Karlsruhe Institute of Technology

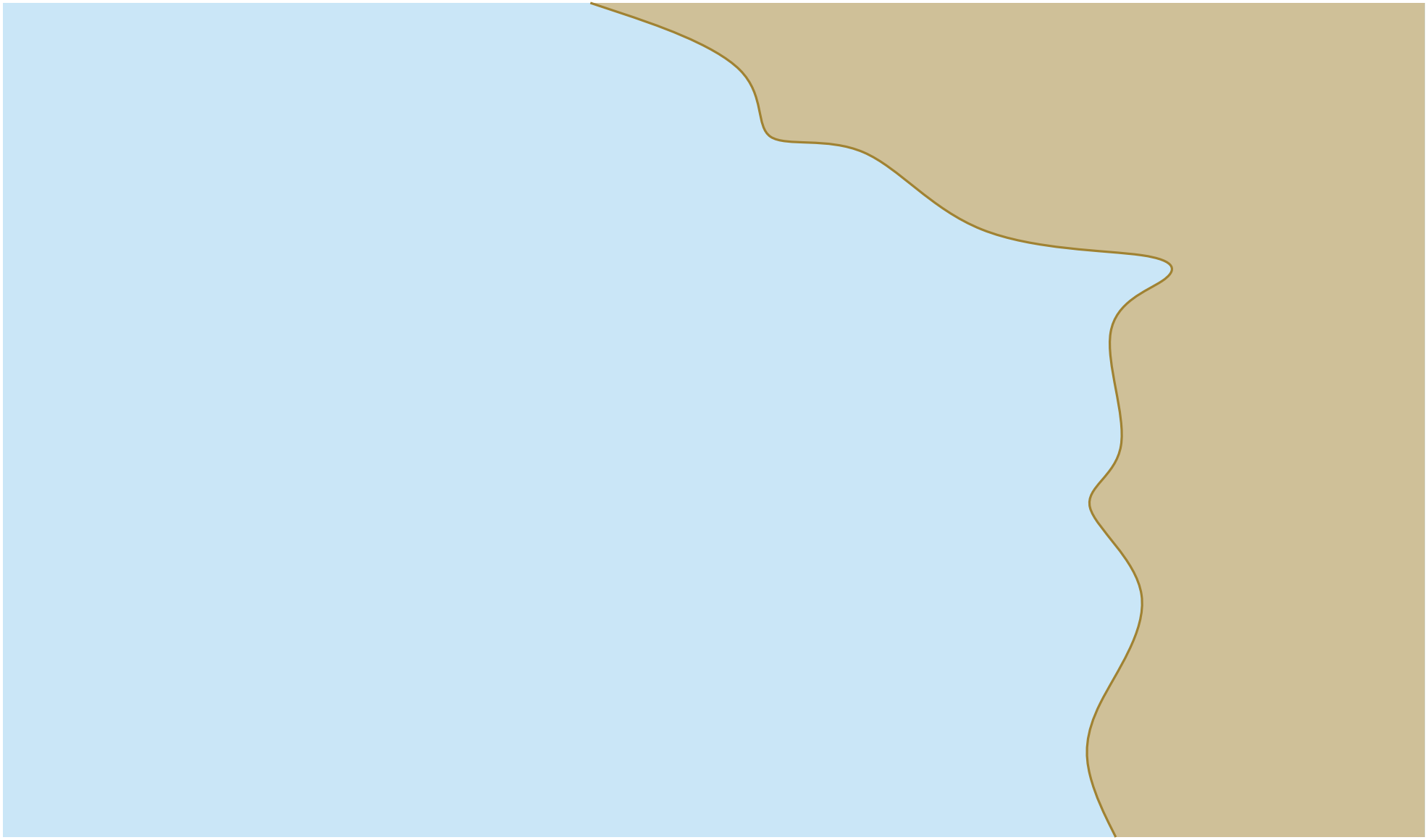
Cabling Optimization in a Wind Farm
Heuristics Based on Simulated Annealing

Master's Thesis · Final Presentation · May 31, 2016

Sebastian Lehmann

INSTITUTE OF THEORETICAL INFORMATICS · ALGORITHMICS GROUP

Components in a Wind Farm



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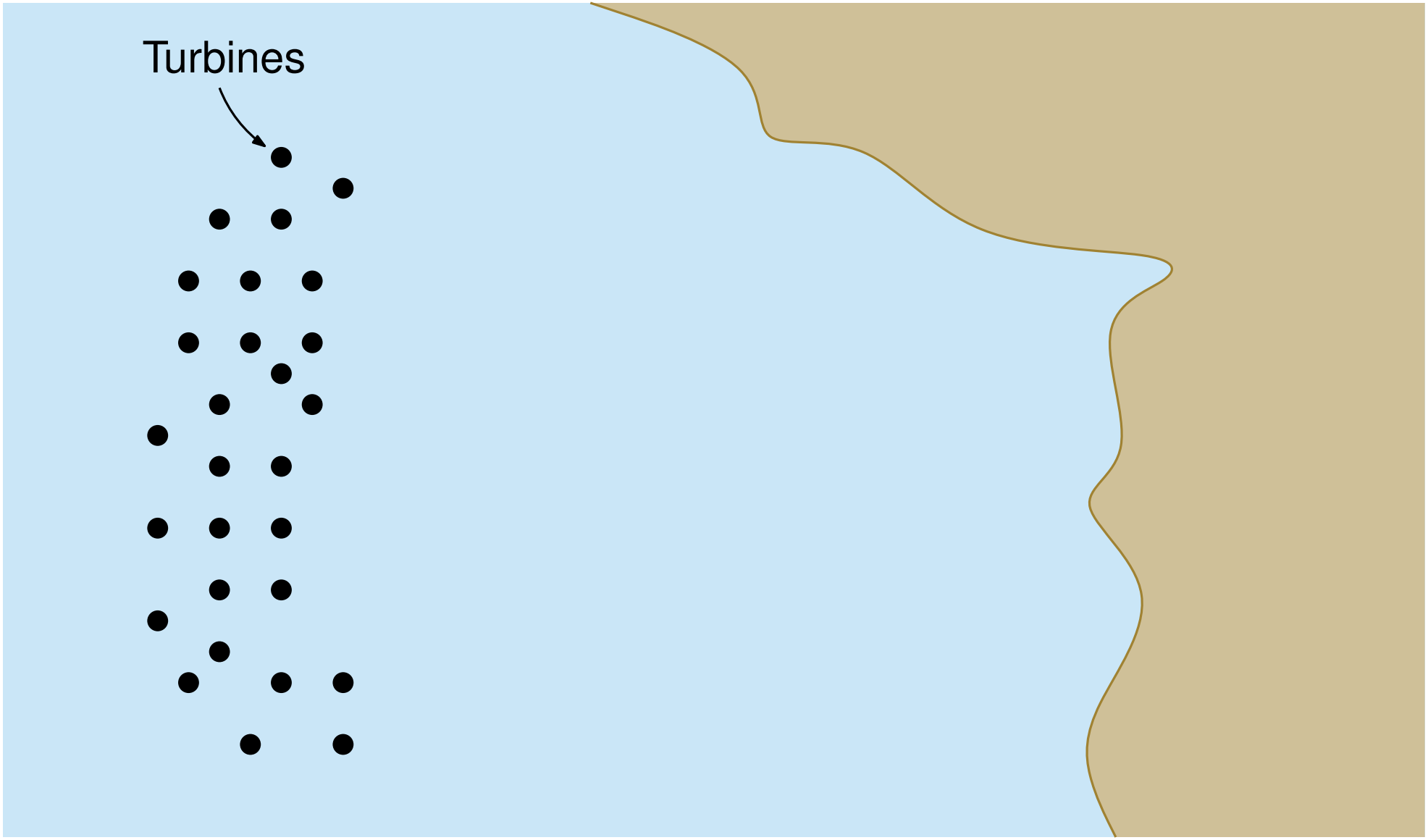

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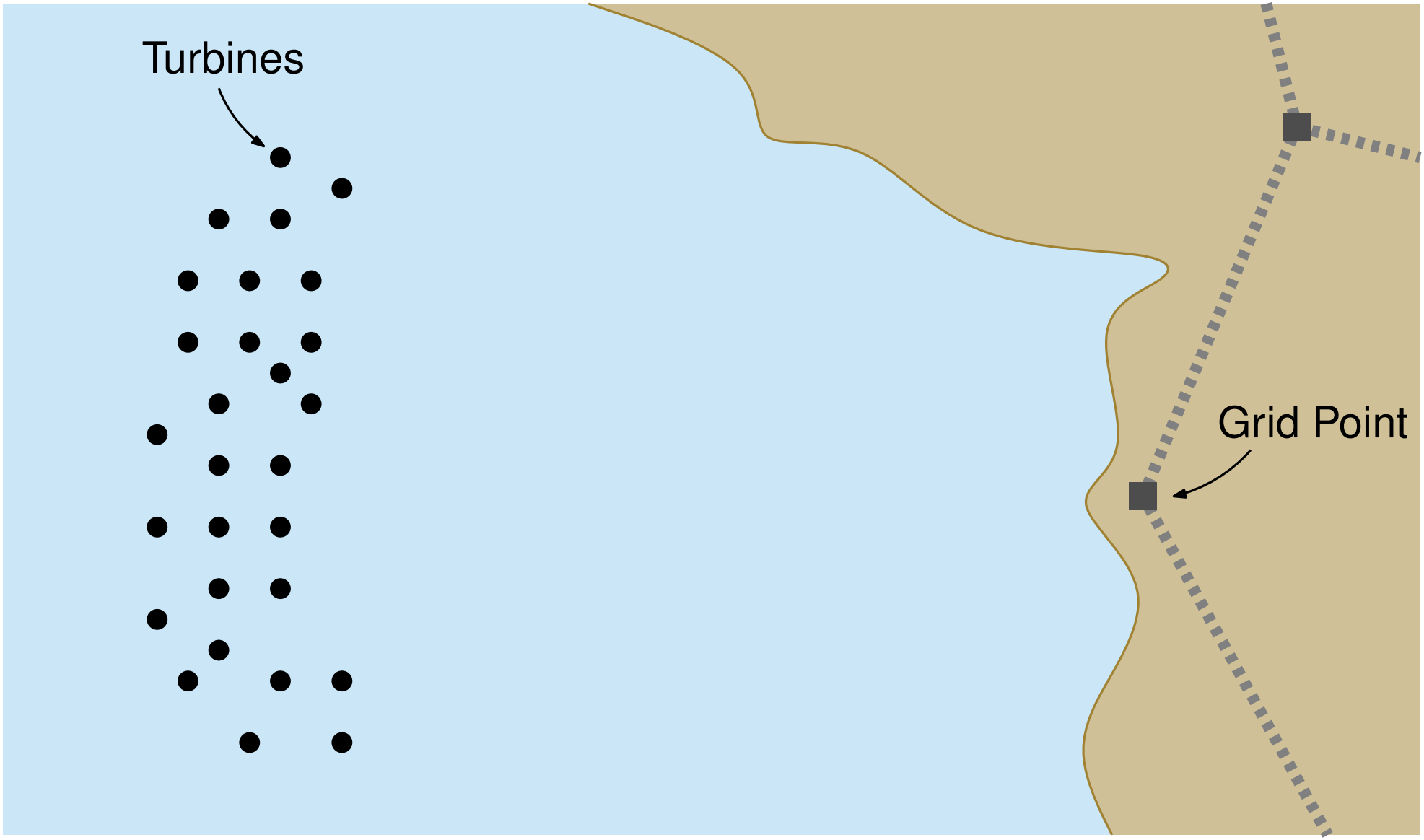

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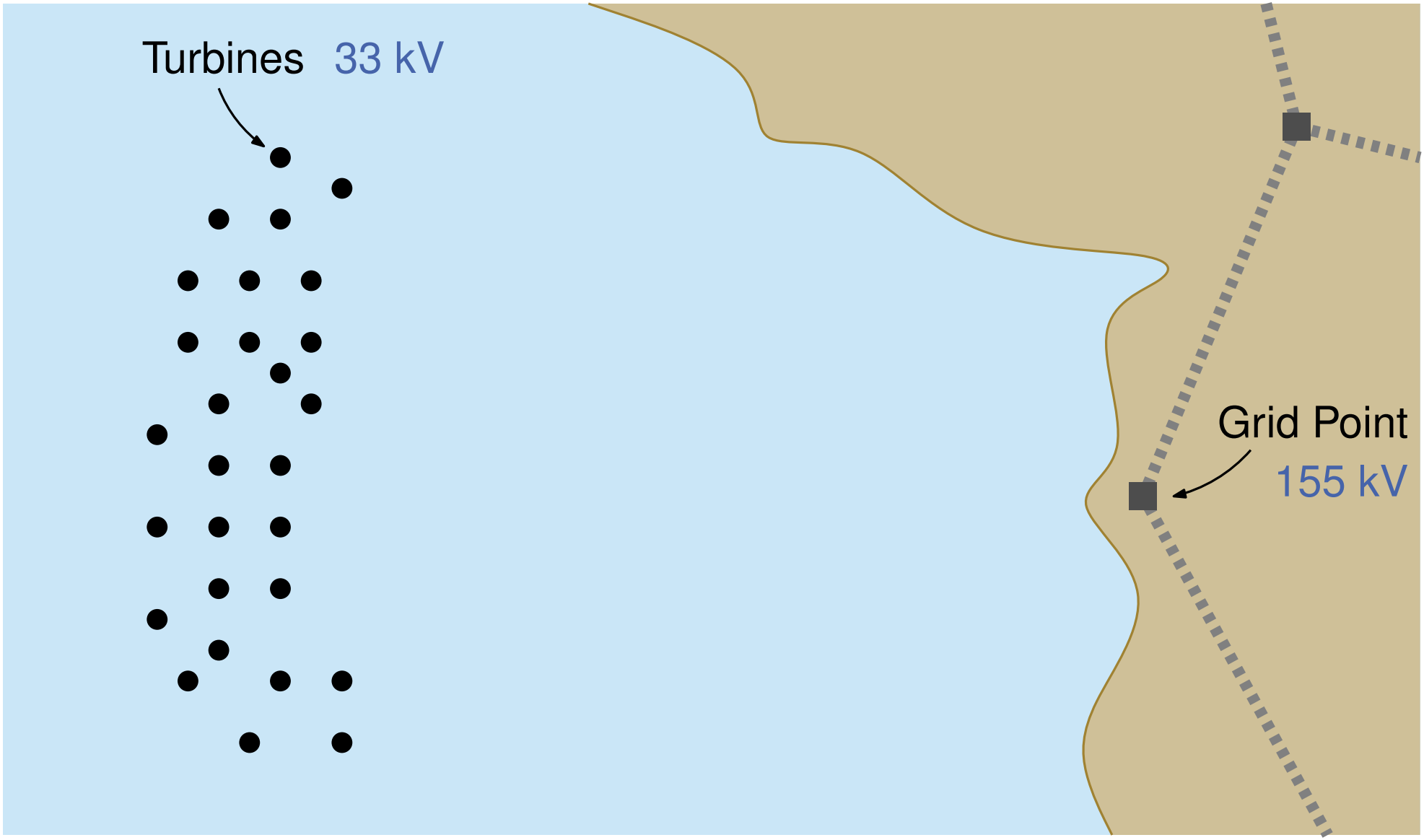

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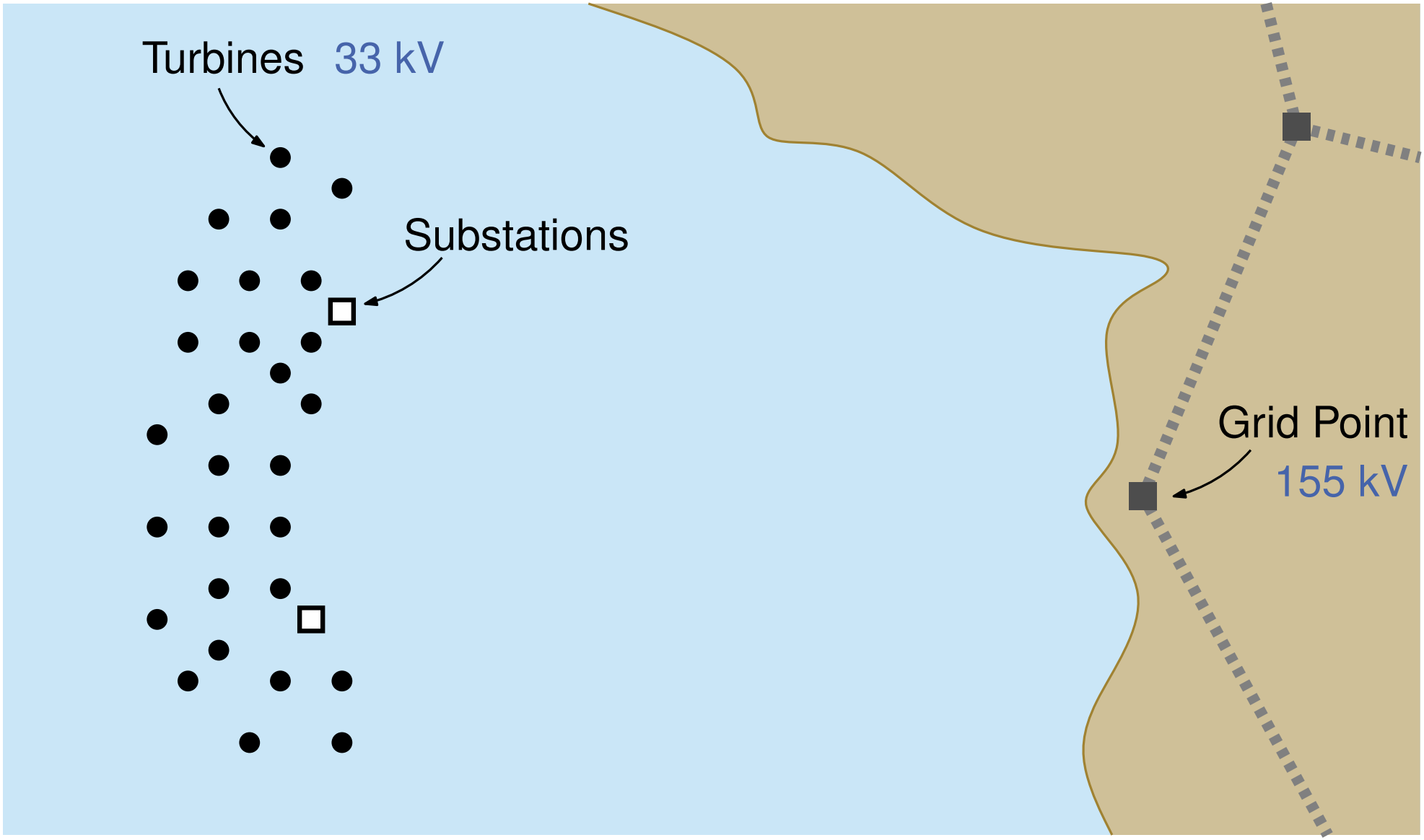

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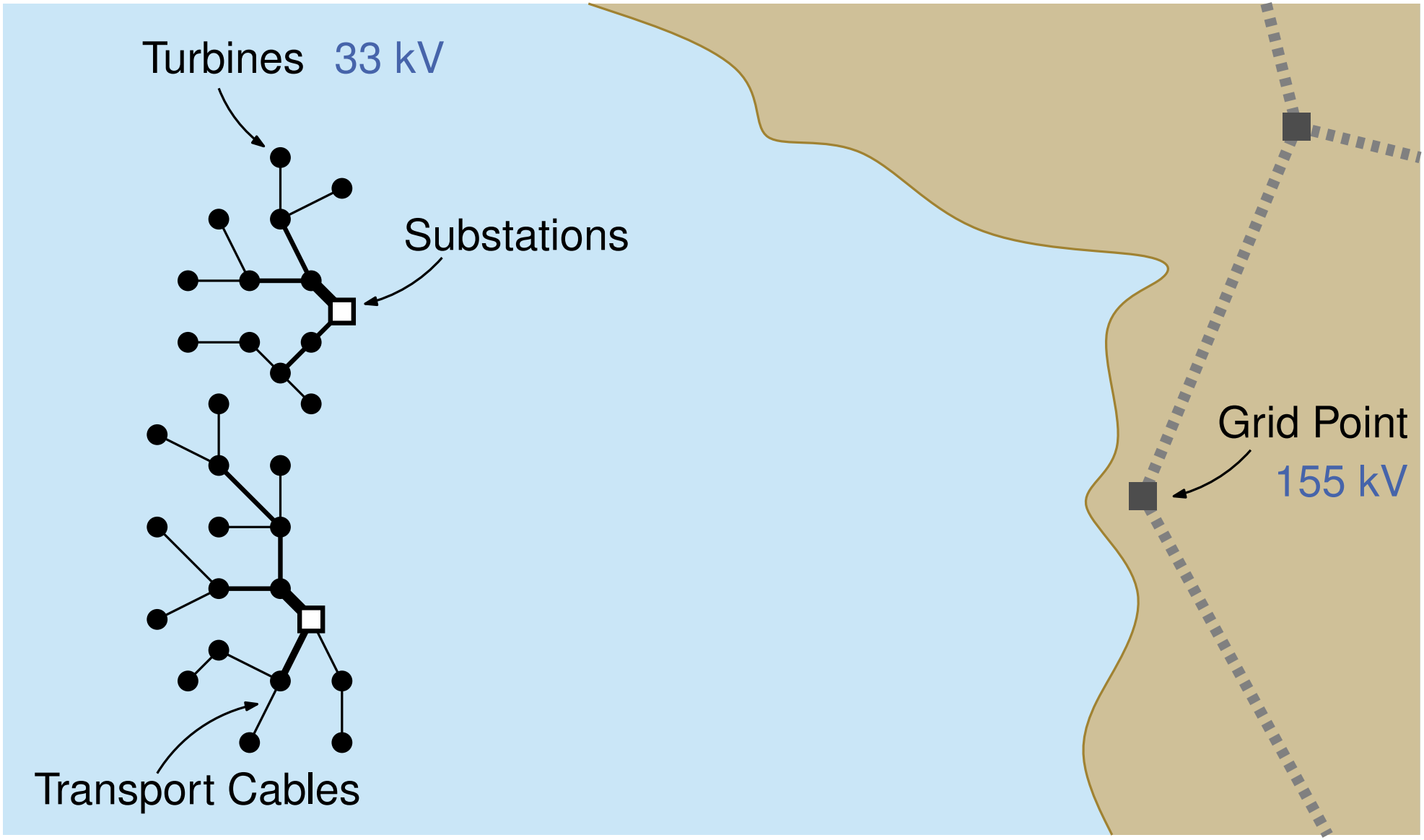

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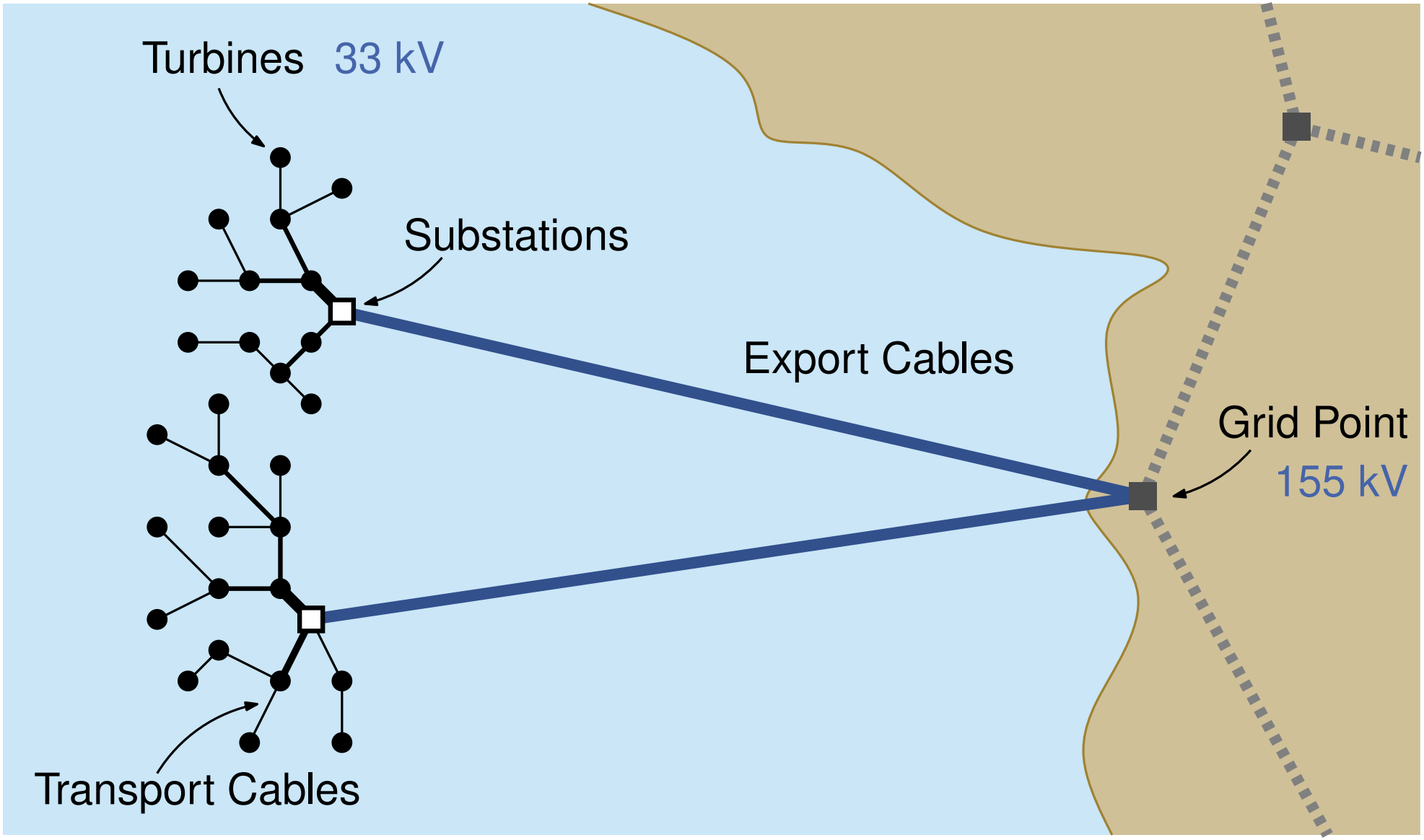

