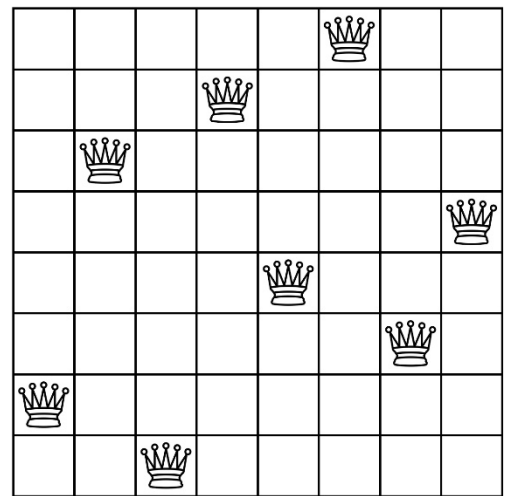
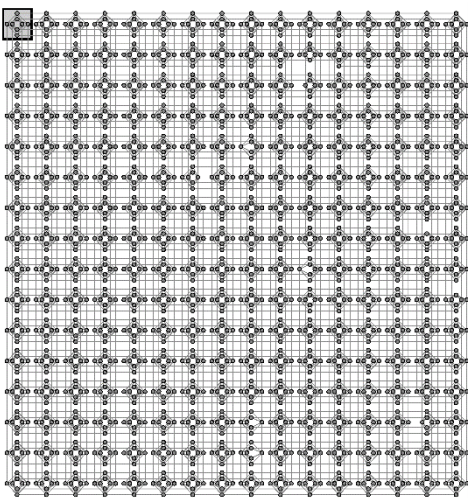


Lösung des n-Damenproblems auf einem adiabatischen Quantencomputer

Resultsbook



Projektidee

Auf einem $n \times n$ großen Schachfeld sollen n Damen so aufgestellt werden, dass keine Dame eine andere bedroht. Dieses klassische Problem haben wir auf einem echten Quantencomputer gelöst. Bei unserem Projekt geht es aber weniger um die eigentliche Lösung des n -Damenproblem (hierfür gibt es bereits viele Algorithmen), sondern um den Weg dieses Problem so aufzubereiten, dass es mit einem "Quantum Annealer" (hierzu später mehr) gelöst werden kann. Unseres Wissens nach ist das n -Damenproblem bisher von niemanden für einen Quanten Annealer adaptiert worden.

Für unser Vorhaben mussten wir das Damenproblem zuerst in die Sprache der Mathematik übersetzen, um dann die Aufgabenstellung auf einen Quantencomputer übertragen zu können. Es galt eine Funktion zu finden, die als Eingabe die einzelnen Positionen der Damen auf dem Schachbrett erhält, wobei alle 2^n möglichen Konstellationen als Eingabewert erlaubt sind, also auch solche, die das Problem nicht lösen, wie etwa keine Dame oder mehr als n Damen auf dem Brett und Konstellationen, bei denen mindestens eine Dame eine andere schlagen kann.

Unsere Funktion liefert für jede mögliche Verteilung der n Damen einen Wert, den man in der Optimierung als "Energie" der Verteilung bezeichnet. Die Lösung des n -Damenproblems läuft dann darauf hinaus, eine Konstellation zu finden, bei der die Energiefunktion ein globales Minimum hat. Dies ist genau dann der Fall ist, wenn n Damen auf dem Brett stehen, die sich gegenseitig nicht schlagen können.

Um die Energiefunktion auf Korrektheit zu testen, schrieben wir zuerst Programme, die unsere Funktion mit Optimierungsalgorithmen wie dem Threshold Accepting, Simulated Annealing oder dem Great Deluge Algorithmus auf klassischen Computern minimiert. Anschließend haben wir unser Programm auf einen adiabatischen Quantencomputer der Firma D-Wave übertragen und ausgeführt. Die Rechenzeit auf dem zehn Millionen Dollar teuren Quantencomputer haben wir über das Forschungszentrum in Jülich (Prof. Dr. Kristel Michielsen) erhalten.

Wie nun so ein adiabatischer Quantencomputers funktioniert, welche Probleme wir lösen mussten, um das Damenproblem auf den Quantencomputer zu übertragen und zu welchen Ergebnissen wir beim Ausführen des Programms gekommen sind, möchten wir im Folgenden genauer erläutern.



