Q.1

for i

Read only: ① N
② data - array

R/W Non-conflicting: ① data - grid x
② data - grid y

R/W conflicting: ① product
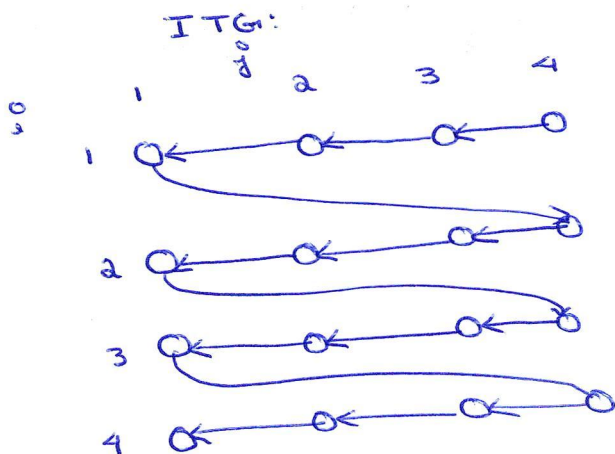② sum
③ i
④ j

for j

Read only: ① N
② data - array
③ sum
④ i

R/W non-conflicting: ① data - grid x
② data - grid y

R/W conflicting: ① product
② measurement
③ j

③ Dependencies (loop carried)

① $S_2[i,j] \xrightarrow{I} S_2[i+1,j]$
② $S_2[i,j] \xrightarrow{A} S_2[i+1,j]$
③ $S_1[i,j] \xrightarrow{T} S_1[i,j-2]$

ITG:
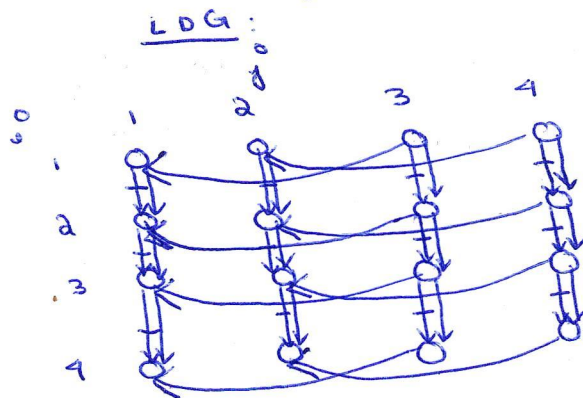

LDG:

ⓐ No, because dependencies ① & ② causes dependencies between i iterations.
This violates condition for DOALL parallelism

ⓑ No, dependency 3 causes dependencies between j iterations. This violates conditions for DOALL parallelism

ⓒ The update of each node along a diagonal is a parallel task
The update of each node along an anti- " is not a parallel "
There are no loop carried dependencies between diagonal loop iterations. However for nodes in anti- diagonal, paths exist between nodes.

(d) The lack of loop carried dependencies in all statements presents an opportunity for parallelism. Note that statement 1 has no dependence loop carried to statement s2.

(e) We can execute the even j iteration in parallel with odd j iterations since $S_1[i,j]$ As $S[i,j-2]$ relates every other j iteration since we have j dependence for every alternate one, we could parallelize the odd and following even iteration.

② (a)
```
for (i=1; i<N; i++) {
    for (j=2; j<N-4; j+=2) {
        S1
        post (i, j+4)
    }
}

for (i=1; i<N; i++) {
    for (j=2; j<N-4; j+=2) {
        if (j > 6) {
            wait (i,j)
        }
        S2
    }
}
```

Loop dependencies

$$S_1[i,j] \xrightarrow{I} S_1[i+1, j+2]$$
$$S_1[i,j] \xrightarrow{A} S_2[i, j+4]$$

(b) serial : time $= (N-1)\dfrac{(N-6)}{2} (TS_1 + TS_2)$

DOPIPE " $= TS_1 + 2TS_2 + max(TS_1, TS_2) * \dfrac{(N-6)}{2} * (N-1)$

Q4.

a.

Index	Name of Function	Number of Calls	Percentage of Execution Time
1.	miniFE::matvec_std<miniFE::CSRMatrix<double, int, int>, miniFE::Vector<double, int, int> >::operator()(miniFE::CSRMatrix<double, int, int>&, miniFE::Vector<double, int, int>&, miniFE::Vector<double, int, int>&)	201	32
2.	frame_dummy	1622833938	15.96
3.	std::_Rb_tree<int, int, std::_Identity<int>, std::less<int>, std::allocator<int> >::_S_key(std::_Rb_tree_node<int> const*)	57598102	5.81
4.	std::_Rb_tree_node<int>::_M_valptr()	435928532	5.57
5.	std::pair<int const, int>* std::__addressof<std::pair<int const, int> >(std::pair<int const, int>&)	510695430	3.93
6.	void miniFE::Hex8::diffusionMatrix_symm<double>(double const*, double const*, double*)	512000	3.44
7.	int* std::lower_bound<int*, unsigned long>(int*, int*, unsigned long const&)	32768000	3.36
8.	std::_Rb_tree<int, int, std::_Identity<int>, std::less<int>, std::allocator<int> >::_S_value(std::_Rb_tree_node<int> const*)	435792686	3.27

b. Speedup = 1/[(1-P)*(P/N)] = 1/[0.68 + 0.32/5] = 1.34408X

c.

```
Performance counter stats for './miniFE.x -nx 40 -ny 80 -nz 160':

     102430.529114      task-clock (msec)          #    1.000 CPUs utilized
               116      context-switches           #    0.001 K/sec
                 0      cpu-migrations             #    0.000 K/sec
            51,330      page-faults                #    0.501 K/sec
   243,621,850,186      cycles                     #    2.378 GHz
   120,929,177,892      stalled-cycles-frontend    #   49.64% frontend cycles idle
     <not supported>    stalled-cycles-backend
   379,615,198,485      instructions               #    1.56  insns per cycle
                                                   #    0.32  stalled cycles per insn
    76,919,383,260      branches                   #  750.942 M/sec
       490,554,048      branch-misses              #    0.64% of all branches

     102.438871644 seconds time elapsed
```

```
Performance counter stats for './miniFE.x -nx 40 -ny 80 -nz 160':

        11,275,934      dTLB-load-misses                                      (80.00%)
       357,840,817      LLC-load-misses            #   54.10% of all LL-cache hits   (80.00%)
       661,408,842      LLC-loads                                             (80.00%)
         8,314,108      L1-icache-load-misses                                 (80.00%)
       755,183,515      L1-dcache-load-misses                                 (80.00%)

     102.631465516 seconds time elapsed
```

```
Performance counter stats for './miniFE.x -nx 40 -ny 80 -nz 160':

   379,606,437,588      instructions               #    1.54  insns per cycle
   245,945,618,784      cpu-cycles
       438,850,986      branch-misses              #    0.57% of all branches
    76,917,186,858      branch-instructions
       355,566,892      cache-references

     103.077571987 seconds time elapsed
```