

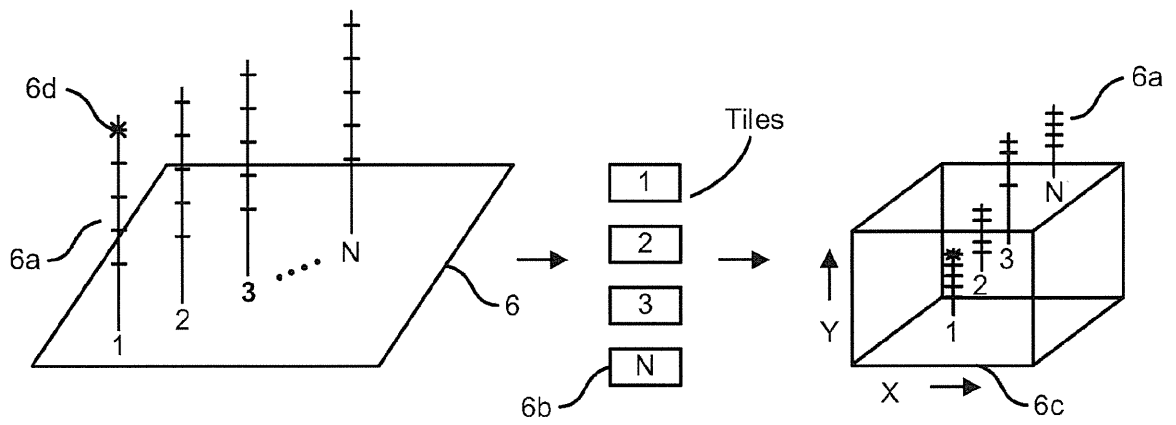


FIG. 1A

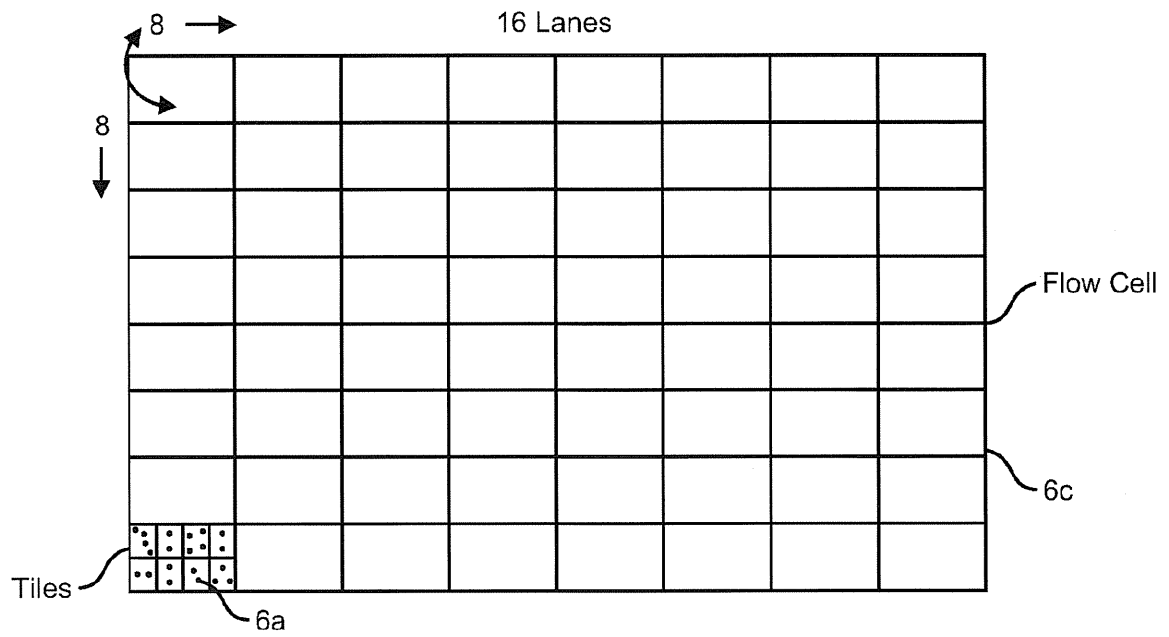


FIG. 1B

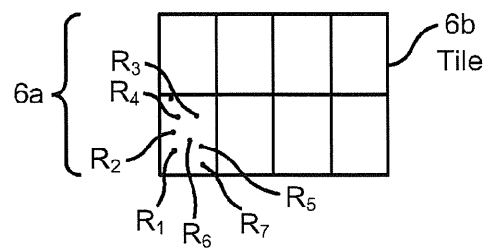


FIG. 1C

	1	2	3	4	5	6		N
1	A_{41}	A_{29}	C_{38}					
2	C_{39}	C_{31}	T_{29}					
3	G_{38}	G_{38}	T_{33}					
4	T_{36}	C_{25}	A_{28}					
5	G_{32}	A_{38}	C_{35}					
...	...	...	...					
N	N	N	N					

FIG. 1D

	1	2	3	4	5	6		N
1	A_{41}	A_{29}	C_{38}	N				
2	C_{39}	C_{31}	T_{29}	N				
3	G_{38}	G_{38}	T_{33}	N				
4	T_{36}	C_{25}	A_{28}	N				
5	G_{32}	A_{38}	C_{35}	N				
...	...	...	...					
N	N	N	N					

FIG. 1E

Read 1	A_{41}	A_{29}	C_{38}	N
Read 2	C_{39}	C_{31}	T_{29}	N
Read 3	G_{38}	G_{38}	T_{33}	N
Read 4	T_{36}	C_{25}	A_{28}	N
Read 5	G_{32}	A_{38}	C_{35}	N

FIG. 1F

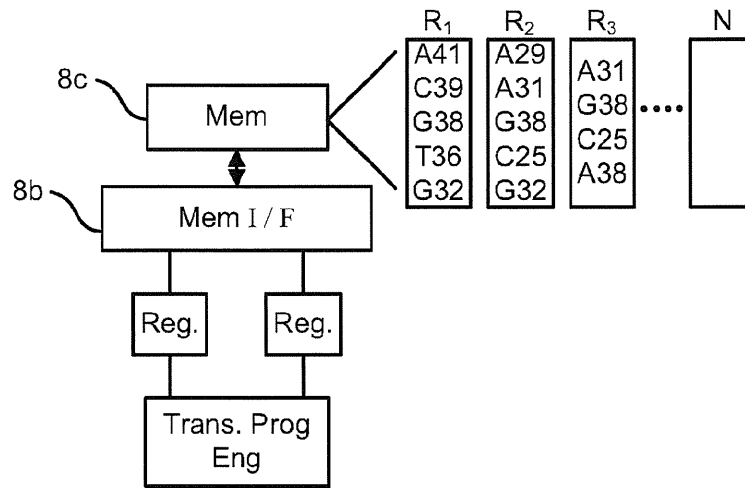


FIG. 1G

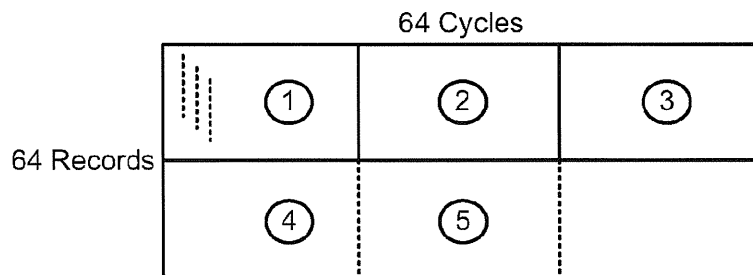


FIG. 1H

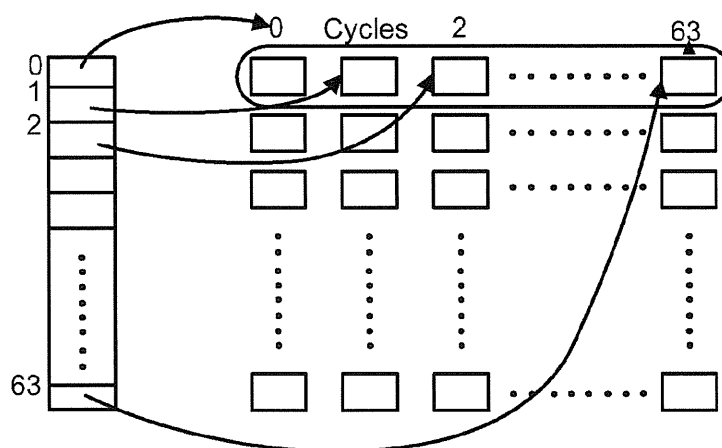


FIG. 1I

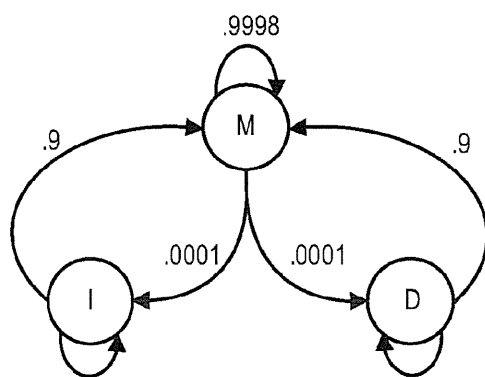


FIG. 2

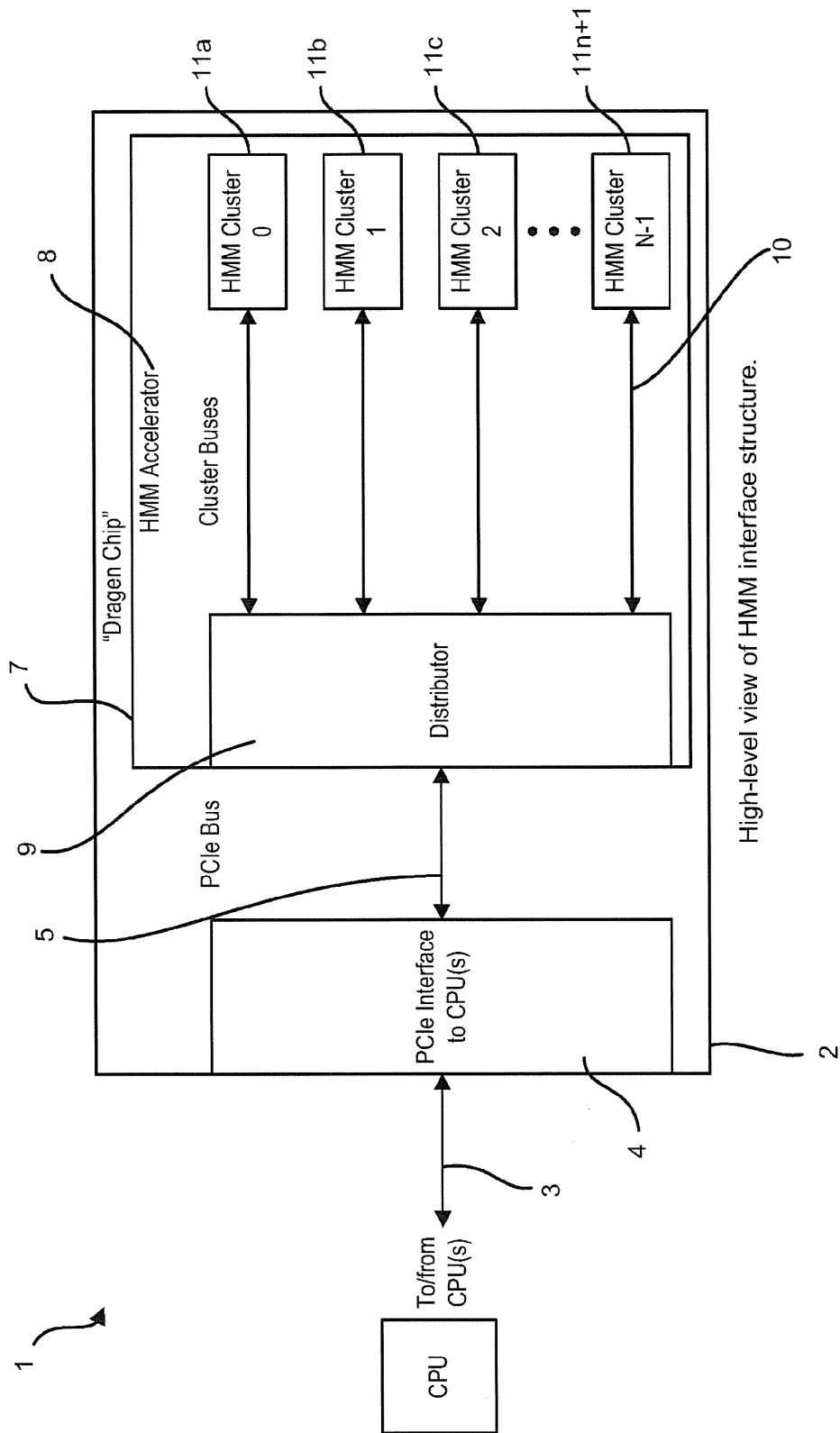


FIG. 3A

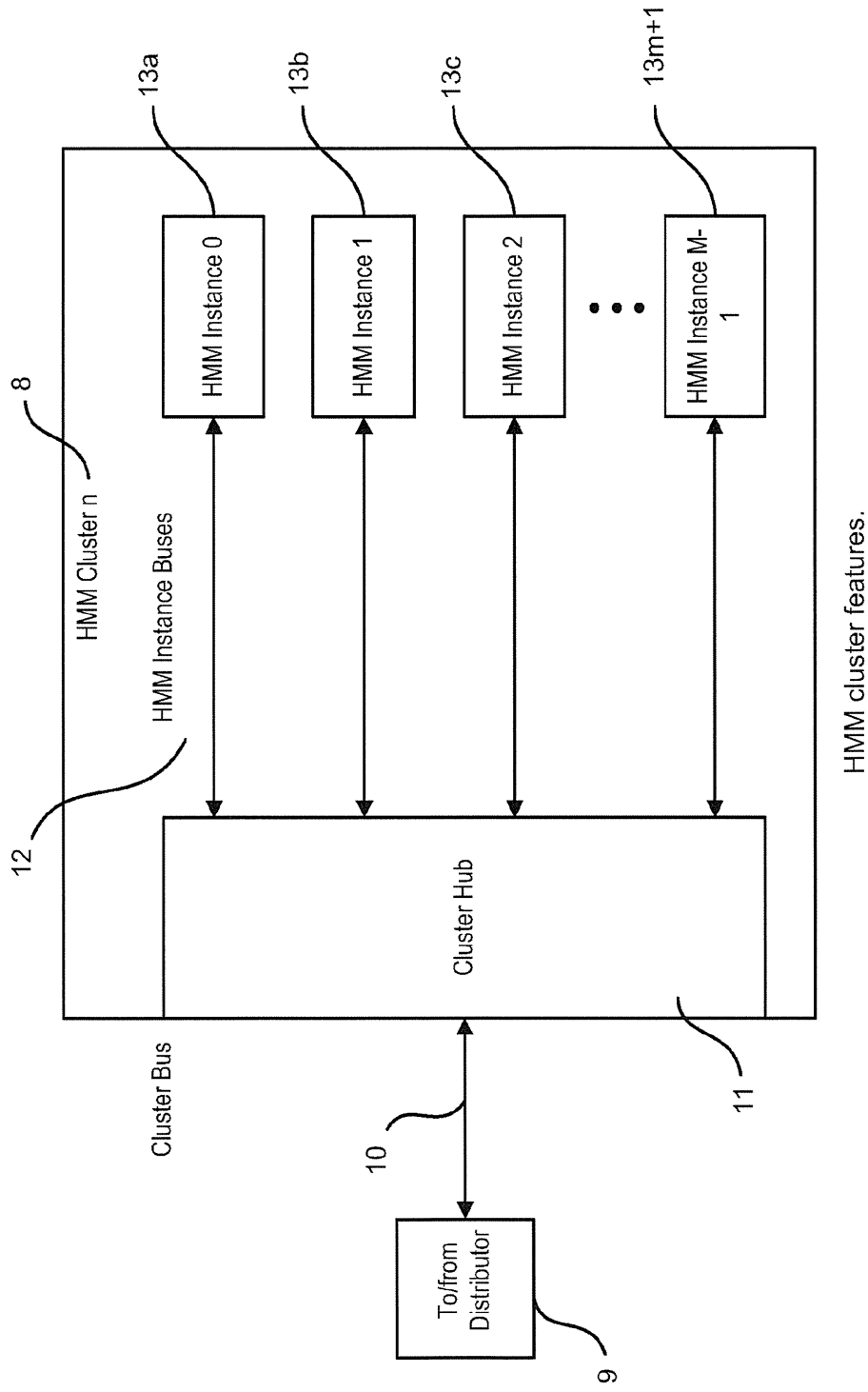
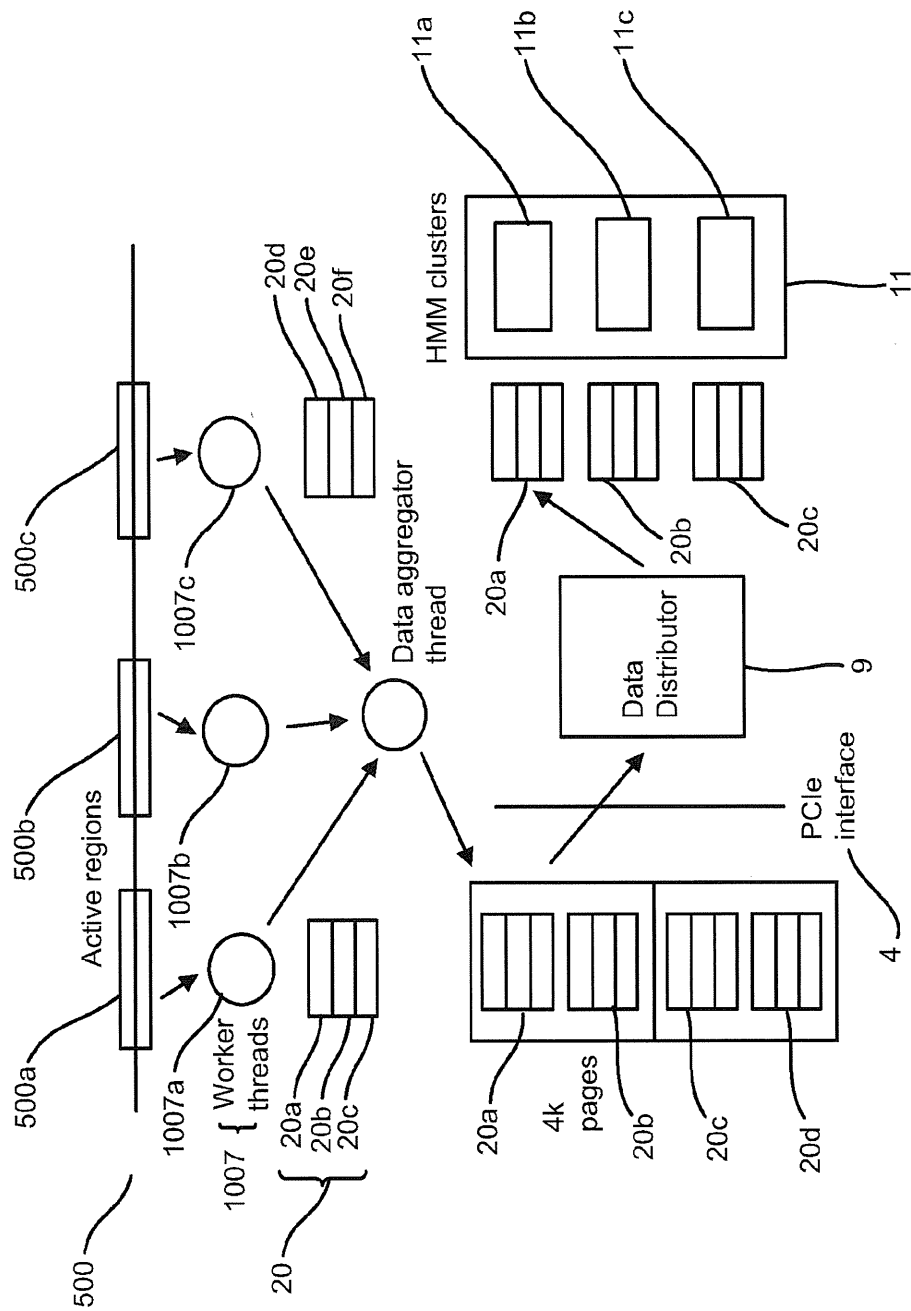
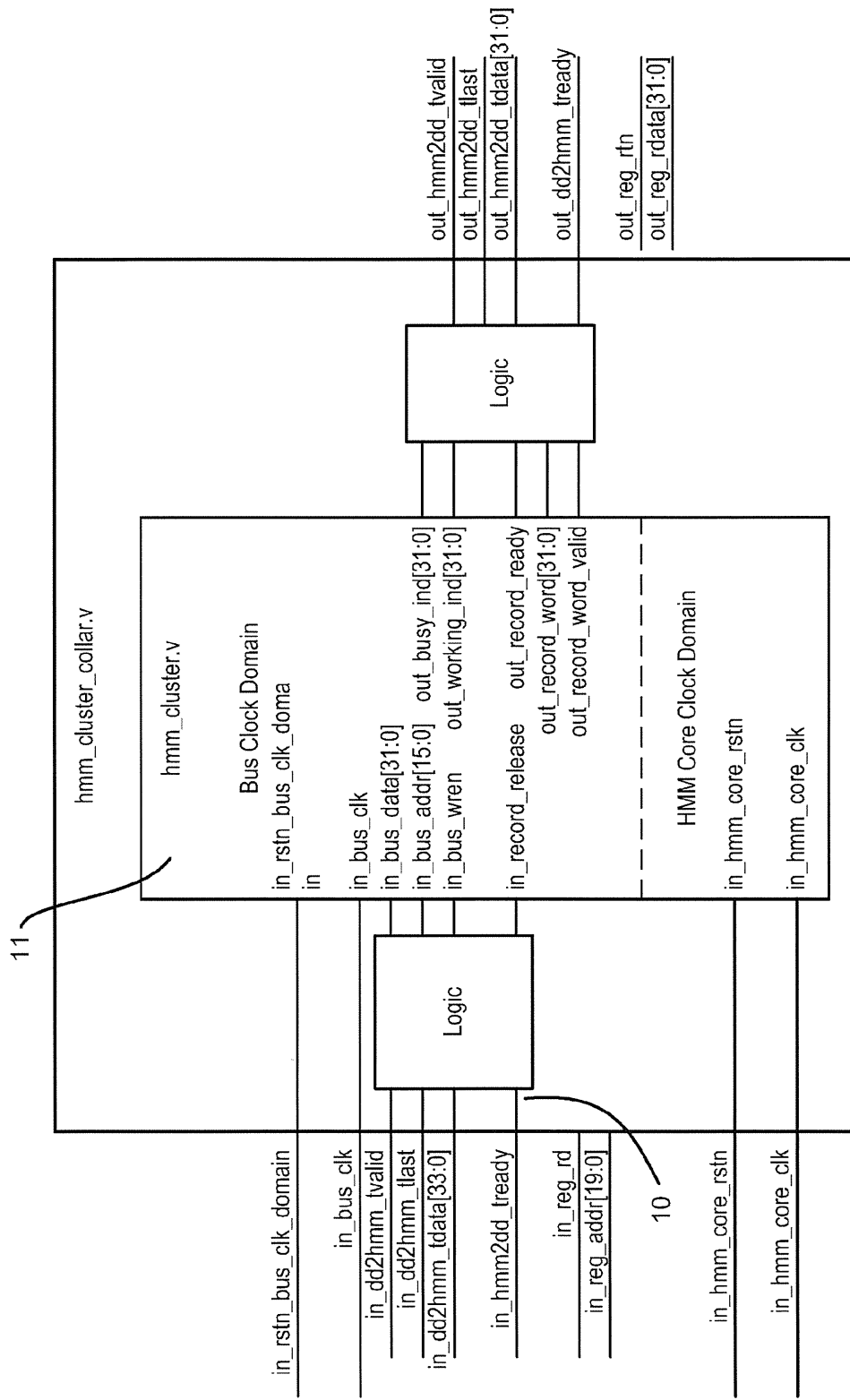


FIG. 3B



HMM data flow and HW/SW interaction overview.

FIG. 4



HMM Cluster Collar connections.

FIG. 5

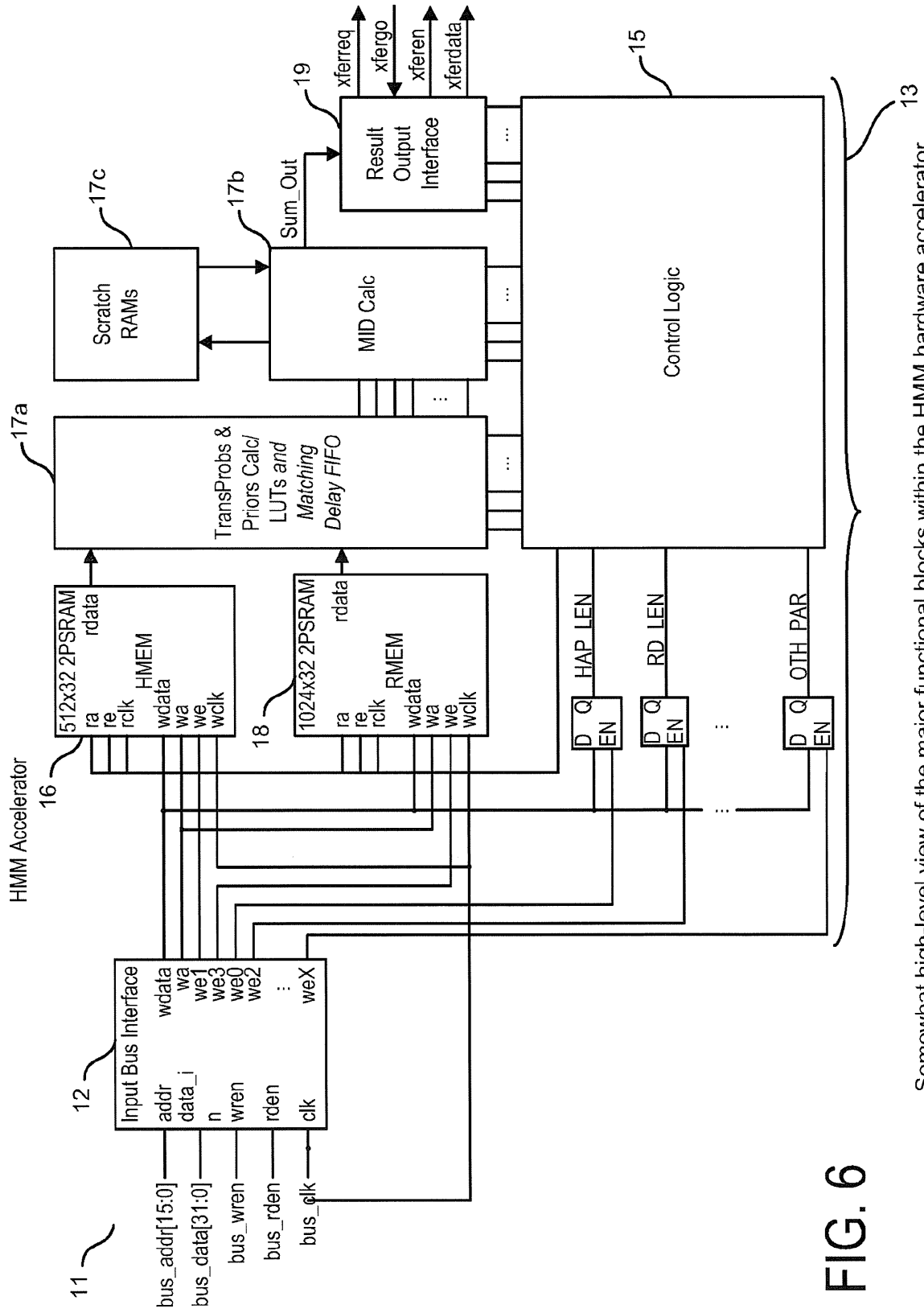
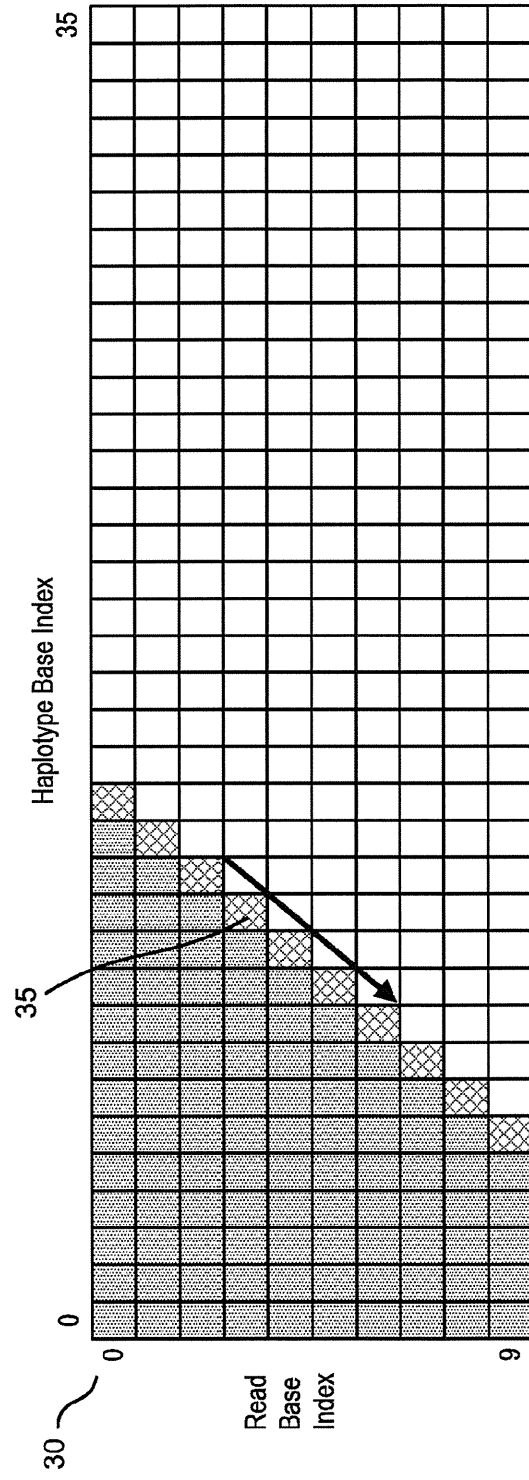
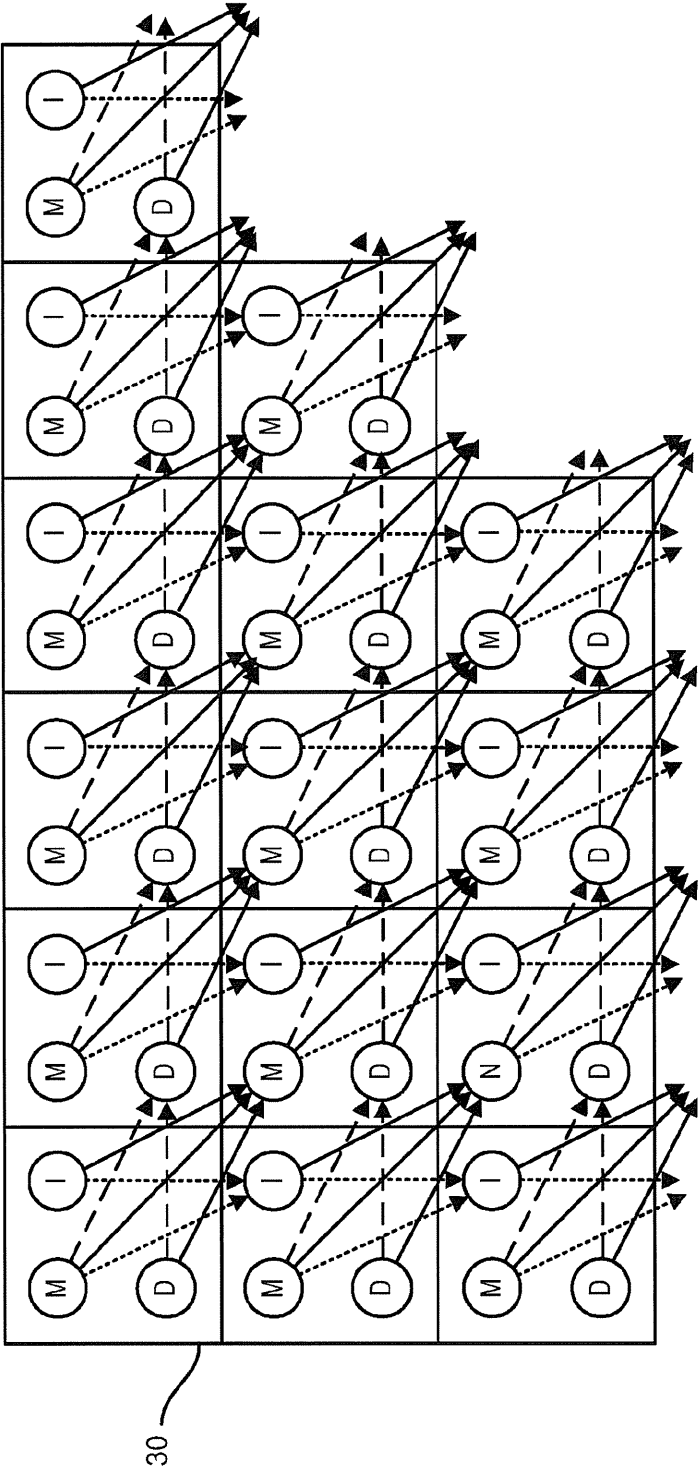