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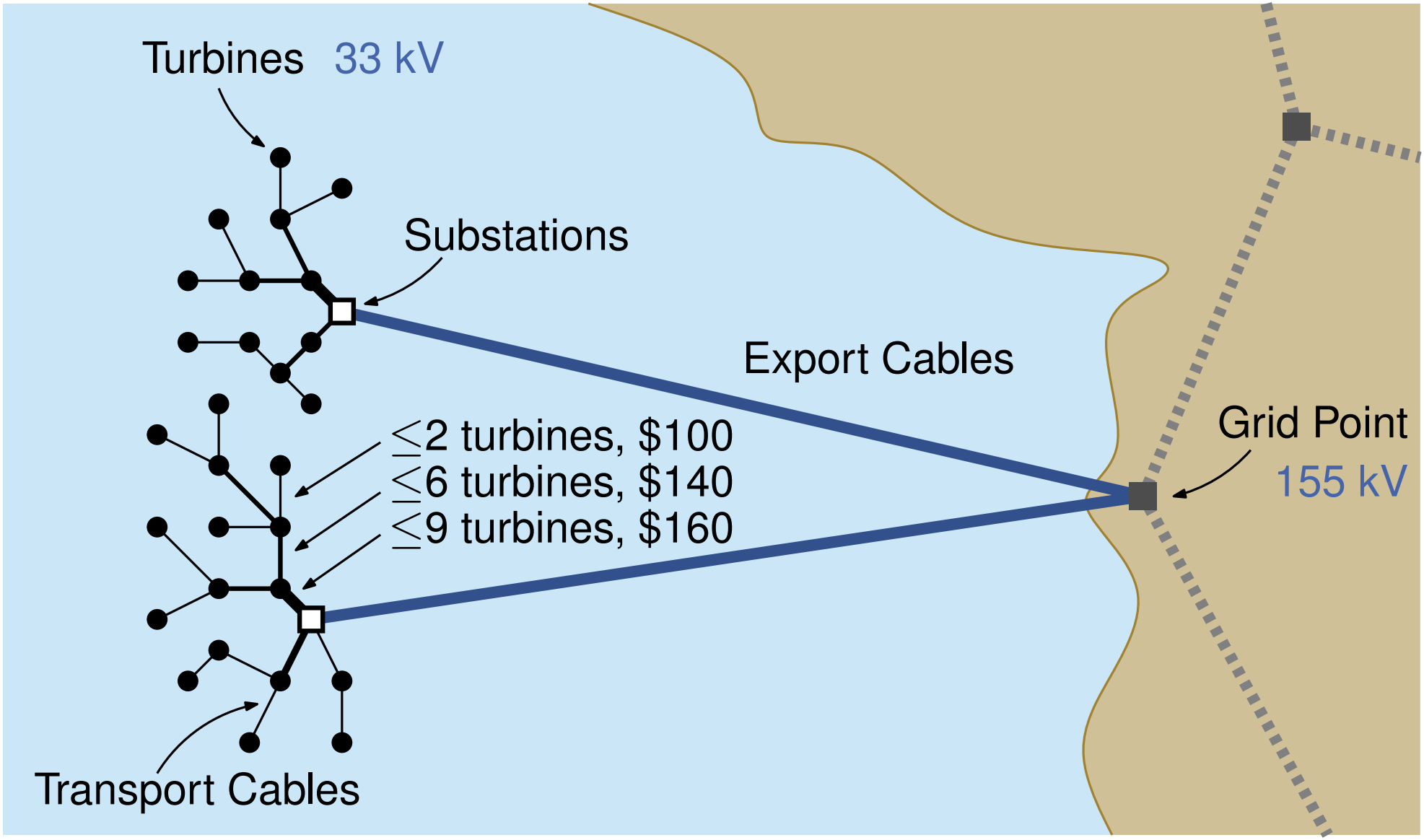

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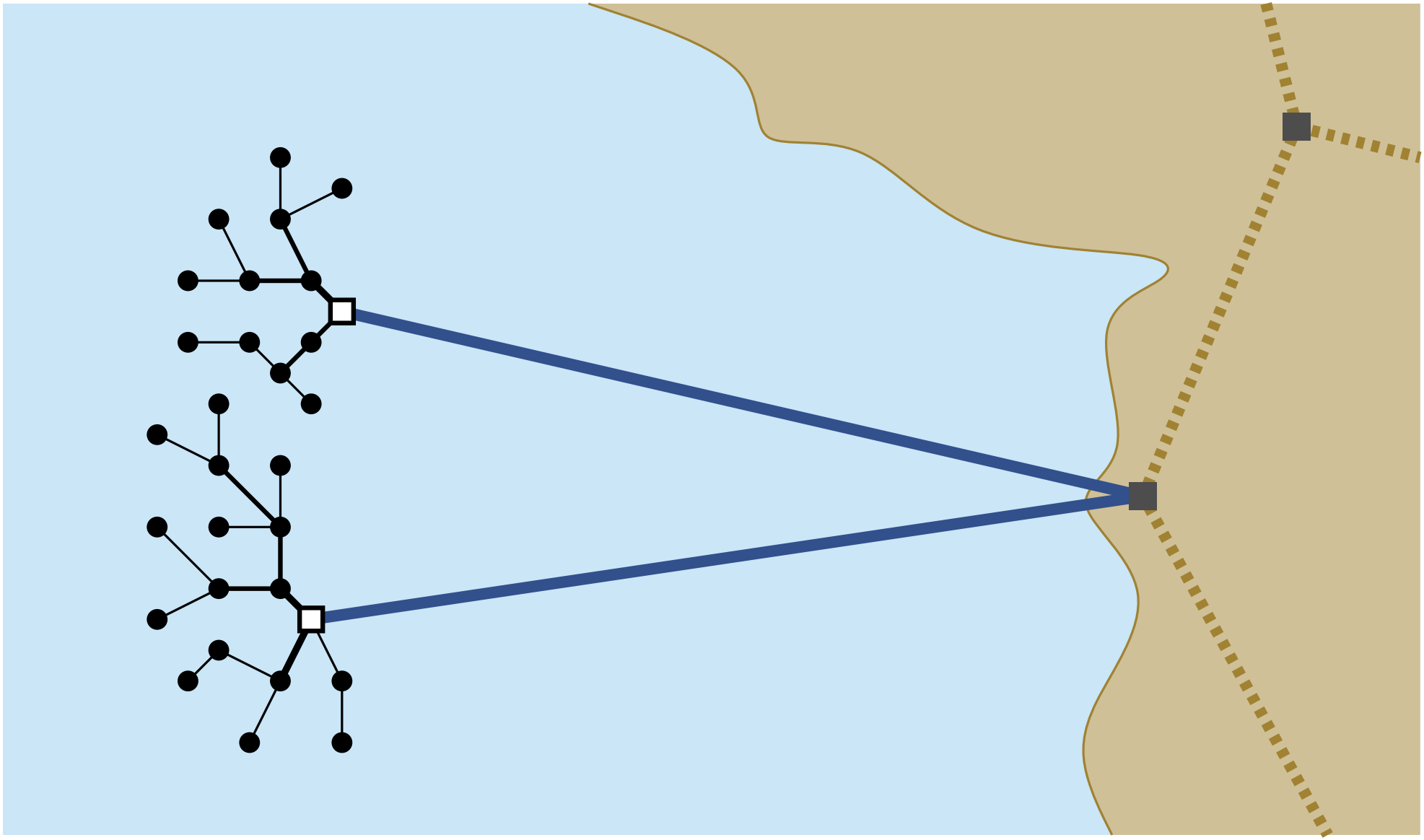
Transmission Network Expansion Planning



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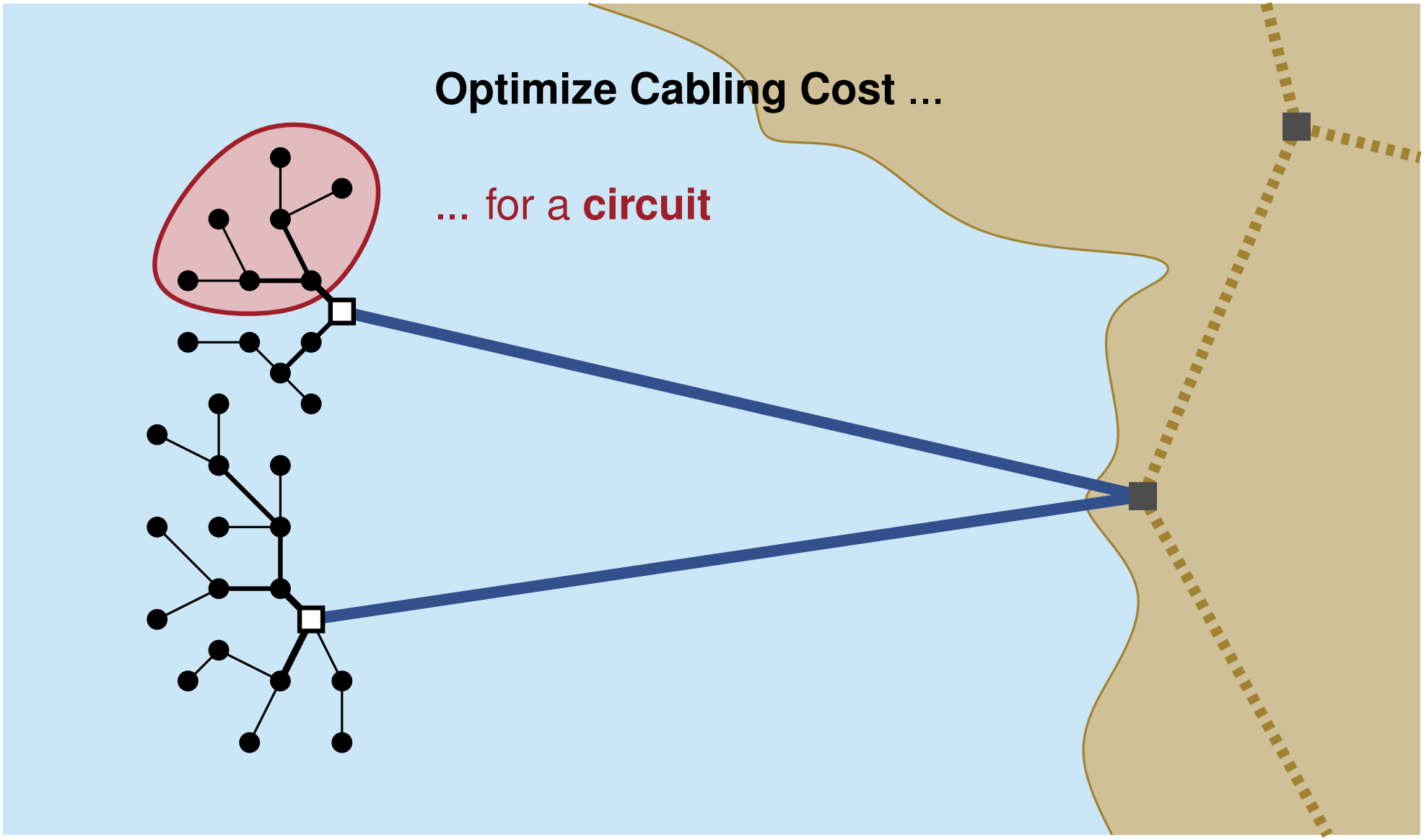

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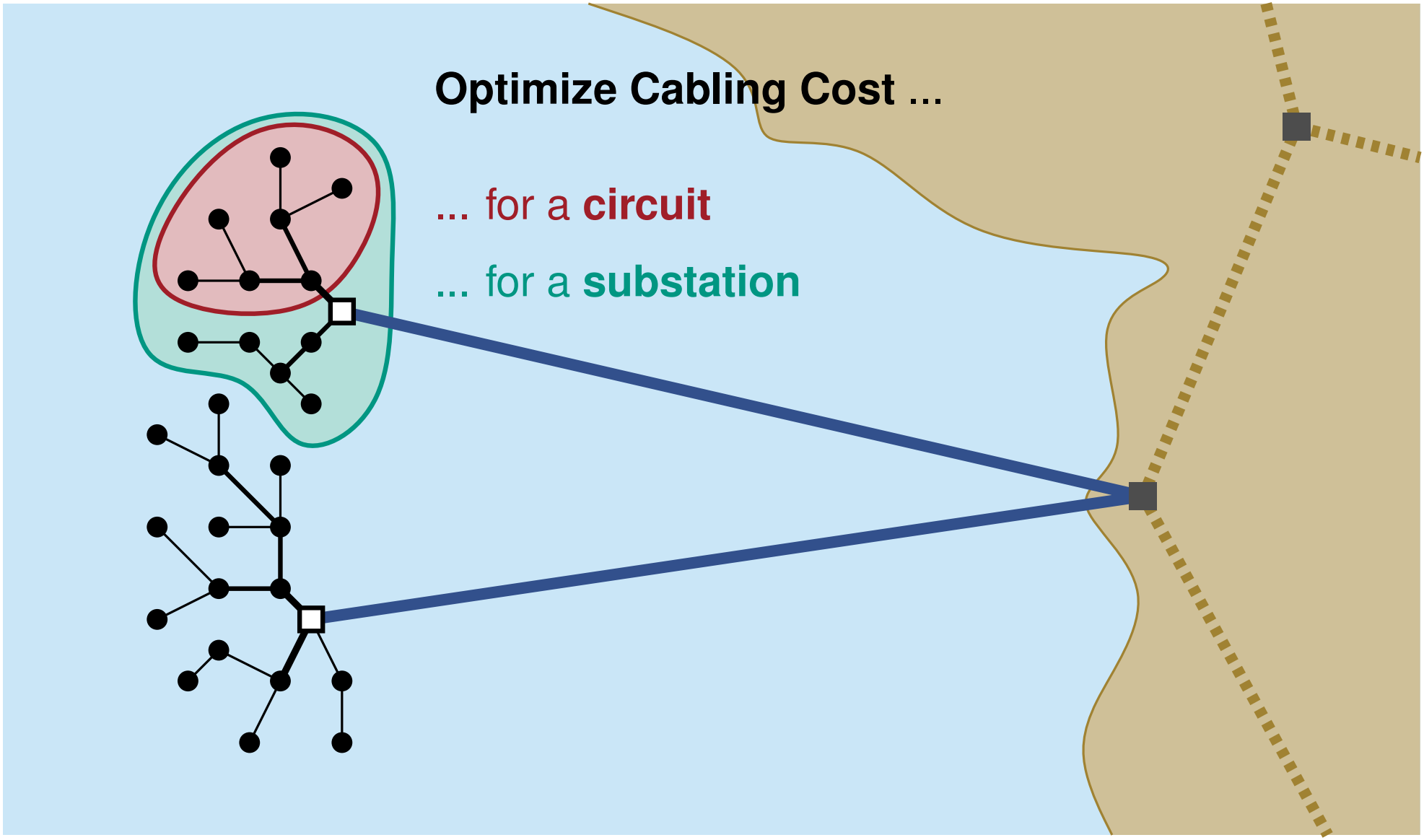

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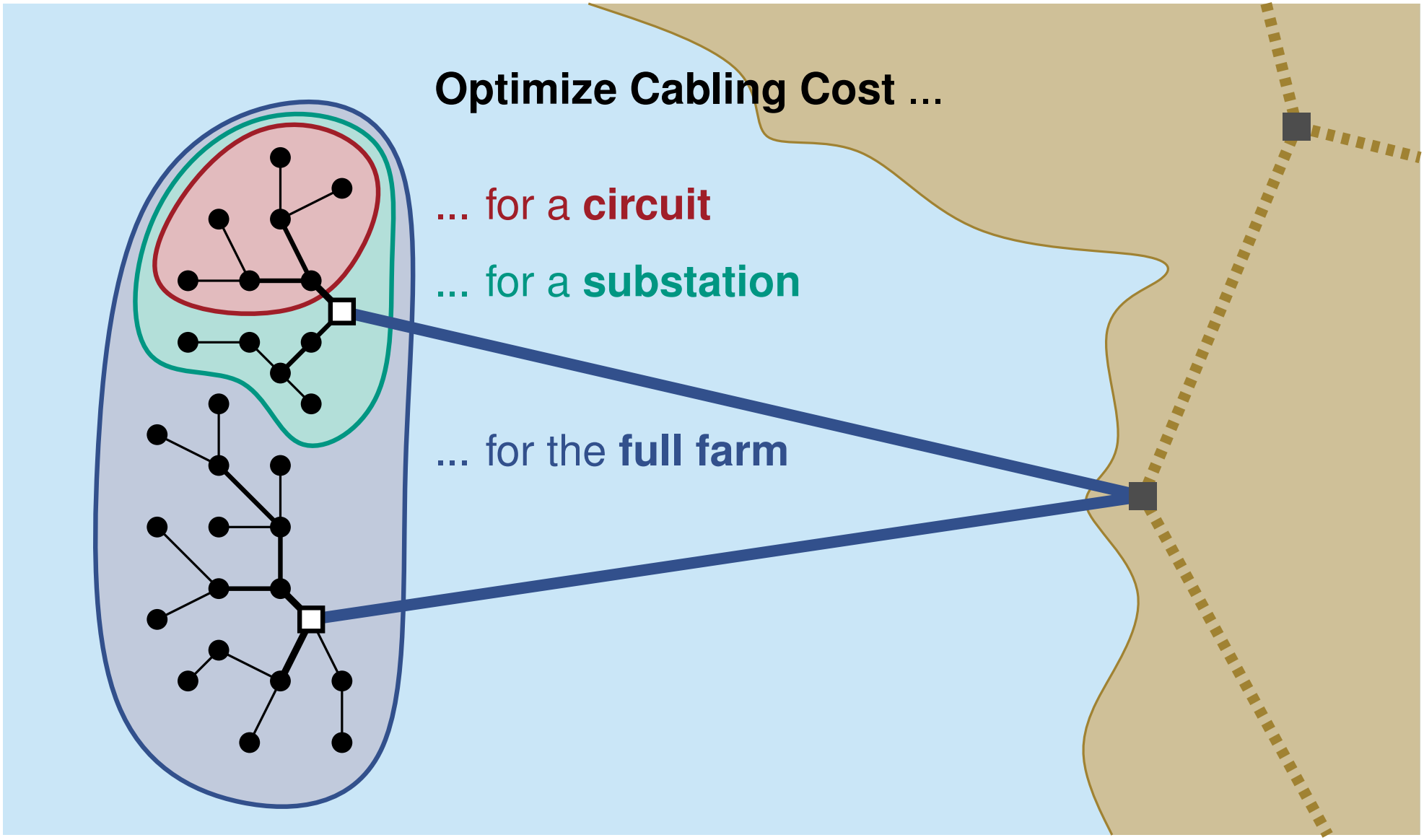

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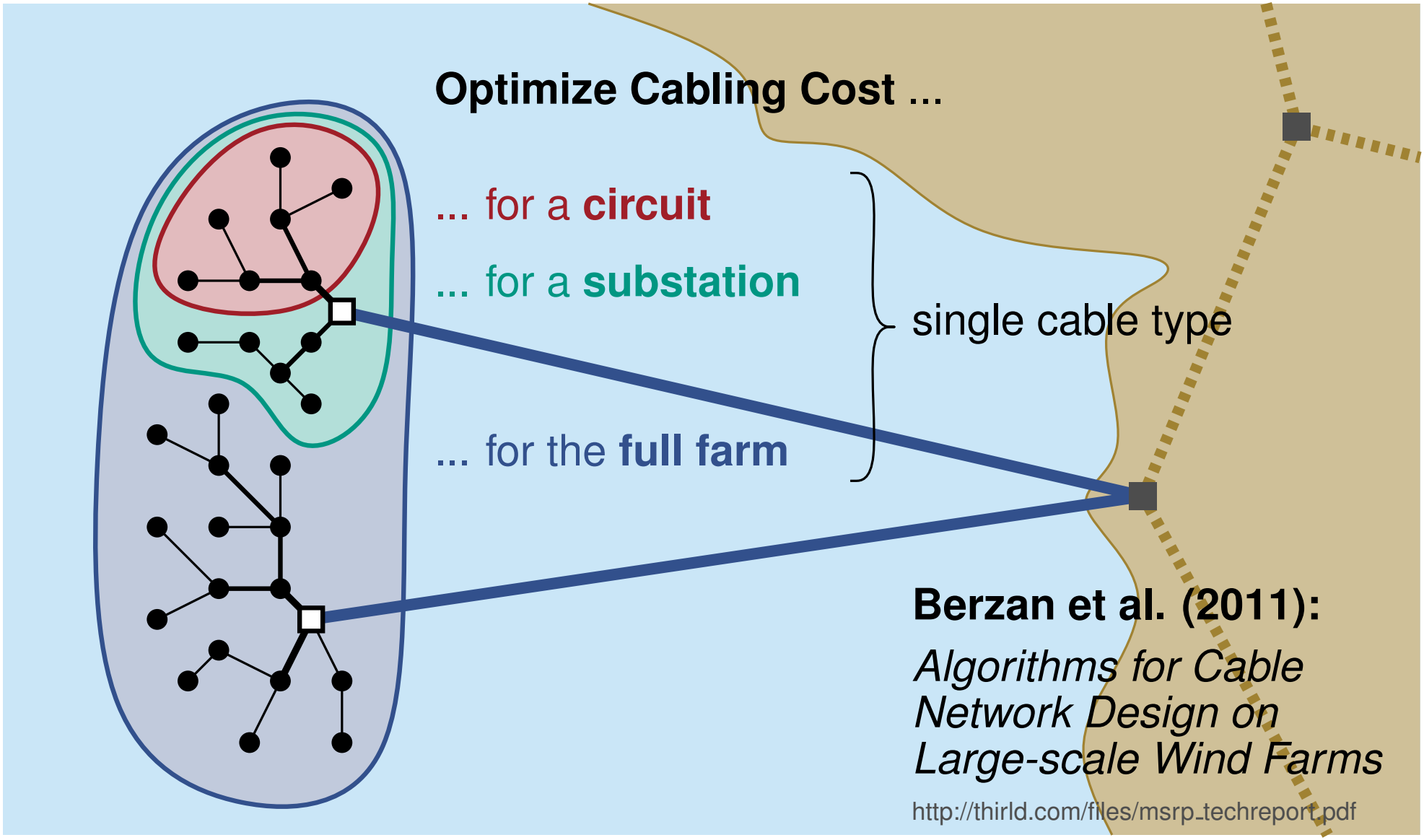

