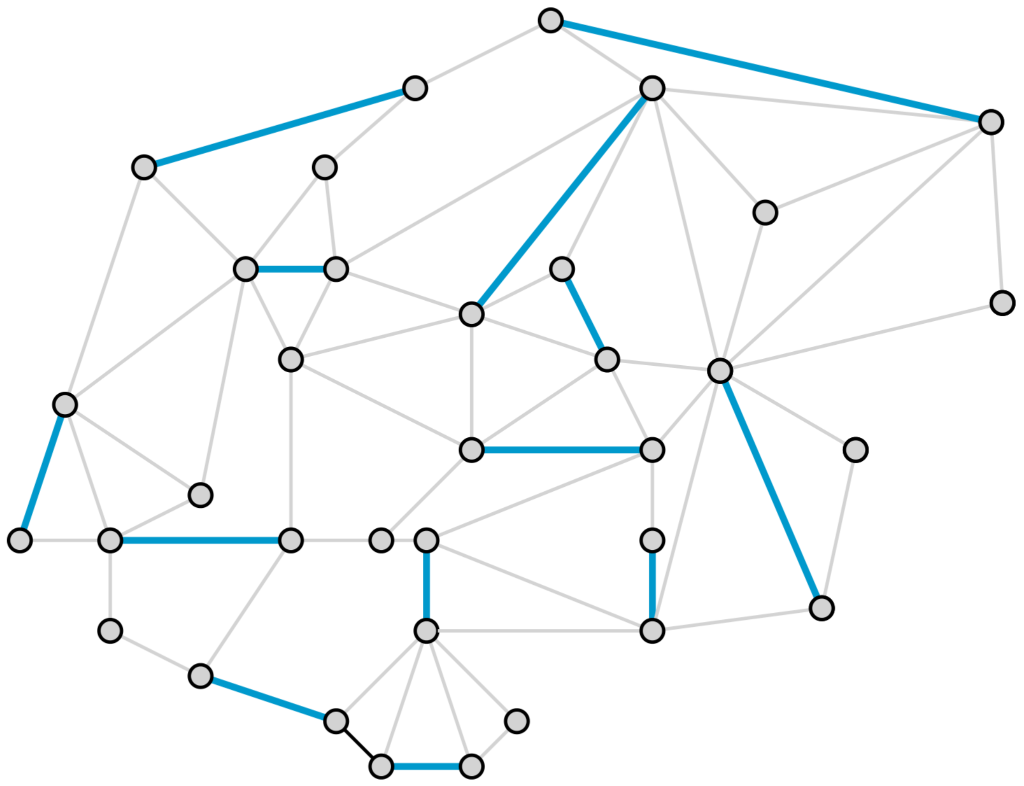
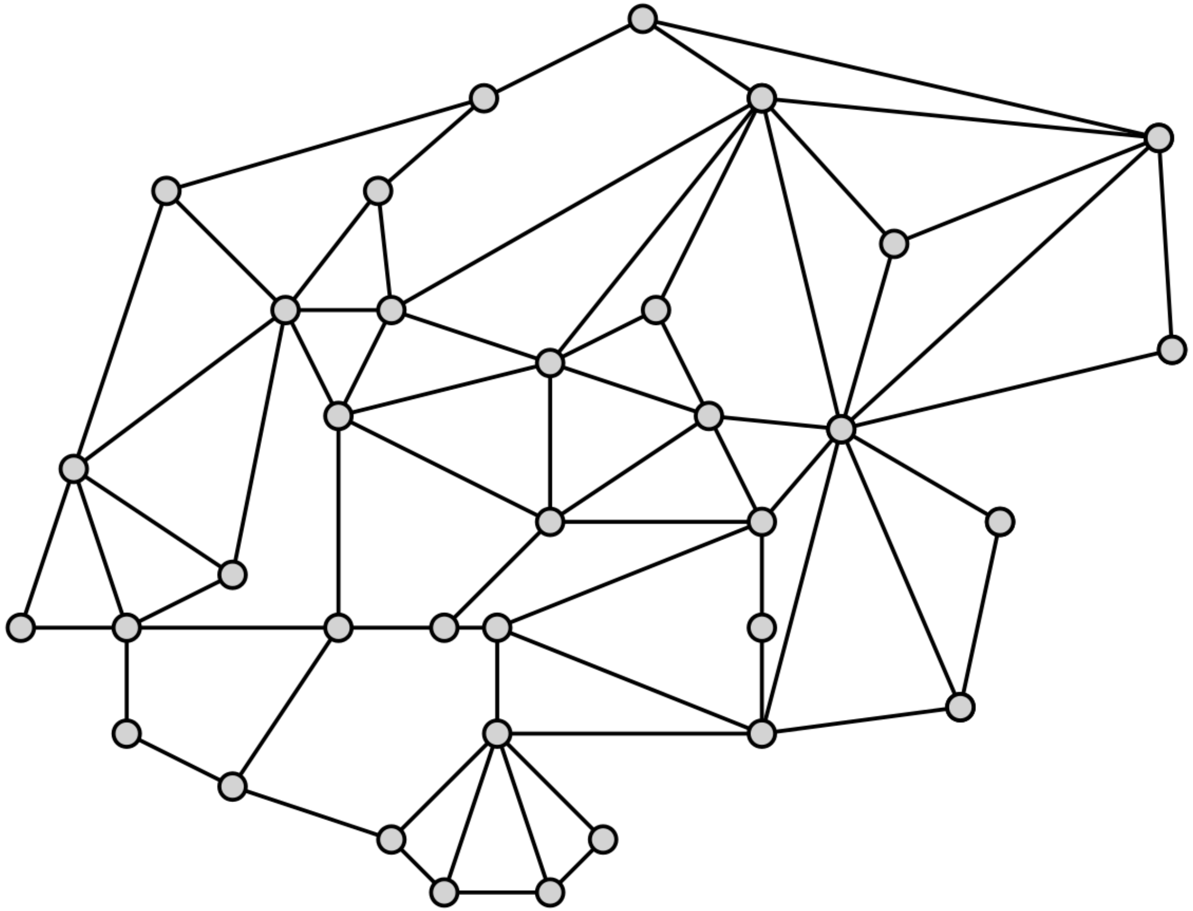


The Locality of Maximal Matching

Manuela Fischer
ETH Zurich

Locality

Locality



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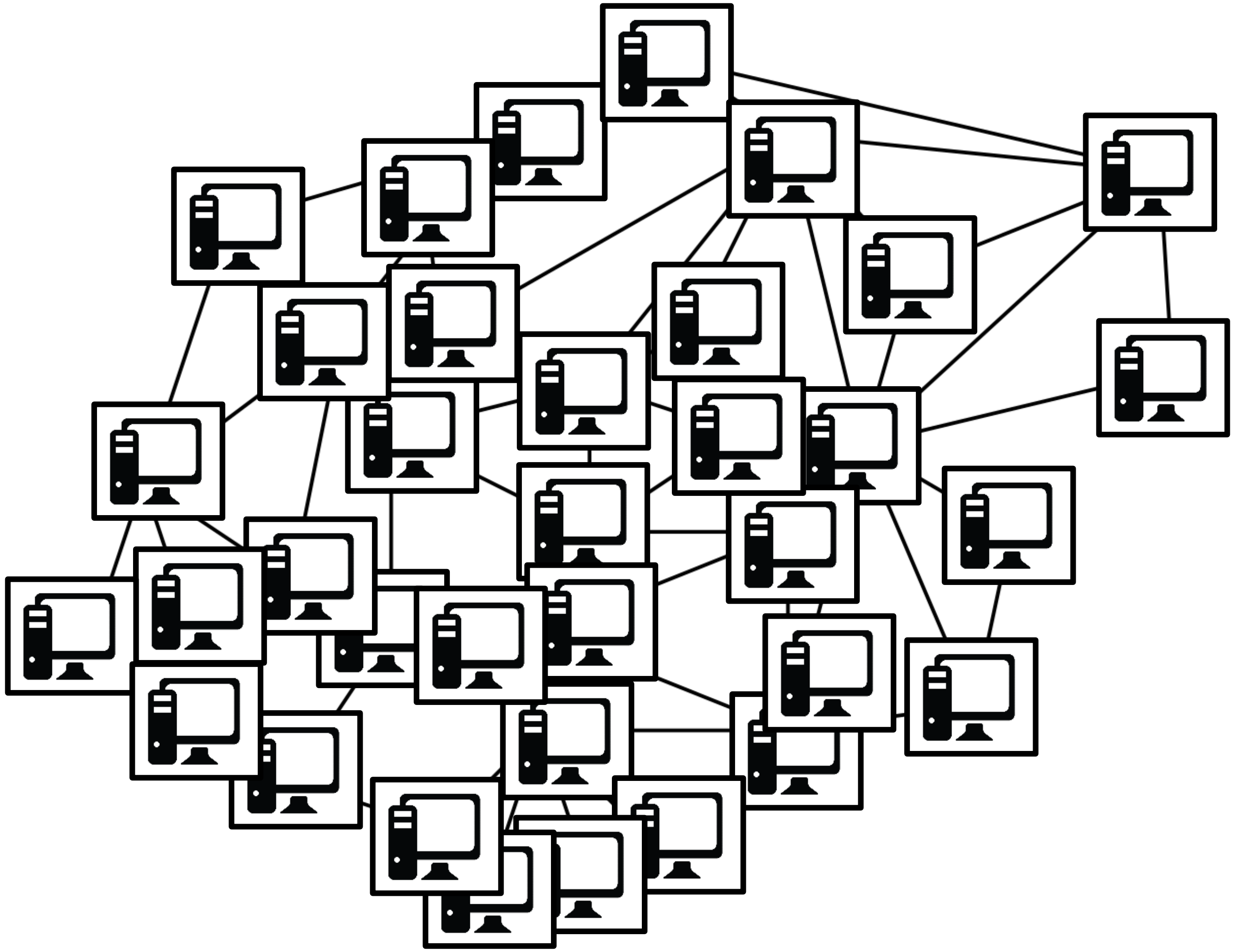

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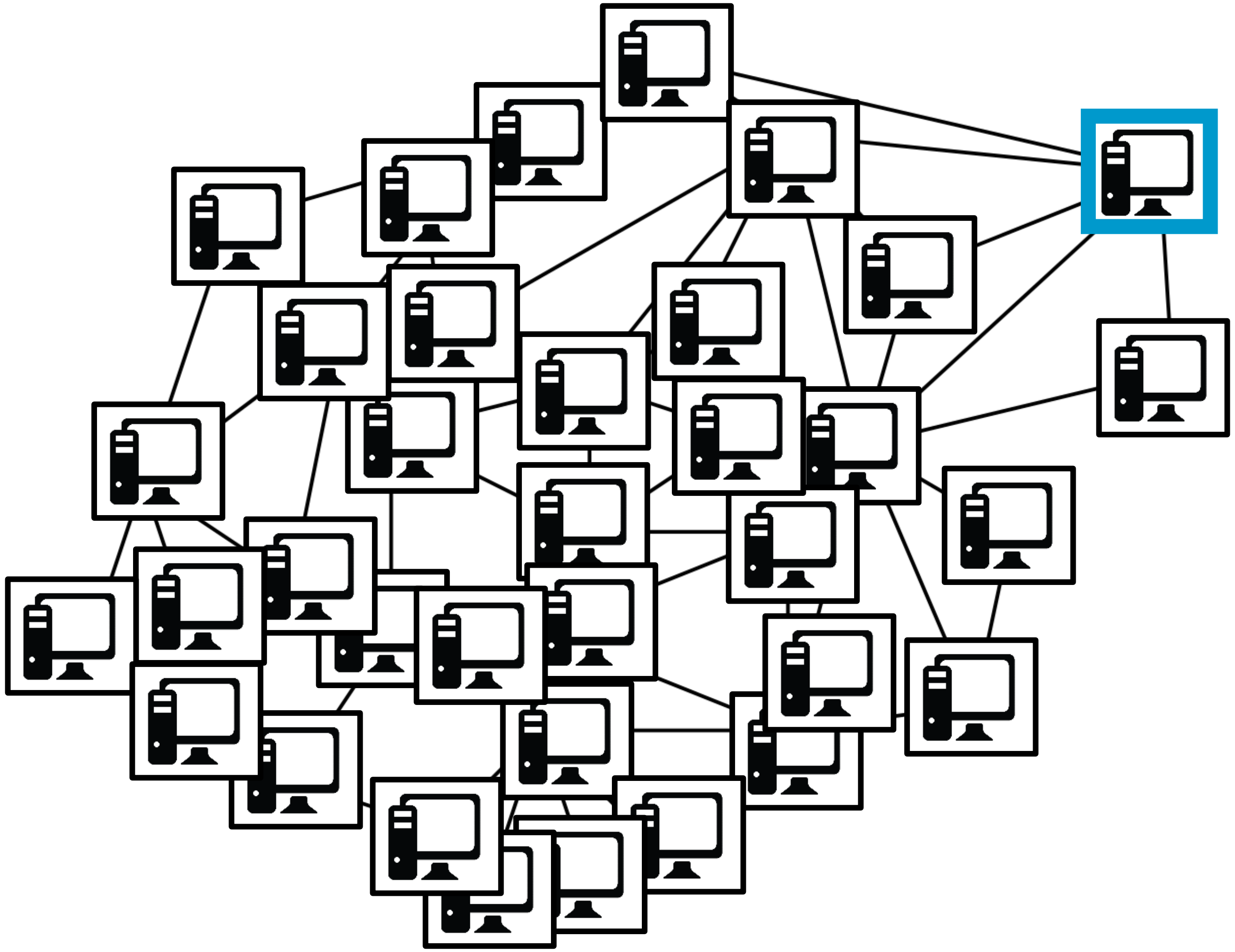

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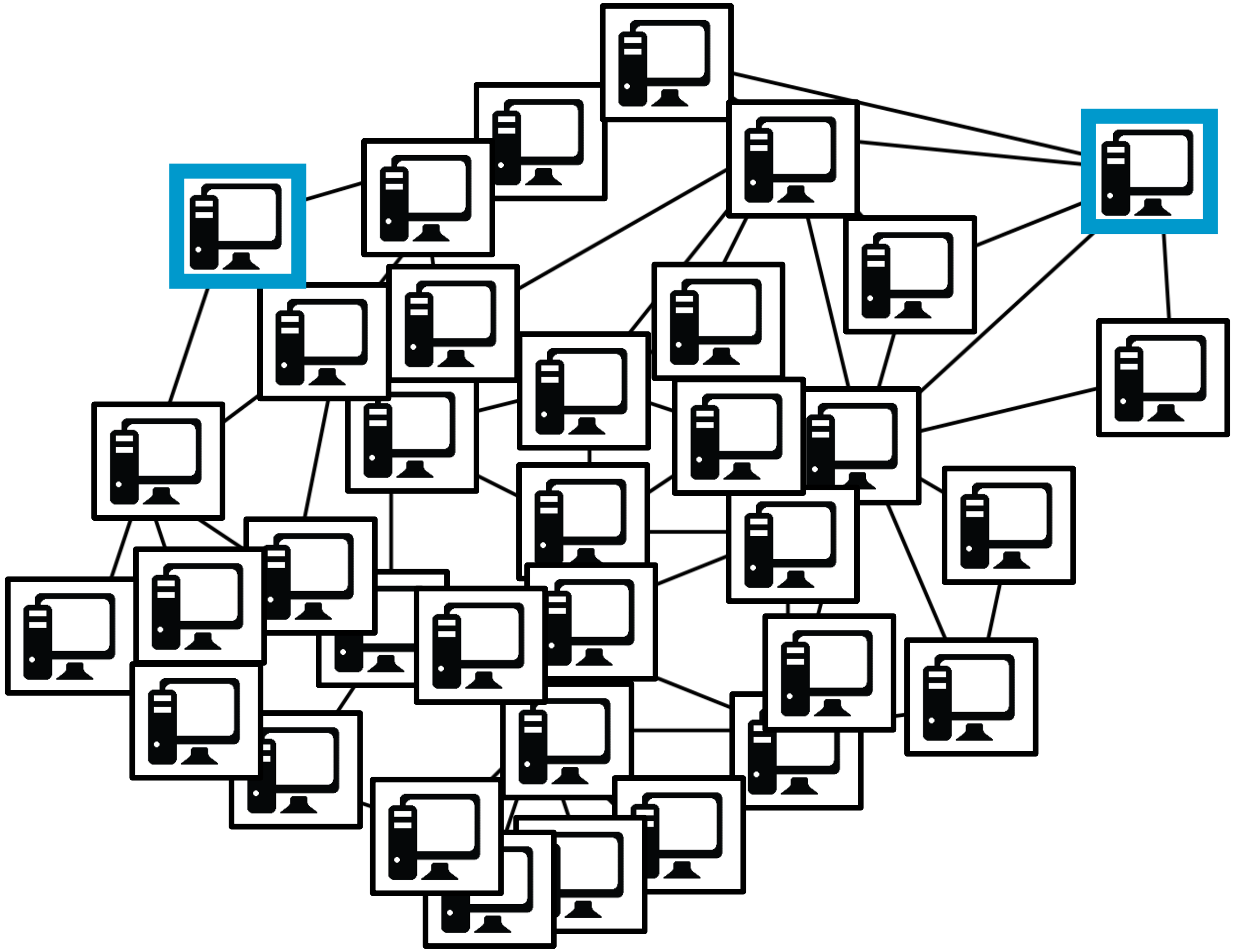

LOCAL Model *Linial* [FOCS'87]

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standard synchronous message-passing model of distributed computing

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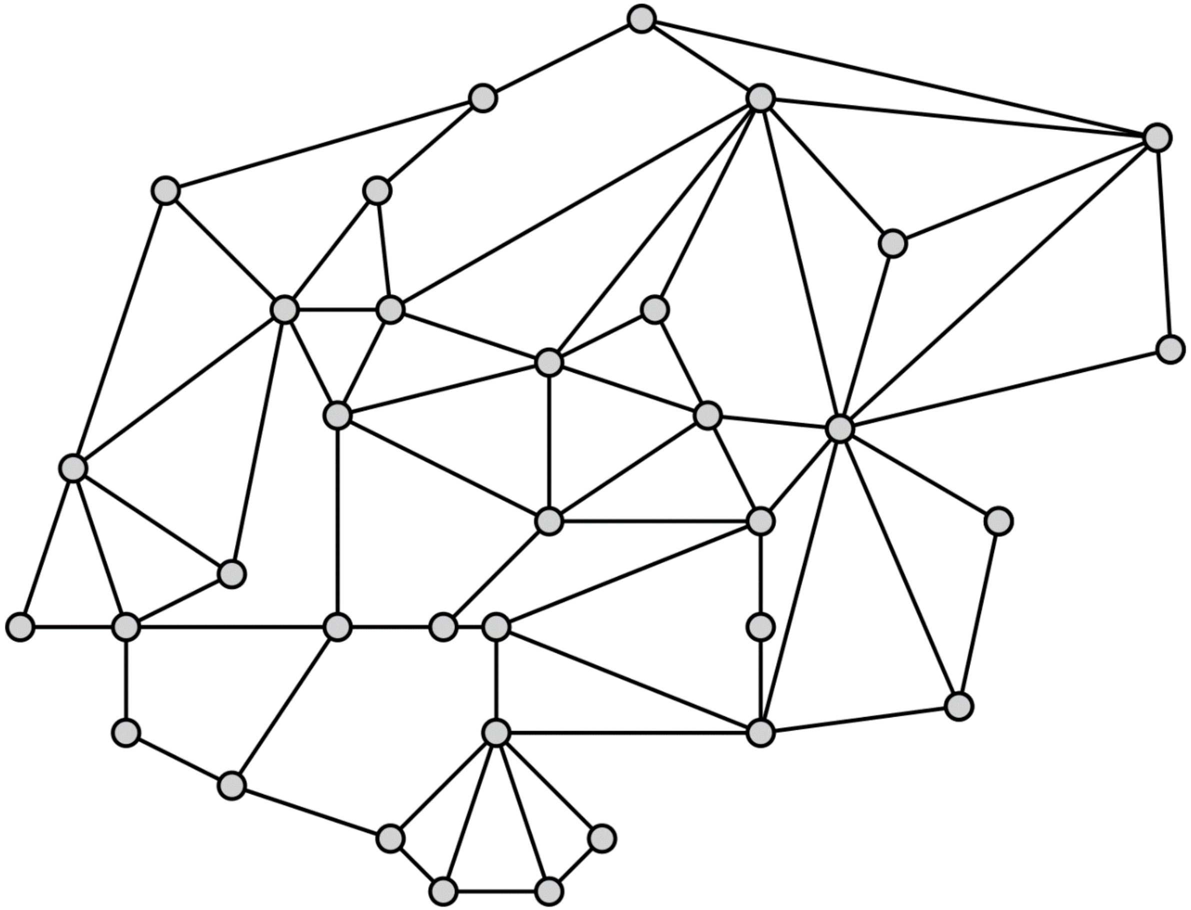

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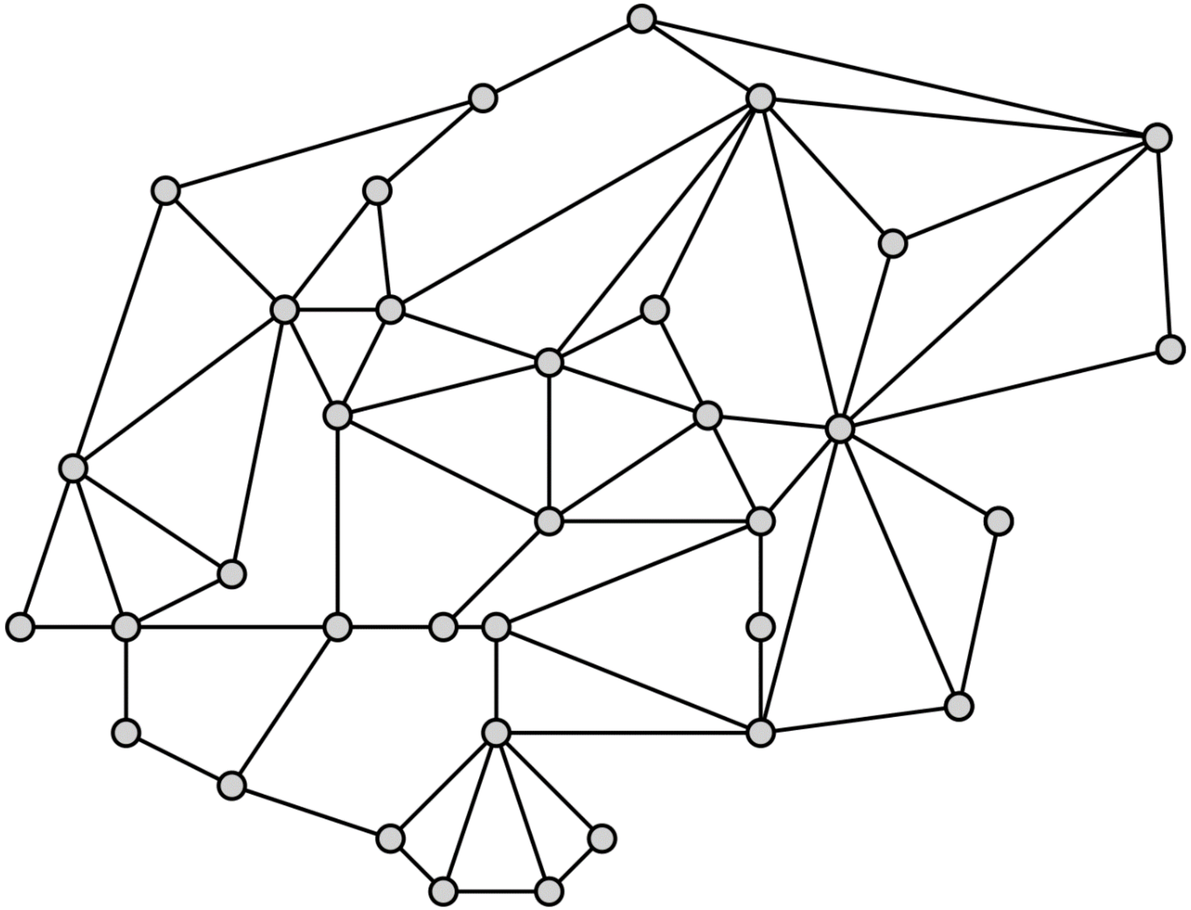

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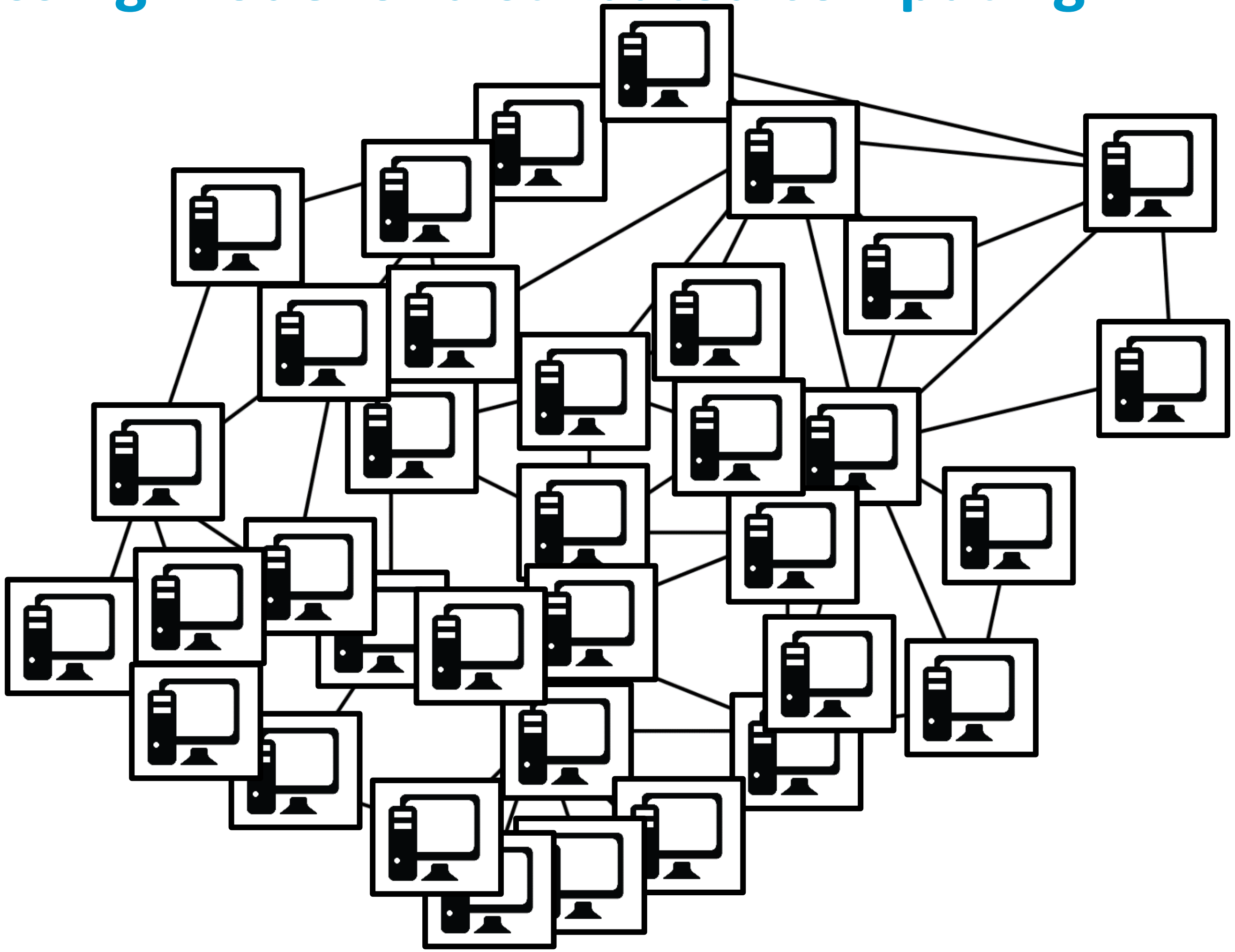

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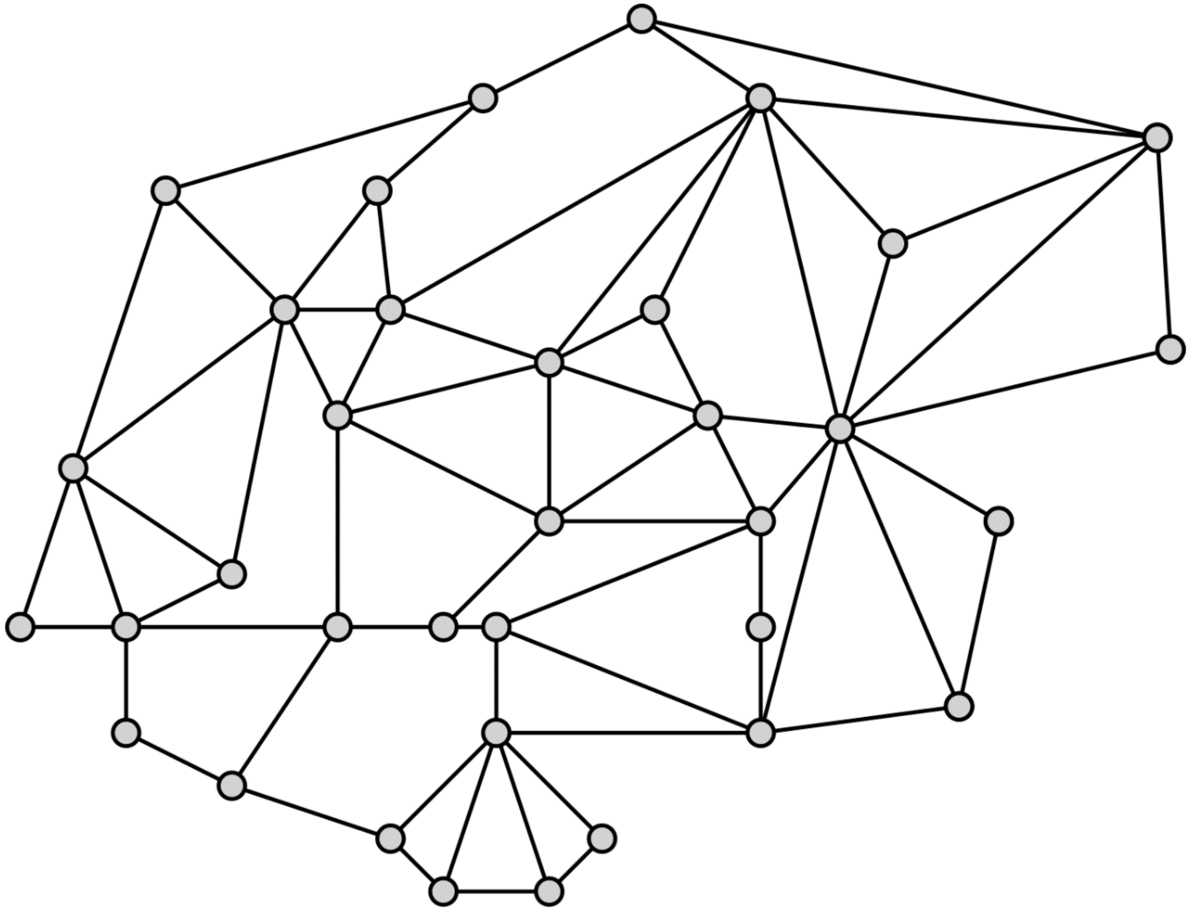

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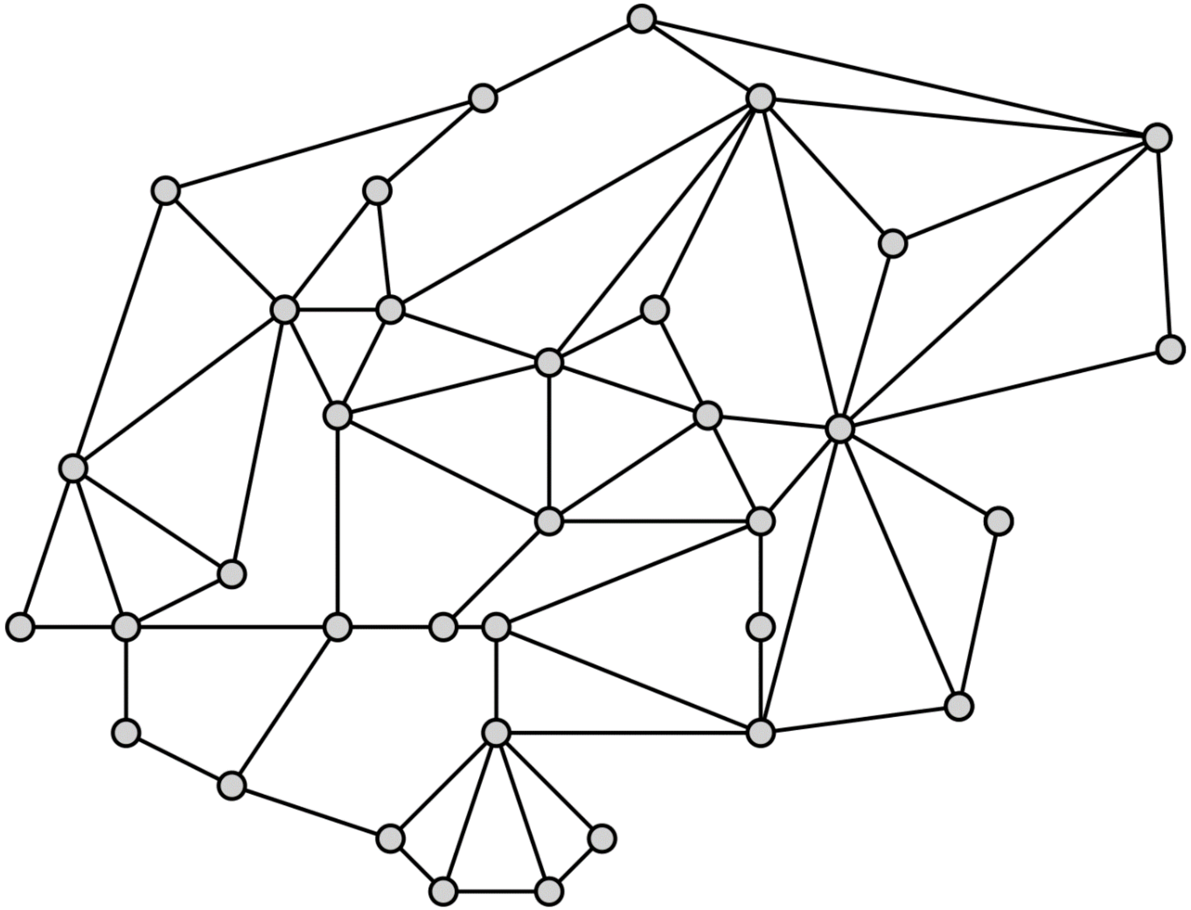

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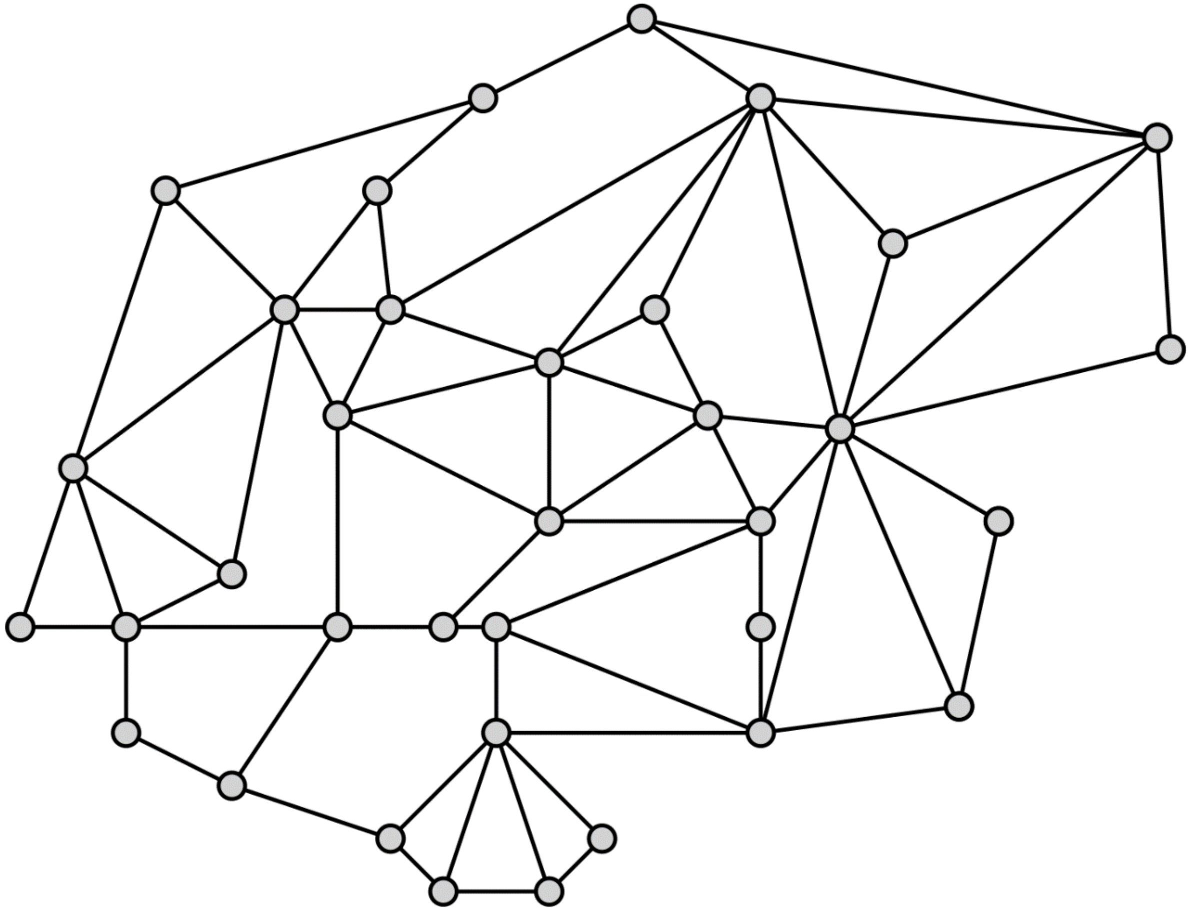

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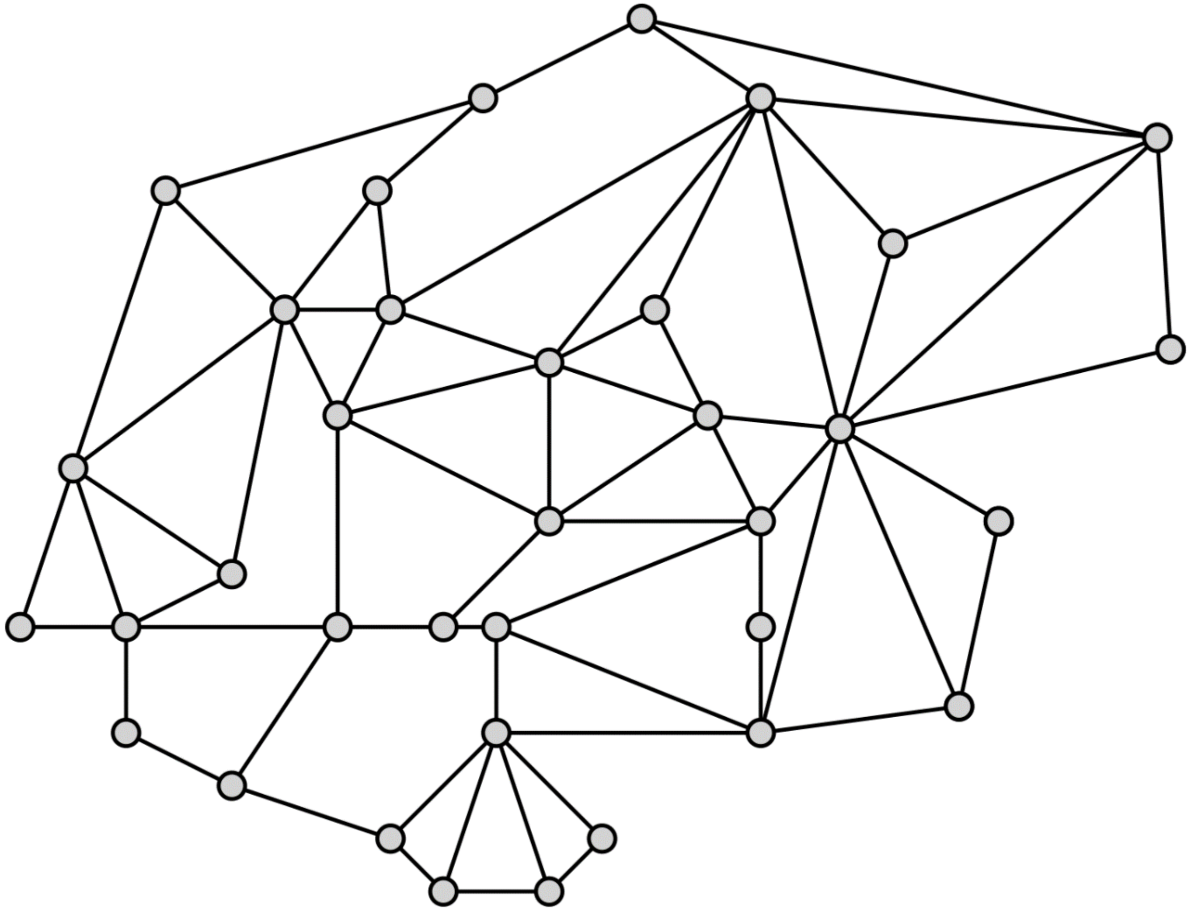

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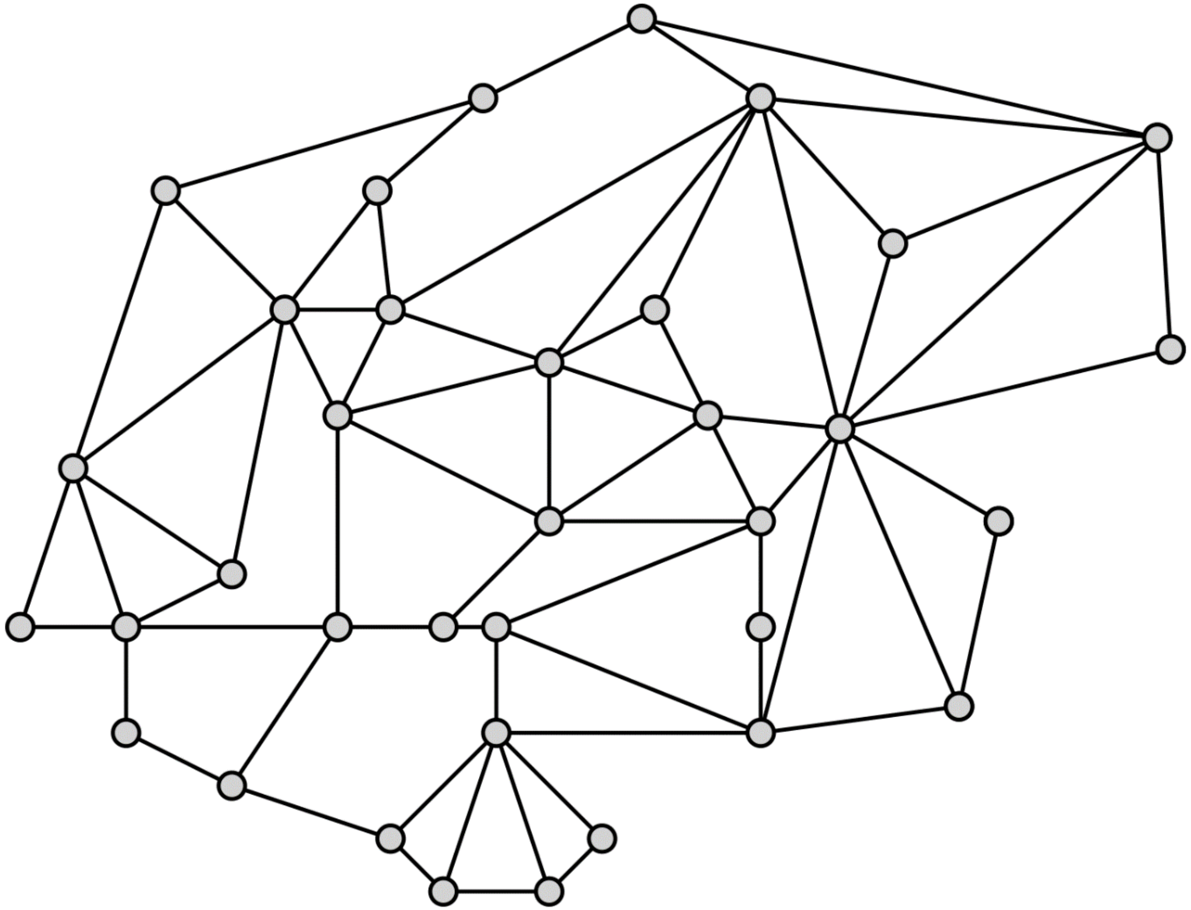
  number of rounds to solve the problem



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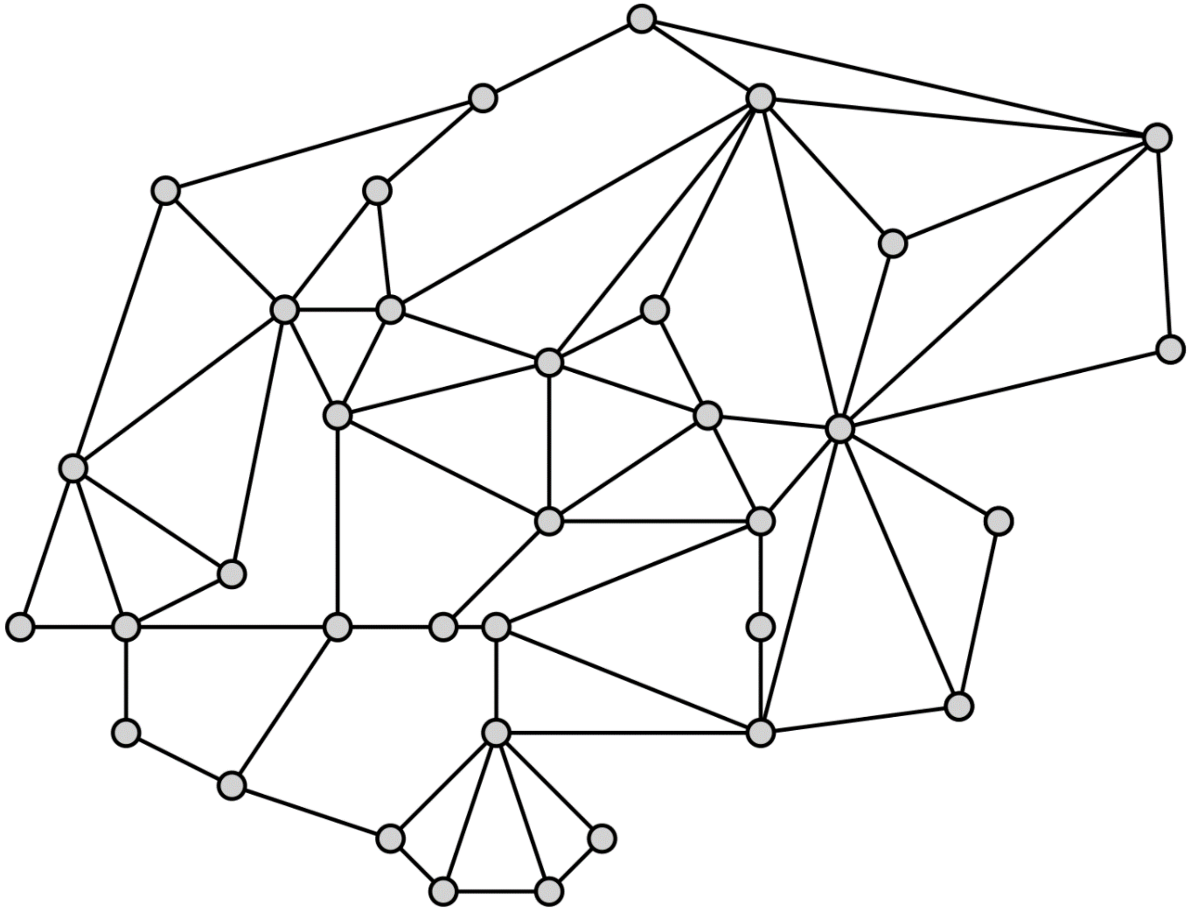

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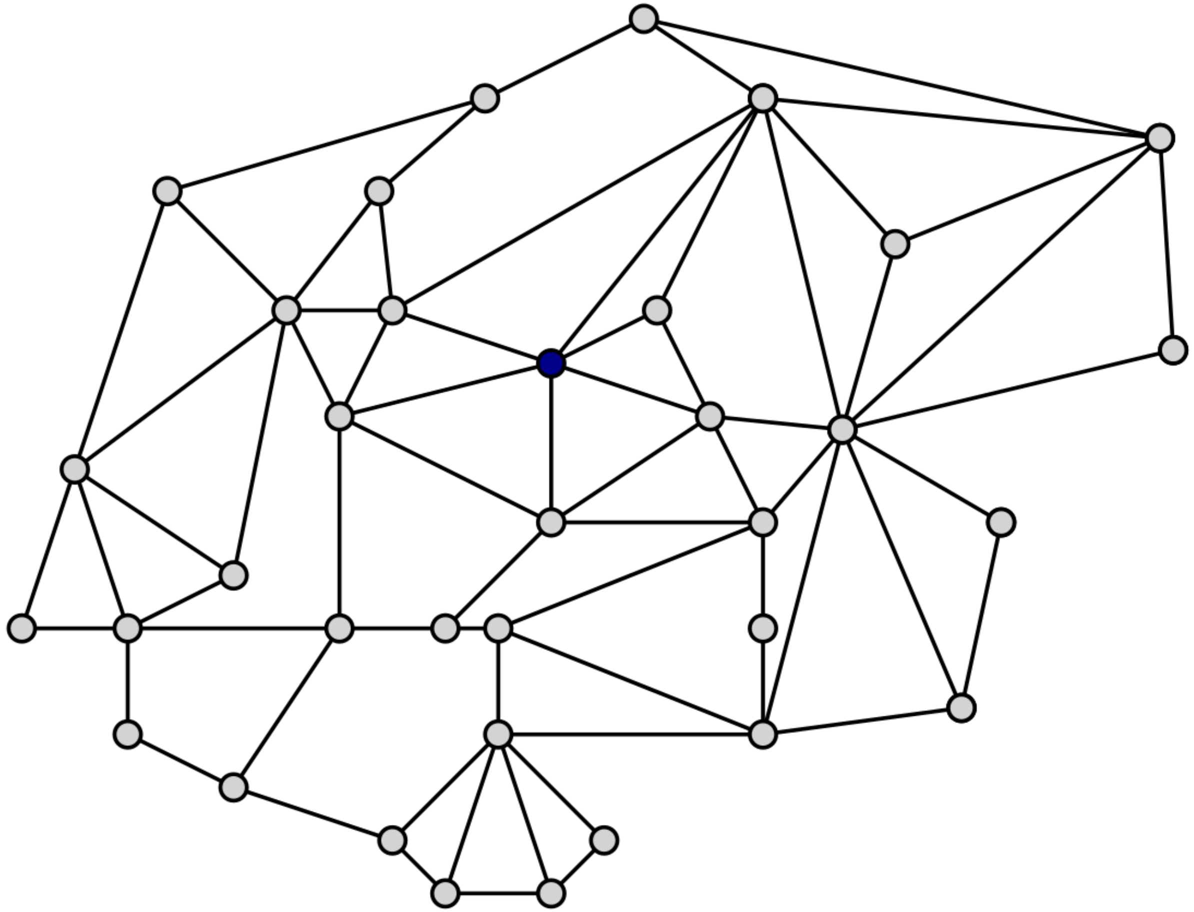

