Exhibit U
Part 1

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(54) **METHOD AND SOFTWARE FOR GROUP FLOATING-POINT ARITHMETIC OPERATIONS**

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See application file for complete search history.

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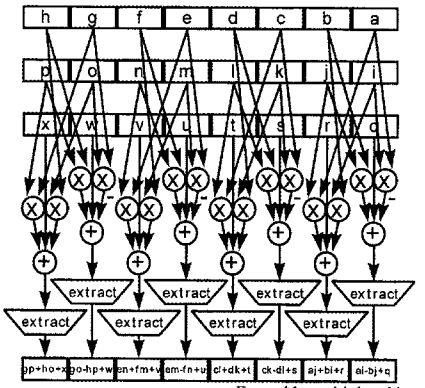
(57) **ABSTRACT**

Methods and software are presented for processing data in a programmable processor, involving (a) decoding instructions for execution using an execution unit operable to execute instructions by partitioning data stored in registers in a register file into multiple data elements, the instructions selected from an instruction set that includes group arithmetic instructions and group data handling instructions, (b) in response to decoding different group data handling instructions, executing group data handling operations that re-arrange data elements in different ways, and (c) in response to decoding different group arithmetic instructions, executing a plurality of different group floating-point and group integer arithmetic operations that each arithmetically operates on the multiple data elements stored in registers in the register file to produce a catenated result that is returned to a register in the register file, wherein the catenated result comprises a plurality of individual results.

22 Claims, 384 Drawing Sheets



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* cited by examiner

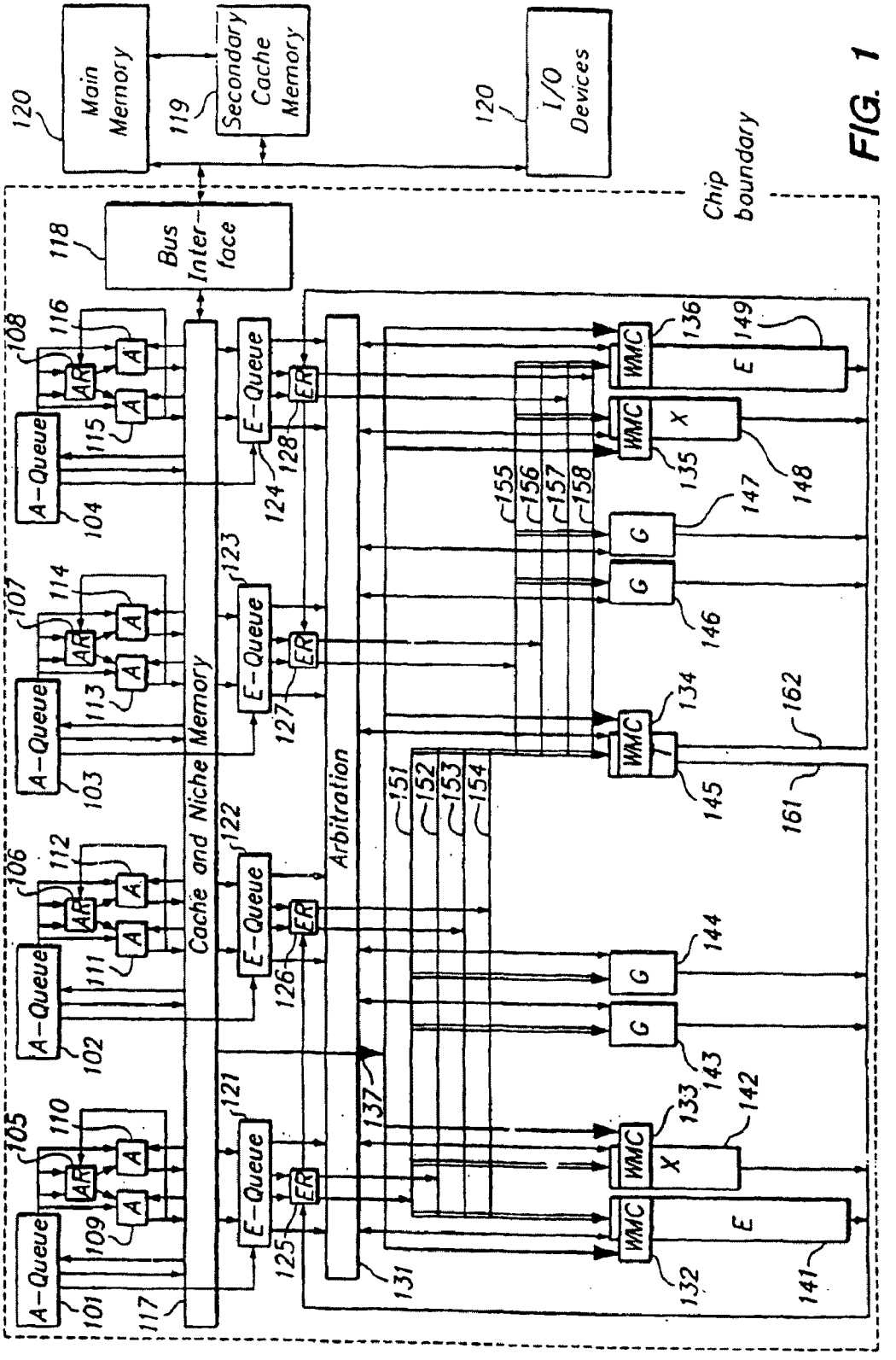

Main Memory
120
Secondary Cache Memory
119
I/O Devices
120
Chip boundary
Bus Interface
118
Cache and Niche Memory
117
Arbitration
131
A-Queue
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
AR
A
E-Queue
121
122
123
124
125
126
127
128
ER
WMC
132
133
134
135
136
137
141
142
143
144
145
146
147
148
149
151
152
153
154
155
156
157
158
161
162
E
X
G
I

FIG. 1

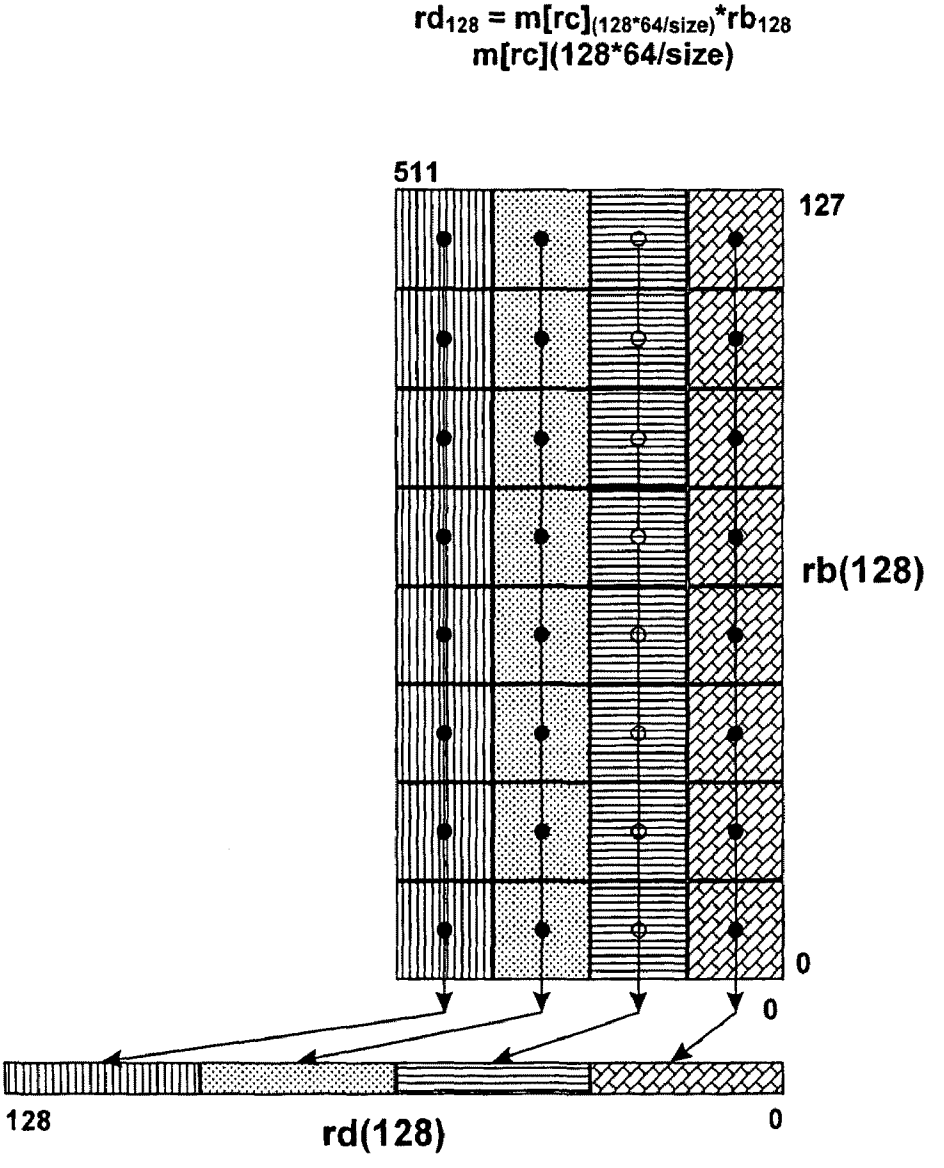

rd128 = m[rc](128*64/size)*rb128
m[rc](128*64/size)
511
127
rb(128)
0
0
128
rd(128)
0

FIG. 2

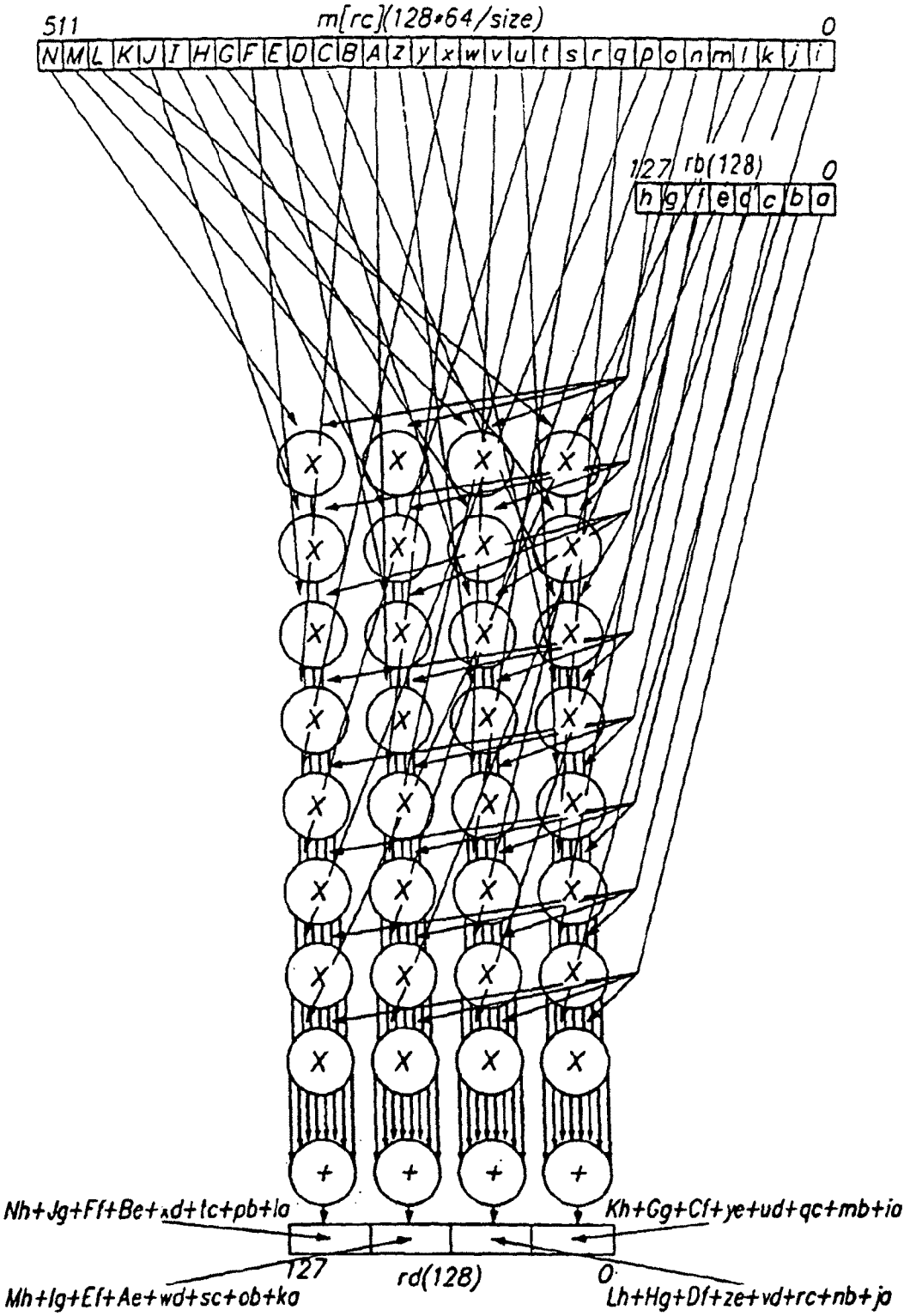

511
m[rc](128*64/size)
0
N M L K J I H G F E D C B A z y x w v u t s r q p o n m l k j i
127
rb(128)
0
h g f e d c b a
Nh+Jg+Ff+Be+xd+tc+pb+la
Kh+Gg+Cf+ye+ud+qc+mb+ia
127
rd(128)
0
Mh+Ig+Ef+Ae+wd+sc+ob+ka
Lh+Hg+Df+ze+vd+rc+nb+ja

