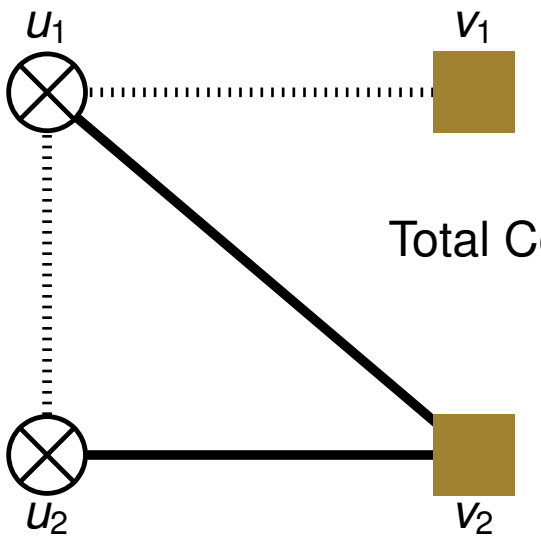

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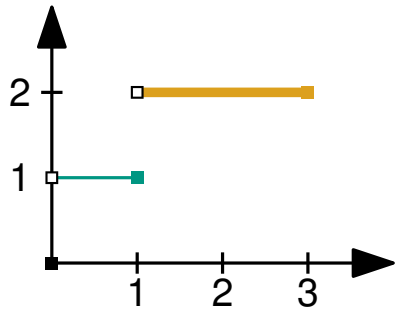

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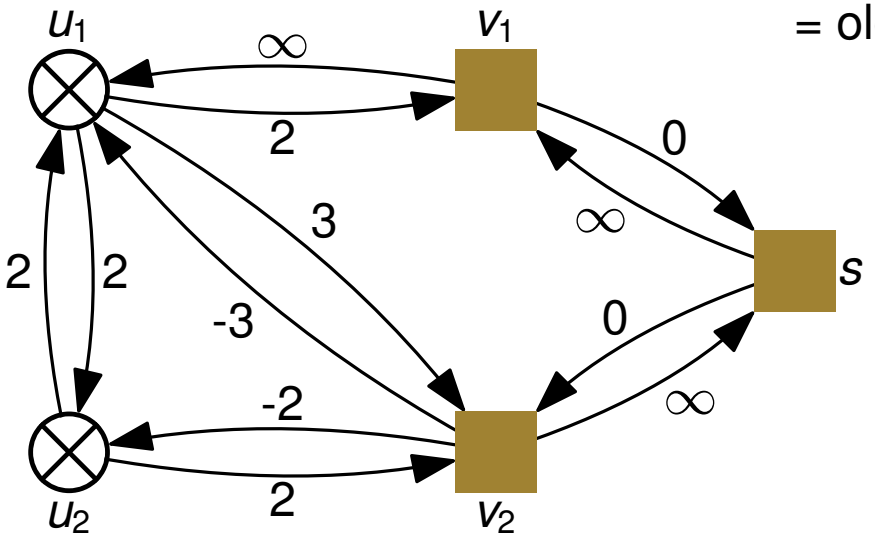

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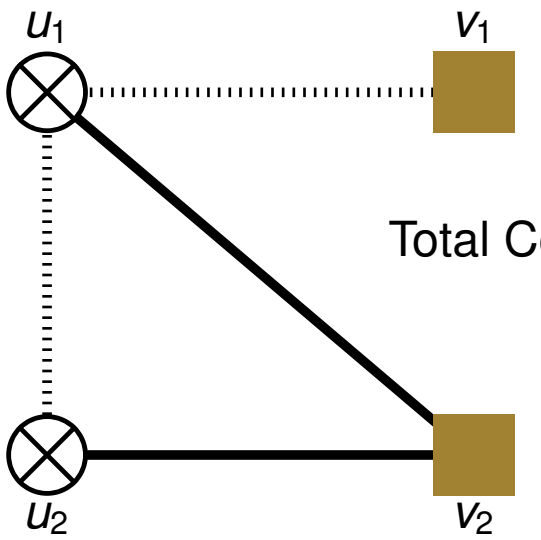