FIG. 6



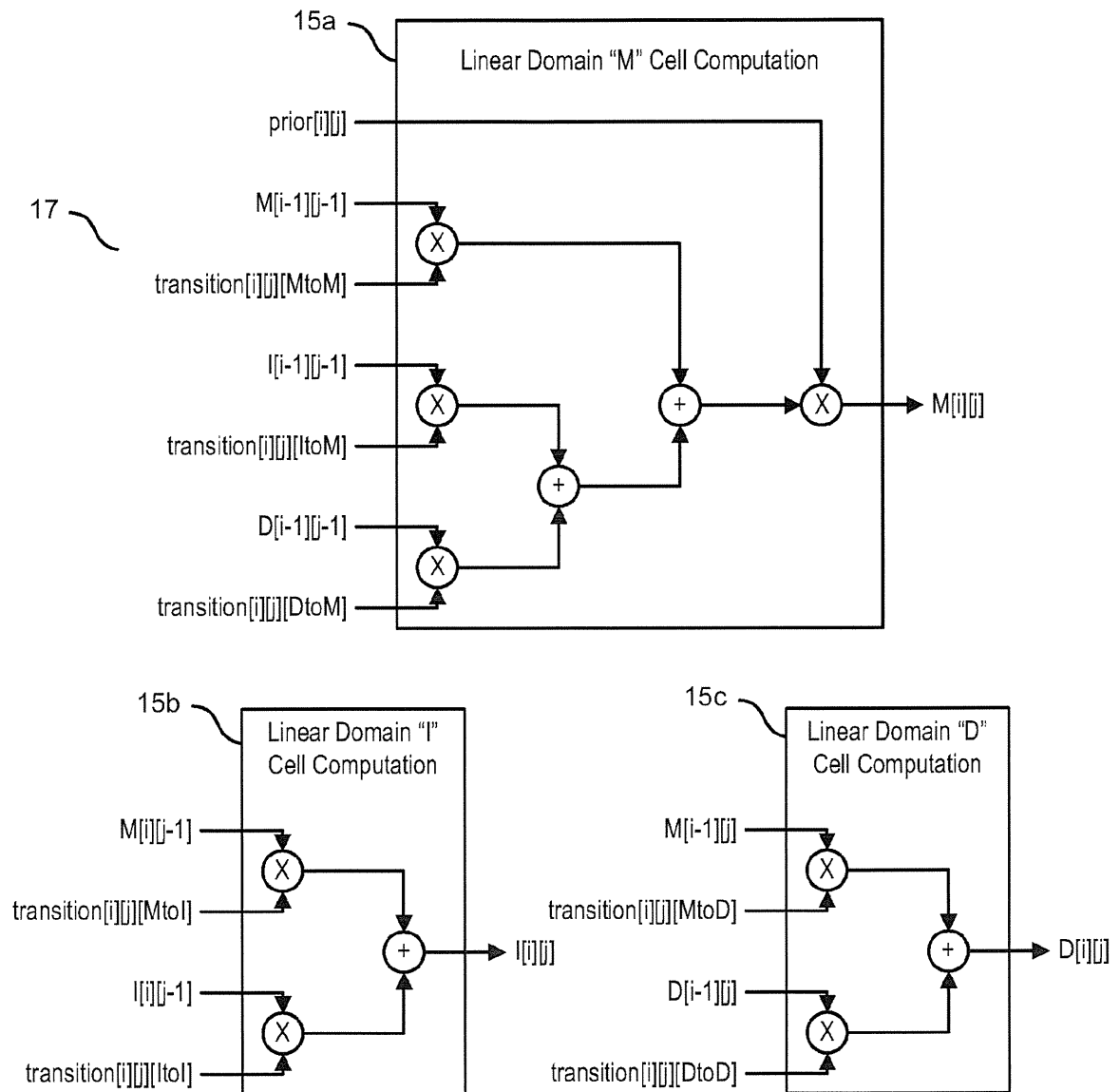
HMM matrix structure and hardware processing flow example.

FIG. 7



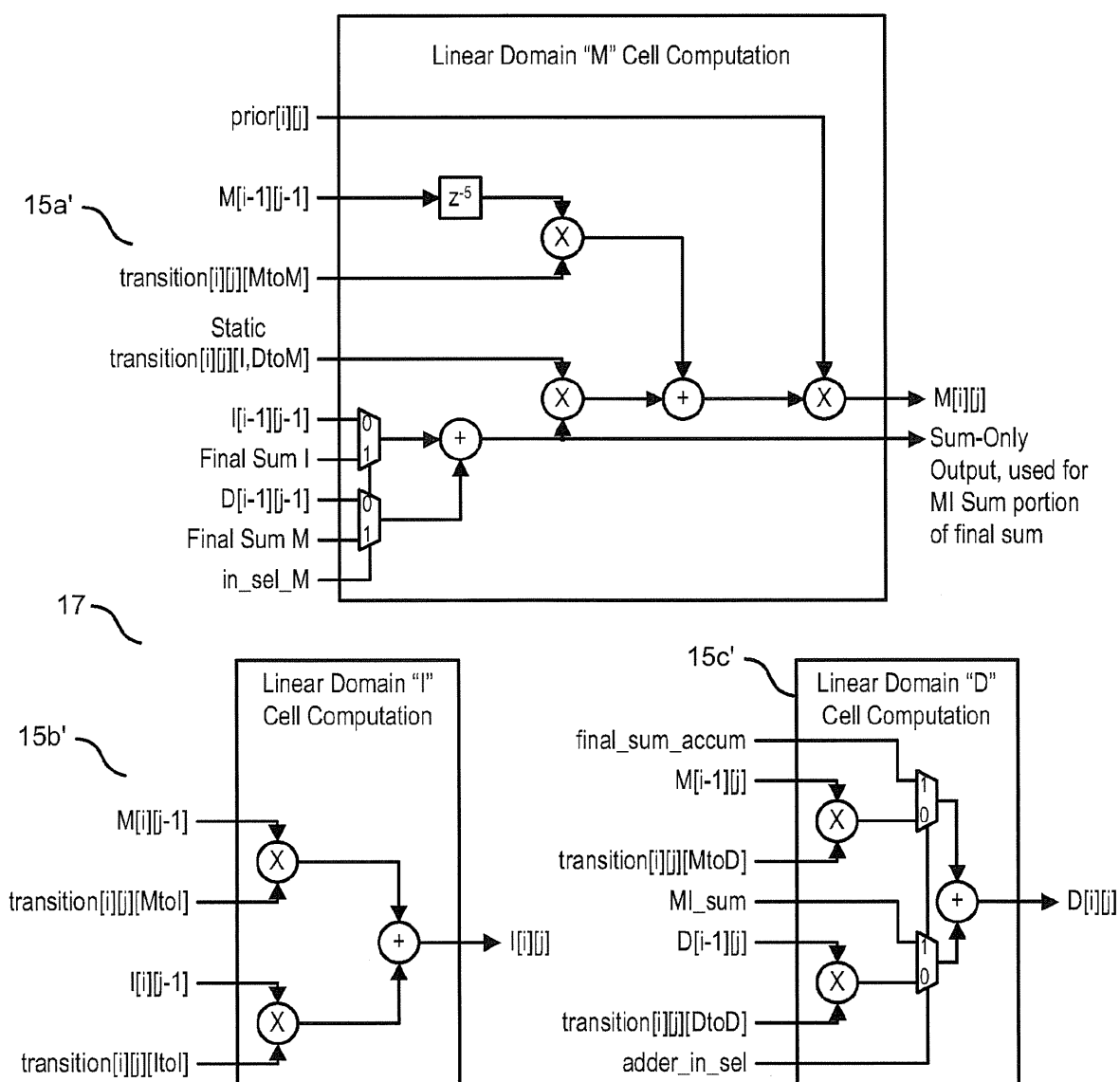
Enlarged view of a portion of Figure 8 showing the data flow and dependencies between nearby cells in the HMM M, I, and D state computations.

FIG. 8



Computations required for M, I, D state updates.

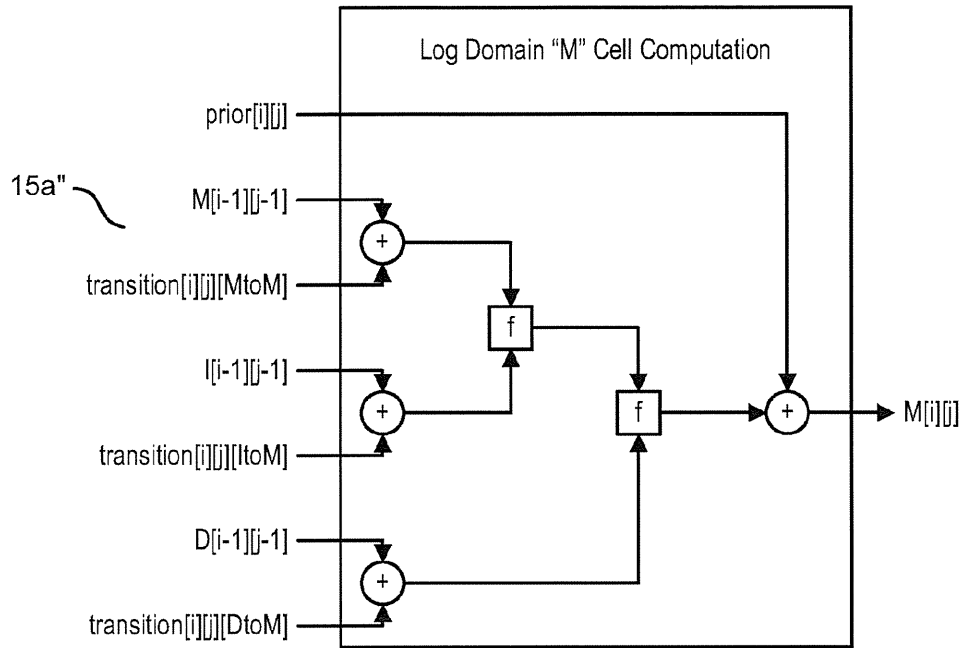
FIG. 9



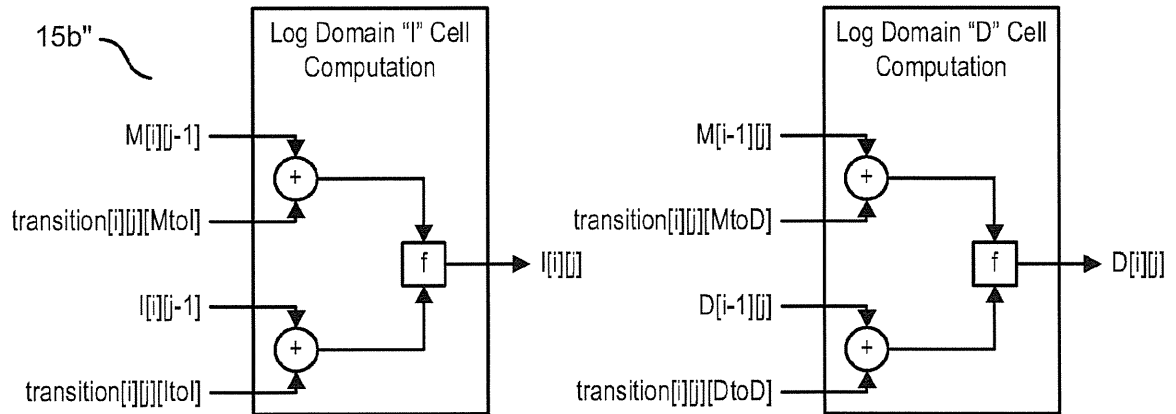
M, I, and D state update circuits, including effects of simplifying assumptions related to transition probabilities and the effect of sharing some M, I, D adder resources with the final sum operations.

FIG. 10

17

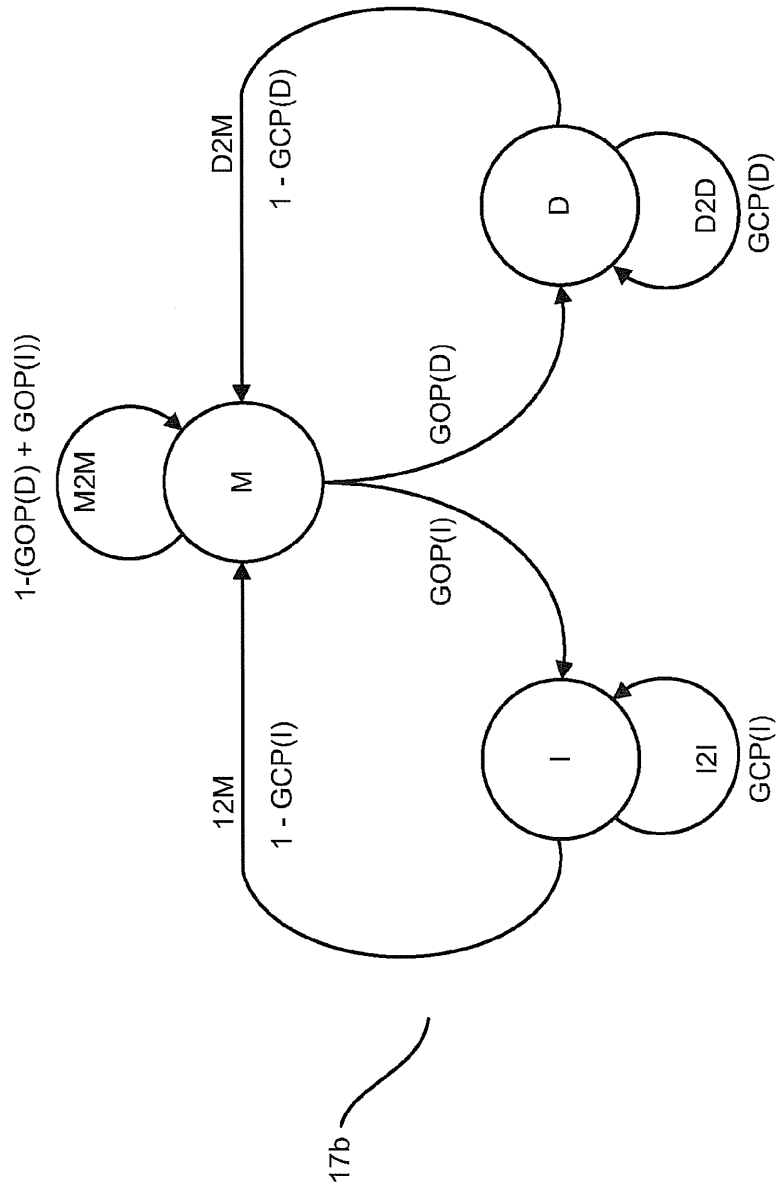


Note: The "f" function is the approximation to log of addition. I.e., $f(a,b) @ \max(a,b) - \log_2(1+2^{-|a-b|})$



Log domain M, I, D state calculation details.

FIG. 11



HMM state transition diagram showing relation between GOP, GCP and transition probabilities.