FIG. 3

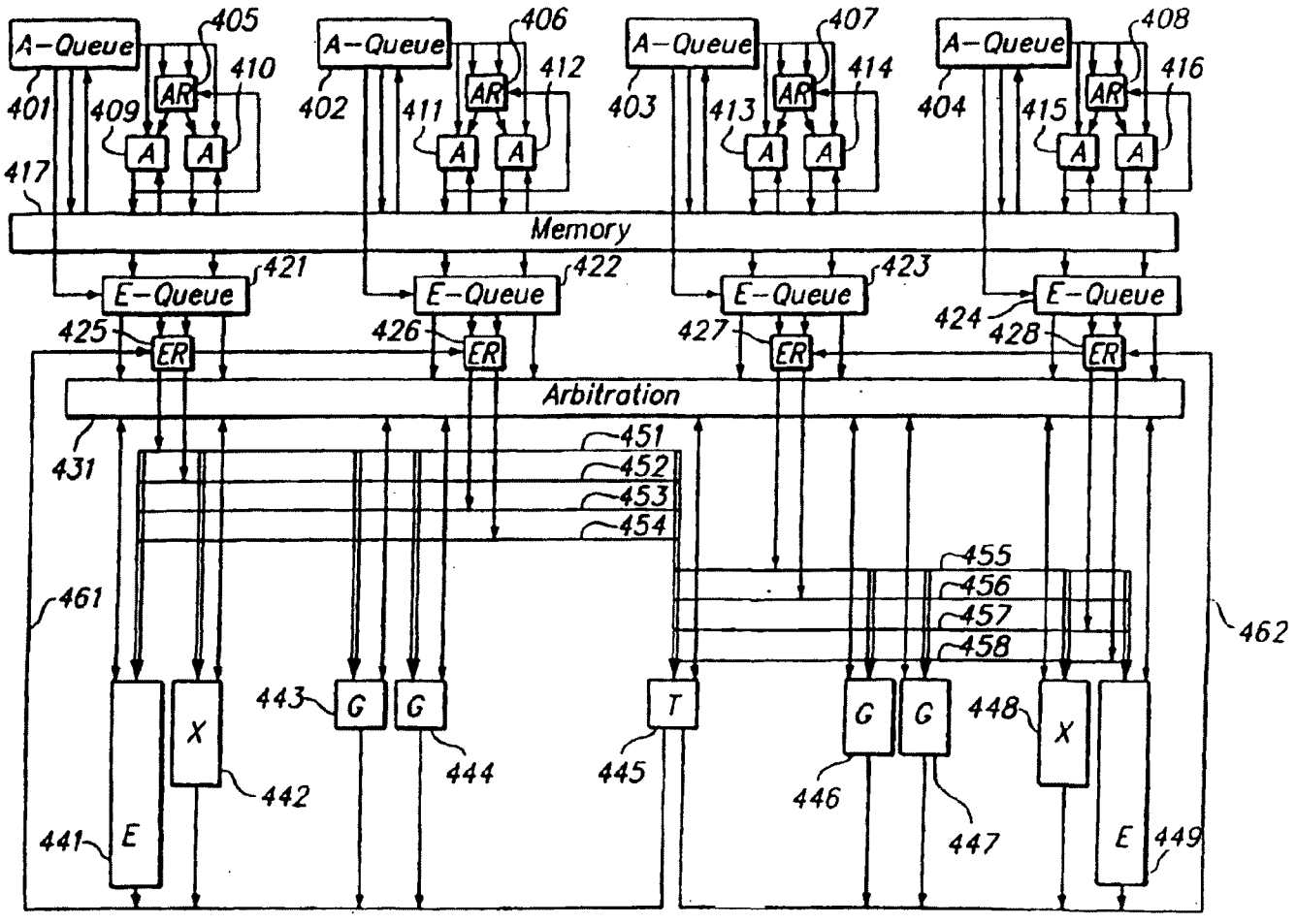
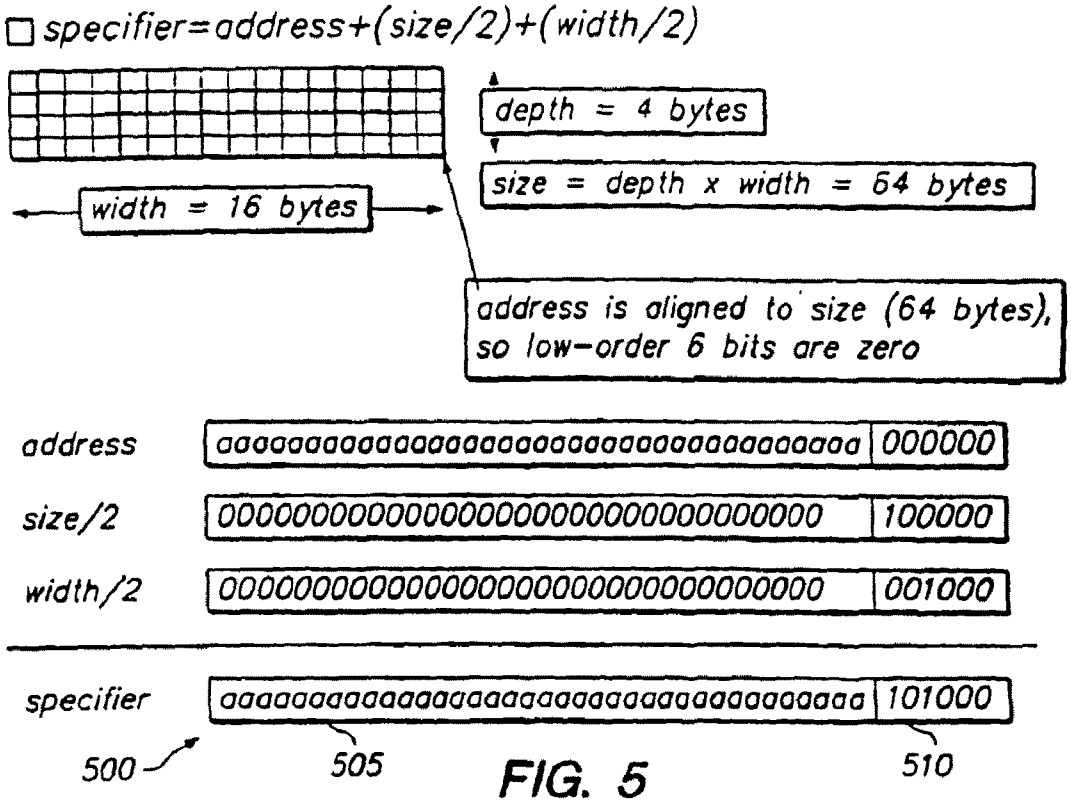

A-Queue
405
406
407
408
401
402
403
404
AR
410
412
414
416
409
411
413
415
A
417
Memory
E-Queue
421
422
423
425
426
427
424
428
ER
Arbitration
431
451
452
453
454
455
456
457
458
461
462
443
G
444
T
445
446
447
448
X
442
441
E
449

FIG. 4


specifier=address+(size/2)+(width/2)
depth = 4 bytes
size = depth x width = 64 bytes
width = 16 bytes
address is aligned to size (64 bytes), so low-order 6 bits are zero
address
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size/2
00000000000000000000000000000000 100000
width/2
00000000000000000000000000000000 001000
specifier
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 101000
500
505
510

FIG. 5

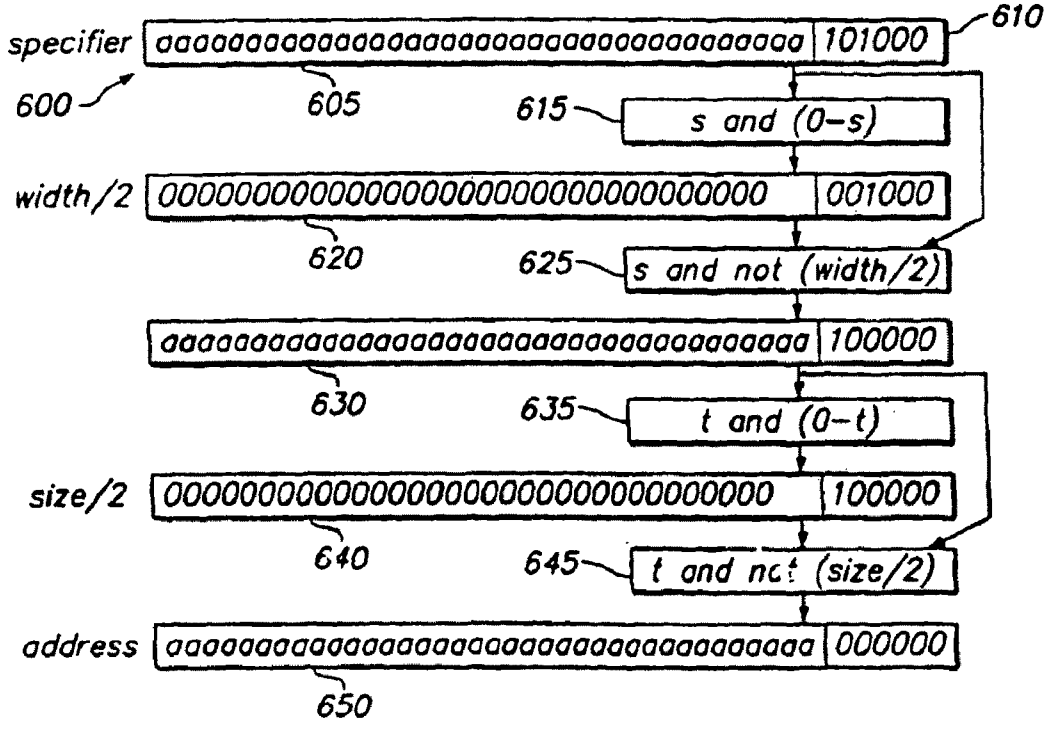

specifier
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 101000
610
600
605
615
s and (0-s)
width/2
00000000000000000000000000000000 001000
620
625
s and not (width/2)
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 100000
630
635
t and (0-t)
size/2
00000000000000000000000000000000 100000
640
645
t and not (size/2)
address
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 000000
650

FIG. 6

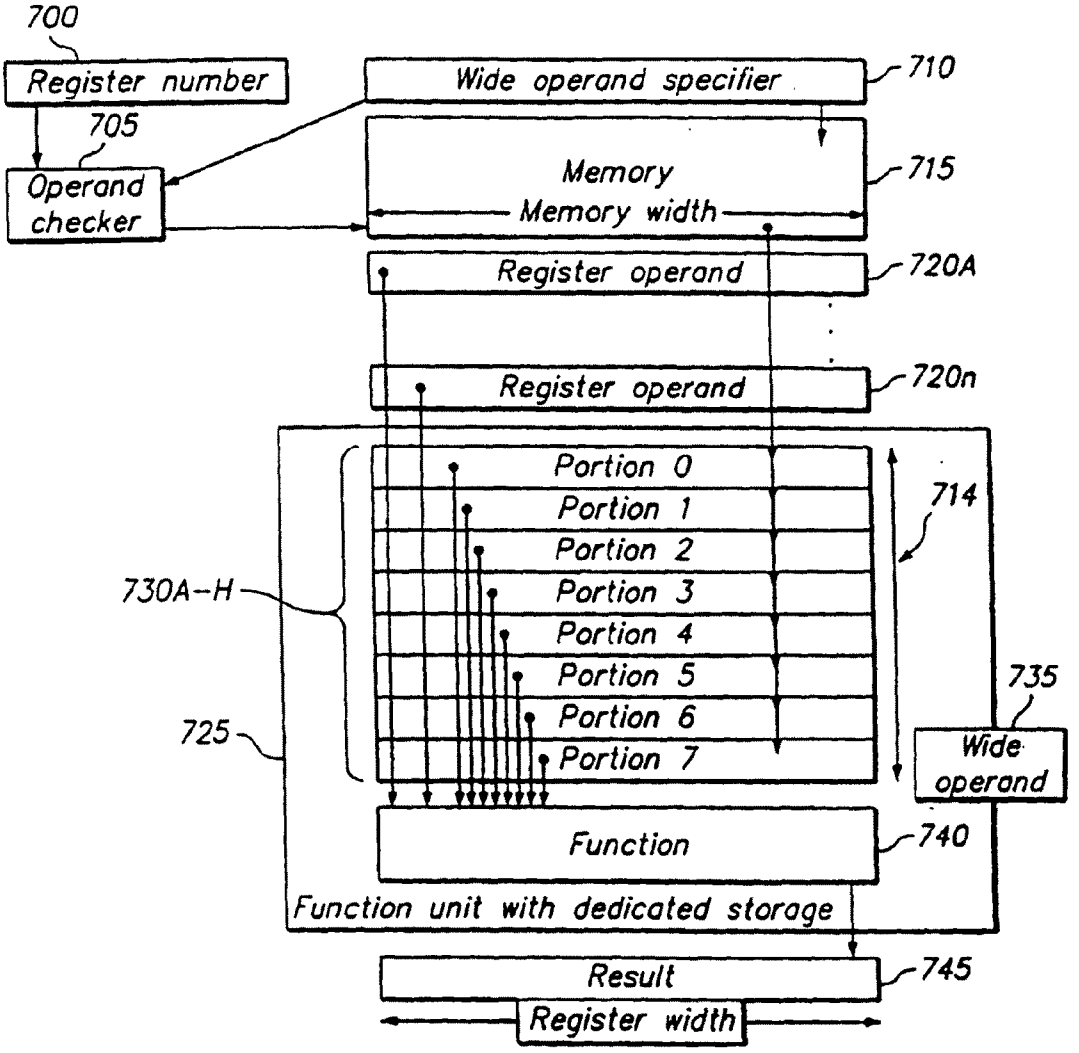

700
Register number
705
Operand checker
Wide operand specifier
710
Memory
Memory width
715
Register operand
720A
Register operand
720n
Portion 0
Portion 1
Portion 2
Portion 3
Portion 4
Portion 5
Portion 6
Portion 7
714
730A-H
725
735
Wide operand
Function
740
Function unit with dedicated storage
Result
745
Register width

