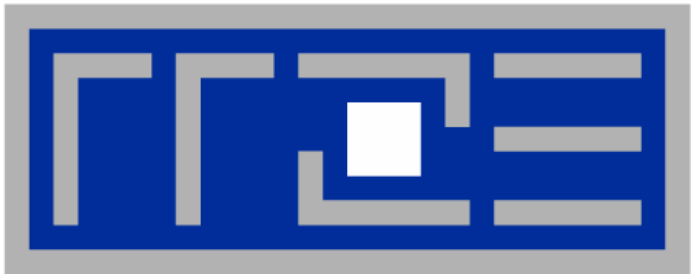

Intel Cluster OpenMP™

Georg Hager
Regionales Rechenzentrum Erlangen
Universität Erlangen-Nürnberg

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Outline

- What is it?
- Process Model & Sharability
- Consistency Protocol
- Compiler Options
- Running a Cluster OpenMP Program

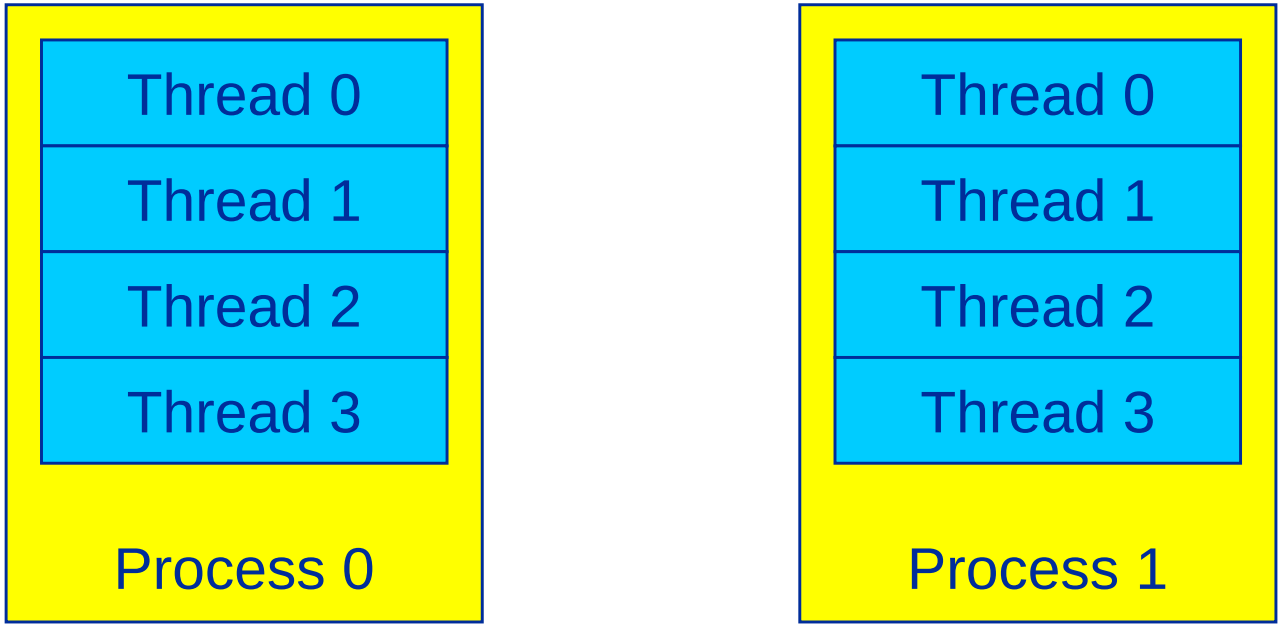
- Benchmarks
  - Low-level
  - Heat Conduction
  - Lattice-Boltzmann Code

Introductory material provided by Jim Cownie and Larry Meadows of Intel

What is it?