FIG. 12A

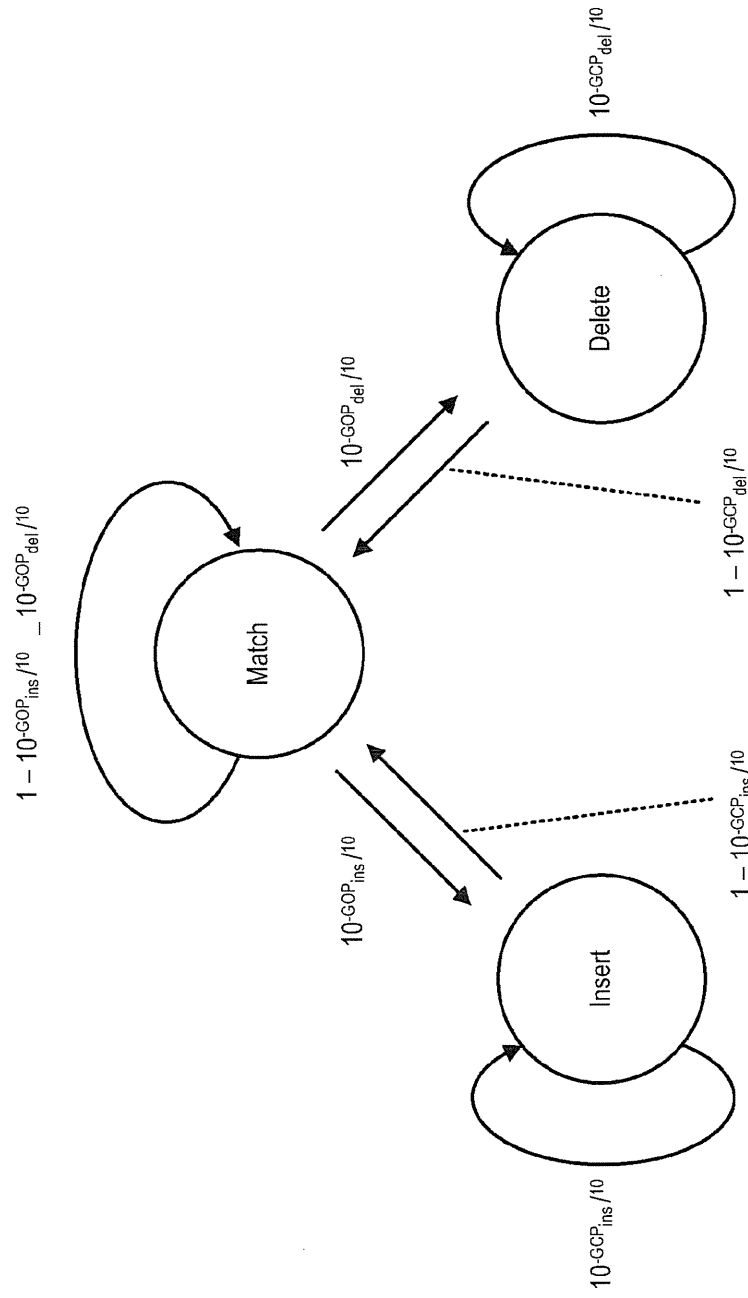


FIG. 12B

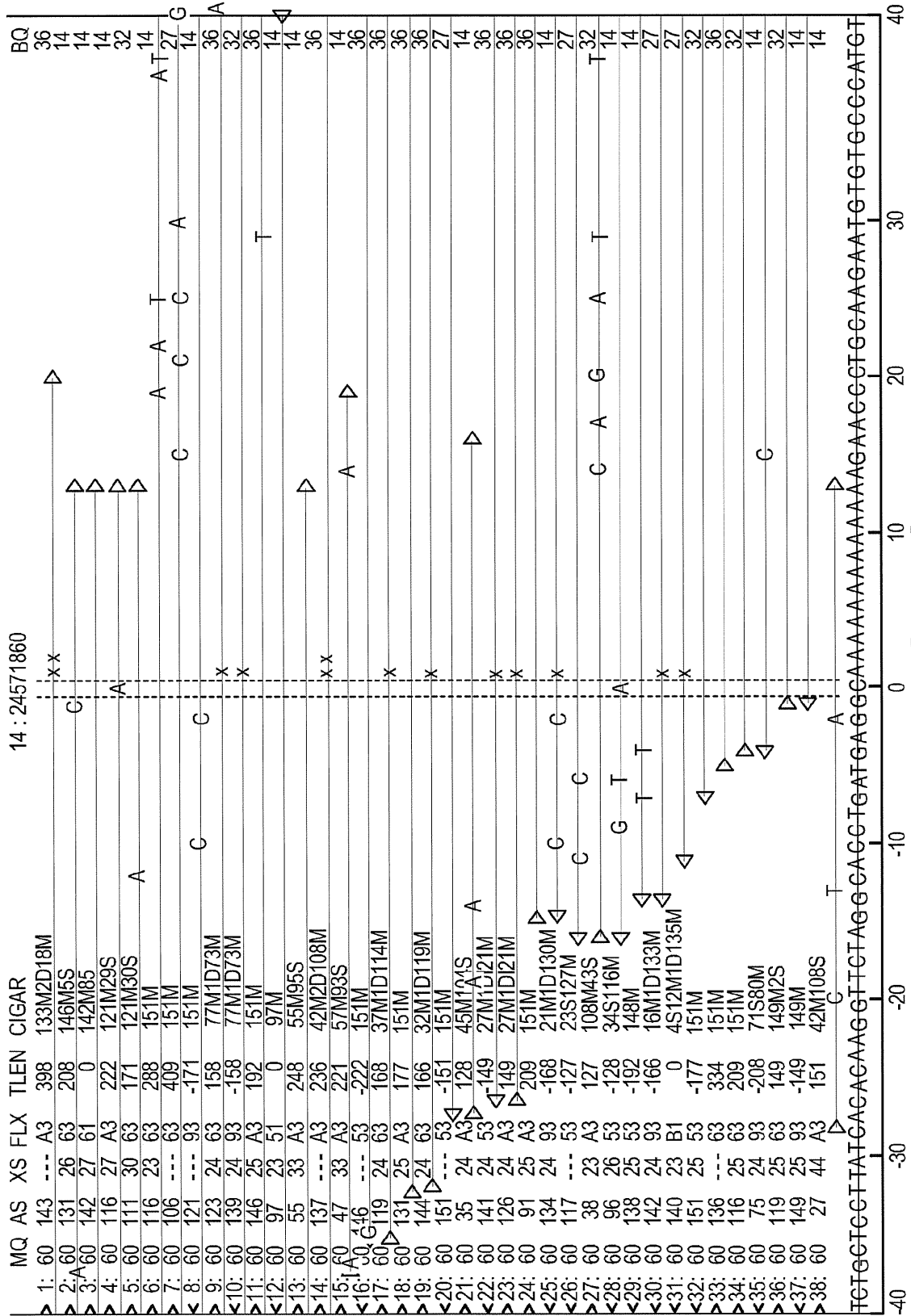


FIG. 12C

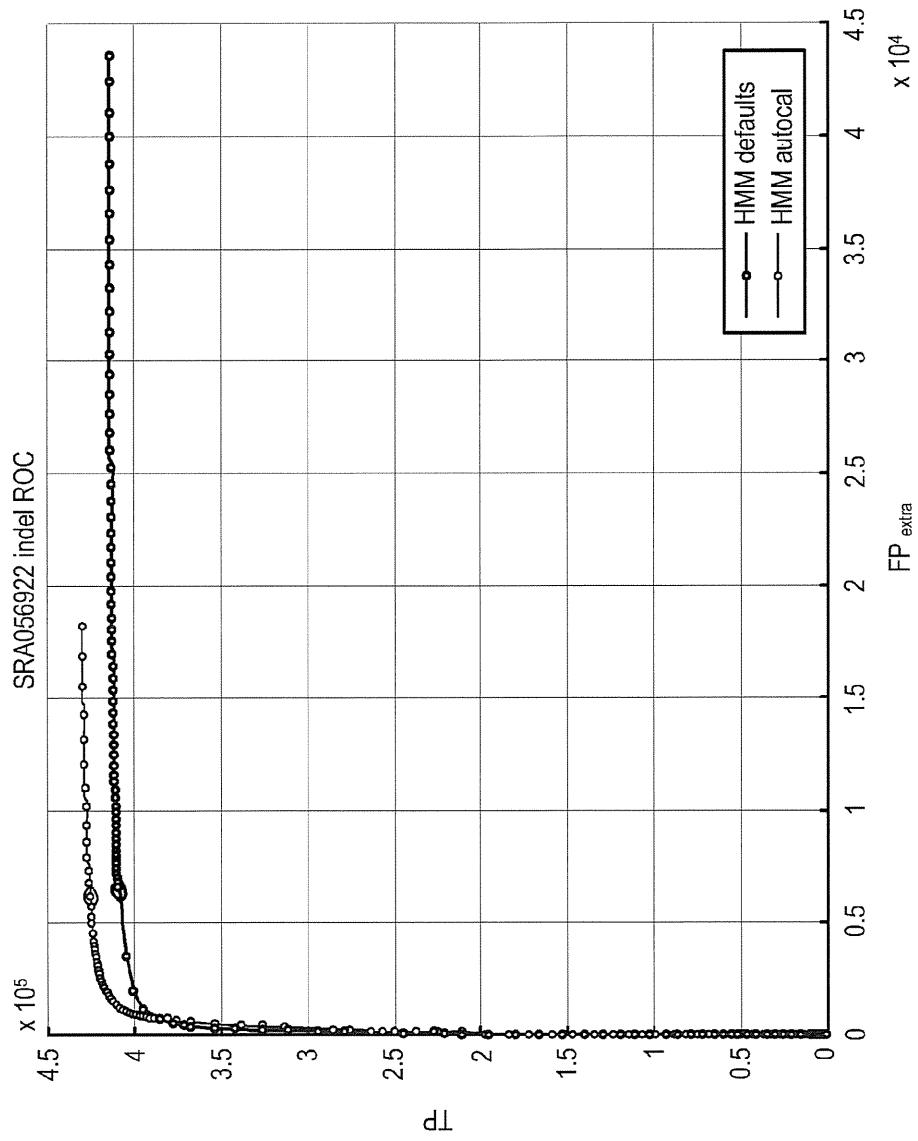
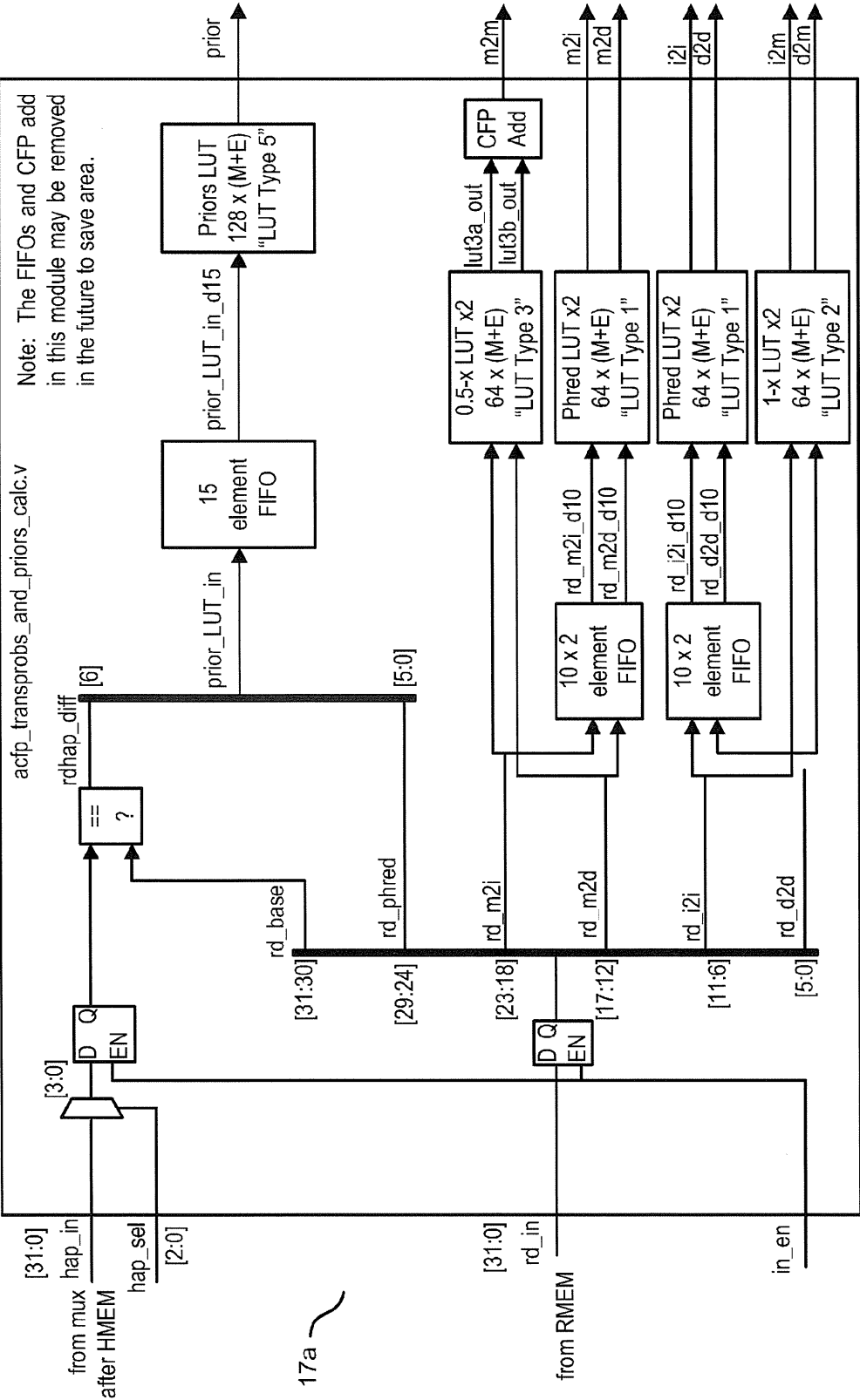
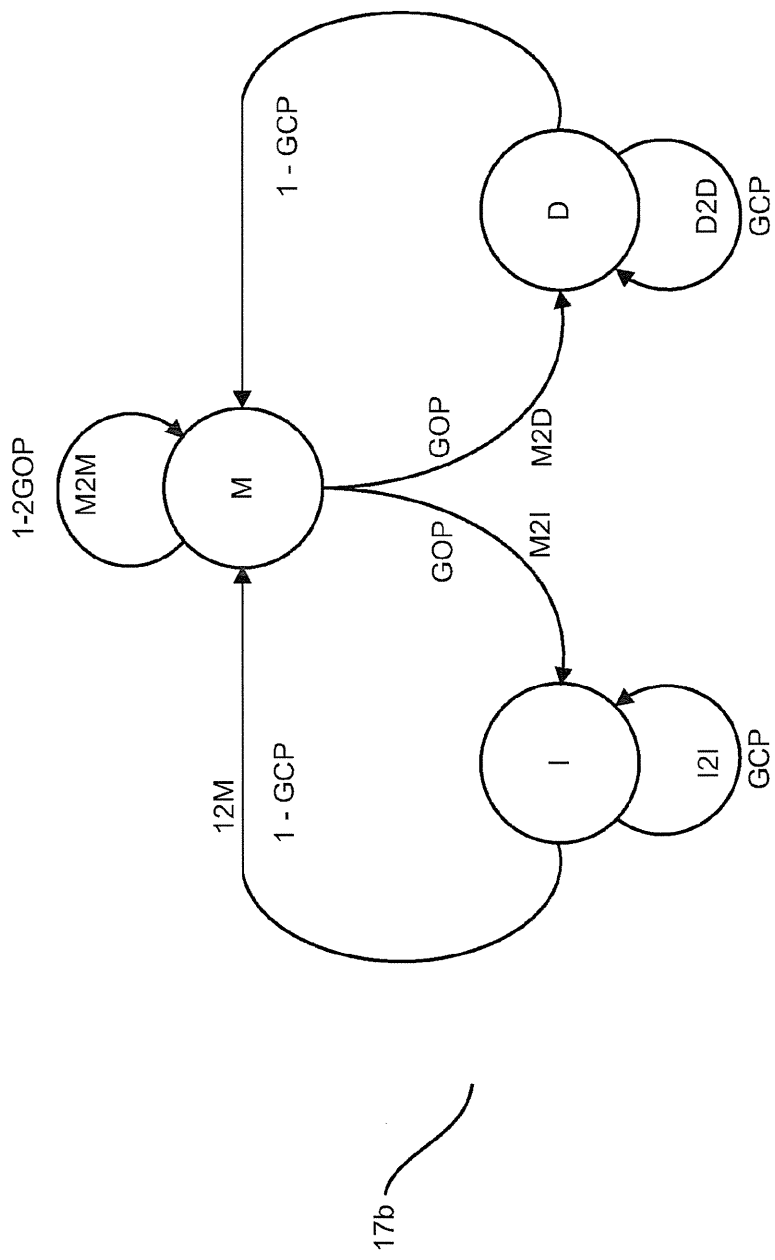


FIG. 12D



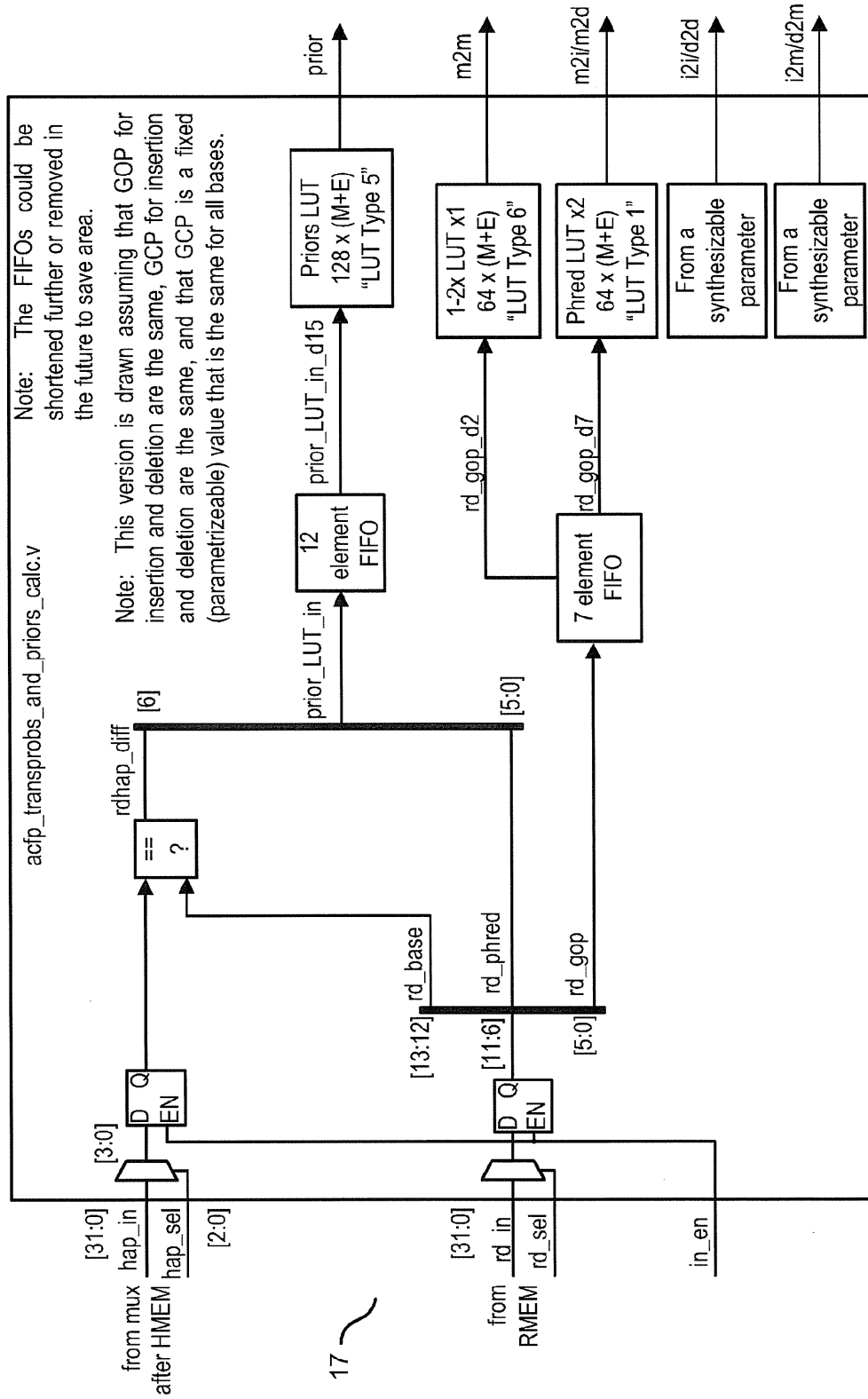
HMM Transprobs and priors generation circuit to support the general state transaction diagram of Figure 17.

FIG. 13



Simplified HMM state transition diagram showing relation between GOP, GCP and transition probabilities.

FIG. 14



HMM transprobs and priors generation circuit to support the simplified state transition diagram of Figure 19.

FIG. 15

Matrix for Read Length = 35 and Hap Length = 14; Total Dead Cycle = 102

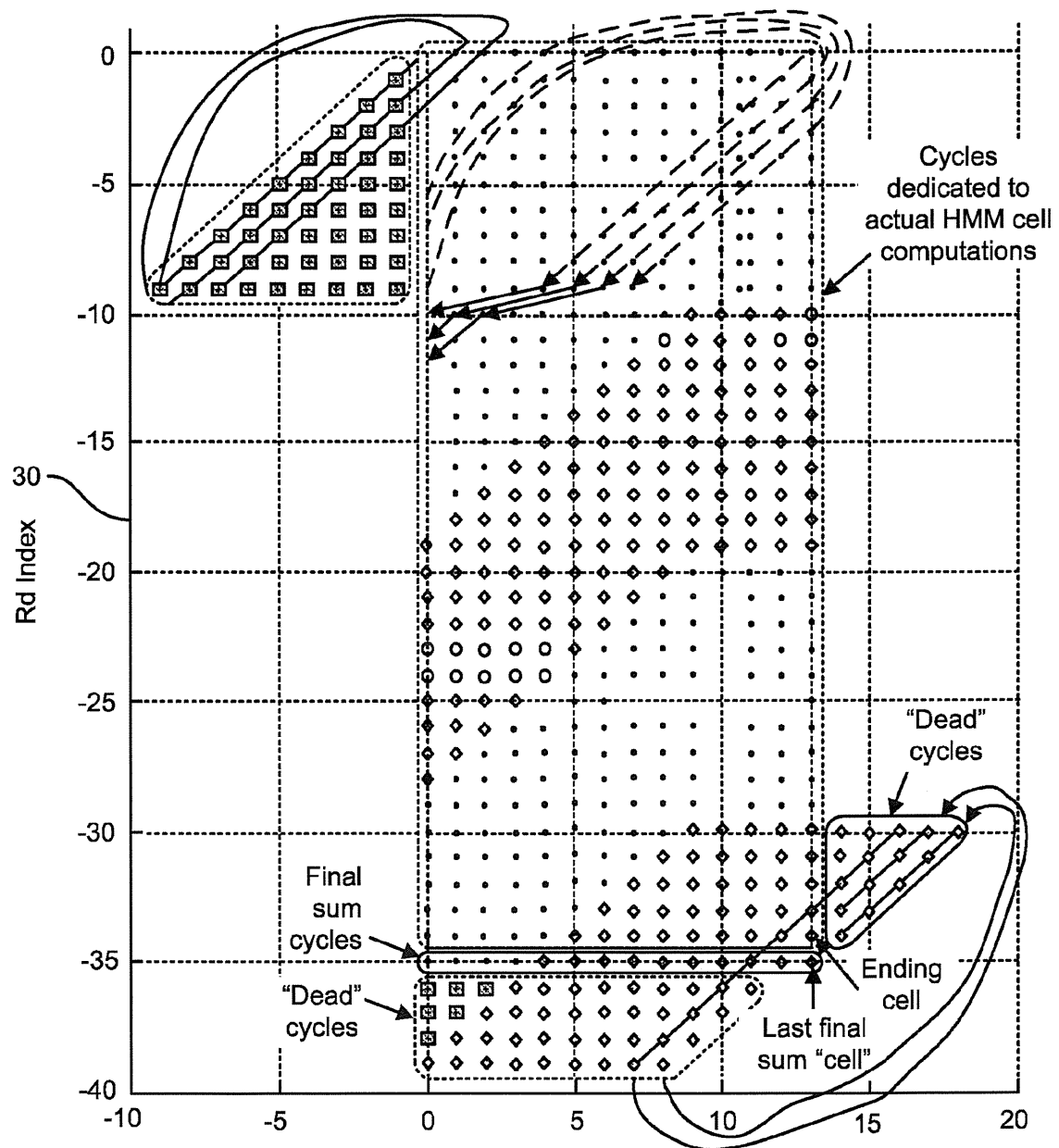


FIG. 16

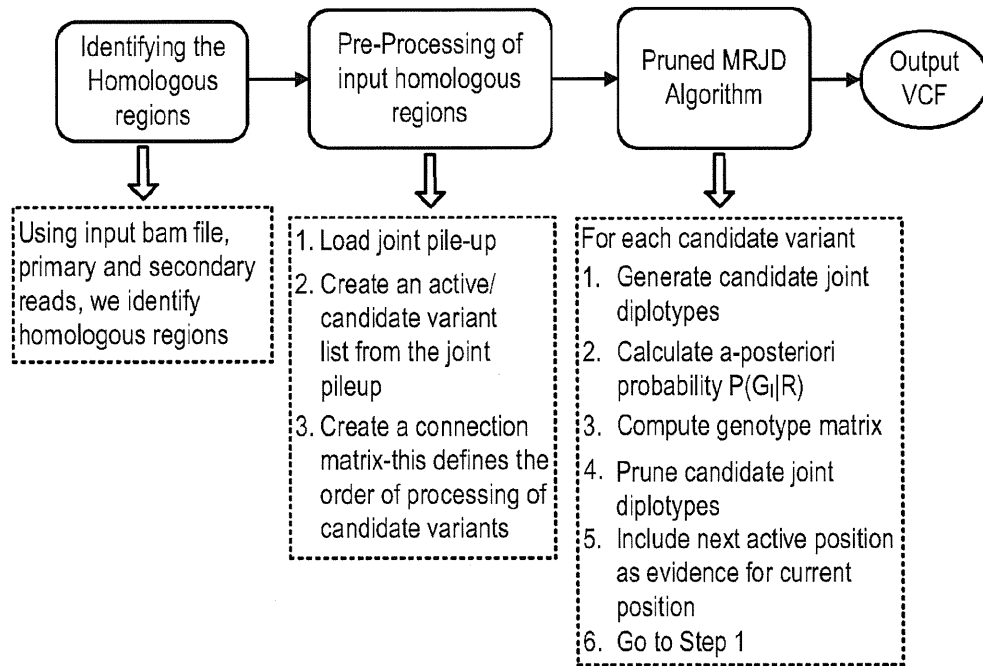


FIG. 17A

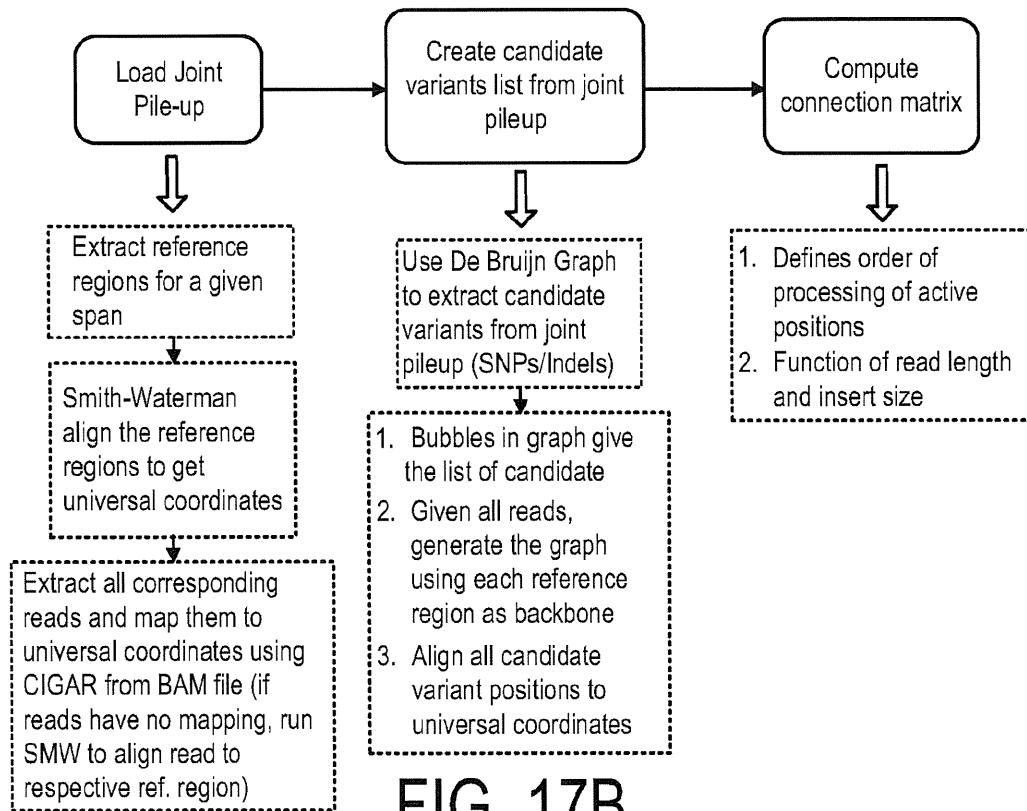


FIG. 17B

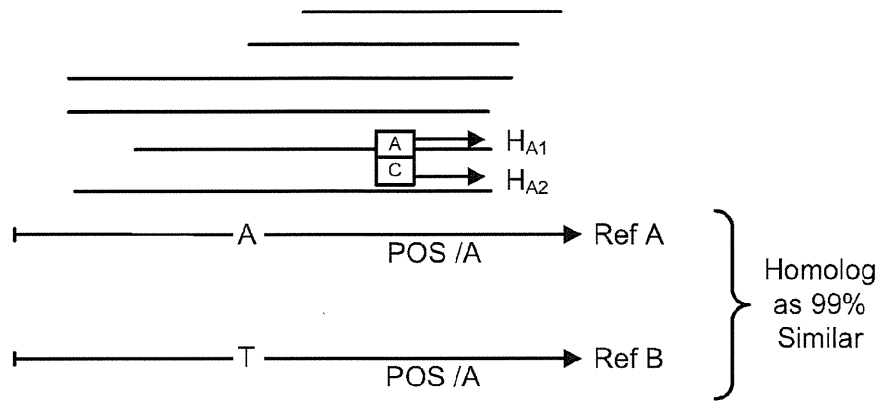


FIG. 18A

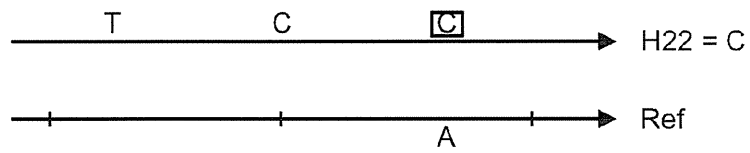


FIG. 18B

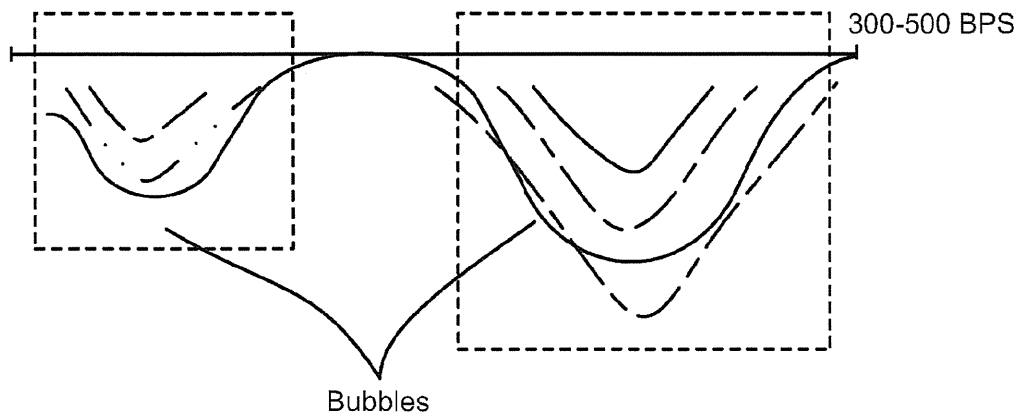


FIG. 18C

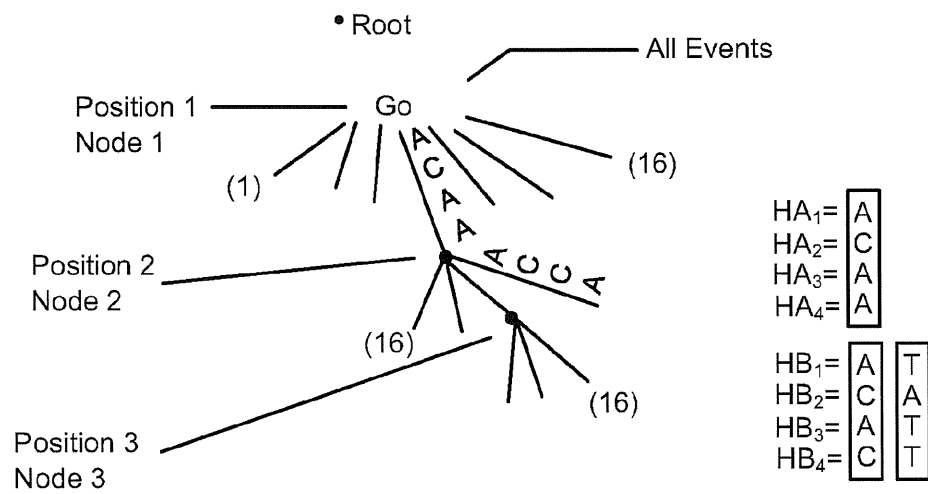


FIG. 18D

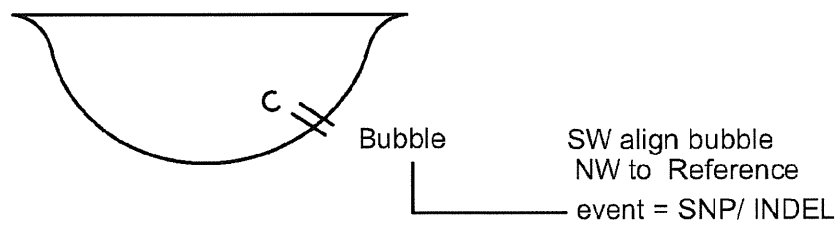


FIG. 18E

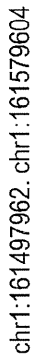


FIG. 19

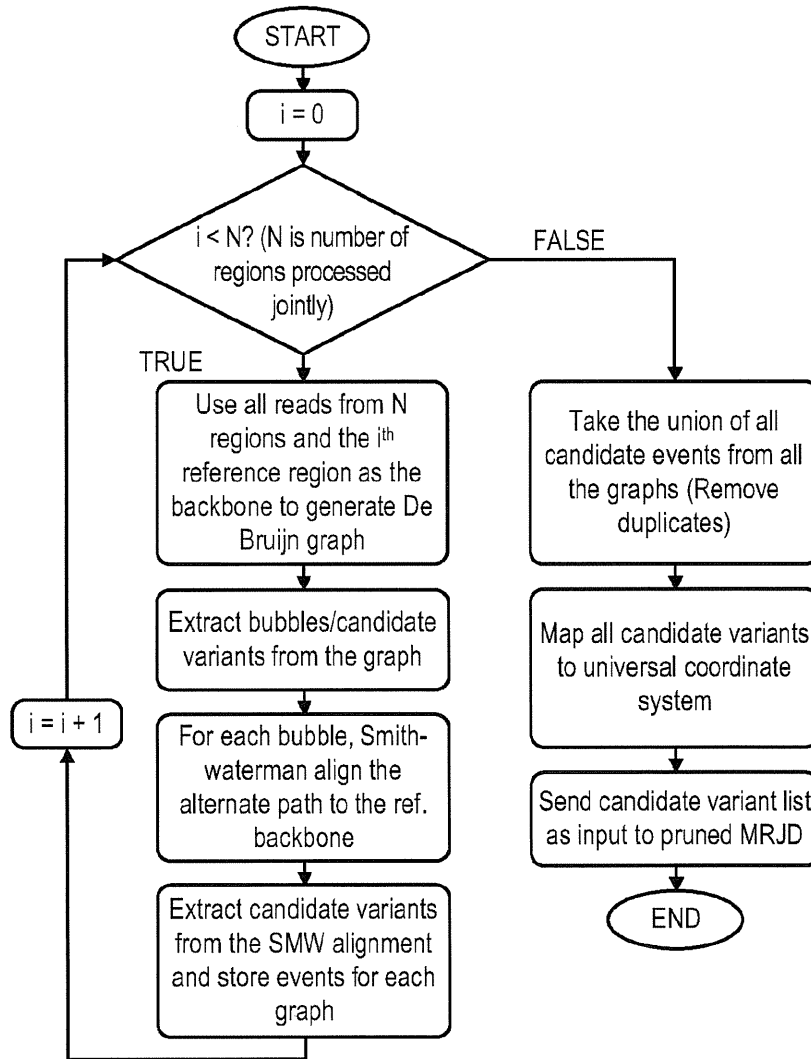


FIG. 20

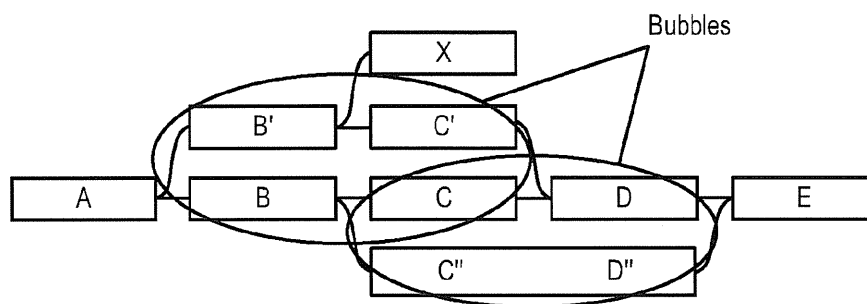
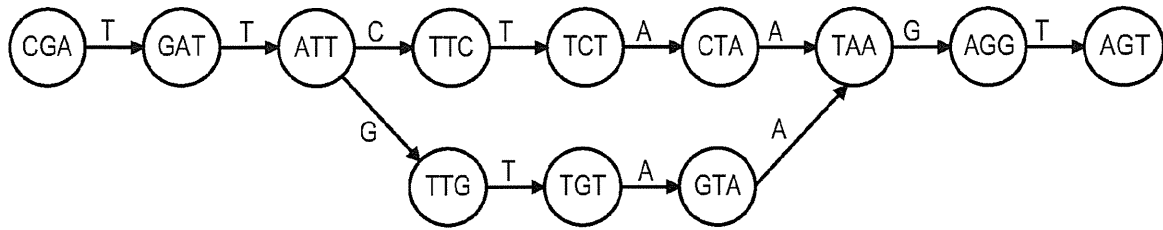