FIG. 7

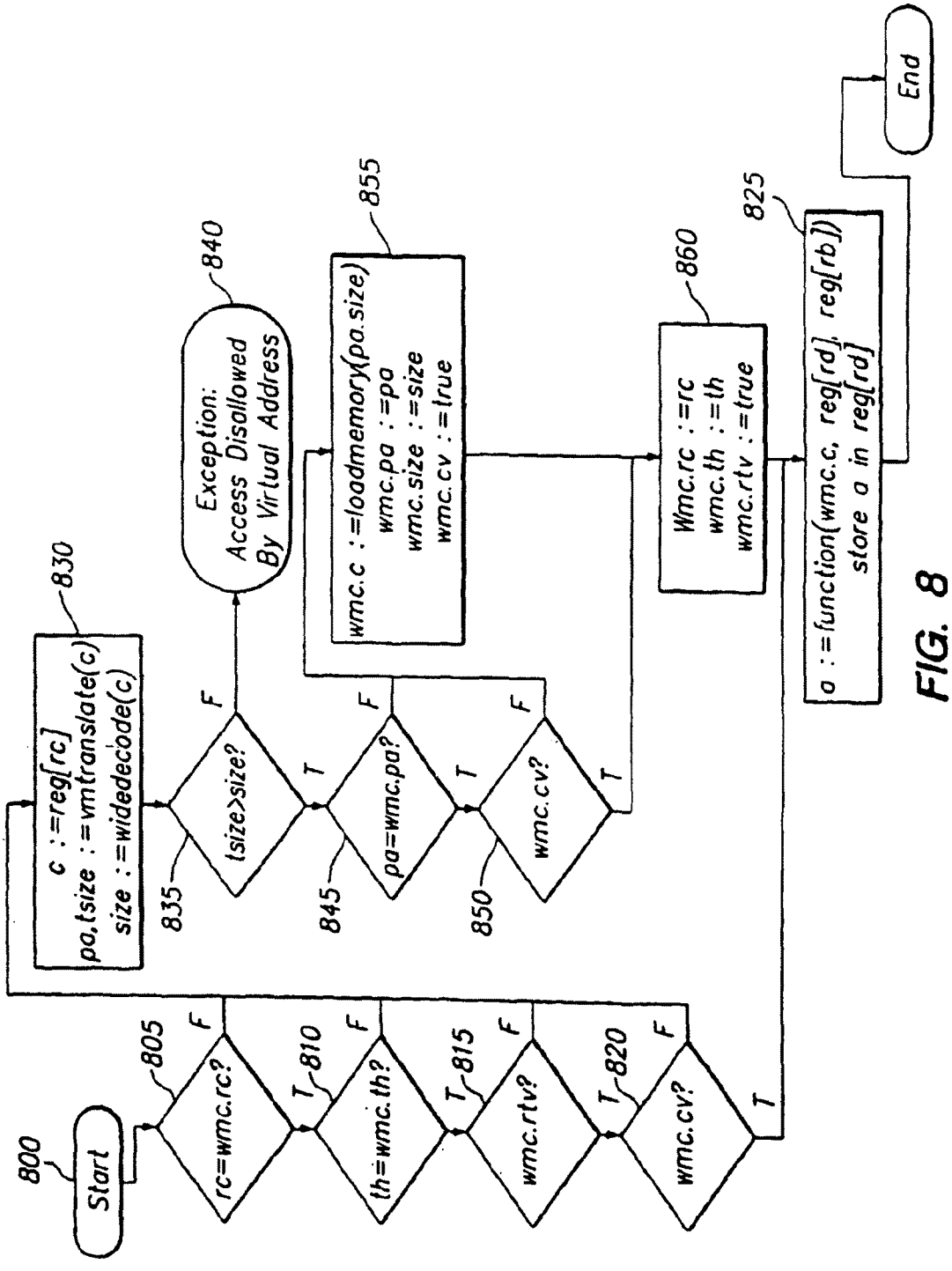

800
Start
805
rc=wmc.rc?
F
T
810
th=wmc.th?
F
T
815
wmc.rtv?
F
T
820
wmc.cv?
F
T
825
o := function(wmc.c, reg[rd], reg[rb])
store o in reg[rd]
End
830
c := reg[rc]
pa,tsize := vmtranslate(c)
size := widedecode(c)
835
tsize>size?
F
T
840
Exception:
Access Disallowed
By Virtual Address
845
pa=wmc.pa?
F
T
850
wmc.cv?
F
T
855
wmc.c := loadmemory(pa.size)
wmc.pa := pa
wmc.size := size
wmc.cv := true
860
Wmc.rc := rc
wmc.th := th
wmc.rtv := true

FIG. 8

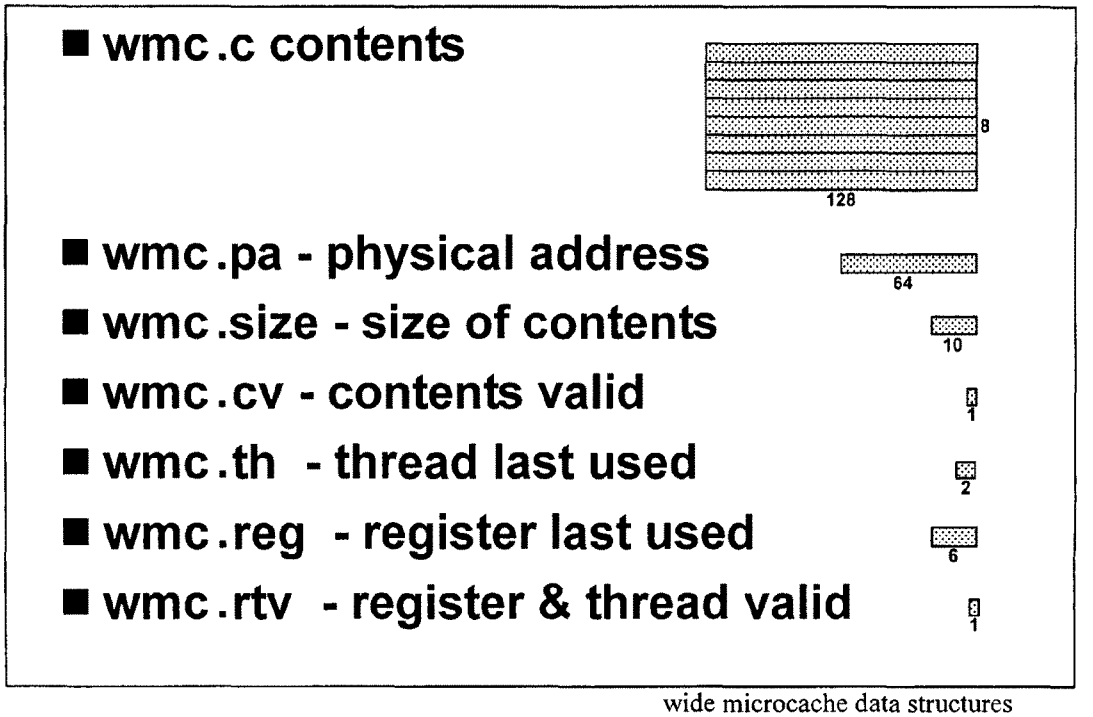

wmc.c contents
8
128
wmc.pa - physical address
64
wmc.size - size of contents
10
wmc.cv - contents valid
1
wmc.th - thread last used
2
wmc.reg - register last used
6
wmc.rtv - register & thread valid
1
wide microcache data structures

FIG. 9

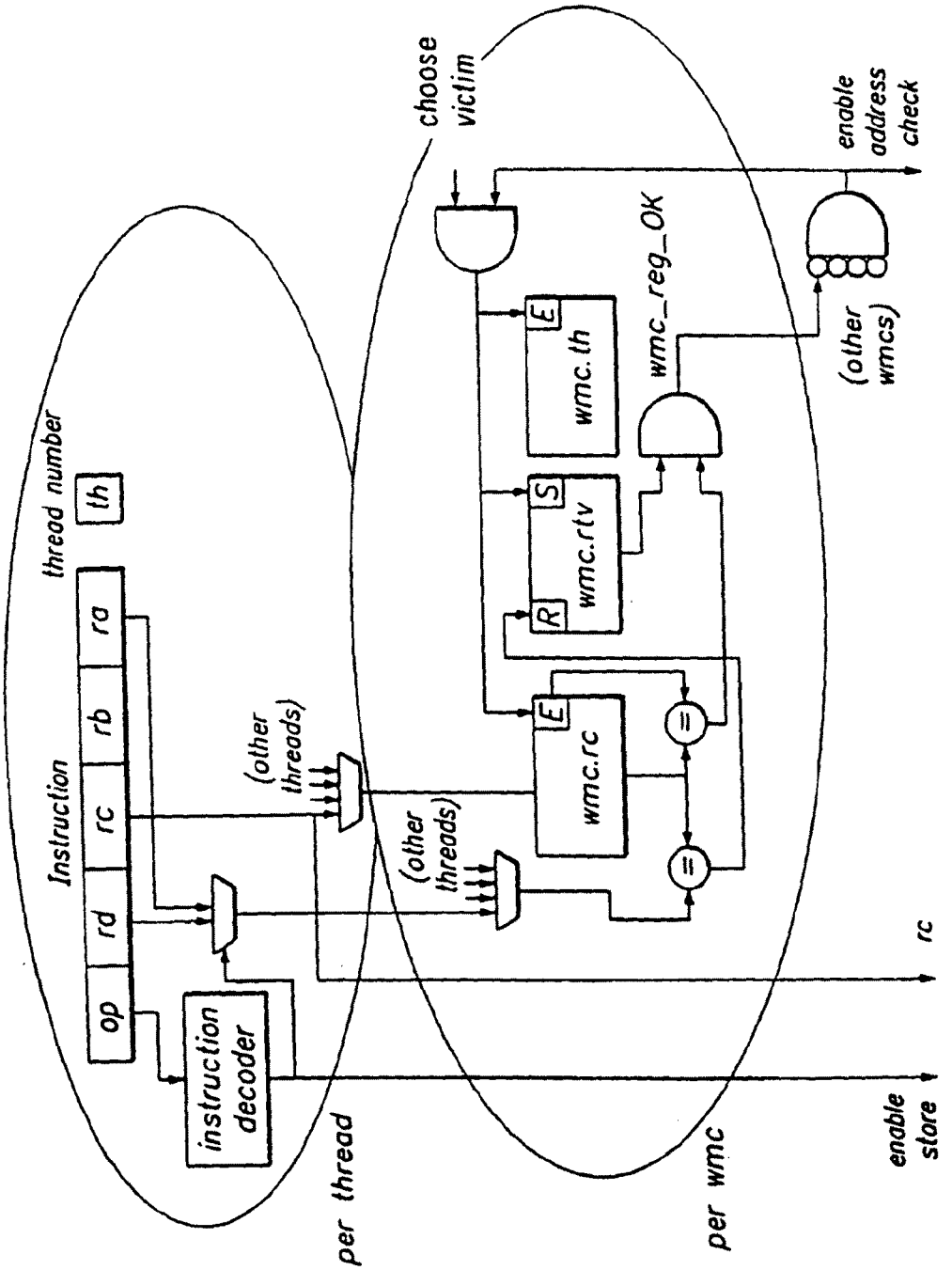

thread number
th
Instruction
op
rd
rc
rb
ra
instruction decoder
(other threads)
(other threads)
choose victim
E
wmc.th
S
R
wmc.rtv
E
wmc.rc
=
=
wmc_reg_OK
enable address check
(other wmcs)
rc
enable store
per thread
per wmc