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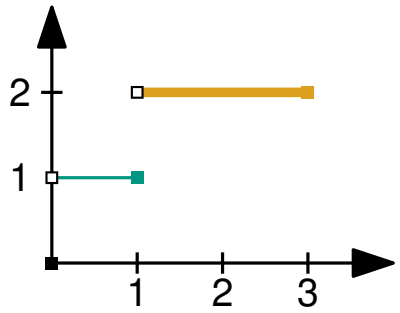
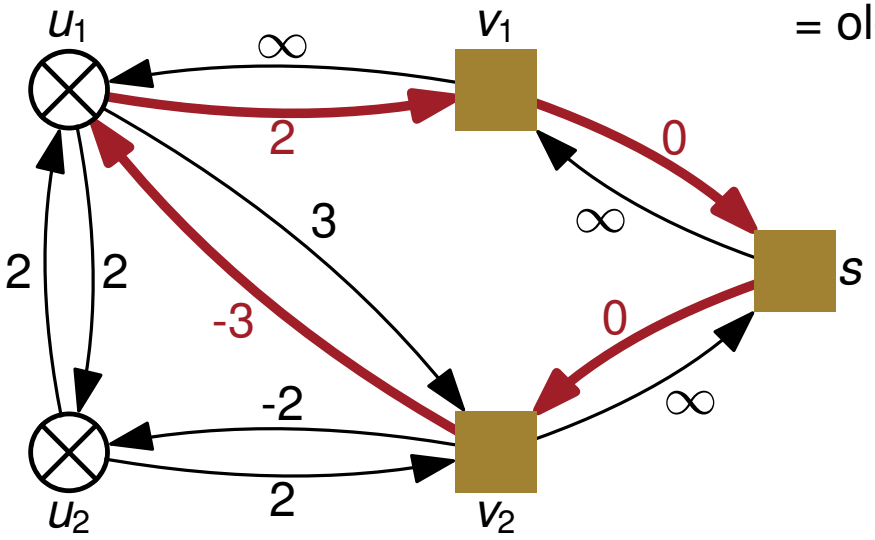


edge weights for change of flow $\Delta = 1$
= old cost - new cost



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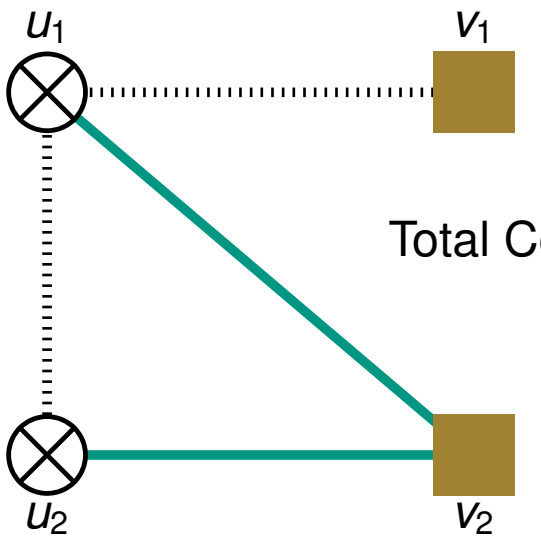
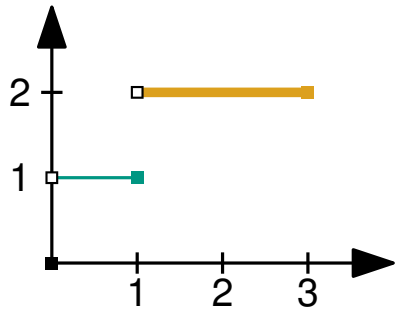
Negative Cycle Canceling

