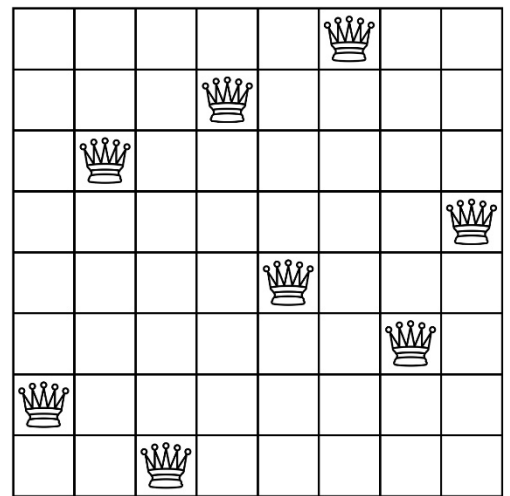
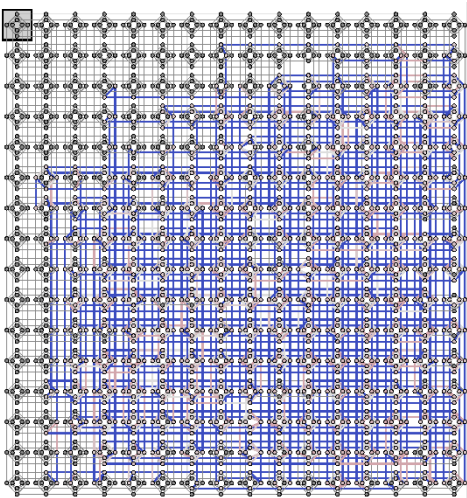


Lösung des n-Damenproblems auf einem adiabatischen Quantencomputer

Resultsbook



Projektidee

Auf einem $n \times n$ großen Schachfeld sollen n Damen so aufgestellt werden, dass keine Dame eine andere bedroht. Dieses bekannte Problem haben wir auf einem echten Quantencomputer gelöst. Bei unserem Projekt geht es aber weniger um das Finden der richtigen Lösung des n -Damenproblems (hierfür gibt es bereits viele gut geeignete Algorithmen), sondern um den Weg: die Aufbereitung des Problems zur Ausführung auf einem "Quantum Annealer". Das n -Damenproblem ist bisher von niemandem für einen Quanten-Annealer adaptiert worden.

Für unser Vorhaben die Aufgabenstellung auf einen Quantencomputer zu übertragen mussten wir das Damenproblem zuerst in die Sprache der Mathematik übersetzen. Es galt eine Funktion zu finden, der die Positionen aller Damen auf dem Schachbrett übergeben werden und die für die eingegebene Konstellation einen Wert, eine Bewertung der Situation zurückgibt, die man in der Optimierung als "Energie" der Verteilung bezeichnet. Diese Funktion muss für die korrekte Lösung des Problems minimal sein, da der Quantencomputer von Natur aus einen möglichst energiearmen Zustand anstrebt, sodass man, wenn er „gerechnet“ hat, die Lösung des Problems an den entsprechenden Werten der Qubits (Entsprechung der herkömmlichen Bits auf einem Computer) ablesen kann, deren Zustände in unserem Fall als boolesche Variablen fungieren.

Um die erschlossene Energiefunktion auf Korrektheit zu testen, haben wir auf klassische Optimierungsalgorithmen wie Simulated Annealing, Threshold Accepting, und den Great Deluge Algorithmus zurückgegriffen, mit denen man das Problem auf konventionellen Computern lösen würde. Diese konnten mit der getesteten Kostenfunktion alle eine Lösung des Problems finden, was grünes Licht für den ersten Test auf einem Quantencomputer bedeutete. Auf diesem haben wir unser „Programm“ dann ausgeführt. Die Rechenzeit auf dem für zehn Millionen Dollar erhältlichen Quantencomputer haben wir vom Forschungszentrum in Jülich (Prof. Dr. Kristel Michielsen) gestellt bekommen.



Der D-Wave Quanten Annealer 2000Q, auf dem wir unsere Programme ausgeführt haben

Datenaustausch mit dem Quantencomputer

-2	2	2	2	2	2	0	0	2	0	2	0	2	0	0	2
0	-2	2	2	2	2	0	0	2	0	2	0	2	0	0	0
0	0	-2	2	0	2	2	2	2	0	2	0	0	0	2	0
0	0	0	-2	0	0	2	2	0	2	0	2	2	0	0	2
0	0	0	0	-2	2	2	2	2	0	0	2	0	2	0	2
0	0	0	0	0	-2	2	2	2	2	0	0	2	0	2	2
0	0	0	0	0	0	-2	0	2	2	0	2	0	2	0	2
0	0	0	0	0	0	0	-2	2	2	2	2	0	0	2	0
0	0	0	0	0	0	0	0	-2	2	2	2	2	0	0	2
0	0	0	0	0	0	0	0	0	-2	2	0	2	2	2	2
0	0	0	0	0	0	0	0	0	0	-2	0	0	2	2	2
0	0	0	0	0	0	0	0	0	0	0	-2	2	2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	-2	2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	-2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2

