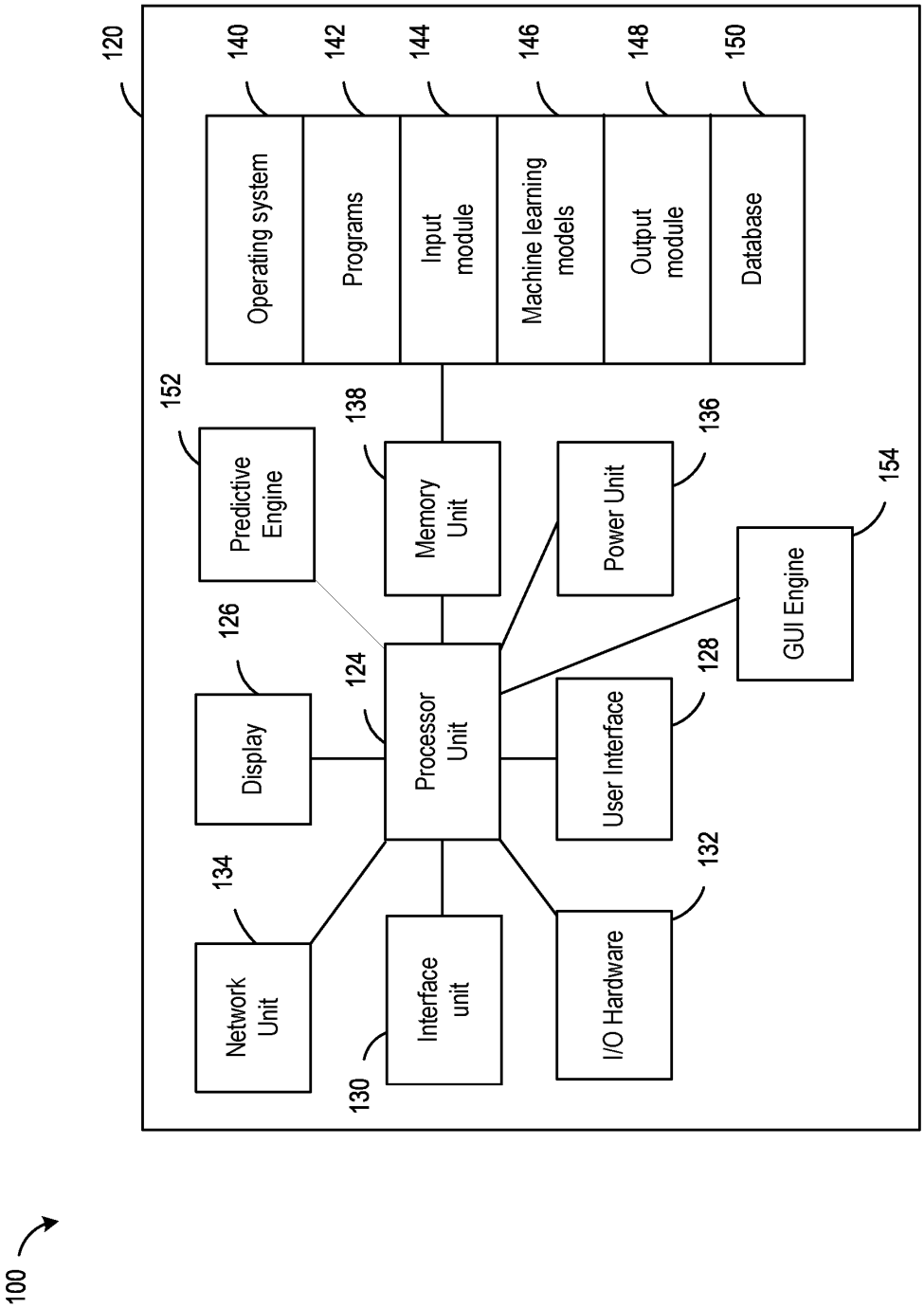

100
120
140
142
144
146
148
150
Operating system
Programs
Input module
Machine learning models
Output module
Database
152
Predictive Engine
138
Memory Unit
136
Power Unit
154
GUI Engine
126
Display
124
Processor Unit
128
User Interface
134
Network Unit
130
Interface unit
132
I/O Hardware

FIG. 1

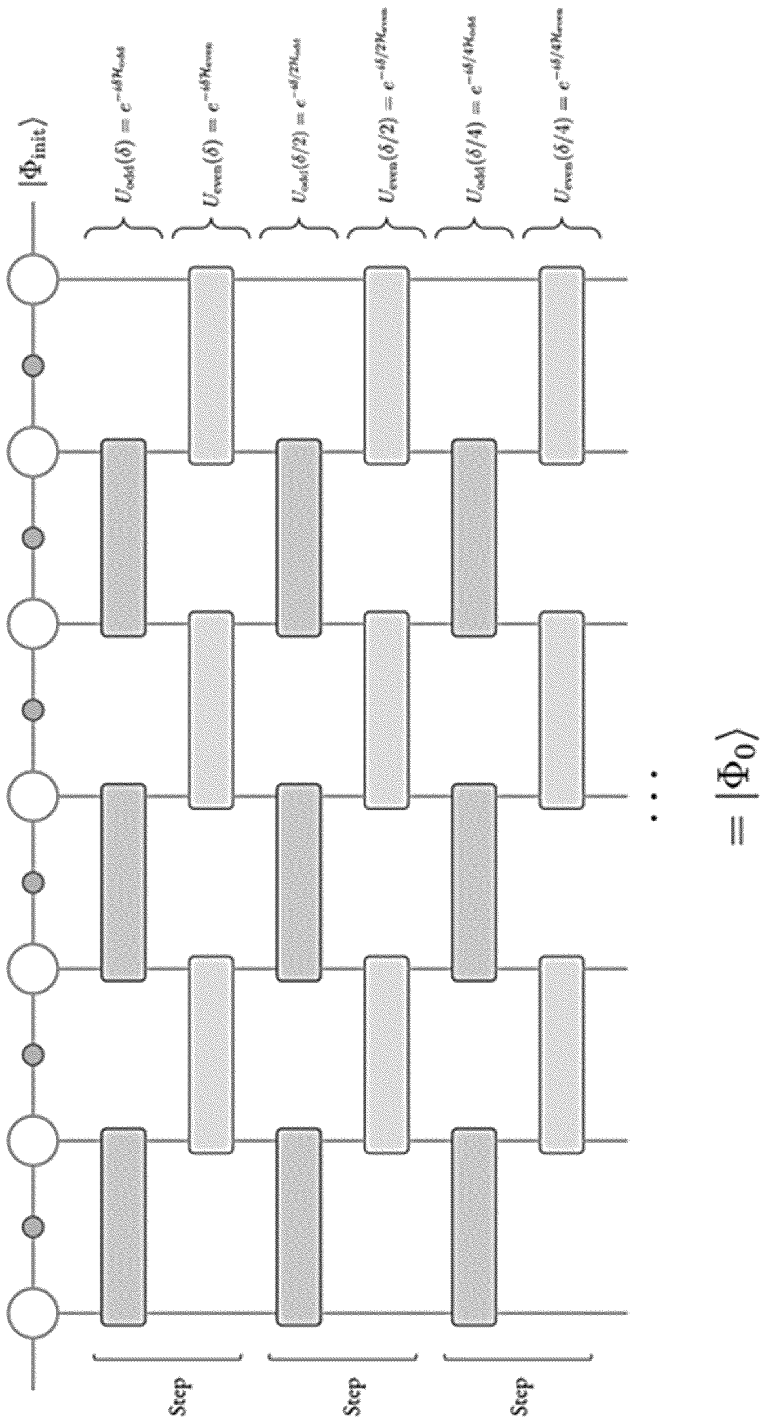

$|\Phi_{\text{init}}\rangle$
$U_{\text{odd}}(\delta) = e^{-i\delta H_{\text{odd}}}$
$U_{\text{even}}(\delta) = e^{-i\delta H_{\text{even}}}$
$U_{\text{odd}}(\delta/2) = e^{-i\delta/2 H_{\text{odd}}}$
$U_{\text{even}}(\delta/2) = e^{-i\delta/2 H_{\text{even}}}$
$U_{\text{odd}}(\delta/4) = e^{-i\delta/4 H_{\text{odd}}}$
$U_{\text{even}}(\delta/4) = e^{-i\delta/4 H_{\text{even}}}$
Step
Step
Step
$\cdots$
$= |\Phi_0\rangle$

FIG. 2

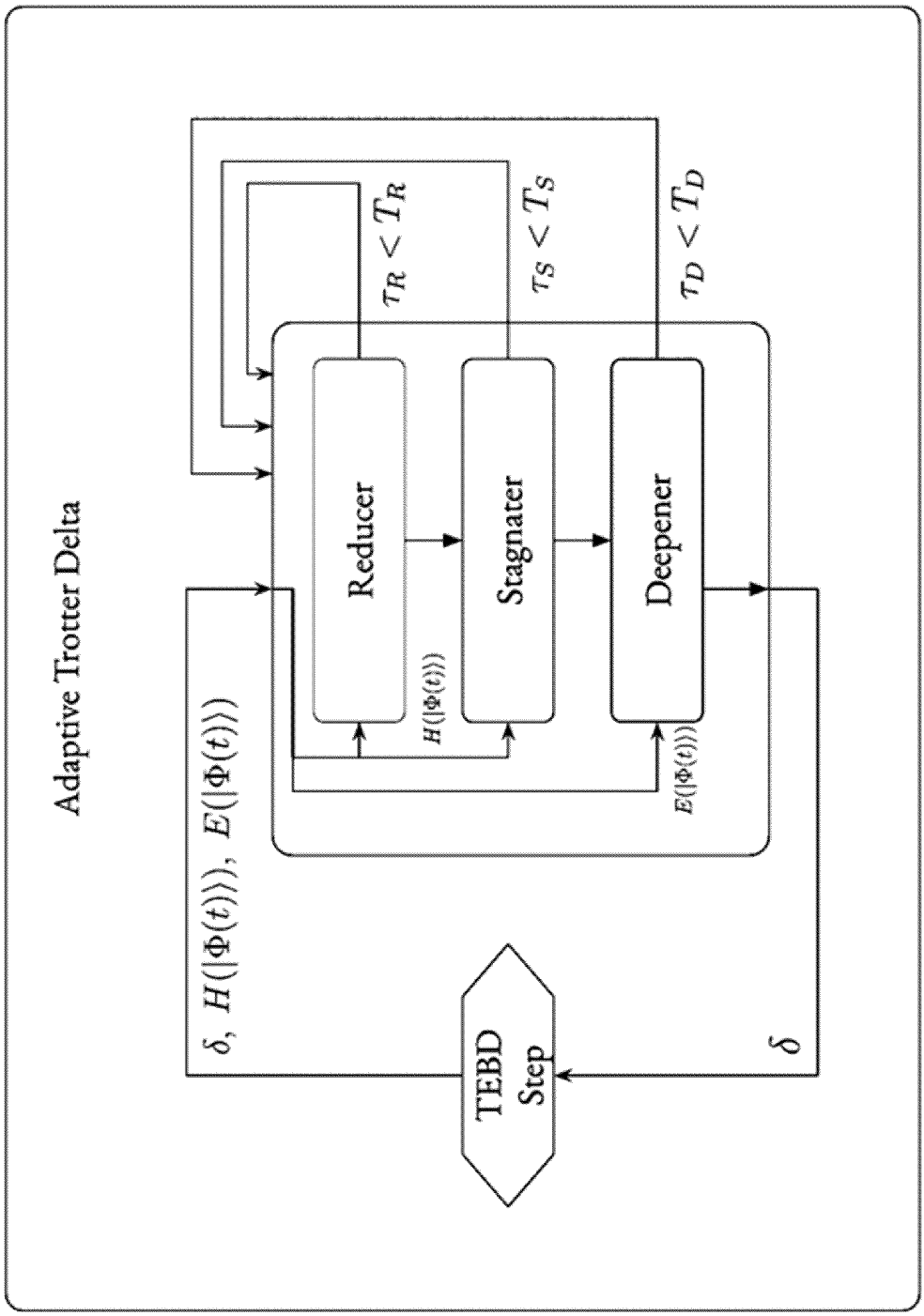

Adaptive Trotter Delta
Reducer
Stagnater
Deepener
$\tau_R < T_R$
$\tau_S < T_S$
$\tau_D < T_D$
$H(|\Phi(t)\rangle)$
$E(|\Phi(t)\rangle)$
$\delta,\ H(|\Phi(t)\rangle),\ E(|\Phi(t)\rangle)$
TEBD Step
δ

