Performance Issue

Cache Behavior, Jacobi relaxation

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OpenMP Performance Issues

- Using OpenMP to parallelize a program isn't as simple as it looks
  - "Just add a few compiler directives"
  - Especially when considering performance issues
  - To get good performance requires many changes to the original program
  - Write programs in explicit parallelism form
    - I.e., "**`omp parallel`**" rather than "**`omp parallel for`**"
    - Almost no difference between OpenMP and pthreads* in terms of programmability
      - Not quite true … compiler support for reductions, privatization, and mixing of loop scheduling creates some benefits over explicit programming with pthreads

*Pthreads – an explicit programming model we will cover elsewhere in the course

OpenMP Performance Issues

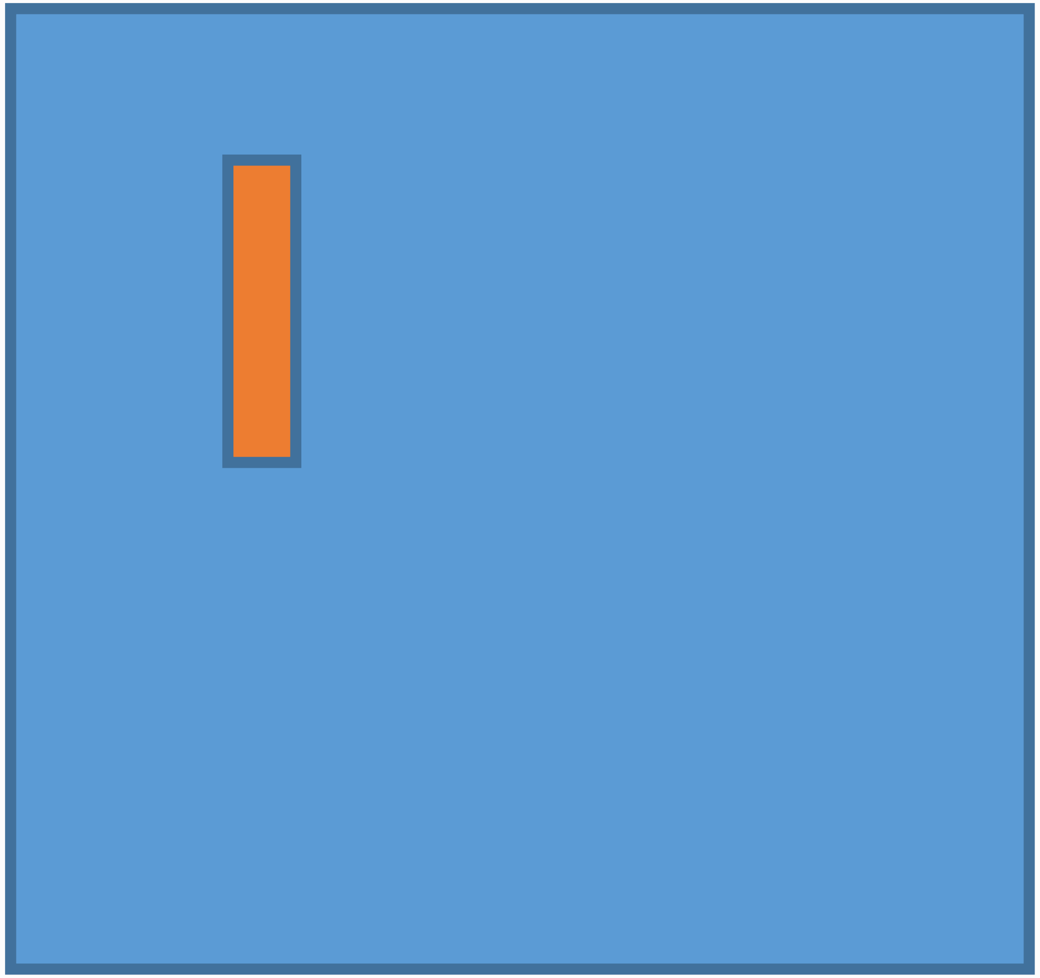
- A major problem is that the programming model does not correspond to the performance model
  - Programmer doesn’t see the cost of the constructs
  - It appears that all memory is “shared” and equally accessible
    - But the costs are affected by another processor’s actions
- You must be aware of communication via cache lines:
  - If a processor writes data and another reads it, it’s a communication, with associated costs, even if it’s a shared memory hardware
    - It takes time (compared with L1 cache, say)
    - It creates contention on the shared bus or communication network, causing additional delays