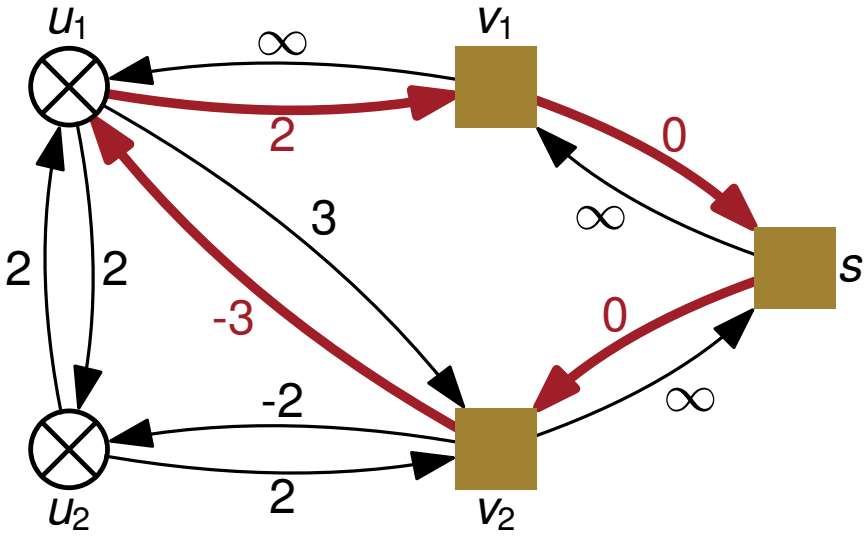


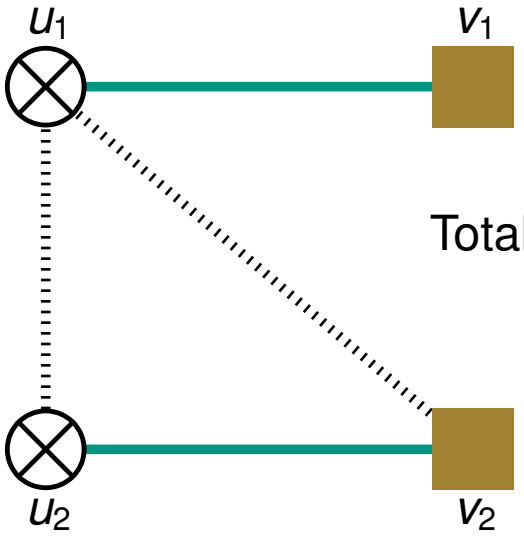
Total Cost: 5

- Substation capacity: 2
- Edge lengths: 2 (edge $u_1 v_2$: 3)
- Cable types:



edge weights for change of flow $\Delta = 1$





Total Cost: 4

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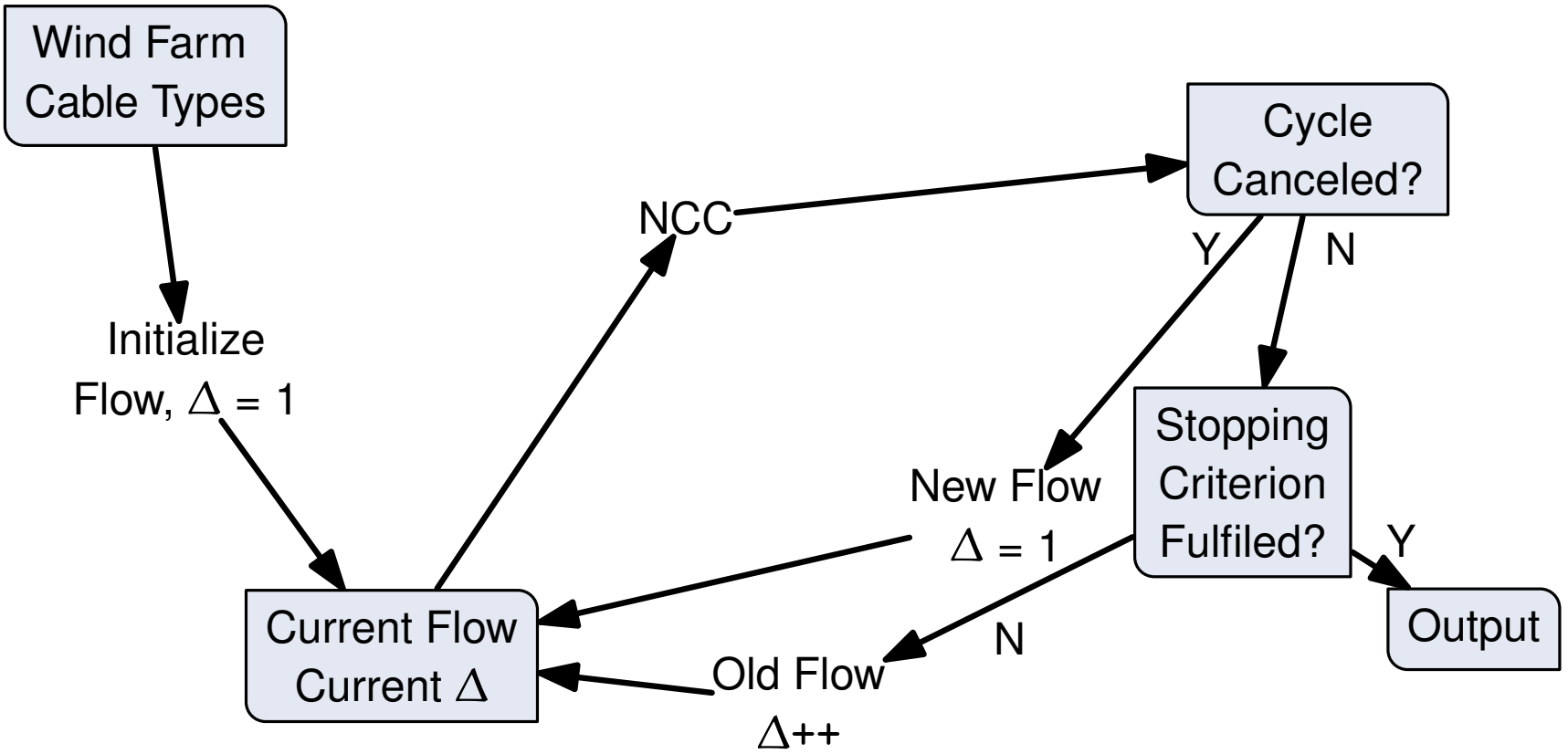
Algorithm