Hamiltonmatrix, die das Problem darstellt

-10.000000	251	[0000100100100000001001000]
-10.000000	1	[0100000010100000010000001]
-10.000000	76	[1000000010010000000100100]
-10.000000	216	[10000000100000010100000010]
-10.000000	82	[0010000001010000001010000]
-10.000000	32	[0100000001001001000000010]
-10.000000	171	[0001001000000010010010000]
-10.000000	36	[0001010000001000000101000]
-10.000000	11	[0000101000000101000000100]
-10.000000	1	[0010000001010000001010000]
-8.000000	21	[0000100100100000000000010]
-8.000000	6	[00001001001000000001000010]
-8.000000	2	[0001000000100000010000001]
-8.000000	36	[1000000100000010000000010]
-8.000000	55	[0000100100100000010000000]
-8.000000	5	[0000100100100000000001010]
-8.000000	3	[0000100100100000010001010]
-8.000000	19	[0000100100100000000001000]
-8.000000	2	[10000001010000001000000010]
-8.000000	6	[1000000001010000000000100]
-8.000000	47	[0000100100000000010010000]
-8.000000	8	[1000000100000010000001010]
-8.000000	30	[1000000100100000000001000]
-8.000000	3	[100000000100100000000100000]
-8.000000	5	[1000000010000000000100100]
-8.000000	29	[1000000000010000000100100]
-8.000000	25	[10000000100000010000001000]
-8.000000	1	[0010010000000010100000001]
-8.000000	1	[1010000001000000100000010]
-8.000000	1	[10000000010100000000101000]

Vom Quantencomputer berechnete Ergebnisse

```
from __future__ import print_function

import numpy as np
from dwave.system.samplers import DWaveSampler
from dwave.system.composites import EmbeddingComposite

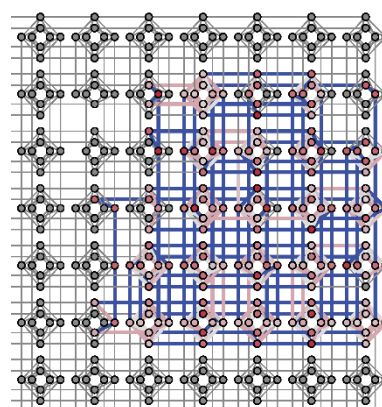
# Laden der Matrix
qubomatrix = np.loadtxt('qubomatrix.txt')
print('Loaded matrix:\n', qubomatrix, '\n')

# Konvertieren in QUBO Form
qubo = {(i,i):0.0 for i in range(len(qubomatrix))}
for index,value in np.ndenumerate(qubomatrix):
    if value != 0:
        qubo[index] = value
print('Converted matrix into QUBO for D-Wave:\n', qubo, '\n')

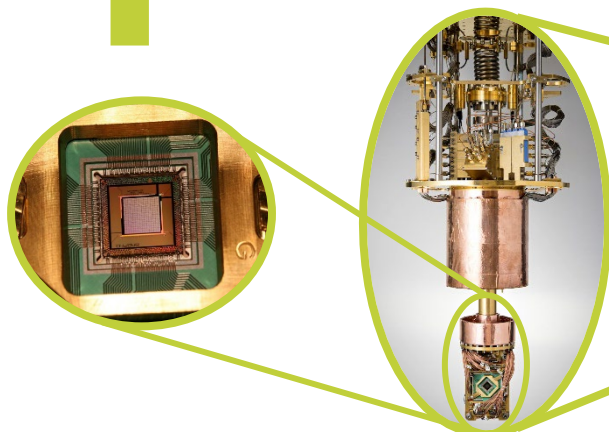
# Erstellen des Chimera-Graphen und rechnen auf dem Quantencomputer
sampler = EmbeddingComposite(DWaveSampler())
response = sampler.sample_qubo(qubo, num_reads=10000, annealing_time=20)
print('Response from the D-Wave:\n', response, '\n')

# Speichern der Ergebnisse in results.txt
with open('results.txt','w') as file:
    file.write('energy\tnum_occurrences\tsample\n')
    for sample, energy, num_occurrences, cbf in response.record:
        file.write('%f\t%d\t%s\n' % (energy, num_occurrences, sample))
    print('Saved results in results.txt')
```

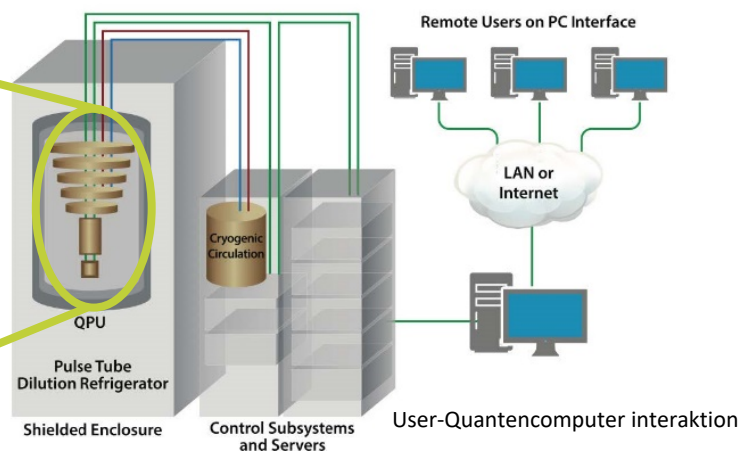
Python Skript berechnet das Embedding und schickt die Daten an den Quantencomputer



