Lect-04

Handshaking Lemma

By

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Outlines

- Handshaking Lemma
- Total Degree

Revisiting a Puzzle

Puzzle

Is it possible to connect some pairs of nine points by segments so that each point is connected to five other points?

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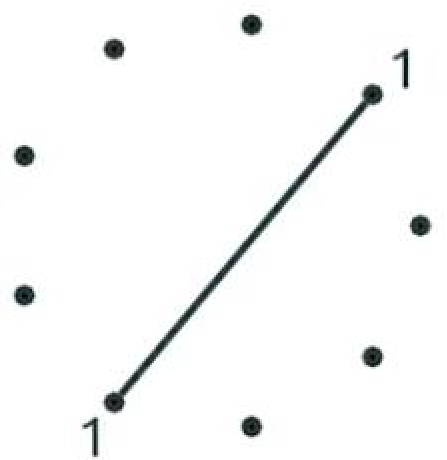

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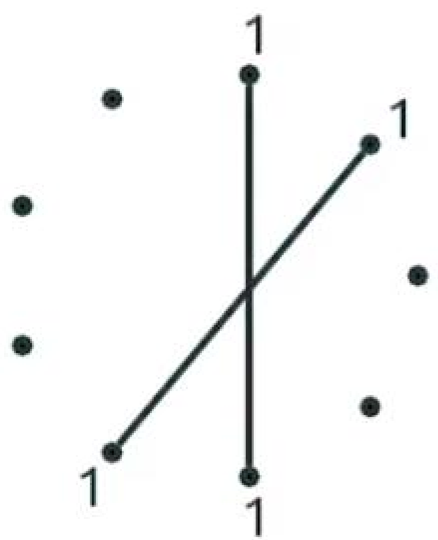

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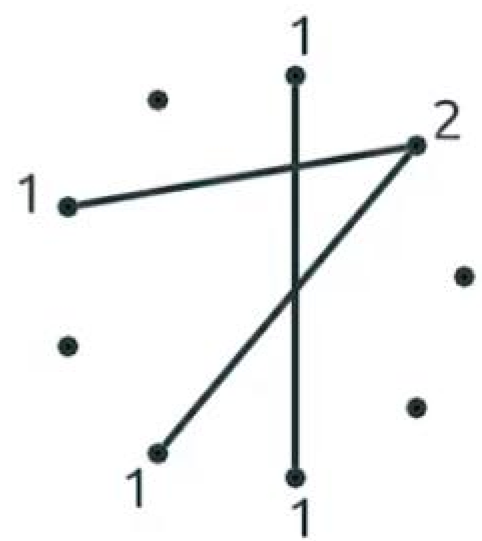

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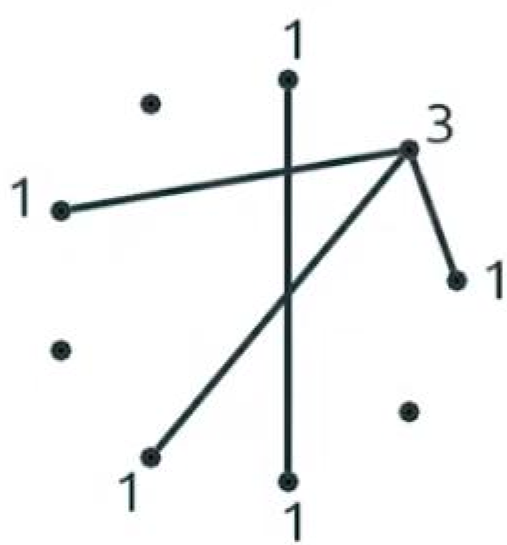

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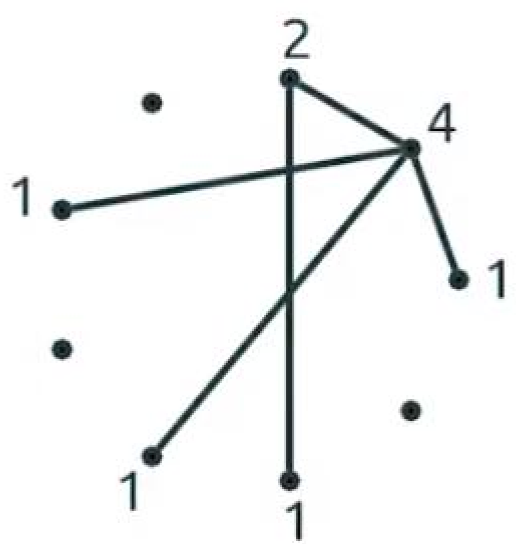

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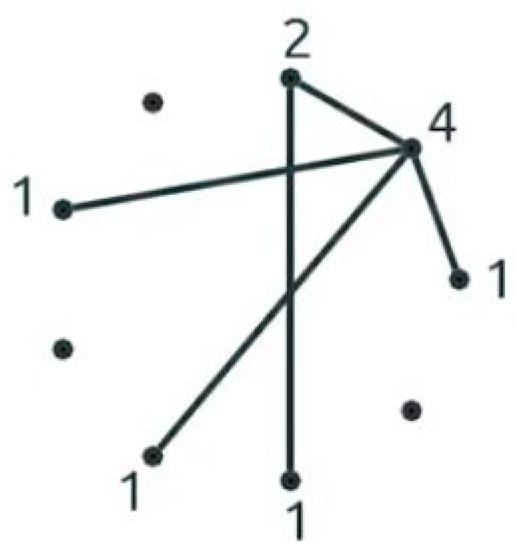

the number of odd points is always even, hence we will never reach a situation when there are 9 points of degree 5

Handshaking

- Before a business meeting, some people shook hands. Then the number of people who made an odd number of handshakes is even
- In graph terms: A graph has an even number of odd nodes

Degree Sum Formula

Lemma

For any graph $G(V, E)$, the sum of degrees of all its nodes is twice the number of edges:

$$\sum_{v \in V} \text{degree}(v) = 2 \cdot |E| \, .$$

Degree Sum Formula

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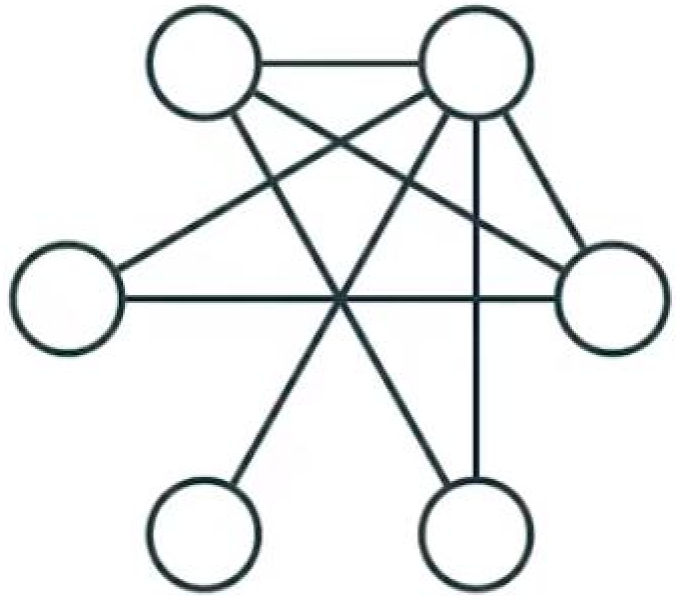
For any graph $G(V, E)$, the sum of degrees of all its nodes is twice the number of edges:

$$\sum_{v \in V} \text{degree}(v) = 2 \cdot |E| \, .$$

Implies the handshaking lemma: if a graph had an odd number of odd nodes, then the sum of degrees would be also odd.