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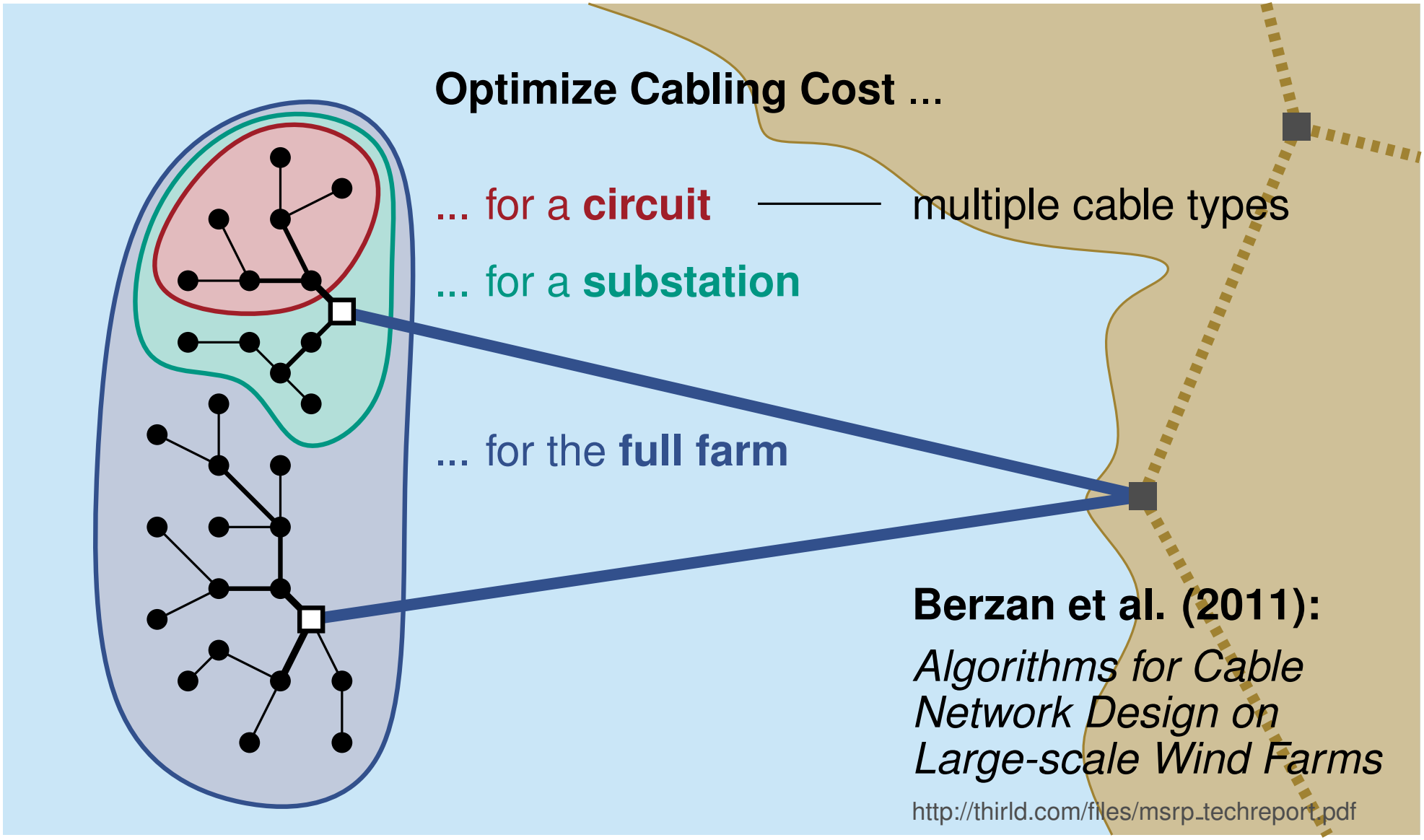

Wind Farm Cable Layout Problem

Given **t** turbines, **s** substations (each with **capacity**),
for each edge: cable types (each with **cost** and **capacity**)

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Wind Farm Cable Layout Problem

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Given **t** turbines, **s** substations (each with **capacity**),
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minimizing their **total cost**

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minimizing	their **total cost**
subject to	cable capacity constraints substation capacity constraints flow conservation constraints

Integer Linear Programming

Given	**t** turbines, **s** substations (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)
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inputs

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Integer Linear Programming

Given **t** turbines, **s** substations (each with **capacity**),
for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

binary variables

minimizing their **total cost**

variables

subject to cable capacity constraints
substation capacity constraints
flow conservation constraints

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Integer Linear Programming

Given **t** turbines, **s** substations (each with **capacity**),
for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

minimizing their **total cost** $= \sum_{\text{edges}} \sum_{\text{cable types}}$ **cable chosen?** $\times$ **cable cost**

objective

subject to cable capacity constraints
substation capacity constraints
flow conservation constraints

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Meta-Heuristic Optimization Techniques

Greedy

Simulated Annealing

Hill Climbing

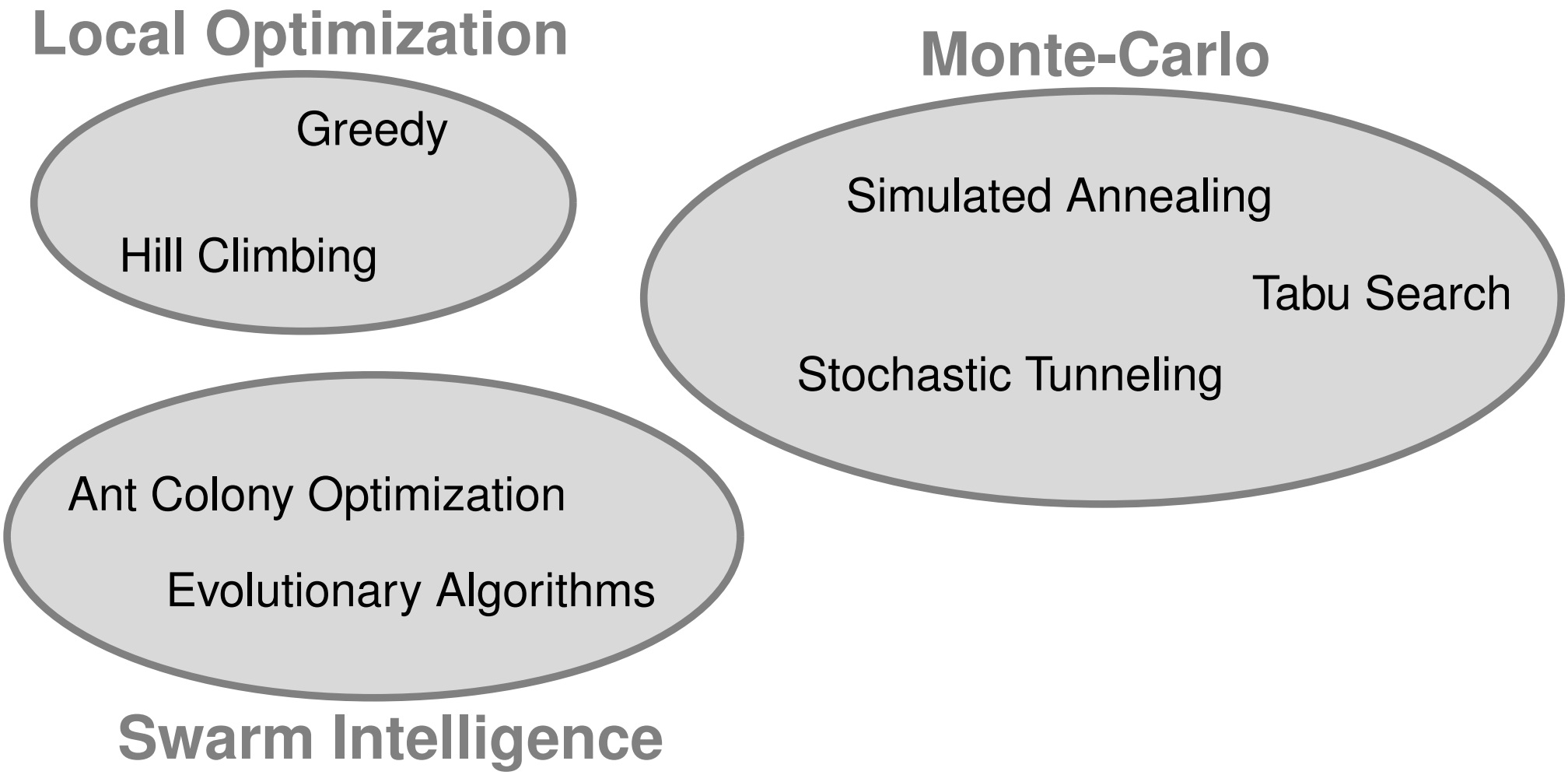
Tabu Search

Stochastic Tunneling

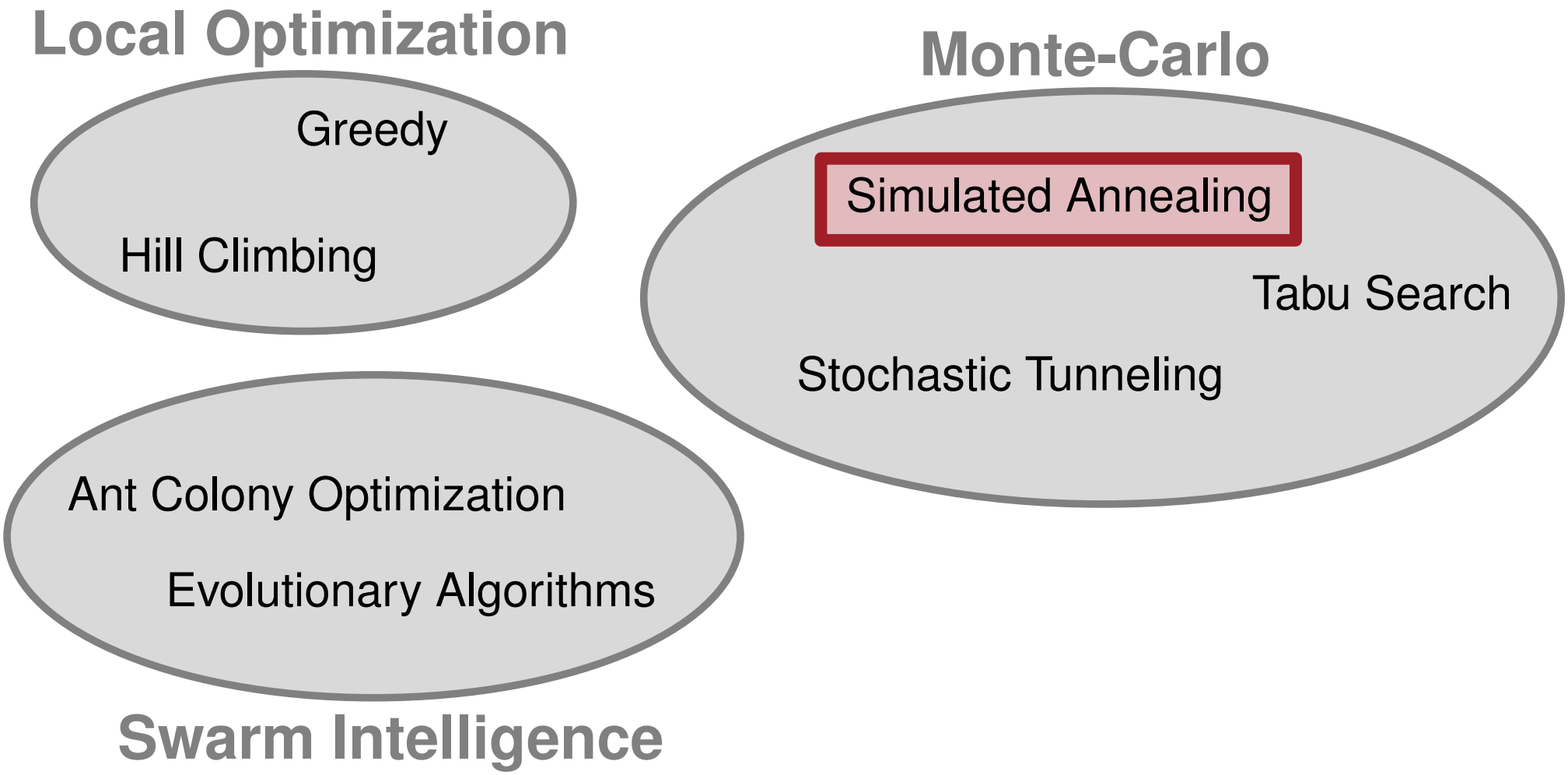
Ant Colony Optimization

Evolutionary Algorithms

Meta-Heuristic Optimization Techniques



Meta-Heuristic Optimization Techniques



Simulated Annealing

- mutate solution candidates
- idea: allow worse solutions temporarily

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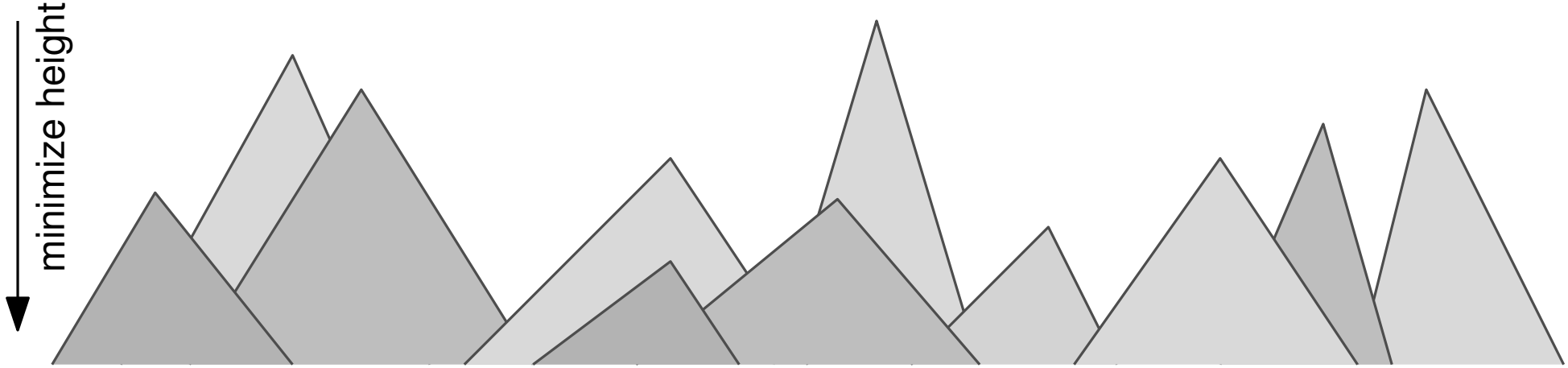

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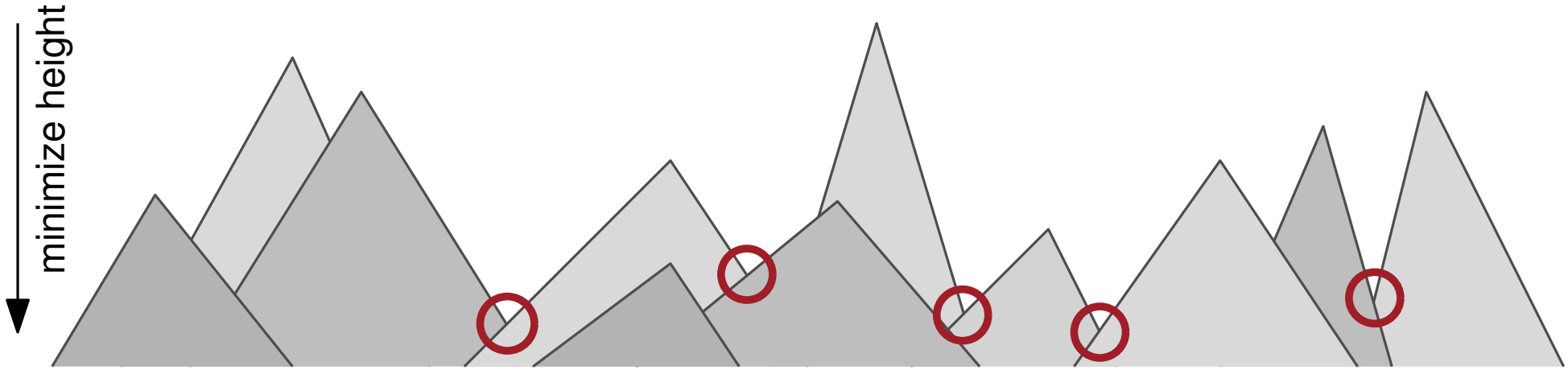

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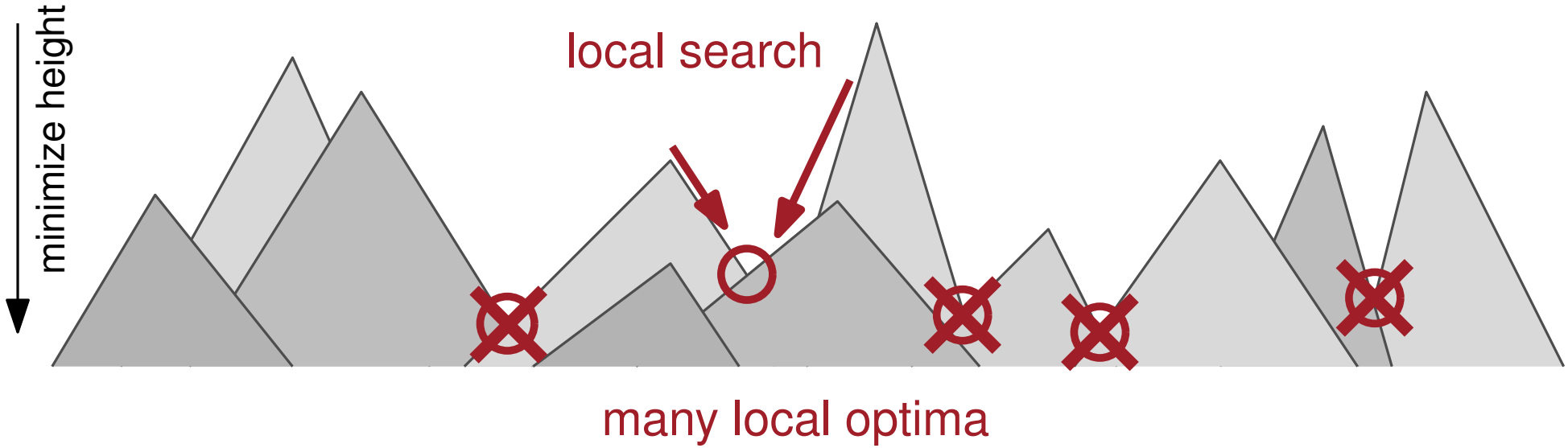

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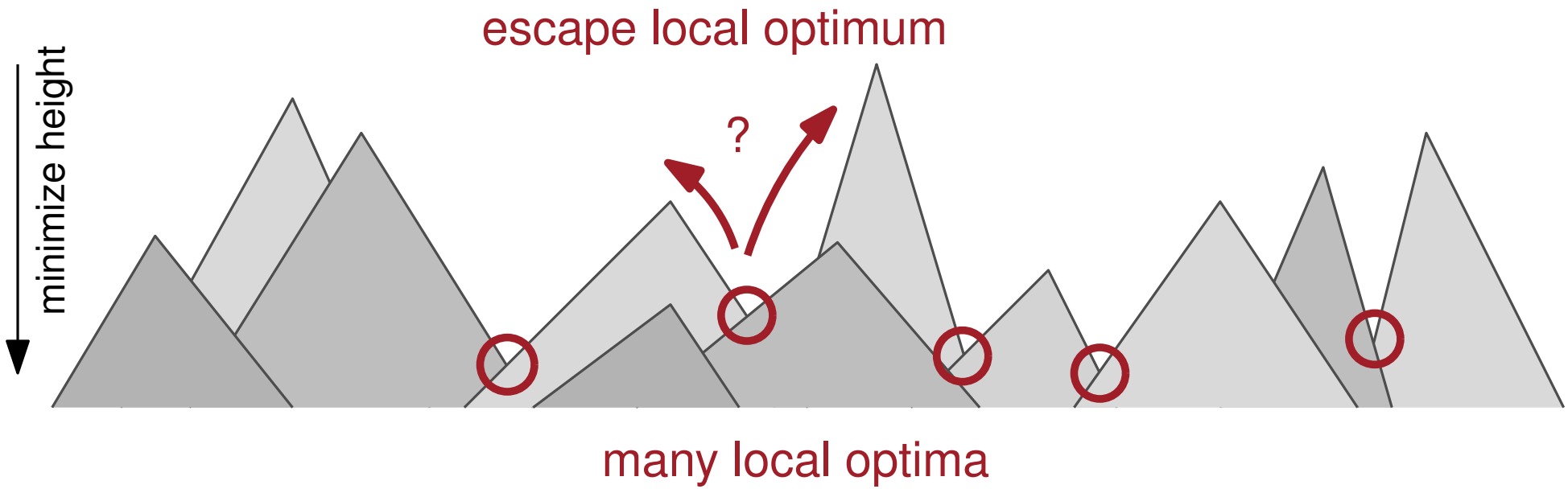

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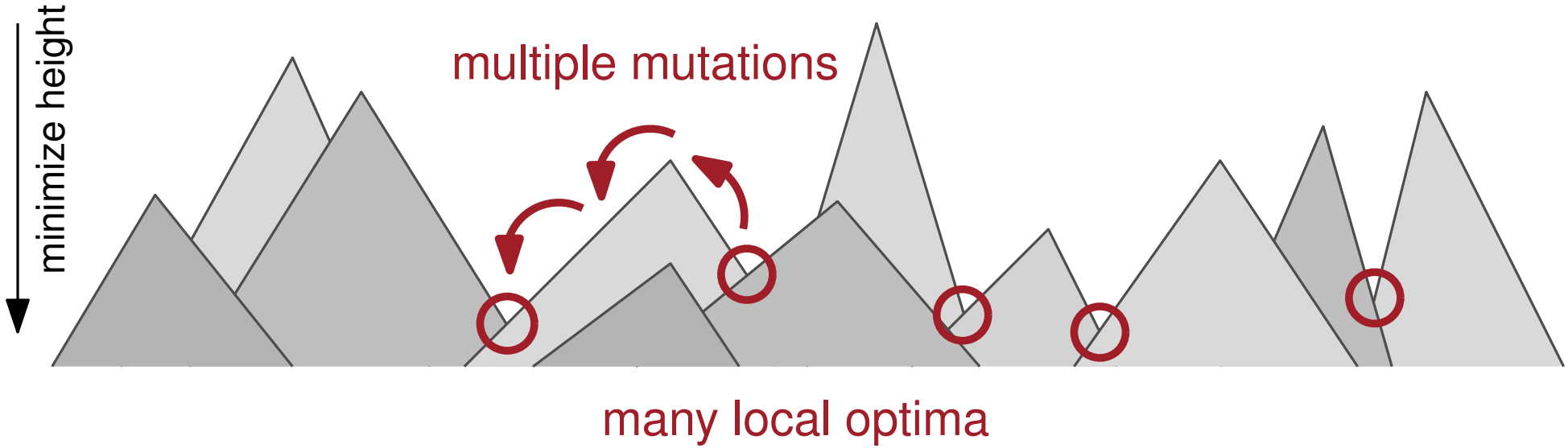

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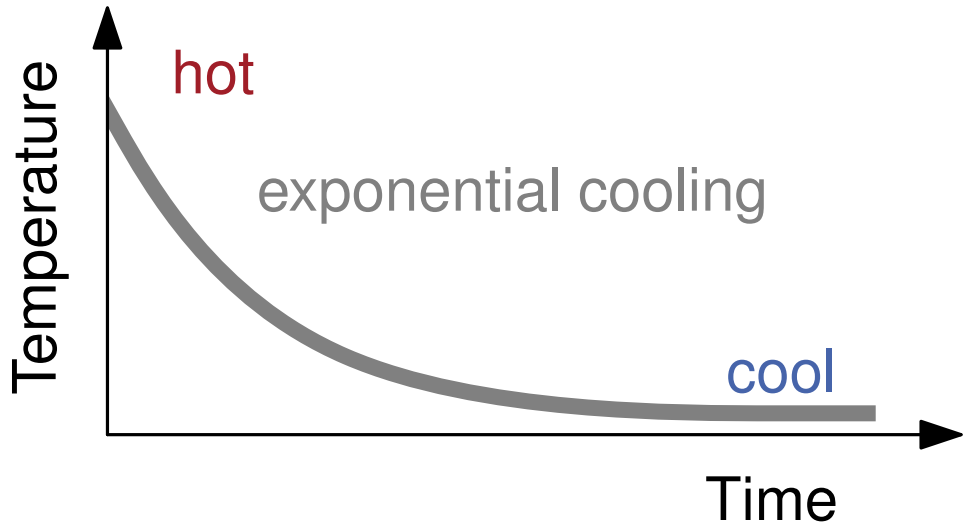

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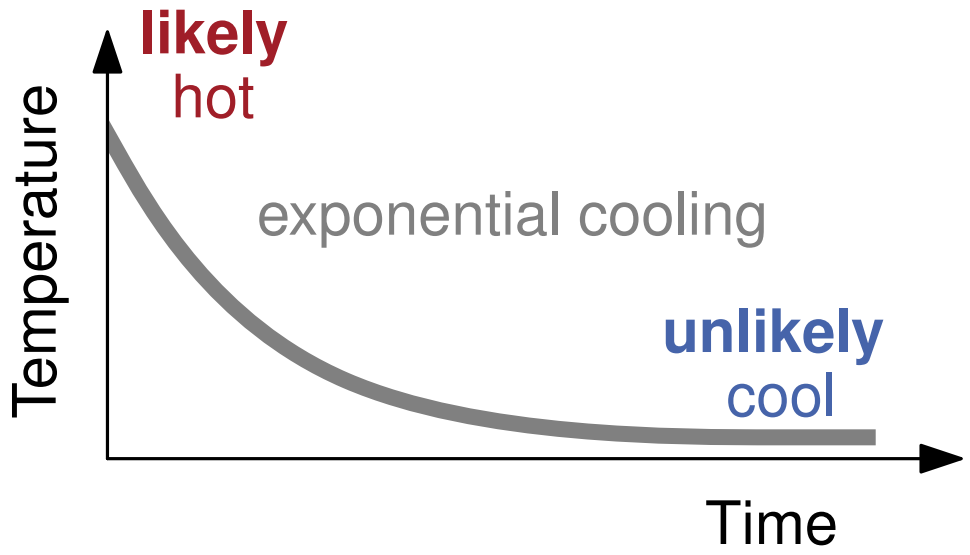
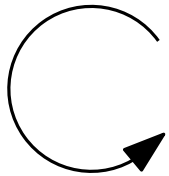