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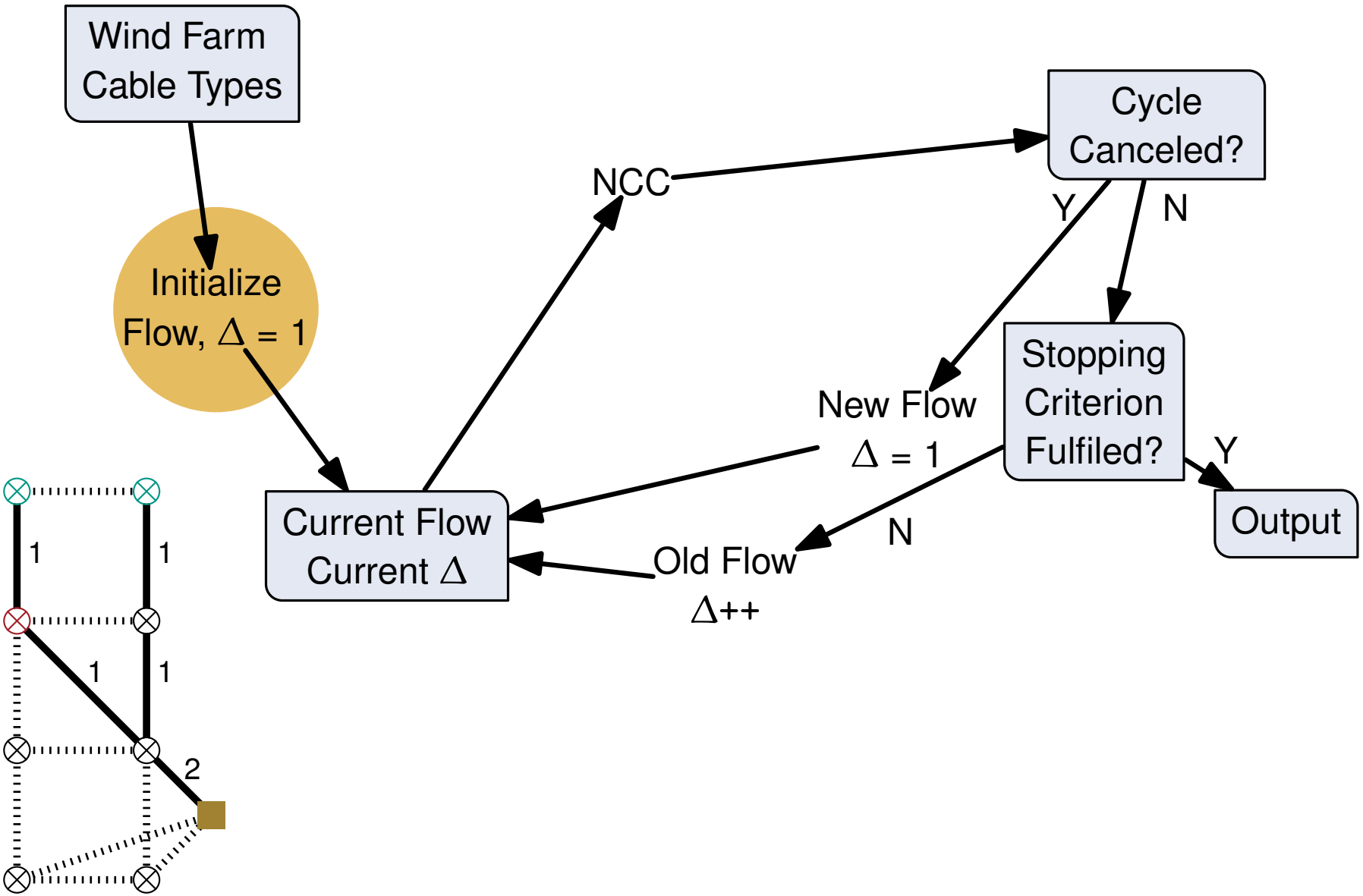
