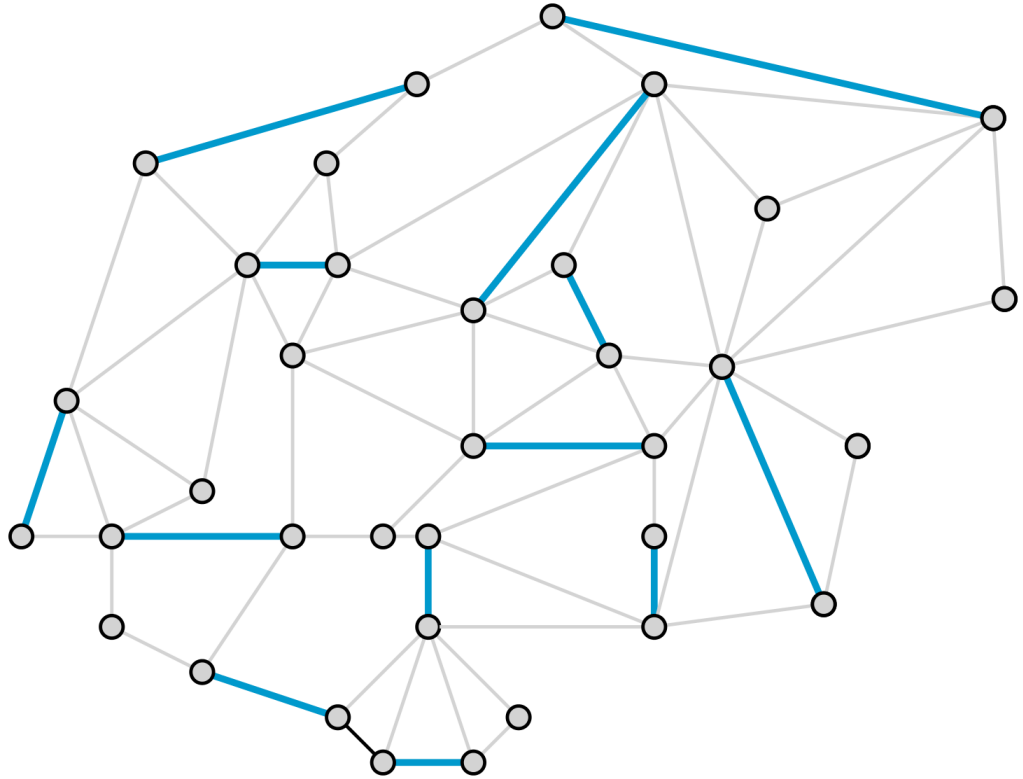
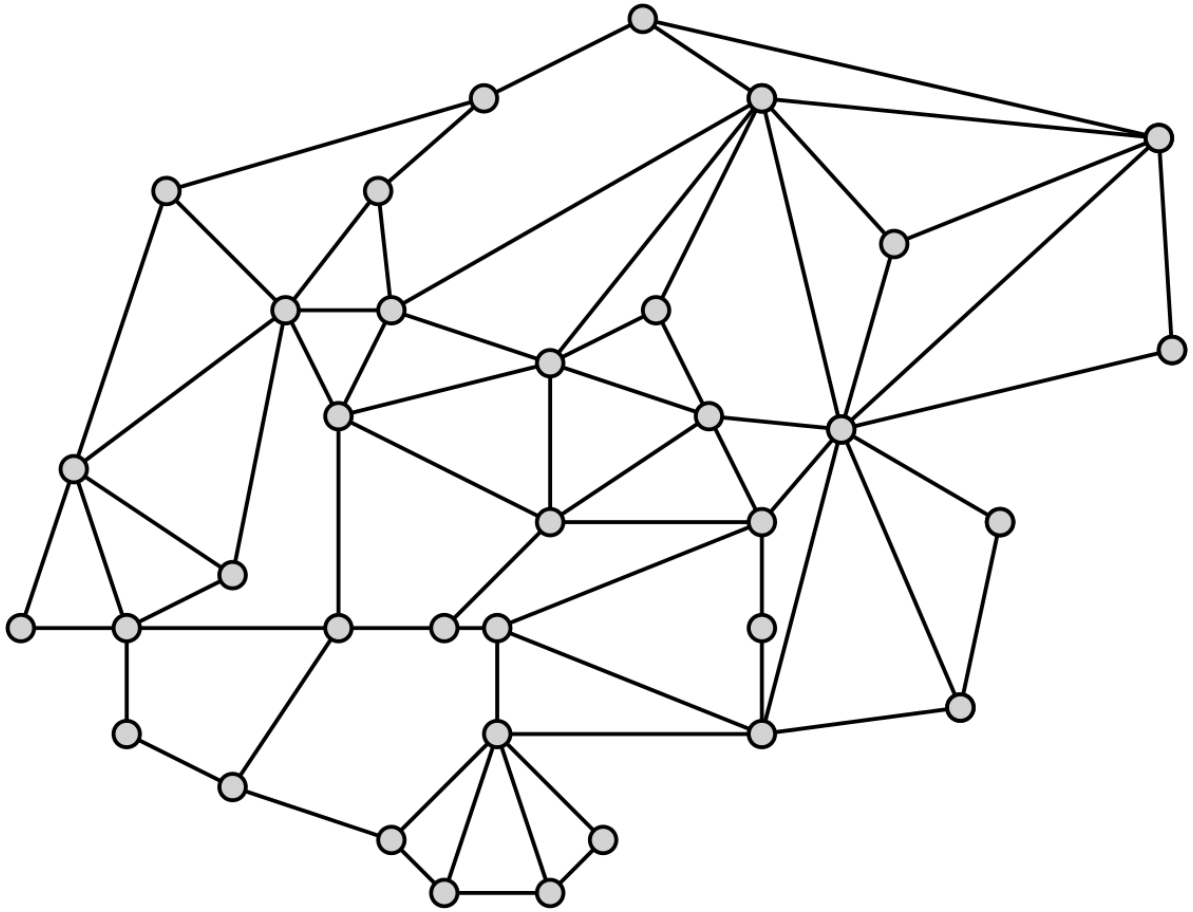


The Locality of Maximal Matching

Manuela Fischer
ETH Zurich

Locality

Locality



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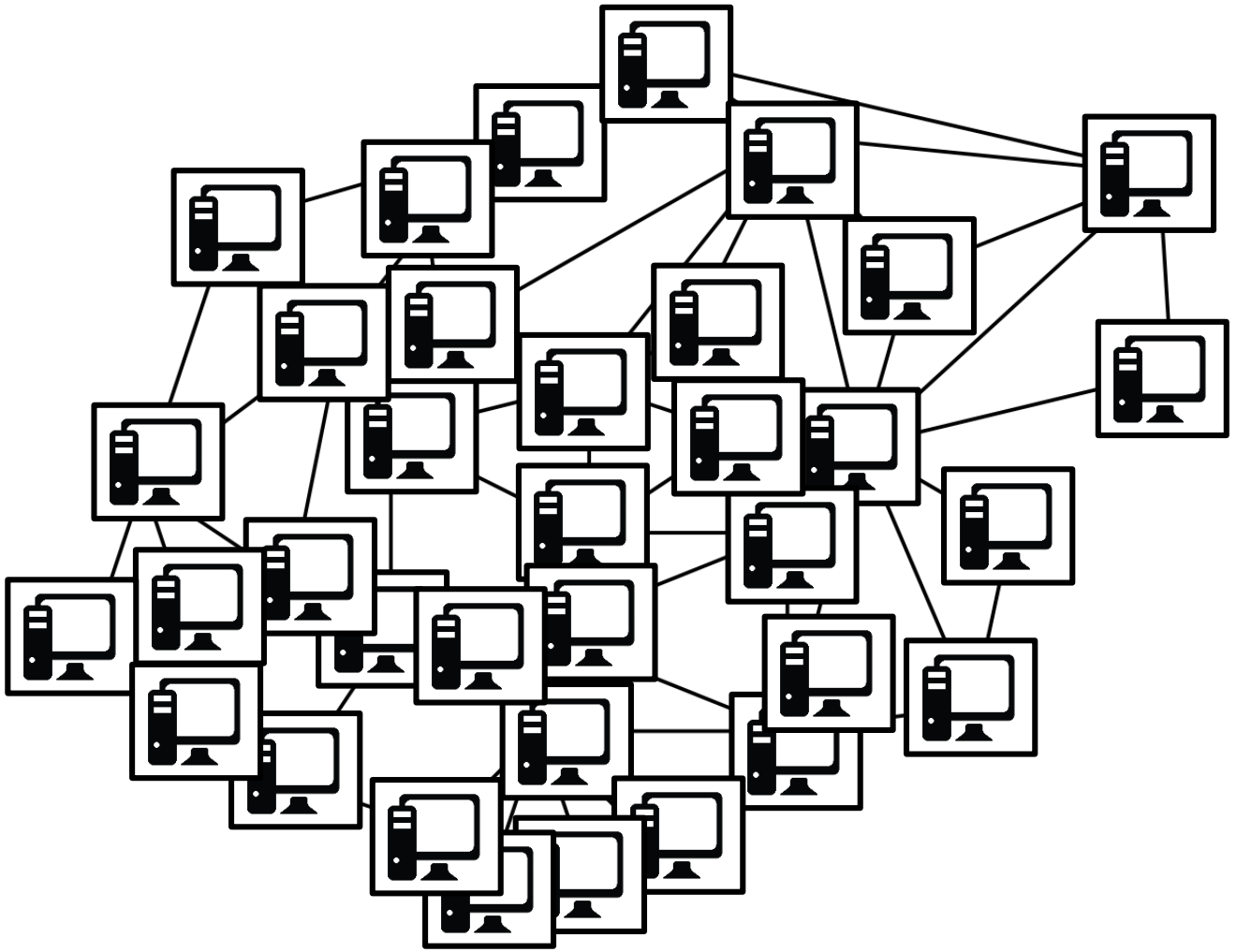

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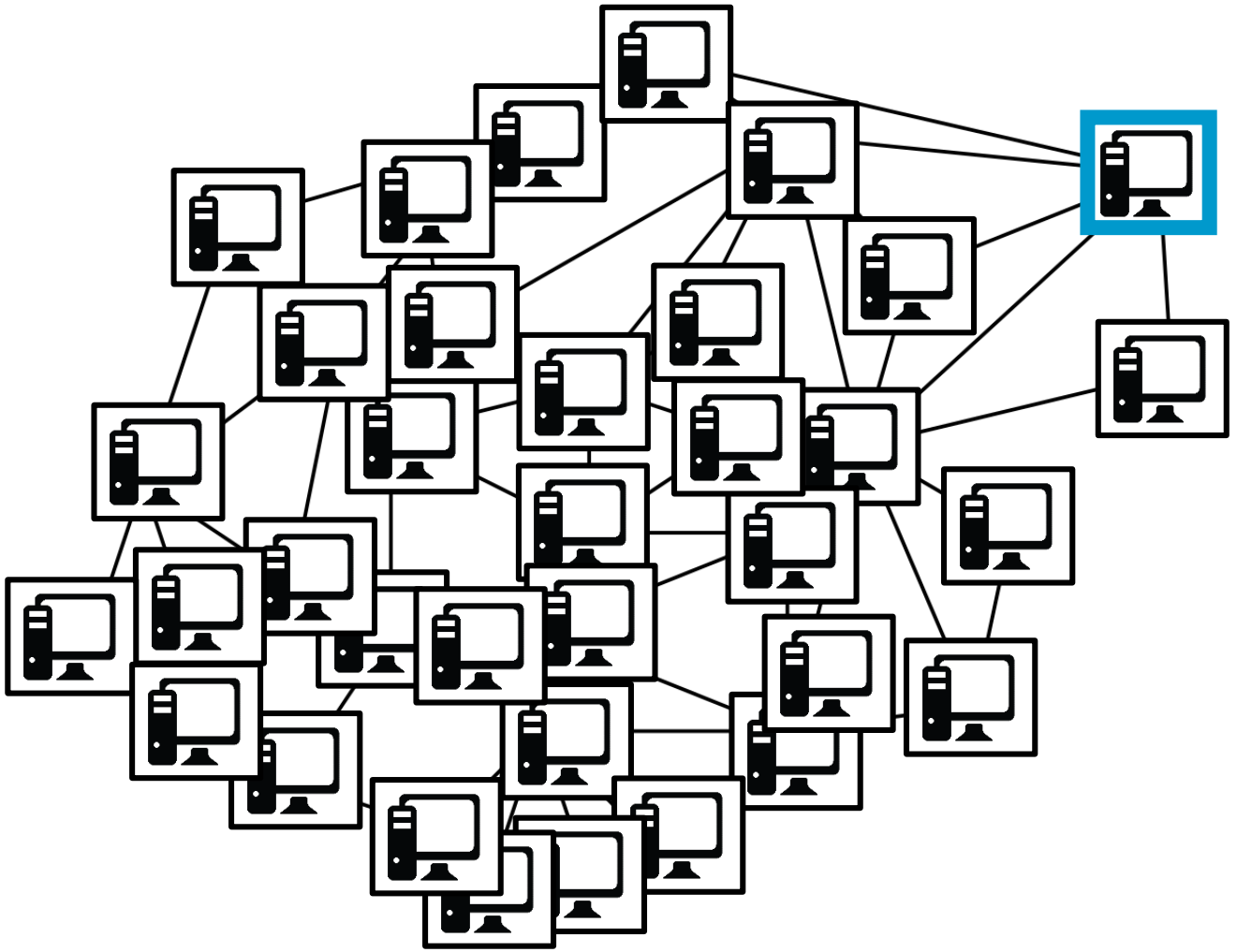

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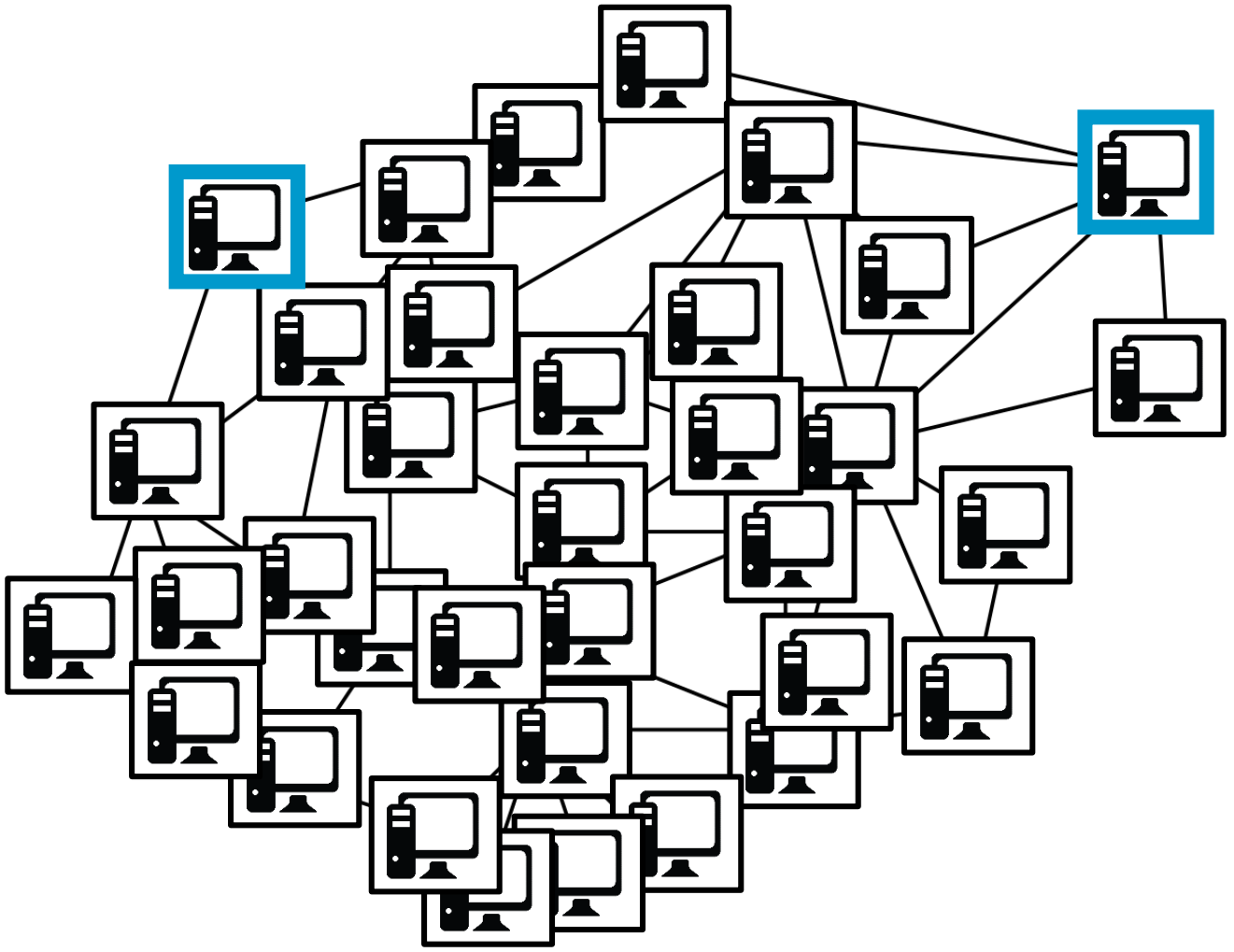

LOCAL Model *Linial* [FOCS'87]

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standard synchronous message-passing model of distributed computing

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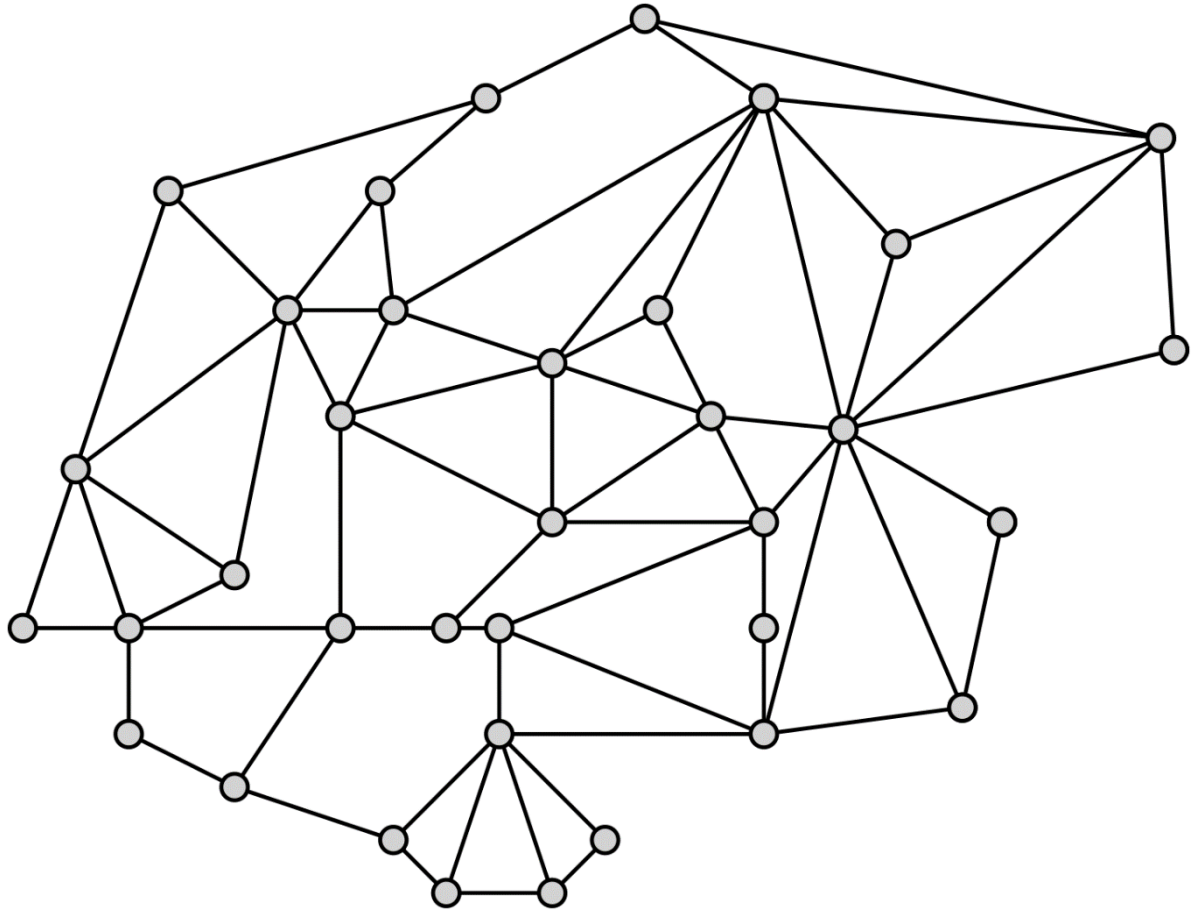

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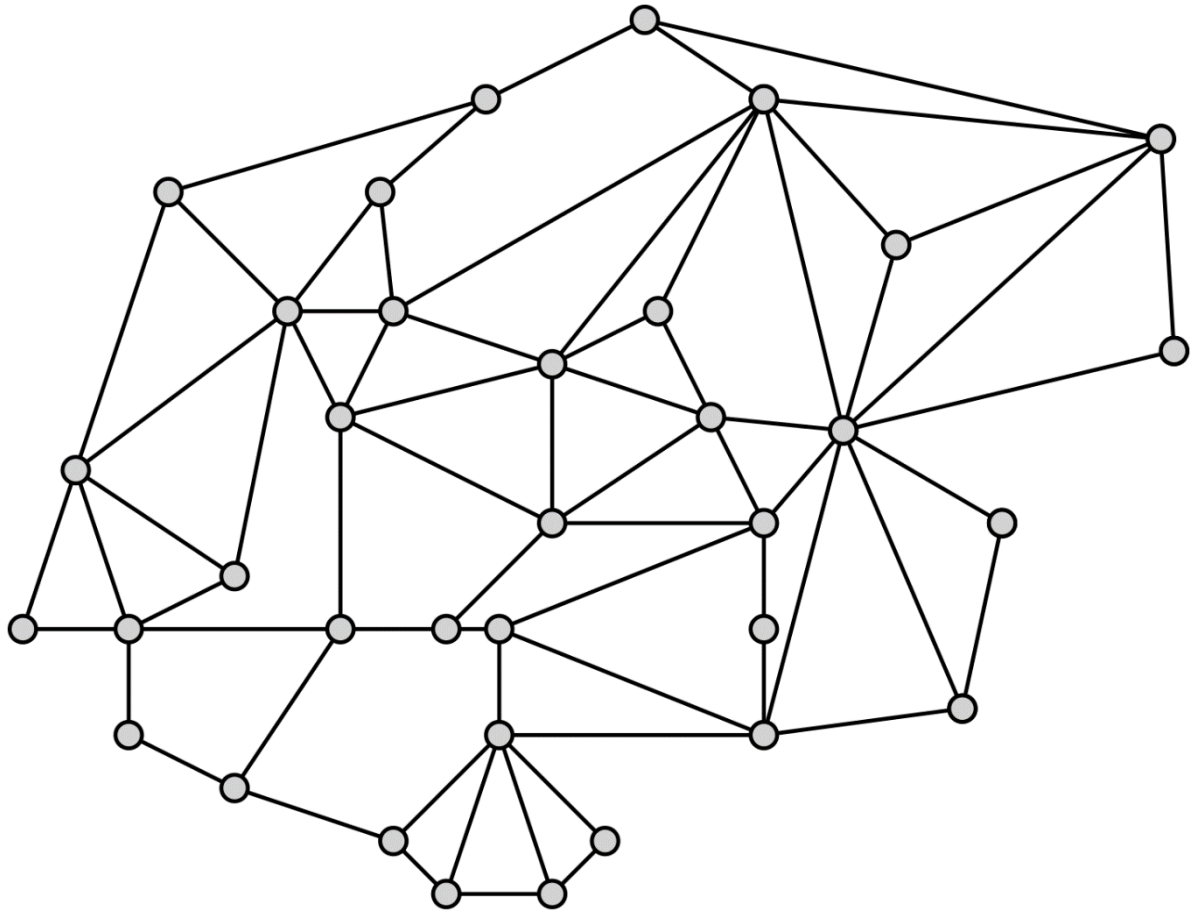

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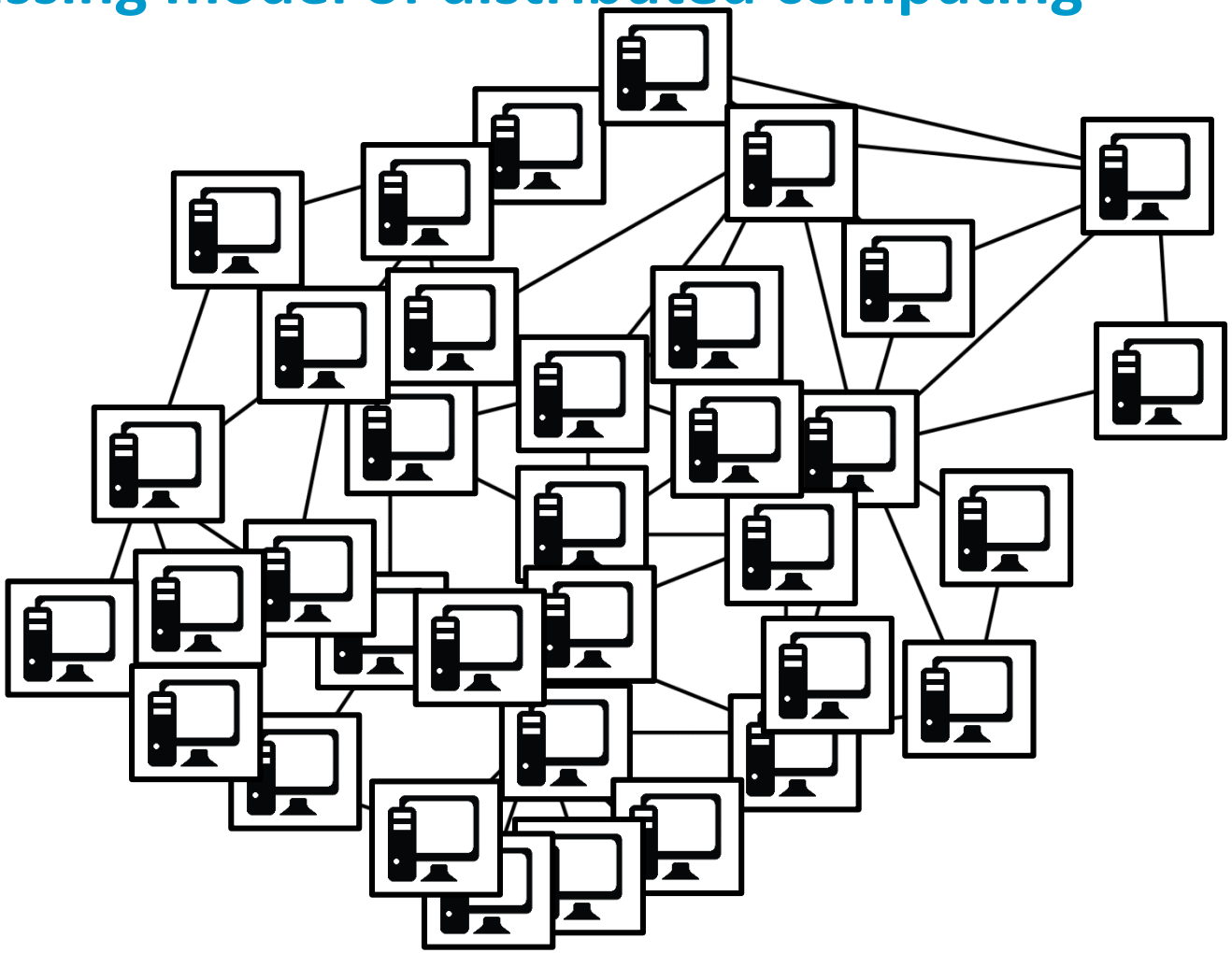

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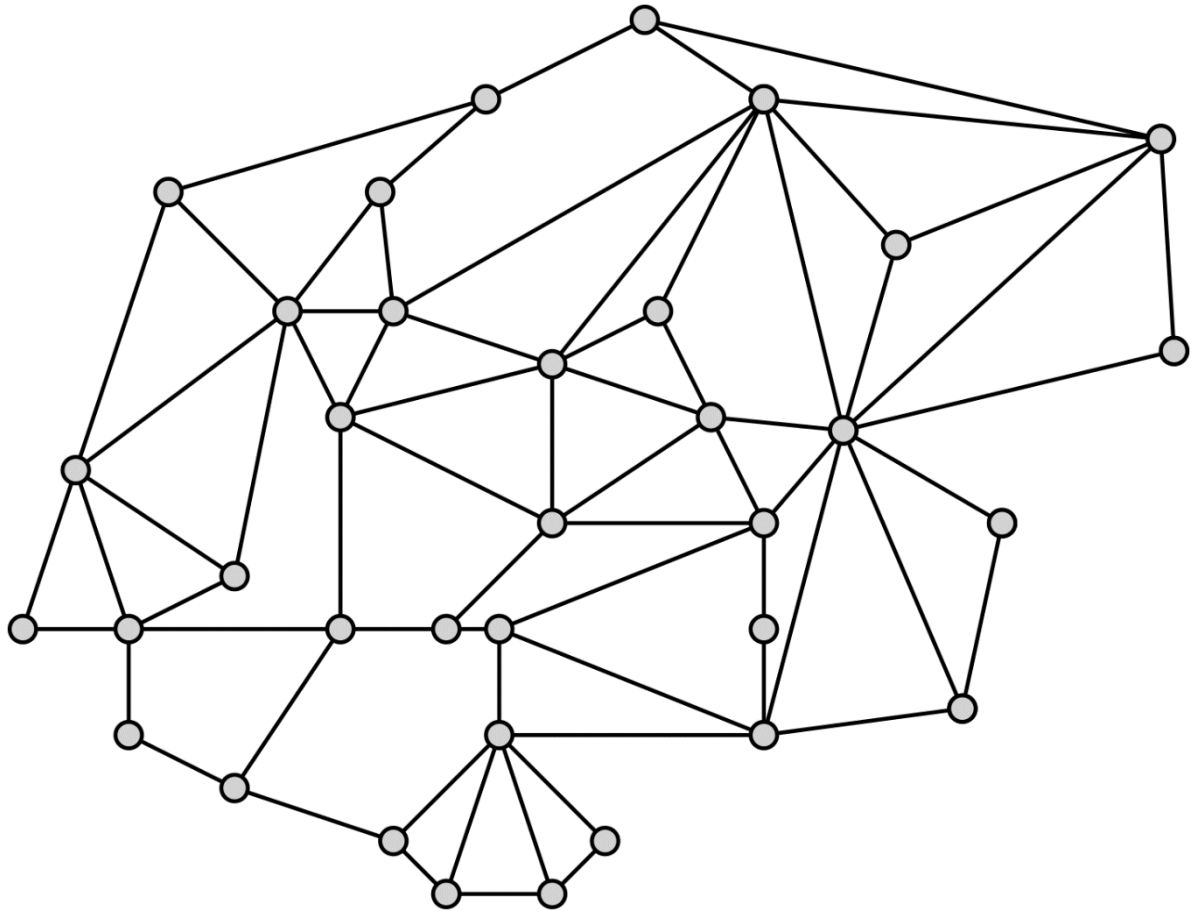

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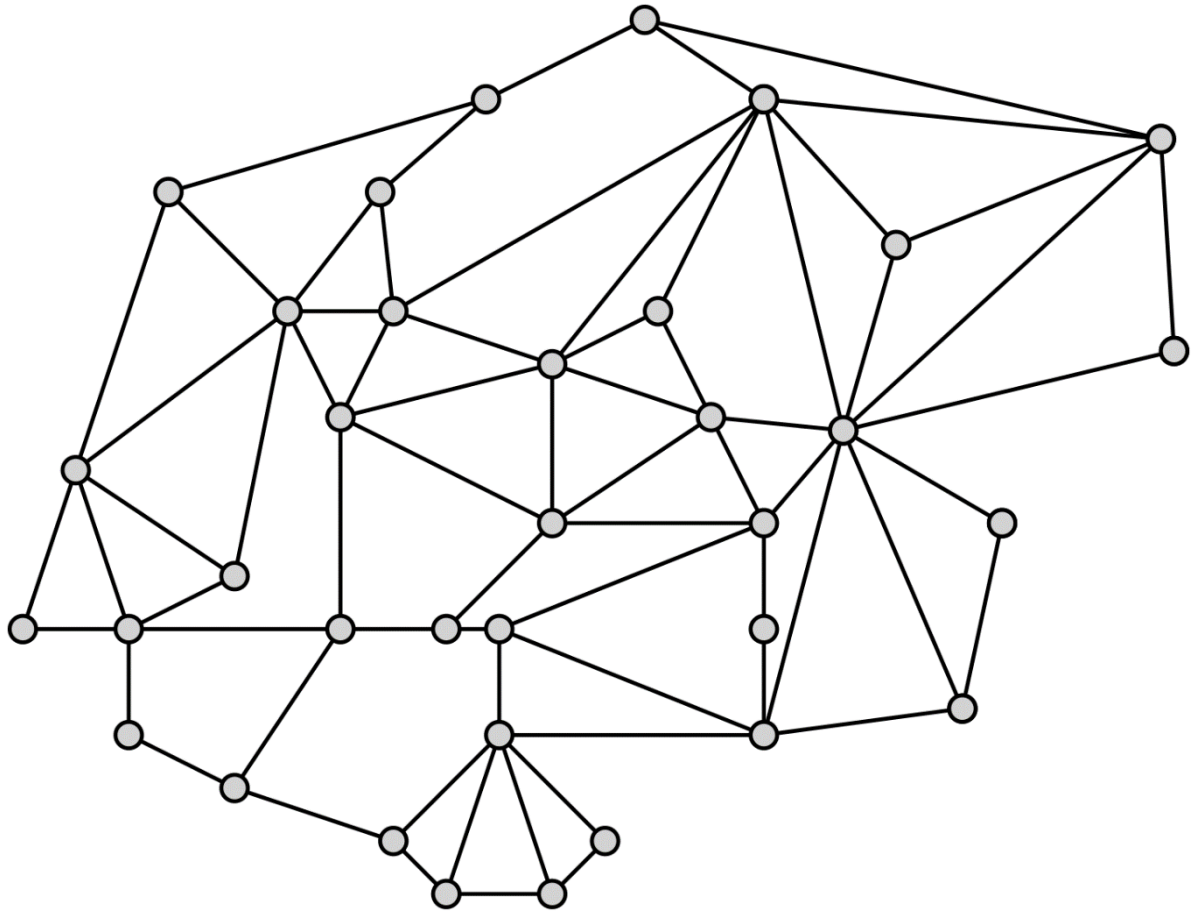

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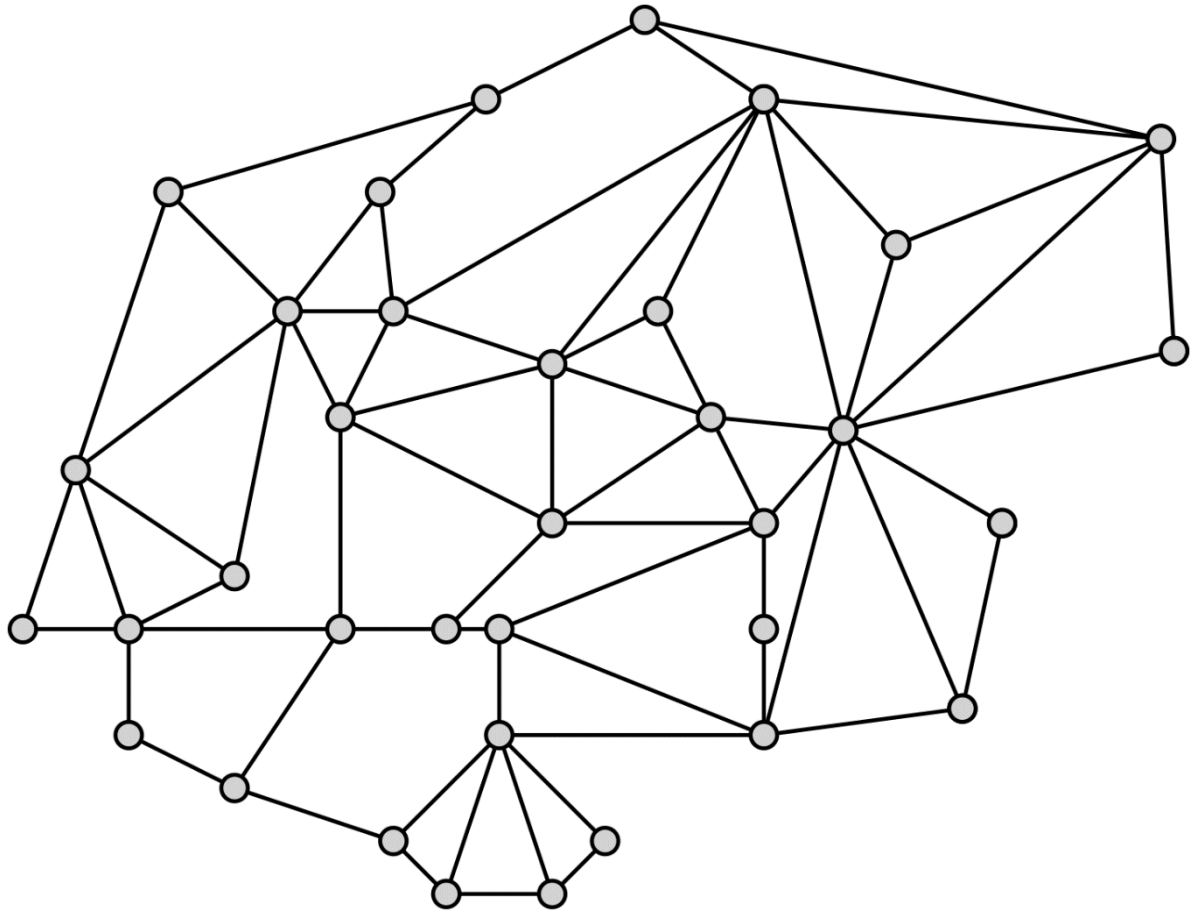

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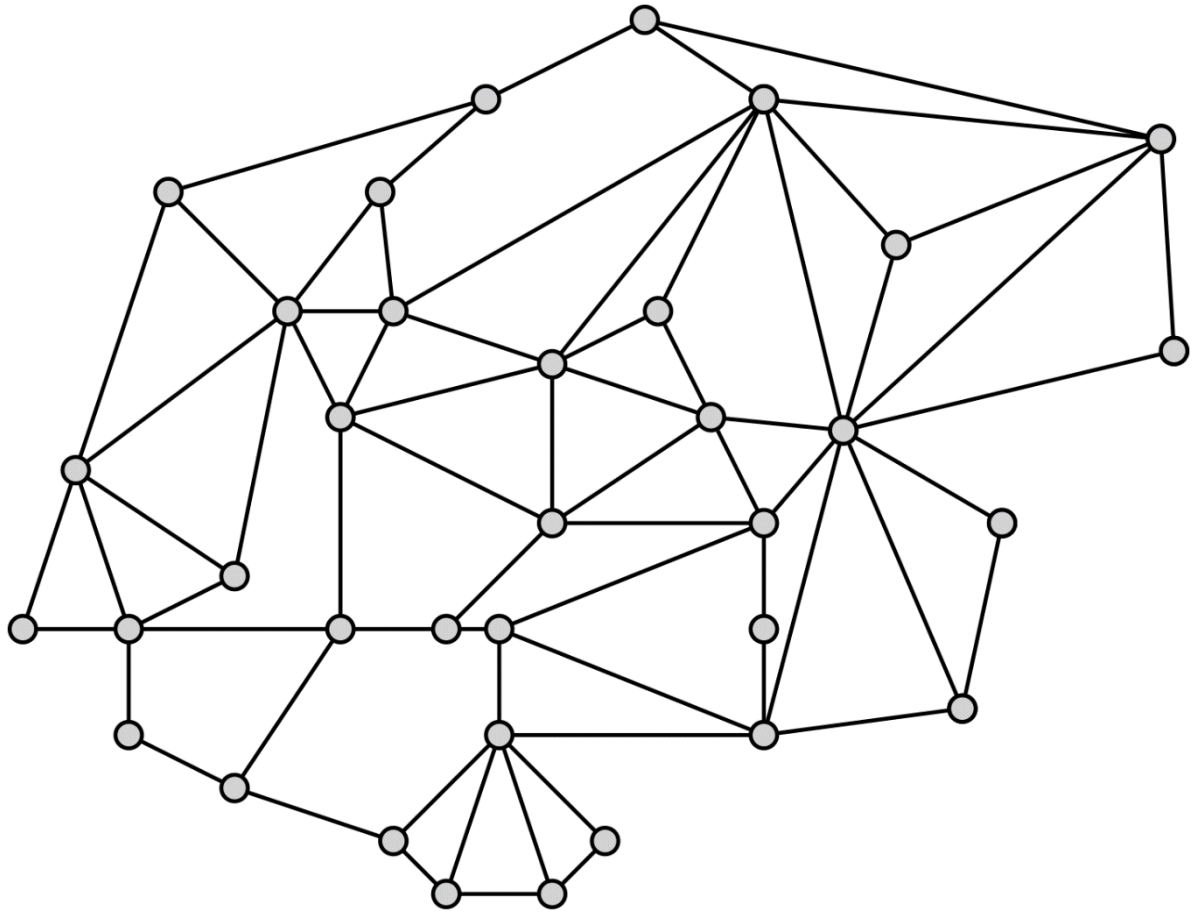

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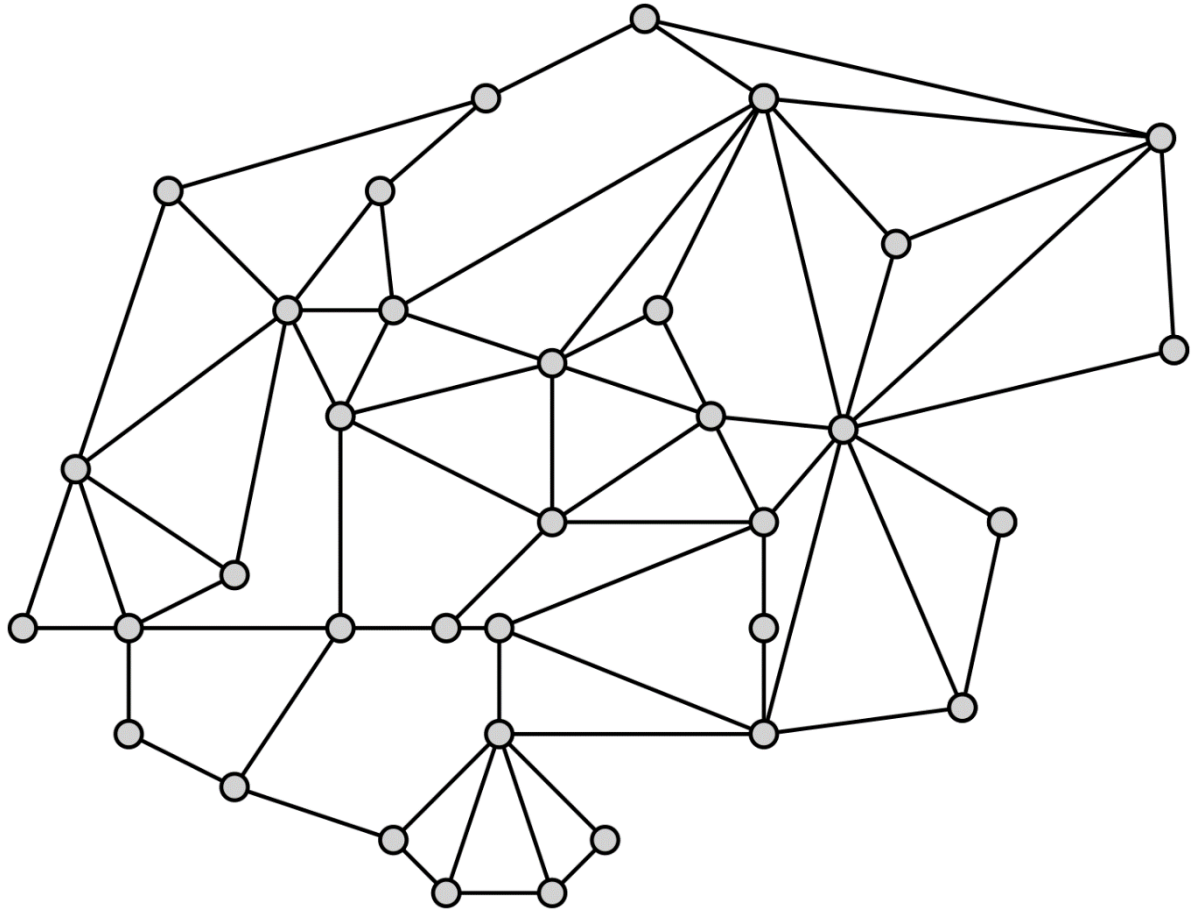

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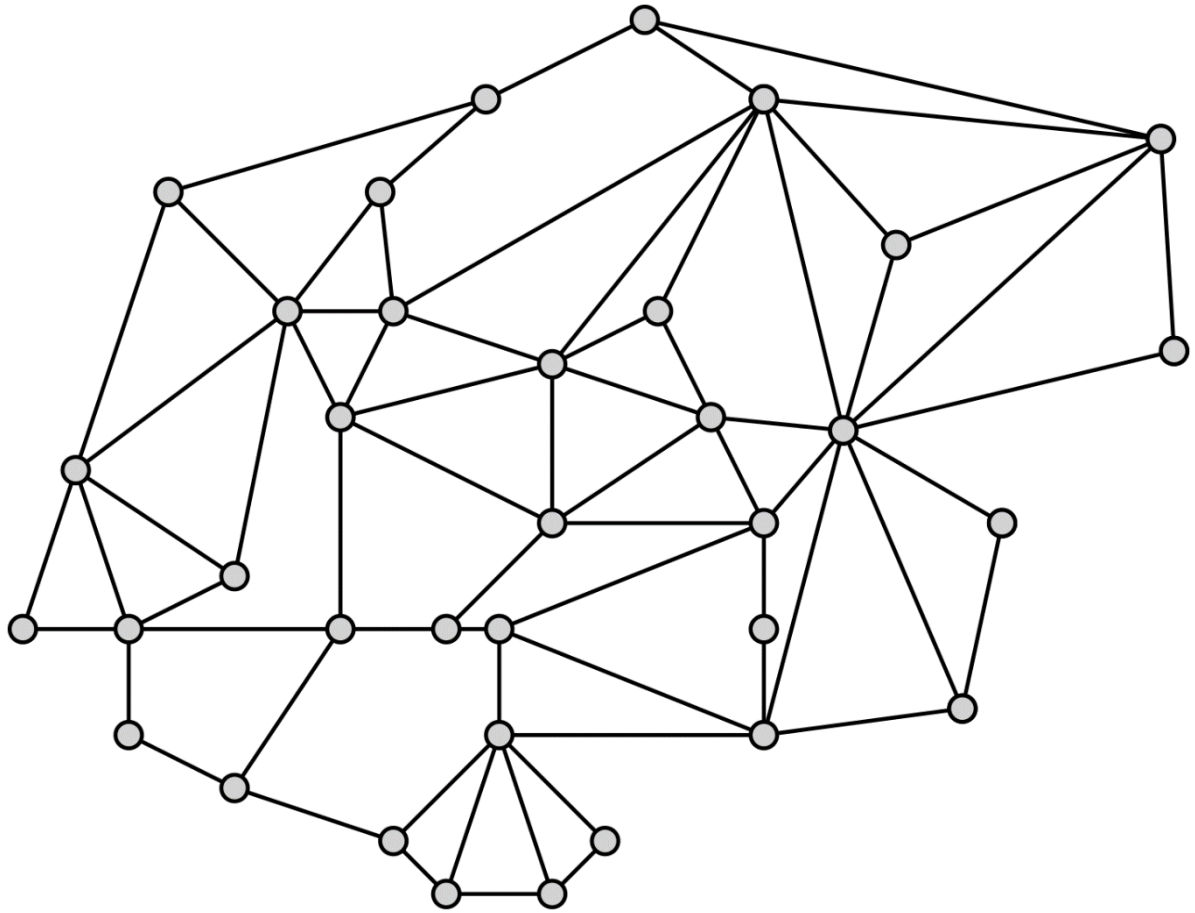

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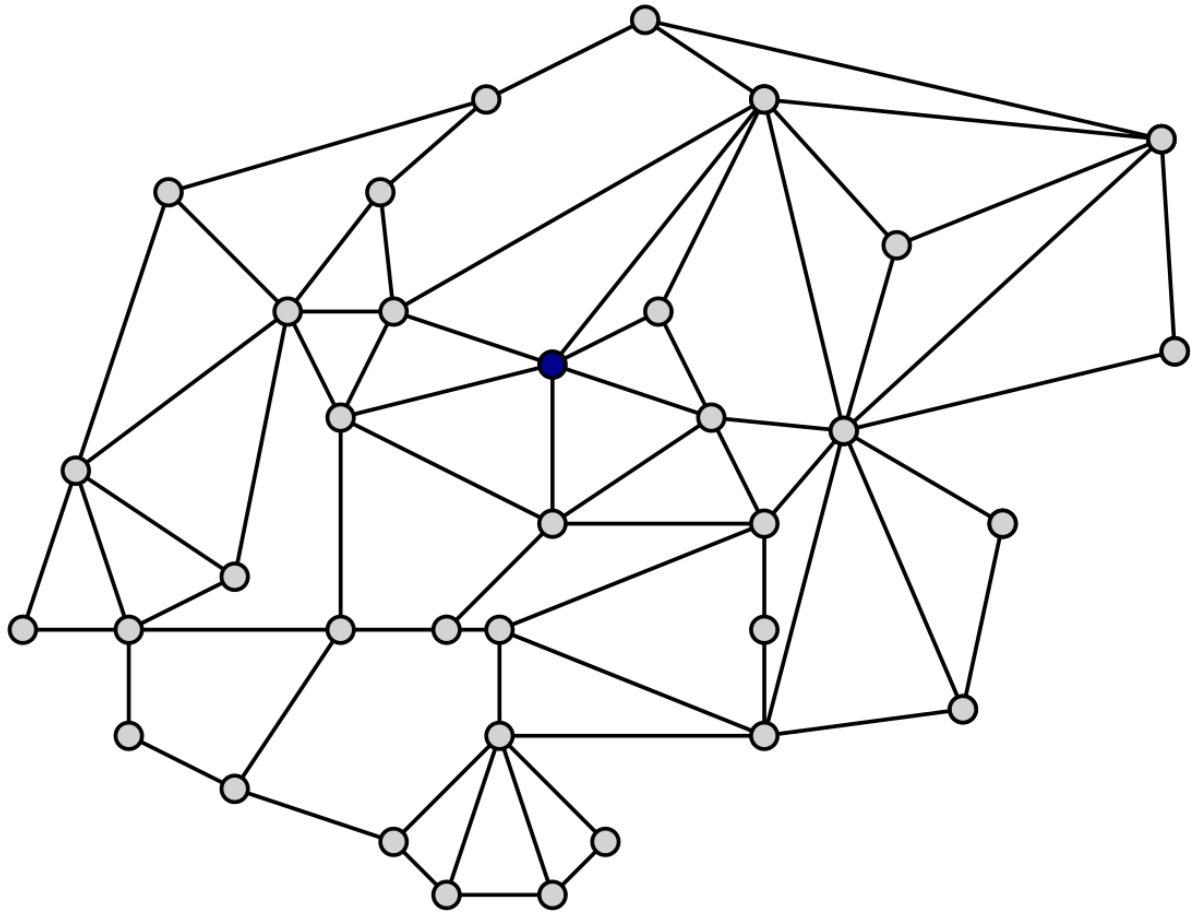