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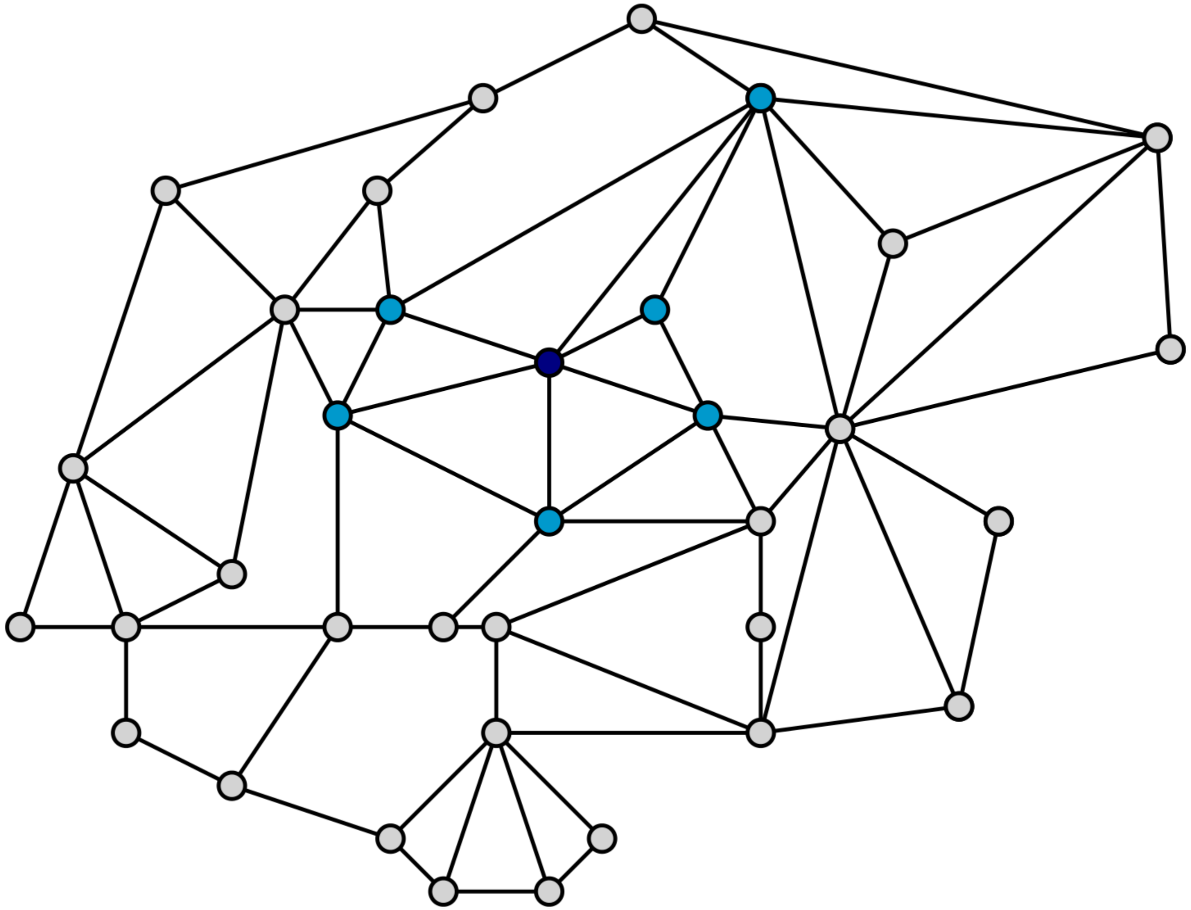

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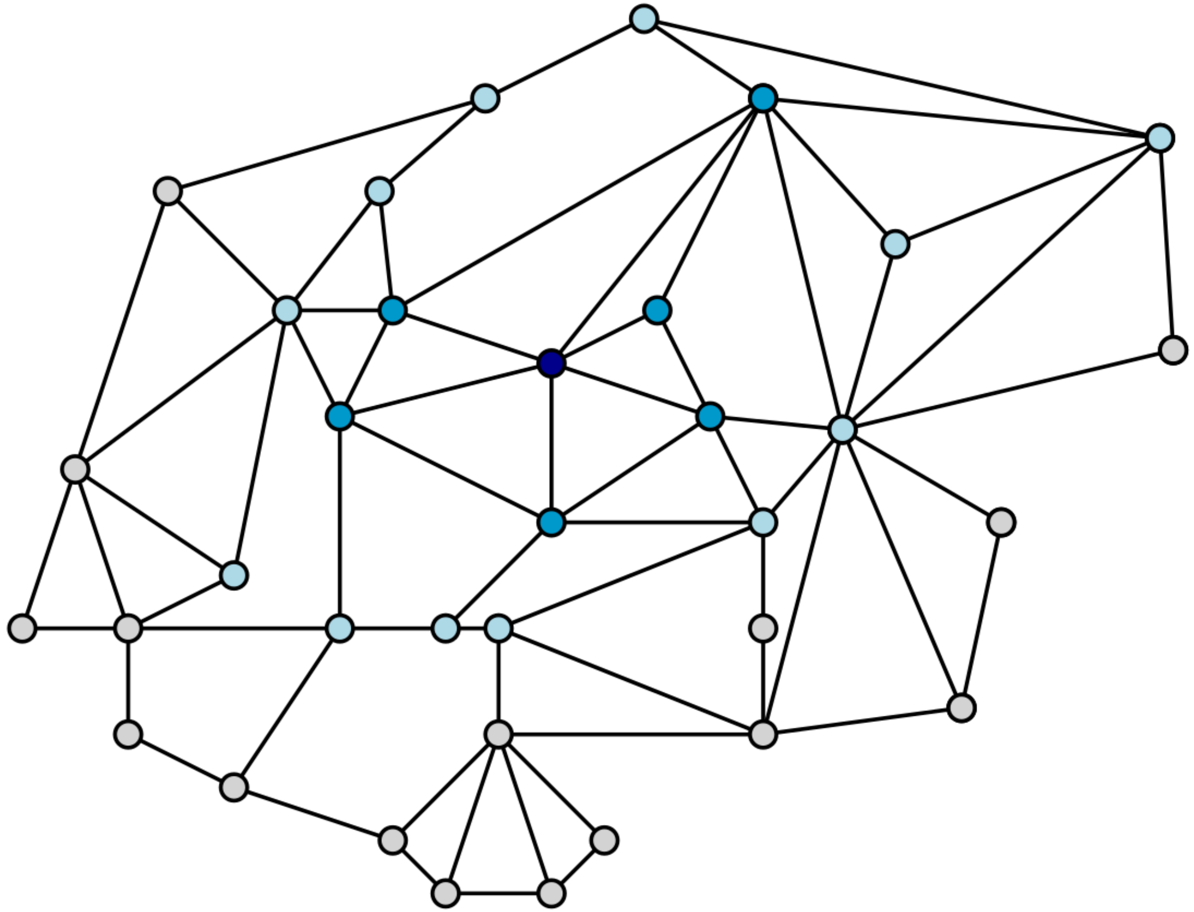

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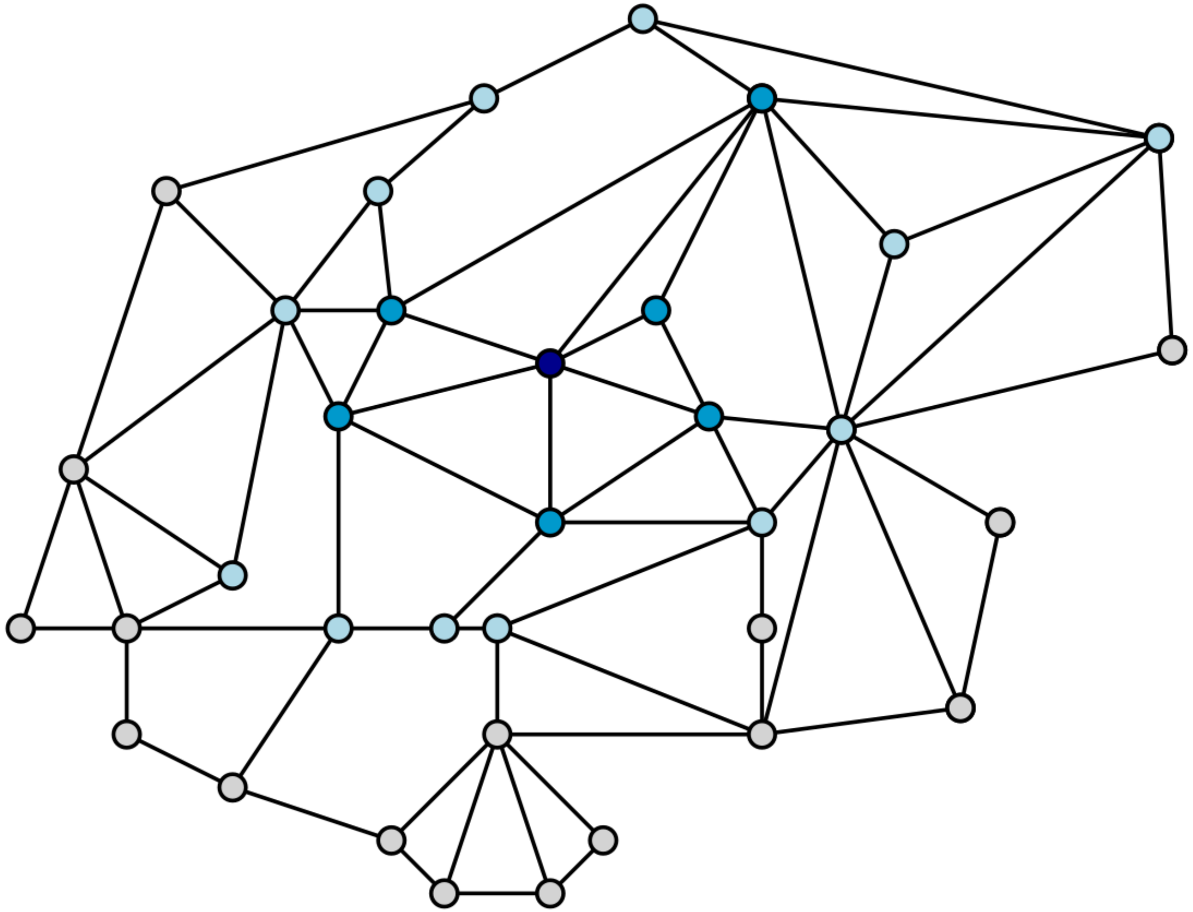

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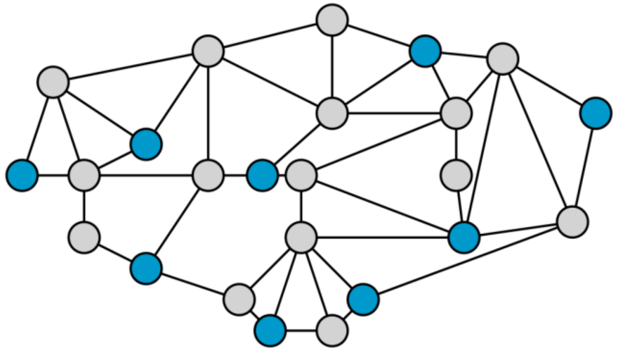
round complexity of a problem in the LOCAL model characterizes its locality

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

Classic LOCAL Graph Problems

Classic LOCAL Graph Problems

Maximal Independent Set



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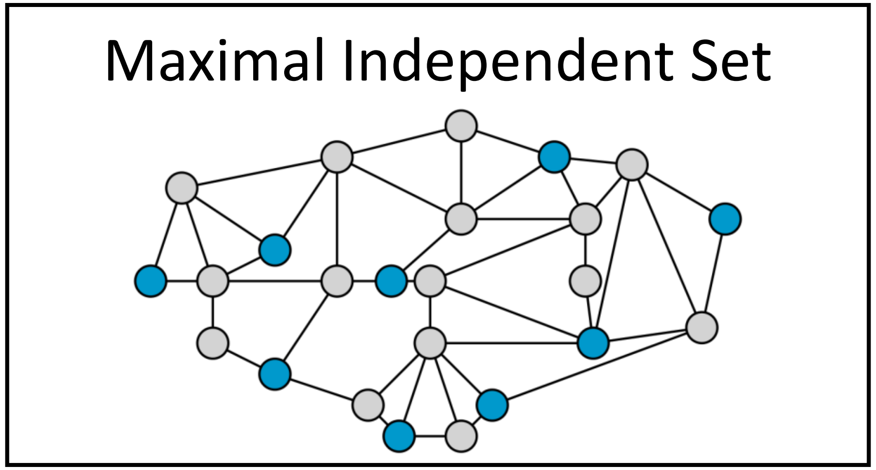

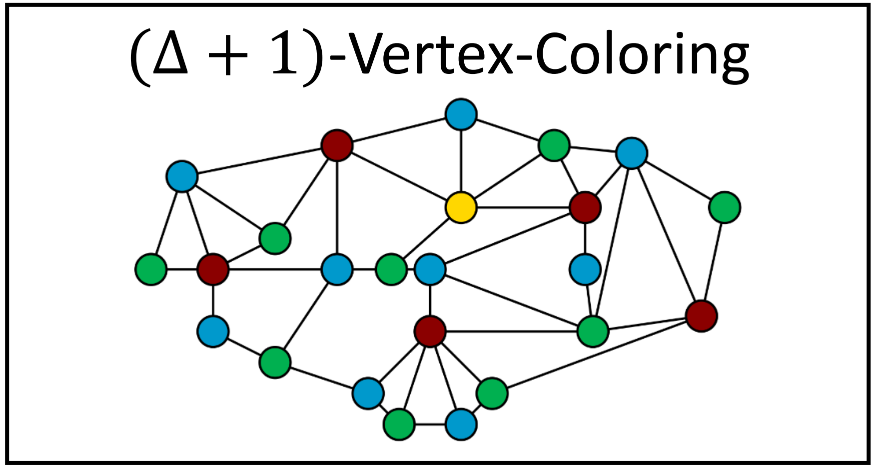

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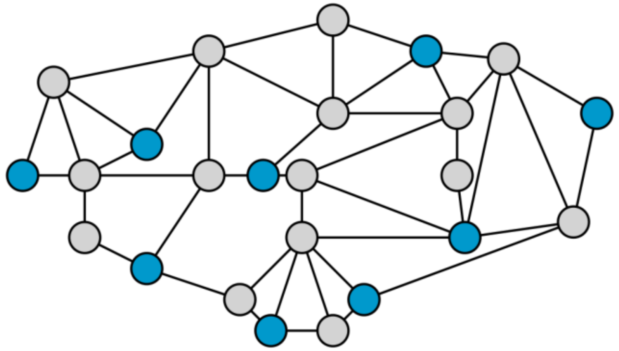
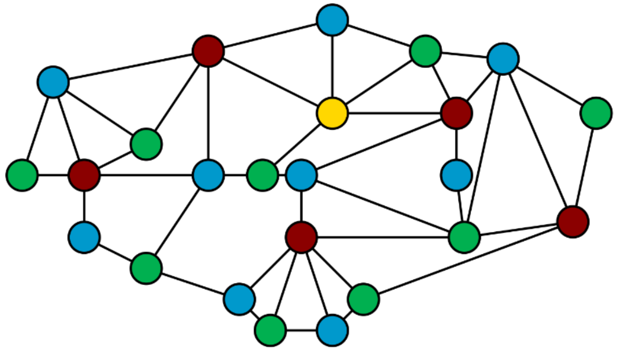
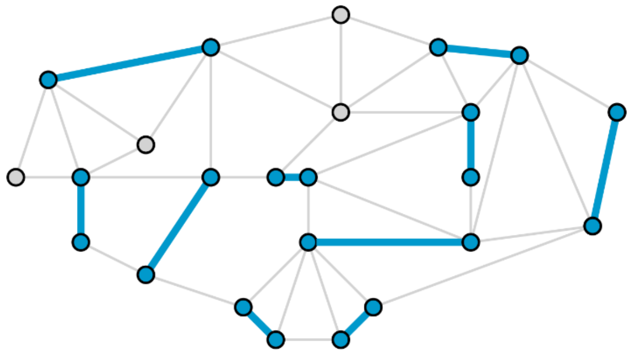


$(\Delta + 1)$-Vertex-Coloring



Maximal Matching



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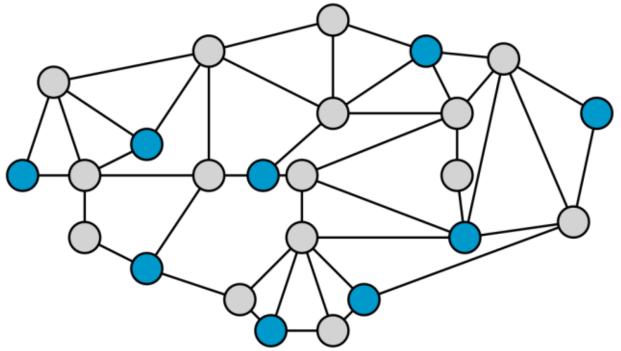

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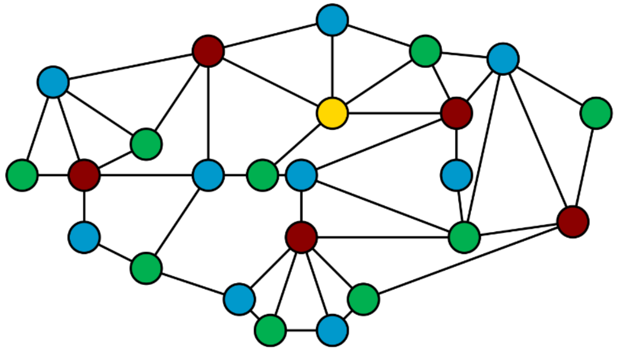

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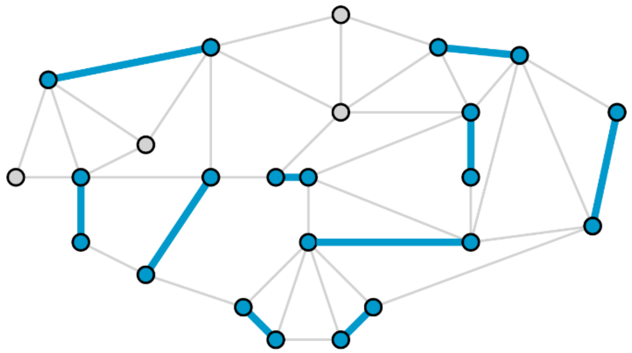
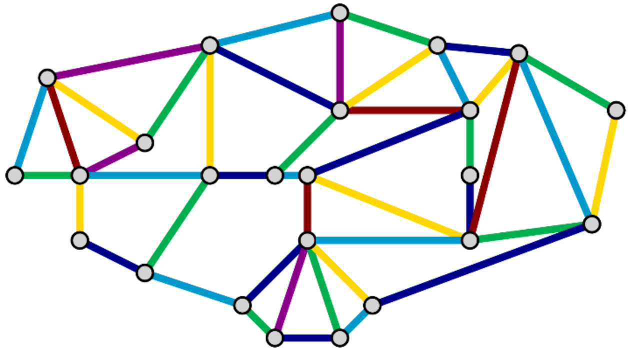


$(2\Delta - 1)$-Edge-Coloring



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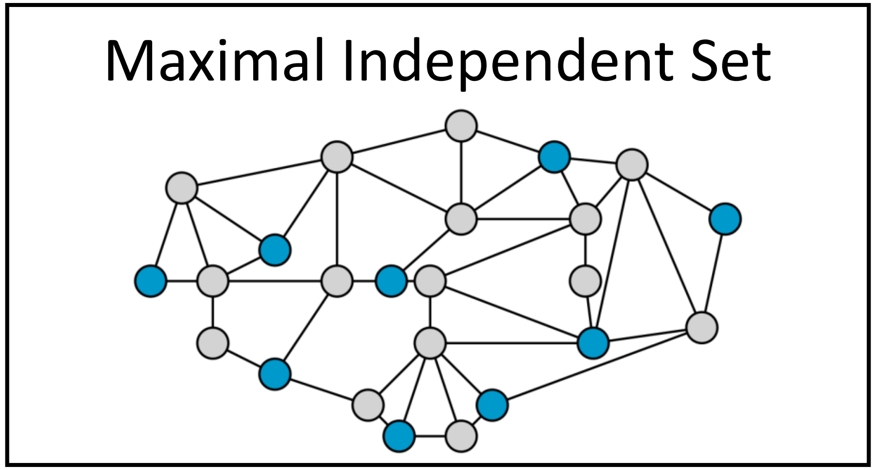
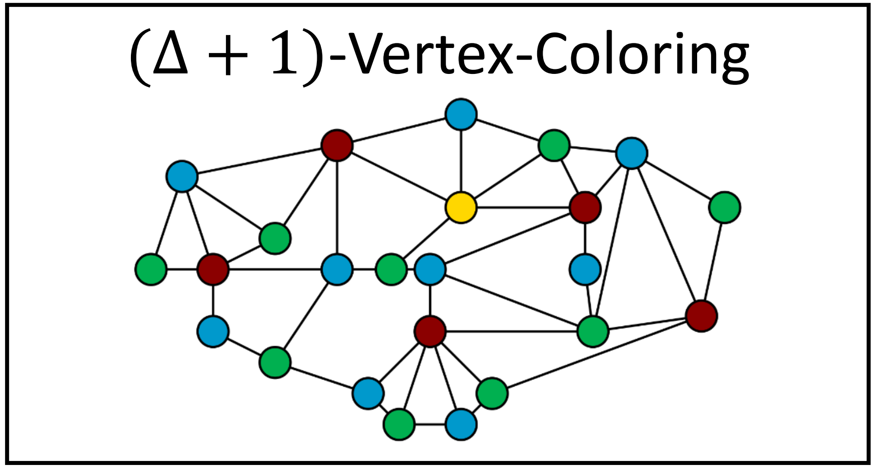
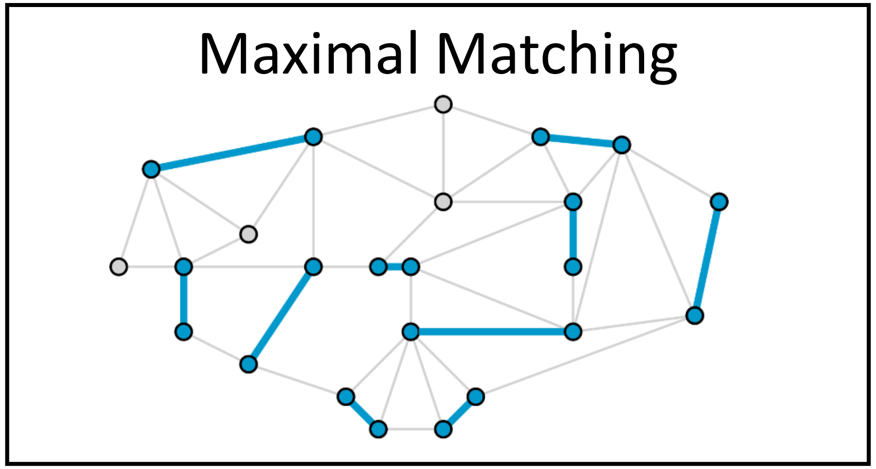
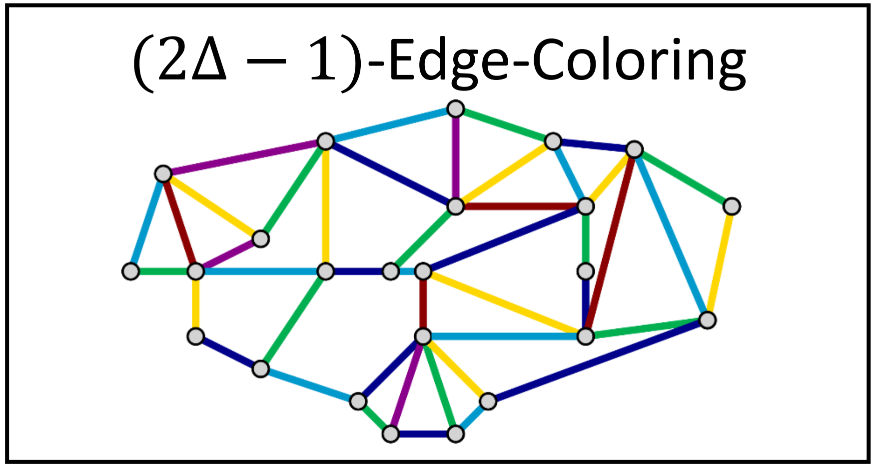




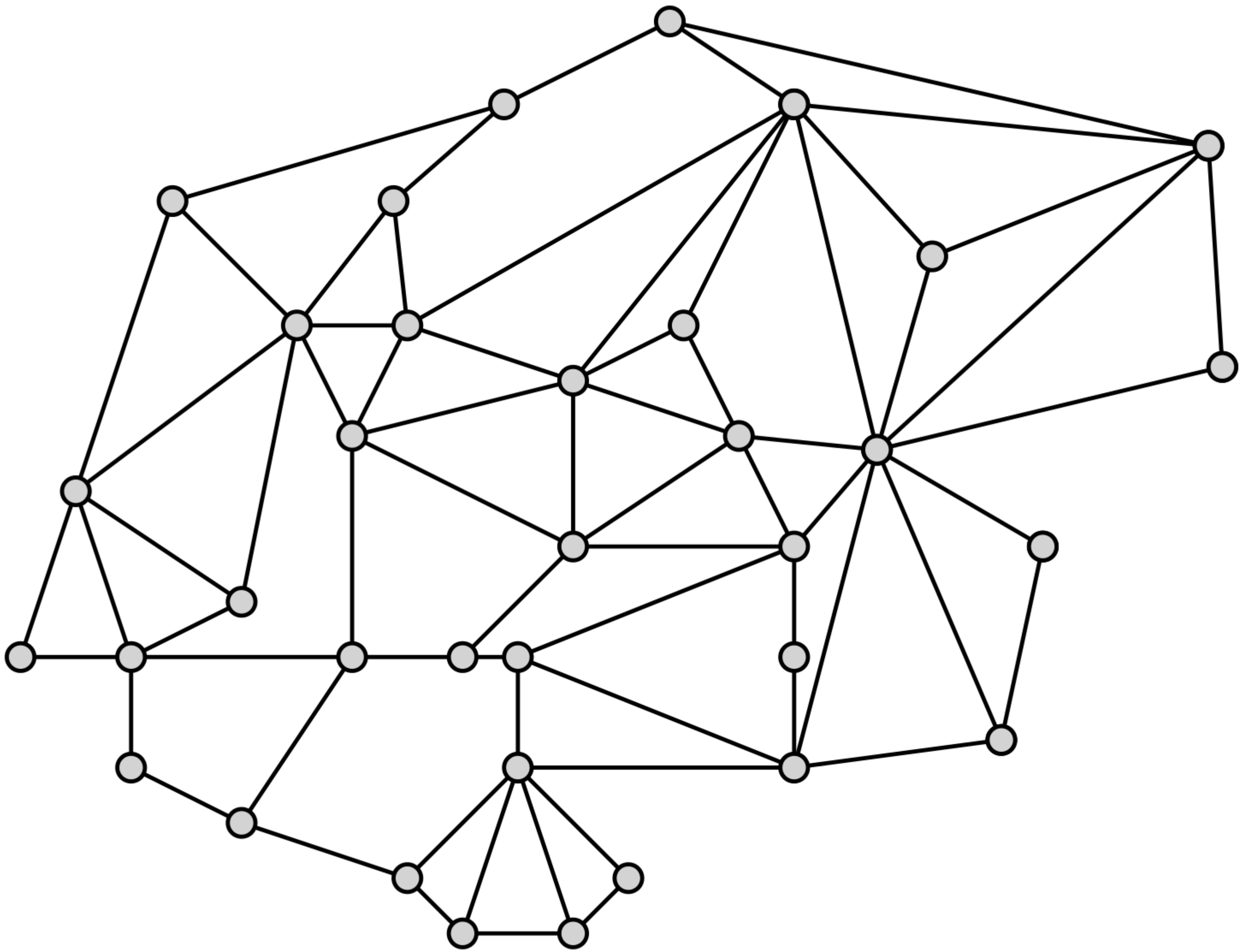




Easy centralized problems: greedy solutions.

Maximal Matching

Maximal Matching



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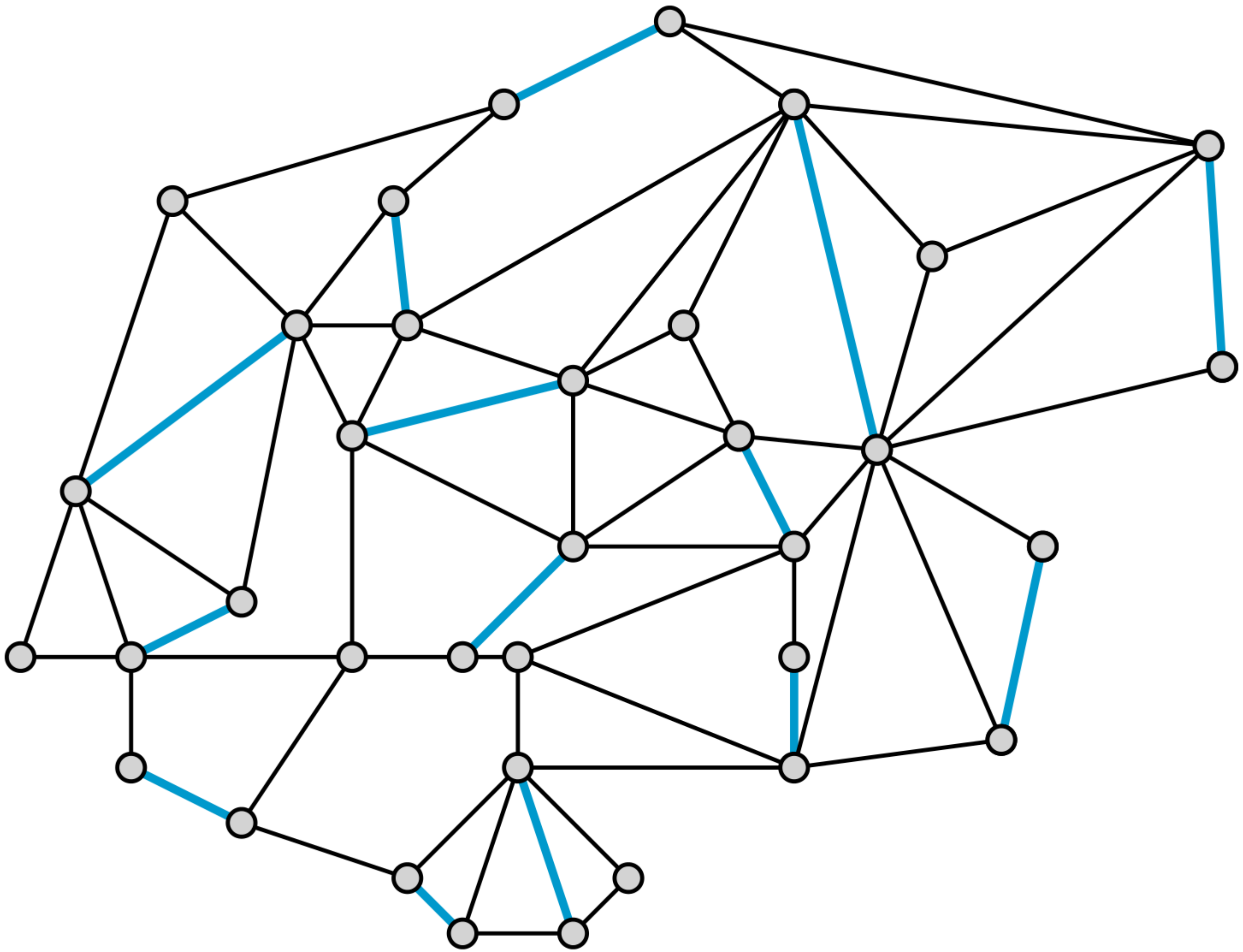
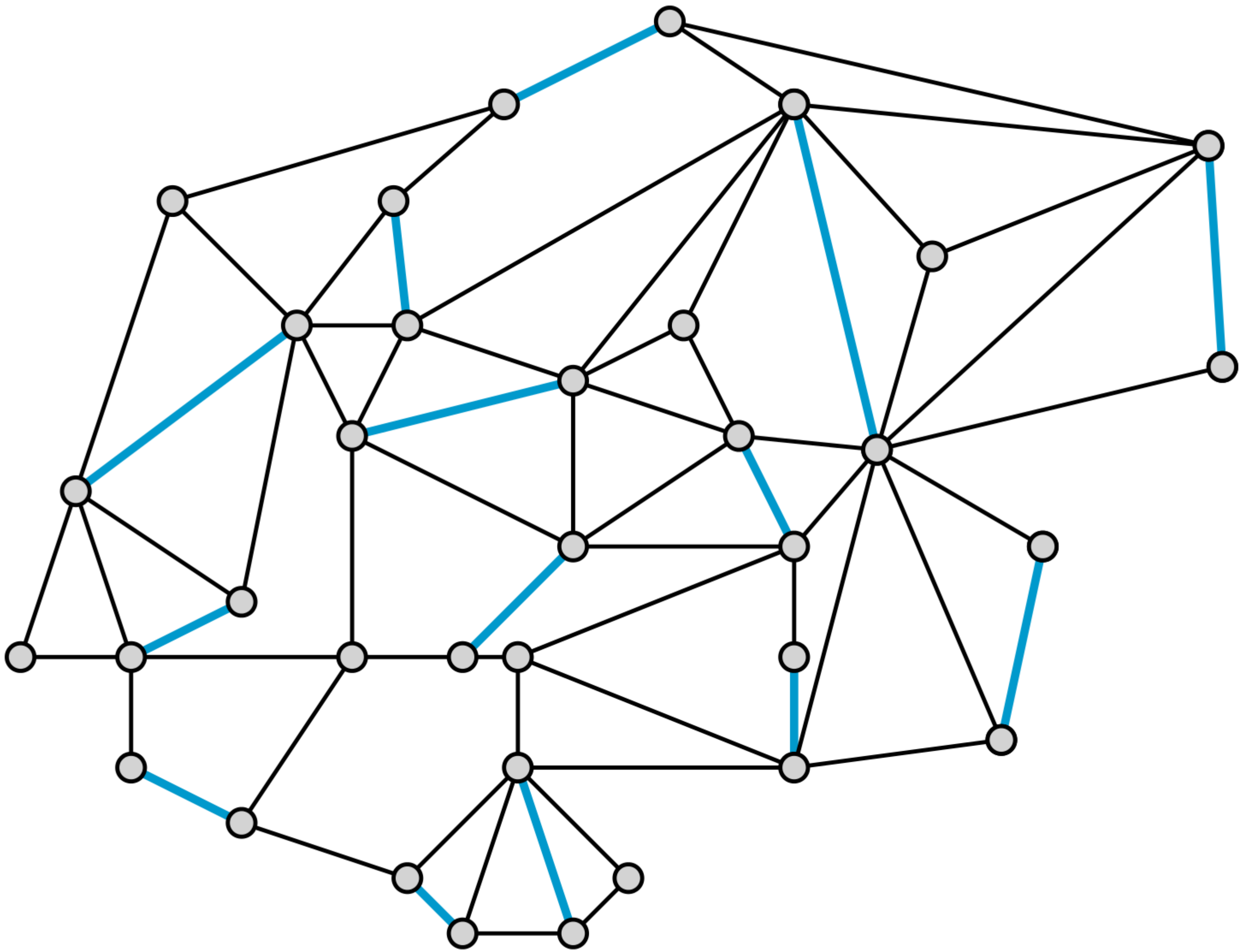


Maximal Matching

Matching:
set of non-incident edges



Maximal Matching

Matching:
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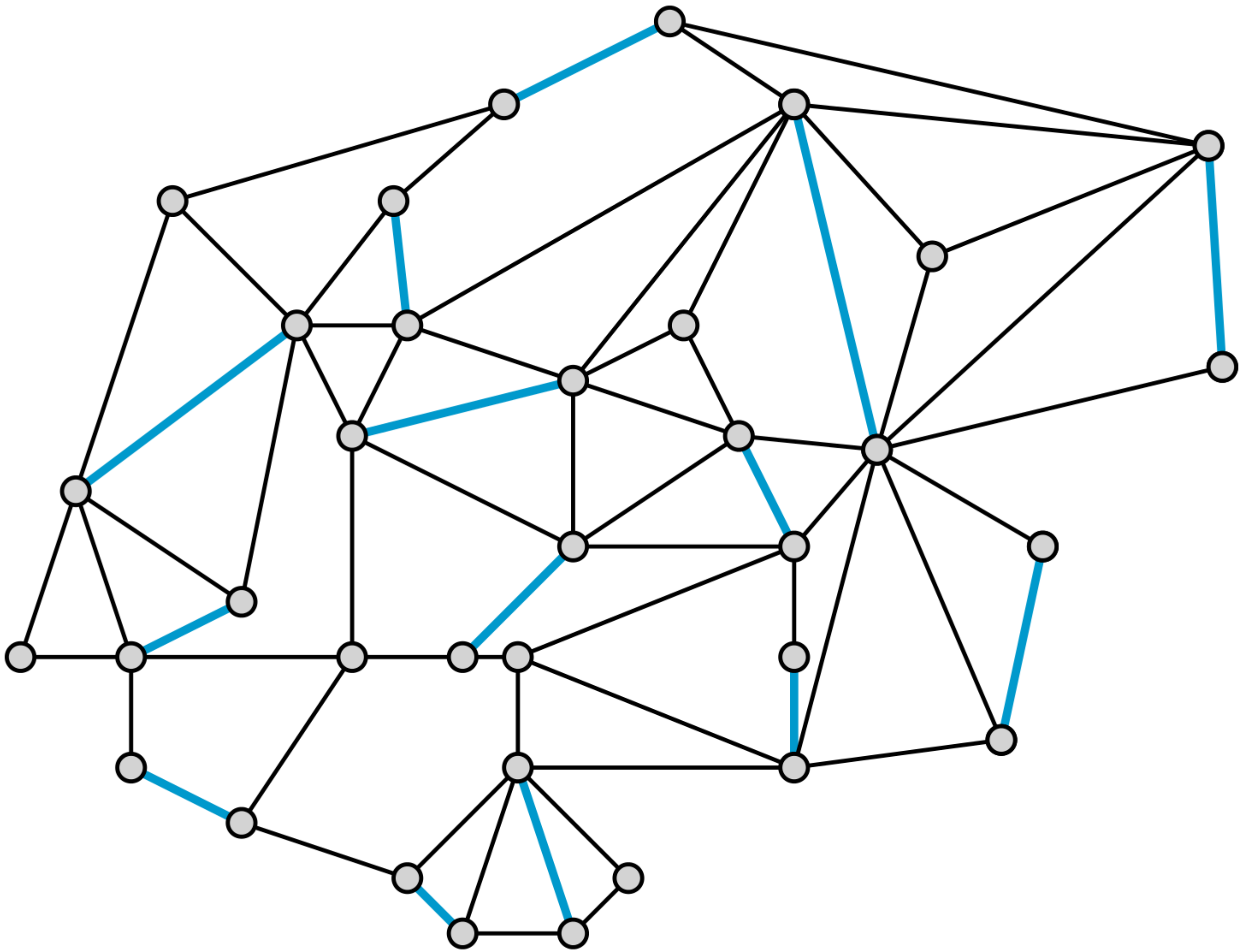
Maximal:
no edge can be added



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Maximal:
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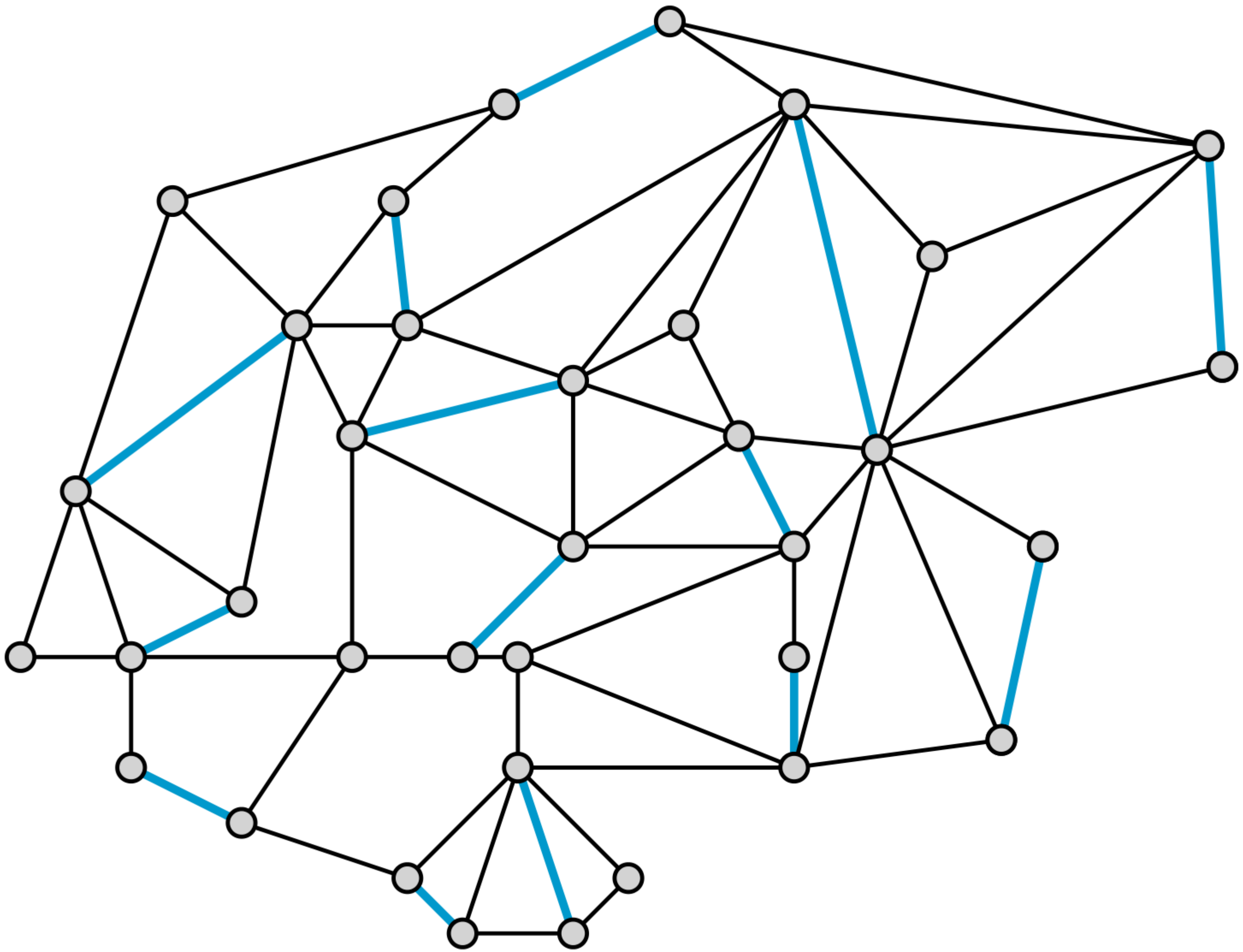
greedy property!



Centralized (Sequential) Algorithm

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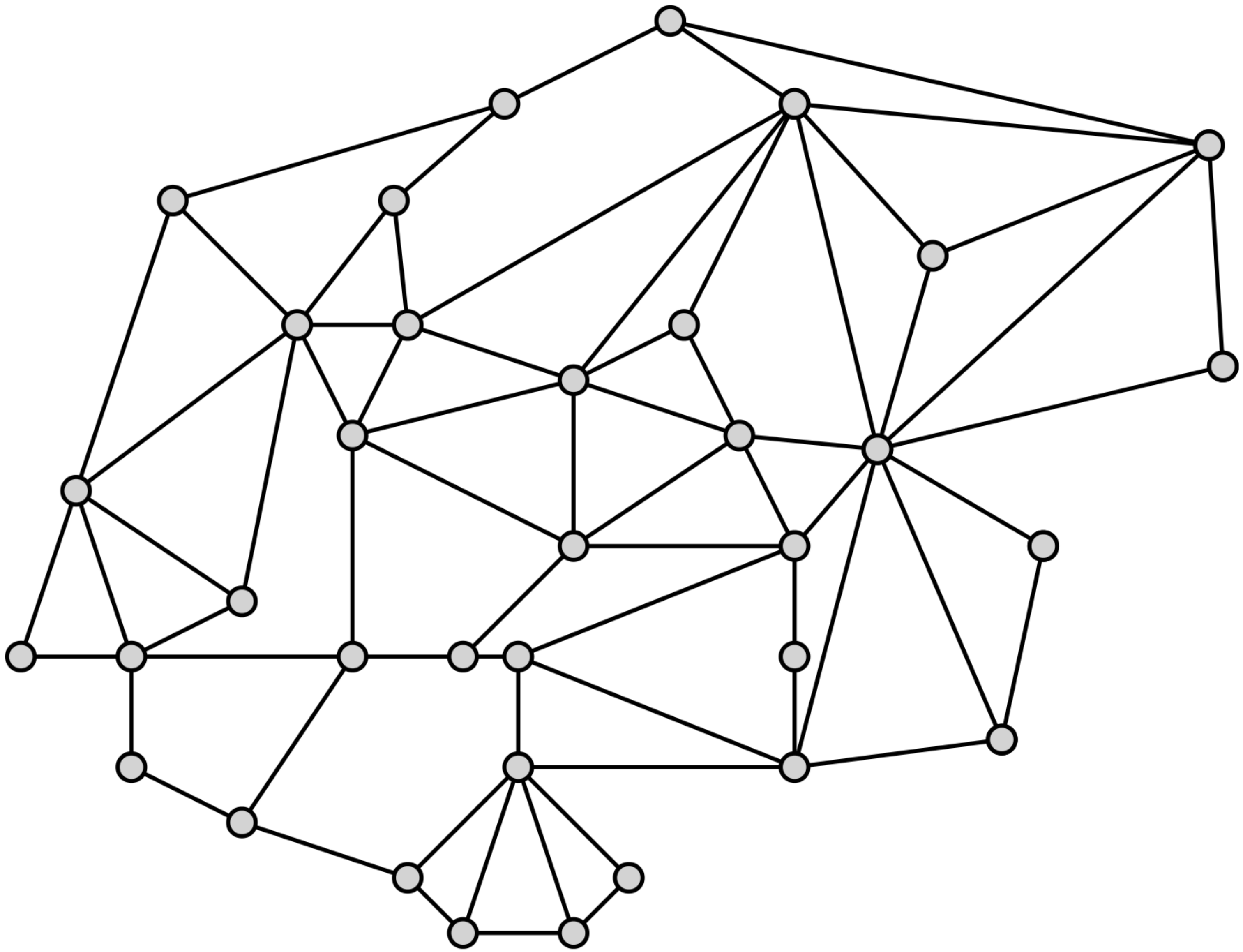

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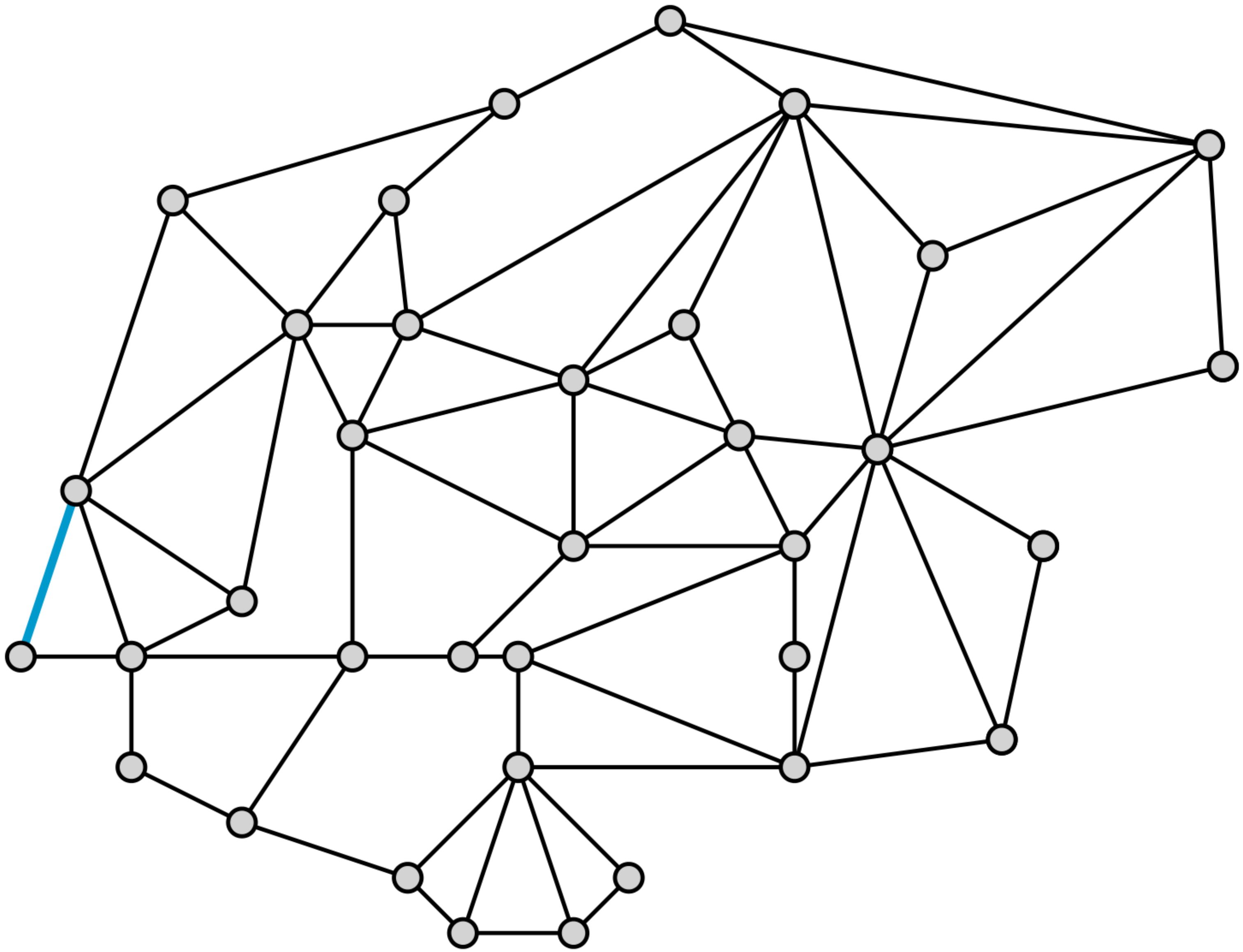