Example



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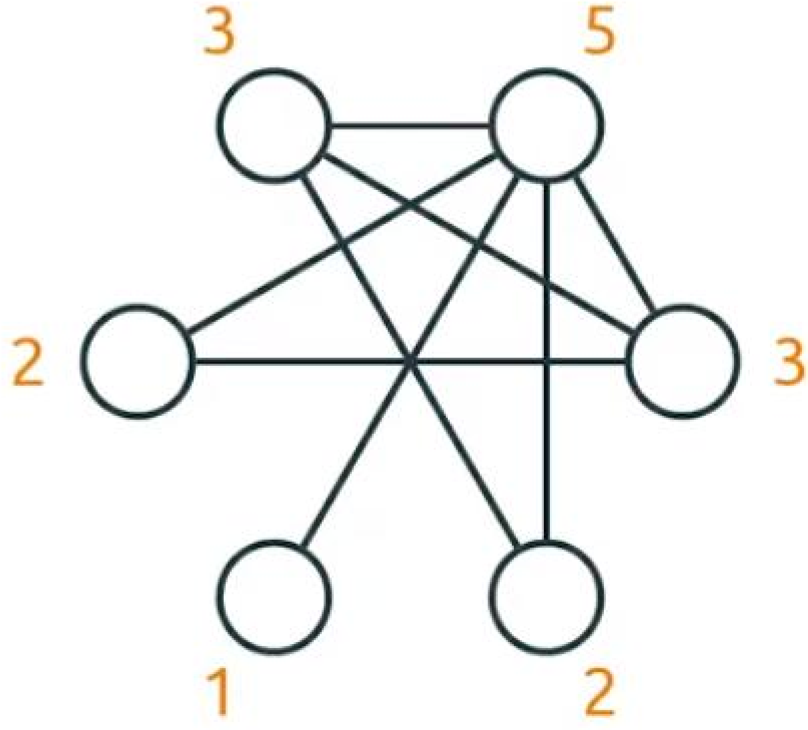

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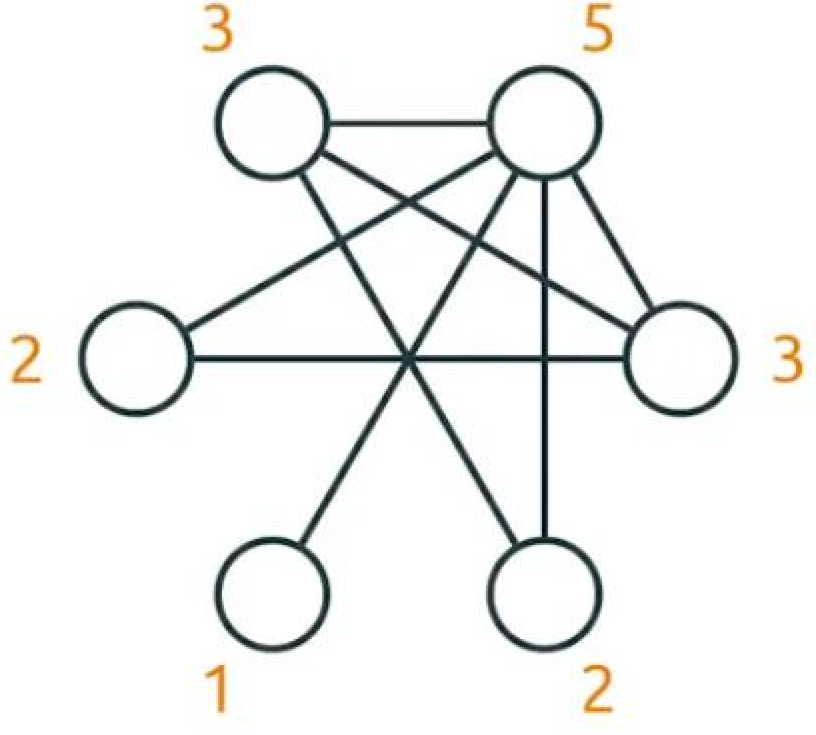
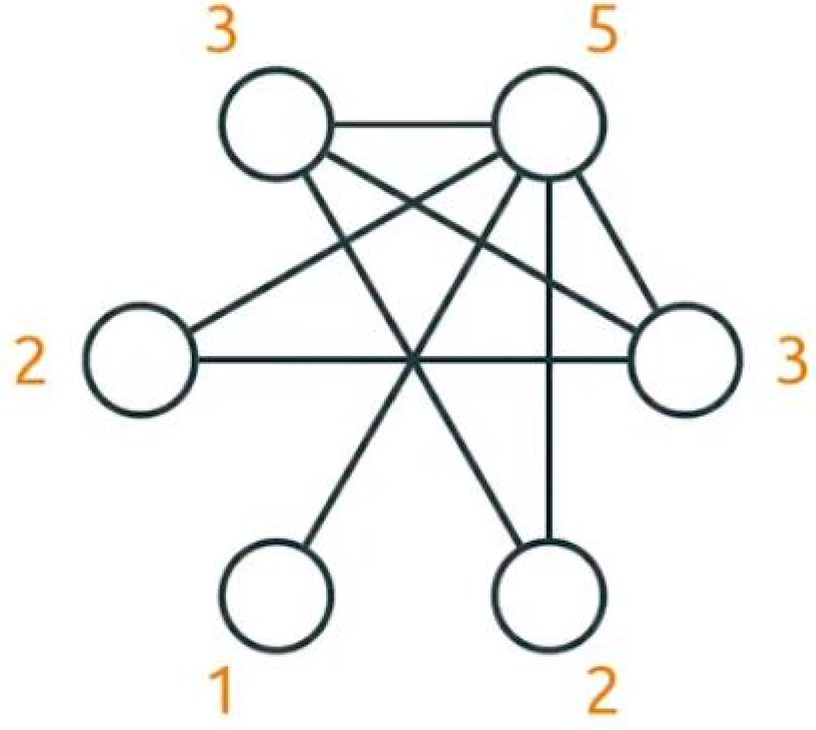