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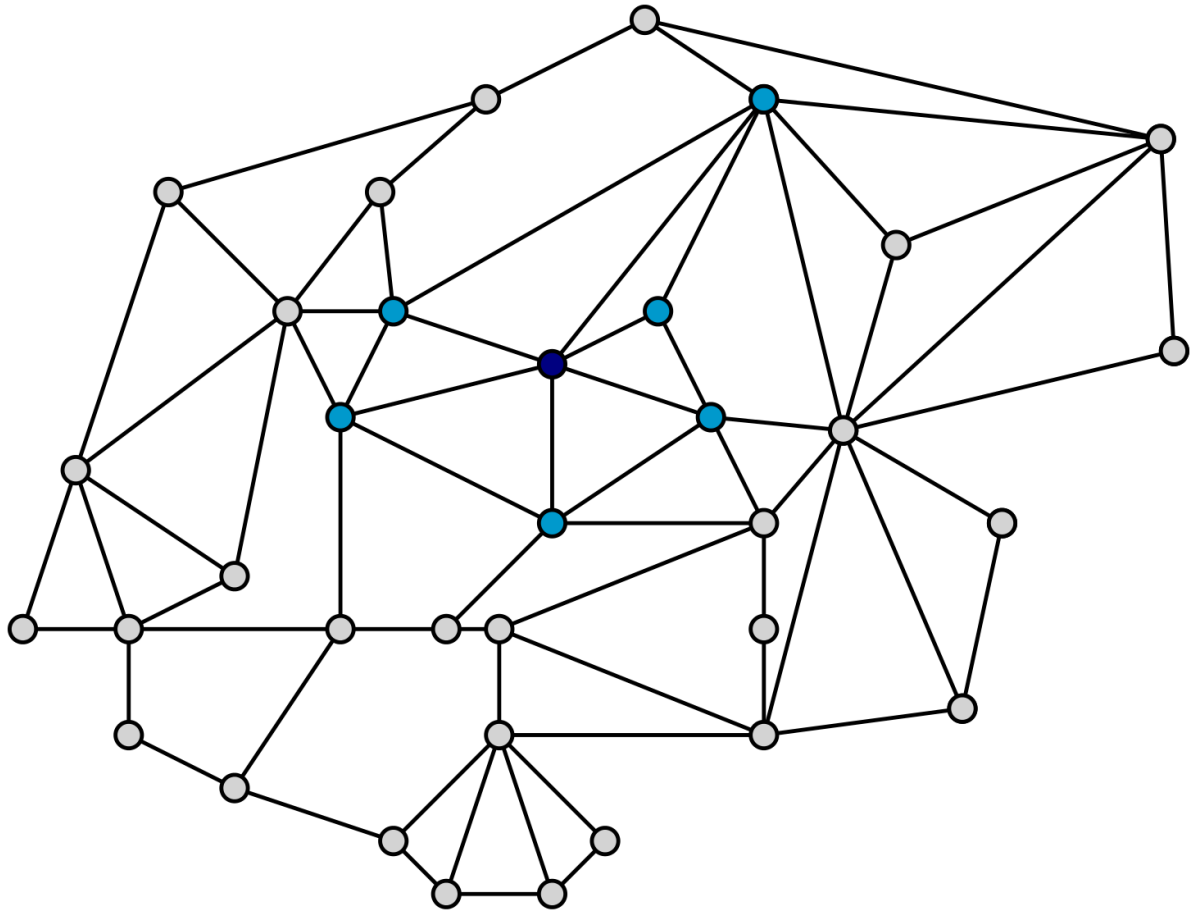

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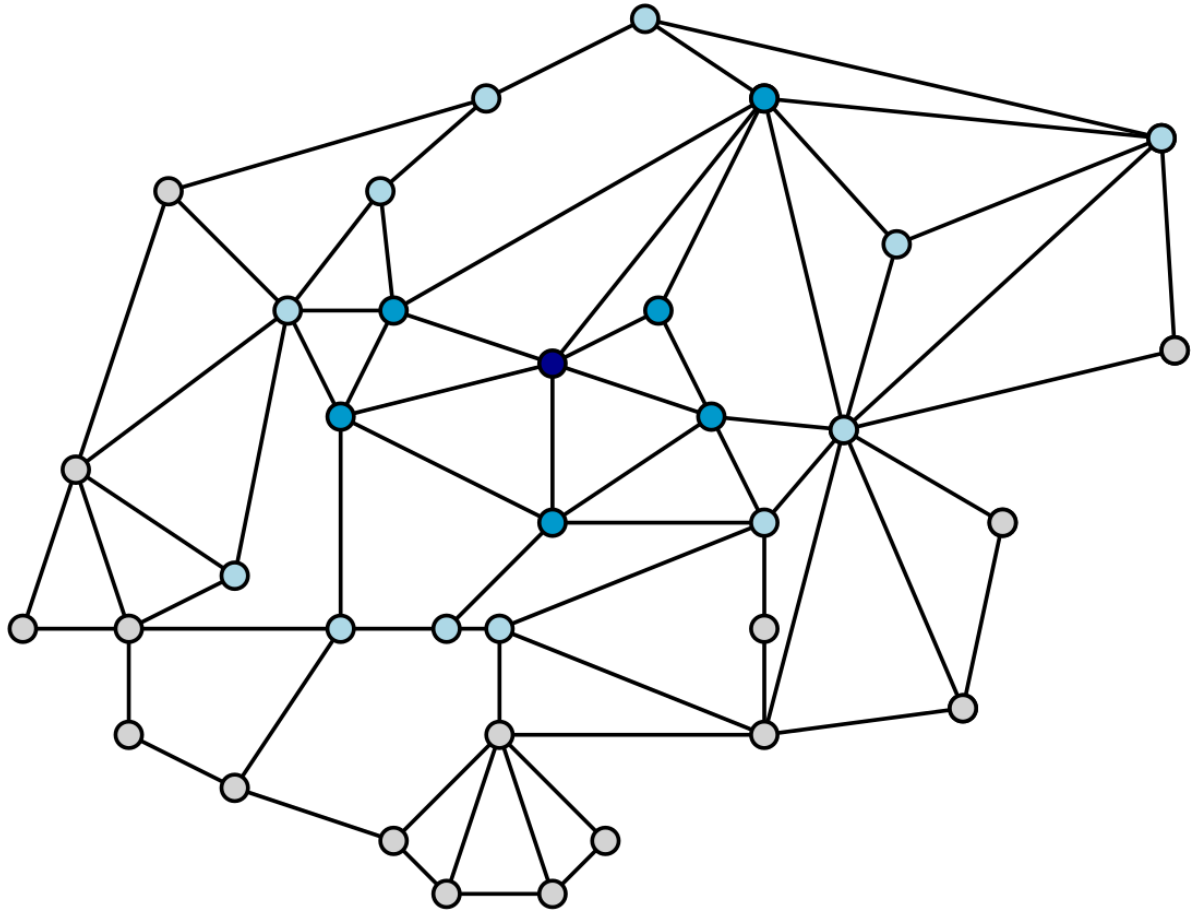

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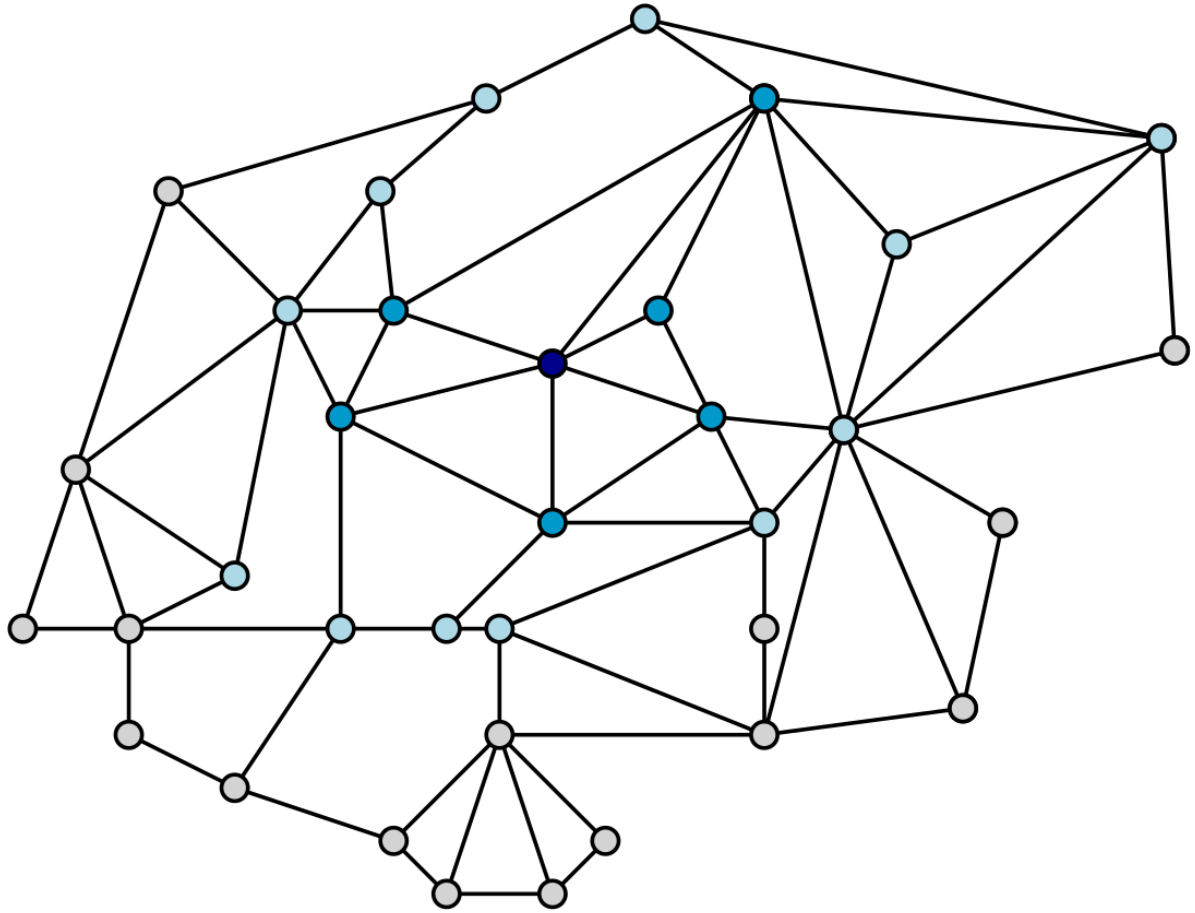

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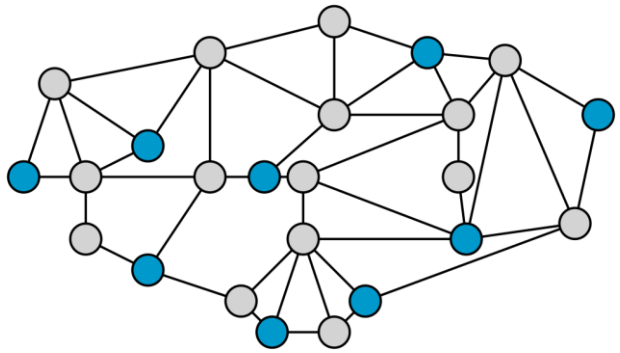
round complexity of a problem in the LOCAL model characterizes its locality

every problem is trivially solvable in $O(\text{diameter})$ rounds

Classic LOCAL Graph Problems

Classic LOCAL Graph Problems

Maximal Independent Set



Classic LOCAL Graph Problems

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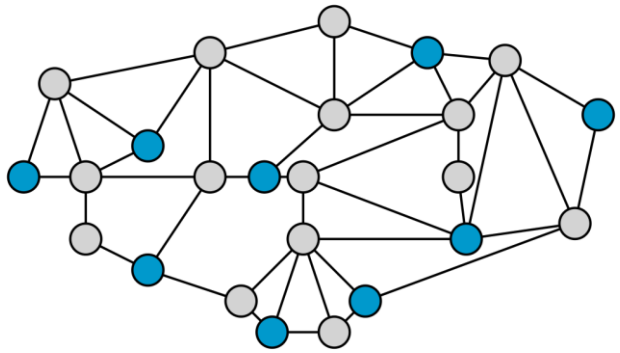
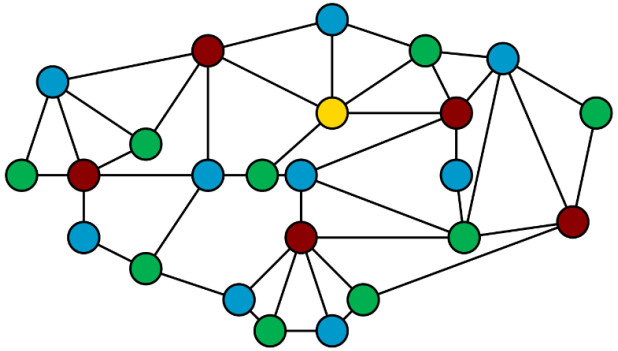


$(\Delta + 1)$-Vertex-Coloring



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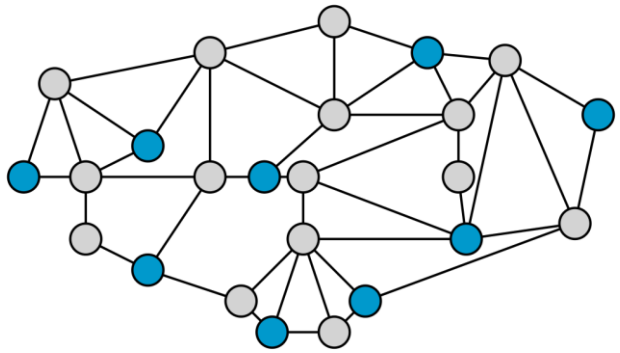

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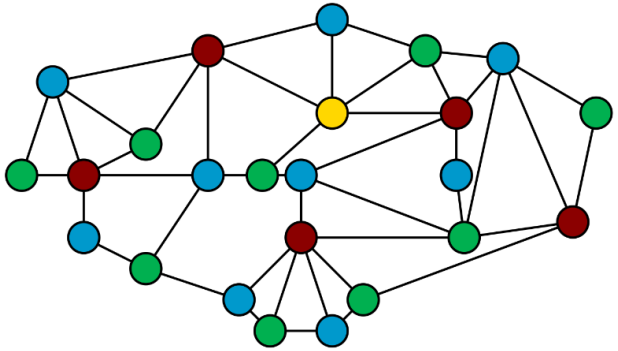
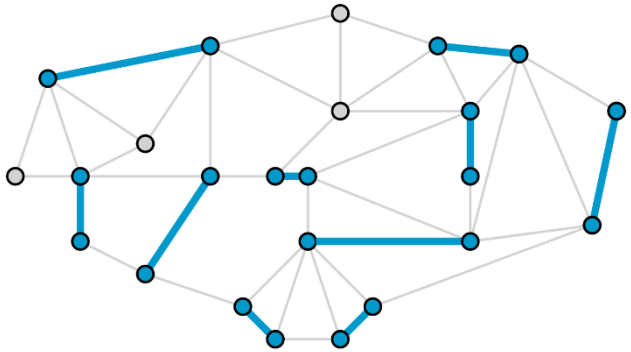


Maximal Matching



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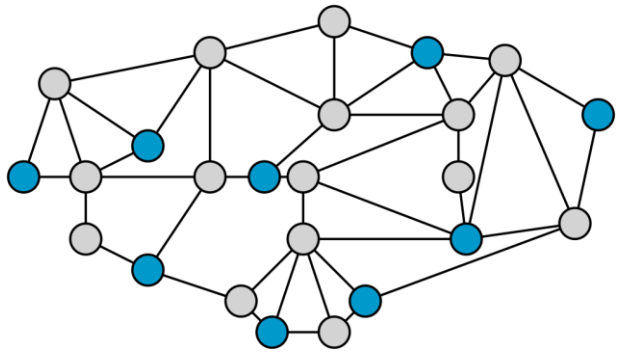

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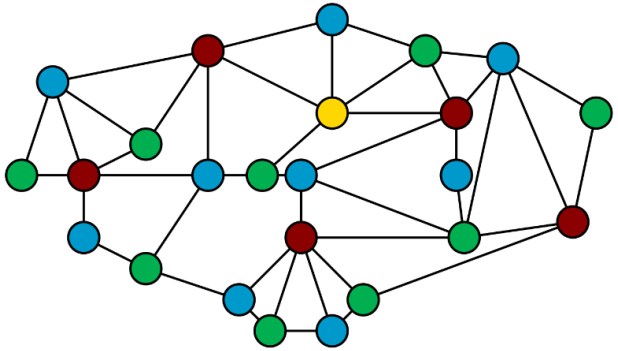

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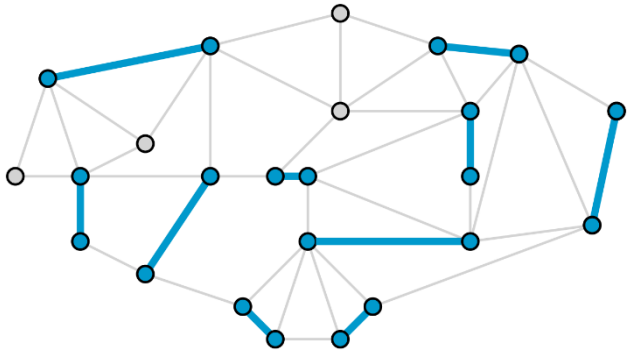
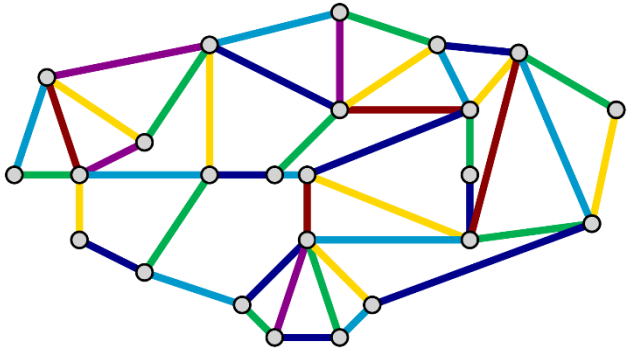


$(2\Delta - 1)$-Edge-Coloring



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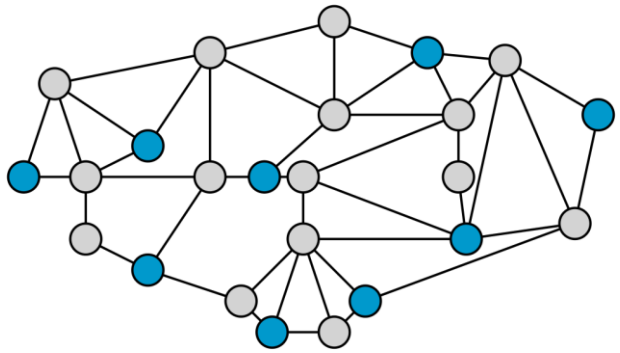

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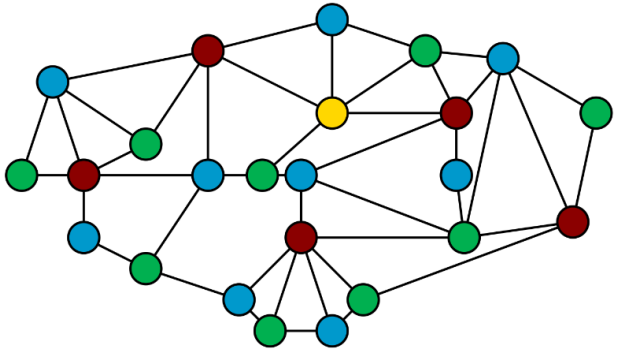

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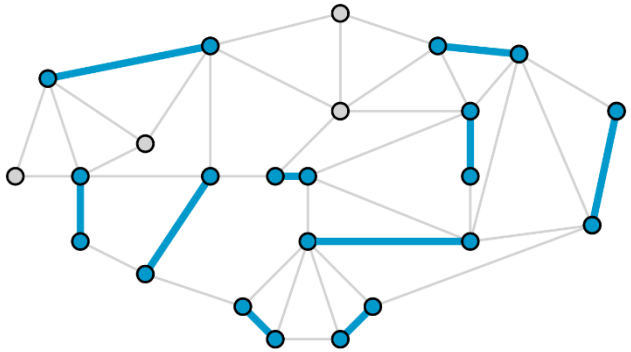

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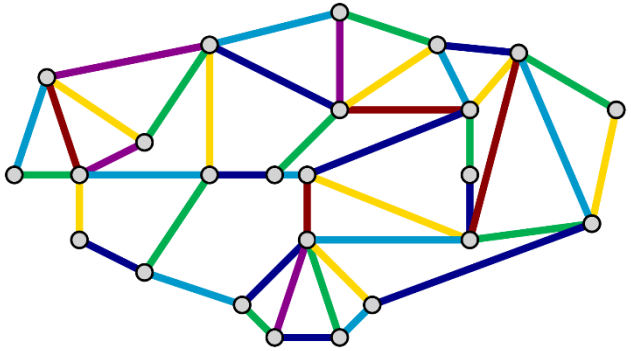
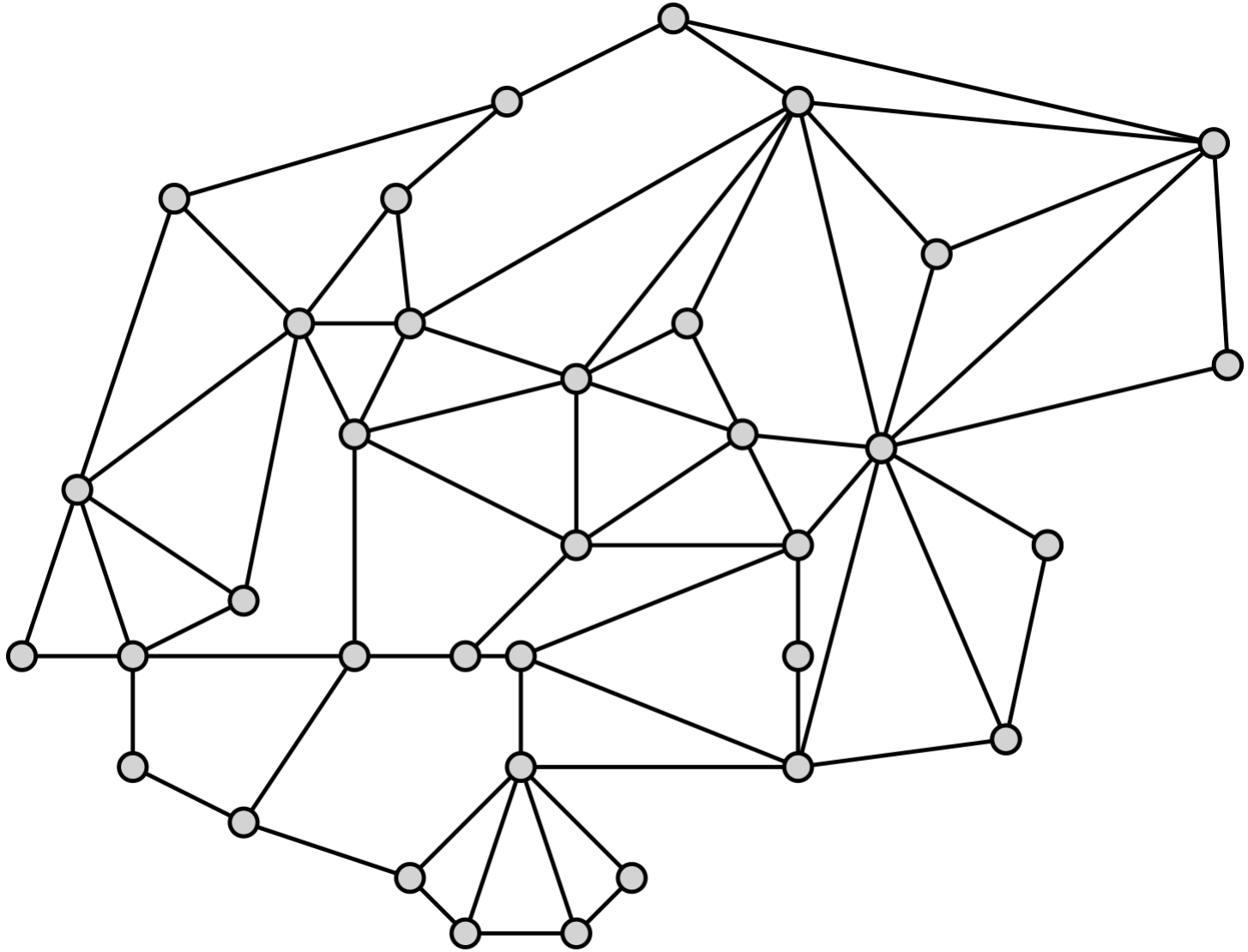


Easy centralized problems: greedy solutions.

Maximal Matching

Maximal Matching



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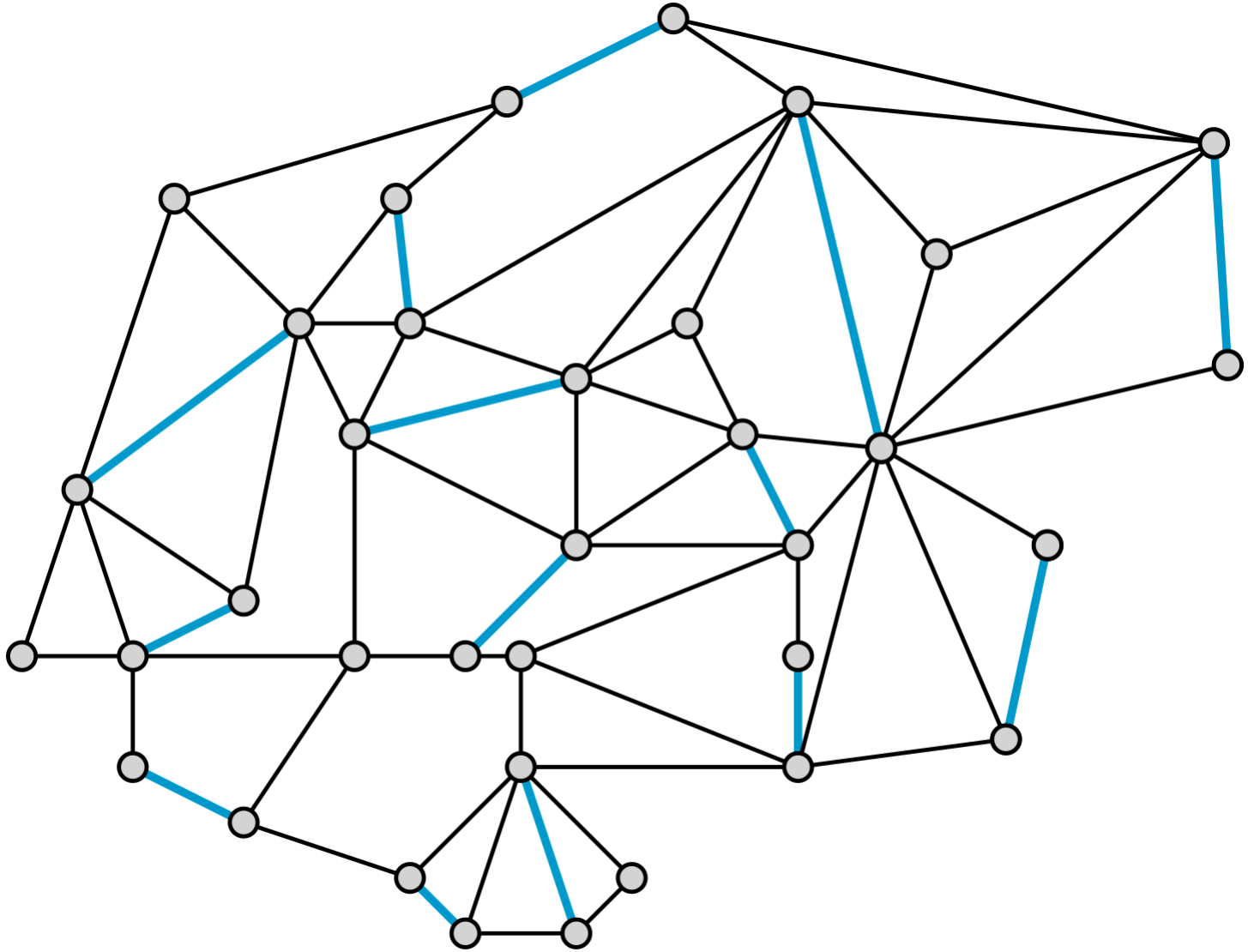
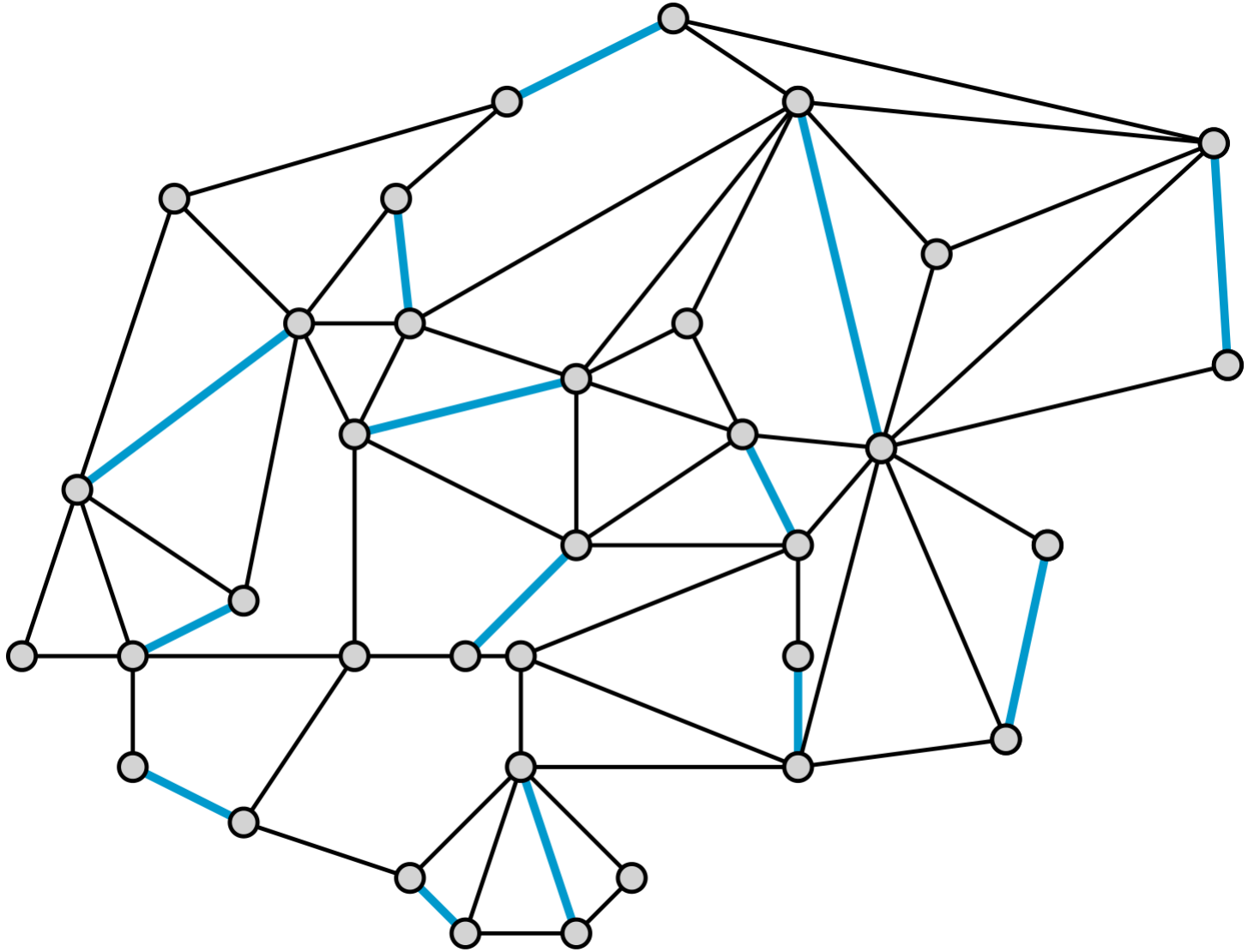


Maximal Matching

<u>Matching:</u>
set of non-incident edges



Maximal Matching

<u>Matching:</u>
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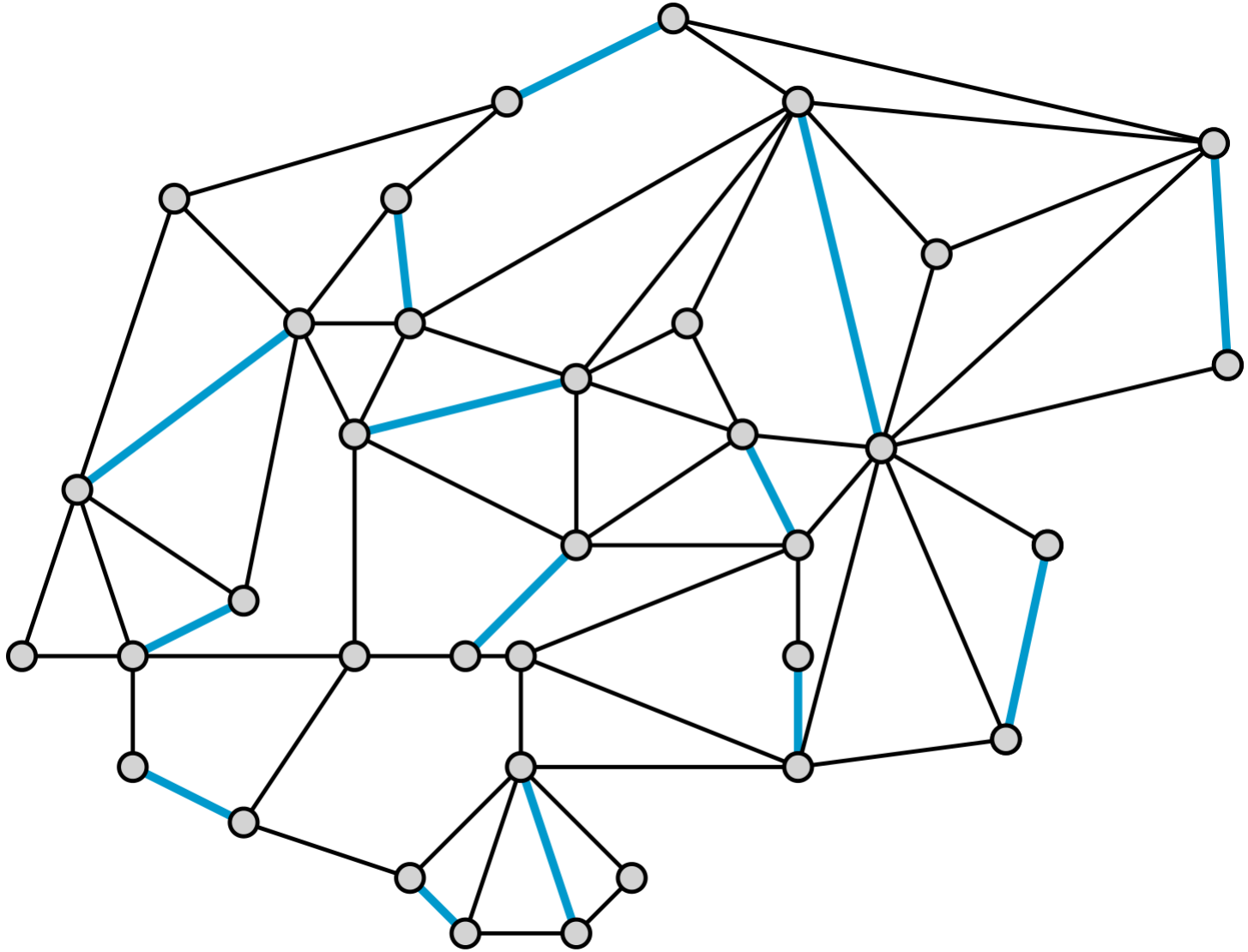
<u>Maximal:</u>
no edge can be added



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Maximal:
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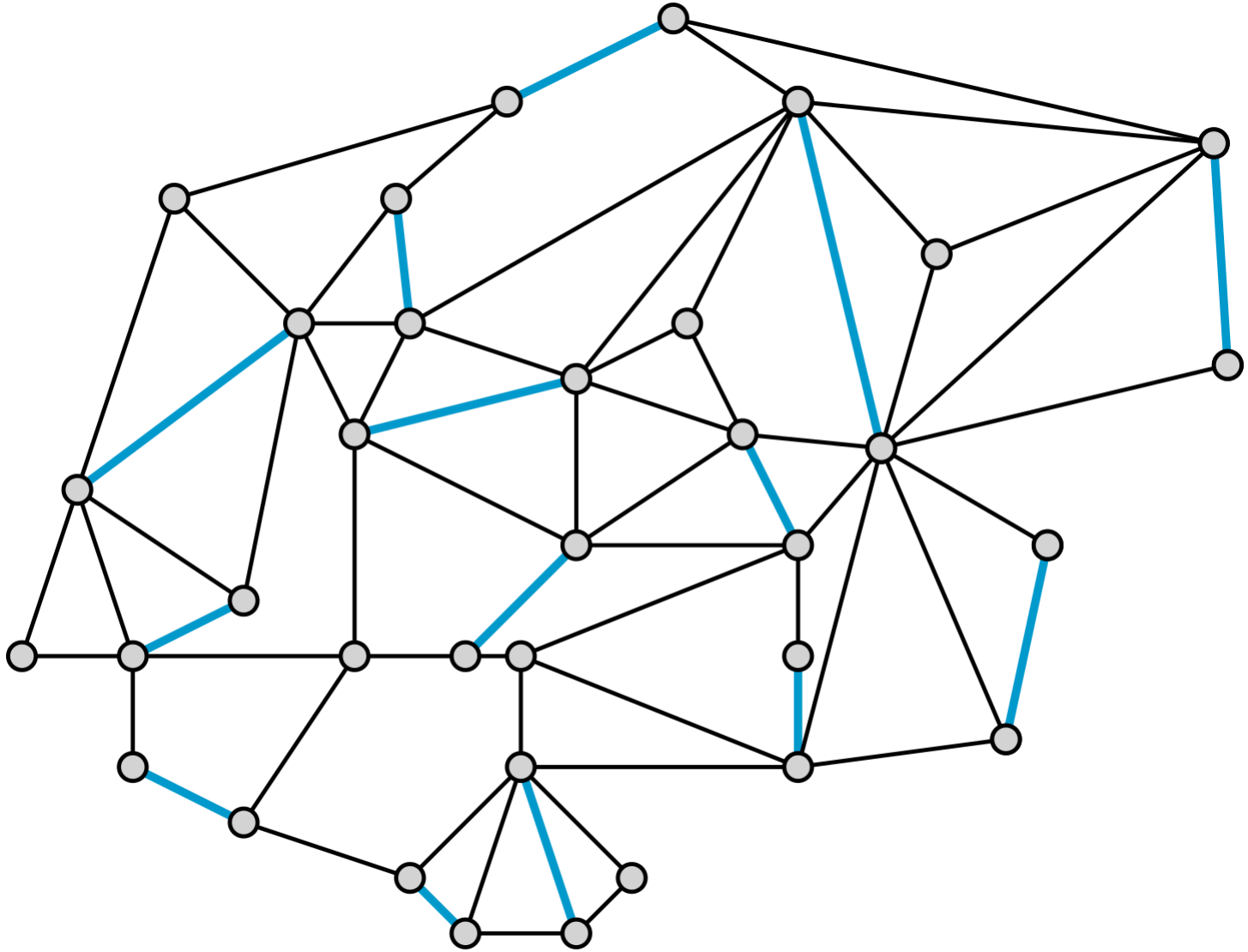
greedy property!



Centralized (Sequential) Algorithm

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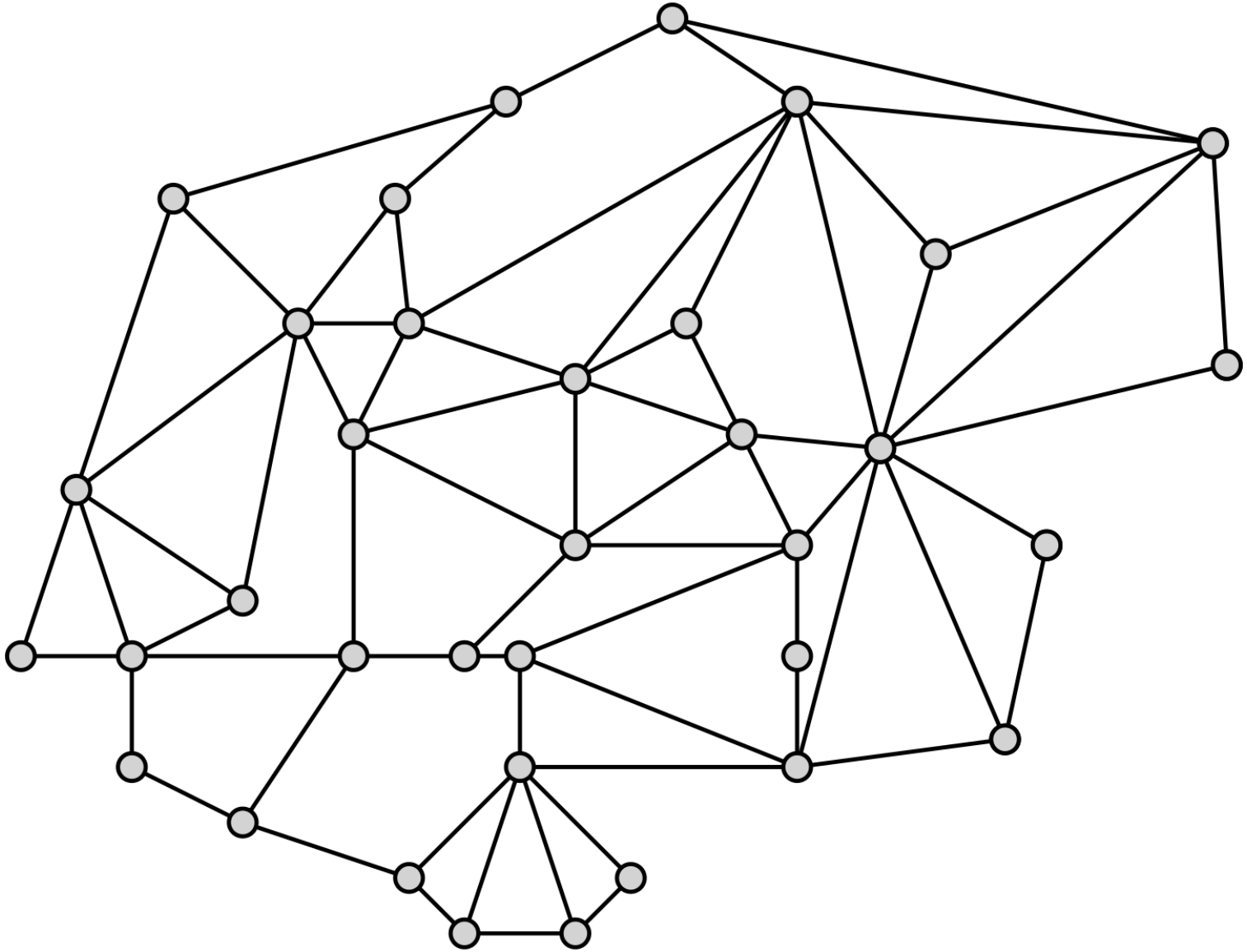

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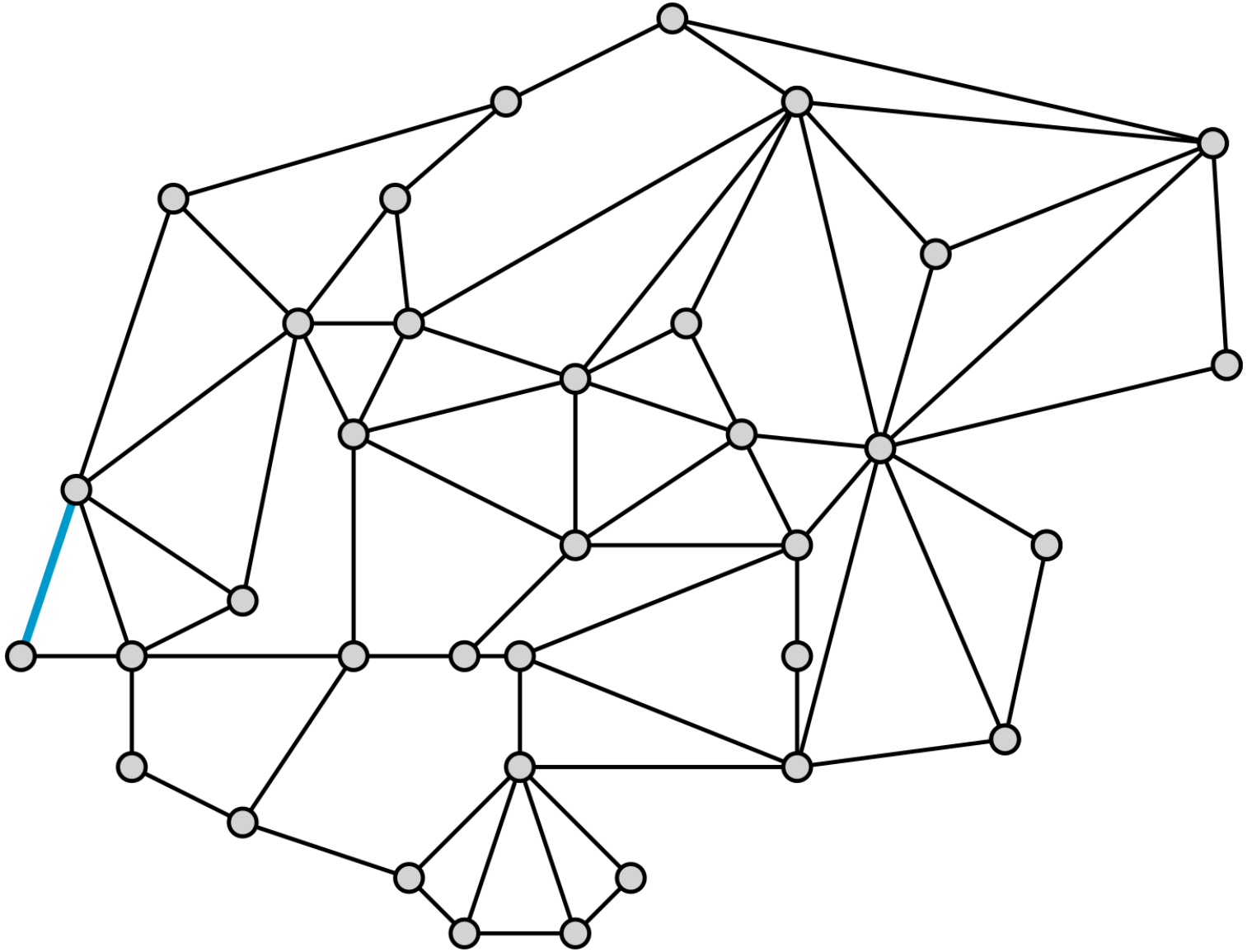

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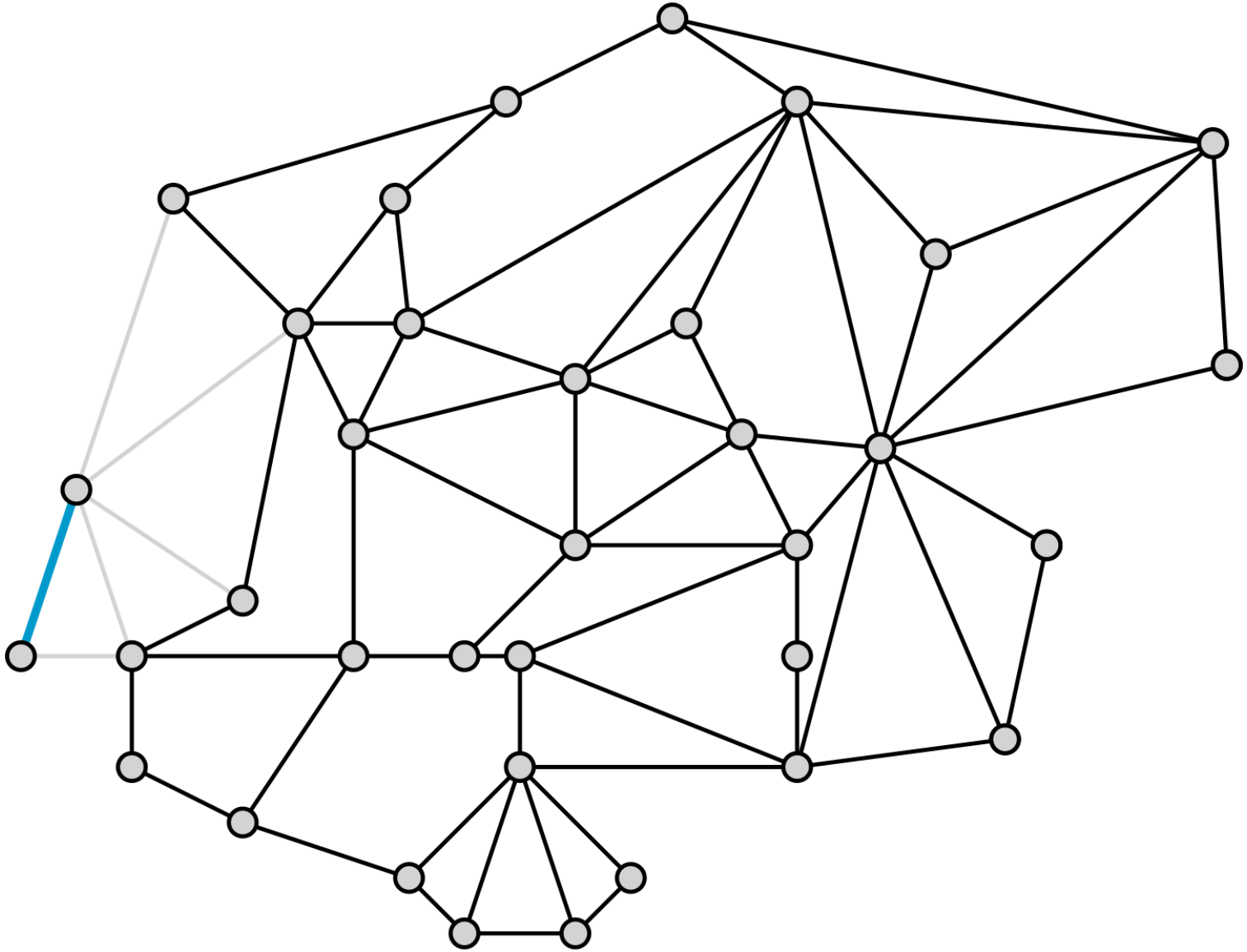