FIG. 21



Candidate haplotypes
 CGATT**C**TAAGT
 CGATT**G**TAAGT

Bubble Extraction
 TT**C**TAA
 TT**G**TAA

FIG. 22

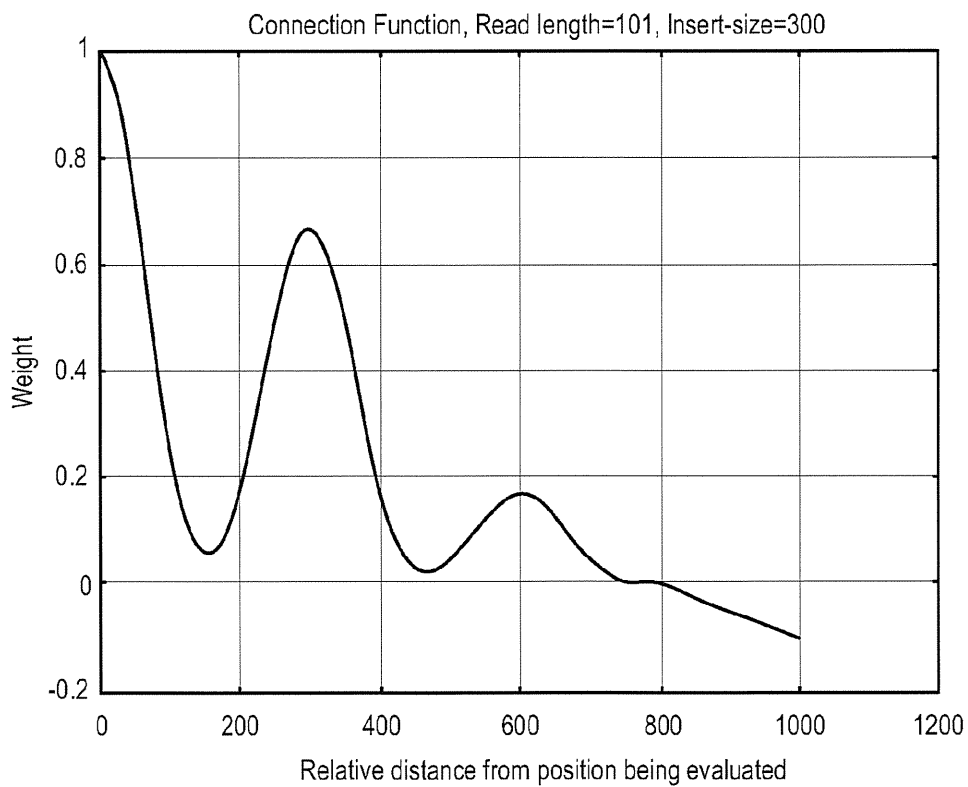


FIG. 23

PRUNED MRJD ALGORITHM

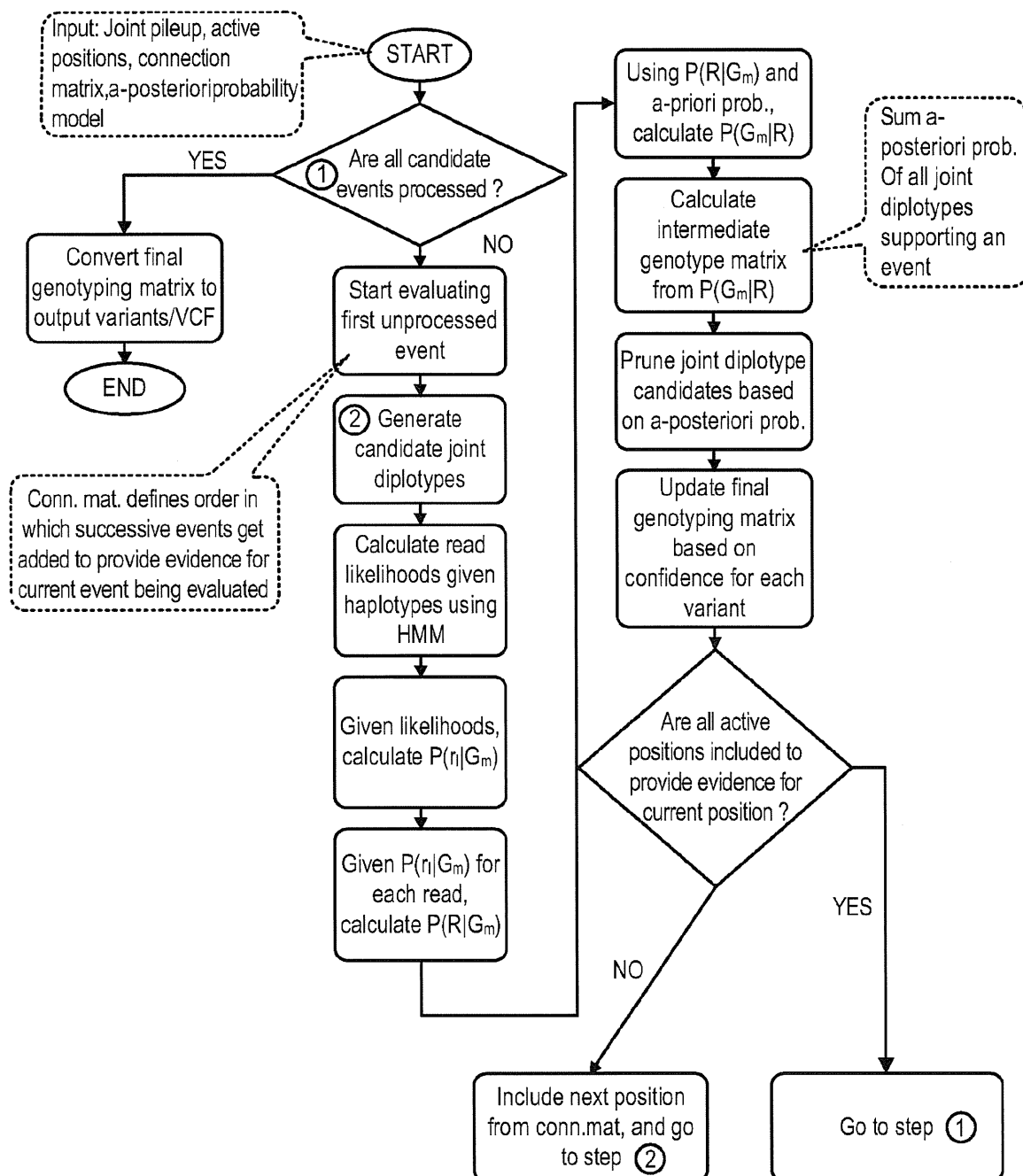


FIG. 24

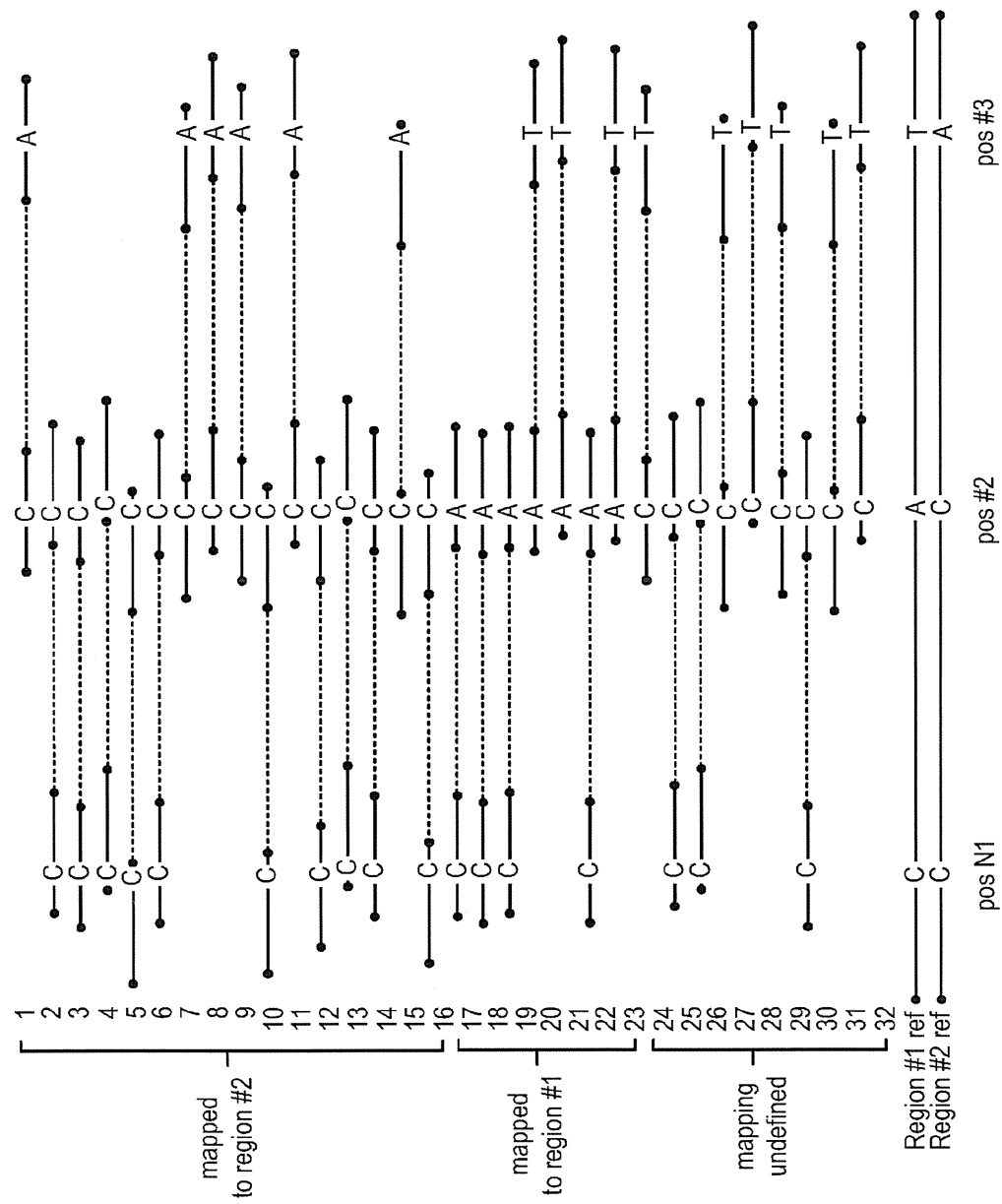


FIG. 25

i	H ₁ =CAT	H ₂ =CAA	H ₃ =CCT	H ₄ =CCA	H ₅ =GAT	H ₆ =GAA	H ₇ =GCT	H ₈ =GCA	CAT GCA	CAT GCA
1	0.0000	0.0033	0.0033	0.9801	0.0000	0.0033	0.0033	0.9801	0.4901	0.4909
2	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
3	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
4	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
5	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
6	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
7	0.0000	0.0033	0.0033	0.9801	0.0000	0.0033	0.0033	0.9801	0.4901	0.4909
8	0.0000	0.0033	0.0033	0.9801	0.0000	0.0033	0.0033	0.9801	0.4901	0.4909
9	0.0000	0.0033	0.0033	0.9801	0.0000	0.0033	0.0033	0.9801	0.4901	0.4909
10	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
11	0.0000	0.0033	0.0033	0.9801	0.0000	0.0033	0.0033	0.9801	0.4901	0.4909
12	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
13	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
14	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
15	0.0000	0.0033	0.0033	0.9801	0.0000	0.0033	0.0033	0.9801	0.4901	0.4909
16	0.0000	0.0000	0.0033	0.0033	0.0033	0.0033	0.9801	0.9801	0.4901	0.4909
17	0.9801	0.9801	0.0033	0.0033	0.0033	0.0033	0.0000	0.0000	0.4901	0.2459
18	0.9801	0.9801	0.0033	0.0033	0.0033	0.0033	0.0000	0.0000	0.4901	0.2459
19	0.9801	0.9801	0.0033	0.0033	0.0033	0.0033	0.0000	0.0000	0.4901	0.2459
20	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.4901	0.2459
21	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.4901	0.2459
22	0.9801	0.9801	0.0033	0.0033	0.0033	0.0033	0.0000	0.0000	0.4901	0.2459
23	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.4901	0.2459
24	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.2475
25	0.0033	0.0033	0.9801	0.9801	0.0000	0.0000	0.0033	0.0033	0.0033	0.2475
26	0.0033	0.0033	0.9801	0.9801	0.0000	0.0000	0.0033	0.0033	0.0033	0.2475
27	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.2475
28	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.2475
29	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.2475
30	0.0033	0.0033	0.9801	0.9801	0.0000	0.0000	0.0033	0.0033	0.0033	0.2475
31	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.2475
32	0.0033	0.0000	0.9801	0.0033	0.0033	0.0000	0.9801	0.0033	0.0033	0.2475
									3.5e-30	2.2e-15

FIG. 26

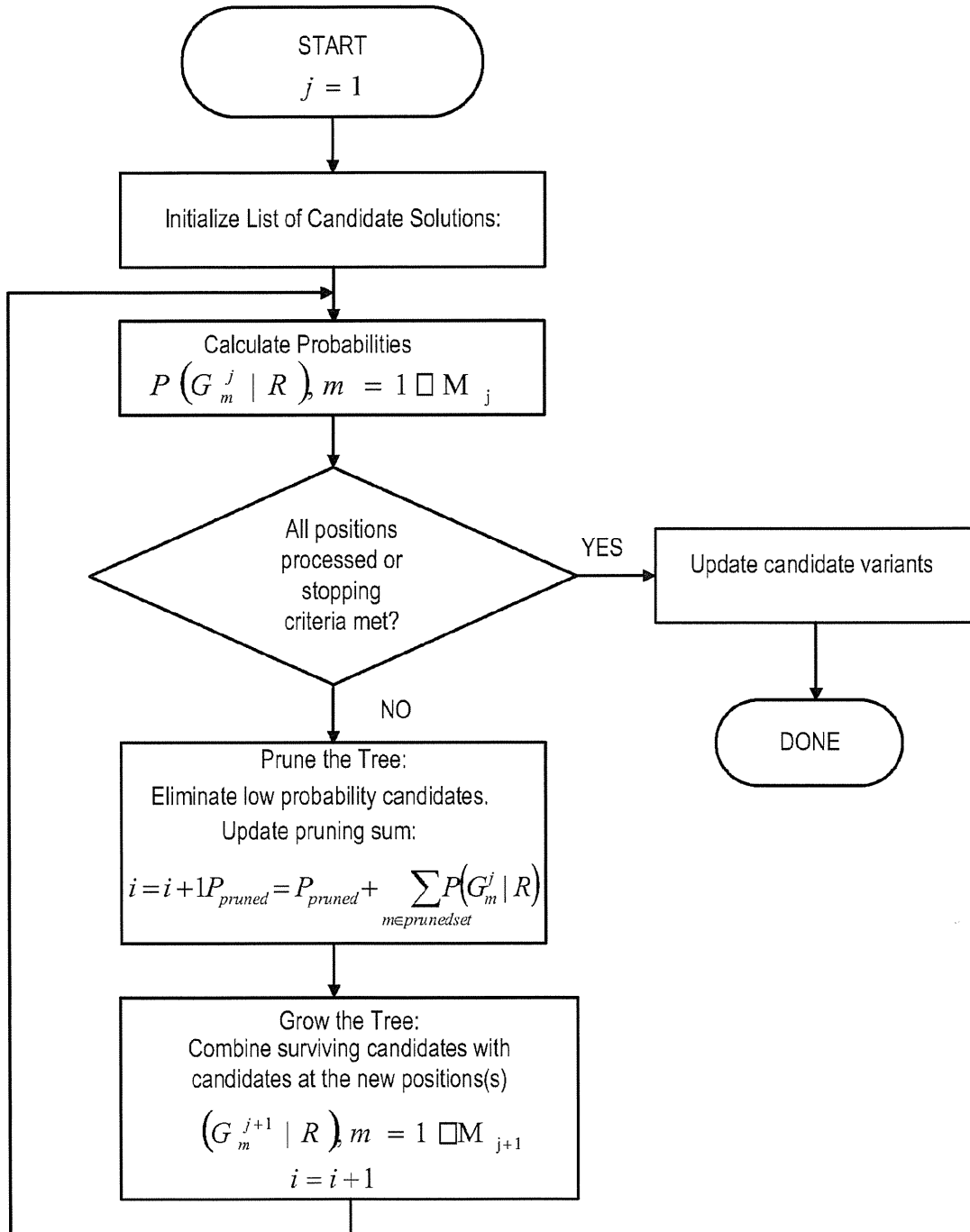


FIG. 27

$G_1^1 =$	$\begin{bmatrix} C & G \\ C & G \end{bmatrix}$	$P(G_1 IR) = 0.99892171$ (phred 0.00)
$G_2^1 =$	$\begin{bmatrix} G & G \\ C & G \end{bmatrix}$	$P(G_2 IR) = 0.00103398$ (phred 29.85)
$G_3^1 =$	$\begin{bmatrix} C & G \\ C & C \end{bmatrix}$	$P(G_3 IR) = 0.00003934$ (phred 44.05)
$G_4^1 =$	$\begin{bmatrix} G & G \\ C & C \end{bmatrix}$	$P(G_4 IR) = 0.00000251$ (phred 56.00)
$G_5^1 =$	$\begin{bmatrix} G & C \\ G & C \end{bmatrix}$	$P(G_5 IR) = 0.00000126$ (phred 59.00)
$G_6^1 =$	$\begin{bmatrix} G & G \\ G & C \end{bmatrix}$	$P(G_6 IR) = 0.00000116$ (phred 59.35)
$G_7^1 =$	$\begin{bmatrix} G & C \\ C & C \end{bmatrix}$	$P(G_7 IR) = 0.00000004$ (phred 73.55)
$G_8^1 =$	$\begin{bmatrix} G & G \\ G & G \end{bmatrix}$	$P(G_8 IR) = 0.00000000$ (phred 151.67)
$G_9^1 =$	$\begin{bmatrix} C & C \\ C & C \end{bmatrix}$	$P(G_9 IR) = 0.00000000$ (phred 225.85)

FIG. 28

$G_1^2 =$	$\begin{bmatrix} CC & GC \\ CA & GC \end{bmatrix}$	$P(G_1 IR) = 0.99799456$ (phred 0.01)
$G_2^2 =$	$\begin{bmatrix} CA & GC \\ CA & GC \end{bmatrix}$	$P(G_2 IR) = 0.00101673$ (phred 29.93)
$G_3^2 =$	$\begin{bmatrix} CA & GC \\ CA & CC \end{bmatrix}$	$P(G_3 IR) = 0.00097796$ (phred 30.10)
$G_4^2 =$	$\begin{bmatrix} CC & GC \\ CA & CC \end{bmatrix}$	$P(G_4 IR) = 0.00000913$ (phred 50.39)
$G_5^2 =$	$\begin{bmatrix} GC & GC \\ CA & CC \end{bmatrix}$	$P(G_5 IR) = 0.00000125$ (phred 59.02)
$G_6^2 =$	$\begin{bmatrix} GC & GC \\ CA & GC \end{bmatrix}$	$P(G_6 IR) = 0.00000015$ (phred 68.29)
$G_7^2 =$	$\begin{bmatrix} GA & GC \\ CA & CC \end{bmatrix}$	$P(G_7 IR) = 0.00000007$ (phred 71.45)
$G_8^2 =$	$\begin{bmatrix} CC & GC \\ CA & GA \end{bmatrix}$	$P(G_8 IR) = 0.00000007$ (phred 71.45)
$G_9^2 =$	$\begin{bmatrix} GA & GC \\ CA & GC \end{bmatrix}$	$P(G_9 IR) = 0.00000006$ (phred 72.06)
$G_{10}^2 =$	$\begin{bmatrix} CC & GC \\ CC & CA \end{bmatrix}$	$P(G_{10} IR) = 0.00000001$ (phred 79.89)
$G_{11}^2 =$	$\begin{bmatrix} GC & CC \\ GC & CA \end{bmatrix}$	$P(G_{11} IR) = 0.00000000$ (phred 88.51)
$G_{12}^2 =$	$\begin{bmatrix} GC & GC \\ CC & CA \end{bmatrix}$	$P(G_{12} IR) = 0.00000000$ (phred 88.51)
$G_{13}^2 =$	$\begin{bmatrix} CC & GC \\ CA & CA \end{bmatrix}$	$P(G_{13} IR) = 0.00000000$ (phred 89.10)
$G_{14}^2 =$	$\begin{bmatrix} GA & GC \\ CC & GC \end{bmatrix}$	$P(G_{14} IR) = 0.00000000$ (phred 116.35)
$G_{15}^2 =$	$\begin{bmatrix} CA & GC \\ CA & GA \end{bmatrix}$	$P(G_{15} IR) = 0.00000000$ (phred 120.60)

(candidates 16-70 not shown)

FIG. 29

$G_1^3 =$	$\begin{bmatrix} \text{CCT} & \text{GCA} \\ \text{CAT} & \text{GCA} \end{bmatrix}$	$P(G_1 IR) = 0.99885810$ (phred 0.00)
$G_2^3 =$	$\begin{bmatrix} \text{CCT} & \text{GCT} \\ \text{CAT} & \text{GCA} \end{bmatrix}$	$P(G_2 IR) = 0.00111991$ (phred 29.51)
$G_3^3 =$	$\begin{bmatrix} \text{CCT} & \text{GCA} \\ \text{CAT} & \text{CCA} \end{bmatrix}$	$P(G_3 IR) = 0.00000914$ (phred 50.39)
$G_4^3 =$	$\begin{bmatrix} \text{CAT} & \text{GCT} \\ \text{CAT} & \text{GCA} \end{bmatrix}$	$P(G_4 IR) = 0.00000462$ (phred 53.36)
$G_5^3 =$	$\begin{bmatrix} \text{CAT} & \text{GCA} \\ \text{CAT} & \text{CCT} \end{bmatrix}$	$P(G_5 IR) = 0.00000222$ (phred 56.53)
$G_6^3 =$	$\begin{bmatrix} \text{CAT} & \text{GCT} \\ \text{CAT} & \text{CCA} \end{bmatrix}$	$P(G_6 IR) = 0.00000222$ (phred 56.53)
$G_7^3 =$	$\begin{bmatrix} \text{CCA} & \text{GCT} \\ \text{CAT} & \text{GCT} \end{bmatrix}$	$P(G_7 IR) = 0.00000126$ (phred 59.01)
$G_8^3 =$	$\begin{bmatrix} \text{GCT} & \text{GCA} \\ \text{CAT} & \text{CCA} \end{bmatrix}$	$P(G_8 IR) = 0.00000126$ (phred 59.01)
$G_9^3 =$	$\begin{bmatrix} \text{CCA} & \text{GCT} \\ \text{CAT} & \text{GCA} \end{bmatrix}$	$P(G_9 IR) = 0.00000126$ (phred 59.01)
$G_{10}^3 =$	$\begin{bmatrix} \text{CCT} & \text{GCA} \\ \text{CAT} & \text{CCT} \end{bmatrix}$	$P(G_{10} IR) = 0.00000001$ (phred 79.89)
$G_{11}^3 =$	$\begin{bmatrix} \text{CCT} & \text{GCT} \\ \text{CAT} & \text{CCA} \end{bmatrix}$	$P(G_{11} IR) = 0.00000001$ (phred 79.89)
$G_{12}^3 =$	$\begin{bmatrix} \text{GCT} & \text{GCA} \\ \text{CAT} & \text{CCT} \end{bmatrix}$	$P(G_{12} IR) = 0.00000000$ (phred 88.52)
$G_{13}^3 =$	$\begin{bmatrix} \text{GCT} & \text{GCT} \\ \text{CAT} & \text{CCA} \end{bmatrix}$	$P(G_{13} IR) = 0.00000000$ (phred 88.52)
$G_{14}^3 =$	$\begin{bmatrix} \text{CAT} & \text{GCT} \\ \text{CAA} & \text{GCA} \end{bmatrix}$	$P(G_{14} IR) = 0.00000000$ (phred 91.82)
$G_{15}^3 =$	$\begin{bmatrix} \text{CCT} & \text{GCA} \\ \text{CAA} & \text{GCA} \end{bmatrix}$	$P(G_{15} IR) = 0.00000000$ (phred 94.70)

(candidates 16-65 not shown)

FIG. 30

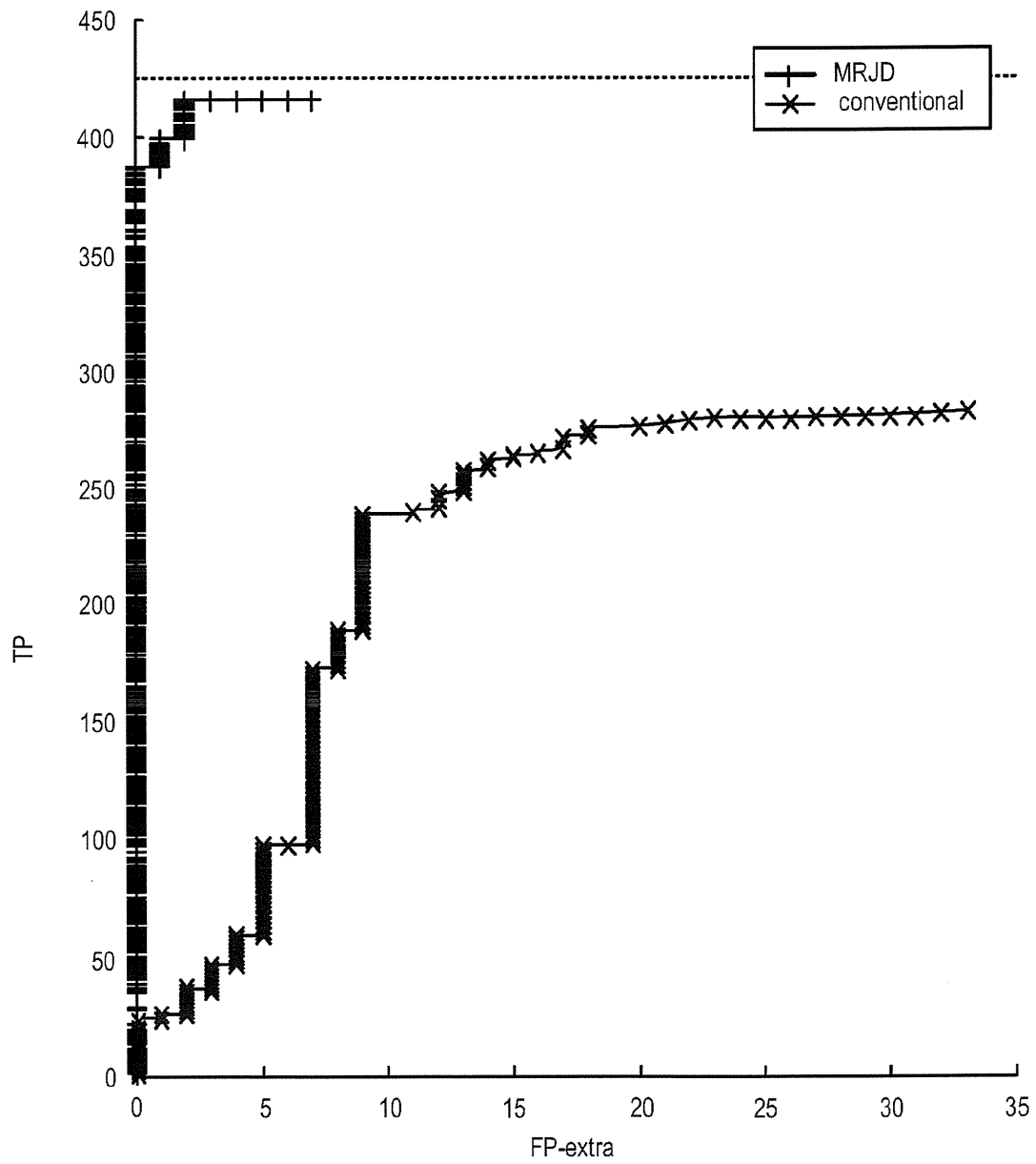


FIG. 31

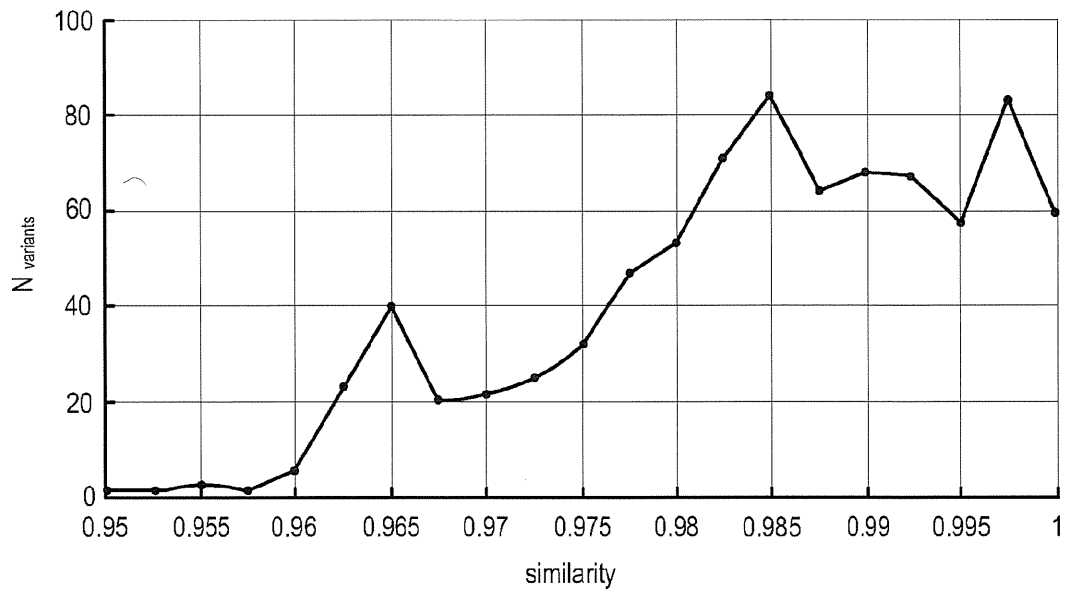
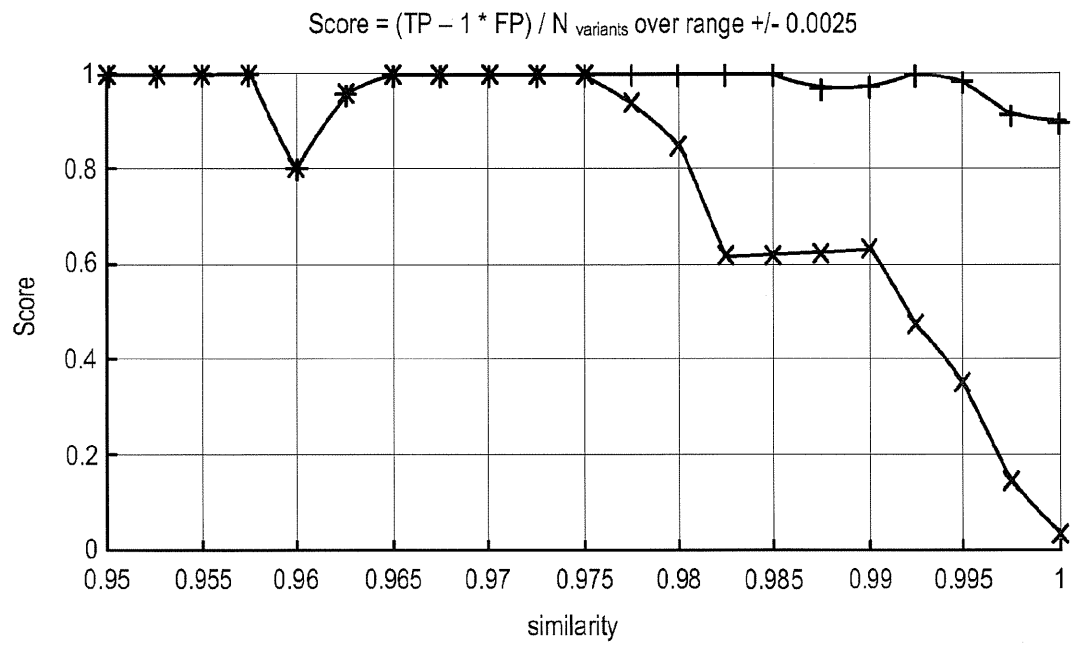


