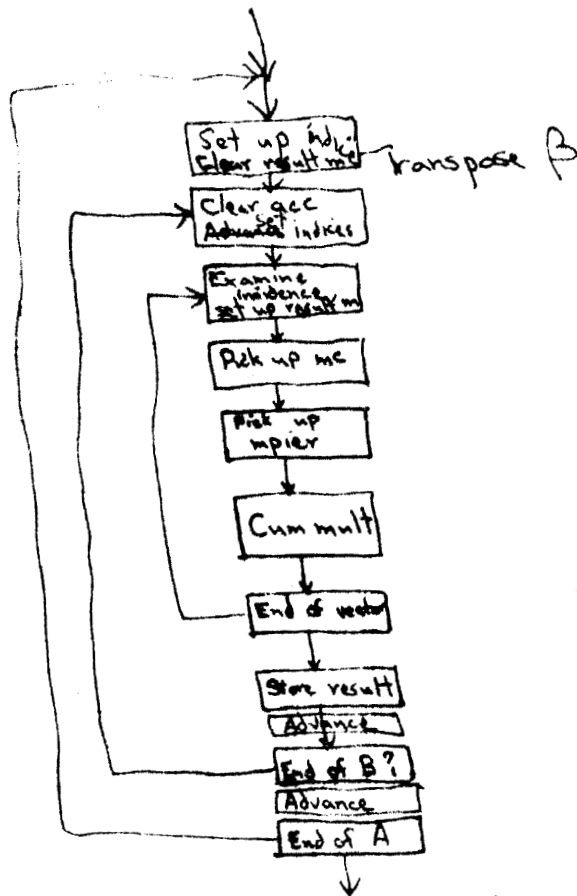


Pages MISSING

7000 Program Proper

Multiplication of ~~64x64~~ Sparse matrices

- Keep 2 64x64 incidence matrices
 - Keep operand matrices in dense lists
 - Keep result matrix in dense list
- Overall chart



$$\alpha \quad \beta = \gamma$$

$$A \quad B = C$$

$$m \times n \quad n \times p$$

given m, n, p

$$m, n, p \leq 64$$

single precision o.k.

incidence matrices 1 wd per row of α , γ
 col of β
 dense lists A, C in row order, B in col order

LZC 11.17-23

bit address

AoC 11.44-50

half-word address

Inner loop sketch

→ CN 0011 $\alpha/X4$
 CNT 0001 $\beta/X5$
 ✓ TMT LZ count to a bit index for setting a one in γ
 ✓ LZ count to ^{two} length fields for finding list positions
~~AO count to zero~~ ^{out}
 use indicator Z to go ~~back~~ switch for vector end

 CNT 0101 — — length modified by ZCT X7
 AO count to word index ~~X1~~
 CNT 0011 ~~$\alpha/X4$~~ length modified by ZCT X7
 AO count to word index X2

^L
~~LMD~~ A/X1
 MPY \bullet B/X2
 AM C/X3
~~up word index X3~~

~~Set bit in γ indexed by X6~~
 repeat
 set γ bit when come out

7000 Coding Sheet

Page: 3 - Knorr Corp
 Project: Matrix Multi
 Date:
 coded by: Brooks

| Location | Operation | Imch. Conn. | Address | I | J | 2nd Address L. 2nd off. | 2nd I | |
|----------|---------------|--------------|--|---|---|-------------------------|----------------|--|
| ILOOP | B L | | α | 4 | | 64 | 8 0 | All numbers are in octal When α and is all zero, go out. |
| | B CN | 0001 | β | 5 | | | | |
| | BIN LN Z | | ENDILOOP | | | | | |
| HIT | LV | | LZCT | | 9 | | | |
| HITZ | CN | M | LZCT | | | 7 | 87 | |
| | LV | | $\beta \cdot \frac{1}{2}$ | | 8 | | | |
| | BIN LN XZ | | NASTY | | | | | If first bit is one, special purpose Turn off first on bit |
| | BB ZN | | 9.0 | 9 | | *+1 | | |
| FINDOPA | CNT | M | α | 4 | | 0 | 0 8 | Find number of signed operands in A list |
| | CN | M | AOCT | | | 7 | 116 | |
| | LV | | $\beta \cdot \frac{1}{2}$ AOCT | | 1 | | | |
| FINDOPB | CNT | M | β | 5 | | 0 | 0 8 | Find number of signed operands in B list |
| | CN | M | AOCT | | | 7 | 110 | |
| | LV | | $\beta \cdot \frac{1}{2}$ AOCT | | 2 | | | |
| MULT | CNM | | $\beta \cdot \frac{1}{2}$ | 6 | | 1 | | Set up result matrix |
| | N L | | A | 1 | | | | |
| | MPY | | B | 2 | | | | |
| | AM | | C | 3 | | | | |
| | B | | ILOOP+1 | | | | | |
| NASTY | I LV | | 0 | | 1 | | | |
| | LV | | 0 | | 2 | | | |
| | BB ZN | | 9.0 | | | | MULT | |
| LZCT | SYN | | 11.17 | | | | | Definitions of symbols |
| AOCT | SYN | | 11.14 | | | | | |
| M | SYN | 0011 | | | | | | |
| A | SYN | 0101 | | | | | | |