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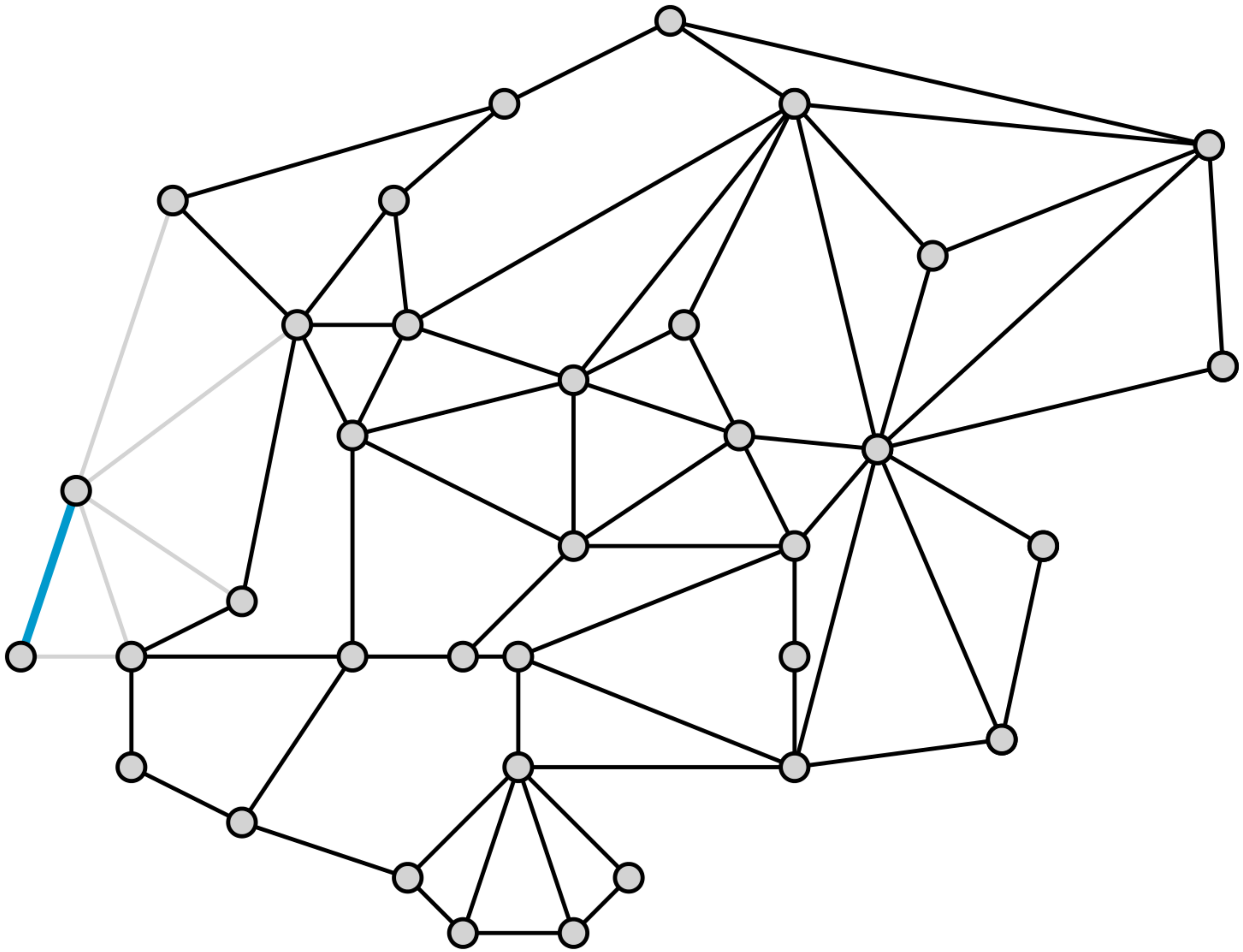

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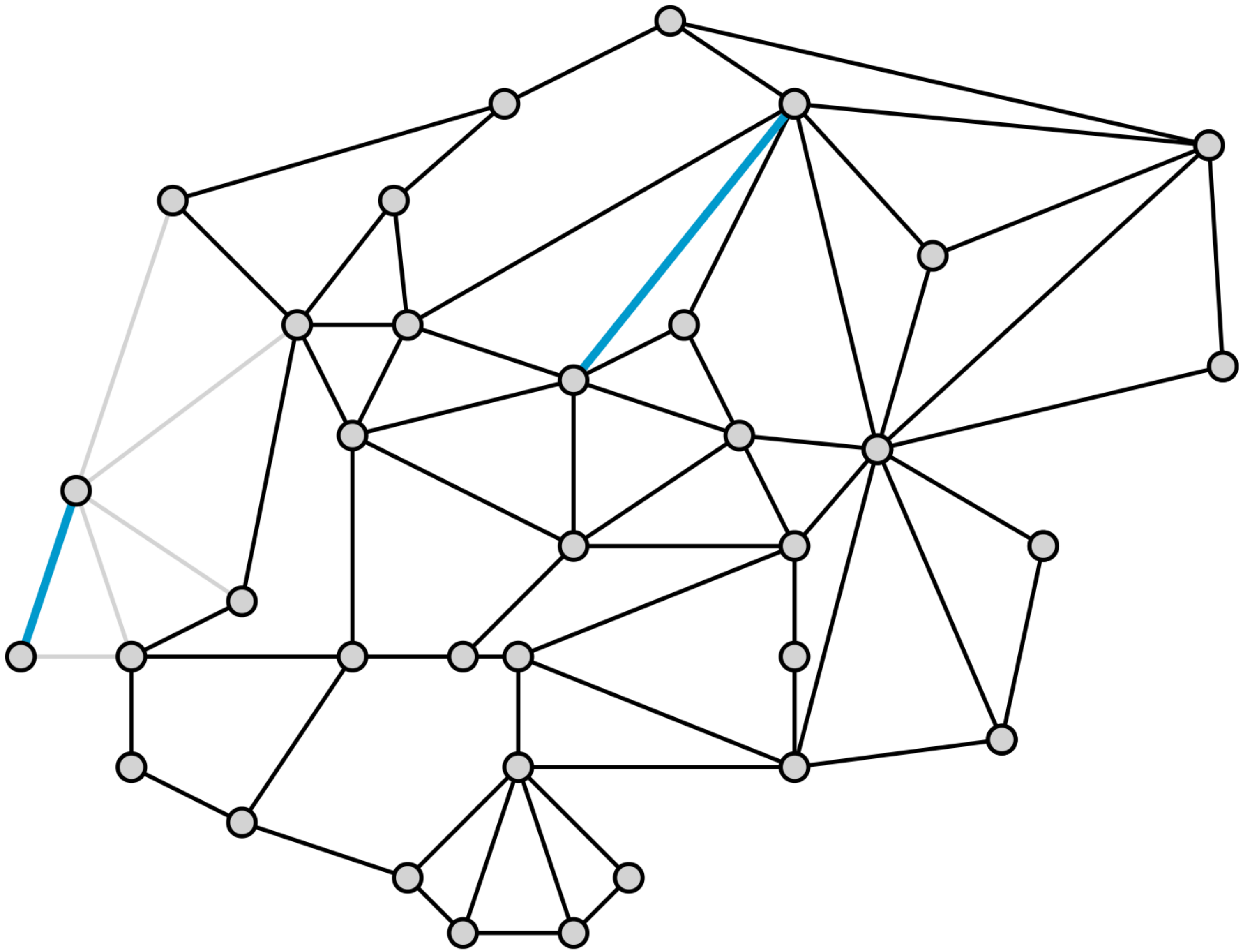

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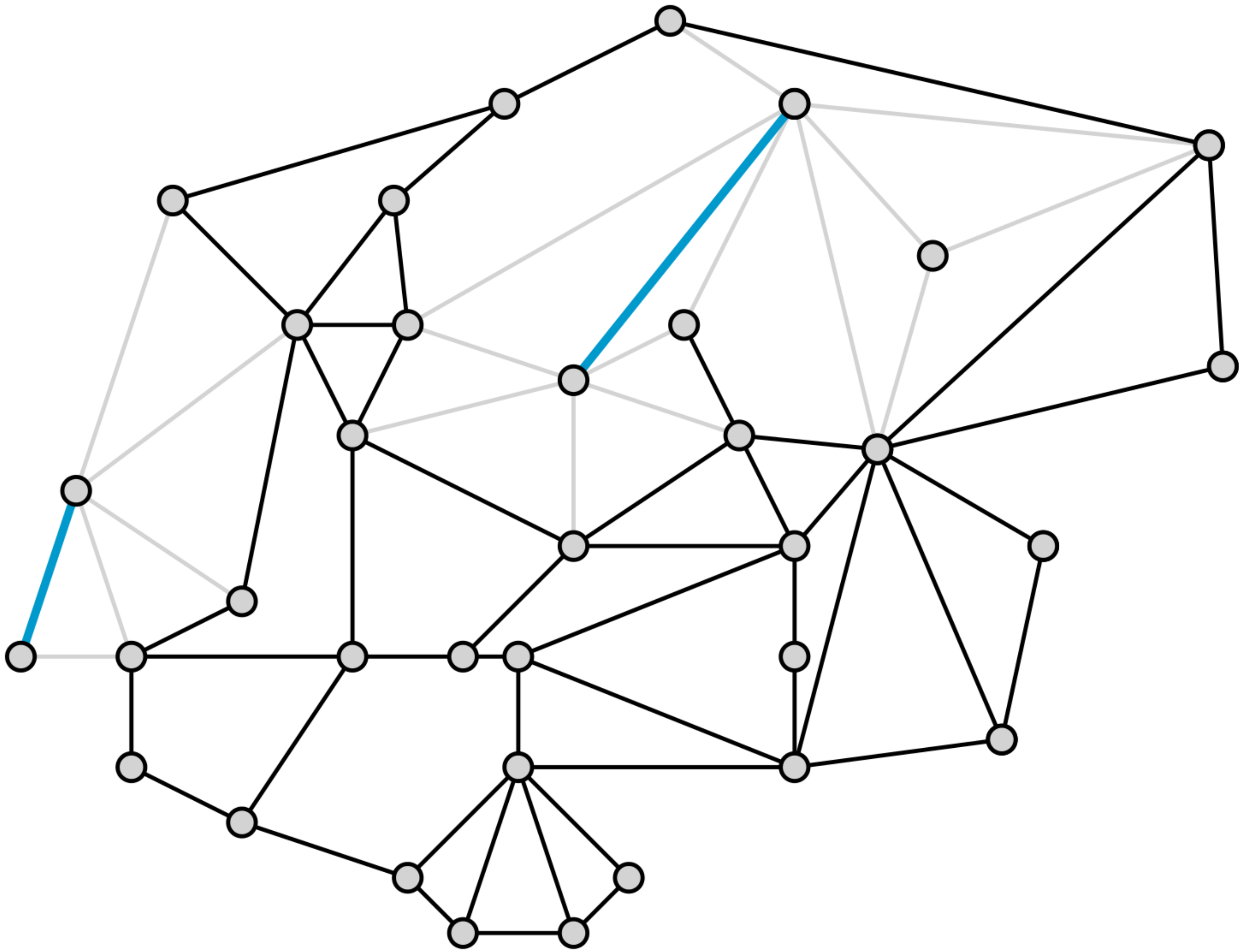

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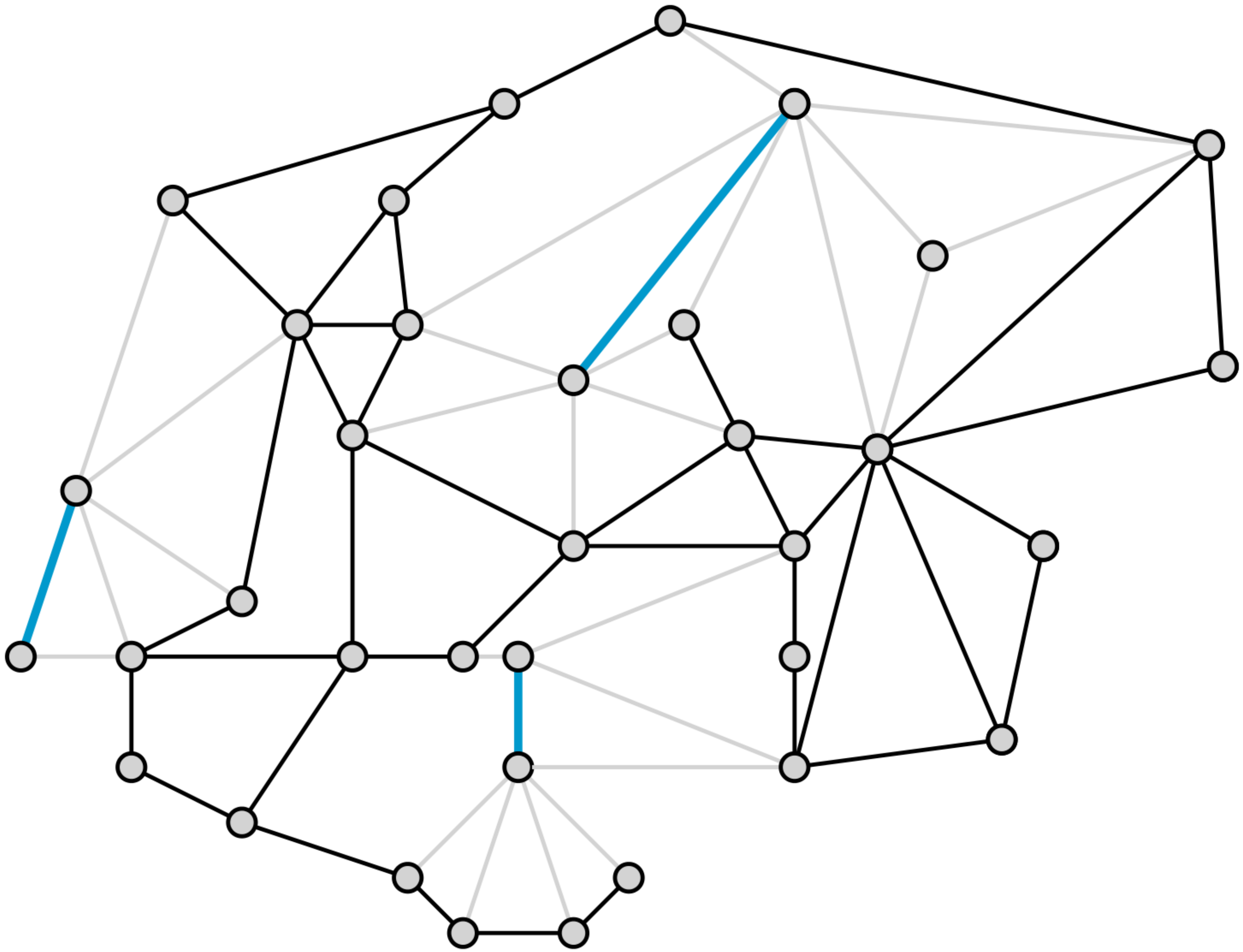

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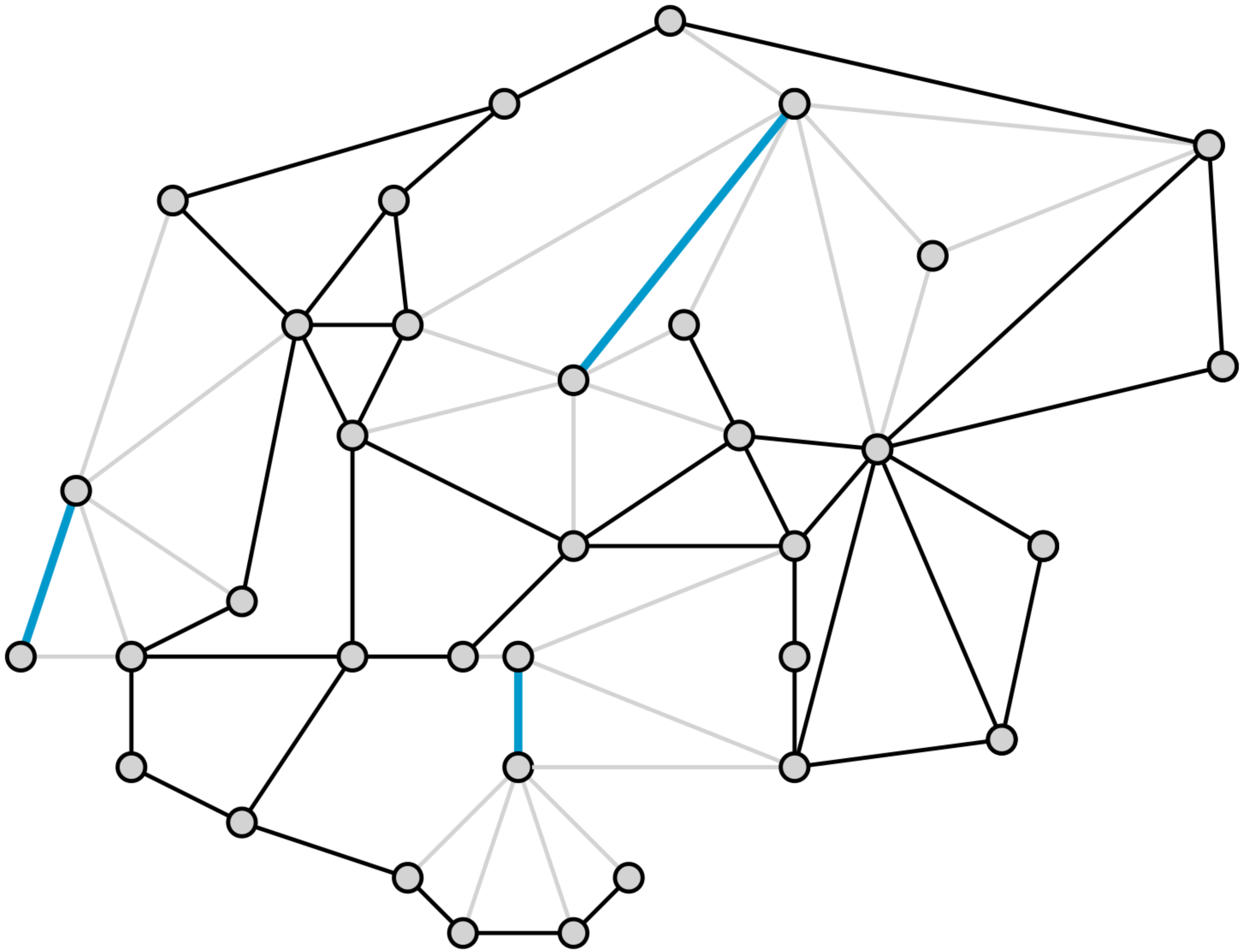

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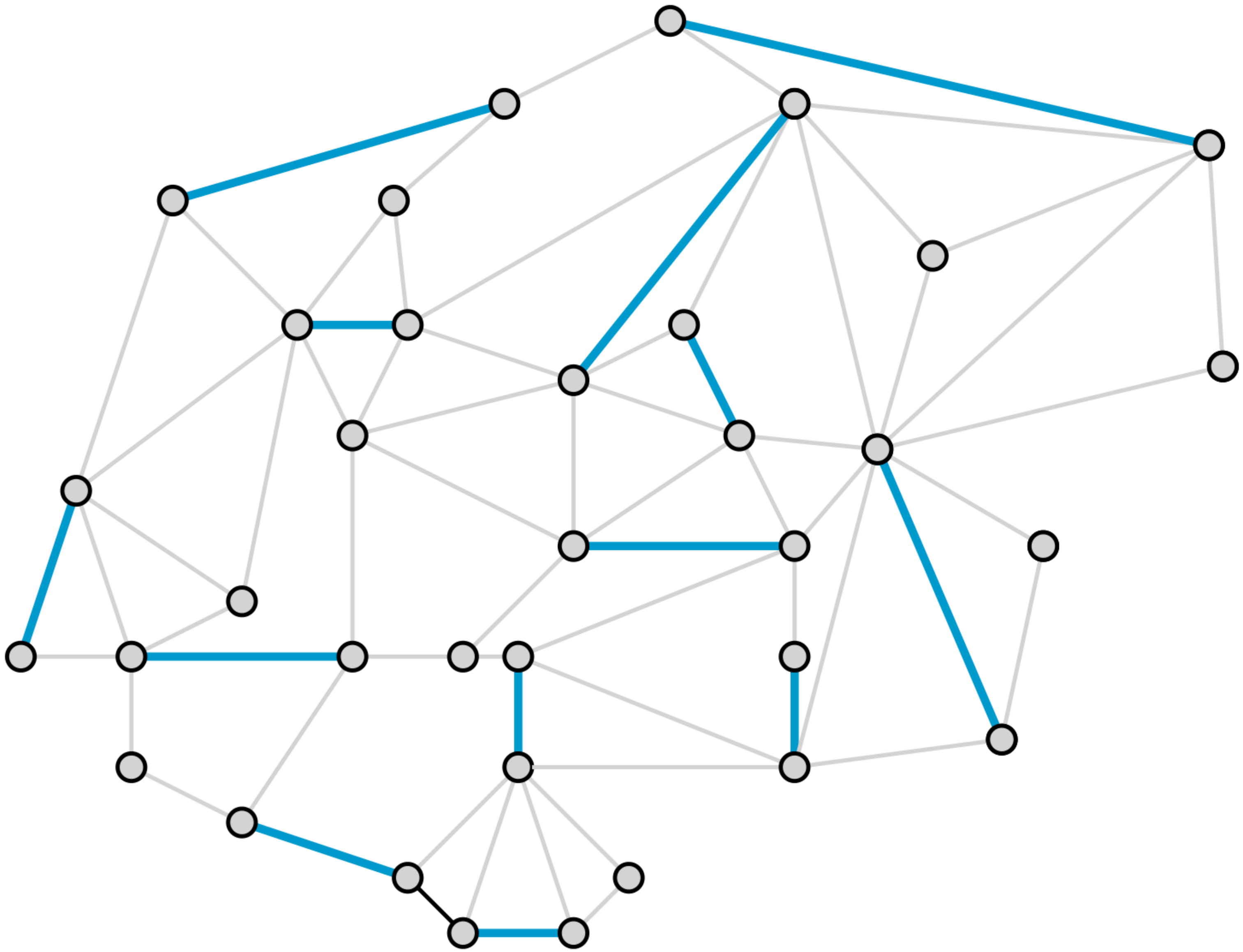

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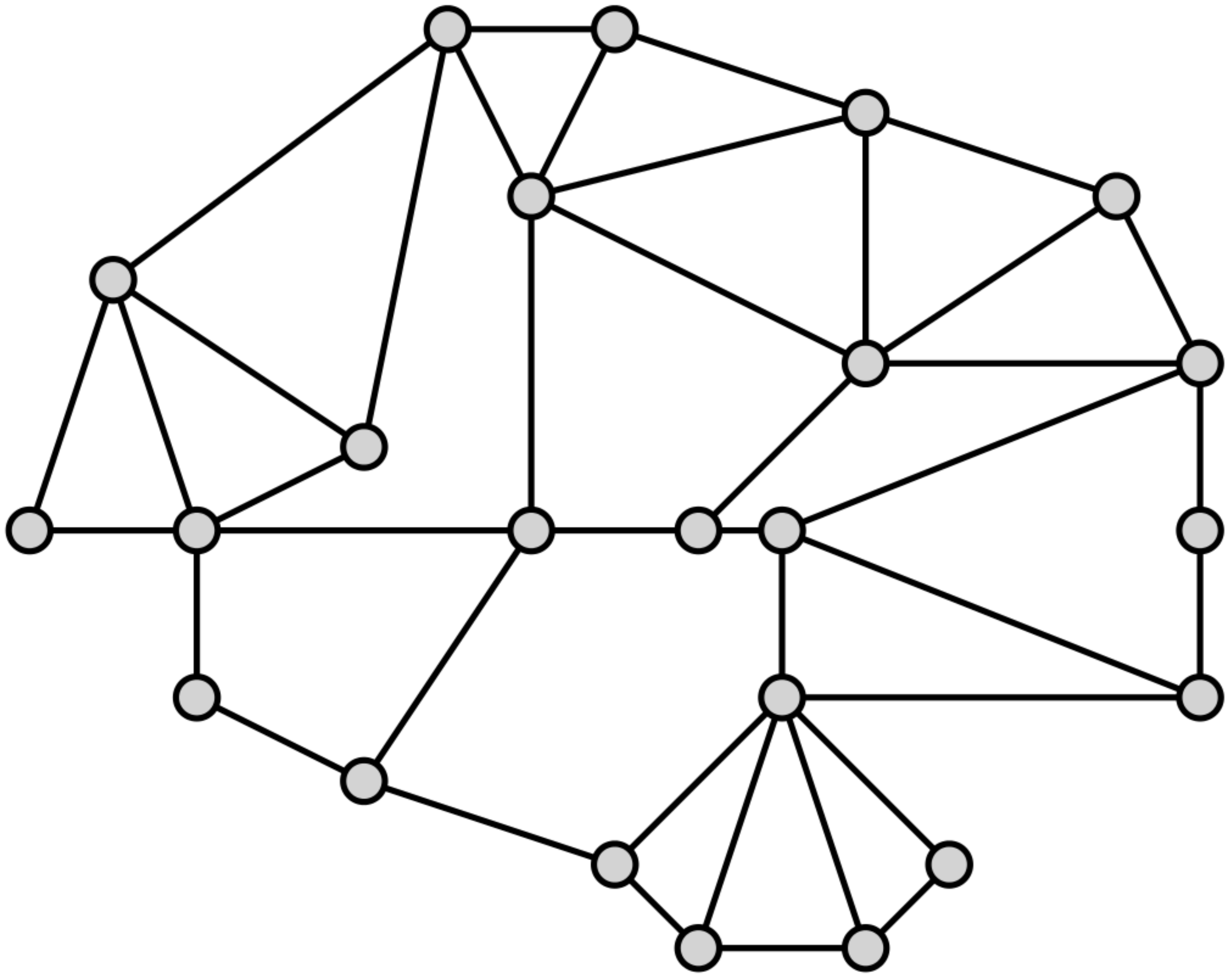

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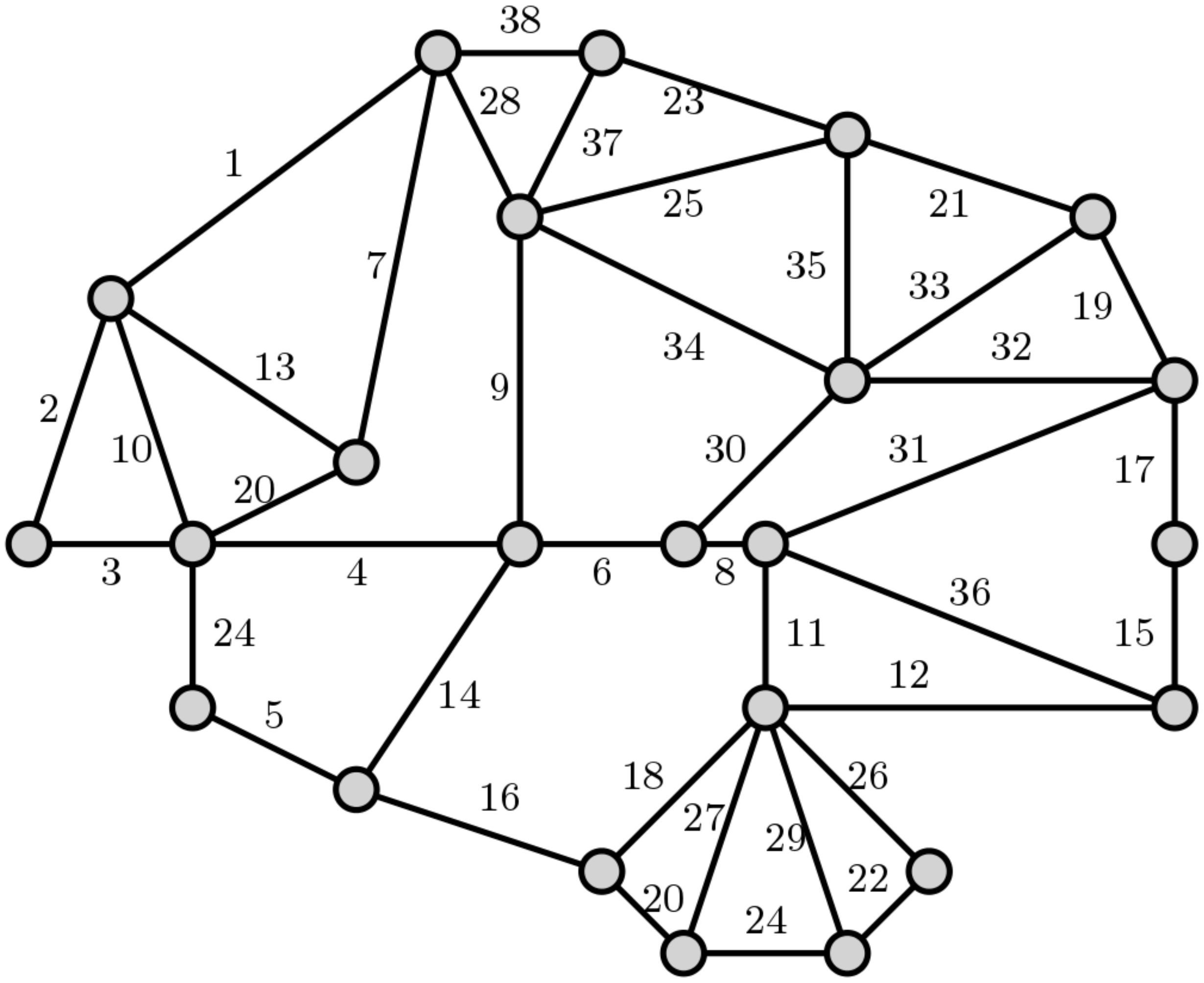

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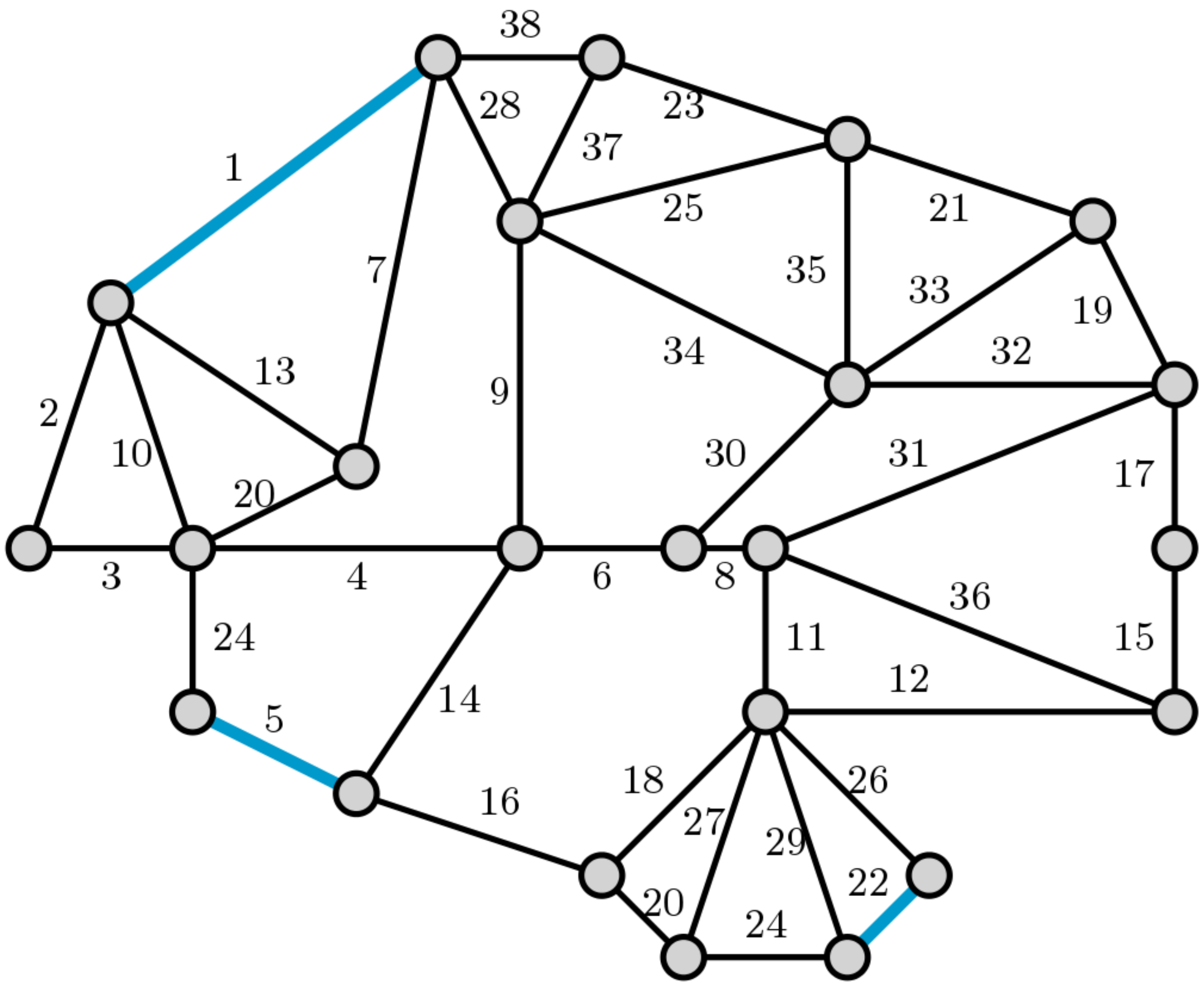

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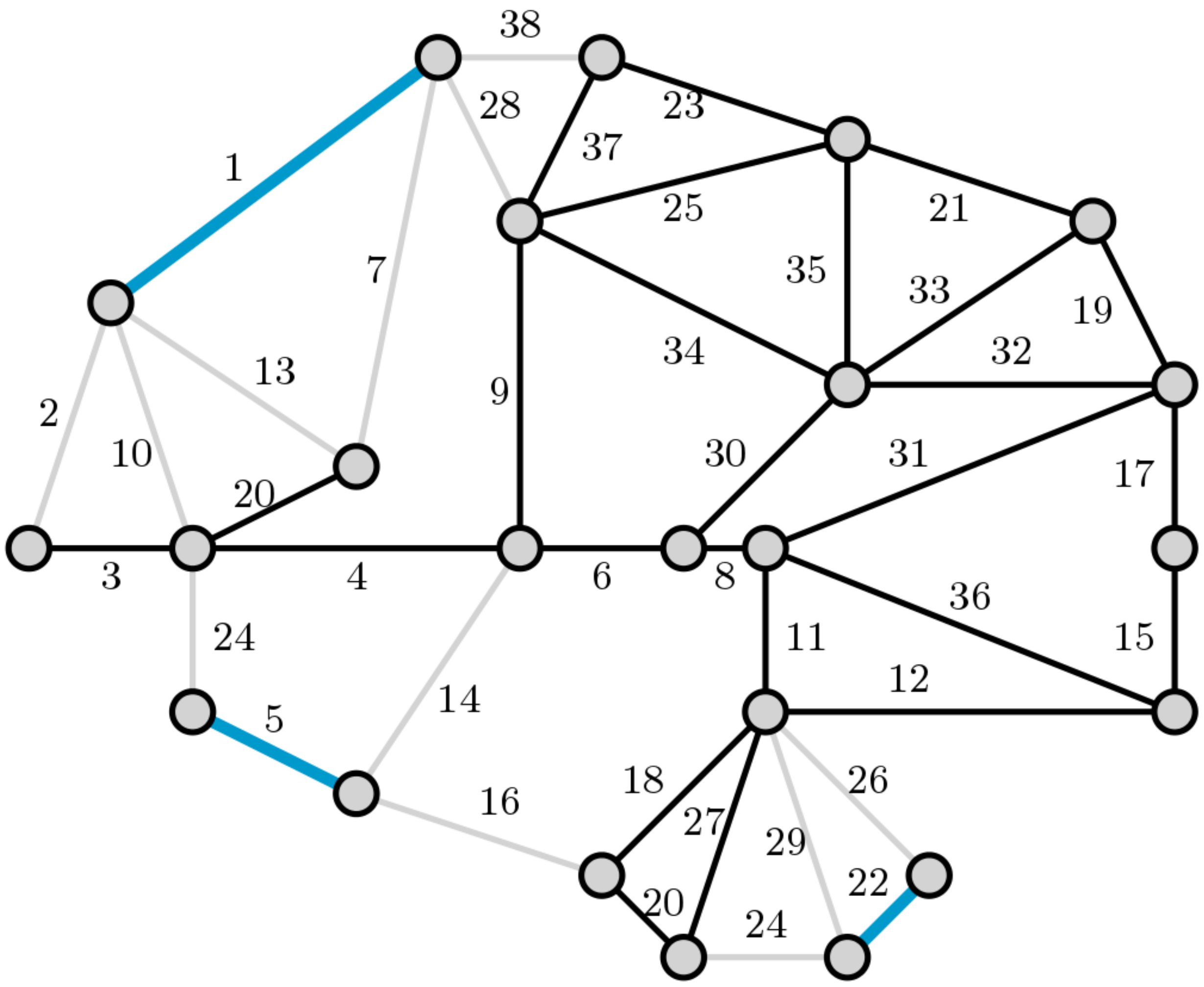

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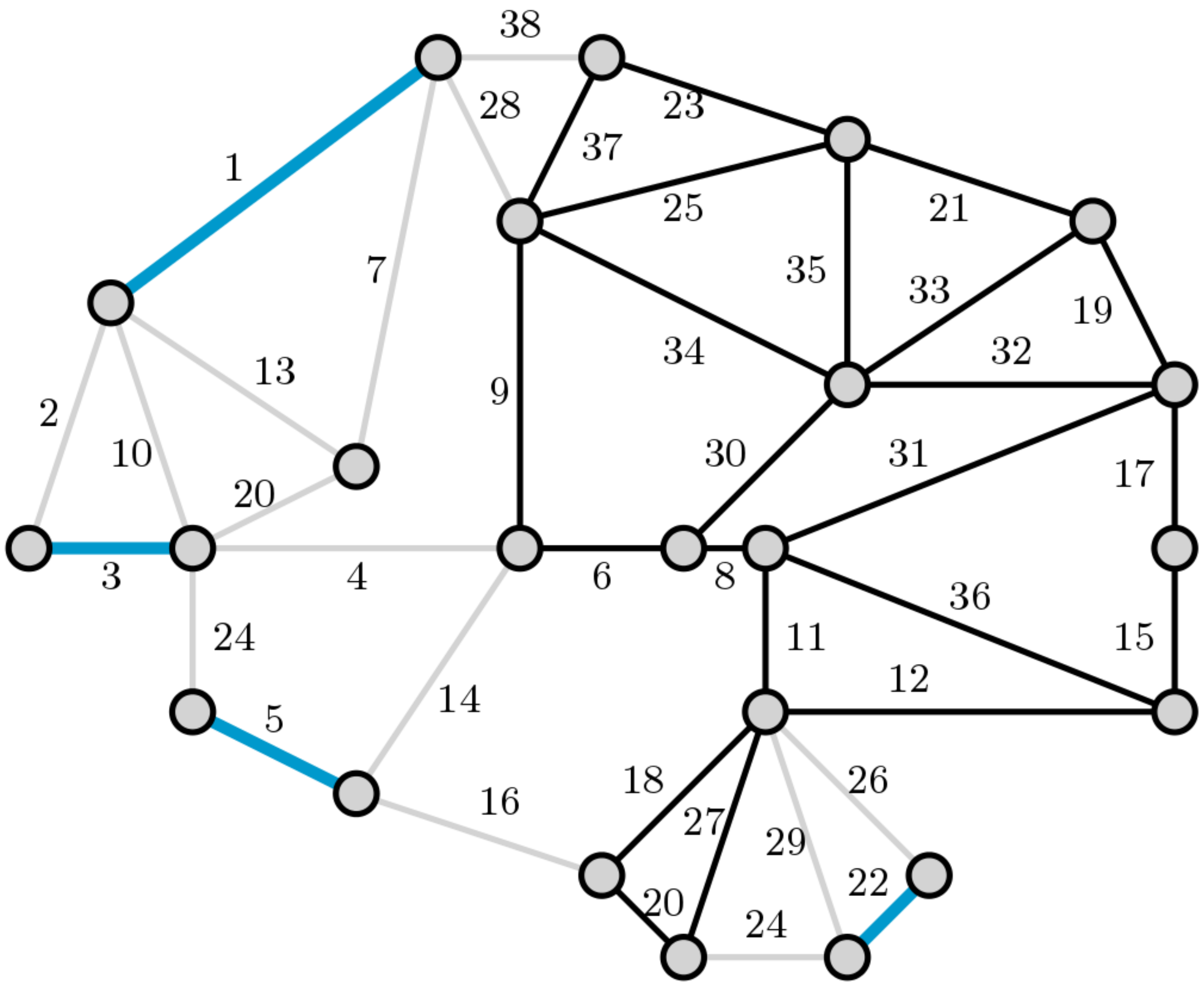

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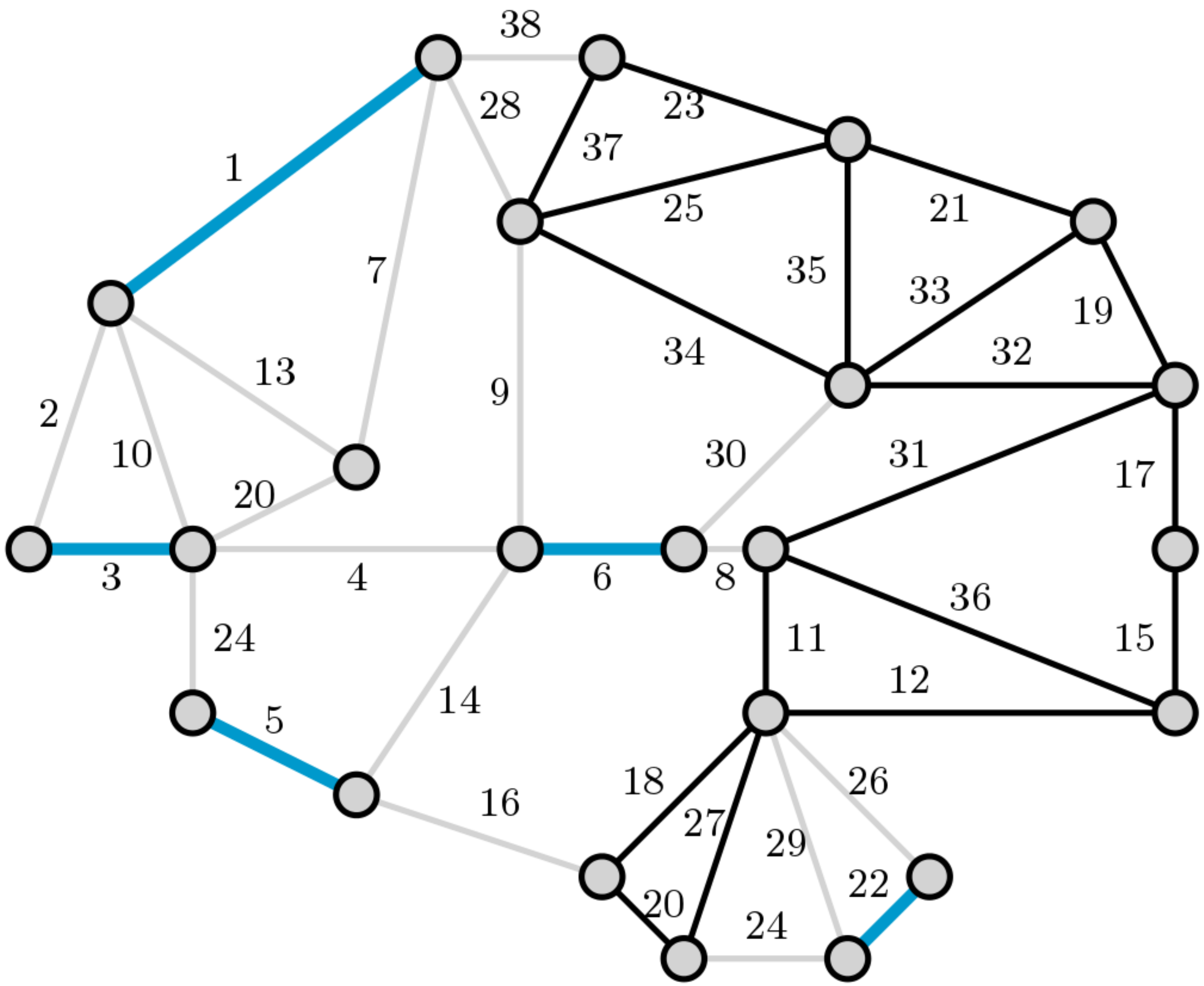

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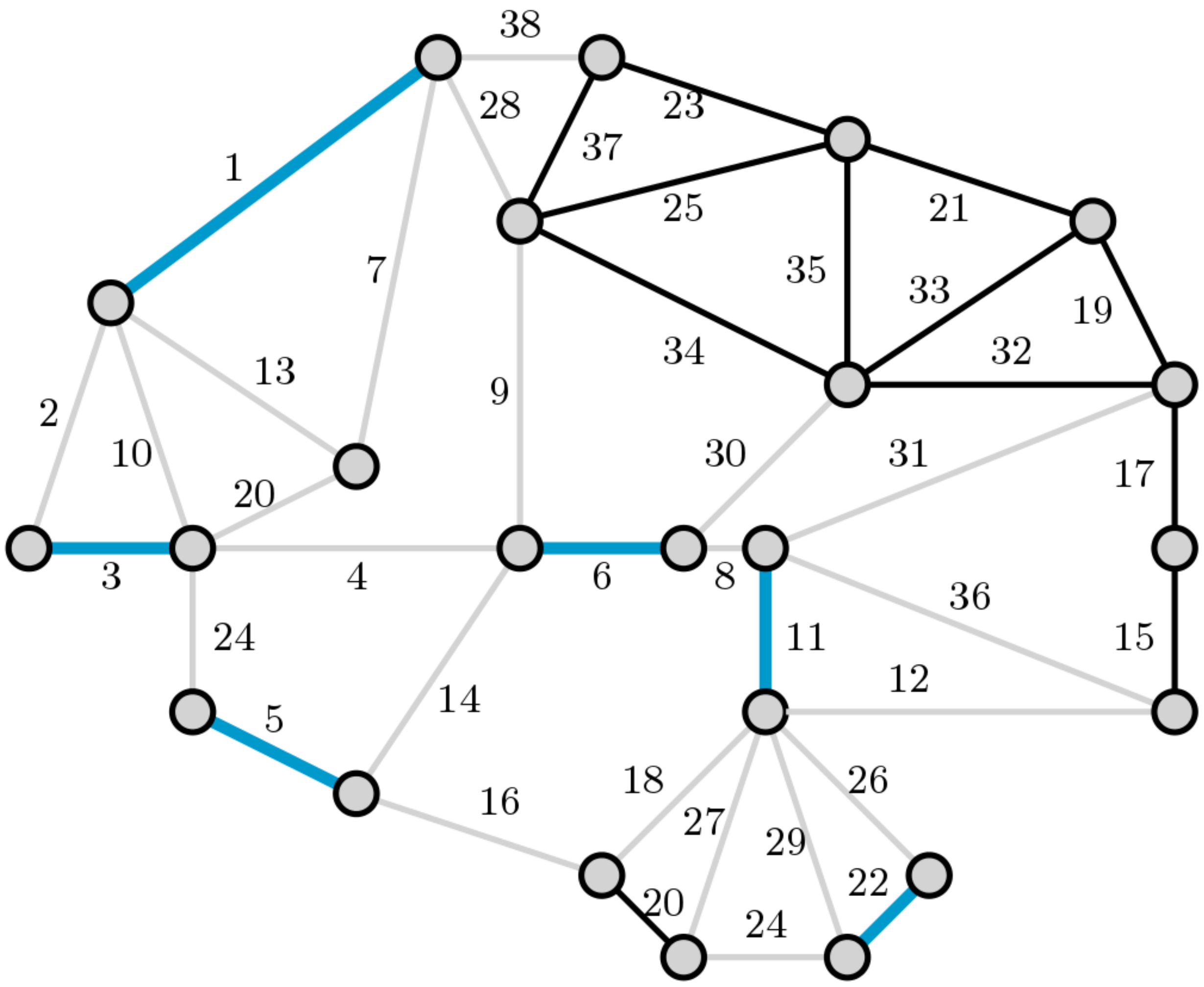

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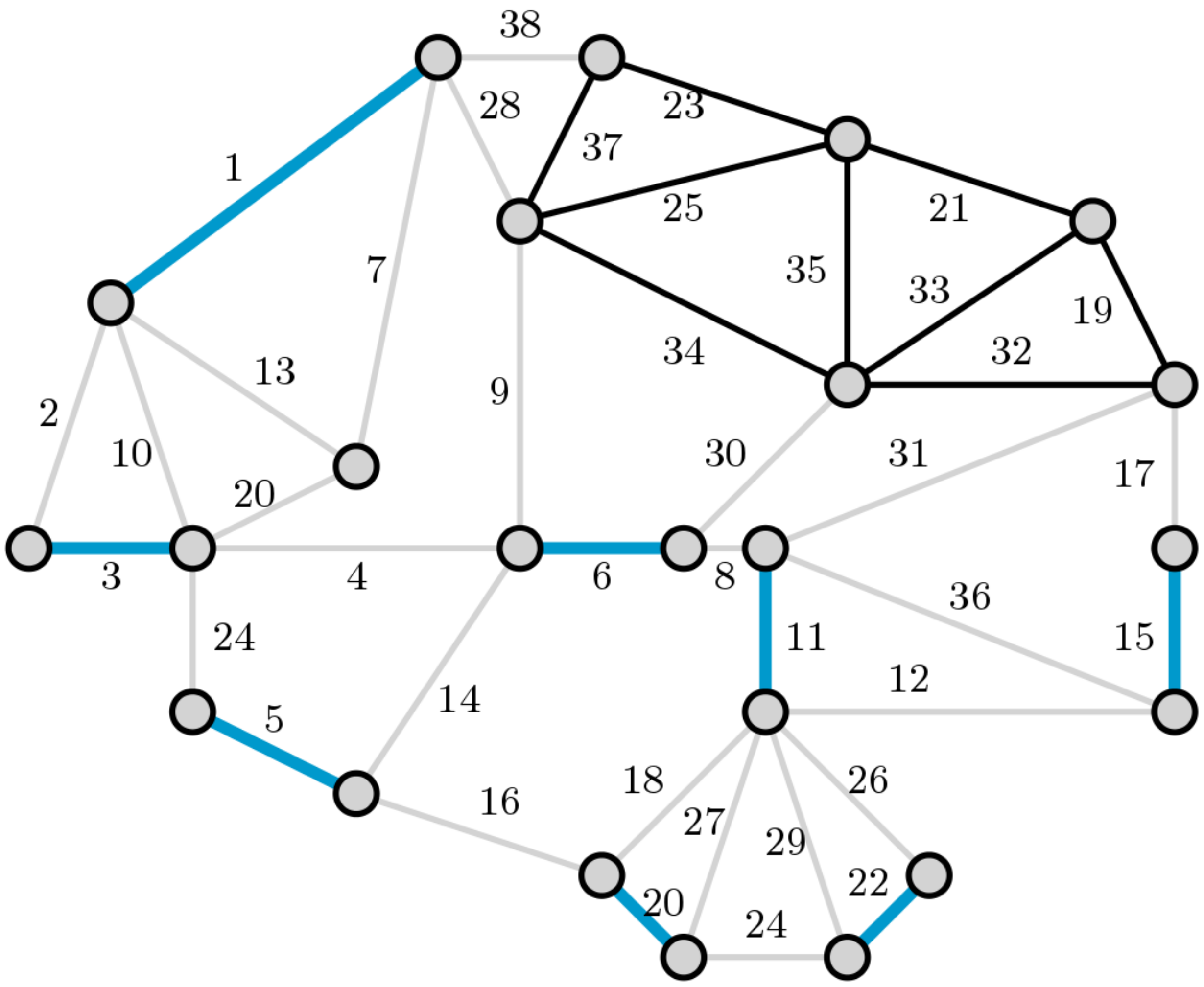