Example: Jacobi Relaxation

- Consider the problem of finding the temperature at every point in a room (or a square plate), where the temperature at the edges is 0°C and temperature of the heating element somewhere in the room is 100°C
- Problems like this, including those involving electric potential or even shape of soap bubbles on metal wireframes, can be solved using Laplace's equation or its generalization, the Poisson equation
- Numerically, there are several algorithms for solving it in a discretized grid
  - We will focus on Gauss-Jacobi Relaxation
  - This is an example of a large class of algorithms called iterative solvers
  - It is also an example of an important class of computation called stencil computations

The Jacobi Relaxation Algorithm

- The space is discretized into an N x N grid\
- The iterative step, that is applied repeatedly, updates the value (*temperature*) at each grid point as its average of its neighboring four points on itself
- The boundary condition – i.e., the fixed temperatures at the heating element and the edges – is enforced every step.
- The iterative computation continues until there is no significant change in temperature at any point



Jacobi with OpenMP:

- The inner loop nest, where most of the work is, is shown below

```
#pragma omp parallel for private(x,y)
for(x=1; x<MATSIZE-1; x++) {
     for (y=1; y<MATSIZE-1; y++) {
       newA[x][y] = (oldA[x][y] + oldA[x+1][y] + oldA[x-1][y] +
                    oldA[x][y+1] + oldA[x][y-1])/5;
     }
}
```

Jacobi with OpenMP: with outer iteration

- Different computation schemes
  - Which dimension to iterate over first, X or Y?
  - Which dimension to parallelize, X or Y?