Chimera-Graph

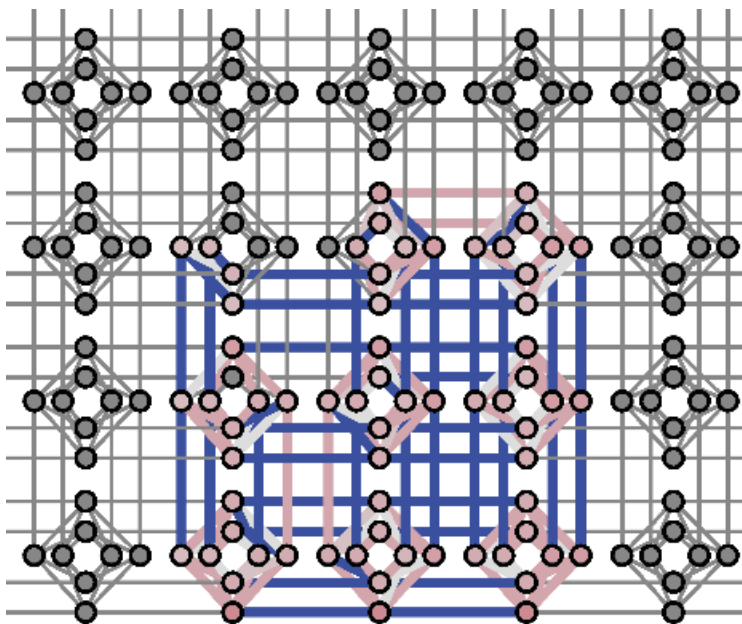
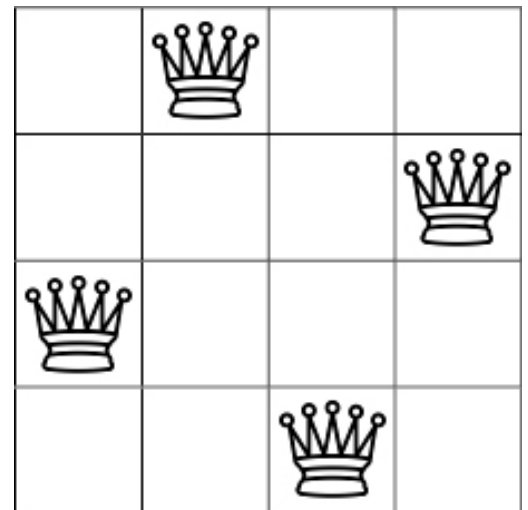


Quantum Processing Unit (QPU)



Lösung des 4-Damenproblems

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0	0	-2	2	0	2	2	2	2	0	2	0	0	0	2	0
0	0	0	-2	0	0	2	2	0	2	0	2	2	0	0	2
0	0	0	0	-2	2	2	2	2	2	0	0	2	0	2	0
0	0	0	0	0	-2	2	2	2	2	2	0	0	2	0	2
0	0	0	0	0	0	-2	2	0	2	2	2	2	0	2	0
0	0	0	0	0	0	0	-2	0	0	2	2	0	2	0	2
0	0	0	0	0	0	0	0	-2	2	2	2	2	2	0	0
0	0	0	0	0	0	0	0	0	-2	2	2	2	2	2	0
0	0	0	0	0	0	0	0	0	0	-2	2	0	2	2	2
0	0	0	0	0	0	0	0	0	0	0	-2	2	2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	-2	2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	-2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2

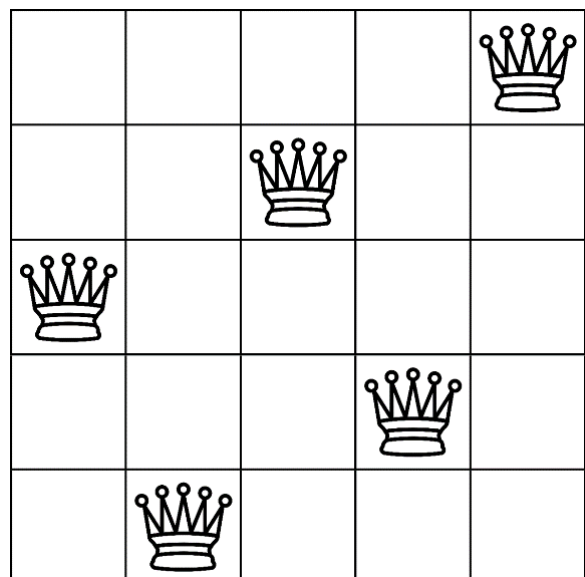
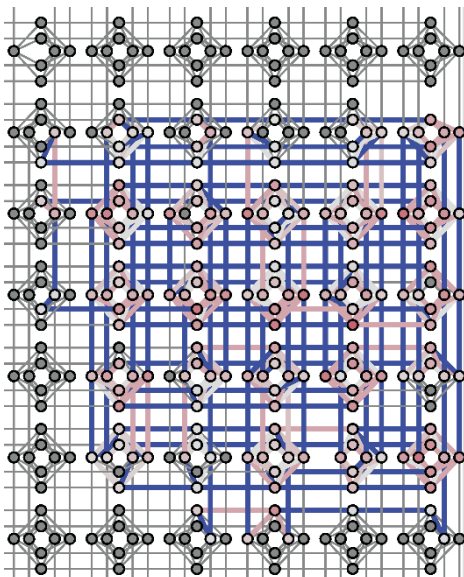