$$3 + 5 + 3 + 2 + 1 + 2 = 2 \cdot 8$$

Proof



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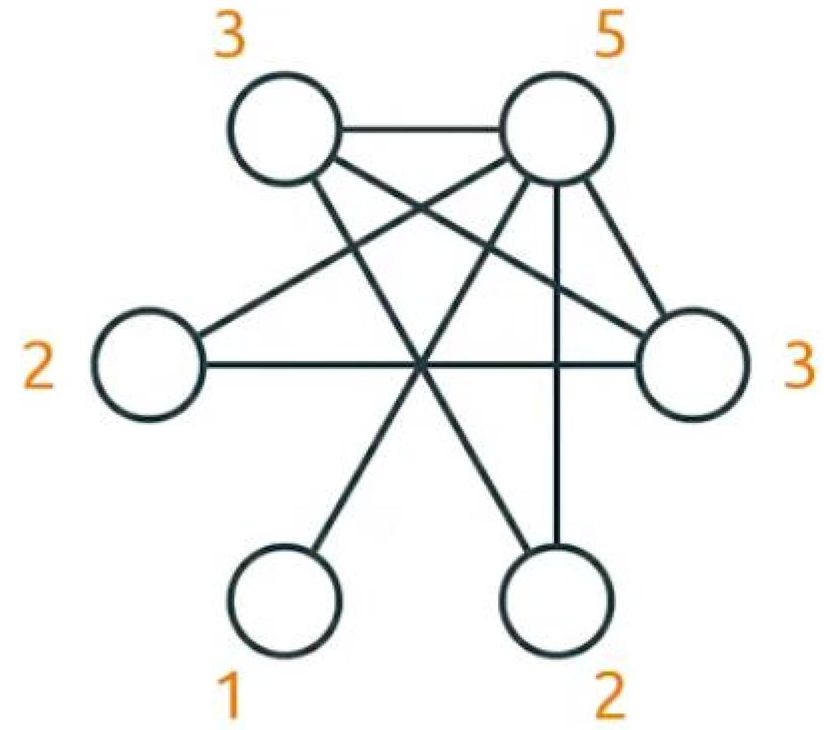

remove all edges

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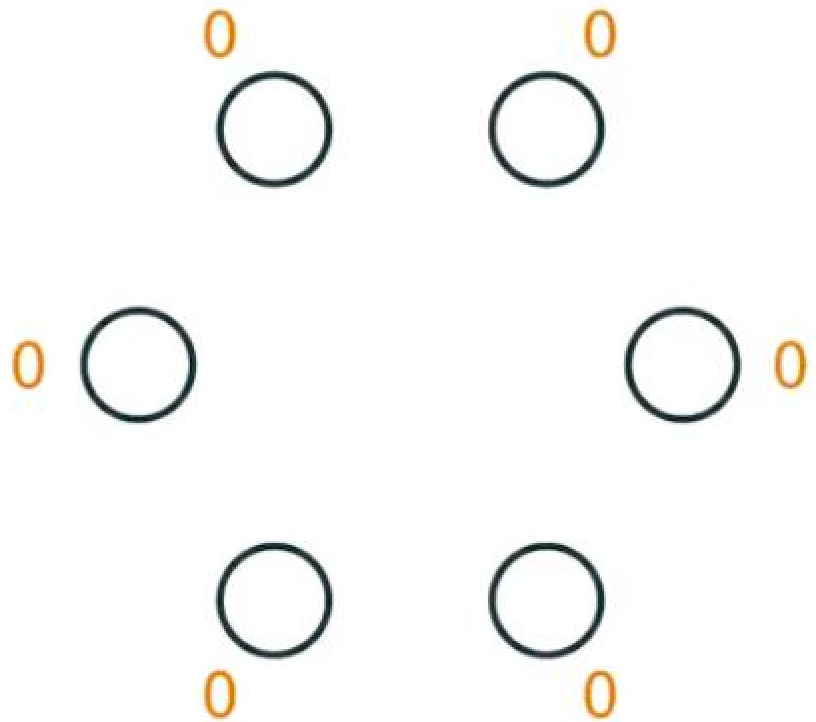

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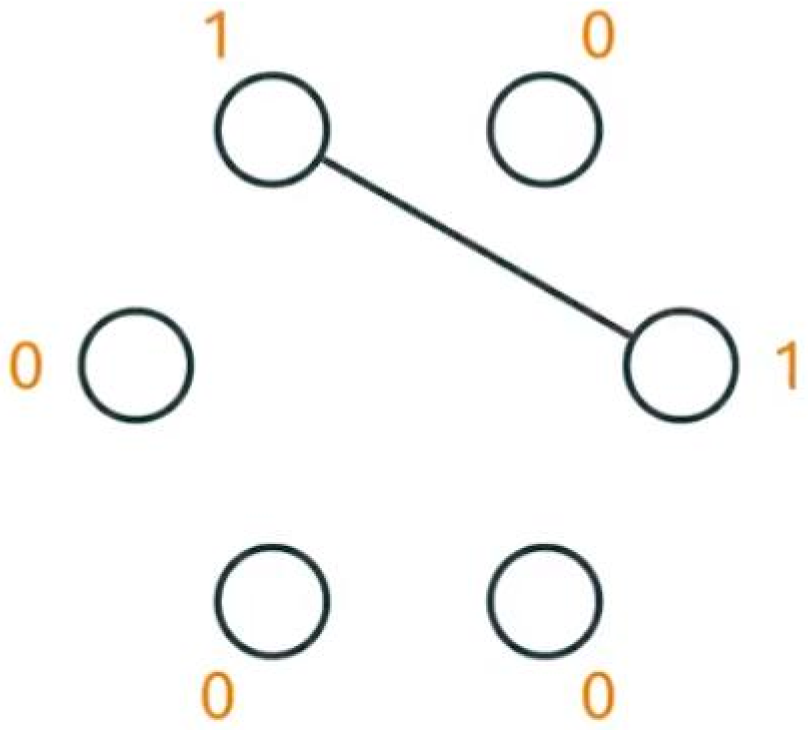