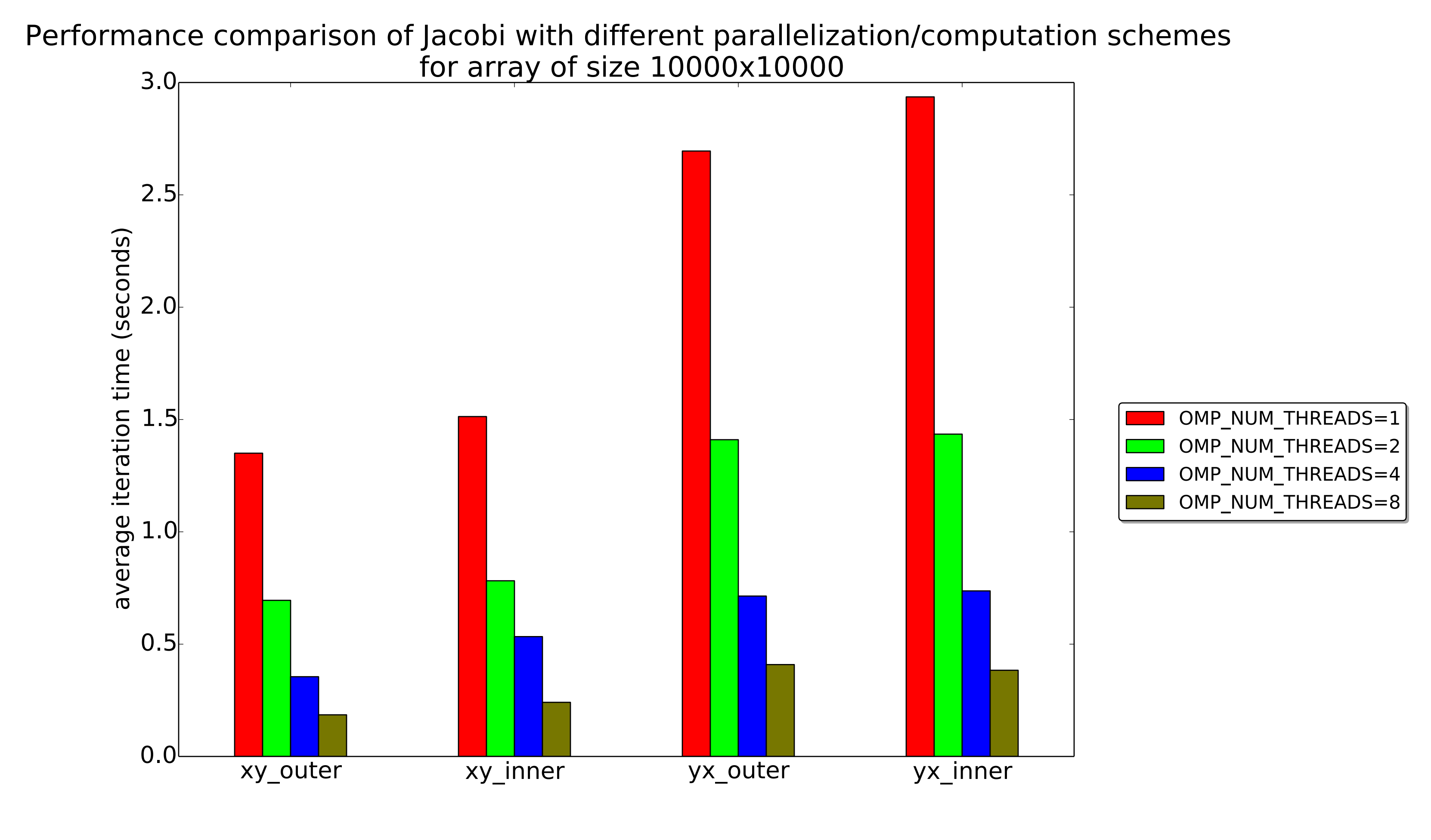
```
while (maxDelta > THRESHOLD) {
#pragma omp parallel for private(x,y), reduction(maxDelta)
  for(x=1; x<MATSIZE-1; x++) {
    for (y=1; y<MATSIZE-1; y++) {
      newA[x][y] = (oldA[x][y] + oldA[x+1][y] + oldA[x-1][y] +
                    oldA[x][y+1] + oldA[x][y-1])/5;
      float delta = abs(newA[x][y] - oldA[x][y]));
      if (delta > maxDelta) maxDelta = delta;
    }
 }
 swap newA and oldA pointers
}
```

Jacobi with OpenMP: focus on a step

- Different computation schemes
  - Which dimension to iterate over first, X or Y?
  - Which dimension to parallelize, X or Y?

```
#pragma omp parallel for private(x,y)
for(x=1; x<MATSIZE-1; x++) {
    for (y=1; y<MATSIZE-1; y++) {
      newA[x][y] = (oldA[x][y] + oldA[x+1][y] + oldA[x-1][y] +
                     oldA[x][y+1] + oldA[x][y-1])/5;
    }
}
```

Different computation schemes



Different way of expressing the same parallelization scheme (1)

- Take xy_inner as an example
  - overhead of creating omp threads in every inner loop
- Implicit → Explicit parallelism expression
  - Removes the above overhead

```
for(x=1; x<MATSIZE-1; x++) {
   #pragma omp parallel for private(y)
   for (y=1; y<MATSIZE-1; y++) {
     newA[x][y] = (A[x][y] + A[x+1][y] +
                   A[x-1][y] + A[x][y+1] +
                   A[x][y-1])/5;
   }
}
```