FIG. 3

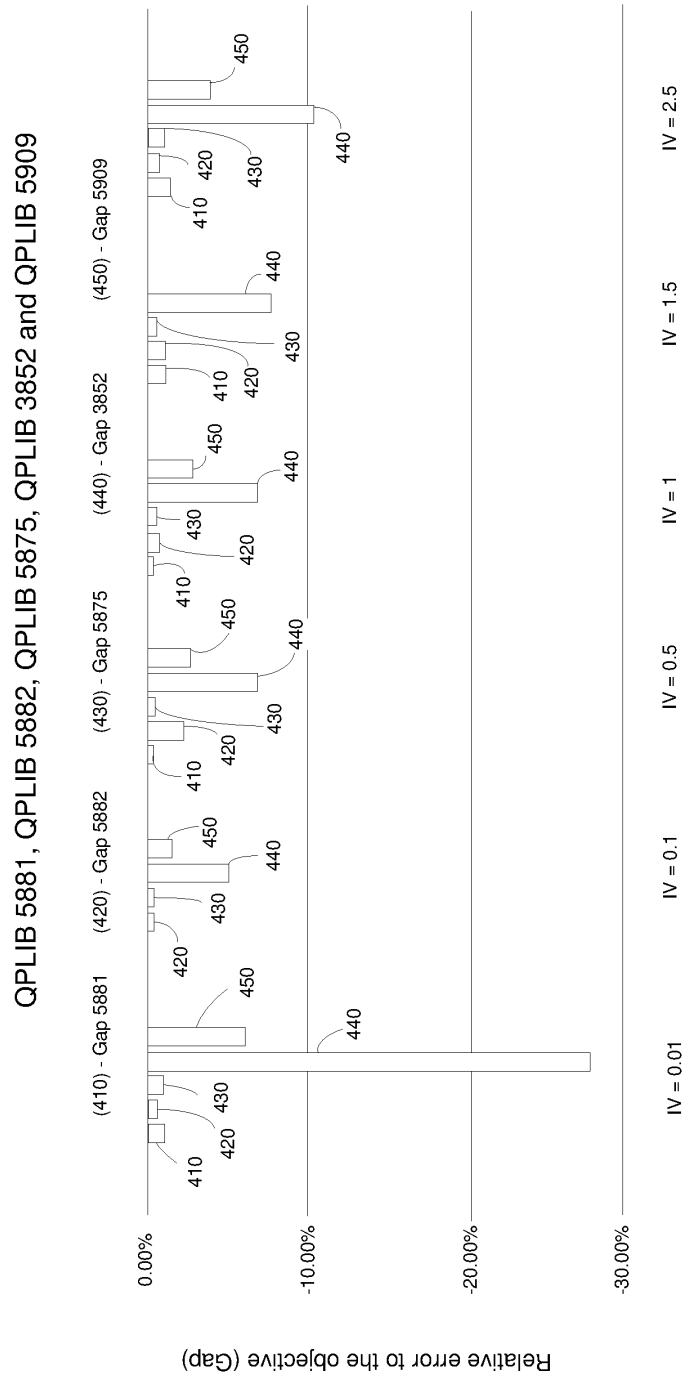

QPLIB 5881, QPLIB 5882, QPLIB 5875, QPLIB 3852 and QPLIB 5909
(410) - Gap 5881
(420) - Gap 5882
(430) - Gap 5875
(440) - Gap 3852
(450) - Gap 5909
0.00%
-10.00%
-20.00%
-30.00%
Relative error to the objective (Gap)
IV = 0.01
IV = 0.1
IV = 0.5
IV = 1
IV = 1.5
IV = 2.5
Different Initial Values

FIG. 4

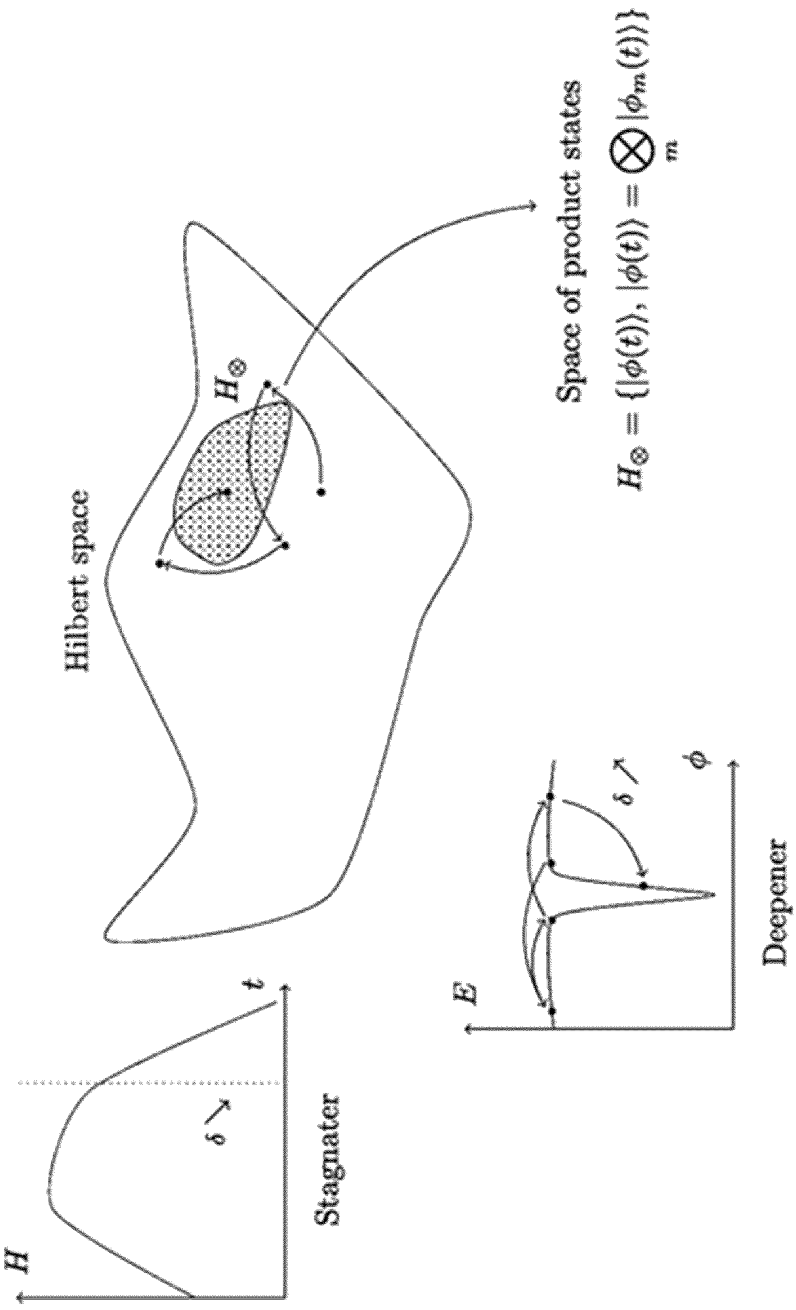

Hilbert space
$H_\otimes$
Space of product states
$H_\otimes = \{|\phi(t)\rangle, |\phi(t)\rangle = \bigotimes_m |\phi_m(t)\rangle\}$
H
t
δ
Stagnater
E
ϕ
δ
Deepener

FIG. 5

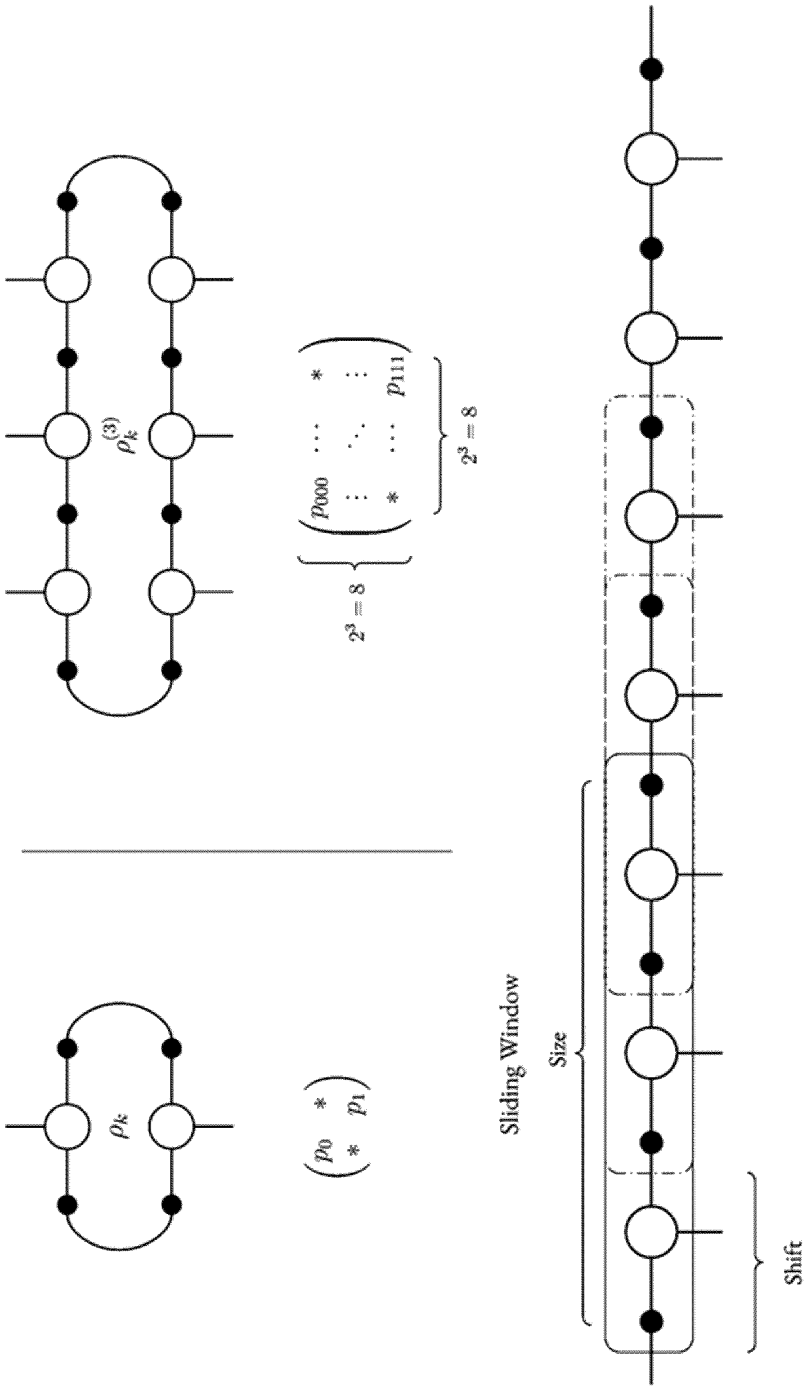

ρ_k
$\begin{pmatrix} p_0 & * \\ * & p_1 \end{pmatrix}$
$\rho_k^{(3)}$
$\begin{pmatrix} p_{000} & \cdots & * & \cdots \\ \vdots & \ddots & \vdots & \\ * & \cdots & p_{111} & \end{pmatrix}$
$2^3 = 8$
$2^3 = 8$
Sliding Window
Size
Shift