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

Ablauf Datenübermittlung Qc

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



```
from __future__ import print_function

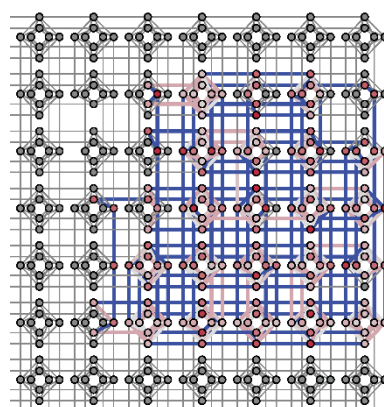
import numpy as np
from dwave.system.samplers import DWaveSampler
from dwave.system.composites import EmbeddingComposite

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

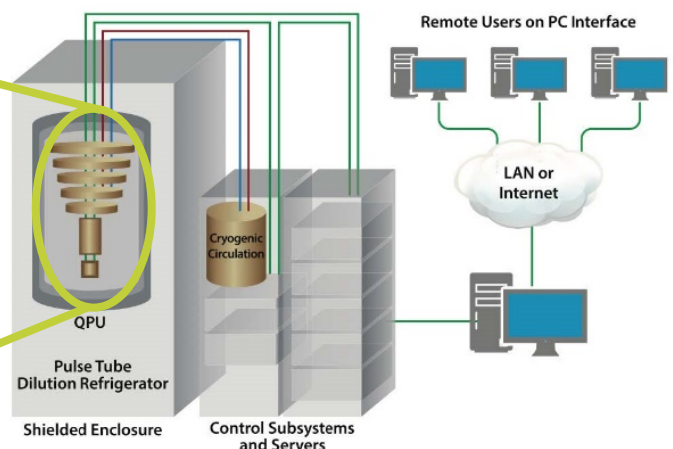
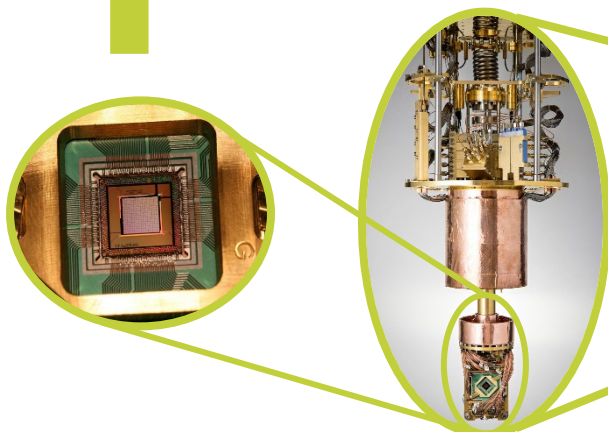
# Konvertiere sie in QUBO Form
qubo = {(i,i):0.0 for i in range(len(qubomatrix))}
for index,value in np.ndenumerate(qubomatrix):
    if value != 0:
        qubo[index] = value
print('Converted matrix into QUBO for D-Wave:\n', qubo, '\n')

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

# Speichere die Ergebnisse in results.txt
with open('results.txt','w') as file:
    file.write('energy\t num_occurrences\t sample\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')
```