FIG. 10

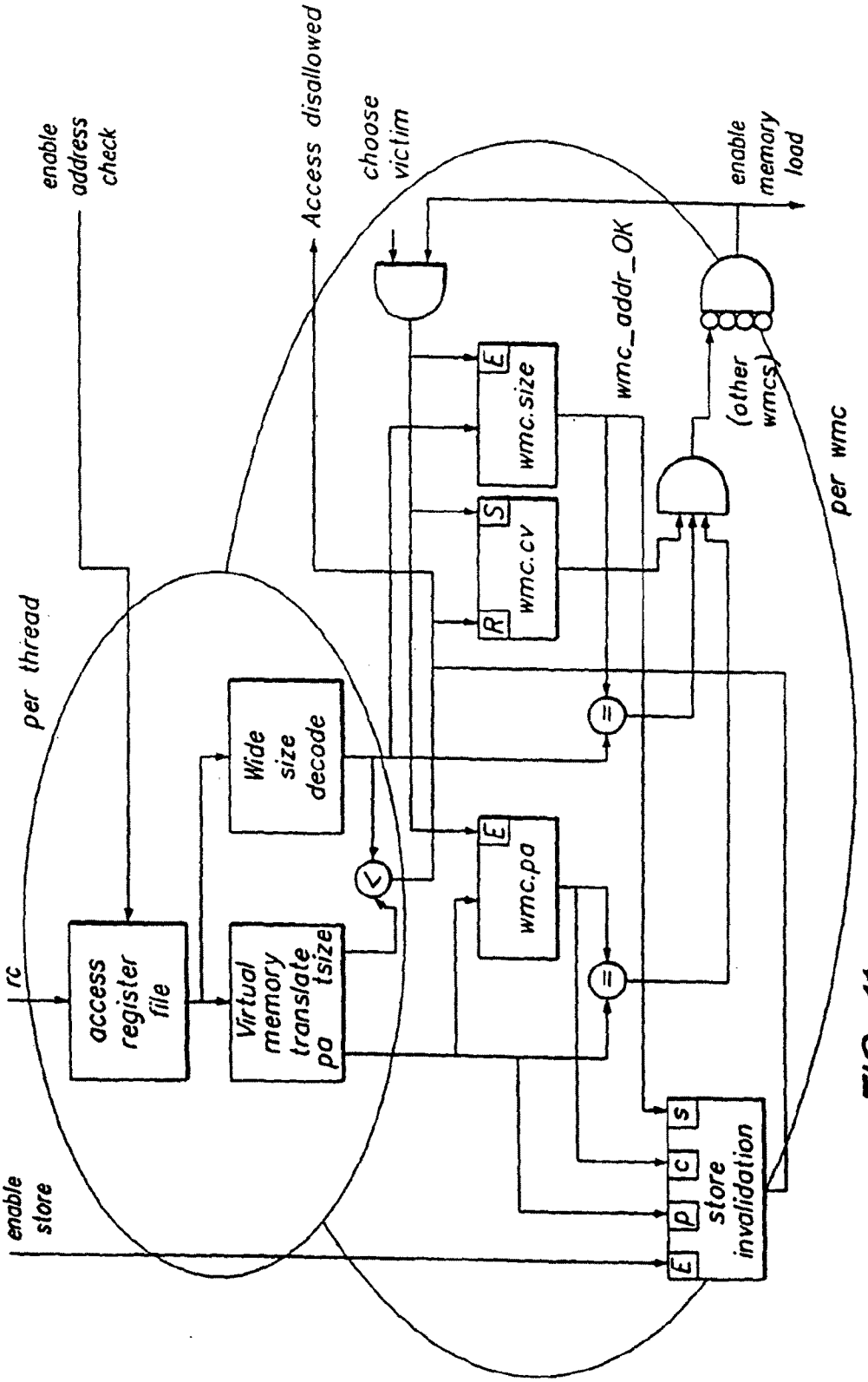

enable address check
Access disallowed
choose victim
enable memory load
wmc_addr_OK
per thread
per wmc
(other wmcs)
wmc.size
wmc.cv
wmc.pa
Wide size decode
access register file
Virtual memory translate pa tsize
store invalidation
rc
enable store

FIG. 11

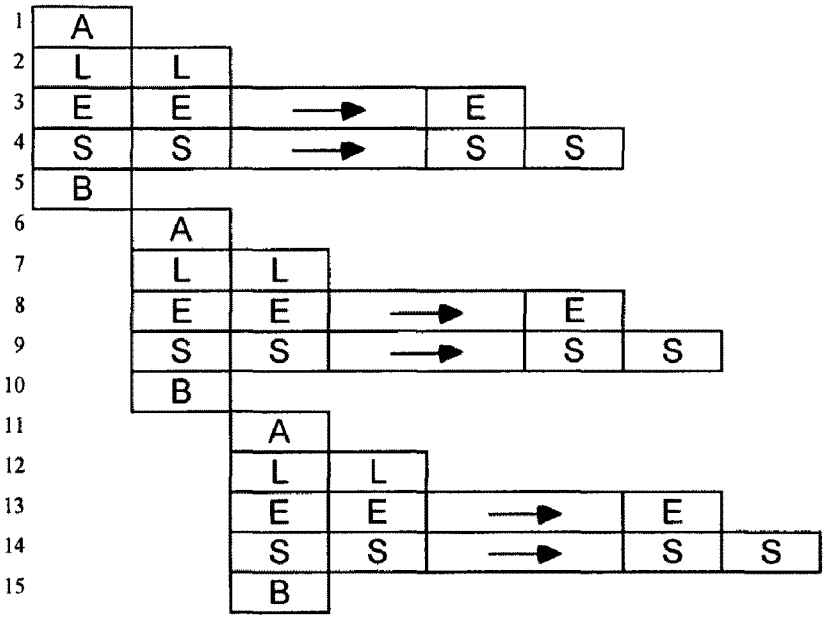

1 A
2 L L
3 E E E
4 S S S S
5 B
6 A
7 L L
8 E E E
9 S S S S
10 B
11 A
12 L L
13 E E E
14 S S S S
15 B

FIG. 12

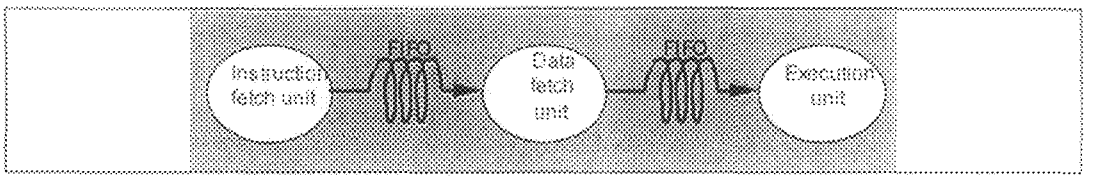
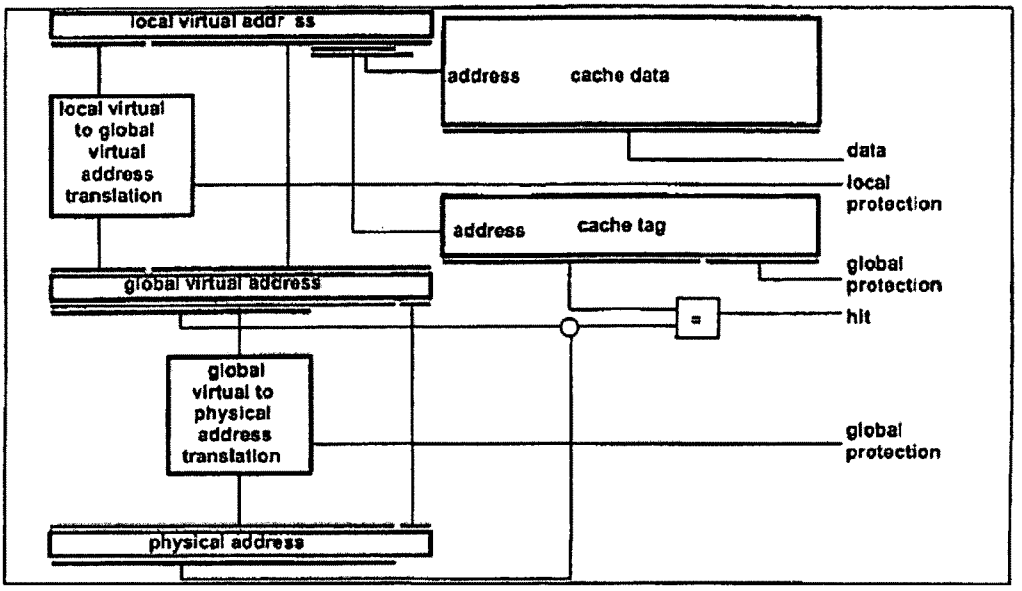

Instruction fetch unit
FIFO
Data fetch unit
FIFO
Execution unit

FIG. 13



memory management organization

FIG. 14

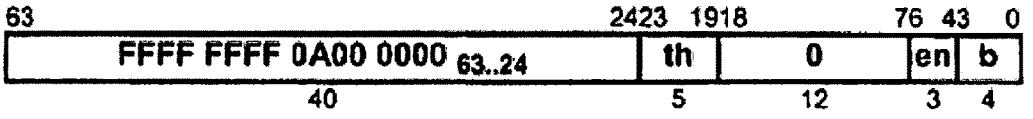


FIG. 15

```
def data,flags ← AccessPhysicalLTB(pa,op,wdata) as
    th ← pa23..19
    en ← pa6..4
    if (en < (1 || 0LE)) and (th < T) and (pa18..6=0) then
        case op of
            R:
                data ← 064 || LTBArray[th][en]
            W:
                LocalTB[th][en] ← wdata63..0
        endcase
    else
        data ← 0
    endif
enddef
```

FIG. 16

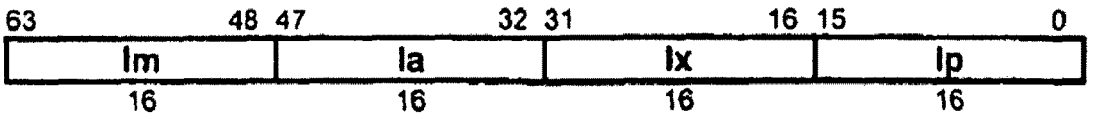


FIG. 17

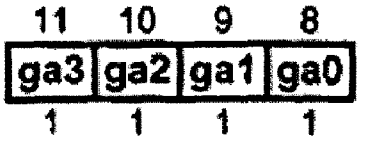


FIG. 18

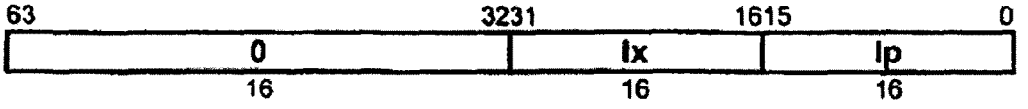


FIG. 19

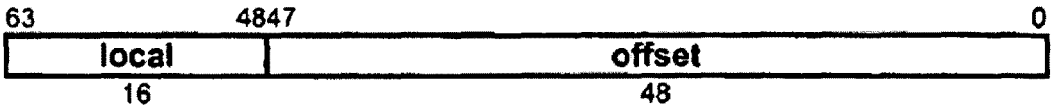


FIG. 20

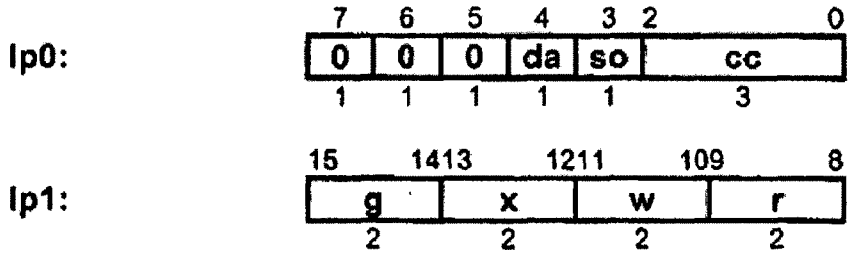

lp0:
7 6 5 4 3 2 0
0 0 0 da so cc
1 1 1 1 1 3
lp1:
15 1413 1211 109 8
g x w r
2 2 2 2

FIG. 21

```
def ga,LocalProtect ← LocalTranslation(th,ba,la,pl) as
    if LB & (ba63..48 ⏲ la63..48) then
        raise AccessDisallowedByVirtualAddress
    endif
    me ← NONE
    for i ← 0 to (1 || 0^LE)-1
        if (la63..48 & ~LocalTB[th][i]63..48) = LocalTB[th][i]47..32 then
            me ← i
        endif
    endfor
    if me = NONE then
        if ~ControlRegisterpl+8 then
            raise LocalTBMiss
        endif
        ga ← la
        LocalProtect ← 0
    else
        ga ← (va63..48 ^ LocalTB[th][me]31..16) || va47..0
        LocalProtect ← LocalTB[th][me]15..0
    endif
enddef
```

FIG. 22

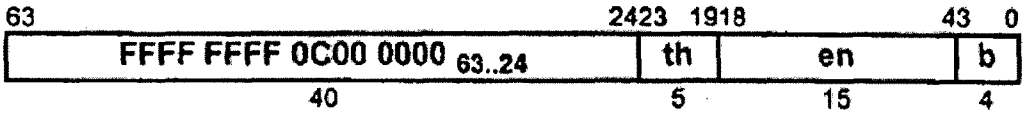


FIG. 23

```
def data,flags ← AccessPhysicalGTB(pa,op,wdata) as
        th ← pa23..19+GT || 0GT
        en ← pa18..4
        if (en < (1 || 0G)) and (th < T) and (pa18+GT..19 = 0) then
                case op of
                        R:
                                data ← GTBArray[th5..GT][en]
                        W:
                                GTBArray[th5..GT][en] ← wdata
                endcase
        else
                data ← 0
        endif
enddef
```

FIG. 24

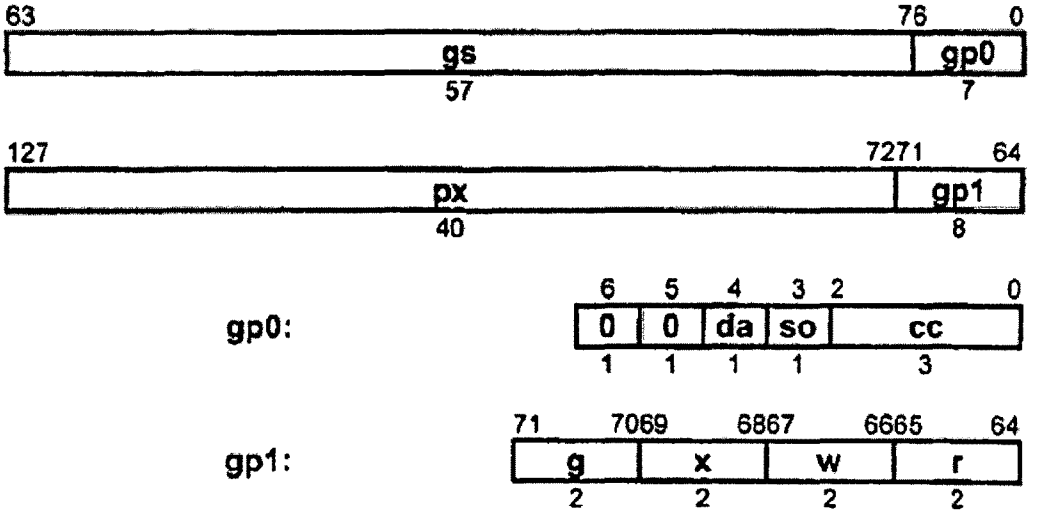

63
76
0
gs
gp0
57
7
127
7271
64
px
gp1
40
8
gp0:
6
5
4
3
2
0
0
0
da
so
cc
1
1
1
1
3
gp1:
71
7069
6867
6665
64
g
x
w
r
2
2
2
2