7000 Coding Sheet

Page: 4
 Program: Squash
 Date:
 coded by: Brooks

| Location | Operation | Ind. Conn. | Address | I | J | 2nd Address L. 2nd Off. | 3rd I | |
|------------------|------------|------------|------------------------|---|---|-------------------------|-------|---|
| BEGIN | D LX | | R5 | | 5 | | | Initialize Index of |
| | LX | | R4 | | 4 | | | program can be run on |
| | LX | | R6 | | 6 | | | new program without re- |
| | I LV | | 1 | | 7 | | | |
| | LV | | 0 | | 3 | | | |
| | I TMT | H | INITA | | 1 | MULT+1 | | Initialize Mpiar address |
| BOLP | TMT | | INITB | | 1 | MULT+2 | | Initialize Mpiar address |
| BMIDLP | SZ | | C | 3 | | | | Zero the location in result list |
| | CNM | 0000 | X 0 0 0 0 | 6 | | 1 | | Zero the bit in result machine var. |
| ILOOP | See page 3 | | | | | | | |
| ENDILOOP | BB | LF | X 0 0 0 0 | 6 | | ENDILOOP+2 | | Do not advance result bit if result=0 |
| | I I | | 1 | | 3 | | | Advance result bit |
| | CNT | M | β Aoct | 5 | | 64 | | Advance Mpiar address |
| | CN | M | MULT+2 | | | 137 | 110 | Offset could be any number $\times 64$ |
| | AM | UP | Aoct MULT+2 | | | 18 | | |
| | S | UP | MULT+2 | | | 18 | | |
| ok \rightarrow | B IER | | 1 (0) | | 6 | | | Advance result bit |
| | CBR | FV | BMIDLP | | 5 | | | Move to new β vector - reset when at end of β |
| ENDMIDLP | I I | | 1 | | 7 | | | Advance result bit to next row |
| | CNT | M | α | 4 | | | | Advance Mpiar address |
| | CN | | MULT+2 Aoct | | | 7 | | |
| | AM | UP | MULT+2 | | | 18 | | |
| | S | UP | MULT+2 | | | 18 | | |
| | CBR | FV | BOLP | | 4 | | | Move to new α vector - reset at end |
| END | V | | Index Values | | | | | To be loaded with program or data |
| X4 | $\alpha=0$ | | m | | | R | R4 | |
| R4 | 0 | | m | | | R | R4 | |
| X5 | $\beta=0$ | | p | | | R | R5 | |
| R5 | 0 | | p | | | R | R5 | |
| X6 | $X_0=0$ | | p | | | X | X7 | |
| R6 | $X_0=0$ | | p | | | X | X7 | |
| X7 | $X_0=1$ | | p | | | X | X7 | |