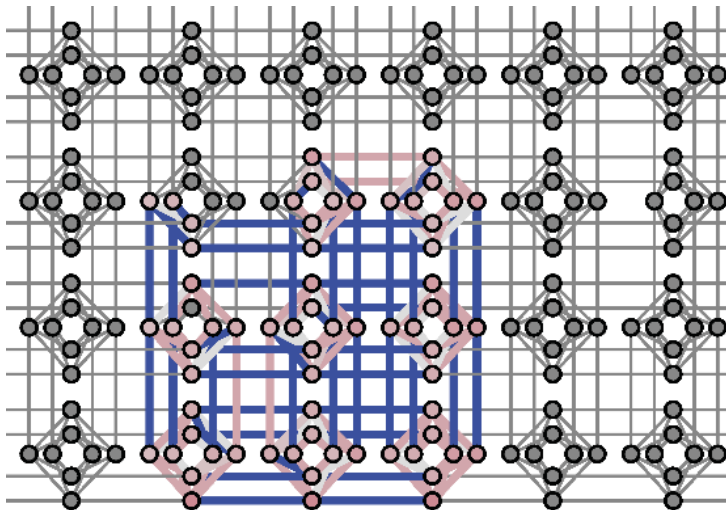






-10.000000	251	[0000100100100000001001000]
-10.000000	1	[01000000010100000010000001]
-10.000000	76	[10000000010010000000100100]
-10.000000	216	[100000001000000010100000010]
-10.000000	82	[001000000010100000001010000]
-10.000000	32	[010000000010010010000000010]
-10.000000	171	[00010010000000010010010000]
-10.000000	36	[000101000000010000000101000]
-10.000000	11	[000010100000000101000000100]
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-8.000000	21	[00001001001000000000000010]
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-8.000000	2	[000100000001000000100000001]
-8.000000	36	[100000001000000010000000010]
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-8.000000	5	[0000100100100000000000001010]
-8.000000	3	[0000100100100000000000001010]
-8.000000	19	[0000100100100000000000001000]
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-8.000000	6	[100000000101000000000000100]
-8.000000	47	[000010010000000000001001000]
-8.000000	8	[1000000010000000100000001010]
-8.000000	30	[100000001001000000000000100]
-8.000000	3	[1000000001001000000000100000]
-8.000000	5	[10000000010000000000100100]
-8.000000	29	[1000000000010000000000100100]
-8.000000	25	[1000000010000000100000001000]
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-8.000000	1	[1010000000100000001000000010]
-8.000000	1	[100000000101000000000101000]



Lösung für $n = 4$

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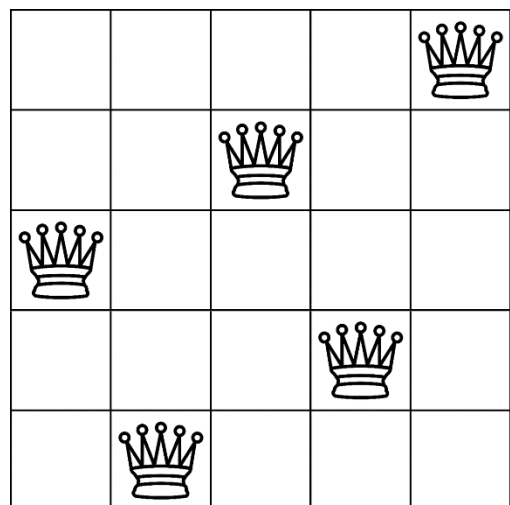
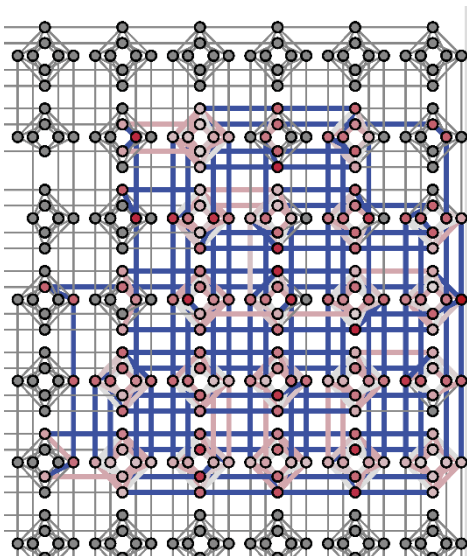