FIG. 25

```
def pa,GlobalProtect ← GlobalAddressTranslation(th,ga,pl,lda) as
    me ← NONE
    for i ← 0 to (1 || 0^G) −1
        if GlobalTB[th5..GT][i] ≠ 0 then
            size ← (GlobalTB[th5..GT][i]63..7 and (0^64-GlobalTB(th5..GT][i]63..7)) || 0^8
            if ((ga63..8||0^8) ^ (GlobalTB[th5..GT][i]63..8||0^8)) and (0^64-size)) = 0 then
                me ← GlobalTB[th5..GT][i]
            endif
        endif
    endfor
    if me = NONE then
        if lda then
            PerformAccessDetail(AccessDetailRequiredByLocalTB)
        endif
        raise GlobalTBMiss
    else
        pa ← (ga63..8 ^ GlobalTB[th5..GT][me]127..72) || ga7..0
        GlobalProtect ← GlobalTB[th5..GT][me]71..64 || 0^1 || GlobalTB[th5..GT][me]6..0
    endif
enddef
```

FIG. 26

```
def GTBUpdateWrite(th,fill,data) as
    me ← NONE
    for i ← 0 to (1 || 0^G) -1
        size ← (GlobalTB[th5..GT][i]63..7 and (0^64-GlobalTB(th5..GT][i]63..7)) || 0^8
        if ((data63..8||0^8) ^ (GlobalTB[th5..GT][i]63..8||0^8)) and (0^64-size) = 0 then
            me ← i
        endif
    endfor
    if me = NONE then
        if fill then
            GlobalTB[th5..GT][GTBLast[th5..GT]] ← data
            GTBLast[th5..GT] ← (GTBLast[th5..GT] + 1)G-1..0
            if GTBLast[th5..GT] = 0 then
                GTBLast[th5..GT] ← GTBFirst[th5..GT]
                GTBBump[th5..GT] ← 1
            endif
        endif
    else
        GlobalTB[th5..GT][me] ← data
    endif
enddef
```

FIG. 27

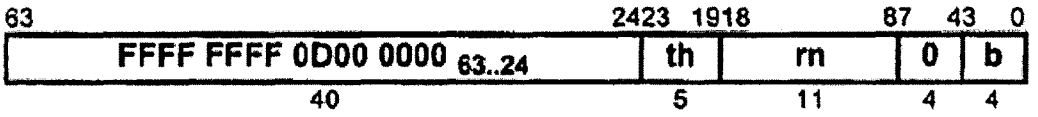


FIG. 28

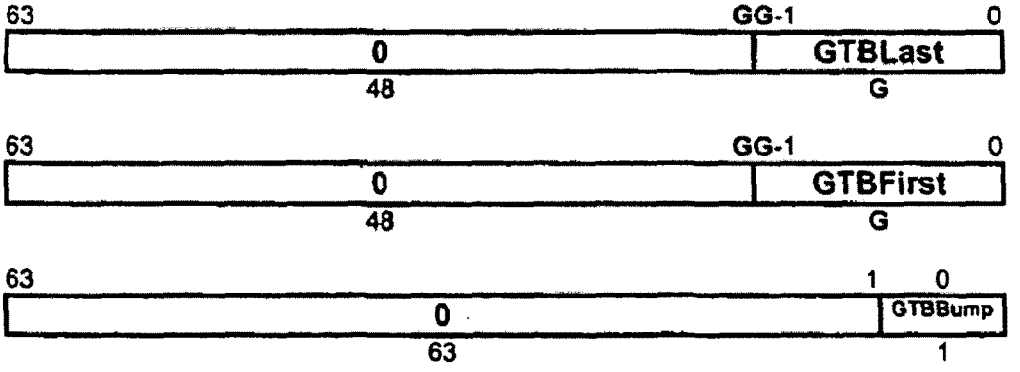

63
GG-1
0
0
GTBLast
48
G
63
GG-1
0
0
GTBFirst
48
G
63
1
0
0
GTBBump
63
1

FIG. 29

```
def data,flags ← AccessPhysicalGTBRegisters(pa,op,wdata) as
    th ← pa23..19+GT || 0GT
    rn ← pa18..8
    if (rn < 5) and (th < T) and (pa18+GT..19 = 0)  and (pa7..4 =
        case rn || op of
            0 || R, 1 || R:
                data ← 0
            0 || W, 1 || W:
                GTBUpdateWrite(th,rn0,wdata)
            2 || R:
                data ← 064-G || GTBLast[th5..GT]
            2 || W:
                GTBLast[th5..GT] ← wdataG-1..0
            3 || R:
                data ← 064-G || GTBFirst[th5..GT]
            3 || W:
                GTBFirst[th5..GT] ← wdataG-1..0
            3 || R:
                data ← 063 || GTBBump[th5..GT]
            3 || W:
                GTBBump[th5..GT] ← wdata0
        endcase
    else
        data ← 0
    endif
enddef
```

FIG. 30

G.BOOLEAN	Group Boolean

Equivalencies

G.AAA	Group three-way and
G.AAA.1	Group add add add bits
G.AAS.1	Group add add subtract bits
G.ADD.1	Group add bits
G.AND	Group and
G.ANDN	Group and not
G.COPY	Group copy
G.NAAA	Group three-way nand
G.NAND	Group nand
G.NOOO	Group three-way nor
G.NOR	Group nor
G.NOT	Group not
G.NXXX	Group three-way exclusive-nor
G.OOO	Group three-way or
G.OR	Group or
G.ORN	Group or not
G.SAA.1	Group subtract add add bits
G.SAS.1	Group subtract add subtract bits
G.SET	Group set
G.SET.AND.E.1	Group set and equal zero bits
G.SET.AND.NE.1	Group set and not equal zero bits
G.SET.E.1	Group set equal bits
G.SET.G.1	Group set greater signed bits
G.SET.G.U.1	Group set greater unsigned bits
G.SET.G.Z.1	Group set greater zero signed bits
G.SET.GE.1	Group set greater equal signed bits
G.SET.GE.Z.1	Group set greater equal zero signed bits
G.SET.L.1	Group set less signed bits
G.SET.L.Z.1	Group set less zero signed bits
G.SET.LE.1	Group set less equal signed bits
G.SET.LE.U.1	Group set less equal unsigned bits
G.SET.LE.Z.1	Group set less equal zero signed bits
G.SET.NE.1	Group set not equal bits
G.SET.GE.U.1	Group set greater equal unsigned bits
G.SET.L.U.1	Group set less unsigned bits

FIG. 31A

G.SSA.1	Group subtract subtract add bits
G.SSS.1	Group subtract subtract subtract bits
G.SUB.1	Group subtract bits
G.XNOR	Group exclusive-nor
G.XOR	Group exclusive-or
G.XXX	Group three-way exclusive-or
G.ZERO	Group zero

G.AAA rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b10000000
G.AAA.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.AAS.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.ADD.1 rd=rc,rb	→	G.XOR rd=rc,rb
G.AND rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b10001000
G.ANDN rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b01000100
G.BOOLEAN rd@rb,rc,i	→	G.BOOLEAN rd@rc,rb,$i_7 i_5 i_6 i_4 i_3 i_1 i_2 i_0$
G.COPY rd=rc	←	G.BOOLEAN rd@rc,rc,0b10001000
G.NAAA. rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b01111111
G.NAND rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b01110111
G.NOOO rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b00000001
G.NOR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b00010001
G.NOT rd=rc	←	G.BOOLEAN rd@rc,rc,0b00010001
G.NXXX rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b01101001
G.OOO rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b11111110
G.OR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b11101110
G.ORN rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b11011101
G.SAA.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SAS.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SET rd	←	G.BOOLEAN rd@rd,rd,0b10000001
G.SET.AND.E.1 rd=rb,rc	→	G.NAND rd=rc,rb
G.SET.AND.NE.1 rd=rb,rc	→	G.AND rd=rc,rb
G.SET.E.1 rd=rb,rc	→	G.XNOR rd=rc,rb
G.SET.G.1 rd=rb,rc	→	G.ANDN rd=rc,rb
G.SET.G.U.1 rd=rb,rc	→	G.ANDN rd=rb,rc
G.SET.G.Z.1 rd=rc	→	G.ZERO rd
G.SET.GE.1 rd=rb,rc	→	G.ORN rd=rc,rb
G.SET.GE.Z.1 rd=rc	→	G.NOT rd=rc

FIG. 31A *continued*

G.SET.L.1 rd=rb,rc	→	G.ANDN rd=rb,rc
G.SET.L.Z.1 rd=rc	→	G.COPY rd=rc
G.SET.LE.1 rd=rb,rc	→	G.ORN rd=rb,rc
G.SET.LE.U.1 rd=rb,rc	→	G.ORN rd=rc,rb
G.SET.LE.Z.1 rd=rc	→	G.SET rd
G.SET.NE.1 rd=rb,rc	→	G.XOR rd=rc,rb
G.SET.GE.U.1 rd=rb,rc	→	G.ORN rd=rb,rc
G.SET.L.U.1 rd=rb,rc	→	G.ANDN rd=rc,rb
G.SSA.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SSS.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SUB.1 rd=rc,rb	→	G.XOR rd=rc,rb
G.XNOR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b10011001
G.XOR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b01100110
G.XXX rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b10010110
G.ZERO rd	←	G.BOOLEAN rd@rd,rd,0b00000000

Selection

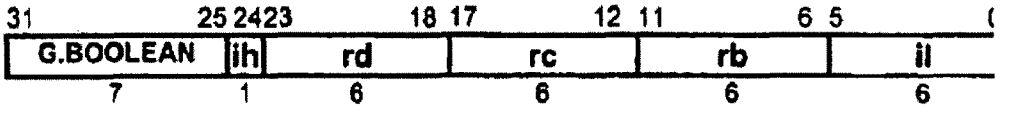
operation	function (binary)	function (decimal)
d	11110000	240
c	11001100	204
b	10101010	176
d&c&b	10000000	128
(d&c)|b	11101010	234
d|c|b	11111110	254
d?c:b	11001010	202
d^c^b	10010110	150
~d^c^b	01101001	105
0	00000000	0

FIG. 31A *continued*

Format

G.BOOLEAN rd@trc,trb,f

rd=gbooleani(rd,rc,rb,f)




```
if f6=f5 then
        if f2=f1 then
                if f2 then
                        rc ← max(trc,trb)
                        rb ← min(trc,trb)
                else
                        rc ← min(trc,trb)
                        rb ← max(trc,trb)
                endif
                ih ← 0
                il ← 0 || f6 || f7 || f4 || f3 || f0
        else
                if f2 then
                        rc ← trb
                        rb ← trc
                else
                        rc ← trc
                        rb ← trb
                endif
                ih ← 0
                il ← 1 || f6 || f7 || f4 || f3 || f0
        endif
else
        ih ← 1
        if f6 then
                rc ← trb
                rb ← trc
                il ← f1 || f2 || f7 || f4 || f3 || f0
        else
                rc ← trc
                rb ← trb
                il ← f2 || f1 || f7 || f4 || f3 || f0
        endif
endif
```

FIG. 31B

Definition

```
def GroupBoolean (ih,rd,rc,rb,il)
        d ← RegRead(rd, 128)
        c ← RegRead(rc, 128)
        b ← RegRead(rb, 128)
        if ih=0 then
                if il5=0 then
                        f ← il3 || il4 || il4 || il2 || il1 || (rc>rb)2 || il0
                else
                        f ← il3 || il4 || il4 || il2 || il1 || 0 || 1 || il0
                endif
        else
                f ← il3 || 0 || 1 || il2 || il1 || il5 || il4 || il0
        endif
        for i ← 0 to 127 by size
                ai ← f(di||ci||bi)
        endfor
        RegWrite(rd, 128, a)
enddef
```

Exceptions

none

FIG.31C

Operation codes

G.MUX	Group multiplex

Redundancies

G.MUX ra=rd,rc,rc	⇔	*G.COPY ra=rc*
G.MUX ra=ra,rc,rb	⇔	G.BOOLEAN ra@rc,rb,0x11001010
G.MUX ra=rd,ra,rb	⇔	G.BOOLEAN ra@rd,rb,0x11100010
G.MUX ra=rd,rc,ra	⇔	G.BOOLEAN ra@rd,rc,0x11011000
G.MUX ra=rd,rd,rb	⇔	G.OR ra=rd,rb
G.MUX ra=rd,rc,rd	⇔	G.AND ra=rd,rc

Format

G.MUX ra=rd,rc,rb

ra=gmux(rd,rc,rb)

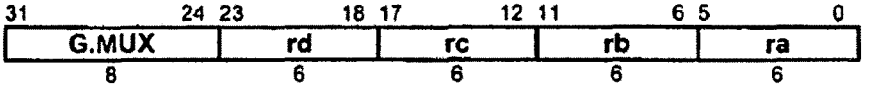


FIG. 31D

Definition

```
def GroupTernary(op,size,rd,rc,rb,ra) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        G.MUX:
            a ← (c and d) or (b and not d)
    endcase
    RegWrite(ra, 128, a)
enddef
```