FIG. 6

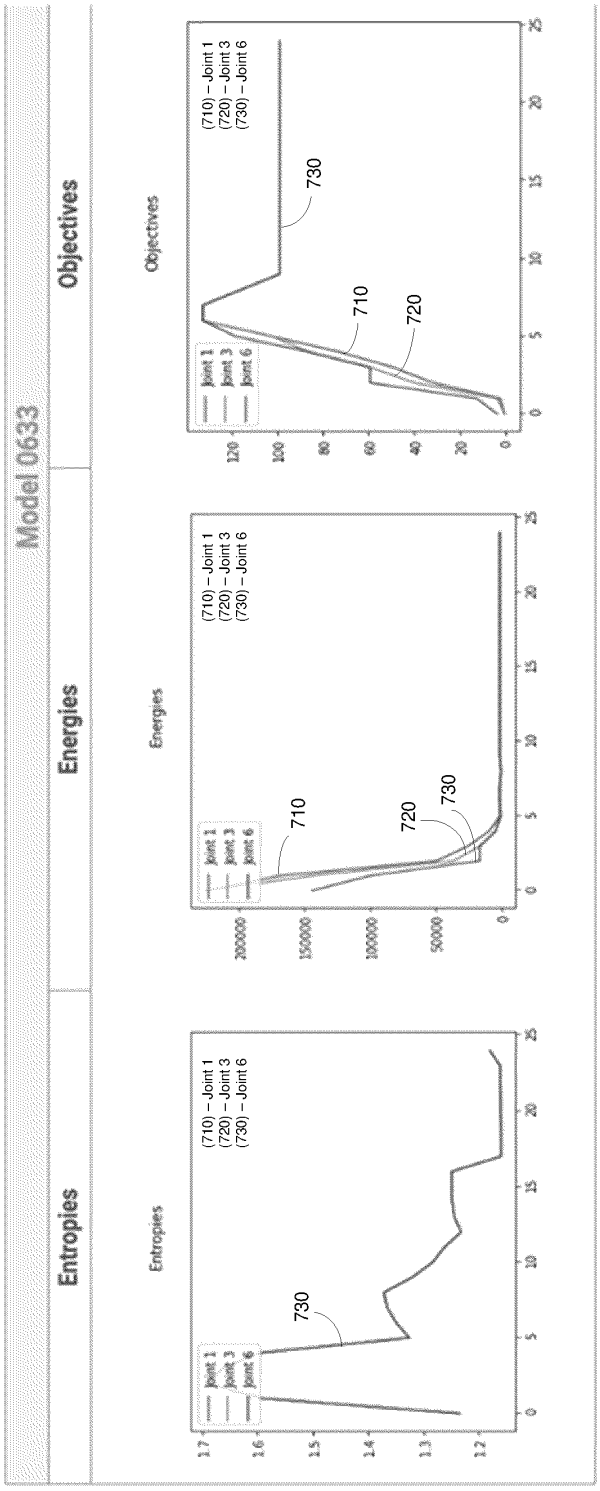

Model 0633
Entropies
Energies
Objectives
Entropies
Energies
Objectives
(710) – Joint 1
(720) – Joint 3
(730) – Joint 6
Joint 1
Joint 3
Joint 6
710
720
730

FIG. 7

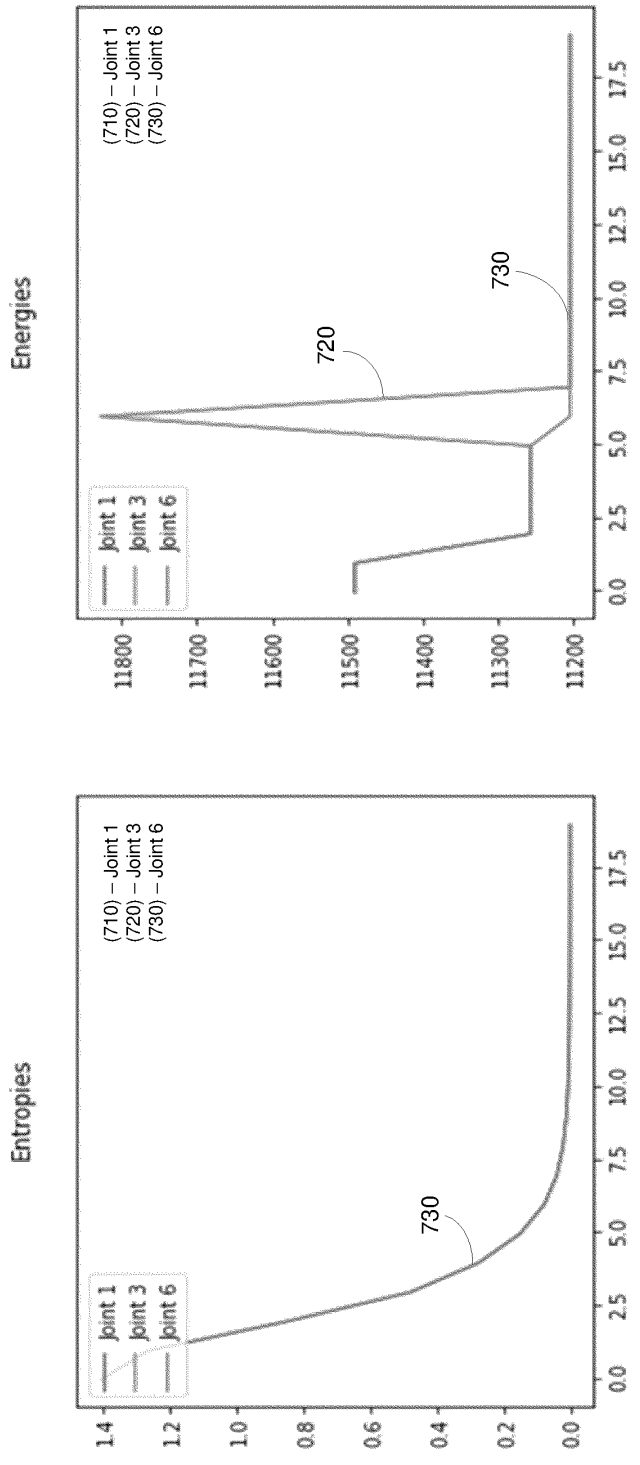

Energies
(710) – Joint 1
(720) – Joint 3
(730) – Joint 6
Joint 1
Joint 3
Joint 6
720
730
11800
11700
11600
11500
11400
11300
11200
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Entropies
(710) – Joint 1
(720) – Joint 3
(730) – Joint 6
Joint 1
Joint 3
Joint 6
730
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

FIG. 8

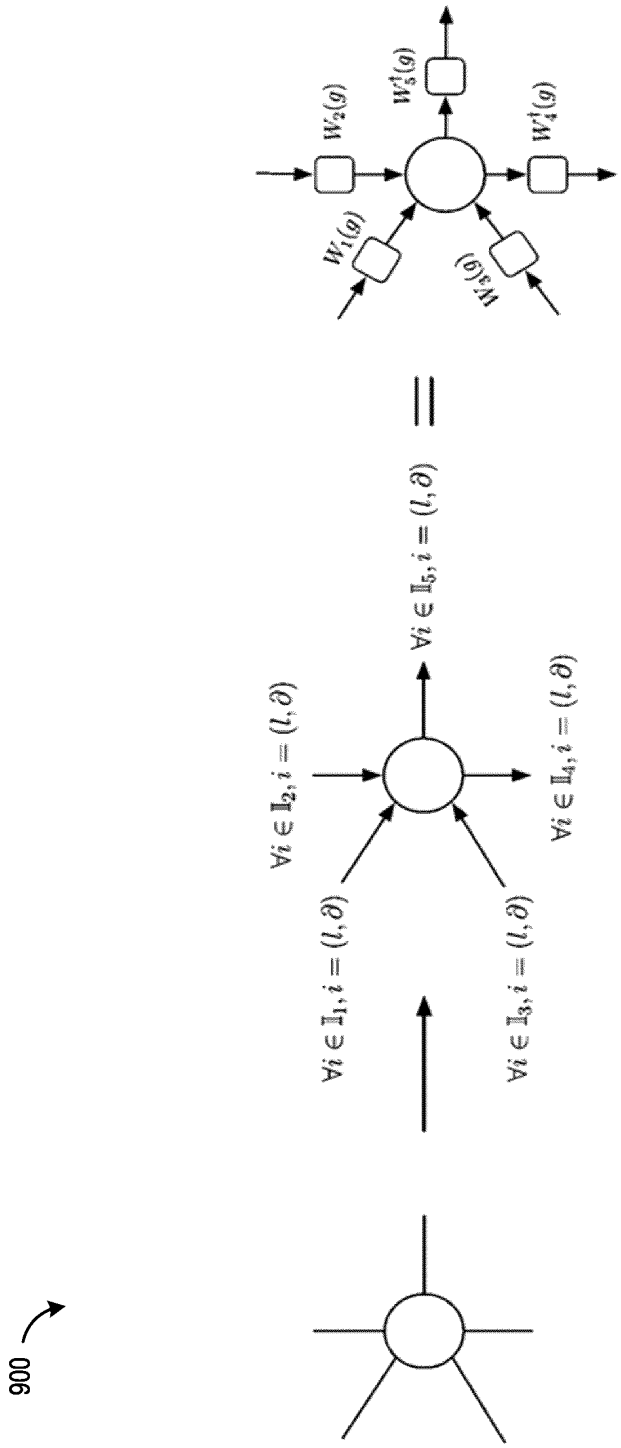

900
$\forall i \in \mathbb{I}_1, i = (l, \partial)$
$\forall i \in \mathbb{I}_2, i = (l, \partial)$
$\forall i \in \mathbb{I}_3, i = (l, \partial)$
$\forall i \in \mathbb{I}_4, i = (l, \partial)$
$\forall i \in \mathbb{I}_5, i = (l, \partial)$
$W_1(g)$
$W_2(g)$
$W_3(g)$
$W_4^1(g)$
$W_5^1(g)$

FIG. 9

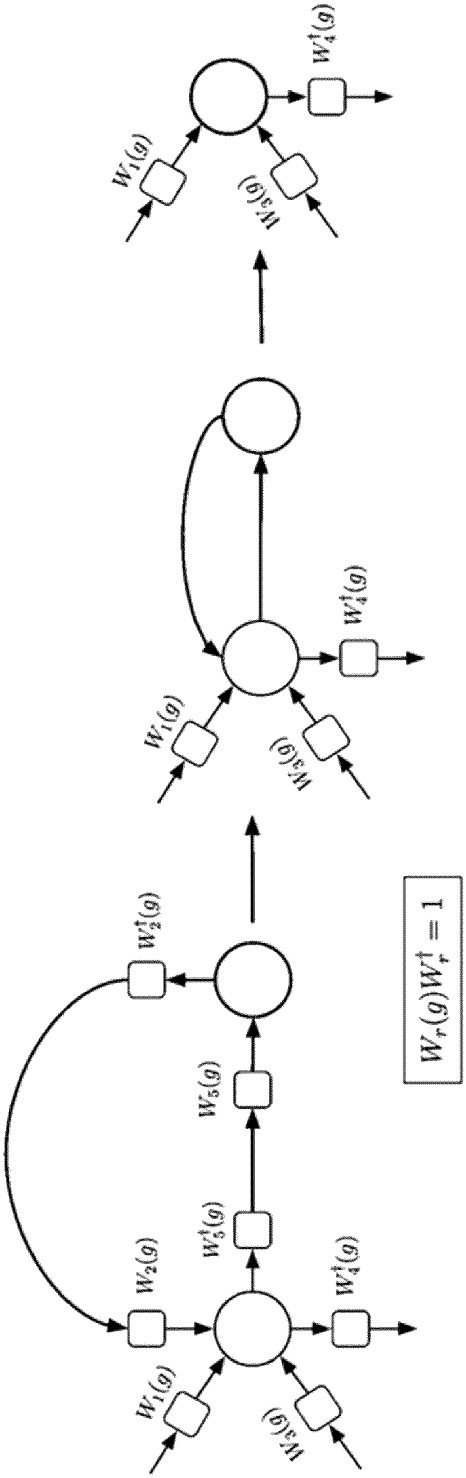

$W_1(g)$
$W_3(g)$
$W_4^1(g)$
$W_1(g)$
$W_3(g)$
$W_4^1(g)$
$W_2^1(g)$
$W_5(g)$
$W_5^1(g)$
$W_2(g)$
$W_1(g)$
$W_3(g)$
$W_4^1(g)$
$W_r(g)W_r^1 = 1$