FIG. 32

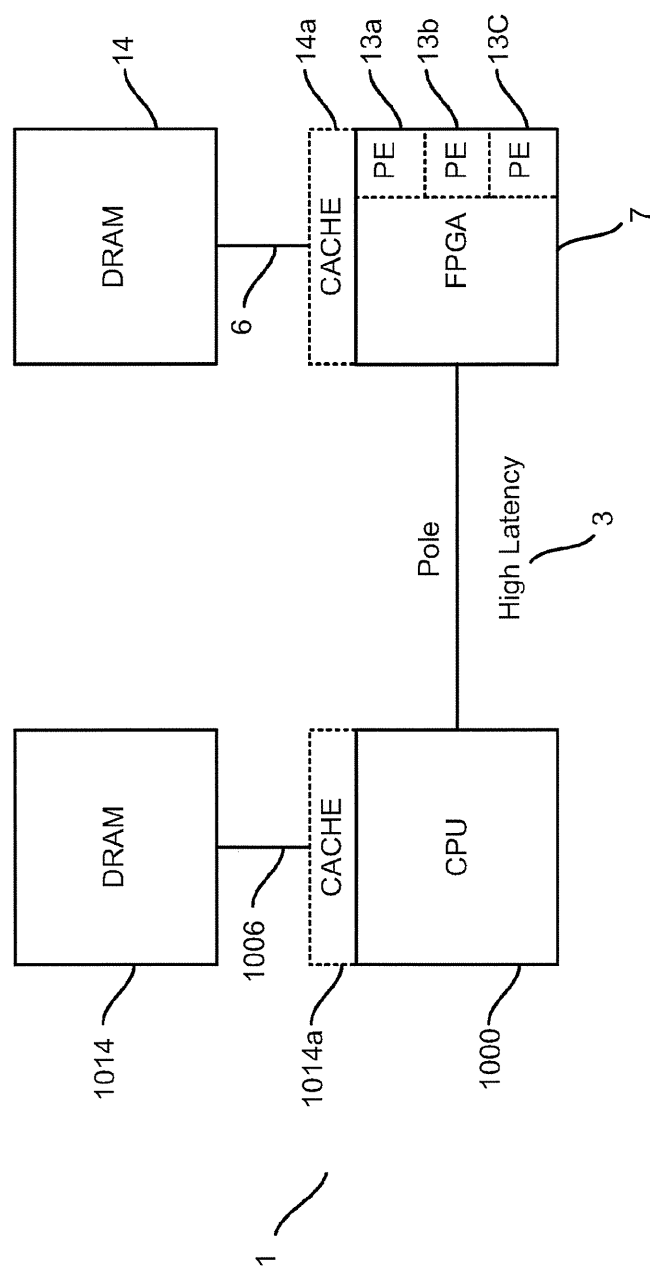


FIG. 33A

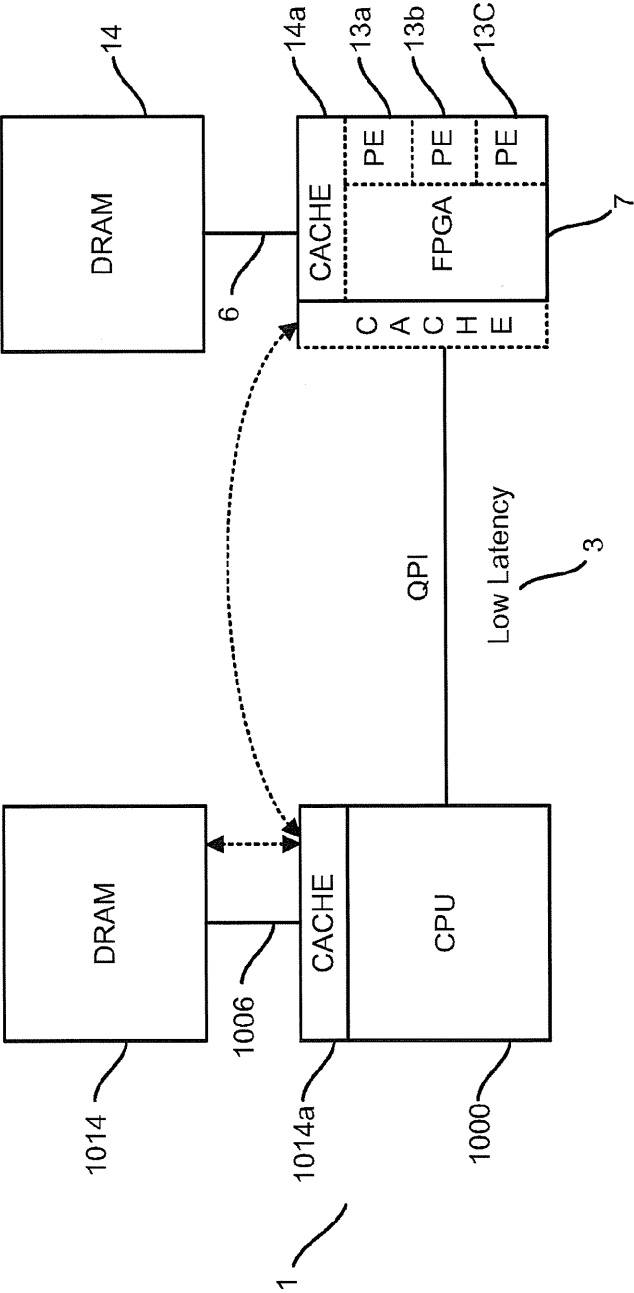


FIG. 33B

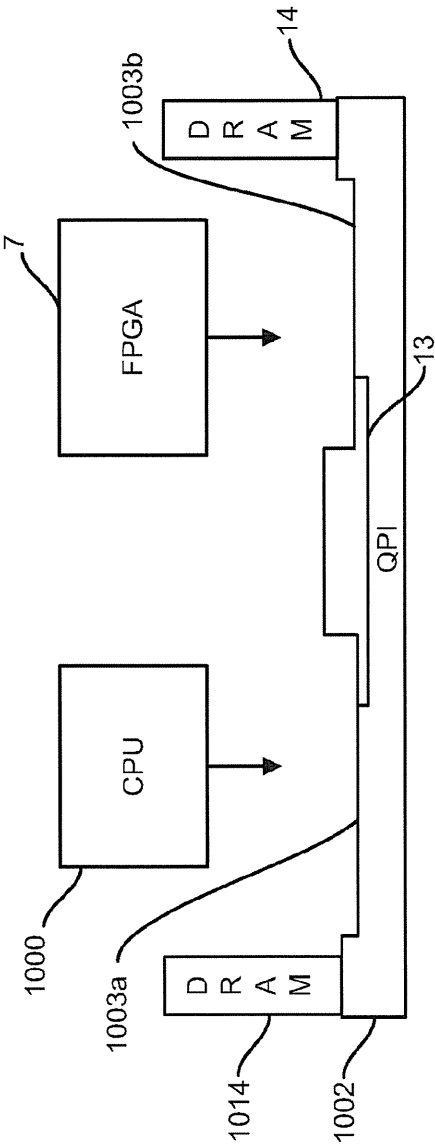


FIG. 34A

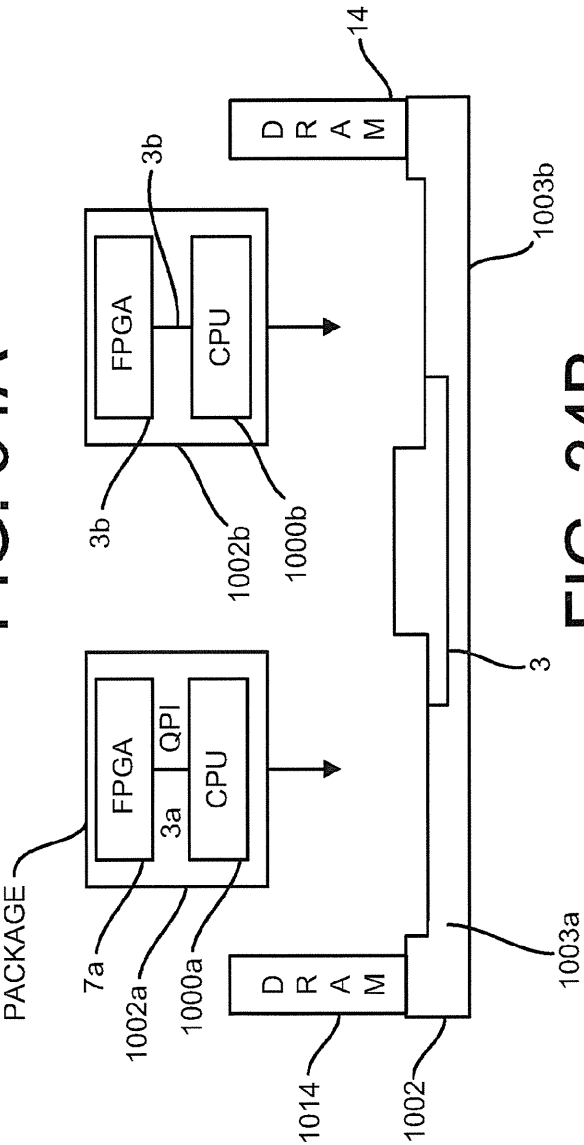


FIG. 34B

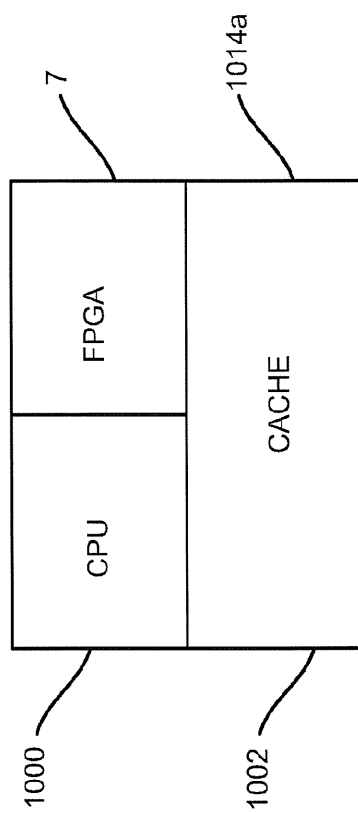


FIG. 35

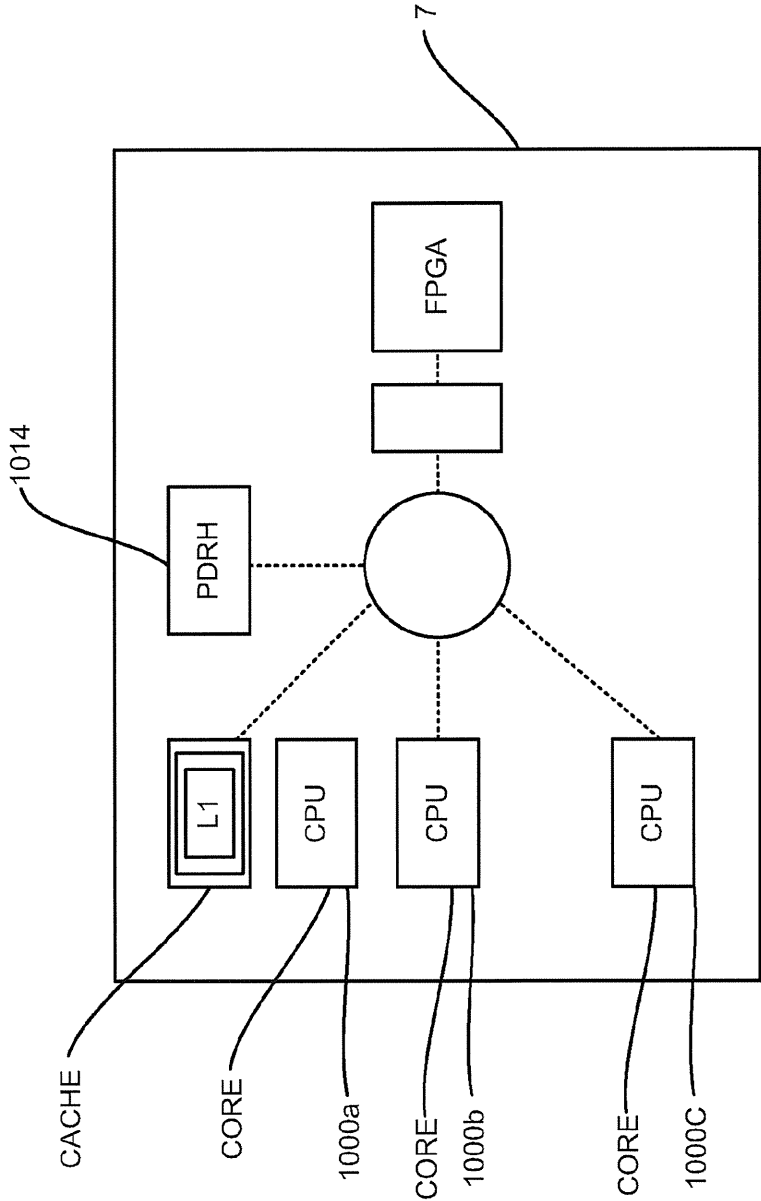


FIG. 36

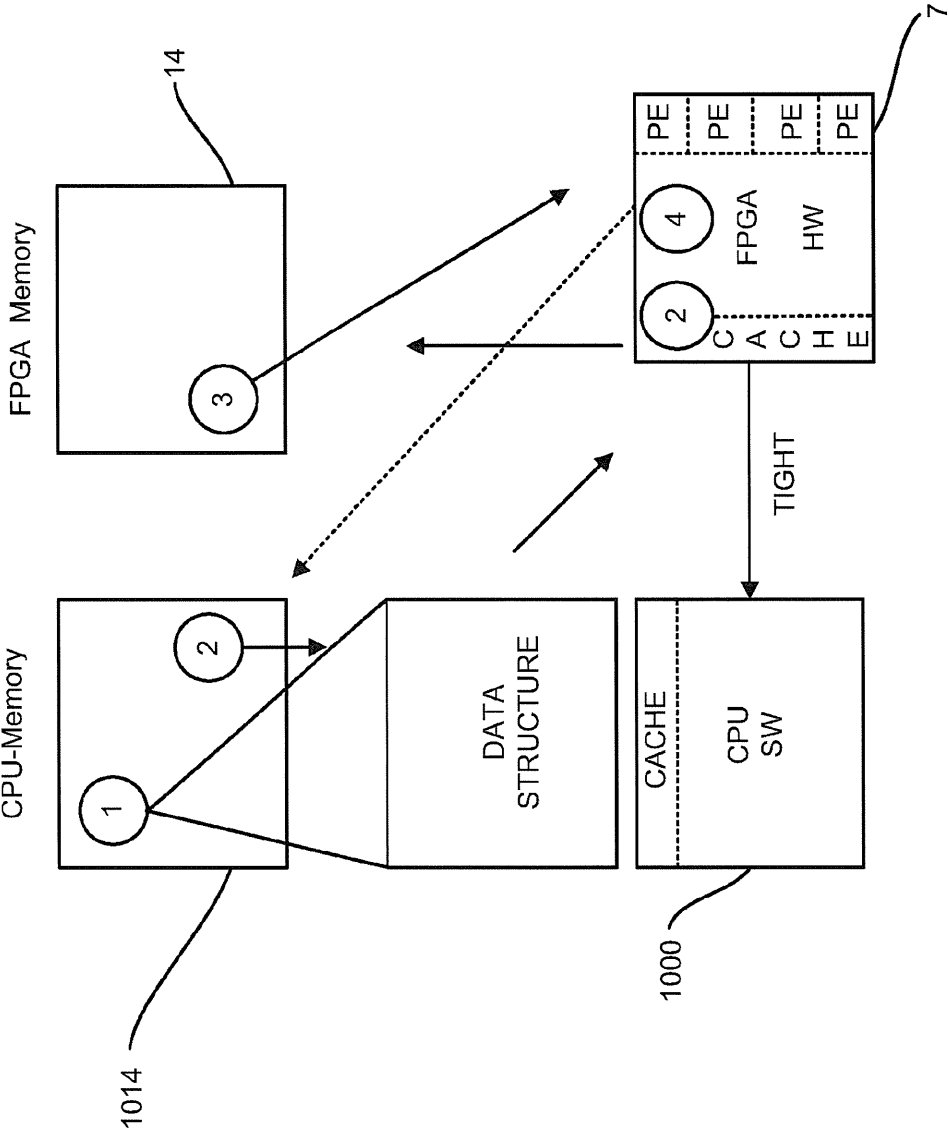


FIG. 37

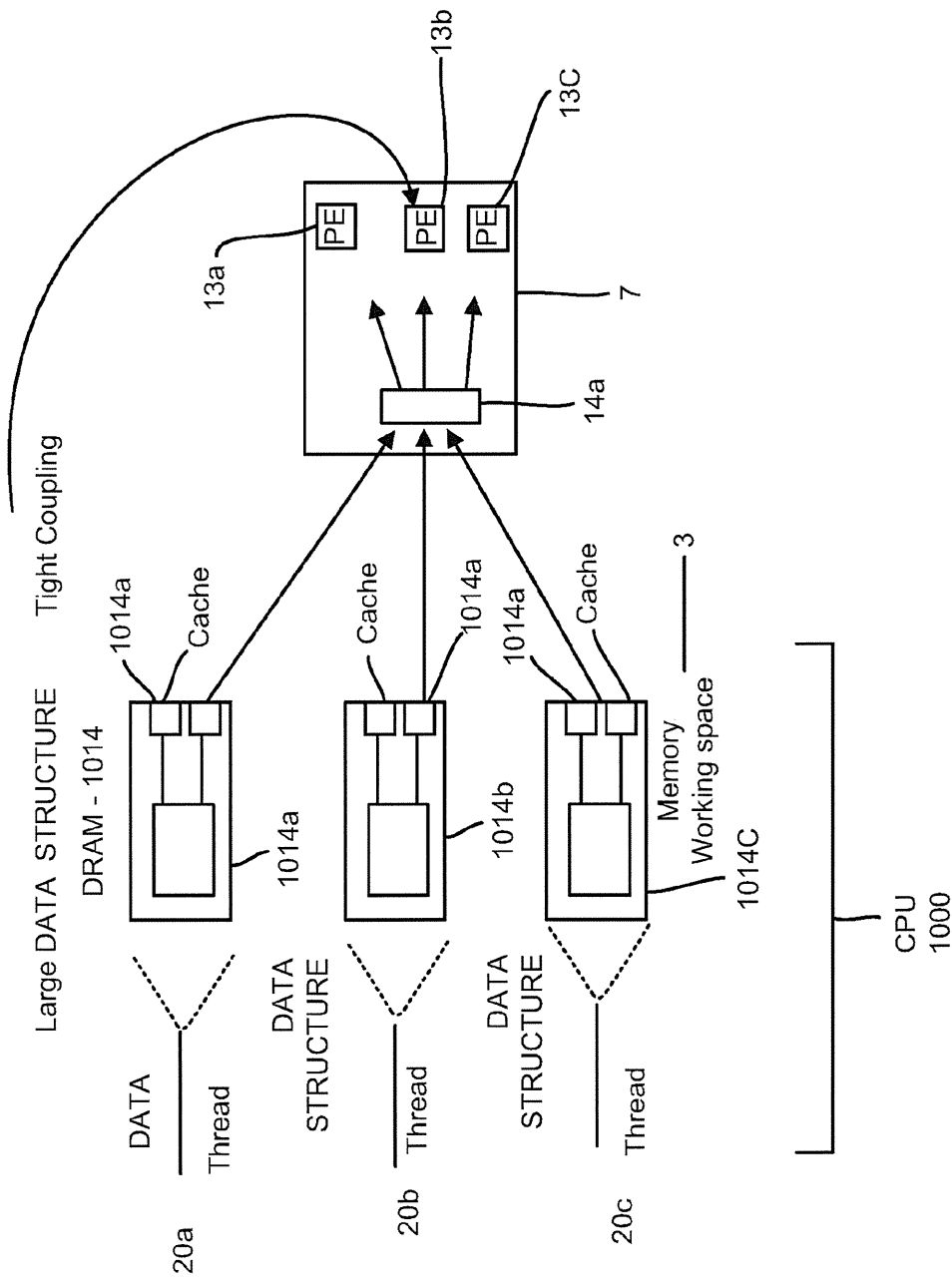


FIG. 38

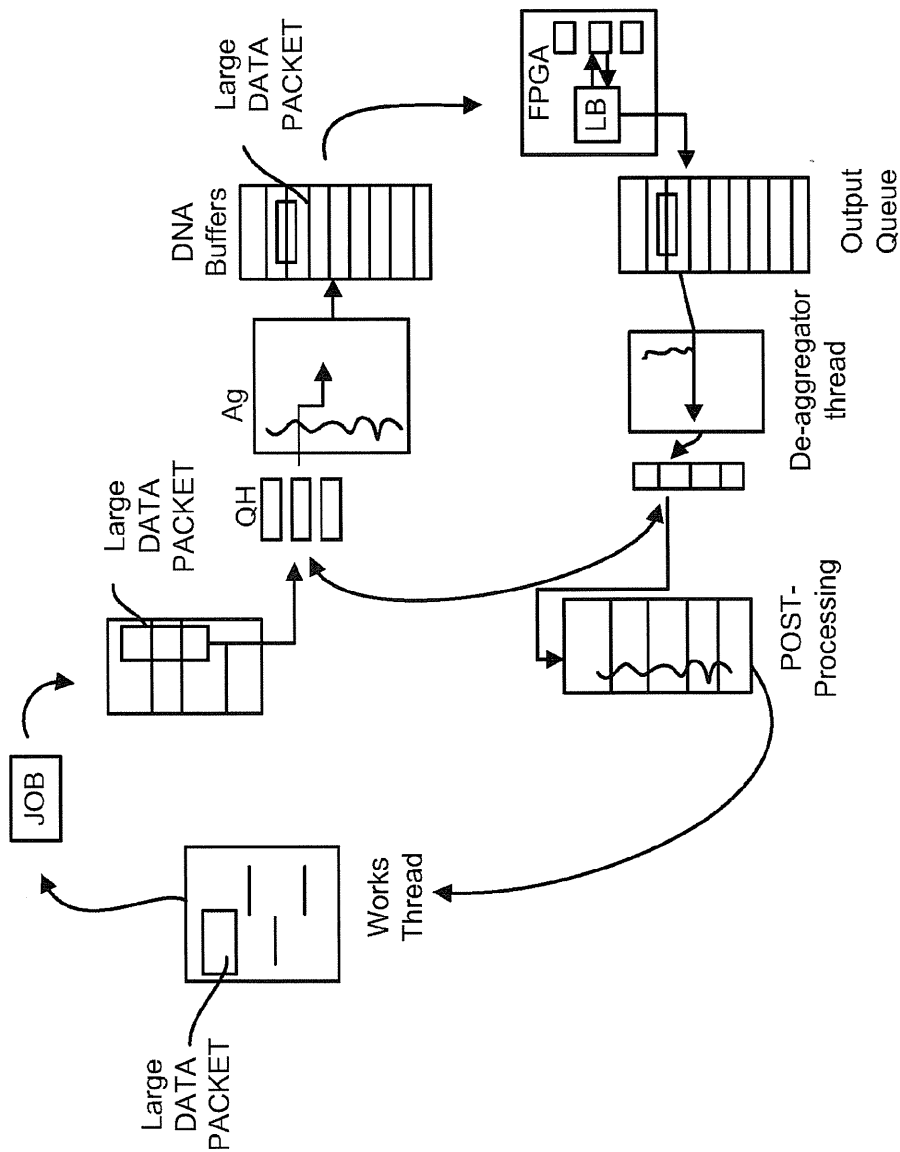


FIG. 39

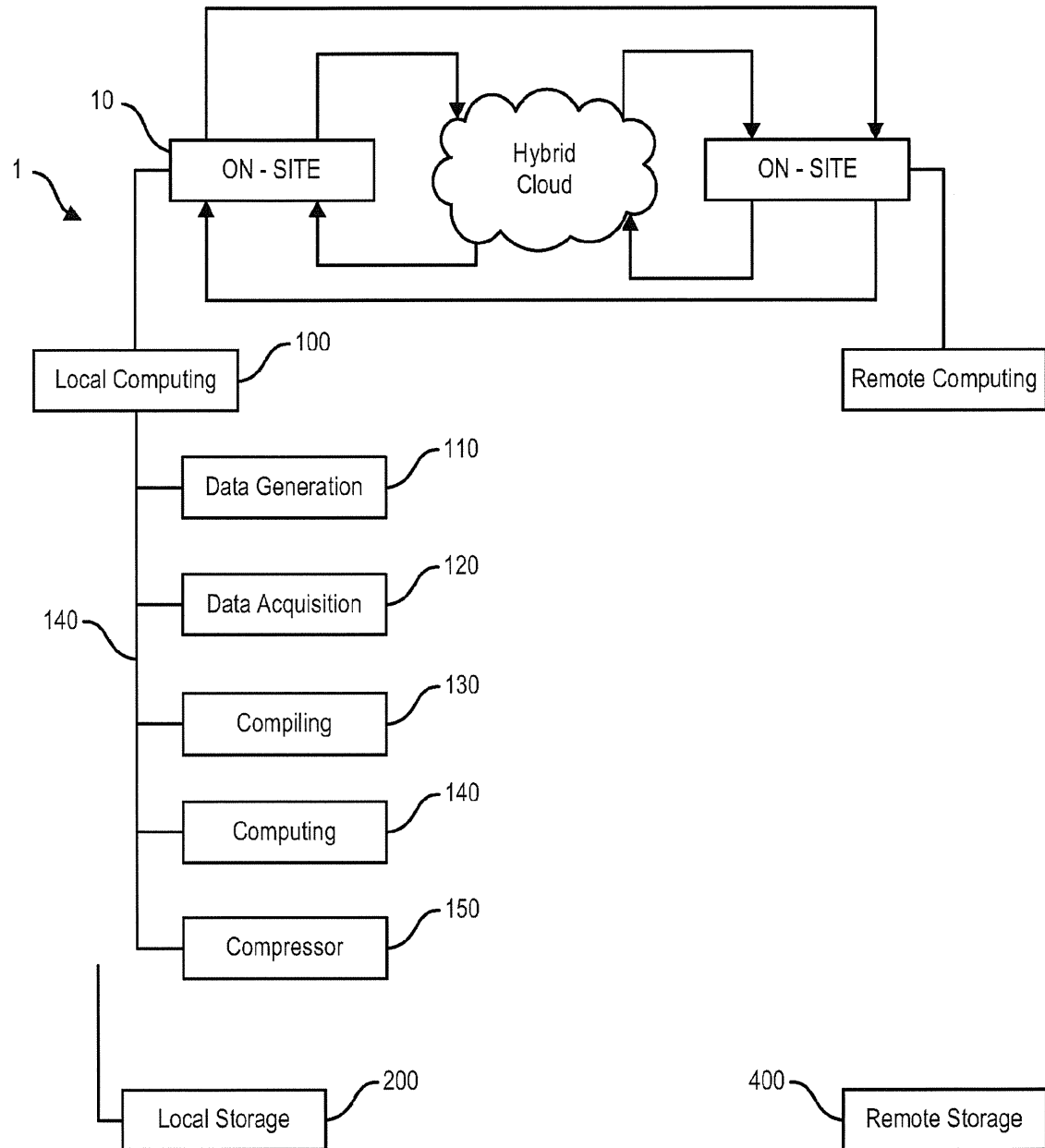
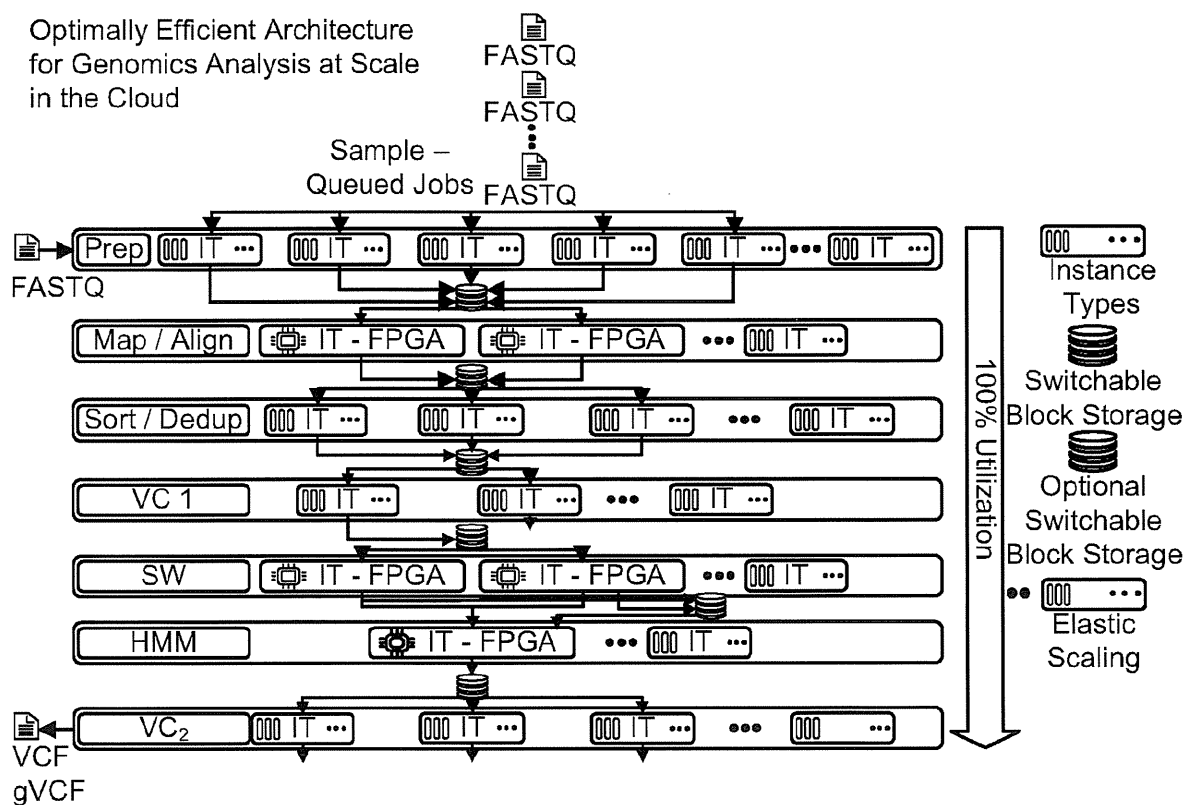