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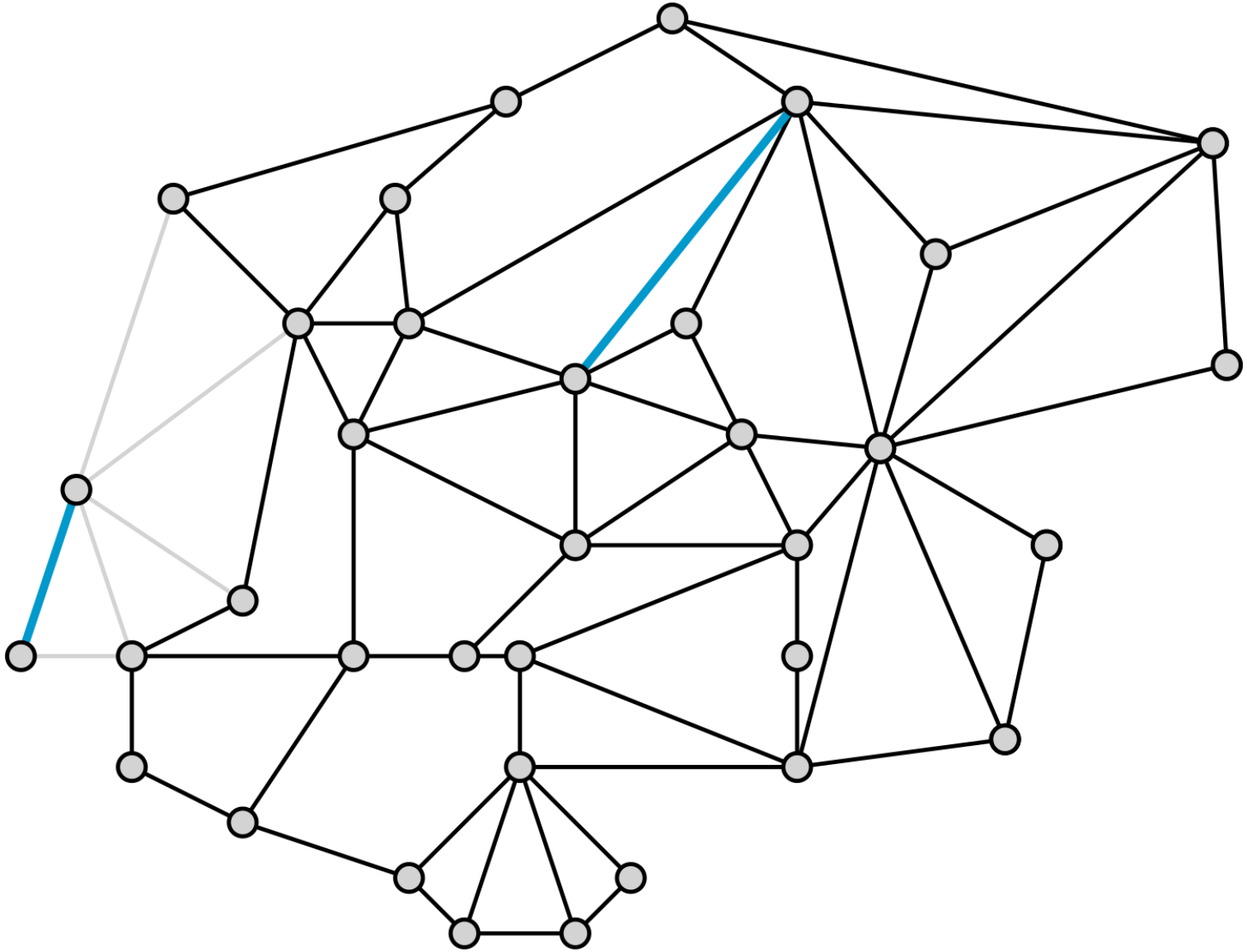

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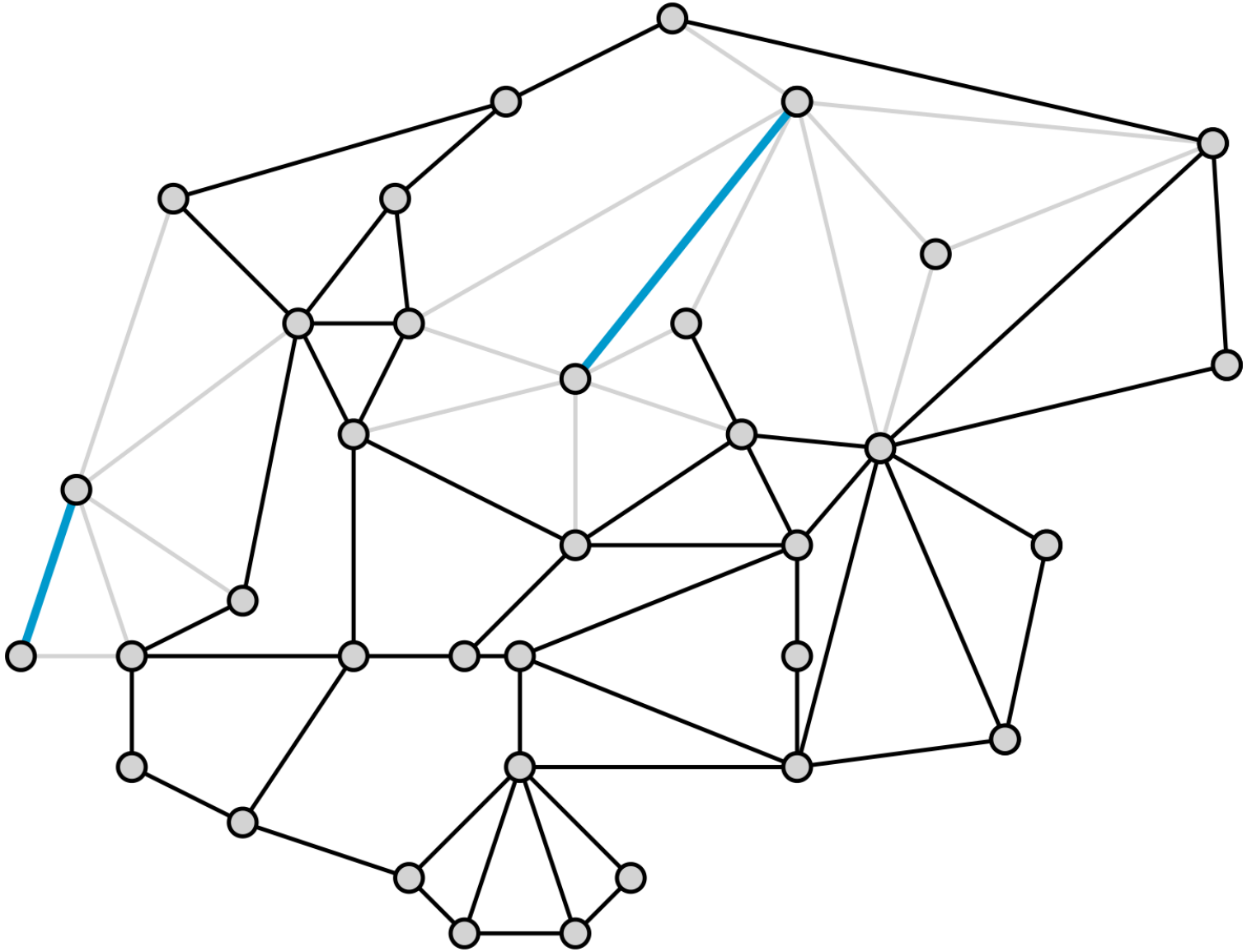

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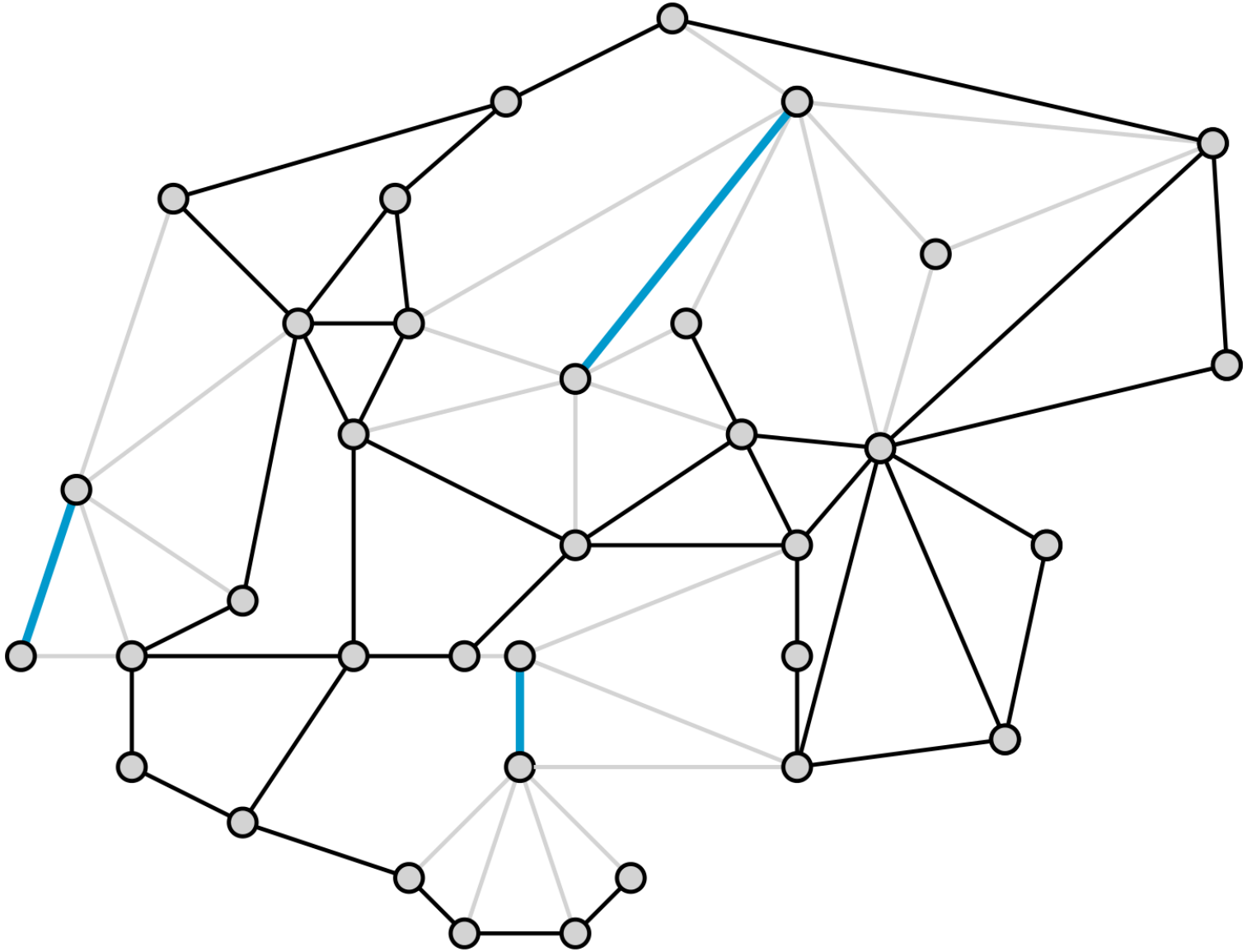

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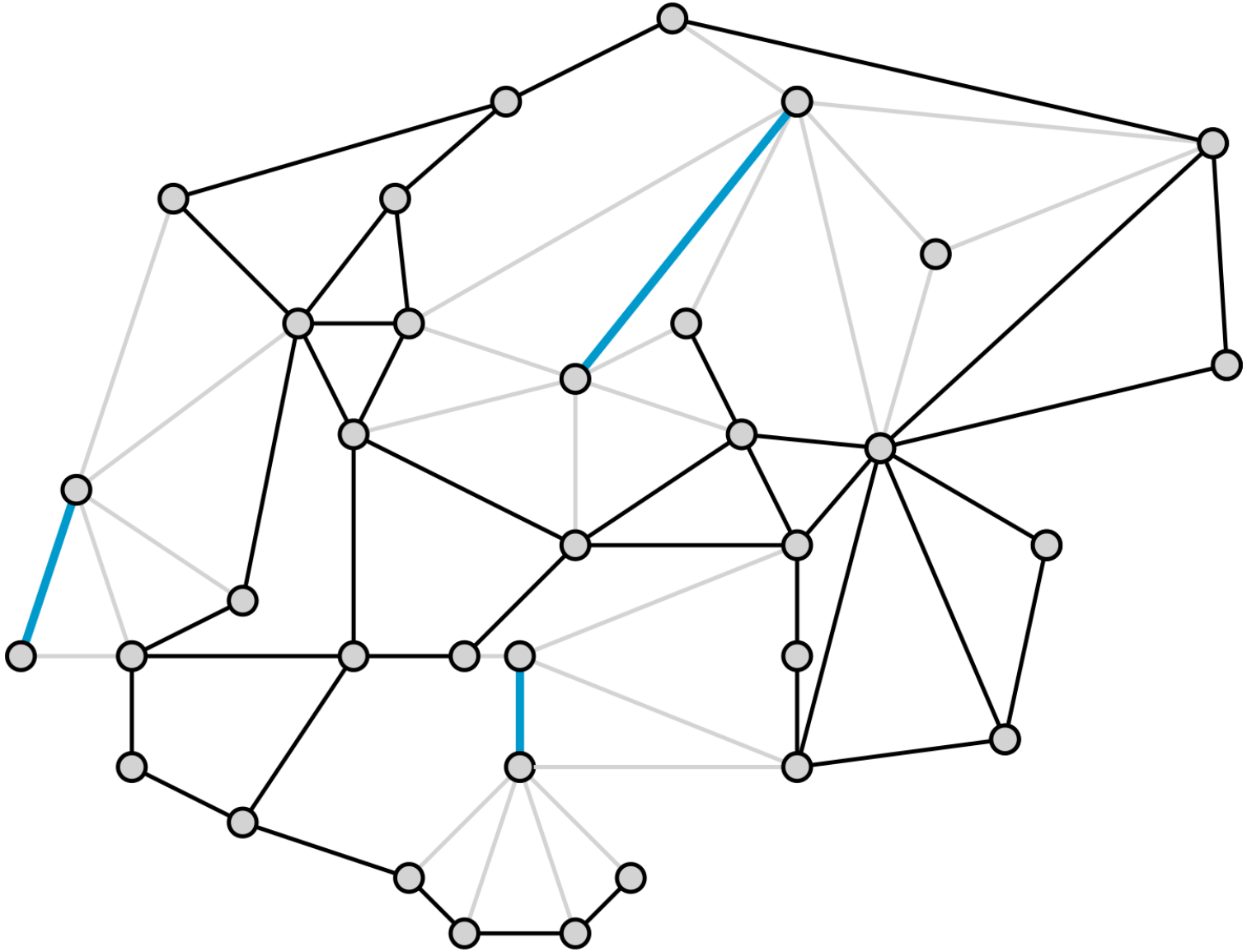

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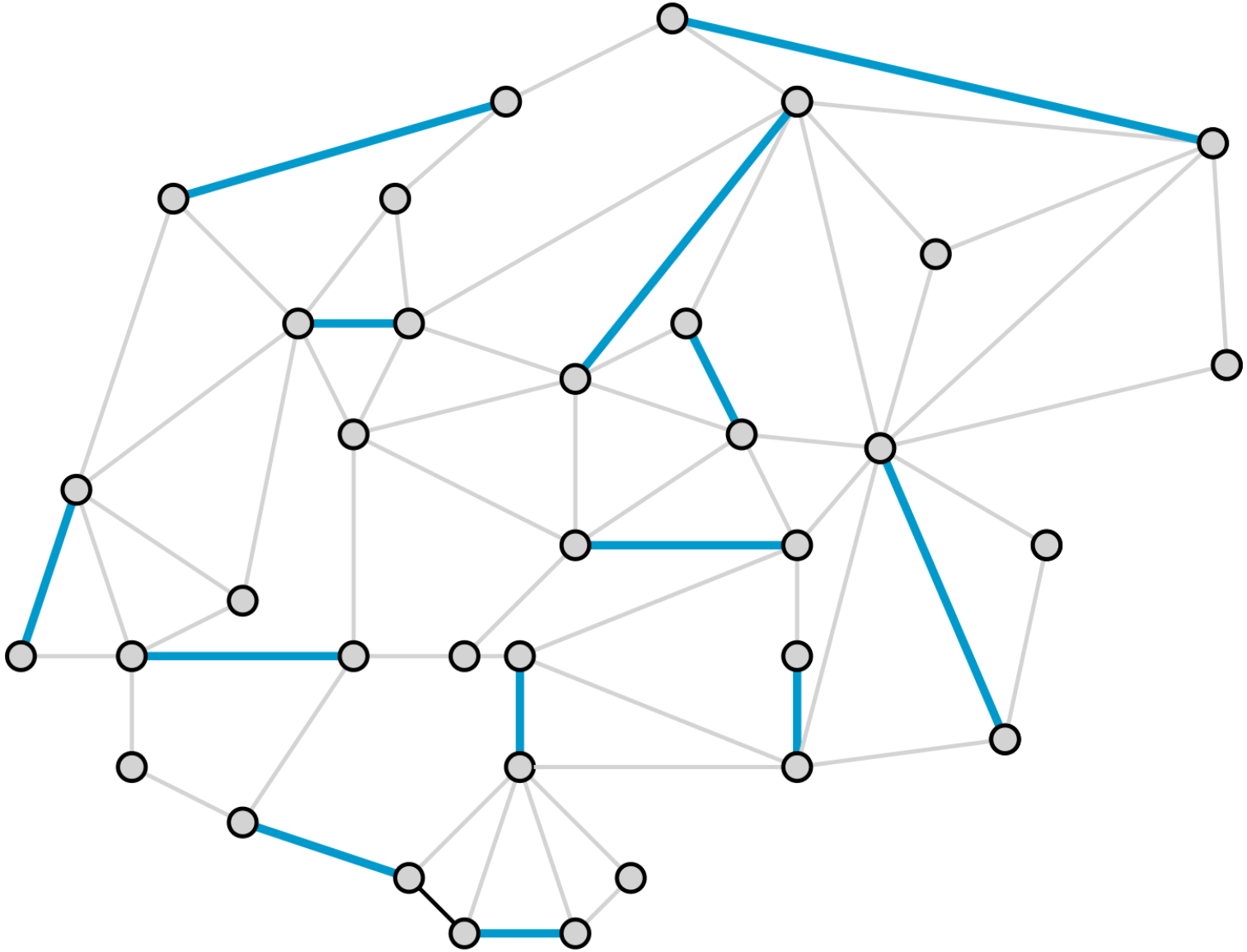

LOCAL Algorithm Mimicking Sequential Algorithm

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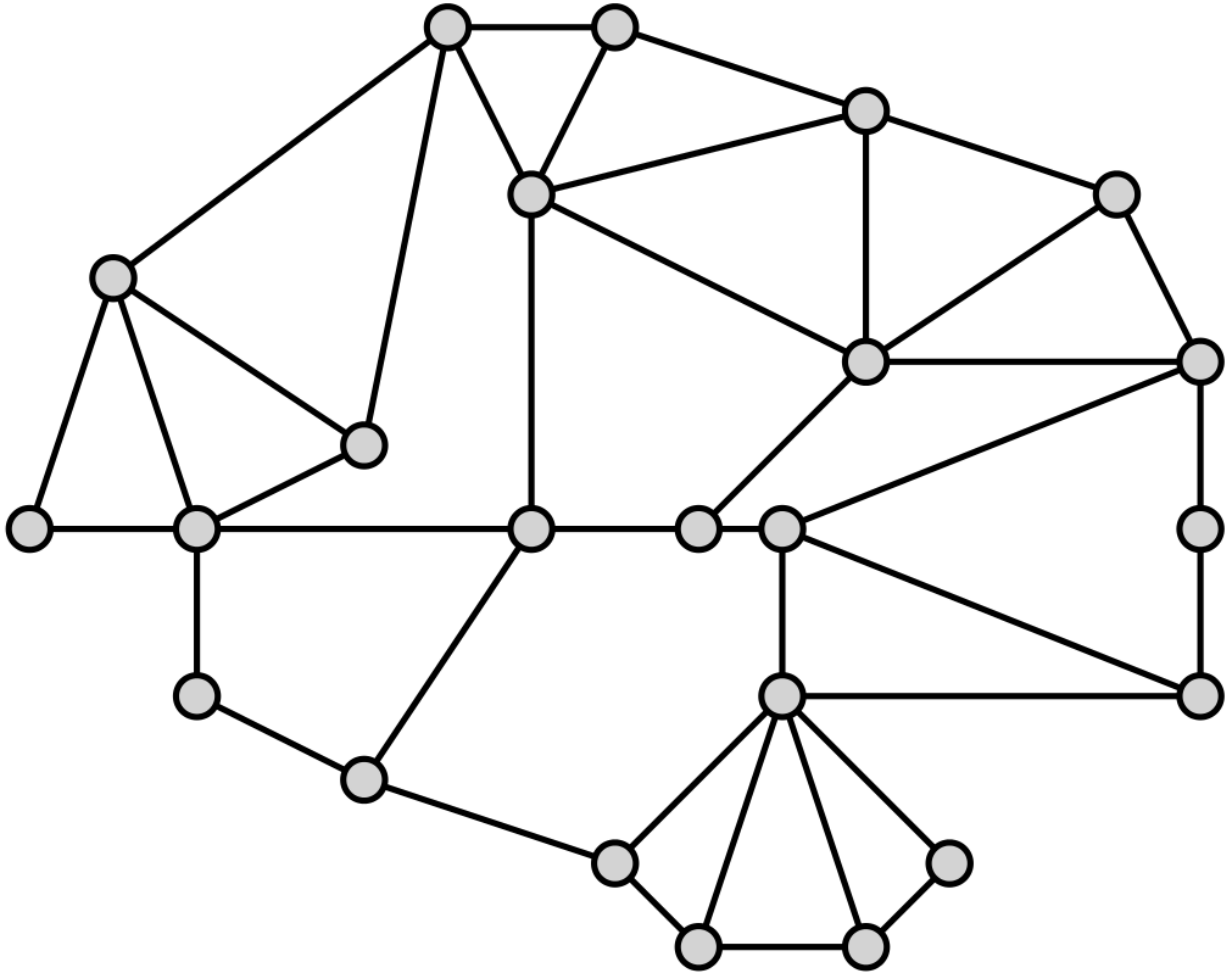

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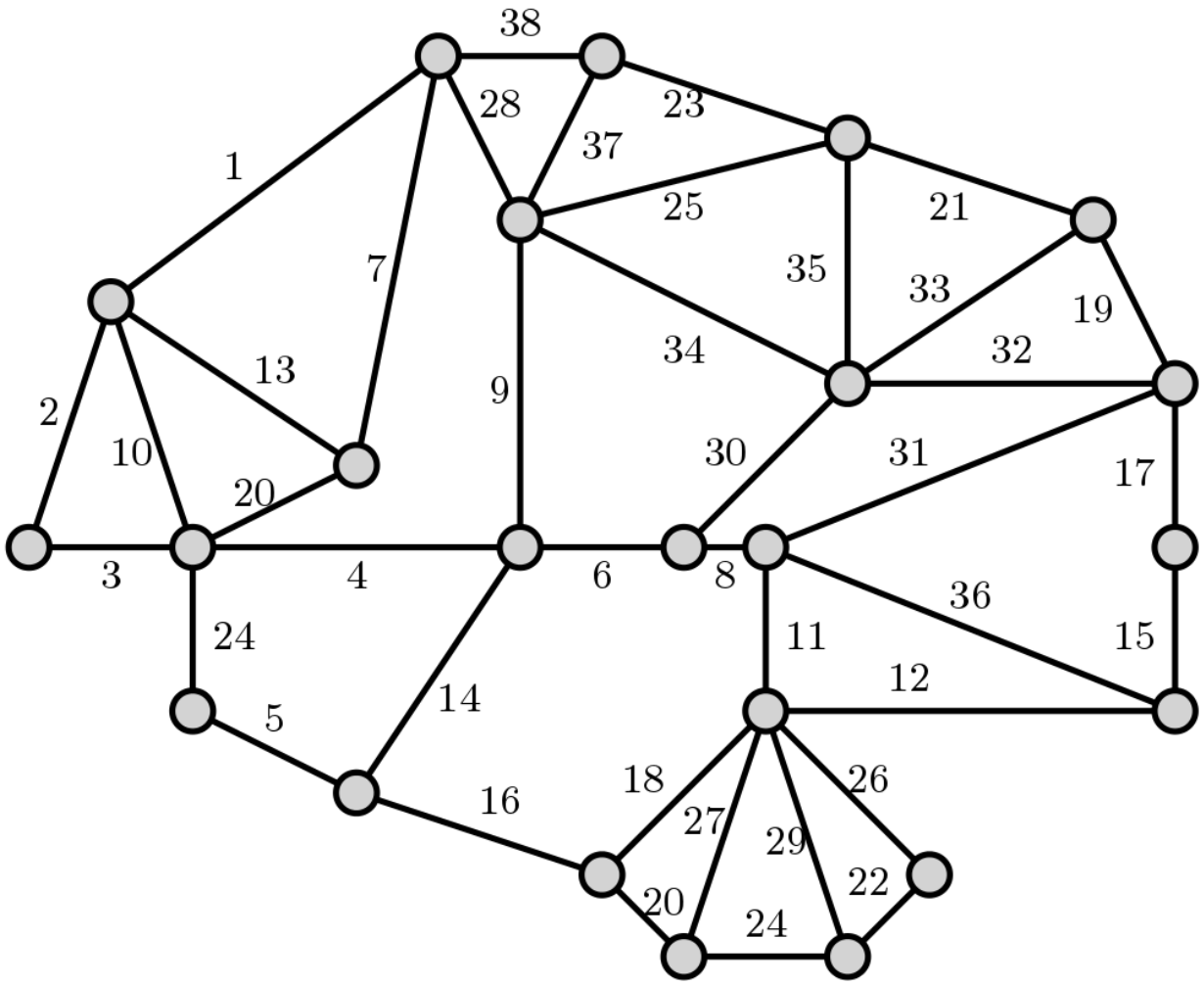

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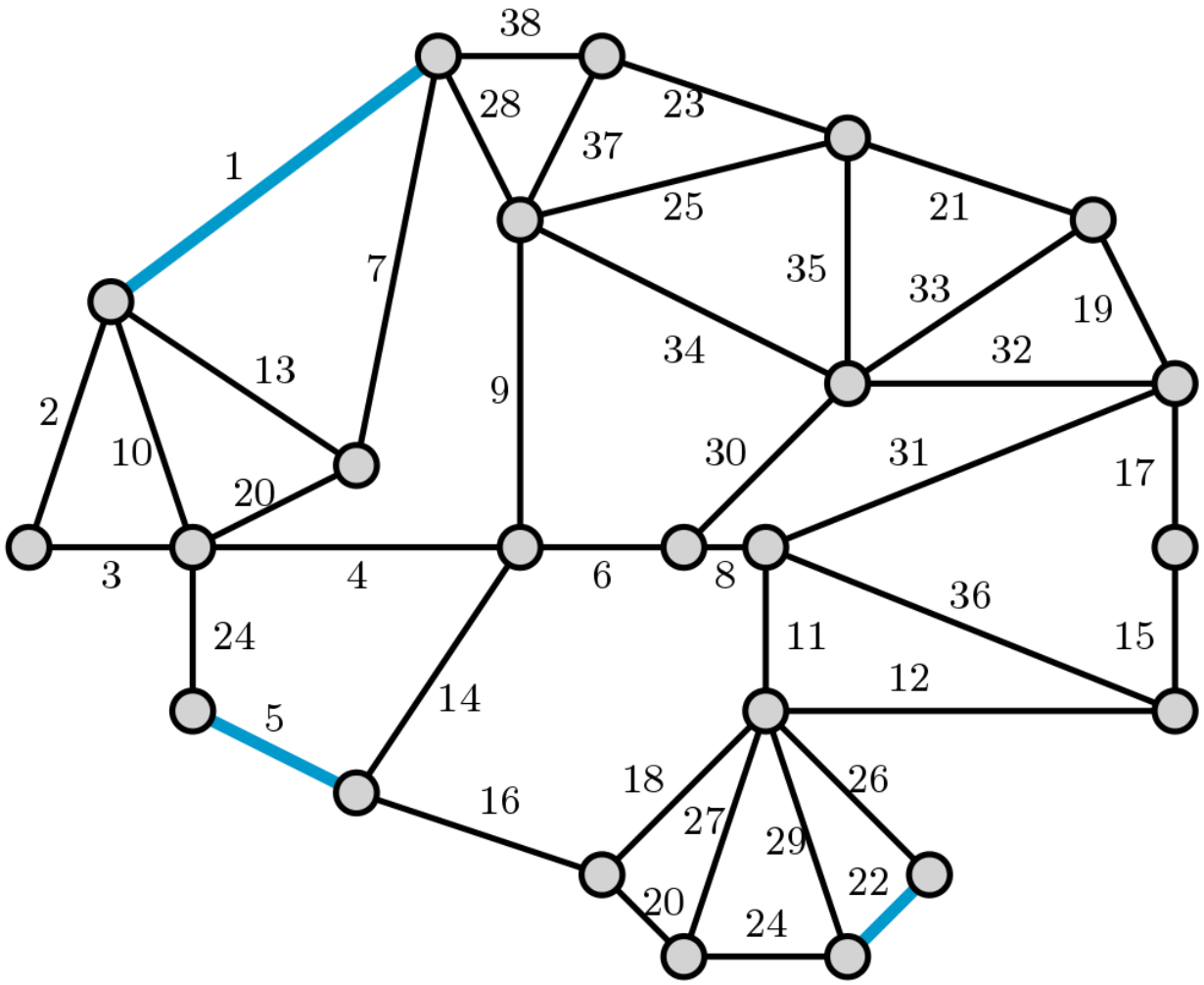

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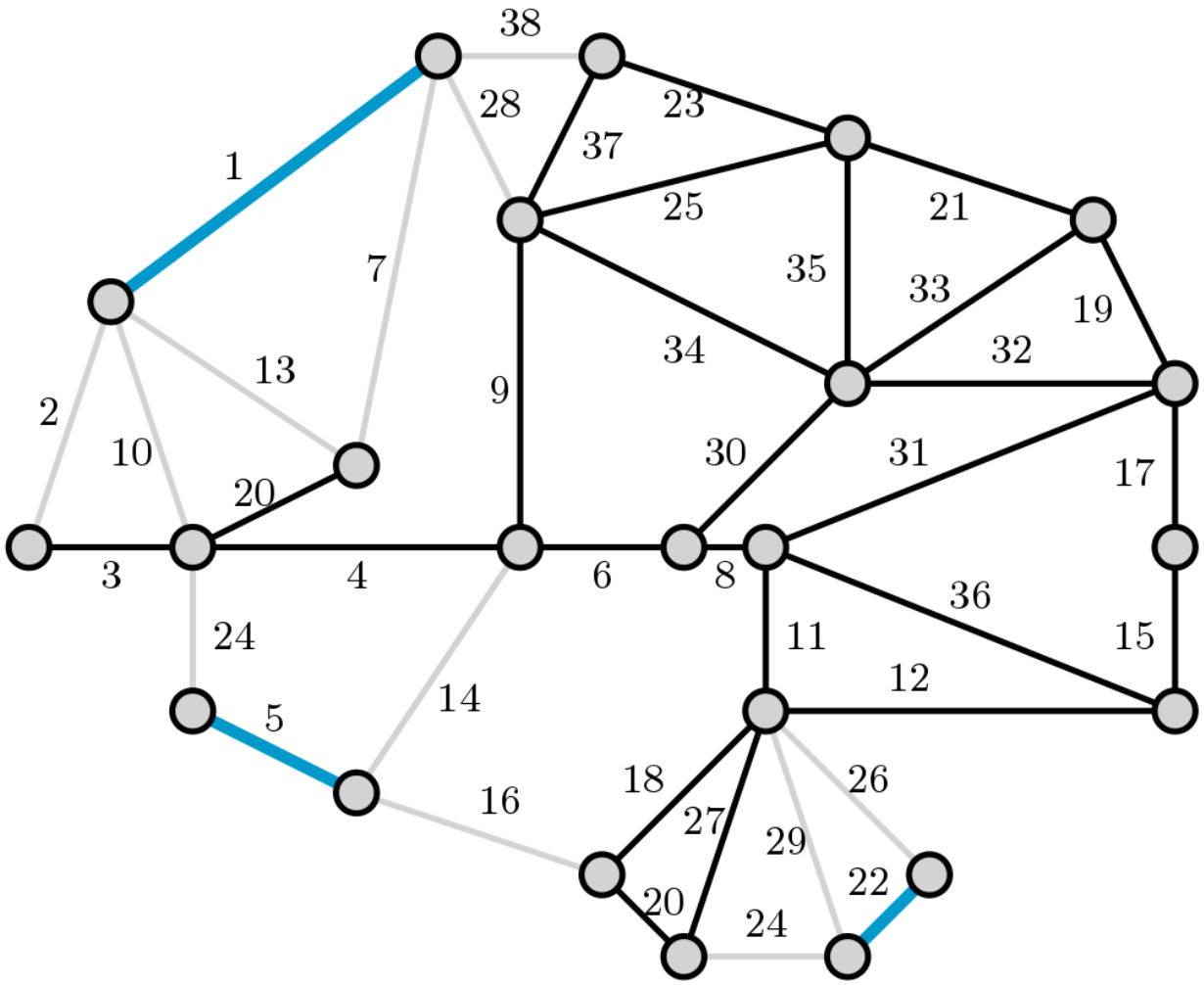

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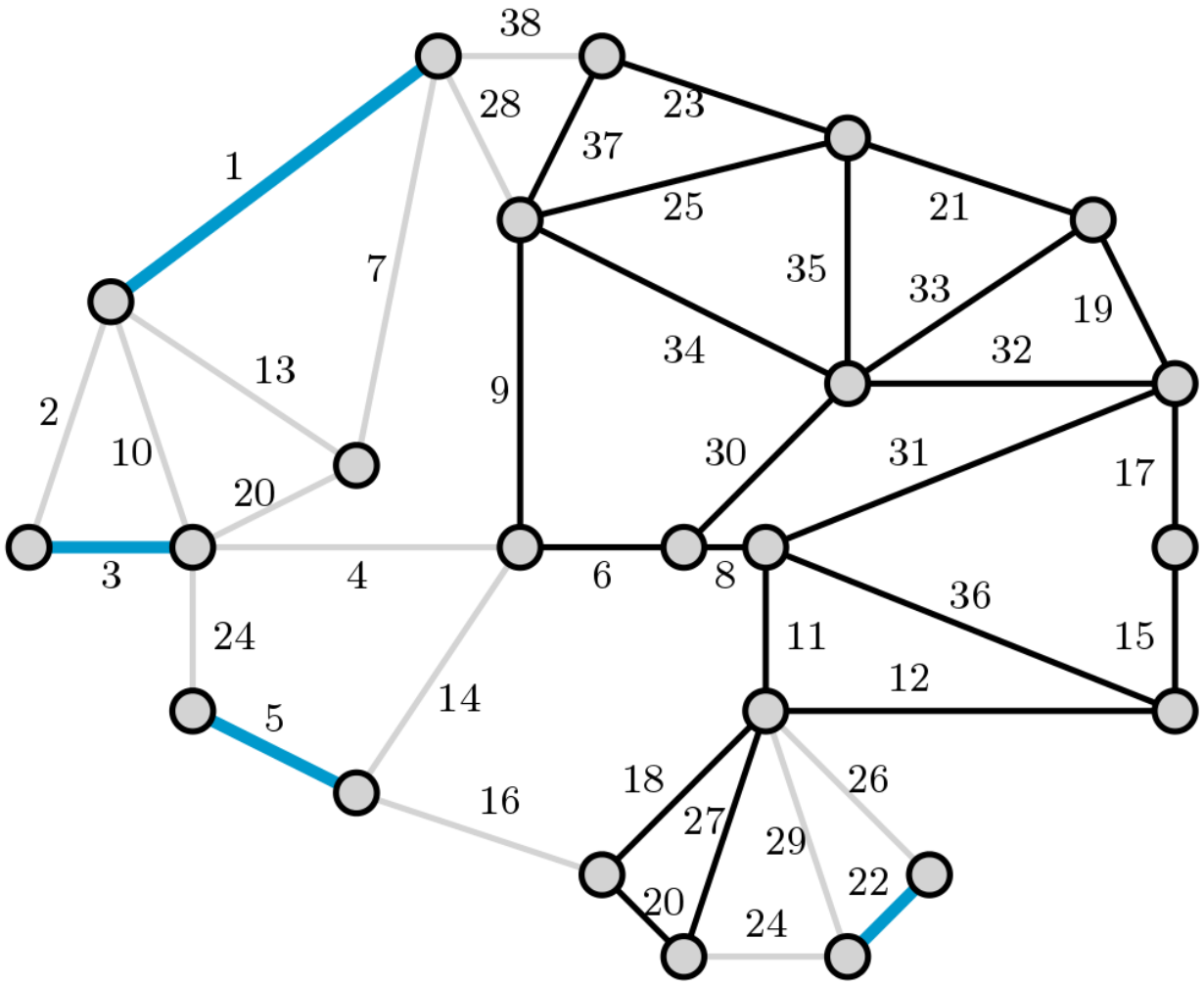

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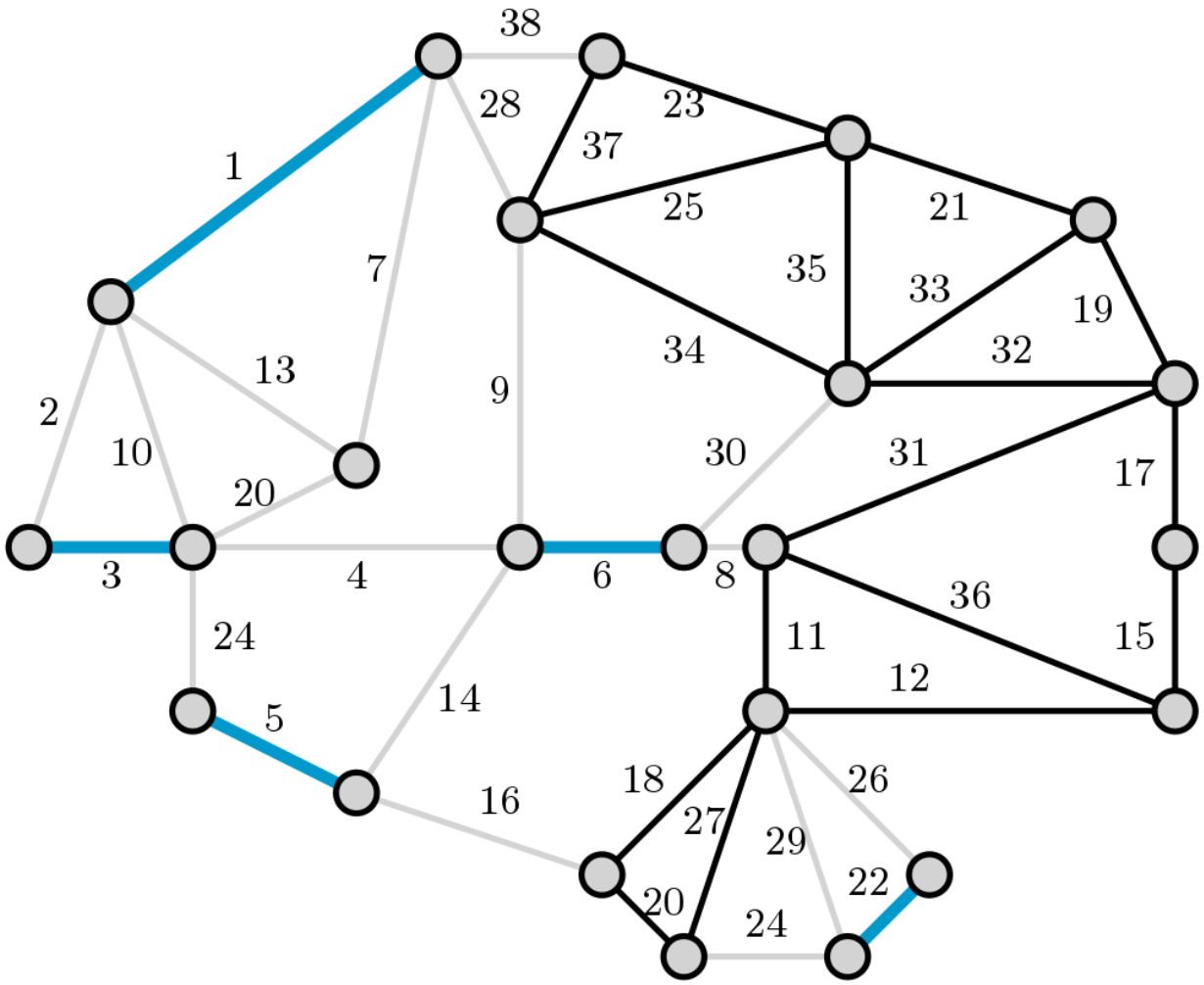

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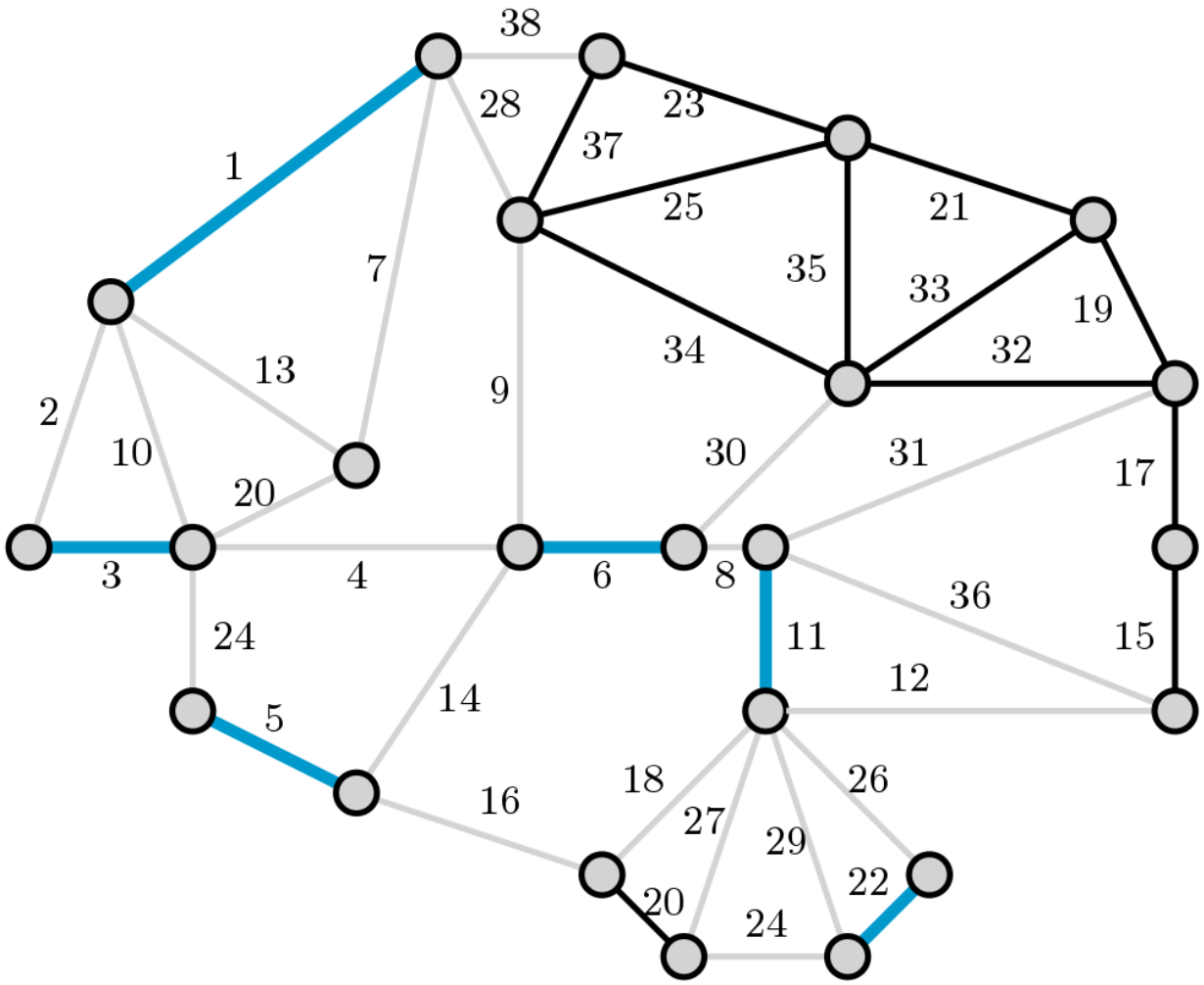

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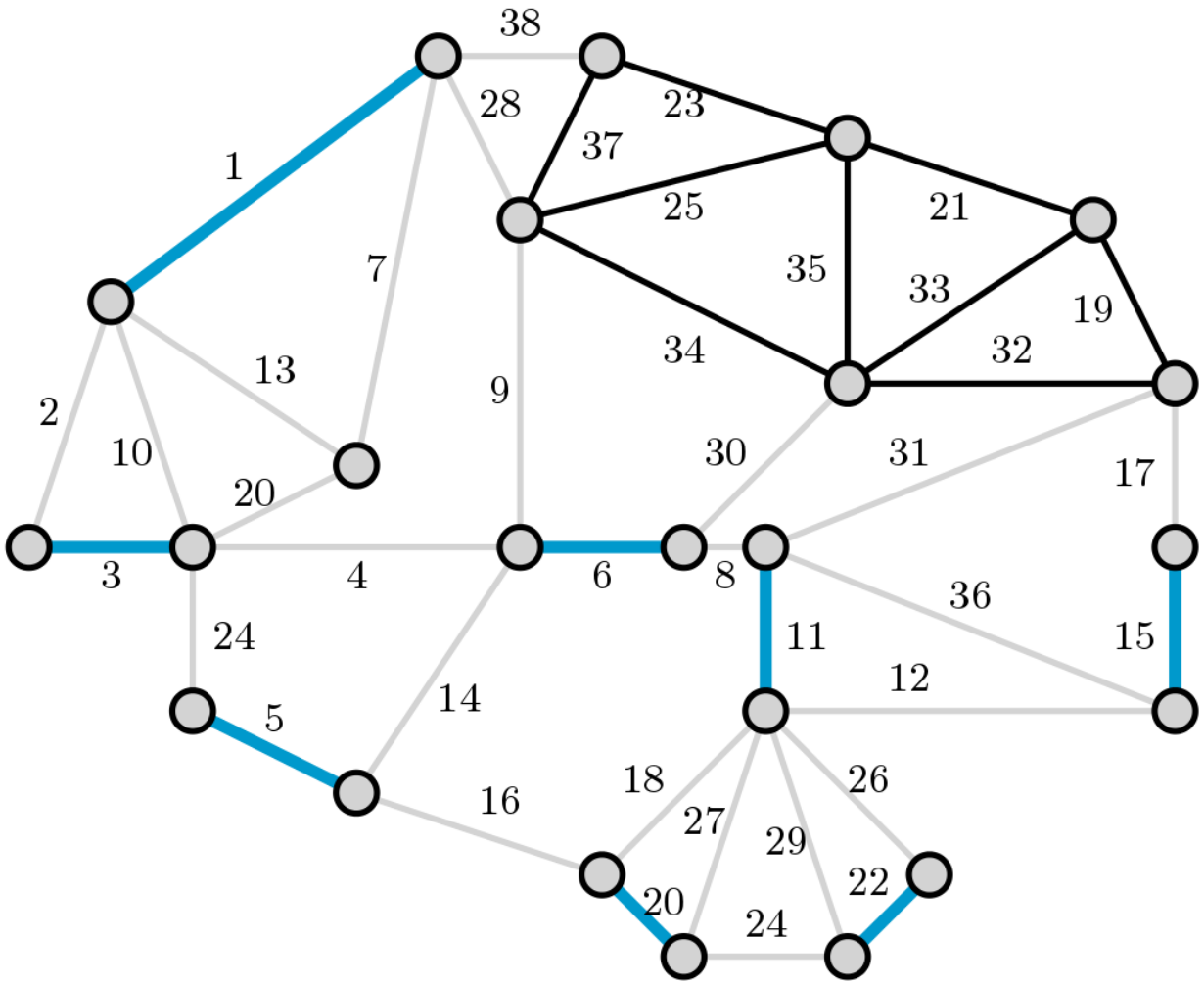

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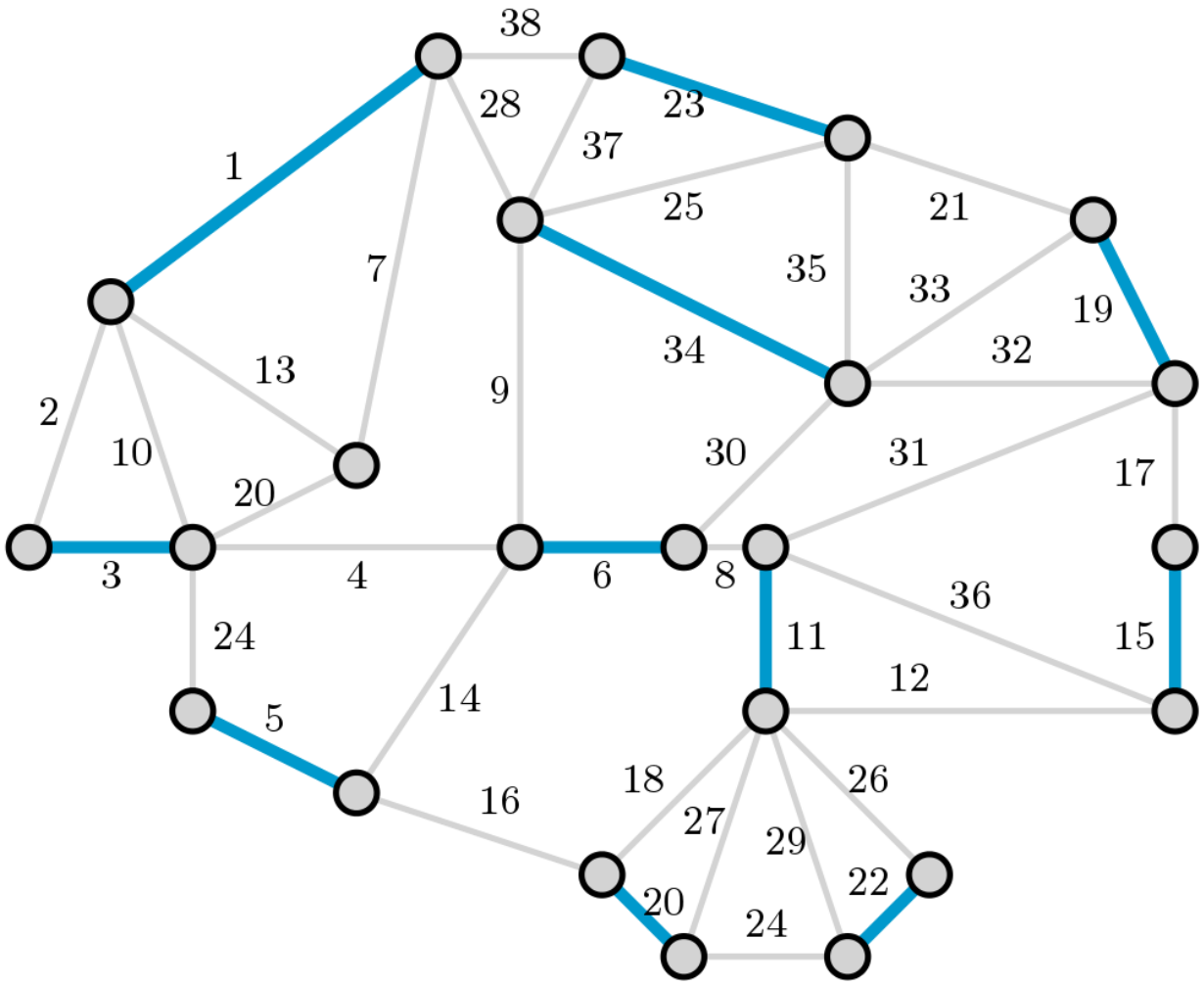