-8.000000	171	[00101000000010100]	-6.000000	83	[0000001010000001]
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-6.000000	2	[10001000000010100]	-6.000000	26	[00011000000100000]
-6.000000	115	[00010000010000010]	-6.000000	13	[00011000000100100]
-6.000000	7	[00100000000010100]	-6.000000	103	[01000000110000001]
-6.000000	10	[10000000101000000]	-6.000000	28	[0100000010000001]
-6.000000	6	[10100000000010100]	-6.000000	179	[01000010100000001]
-6.000000	12	[100000001010000010]	-6.000000	73	[0100000010000011]
-6.000000	128	[01000000100000010]	-6.000000	108	[01000000110000011]
-6.000000	12	[00101000000010000]	-6.000000	140	[01000000110001000]
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-6.000000	16	[00011000000000100]	-8.000000	1	[01000000110000010]
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-6.000000	101	[00010001100000010]	-8.000000	2	[01000000110000010]
-6.000000	4	[10101000000010100]	-6.000000	2	[01000000100001000]
-6.000000	131	[01000000100001010]	-6.000000	1	[01000000110000000]
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-6.000000	87	[010100000100000010]	-6.000000	2	[01000010100000001]
-6.000000	44	[110000001100000010]	-6.000000	2	[010000001100000001]
-6.000000	90	[010000000100000010]	-6.000000	2	[01000000110001000]
-6.000000	31	[000000001100000010]	-8.000000	1	[00101000000010100]
-6.000000	28	[00101000000011000]	-8.000000	1	[010000001100000010]
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-6.000000	93	[010100001100000010]	-4.000000	2	[00010100000100010]
-6.000000	4	[00101000000011100]	-4.000000	1	[00010000000000110]
-6.000000	131	[01000000100001000]	-4.000000	1	[00000010000010100]
-6.000000	41	[01000000110000000]	-4.000000	2	[10000001000000000]
-6.000000	12	[001000000010000001]	-4.000000	1	[01000000100000000]
-6.000000	46	[100000001100000010]	-4.000000	1	[100000000000000110]
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-6.000000	3	[00101000000010001]	-4.000000	1	[101000010000010100]
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Lösung für $n = 5$

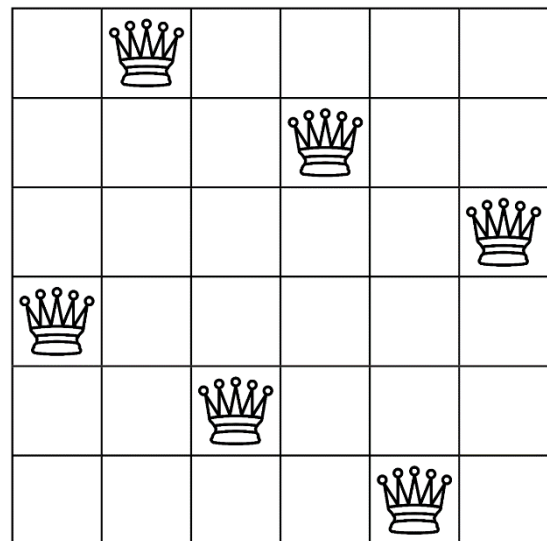
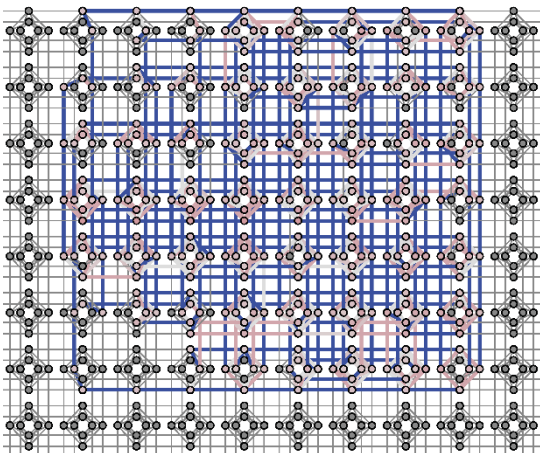
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-10.000000	251	[00001001001000000001001000]			
-10.000000	1	[010000000101000000010000001]	-8.000000	36	[0101000000000000010010010000]
-10.000000	76	[100000000100100000000100100]	-8.000000	55	[010000000100000001000000101]
-10.000000	216	[10000000100000000101000000010]	-8.000000	7	[001000000000100000001110000]
-10.000000	82	[0010000000010100000001010000]	-8.000000	22	[0001000000001000000000101000]
-10.000000	32	[01000000000100100100000000010]	-8.000000	1	[0001000000000010000000101000]
-10.000000	171	[000100100000000010010010000]	-8.000000	10	[000011000001000000001001000]
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-10.000000	1	[0010000000010100000001010000]	-8.000000	9	[001000000010000010000000010]
-8.000000	21	[0000100100100000000000000010]	-8.000000	16	[001000000000100000000110000]
-8.000000	6	[000010010010000000010000010]	-8.000000	44	[0100000000000000010010010000]
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-8.000000	30	[10000000010010000000000000100]	-8.000000	28	[00001100000000000000001001000]
-8.000000	3	[10000000010010000000001000000]	-8.000000	1	[000000010000000010010010000]
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-8.000000	25	[1000000010000000100000001000]	-8.000000	5	[000101000000010000000100100]
-8.000000	1	[00100100000000010100000000001]	-8.000000	51	[0000101000000000010000000010]
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-8.000000	2	[00100000000100000000001010000]	-8.000000	8	[00010100000000000101000000001]
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-8.000000	75	[00100000000001000000001010000]	-8.000000	16	[00010100000000000000000100100]
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-8.000000	1	[01000000000000000100000000001]	-8.000000	1	[001001000000000000000001001000]