FIG. 10

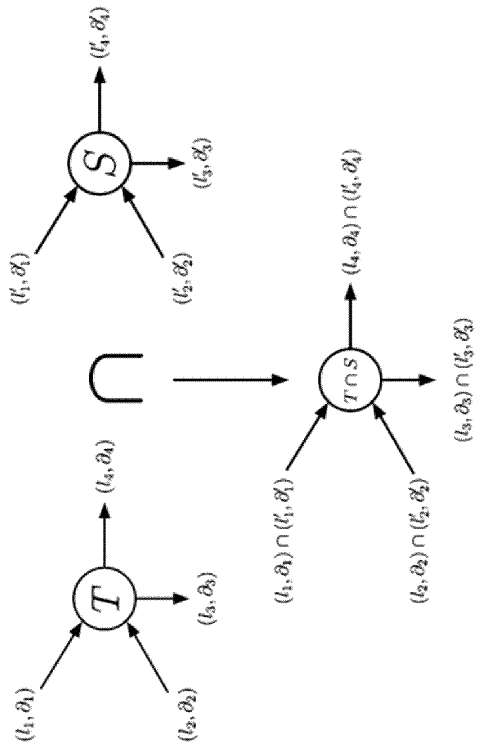

(l'_1, ∂'_1)
(l'_2, ∂'_2)
S
(l'_3, ∂'_3)
(l'_4, ∂'_4)
(l_1, ∂_1)
(l_2, ∂_2)
T
(l_3, ∂_3)
(l_4, ∂_4)
$(l_1, \partial_1) \cap (l'_1, \partial'_1)$
$(l_2, \partial_2) \cap (l'_2, \partial'_2)$
$T \cap S$
$(l_3, \partial_3) \cap (l'_3, \partial'_3)$
$(l_4, \partial_4) \cap (l'_4, \partial'_4)$

FIG. 12

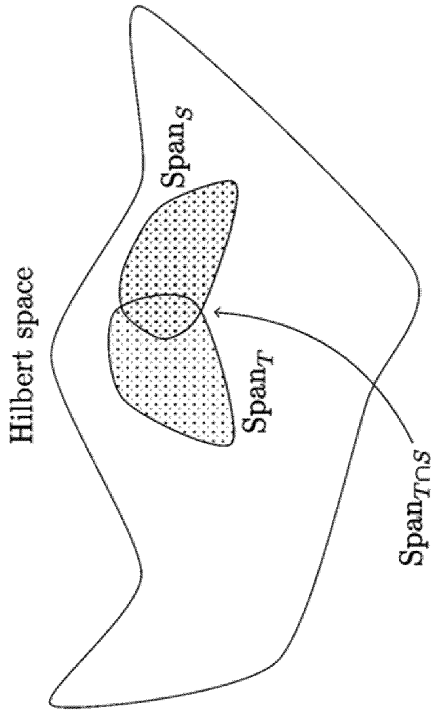

Hilbert space
Span_S
Span_T
$\mathrm{Span}_{T \cap S}$

FIG. 11

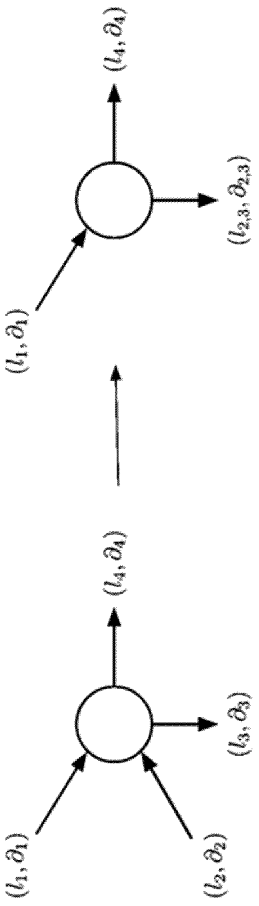

(l_1, ∂_1)
(l_2, ∂_2)
(l_3, ∂_3)
(l_4, ∂_4)
(l_1, ∂_1)
$(l_{2,3}, \partial_{2,3})$
(l_4, ∂_4)

FIG. 13

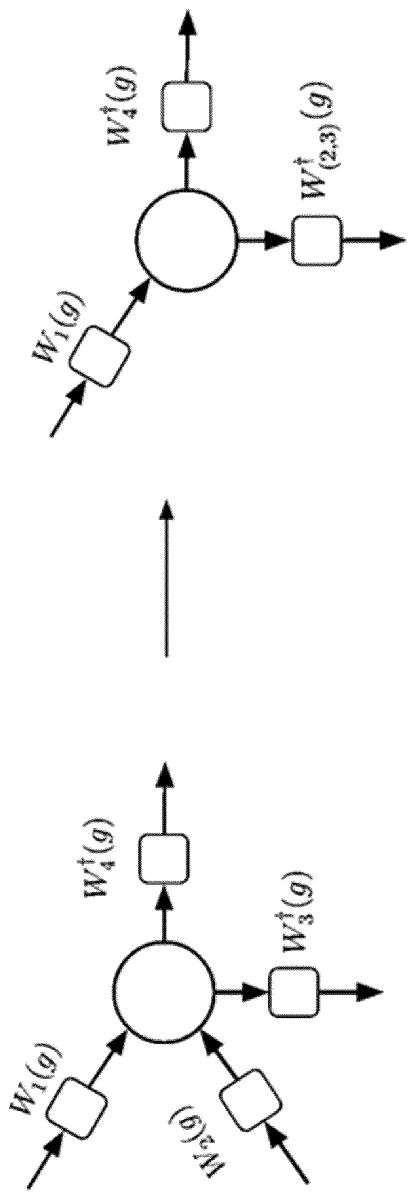

$W_1(g)$
$W_3(g)$
$W_4^\dagger(g)$
$W_3^\dagger(g)$
$W_1(g)$
$W_{(2,3)}^\dagger(g)$
$W_4^\dagger(g)$

FIG. 14

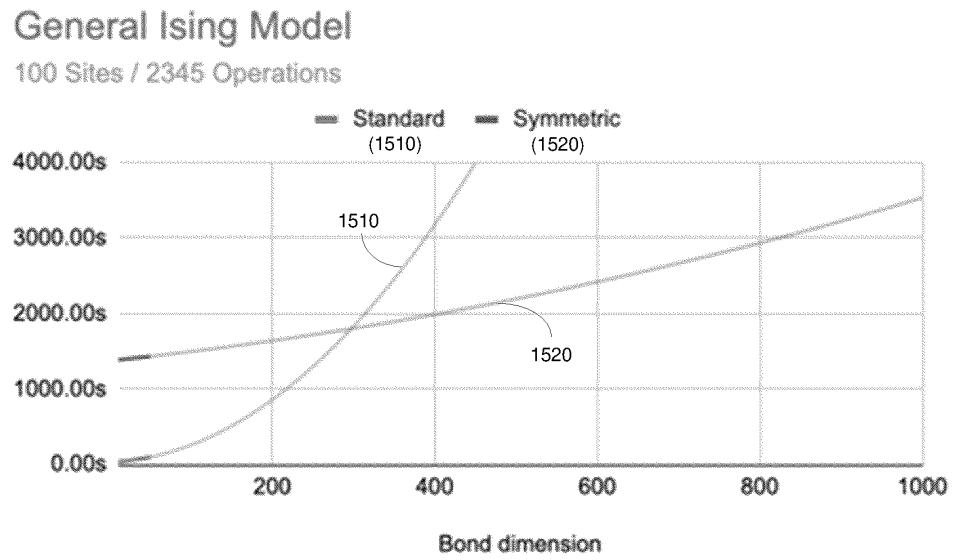

General Ising Model
100 Sites / 2345 Operations
Standard
(1510)
Symmetric
(1520)
4000.00s
3000.00s
2000.00s
1000.00s
0.00s
1510
1520
200
400
600
800
1000
Bond dimension

FIG. 15

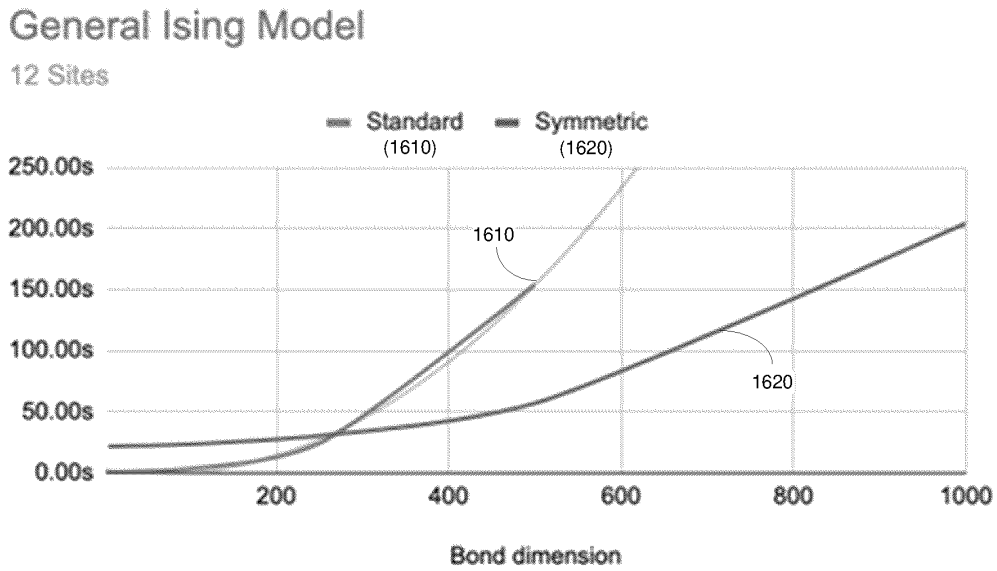

General Ising Model
12 Sites
Standard
(1610)
Symmetric
(1620)
250.00s
200.00s
150.00s
100.00s
50.00s
0.00s
1610
1620
200
400
600
800
1000
Bond dimension

FIG. 16

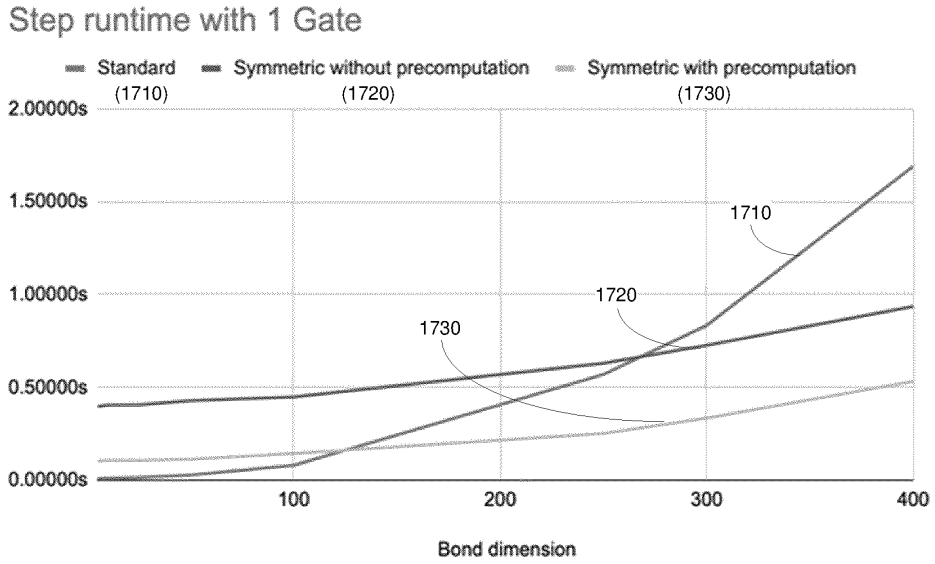

Step runtime with 1 Gate
Standard
(1710)
Symmetric without precomputation
(1720)
Symmetric with precomputation
(1730)
2.00000s
1.50000s
1.00000s
0.50000s
0.00000s
1710
1720
1730
100
200
300
400
Bond dimension