Exceptions

none

FIG. 31E

Operation codes

G.ADD. 8	Group add bytes
G.ADD. 16	Group add doublets
G.ADD. 32	Group add quadlets
G.ADD. 64	Group add octlets
G.ADD.128	Group add hexlet
G.ADD.L. 8	Group add limit signed bytes
G.ADD.L. 16	Group add limit signed doublets
G.ADD.L. 32	Group add limit signed quadlets
G.ADD.L. 64	Group add limit signed octlets
G.ADD.L.128	Group add limit signed hexlet
G.ADD.L.U. 8	Group add limit unsigned bytes
G.ADD.L.U. 16	Group add limit unsigned doublets
G.ADD.L.U. 32	Group add limit unsigned quadlets
G.ADD.L.U. 64	Group add limit unsigned octlets
G.ADD.L.U.128	Group add limit unsigned hexlet
G.ADD. 8.O	Group add signed bytes check overflow
G.ADD. 16.O	Group add signed doublets check overflow
G.ADD. 32.O	Group add signed quadlets check overflow
G.ADD. 64.O	Group add signed octlets check overflow
G.ADD.128.O	Group add signed hexlet check overflow
G.ADD.U. 8.O	Group add unsigned bytes check overflow
G.ADD.U. 16.O	Group add unsigned doublets check overflow
G.ADD.U. 32.O	Group add unsigned quadlets check overflow
G.ADD.U. 64.O	Group add unsigned octlets check overflow
G.ADD.U.128.O	Group add unsigned hexlet check overflow

Redundancies

G.ADD.size rd=rc,rc	⇔	G.SHL.I.size rd=rc,1
G.ADD.size.O rd=rc,rc	⇔	G.SHL.I.size.O rd=rc,1
G.ADD.U.size.O rd=rc,rc	⇔	G.SHL.I.U.size.O rd=rc,1

FIG. 32A

Format

G.op.size rd=rc,rb

rd=gopsize(rc,rb)

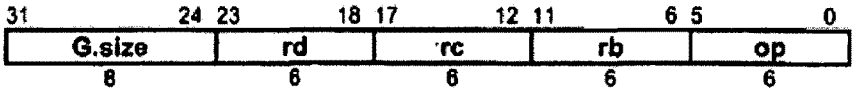


FIG 32B

Definition

```
def Group(op,size,rd,rc,rb)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        G.ADD:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← c[i+size-1..i] + b[i+size-1..i]
            endfor
        G.ADD.L:
            for i ← 0 to 128-size by size
                t ← (c[i+size-1] || c[i+size-1..i]) + (b[i+size-1] || b[i+size-1..i])
                a[i+size-1..i] ← (t[size] ≠ t[size-1]) ? (t[size] || t[size-1]^(size-1)) : t[size-1..0]
            endfor
        G.ADD.L.U:
            for i ← 0 to 128-size by size
                t ← (0^1 || c[i+size-1..i]) + (0^1 || b[i+size-1..i])
                a[i+size-1..i] ← (t[size] ≠ 0) ? (1^size) : t[size-1..0]
            endfor
        G.ADD.O:
            for i ← 0 to 128-size by size
                t ← (c[i+size-1] || c[i+size-1..i]) + (b[i+size-1] || b[i+size-1..i])
                if t[size] ≠ t[size-1] then
                    raise FixedPointArithmetic
                endif
                a[i+size-1..i] ← t[size-1..0]
            endfor
        G.ADD.U.O:
            for i ← 0 to 128-size by size
                t ← (0^1 || c[i+size-1..i]) + (0^1 || b[i+size-1..i])
                if t[size] ≠ 0 then
                    raise FixedPointArithmetic
                endif
                a[i+size-1..i] ← t[size-1..0]
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Fixed-point arithmetic

FIG. 32C

Operation codes

G.SET.AND.E.8	Group set and equal zero bytes
G.SET.AND.E.16	Group set and equal zero doublets
G.SET.AND.E.32	Group set and equal zero quadlets
G.SET.AND.E.64	Group set and equal zero octlets
G.SET.AND.E.128	Group set and equal zero hexlet
G.SET.AND.NE.8	Group set and not equal zero bytes
G.SET.AND.NE.16	Group set and not equal zero doublets
G.SET.AND.NE.32	Group set and not equal zero quadlets
G.SET.AND.NE.64	Group set and not equal zero octlets
G.SET.AND.NE.128	Group set and not equal zero hexlet
G.SET.E.8	Group set equal bytes
G.SET.E.16	Group set equal doublets
G.SET.E.32	Group set equal quadlets
G.SET.E.64	Group set equal octlets
G.SET.E.128	Group set equal hexlet
G.SET.GE.8	Group set greater equal signed bytes
G.SET.GE.16	Group set greater equal signed doublets
G.SET.GE.32	Group set greater equal signed quadlets
G.SET.GE.64	Group set greater equal signed octlets
G.SET.GE.128	Group set greater equal signed hexlet
G.SET.GE.U.8	Group set greater equal unsigned bytes
G.SET.GE.U.16	Group set greater equal unsigned doublets
G.SET.GE.U.32	Group set greater equal unsigned quadlets
G.SET.GE.U.64	Group set greater equal unsigned octlets
G.SET.GE.U.128	Group set greater equal unsigned hexlet
G.SET.L.8	Group set signed less bytes
G.SET.L.16	Group set signed less doublets
G.SET.L.32	Group set signed less quadlets
G.SET.L.64	Group set signed less octlets
G.SET.L.128	Group set signed less hexlet
G.SET.L.U.8	Group set less unsigned bytes
G.SET.L.U.16	Group set less unsigned doublets
G.SET.L.U.32	Group set less unsigned quadlets
G.SET.L.U.64	Group set less unsigned octlets
G.SET.L.U.128	Group set less unsigned hexlet
G.SET.NE.8	Group set not equal bytes
G.SET.NE.16	Group set not equal doublets

FIG 33A

G.SET.NE.32	Group set not equal quadlets
G.SET.NE.64	Group set not equal octlets
G.SET.NE.128	Group set not equal hexlet
G.SUB.8	Group subtract bytes
G.SUB.8.O	Group subtract signed bytes check overflow
G.SUB.16	Group subtract doublets
G.SUB.16.O	Group subtract signed doublets check overflow
G.SUB.32	Group subtract quadlets
G.SUB.32.O	Group subtract signed quadlets check overflow
G.SUB.64	Group subtract octlets
G.SUB.64.O	Group subtract signed octlets check overflow
G.SUB.128	Group subtract hexlet
G.SUB.128.O	Group subtract signed hexlet check overflow
G.SUB.L.8	Group subtract limit signed bytes
G.SUB.L.16	Group subtract limit signed doublets
G.SUB.L.32	Group subtract limit signed quadlets
G.SUB.L.64	Group subtract limit signed octlets
G.SUB.L.128	Group subtract limit signed hexlet
G.SUB.L.U.8	Group subtract limit unsigned bytes
G.SUB.L.U.16	Group subtract limit unsigned doublets
G.SUB.L.U.32	Group subtract limit unsigned quadlets
G.SUB.L.U.64	Group subtract limit unsigned octlets
G.SUB.L.U.128	Group subtract limit unsigned hexlet
G.SUB.U.8.O	Group subtract unsigned bytes check overflow
G.SUB.U.16.O	Group subtract unsigned doublets check overflow
G.SUB.U.32.O	Group subtract unsigned quadlets check overflow
G.SUB.U.64.O	Group subtract unsigned octlets check overflow
G.SUB.U.128.O	Group subtract unsigned hexlet check overflow

FIG 33A *continued*

Equivalencies

G.SET.E.Z.8	Group set equal zero bytes
G.SET.E.Z.16	Group set equal zero doublets
G.SET.E.Z.32	Group set equal zero quadlets
G.SET.E.Z.64	Group set equal zero octlets
G.SET.E.Z.128	Group set equal zero hexlet
G.SET.G.Z.8	Group set greater zero signed bytes
G.SET.G.Z.16	Group set greater zero signed doublets
G.SET.G.Z.32	Group set greater zero signed quadlets
G.SET.G.Z.64	Group set greater zero signed octlets
G.SET.G.Z.128	Group set greater zero signed hexlet
G.SET.GE.Z.8	Group set greater equal zero signed bytes
G.SET.GE.Z.16	Group set greater equal zero signed doublets
G.SET.GE.Z.32	Group set greater equal zero signed quadlets
G.SET.GE.Z.64	Group set greater equal zero signed octlets
G.SET.GE.Z.128	Group set greater equal zero signed hexlet
G.SET.L.Z.8	Group set less zero signed bytes
G.SET.L.Z.16	Group set less zero signed doublets
G.SET.L.Z.32	Group set less zero signed quadlets
G.SET.L.Z.64	Group set less zero signed octlets
G.SET.L.Z.128	Group set less zero signed hexlet
G.SET.LE.Z.8	Group set less equal zero signed bytes
G.SET.LE.Z.16	Group set less equal zero signed doublets
G.SET.LE.Z.32	Group set less equal zero signed quadlets
G.SET.LE.Z.64	Group set less equal zero signed octlets
G.SET.LE.Z.128	Group set less equal zero signed hexlet
G.SET.NE.Z.8	Group set not equal zero bytes
G.SET.NE.Z.16	Group set not equal zero doublets
G.SET.NE.Z.32	Group set not equal zero quadlets
G.SET.NE.Z.64	Group set not equal zero octlets
G.SET.NE.Z.128	Group set not equal zero hexlet

FIG. 33A *continued*

G.SET.LE.8	Group set less equal signed bytes
G.SET.LE.16	Group set less equal signed doublets
G.SET.LE.32	Group set less equal signed quadlets
G.SET.LE.64	Group set less equal signed octlets
G.SET.LE.128	Group set less equal signed hexlet
G.SET.LE.U.8	Group set less equal unsigned bytes
G.SET.LE.U.16	Group set less equal unsigned doublets
G.SET.LE.U.32	Group set less equal unsigned quadlets
G.SET.LE.U.64	Group set less equal unsigned octlets
G.SET.LE.U.128	Group set less equal unsigned hexlet
G.SET.G.8	Group set signed greater bytes
G.SET.G.16	Group set signed greater doublets
G.SET.G.32	Group set signed greater quadlets
G.SET.G.64	Group set signed greater octlets
G.SET.G.128	Group set signed greater hexlet
G.SET.G.U.8	Group set greater unsigned bytes
G.SET.G.U.16	Group set greater unsigned doublets
G.SET.G.U.32	Group set greater unsigned quadlets
G.SET.G.U.64	Group set greater unsigned octlets
G.SET.G.U.128	Group set greater unsigned hexlet

G.SET.E.Z.size rd=rc	←	G.SET.AND.E.size rd=rc,rc
G.SET.G.Z.size rd=rc	⇐	G.SET.L.U.size rd=rc,rc
G.SET.GE.Z.size rd=rc	⇐	G.SET.GE.size rd=rc,rc
G.SET.L.Z.size rd=rc	⇐	G.SET.L.size rd=rc,rc
G.SET.LE.Z.size rd=rc	⇐	G.SET.GE.U.size rd=rc,rc
G.SET.NE.Z.size rd=rc	←	G.SET.AND.NE.size rd=rc,rc
G.SET.G.size rd=rb,rc	→	G.SET.L.size rd=rc,rb
G.SET.G.U.size rd=rb,rc	→	G.SET.L.U.size rd=rc,rb
G.SET.LE.size rd=rb,rc	→	G.SET.GE.size rd=rc,rb
G.SET.LE.U.size rd=rb,rc	→	G.SET.GE.U.size rd=rc,rb

FIG. 33A *continued*

Redundancies

G.SET.E.size rd=rc,rc	⇔	*G.SET rd*
G.SET.NE.size rd=rc,rc	⇔	*G.ZERO rd*
G.SUB.size rd=rc,rc	⇔	*G.ZERO rd*
G.SUB.L.size rd=rc,rc	⇔	*G.ZERO rd*
G.SUB.L.U.size rd=rc,rc	⇔	*G.ZERO rd*
G.SUB.size.O rd=rc,rc	⇔	*G.ZERO rd*
G.SUB.U.size.O rd=rc,rc	⇔	*G.ZERO rd*

Selection

class	operation	cond	operand	size	check
arithmetic	SUB			8 16 32 64 128	
			NONE U	8 16 32 64 128	O
	SUB.L		NONE U	8 16 32 64 128	
boolean	SET.AND SET	E NE		8 16 32 64 128	
	SET	L GE *G LE*	NONE U	8 16 32 64 128	
	SET	*G GE L LE*	*Z*	8 16 32 64 128	

Format

G.op.size rd=rb,rc

rd=gopsize(rb,rc)

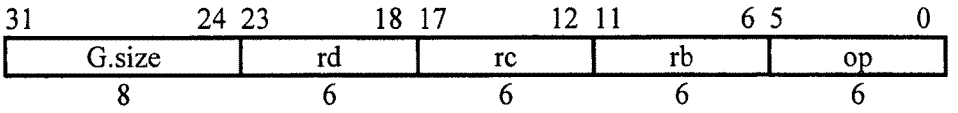


FIG. 33B

Definition