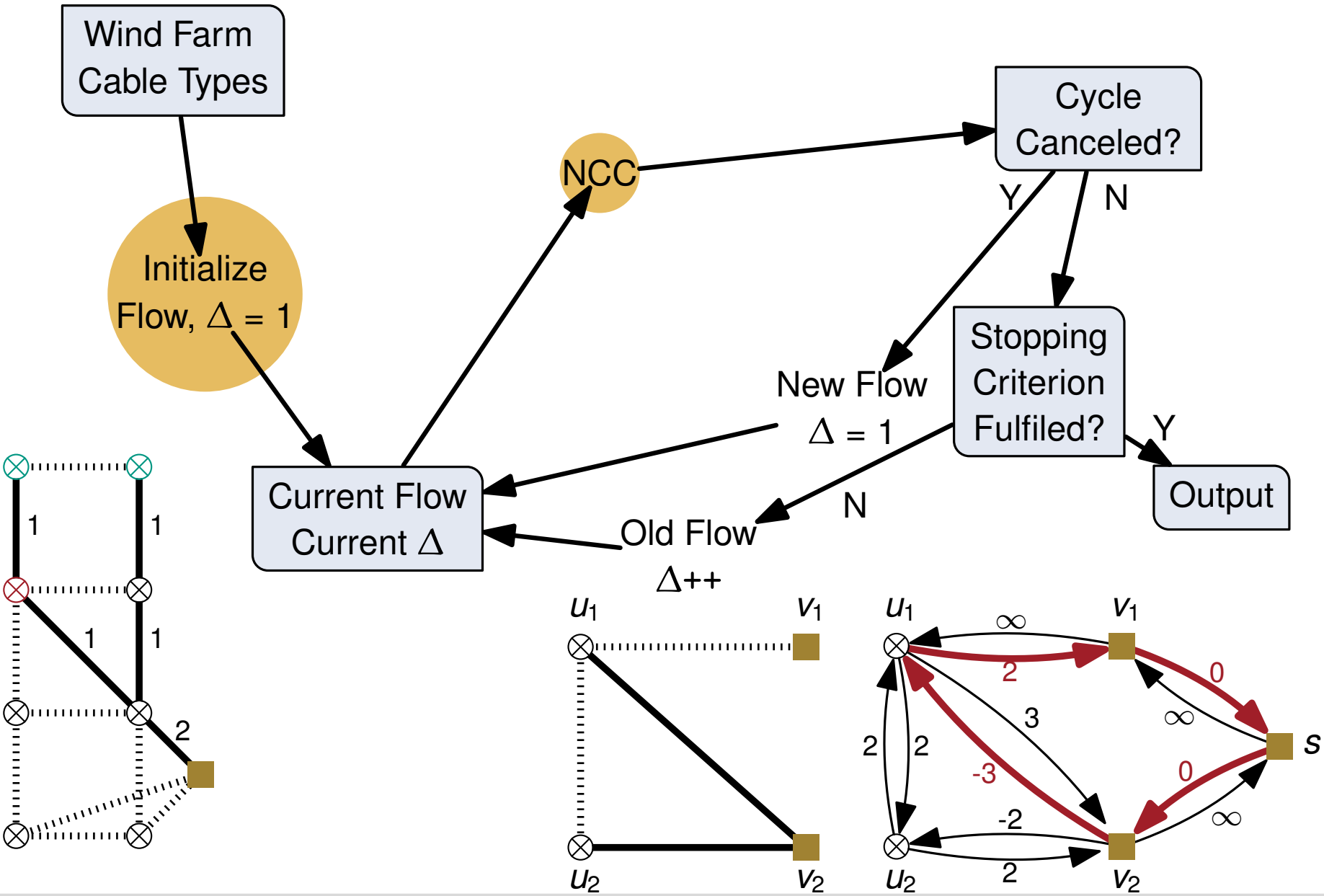
Algorithm