-8.000000	171	[00101000000010100]	-6.000000	83	[0000001010000001]
-8.000000	6794	[01000000110000010]	-6.000000	162	[01000000110001010]
-6.000000	2	[10001000000010100]	-6.000000	26	[00011000000100000]
-6.000000	115	[00010000010000010]	-6.000000	13	[00011000000100100]
-6.000000	7	[00100000000010100]	-6.000000	103	[01000000110000001]
-6.000000	10	[10000000101000000]	-6.000000	28	[0100000010000001]
-6.000000	6	[10100000000010100]	-6.000000	179	[0100001010000001]
-6.000000	12	[10000000101000010]	-6.000000	73	[0100000010000011]
-6.000000	128	[01000000100000010]	-6.000000	108	[01000000110000011]
-6.000000	12	[00101000000010000]	-6.000000	140	[01000000110001000]
-6.000000	26	[00011000000010100]	-6.000000	27	[01000000100101000]
-6.000000	1	[00101000000000100]	-6.000000	22	[01000000000101000]
-6.000000	16	[00011000000000100]	-8.000000	1	[01000000110000010]
-6.000000	154	[00010100000000010]	-8.000000	3	[01000000110000010]
-6.000000	12	[10000000000010100]	-6.000000	1	[100000010000000100]
-6.000000	51	[110000001000000010]	-6.000000	1	[01000000110000000]
-6.000000	11	[00001000000010100]	-8.000000	1	[01000000110000010]
-6.000000	25	[100000010000010100]	-6.000000	4	[01000000100001000]
-6.000000	87	[00010100010000010]	-6.000000	3	[01000000110000001]
-6.000000	34	[10000000100000010]	-6.000000	1	[01000001010000001]
-6.000000	1	[00111000000000100]	-6.000000	3	[00000001010000001]
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-6.000000	4	[10101000000010100]	-6.000000	2	[01000000100001000]
-6.000000	131	[01000000100001010]	-6.000000	1	[01000000110000000]
-6.000000	53	[00100000000011000]	-8.000000	2	[01000000110000010]
-6.000000	87	[01010000010000010]	-6.000000	2	[01000001010000001]
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-6.000000	90	[01000000010000010]	-6.000000	2	[01000000110001000]
-6.000000	31	[00000000110000010]	-8.000000	1	[00101000000010100]
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-6.000000	30	[000000100000011000]	-8.000000	2	[01000000110000010]
-6.000000	24	[00100100000011000]	-8.000000	3	[01000000110000010]
-6.000000	19	[00100000000011100]	-8.000000	1	[01000000110000010]
-6.000000	93	[01010000110000010]	-4.000000	2	[00010100000100010]
-6.000000	4	[00101000000011100]	-4.000000	1	[00010000000000110]
-6.000000	131	[01000000100001000]	-4.000000	1	[00000001000010100]
-6.000000	41	[01000000110000000]	-4.000000	2	[10000001100000000]
-6.000000	12	[00100000001000001]	-4.000000	1	[01000000100000000]
-6.000000	46	[10000000110000010]	-4.000000	1	[100000000000000110]
-6.000000	4	[00101000001000001]	-4.000000	2	[00011000000000110]
-6.000000	3	[00101000000010001]	-4.000000	1	[10100001000010100]
-6.000000	2	[00101000000000101]	-4.000000	1	[10100000001010000]
-6.000000	2	[00101000000010101]	-4.000000	1	[10000000001000010]
-6.000000	3	[00101000000000001]			

-4.000000	1	[1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0]	-4.000000	2	[0 1 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
-4.000000	2	[0 0 0 1 1 0 0 0 0 0 0 0 0 0 1 1 0]	-4.000000	1	[1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1]
-4.000000	1	[1 0 1 0 0 0 1 0 0 0 0 1 0 1 0 0]	-4.000000	2	[0 1 0 0 0 1 0 1 0 0 0 0 1 0 0 0]
-4.000000	1	[1 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0]	-4.000000	1	[0 0 1 0 0 0 0 0 0 1 0 1 1 0 0 0]
-4.000000	1	[1 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0]	-4.000000	3	[0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0]
-4.000000	1	[1 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0]	-4.000000	1	[0 0 0 1 0 0 0 1 1 0 0 0 0 0 0 0]
-4.000000	1	[0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0]	-4.000000	5	[0 0 0 1 1 0 0 0 1 0 0 0 0 0 1 0]
-4.000000	1	[0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0]	-4.000000	1	[0 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0]
-4.000000	1	[1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0]	-4.000000	2	[0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0]
-4.000000	1	[0 0 0 1 0 0 0 1 0 0 0 0 0 0 1 0]	-4.000000	1	[1 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0]
-4.000000	2	[0 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0]	-4.000000	1	[1 0 1 0 0 0 0 0 0 0 0 0 1 1 1 0 0]
-4.000000	2	[1 0 0 1 0 0 0 0 0 0 0 0 0 0 1 1 0]	-4.000000	2	[0 0 0 0 1 1 0 0 0 0 0 1 1 0 0 0]
-4.000000	1	[0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0]	-4.000000	1	[0 1 0 0 0 0 1 1 1 0 0 0 0 0 0 0]
-4.000000	1	[0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0]	-4.000000	2	[0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 1]
-4.000000	2	[1 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 0]	-4.000000	1	[0 0 1 0 0 0 0 0 0 0 1 0 0 1 0 0 0]
-4.000000	1	[0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	2	[0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1]
-4.000000	1	[0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0]	-4.000000	1	[1 1 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0]
-4.000000	3	[1 0 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0]	-4.000000	1	[0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0]
-4.000000	1	[0 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0]	-4.000000	1	[0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 1]
-4.000000	2	[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 1 0]
-4.000000	1	[0 0 0 0 1 1 0 0 0 0 0 0 1 0 1 0 0]	-4.000000	1	[0 1 0 0 0 0 1 1 1 0 0 0 0 0 0 0]
-4.000000	1	[1 0 0 1 1 0 0 0 0 0 0 0 0 0 1 0 0]	-4.000000	1	[0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 1]
-4.000000	1	[1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 1 0]	-4.000000	1	[0 0 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0]
-4.000000	1	[0 0 0 1 1 1 0 0 0 0 0 0 1 0 0 0 0]	-4.000000	1	[1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0]
-4.000000	3	[1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0]	-4.000000	1	[0 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0]
-4.000000	4	[0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[1 0 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0]
-4.000000	1	[0 0 0 1 1 1 0 0 0 0 0 0 0 0 1 0 0]	-4.000000	1	[1 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0]
-4.000000	1	[1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[0 1 0 0 0 0 0 1 0 0 0 0 1 1 0 0 0]
-4.000000	1	[0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 0]	-4.000000	5	[0 1 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0]
-4.000000	1	[1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0]	-4.000000	2	[0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1]
-4.000000	3	[0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[0 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
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-4.000000	2	[0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[1 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0]
-4.000000	2	[0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	3	[0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 1 0]
-4.000000	1	[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0]	-4.000000	1	[0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 1]
-4.000000	4	[1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[0 1 0 0 0 0 0 1 1 1 0 0 0 0 0 1 0]
-4.000000	3	[0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0]
-4.000000	1	[0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0]	-4.000000	1	[0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 1]
-4.000000	2	[1 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0]	-4.000000	2	[0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1]
-4.000000	2	[1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0]	-4.000000	1	[0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 1]
-4.000000	1	[1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0]	-4.000000	2	[0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 0 1 0]
-4.000000	3	[1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0]	-4.000000	1	[0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 1]
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-4.000000	1	[0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0]	-4.000000	7	[0 1 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 1]
-4.000000	4	[0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 1 0]	-4.000000	3	[0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0]
-4.000000	1	[1 0 0 0 0 1 0 0 0 0 0 0 1 1 0 0 0]	-4.000000	1	[0 0 0 1 1 0 0 0 0 0 0 1 0 0 0 0 1 0]
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Lösung des 5-Damenproblems