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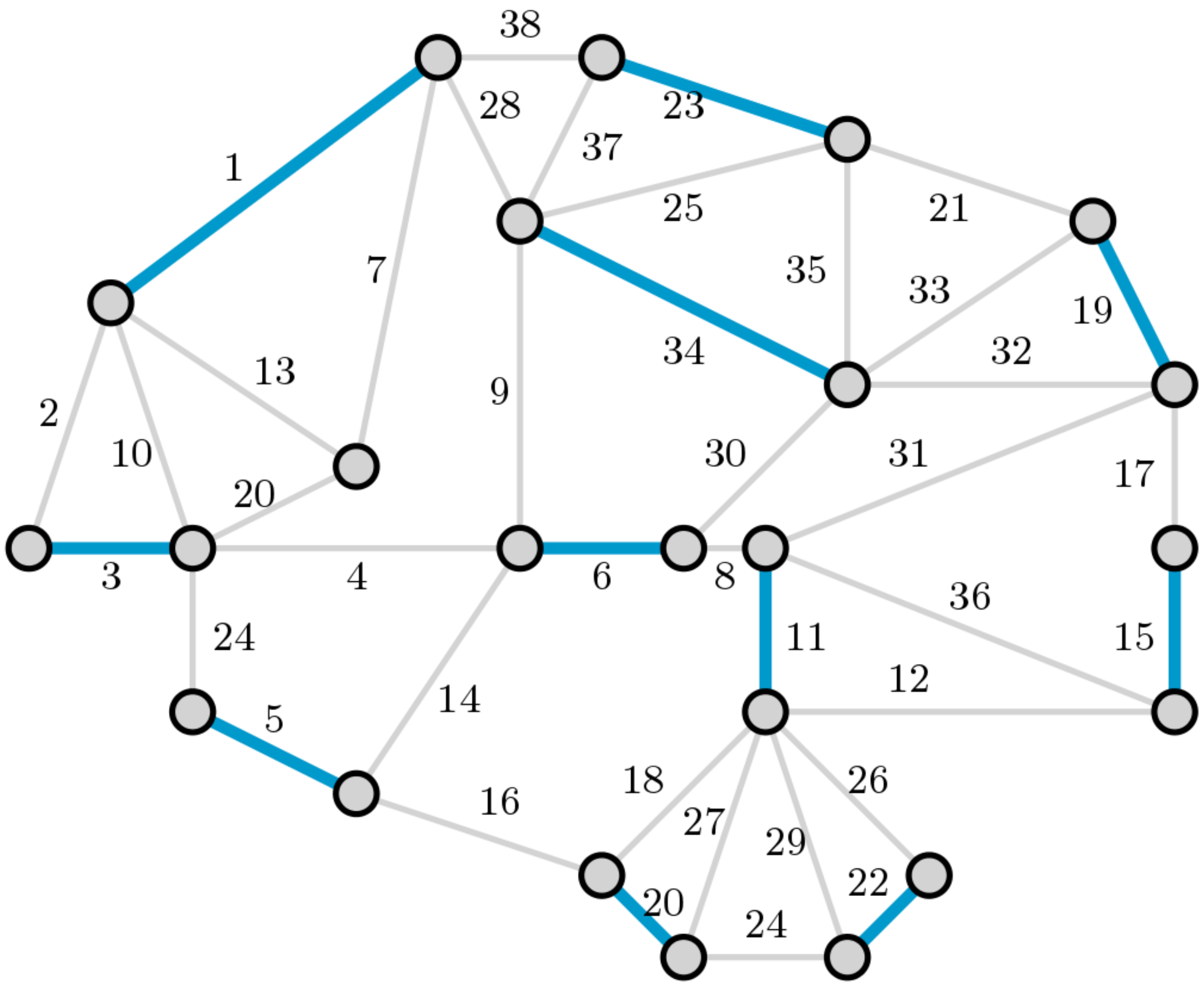

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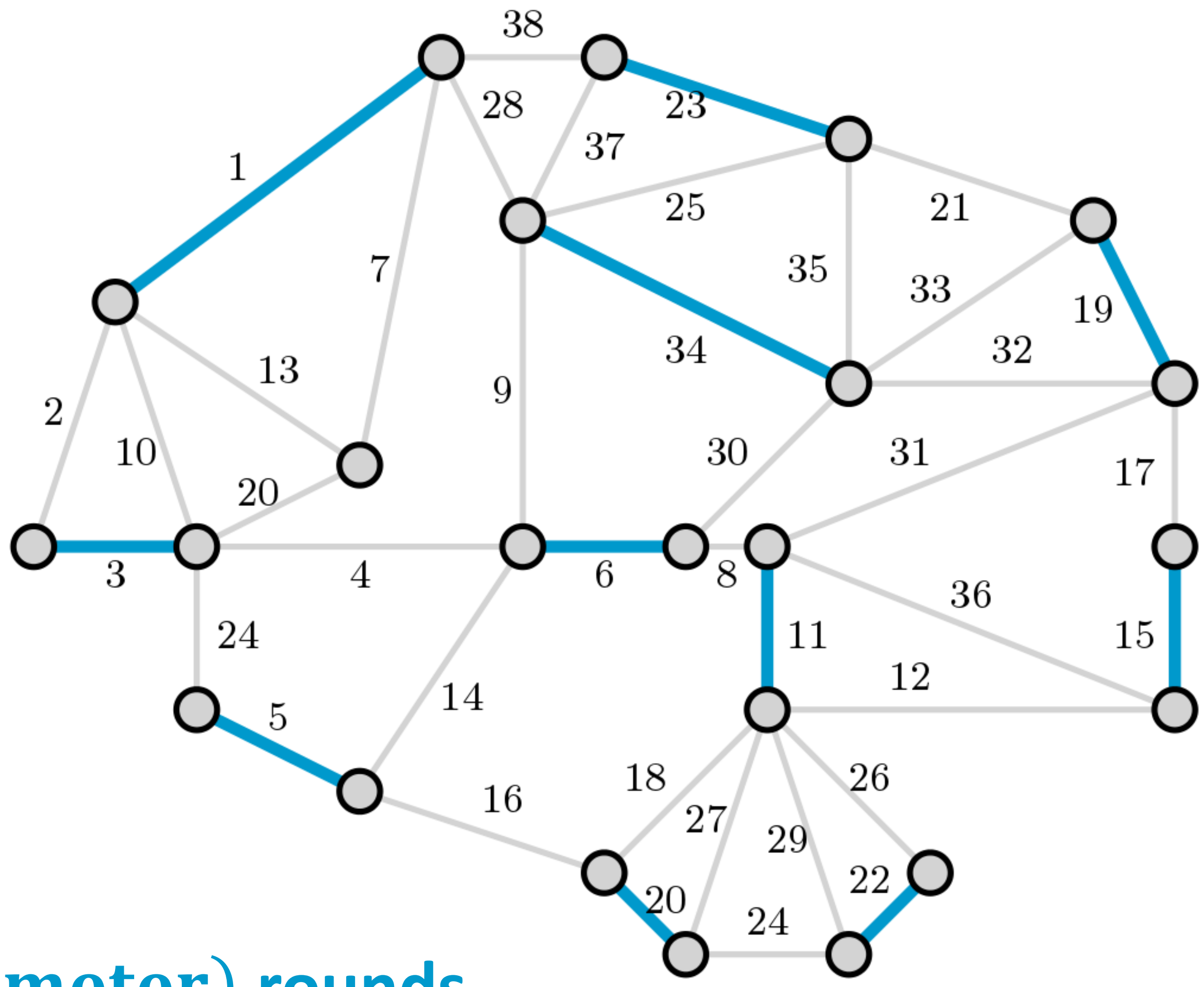

can take $\Omega(\text{diameter})$ rounds in worst case

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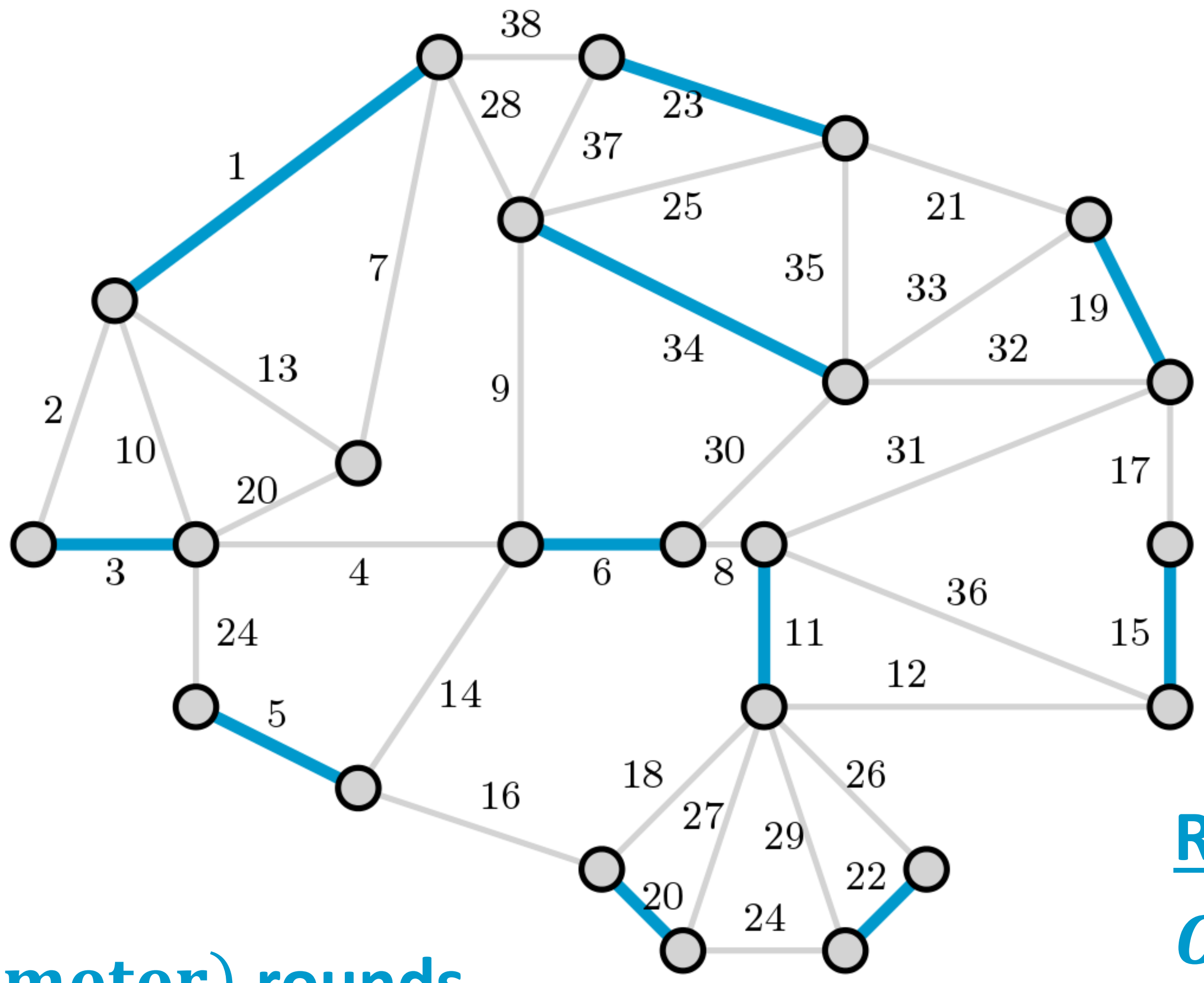

can take $\Omega(\text{diameter})$ rounds in worst case

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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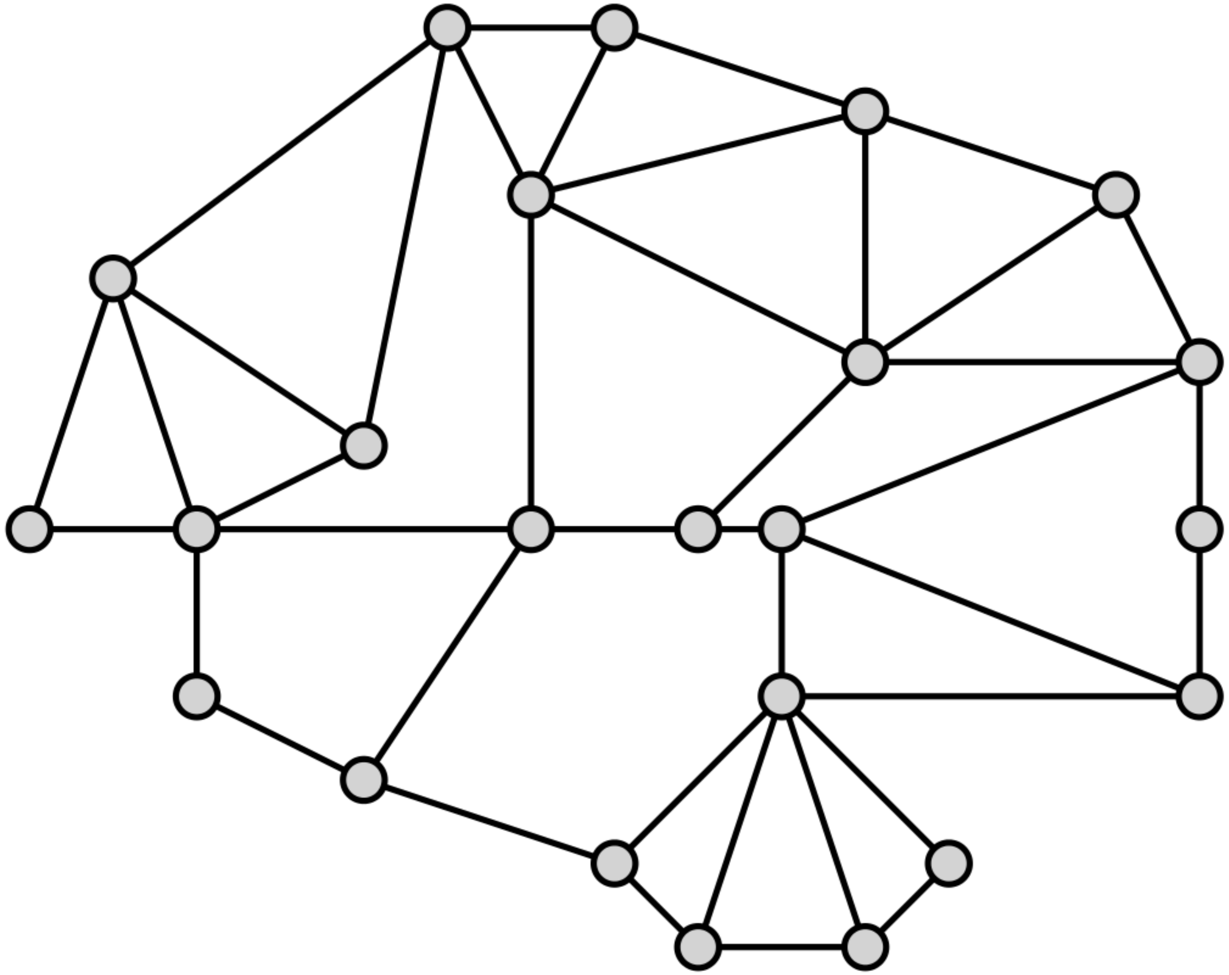

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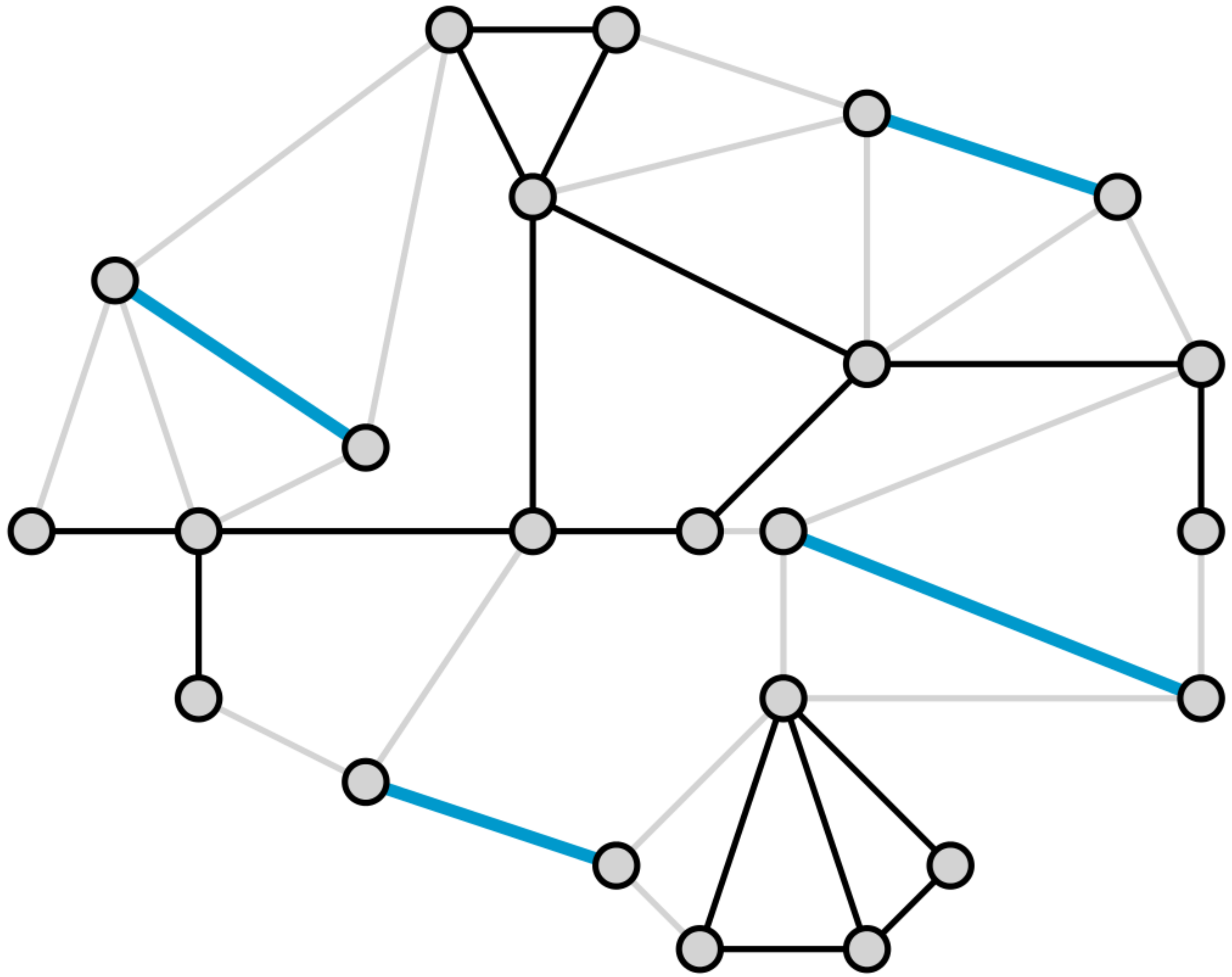

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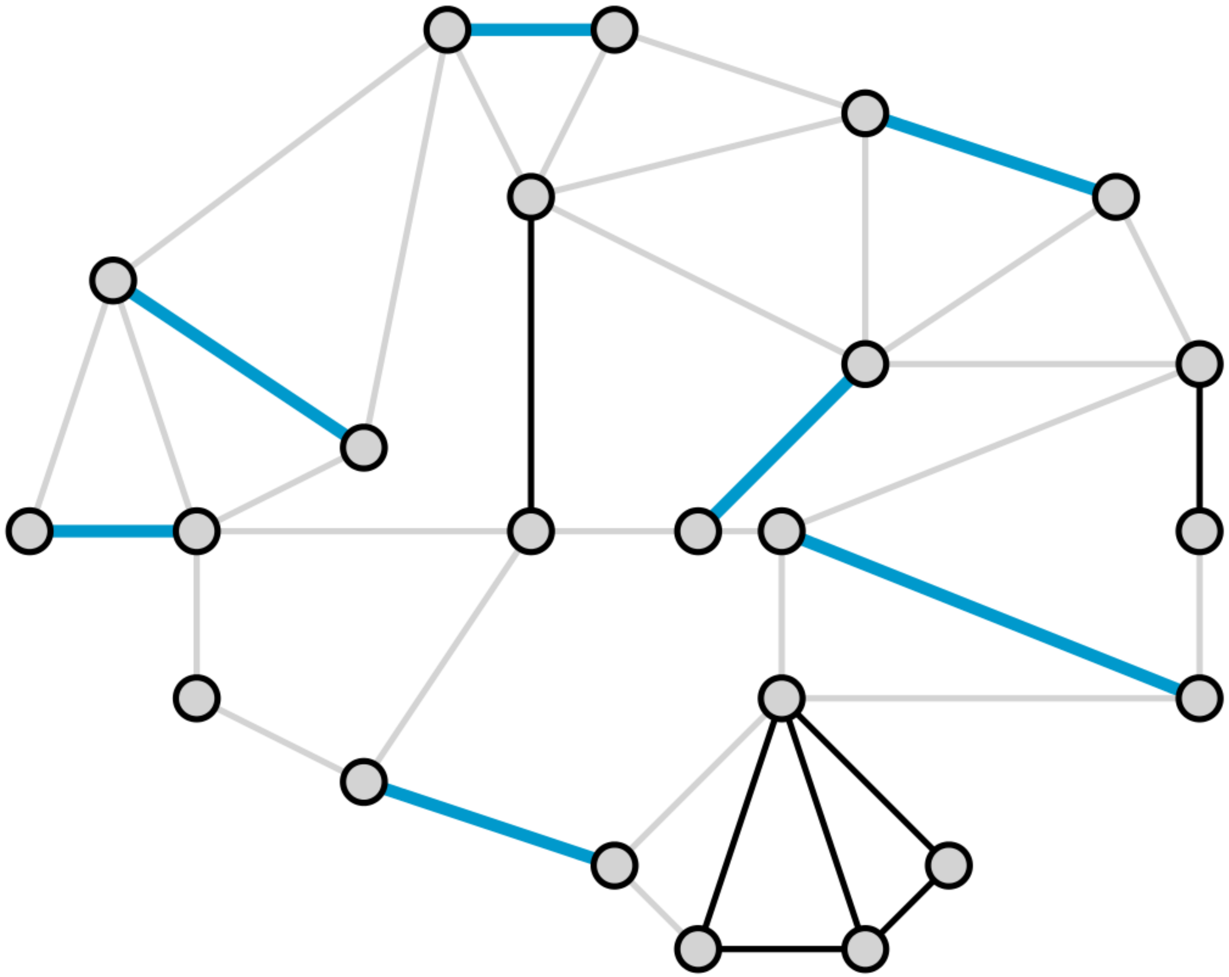

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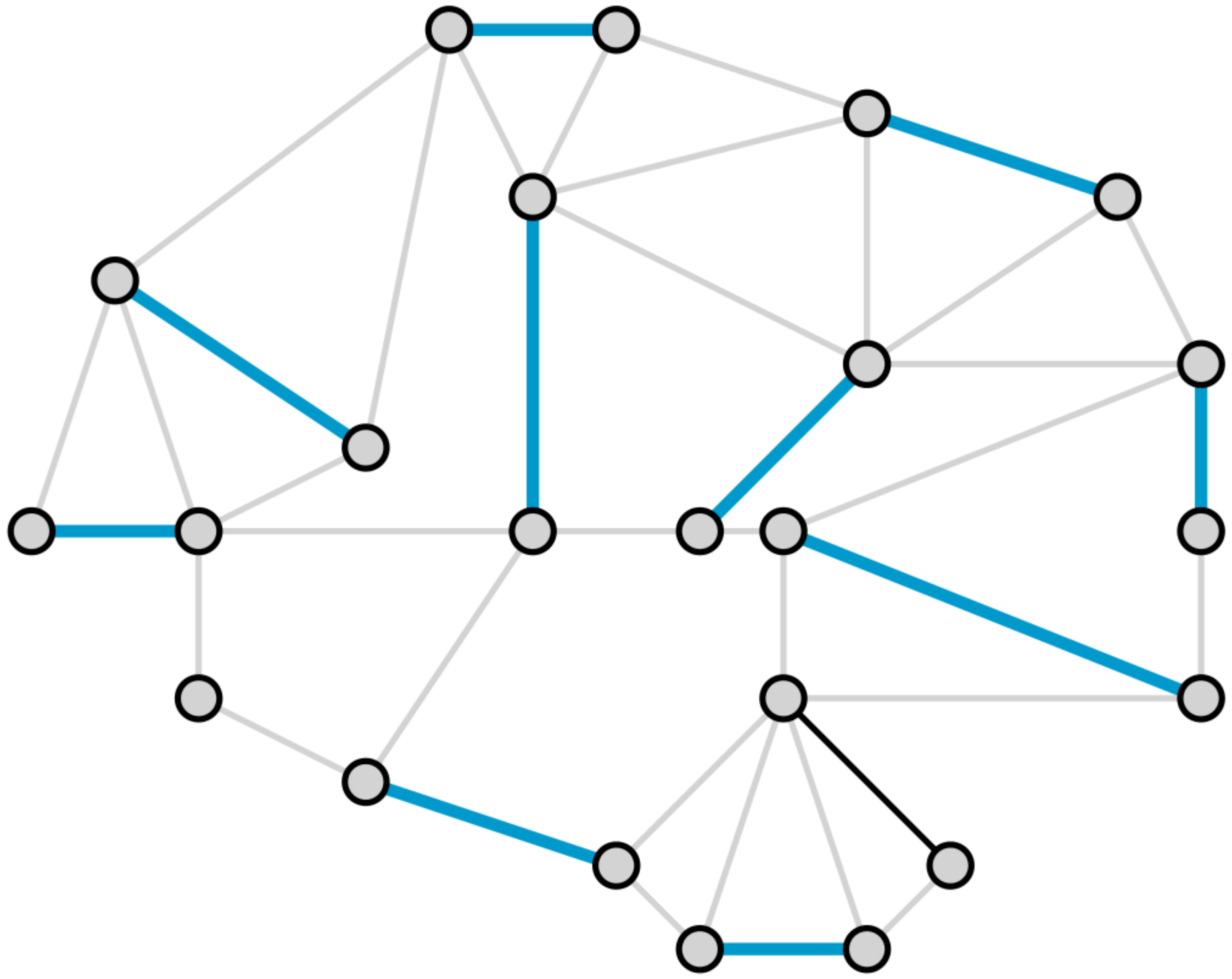
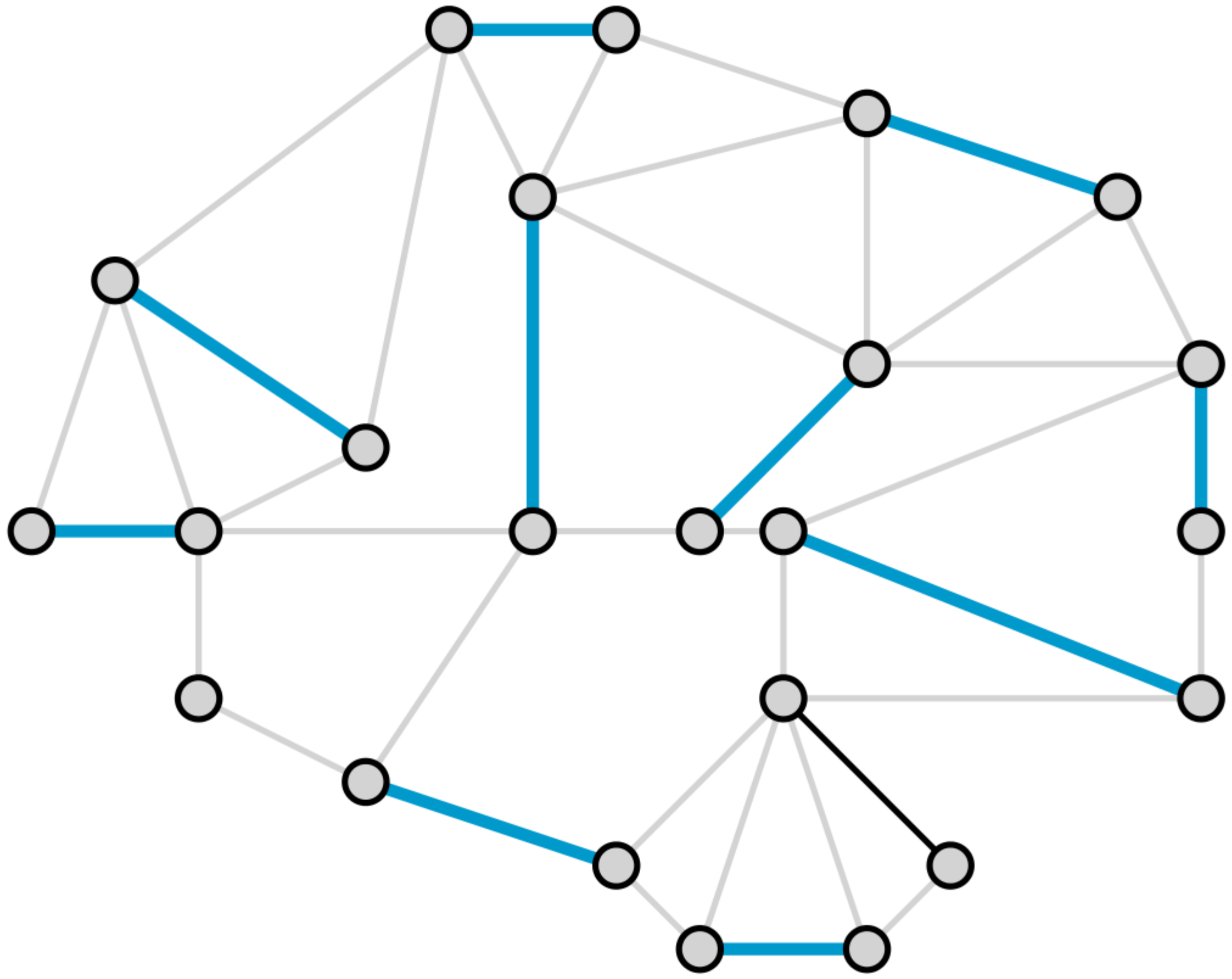


LOCAL Algorithm: Luby's Randomized Algorithm



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

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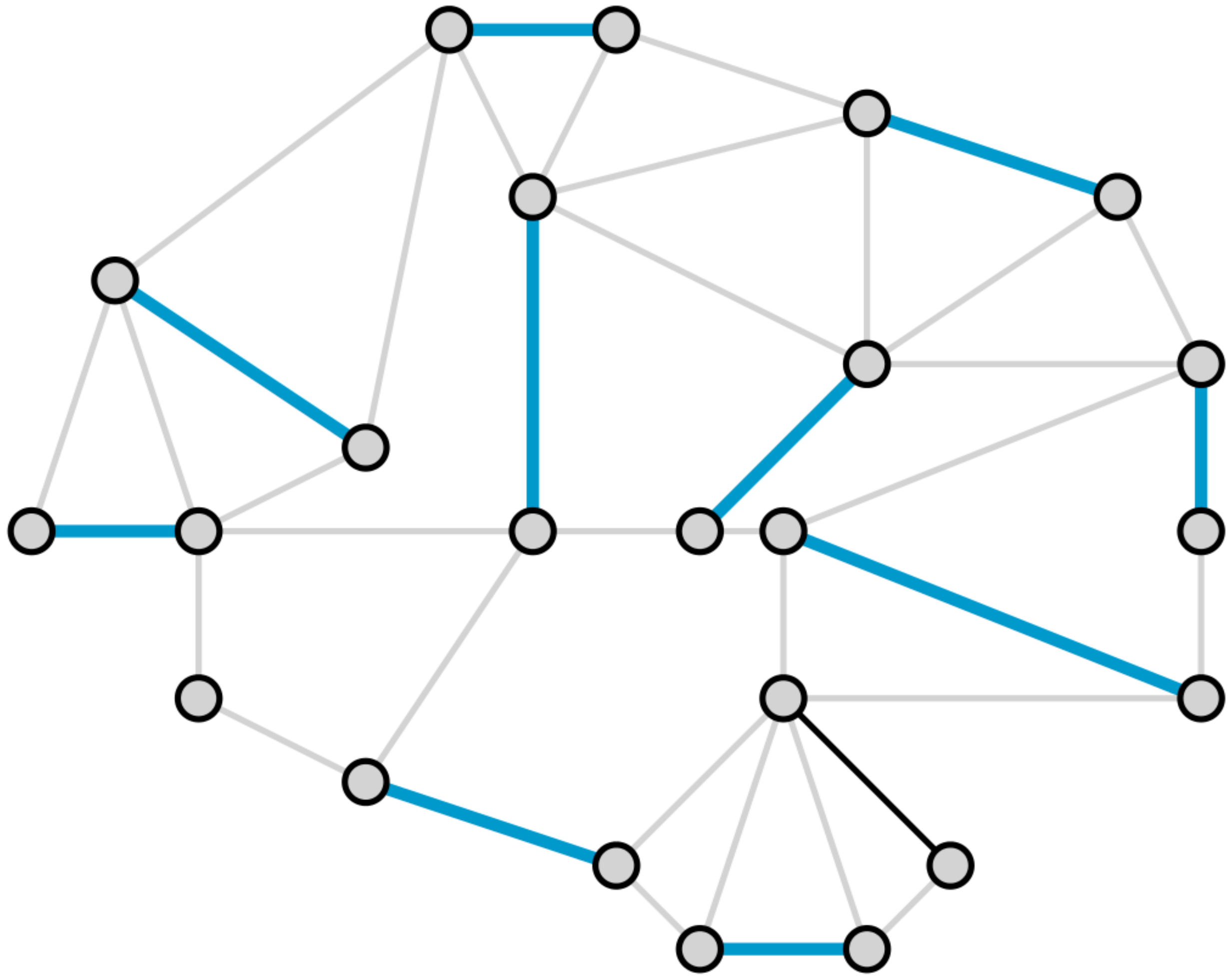

$\mathbb{E}[\#\text{removed edges per round}] \geq c|E_i|$

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

Our Result

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

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improving over

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$O(\log^4 n)$
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Our Result

<u>deterministic</u> $O(\log^2 \Delta \cdot \log n)$-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	$O(\log^2 \Delta \cdot \log n)$
• Randomized Maximal Matching	$O(\log^3 \log n + \log \Delta)$

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 $O(\log^2 \Delta)$ 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

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

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

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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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LOCAL Greedy Algorithm

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

repeat until all edges are blocked

mark half-tight nodes

block its edges

double value of unblocked edges

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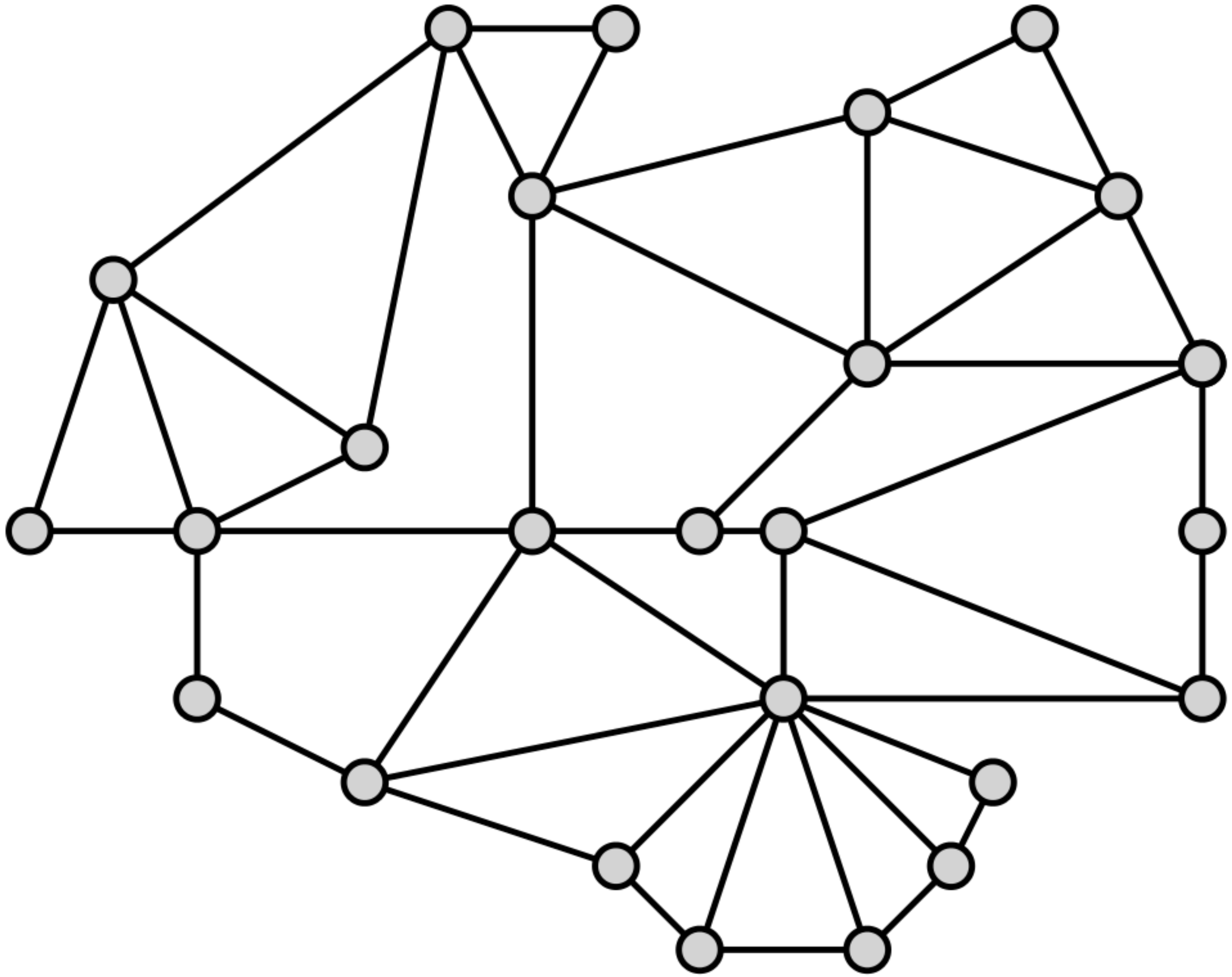

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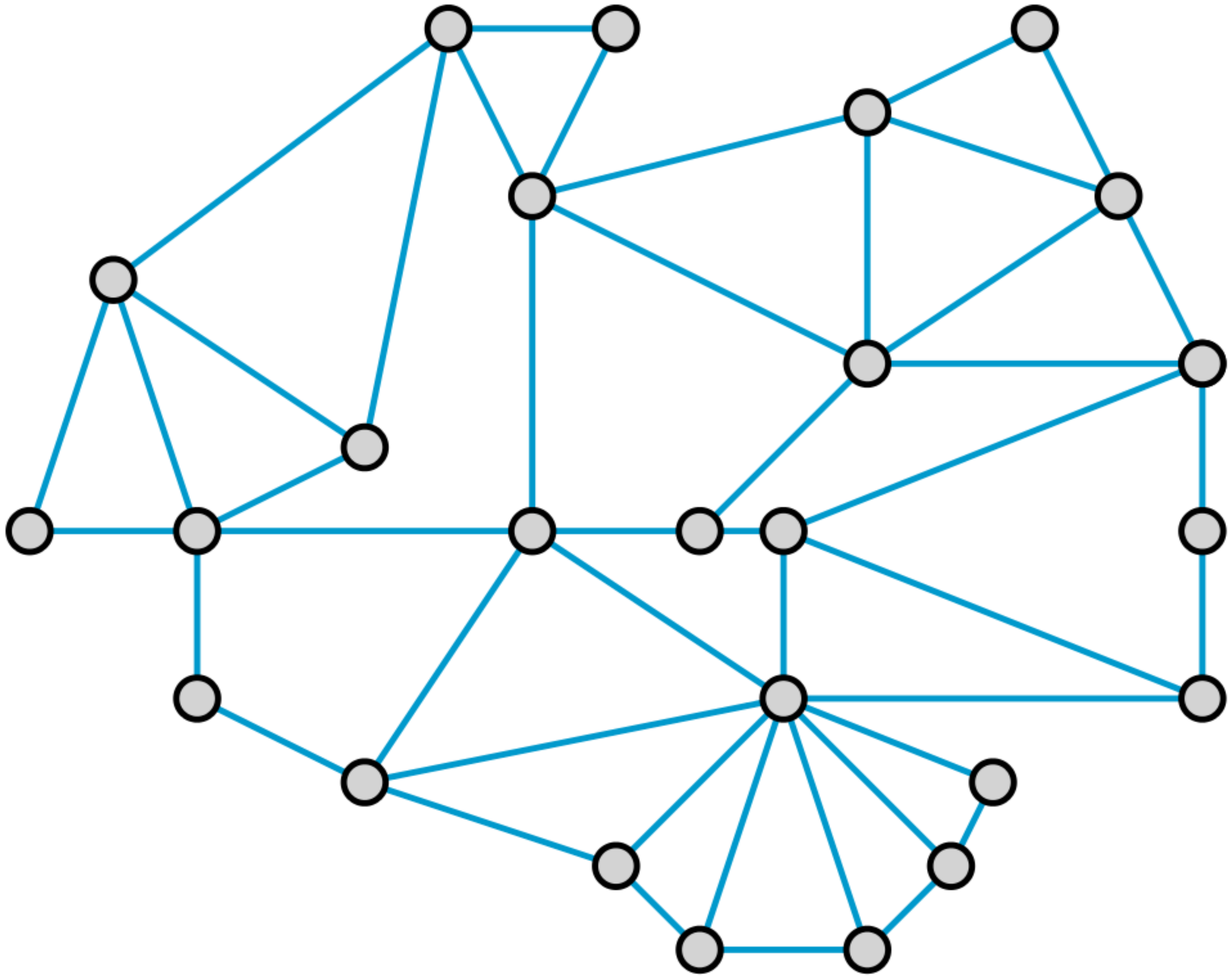

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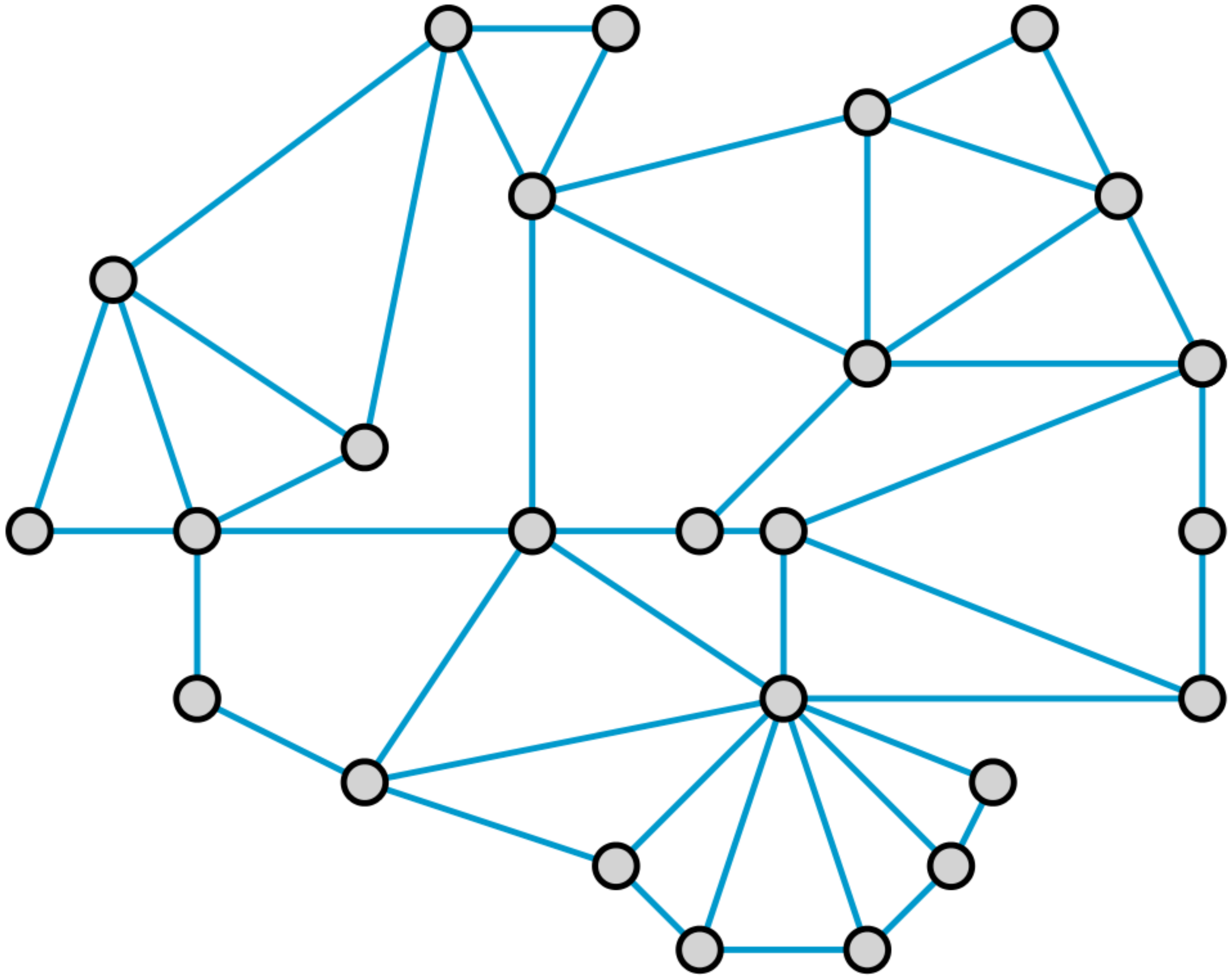

$\frac{1}{16}$

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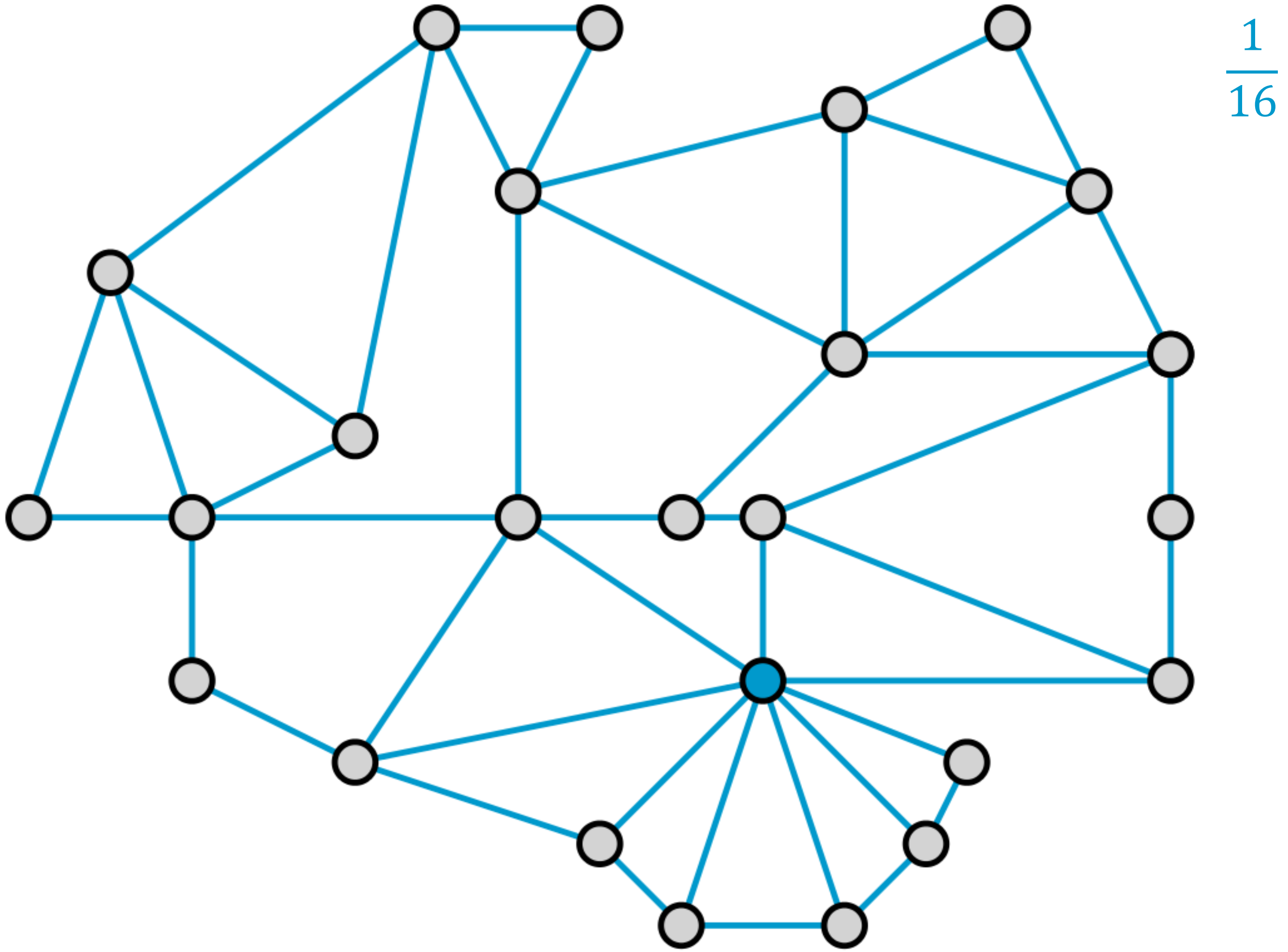

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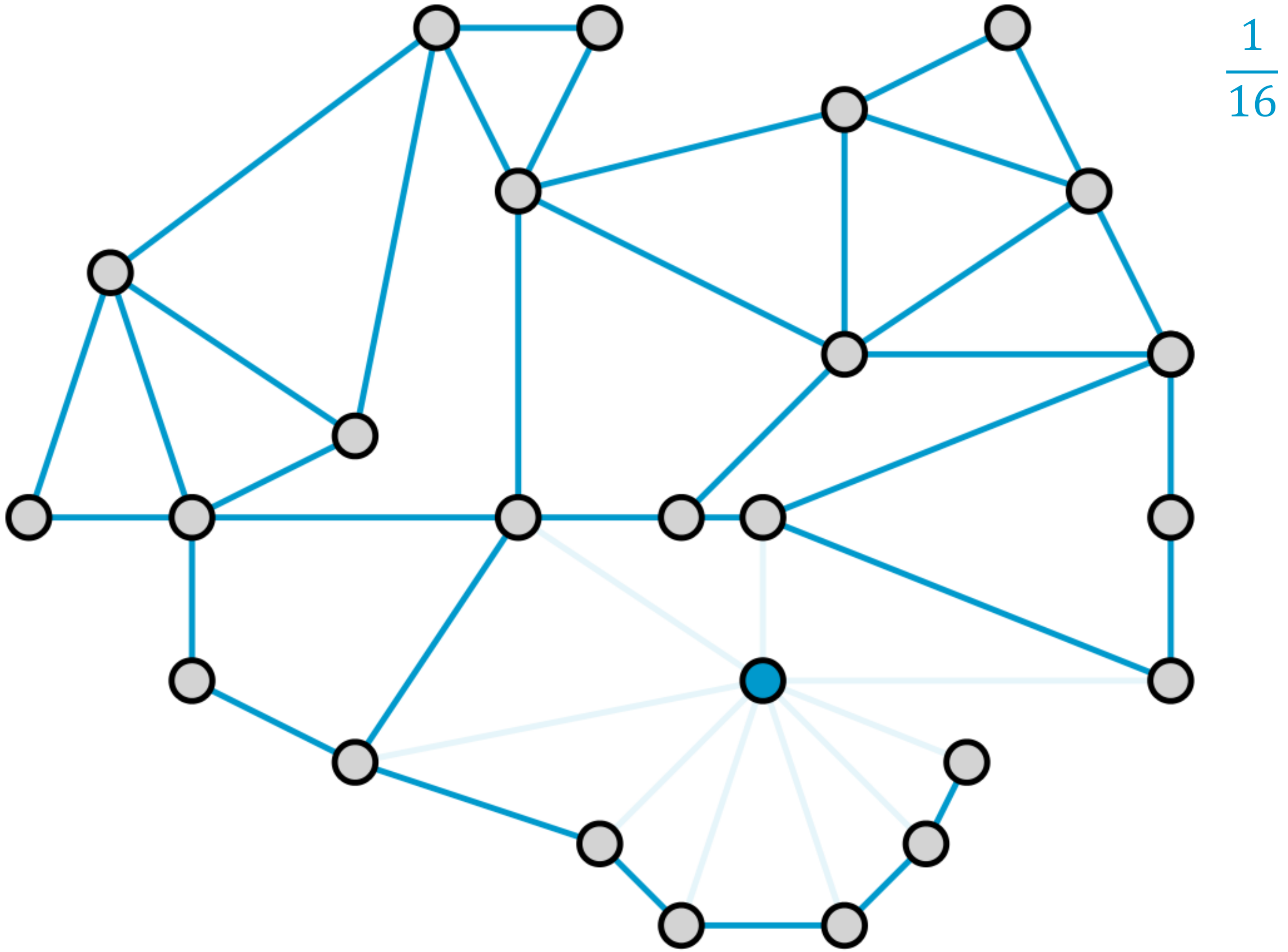
$O(\log \Delta)$ rounds