now, start adding them back, one by one

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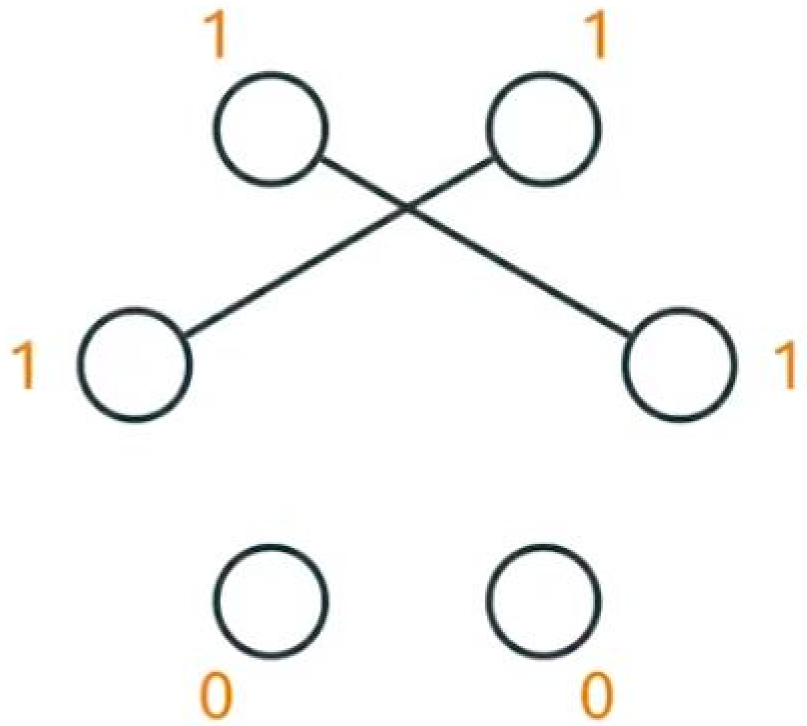

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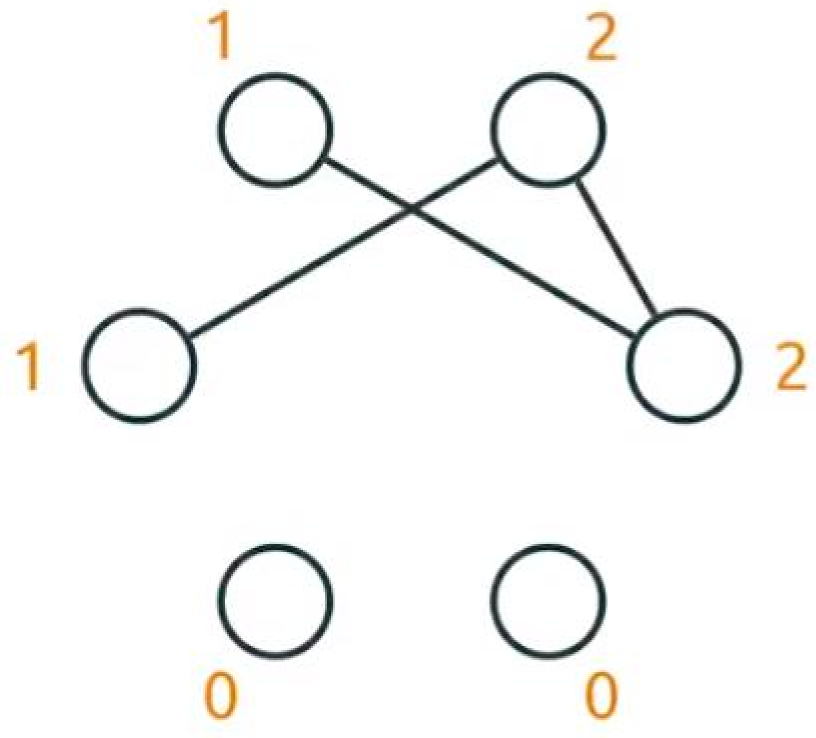

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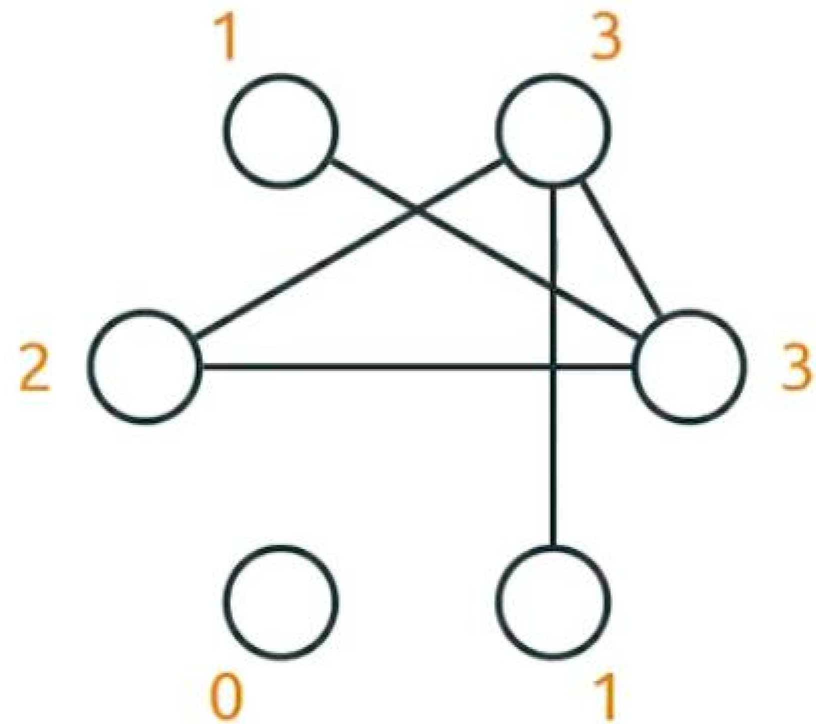

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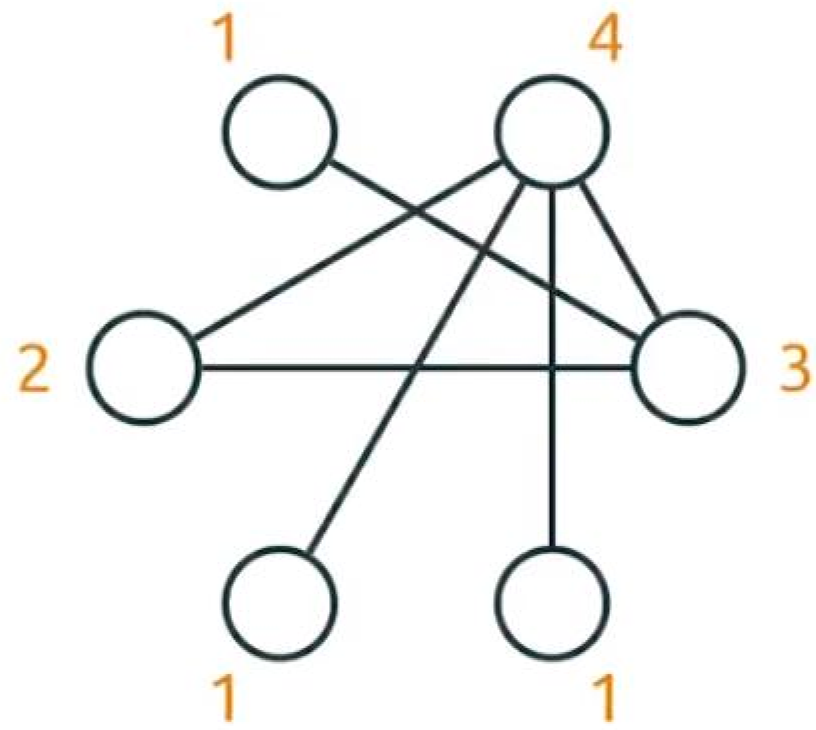