FIG. 40A

Optimally Efficient Architecture for Genomics Analysis at Scale in the Cloud



Optimally Efficient Architecture for Genomics Analysis at Scale in the Cloud

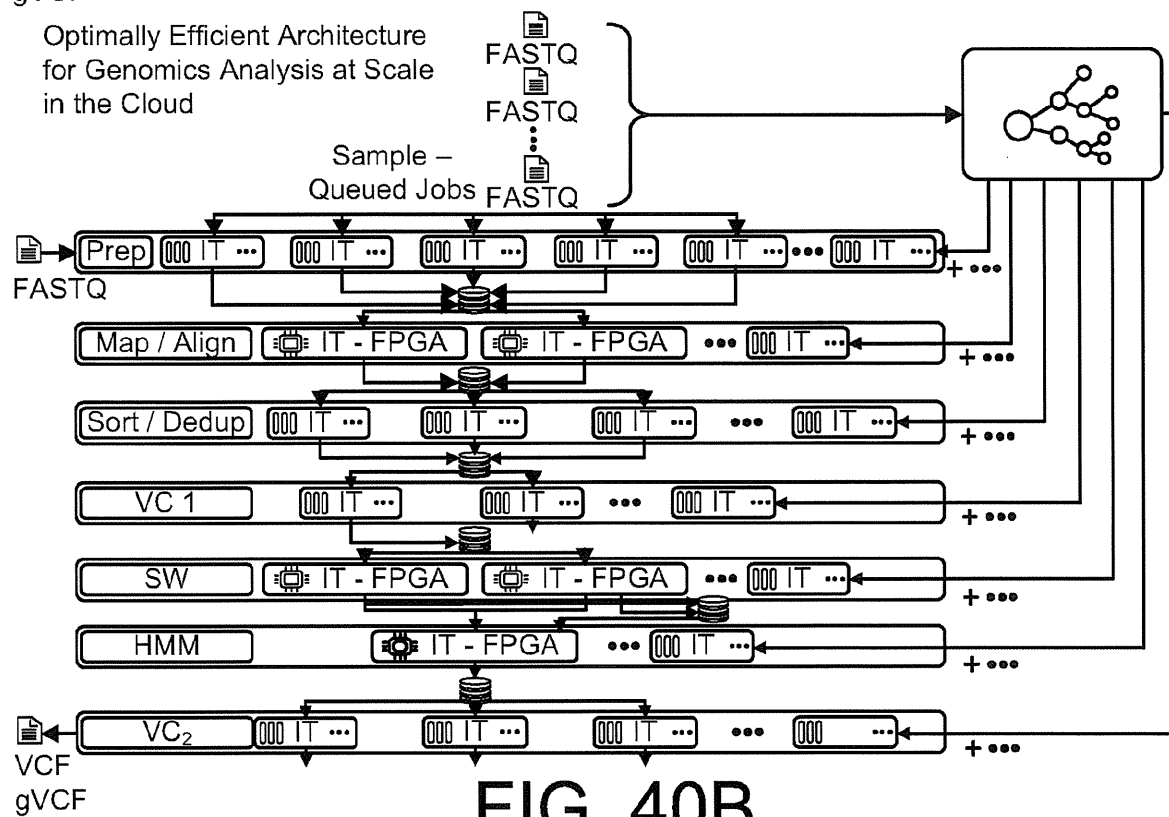


FIG. 40B

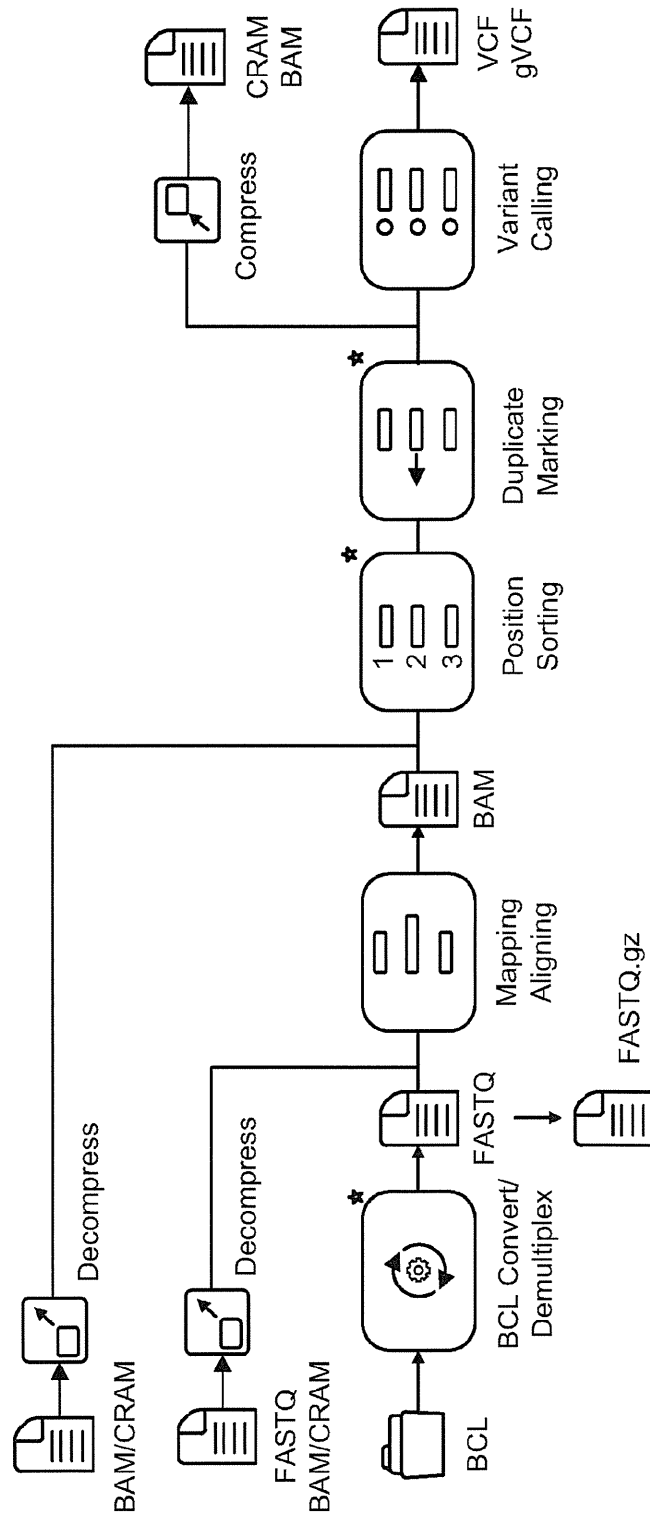
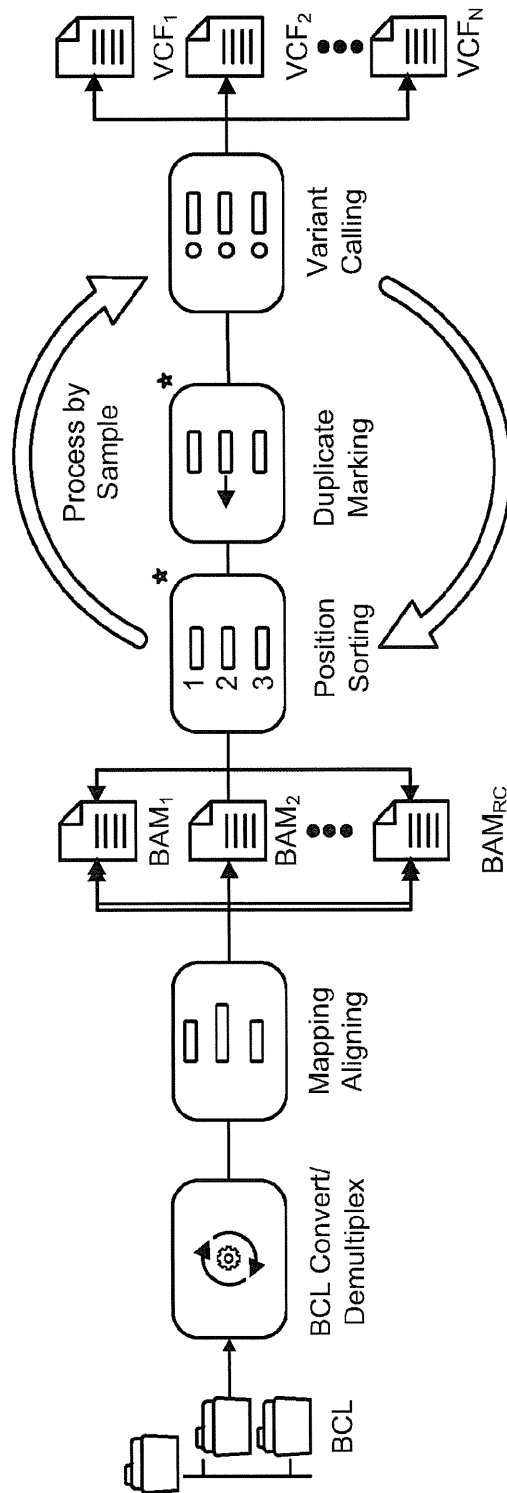