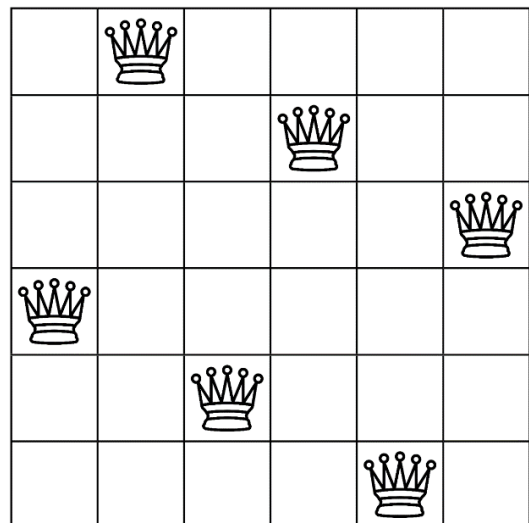
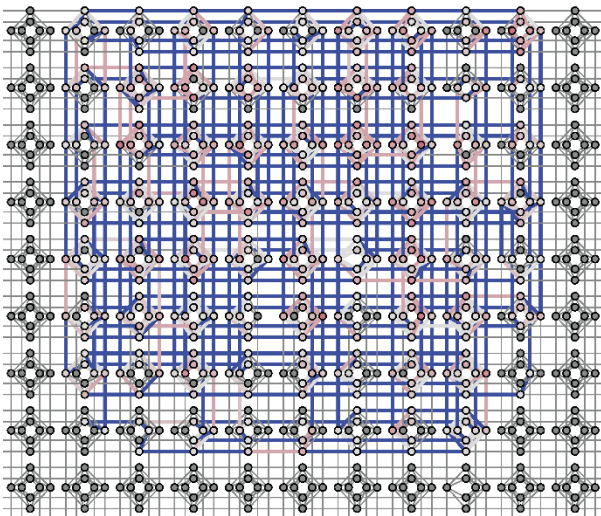
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Lösung des 6-Damenproblems