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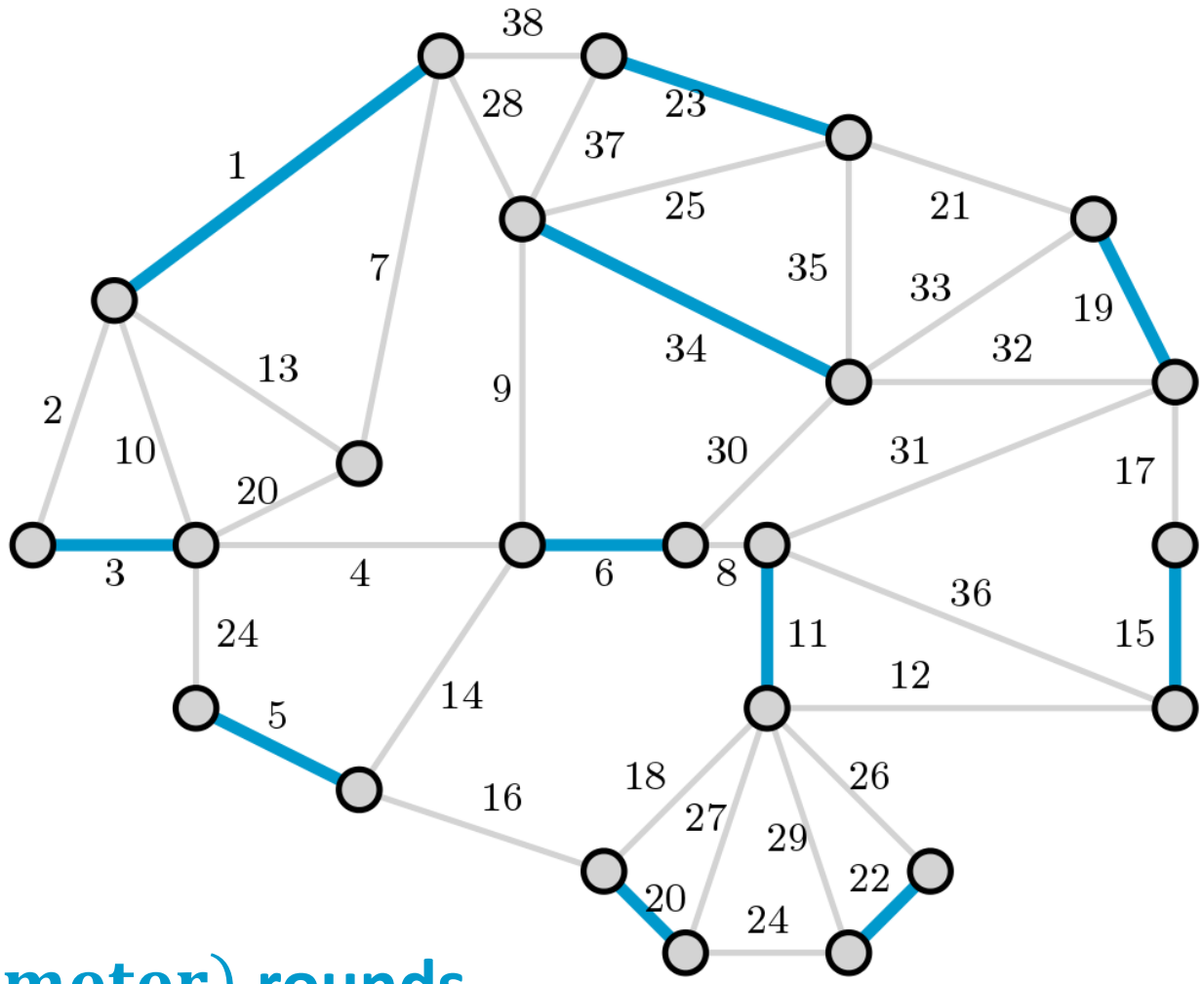

can take $\Omega(\text{diameter})$ rounds in worst case

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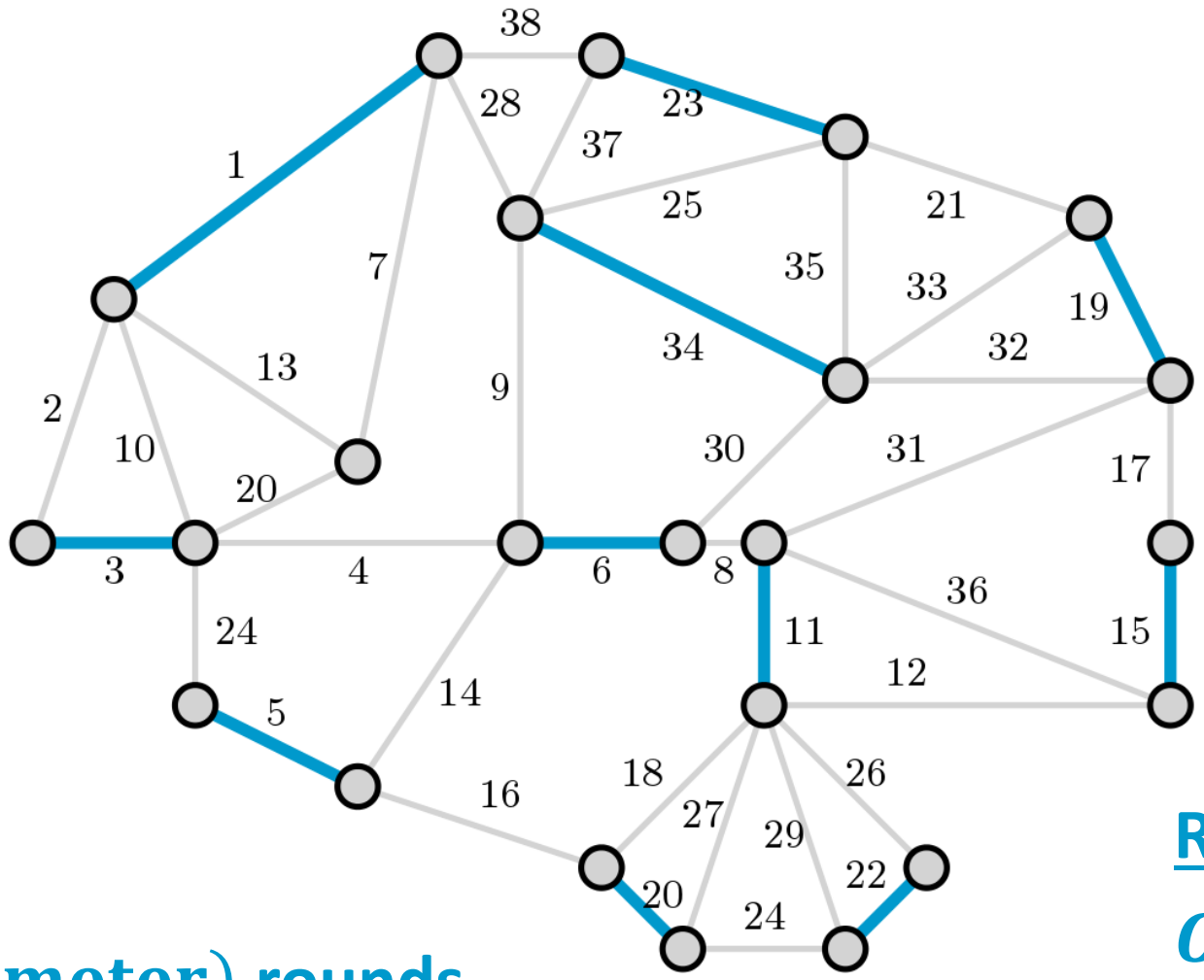

can take $\Omega(\text{diameter})$ rounds in worst case

Random Numbers:

$O(\log n)$ rounds w.h.p.

Luby [STOC'85]

F., Noever [SODA'18]

LOCAL Algorithm: Luby's Randomized Algorithm

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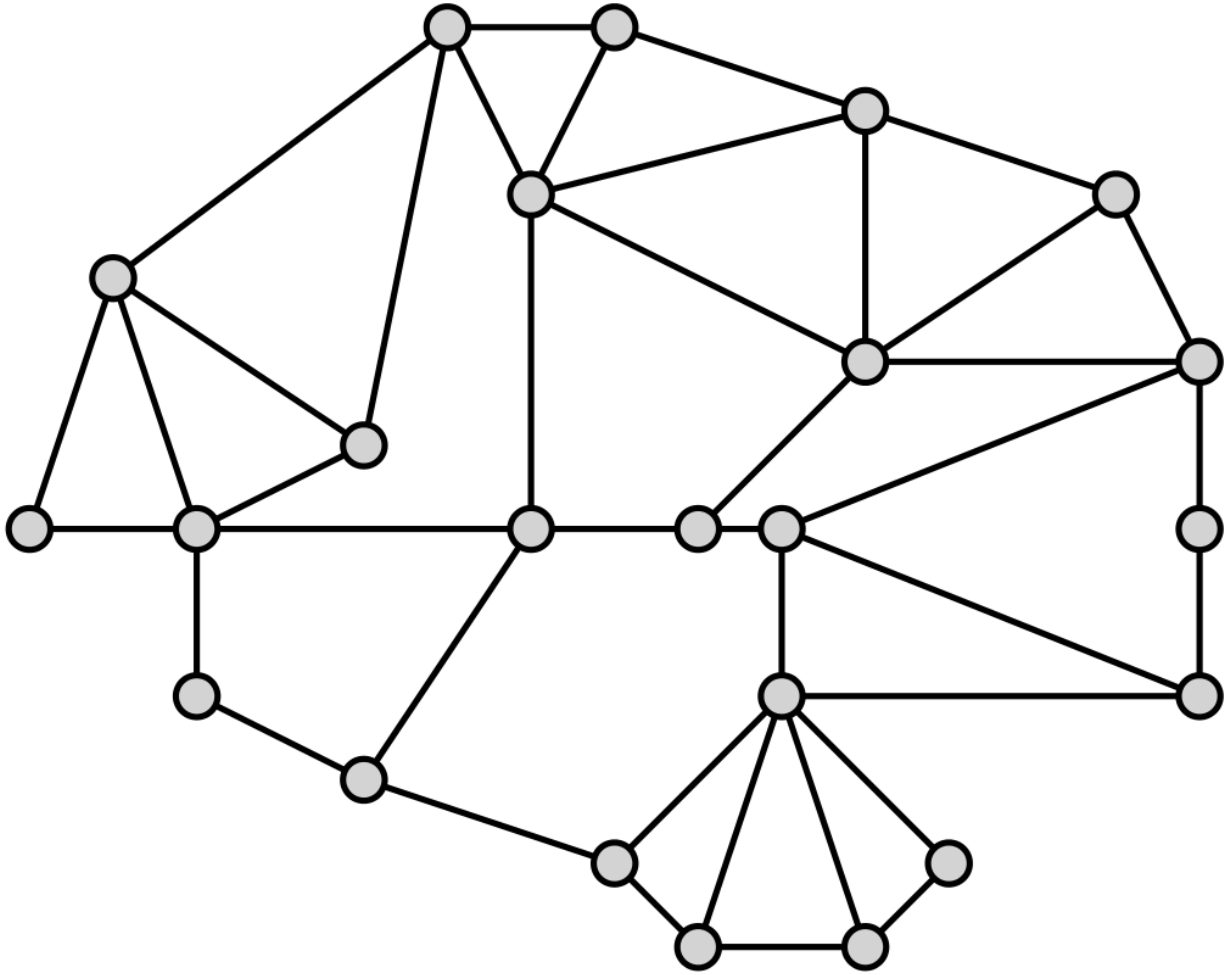

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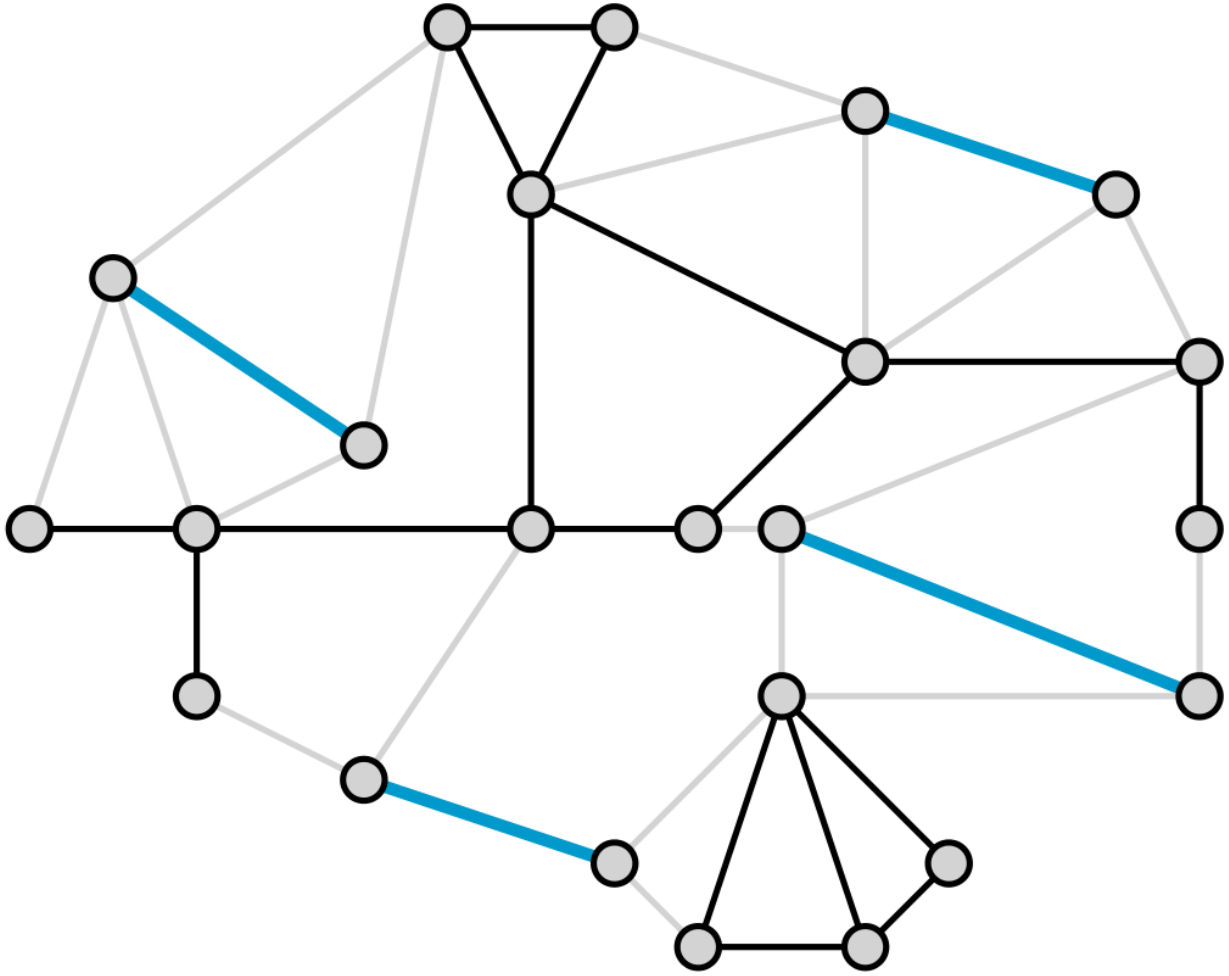

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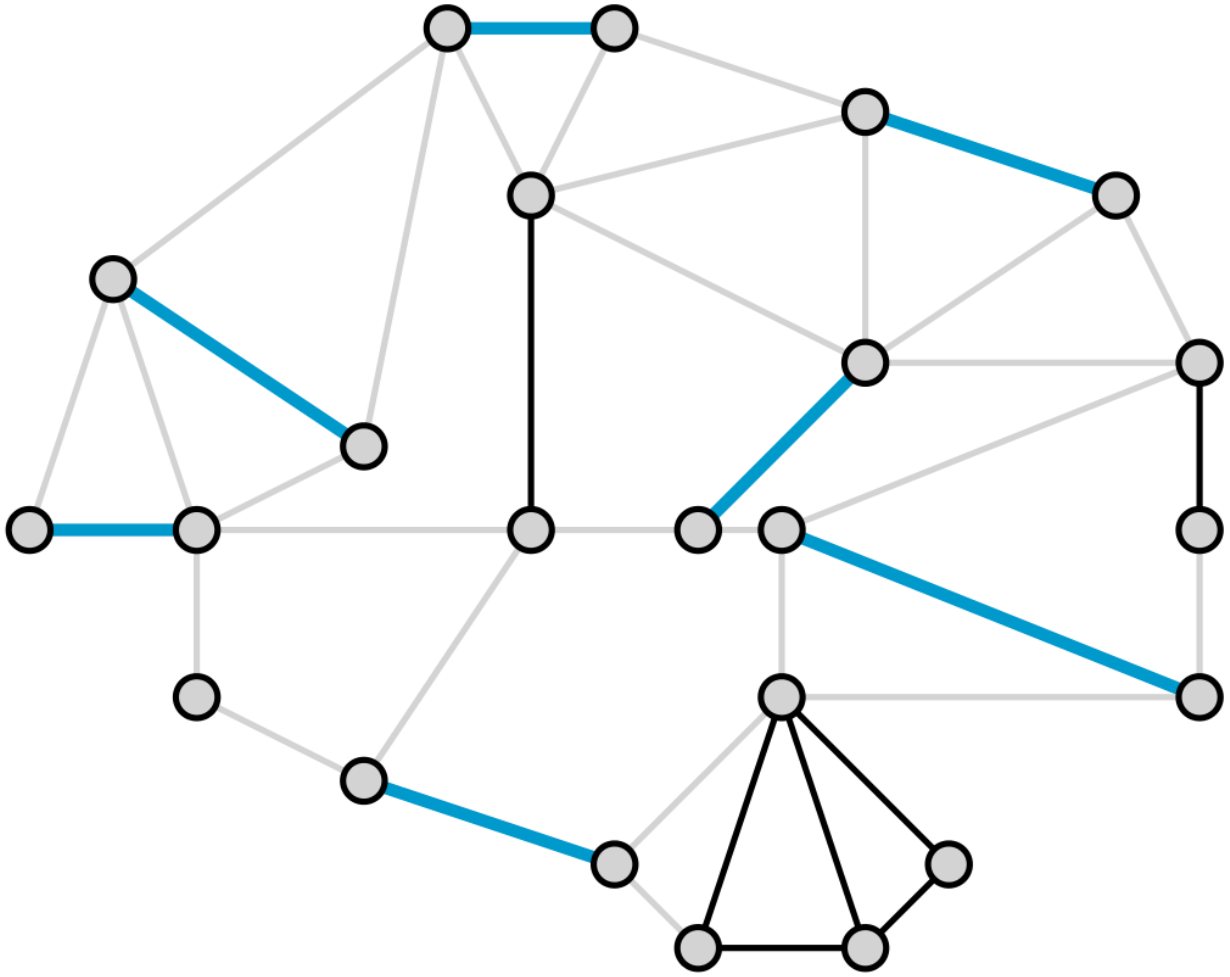

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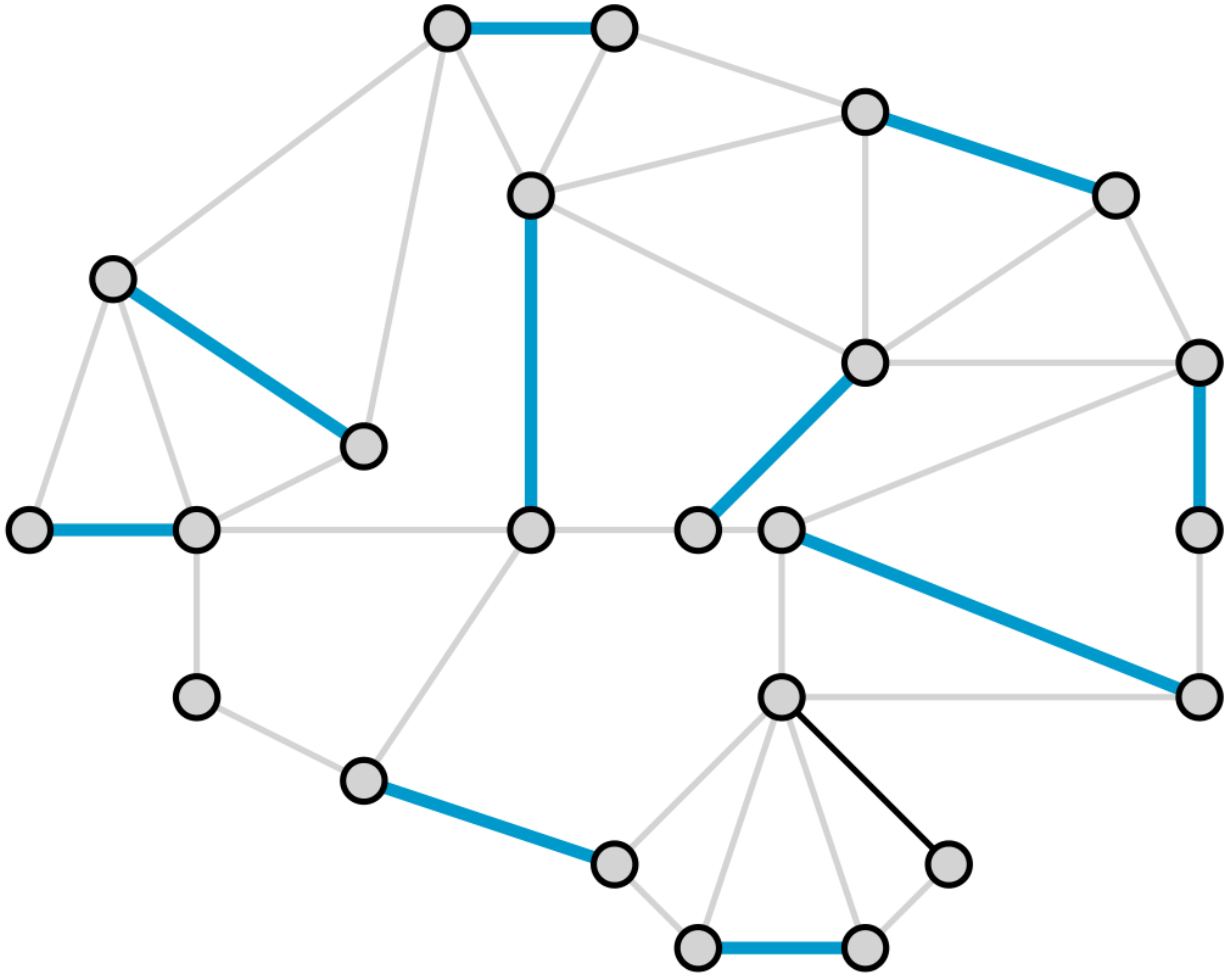

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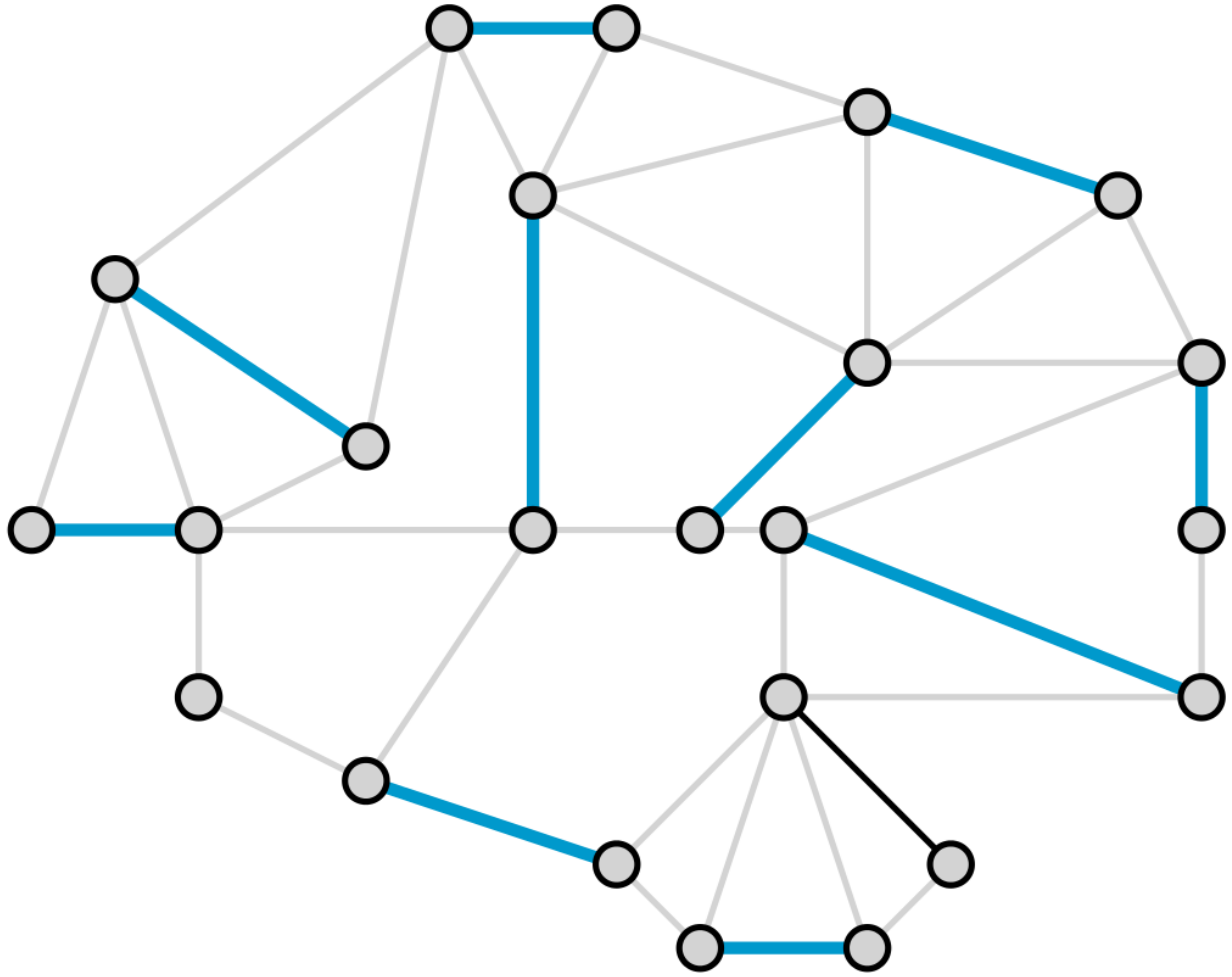
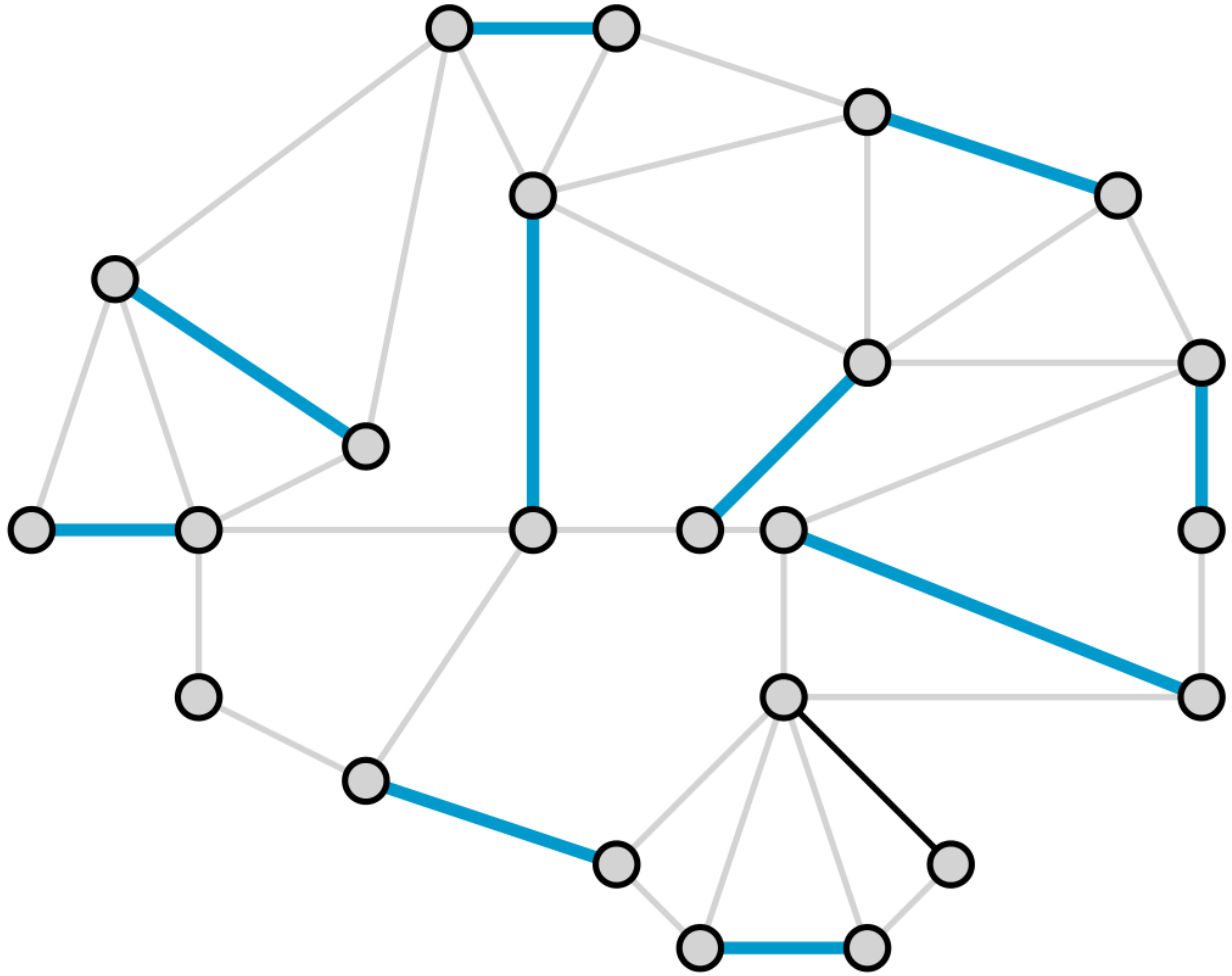


$\mathbb{E}[\#\text{removed edges per round}] \geq c|E_i|$

LOCAL Algorithm: Luby's Randomized Algorithm



$\mathbb{E}[\#\text{removed edges per round}] \geq c|E_i|$

$O(\log n)$ rounds w.h.p.

Our Result

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deterministic $O\left(\log^2 \Delta \cdot \log n\right)$-round Maximal Matching

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improving over

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$O(\log^4 n)$

Hańćkowiak, Karoński, Panconesi [SODA’98, PODC'99]

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deterministic $O\left(\log^2 \Delta \cdot \log n\right)$-round Maximal Matching

improving over

$O(\log^4 n)$
Hańćkowiak, Karoński, Panconesi [SODA’98, PODC'99]

$O(\Delta + \log^* n)$
Panconesi, Rizzi [DIST’01]

Overview of Results

Maximal Matching

- Maximal Matching $O\left(\log^2 \Delta \cdot \log n\right)$
- Randomized Maximal Matching $O\left(\log^3 \log n + \log \Delta\right)$

Approximate Matching

- $(2+\varepsilon)$ - Approximate Maximum Matching $O\left(\log^2 \Delta \cdot \log \frac{1}{\varepsilon} + \log^* n\right)$
- $(2+\varepsilon)$ - Approximate Maximum Weighted Matching $O\left(\log^2 \Delta \cdot \log \frac{1}{\varepsilon} + \log^* n\right)$

- $(2+\varepsilon)$ - Approximate Maximum B-Matching $O\left(\log^2 \Delta \cdot \log \frac{1}{\varepsilon} + \log^* n\right)$
- $(2+\varepsilon)$ - Approximate Maximum Weighted B-Matching $O\left(\log^2 \Delta \cdot \log \frac{1}{\varepsilon} + \log^* n\right)$

- ε - Maximal Matching $O\left(\log^2 \Delta \cdot \log \frac{1}{\varepsilon}\right)$
- $(2+\varepsilon)$ - Approximate Minimum Edge Dominating Set $O\left(\log^2 \Delta \cdot \log \frac{1}{\varepsilon}\right)$

Constant - Approximate Bipartite Matching $O\left(\log^2 \Delta\right)$ rounds

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I) 4 - Approximate Fractional Matching

$O(\log \Delta)$ rounds

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$O(\log \Delta)$ rounds

II) Rounding Fractional Bipartite Matching

$O(\log^2 \Delta)$ rounds, $O(1)$ loss

I) 4-Approximate Fractional Matching $O(\log \Delta)$ rounds

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$O(\log \Delta)$ rounds

Fractional Maximum Matching

$$\max \sum_{e \in E} x_e$$

$$\text{s.t.} \sum_{e \in E(v)} x_e \leq 1 \quad \text{for all } v \in V$$

$$x_e \in [0,1] \quad \text{for all } e \in E$$

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$O(\log \Delta)$ rounds

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$x_e = 2^{-\lceil \log \Delta \rceil}$ for all $e \in E$

repeat until all edges are blocked

mark half-tight nodes

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double value of unblocked edges

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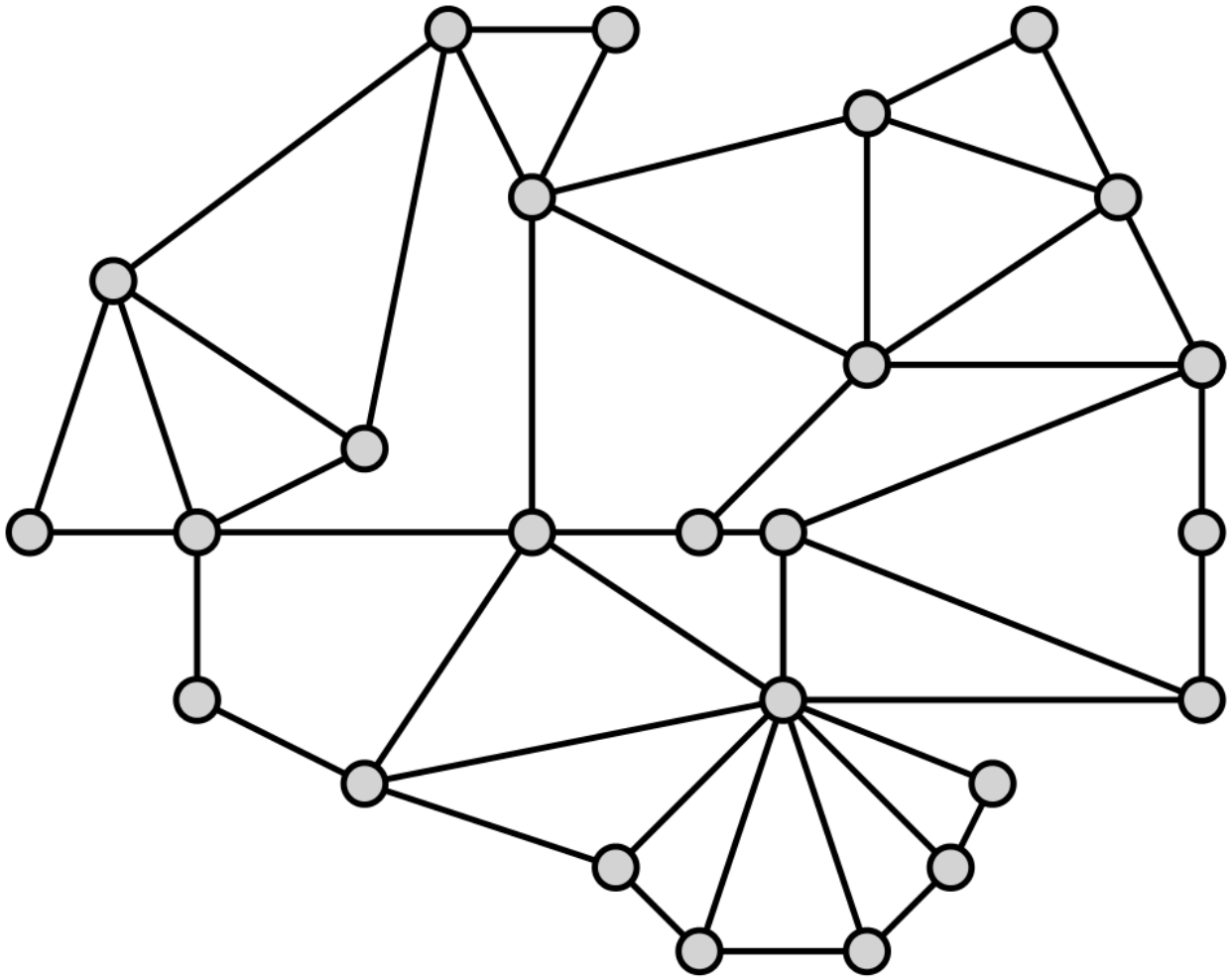
$O(\log \Delta)$ rounds



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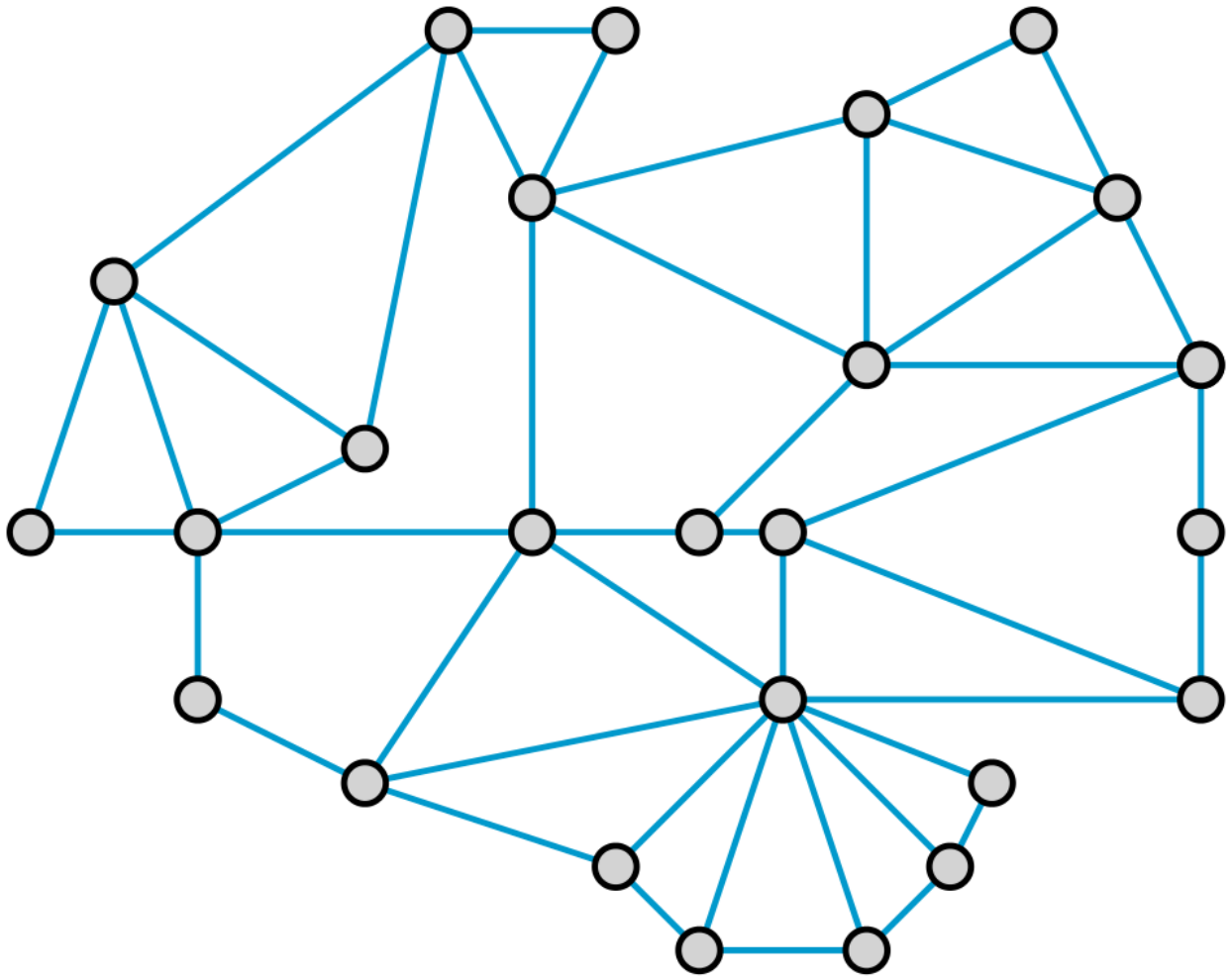

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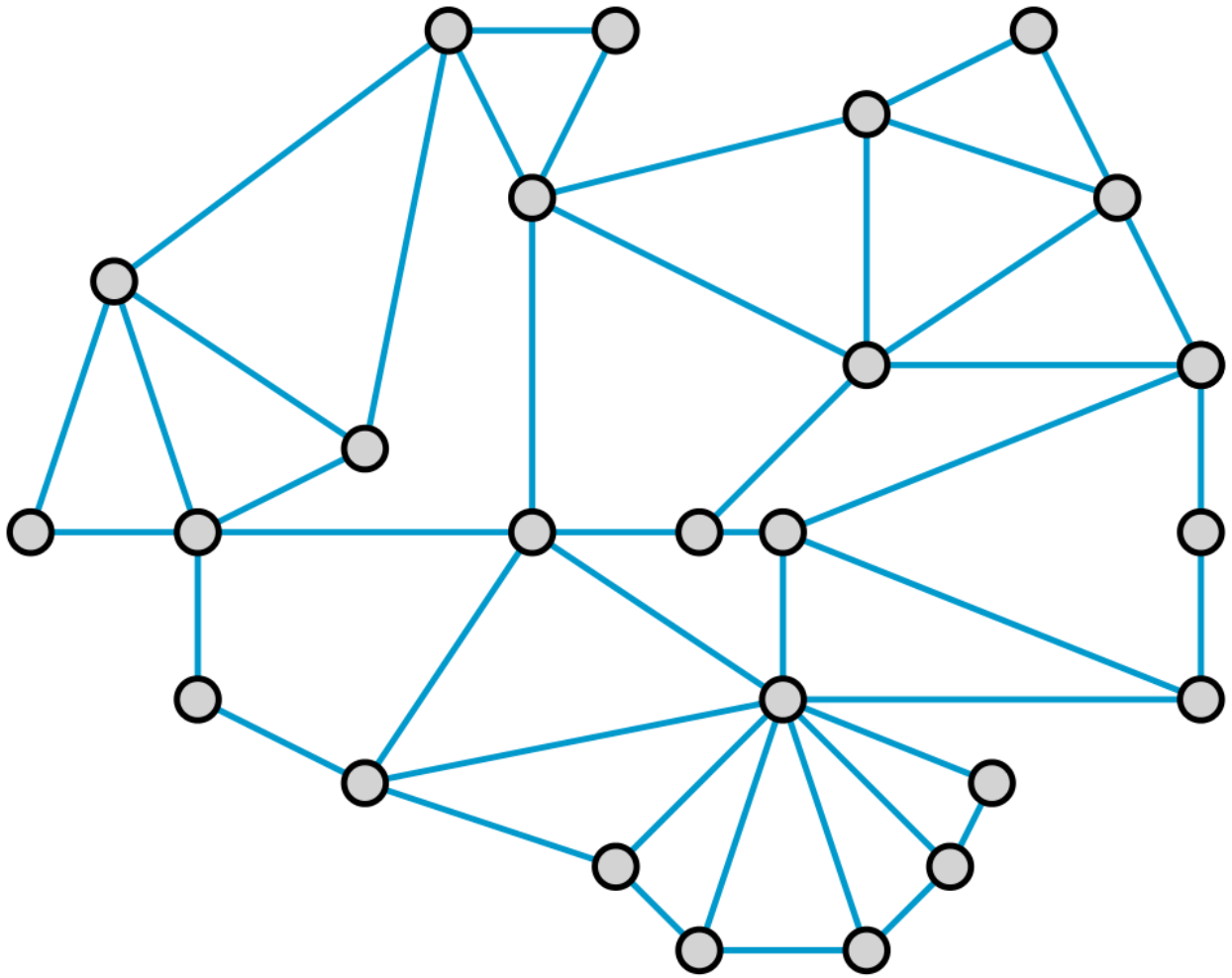

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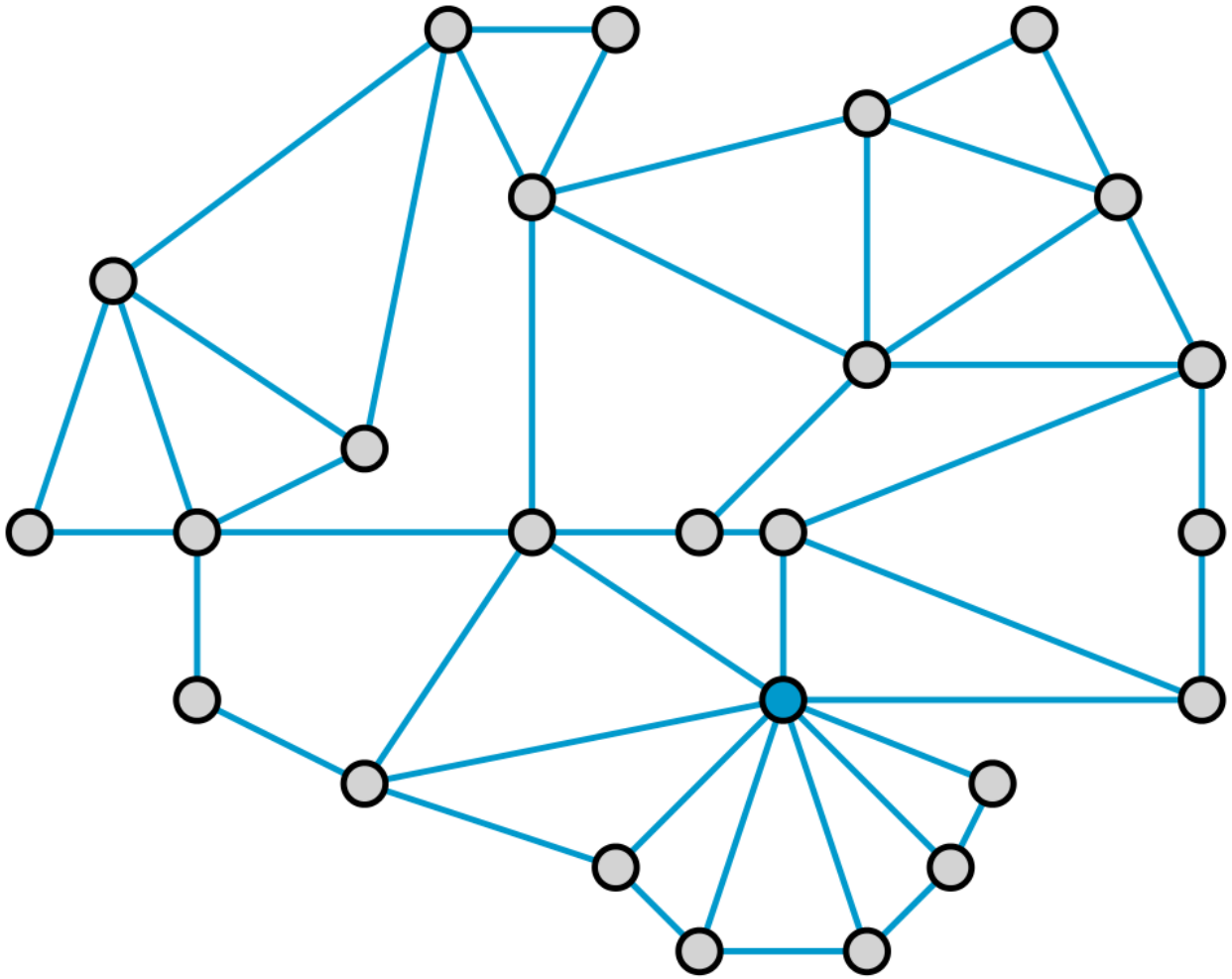

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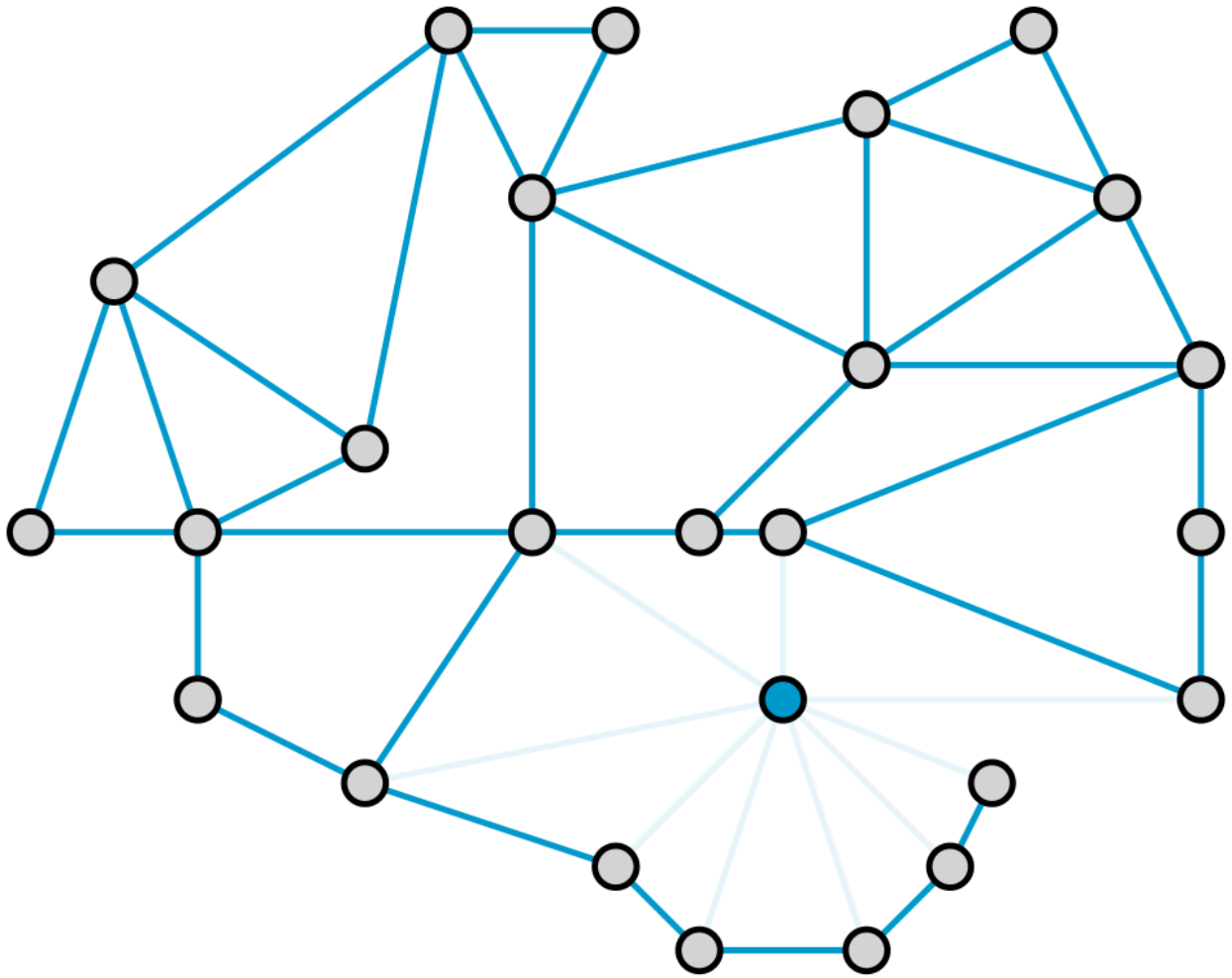