Simulated Annealing

mutation  **solution candidate**

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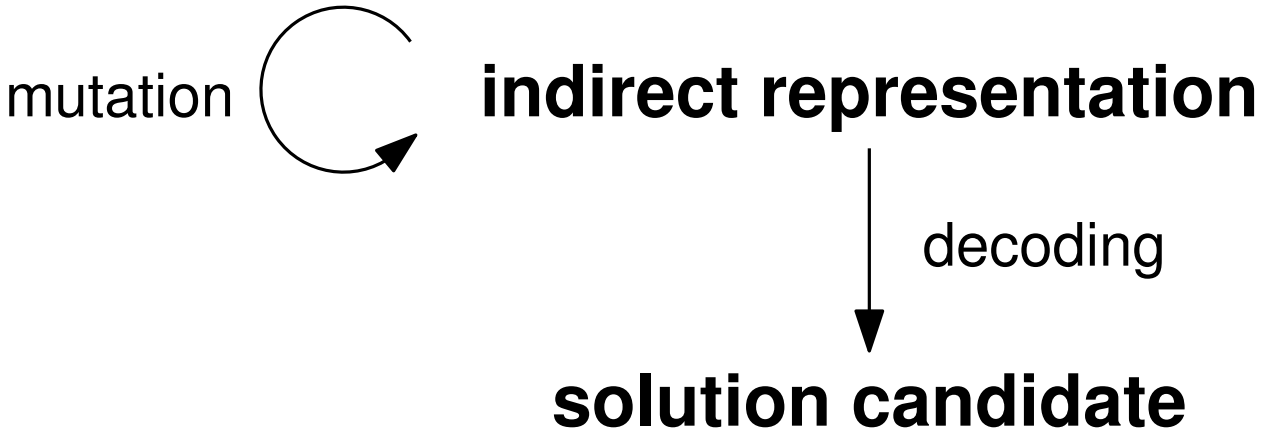
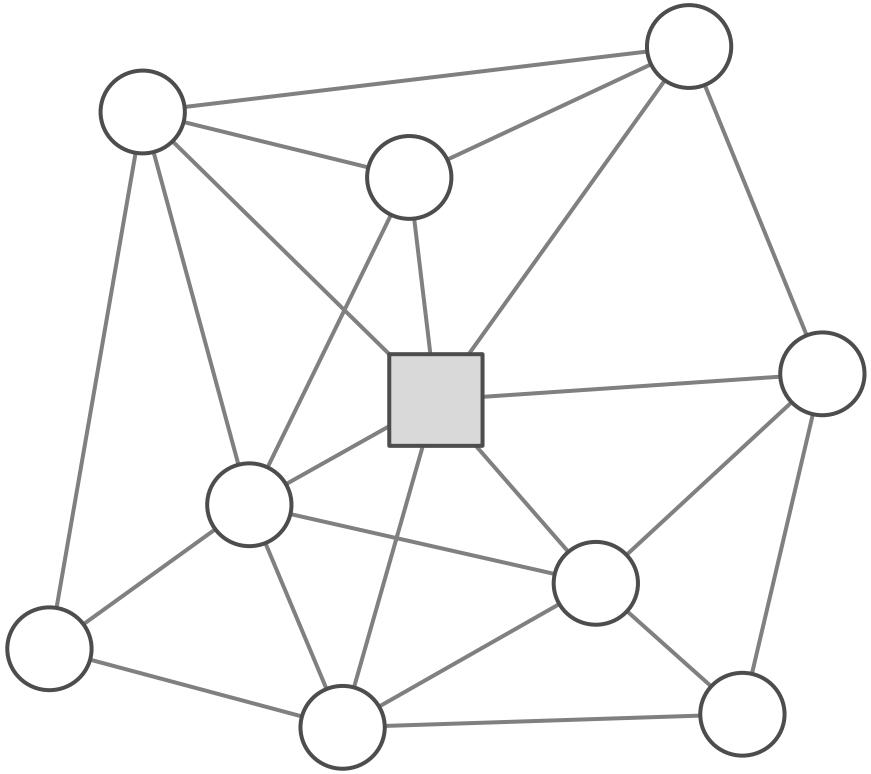
Simulated Annealing



Our Representation



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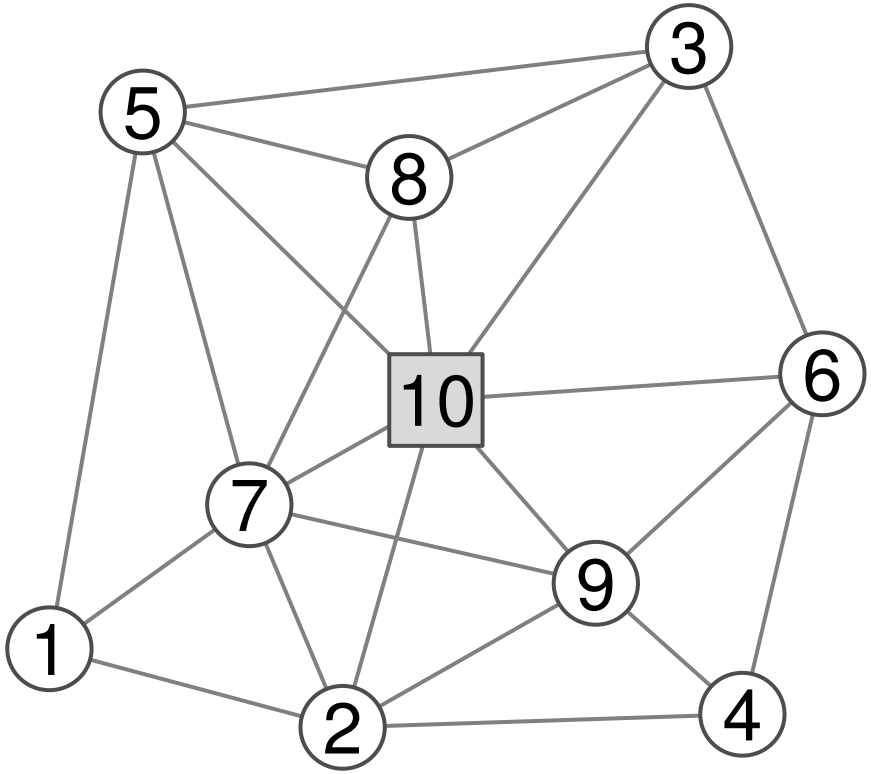

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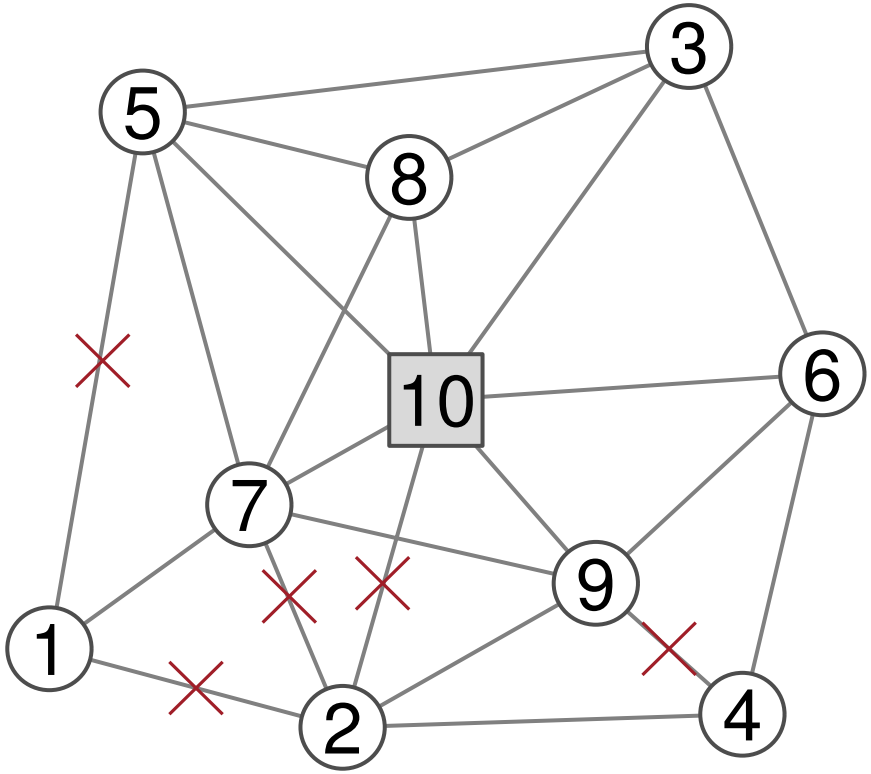

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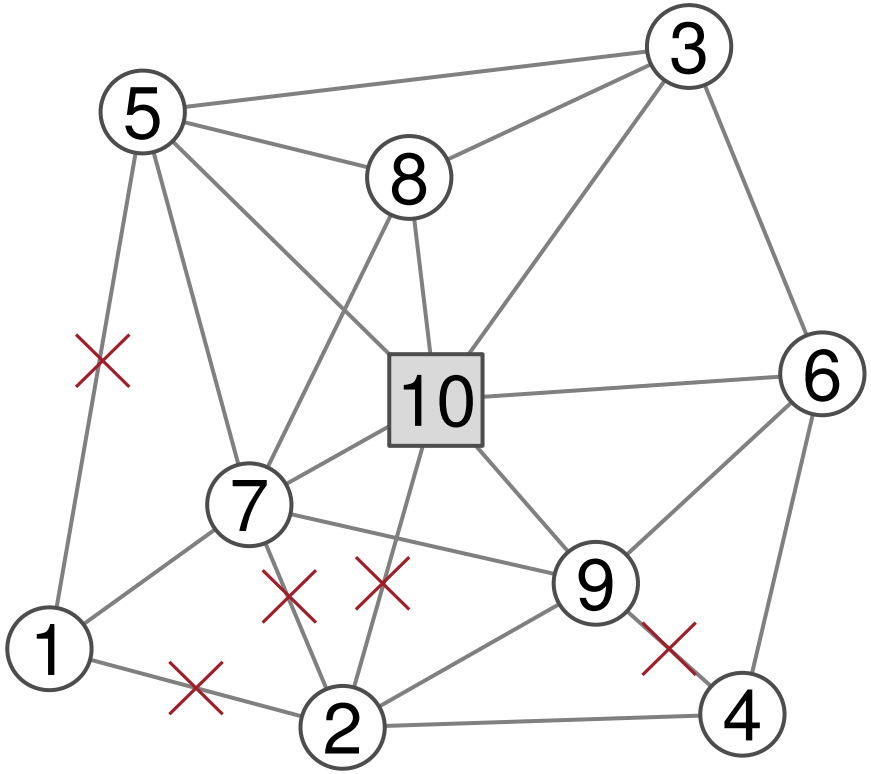
Decoding

- each turbine: construct path



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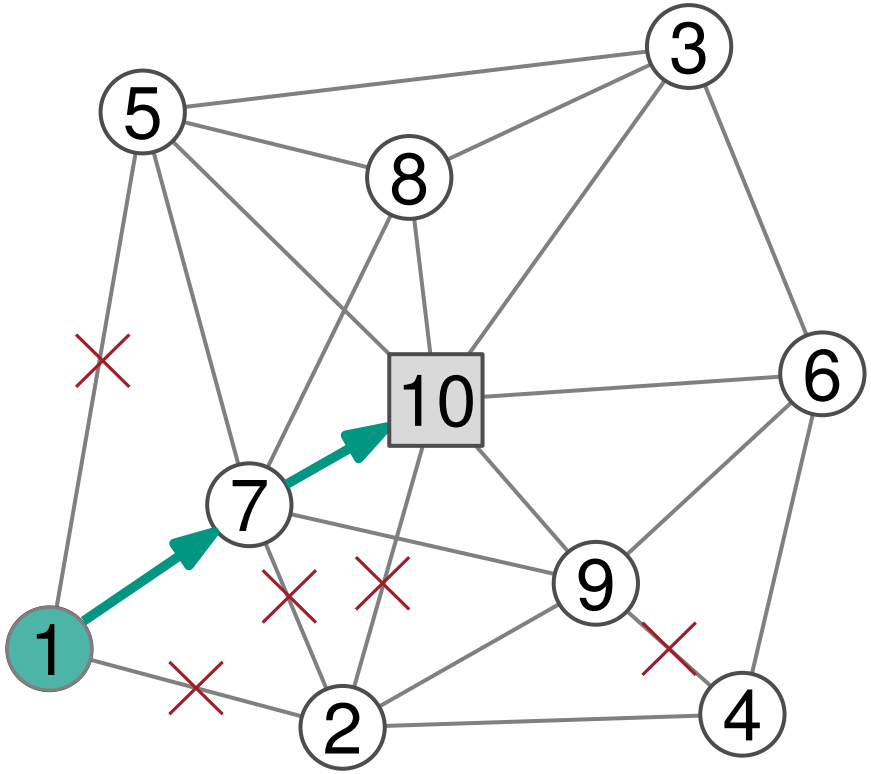

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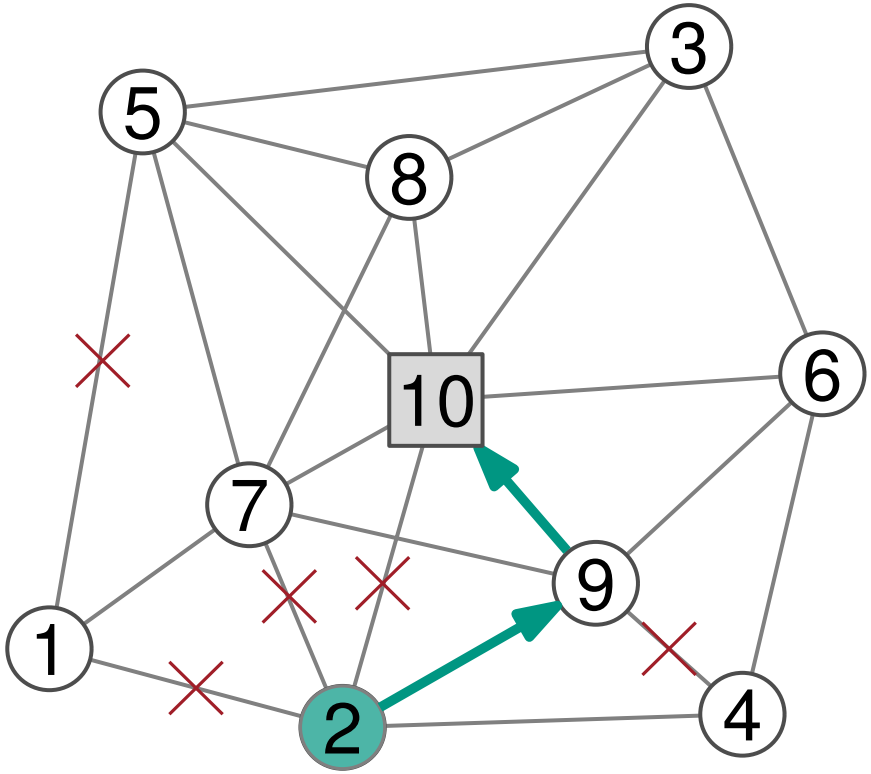

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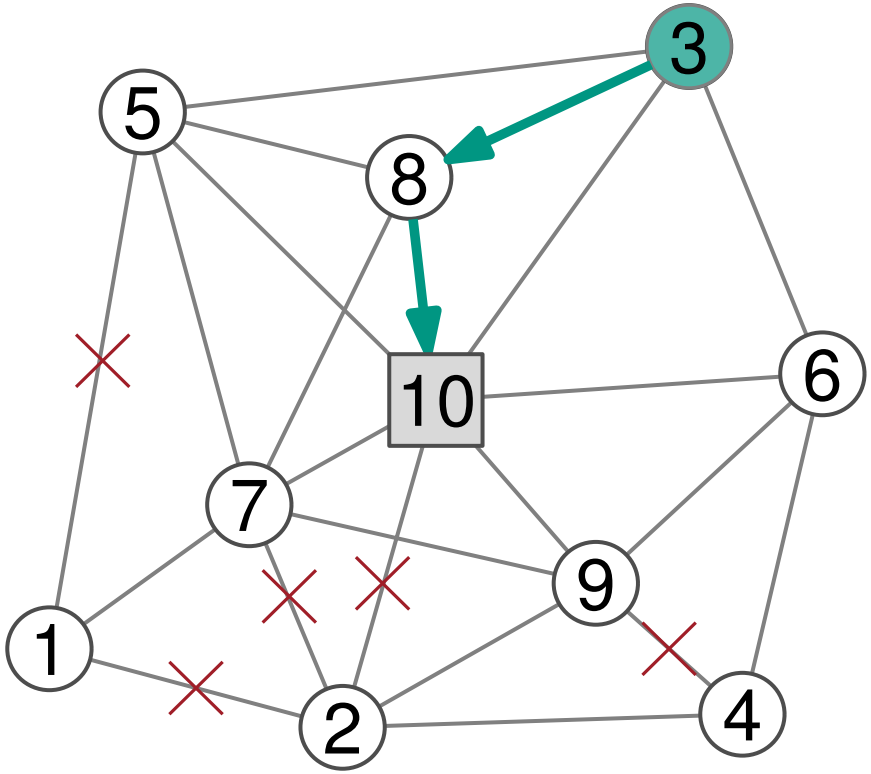

Our Representation

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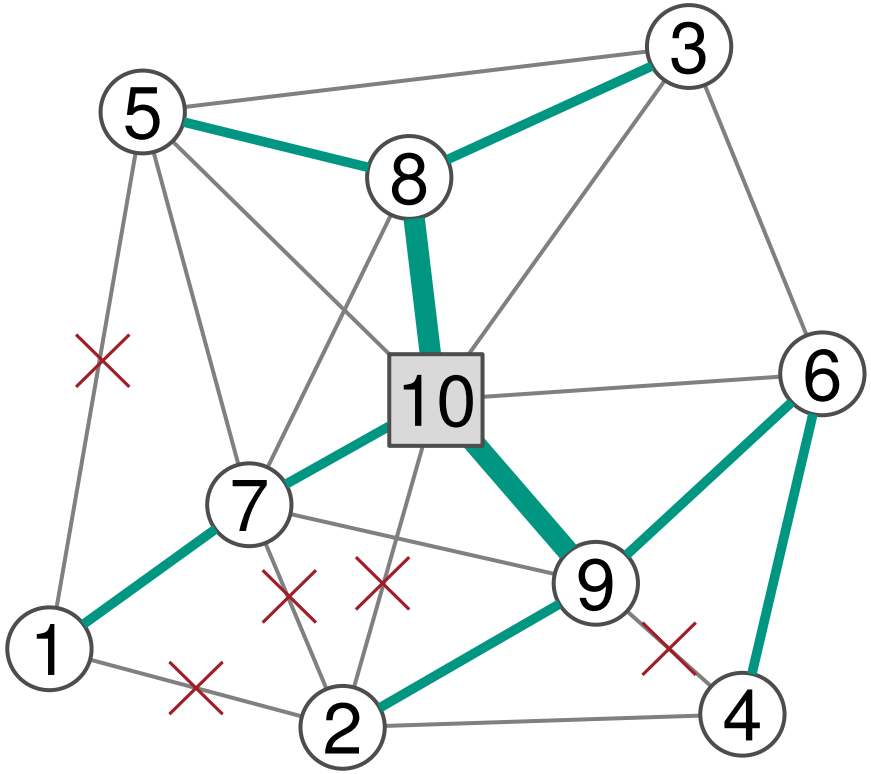
Decoding

- each turbine: construct path
- each edge: find suited cable



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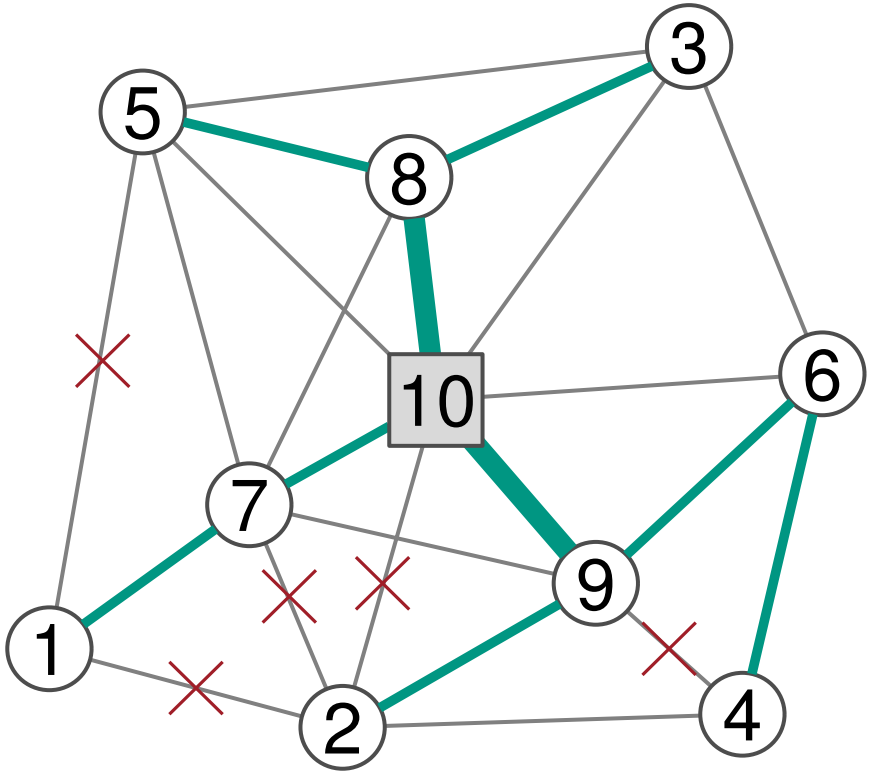
Mutation 



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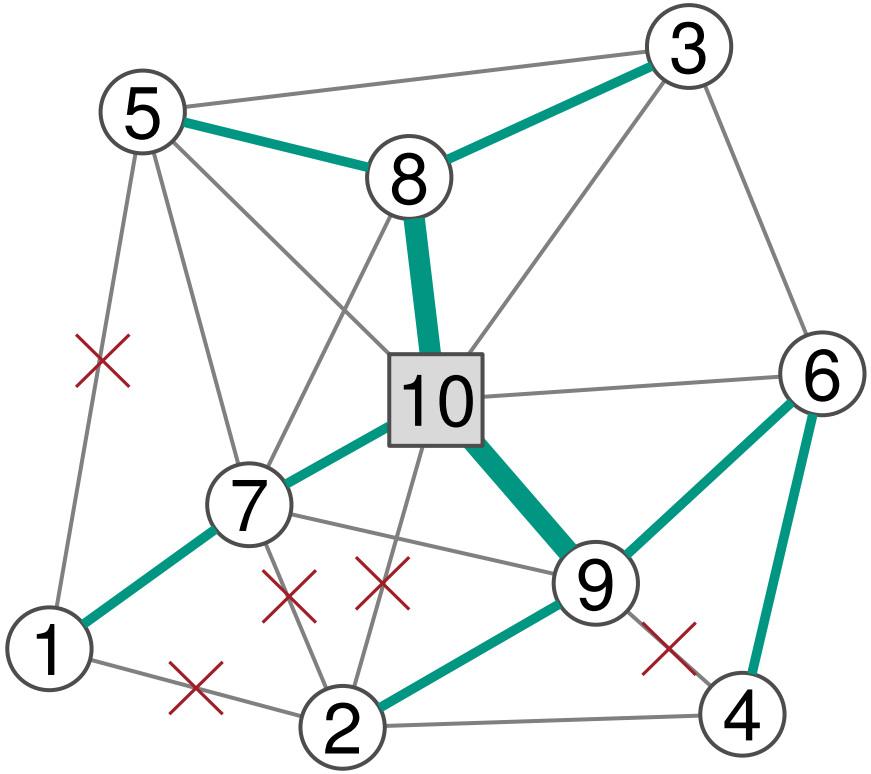
Mutation 