FIG. 17

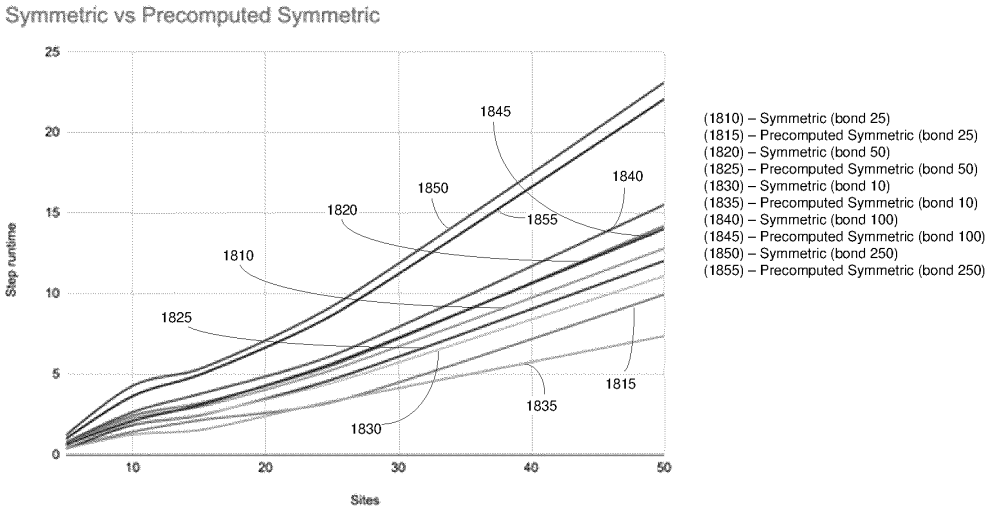

Symmetric vs Precomputed Symmetric
Step runtime
Sites
25
20
15
10
5
0
10
20
30
40
50
1845
1850
1840
1820
1855
1810
1825
1815
1835
1830
(1810) – Symmetric (bond 25)
(1815) – Precomputed Symmetric (bond 25)
(1820) – Symmetric (bond 50)
(1825) – Precomputed Symmetric (bond 50)
(1830) – Symmetric (bond 10)
(1835) – Precomputed Symmetric (bond 10)
(1840) – Symmetric (bond 100)
(1845) – Precomputed Symmetric (bond 100)
(1850) – Symmetric (bond 250)
(1855) – Precomputed Symmetric (bond 250)

FIG. 18

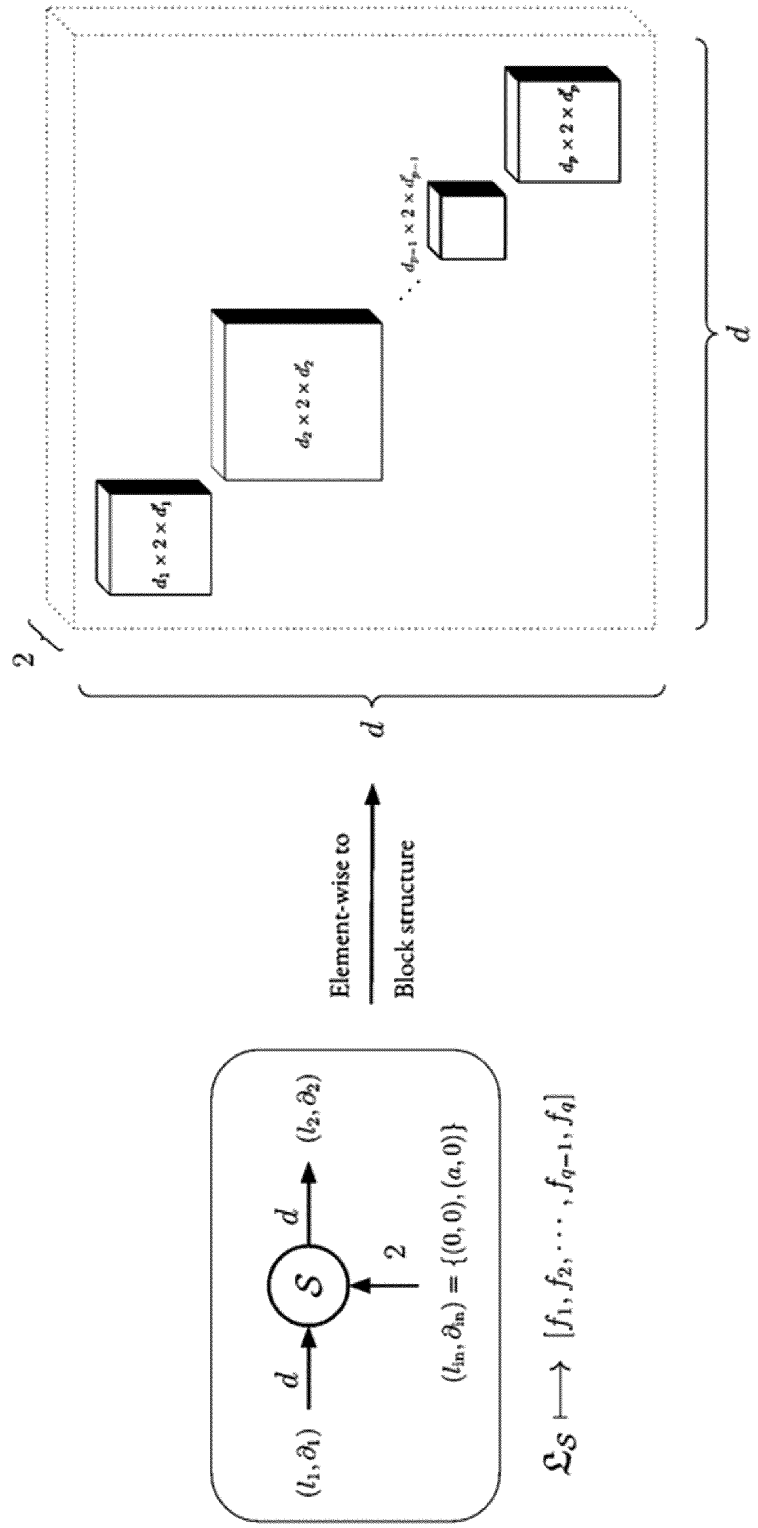

$d_1 \times 2 \times d_1$
$d_2 \times 2 \times d_2$
$\ddots$ $d_{q-1} \times 2 \times d_{q-1}$
$d_q \times 2 \times d_q$
2
d
d
Element-wise to
Block structure
(l_1, ∂_1)
d
S
d
(l_2, ∂_2)
2
$(l_{\text{in}}, \partial_{\text{in}}) = \{(0,0), (a,0)\}$
$\mathcal{S}_S \longmapsto [f_1, f_2, \cdots, f_{q-1}, f_q]$

FIG. 19

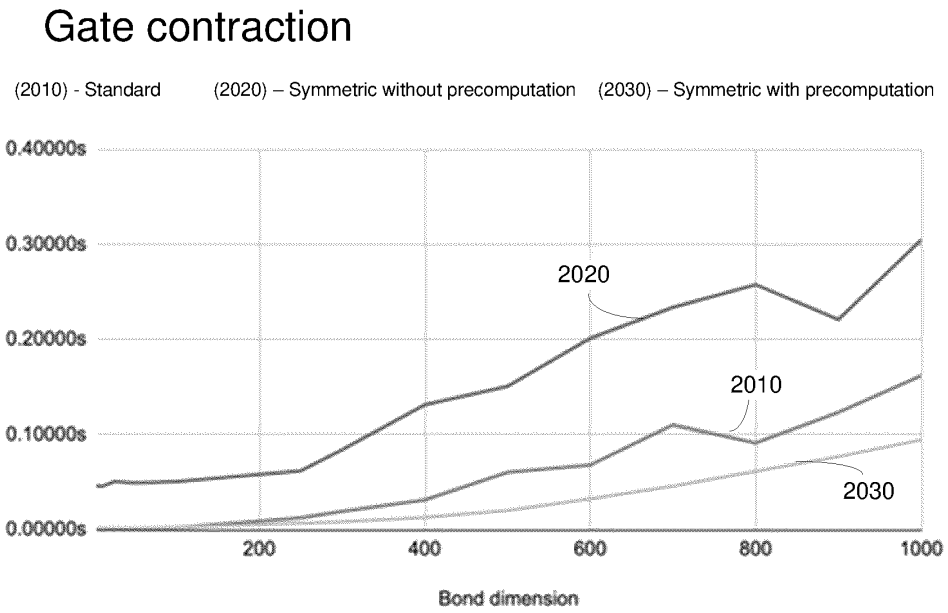

Gate contraction
(2010) - Standard
(2020) – Symmetric without precomputation
(2030) – Symmetric with precomputation
0.40000s
0.30000s
0.20000s
0.10000s
0.00000s
2020
2010
2030
200
400
600
800
1000
Bond dimension

FIG. 20

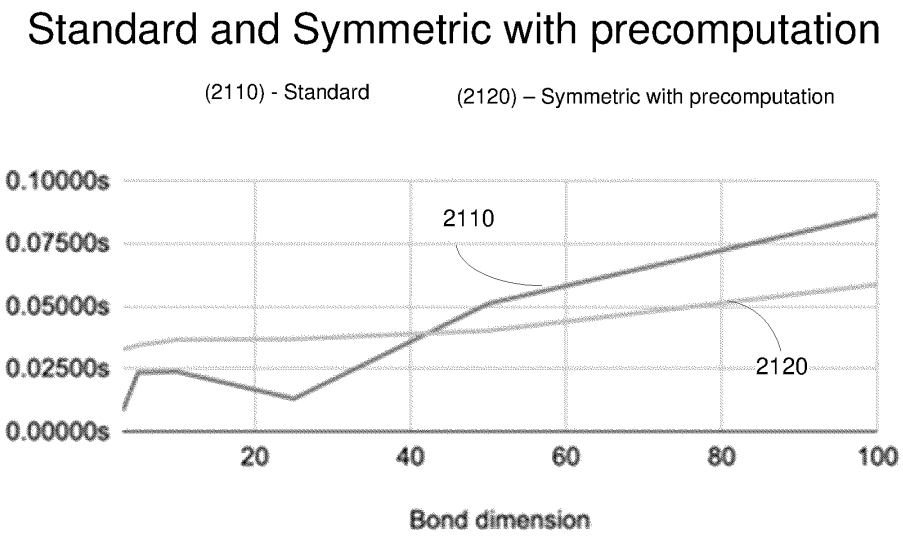

Standard and Symmetric with precomputation
(2110) - Standard
(2120) – Symmetric with precomputation
0.10000s
0.07500s
0.05000s
0.02500s
0.00000s
2110
2120
20
40
60
80
100
Bond dimension