```
def GroupReversed(op,size,rd,rc,rb)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        G.SUB:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← b[i+size-1..i] - c[i+size-1..i]
            endfor
        G.SUB.L:
            for i ← 0 to 128-size by size
                t ← (b[i+size-1] || b[i+size-1..i]) - (c[i+size-1] || c[i+size-1..i])
                a[i+size-1..i] ← (t[size] ≠ t[size-1]) ? (t[size] || t[size-1]^size) : t[size-1..0]
            endfor
        G.SUB.LU:
            for i ← 0 to 128-size by size
                t ← (0^1 || b[i+size-1..i]) - (0^1 || c[i+size-1..i])
                a[i+size-1..i] ← (t[size] ≠ 0) ? 0^size : t[size-1..0]
            endfor
        G.SUB.O:
            for i ← 0 to 128-size by size
                t ← (b[i+size-1] || b[i+size-1..i]) - (c[i+size-1] || c[i+size-1..i])
                if (t[size] ≠ t[size-1]) then
                    raise FixedPointArithmetic
                endif
                a[i+size-1..i] ← t[size-1..0]
            endfor
        G.SUB.U.O:
            for i ← 0 to 128-size by size
                t ← (0^1 || b[i+size-1..i]) - (0^1 || c[i+size-1..i])
                if (t[size] ≠ 0) then
                    raise FixedPointArithmetic
                endif
                a[i+size-1..i] ← t[size-1..0]
            endfor
        G.SET.E:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← (b[i+size-1..i] = c[i+size-1..i])^size
            endfor
        G.SET.NE:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← (b[i+size-1..i] ≠ c[i+size-1..i])^size
            endfor
        G.SET.AND.E:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((b[i+size-1..i] and c[i+size-1..i]) = 0)^size
            endfor
```

FIG. 33C

```
        G.SET.AND.NE:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((b[i+size-1..i] and c[i+size-1..i]) ≠ 0)^size
            endfor
        G.SET.L:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rc = rb) ? (b[i+size-1..i] < 0) : (b[i+size-1..i] < c[i+size-1..i]))^size
            endfor
        G.SET.GE:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rc = rb) ? (b[i+size-1..i] ≥ 0) : (b[i+size-1..i] ≥ c[i+size-1..i]))^size
            endfor
        G.SET.L.U:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rc = rb) ? (b[i+size-1..i] > 0) :
                    ((0 || b[i+size-1..i]) < (0 || c[i+size-1..i])))^size
            endfor
        G.SET.GE.U:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rc = rb) ? (b[i+size-1..i] ≤ 0) :
                    ((0 || b[i+size-1..i]) ≥ (0 || c[i+size-1..i])))^size
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Fixed-point arithmetic

FIG. 33C *continued*

E.DIV.64	Ensemble divide signed octlets
E.DIV.U.64	Ensemble divide unsigned octlets
E.MUL.8	Ensemble multiply signed bytes
E.MUL.16	Ensemble multiply signed doublets
E.MUL.32	Ensemble multiply signed quadlets
E.MUL.64	Ensemble multiply signed octlets
E.MUL.SUM.8	Ensemble multiply sum signed bytes
E.MUL.SUM.16	Ensemble multiply sum signed doublets
E.MUL.SUM.32	Ensemble multiply sum signed quadlets
E.MUL.SUM.64	Ensemble multiply sum signed octlets
E.MUL.C.8	Ensemble complex multiply bytes
E.MUL.C.16	Ensemble complex multiply doublets
E.MUL.C.32	Ensemble complex multiply quadlets
E.MUL.M.8	Ensemble multiply mixed-signed bytes
E.MUL.M.16	Ensemble multiply mixed-signed doublets
E.MUL.M.32	Ensemble multiply mixed-signed quadlets
E.MUL.M.64	Ensemble multiply mixed-signed octlets
E.MUL.P.8	Ensemble multiply polynomial bytes
E.MUL.P.16	Ensemble multiply polynomial doublets
E.MUL.P.32	Ensemble multiply polynomial quadlets
E.MUL.P.64	Ensemble multiply polynomial octlets
E.MUL.SUM.C.8	Ensemble multiply sum complex bytes
E.MUL.SUM.C.16	Ensemble multiply sum complex doublets
E.MUL.SUM.C.32	Ensemble multiply sum complex quadlets
E.MUL.SUM.M.8	Ensemble multiply sum mixed-signed bytes
E.MUL.SUM.M.16	Ensemble multiply sum mixed-signed doublets
E.MUL.SUM.M.32	Ensemble multiply sum mixed-signed quadlets
E.MUL.SUM.M.64	Ensemble multiply sum mixed-signed octlets
E.MUL.SUM.U.8	Ensemble multiply sum unsigned bytes
E.MUL.SUM.U.16	Ensemble multiply sum unsigned doublets
E.MUL.SUM.U.32	Ensemble multiply sum unsigned quadlets
E.MUL.SUM.U.64	Ensemble multiply sum unsigned octlets
E.MUL.U.8	Ensemble multiply unsigned bytes
E.MUL.U.16	Ensemble multiply unsigned doublets
E.MUL.U.32	Ensemble multiply unsigned quadlets
E.MUL.U.64	Ensemble multiply unsigned octlets

FIG. 34A

Format

E.op.size rd=rc,rb

rd=eopsize(rc,rb)

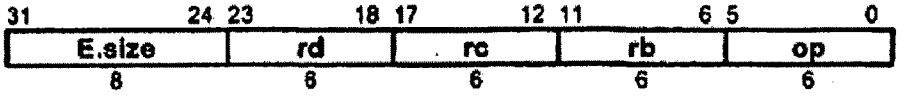


FIG. 34B

Definition

```
def mul(size,h,vs,v,i,ws,w,j) as
        mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i,..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j,..j})
enddef

def c ← PolyMultiply(size,a,b) as
        p[0] ← 0^{2*size}
        for k ← 0 to size-1
                p[k+1] ← p[k] ^ a_k ? (0^{size-k} || b || 0^k) : 0^{2*size}
        endfor
        c ← p[size]
enddef

def Ensemble(op,size,rd,rc,rb)
        c ← RegRead(rc, 128)
        b ← RegRead(rb, 128)
        case op of
                E.MUL:, E.MUL.C:, EMUL.SUM, E.MUL.SUM.C, E.CON, E.CON.C, E.DIV:
                        cs ← bs ← 1
                E.MUL.M:, EMUL.SUM.M, E.CON.M:
                        cs ← 0
                        bs ← 1
                E.MUL.U:, EMUL.SUM.U, E.CON.U, E.DIV.U, E.MUL.P:
                        cs ← bs ← 0
        endcase
        case op of
                E.MUL, E.MUL.U, E.MUL.M:
                        for i ← 0 to 64-size by size
                                d_{2*(i+size)-1..2*i} ← mul(size,2*size,cs,c,i,bs,b,i)
                        endfor
                E.MUL.P:
                        for i ← 0 to 64-size by size
                                d_{2*(i+size)-1..2*i} ← PolyMultiply(size,c_{size-1+i,..i},b_{size-1+i,..i})
                        endfor
                E.MUL.C:
                        for i ← 0 to 64-size by size
                                if (i and size) = 0 then
                                        p ← mul(size,2*size,1,c,i,1,b,i) - mul(size,2*size,1,c,i+size,1,b,i+size)
                                else
                                        p ← mul(size,2*size,1,c,i,1,b,i+size) + mul(size,2*size,1,c,i,1,b,i+size)
                                endif
                                d_{2*(i+size)-1..2*i} ← p
                        endfor
                E.MUL.SUM, E.MUL.SUM.U, E.MUL.SUM.M:
                        p[0] ← 0^{128}
                        for i ← 0 to 128-size by size
                                p[i+size] ← p[i] + mul(size,128,cs,c,i,bs,b,i)
                        endfor
                        a ← p[126]
                E.MUL.SUM.C:
                        p[0] ← 0^{64}
                        p[size] ← 0^{64}
                        for i ← 0 to 128-size by size
                                if (i and size) = 0 then
                                        p[i+2*size] ← p[i] + mul(size,64,1,c,i,1,b,i)
                                                          - mul(size,64,1,c,i+size,1,b,i+size)
                                else
                                        p[i+2*size] ← p[i] + mul(size,64,1,c,i,1,b,i+size)
                                                          + mul(size,64,1,c,i+size,1,b,i)
                                endif
                        endfor
                        a ← p[128+size] || p[128]
```

FIG. 34C

```
        E.CON, E.CON.U, E.CON.M:
            p[0] ← 0^128
            for j ← 0 to 64-size by size
                for i ← 0 to 64-size by size
                    p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                        mul(size,2*size,cs,c,i+64-j,bs,b,j)
                endfor
            endfor
            a ← p[64]
        E.CON.C:
            p[0] ← 0^128
            for j ← 0 to 64-size by size
                for i ← 0 to 64-size by size
                    if ((-i) and j and size) = 0 then
                        p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                            mul(size,2*size,1,c,i+64-j,1,b,j)
                    else
                        p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                            mul(size,2*size,1,c,i+64-j+2*size,1,b,j)
                    endif
                endfor
            endfor
            a ← p[64]
        E.DIV:
            if (b = 0) or ( (c = (1||0^63)) and (b = 1^64) ) then
                a ← undefined
            else
                q ← c / b
                r ← c - q*b
                a ← r63..0 || q63..0
            endif
        E.DIV.U:
            if b = 0 then
                a ← undefined
            else
                q ← (0 || c) / (0 || b)
                r ← c - (0 || q)*(0 || b)
                a ← r63..0 || q63..0
            endif
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

none

FIG 34C *continued*

Operation codes

G.COM.AND.E. 8	Group compare and equal zero bytes
G.COM.AND.E. 16	Group compare and equal zero doublets
G.COM.AND.E. 32	Group compare and equal zero quadlets
G.COM.AND.E. 64	Group compare and equal zero octlets
G.COM.AND.E.128	Group compare and equal zero hexlet
G.COM.AND.NE. 8	Group compare and not equal zero bytes
G.COM.AND.NE. 16	Group compare and not equal zero doublets
G.COM.AND.NE. 32	Group compare and not equal zero quadlets
G.COM.AND.NE. 64	Group compare and not equal zero octlets
G.COM.AND.NE.128	Group compare and not equal zero hexlet
G.COM.E. 8	Group compare equal bytes
G.COM.E. 16	Group compare equal doublets
G.COM.E. 32	Group compare equal quadlets
G.COM.E. 64	Group compare equal octlets
G.COM.E.128	Group compare equal hexlet
G.COM.GE. 8	Group compare greater equal signed bytes
G.COM.GE. 16	Group compare greater equal signed doublets
G.COM.GE. 32	Group compare greater equal signed quadlets
G.COM.GE. 64	Group compare greater equal signed octlets
G.COM.GE.128	Group compare greater equal signed hexlet
G.COM.GE.U. 8	Group compare greater equal unsigned bytes
G.COM.GE.U. 16	Group compare greater equal unsigned doublets
G.COM.GE.U. 32	Group compare greater equal unsigned quadlets
G.COM.GE.U. 64	Group compare greater equal unsigned octlets
G.COM.GE.U.128	Group compare greater equal unsigned hexlet
G.COM.L. 8	Group compare signed less bytes
G.COM.L. 16	Group compare signed less doublets
G.COM.L. 32	Group compare signed less quadlets
G.COM.L. 64	Group compare signed less octlets
G.COM.L.128	Group compare signed less hexlet
G.COM.L.U. 8	Group compare less unsigned bytes
G.COM.L.U. 16	Group compare less unsigned doublets
G.COM.L.U. 32	Group compare less unsigned quadlets
G.COM.L.U. 64	Group compare less unsigned octlets
G.COM.L.U.128	Group compare less unsigned hexlet
G.COM.NE. 8	Group compare not equal bytes
G.COM.NE. 16	Group compare not equal doublets
G.COM.NE. 32	Group compare not equal quadlets
G.COM.NE. 64	Group compare not equal octlets
G.COM.NE.128	Group compare not equal hexlet

FIG. 35A

Equivalencies

G.COM.E.Z. 8	Group compare equal zero signed bytes
G.COM.E.Z. 16	Group compare equal zero signed doublets
G.COM.E.Z. 32	Group compare equal zero signed quadlets
G.COM.E.Z. 64	Group compare equal zero signed octlets
G.COM.E.Z.128	Group compare equal zero signed hexlet
G.COM.G. 8	Group compare signed greater bytes
G.COM.G. 16	Group compare signed greater doublets
G.COM.G. 32	Group compare signed greater quadlets
G.COM.G. 64	Group compare signed greater octlets
G.COM.G.128	Group compare signed greater hexlet
G.COM.G.U. 8	Group compare greater unsigned bytes
G.COM.G.U. 16	Group compare greater unsigned doublets
G.COM.G.U. 32	Group compare greater unsigned quadlets
G.COM.G.U. 64	Group compare greater unsigned octlets
G.COM.G.U.128	Group compare greater unsigned hexlet
G.COM.G.Z. 8	Group compare greater zero signed bytes
G.COM.G.Z. 16	Group compare greater zero signed doublets
G.COM.G.Z. 32	Group compare greater zero signed quadlets
G.COM.G.Z. 64	Group compare greater zero signed octlets
G.COM.G.Z.128	Group compare greater zero signed hexlet
G.COM.GE.Z. 8	Group compare greater equal zero signed bytes
G.COM.GE.Z. 16	Group compare greater equal zero signed doublets
G.COM.GE.Z. 32	Group compare greater equal zero signed quadlets
G.COM.GE.Z. 64	Group compare greater equal zero signed octlets
G.COM.GE.Z.128	Group compare greater equal zero signed hexlet
G.COM.L.Z. 8	Group compare less zero signed bytes
G.COM.L.Z. 16	Group compare less zero signed doublets
G.COM.L.Z. 32	Group compare less zero signed quadlets
G.COM.L.Z. 64	Group compare less zero signed octlets
G.COM.L.Z.128	Group compare less zero signed hexlet
G.COM.LE. 8	Group compare less equal signed bytes
G.COM.LE. 16	Group compare less equal signed doublets
G.COM.LE. 32	Group compare less equal signed quadlets
G.COM.LE. 64	Group compare less equal signed octlets
G.COM.LE.128	Group compare less equal signed hexlet
G.COM.LE.U. 8	Group compare less equal unsigned bytes
G.COM.LE.U. 16	Group compare less equal unsigned doublets
G.COM.LE.U. 32	Group compare less equal unsigned quadlets
G.COM.LE.U. 64	Group compare less equal unsigned octlets
G.COM.LE.U.128	Group compare less equal unsigned hexlet

FIG. 35A *continued*

G.COM.LE.Z. 8	Group compare less equal zero signed bytes
G.COM.LE.Z. 16	Group compare less equal zero signed doublets
G.COM.LE.Z. 32	Group compare less equal zero signed quadlets
G.COM.LE.Z. 64	Group compare less equal zero signed octlets
G.COM.LE.Z.128	Group compare less equal zero signed hexlet
G.COM.NE.Z. 8	Group compare not equal zero signed bytes
G.COM.NE.Z. 16	Group compare not equal zero signed doublets
G.COM.NE.Z. 32	Group compare not equal zero signed quadlets
G.COM.NE.Z. 64	Group compare not equal zero signed octlets
G.COM.NE.Z.128	Group compare not equal zero signed hexlet
G.FIX	Group fixed point arithmetic exception
G.NOP	Group no operation

G.COM.E.Z.size rc	←	G.COM.AND.E.size rc,rc
G.COM.G.size rd,rc	→	G.COM.L.size rc,rd
G.COM.G.U.size rd,rc	→	G.COM.L.U.size rc,rd
G.COM.G.Z.size rc	⇐	G.COM.L.U.size rc,rc
G.COM.GE.Z.size rc	⇐	G.COM.GE.size rc,rc
G.COM.L.Z.size rc	⇐	G.COM.L.size rc,rc
G.COM.LE.size rd,rc	→	G.COM.GE.size rc,rd
G.COM.LE.U.size rd,rc	→	G.COM.GE.U.size rc,rd
G.COM.LE.Z.size rc	⇐	G.COM.GE.U.size rc,rc
G.COM.NE.Z.size rc	←	G.COM.AND.NE.size rc,rc
G.FIX	←	G.COM.E.128 r0,r0
G.NOP	←	G.COM.NE.128 r0,r0

FIG. 35A *continued*

Redundancies

G.COM.E.size rd,rd	⇔	*G.FIX*
G.COM.NE.size rd,rd	⇔	*G.NOP*

Selection

class	operation	cond	type	size
boolean	COM.AN D COM	E NE		8 16 32 64 128
arithmetic	COM	L GE *G LE*	NONE U	□ 16 32 64 128
	COM	*L GE G LE E NE*	*Z*	8 16 32 64 128

Format

G.COM.op.size rd,rc
G.COM.opz.size rcd

gcomopsize(rd,rc)

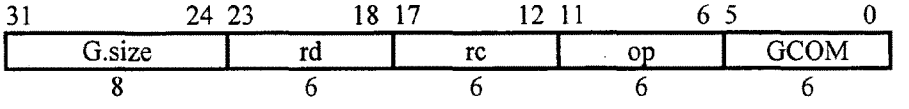


FIG. 35B

Definition