~~Multiple Loop~~
Check out sheet

57

011
001

001 LZCT=2

A_{OCT} = 1 → X~~1~~ 1

A_{OCT} = 0 → X 2

a₀₂ · b₀₀ should be a₀₂b₂₁

I Loop

UNDI LOOP

α
3
2
0 1 1
1 0 1
~~0 1 0~~

β
+
3
1 0 0 1
0 0 0 0
0 1 1 0

γ
0 1 1 0
1 1 1 1

A₀ a₀₁
A₁ a₀₂
A₂ a₁₀
A₃ a₁₂

B₀ b₀₀
B₁ b₂₁
B₂ b₂₂
B₃ b₀₃
B₄ b₂₃

C₀ C₀₁ = a₀₂ · b₂₁
C₁ C₀₂ = a₀₂ · b₂₂
C₂ C₀₃ = a₀₂ · b₂₃
C₃ C₁₀ = a₀₀ · b₀₀
C₄ C₁₁ = a₁₂ · b₂₁
C₅ C₁₂ = a₁₂ · b₂₂
C₆ C₁₃ = a₁₀ · b₀₃ + a₁₂ · b₂₃

| LOCATION | CL | OP | M | CI | ADDRESS | | X | J | ADDRESS | | | X | REMARKS | | | |
|----------------------|----|----|---|----|---------|-----|-----|-----|---------|----|-----|-----|----------------|--------|---|--------------------|
| | | | | | 4 | 5 | | | EX | IL | BI | | OF | MULT+1 | MULT+2 | C |
| BEGIN | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | MULT+1 | MULT+2 | C | X |
| BOLP | | | | 0 | 0/2 | 0/4 | 0/1 | 1/4 | | | | | A | | | |
| BMDLP | | | | | | | | | | | | | B | | | |
| ILOOP | | | | | | | | | | | | | | | C=0 | X=0 |
| END ILOOP | | | | | | | | | | | 1/3 | 0/1 | | | | |
| BMDLP | | | | | | | | | | | | | B | | | |
| ILOOP | | | | | | | | | | | | | | | C=0 | X=0 |
| HIT | | | | | | | | | | | | | | | | |
| FINDOPA | | 1 | | | | | | | 2 | 2 | | | | | | |
| FINDOPB | | | 0 | | | | | | | | | | | | | |
| MULT | | | | | | | | | | | | | | | | |
| ILOOP+1 | | | | | | | | | | | | | | | C ₀ =A ₁ B ₀ | X ₀₁ =1 |
| END ILOOP | | | | 1 | | 2/2 | 0/2 | | | | | | | | | |
| BMDLP | | | | | | | | | | | | | B ₂ | | | |
| ILOOP | | | | | | | | | | | | | | | C ₁ =0 | X ₀₂ =0 |
| HIT | | | | | | | | | | | | | | | | |
| FINDOPA | | 1 | | | | | | | 2 | 2 | | | | | | |
| FINDOPB | | | 0 | | | | | | | | | | | | | |
| MULT | | | | | | | | | | | | | | | | |
| ILOOP+1 | | | | | | | | | | | | | | | C ₁ =A ₁ B ₂ | X ₀₂ =1 |
| END ILOOP | | | | 2 | | 3/1 | 0/1 | | | | | | | | | |
| BMDLP | | | | | | | | | | | | | B ₃ | | | |
| ILOOP | | | | | | | | | | | | | | | C ₂ =0 | X ₀₃ =0 |
| END ILOOP | | | | | | | | | | | | | | | | |
| ILOOP | | | | | | | | | | | | | | | | |
| HIT | | | | | | | | | | | | | | | | |
| FINDOPA | | 1 | | | | | | | 2 | 2 | | | | | | |
| FINDOPB | | | 1 | | | | | | | | | | | | | |
| MULT | | | | | | | | | | | | | | | | |
| ILOOP+1 | | | | | | | | | | | | | | | C ₂ =A ₁ B ₄ | X ₀₂ =1 |
| END ILOOP | | | | 3 | | 4/0 | 0/4 | | | | | | | | | |
| END MIDLOOP | | | | | 1/1 | | | 2/4 | | | | | A ₂ | | | |
| BOLP | | | | | | | | | | | | | | | | |