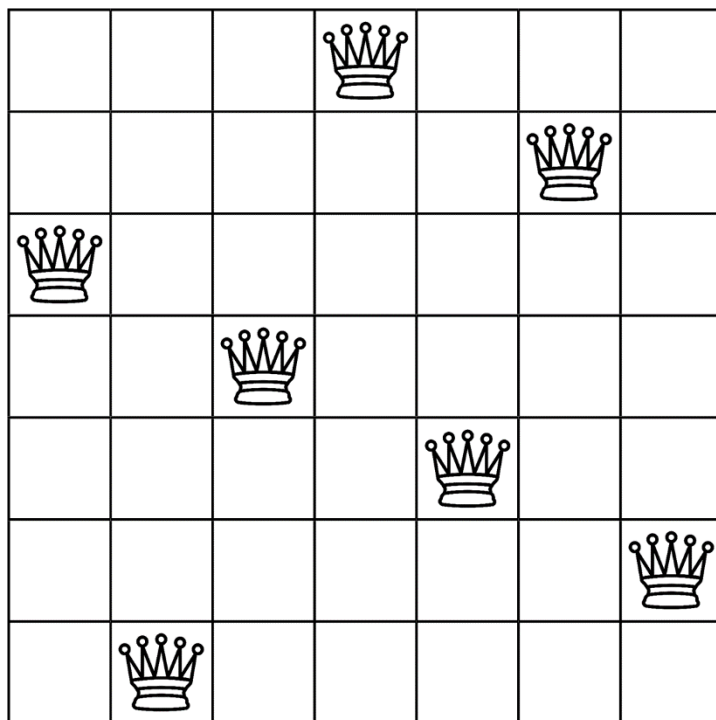
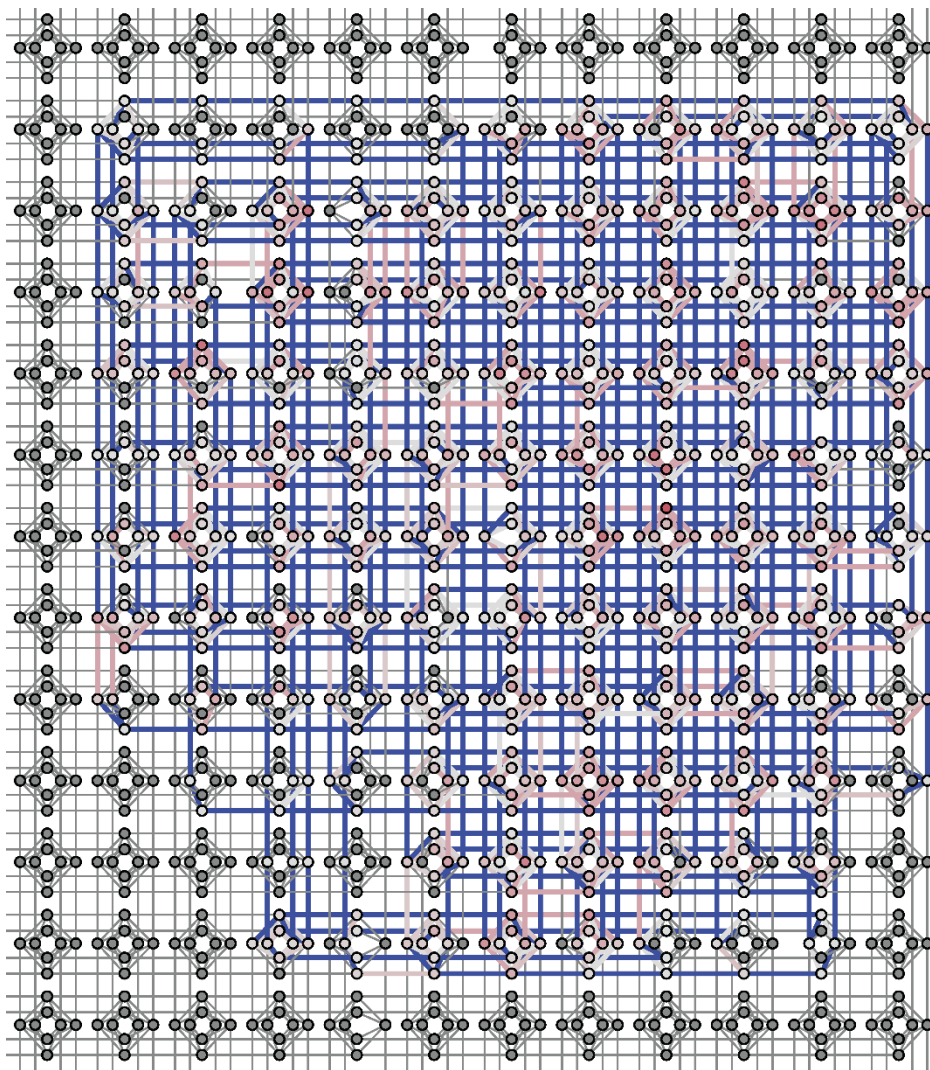
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Lösung des 7-Damenproblems