```
def GroupCompare(op,size,rd,rc)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    case op of
        G.COM.E:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← (d[i+size-1..i] = c[i+size-1..i])^size
            endfor
        G.COM.NE:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← (d[i+size-1..i] ≠ c[i+size-1..i])^size
            endfor
        G.COM.AND.E:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((c[i+size-1..i] and d[i+size-1..i]) = 0)^size
            endfor
        G.COM.AND.NE:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((c[i+size-1..i] and d[i+size-1..i]) ≠ 0)^size
            endfor
        G.COM.L:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rd = rc) ? (c[i+size-1..i] < 0) : (d[i+size-1..i] < c[i+size-1..i]))^size
            endfor
        G.COM.GE:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rd = rc) ? (c[i+size-1..i] ≥ 0) : (d[i+size-1..i] ≥ c[i+size-1..i]))^size
            endfor
        G.COM.L.U:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rd = rc) ? (c[i+size-1..i] > 0) :
                    ((0 || d[i+size-1..i]) < (0 || c[i+size-1..i])))^size
            endfor
        G.COM.GE.U:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← ((rd = rc) ? (c[i+size-1..i] ≤ 0) :
                    ((0 || d[i+size-1..i]) ≥ (0 || c[i+size-1..i])))^size
            endfor
    endcase
    if (a ≠ 0) then
        raise FixedPointArithmetic
    endif
enddef
```

Exceptions

Fixed-point arithmetic

FIG. 35C

E.LOG.MOST.8	Ensemble log of most significant bit signed bytes
E.LOG.MOST.16	Ensemble log of most significant bit signed doublets
E.LOG.MOST.32	Ensemble log of most significant bit signed quadlets
E.LOG.MOST.64	Ensemble log of most significant bit signed octlets
E.LOG.MOST.128	Ensemble log of most significant bit signed hexlet
E.LOG.MOST.U.8	Ensemble log of most significant bit unsigned bytes
E.LOG.MOST.U.16	Ensemble log of most significant bit unsigned doublets
E.LOG.MOST.U.32	Ensemble log of most significant bit unsigned quadlets
E.LOG.MOST.U.64	Ensemble log of most significant bit unsigned octlets
E.LOG.MOST.U.128	Ensemble log of most significant bit unsigned hexlet
E.SUM.8	Ensemble sum signed bytes
E.SUM.16	Ensemble sum signed doublets
E.SUM.32	Ensemble sum signed quadlets
E.SUM.64	Ensemble sum signed octlets
E.SUM.U.1	Ensemble sum unsigned bits
E.SUM.U.8	Ensemble sum unsigned bytes
E.SUM.U.16	Ensemble sum unsigned doublets
E.SUM.U.32	Ensemble sum unsigned quadlets
E.SUM.U.64	Ensemble sum unsigned octlets

Selection

class	op	size
sum	SUM	8 16 32 64
	SUM.U	1 8 16 32 64 ..
log most significant bit	LOG.MOST LOG.MOST.U	8 16 32 64 128

FIG. 36A

Format

E.op.size rd=rc

rd=eopsize(rc)

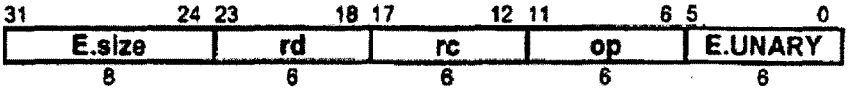


FIG. 36B

Definition

```
def EnsembleUnary(op,size,rd,rc)
    c ← RegRead(rc, 128)
    case op of
        E.LOG.MOST:
            for i ← 0 to 128-size by size
                if (c_{i+size-1..i} =0) then
                    a_{i+size-1..i} ← -1
                else
                    for j ← 0 to size-1
                        if c_{size-1+i..j+i} = (c^{size-1-j}_{size-1+i} || not c_{size-1+i}) then
                            a_{i+size-1..i} ← j
                        endif
                    endfor
                endif
            endfor
        E.LOG.MOSTU:
            for i ← 0 to 128-size by size
                if (c_{i+size-1..i} =0) then
                    a_{i+size-1..i} ← -1
                else
                    for j ← 0 to size-1
                        if c_{size-1+i..j+i} = (0^{size-1-j} || 1) then
                            a_{i+size-1..i} ← j
                        endif
                    endfor
                endif
            endfor
        E.SUM:
            p[0] ← 0^128
            for i ← 0 to 128-size by size
                p[i+size] ← p[i] + (c^{128-size}_{size-1+i} || c_{size-1+i..i})
            endfor
            a ← p[128]
        E.SUMU:
            p[0] ← 0^128
            for i ← 0 to 128-size by size
                p[i+size] ← p[i] + (0^{128-size} || c_{size-1+i..i})
            endfor
            a ← p[128]
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

none

FIG. 36C

Floating-point function Definitions

```
def eb ← ebits(prec) as
    case pref of
        16:
            eb ← 5
        32:
            eb ← 8
        64:
            eb ← 11
        128:
            eb ← 15
    endcase
enddef

def eb ← ebias(prec) as
    eb ← 0 || 1^(ebits(prec)-1)
enddef

def fb ← fbits(prec) as
    fb ← prec – 1 – eb
enddef

def a ← F(prec, ai) as
    a.s ← ai_(prec-1)
    ae ← ai_(prec-2..fbits(prec))
    af ← ai_(fbits(prec)-1..0)
    if ae = 1^(ebits(prec)) then
        If af = 0 then
            a.t ← INFINITY
        elseif af_(fbits(prec)-1) then
            a.t ← SNaN
            a.e ← -fbits(prec)
            a.f ← 1 || af_(fbits(prec)-2..0)
        else
            a.t ← QNaN
            a.e ← -fbits(prec)
            a.f ← af
        endif
```

FIG. 37

```
        elseif ae = 0 then
            if af = 0 then
                a.t ← ZERO
            else
                a.t ← NORM
                a.e ← 1-ebias(prec)-fbits(prec)
                a.f ← 0 || af
            endif
        else
            a.t ← NORM
            a.e ← ae-ebias(prec)-fbits(prec)
            a.f ← 1 || af
        endif
enddef

def a ← DEFAULTQNAN as
        a.s ← 0
        a.t ← QNAN
        a.e ← -1
        a.f ← 1
enddef

def a ← DEFAULTSNAN as
        a.s ← 0
        a.t ← SNAN
        a.e ← -1
        a.f ← 1
enddef

def fadd(a,b) as faddr(a,b,N) enddef

def c ← faddr(a,b,round) as
        if a.t=NORM and b.t=NORM then
            // d,e are a,b with exponent aligned and fraction adjusted
            if a.e > b.e then
                d ← a
                e.t ← b.t
                e.s ← b.s
                e.e ← a.e
                e.f ← b.f || 0^(a.e-b.e)
            else if a.e < b.e then
                d.t ← a.t
                d.s ← a.s
                d.e ← b.e
                d.f ← a.f || 0^(b.e-a.e)
                e ← b
            endif
            c.t ← d.t
            c.e ← d.e
            if d.s = e.s then
                c.s ← d.s
                c.f ← d.f + e.f
            elseif d.f > e.f then
                c.s ← d.s
                c.f ← d.f – e.f
```

FIG. 37 *continued*

```
            elseif d.f < e.f then
                c.s ← e.s
                c.f ← e.f − d.f
            else
                c.s ← r=F
                c.t ← ZERO
            endif
        // priority is given to b operand for NaN propagation
        elseif (b.t=SNAN) or (b.t=QNAN) then
            c ← b
        elseif (a.t=SNAN) or (a.t=QNAN) then
            c ← a
        elseif a.t=ZERO and b.t=ZERO then
            c.t ← ZERO
            c.s ← (a.s and b.s) or (round=F and (a.s or b.s))
        // NULL values are like zero, but do not combine with ZERO to alter sign
        elseif a.t=ZERO or a.t=NULL then
            c ← b
        elseif b.t=ZERO or b.t=NULL then
            c ← a
        elseif a.t=INFINITY and b.t=INFINITY then
            if a.s ≠ b.s then
                c ← DEFAULTSNAN // Invalid
            else
                c ← a
            endif
        elseif a.t=INFINITY then
            c ← a
        elseif b.t=INFINITY then
            c ← b
        else
            assert FALSE // should have covered al the cases above
        endif
enddef

def b ← fneg(a) as
        b.s ← ~a.s
        b.t ← a.t
        b.e ← a.e
        b.f ← a.f
enddef

def fsub(a,b) as fsubr(a,b,N) enddef

def fsubr(a,b,round) as faddr(a,fneg(b),round) enddef

def frsub(a,b) as frsubr(a,b,N) enddef

def frsubr(a,b,round) as faddr(fneg(a),b,round) enddef

def c ← fcom(a,b) as
        if (a.t=SNAN) or (a.t=QNAN) or (b.t=SNAN) or (b.t=QNAN) then
            c ← U
        elseif a.t=INFINITY and b.t=INFINITY then
            if a.s ≠ b.s then
                c ← (a.s=0) ? G: L
```

FIG. 37 *continued*

```
            else
                c ← E
            endif
        elseif a.t=INFINITY then
            c ← (a.s=0) ? G: L
        elseif b.t=INFINITY then
            c ← (b.s=0) ? G: L
        elseif a.t=NORM and b.t=NORM then
            if a.s ≠ b.s then
                c ← (a.s=0) ? G: L
            else
                if a.e > b.e then
                    af ← a.f
                    bf ← b.f || 0^(a.e-b.e)
                else
                    af ← a.f || 0^(b.e-a.e)
                    bf ← b.f
                endif
                if af = bf then
                    c ← E
                else
                    c ← ((a.s=0) ^ (af > bf)) ? G : L
                endif
            endif
        elseif a.t=NORM then
            c ← (a.s=0) ? G: L
        elseif b.t=NORM then
            c ← (b.s=0) ? G: L
        elseif a.t=ZERO and b.t=ZERO then
            c ← E
        else
            assert FALSE // should have covered all the cases above
        endif
    enddef

    def c ← fmul(a,b) as
        if a.t=NORM and b.t=NORM then
            c.s ← a.s ^ b.s
            c.t ← NORM
            c.e ← a.e + b.e
            c.f ← a.f * b.f
        // priority is given to b operand for NaN propagation
        elseif (b.t=SNAN) or (b.t=QNAN) then
            c.s ← a.s ^ b.s
            c.t ← b.t
            c.e ← b.e
            c.f ← b.f
        elseif (a.t=SNAN) or (a.t=QNAN) then
            c.s ← a.s ^ b.s
            c.t ← a.t
            c.e ← a.e
            c.f ← a.f
        elseif a.t=ZERO and b.t=INFINITY then
            c ← DEFAULTSNAN // Invalid
        elseif a.t=INFINITY and b.t=ZERO then
            c ← DEFAULTSNAN // Invalid
```

FIG. 37 *continued*