ok

ok

ok

ok

ok

ok

ok

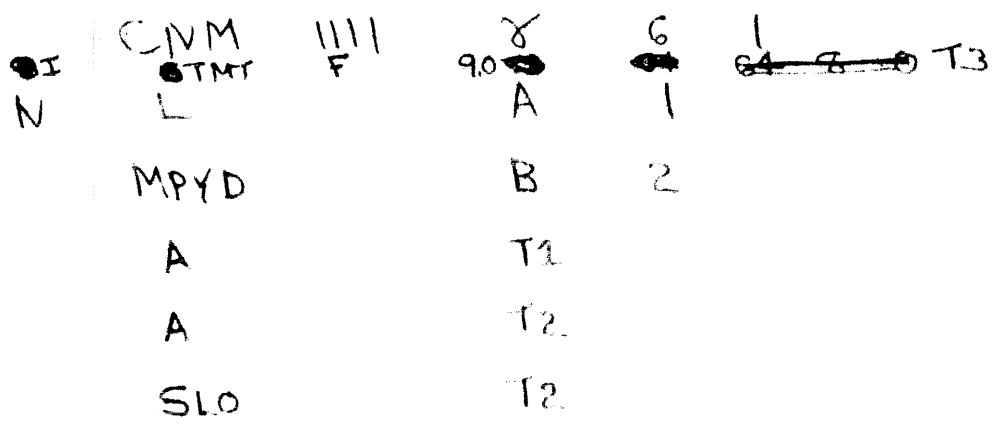
| LOCATION | CL | OP | M | CI | ADDRESS | | ADDRESS | | | | REMARKS | | | | |
|----------|----|----|---|----|---------|-------|---------|-----|----|----|---------|----|----|----|--|
| | | | | | 6 | 7 | 8 | 9 | 10 | 11 | | 12 | 13 | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | not executed again - repeat of last line |
| | | | | | | | | | | | | | | | shows status at end |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 8 | | 1 | 1 | 3 | 1/1 | 0/4 | 1/4 | 2/4 | | | 1 | 2 | | | A_2 B_0 |
| | | | | | | | | | | | | | | | $C_3=0$ $\gamma_{10}=0$ |
| | | | | | | | | | | | 0 | 1 | | | |
| | | | | | | | | | | | 0 | | | | |
| | | 0 | 0 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | $C_2=A_2B_2$ $\gamma_{10}=1$ |
| | | | | | | | | | | | 64 | 0 | | | |
| | | | | 4 | 1/3 | 1/3 | | | | | | 0 | 1 | | B_1 |
| | | | | | | | | | | | | | | | $C_4=0$ $\gamma_{11}=0$ |
| | | | | | | | | | | | | 2 | 1 | | |
| | | | | | | | | | 2 | 2 | | | | | |
| | | 1 | | | | | | | | | | 0 | 1 | | |
| | | | 0 | | | | | | | | | 0 | 0 | | |
| | | | | | | | | | | | | | | | $C_4=A_3B_1$ $\gamma_{11}=1$ |
| | | | | | | | | | | | | 64 | 0 | | |
| | | | | 5 | 2/2 | 1/2/2 | | | | | | 2 | 1 | | B_2 |
| | | | | | | | | | | | | | | | $C_5=0$ $\gamma_{12}=0$ |
| | | | | | | | | | | | | 2 | 1 | | |
| | | | | | | | | | 2 | 2 | | | | | |
| | | 1 | | | | | | | | | | 0 | 1 | | |
| | | | 0 | | | | | | | | | 0 | 0 | | |
| | | | | | | | | | | | | | | | $C_5=A_3B_2$ $\gamma_{12}=1$ |
| | | | | | | | | | | | | 64 | 0 | | |
| | | | | 6 | 3/1 | 1/3/1 | | | | | | 2 | 1 | | B_3 |
| | | | | | | | | | | | | | | | $C_6=0$ $\gamma_{12}=0$ |
| | | | | | | | | | | | | | 0 | 2 | |
| | | | | | | | | | | | | 0 | | | |
| | | 0 | 0 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | $C_6=A_2B_3$ $\gamma_{13}=1$ |
| | | | | | | | | | | | | | 2 | 1 | |
| | | | | | | | | | 2 | 2 | | | | | |
| | | 1 | | | | | | | | | | | 0 | 1 | |
| | | | 1 | | | | | | | | | | 0 | 1 | |
| | | | | | | | | | | | | | | | $C_6=A_3B_4 + A_2B_3$ $\gamma_{13}=1$ |