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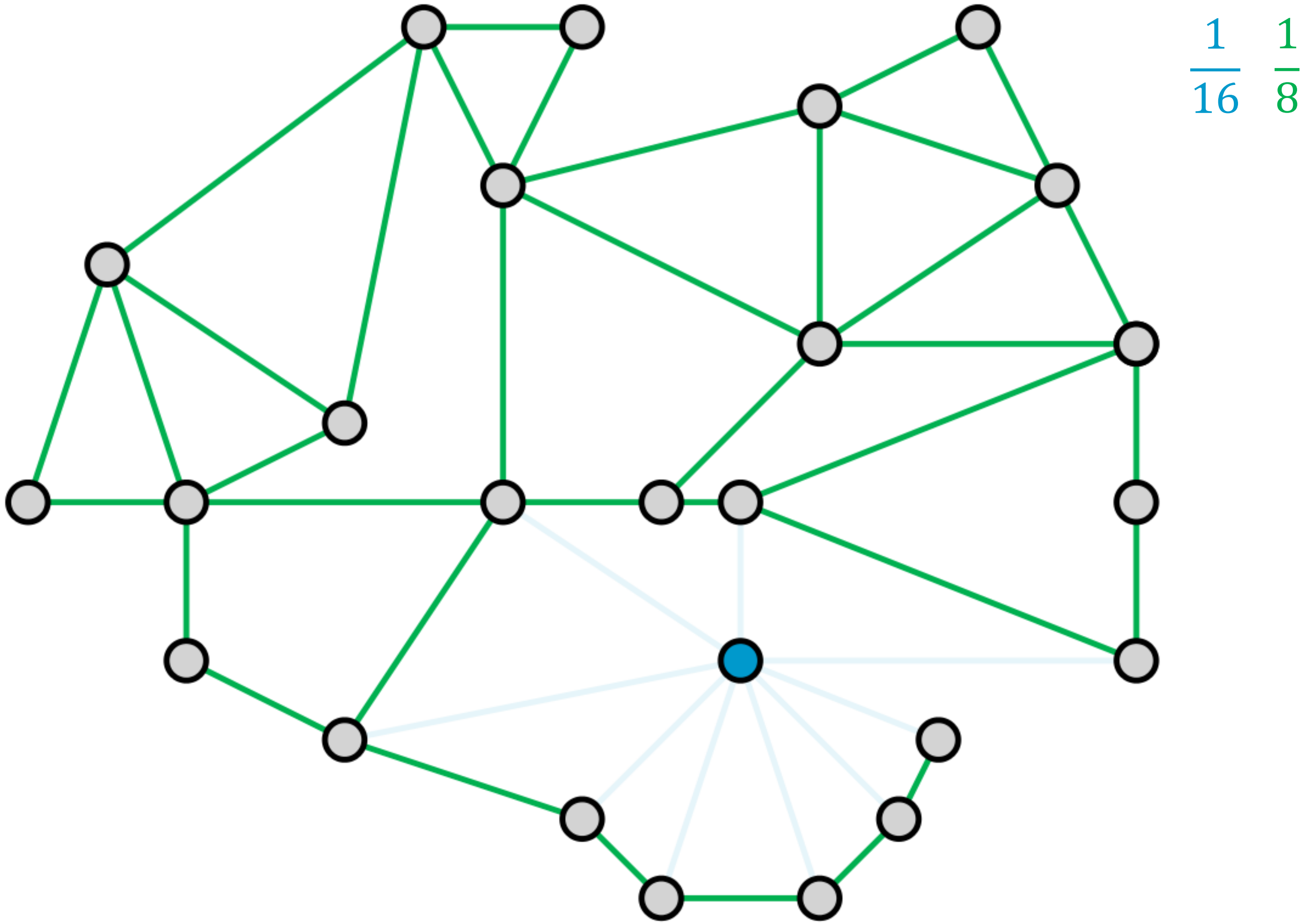

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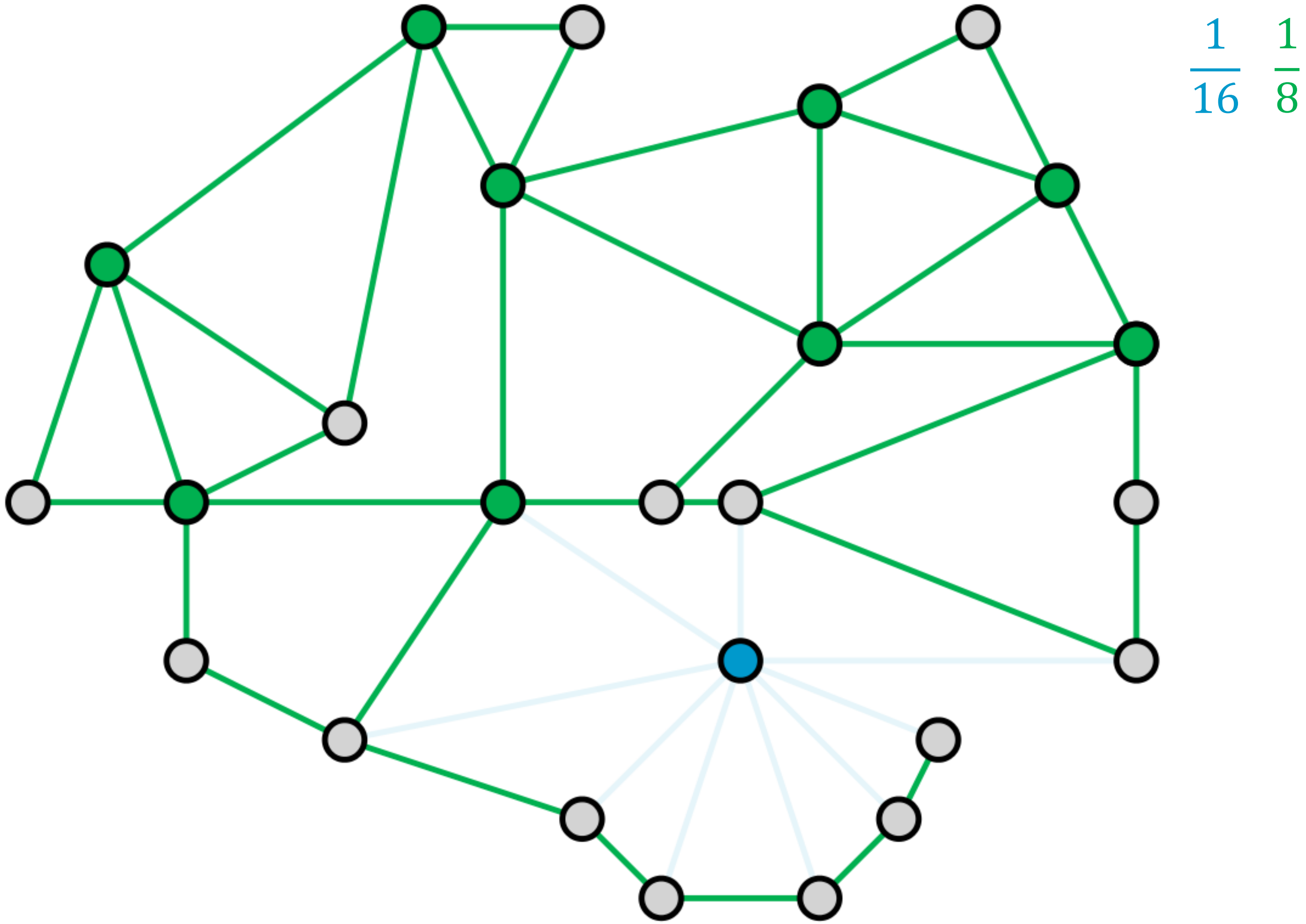

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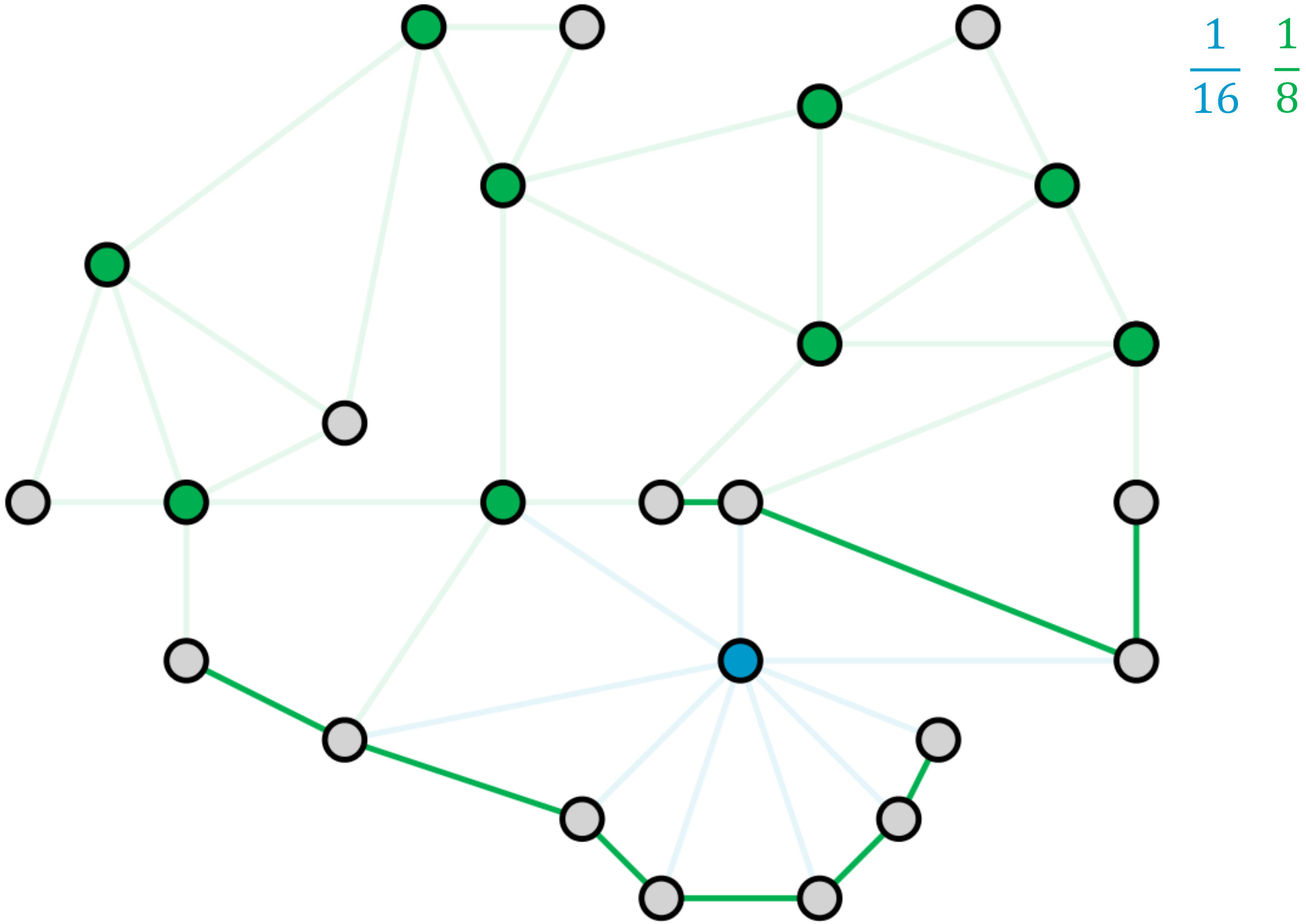

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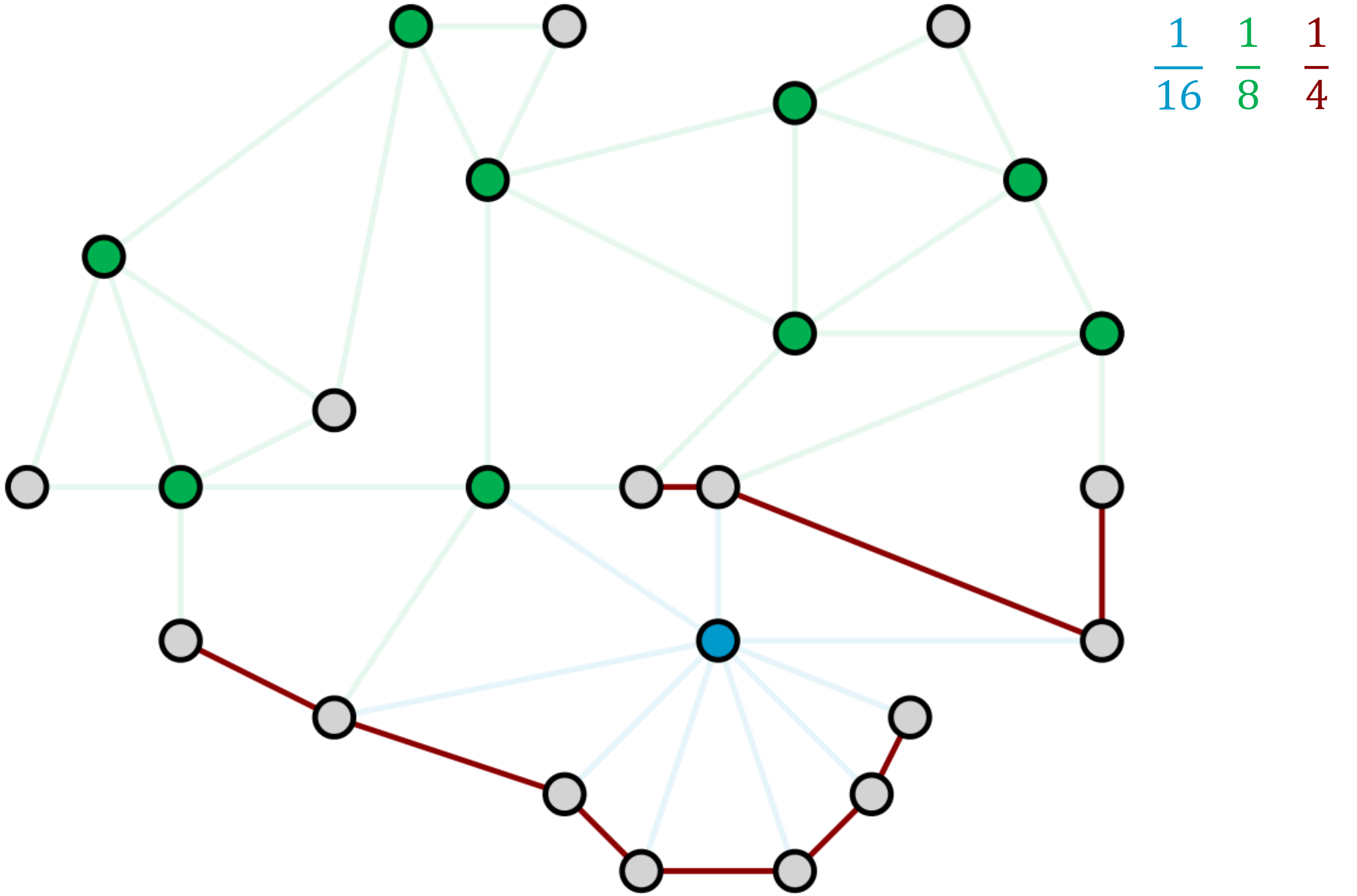

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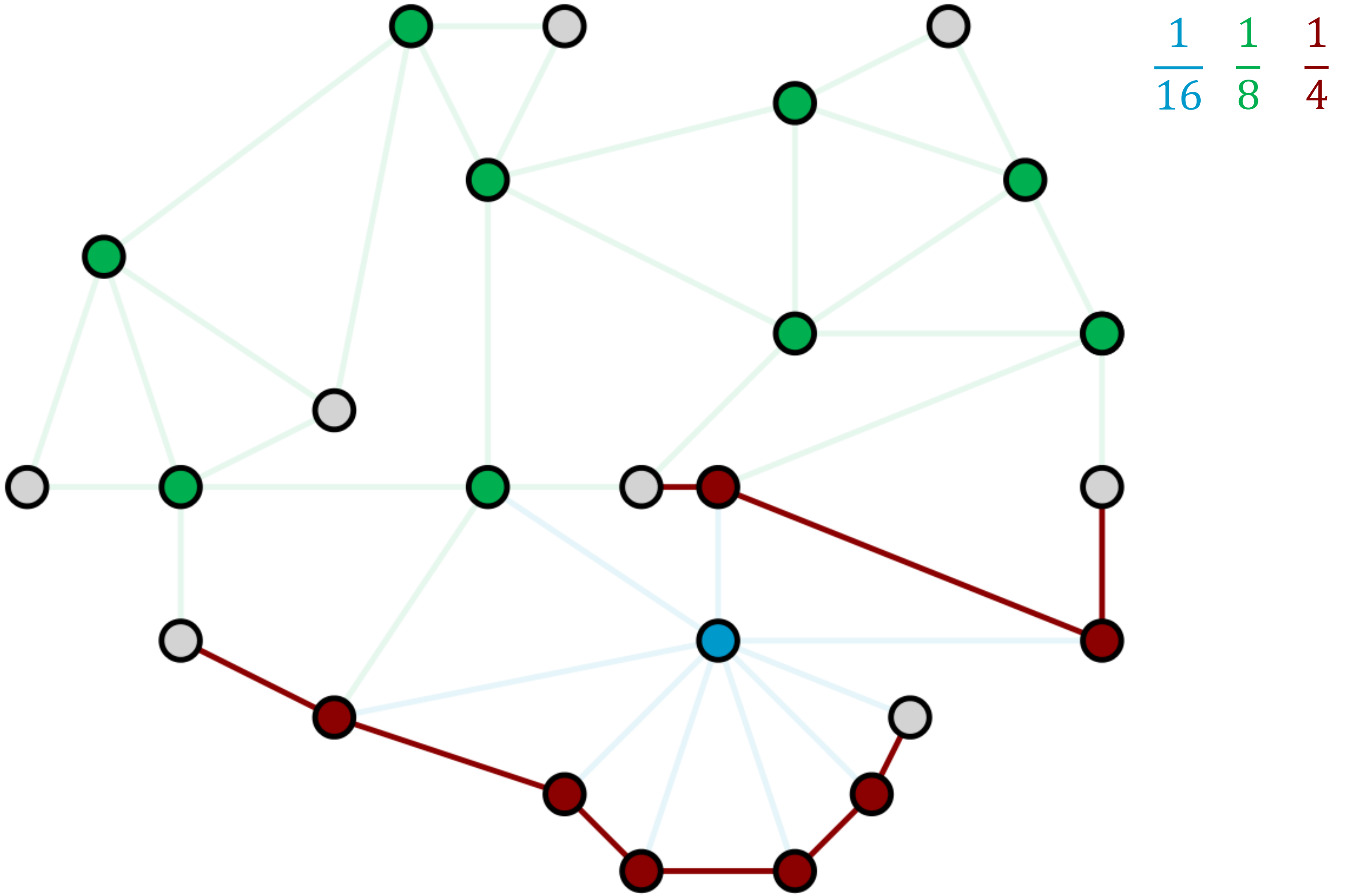

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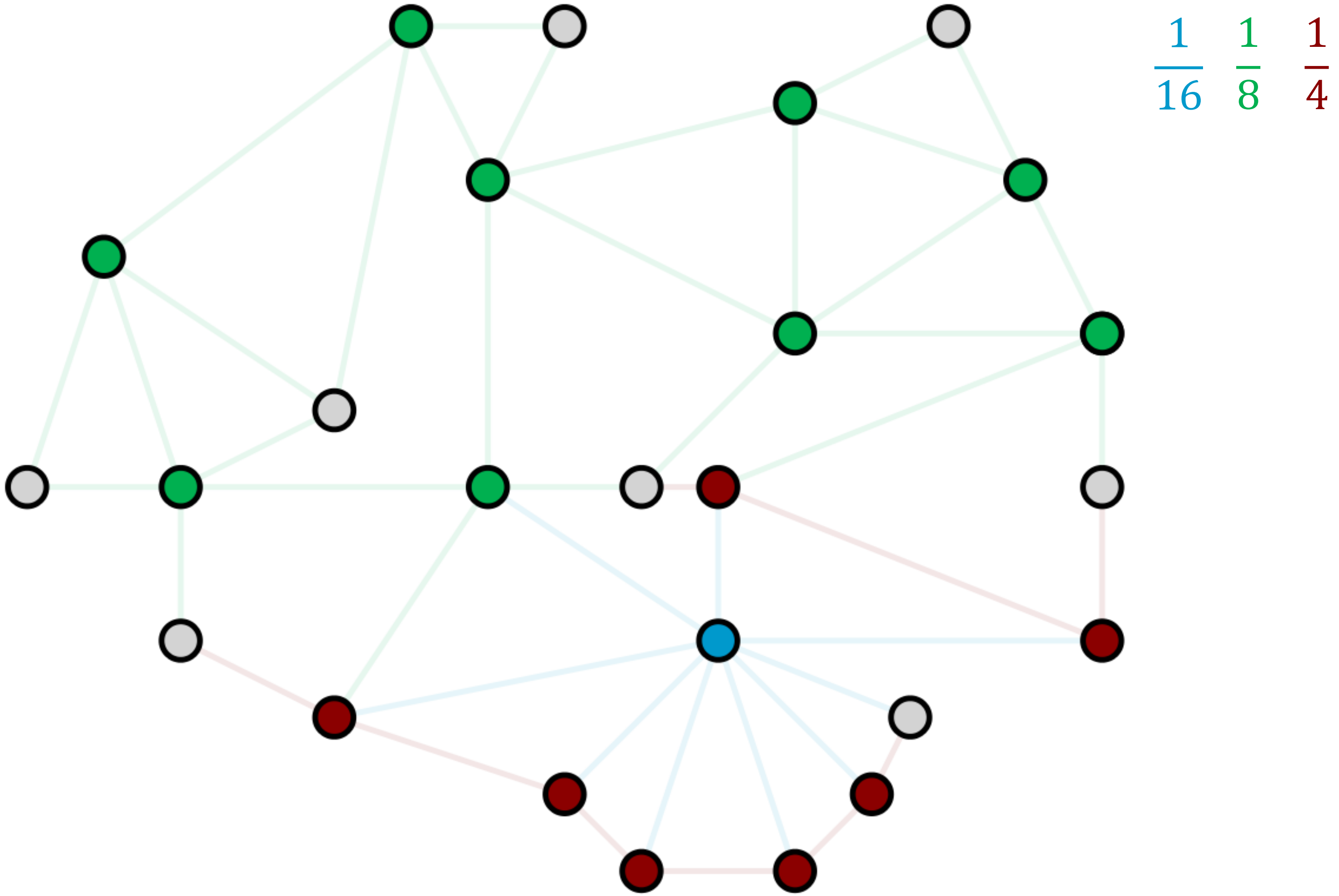

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Constant - Approximate Bipartite Matching

$O(\log^2 \Delta)$ rounds

I) 4-Approximate Fractional Matching

$O(\log \Delta)$ rounds

II) Rounding Fractional Bipartite Matching

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

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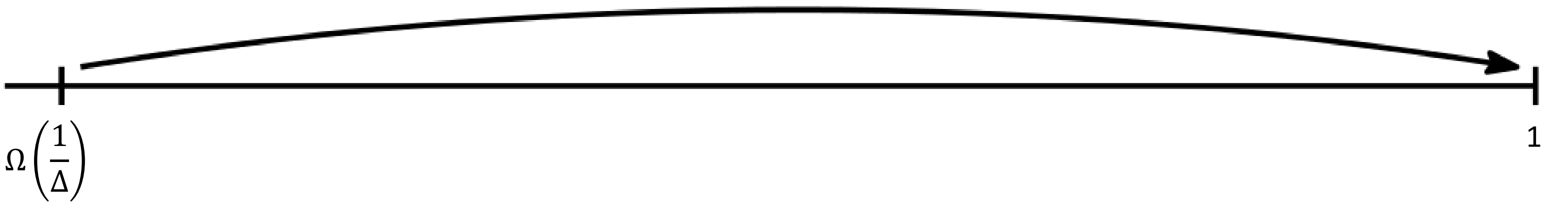
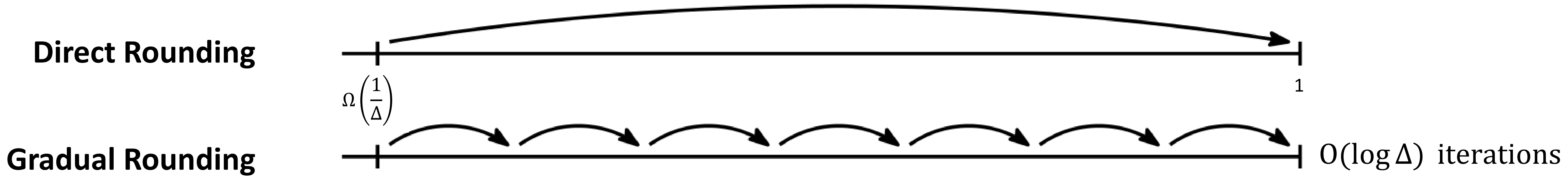
$O(\log^2 \Delta)$ rounds, $O(1)$ loss

Direct Rounding



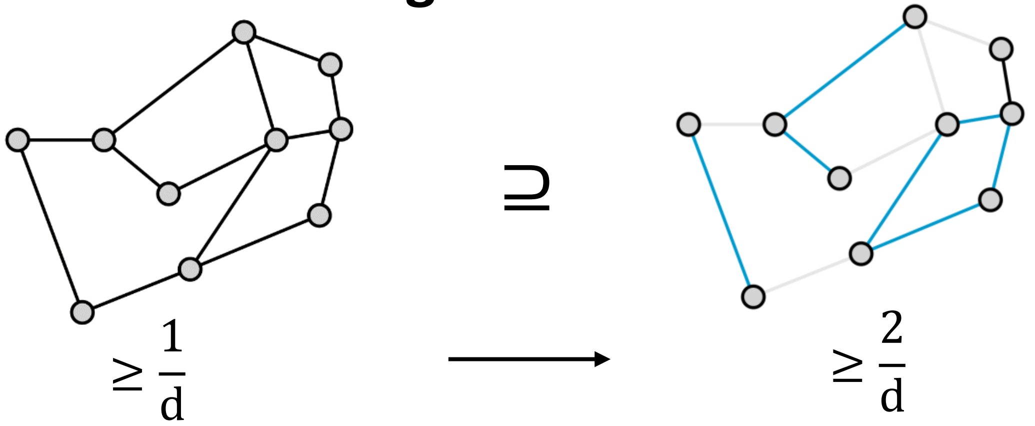
II) Rounding Fractional Bipartite Matching $O(\log^2 \Delta)$ rounds, $O(1)$ loss

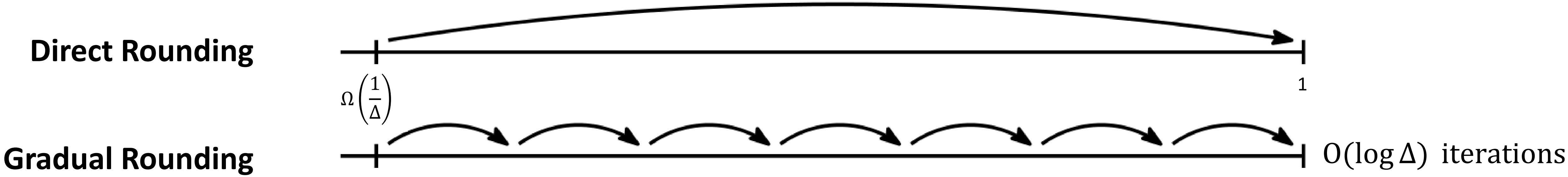


II) Rounding Fractional Bipartite Matching

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

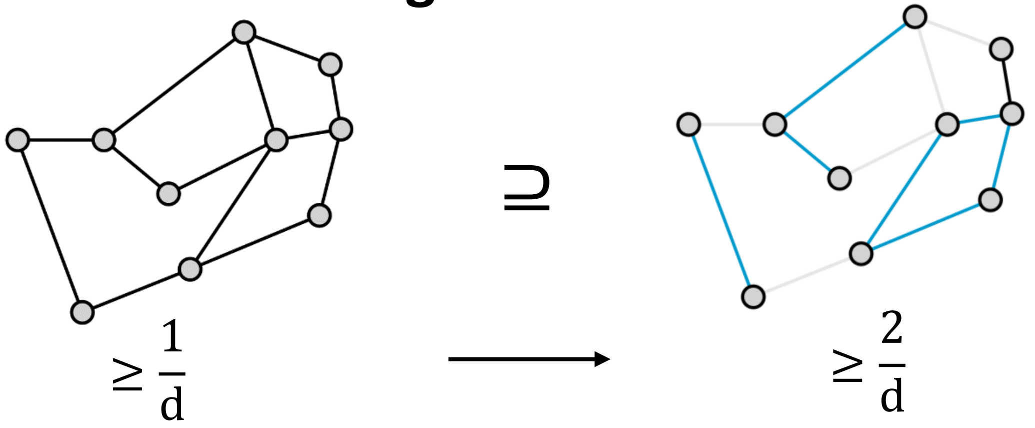
Factor-2-Rounding





II) Rounding Fractional Bipartite Matching — $O(\log^2 \Delta)$ rounds, $O(1)$ loss

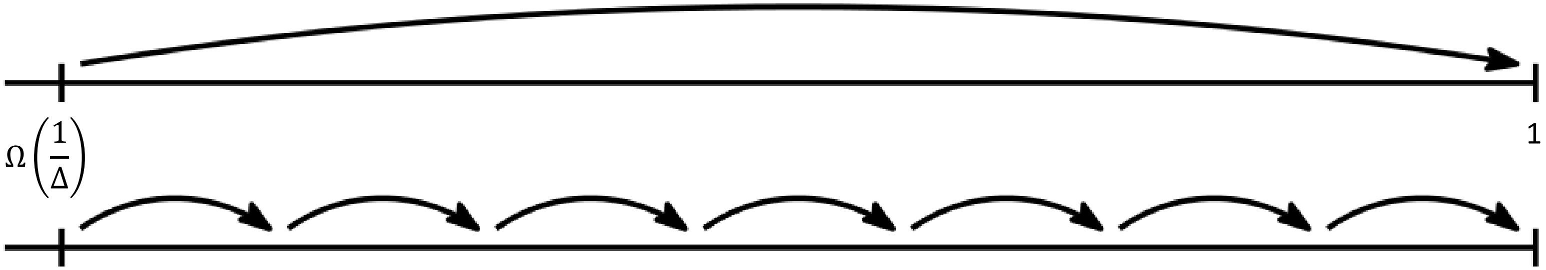
Factor-2-Rounding



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

Direct Rounding

Gradual Rounding



$O(\log \Delta)$ iterations

II) Rounding Fractional Bipartite Matching $O(\log^2 \Delta)$ rounds, $O(1)$ loss

Iterated Factor-2-Rounding using Locally Balanced Splitting

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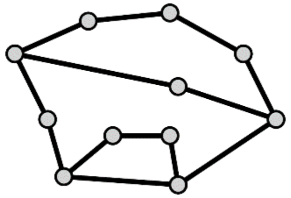
Iterated Factor-2-Rounding using Locally Balanced Splitting

<u>Locally Balanced Splitting:</u>
2-edge-coloring so that
every node roughly balanced



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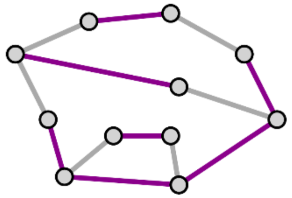

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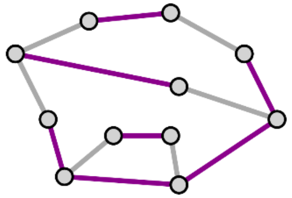

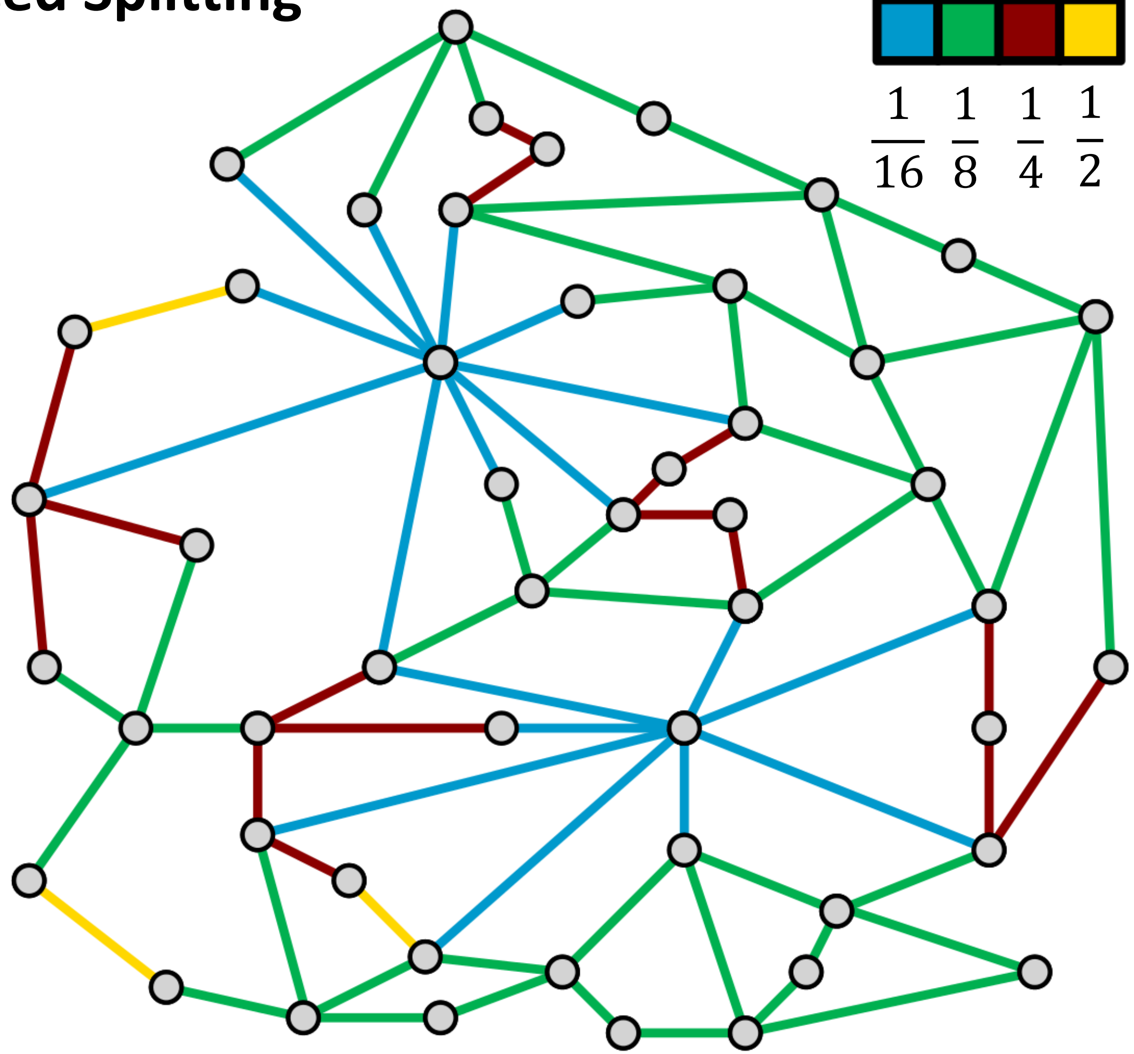

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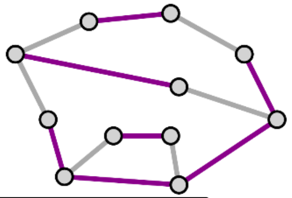


Iterated Factor-2-Rounding

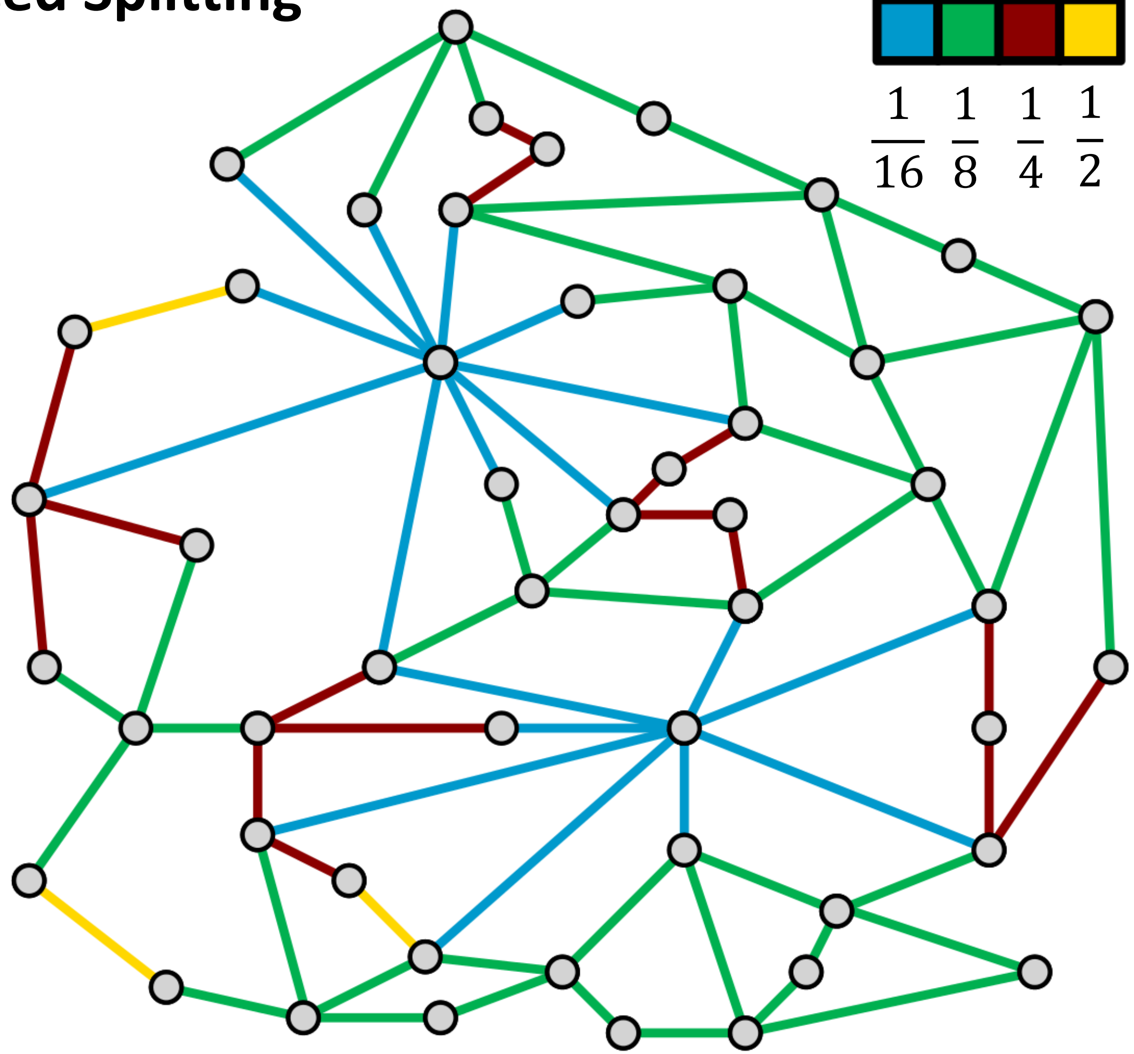
for $i = \lceil \log \Delta \rceil, \ldots, 1$

$E_i = \{e \in E : x_e = 2^{-i}\}$

splitting of E_i into ■■

increase ■ to 2^{-i+1}

decrease ■ to 0



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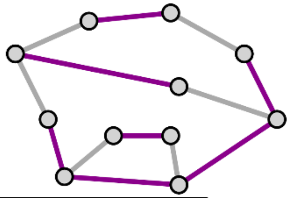

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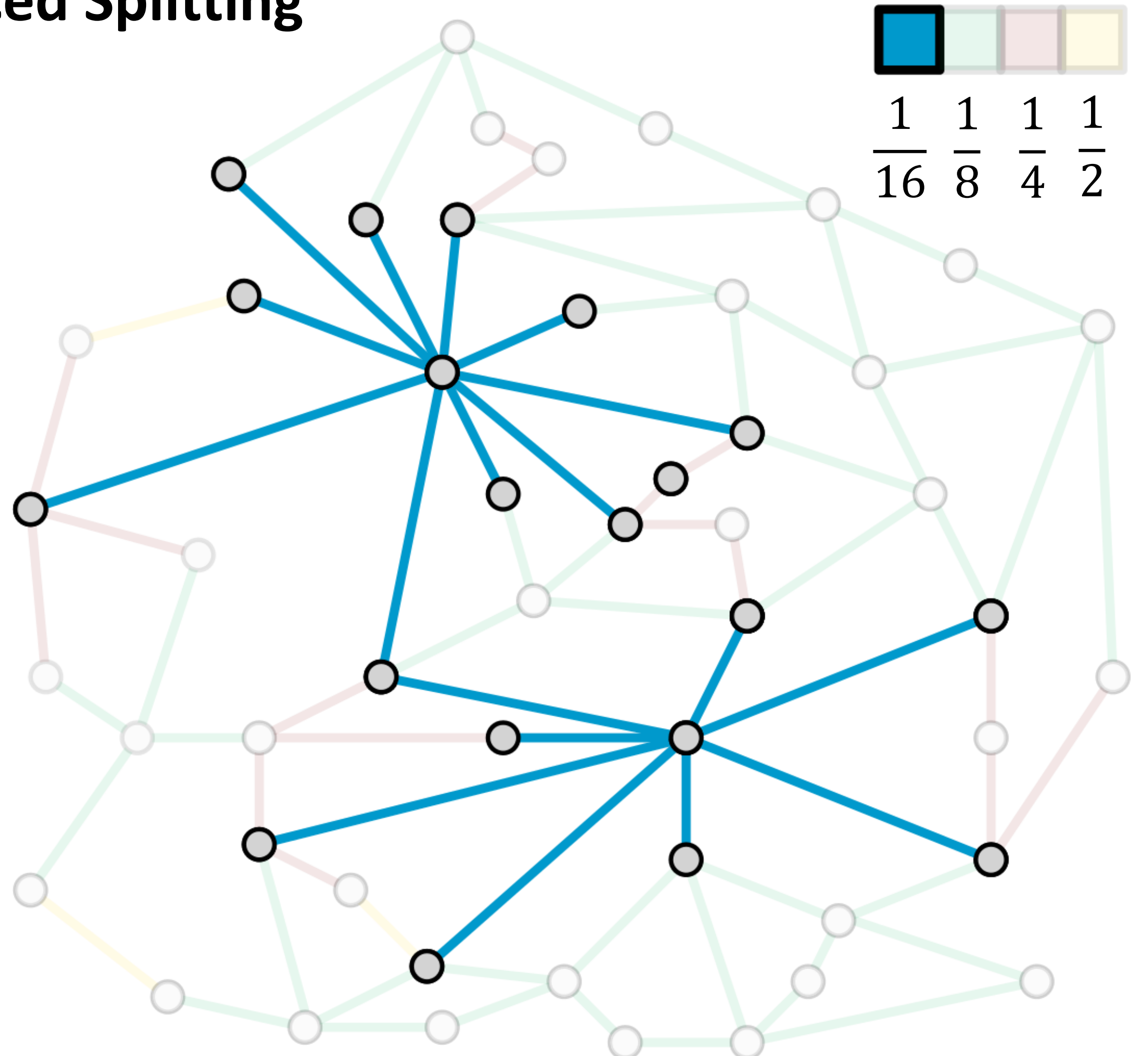

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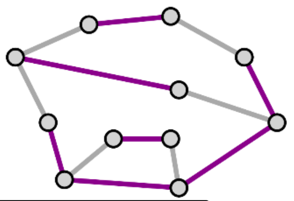

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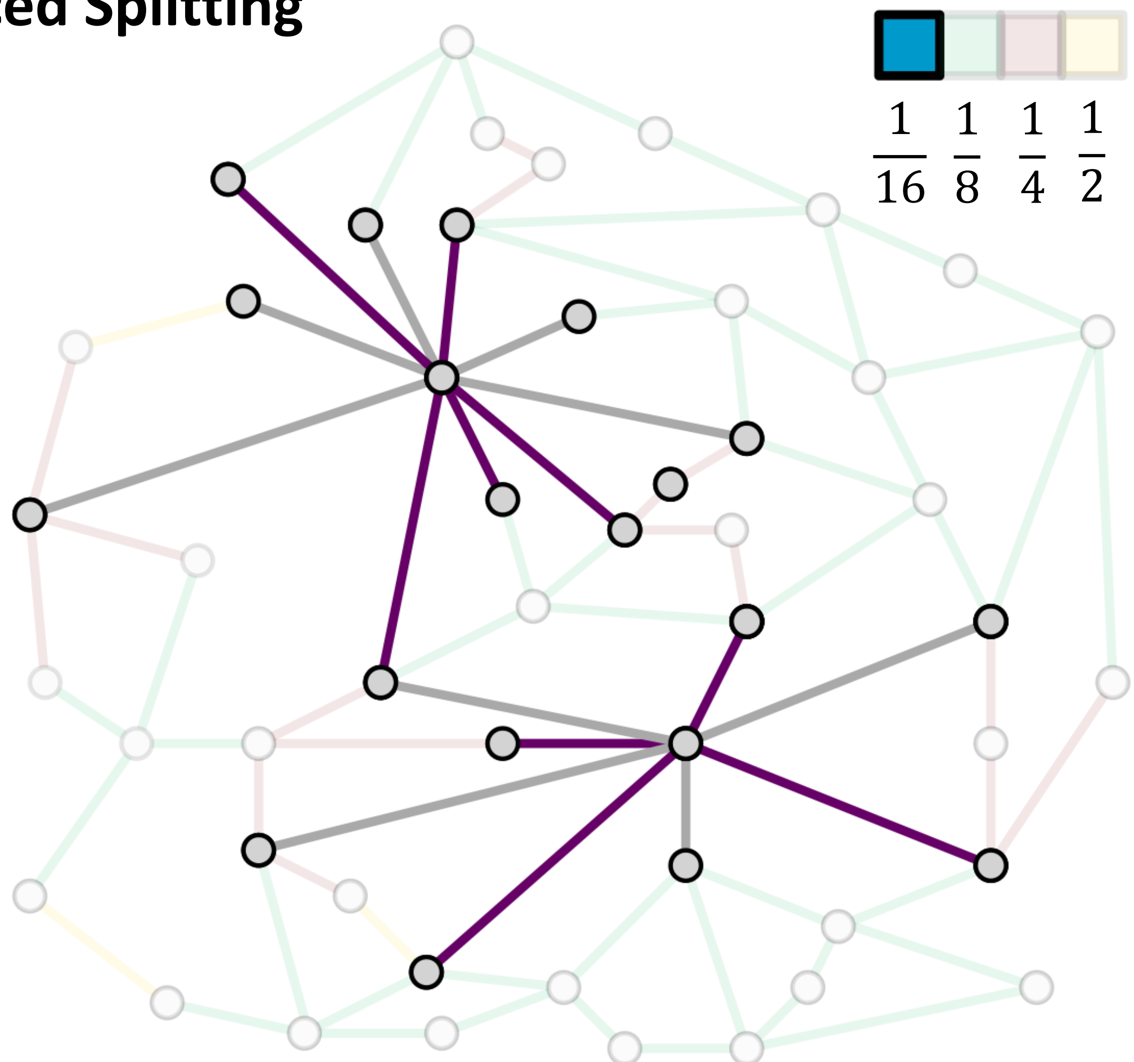

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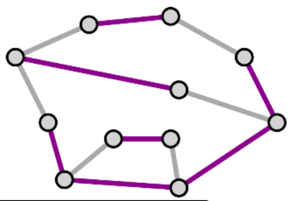

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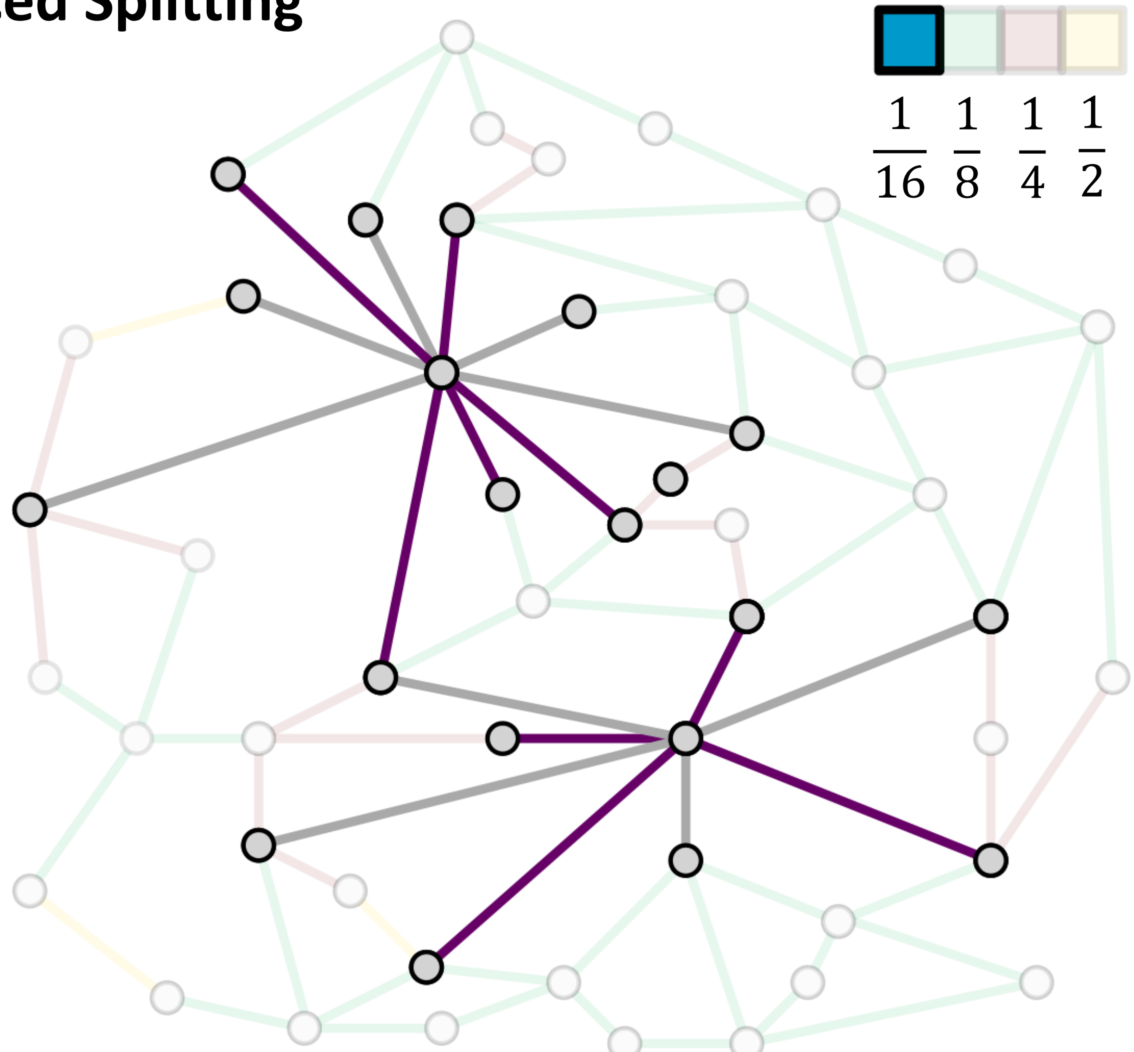
In case of **perfect** locally balanced **splitting**:
no constraint violated & no loss in total value
(i.e., **perfect rouding**)