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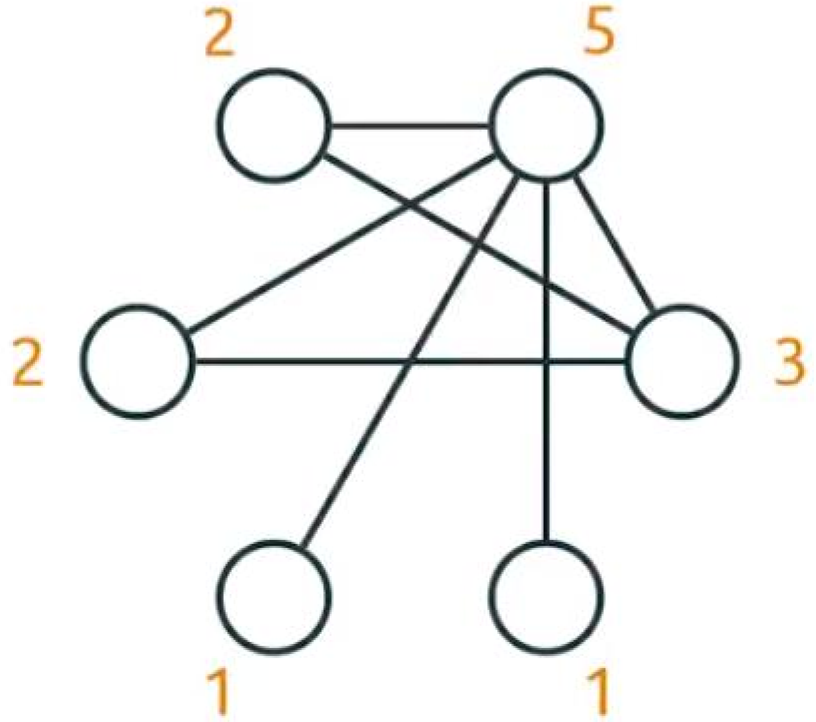

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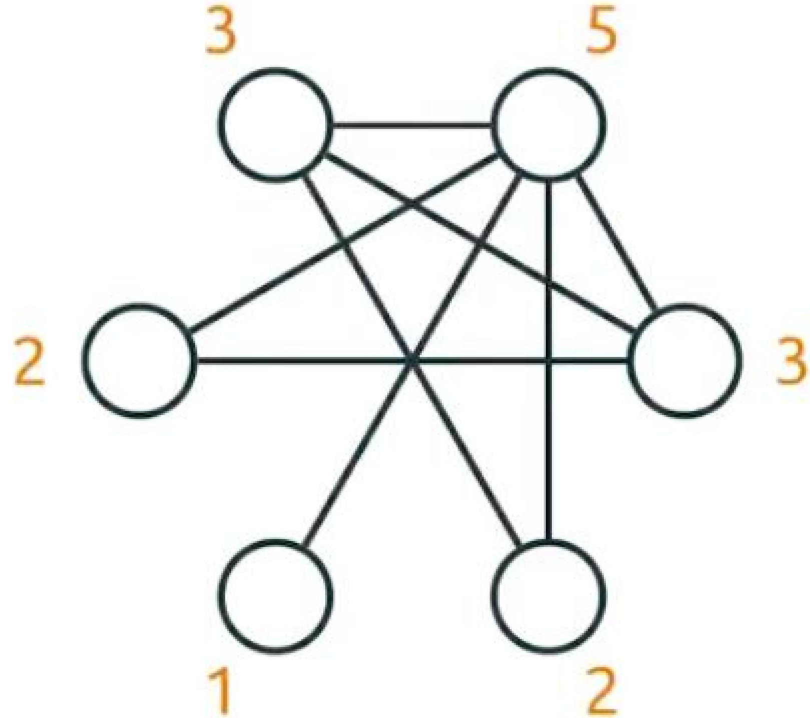

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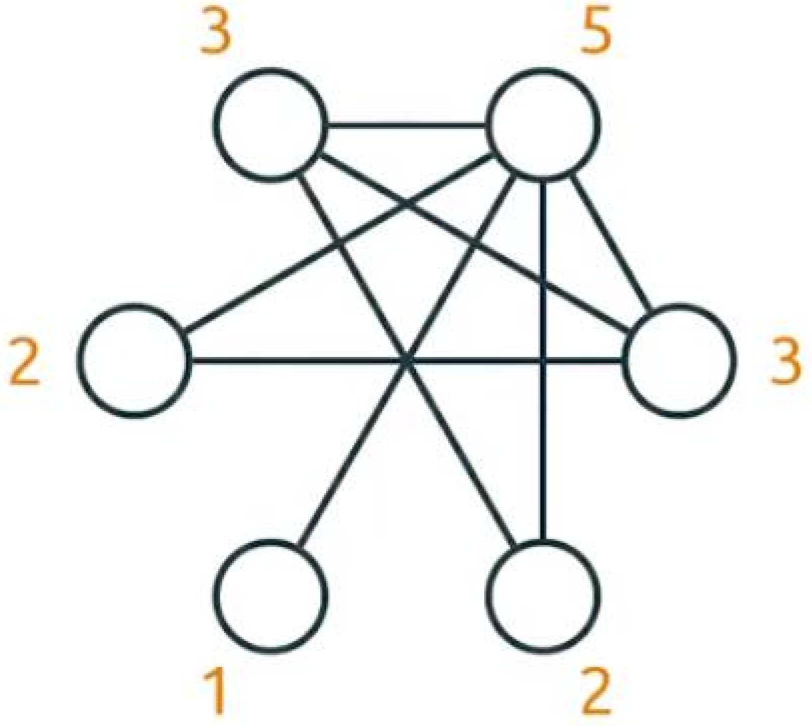
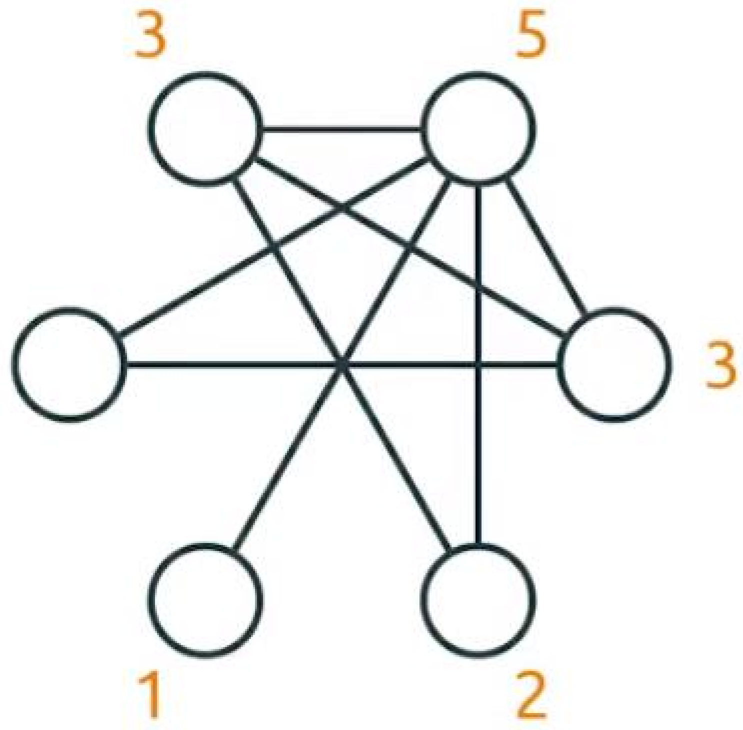