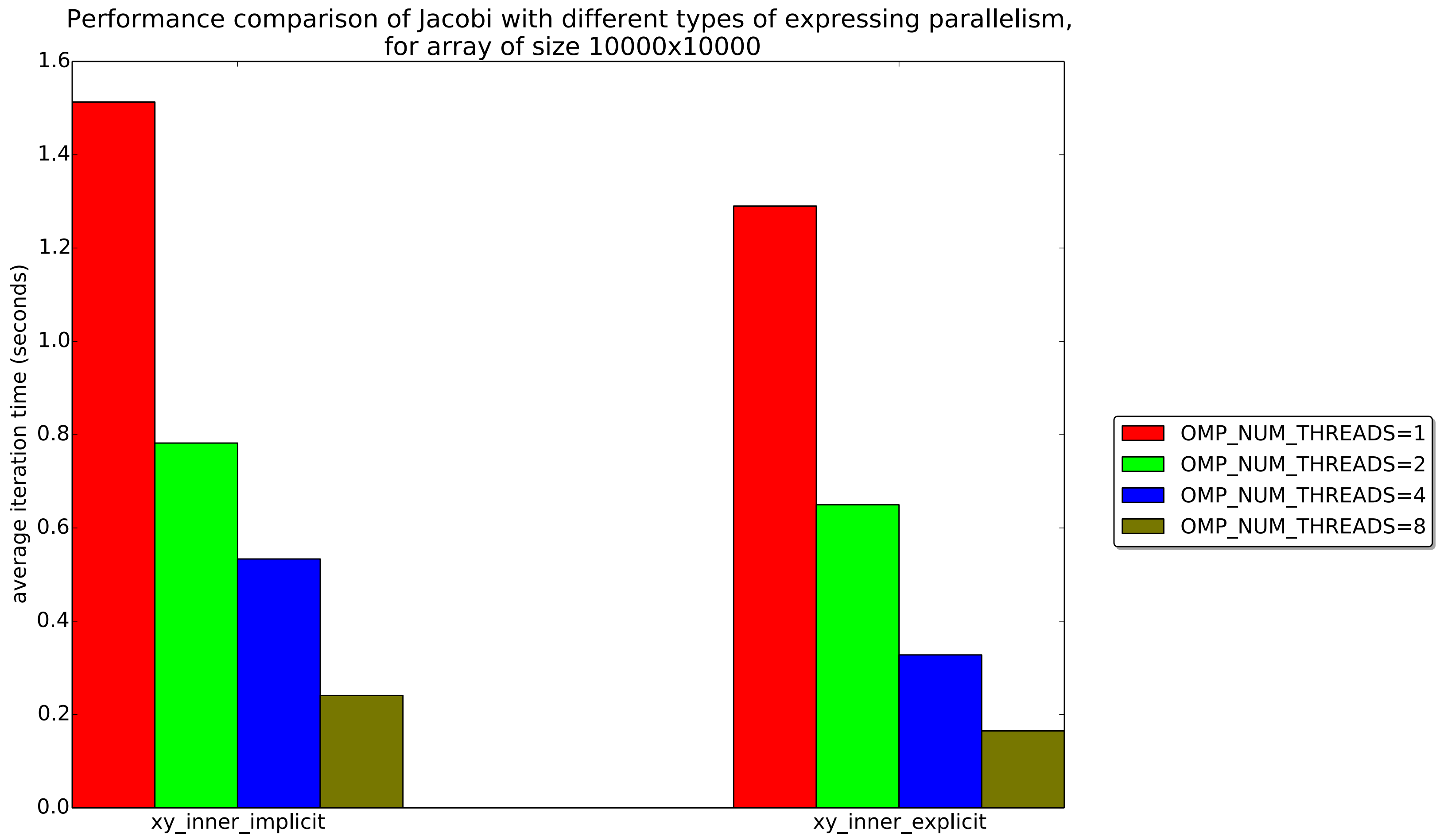
Implicit

→

```
#pragma omp parallel private(x,y)
{
   int chunksize = (MATSIZE-2)/omp_get_num_threads();
   int mystart = 1 + omp_get_threads_num()*chunksize;
   for(x=1; x<MATSIZE-1; x++) {
      for(y=mystart; y<mystart+chunksize; y++) {
         newA[x][y] = (A[x][y] + A[x+1][y] +
                       A[x-1][y] + A[x][y+1] +
                       A[x][y-1])/5;
      }
   }
}
```

Explicit

Different way of expressing the same parallelization scheme (2)