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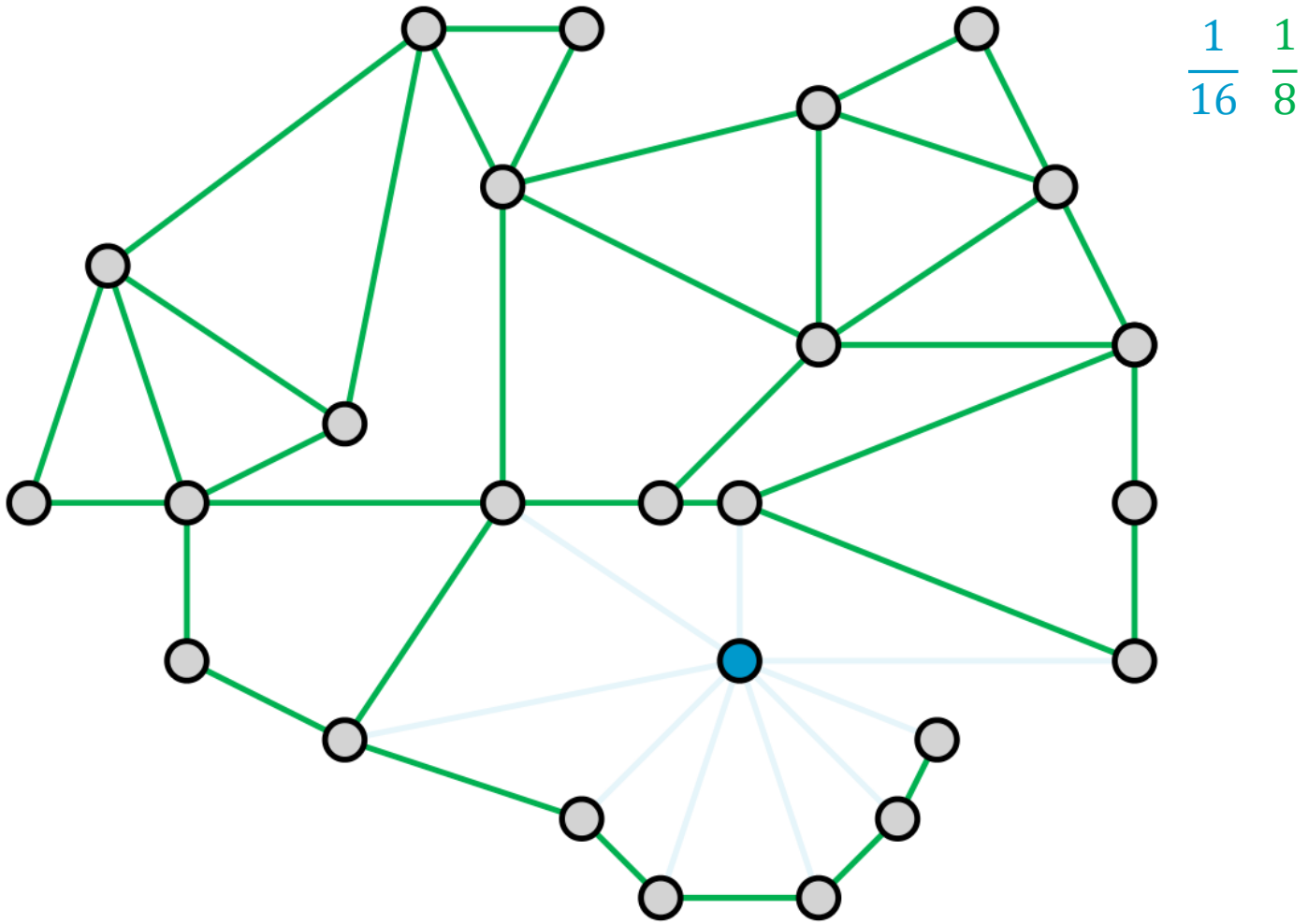

$\frac{1}{16}$ $\frac{1}{8}$

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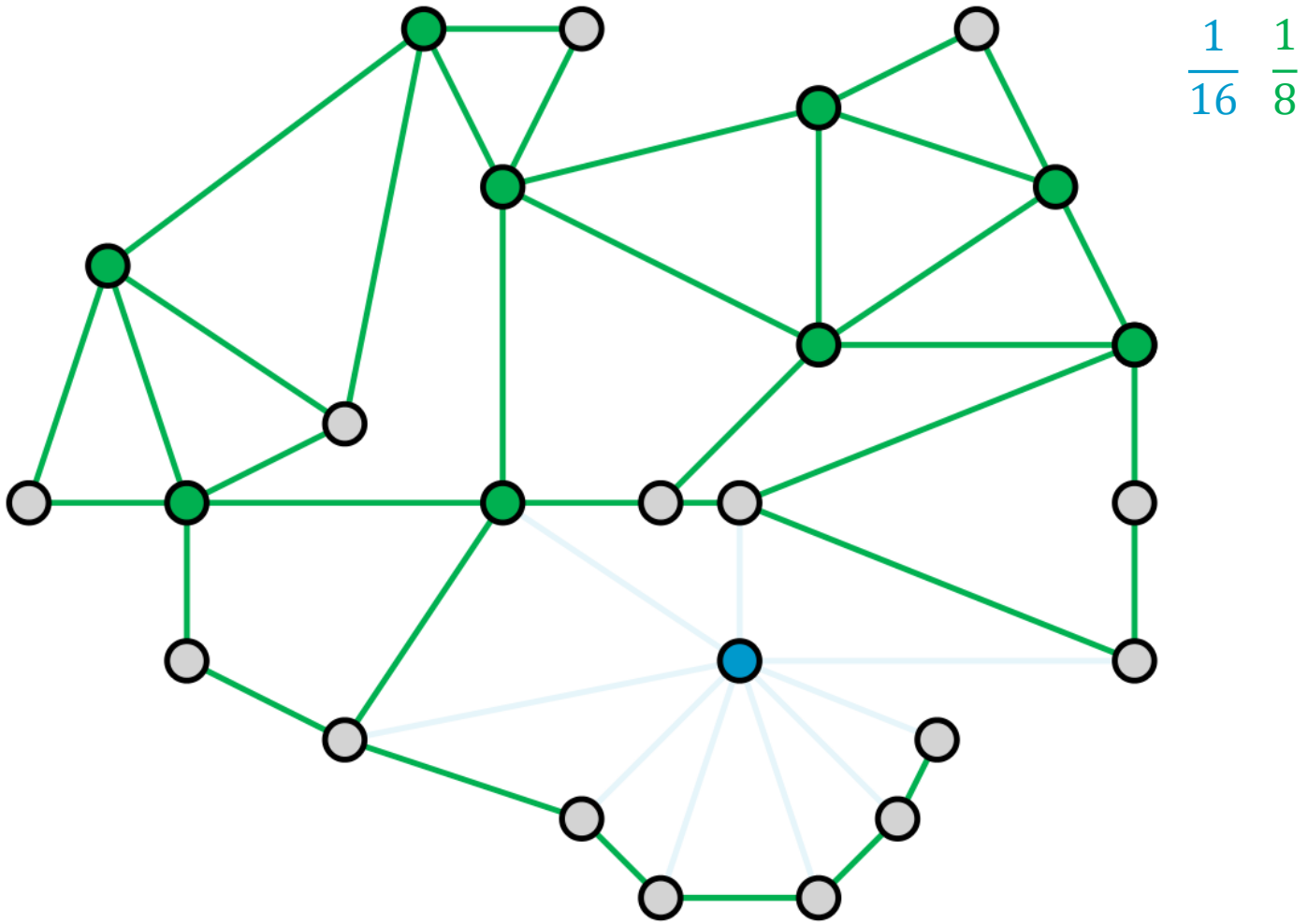

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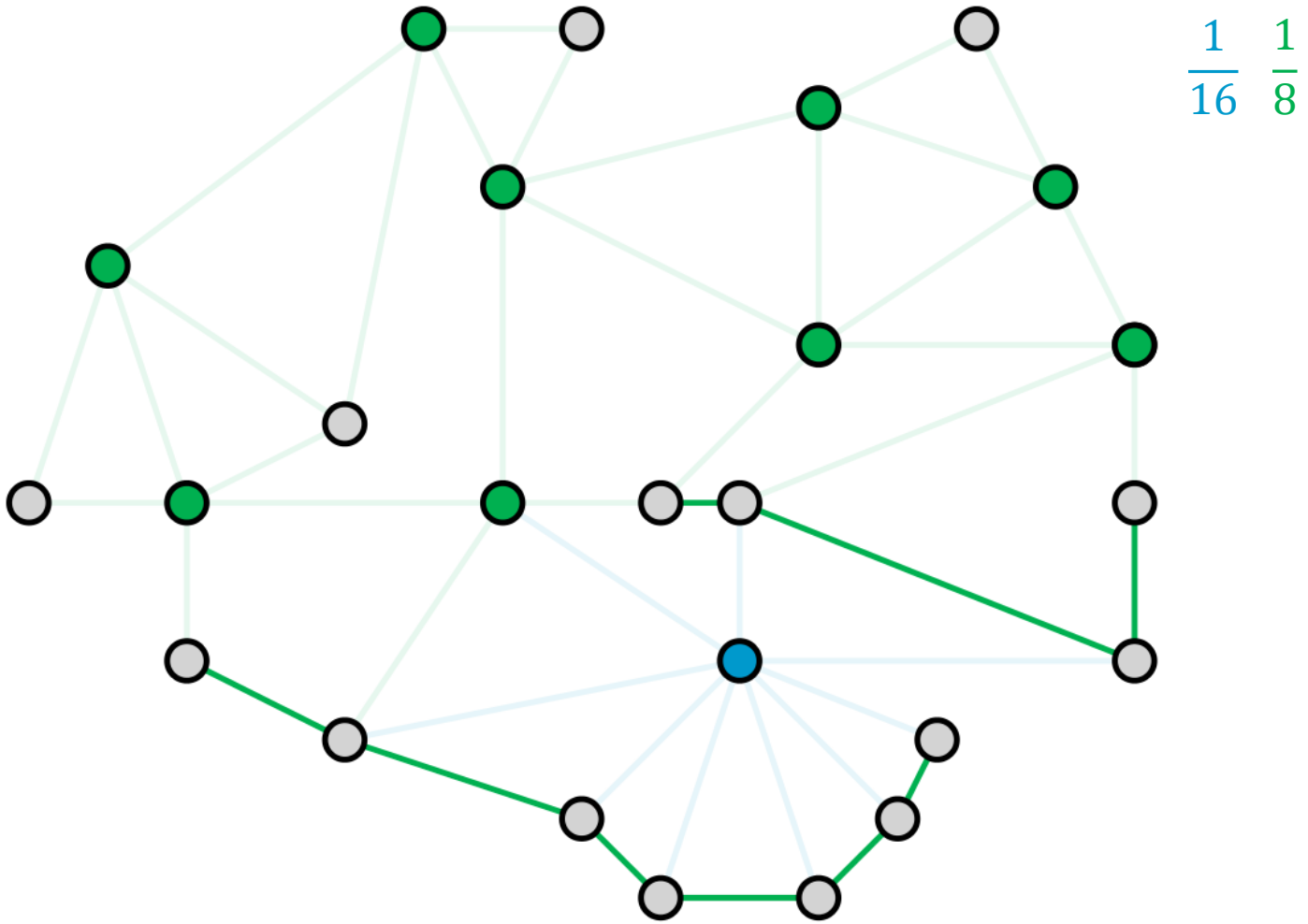

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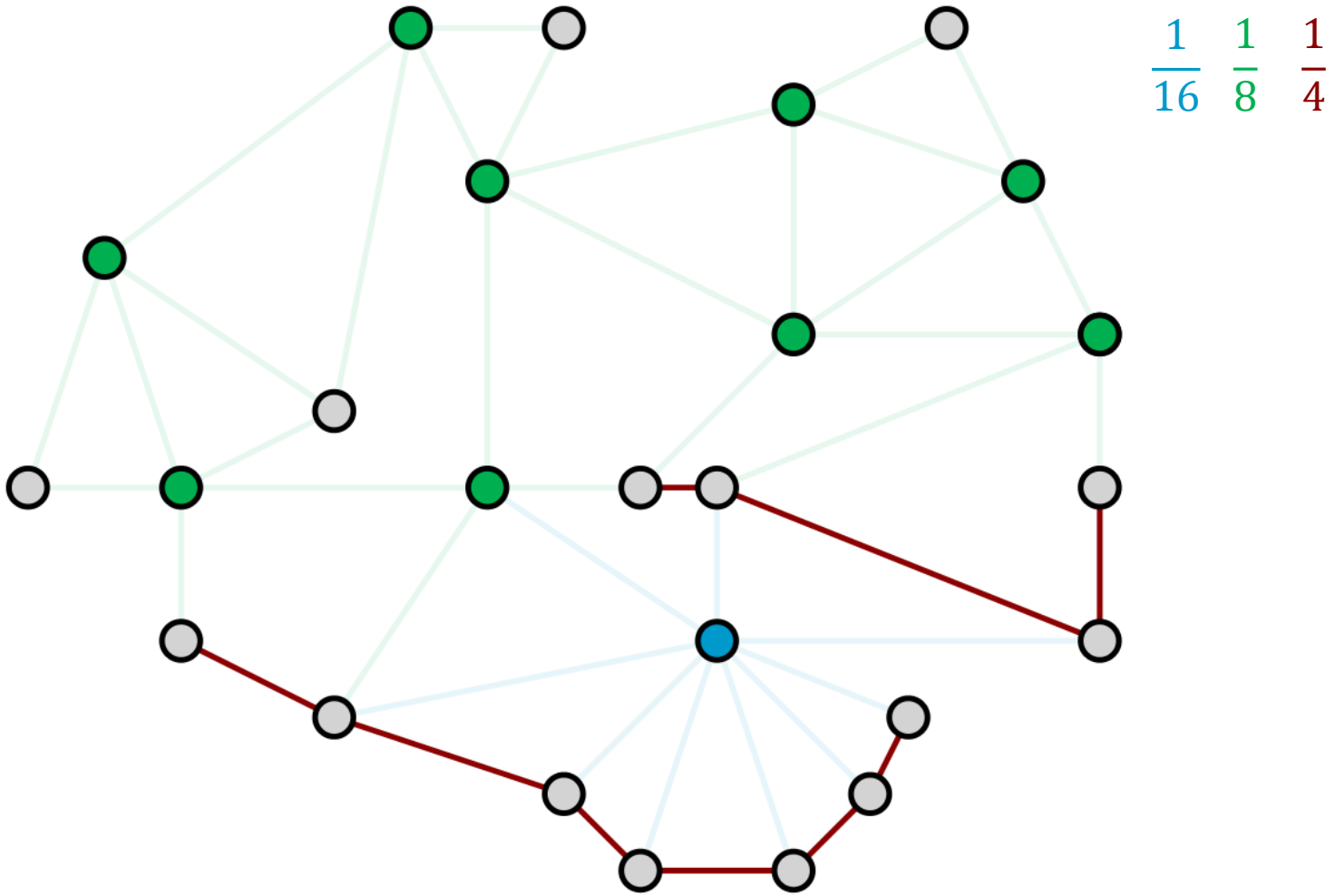

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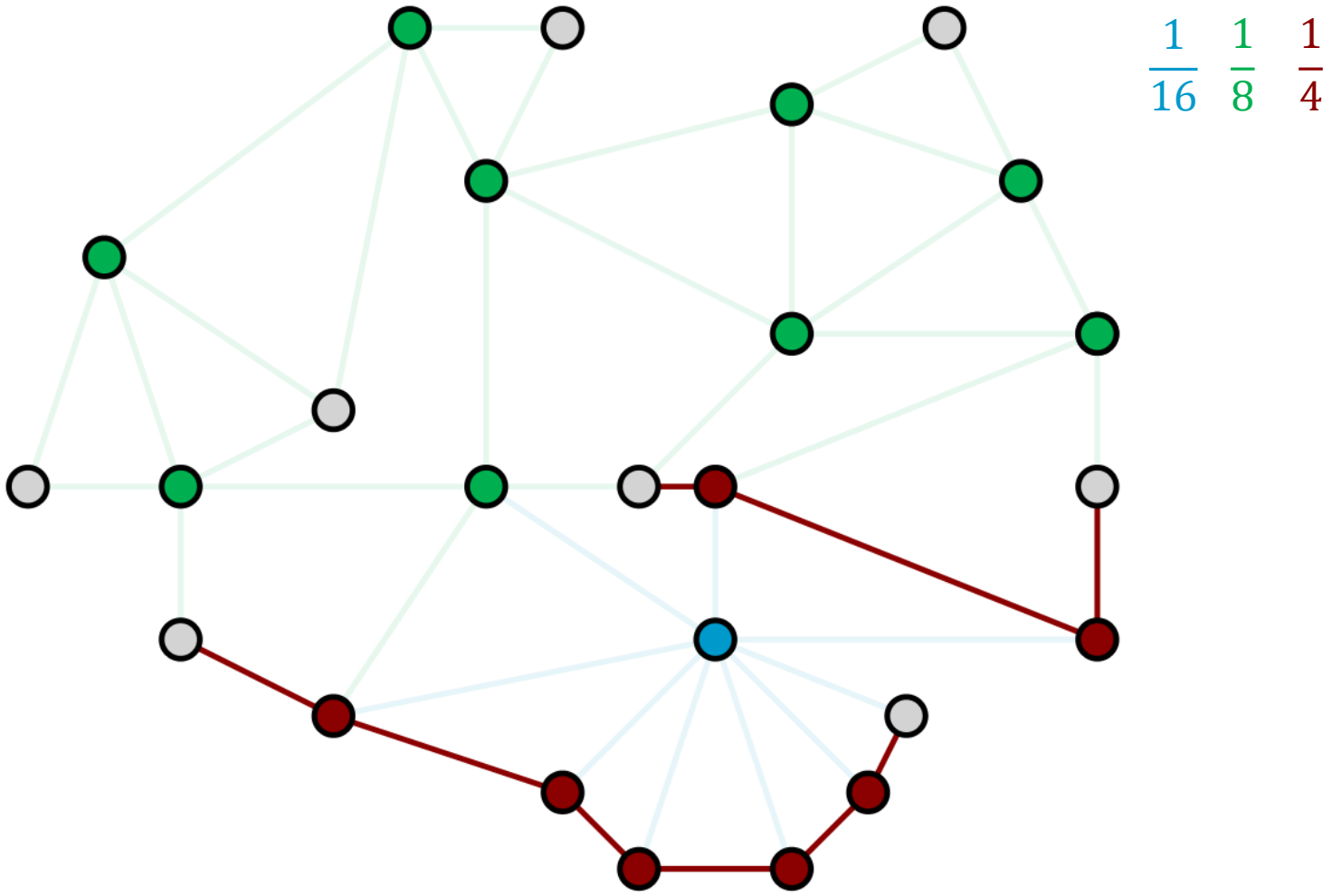

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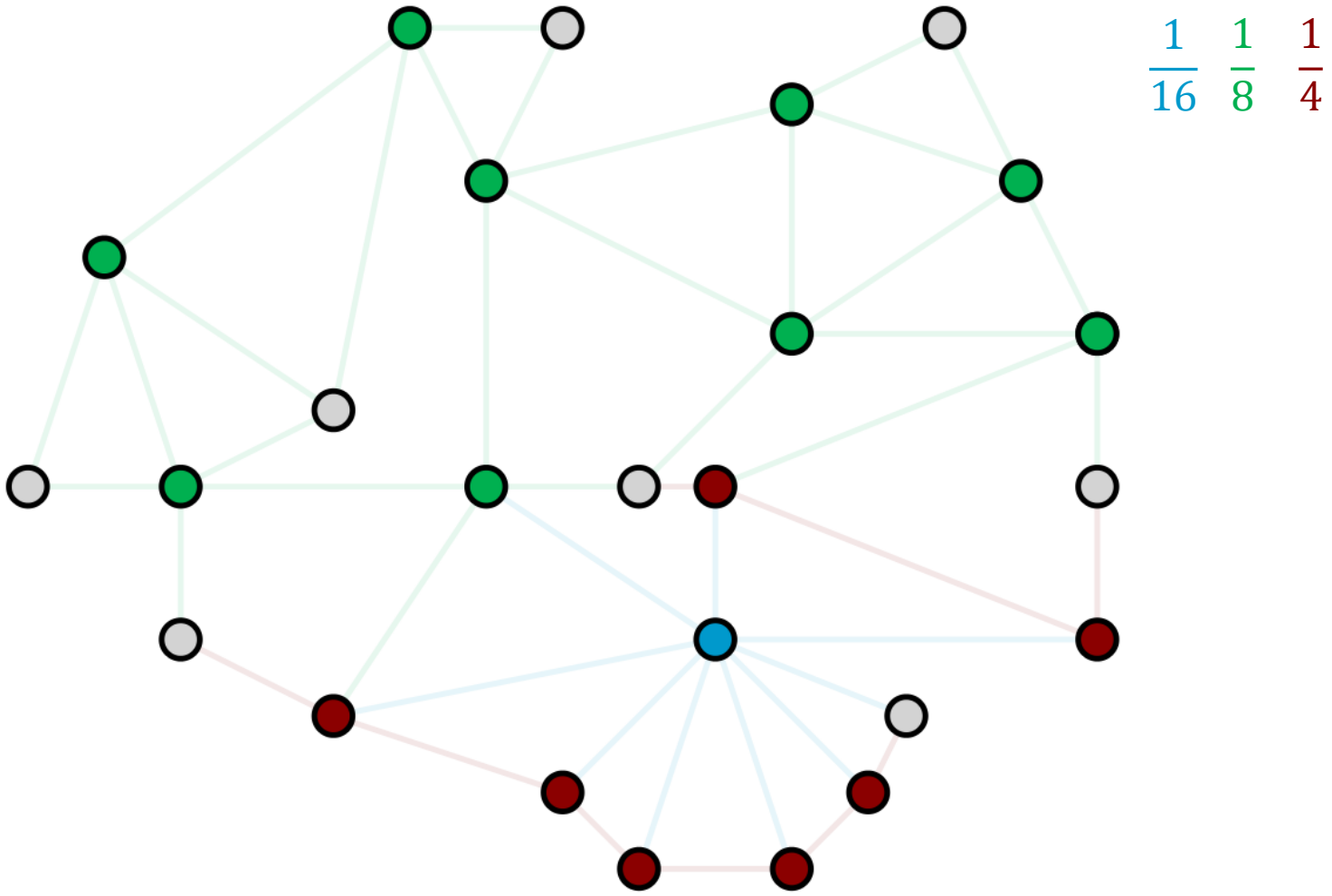

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Constant - Approximate Bipartite Matching $O\left(\log^2 \Delta\right)$ rounds

I) 4-Approximate Fractional Matching

$O(\log \Delta)$ rounds

II) Rounding Fractional Bipartite Matching

$O\left(\log^2 \Delta\right)$ rounds, $O(1)$ loss

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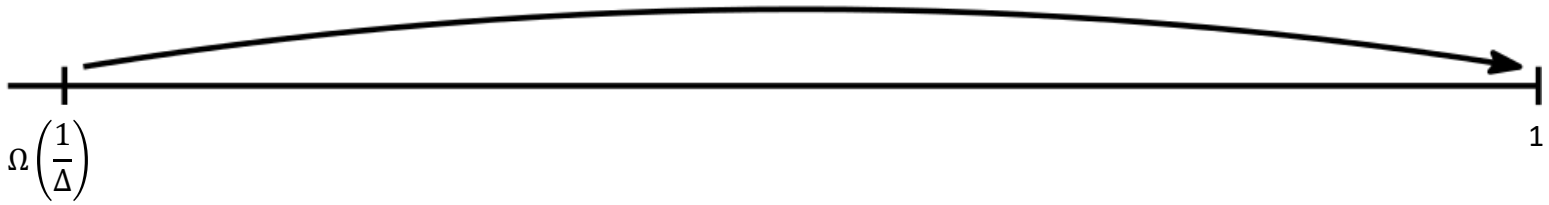
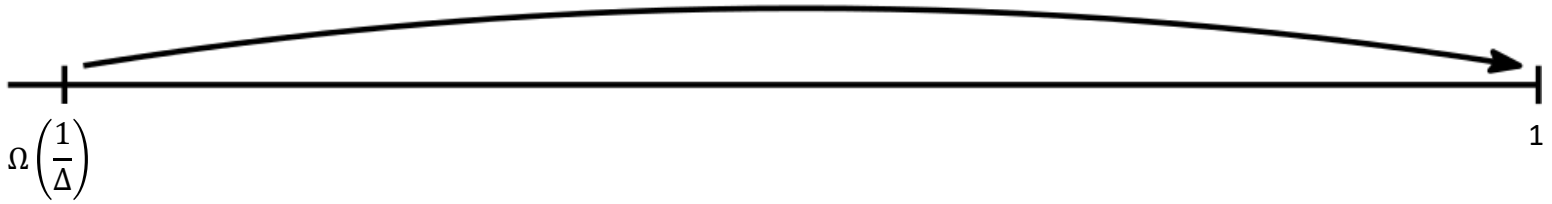


II) Rounding Fractional Bipartite Matching

$O\left(\log^2 \Delta\right)$ rounds, $O(1)$ loss

Direct Rounding



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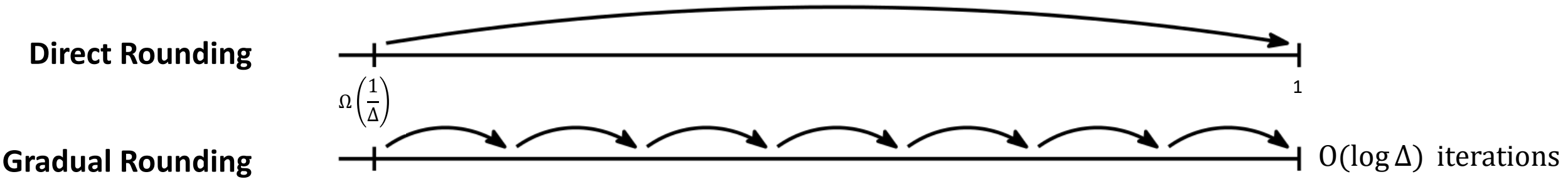
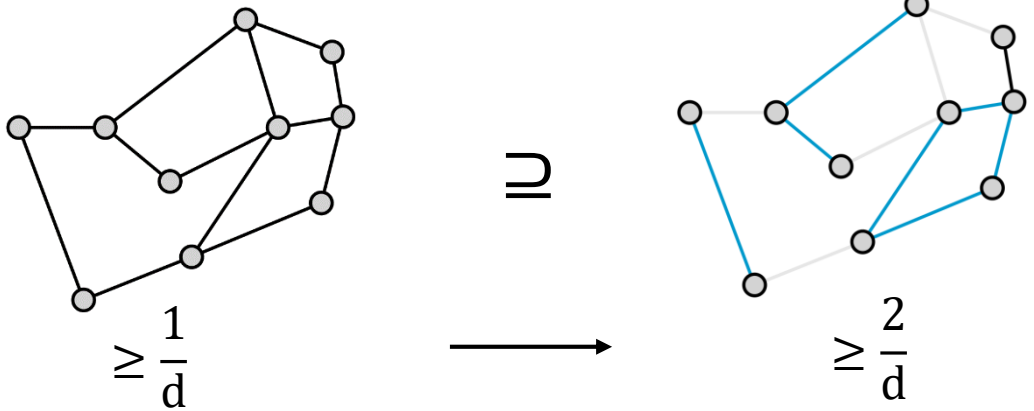
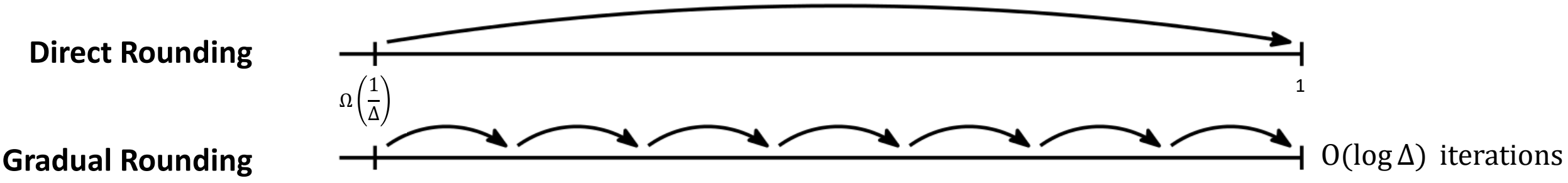


II) Rounding Fractional Bipartite Matching

$O(\log^2 \Delta)$ rounds, $O(1)$ loss

Factor-2-Rounding

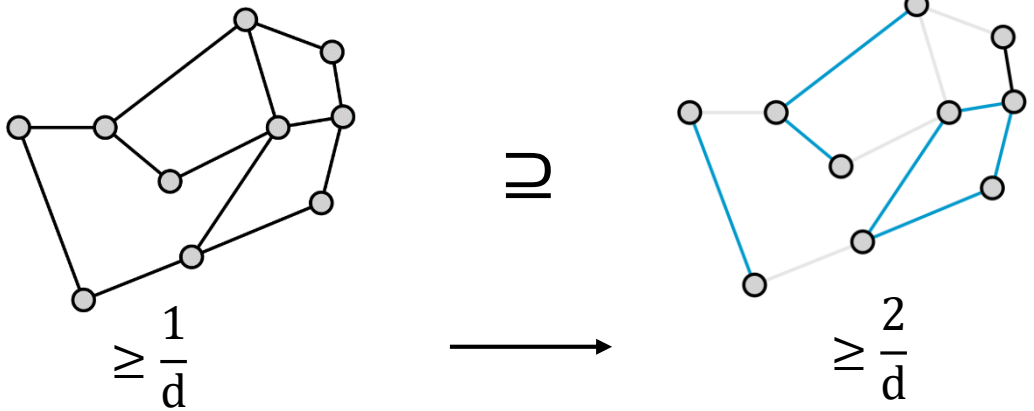




II) Rounding Fractional Bipartite Matching

$O(\log^2 \Delta)$ rounds, $O(1)$ loss

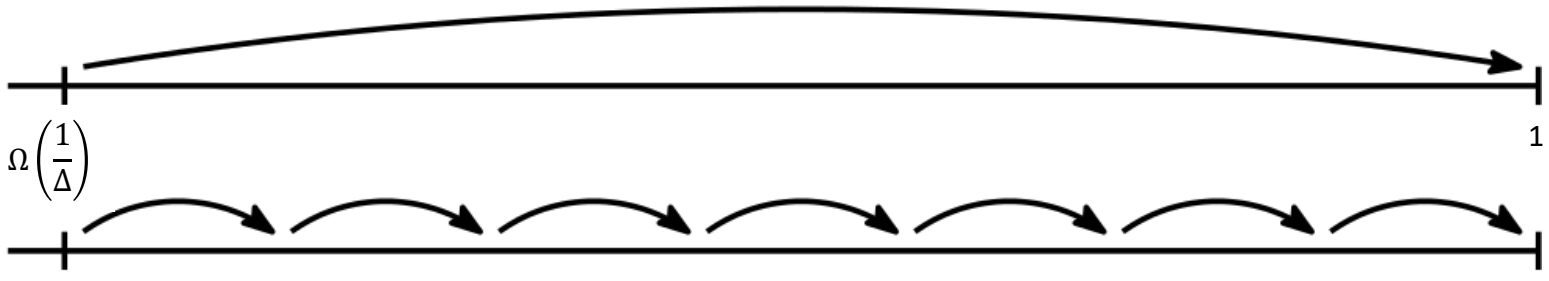
Factor-2-Rounding



using Locally Balanced Splitting,
inspired by
Hańćkowiak, Karoński, Panconesi [SODA'98,PODC'99]

Direct Rounding

Gradual Rounding



$O(\log \Delta)$ iterations

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$O\left(\log^2 \Delta\right)$ rounds, $O(1)$ loss

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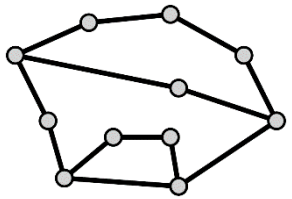

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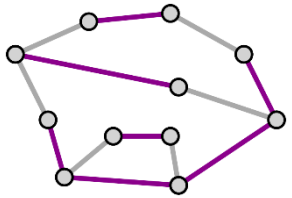

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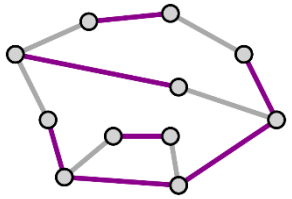

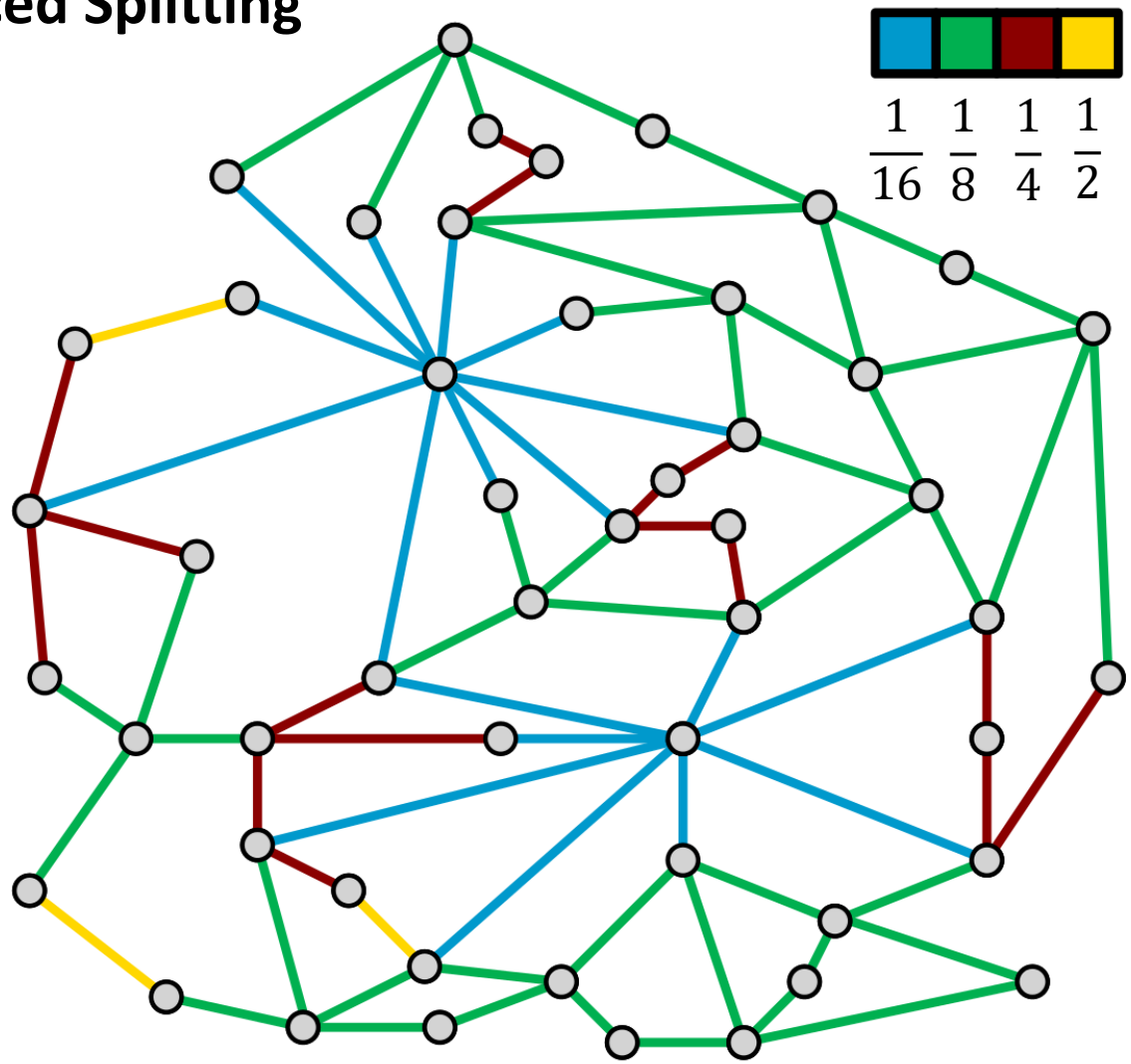

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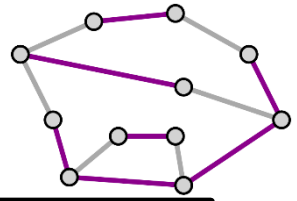

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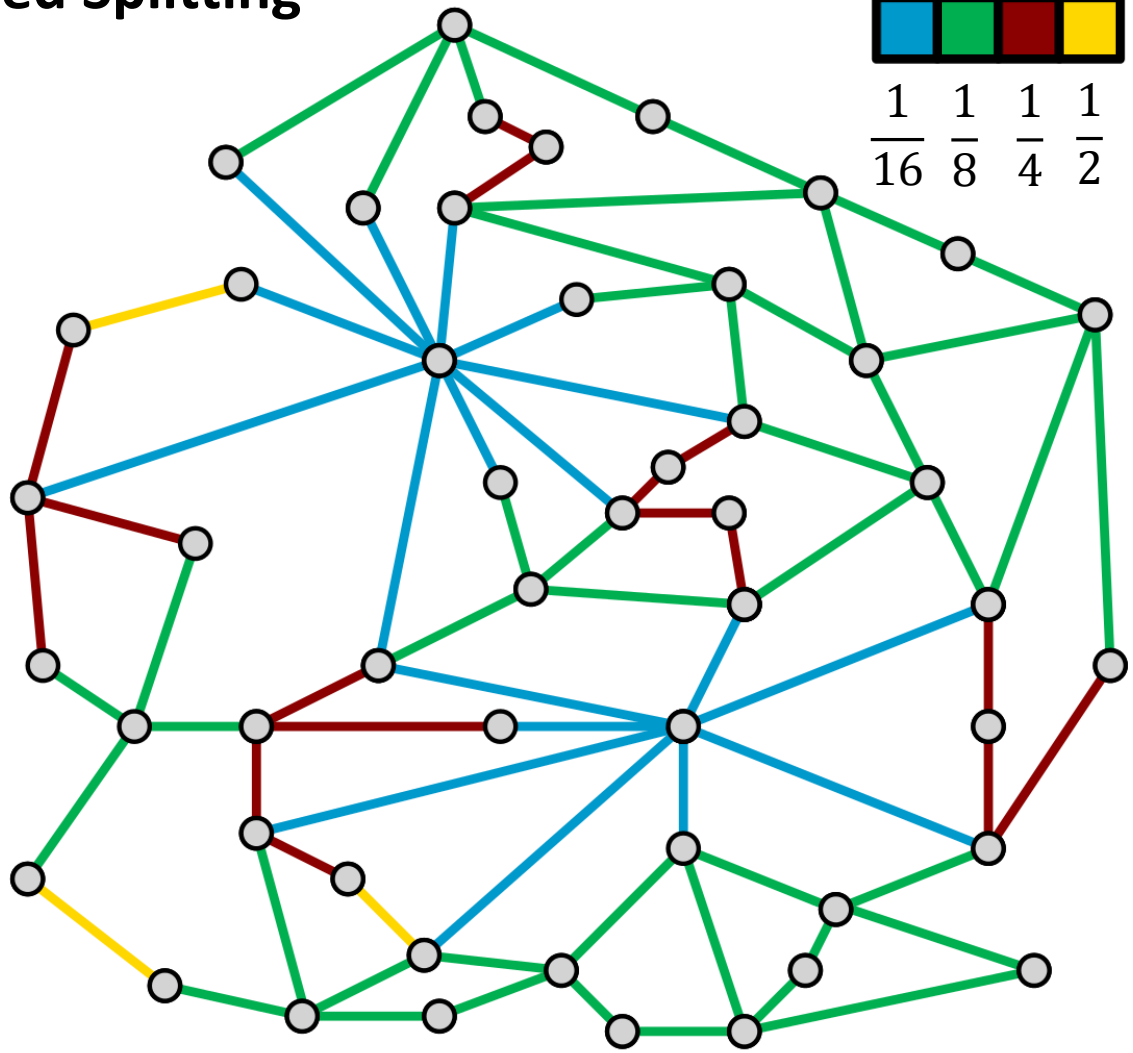

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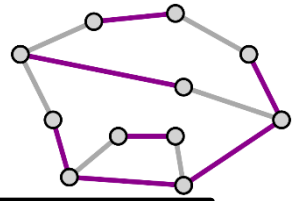

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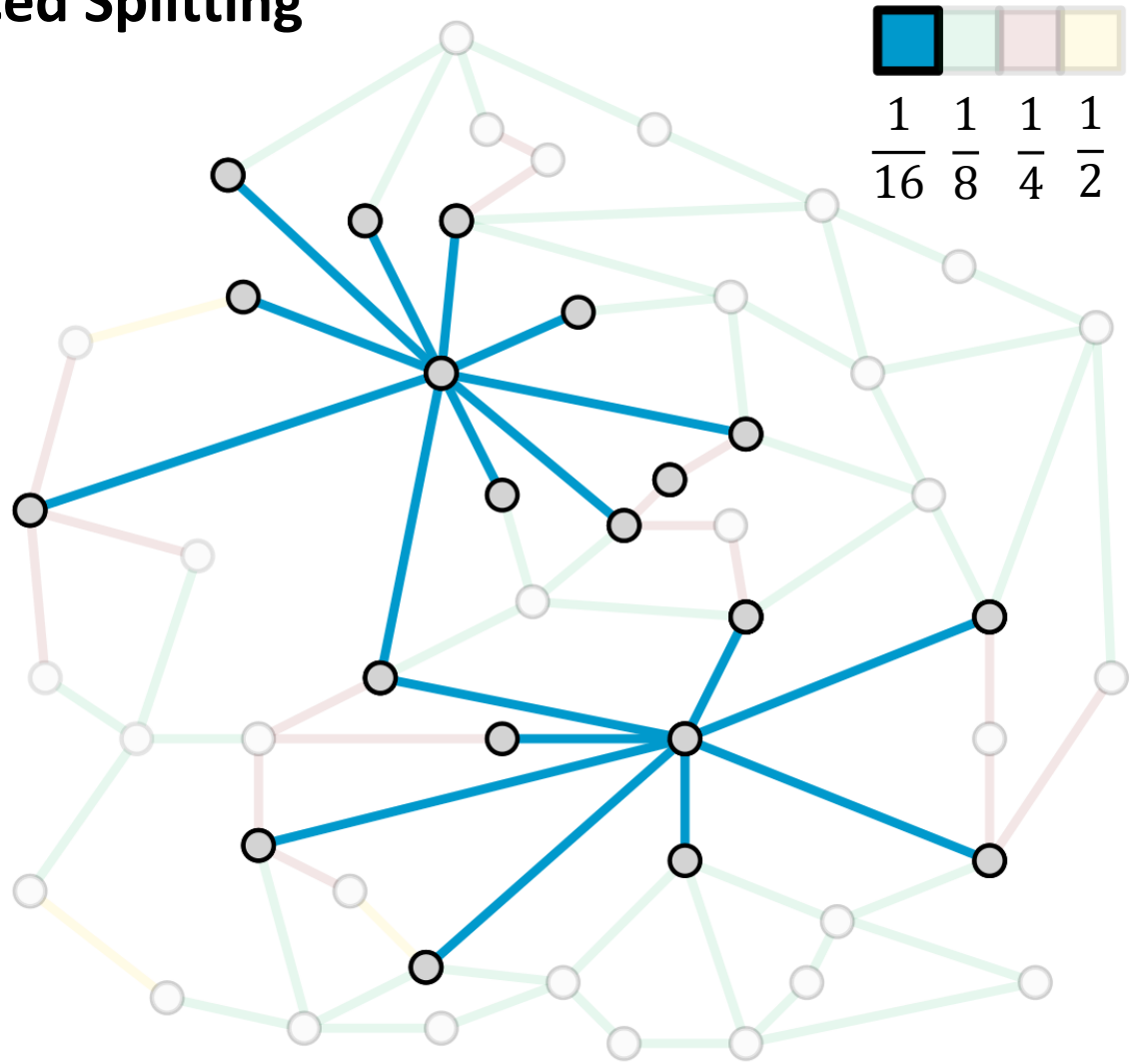

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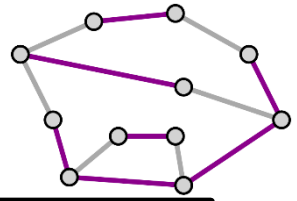

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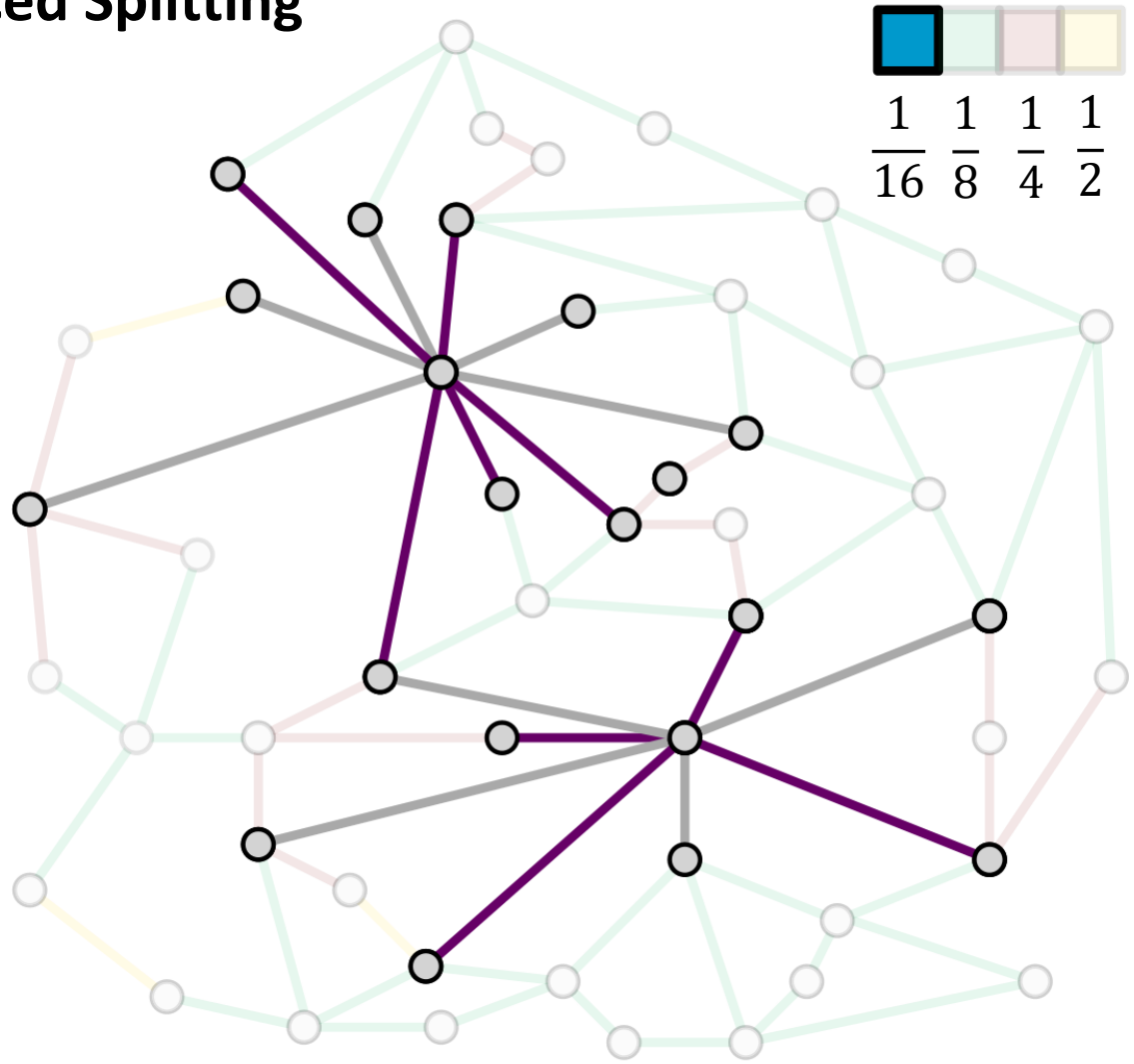

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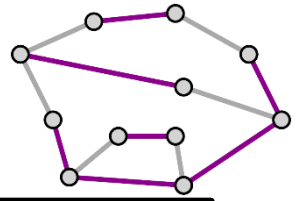

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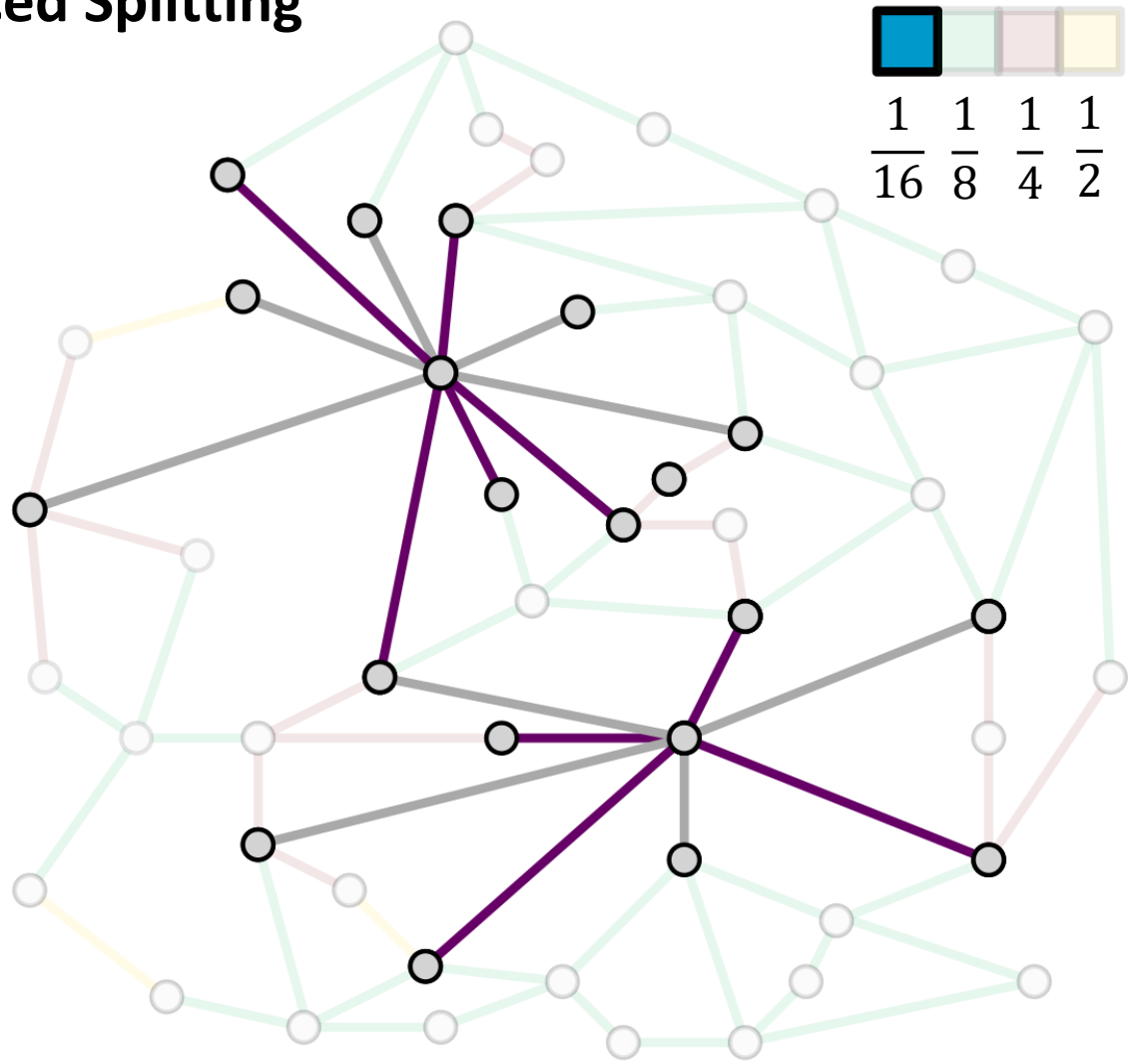