Wind Farm
Cable Types
Initialize
Flow, Δ = 1
Current Flow
Current Δ
NCC
Cycle
Canceled?
Y
N
Stopping
Criterion
Fulfiled?
Y
Output
N
New Flow
Δ = 1
Old Flow
Δ++
1
1
1
1
2

Algorithm



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Simulations

- Code in C++14
- Gurobi 7.0.2
- Benchmark sets by Lehmann et al. [3]:

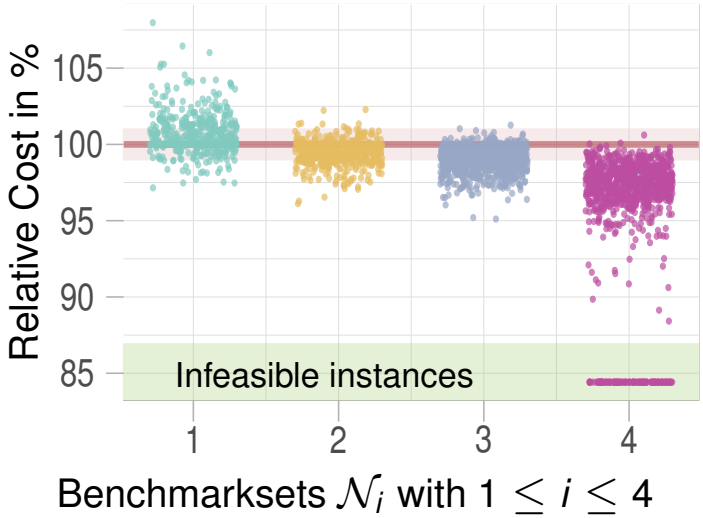
Benchmark Set	$\lvert V_T \rvert$	$\lvert V_S \rvert$	$\frac{\lvert V_T \rvert}{\lvert V_S \rvert}$	$\lvert \mathcal{N}_i \rvert$
$\mathcal{N}_1$ single	10–79	1		500
$\mathcal{N}_2$ small	20–79	2–7	10–20	500
$\mathcal{N}_3$ medium	80–180	4–9	10–20	1000
$\mathcal{N}_4$ large	200–499	10–39	10–50	1000

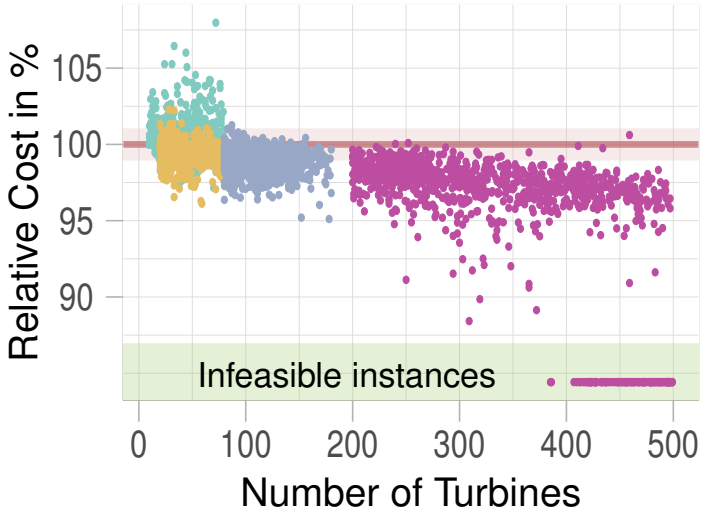
- Running times – Gurobi: 1 hour, our algorithm: until termination

[3] S. Lehmann, I. Rutter, D. Wagner, F. Wegner. A Simulated-Annealing-Based Approach for Wind Farm Cabling. *Proceedings of the 8th ACM e-Energy International Conference on Future Energy Systems (ACM eEnergy '17)*, p. 203–215, ACM Press, 2017.

Evaluation

- Comparison to Gurobi:





- Running times:

$\mathcal{N}_i$	Time in ms (min)	(avg)	(max)
1	0.72	40.63	293.42
2	3.77	51.72	220.92
3	157.69	575.02	2 968.56
4	2 815.12	149 209.92	440 235.07