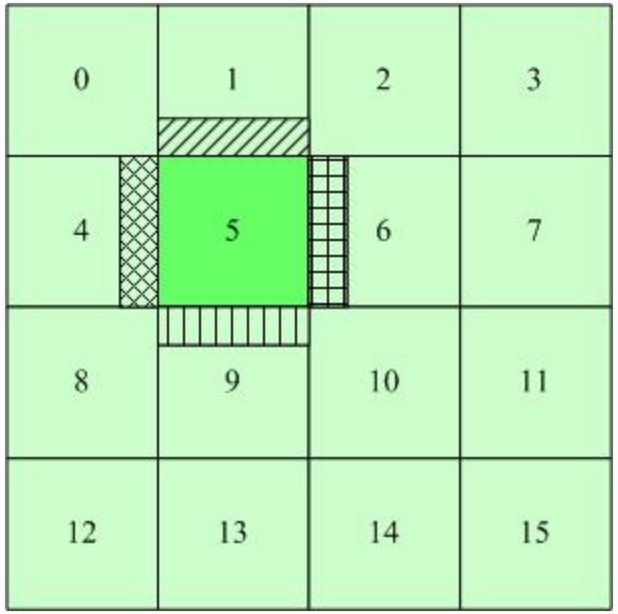


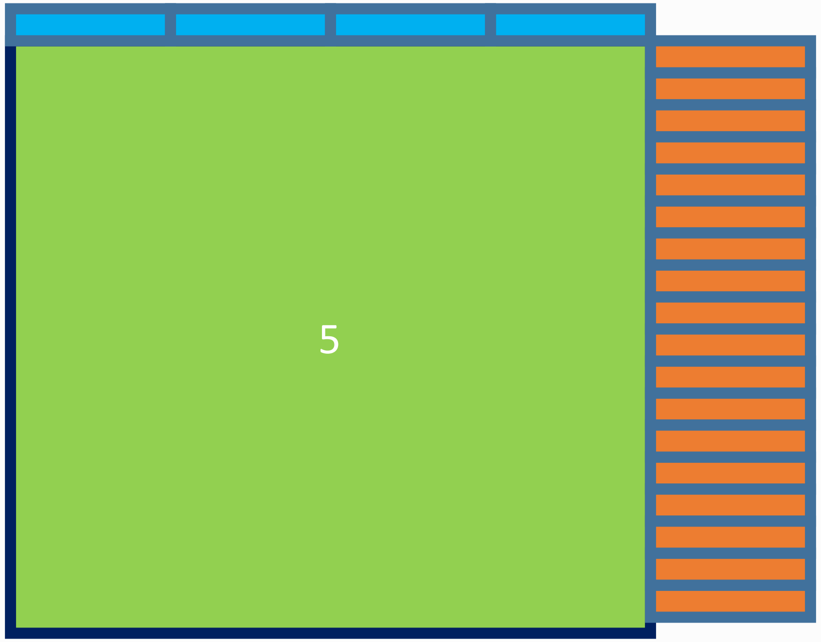
Parallelization for Absolute Performance

- Implicit barrier for each parallel construct in OpenMP
  - Each iteration of the outermost loop is separated by an implicit OpenMP barrier
- Is it possible that one thread starts the next iteration without waiting for all other threads to finish the current iteration?
  - Removing the barrier could lead to the overlap of computation from different iterations, thus saving time!

Is Square Decomposition Good?

Instead of parallelizing the first or second loop





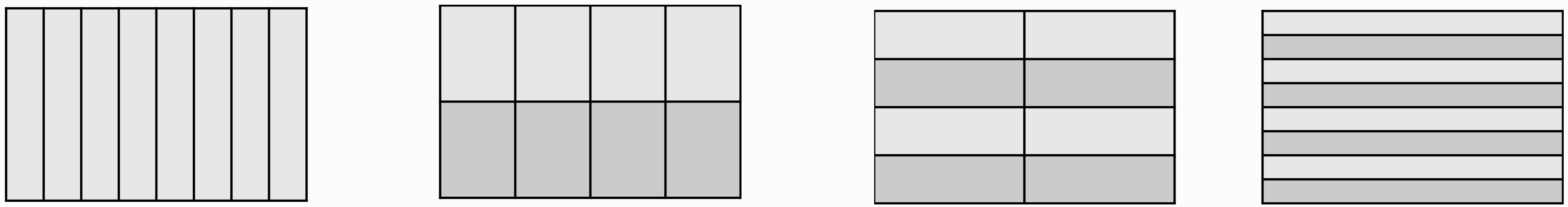
Not quite, because the situation is asymmetric across dimensions

It should be a rectangle with longer dimension along rows ...