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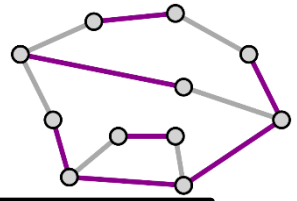

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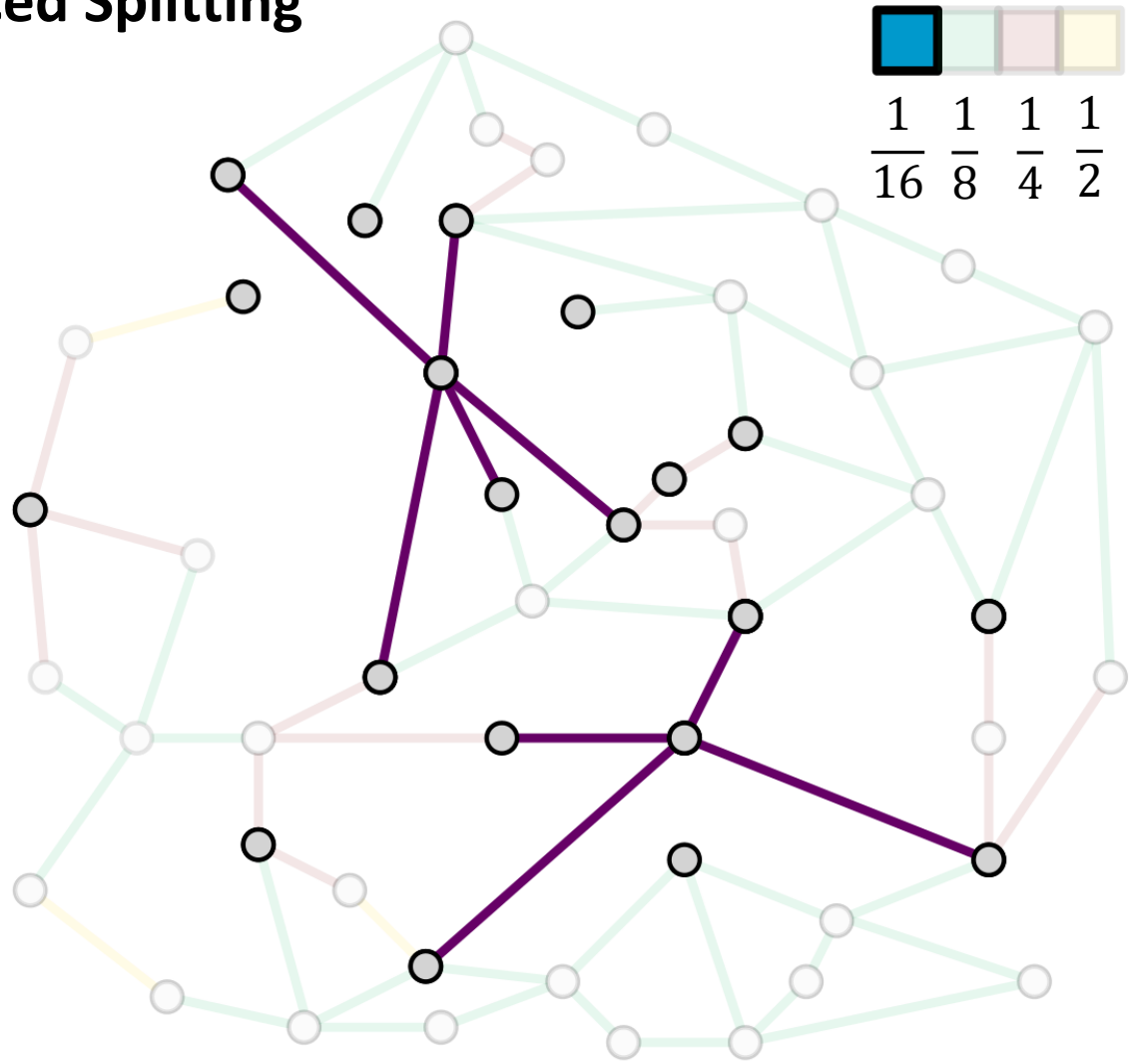

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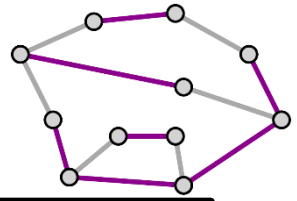

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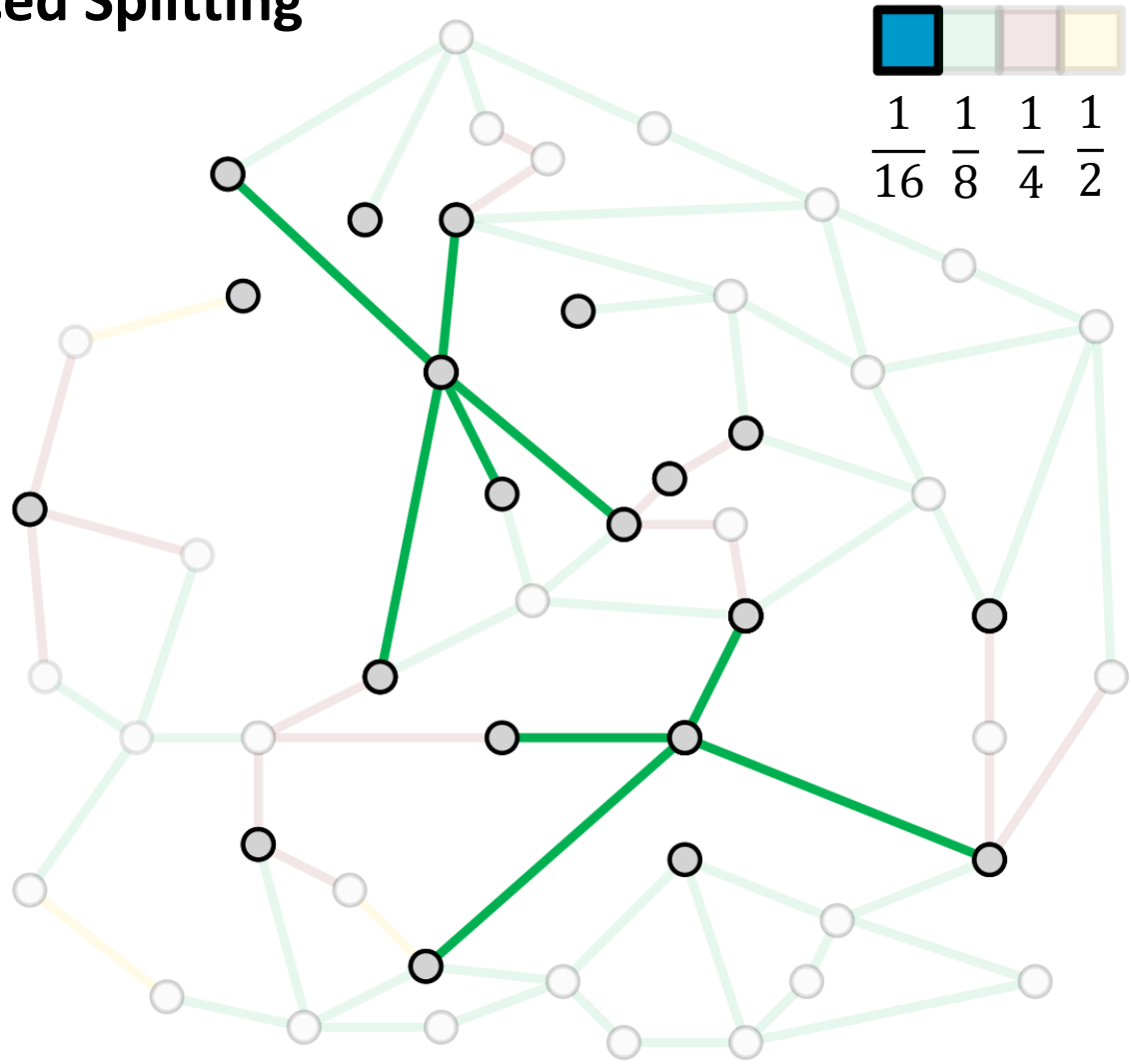

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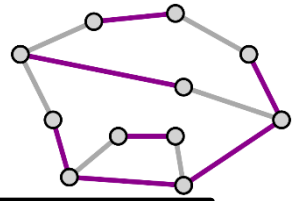

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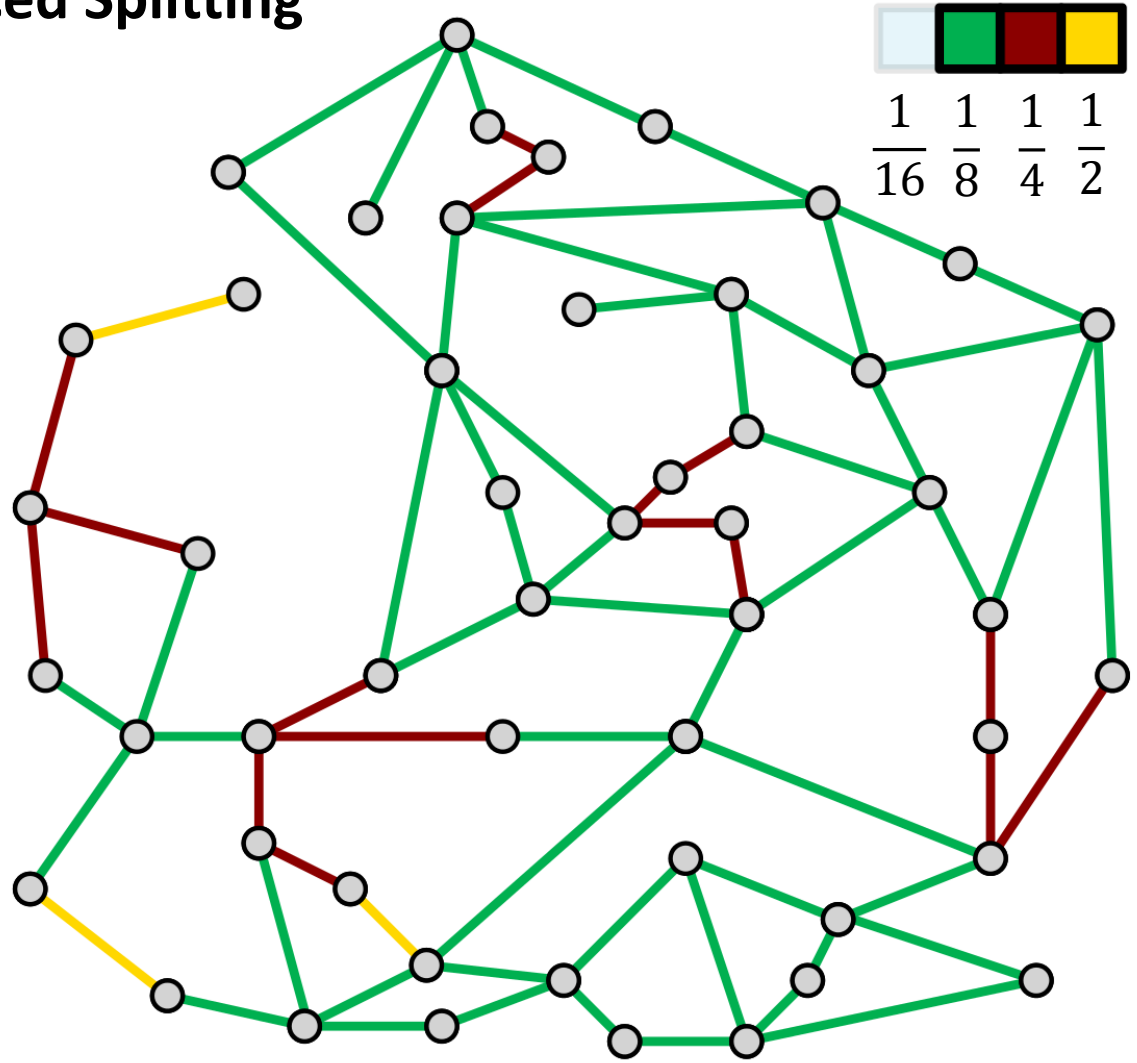

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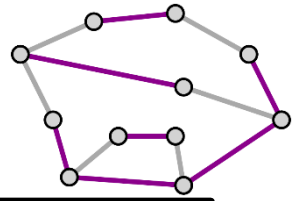

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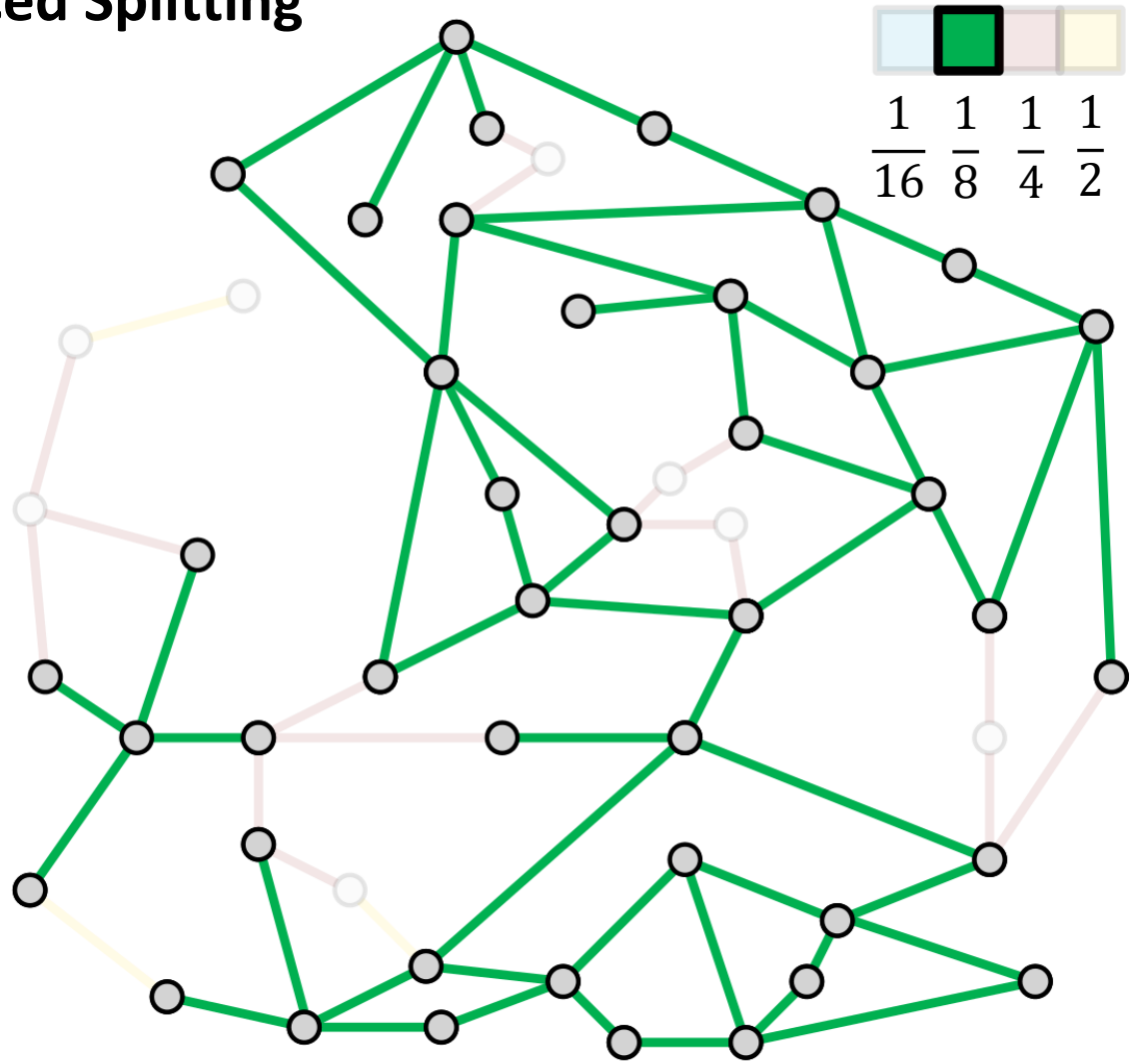

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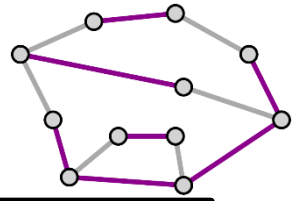

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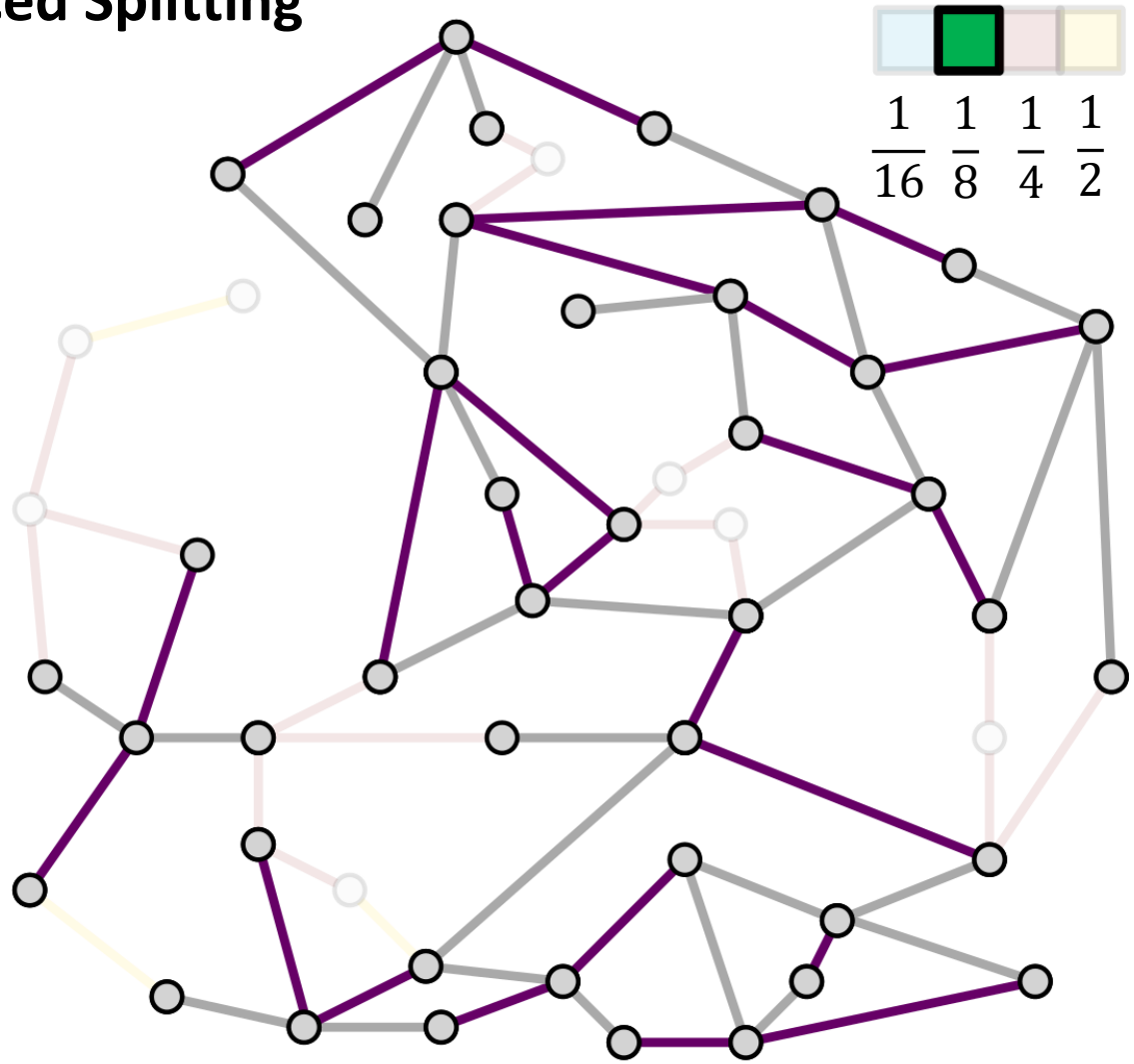

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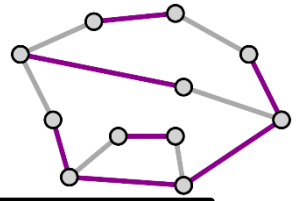

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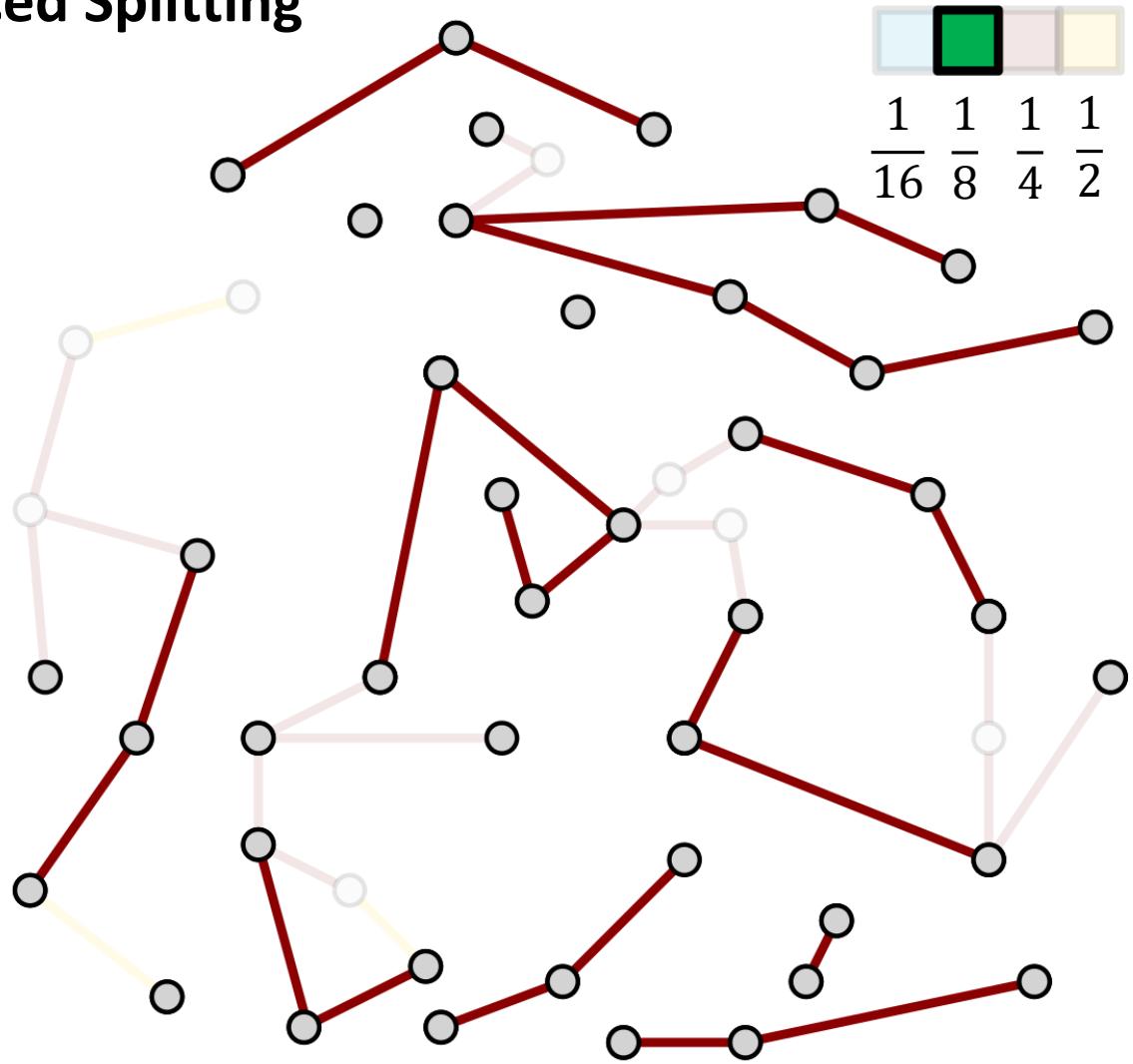

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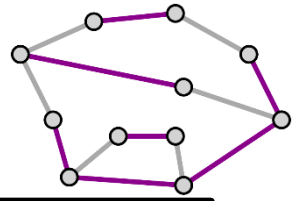

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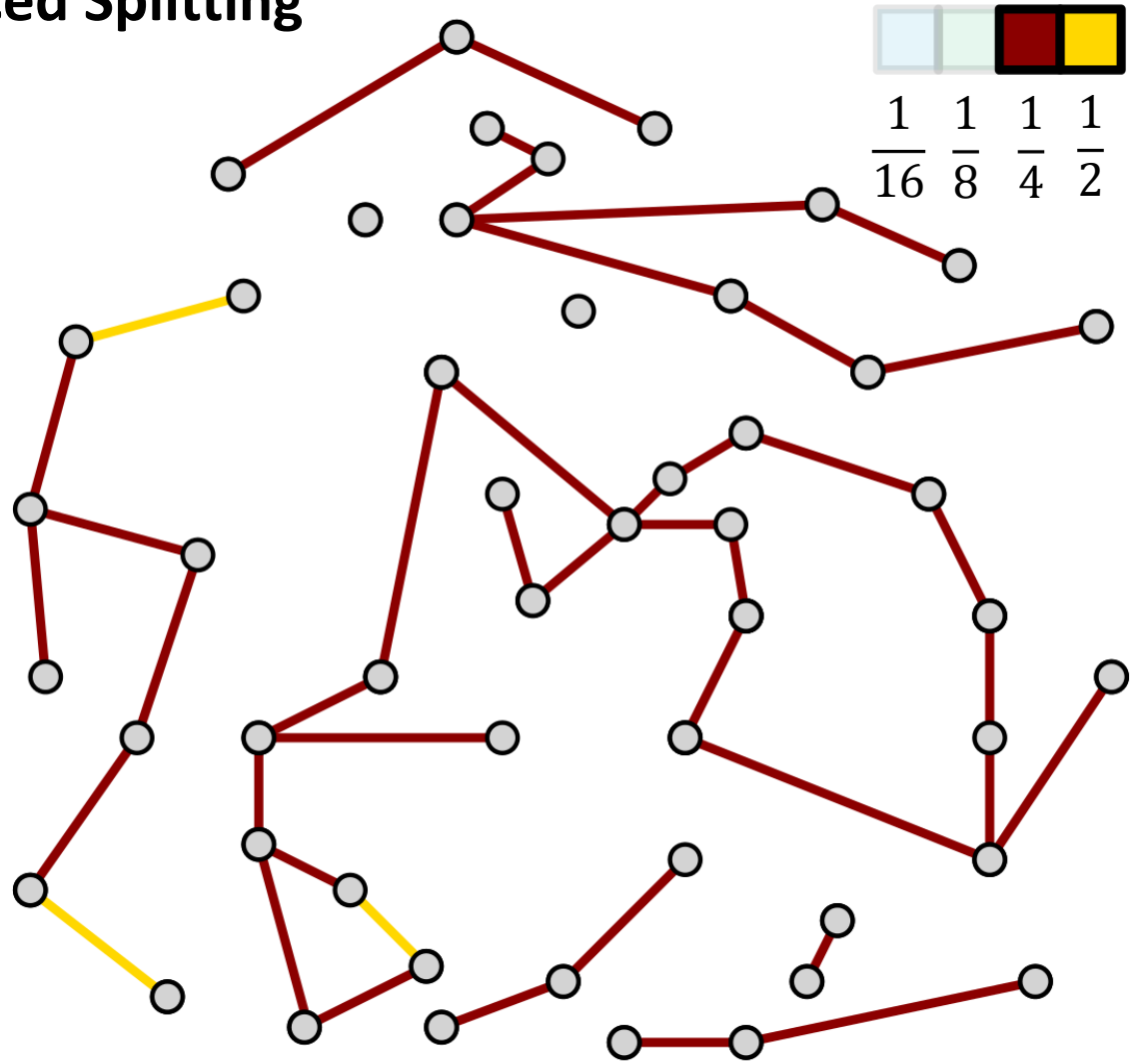

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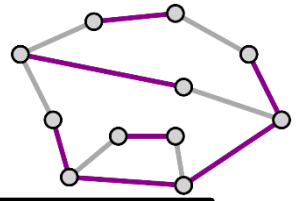

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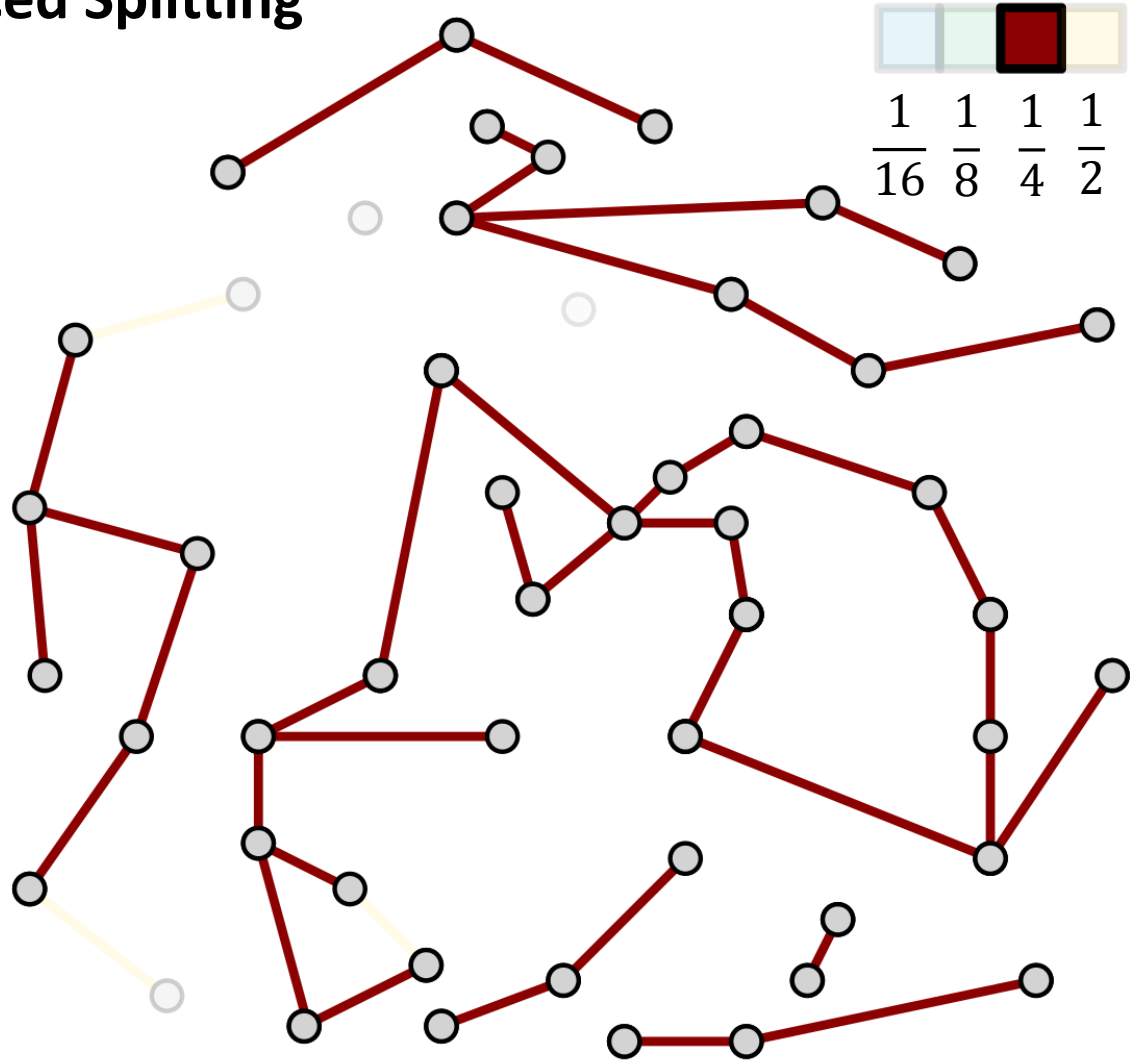

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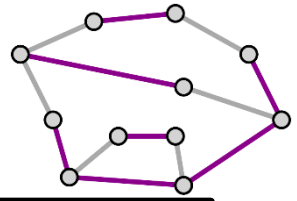

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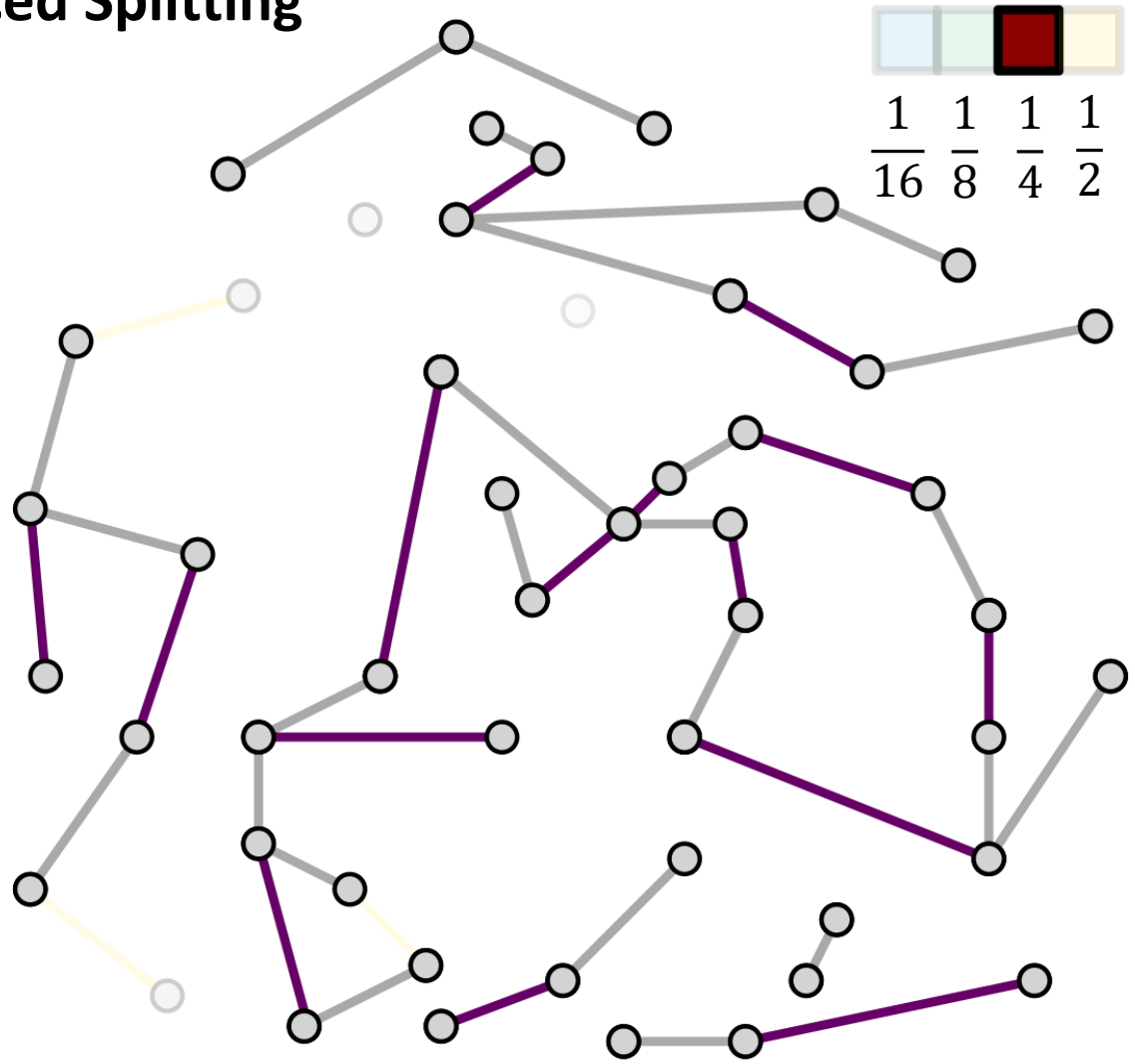

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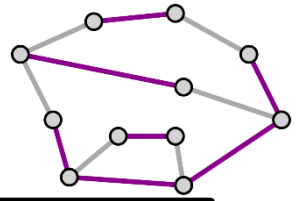

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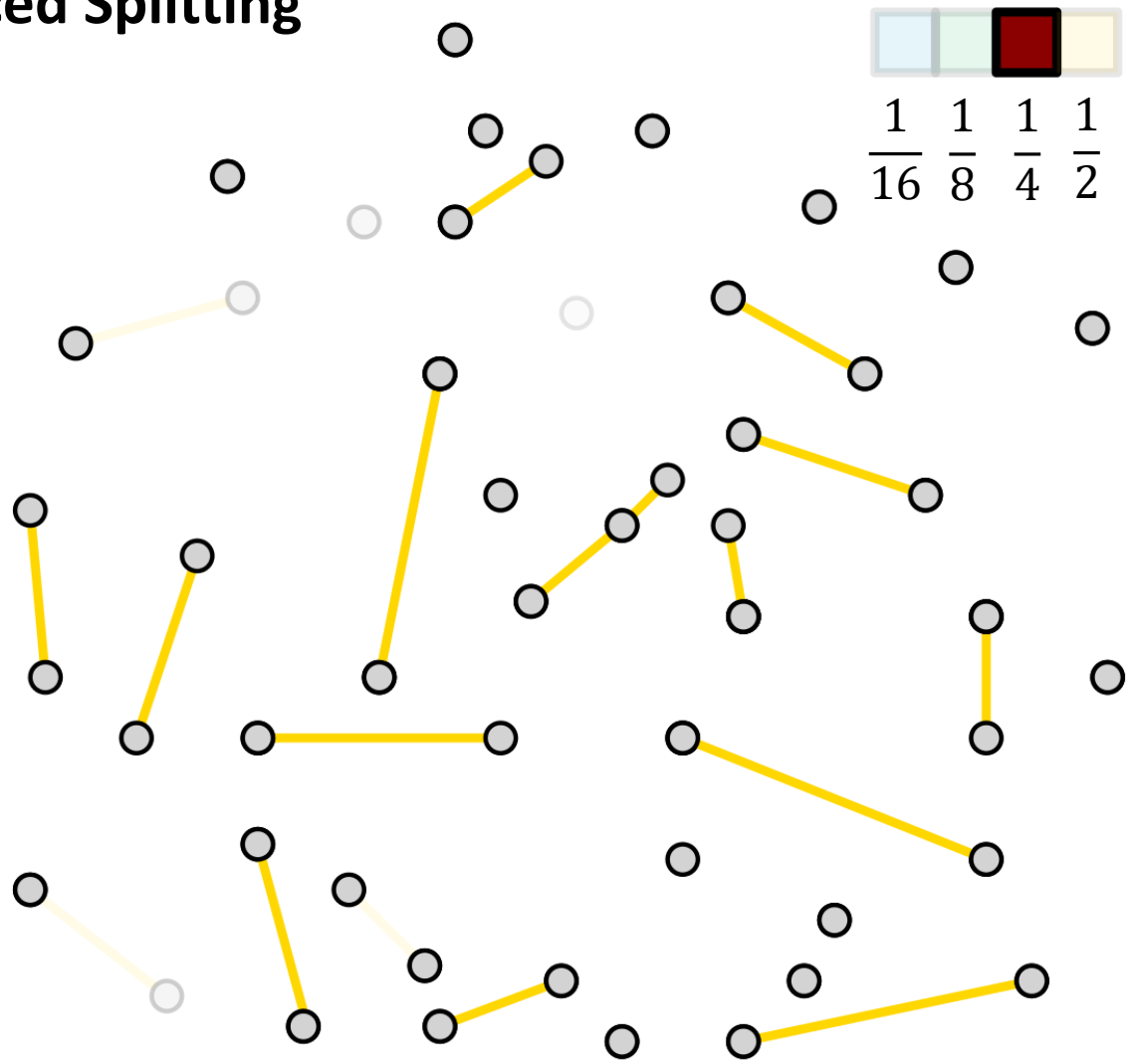

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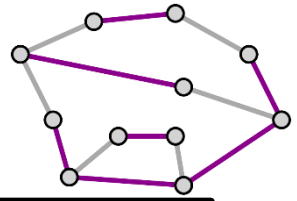

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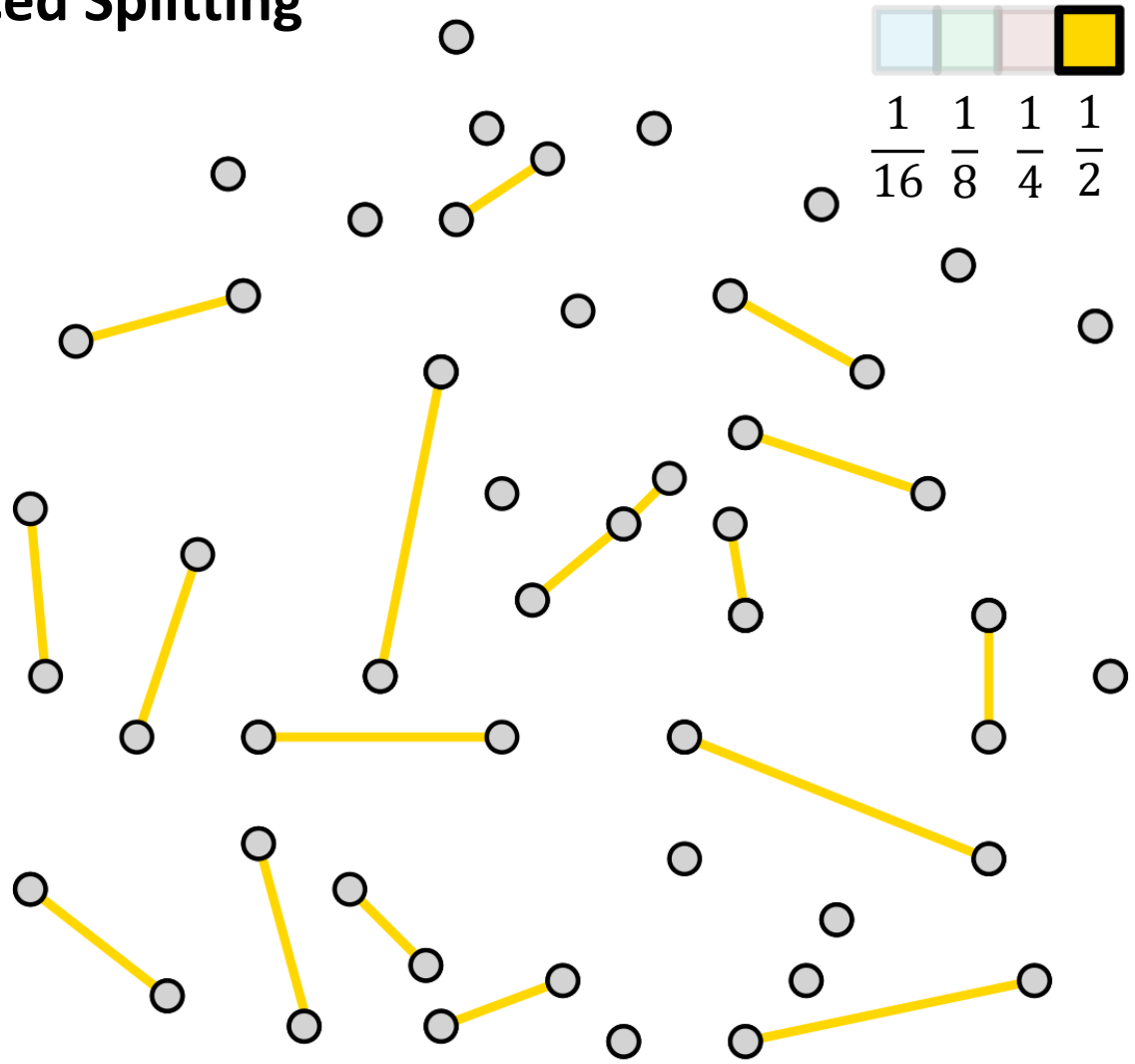

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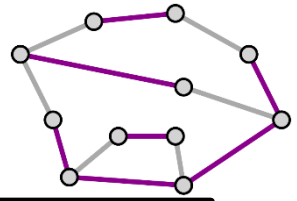

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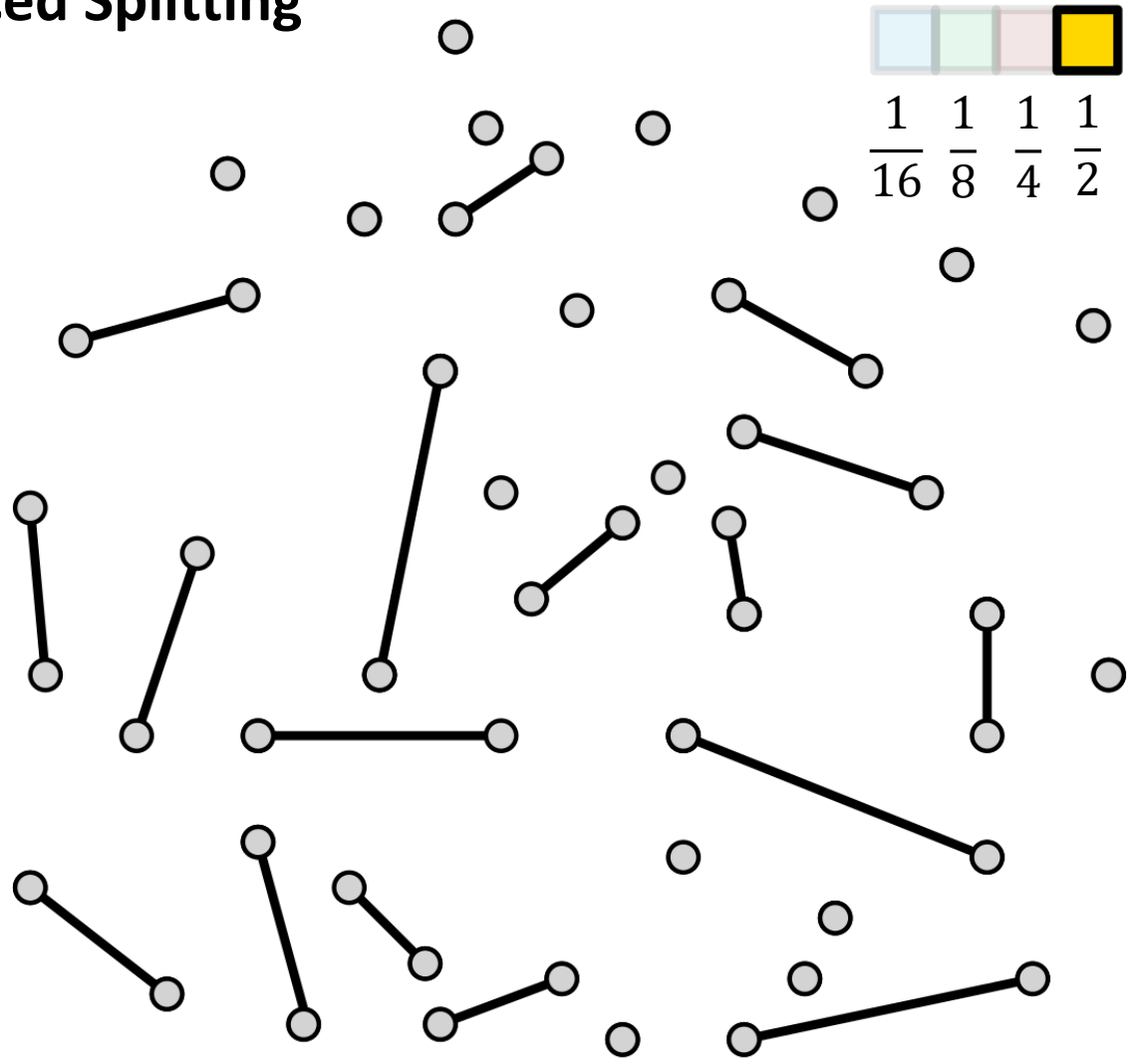

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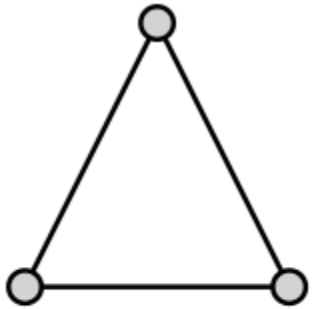

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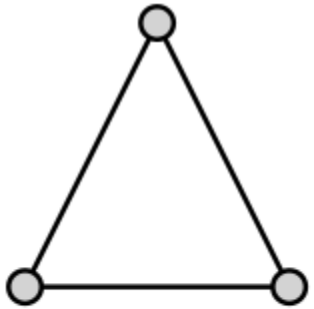

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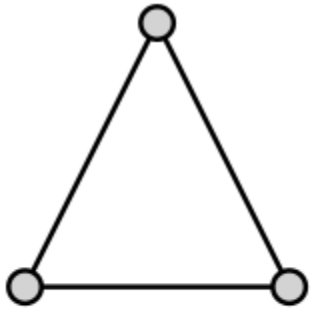

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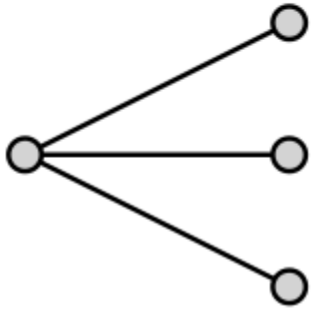

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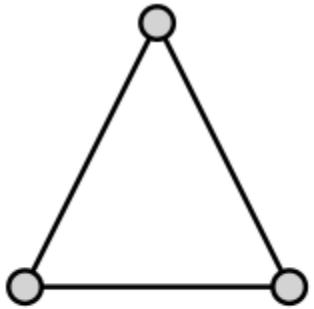

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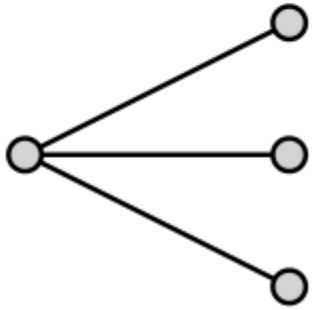

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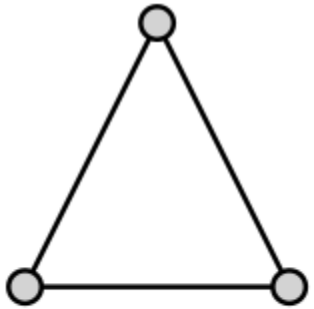

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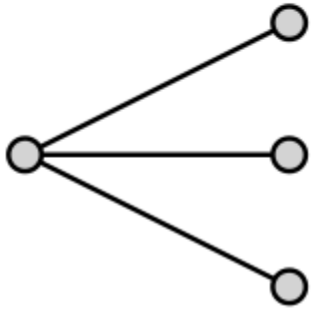

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Suppose that bipartite and even degree!