FIG. 40C

**FIG. 40D**

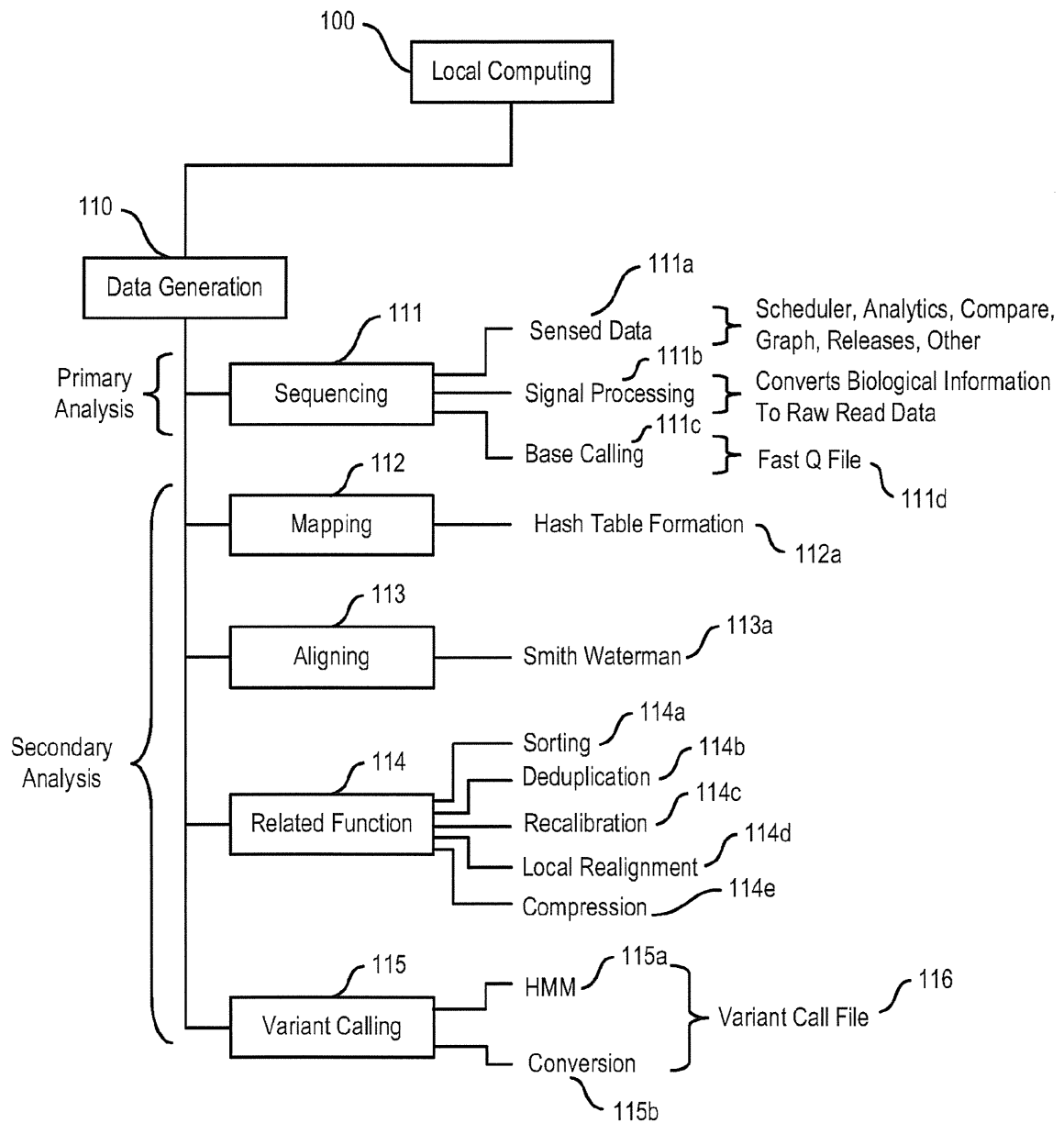


FIG. 41A

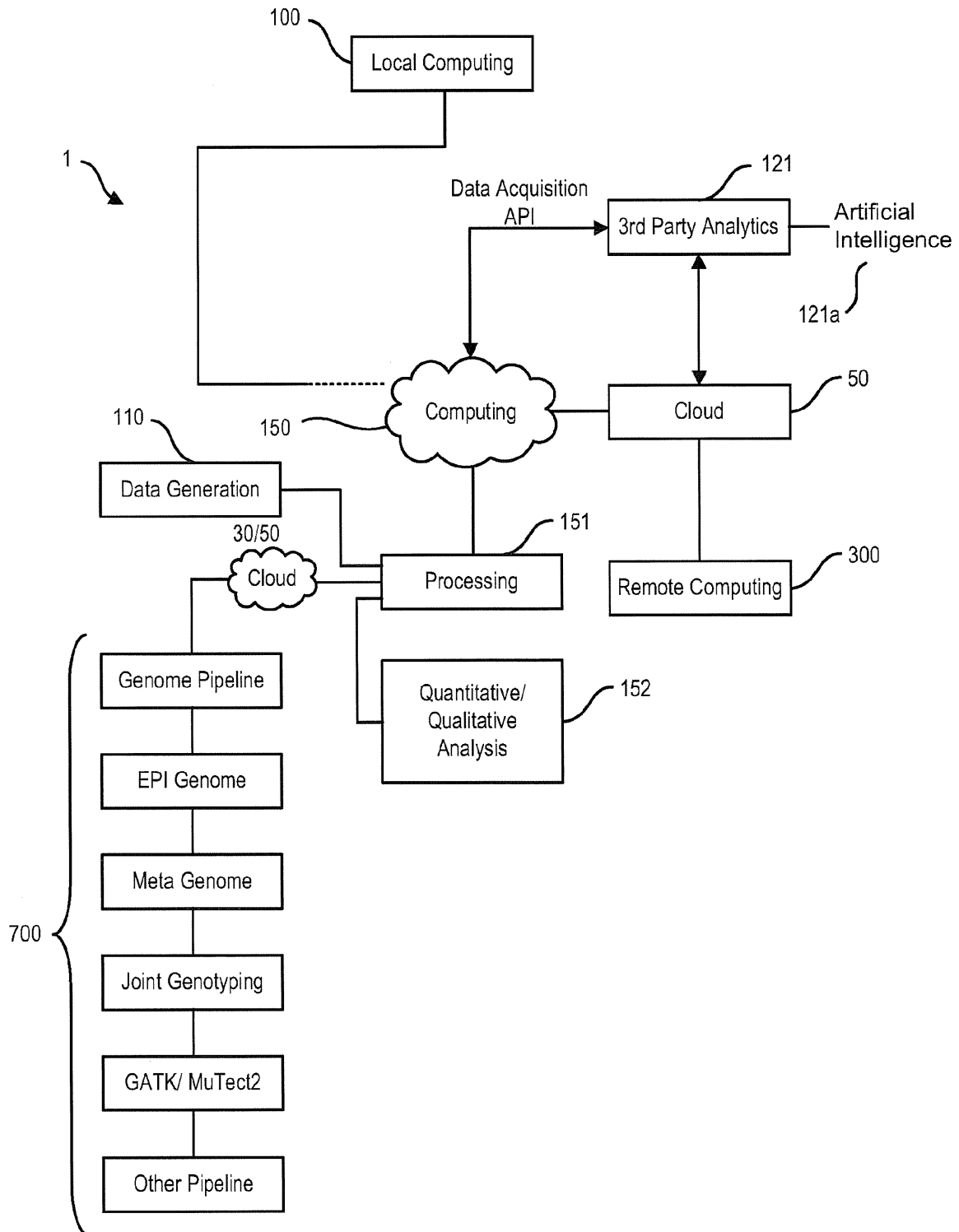


FIG. 41B

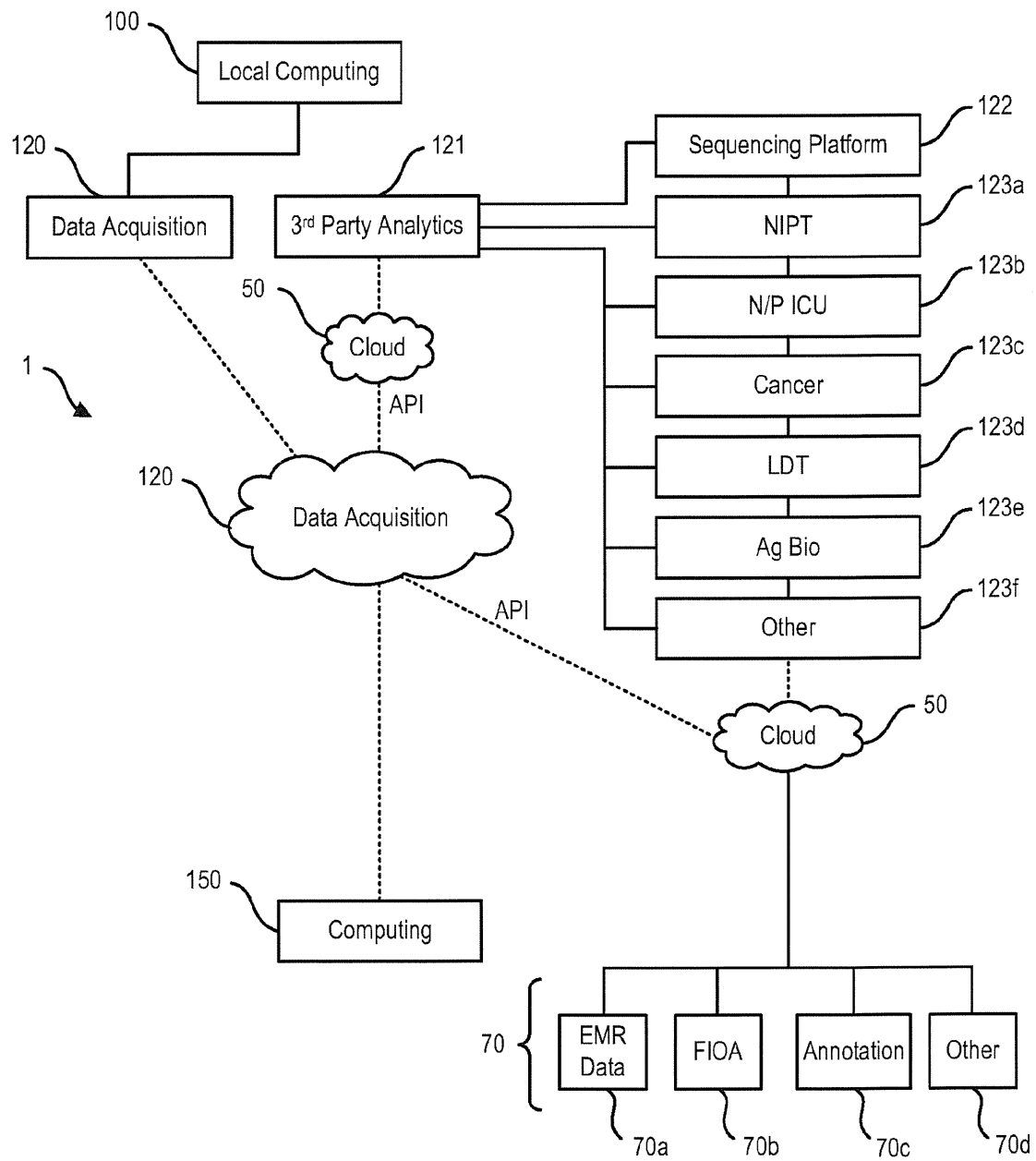


FIG. 41C

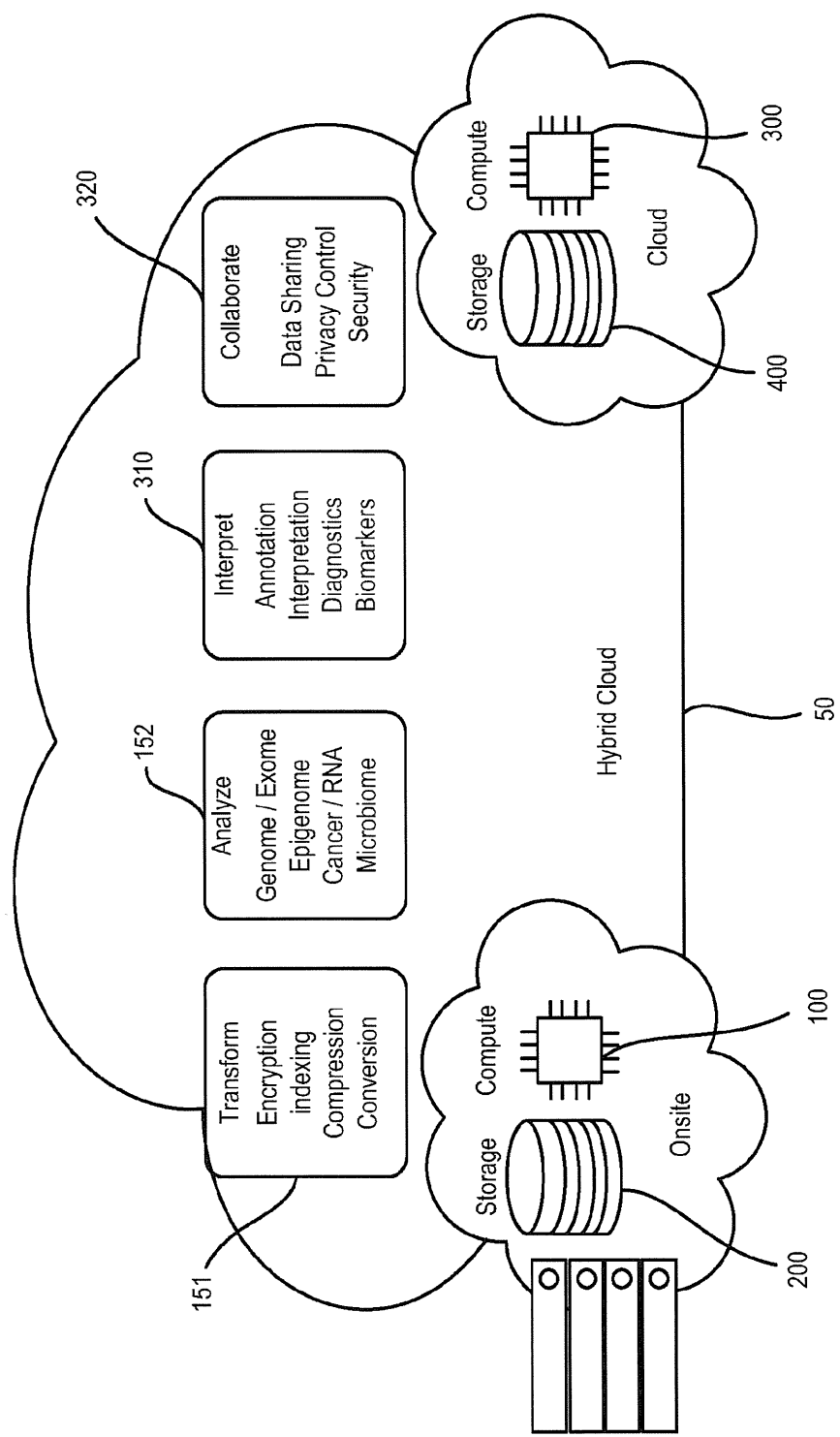


FIG. 42A

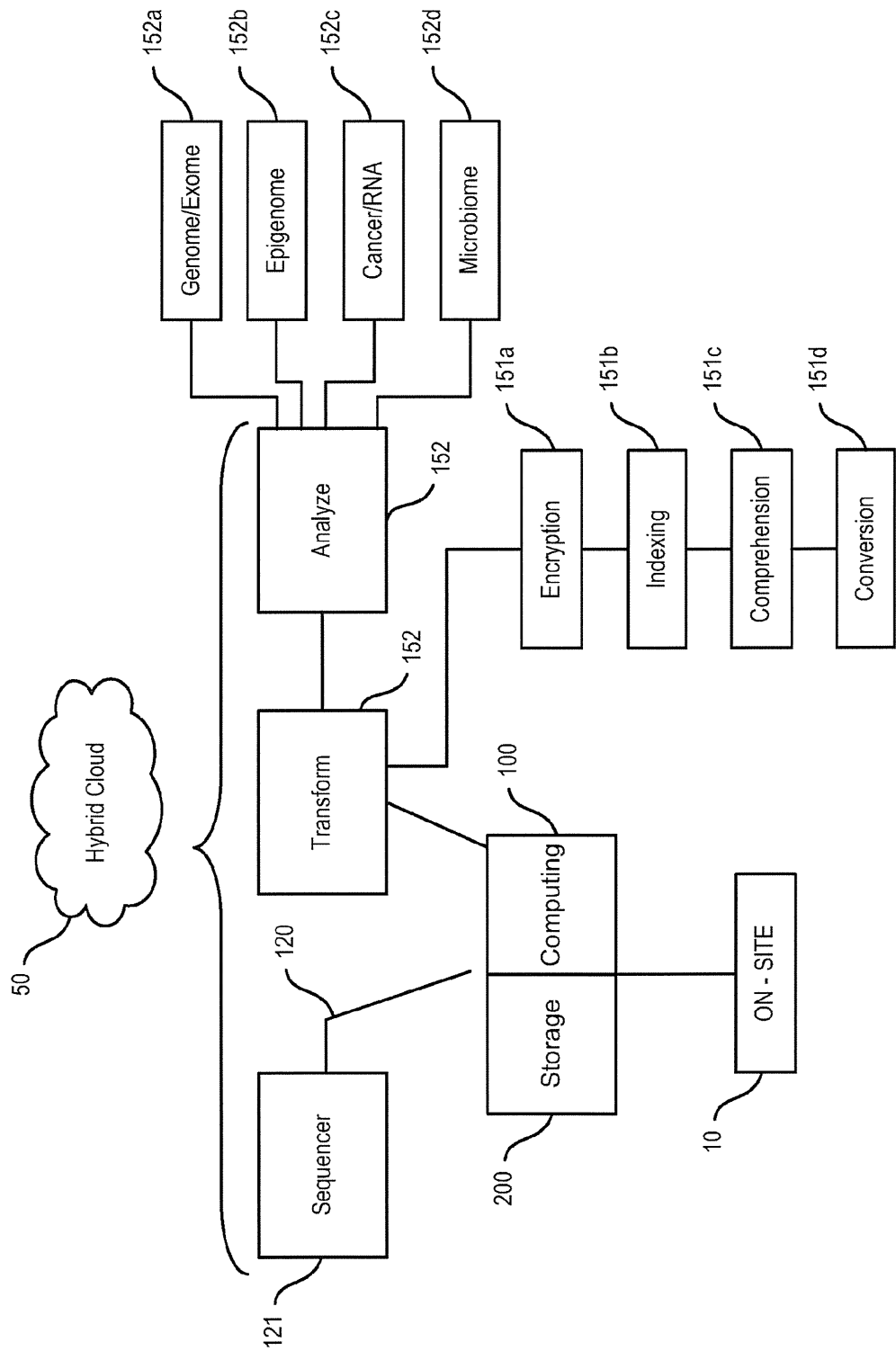


FIG. 42B

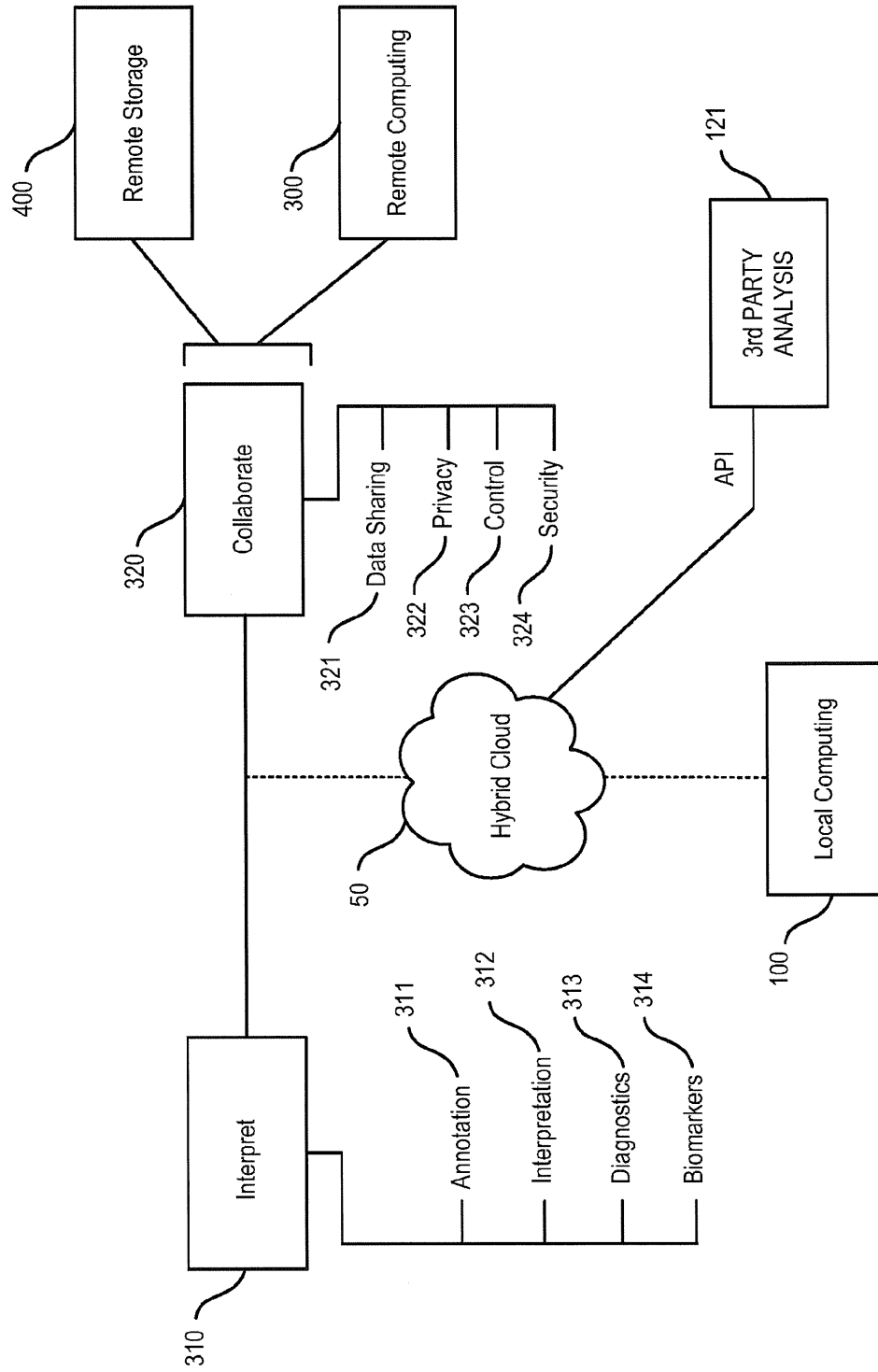


FIG. 42C

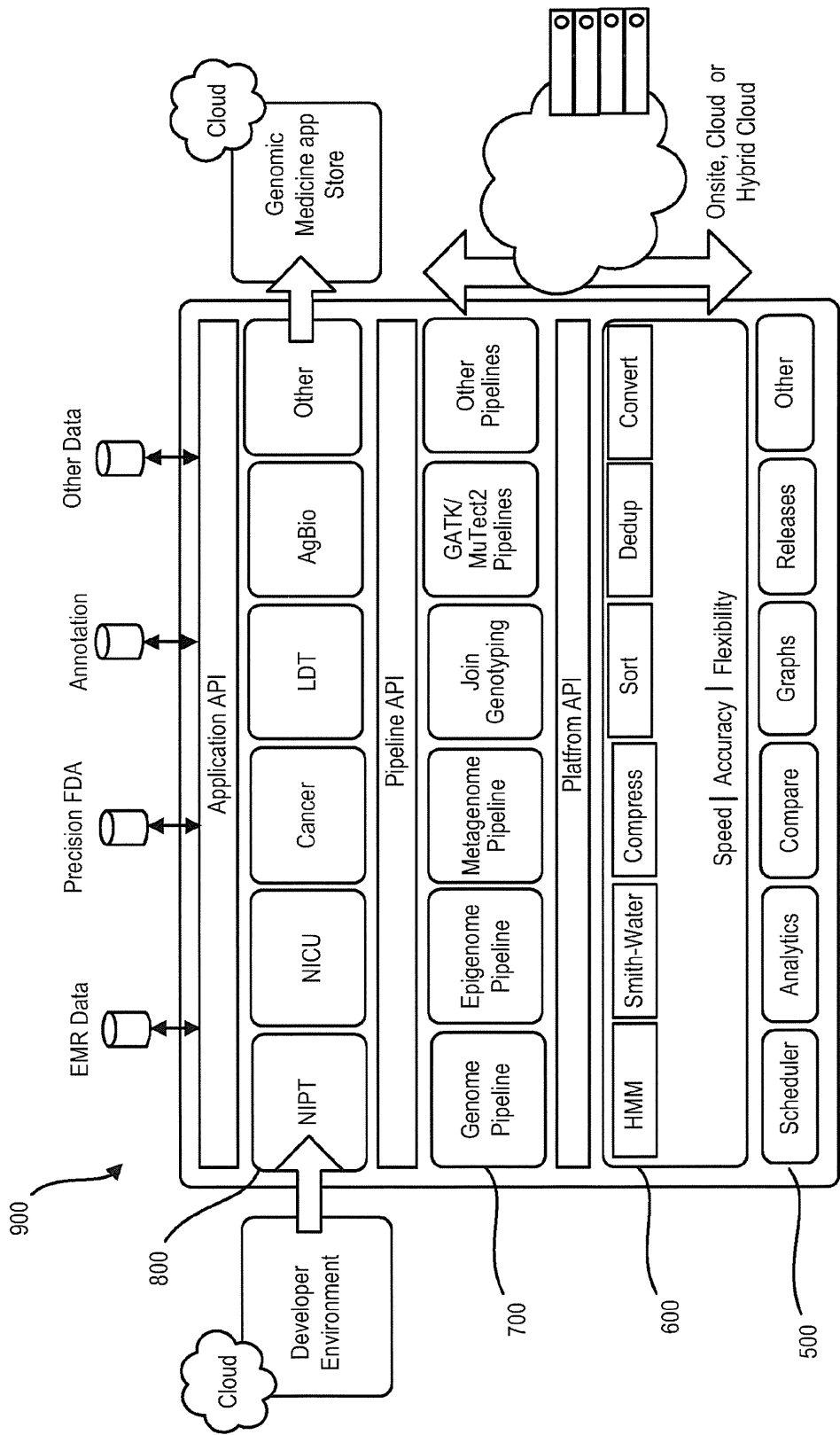


FIG. 43A

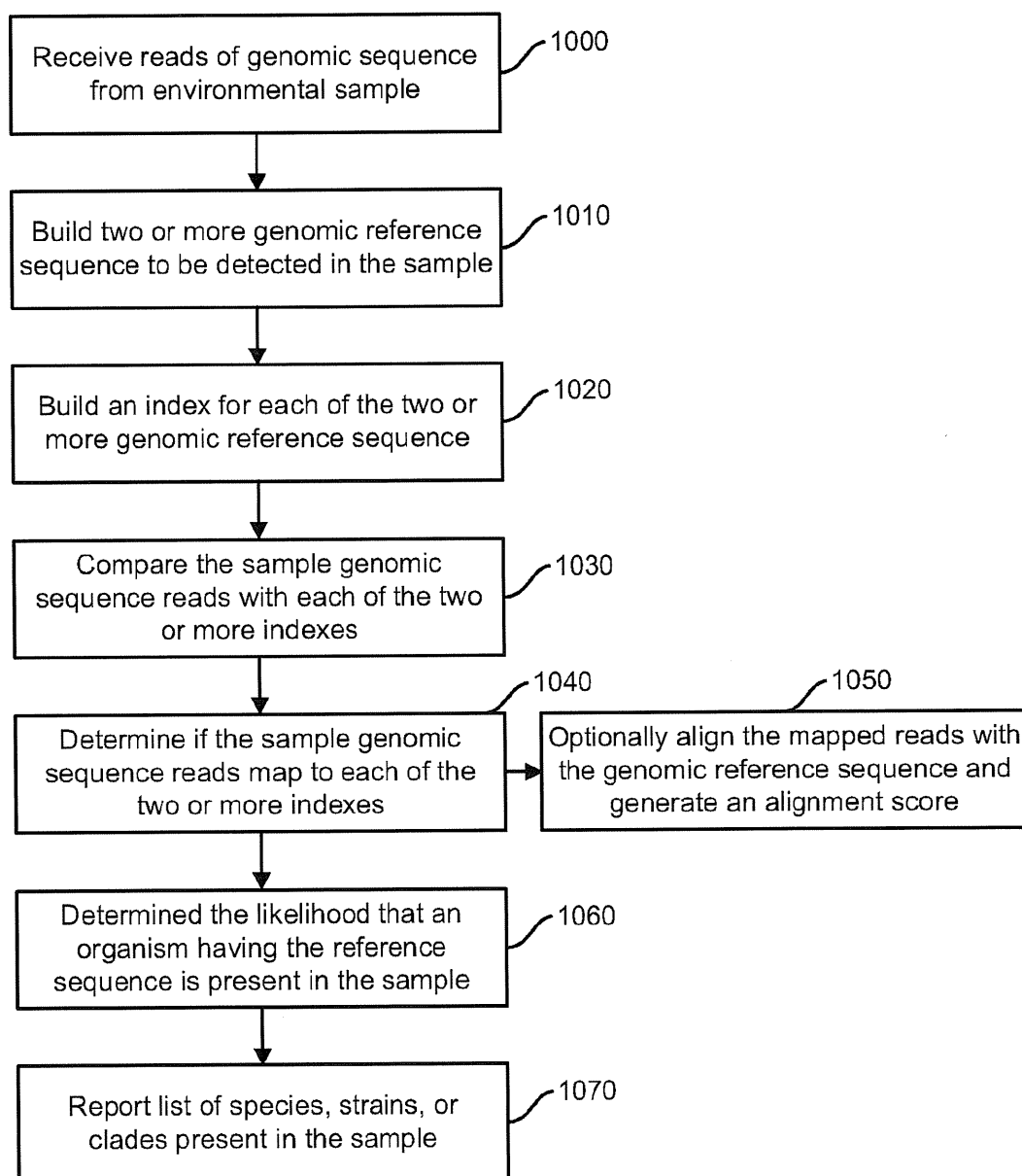


FIG. 43B

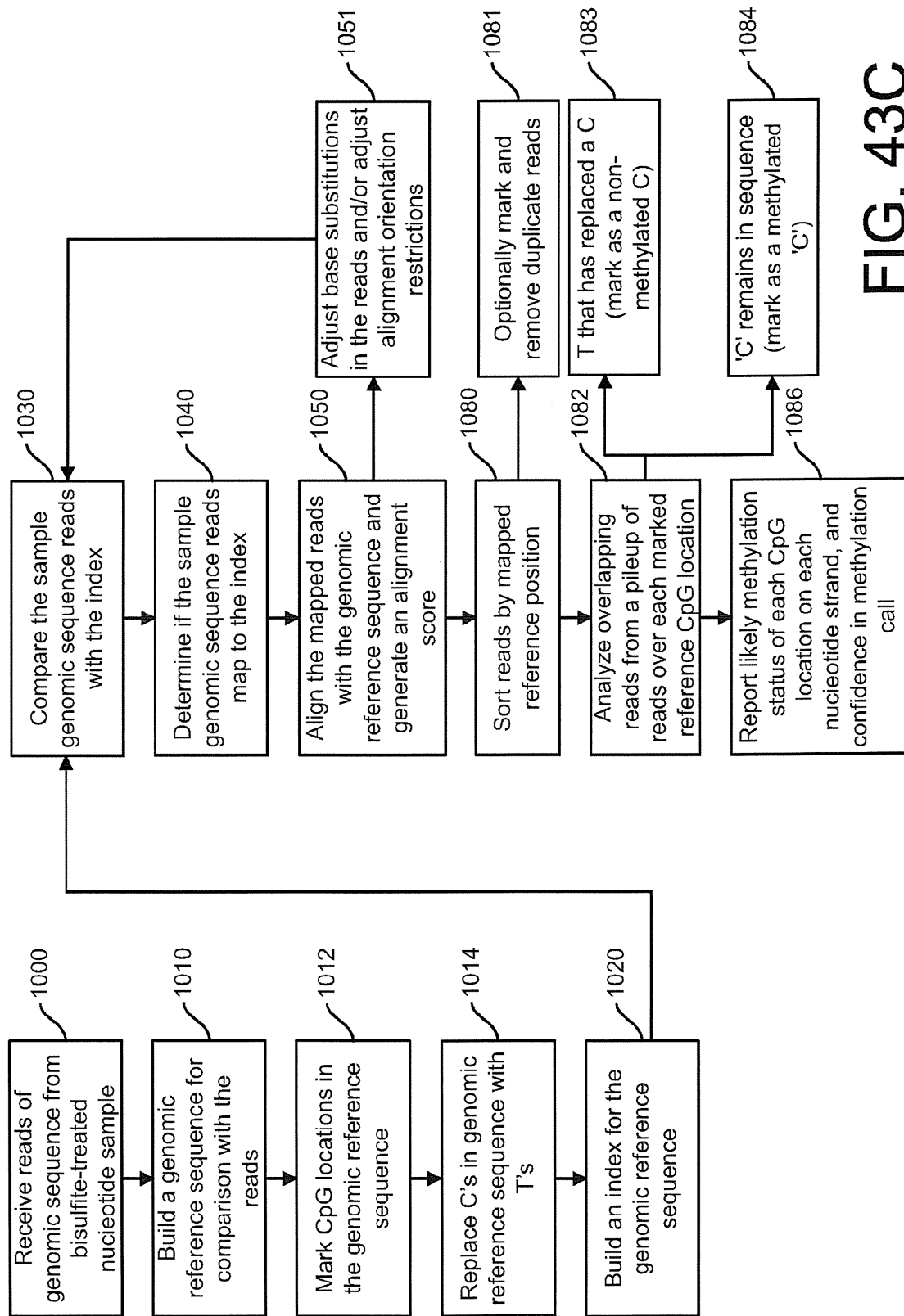


FIG. 43C

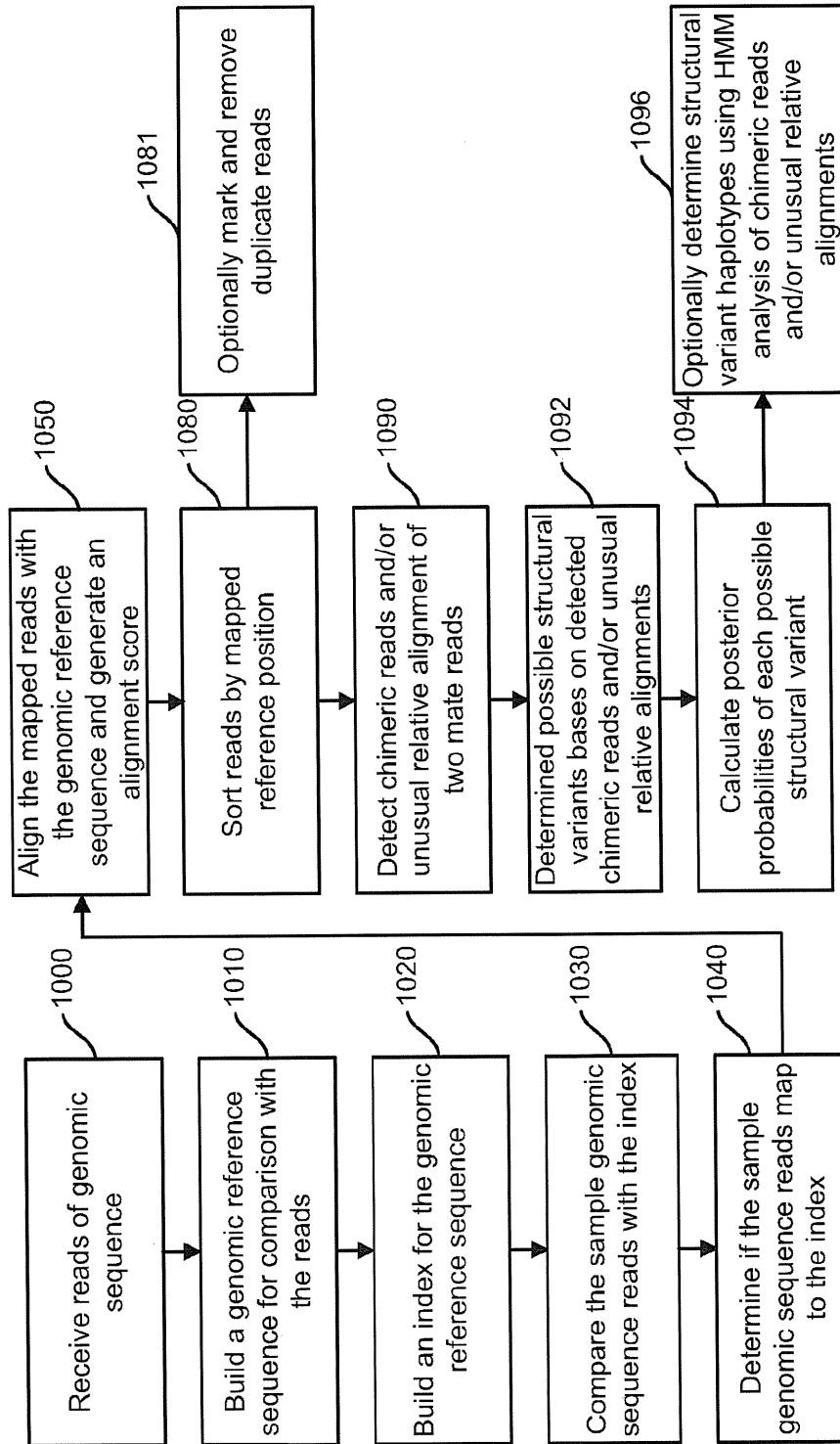


FIG. 43D