Lösung für n = 6

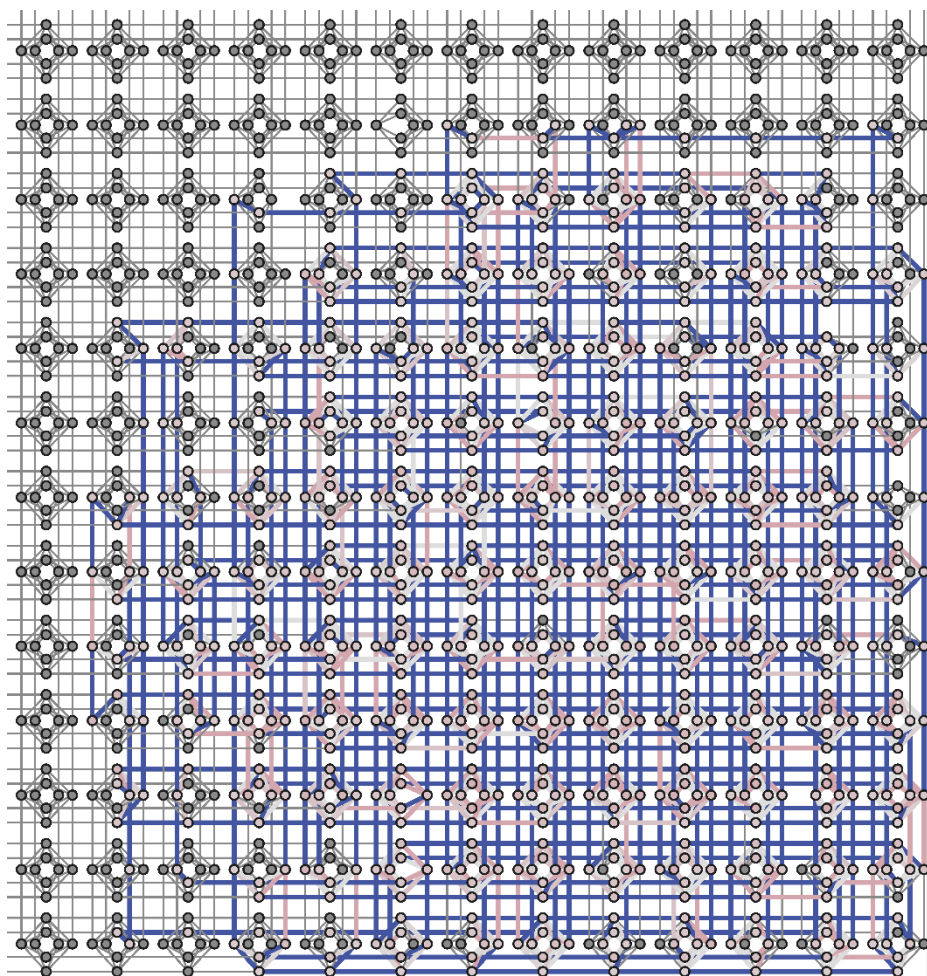
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Lösung für $n = 7$

[illegible]