FIG. 21

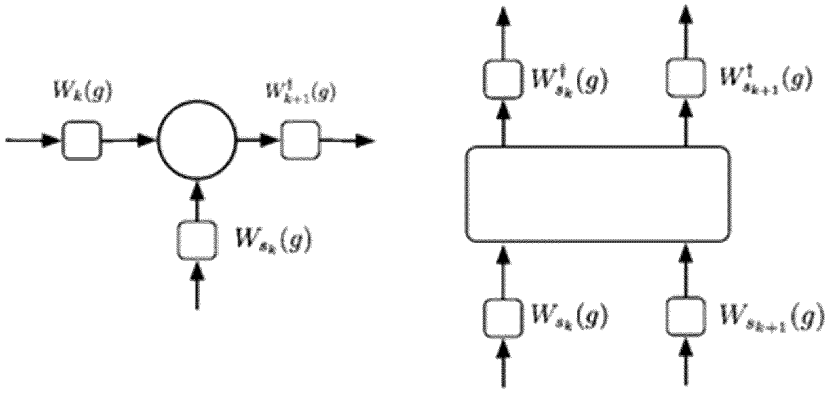


FIG. 22

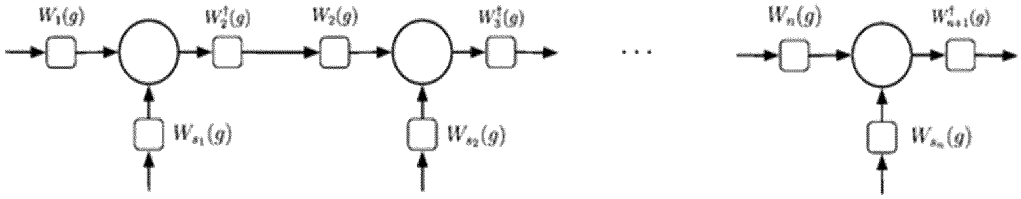


FIG. 23

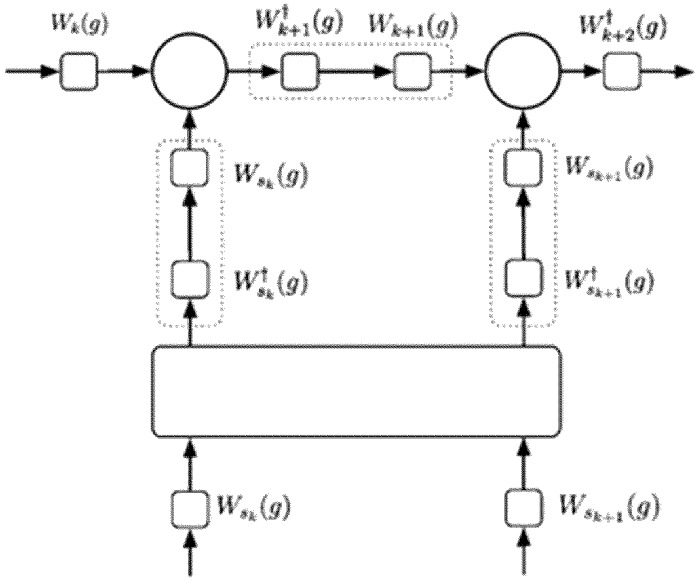


FIG. 24

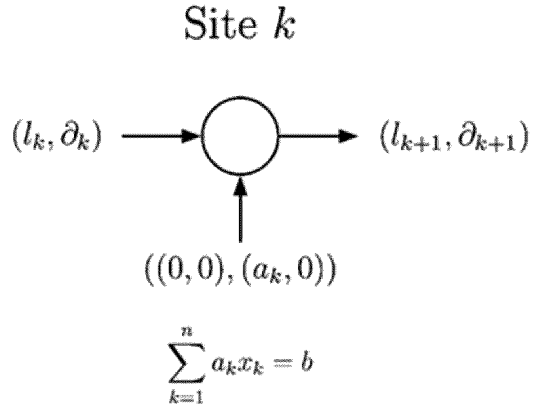


FIG. 25

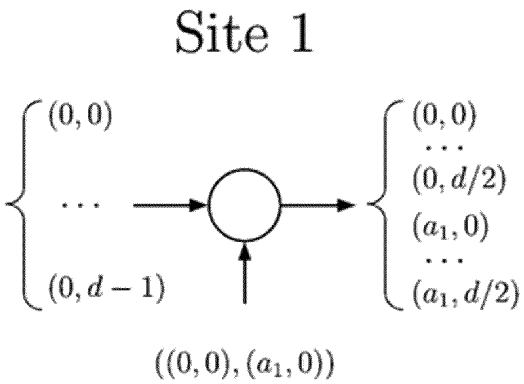


FIG. 26

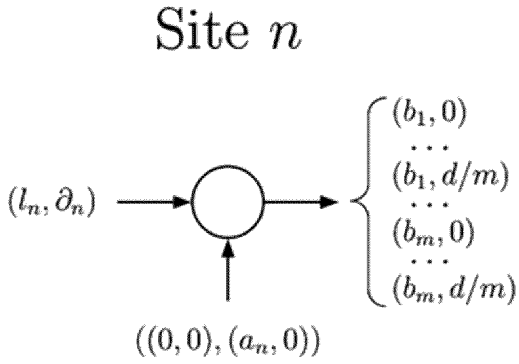


FIG. 27

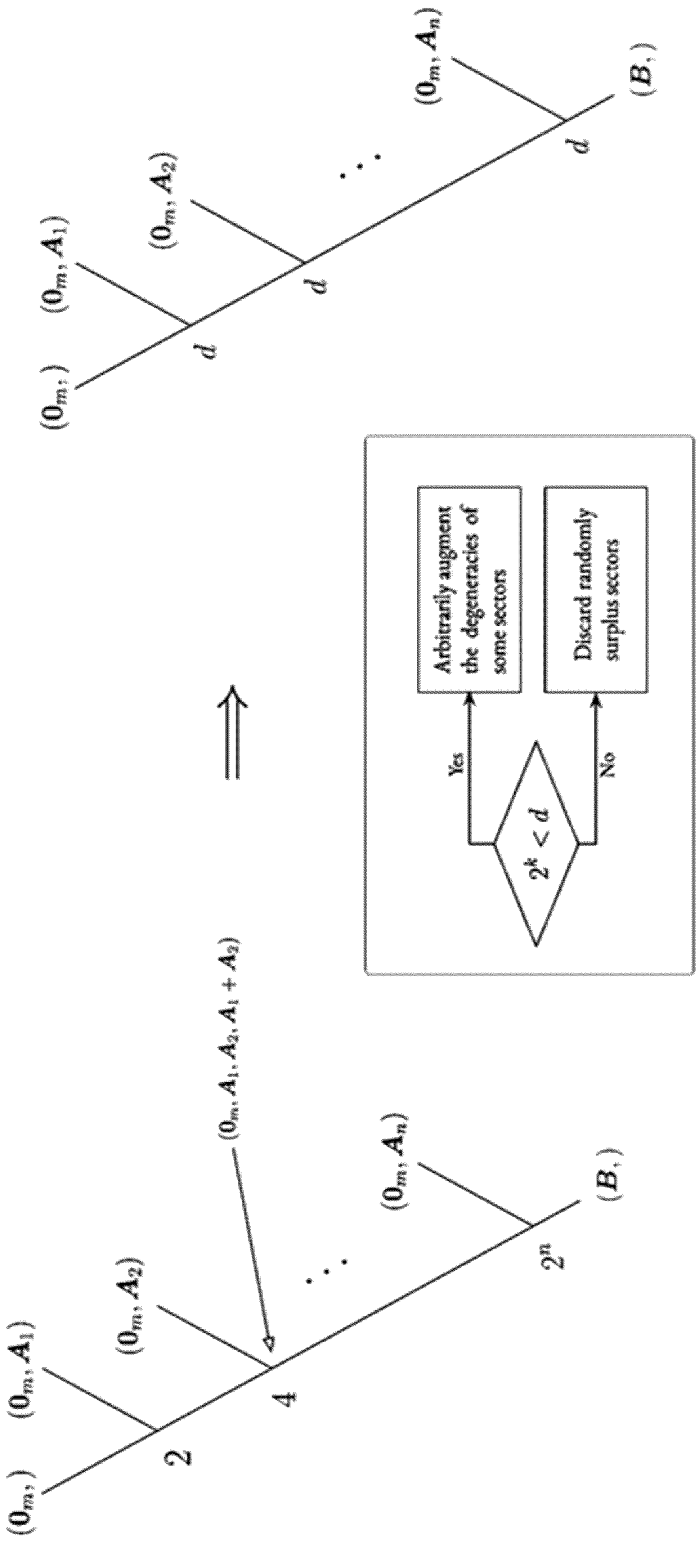

$(\mathbf{0}_m,)$
$(\mathbf{0}_m, \boldsymbol{A}_1)$
$(\mathbf{0}_m, \boldsymbol{A}_2)$
$(\mathbf{0}_m, \boldsymbol{A}_n)$
$(\boldsymbol{B},)$
d
2
4
2^n
$(\mathbf{0}_m, \boldsymbol{A}_1, \boldsymbol{A}_2, \boldsymbol{A}_1 + \boldsymbol{A}_2)$
$2^k < d$
Yes
No
Arbitrarily augment the degeneracies of some sectors
Discard randomly surplus sectors