each edge contributes 2 to the sum of degrees

Proof



as well as to twice the number of edges!

Summary

- Essentially, we proved the formula by induction on the number of edges
- Base case: the formula holds if there are no edges (all degrees are equal to 0)
- Induction step: when we add an edge, the sum of degrees increases by 2

Total Degree

Exam

Problem

At an exam, each of 20 students solved 3 problems. Each problem was solved by 5 students. What was the number of problems?

https://commons.wikimedia.org/wiki/File%3AATC_Admission_Exam.JPG

Solution

- Assume that each student wrote a solution on a separate piece of paper
- Then, there are $20 \times 3 = 60$ pieces of paper
- For each problem, let's stack together all its five solutions
- Thus, the number of problems is $60/5 = 12$

In Graph Terms

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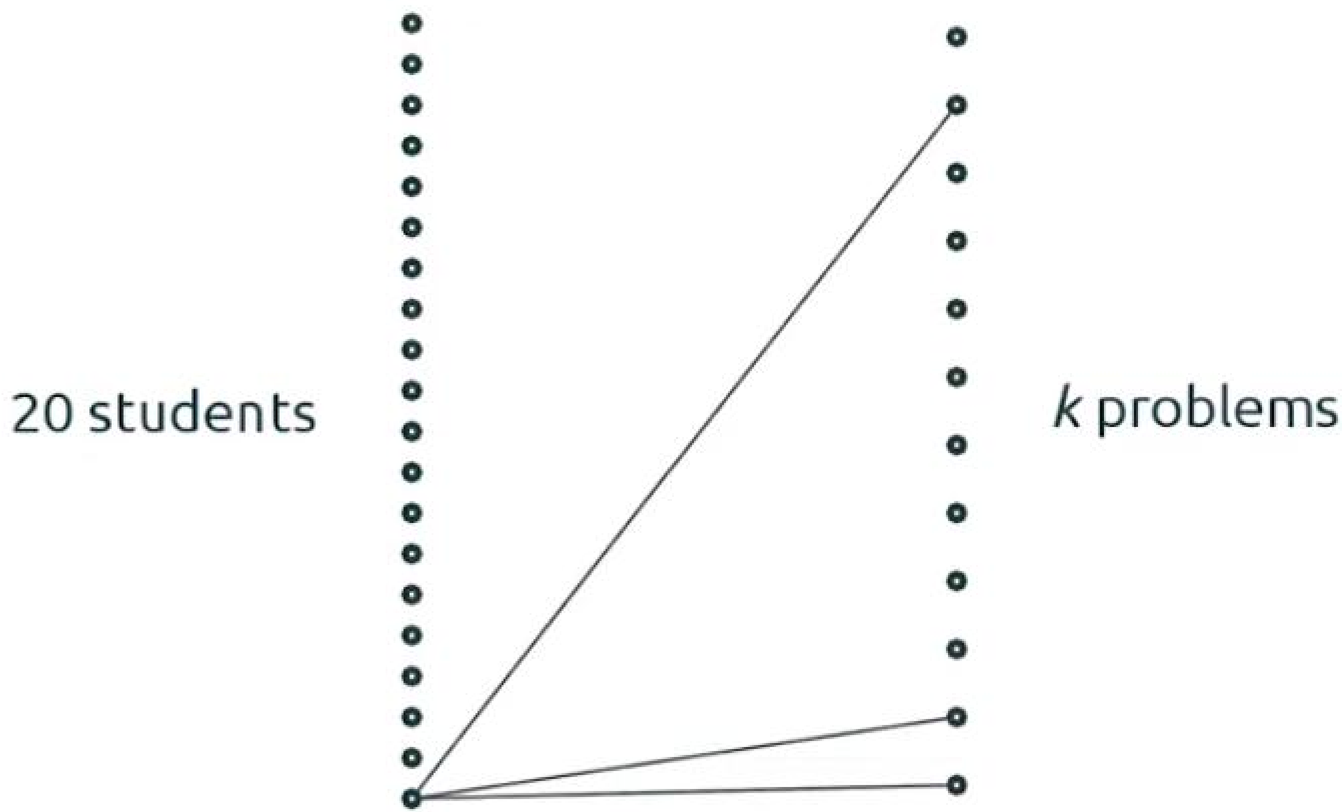