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Iterated Factor-2-Rounding using Locally Balanced Splitting

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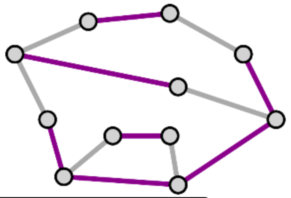

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splitting of E_i into ■■

increase ■ to 2^{-i+1}

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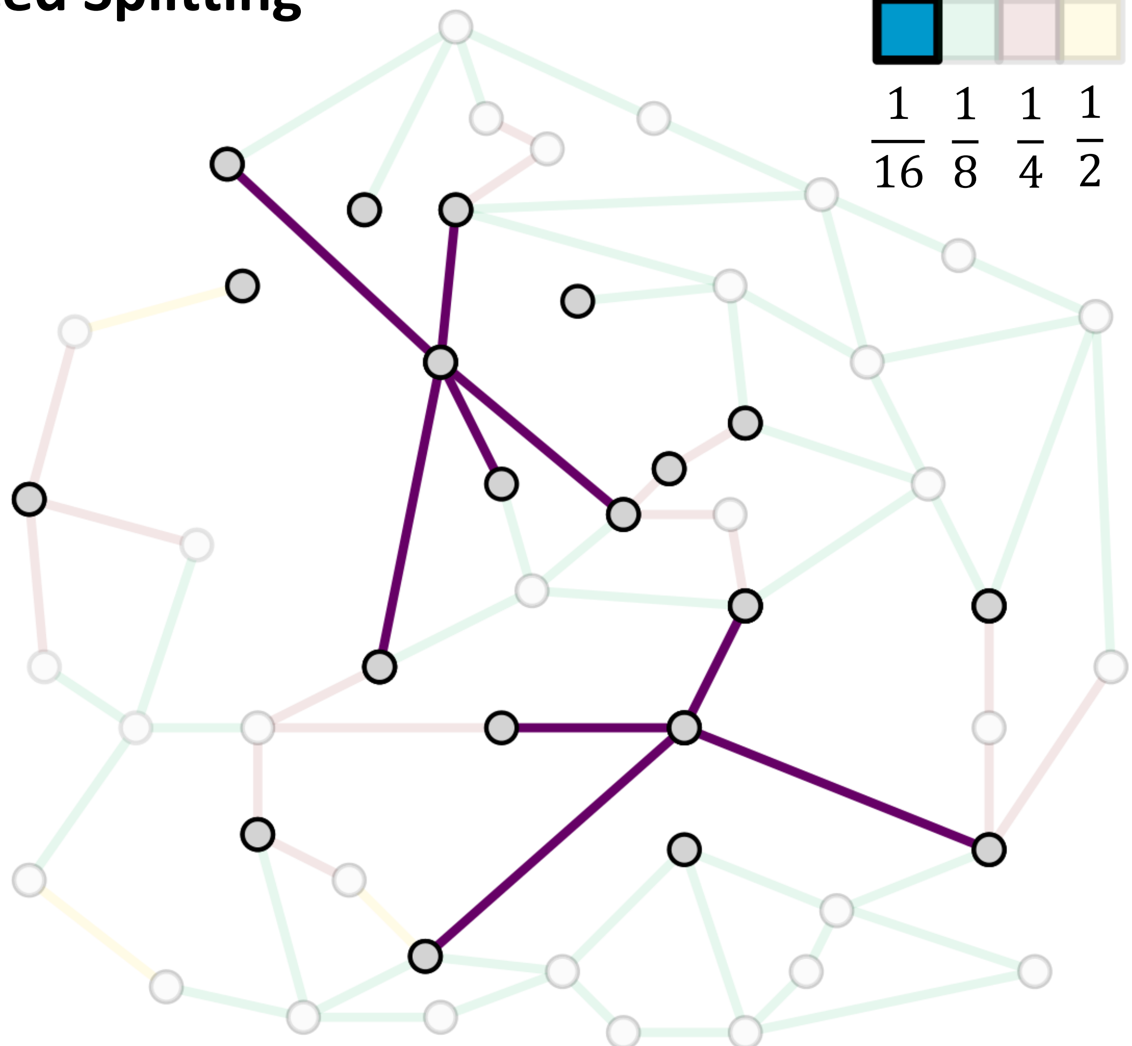
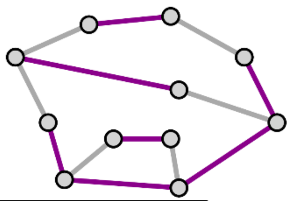


II) Rounding Fractional Bipartite Matching $O(\log^2 \Delta)$ rounds, $O(1)$ loss

Iterated Factor-2-Rounding using Locally Balanced Splitting

Locally Balanced Splitting:
2-edge-coloring so that every node roughly balanced



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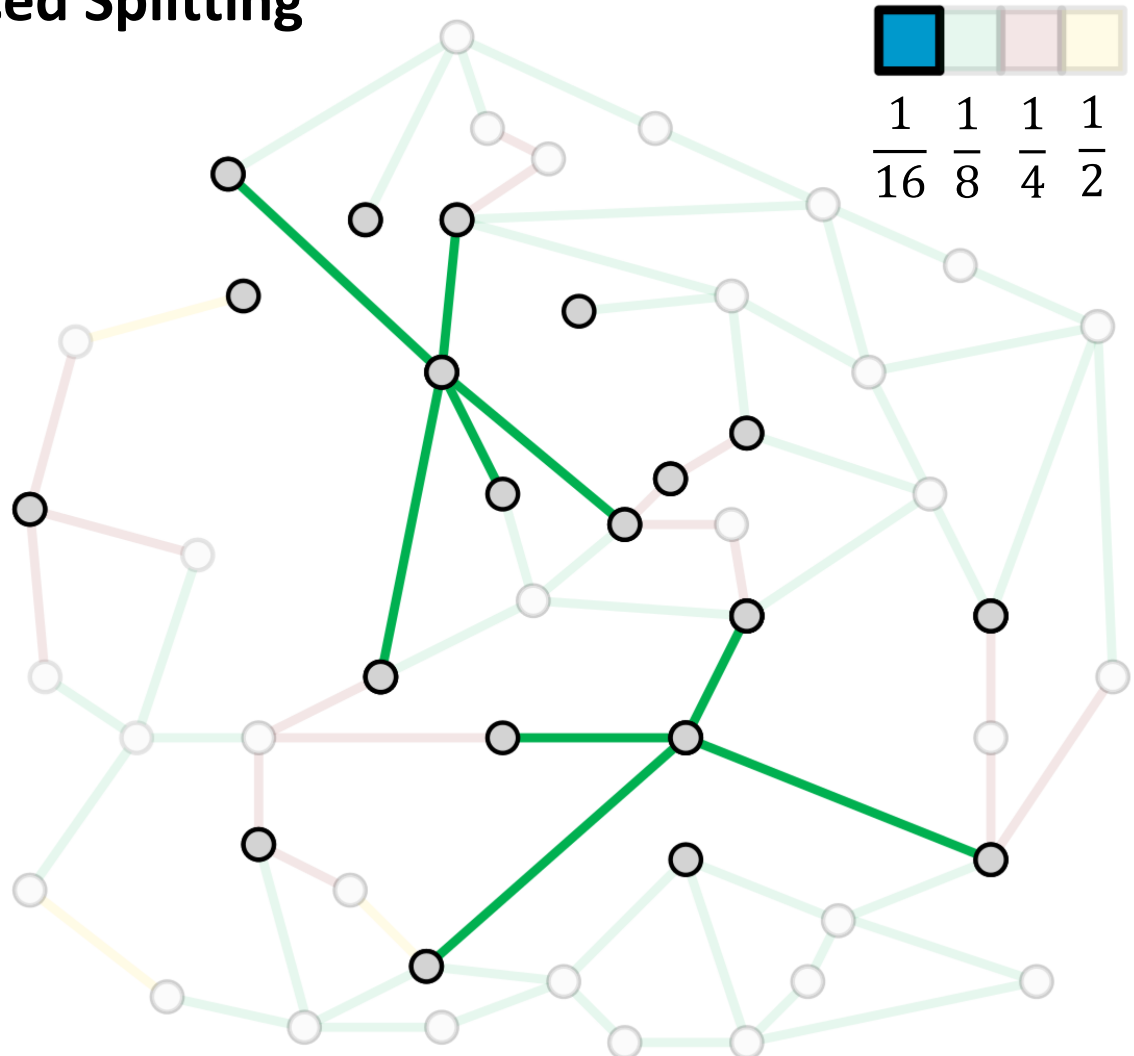

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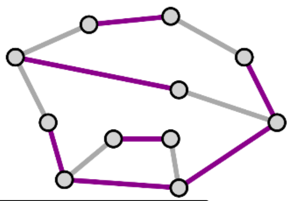

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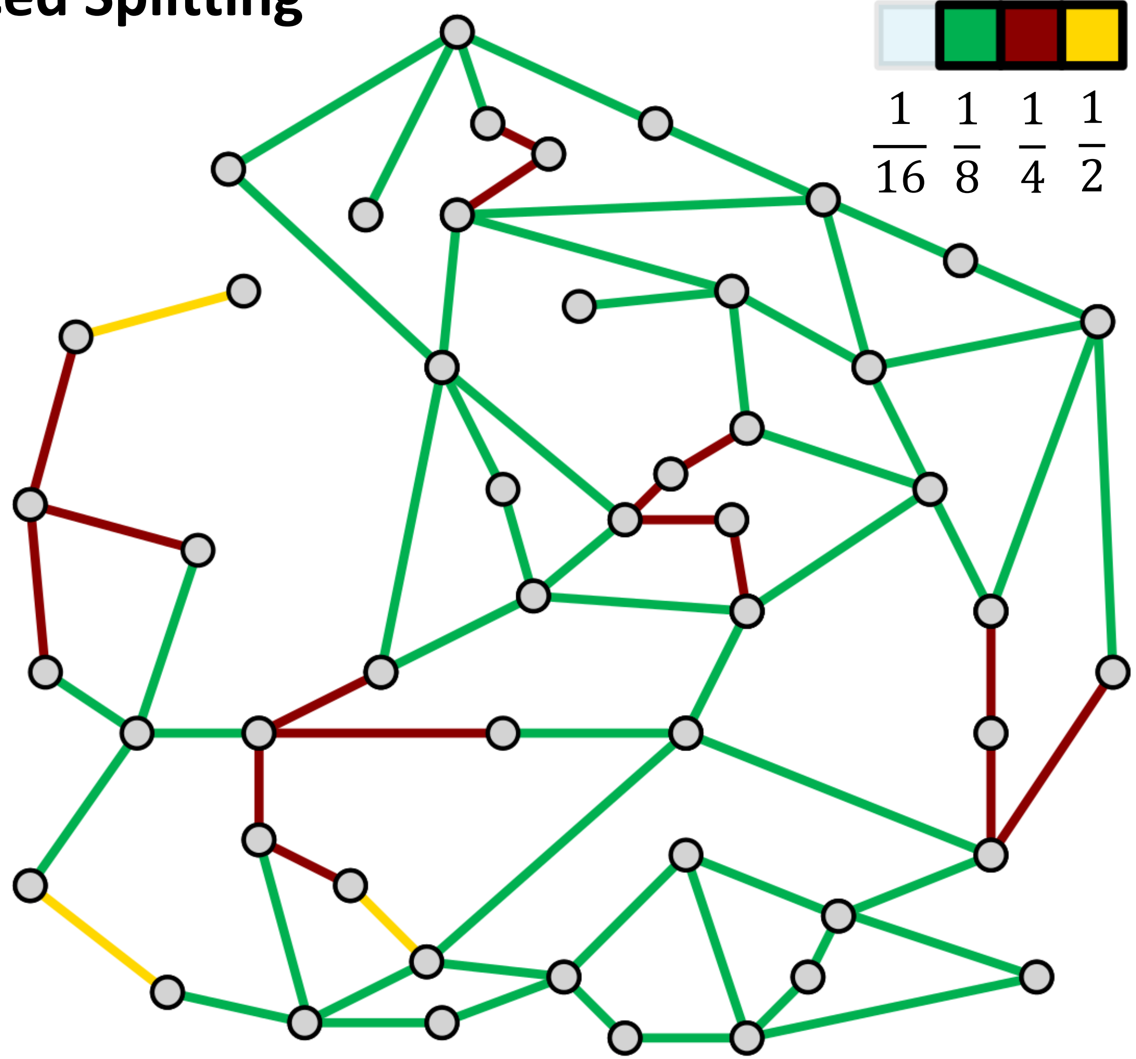

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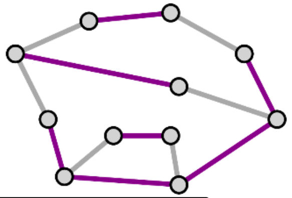

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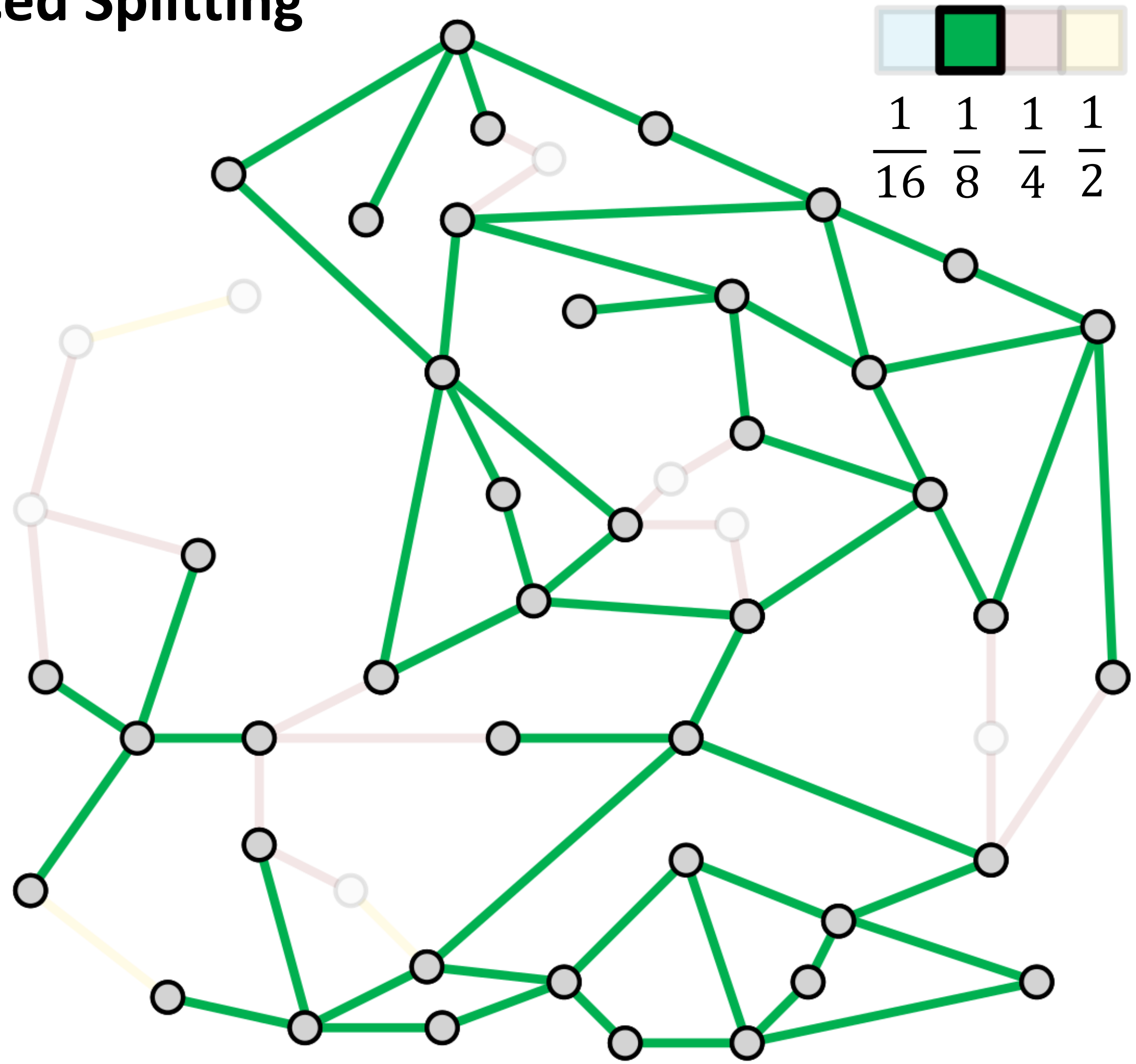

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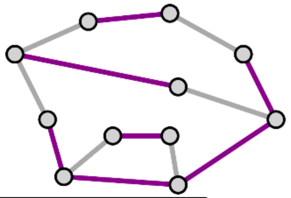

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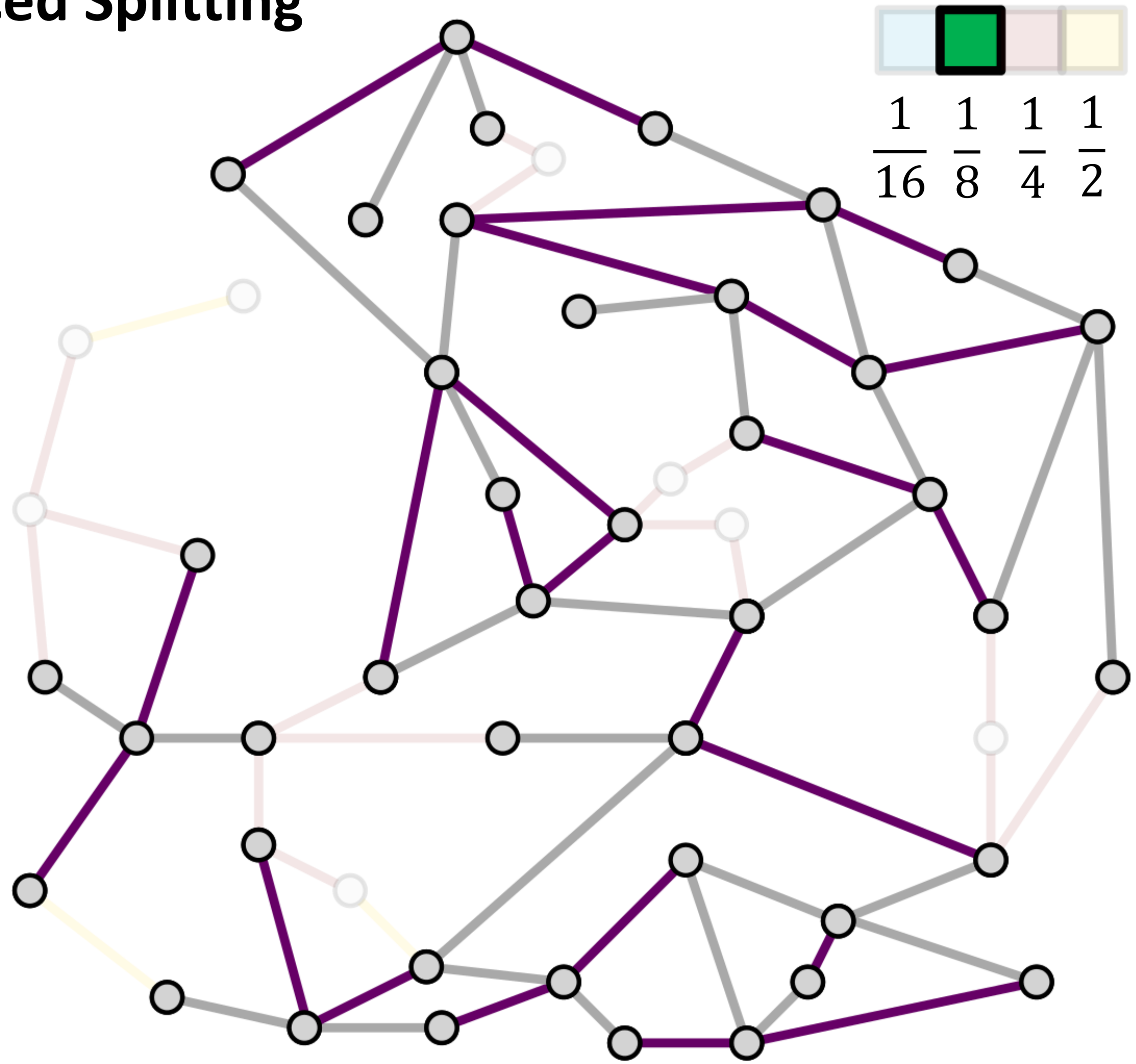

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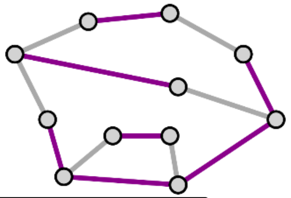

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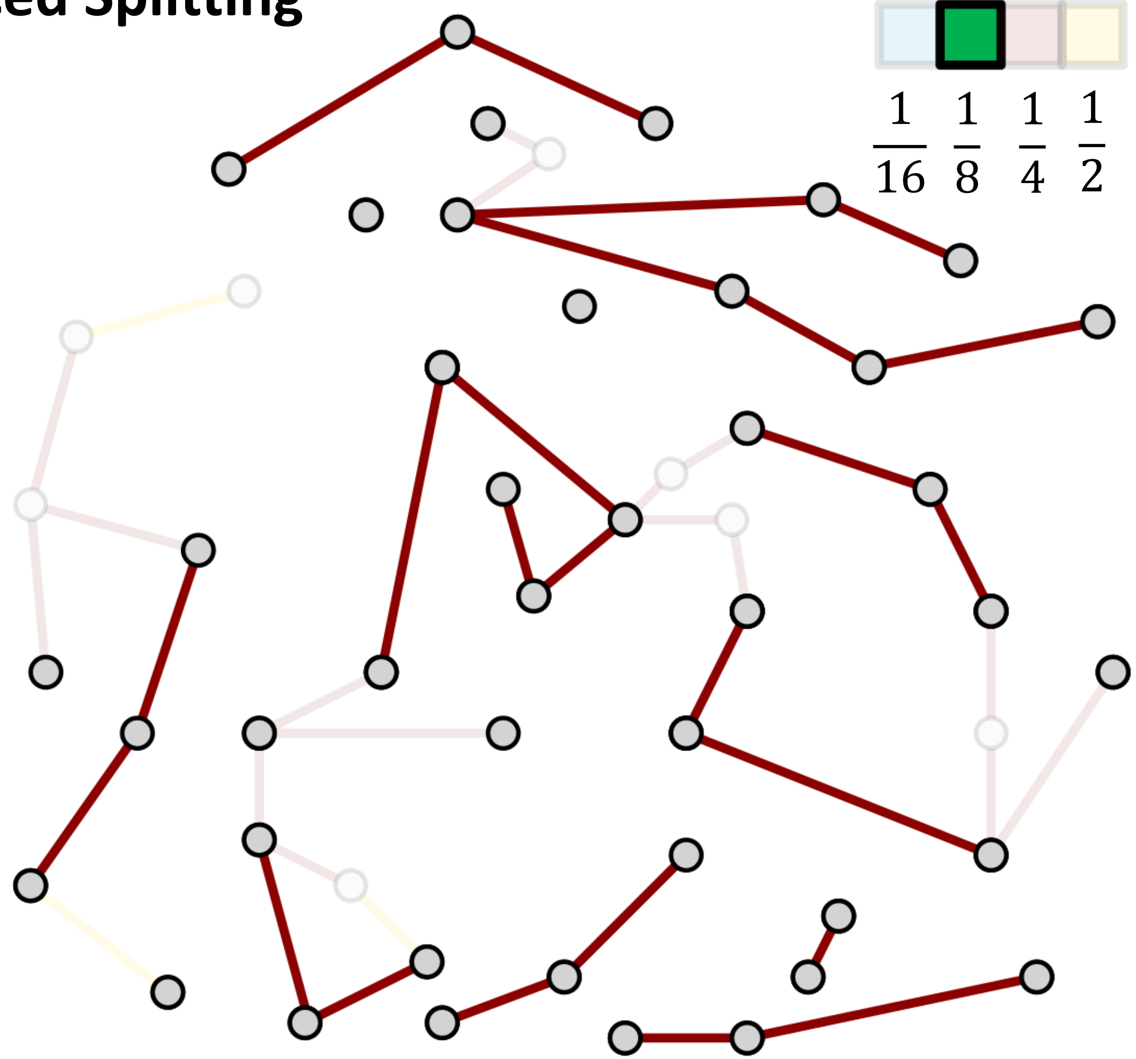

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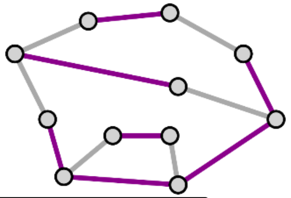

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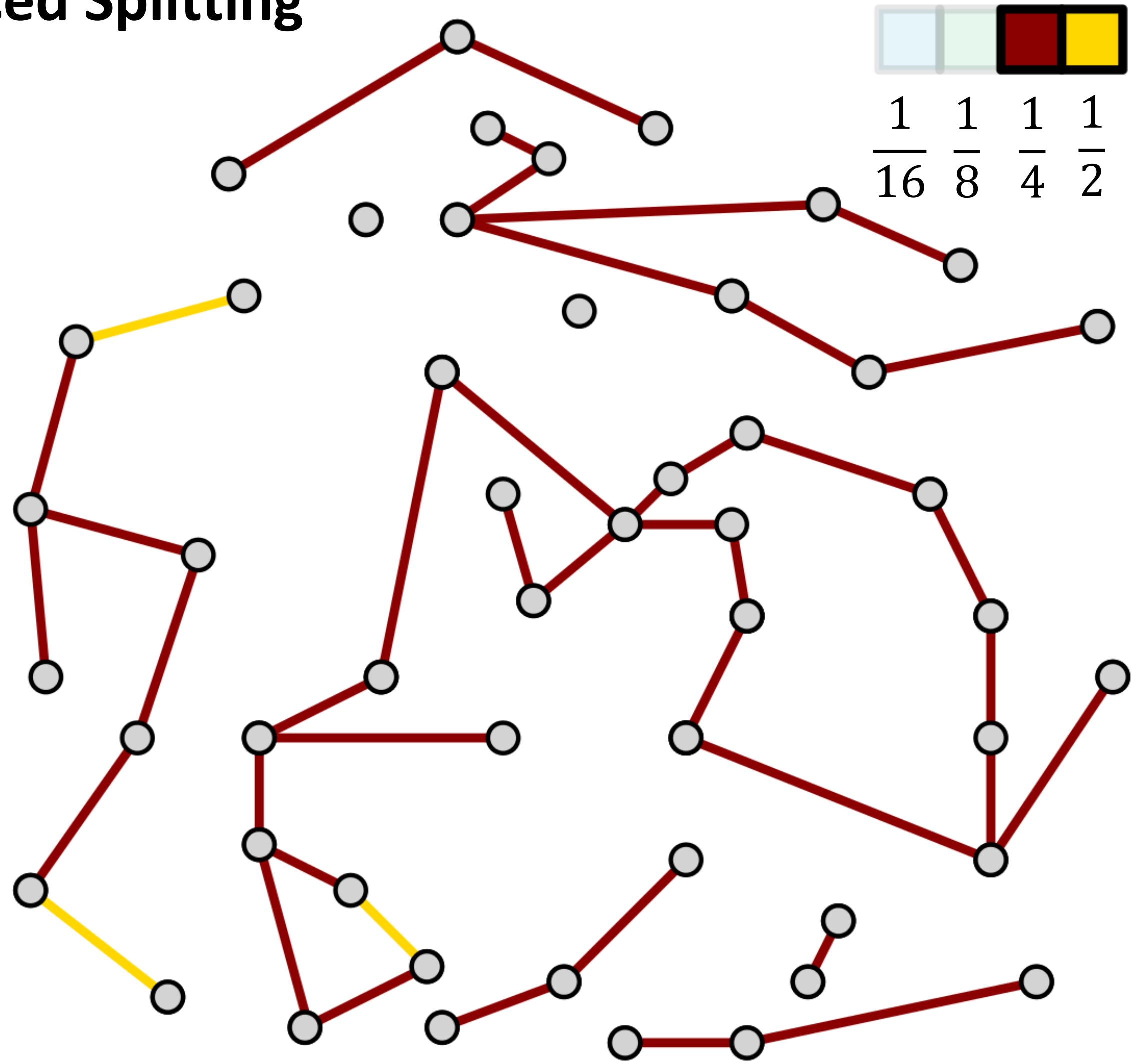

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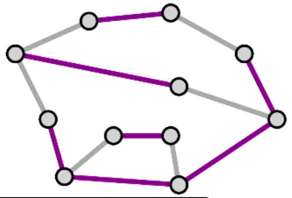

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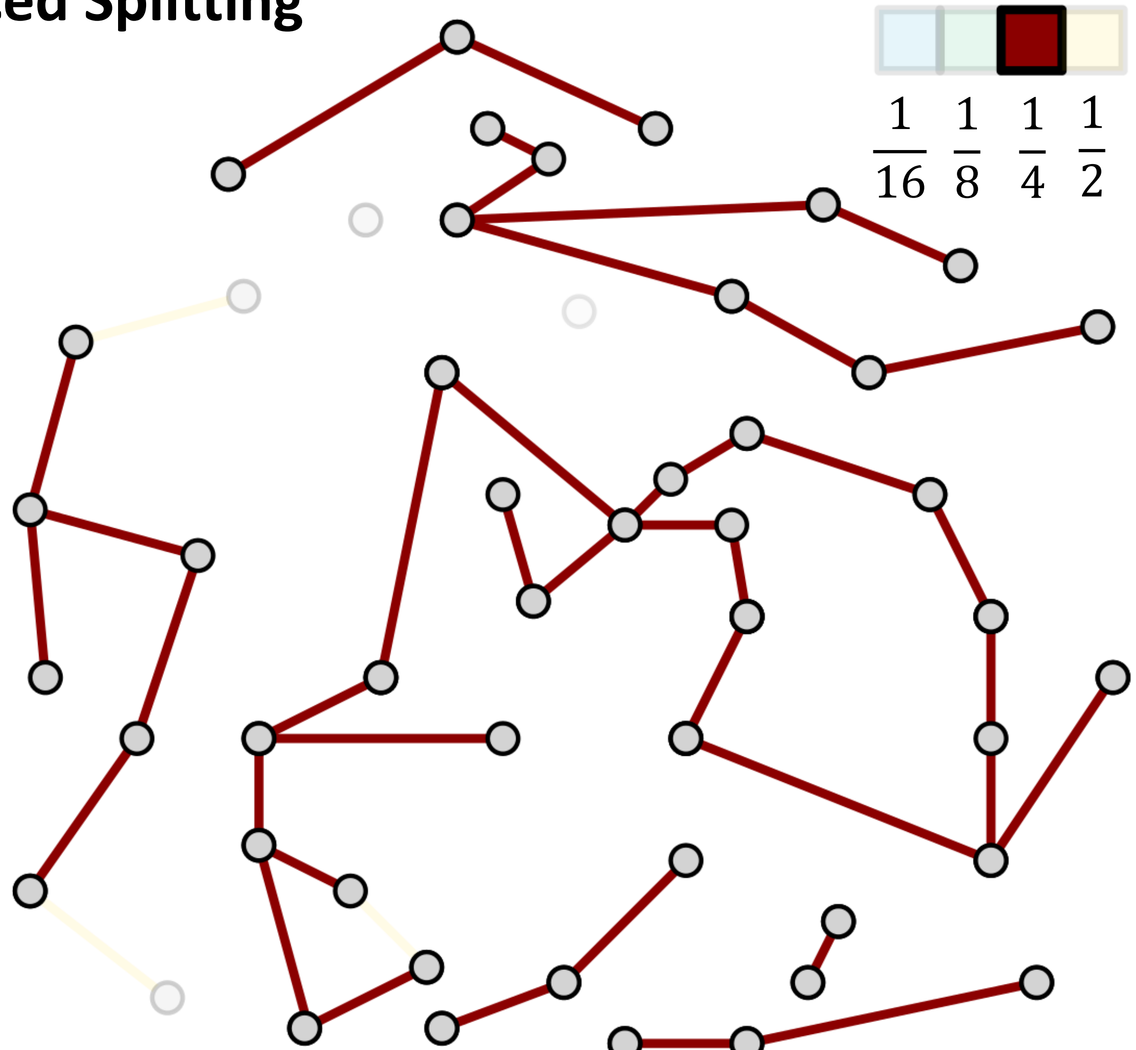

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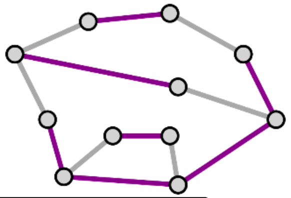

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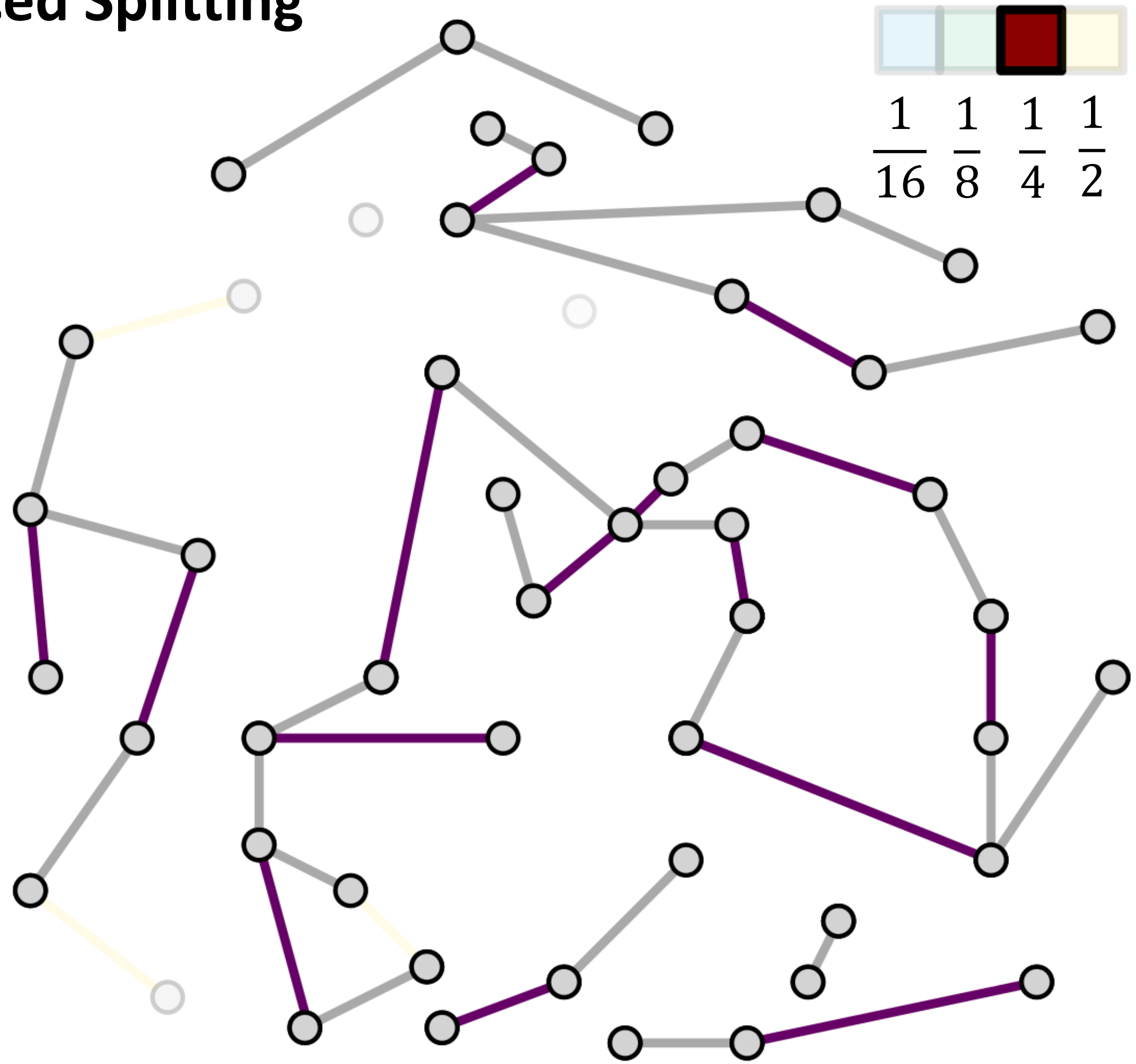

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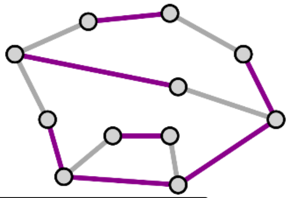

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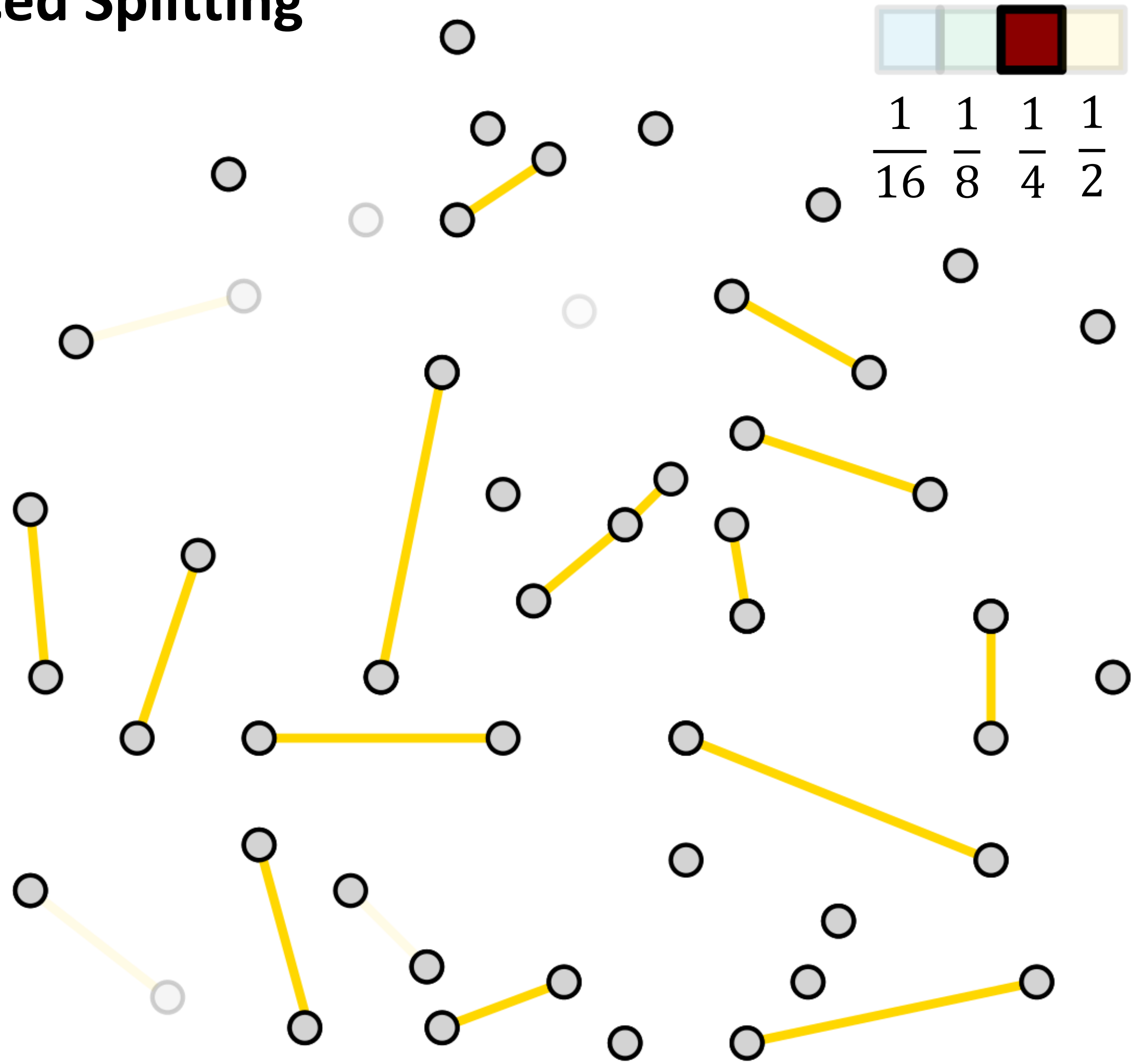

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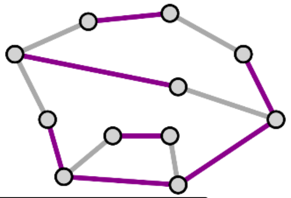

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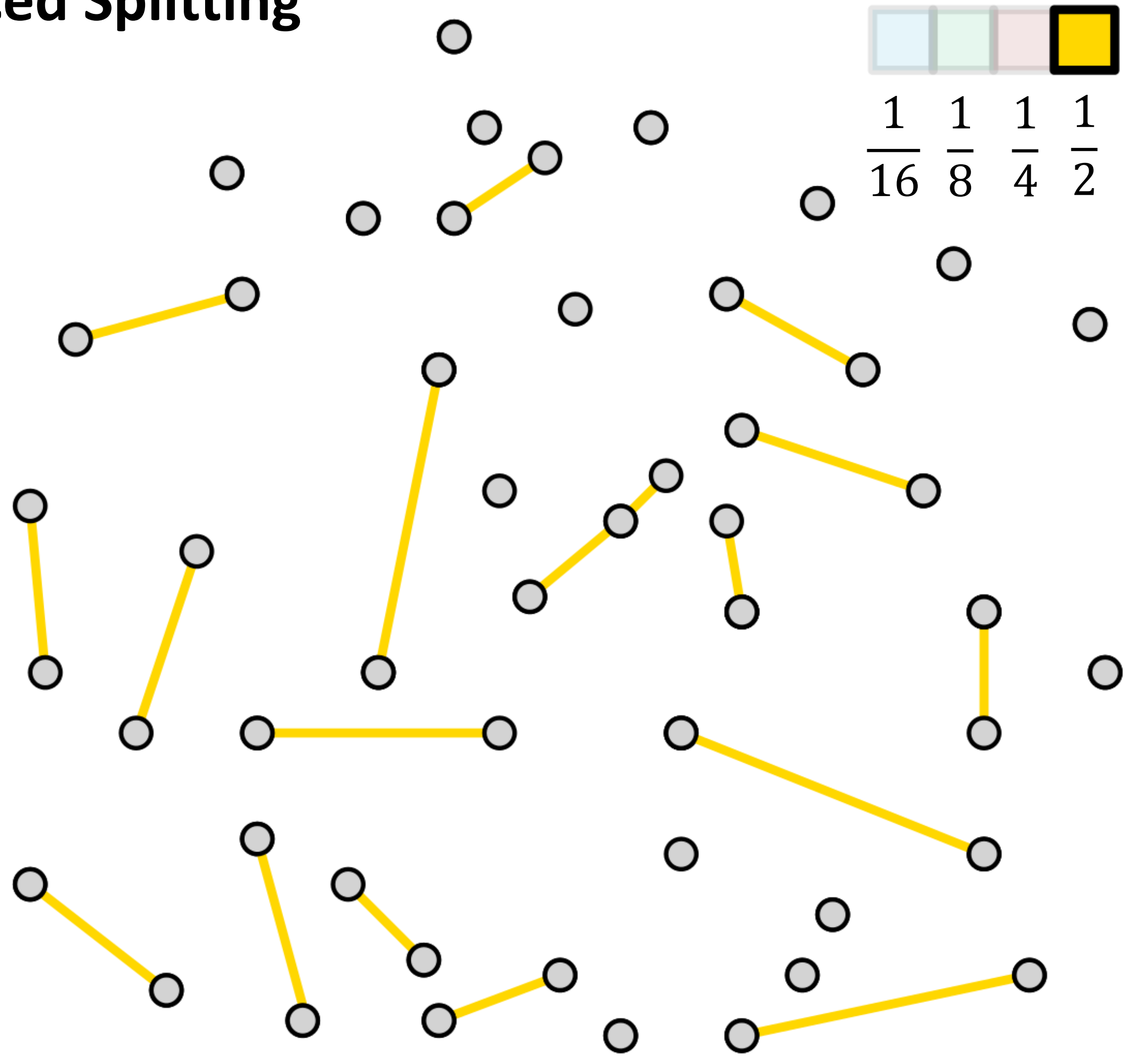

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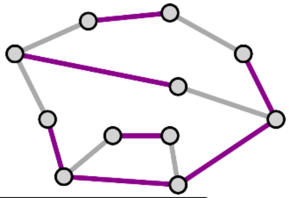

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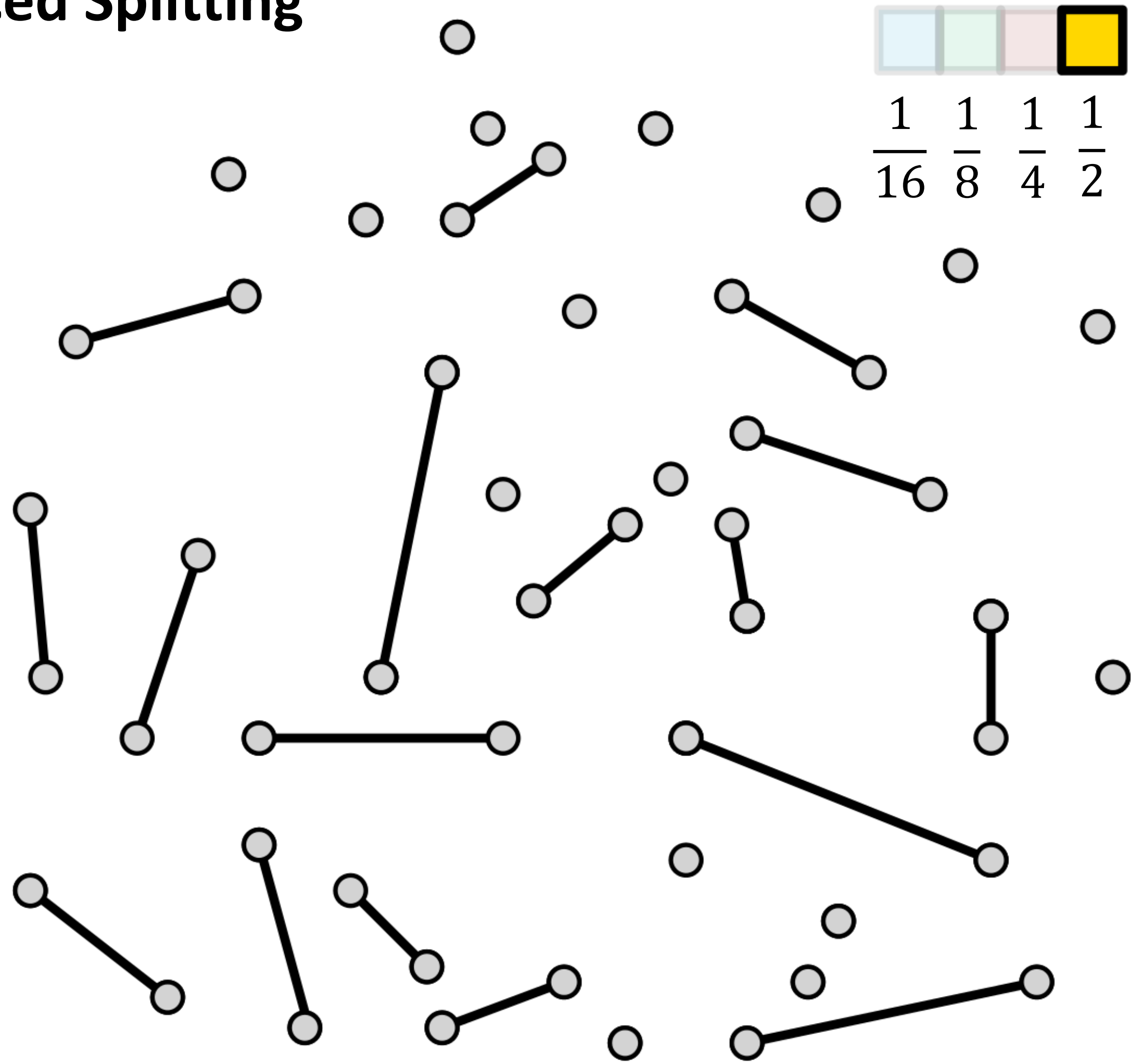

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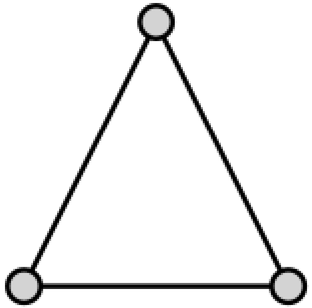

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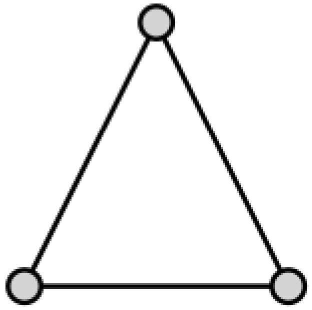

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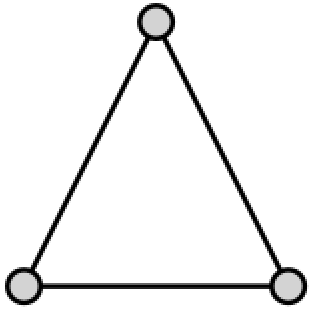

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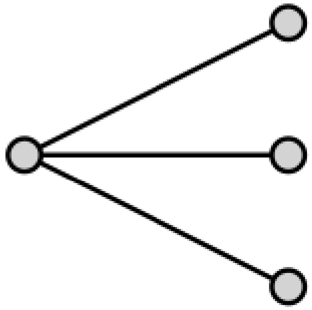