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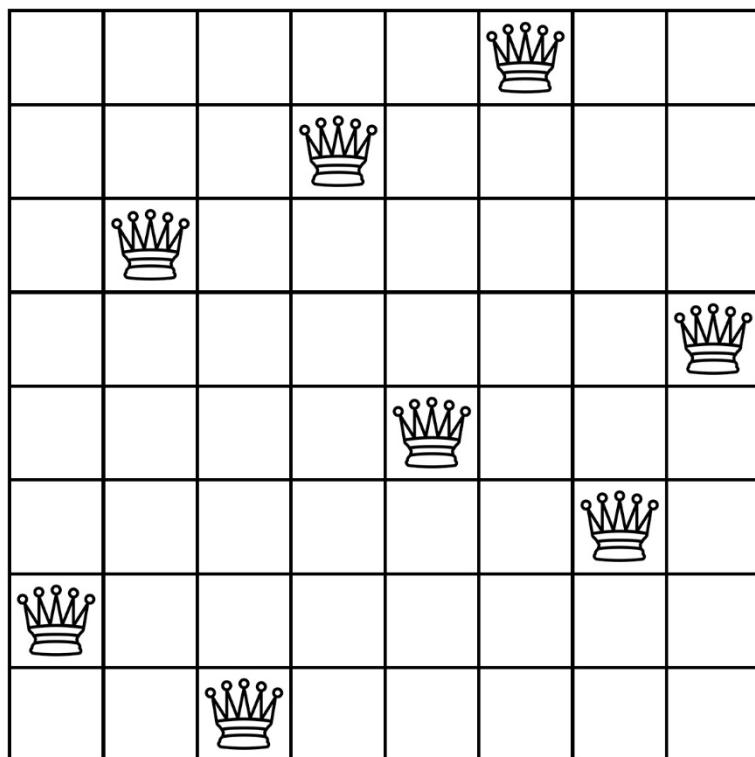
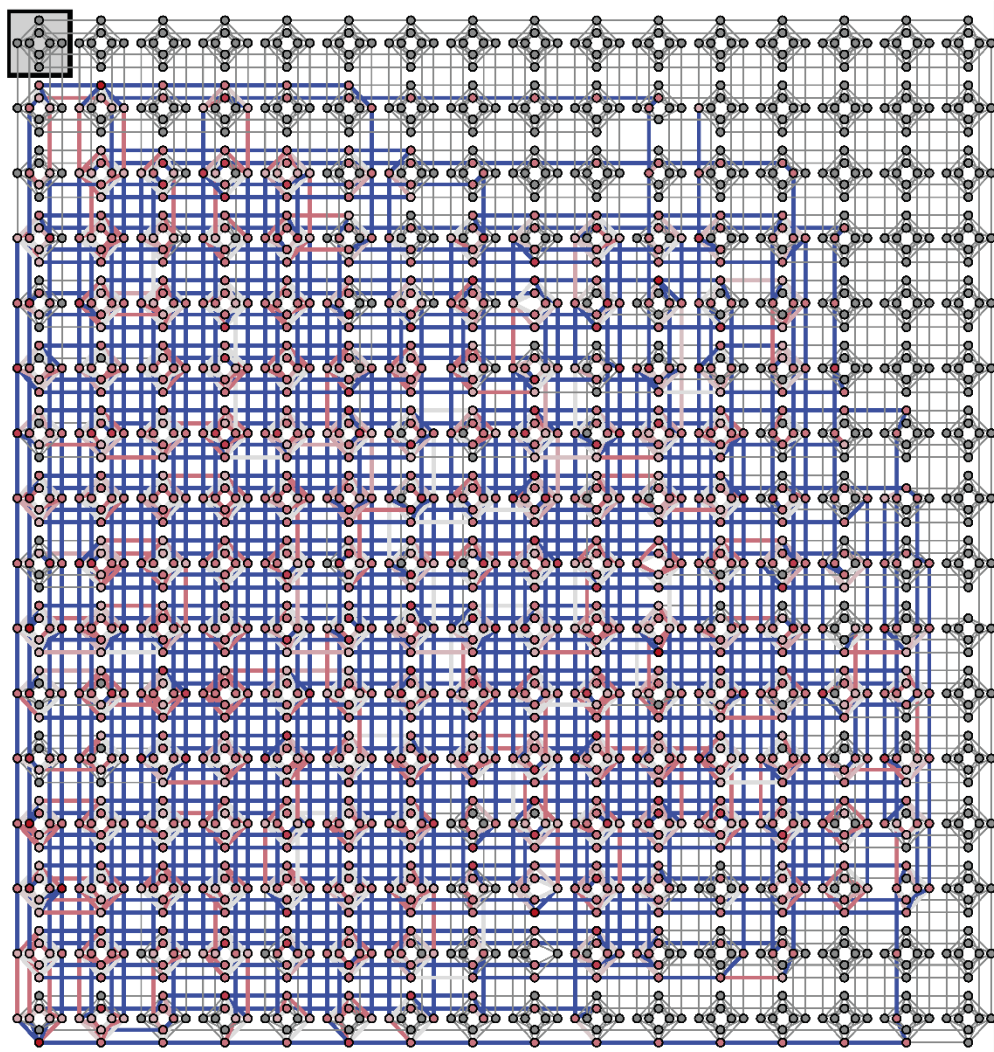


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Lösung des 8-Damenproblems

[illegible]

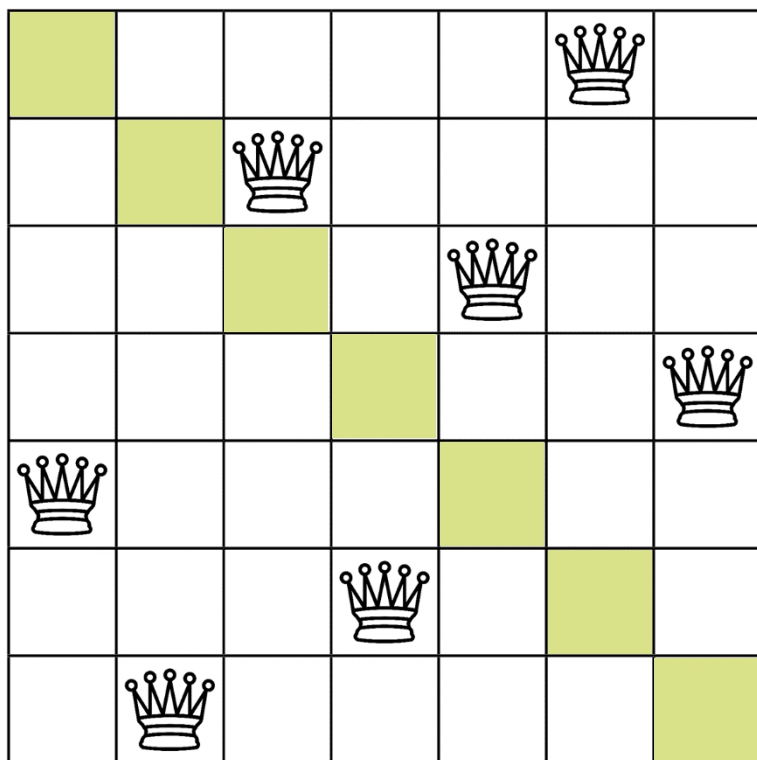
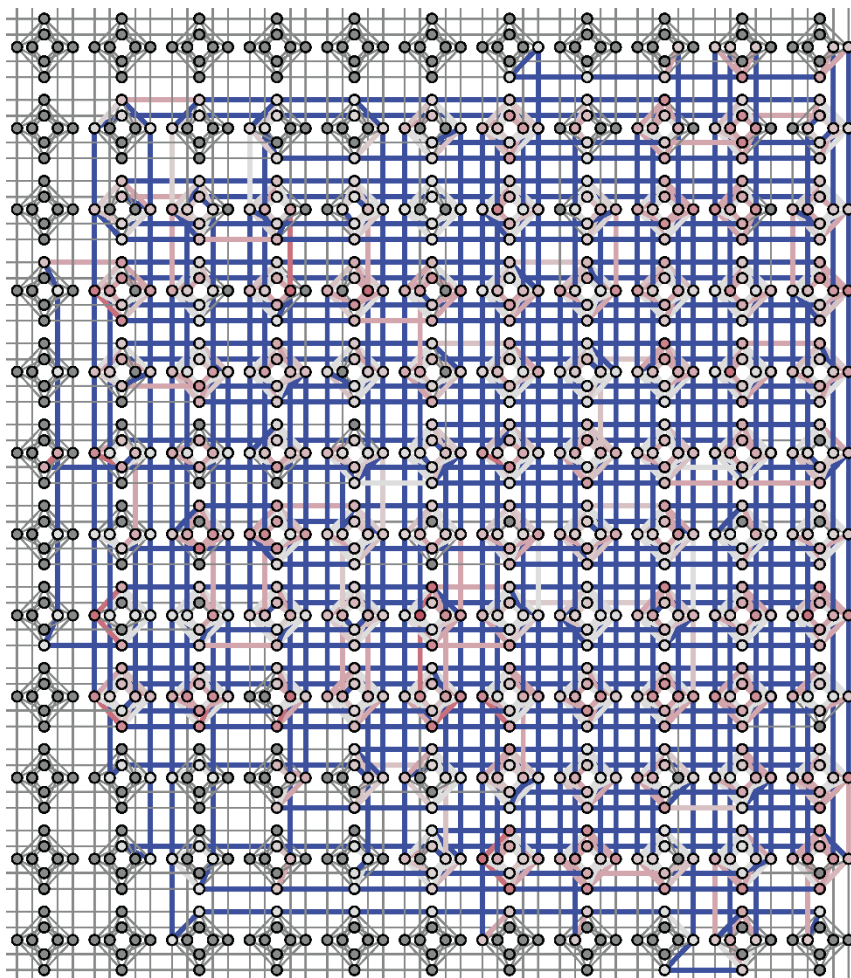