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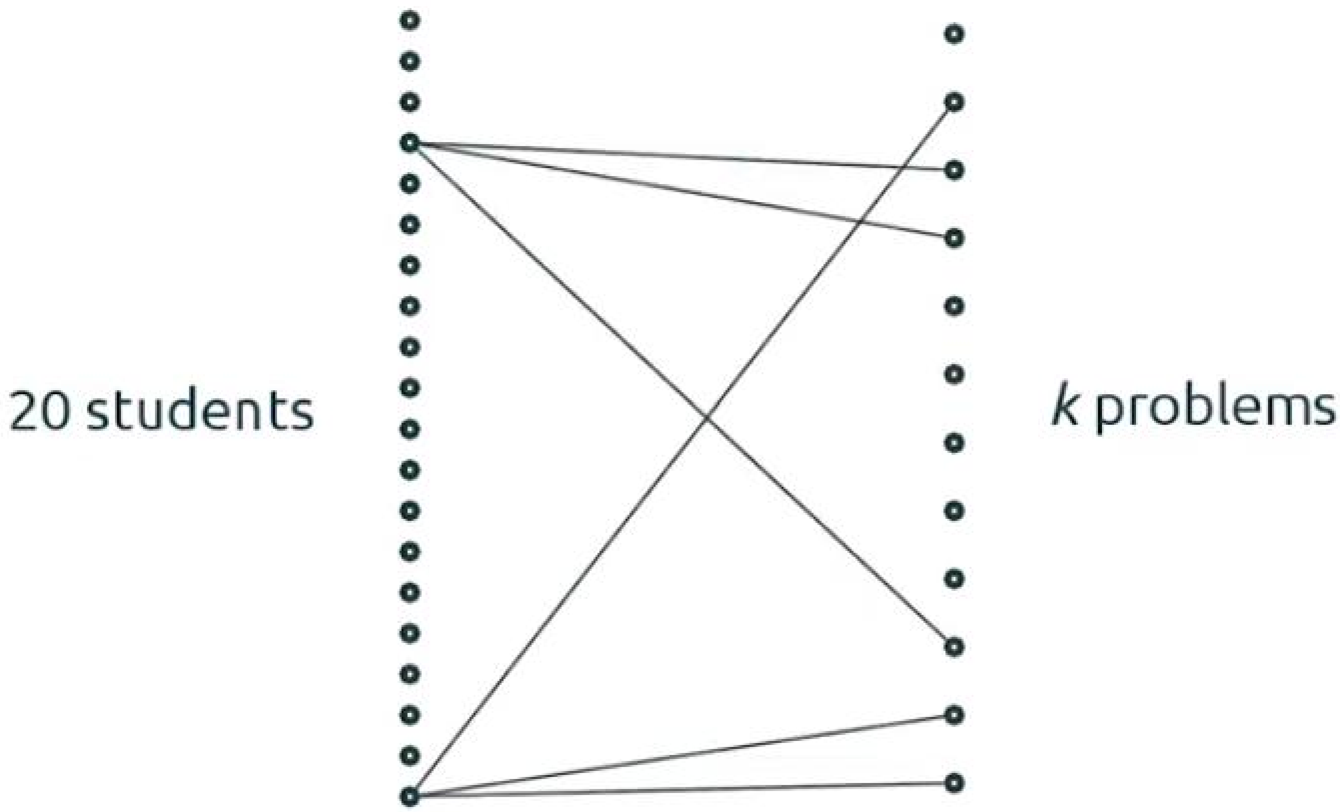

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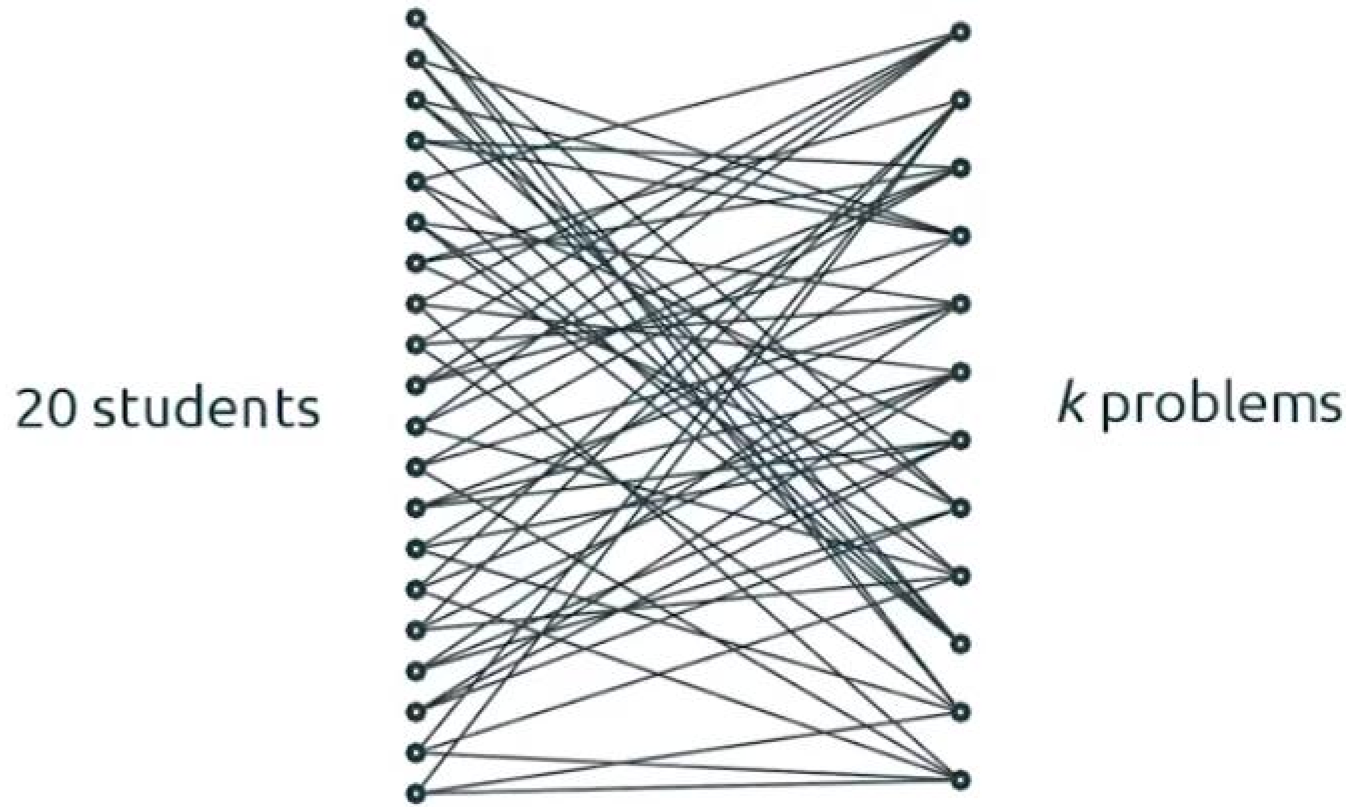