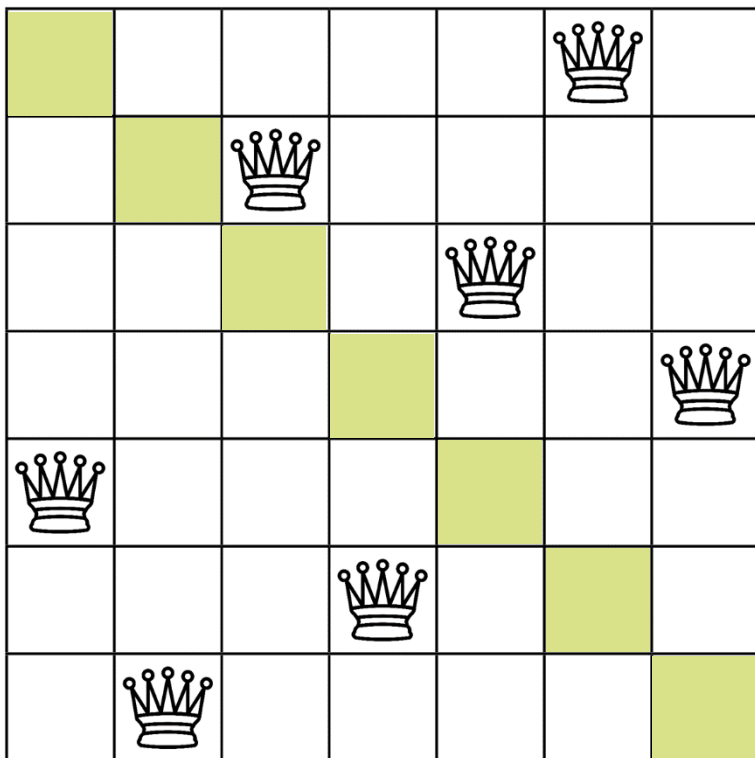
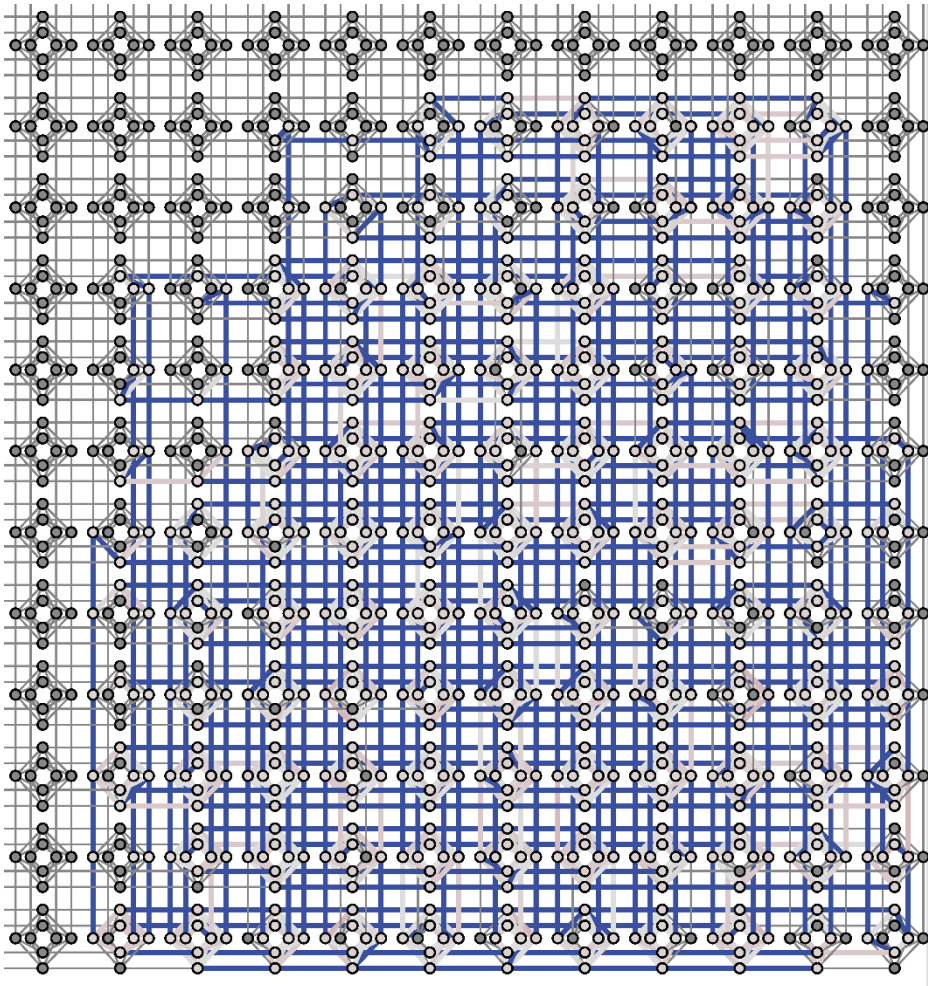


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Lösung für $n = 7$ mit einer freien Gesamtdiagonale

[illegible]



[illegible]

Lösung für das Springerproblem

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