For 1/2 precision

A B C still one word elements

the following block must be substituted for

MULT



● I S TMT F T1
 B and the following must be added to
~~64 8~~ 9.0

ENDLOOP



For full double precision

A, B, C each two words long

change offset on FINDOPA+1, FINDOPB+1 from 110 to 111

address in ENDLOOP+1 to 2

offset in ENDLOOP+3 to 111 keep ENDLOOP+4 at 110

offset in ENDMIDL+2 to 111 keep ENDMIDL+3 at 110

ENDLOOP for SZ, put 1 TMT F after SZ C, 3 add SZ A, B

and MULT becomes

For 128 by 8 matrices, replace ENDILOOP by

~~ENDILOOP~~

| | | | | | | | |
|----------|-----|----|-----------|---|-----|----|----|
| ENDILOOP | CNT | M | β | 5 | 64 | 12 | |
| | CN | M | AOCT | | 7 | 7 | |
| | AM | UP | MULT+2 | | 18 | 9 | |
| I | I | | | 1 | 5 | 8 | |
| | CBR | N | ENDILOOP2 | | 0 | 2 | |
| | CNT | M | α | 4 | 64 | 12 | |
| | CN | M | AOCT | | 7 | 7 | |
| | LV | | 8.0 | | 0 | 8 | |
| | AM | UP | MULT+1 | | 18 | 9 | |
| | I | B | ILOOP | 1 | 4 | 8 | 34 |
| | L | | XO | | 110 | 8 | |
| | AM | N | MULT+1 | | 18 | 9 | |
| I | I | N | | 1 | 4 | 5 | |
| I | LC | | | 2 | | 8 | 71 |



same as old:

| | | | | | | | |
|---|-----|----|---------|-----|---|-------------|------|
| | BB | LF | | 8 | 6 | ENDILOOP2+6 | 10 |
| I | I | | | 1 | 3 | | 8 |
| | ICR | | | .01 | 6 | | 5 |
| | CBR | FV | BMIDL P | | 5 | | 2 28 |

and replace ENDMIDL P by

| | | | | | |
|---------|-------|--------|----|-----|----|
| ENDMIDL | I | 1 | 7 | | 8 |
| | CNT M | a+1 | 4 | | 12 |
| | L UP | AOCT | 7 | 110 | 8 |
| | A UP | XO | 18 | 110 | 8 |
| | AM UP | MULT+1 | 18 | | 4 |
| I | I | 2 | 4 | | 8 |
| | CBR F | BoLP | 4 | | 2 |

Extension to larger sizes is similarly straight forward

Equations

7000 A equations

Time for matrix problem $p = \text{prob of zero}$

$$106 [N^3(1-p)^2] + 66 [N^3(1-p)^2] - 66 [N^2(1-p)^2] + 21 [N^2(1-p)^2] \\ + 96 N^2 + 44 N + 43.$$

Final equation

$$172 [N^3(1-p)^2] - 45 [N^2(1-p)^2] + 96 N^2 + 44 N + 43.$$

$$+ 468 (1-p)^2 + O(N^2)$$

10% est

Executions

$$9 [N^3(1-p)^2] + 7 [N^3(1-p)^2] - 7 [N^2(1-p)^2]$$

$$+ 3 [N^2(1-p)^2] + 12 N^2 + 6 N + 6$$

$$16 [N^3(1-p)^2] + 12 N^2 - 4 [N^2(1-p)^2] + 6 N + 6$$

704 equation

$$N^3 [4p + 9(1-p)] + O(N^2)$$

10%

704 Equations

~~704 Double precision~~

Executions

$$N^3 [4p + 9(1-p)] + N^2 [19 + 6p + 8(1-p)] + O(N)$$

Double: $N^3 [4p + 52(1-p)] +$ " "

so for double add $43N^3(1-p)$

Time

$$N^3 [96p + 288p(1-p) + 468(1-p)^2]$$

$$+ N^2 [456 + 144p + 192(1-p)] + O(N)$$

Double:

$$N^3 [96p + 1620p(1-p) + 2160(1-p)^2] + \text{same}$$

For double, add $N^3 [1332p(1-p) + 1692(1-p)^2]$

Evaluation Equations

704 N^2 terms

Execution

$$N^2 \left\{ 8(1-p) + 6p \right\} + 7 + 9 + 3$$

$$N^2 \left[8(1-p) + 6p + 19 \right]$$

Time

$$N^2 \left\{ \left[8 \cdot 24(1-p) + 6 \cdot 24 p \right] + 7 \cdot 24 + 9 \cdot 24 + 3 \cdot 24 \right\}$$

^
8 for zero result elem
10 for nonzero " "

$$N^2 \left[192(1-p) + 144p + 456 \right]$$