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Sequential Perfect Splitting*

Repeat until all edges colored
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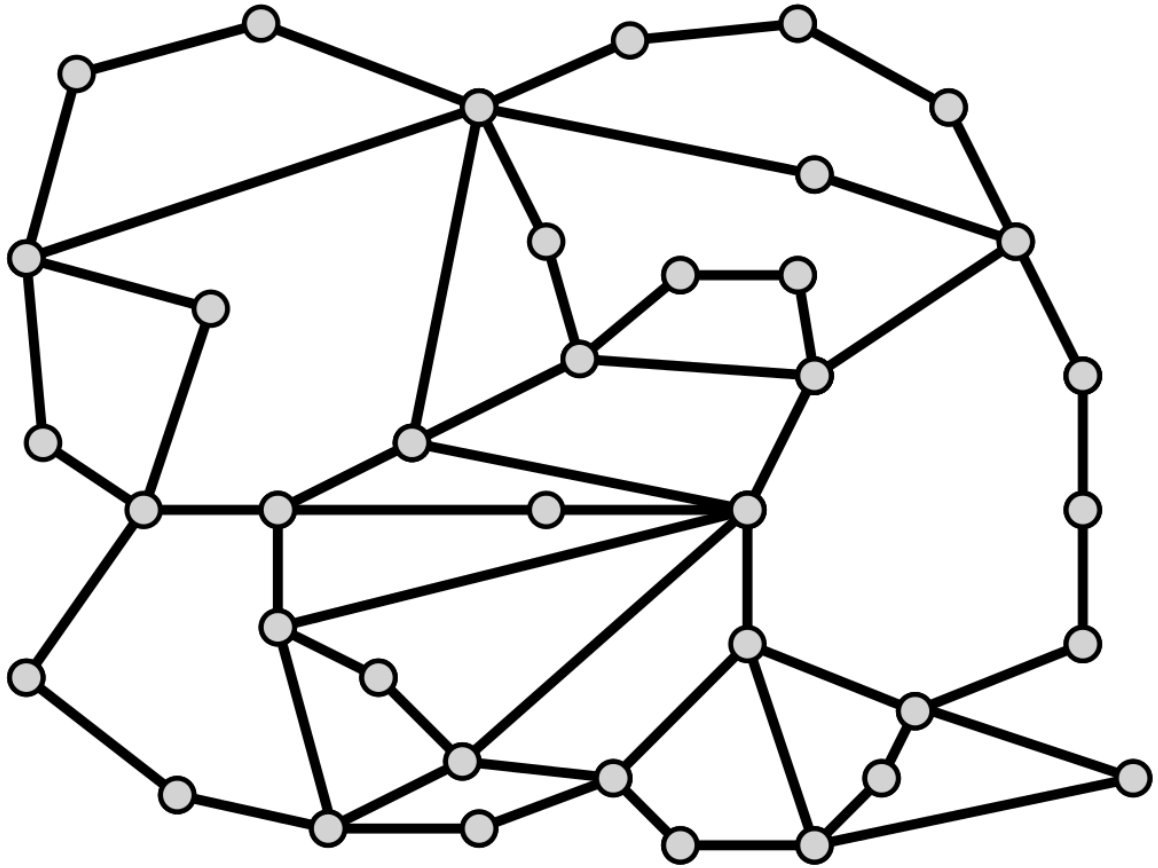

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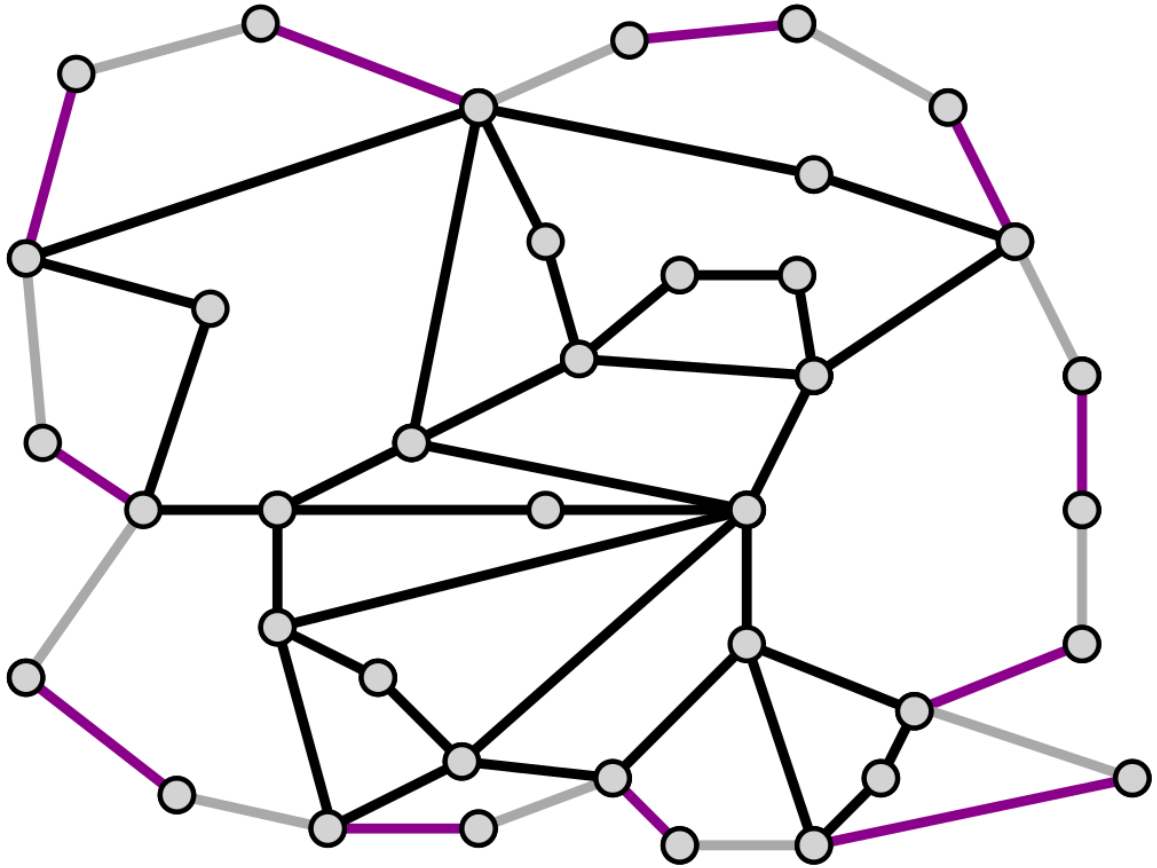

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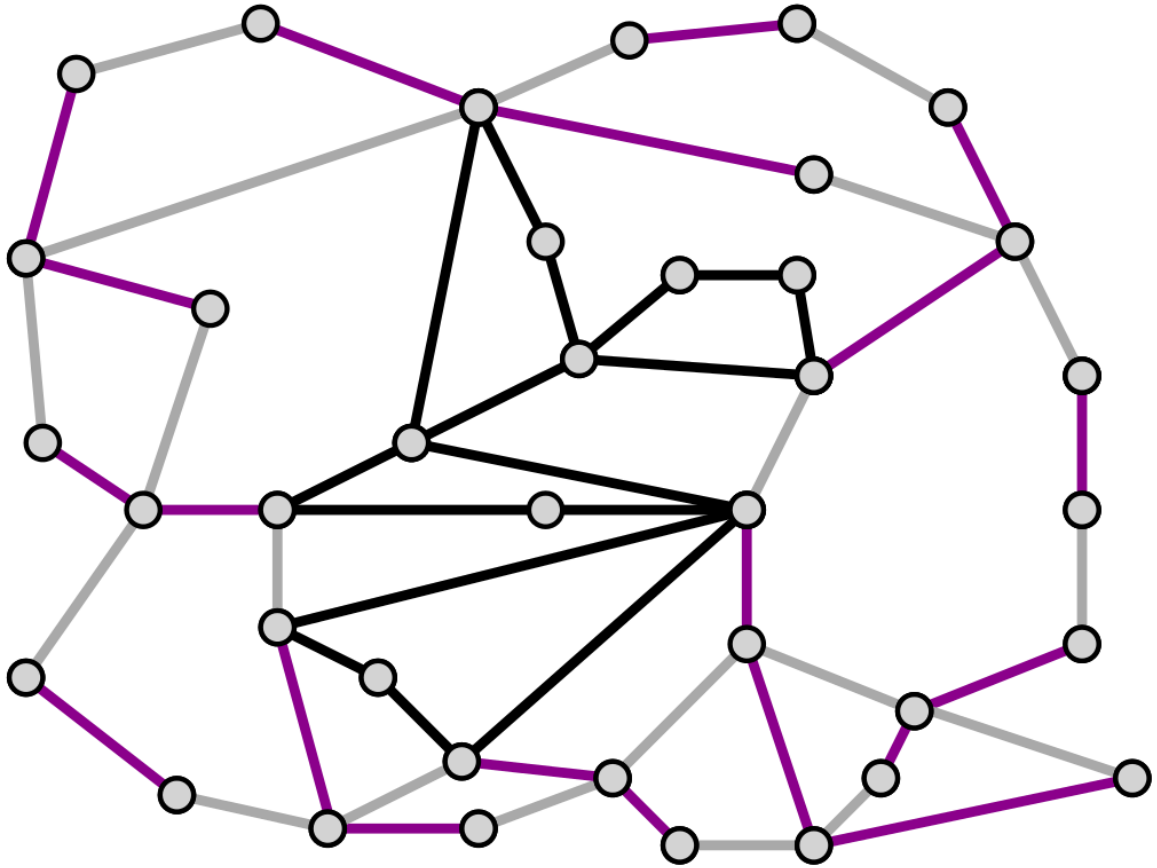

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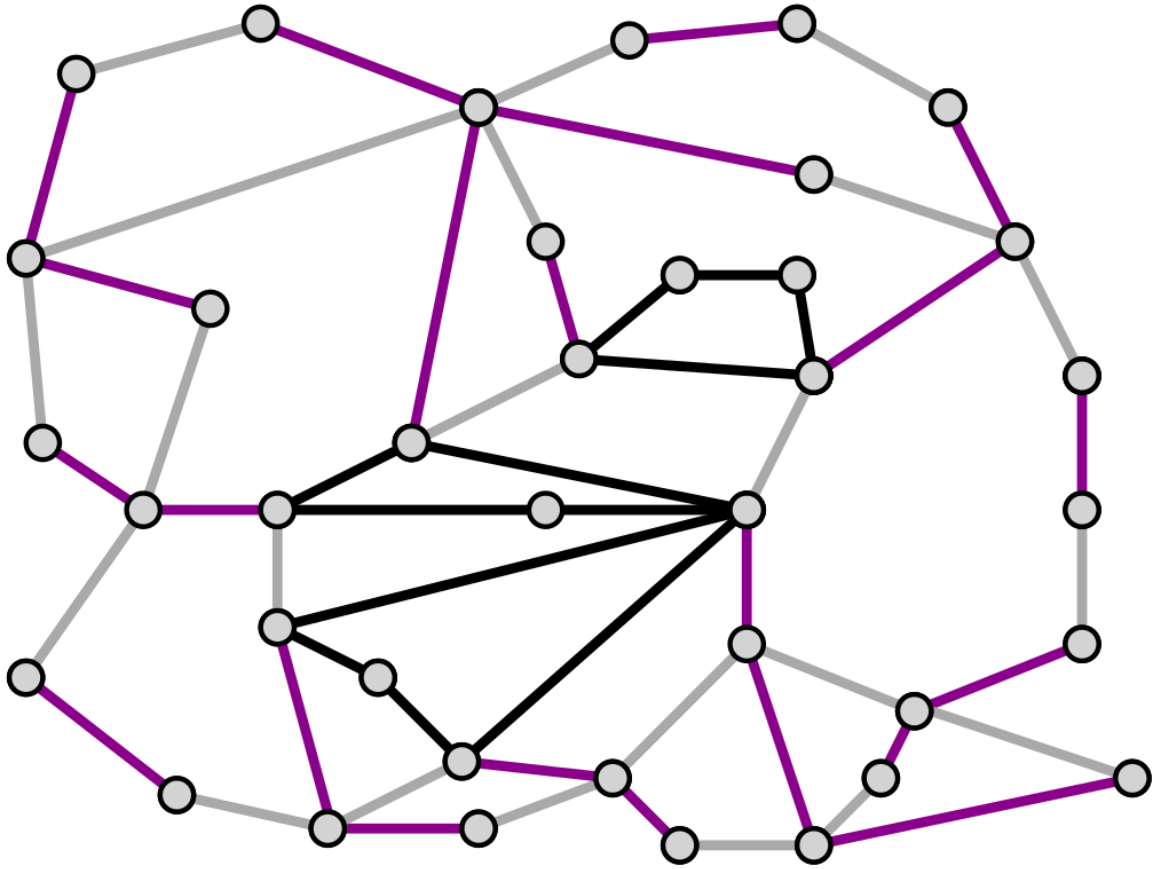

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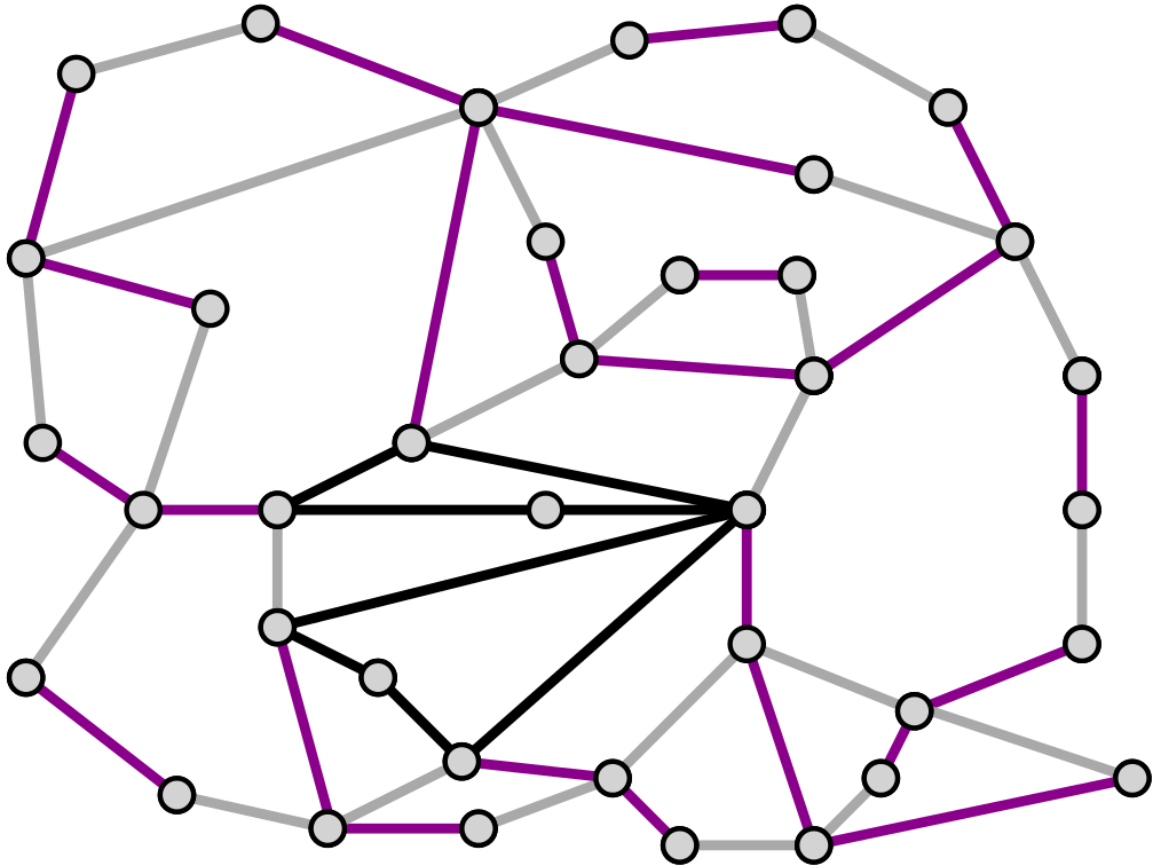

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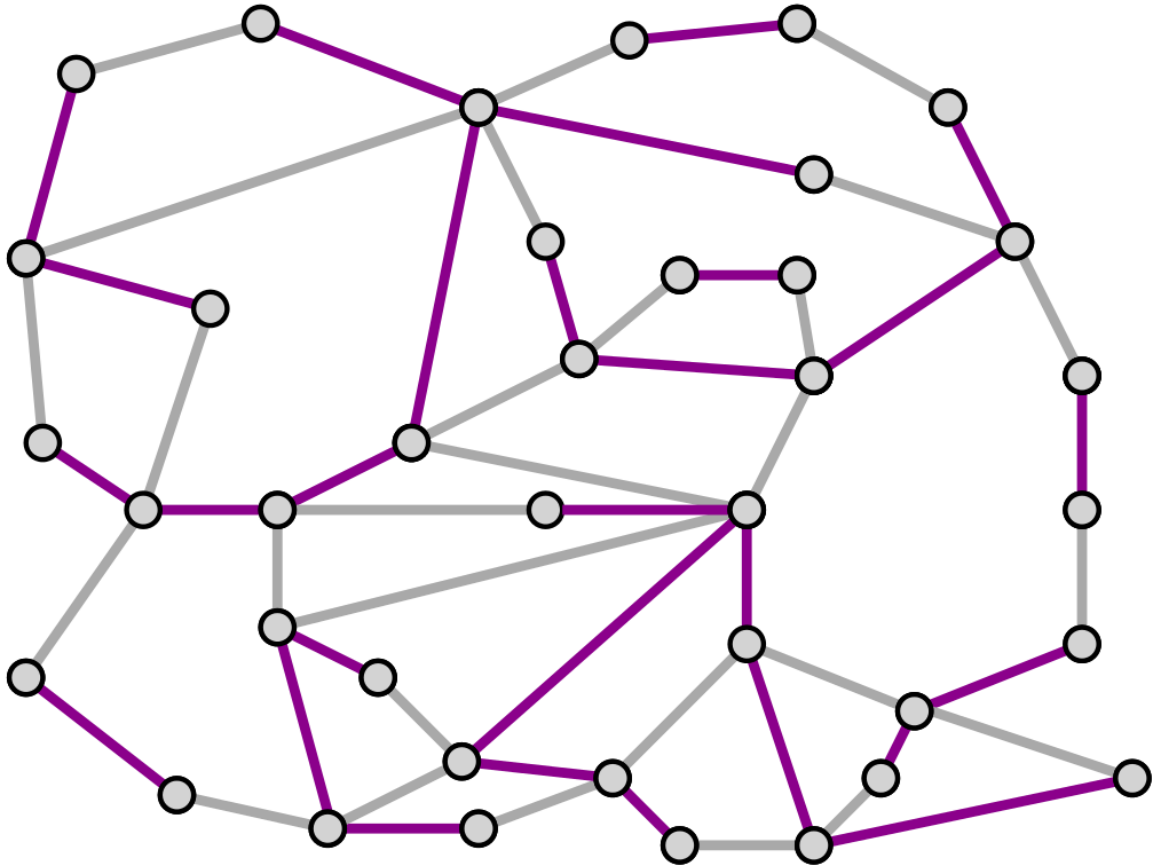

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LOCAL Almost-Perfect Splitting*

Decompose into edge-disjoint cycles

In parallel, for all cycles

A) **Short cycles** of length $O(\log \Delta)$
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- chop at length $\Theta(\log \Delta)$
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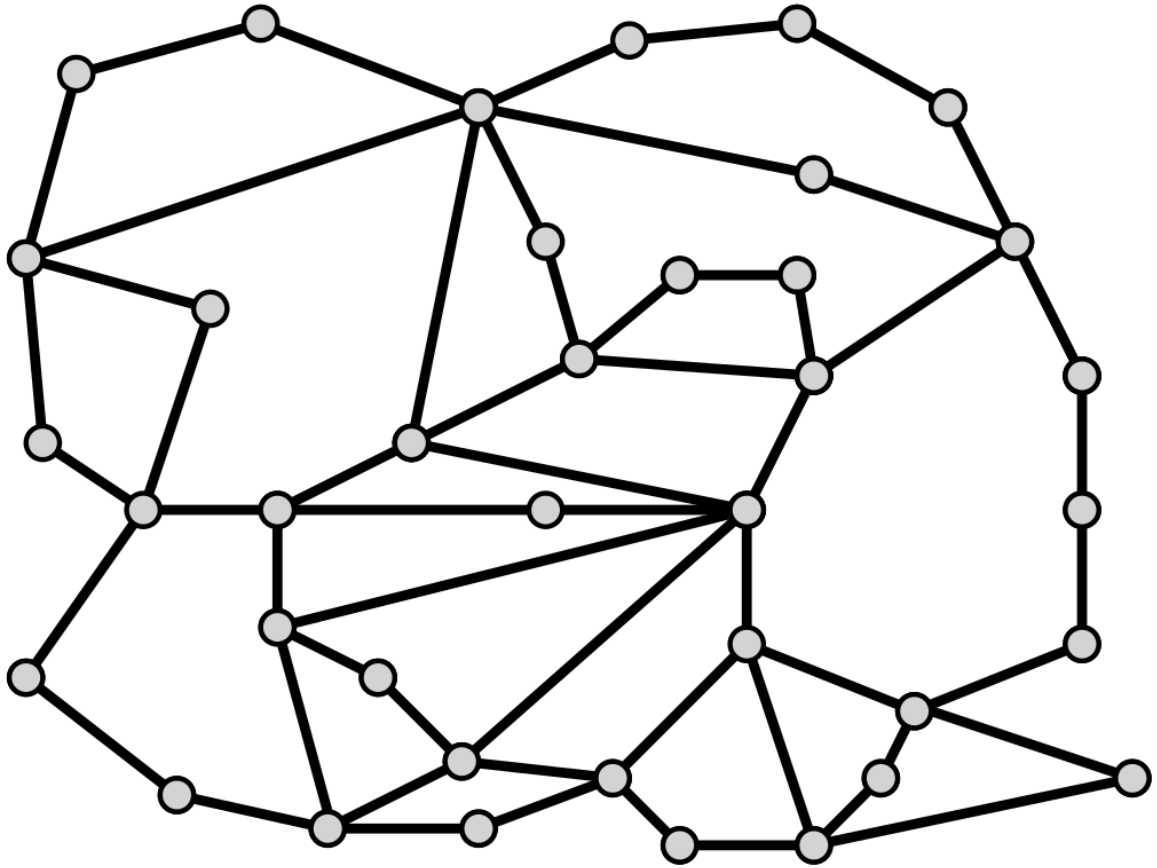

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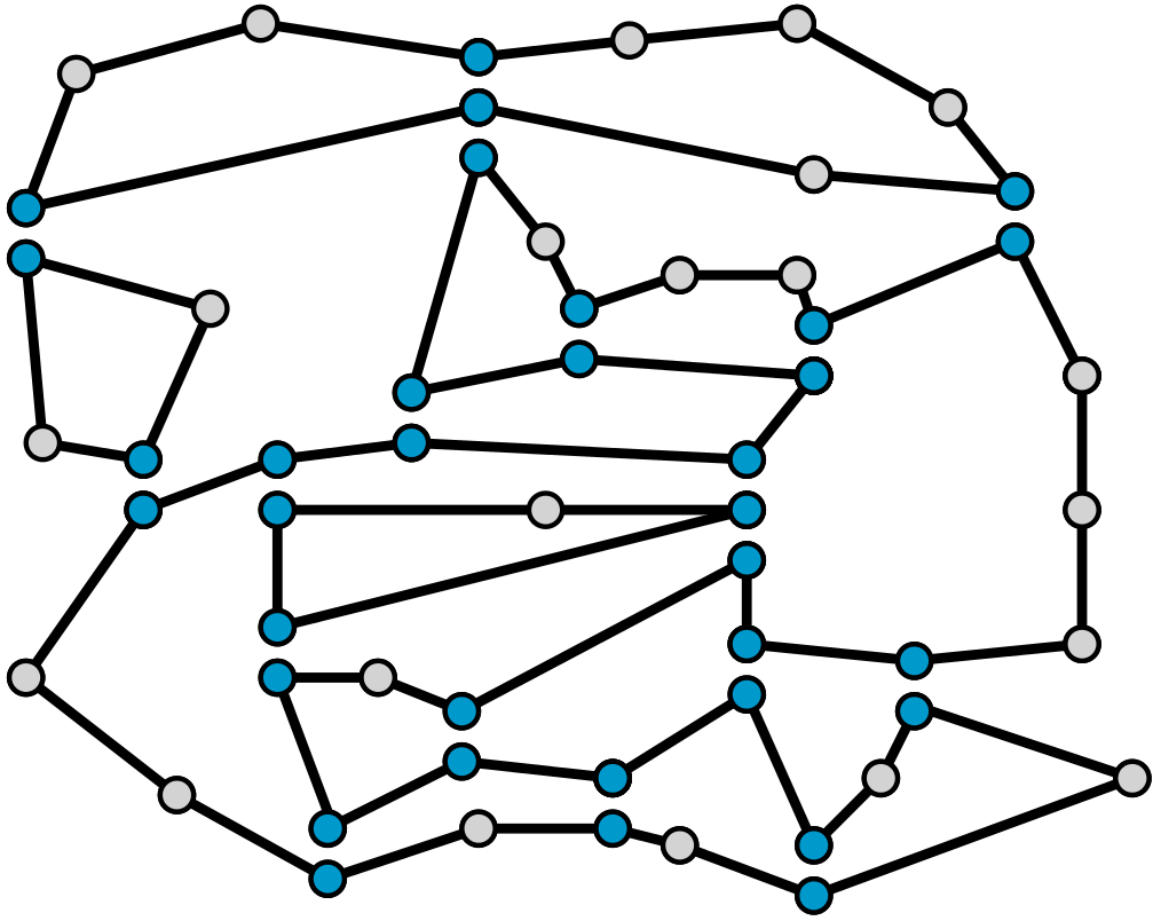

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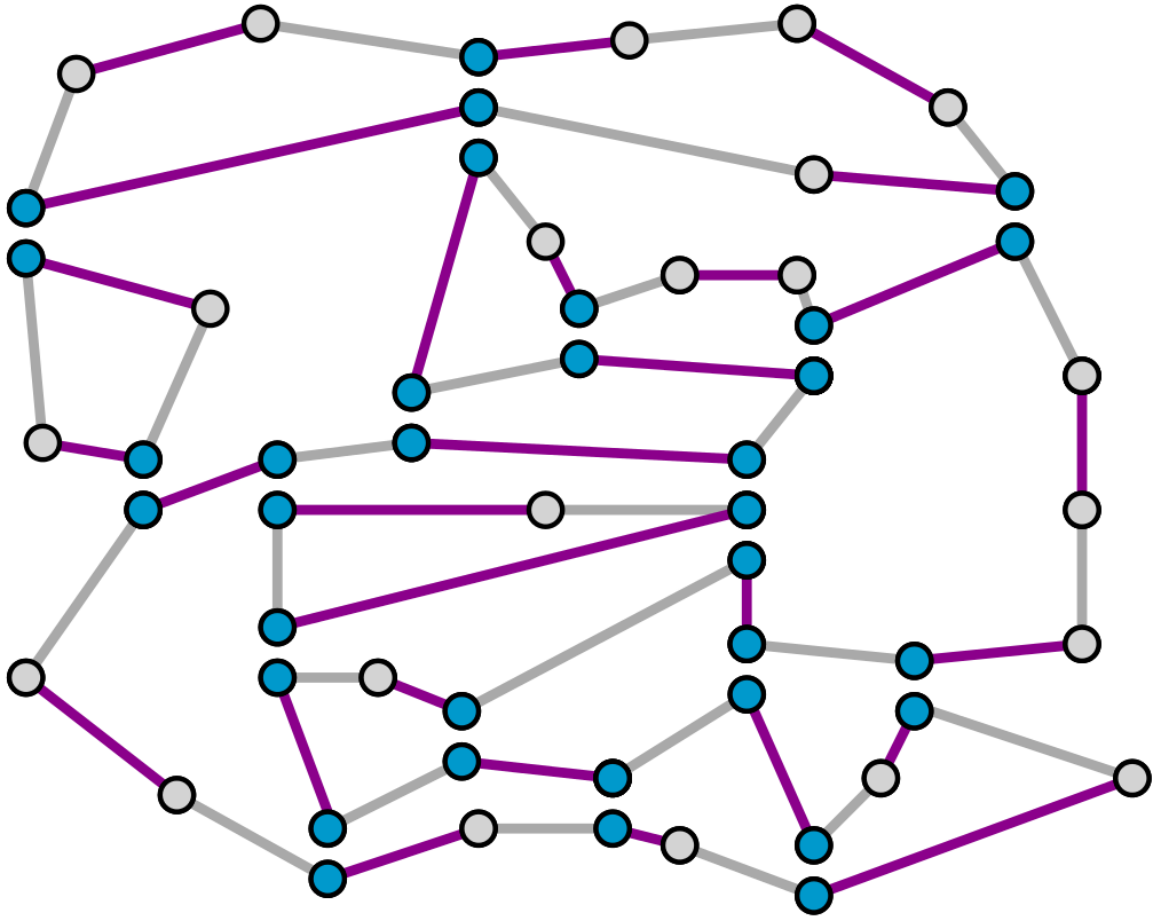

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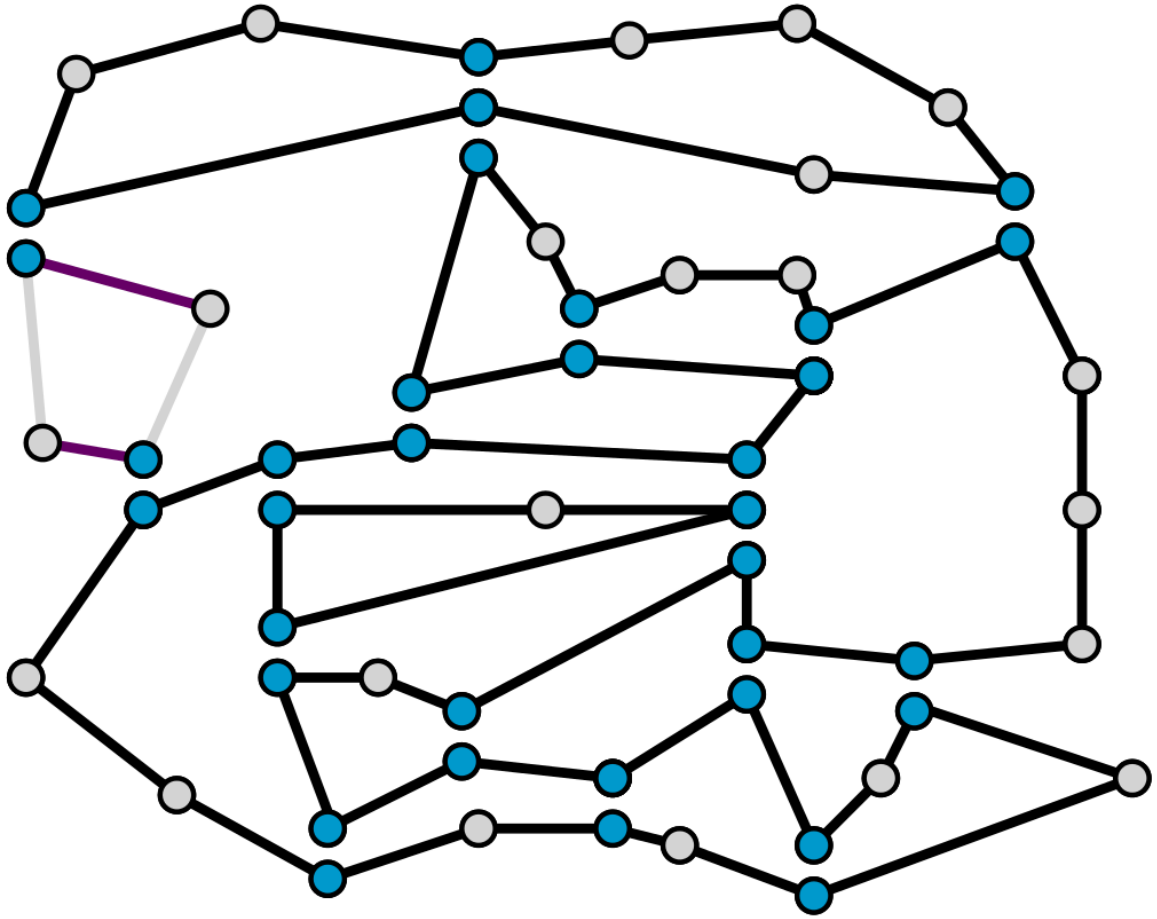

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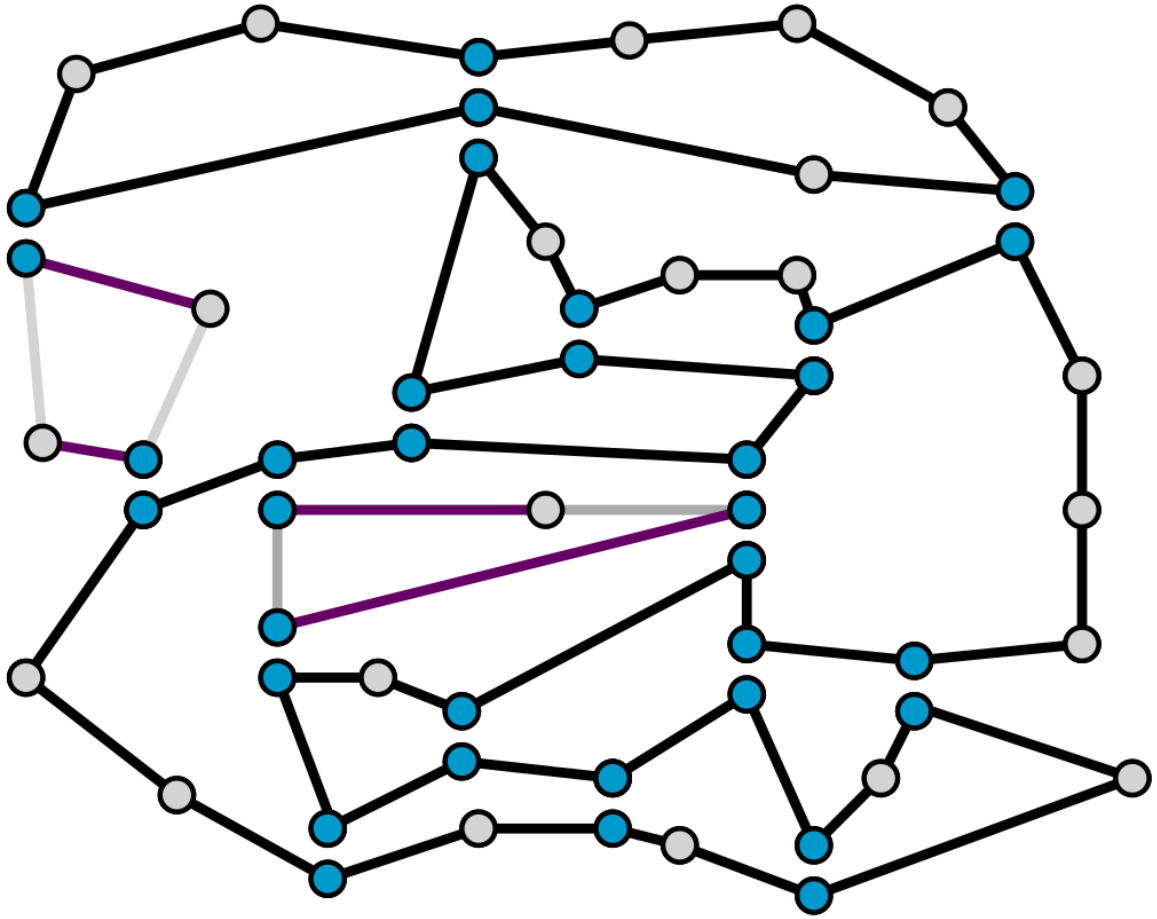

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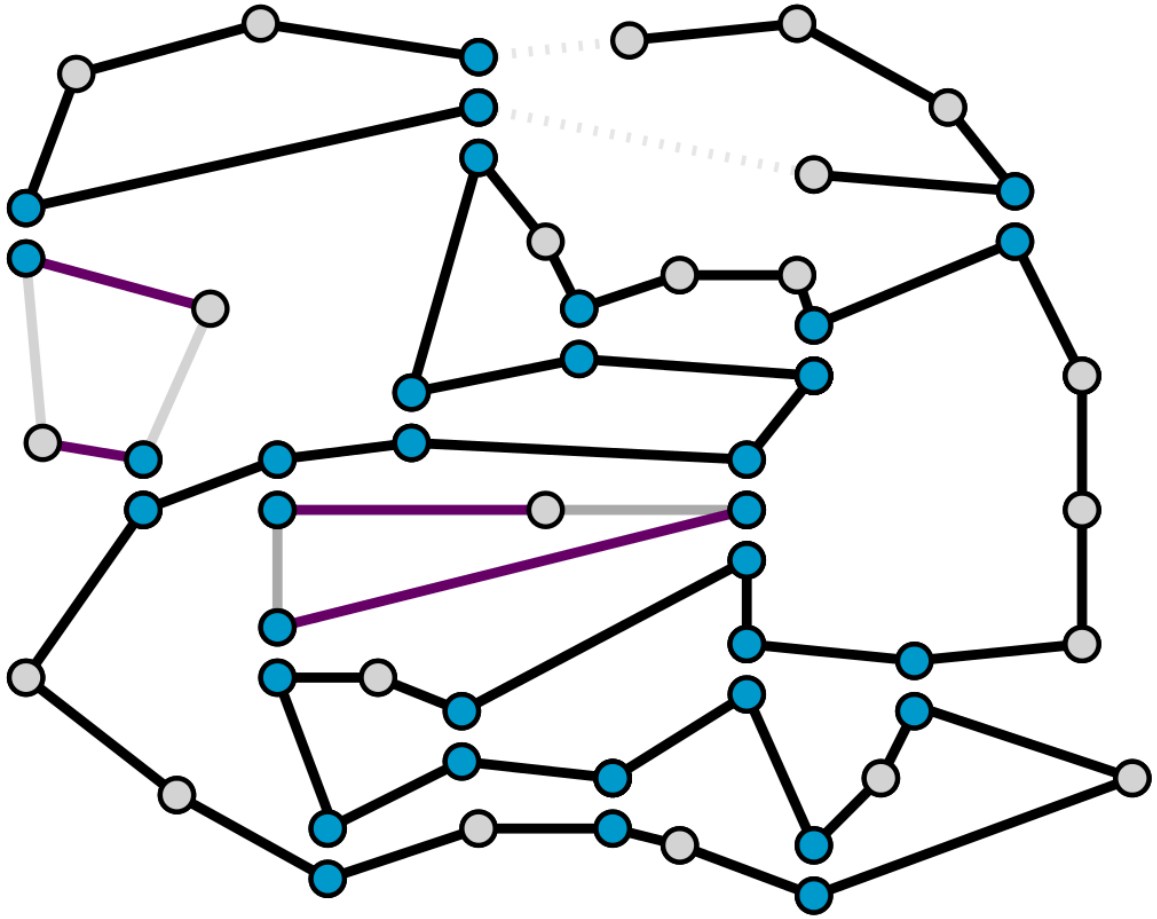

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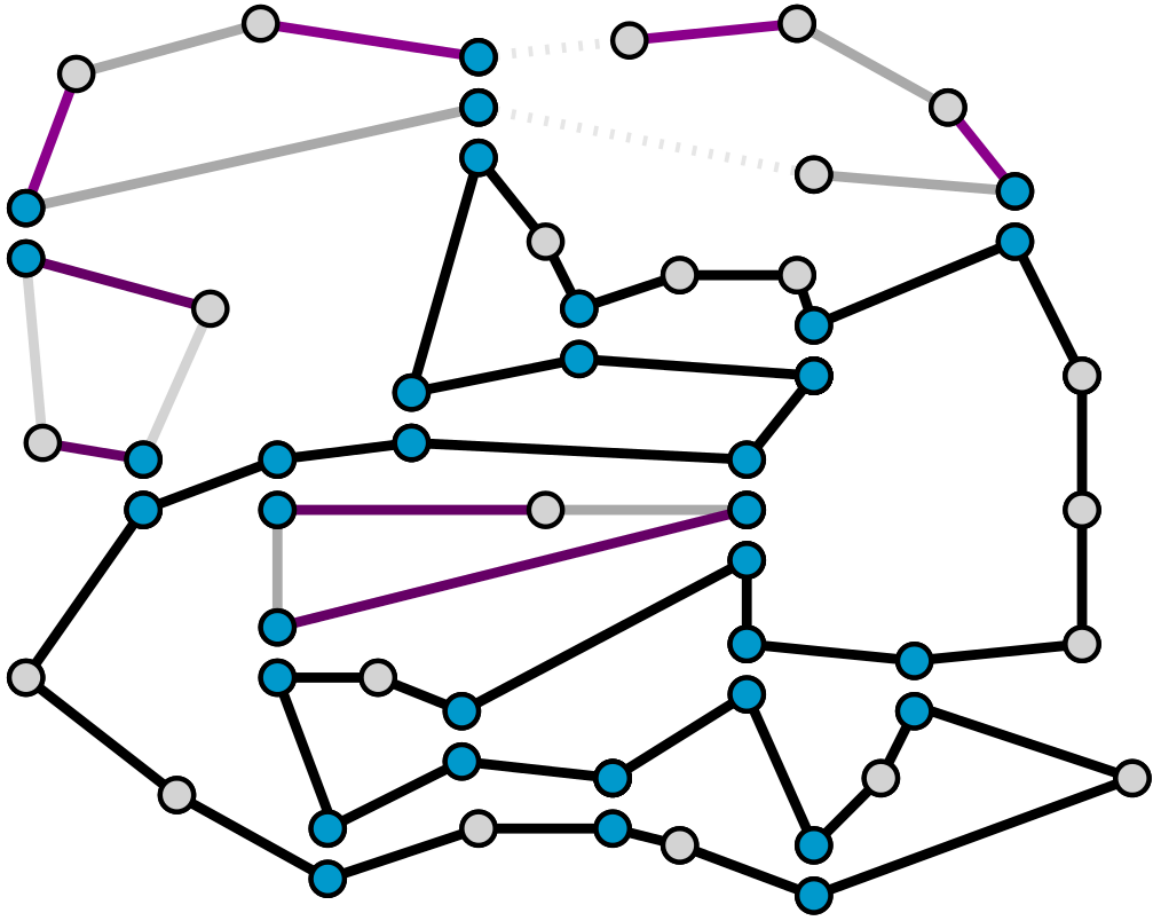

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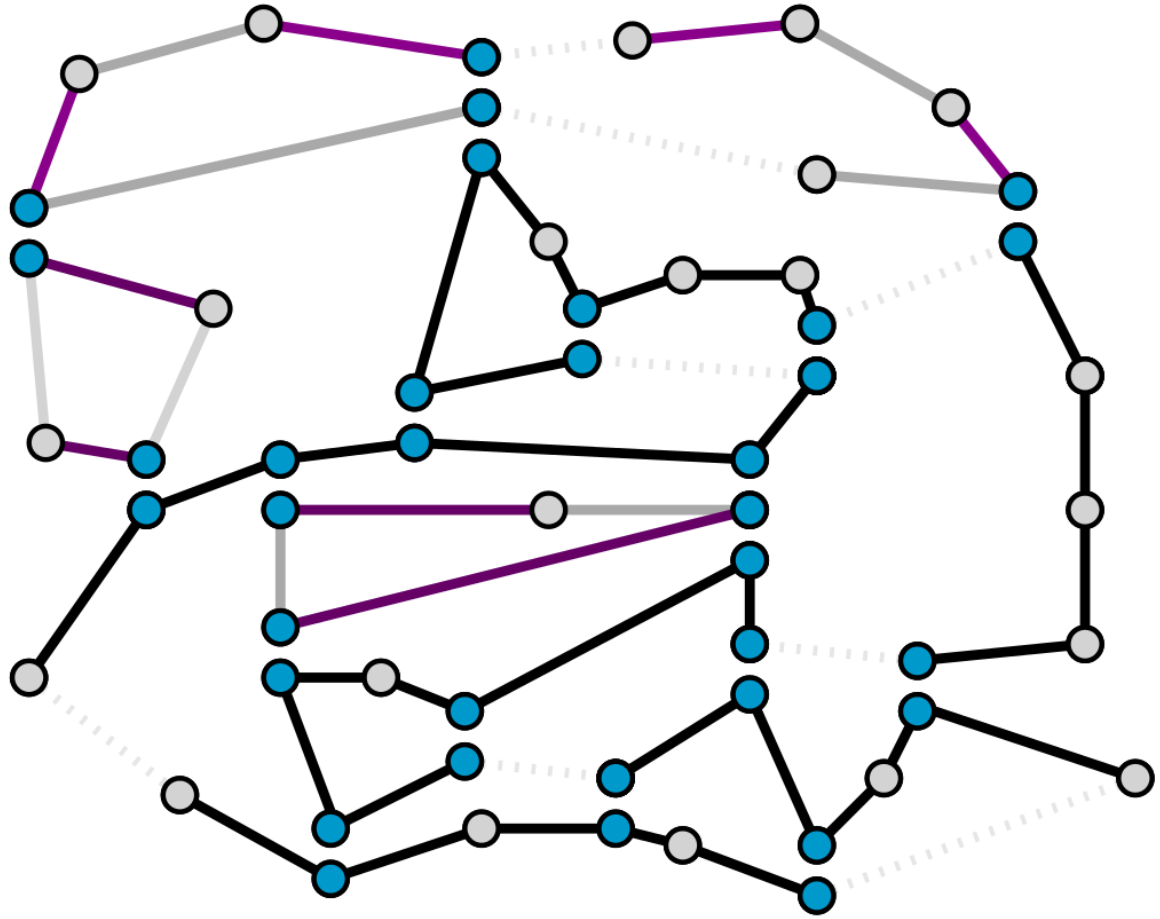

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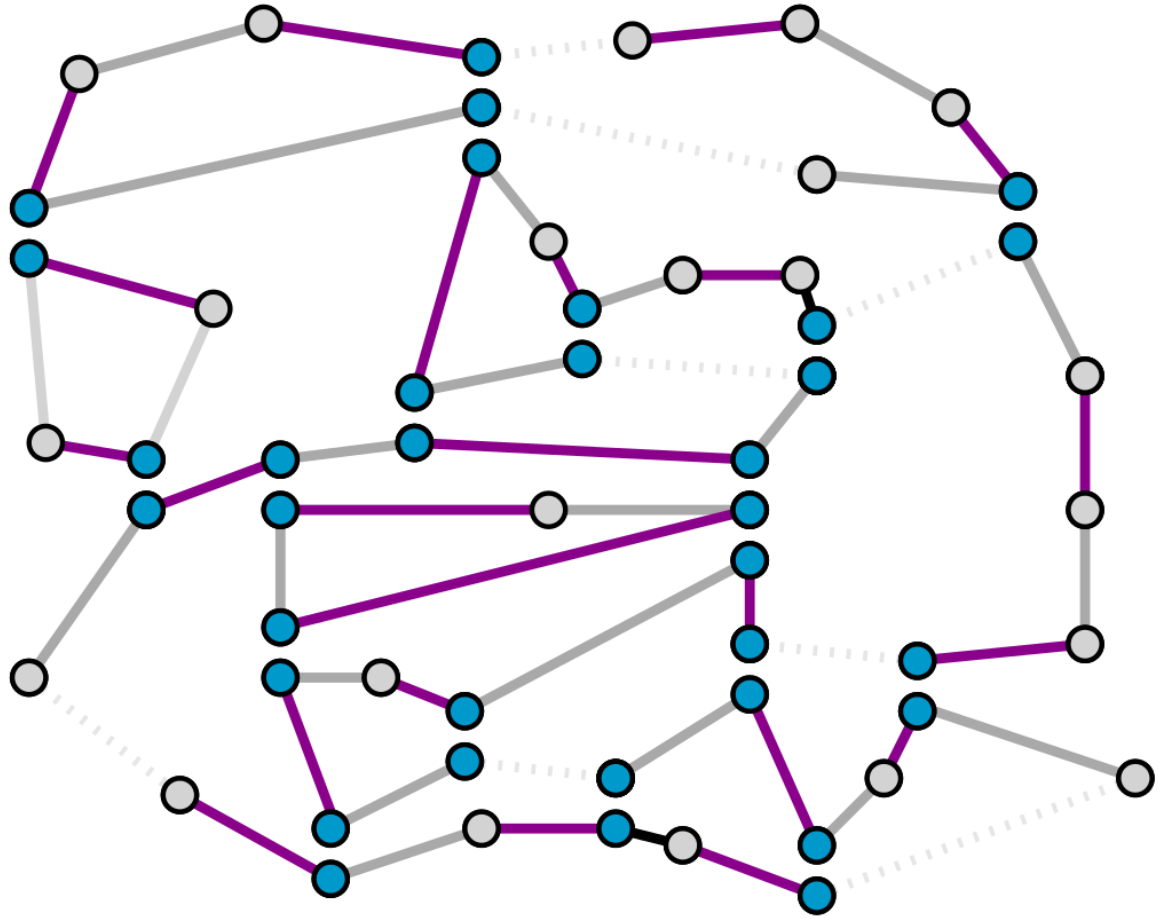

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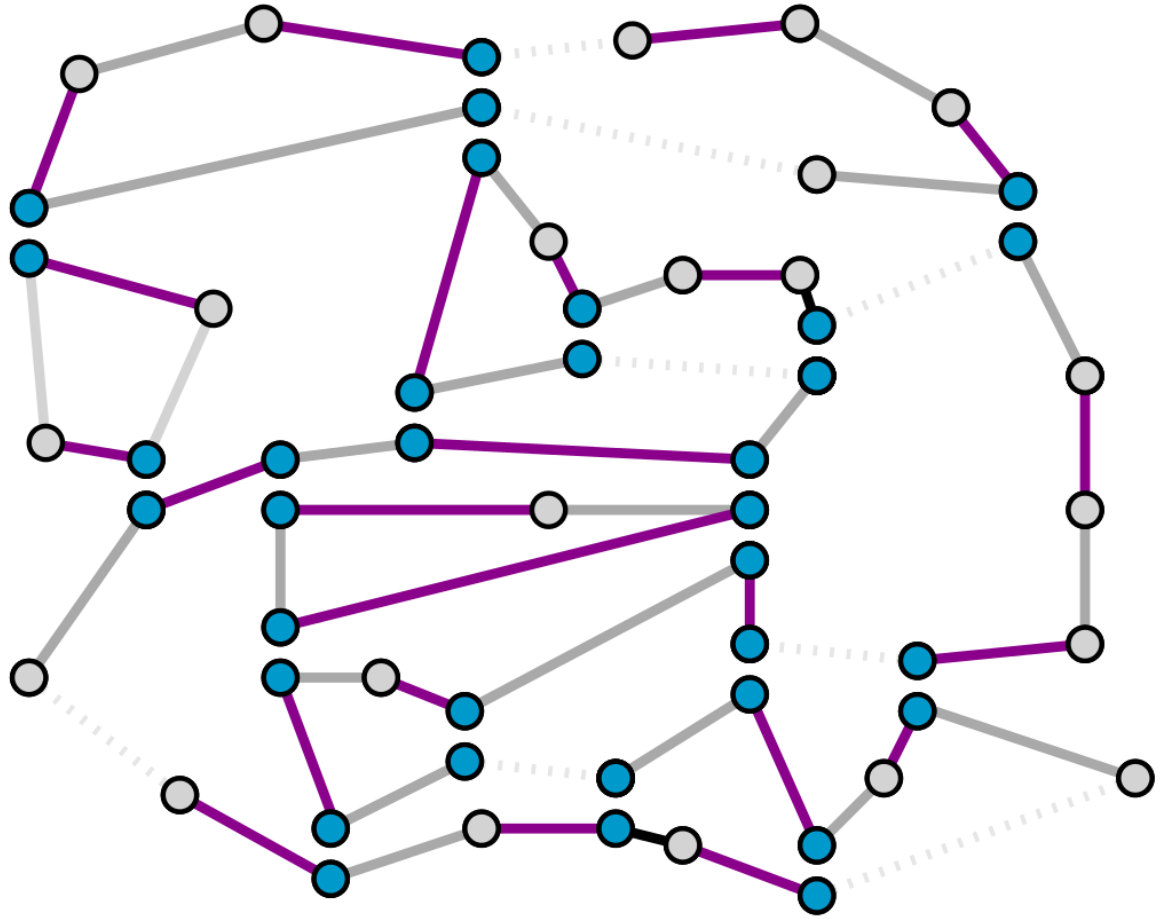