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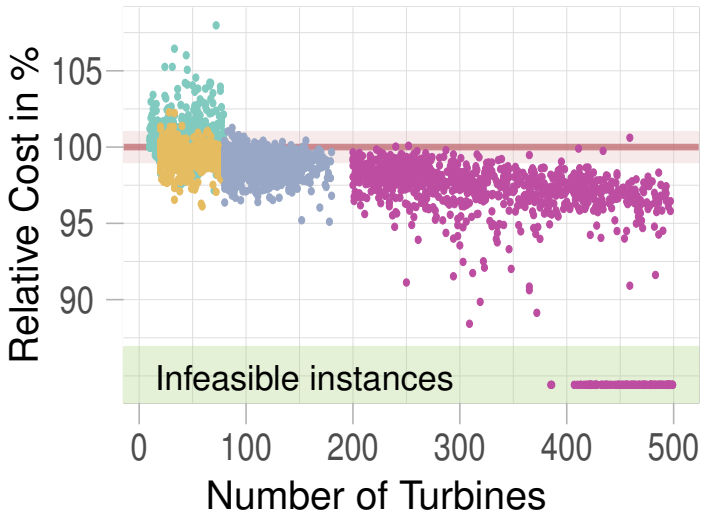
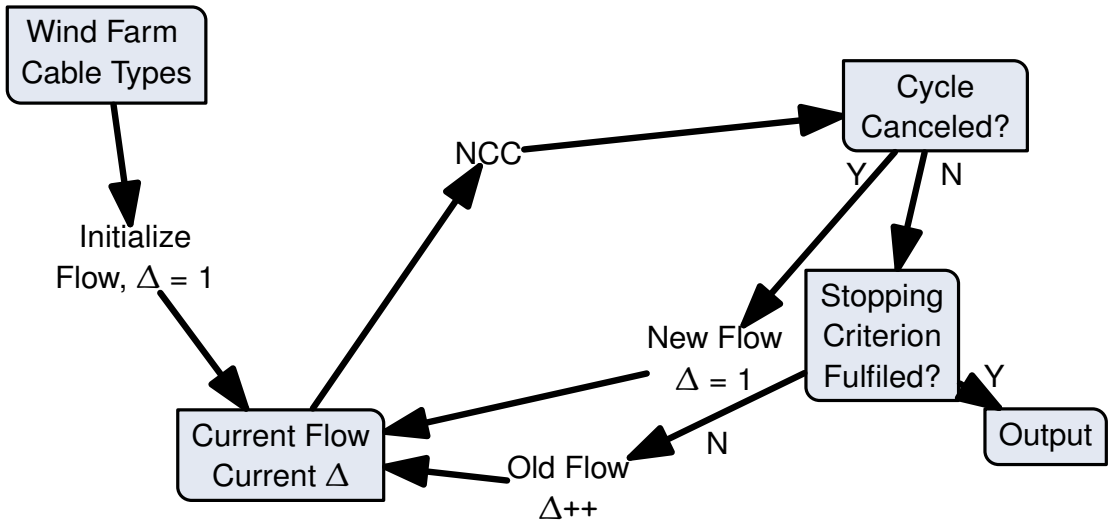
Conclusion and Outlook

Summary:

- Very fast heuristic to solve the Wind Farm Cabling Problem
- Works very well on large instances
- Allows various strategies for improvement





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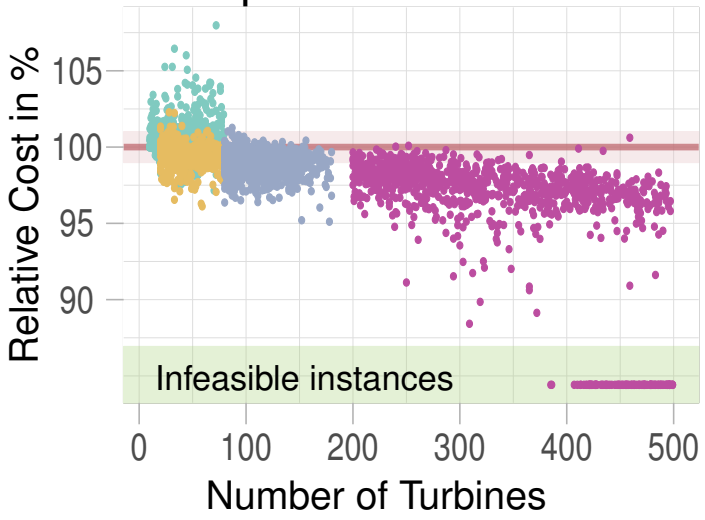
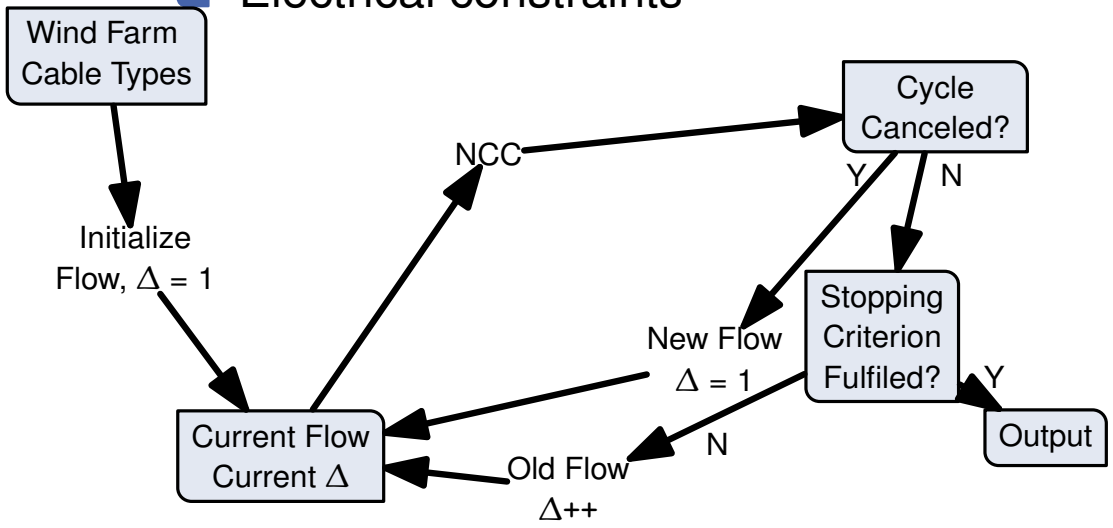
Future Work:

- Implement and test strategies
- Give Gurobi more time
- Compare to metaheuristics
- Escape local minima
- Find more complex structures
- Electrical constraints





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Thank you!