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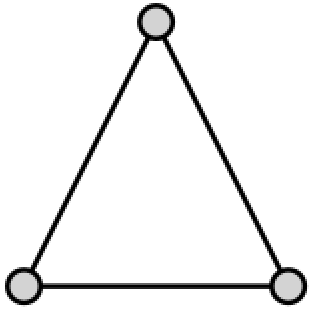

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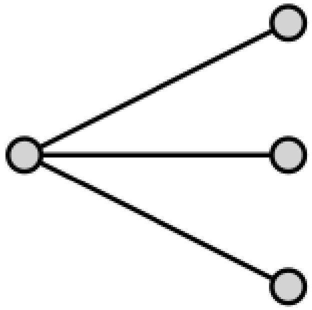

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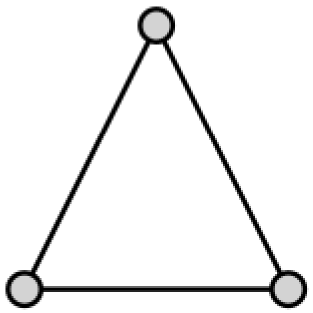

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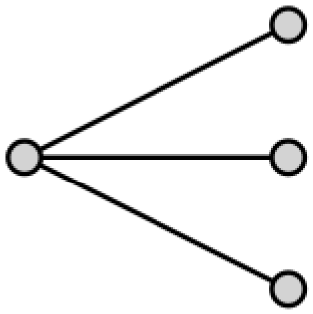

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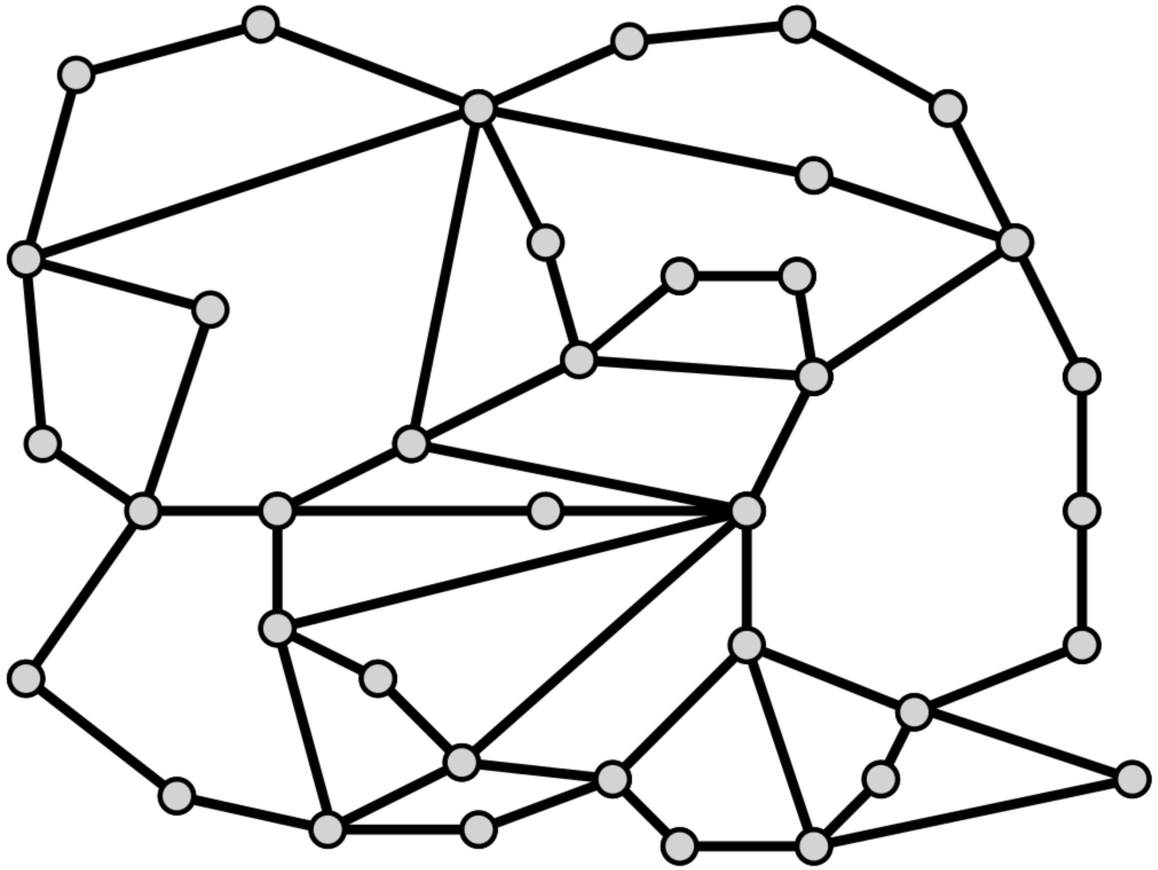

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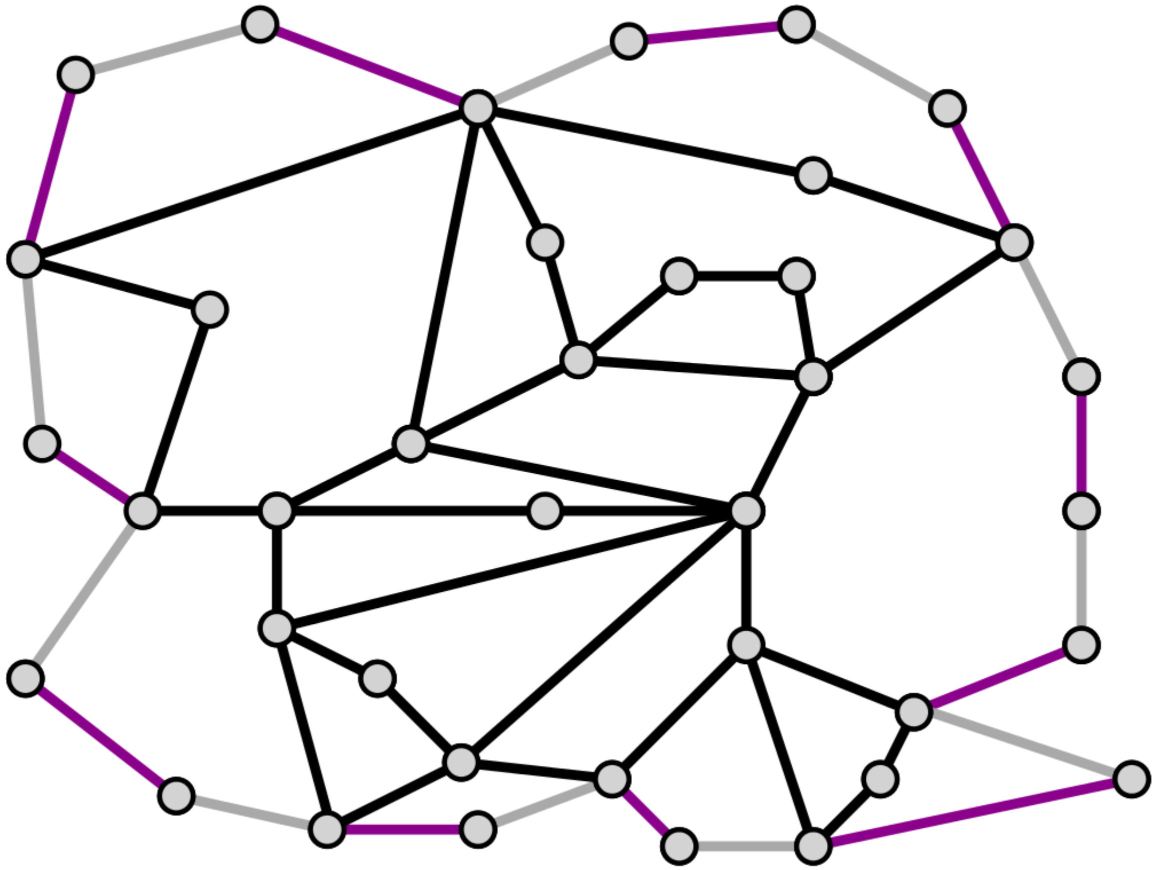

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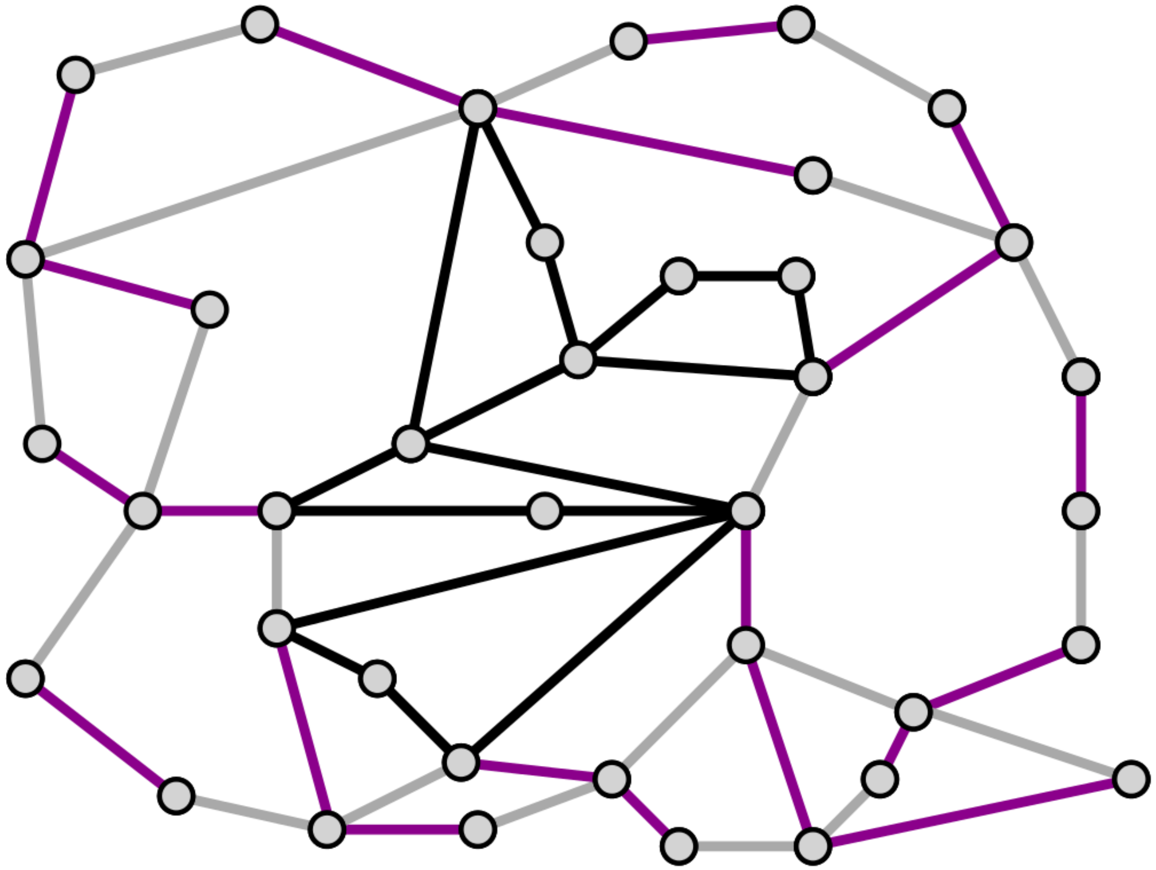

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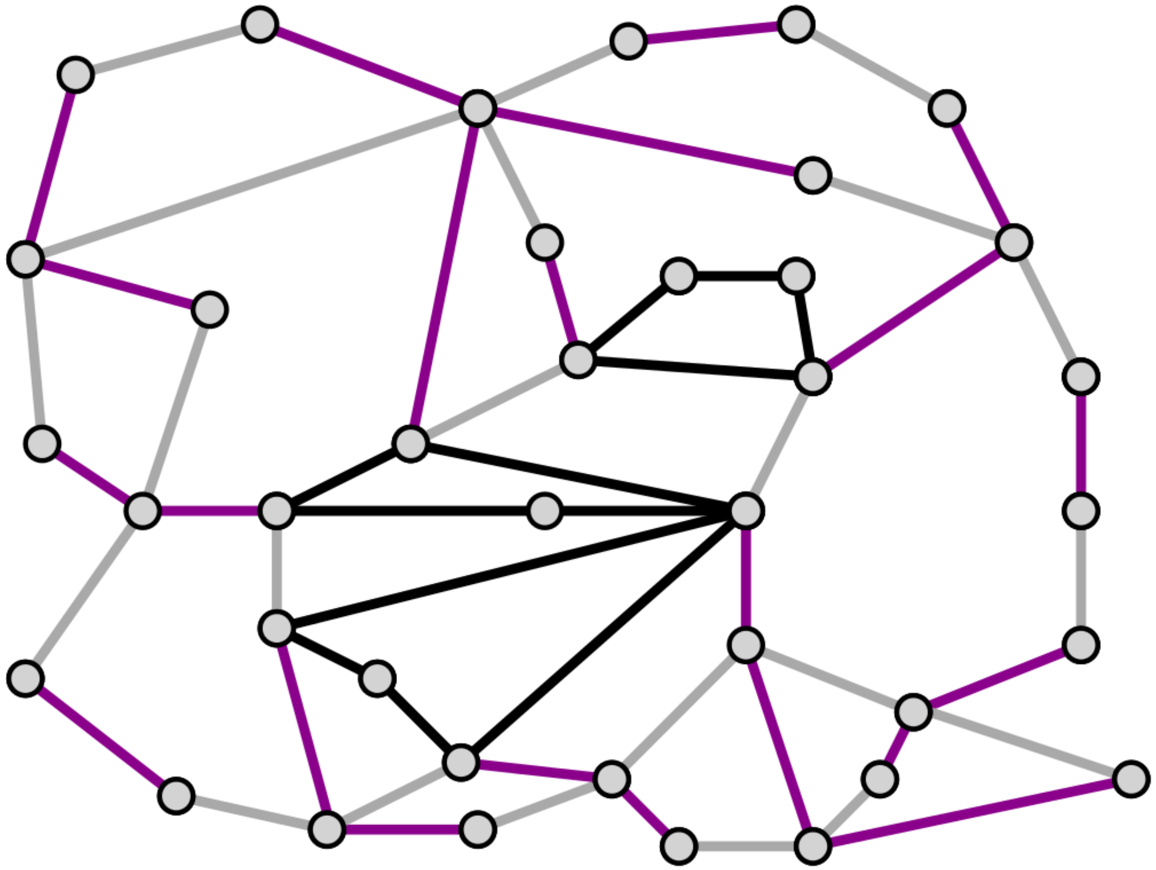

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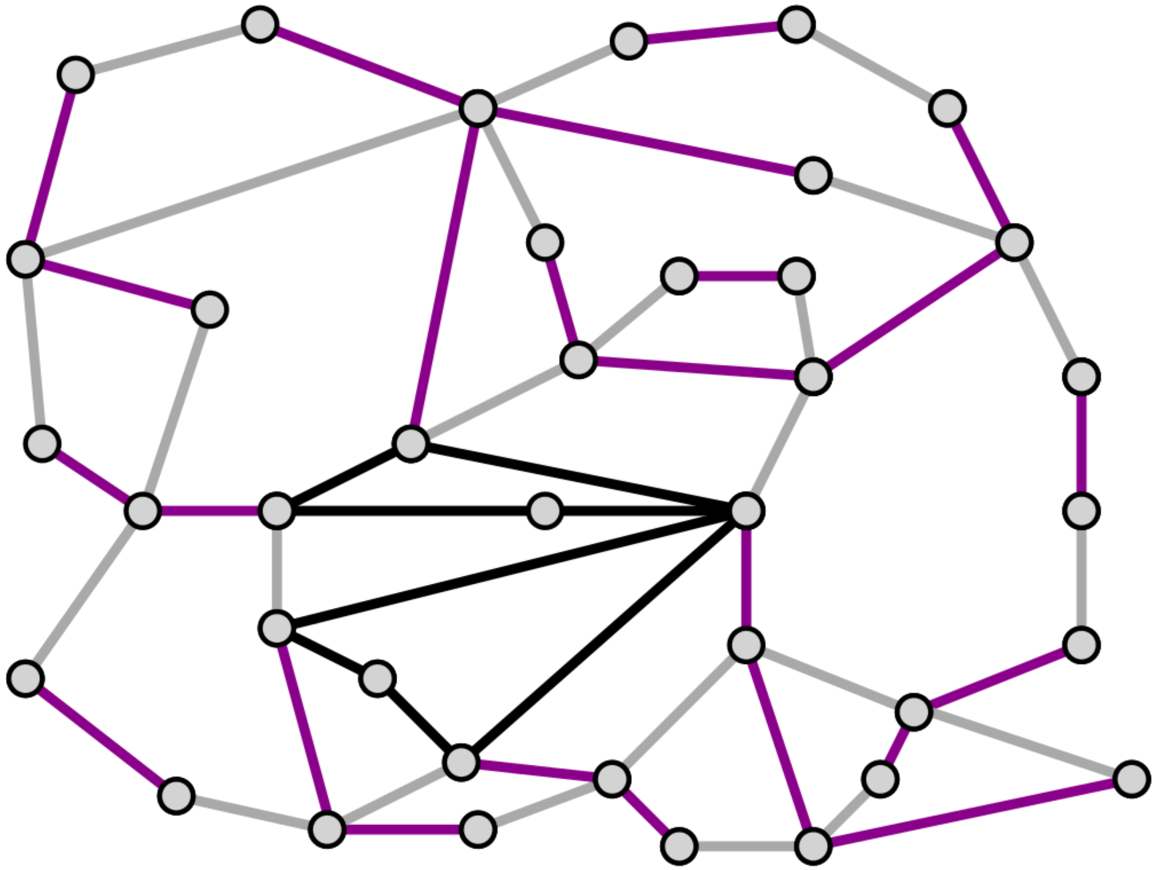

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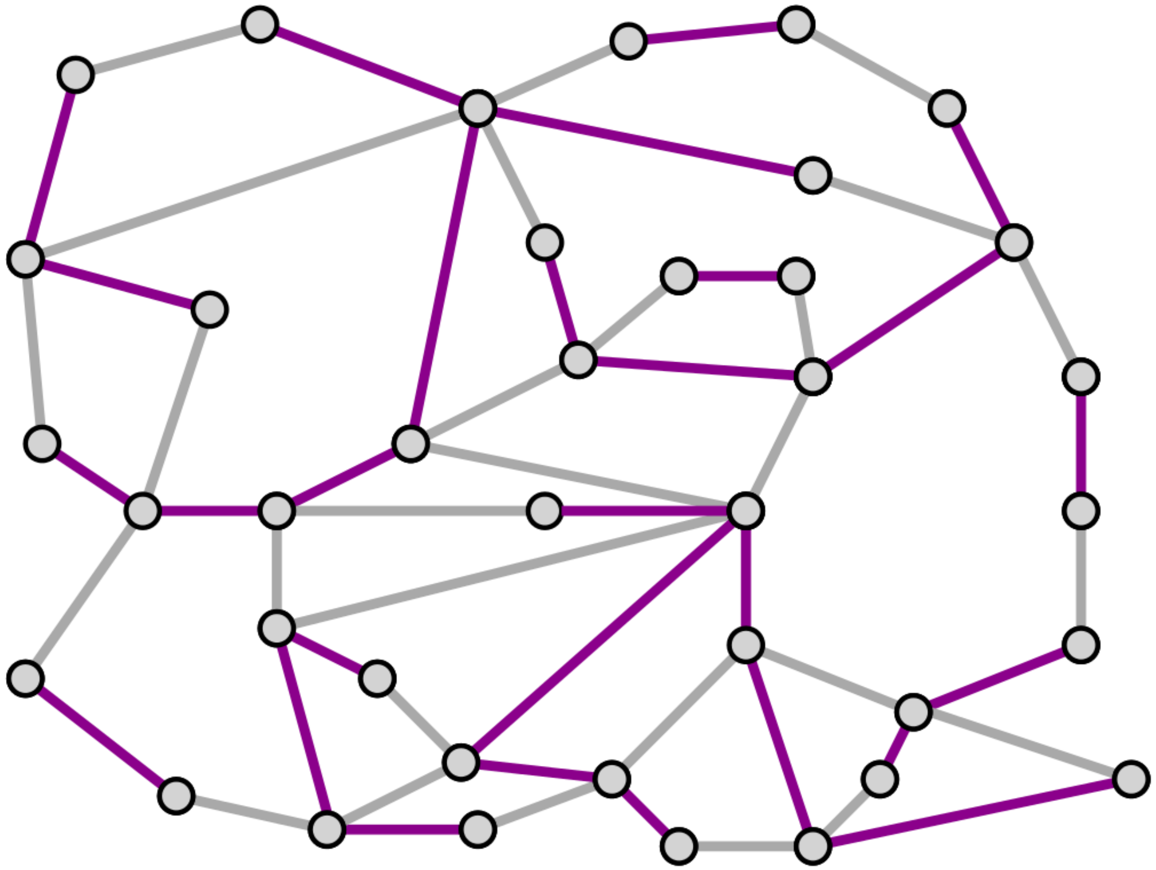

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Decompose into edge-disjoint cycles
In parallel, for all cycles
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  B) **Long cycles**
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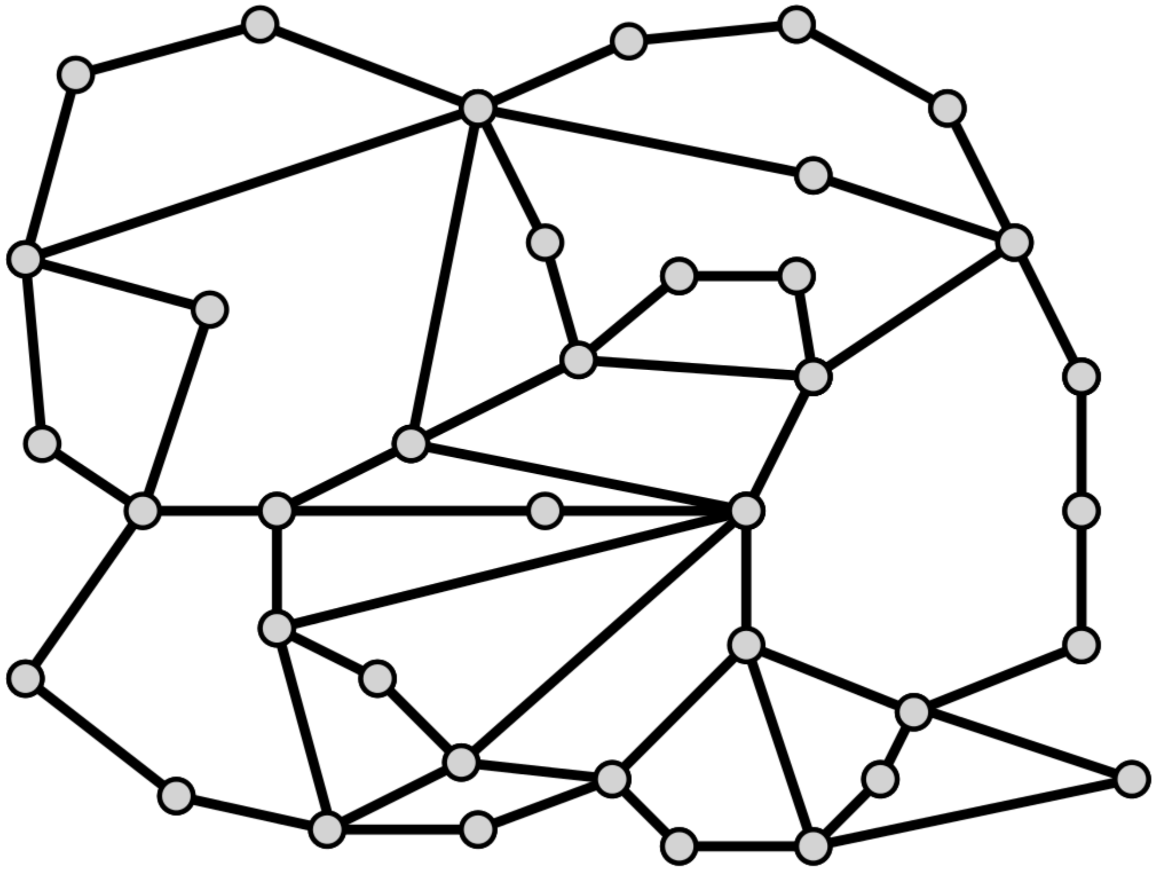

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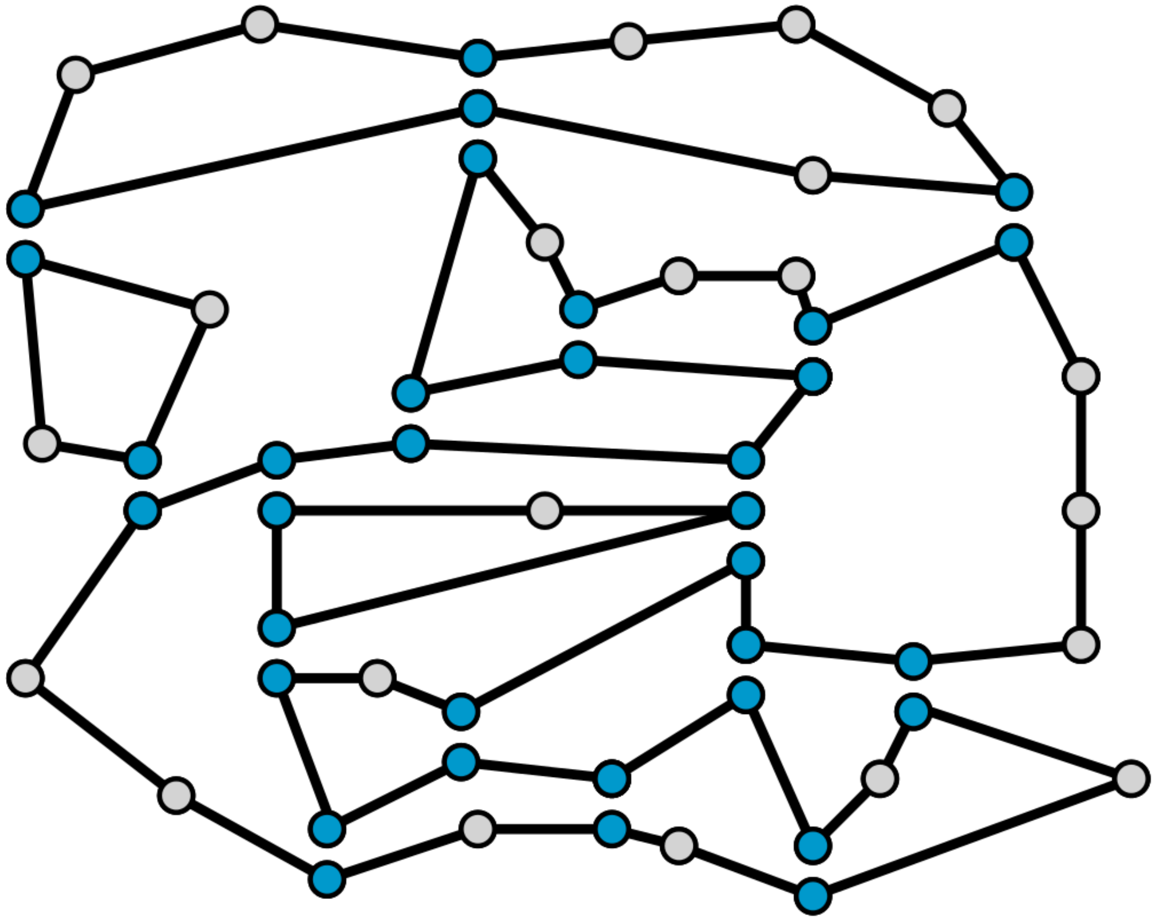

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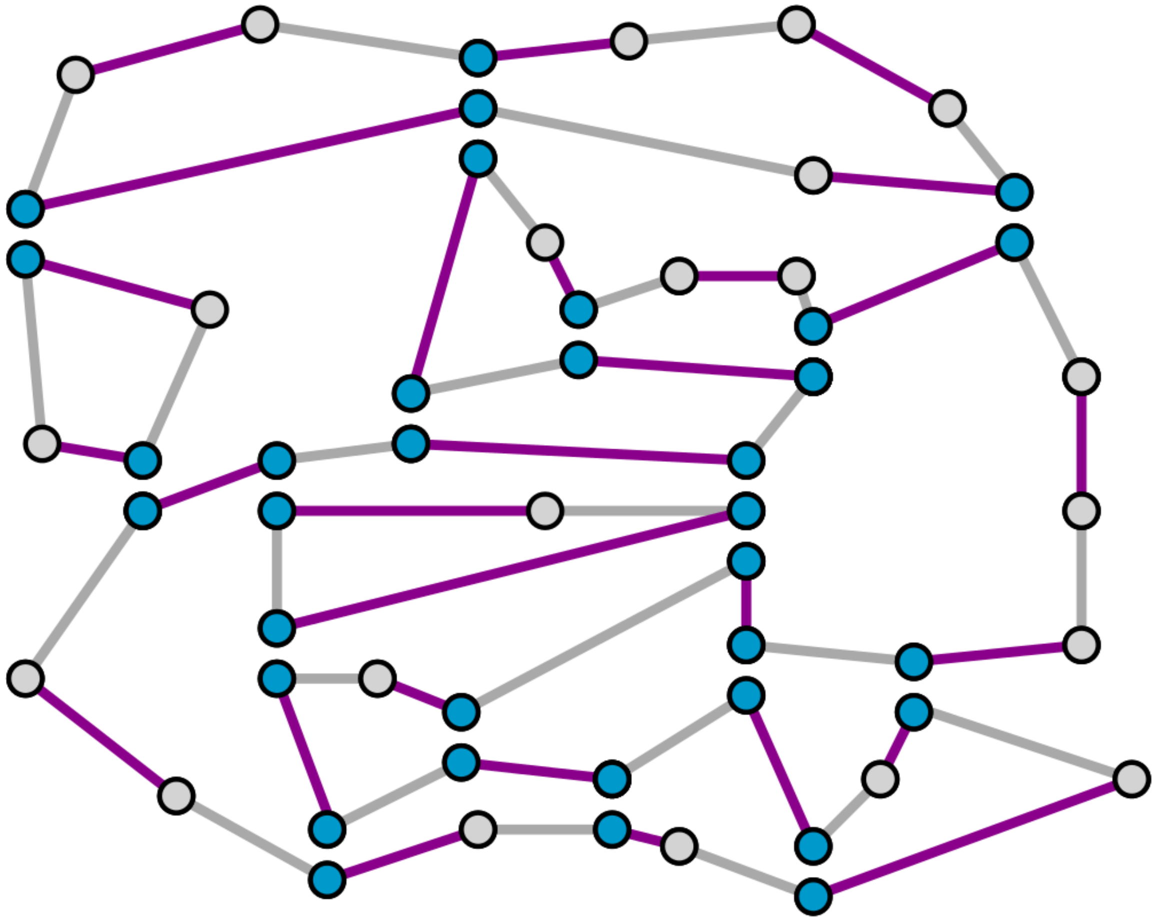

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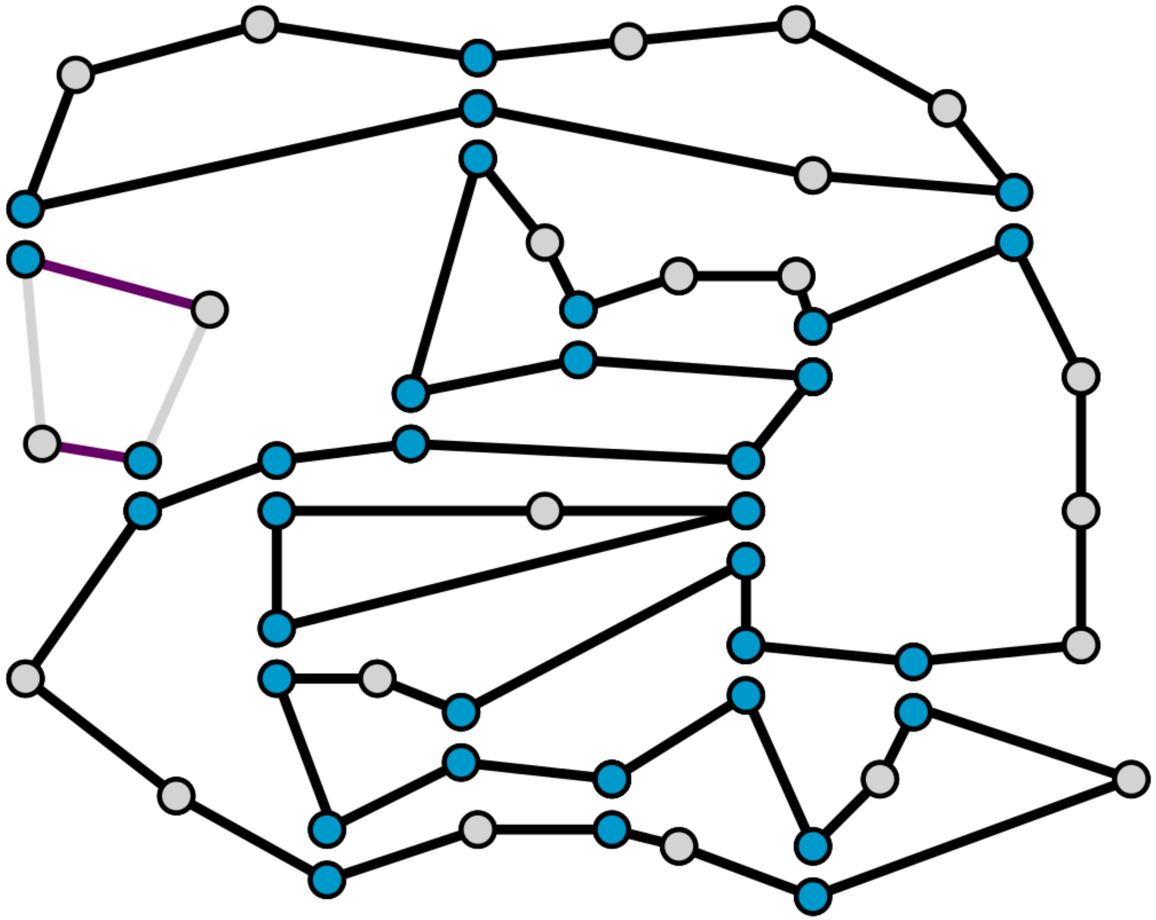

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LOCAL Almost-Perfect Splitting*

Decompose into edge-disjoint cycles
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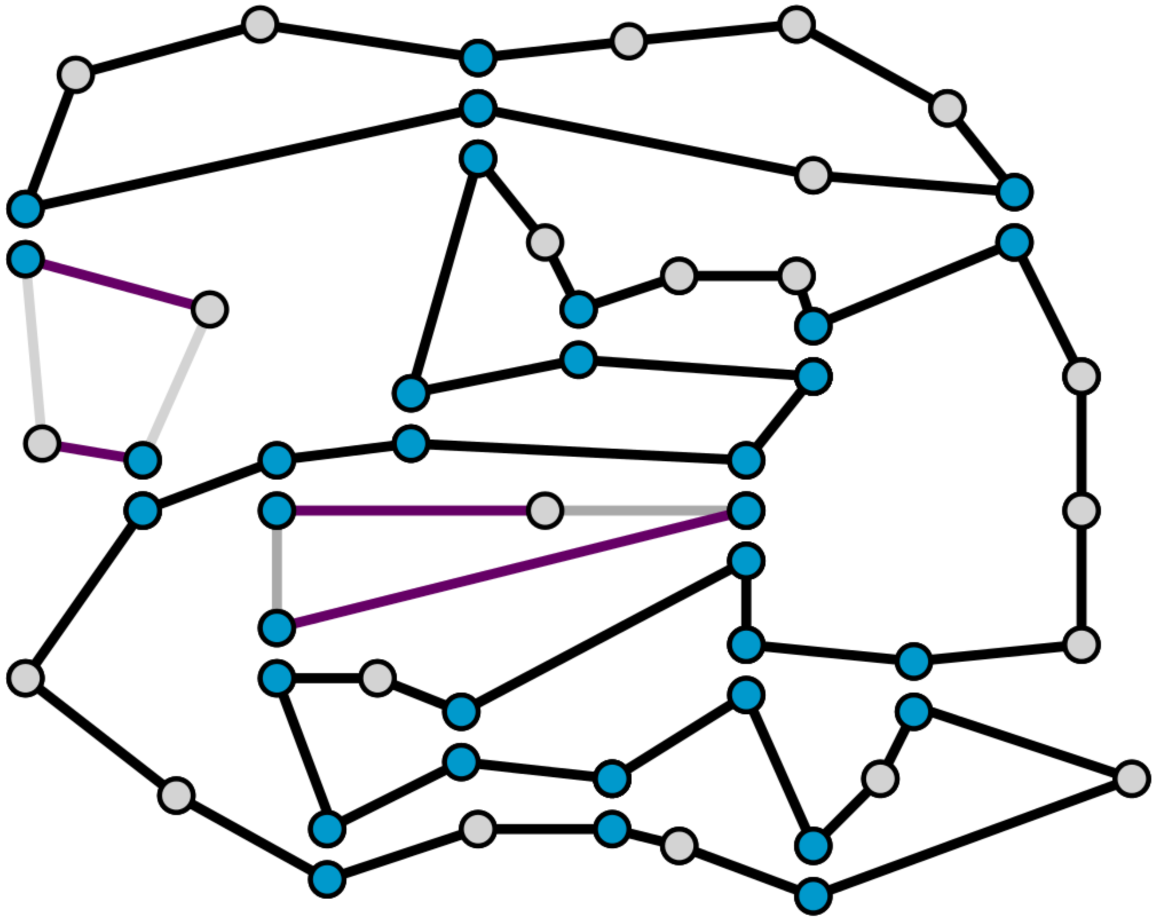

*** bipartite and even degree!**

II) Rounding Fractional Bipartite Matching

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

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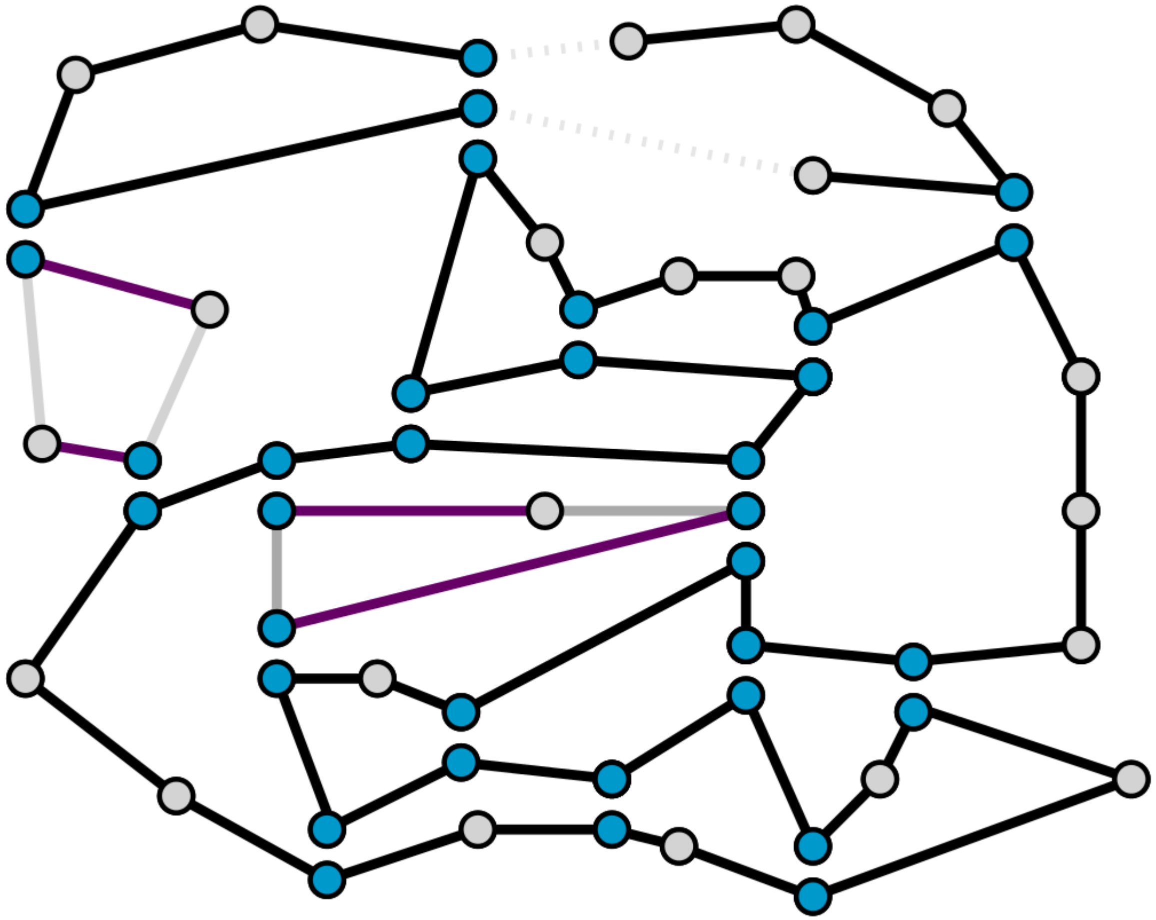

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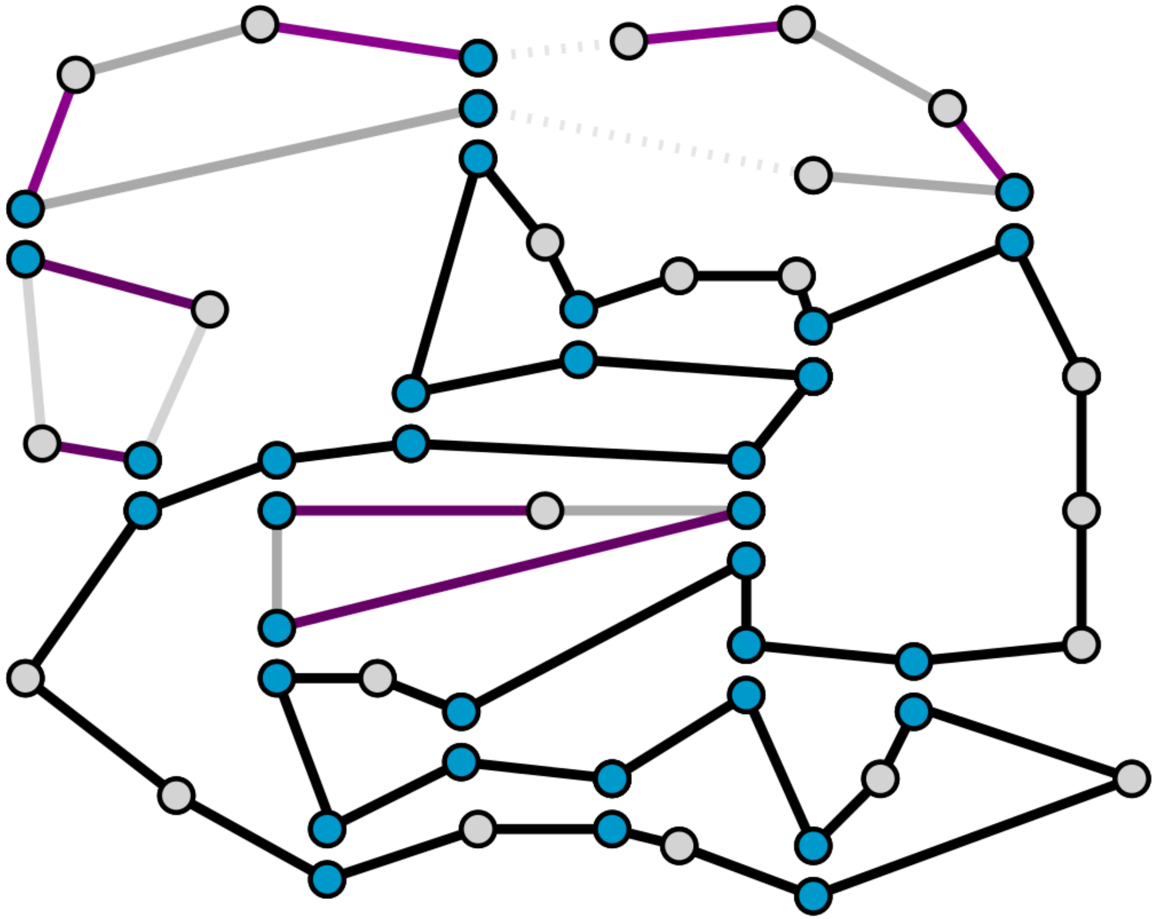

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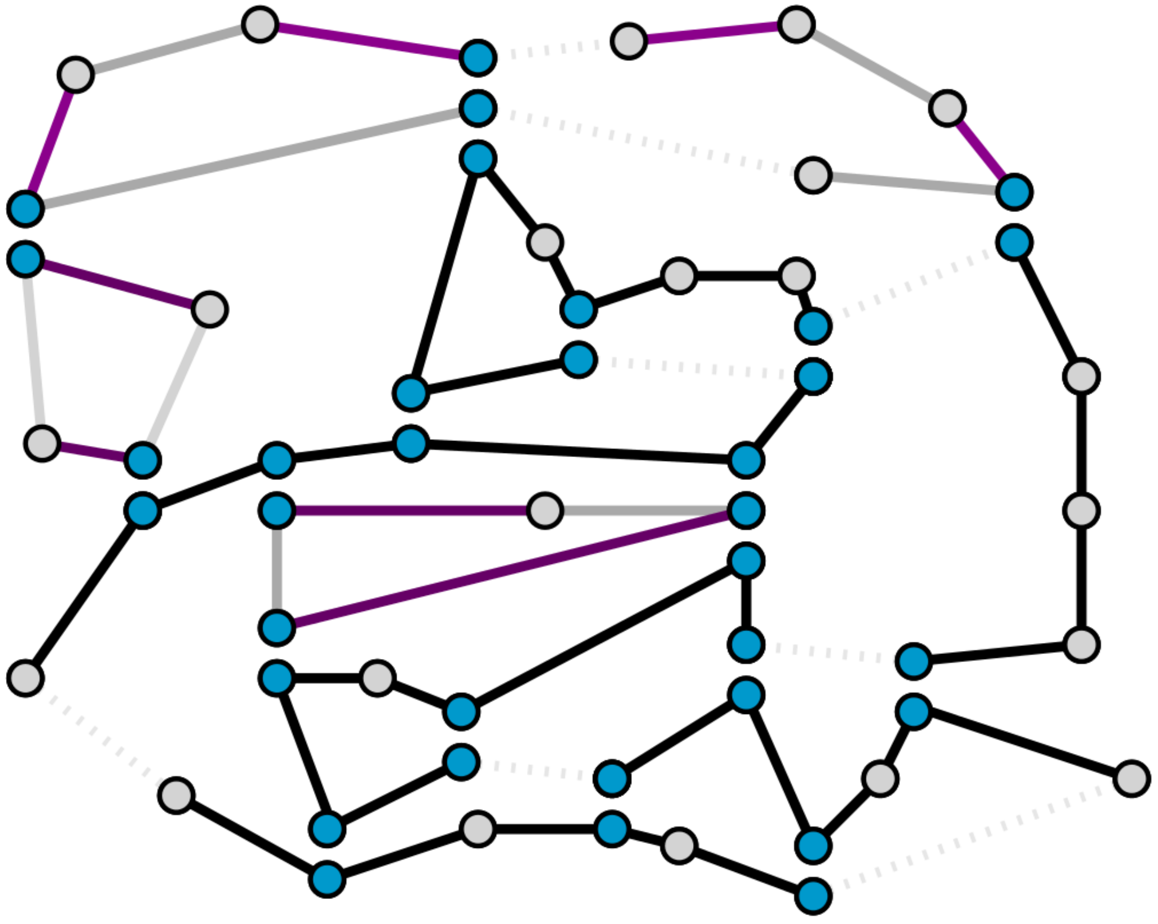

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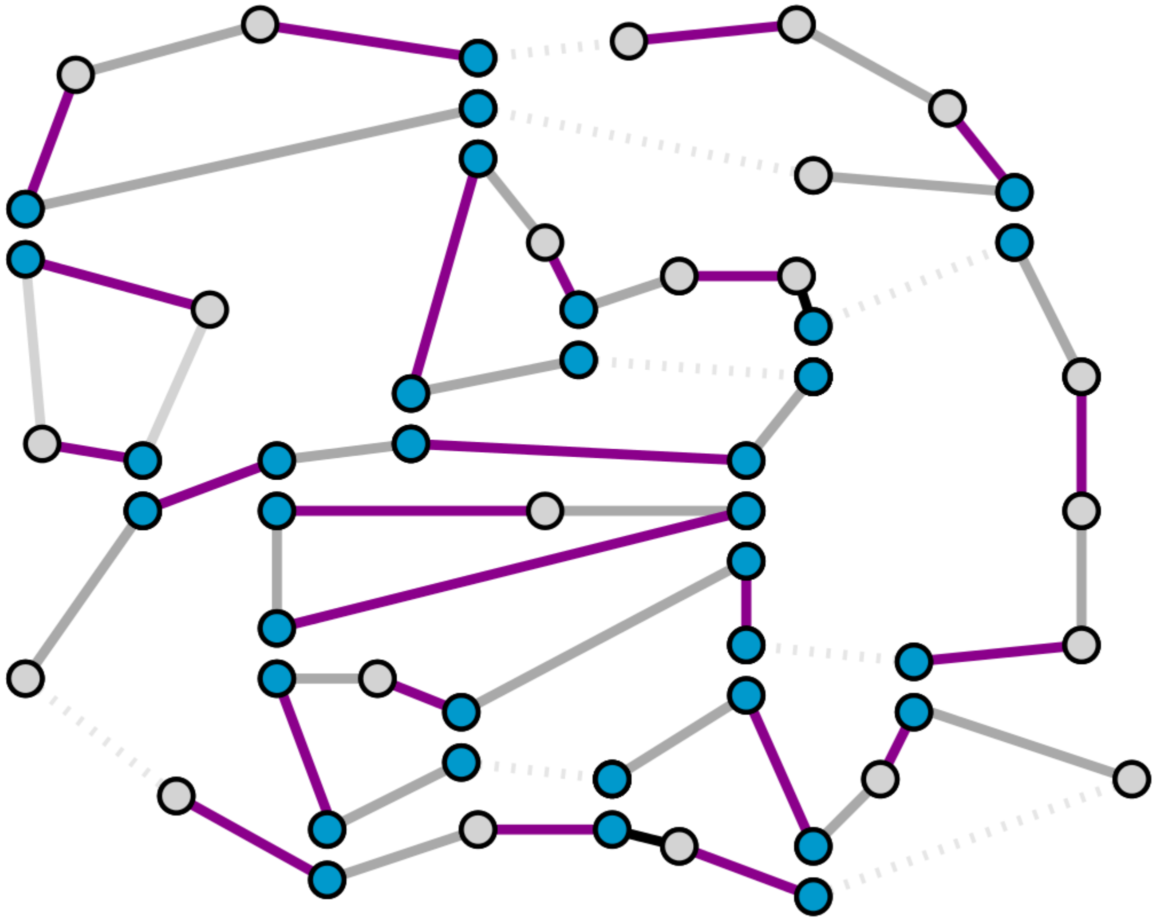