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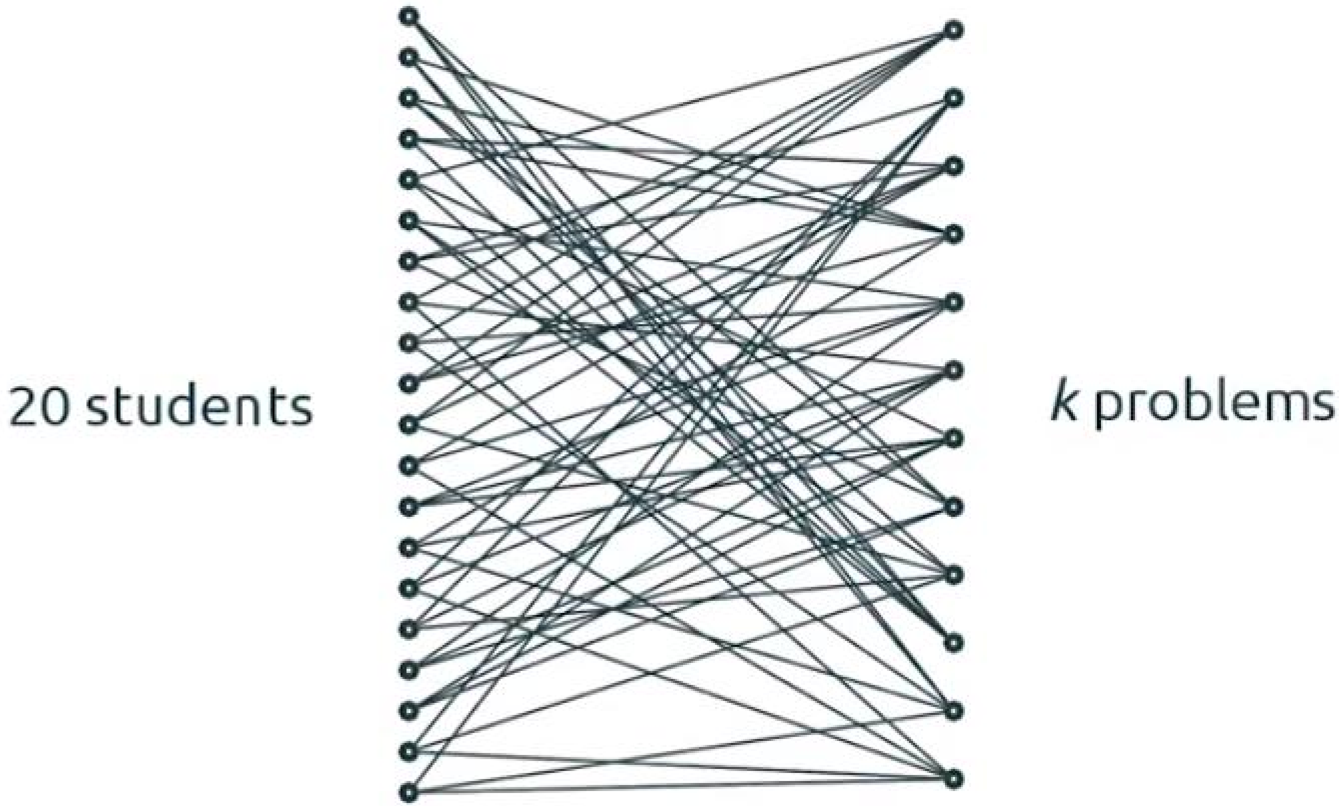
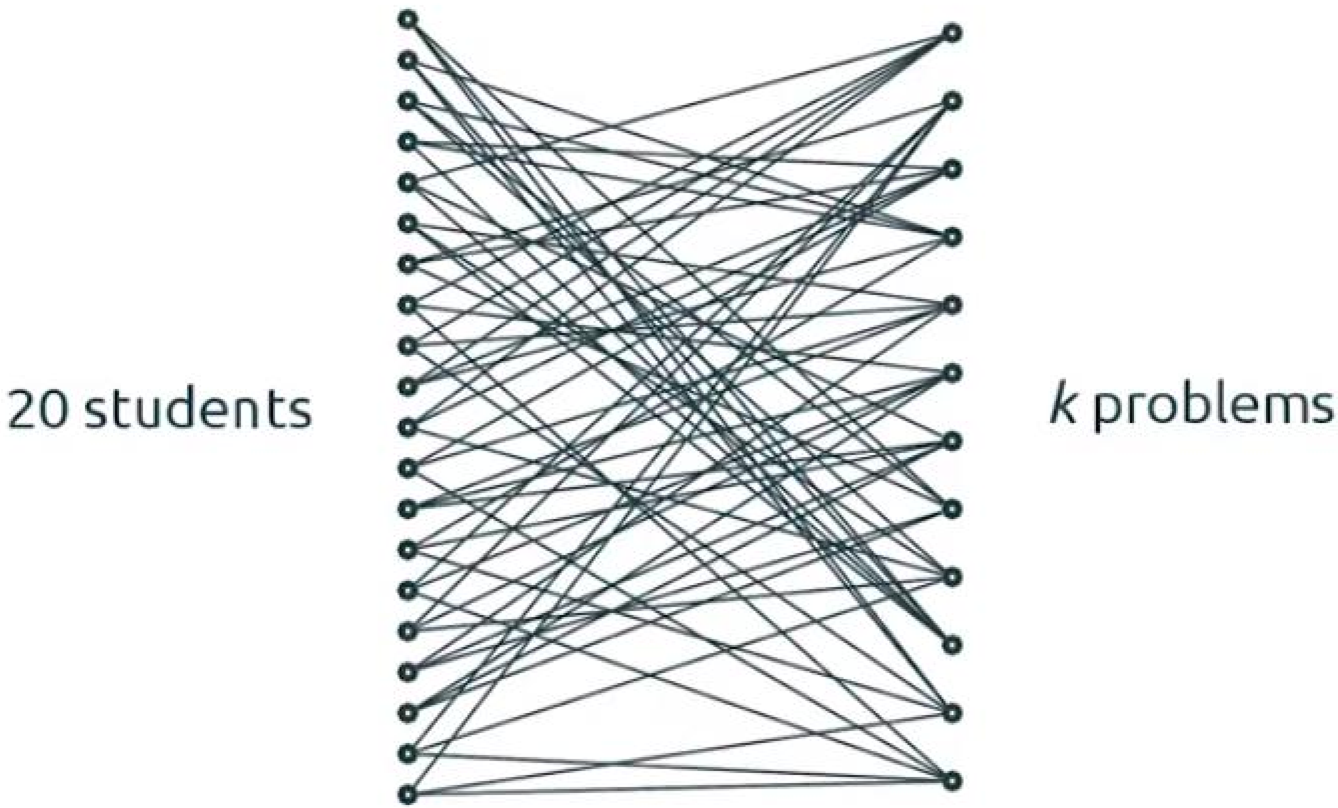


$$20 \times 3 = |E| = 5 \times k$$

In Graph Terms



$k = 12$

Summary

- This is a bipartite graph: each edge joins a student and a problem
- We used the double counting technique to solve the problem:
    - on one hand, the number of edges is equal to the total degree of the left part (i.e., the sum of all degree of the nodes from the left
    - on the other hand, it is equal to the total degree of the right part