- swap node potentials



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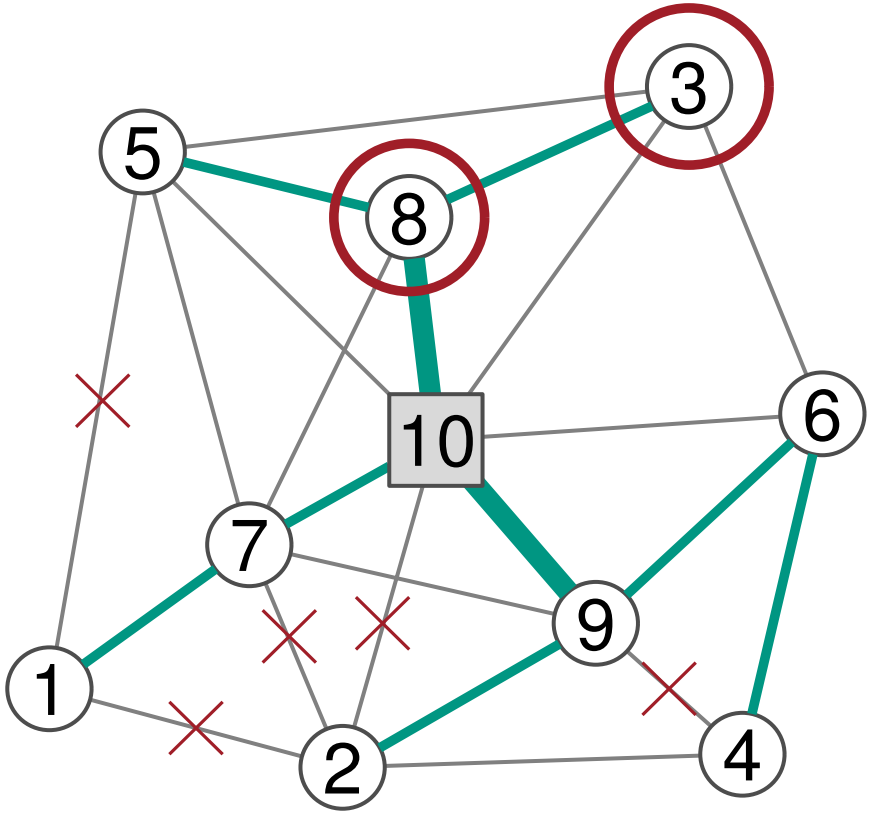

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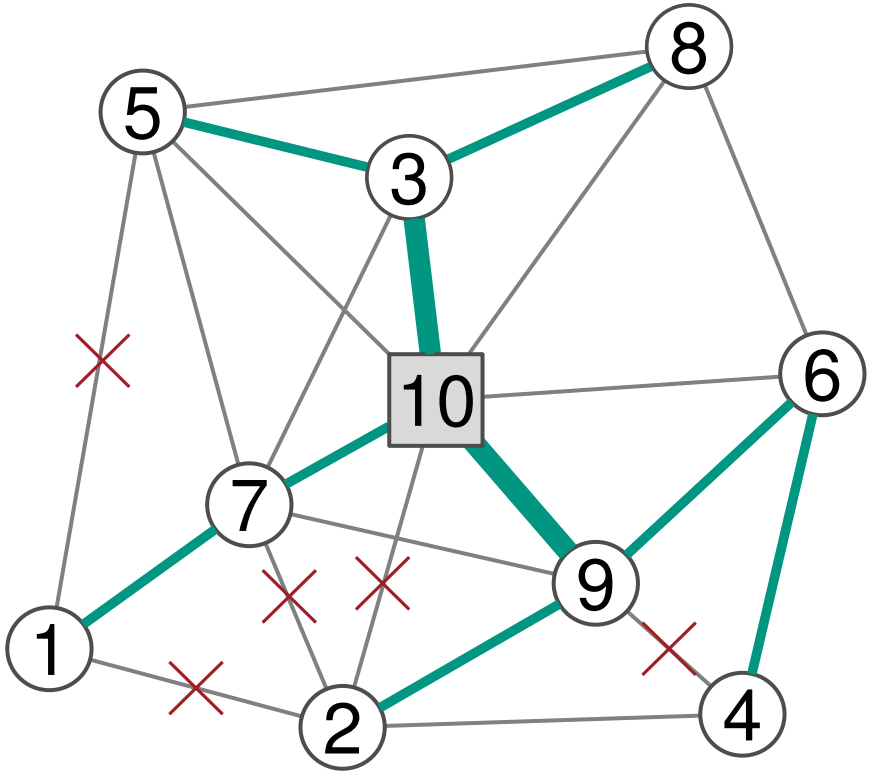

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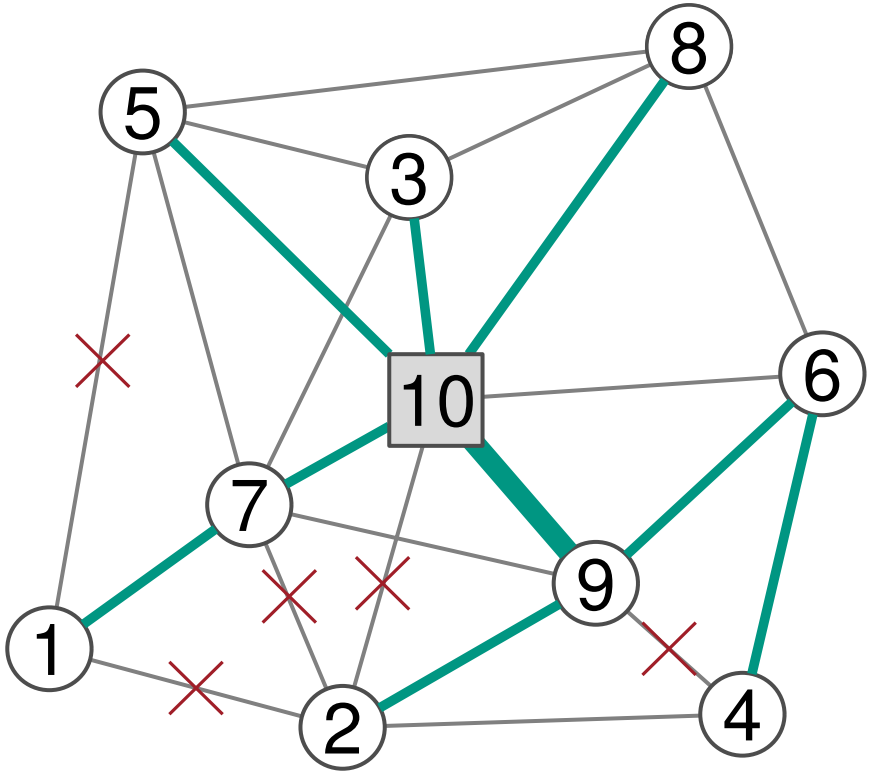

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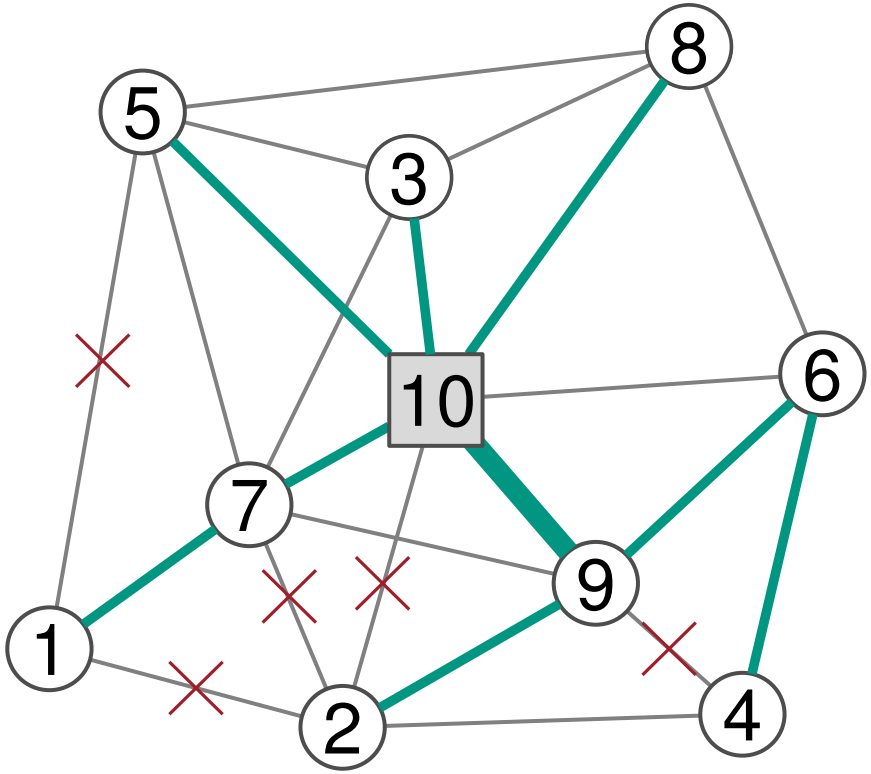
- forbid / allow an edge



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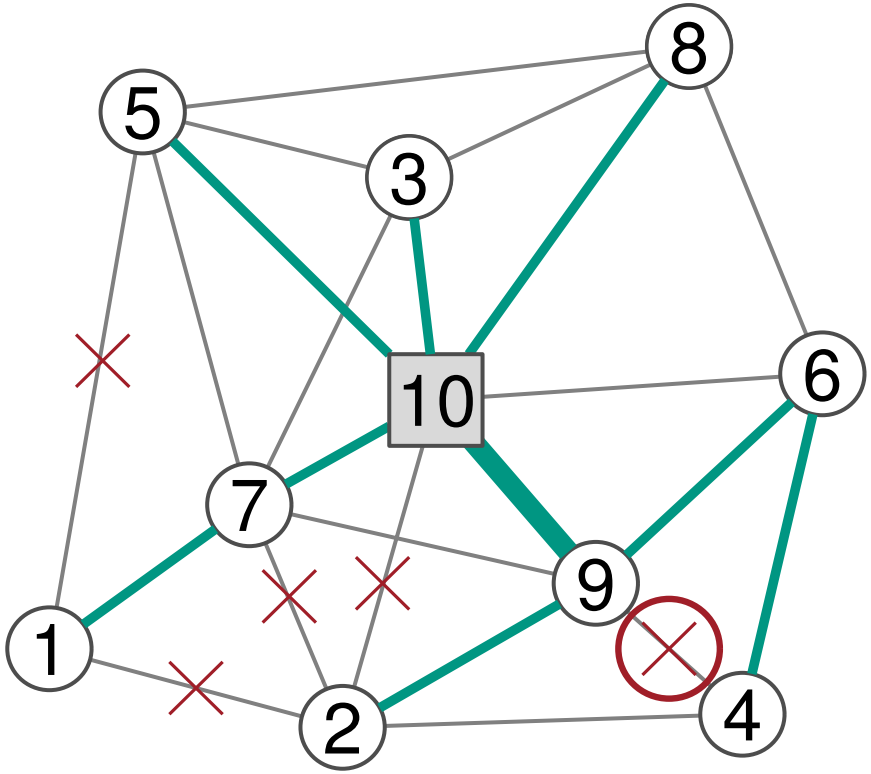

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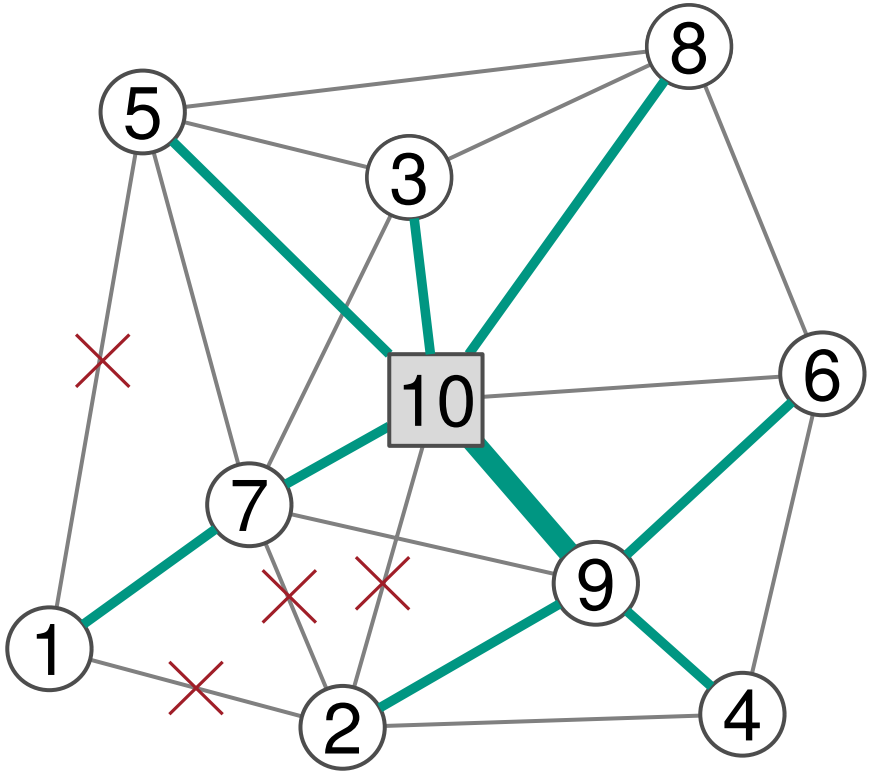
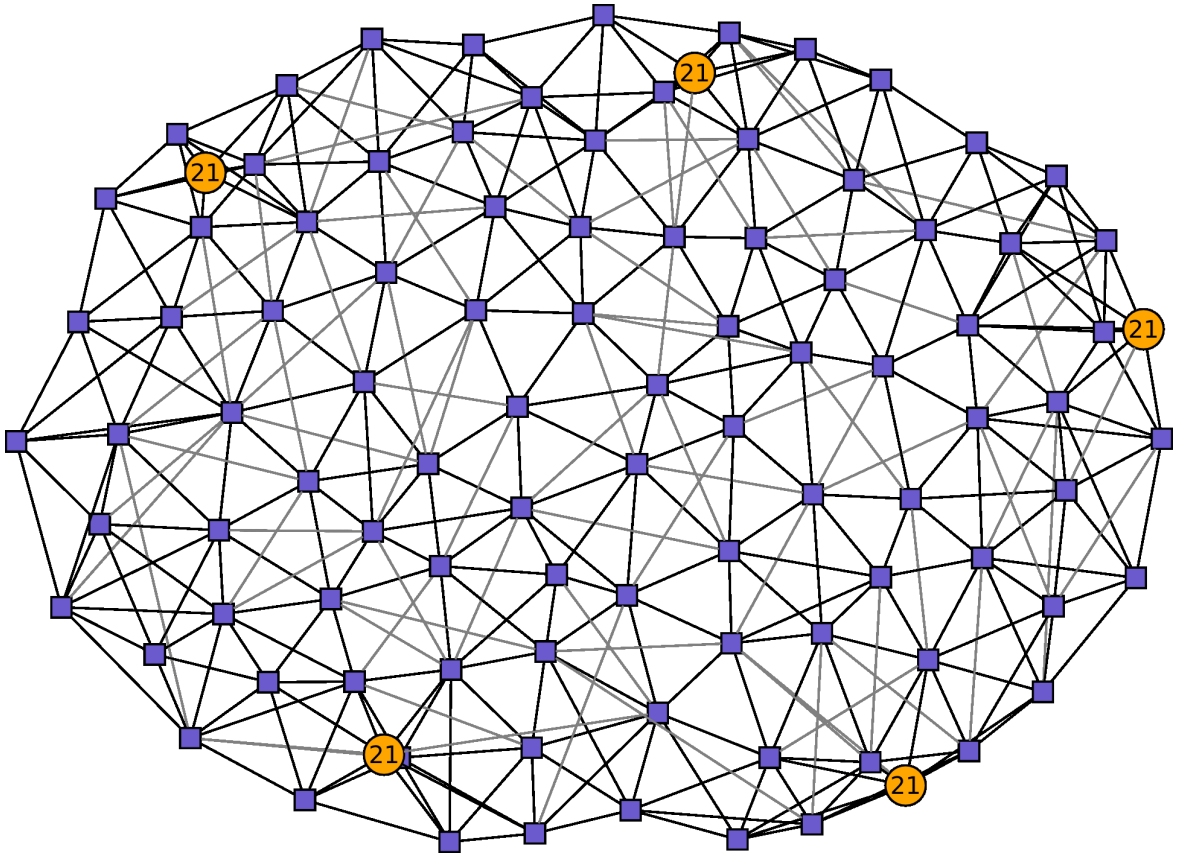


Generating Instances

- Turbines & substations evenly distributed (Poisson Disk Sampling)
- Edges: 6 nearest neighbors + shortcuts
- Substation capacities: tight vs. loose



Observations & Problems

good results for medium-sized farms ($\mathbf{t} < 350$: faster than Gurobi)

long running time required for large farms

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reference solution:
run Gurobi for 1h

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Observations & Problems

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better results after 30 min

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Observations & Problems

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converges slower than Gurobi

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- **temperature** curve: parameter tuning difficult
- result depends on **random seed**
- bad results for **tight** substation capacities
- bad results for **many** substations

Dynamic Temperature Curve

temperature curve: parameter tuning difficult

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Dynamic Temperature Curve

temperature curve: parameter tuning difficult

Observation:

- escaping deep local optimum takes **long time**

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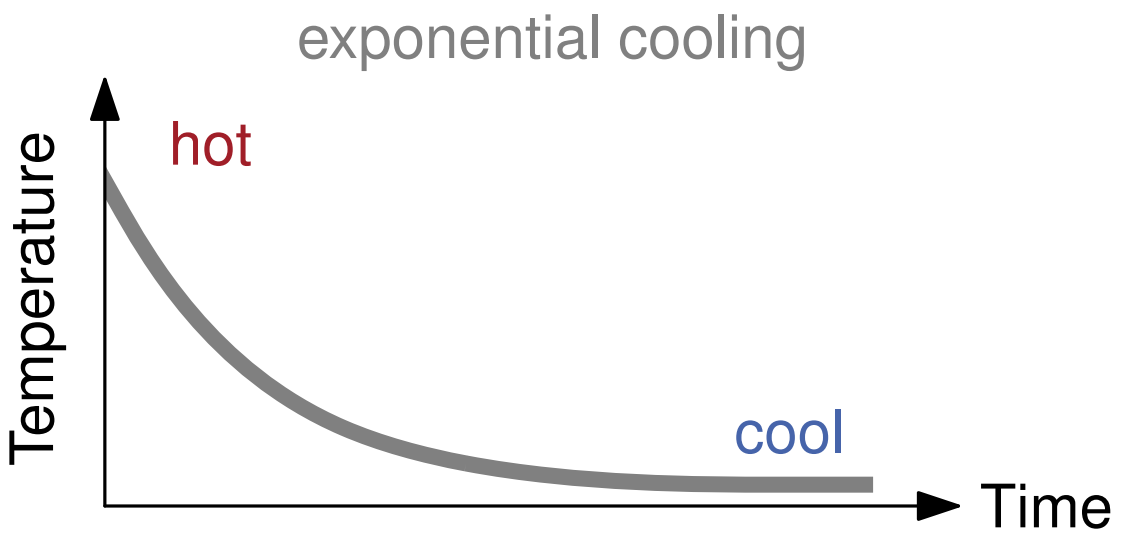

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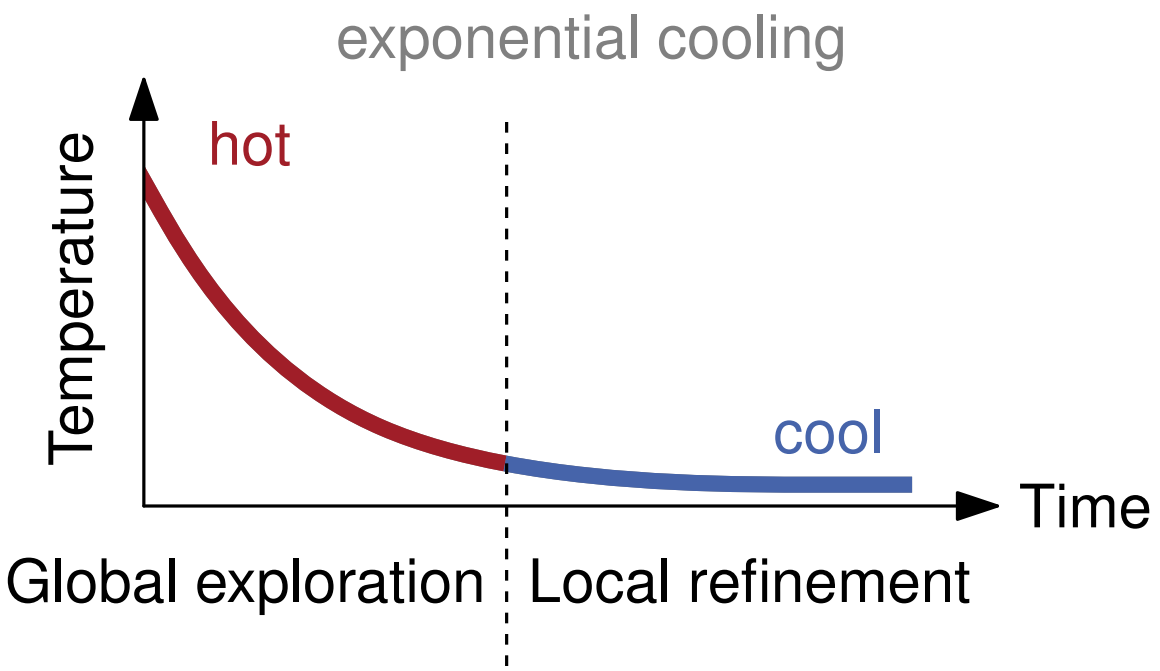

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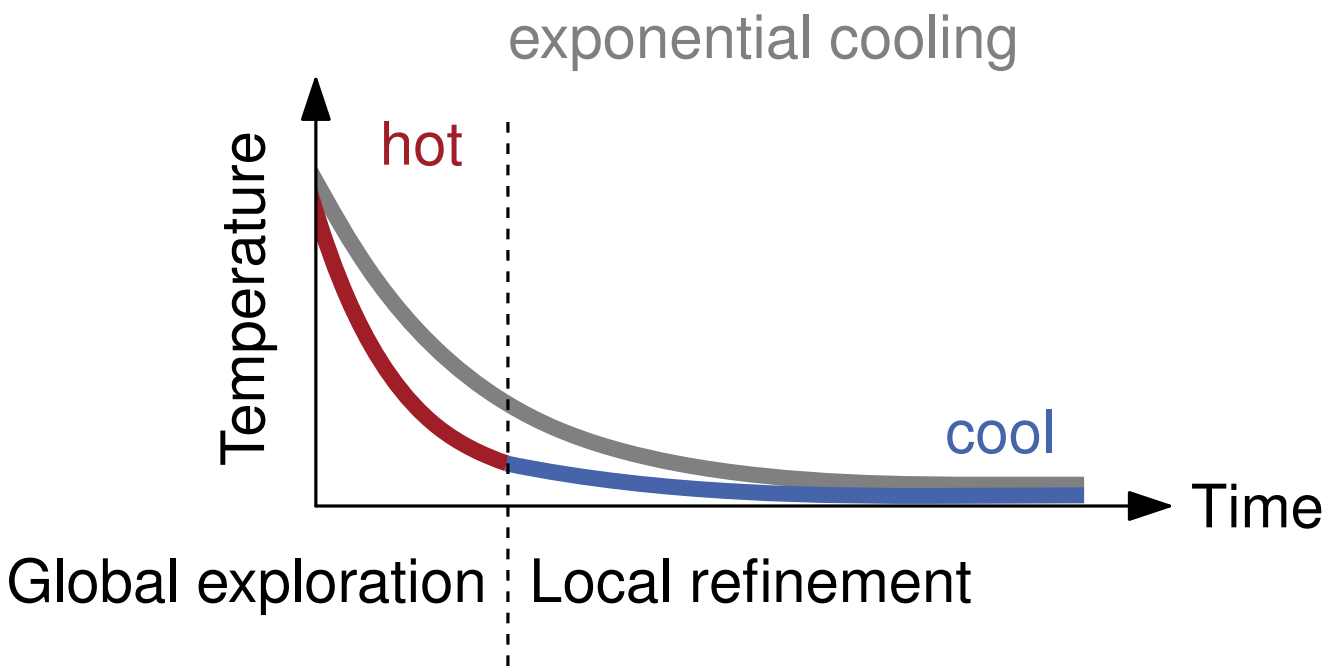