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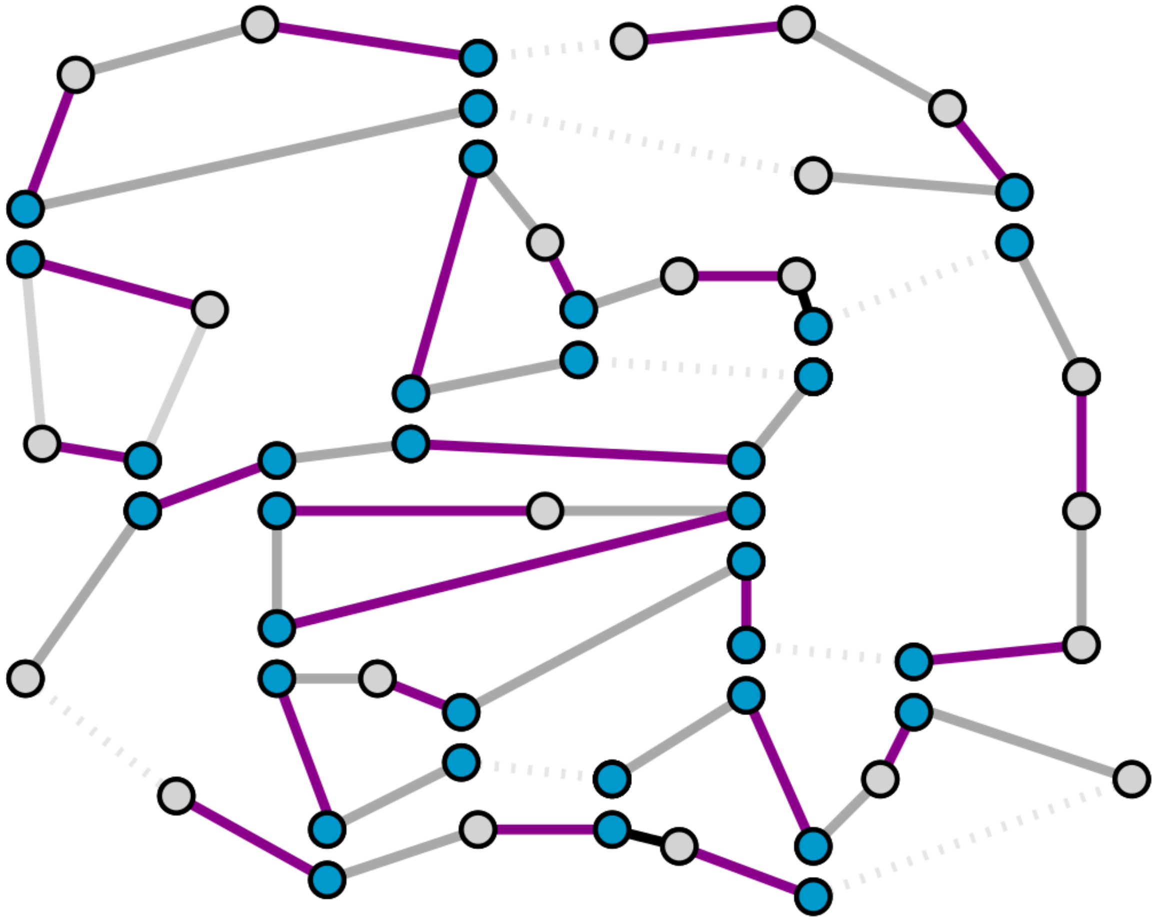

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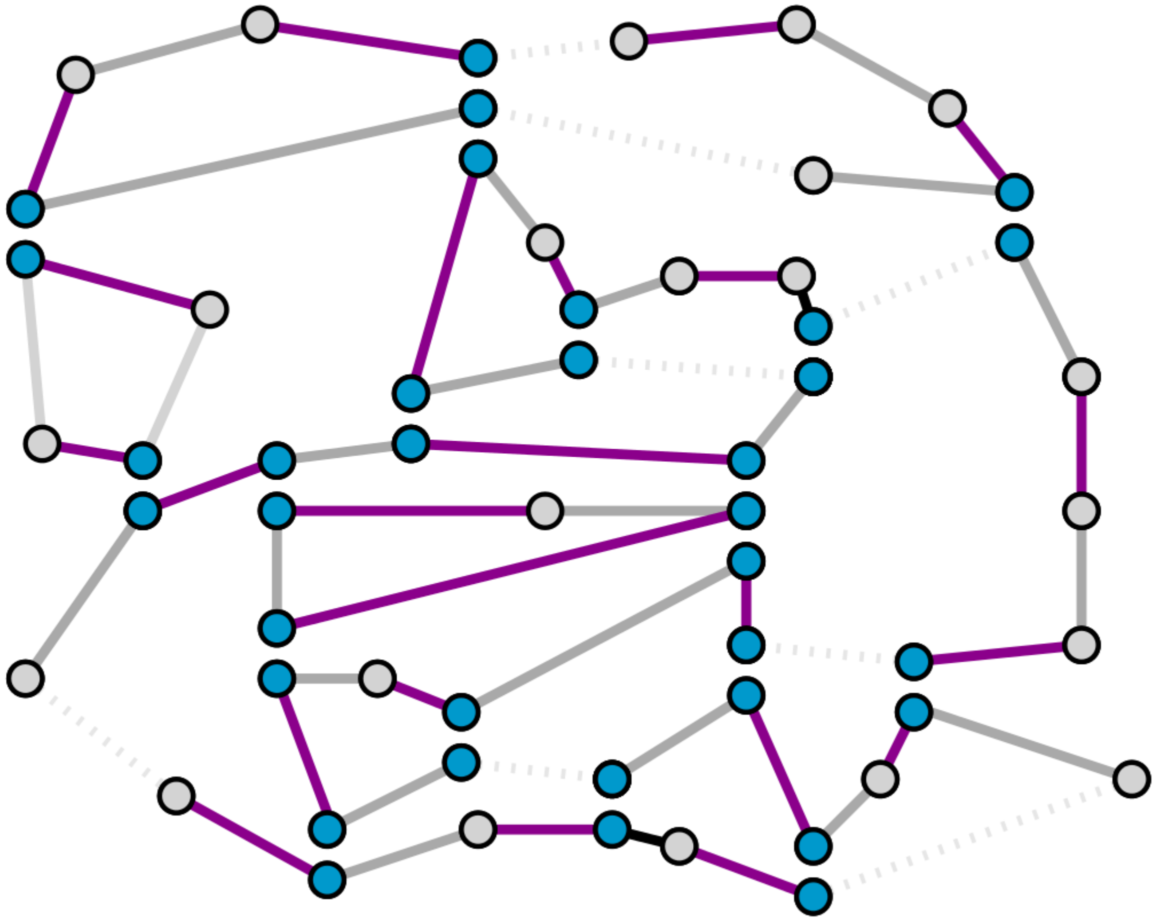

* by *Hańćkowiak, Karoński, Panconesi* [SODA'98,PODC'99] in $O(\log \Delta)$

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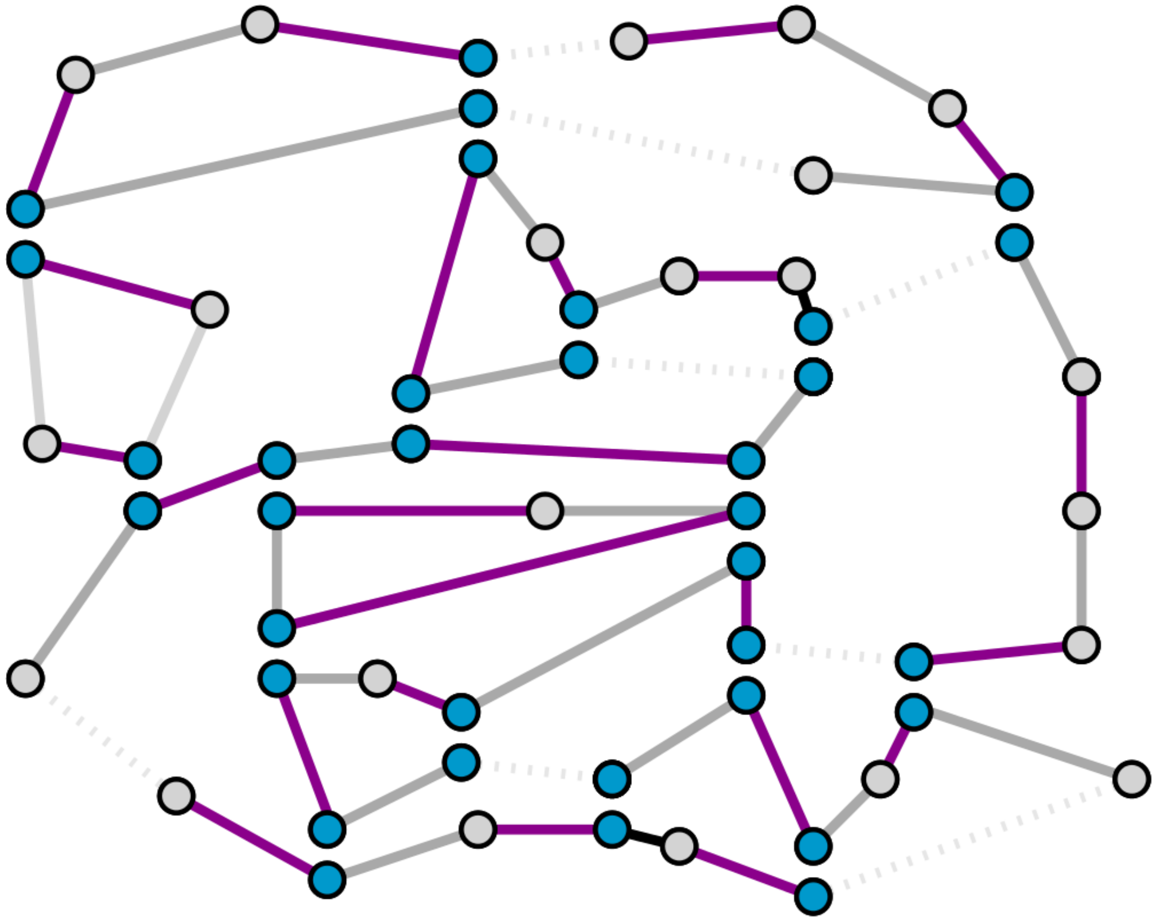

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Over all O($\log \Delta$) rounding iterations, total loss still constant!

*** bipartite and even degree!**

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

I) 4-Approximate Fractional Matching

$O(\log \Delta)$ rounds

II) Rounding Fractional Bipartite Matching

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

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

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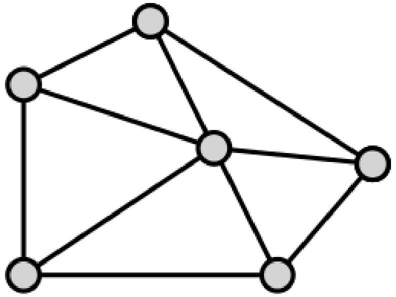

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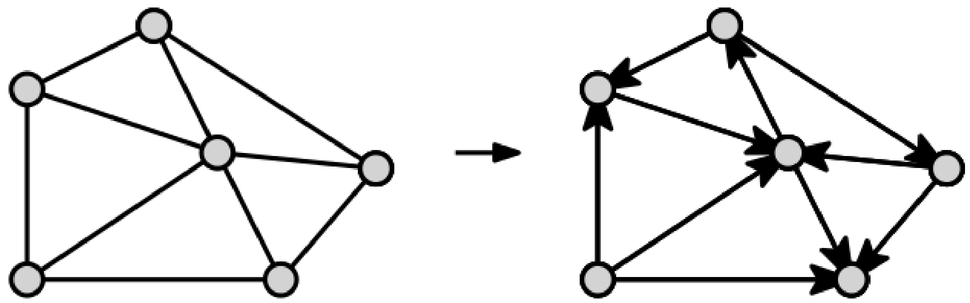

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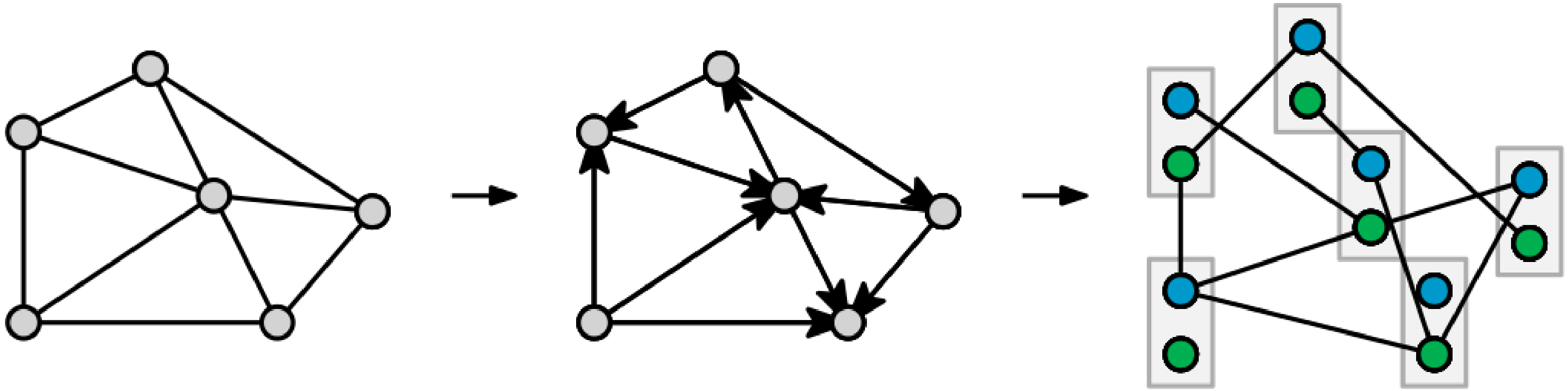

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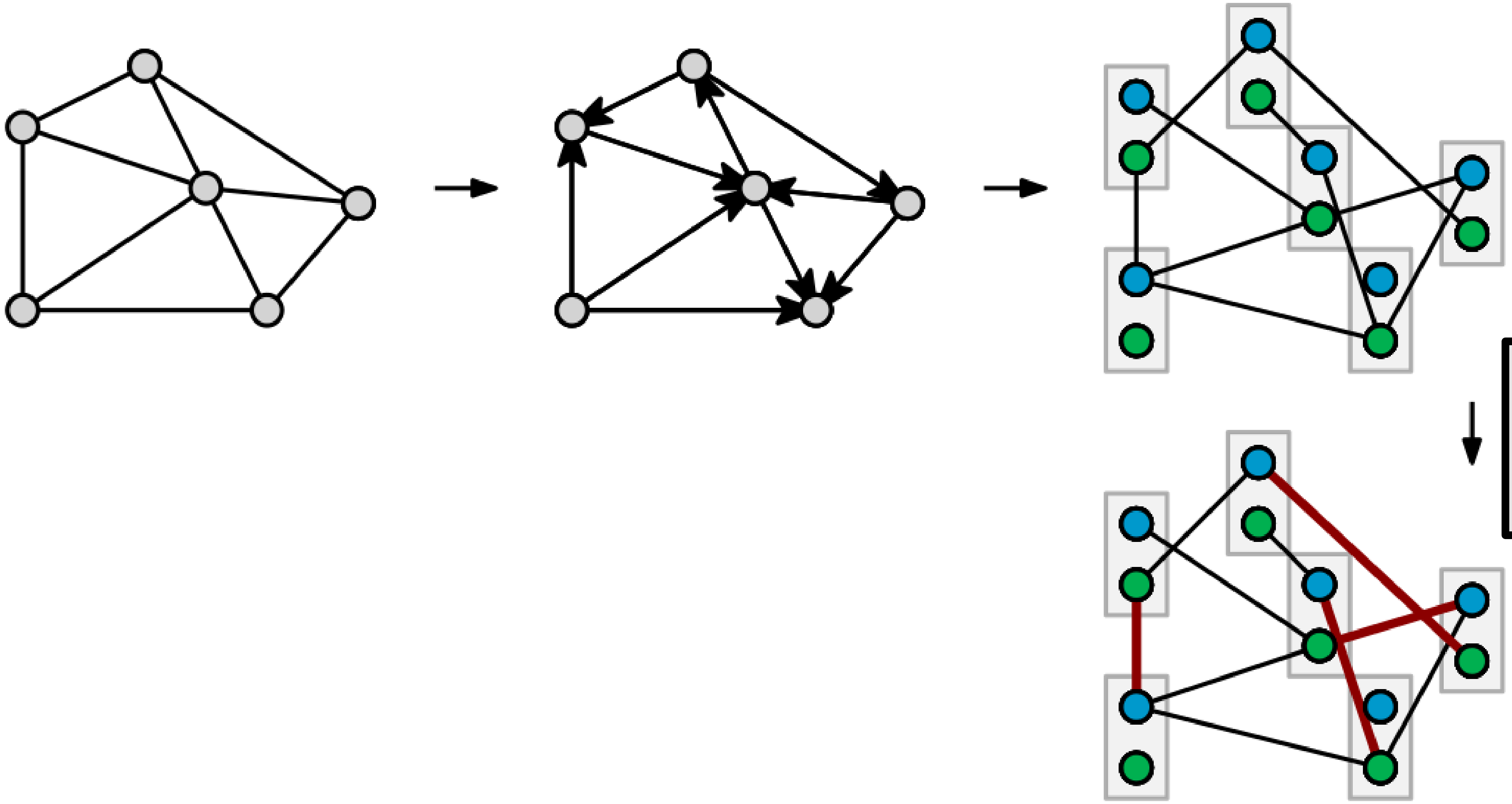

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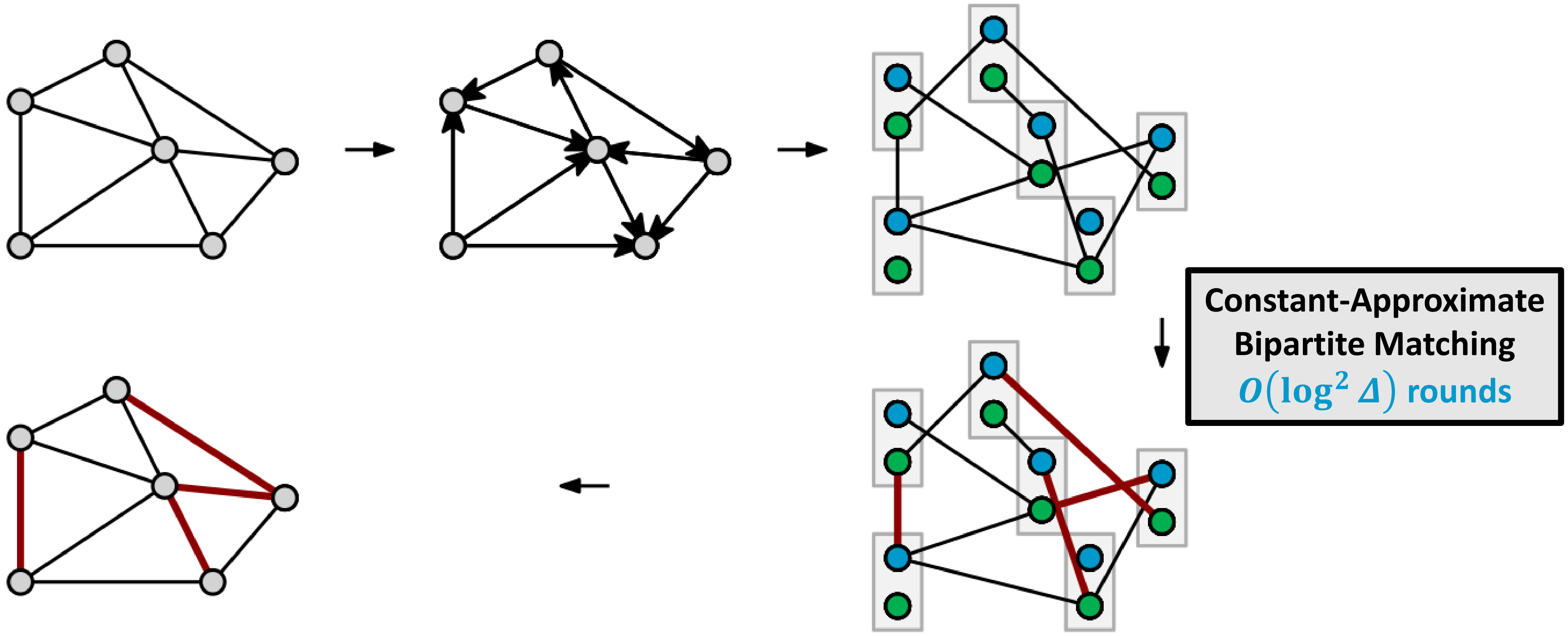

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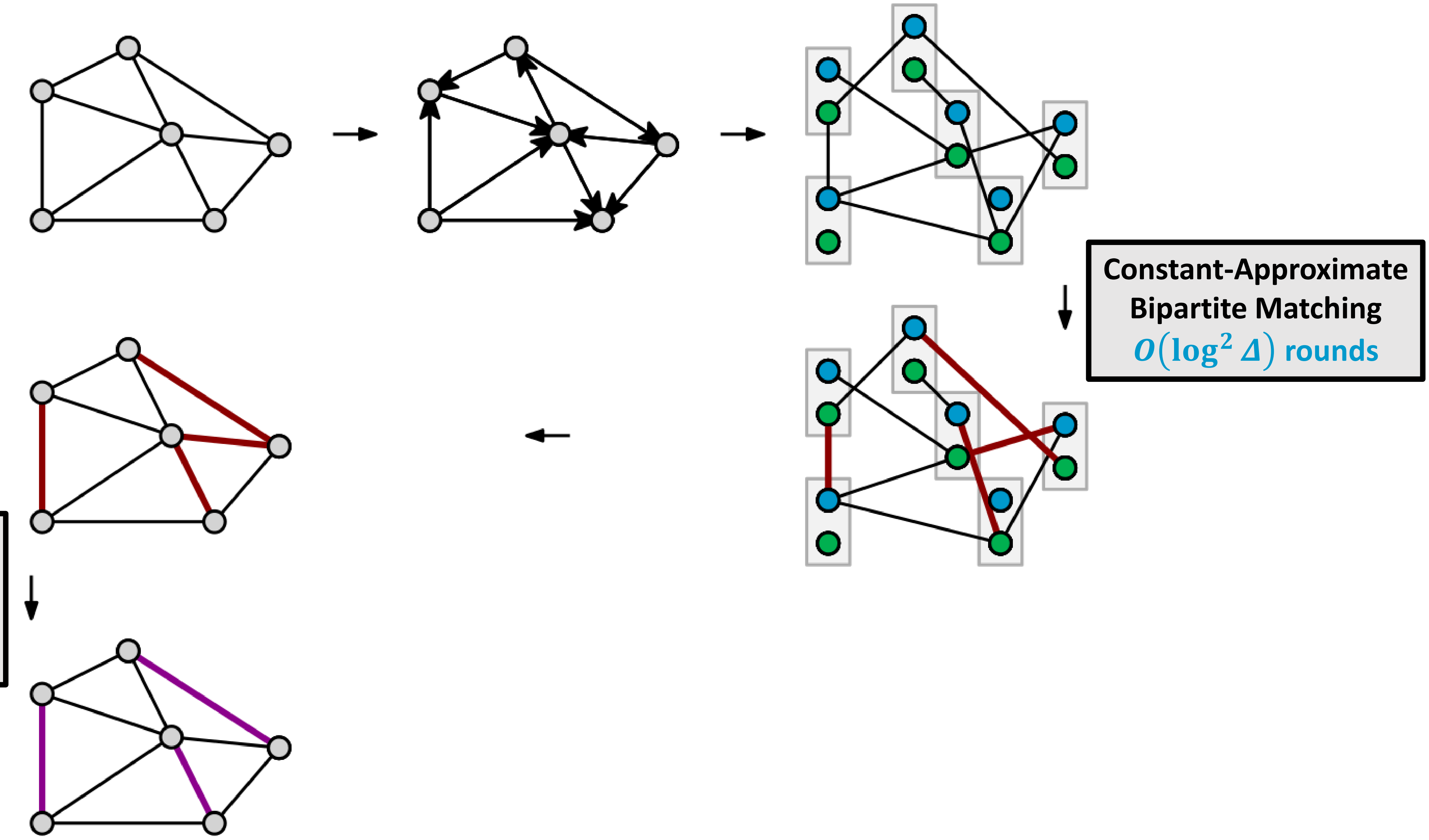

Panconesi, Rizzi [DIST'01]

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

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

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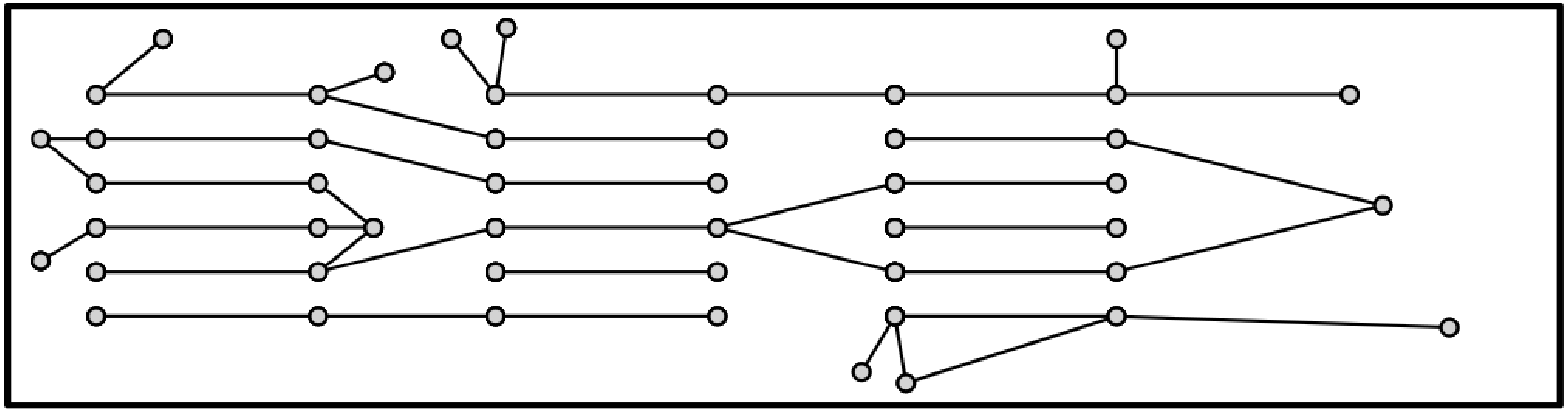

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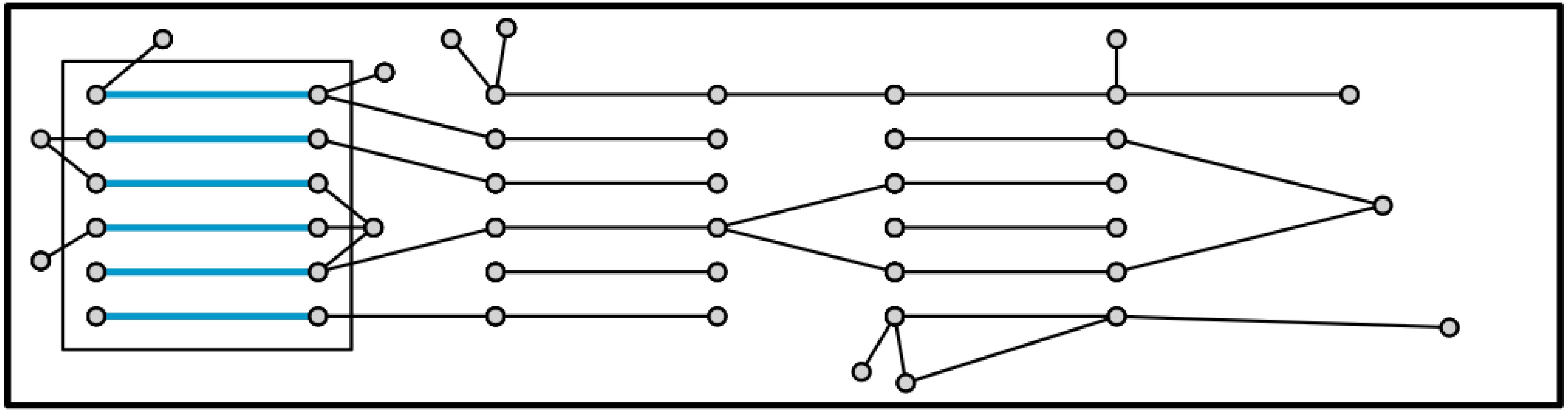

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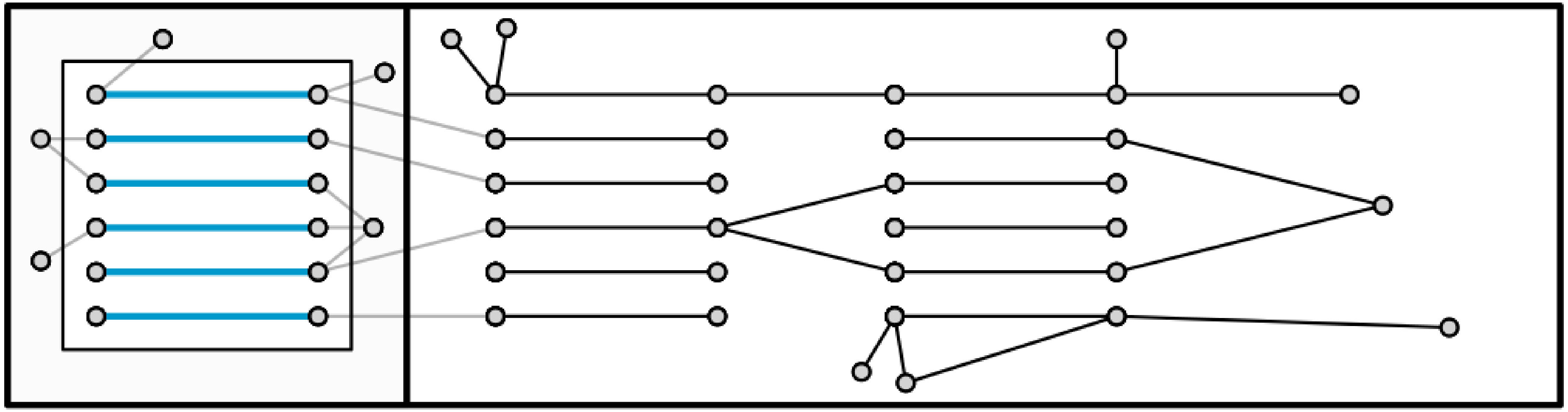

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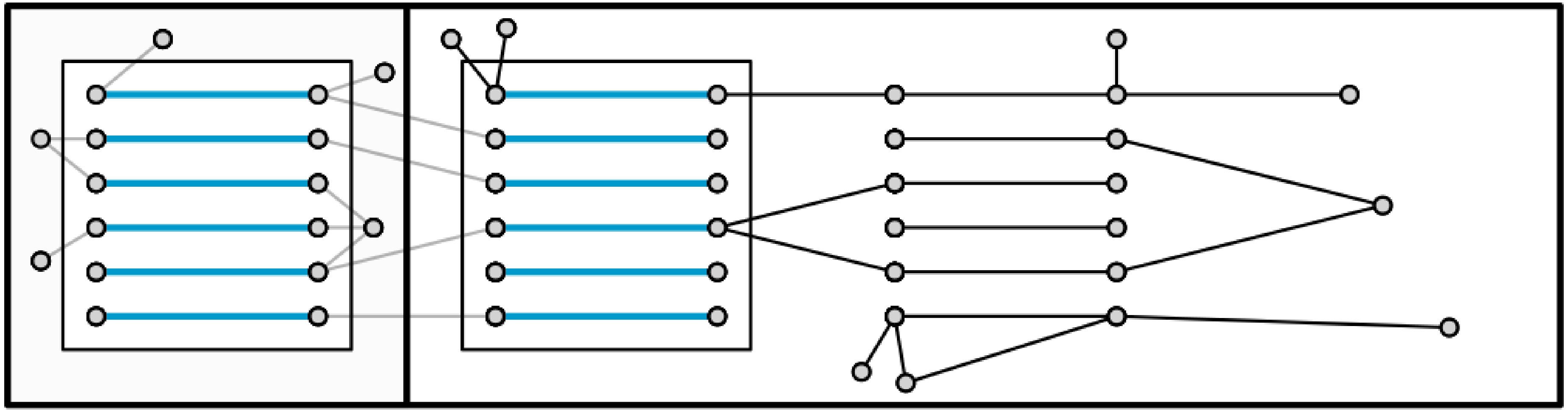

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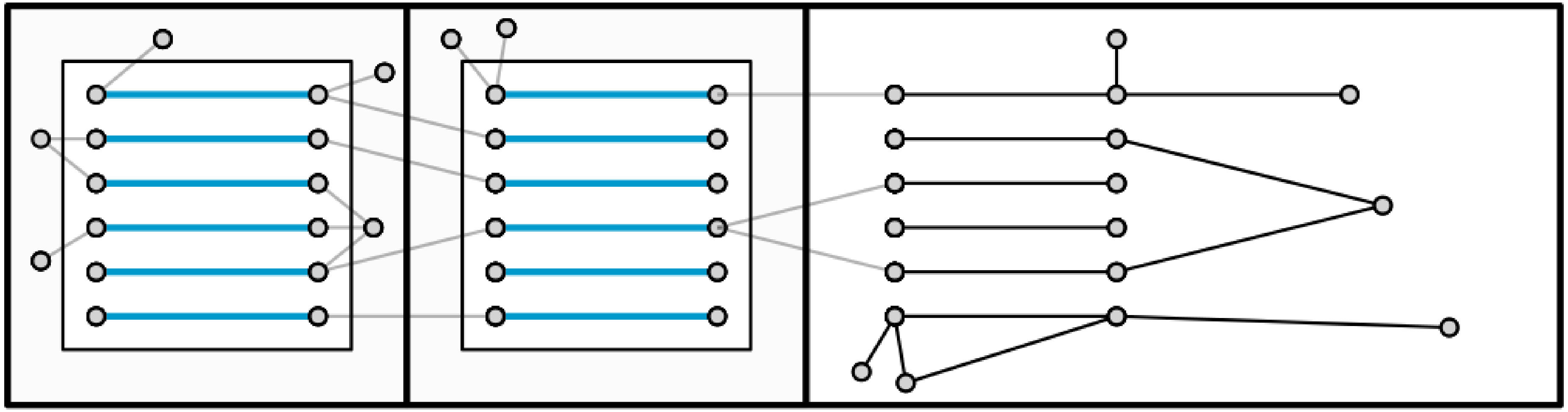

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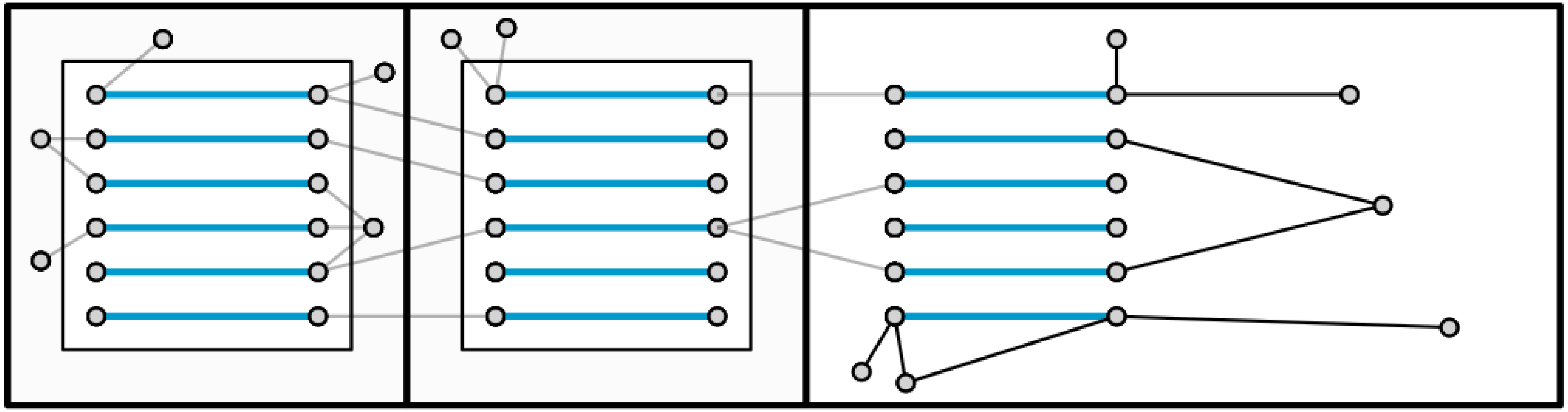

Constant - Approximate Matching

$O(\log^2 \Delta)$ rounds

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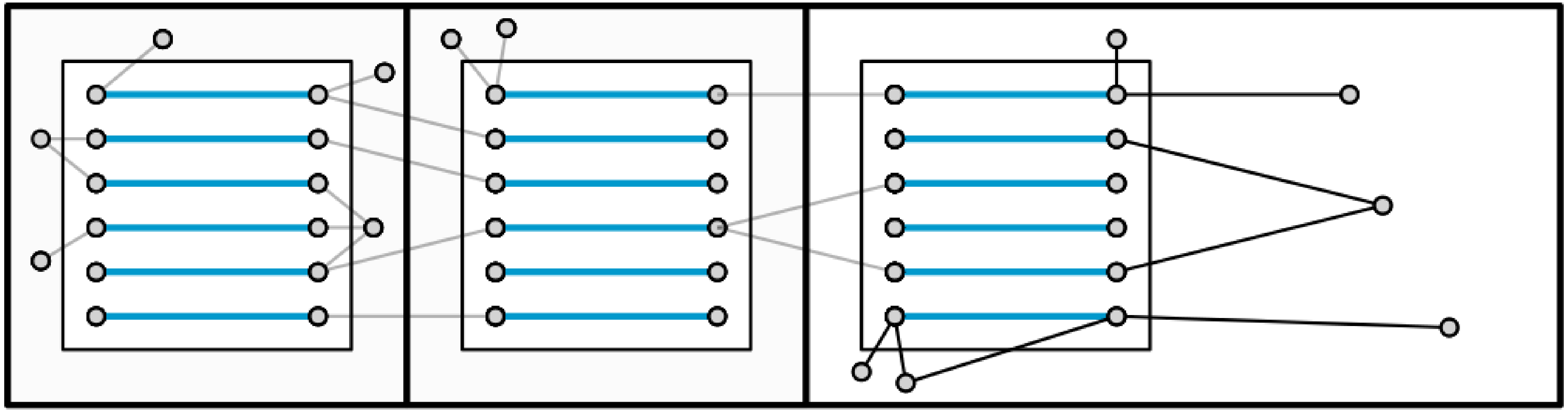

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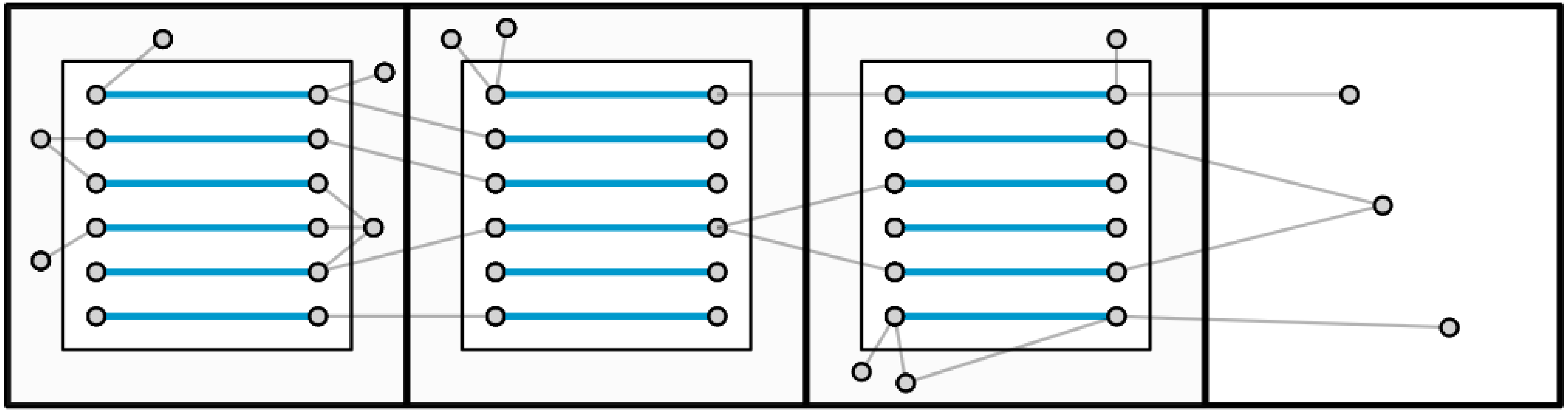

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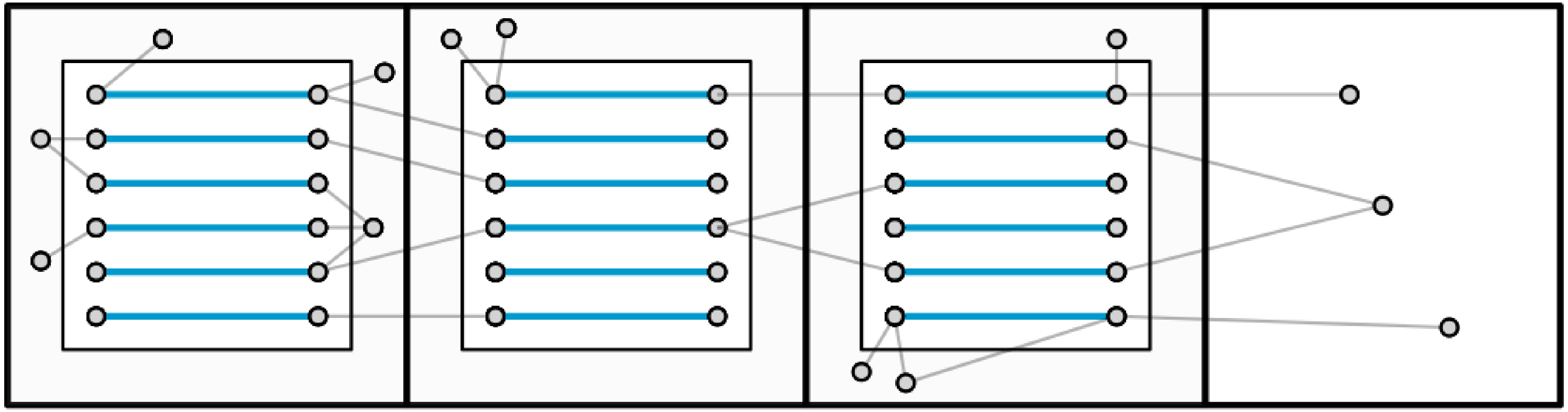

maximum matching size in remainder graph decreases by constant factor

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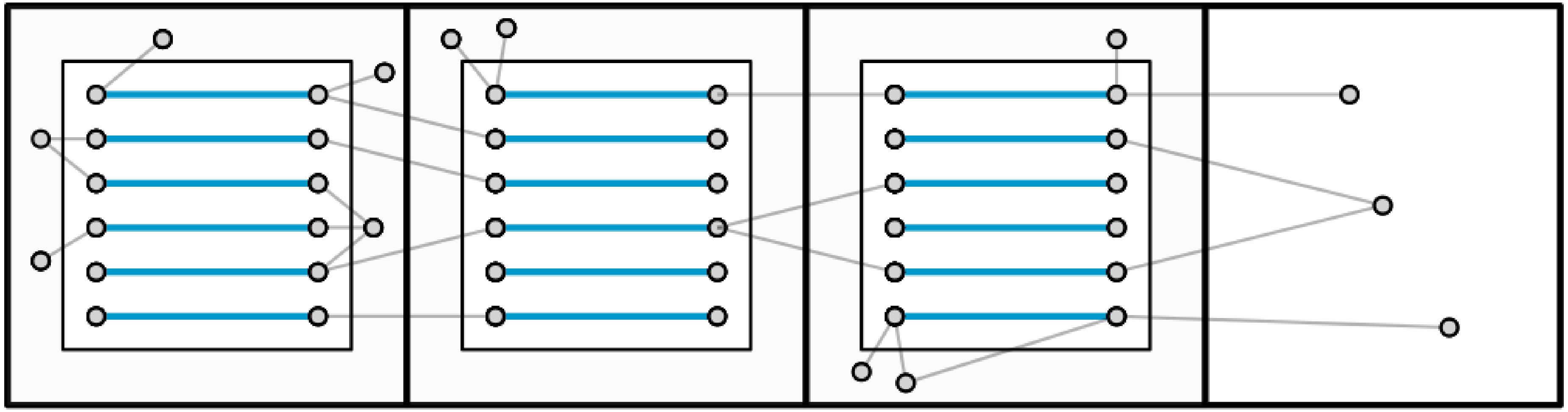
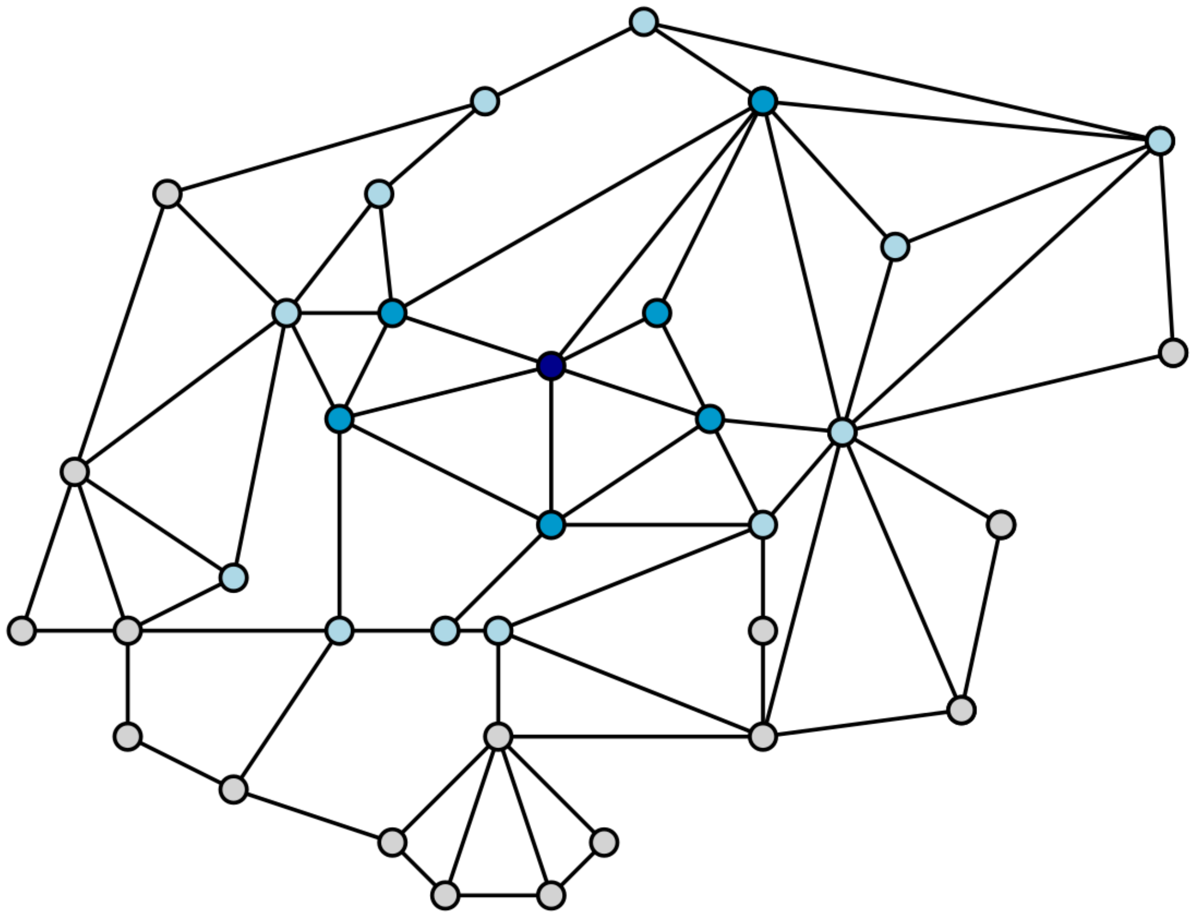
Maximal $O(\log^2 \Delta \cdot \log n)$



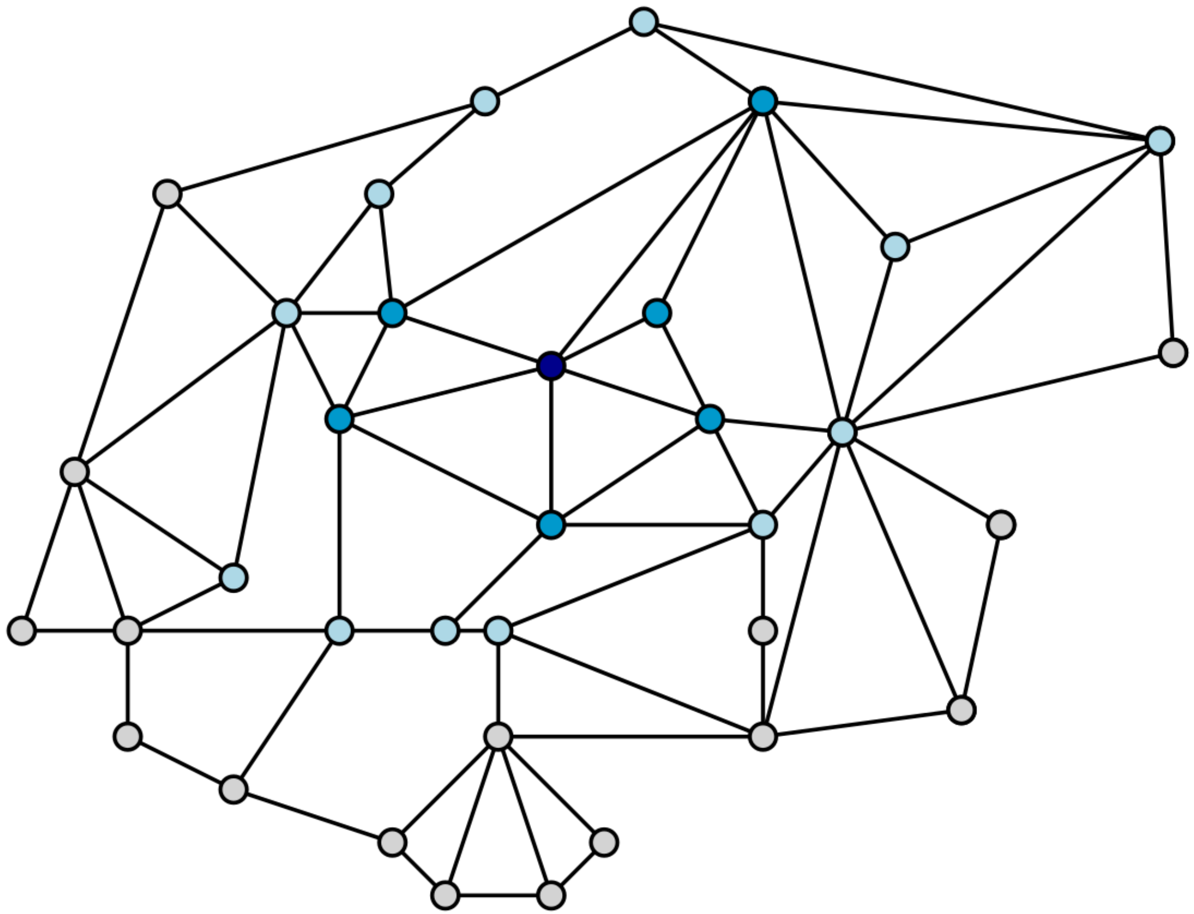
maximum matching size in remainder graph decreases by constant factor

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



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

What is Locality of Maximal Matching?



Thank you!

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

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