FIG. 28

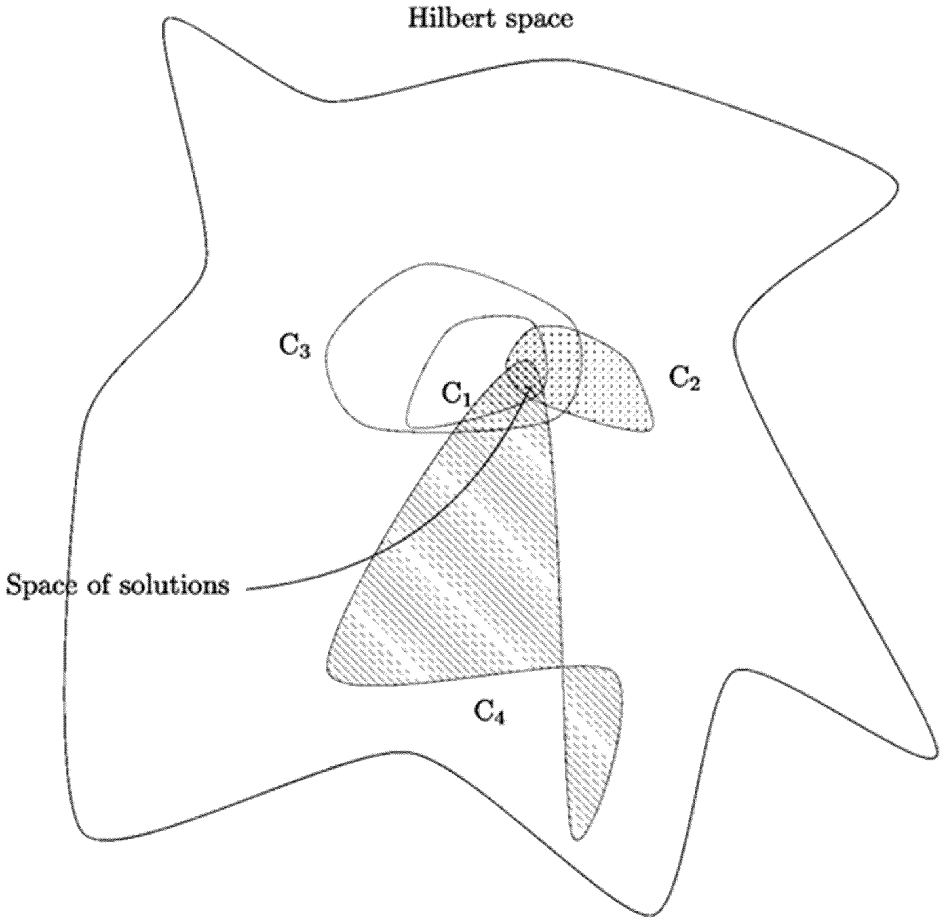


FIG. 29

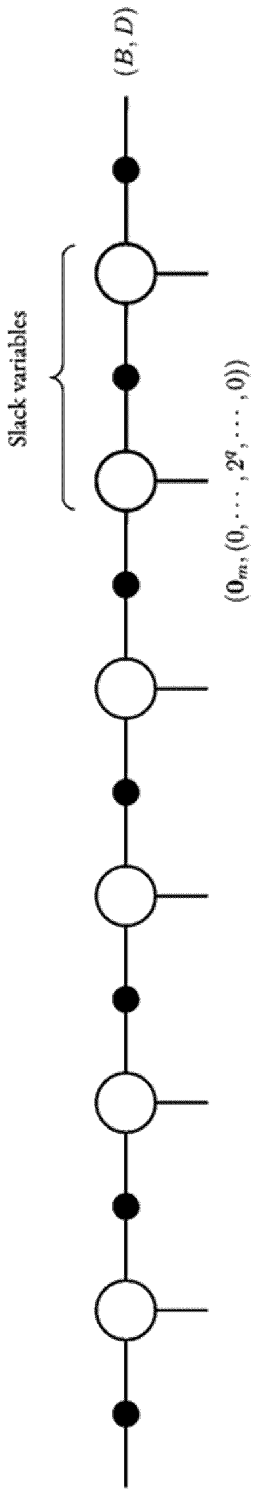


FIG. 30

$$\sum_{i=1}^{n} a_i x_i = b$$

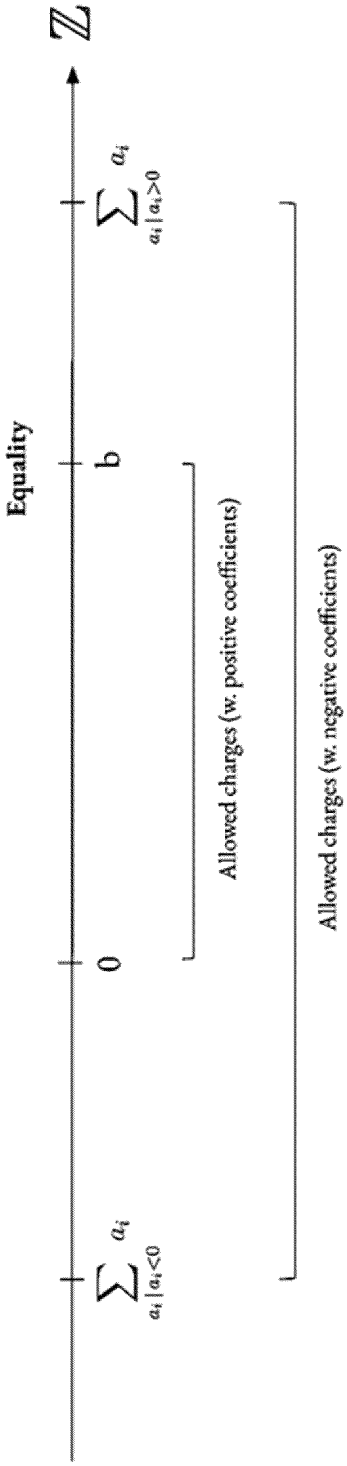


FIG. 31

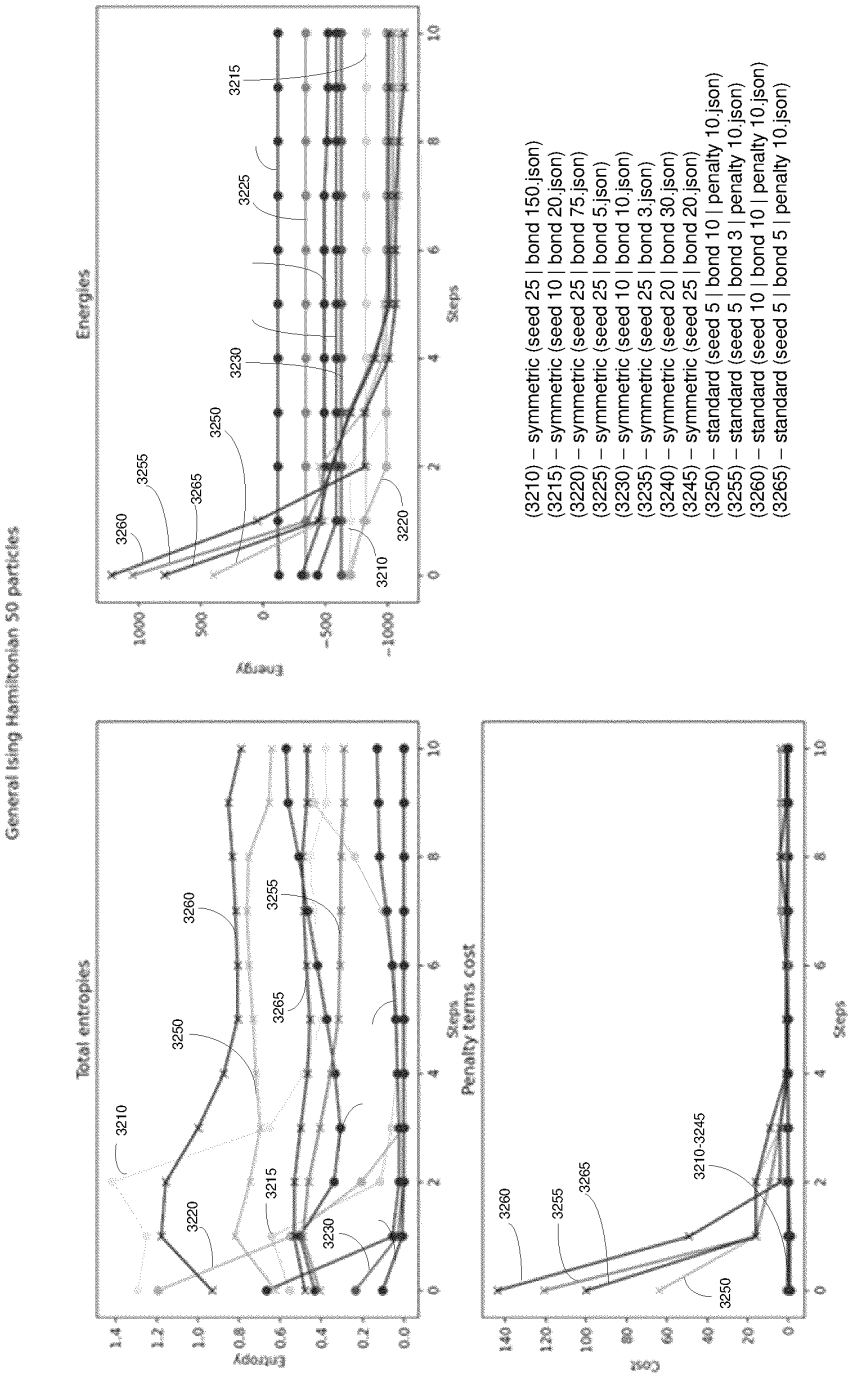

General Ising Hamiltonian 50 particles
Energies
Energy
Steps
Total entropies
Entropy
Steps
Penalty terms cost
Cost
Steps
(3210) – symmetric (seed 25 | bond 150.json)
(3215) – symmetric (seed 10 | bond 20.json)
(3220) – symmetric (seed 25 | bond 75.json)
(3225) – symmetric (seed 25 | bond 5.json)
(3230) – symmetric (seed 10 | bond 10.json)
(3235) – symmetric (seed 25 | bond 3.json)
(3240) – symmetric (seed 20 | bond 30.json)
(3245) – symmetric (seed 25 | bond 20.json)
(3250) – standard (seed 5 | bond 10 | penalty 10.json)
(3255) – standard (seed 5 | bond 3 | penalty 10.json)
(3260) – standard (seed 10 | bond 10 | penalty 10.json)
(3265) – standard (seed 5 | bond 5 | penalty 10.json)