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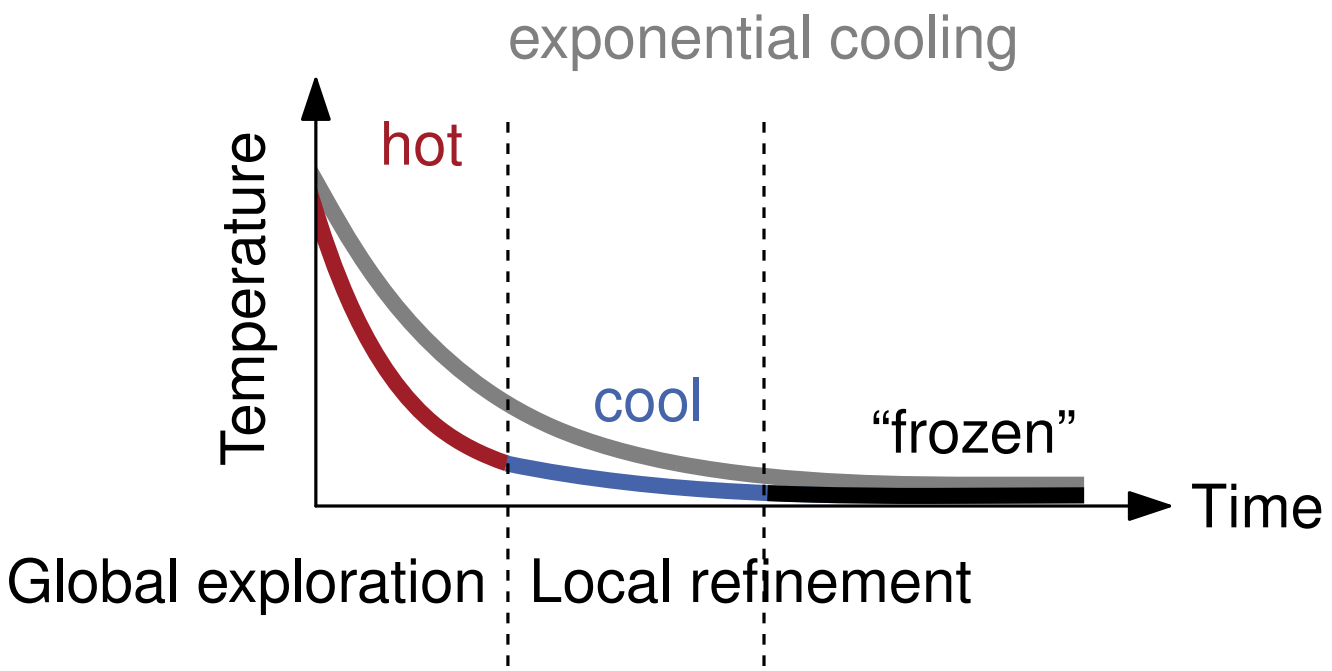

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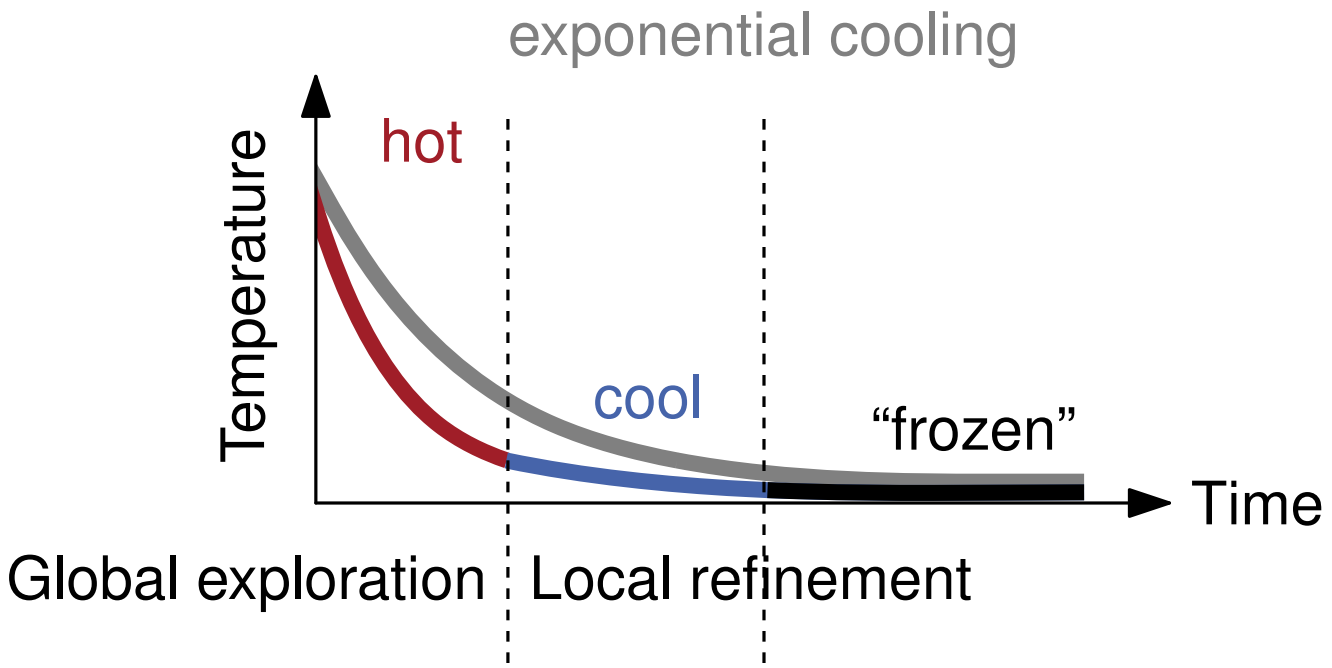

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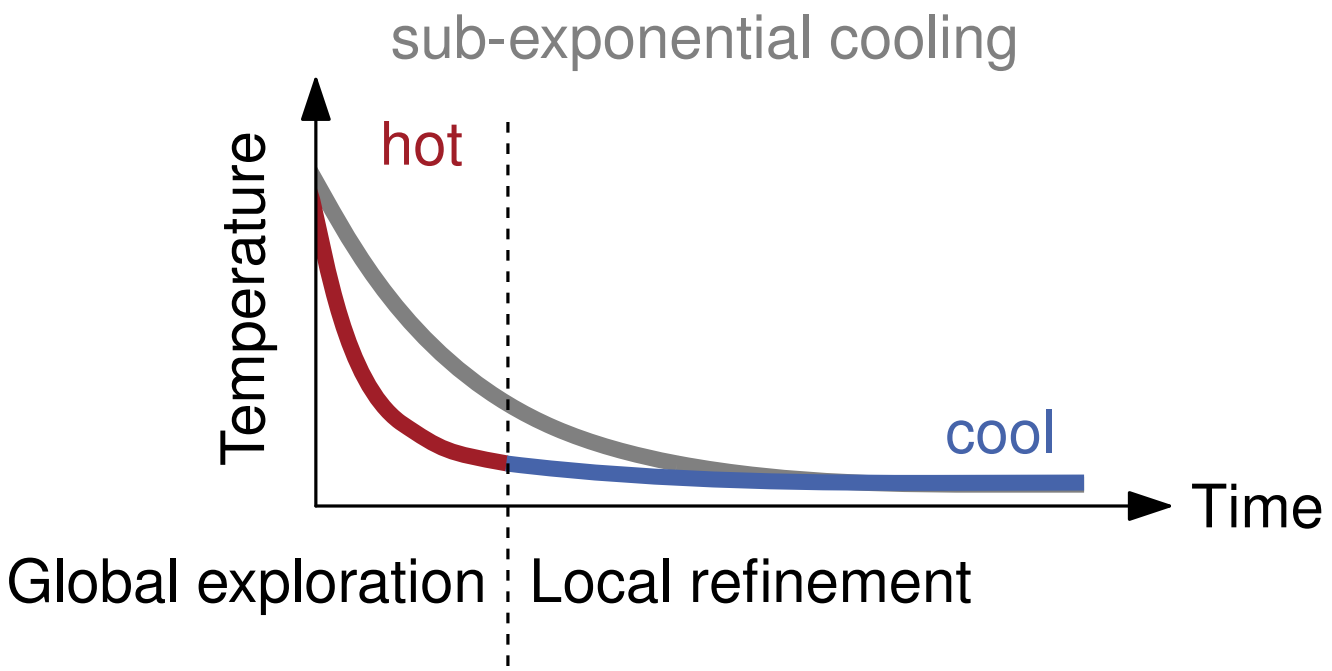

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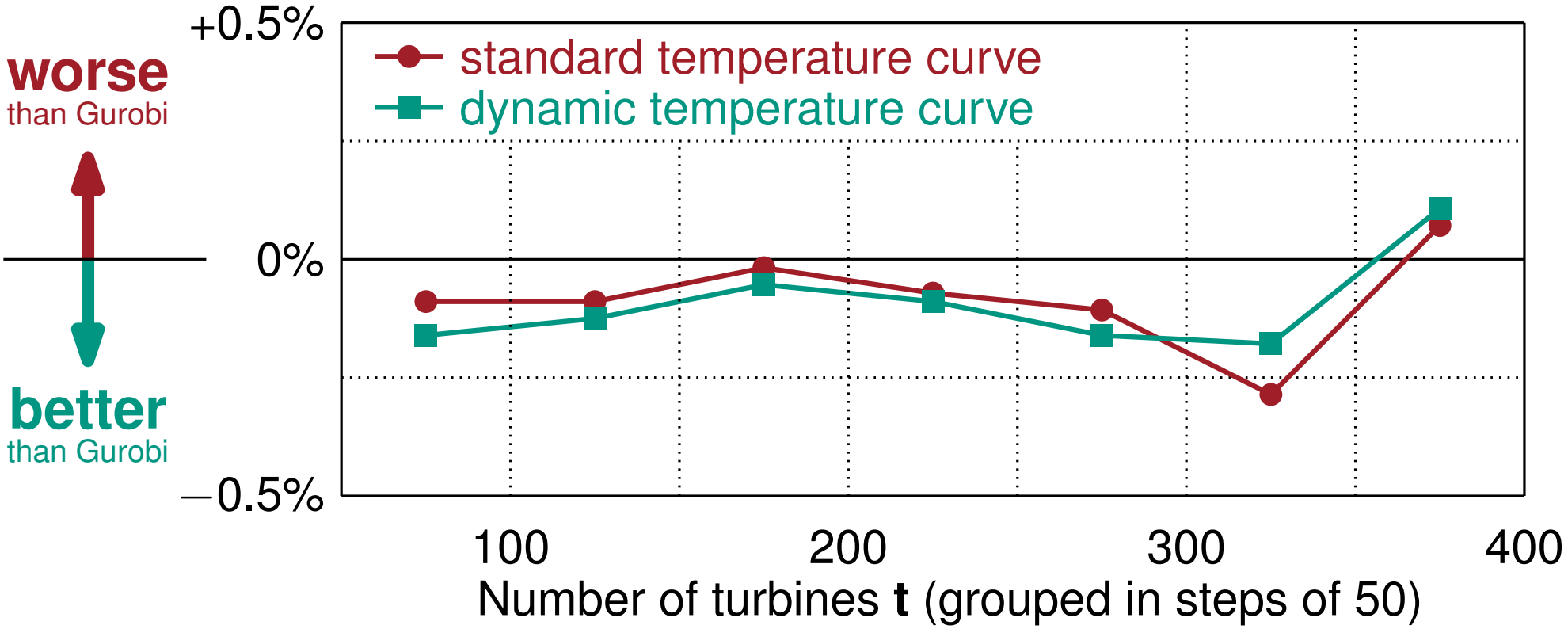

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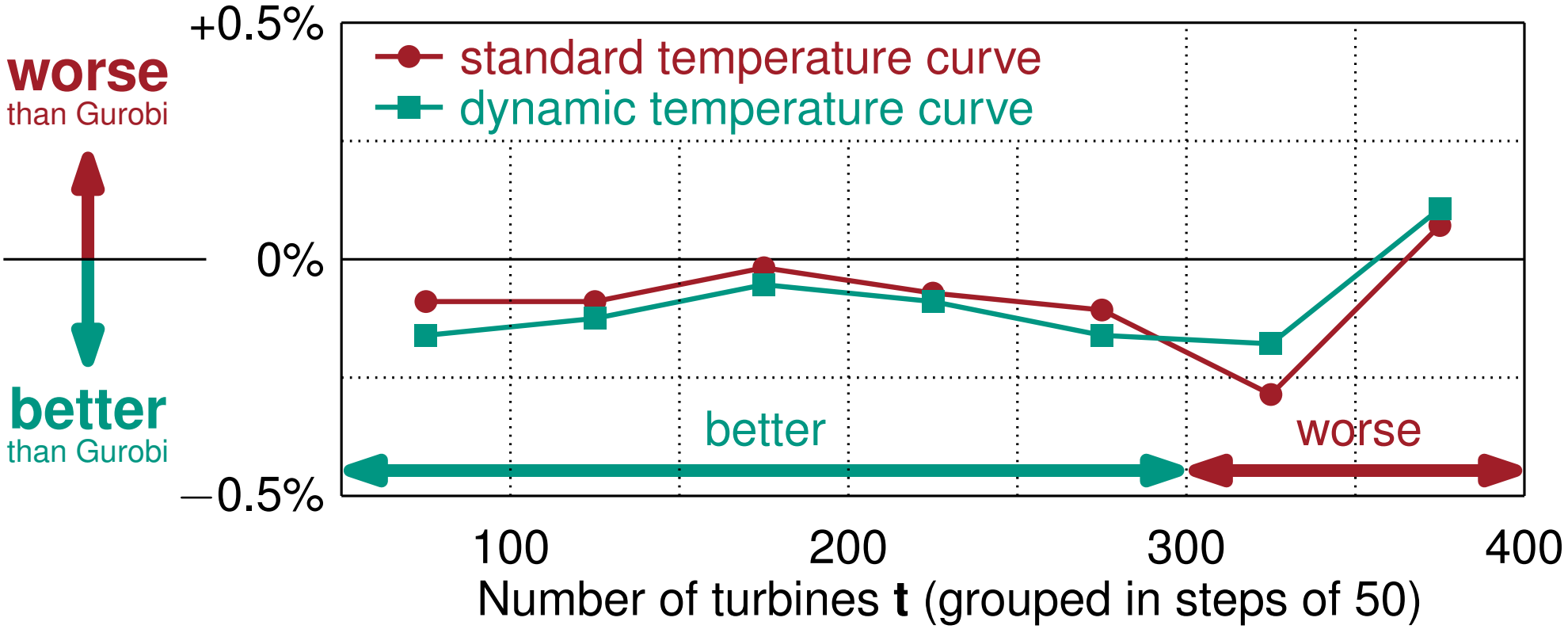

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result depends on **random seed**

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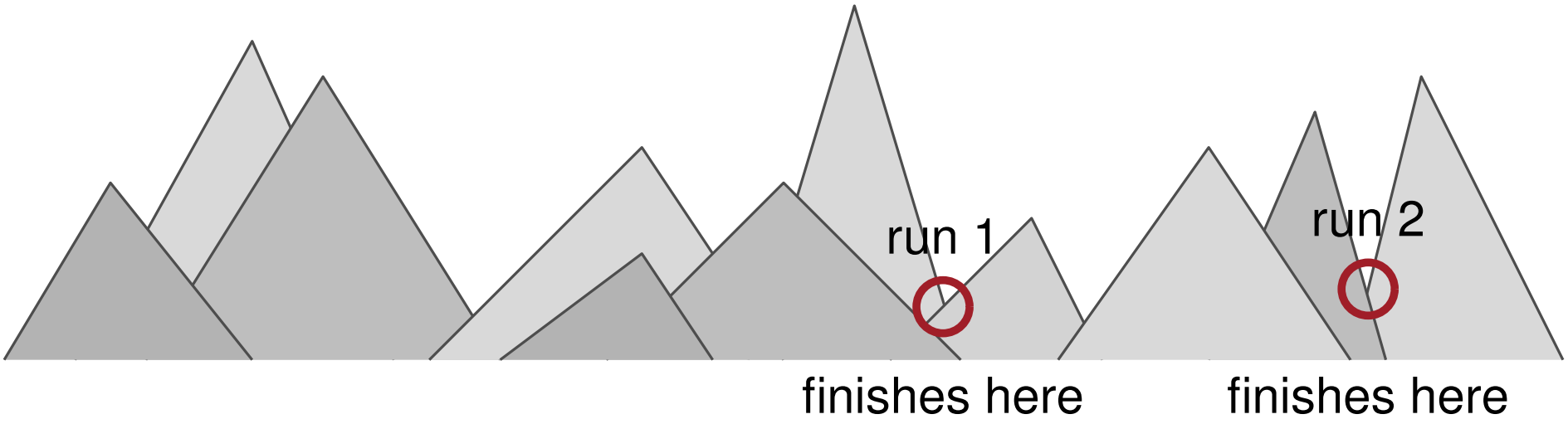

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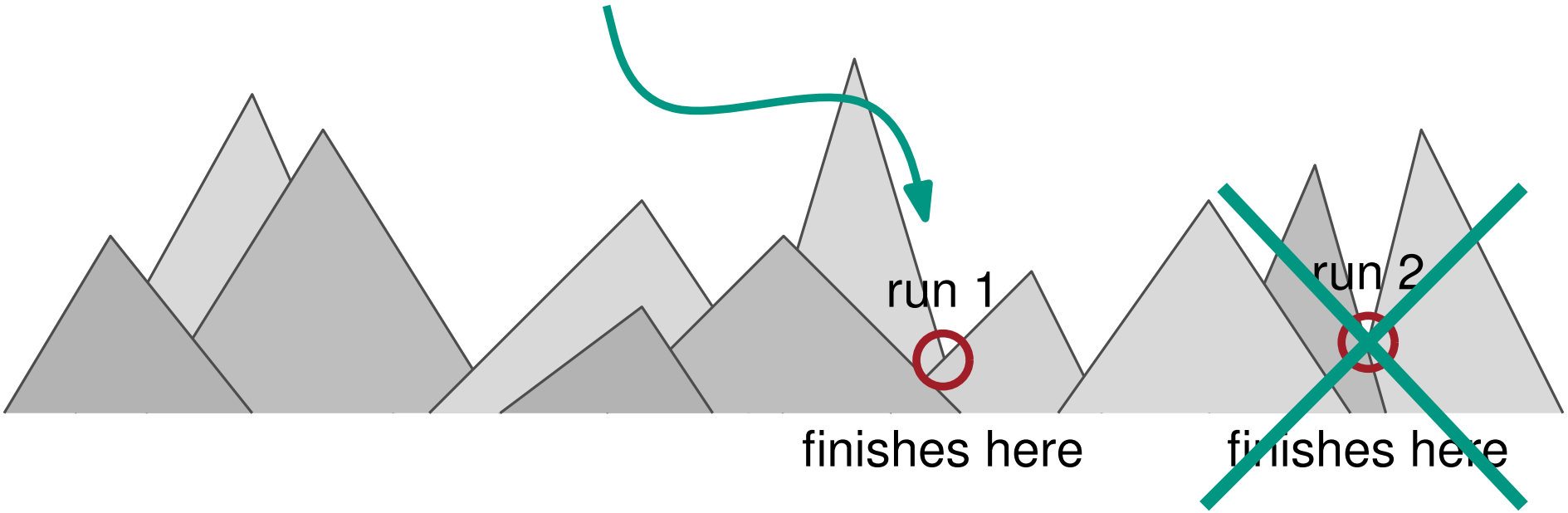

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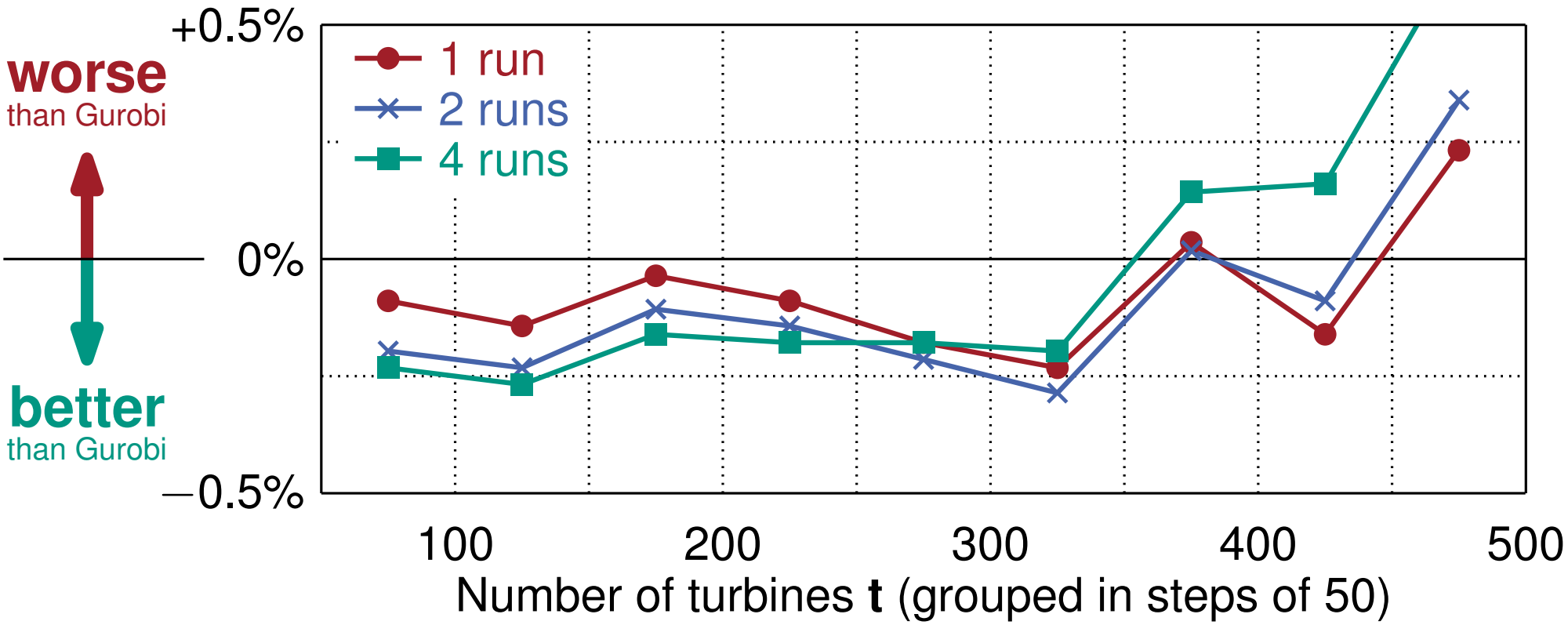

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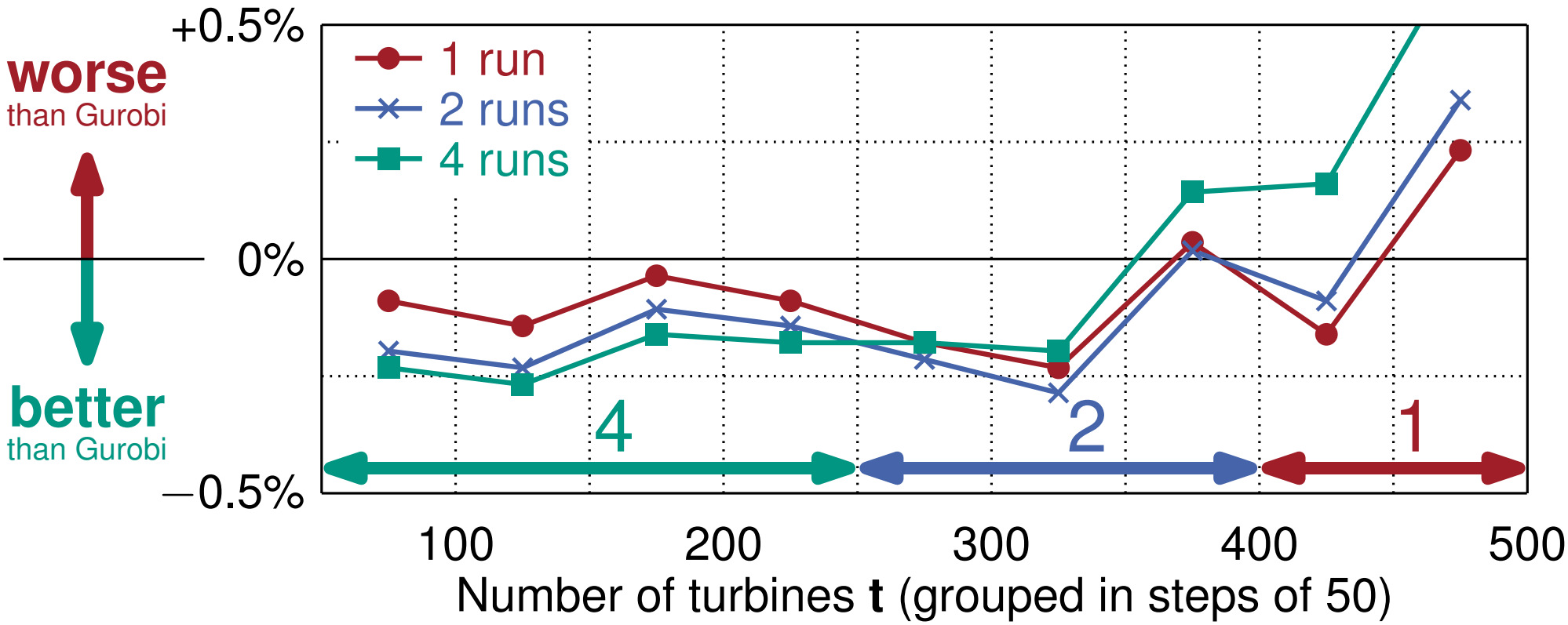