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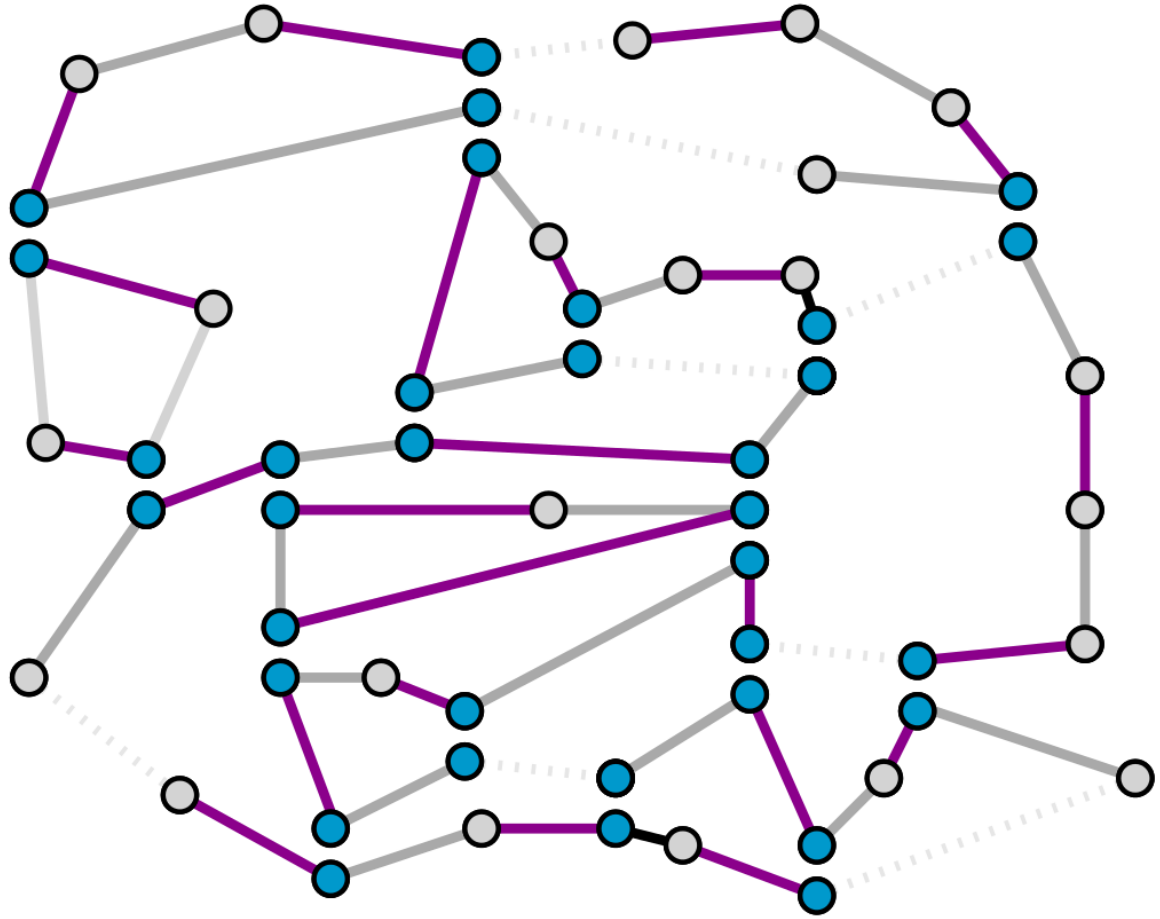

* by *Hańćkowiak, Karoński, Panconesi* [SODA'98,PODC'99] in $O(\log \Delta)$

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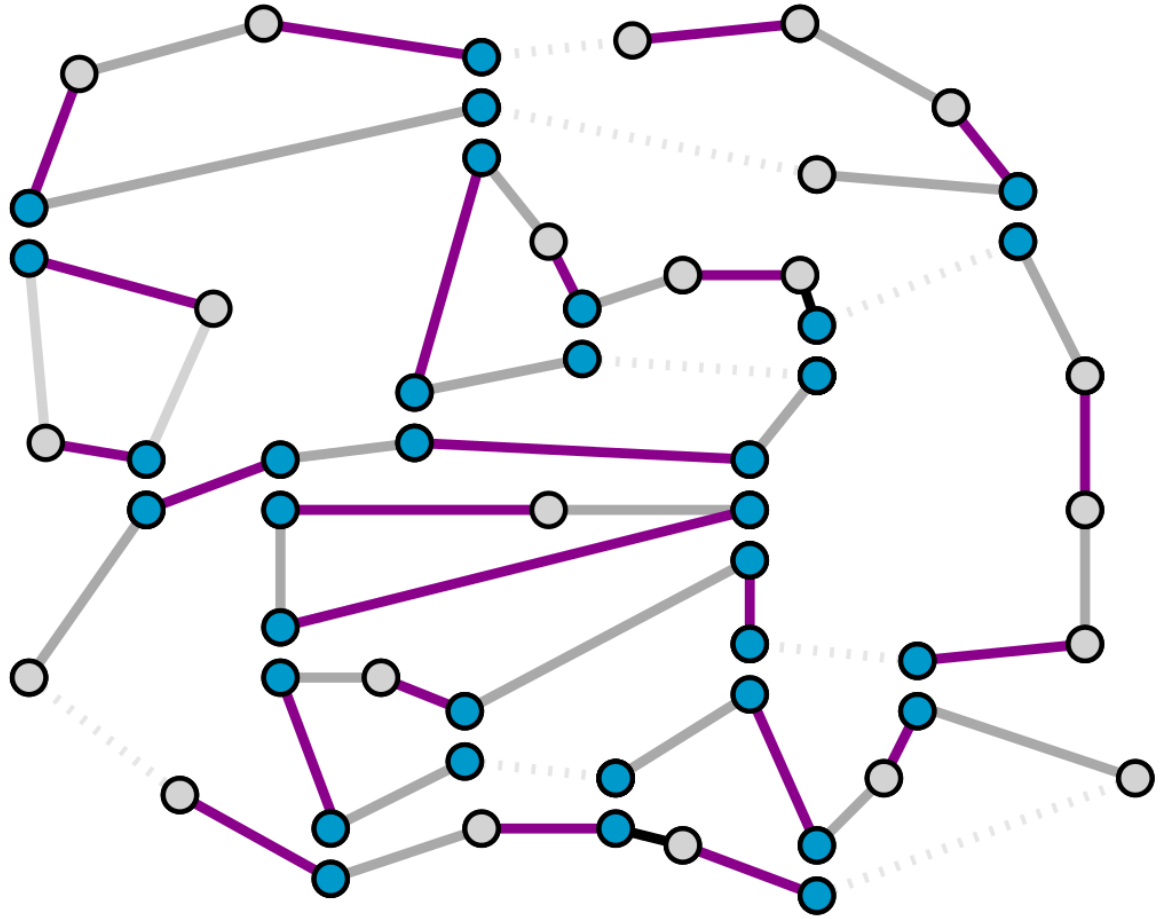

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Over all $O(\log \Delta)$ rounding iterations, total loss still constant!

*** bipartite and even degree!**

Constant - Approximate Bipartite Matching $O\left(\log^2 \Delta\right)$ rounds

I) 4-Approximate Fractional Matching

$O(\log \Delta)$ rounds

II) Rounding Fractional Bipartite Matching

$O\left(\log^2 \Delta\right)$ rounds, $O(1)$ loss

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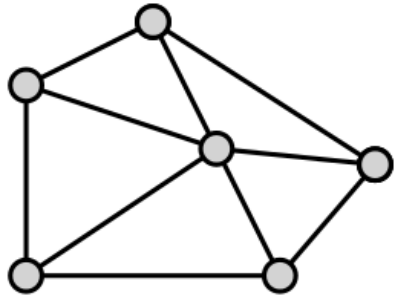

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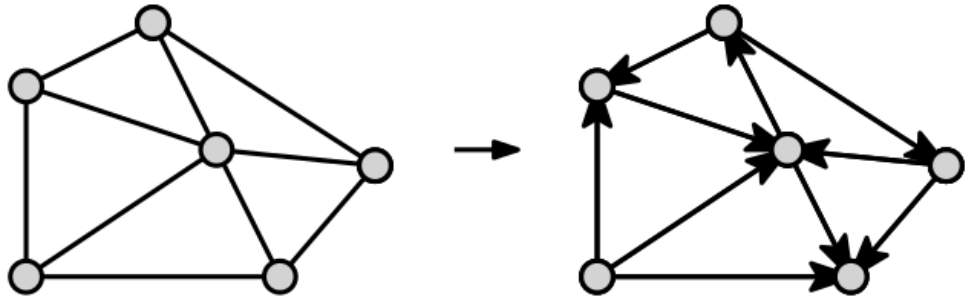

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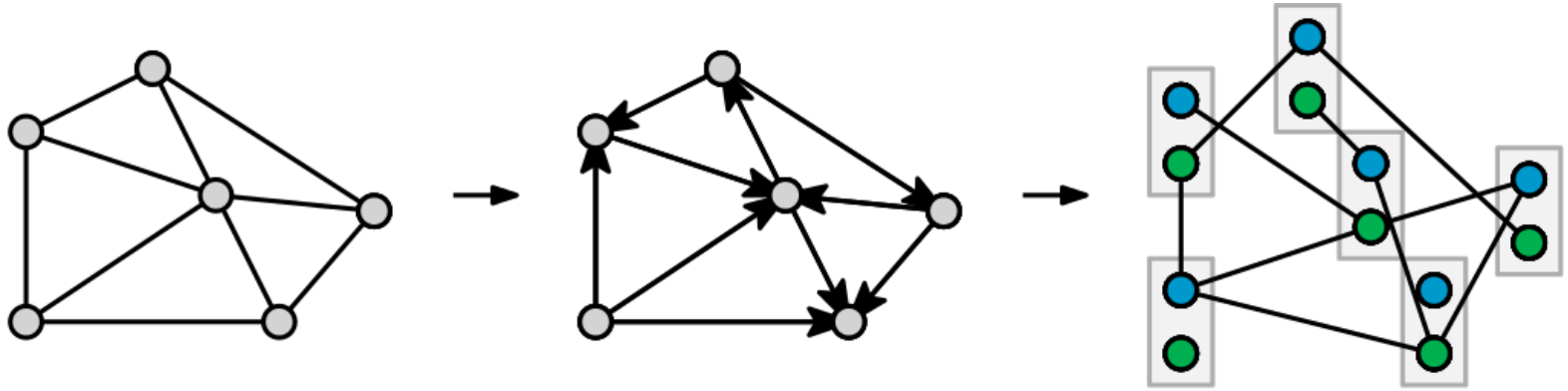

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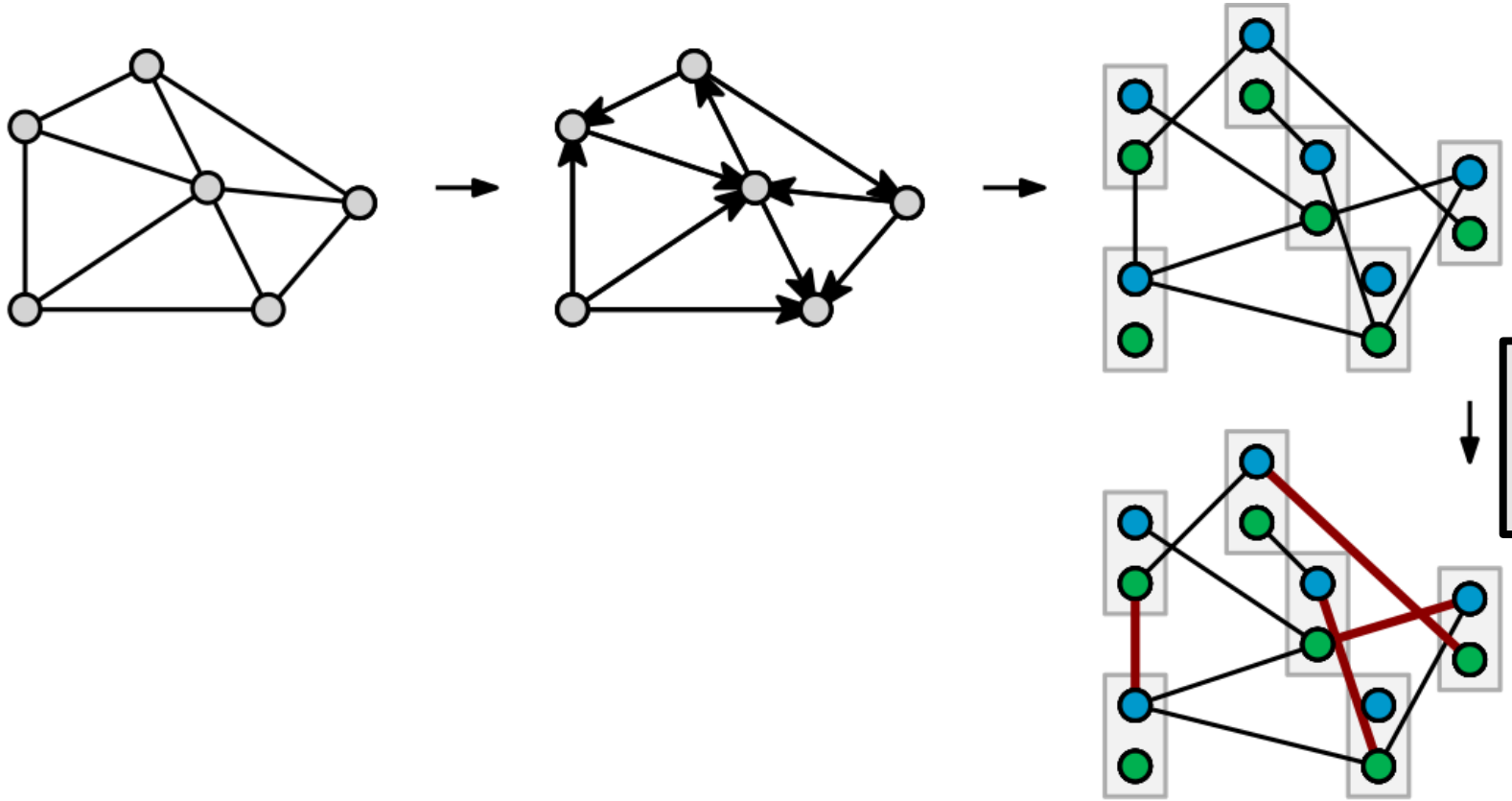

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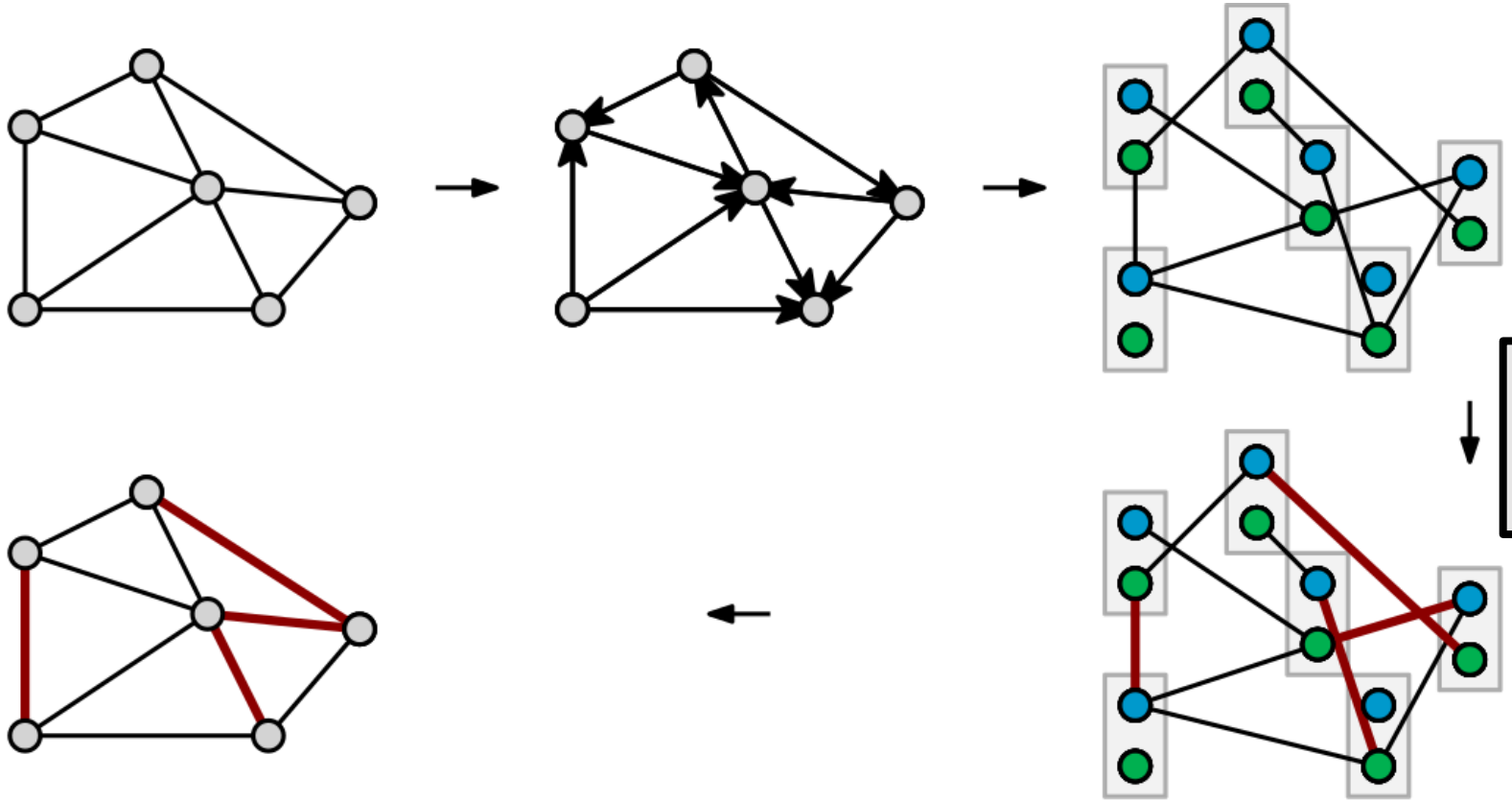

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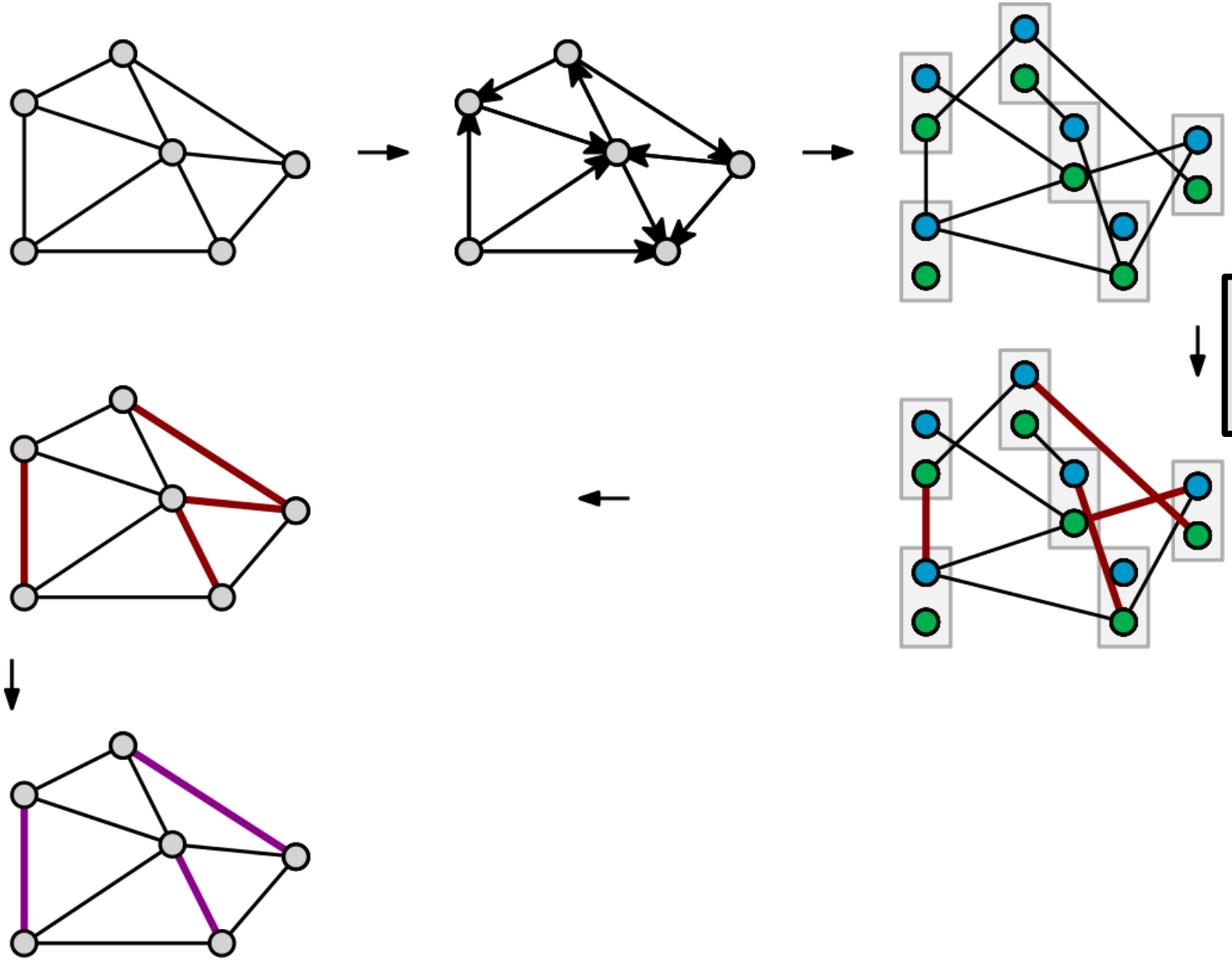

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Maximal $\boldsymbol{O(\log^2 \Delta \cdot \log n)}$

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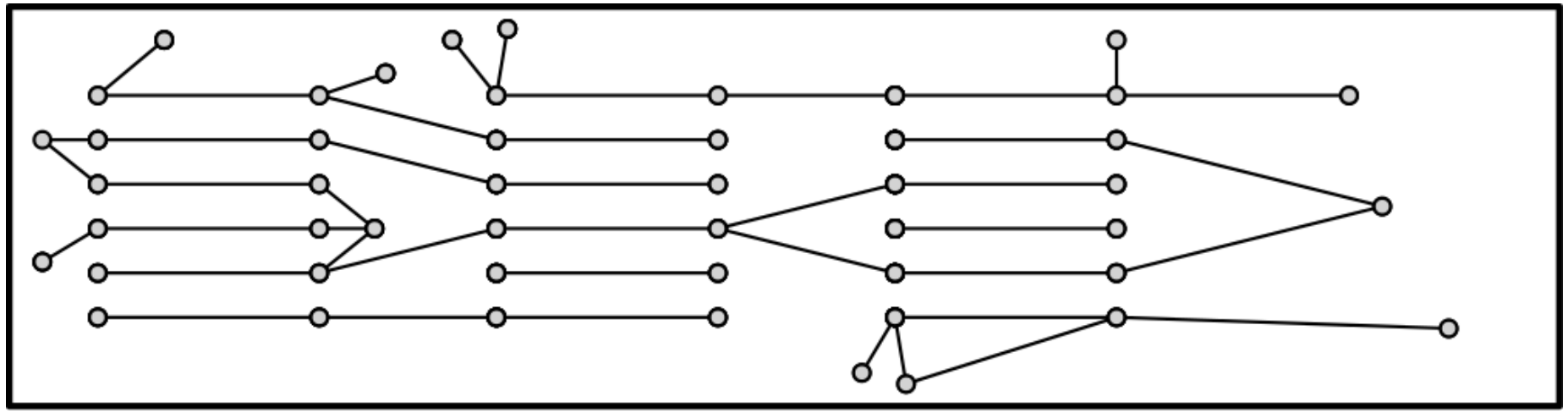

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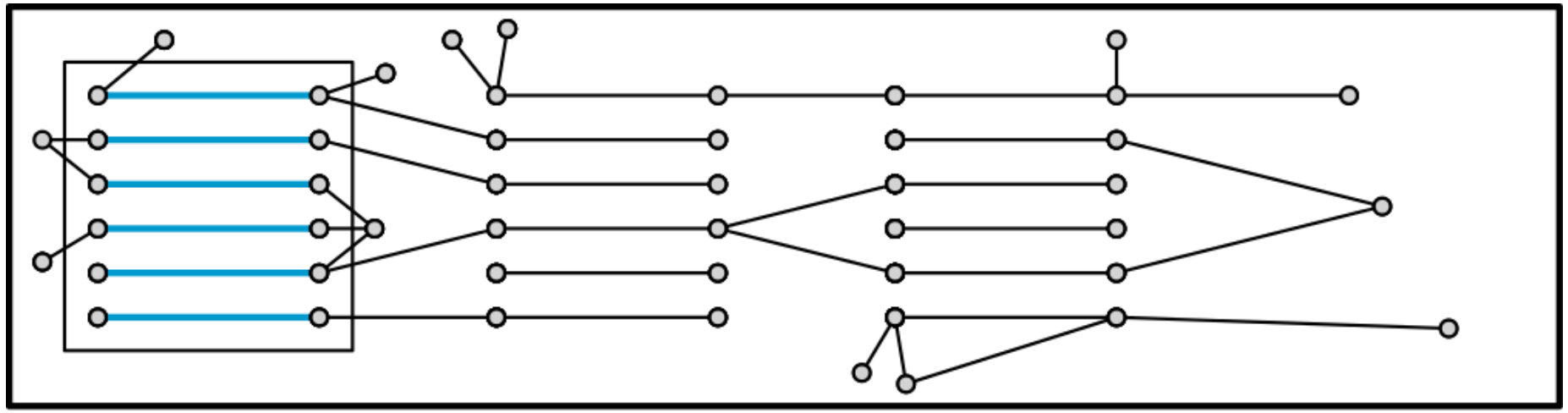

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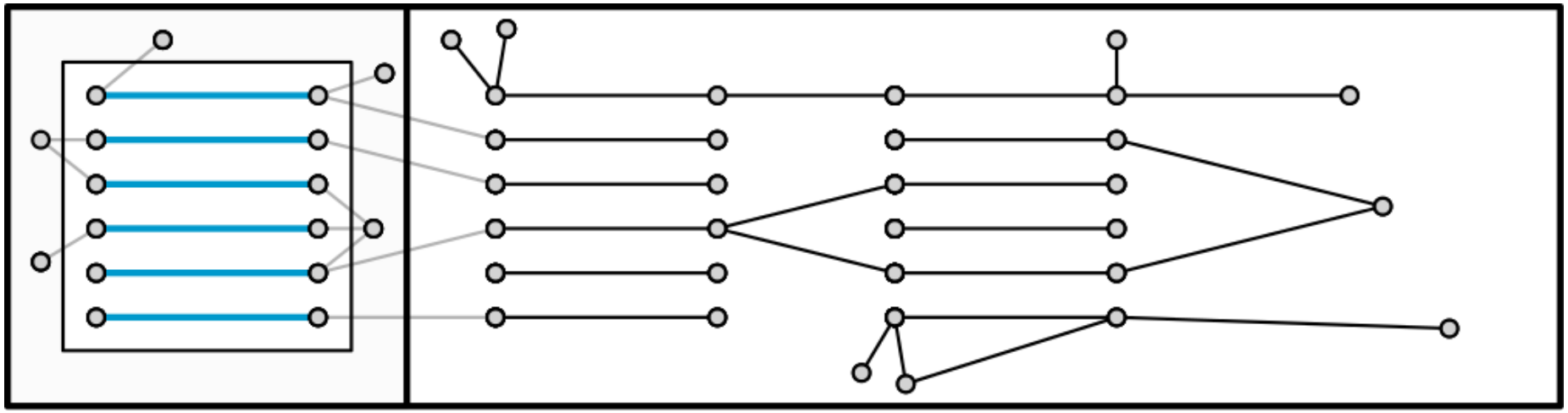

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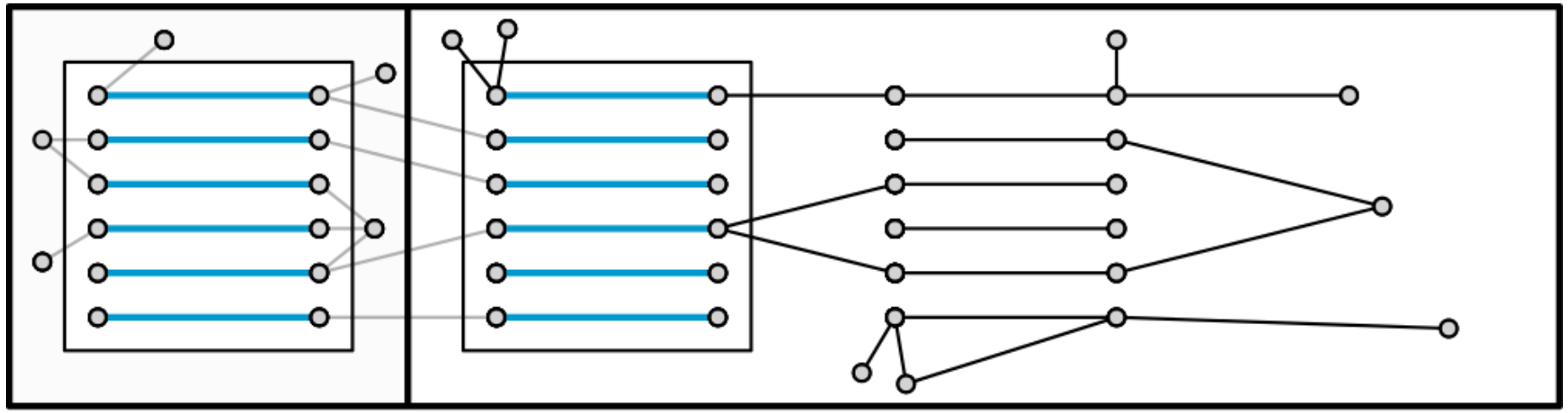

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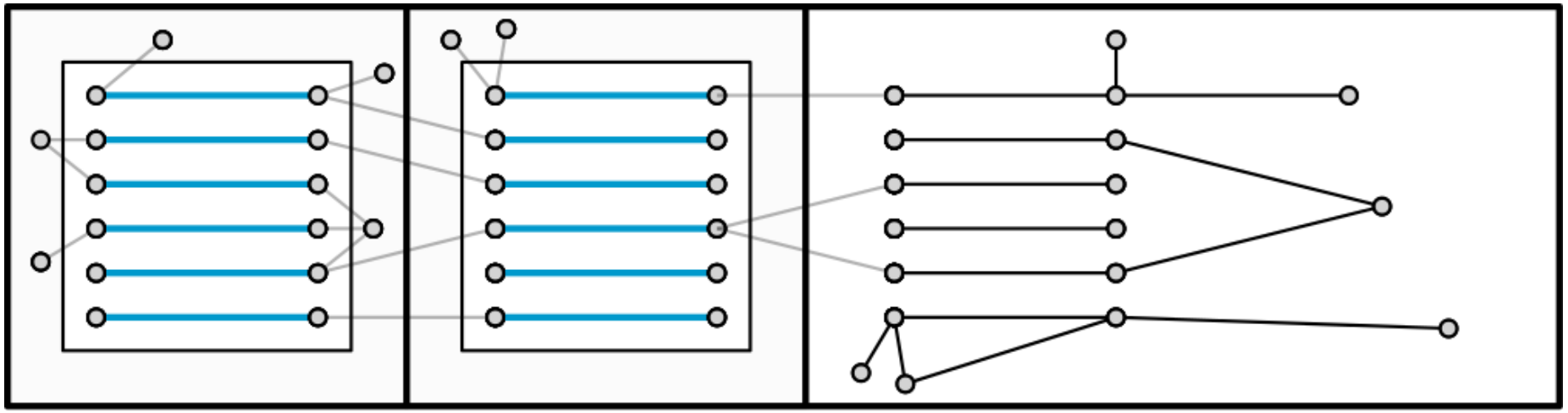

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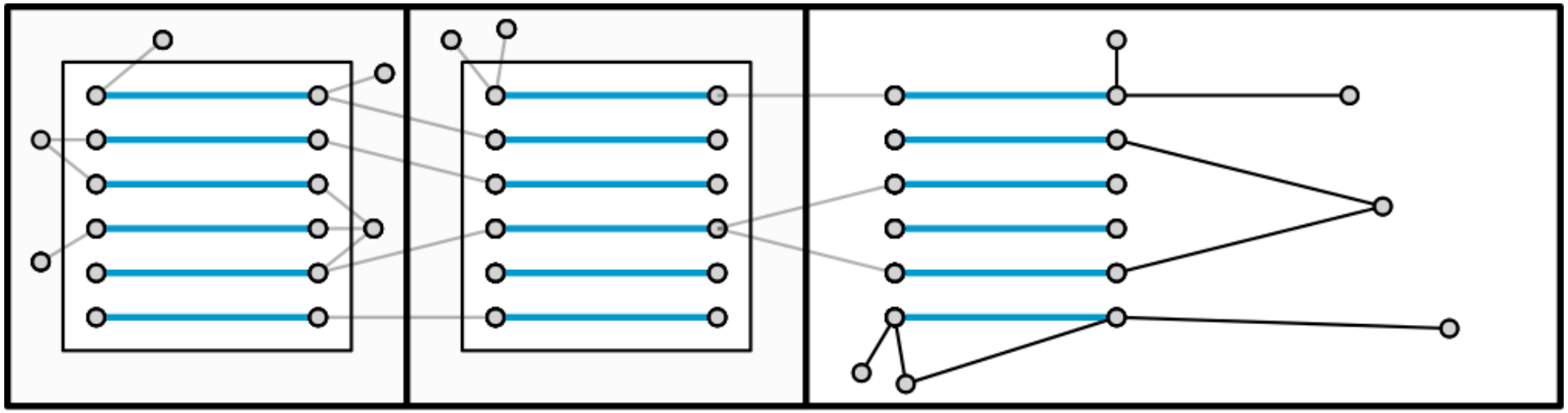

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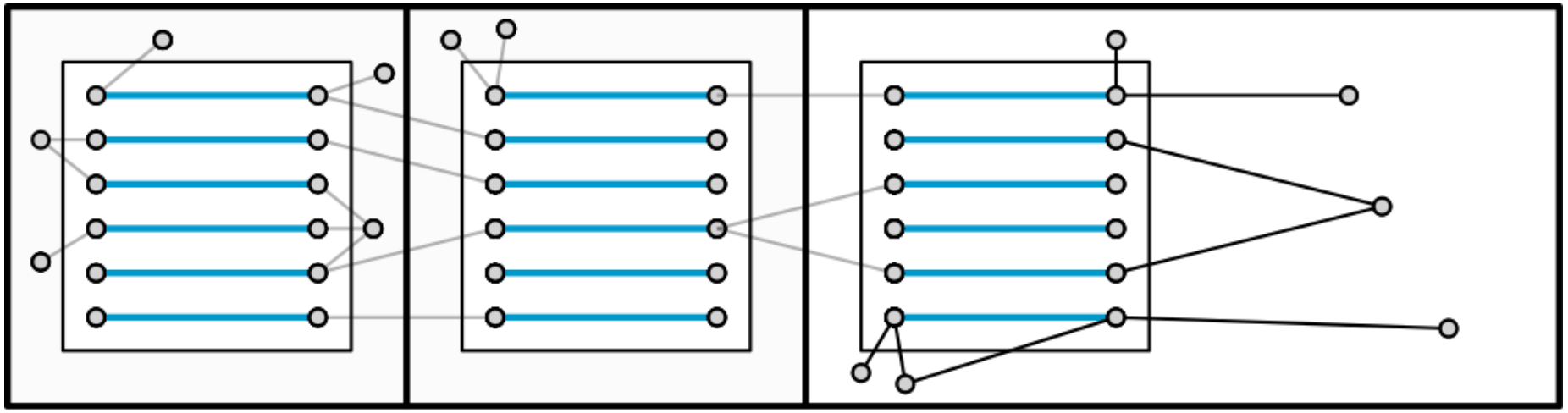

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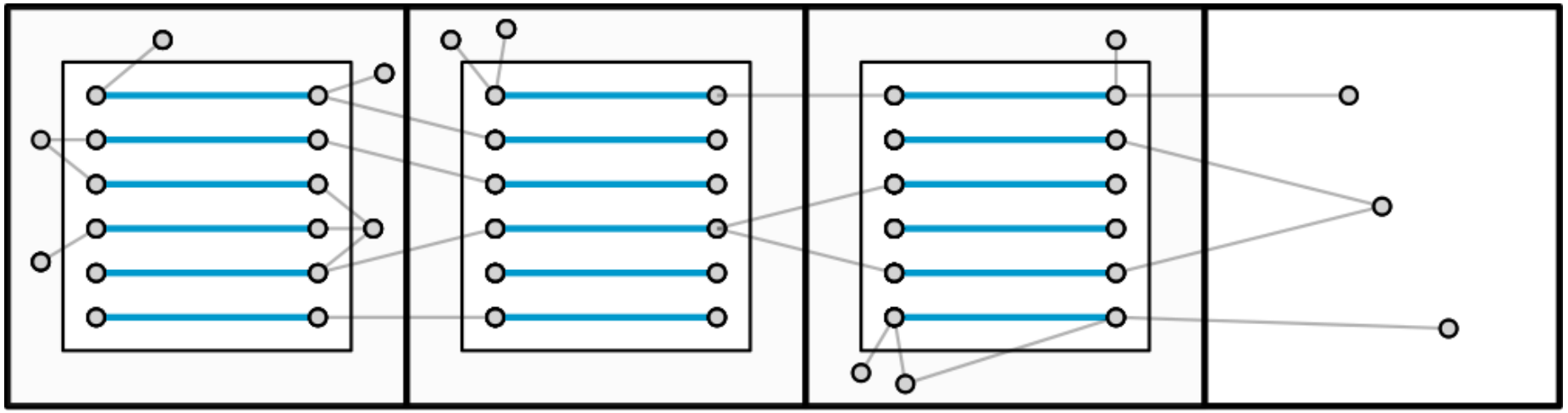

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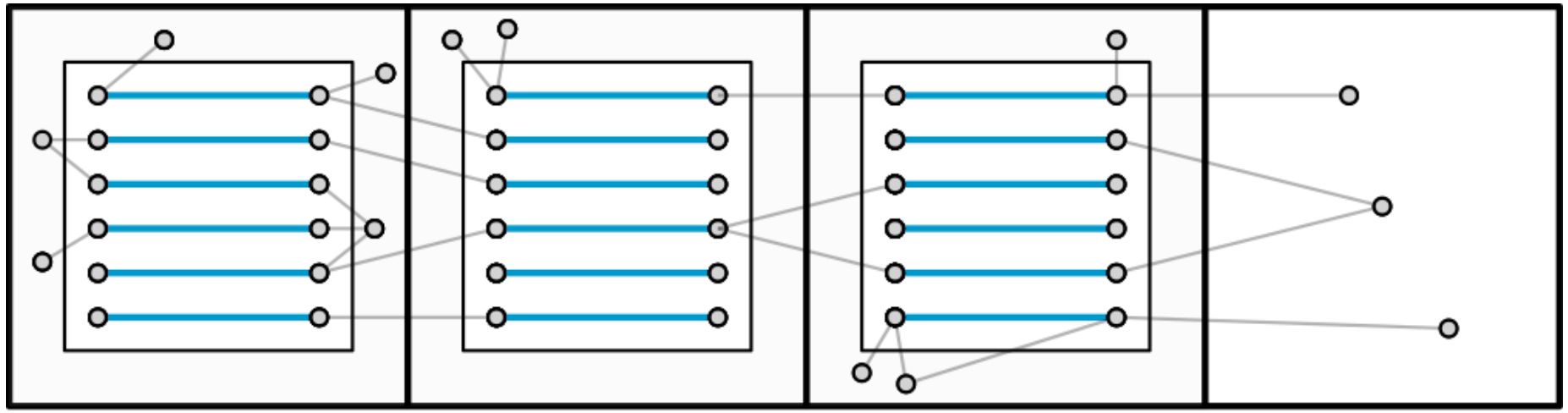

maximum matching size in remainder graph decreases by constant factor

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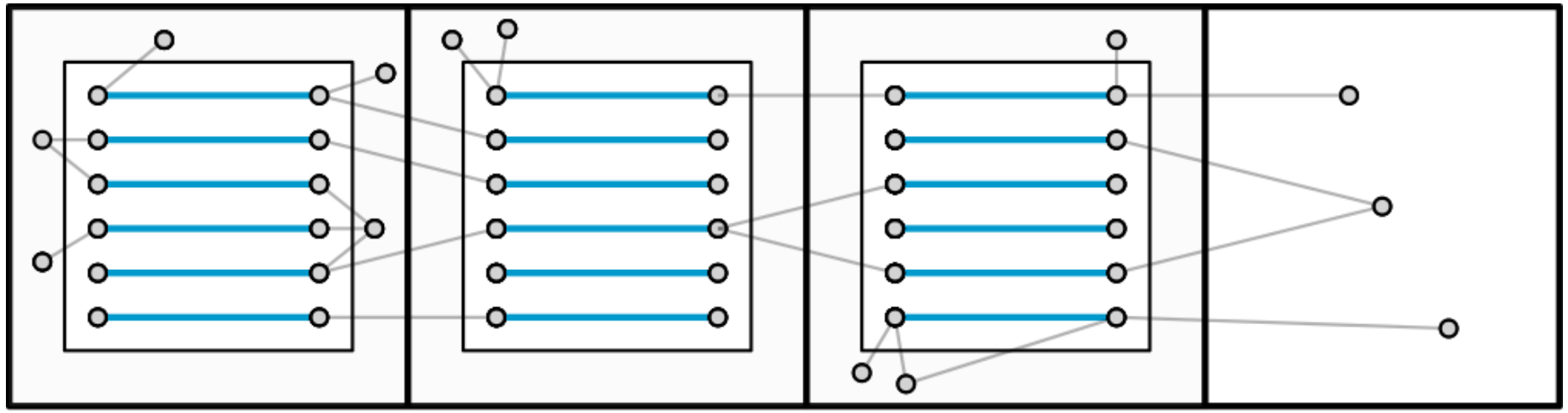

maximum matching size in remainder graph decreases by constant factor

after $O(\log n)$ iterations, maximum matching size is 0, hence graph empty

deterministic $O\left(\log^2 \Delta \cdot \log n\right)$-round Maximal Matching

deterministic $O\left(\log^2 \Delta \cdot \log n\right)$-round Maximal Matching

Lower bound: $\Omega\left(\min\left\{\sqrt{\frac{\log n}{\log\log n}}, \frac{\log \Delta}{\log\log \Delta}\right\}\right)$

Kuhn, Moscibroda, Wattenhofer [PODC'04]

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Open Question: $O(\log \Delta \cdot \log n)$?

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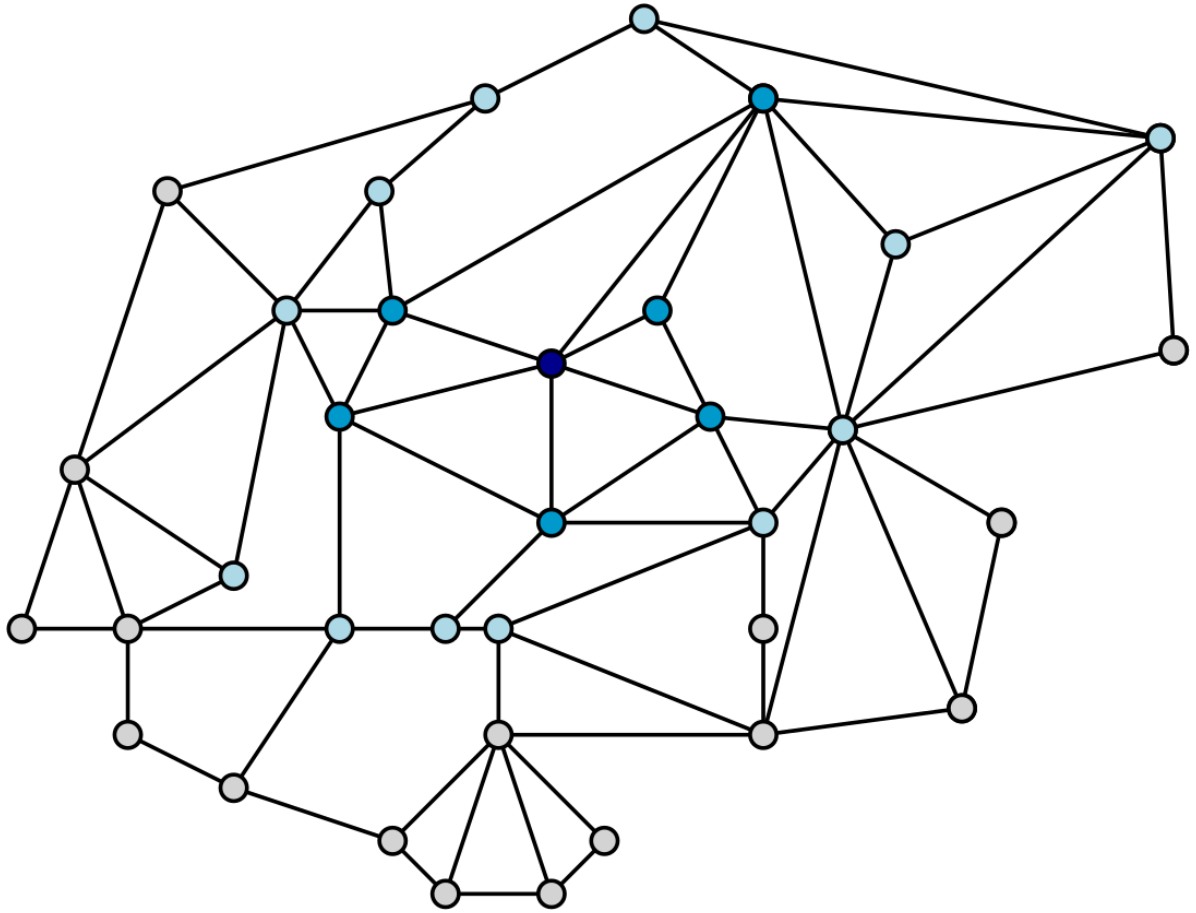
What is Locality of Maximal Matching?



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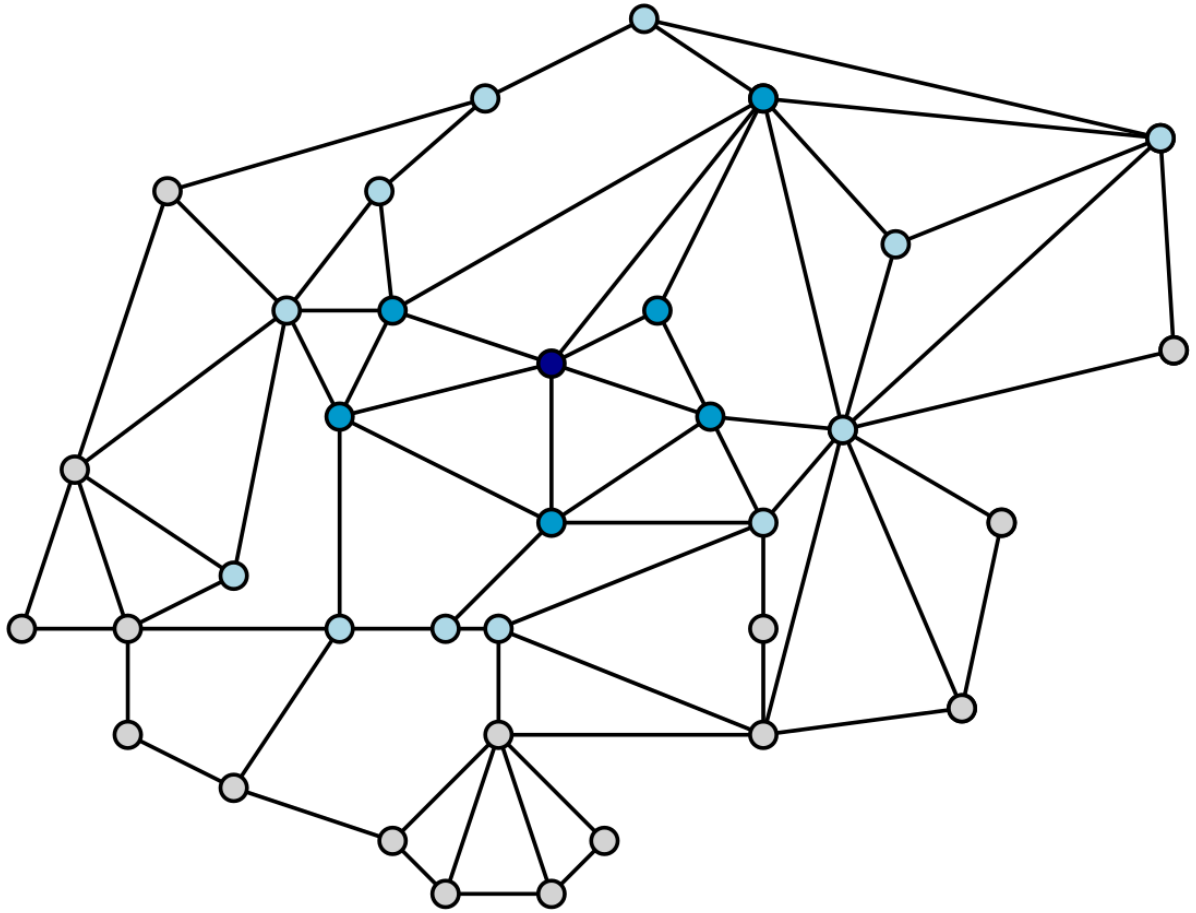

Thank you!

Open Question: $O(\log \Delta \cdot \log n)$?

What is Locality of Maximal Matching?