FIG. 32

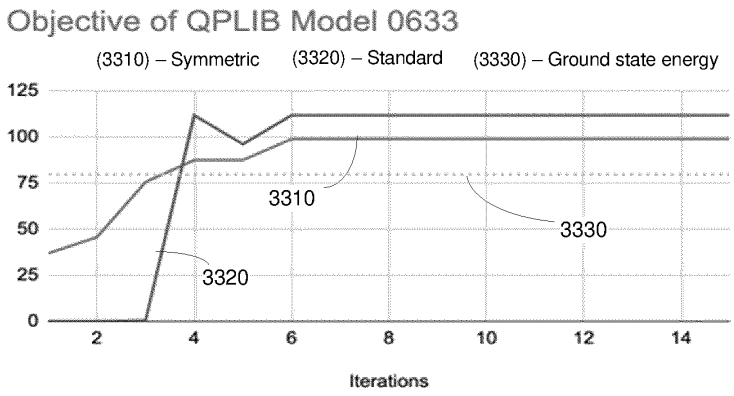


FIG. 33A

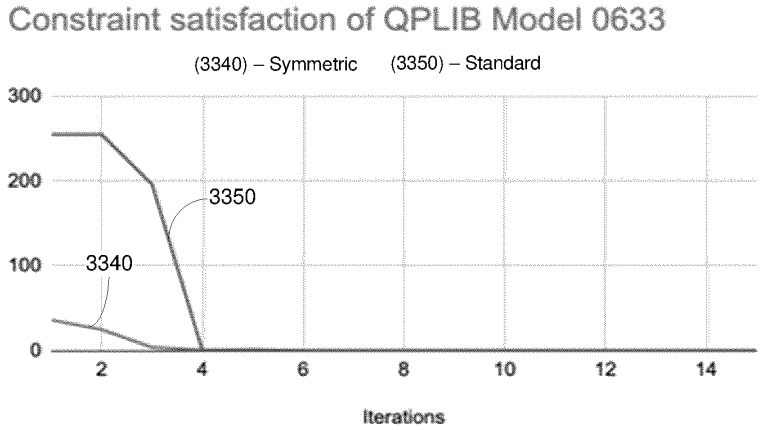


FIG. 33B

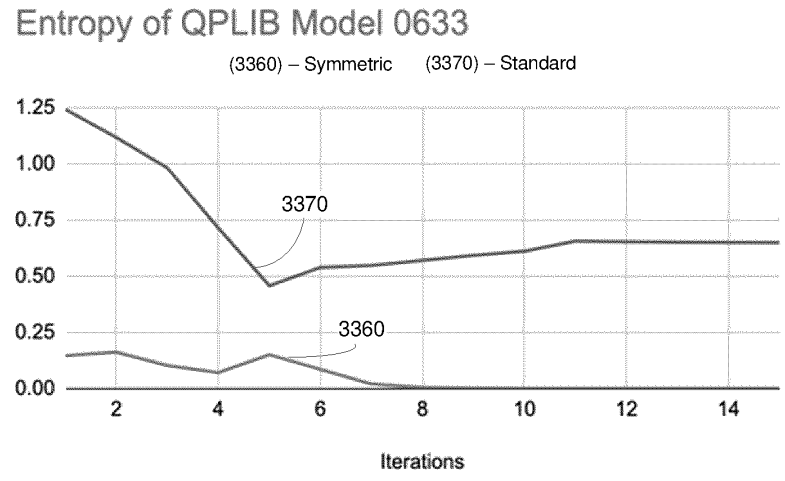


FIG. 33C

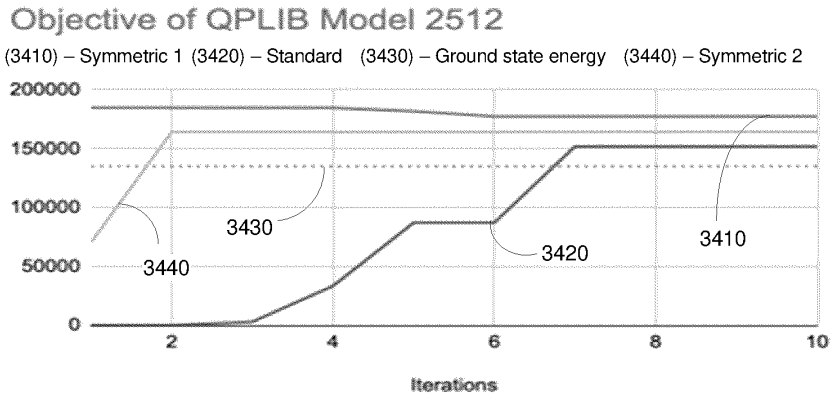


FIG. 34A

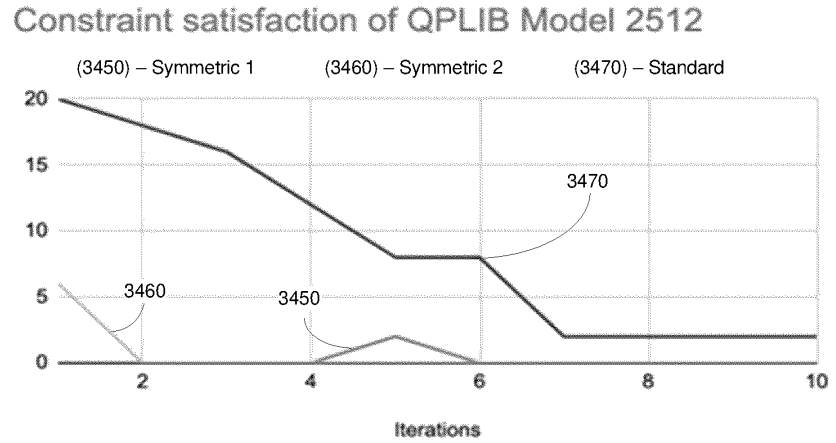


FIG. 34B

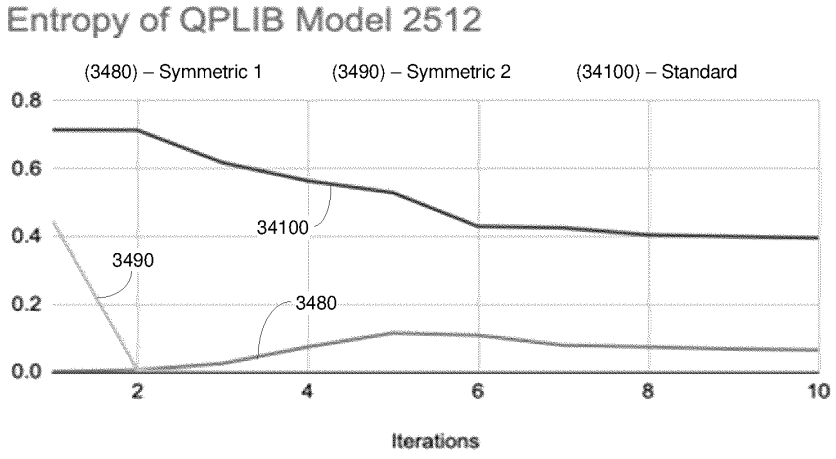


FIG. 34C

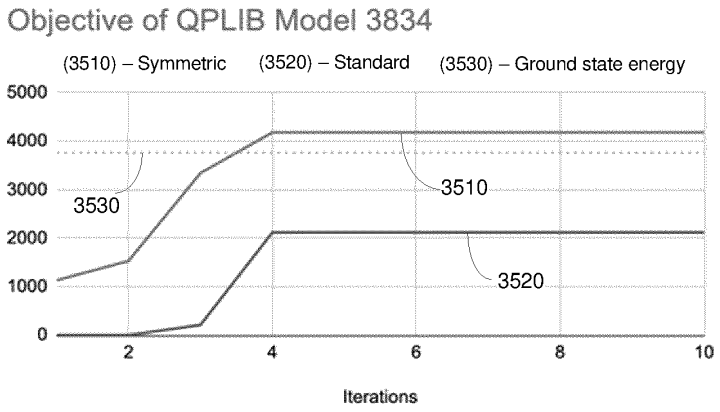


FIG. 35A

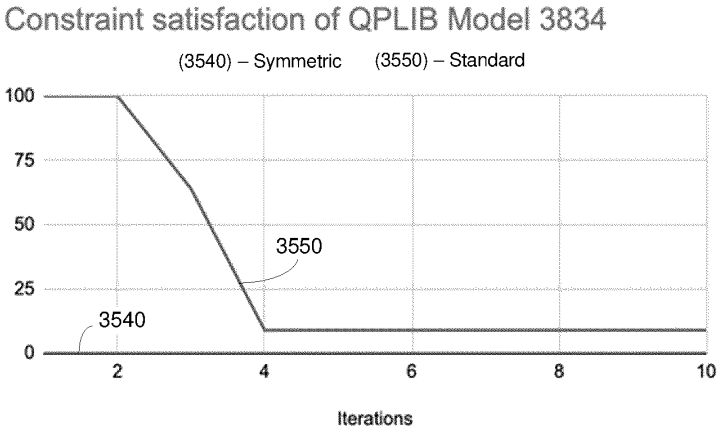


FIG. 35B

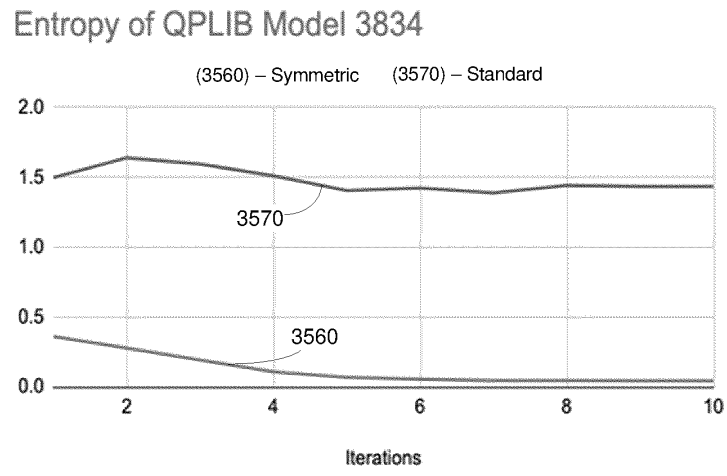


FIG. 35C

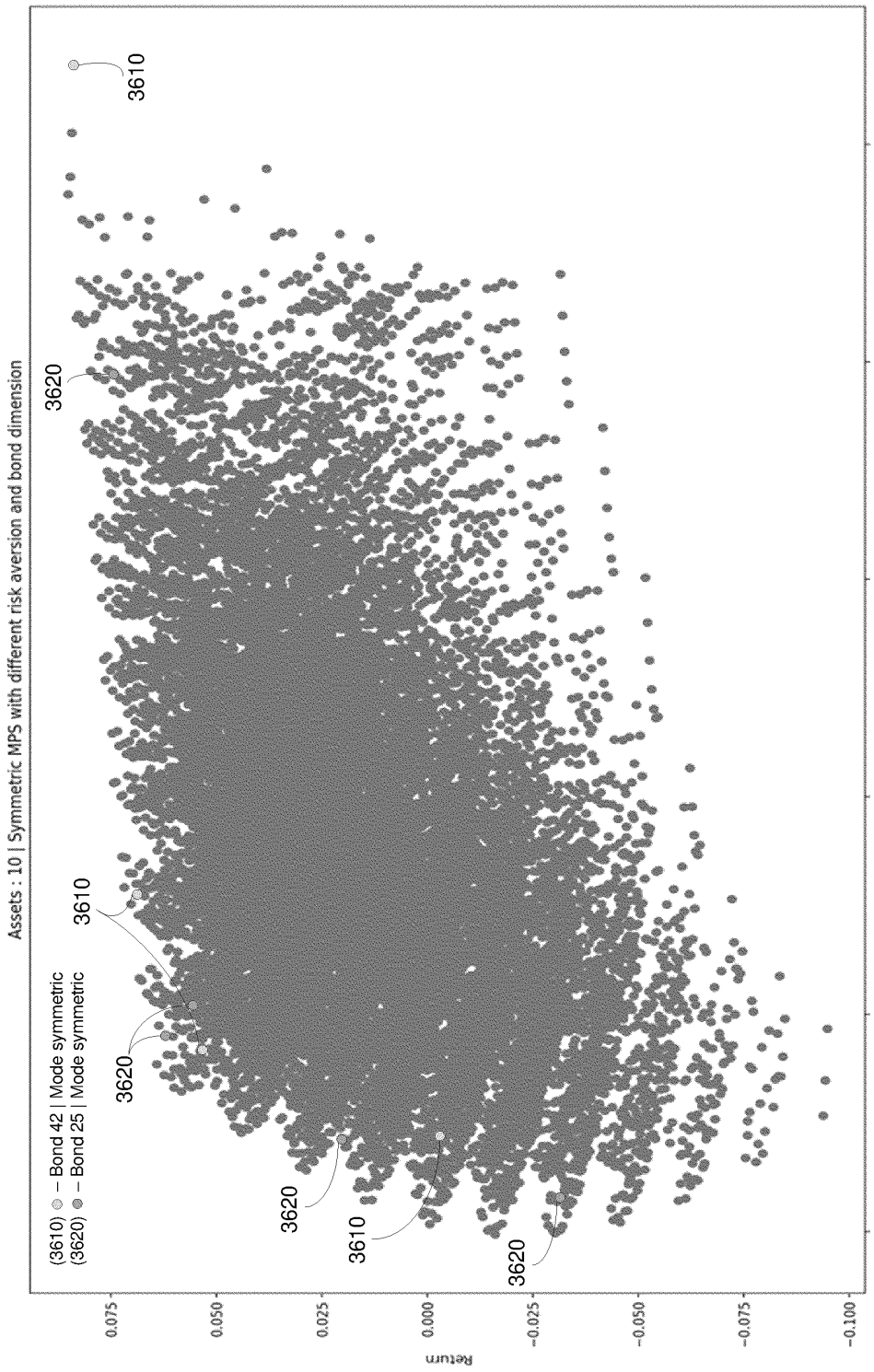

Assets : 10 | Symmetric MPS with different risk aversion and bond dimension
(3610) – Bond 42 | Mode symmetric
(3620) – Bond 25 | Mode symmetric
3610
3620
3620
3610
3620
3610
3620
Return
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100
Volatility
0.01
0.02
0.03
0.04
0.05
0.06

FIG. 36A

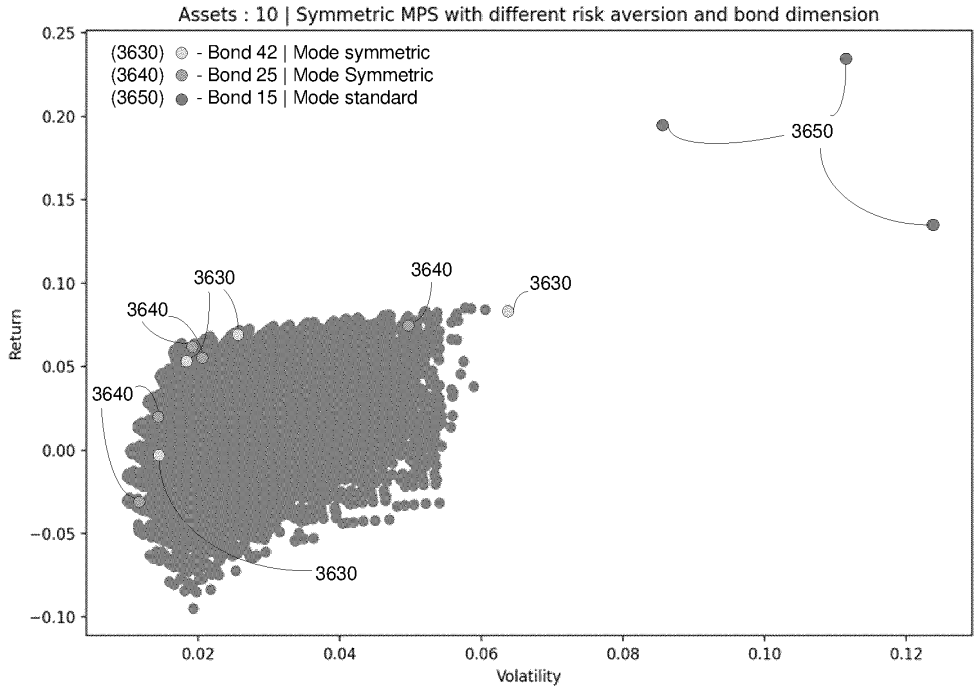


FIG. 36B

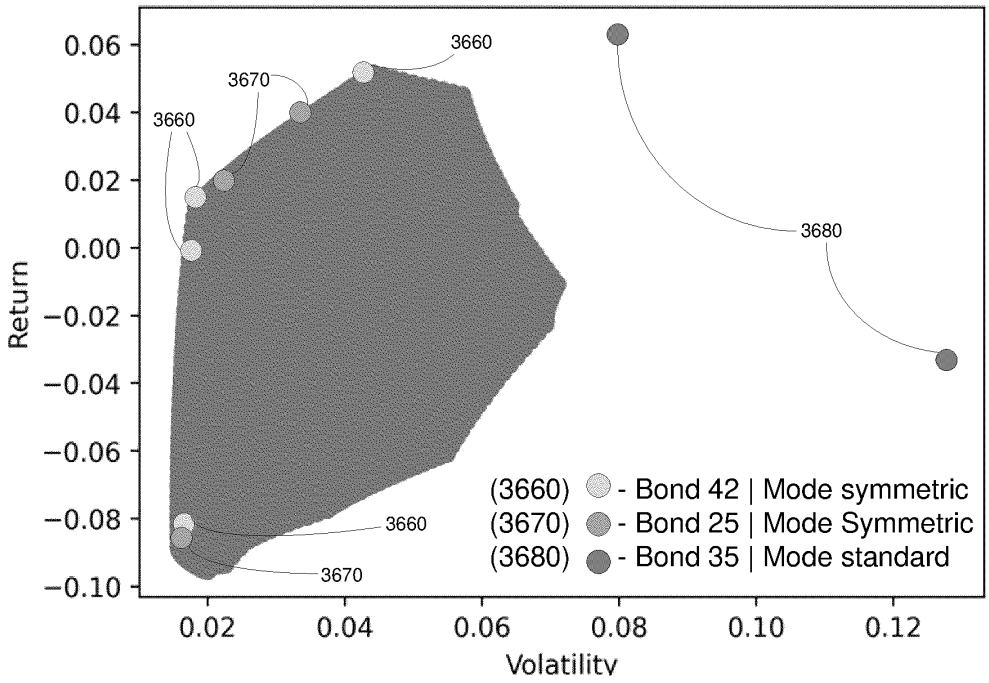


FIG. 36C