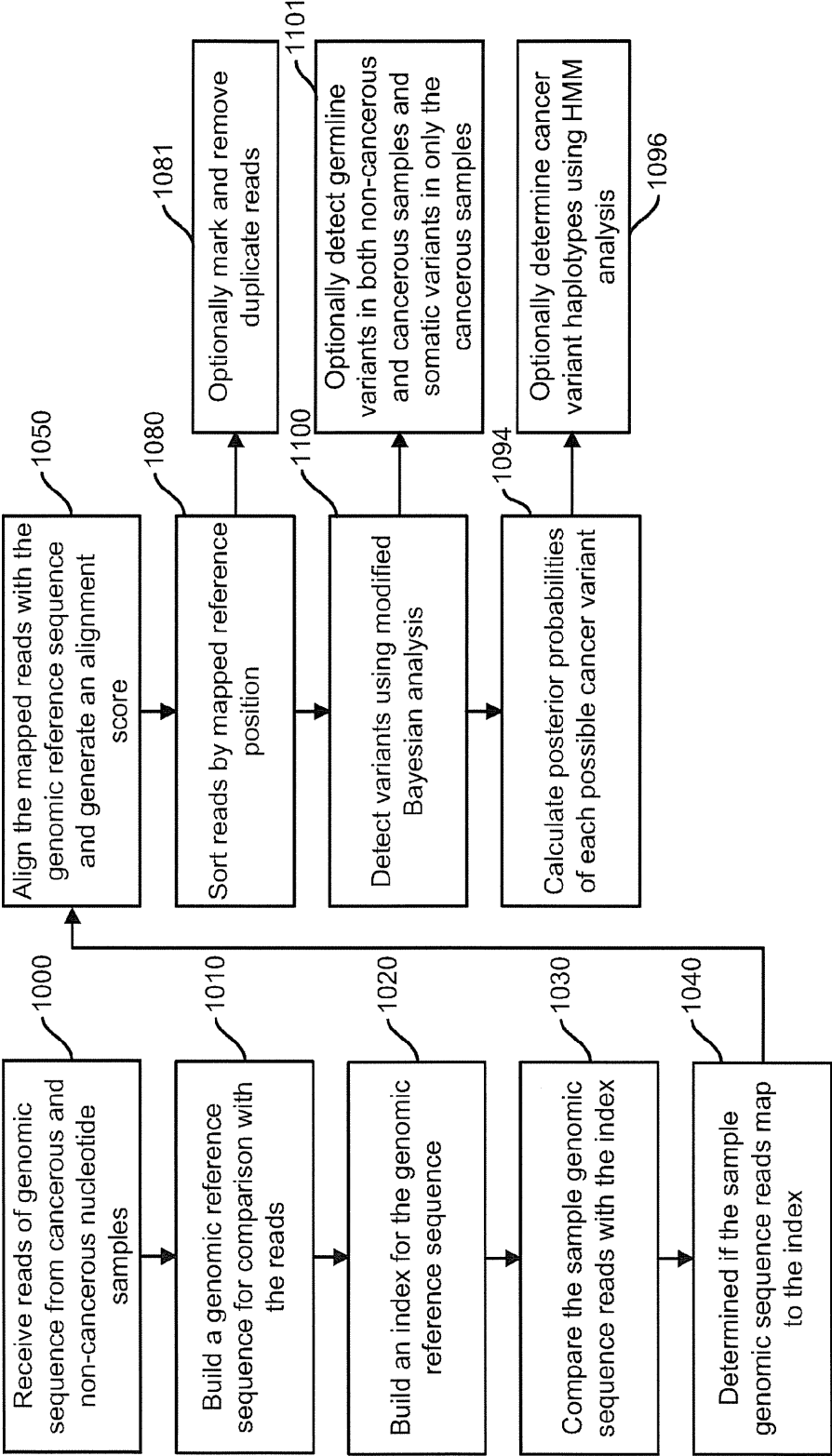


FIG. 43E

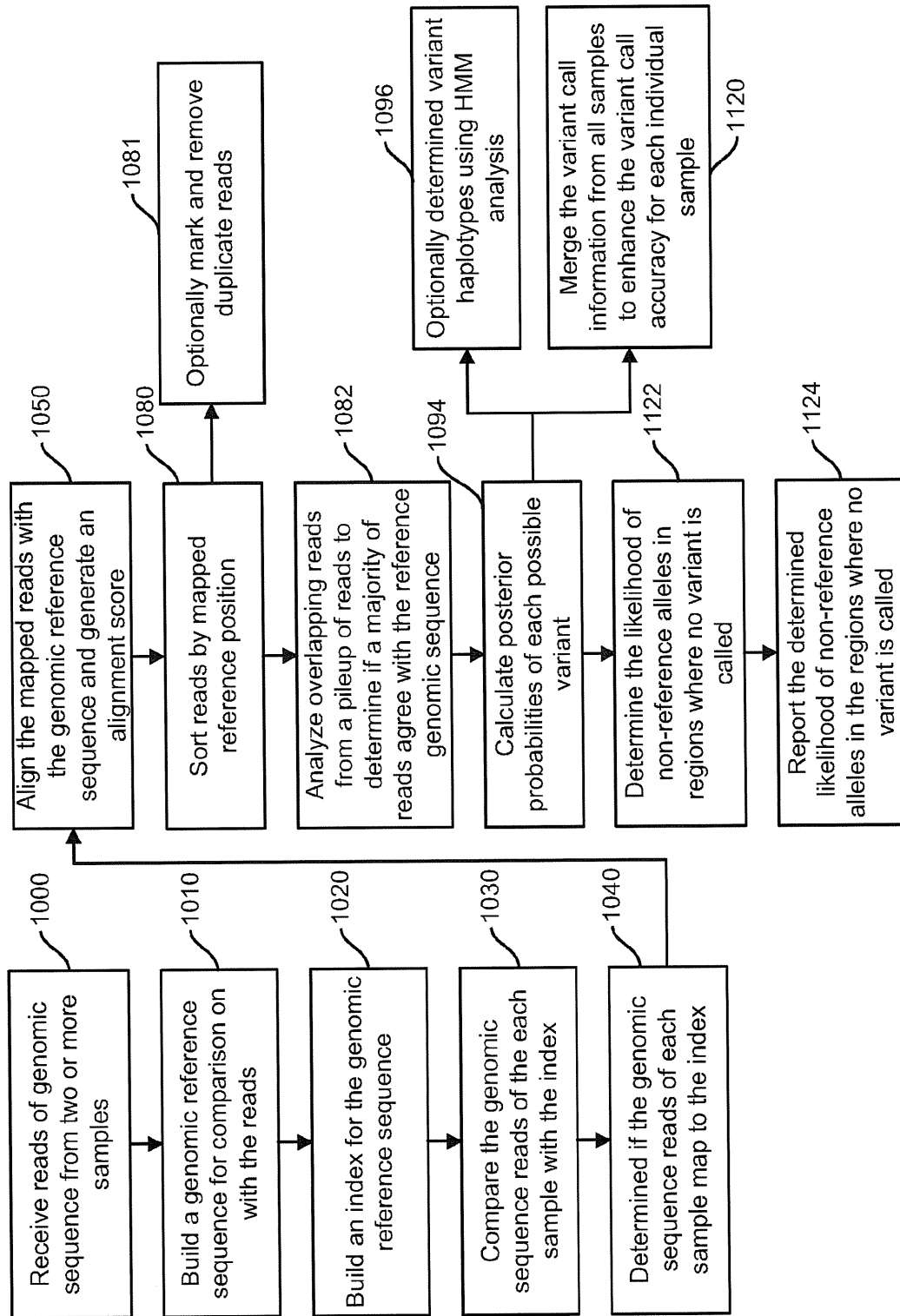


FIG. 43F

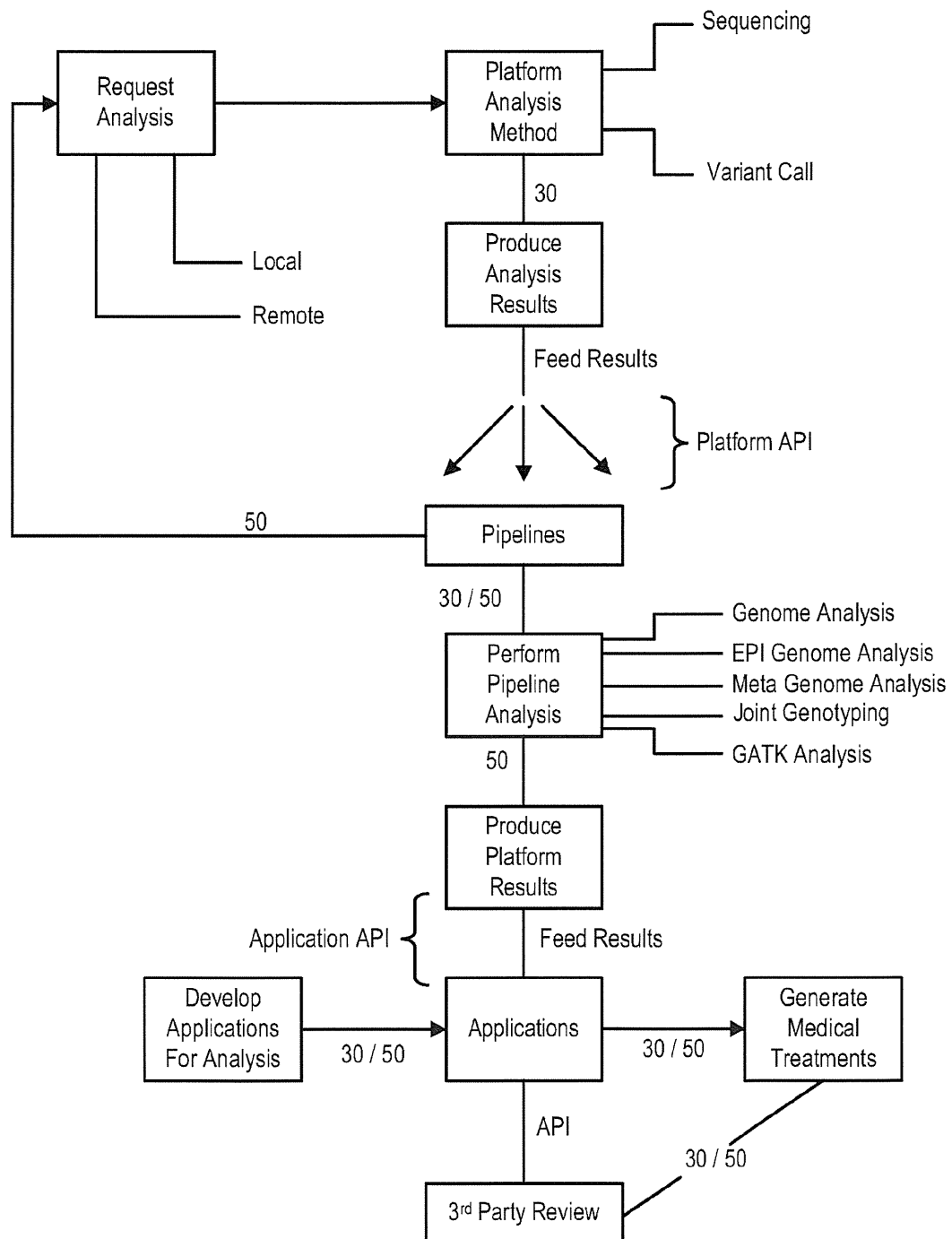


FIG. 44

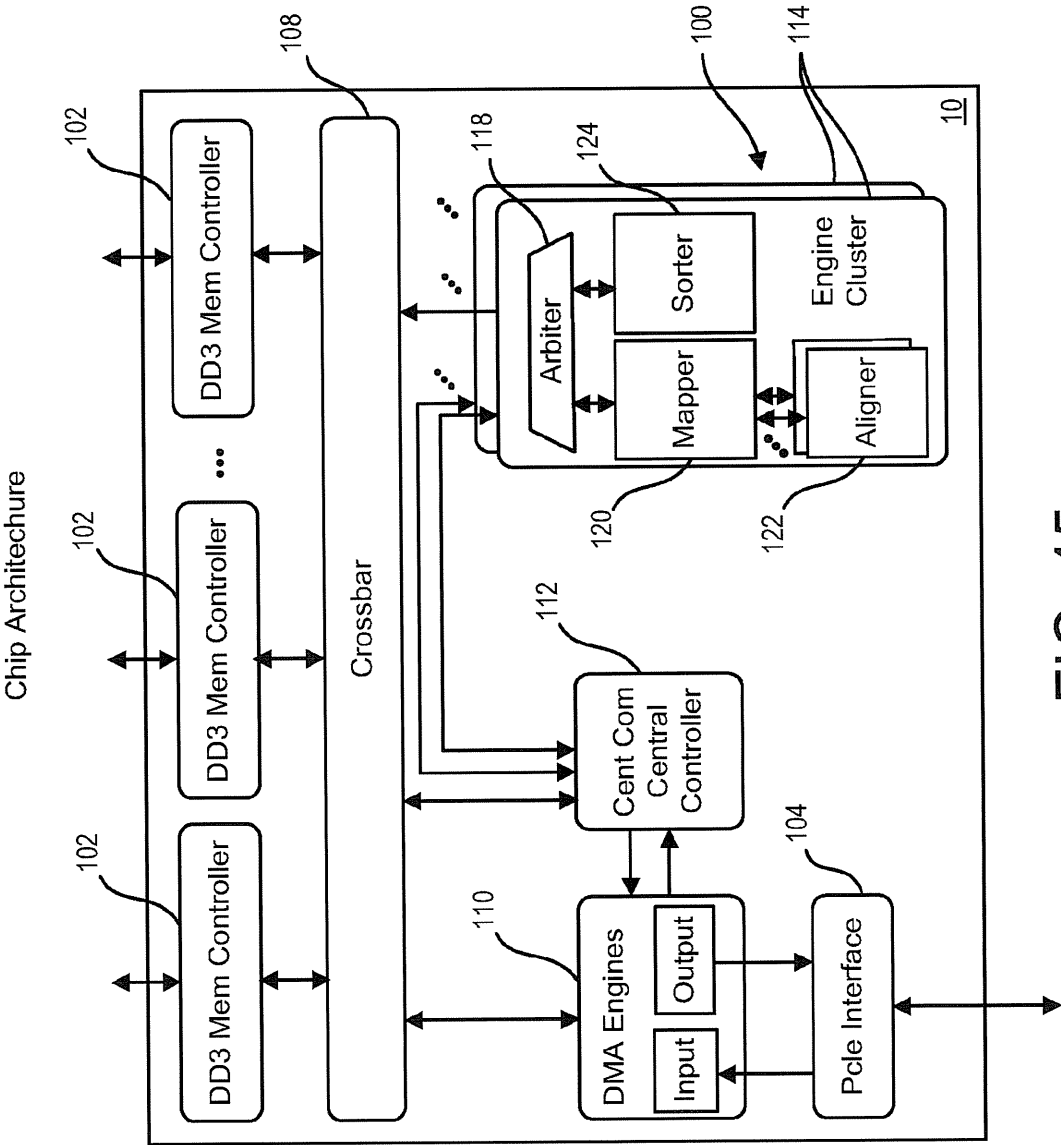


FIG. 45

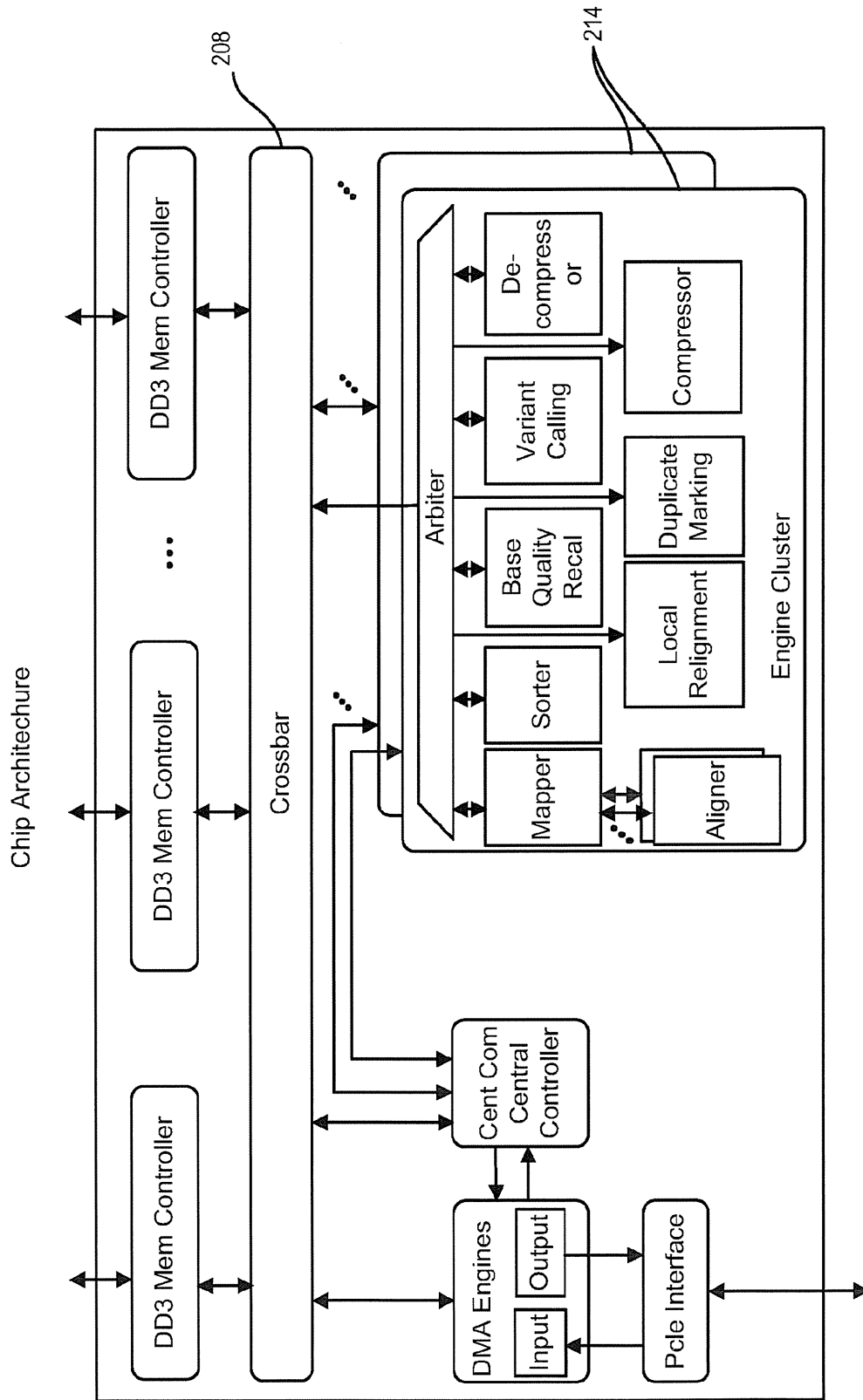


FIG. 46

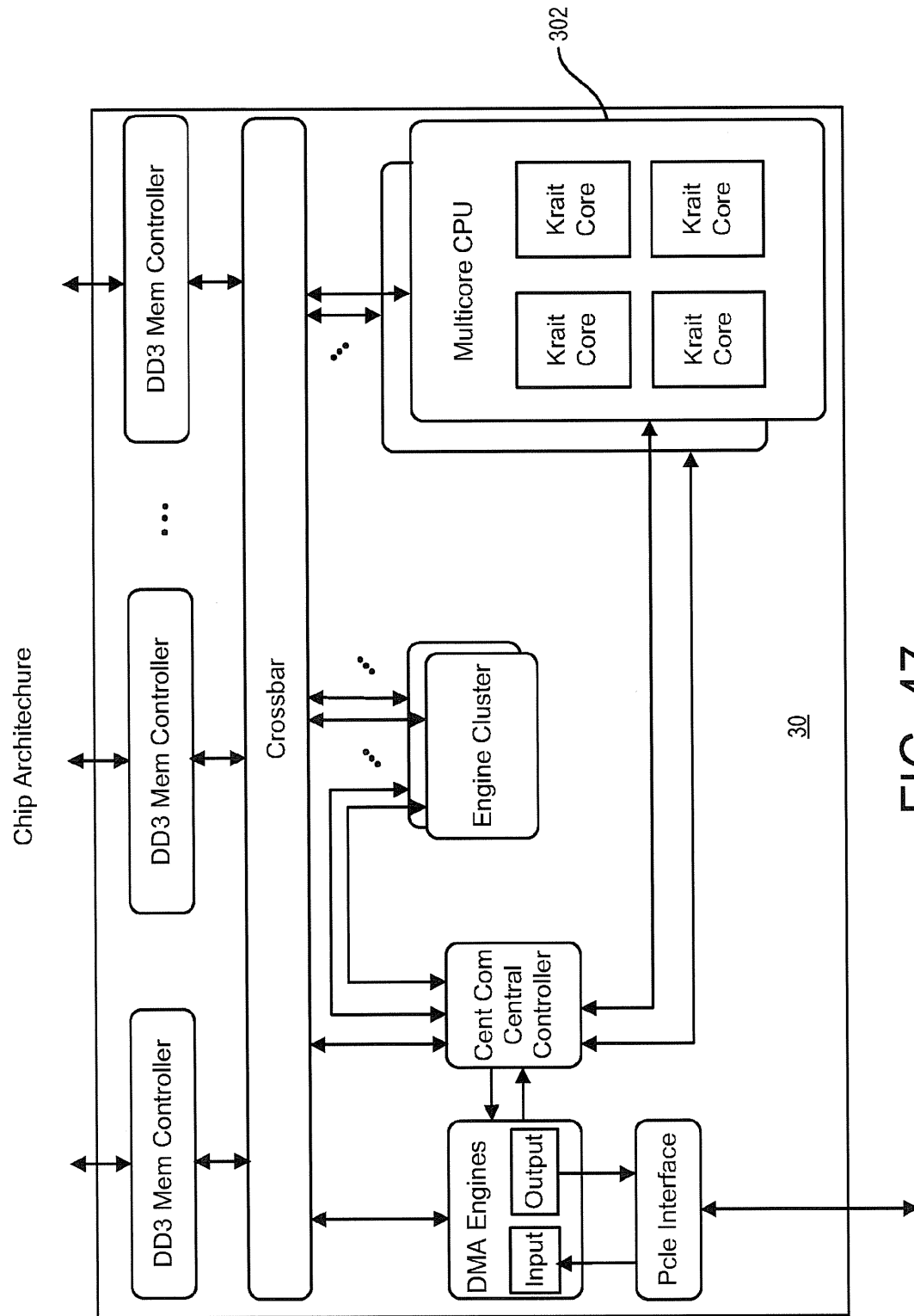


FIG. 47

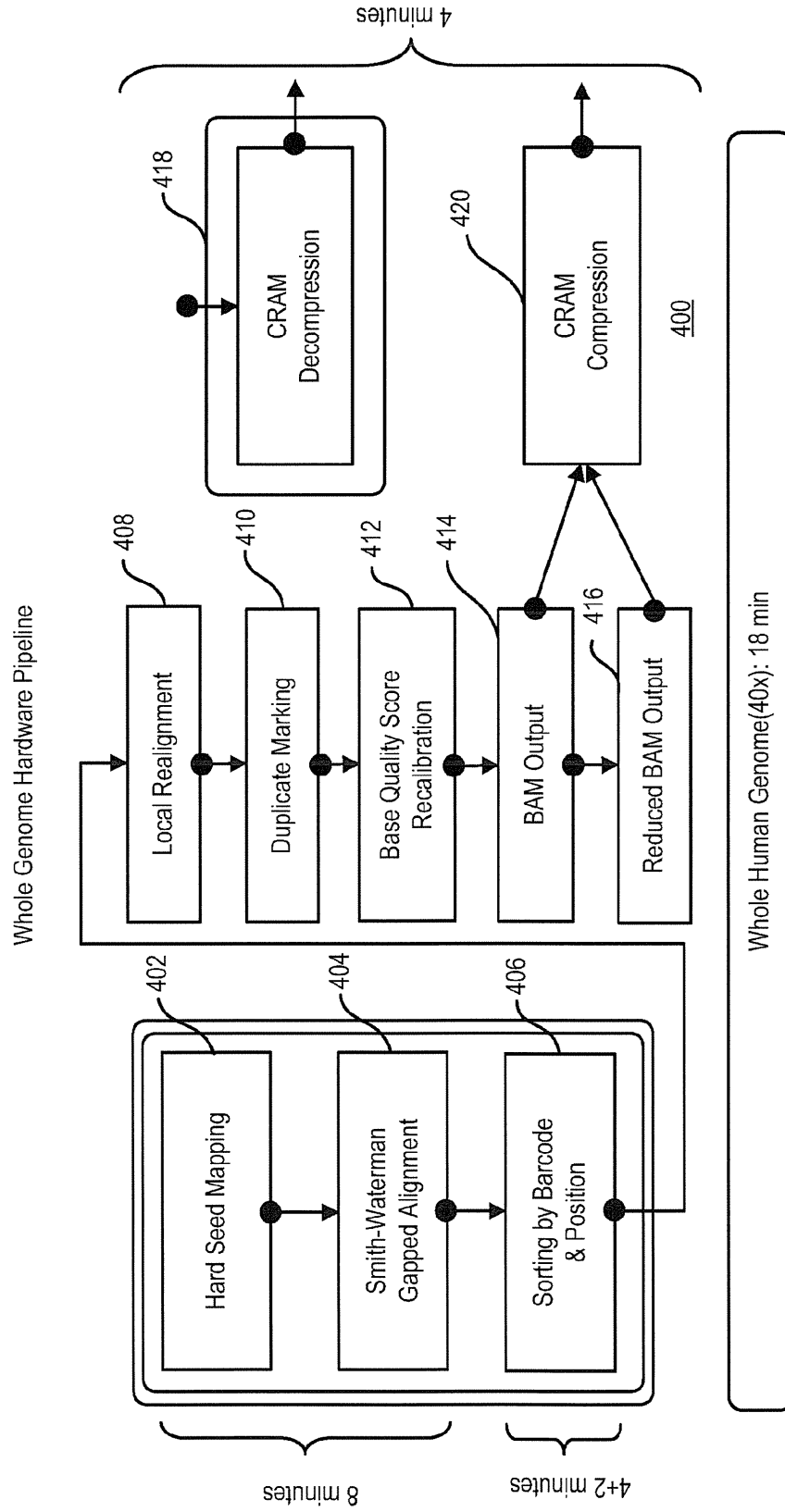


FIG. 48

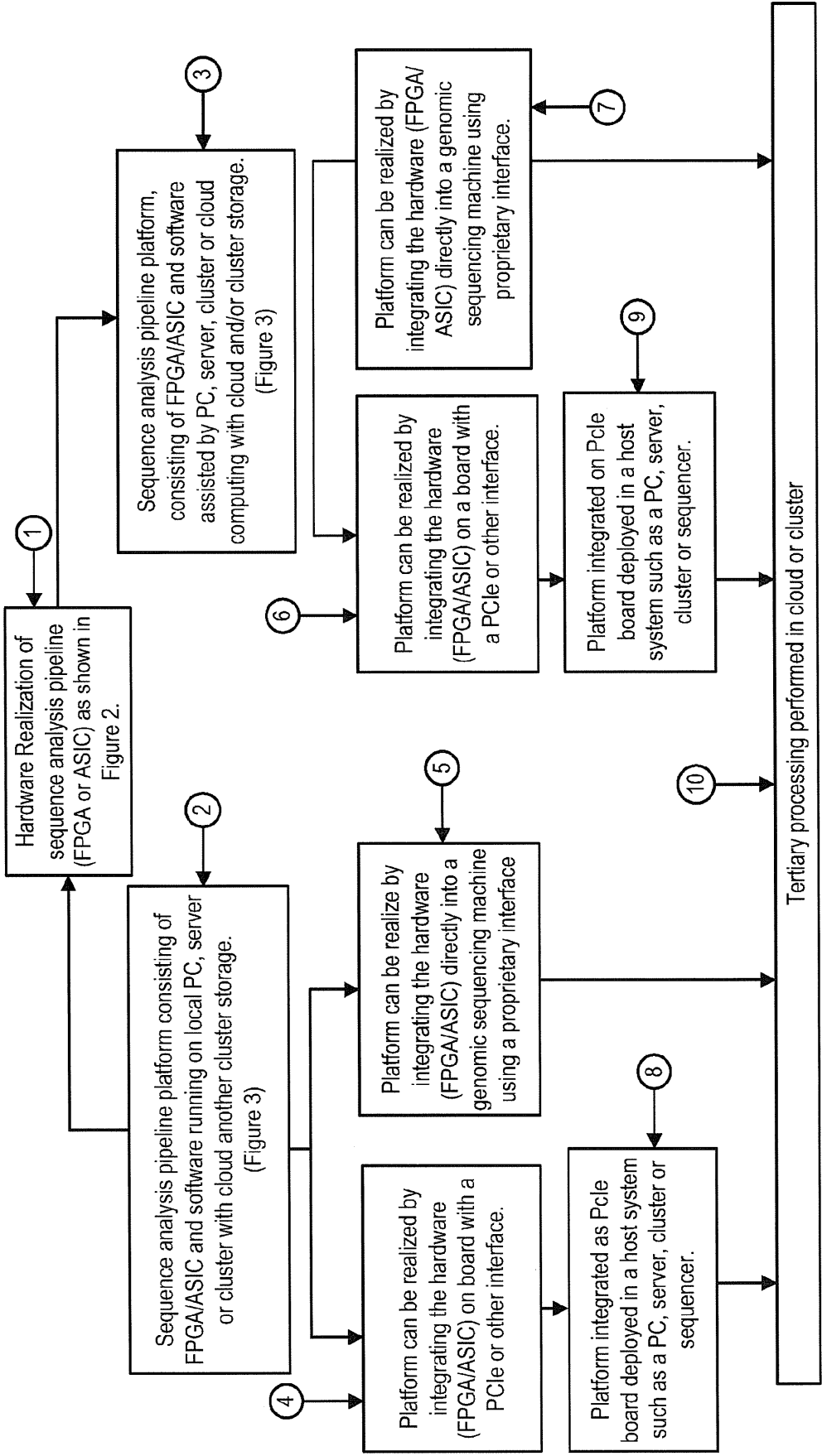


FIG. 49

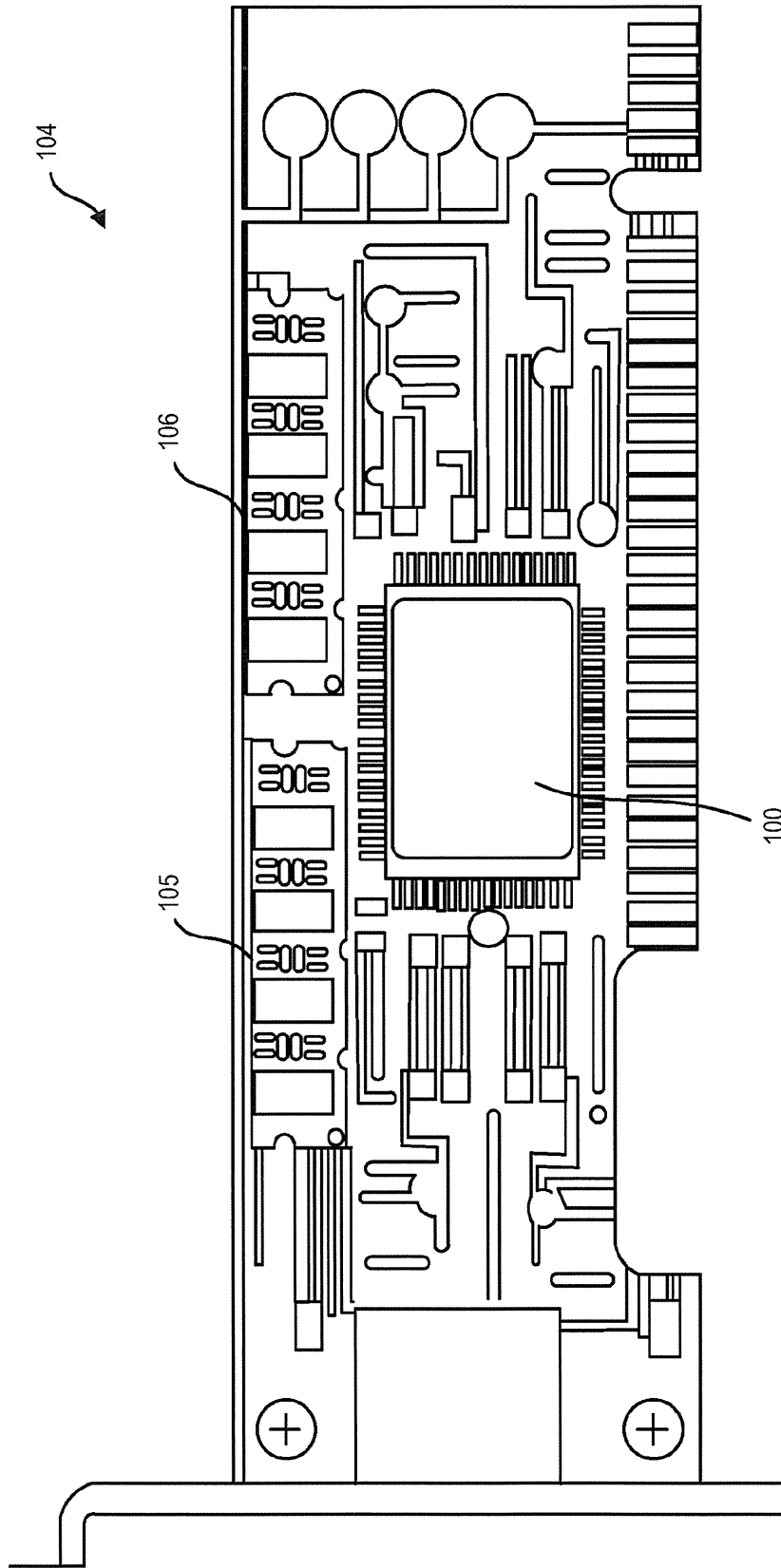


FIG. 50A

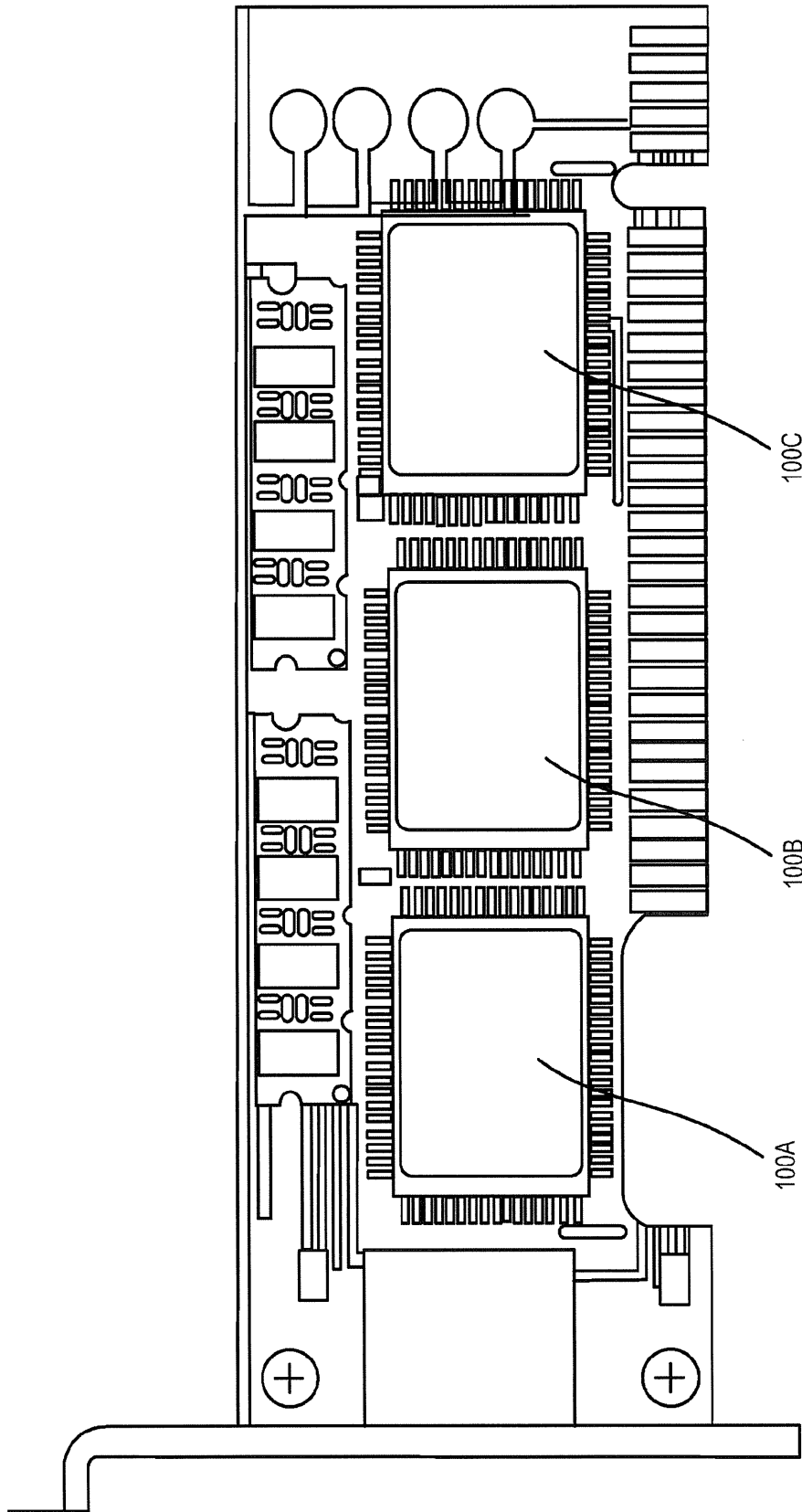


FIG. 50B

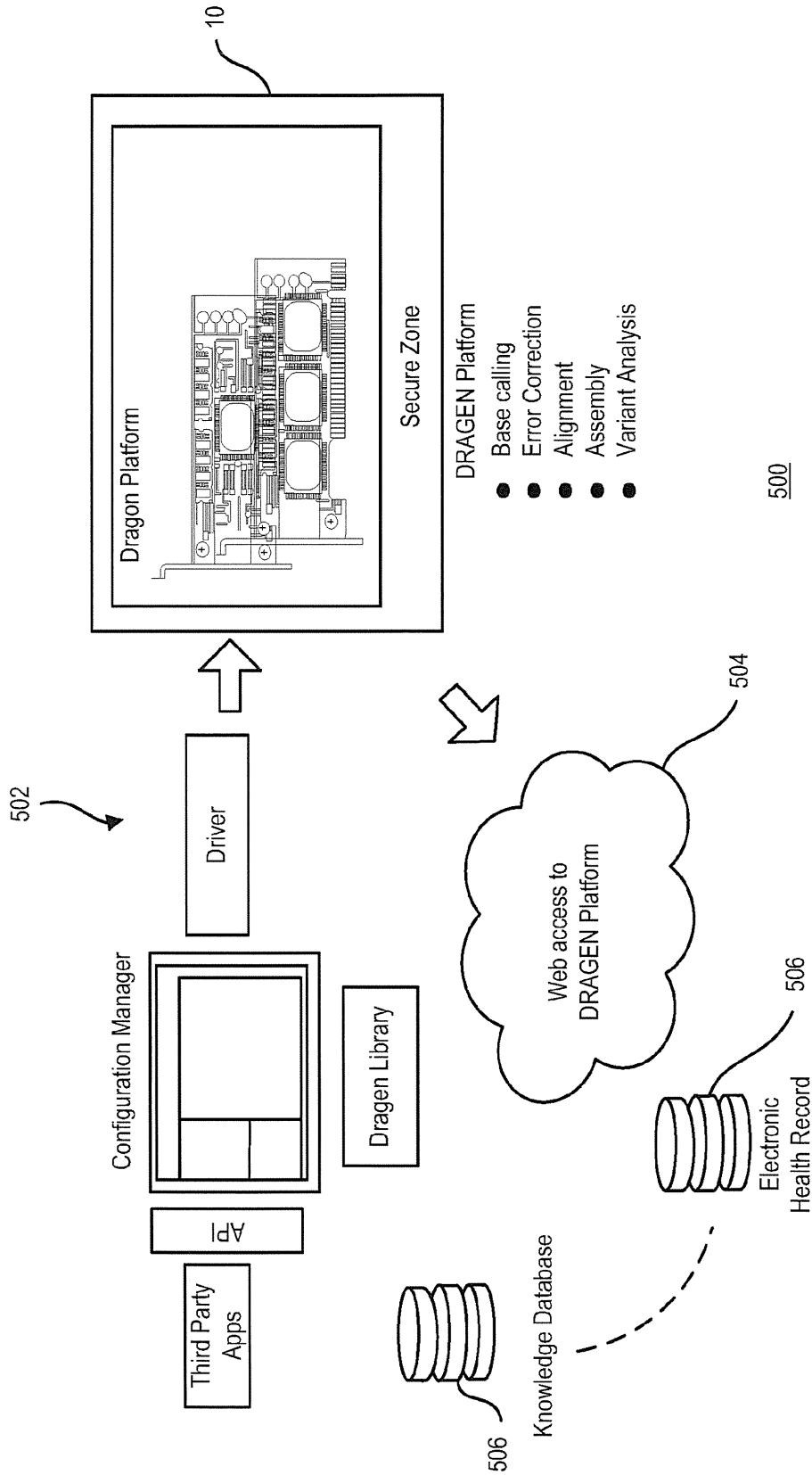


FIG. 51