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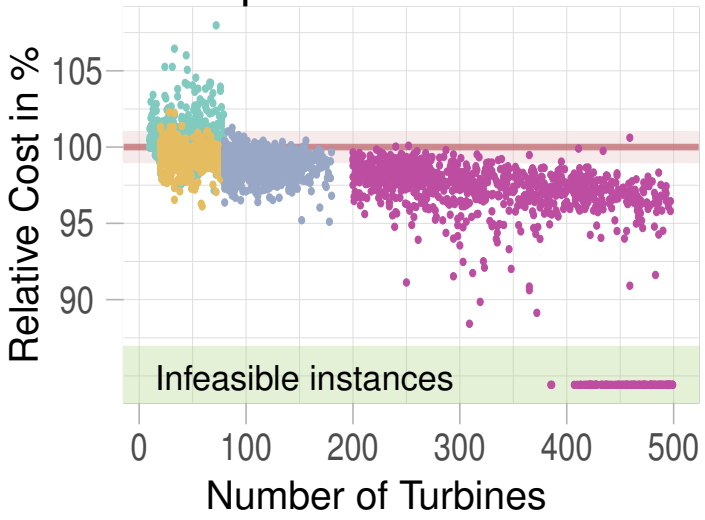

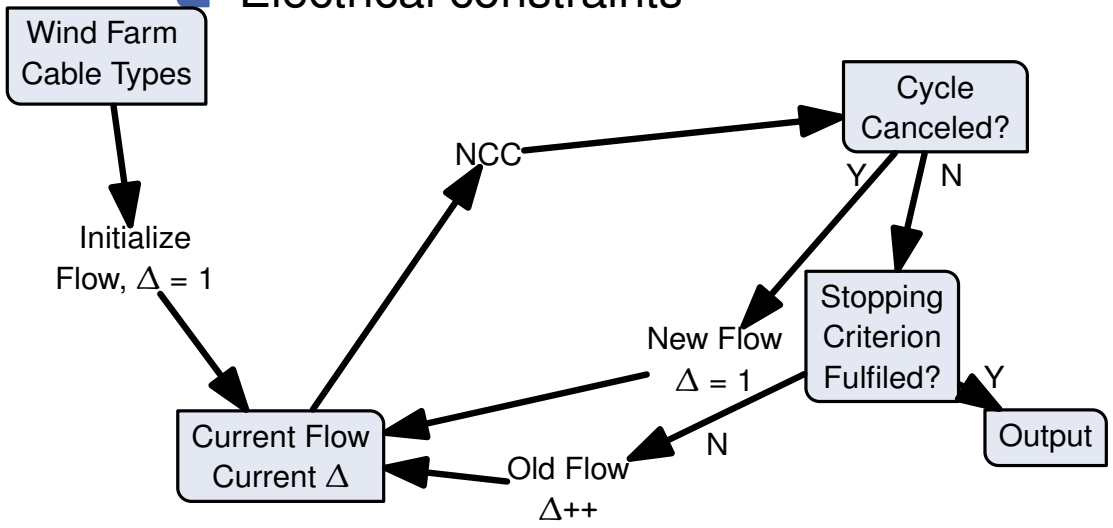

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References

[0] S. Gritzbach, T. Ueckerdt, D. Wagner, F. Wegner, M. Wolf. Towards egative cycle canceling in wind farm cable layout optimization. *Energy Informatics*, 1 (Suppl 1) :51, 2018

[1] *Energy datasheets: EU28 countries*. European Commission DG ENER Unit A4, 2018.

[2] P. Santos Valverde, A. J. N. A. Sarmento, M. Alves. Offshore wind farm layout optimization – state of the art. *Journal of Ocean and Wind Energy*, 1(1):23–29, 2014.

[3] S. Lehmann, I. Rutter, D. Wagner, F. Wegner. A Simulated-Annealing-Based Approach for Wind Farm Cabling. *Proceedings of the 8th ACM e-Energy International Conference on Future Energy Systems (ACM eEnergy '17)*, p. 203–215, ACM Press, 2017.