Two-Level Approach

bad results for **tight** substation capacities / **many** substations

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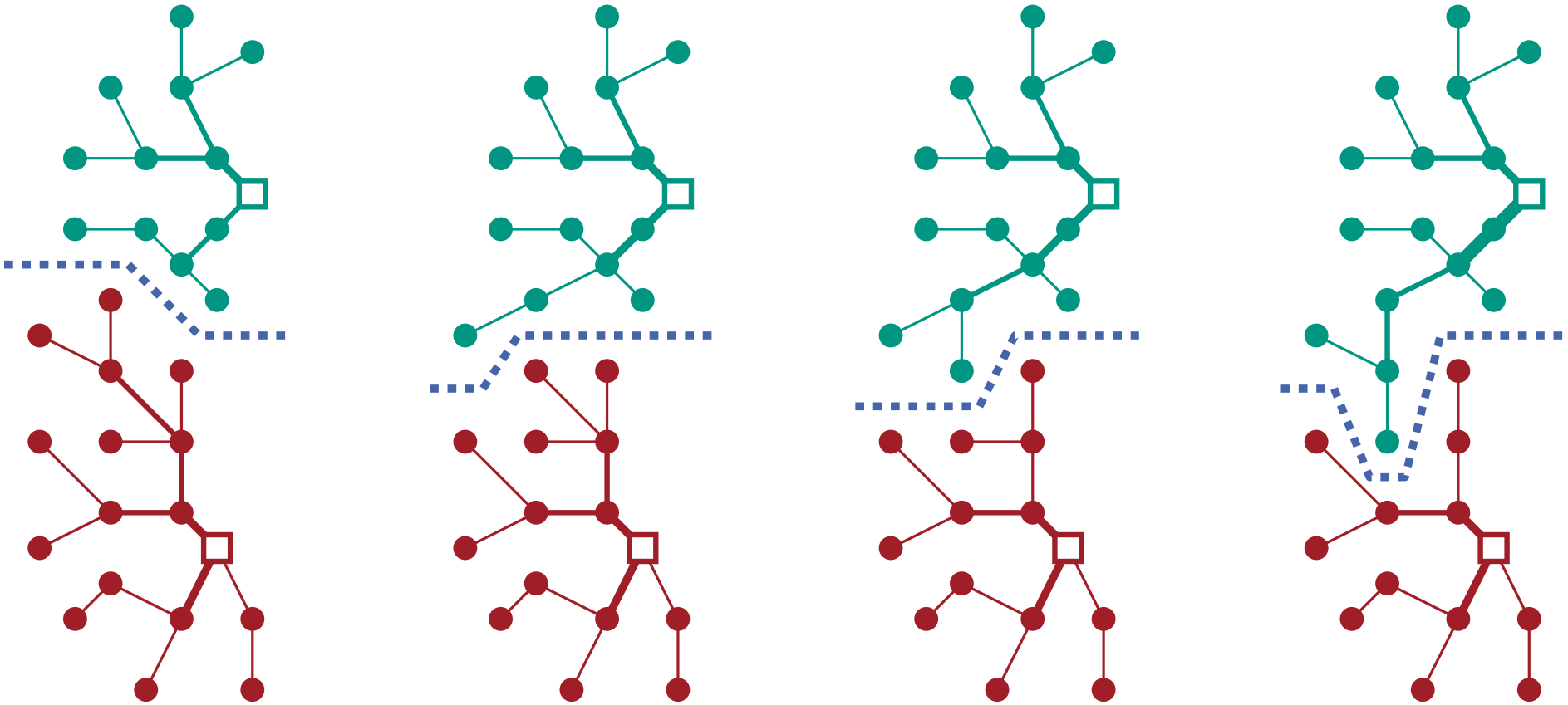

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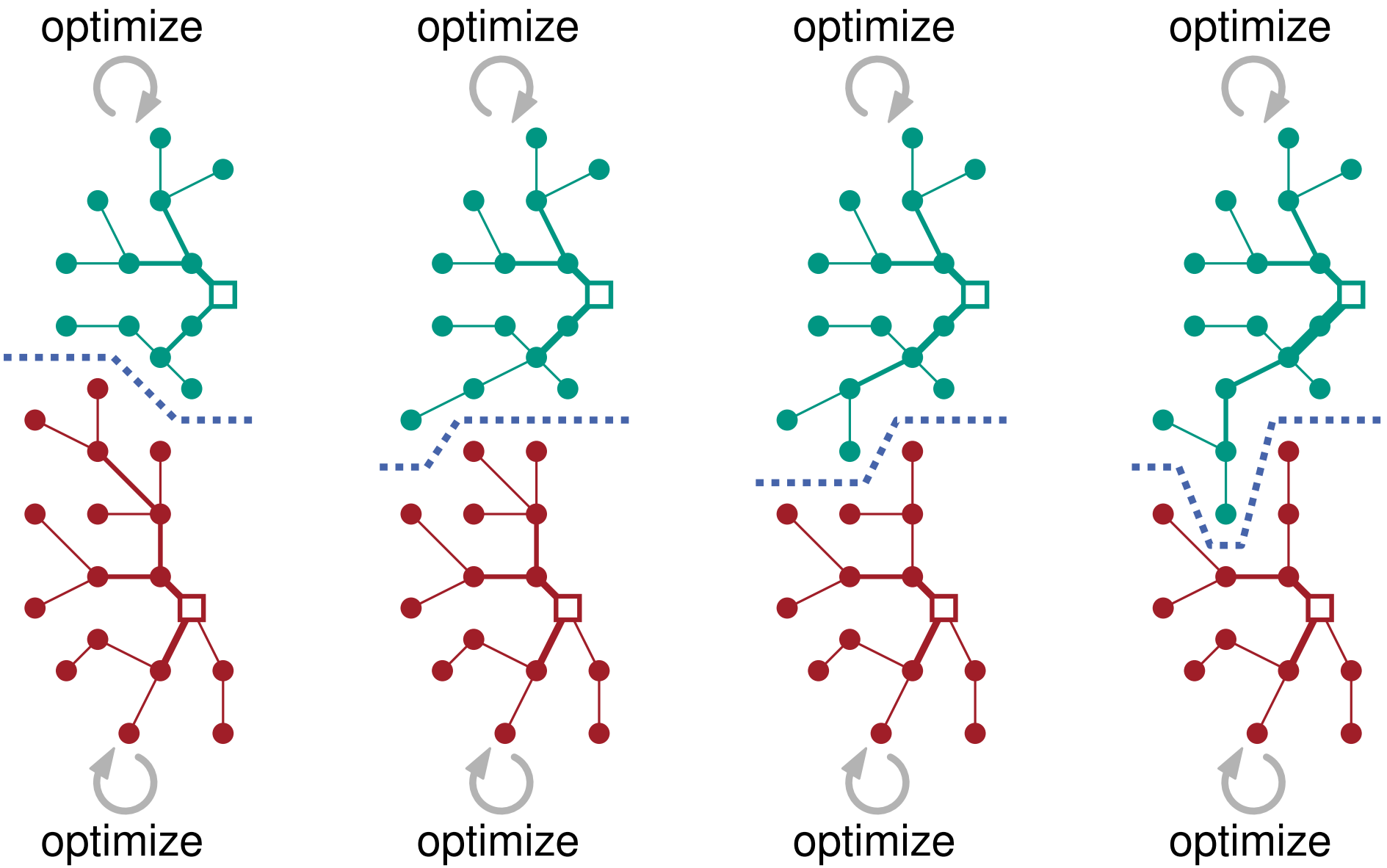

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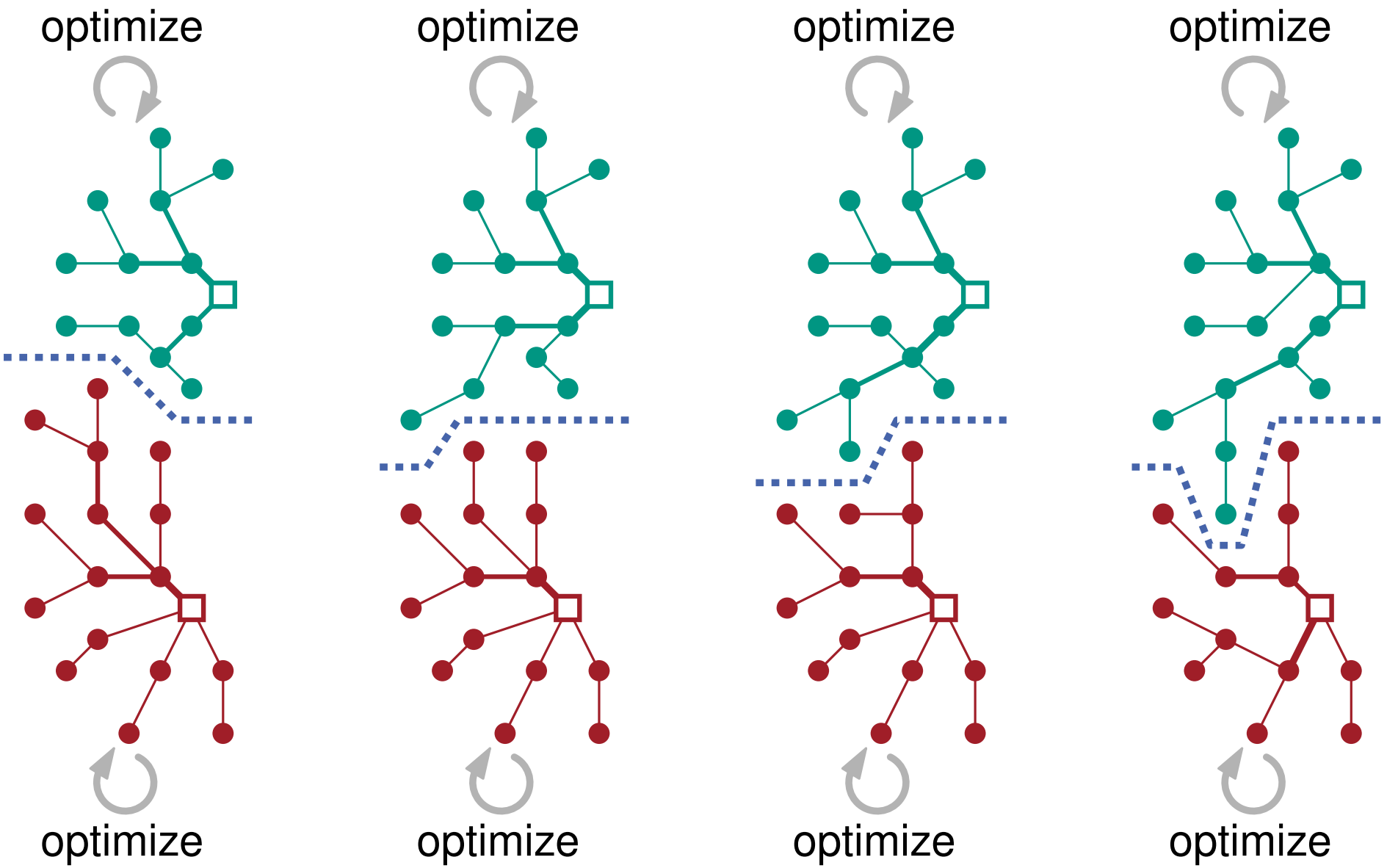

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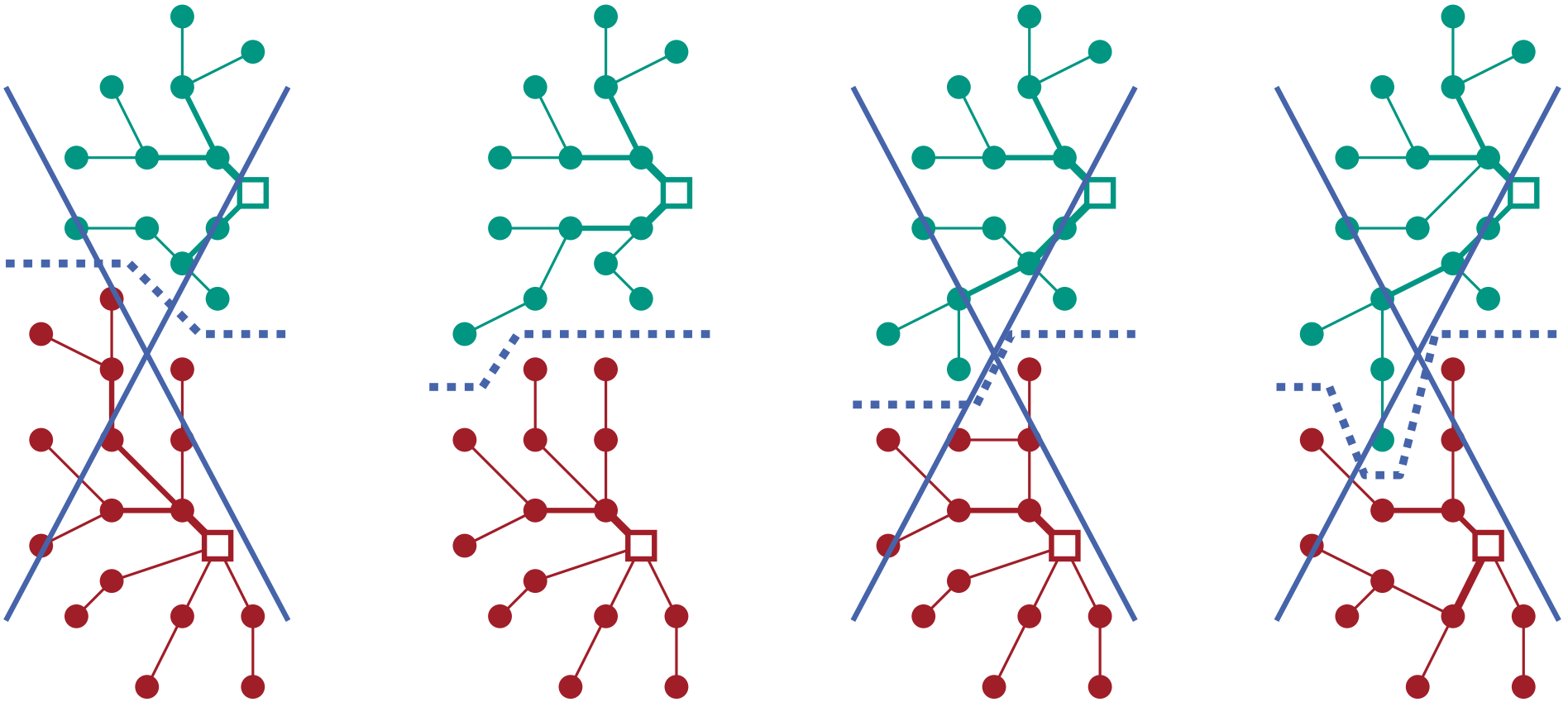
best final result



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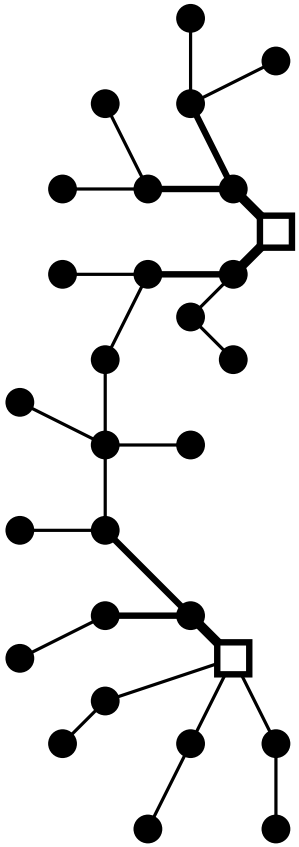

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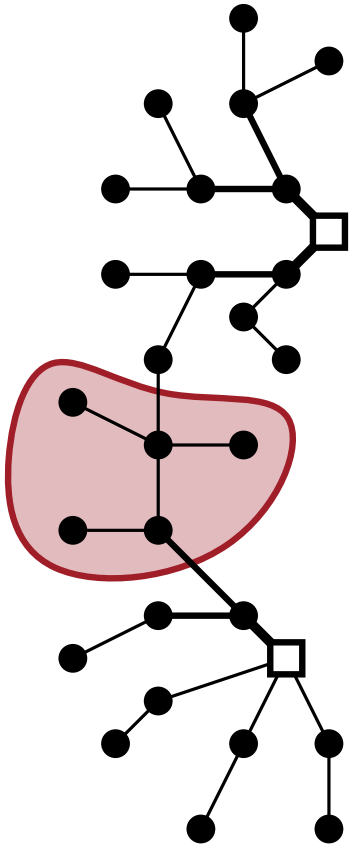

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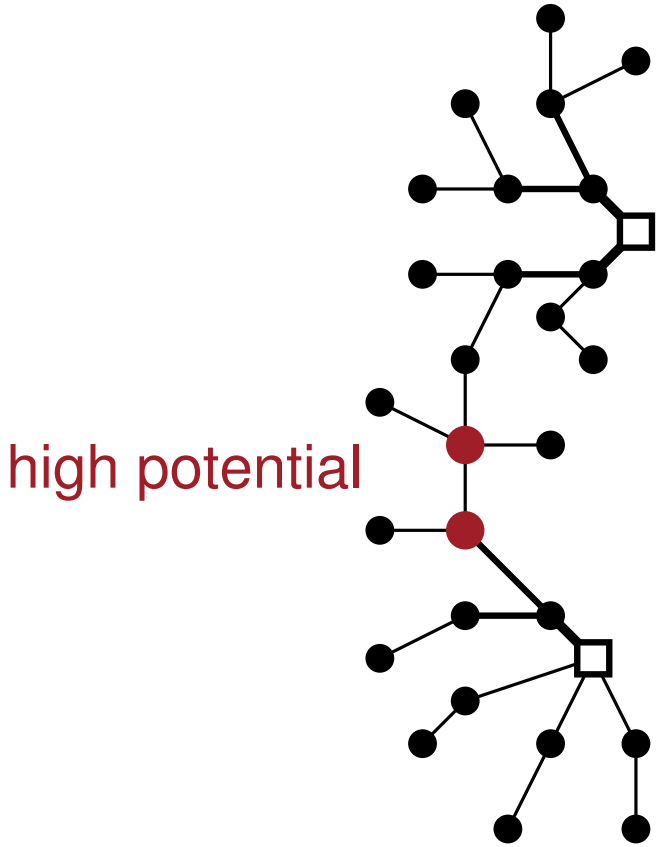

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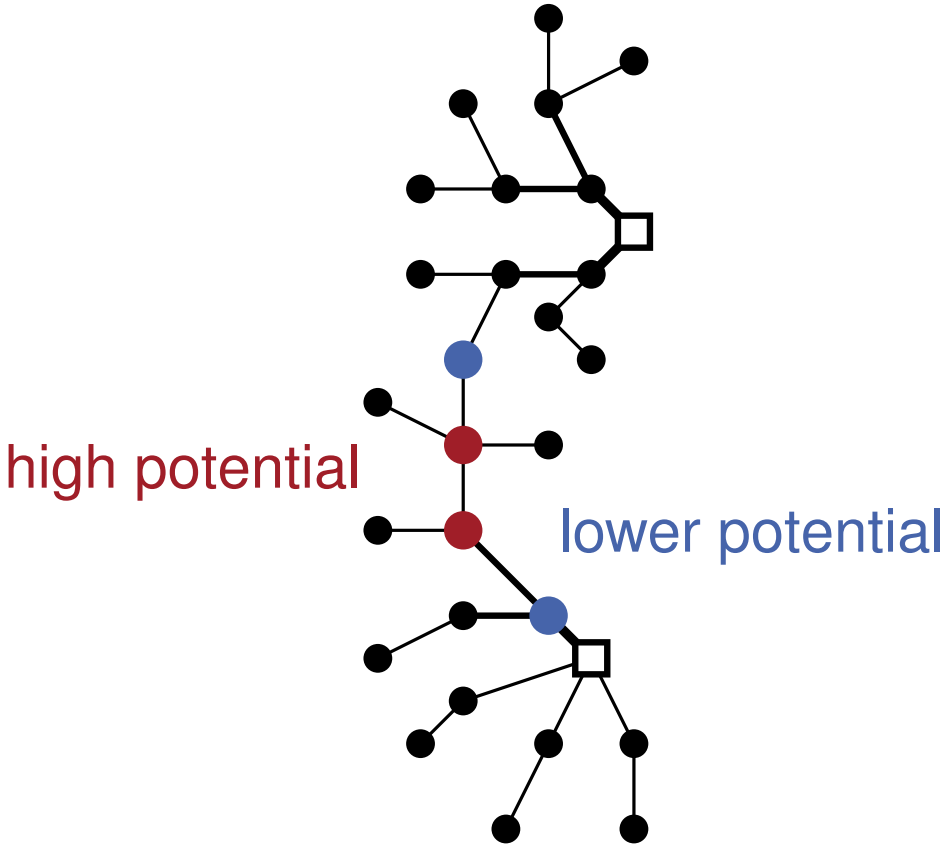

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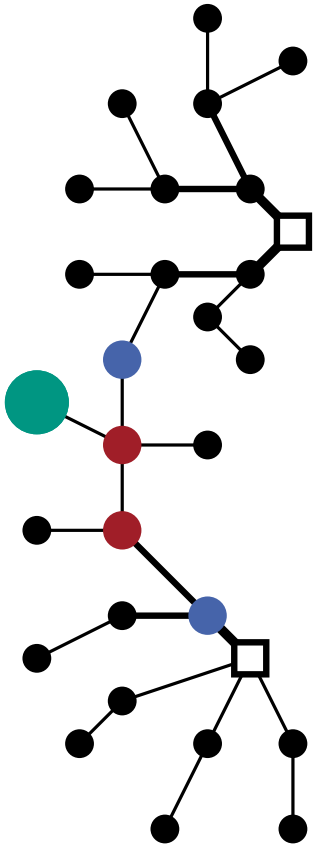

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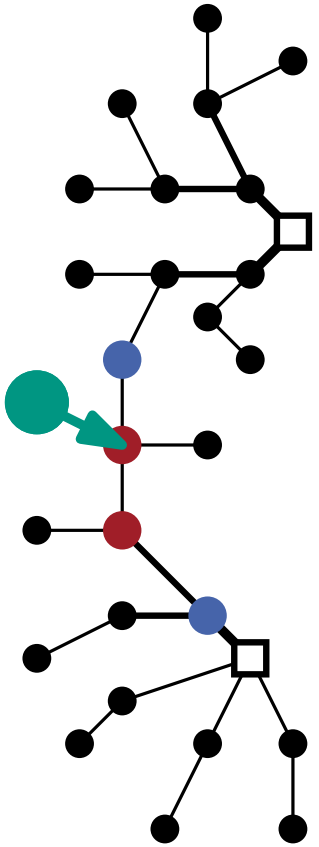

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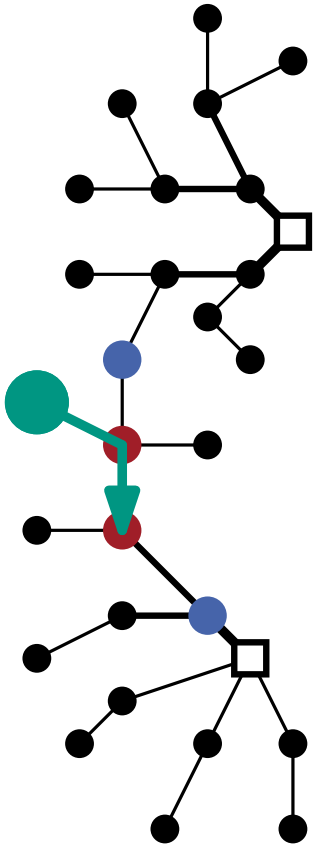

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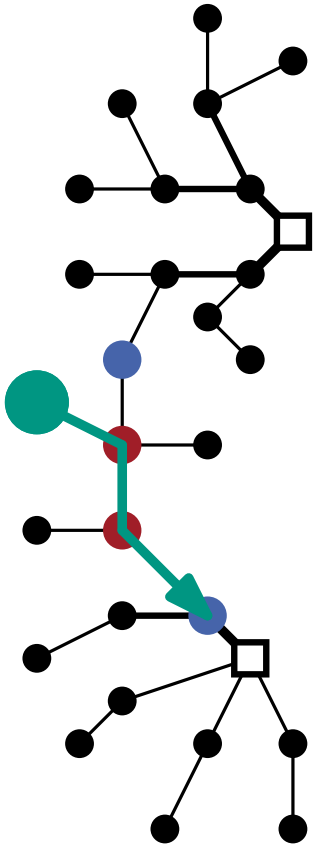

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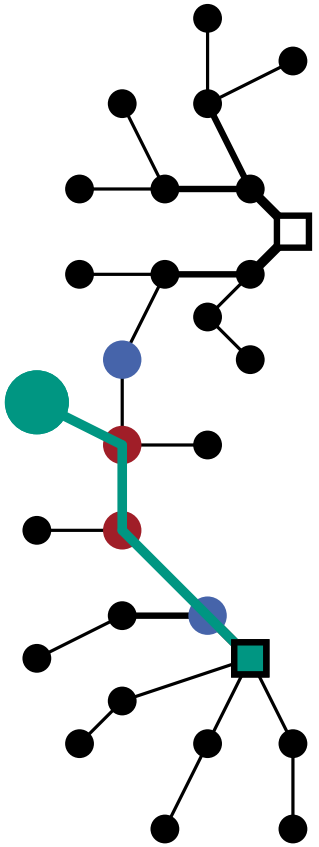