Parallelization for Scalability

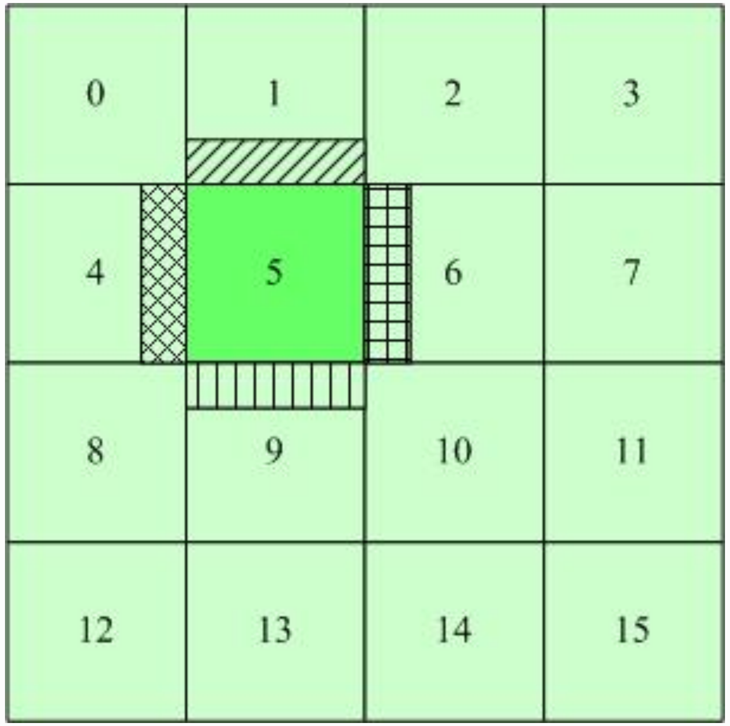
```
#pragma omp parallel for private(x,y,xx,yy,i)
for(i=0; i<numBlkX*numBlkY; i++) {
    xx = 1+(i/numBlkY)*BLKX;      /*BLKX is #elems in X-dim of tile*/
    yy = 1+(i%numBlkY)*BLKY;     /*BLKY is #elems in Y-dim of tile*/
    for(x=xx; x<xx+BLKX; x++) {
        for(y=yy; y<yy+BLKY; y++) {
            newA[x][y] = (oldA[x][y] + oldA[x+1][y] + oldA[x-1][y] +
                          oldA[x][y+1] + oldA[x][y-1])/5;
        }
    }
}
```

Alternatively, use "omp parallel" to explicitly partition work according to the following picture, assuming 8 cores



Parallelization for Absolute Performance

- Considering block decomposition of the matrix
- For simplicity, each thread holds one block



- Observation:
  - Thread 5 can start the next iteration when its neighbor threads 1,4,6,9 finish their updates for the shaded parts, respectively
  - Thread 5 doesn’t need to wait for its non-neighbor threads (such as 0,3,7,13, etc.) to finish the current iteration to start the next iteration
  - How to do this? Use flags to signal readiness, e.g., using flush primitive

Some Lessons for Good Performance

- Sequential cache performance issues are still important
  - E.g., In Jacobi relaxation, xy order was better than yx
- All things being equal, parallelizing outer loop is better than inner loop
- You can regain efficiency using parallelization of inner loop by using "**`omp parallel`**"
  - Avoids thread creation and synchronization overhead
- Communication analyses, to see how much data created by one thread is read by another, is useful
  - And can be optimized by techniques such as block/tile decomposition
- Eliminating global barriers is important