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Lösung des 7-Damenproblems mit einer freien Gesamtdiagonale

[illegible]

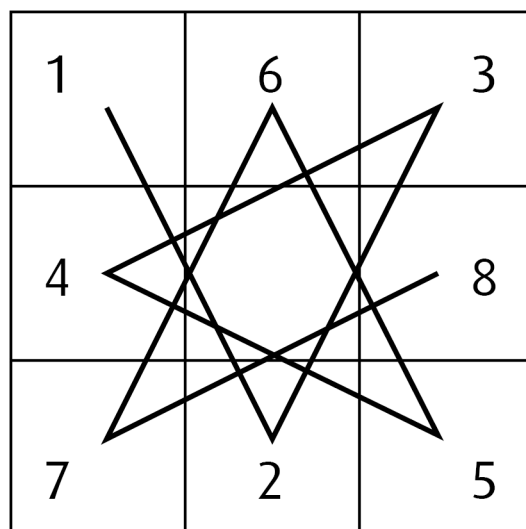
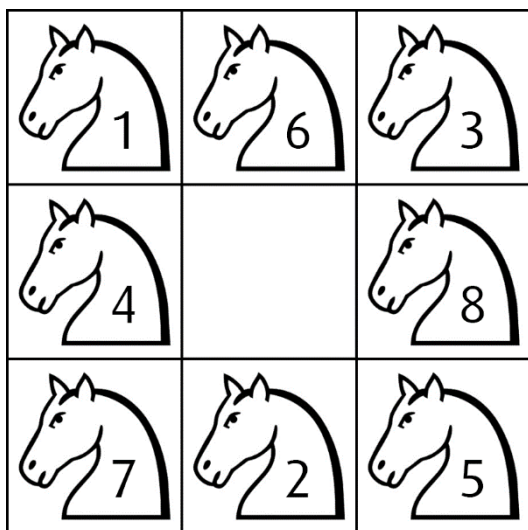
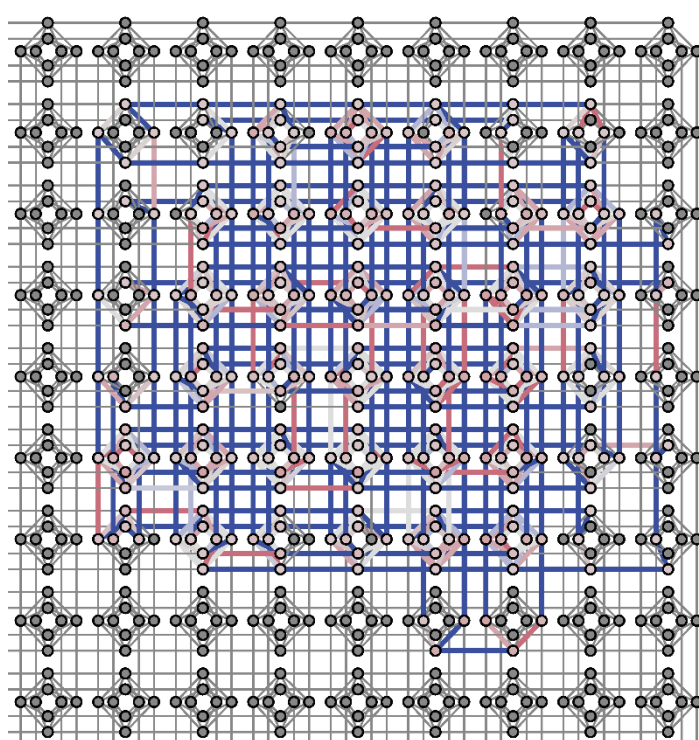


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Lösung des Springerproblems

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