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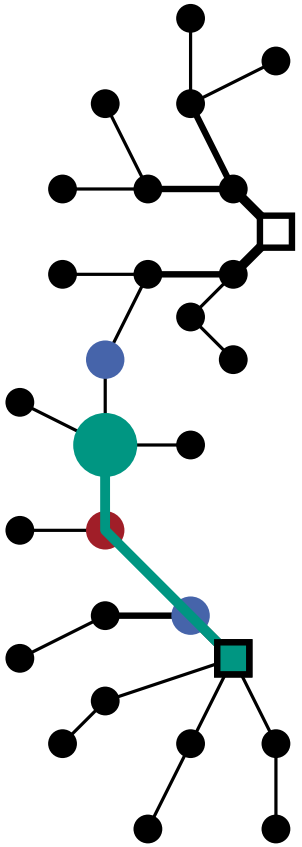

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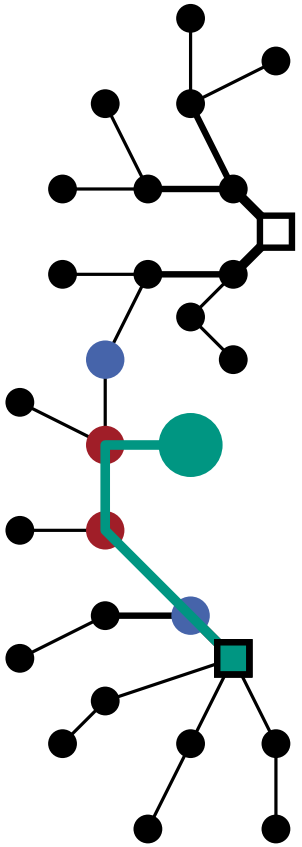

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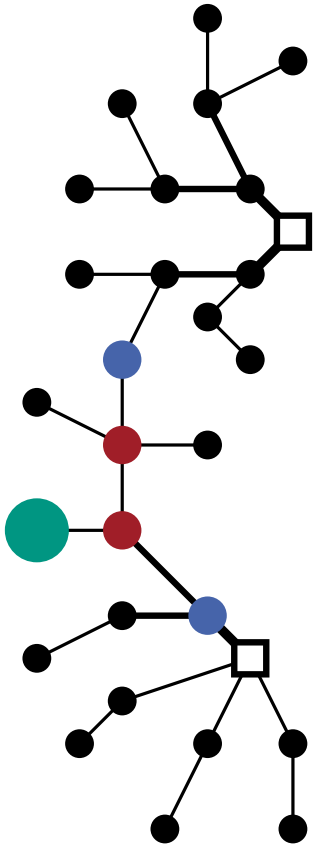

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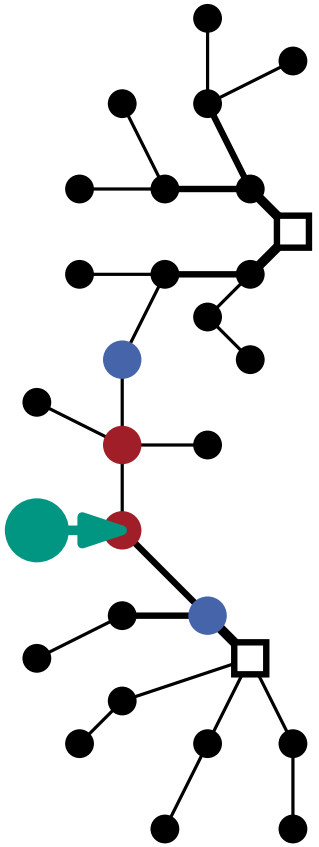

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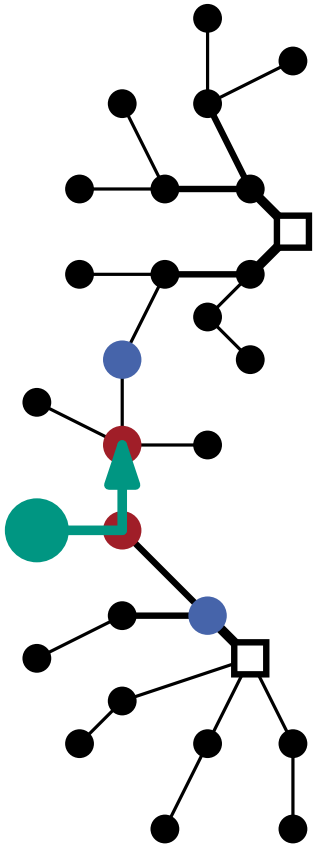

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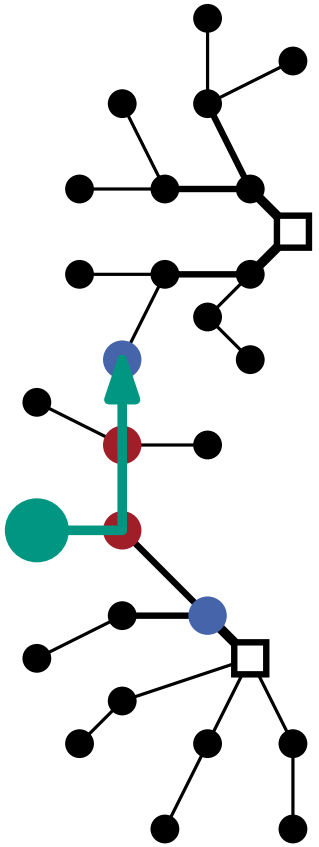

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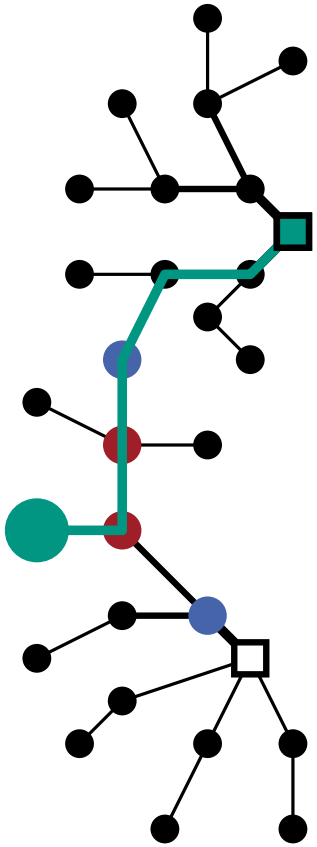

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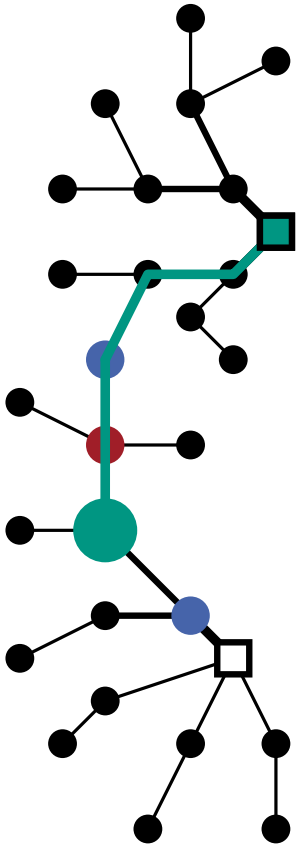

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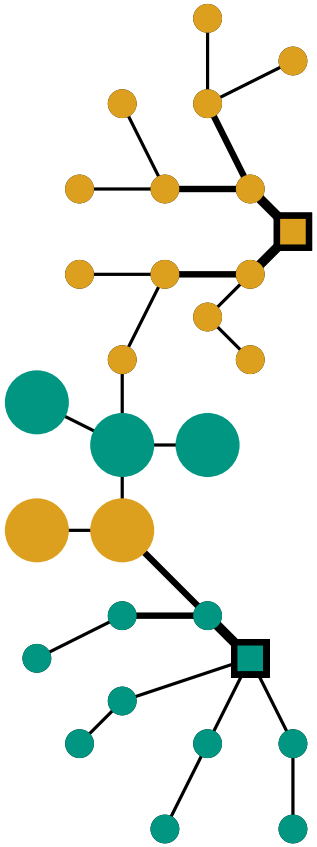

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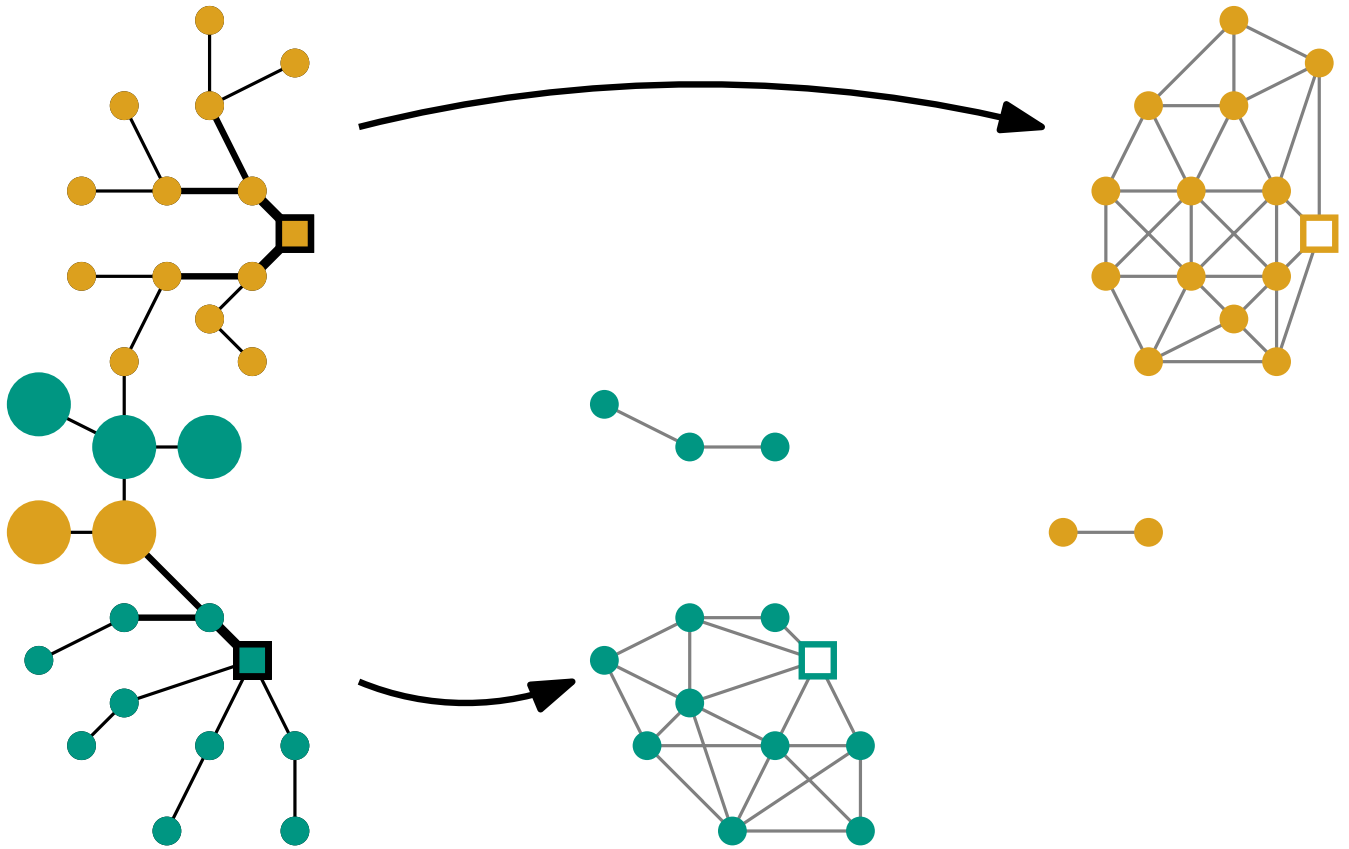

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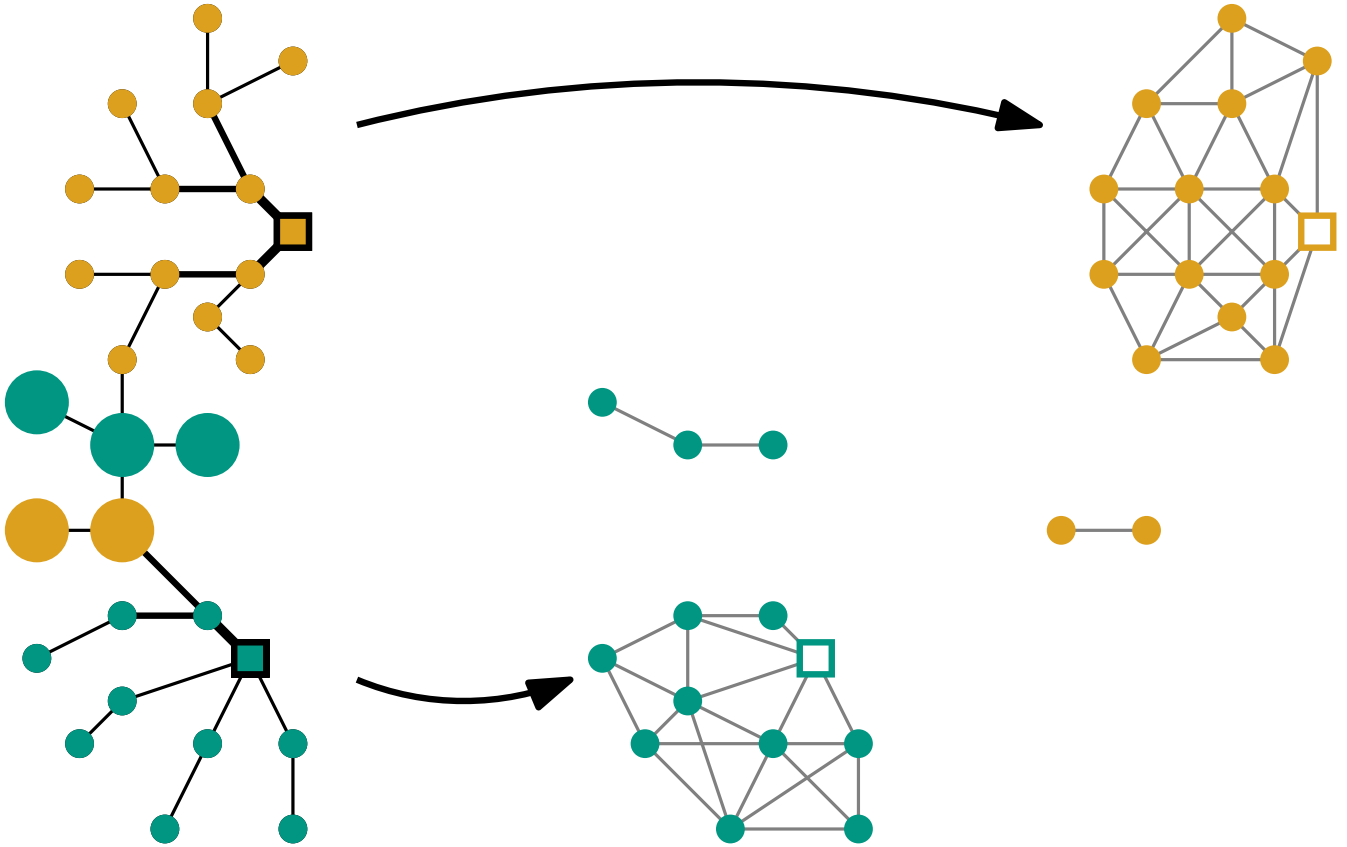

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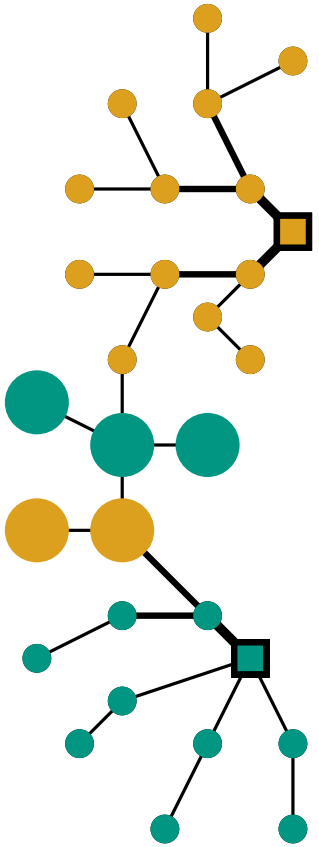

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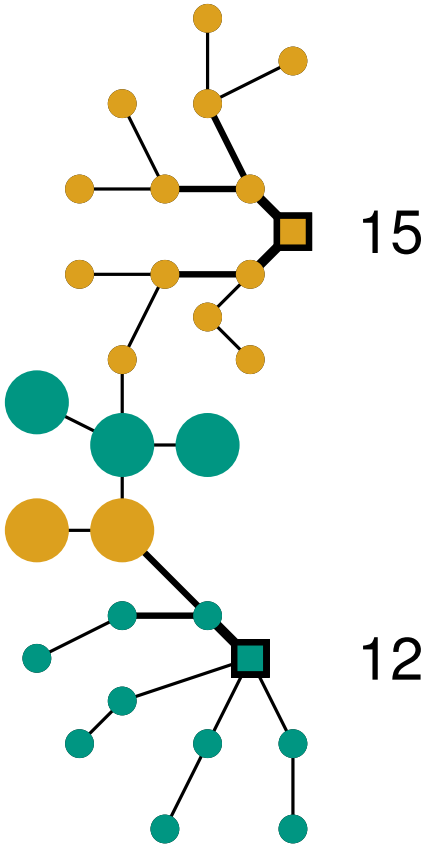

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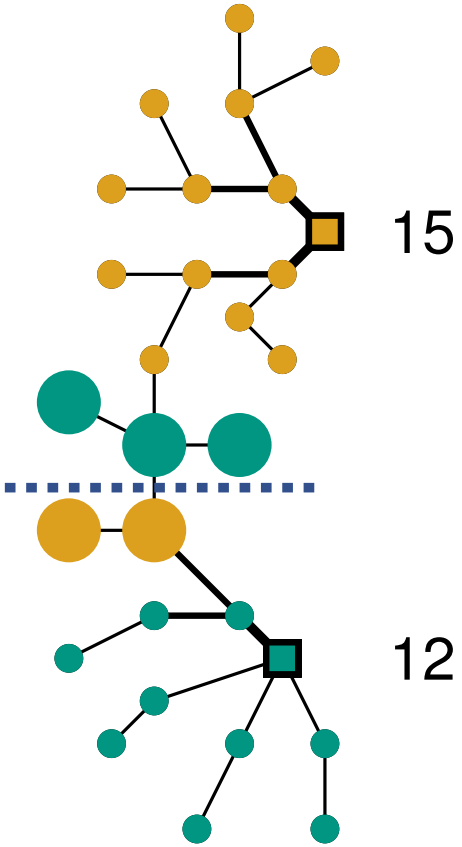

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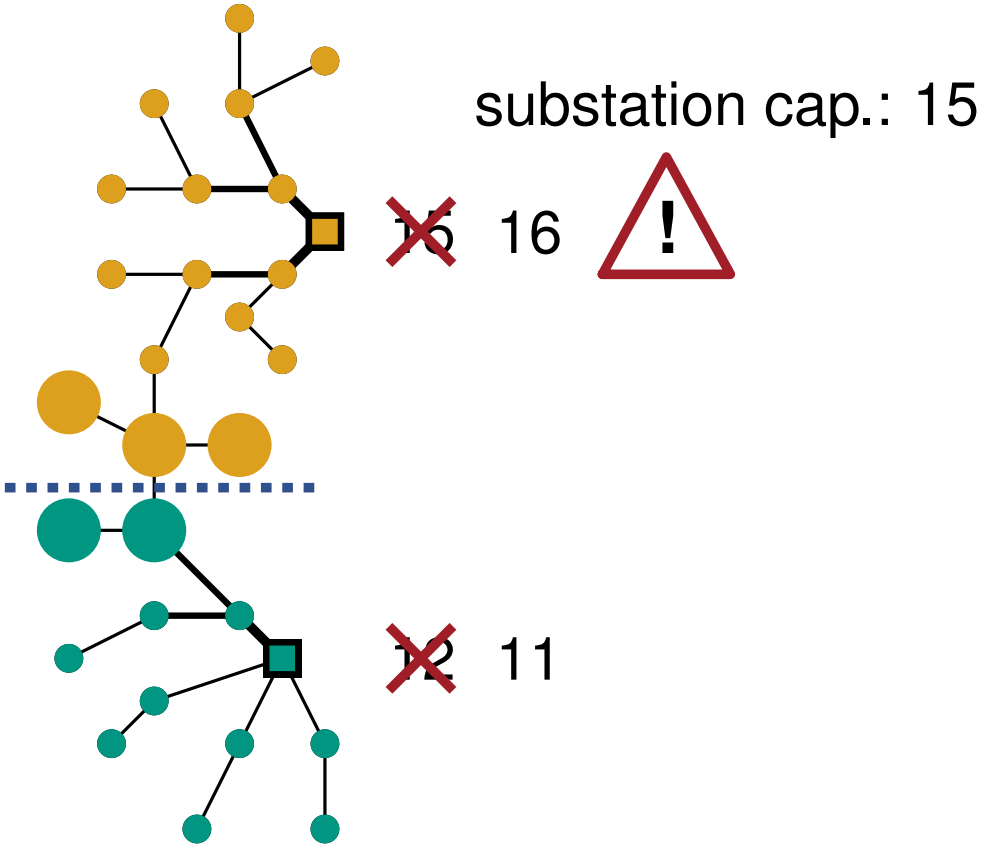

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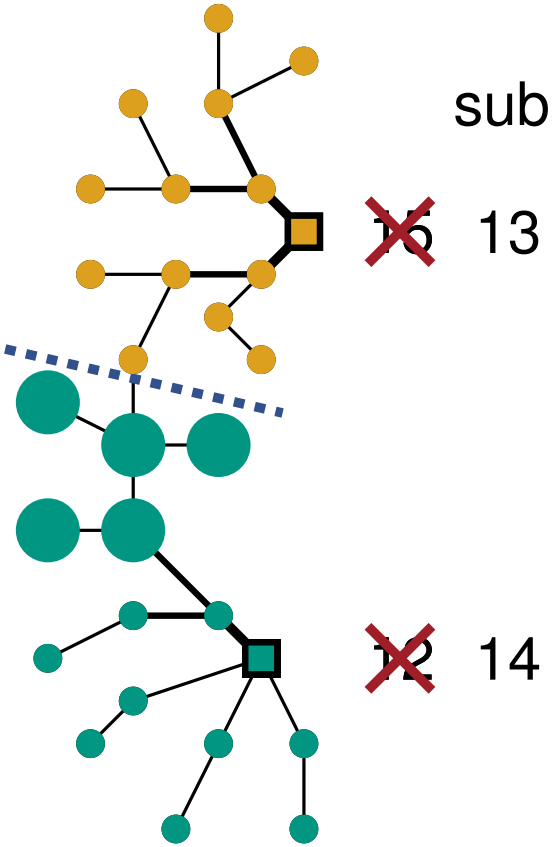

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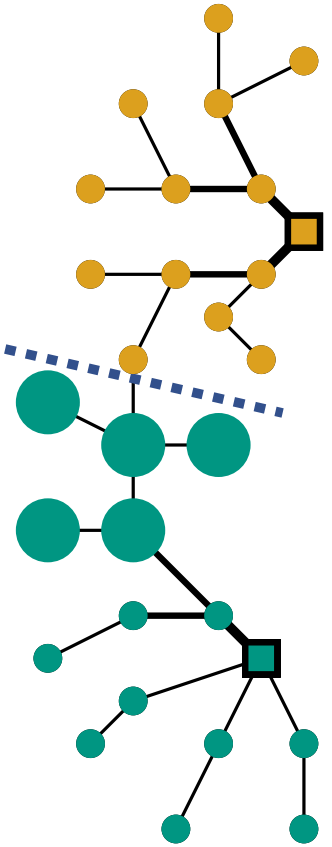

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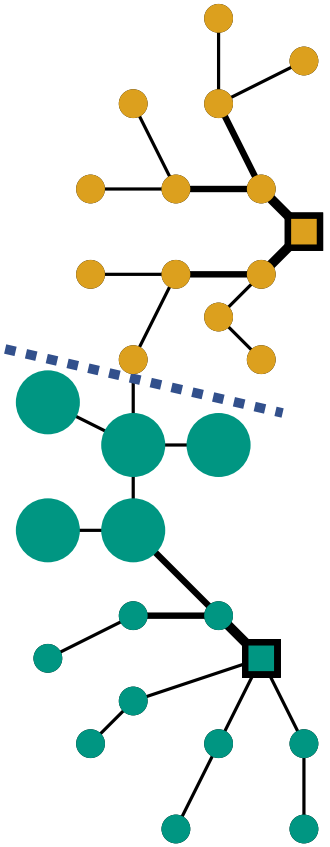

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Future Work

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  Problem: How detect this?
- Hybrid Simulated Annealing & Evolutionary Algorithm
  Problem: How cross two solutions?

Related Problems (Future Work)

- Optimize locations of substations
- Optimize types of substations (similar to types of cables)
- Allow adding merge points ($\Rightarrow$ Steiner Tree)
- Avoid intersections
- Redundant cables for failure safety