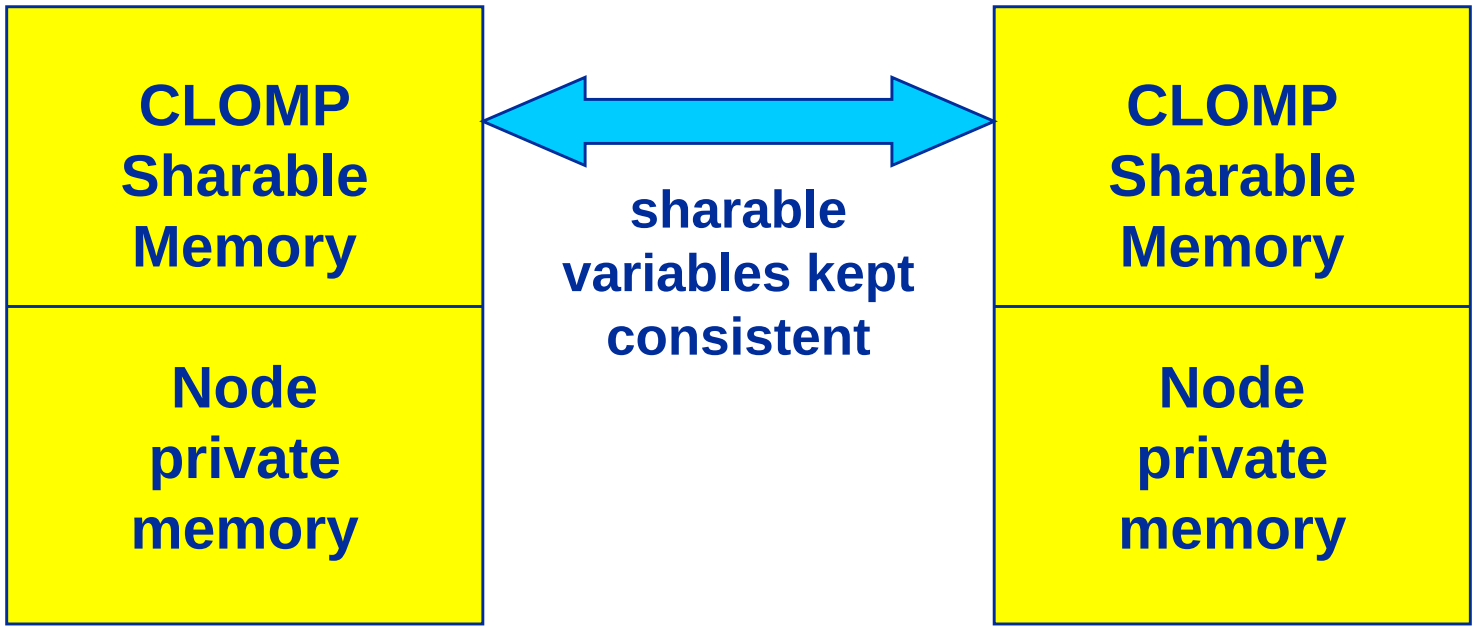
- Cluster OpenMP supports running OpenMP code on the nodes of a cluster
  - Compiler extensions and runtime library
- Part of Intel compilers since version 9.1
  - Separate license required
- “Shared memory” structure is simulated in software
- Pros
  - All the good things from OpenMP + ccNUMA… ☺
  - Memory bandwidth, automatic page replication/migration
  - Inexpensive hardware a.o.t. OpenMP on shared memory
- Cons
  - Synchronization very expensive
  - Remote access very expensive
  - Sharability sometimes not recognized by compiler
  - False sharing on page basis is catastrophic for performance

Cluster OpenMP Process Model



- **Usually one process per node, one OpenMP thread per core**
- **Cluster OpenMP global thread ID runs from 0 to (number of nodes)x(threads per node)**
- **“Hybrid” programming in disguise**

Cluster OpenMP Memory Model



- **If multiple threads access a variable, it must be sharable**
- **A sharable variable must be allocated in the sharable reagion of address space**

Cluster OpenMP Sharability

- OpenMP shared data must be made sharable in Cluster OpenMP
  - implicitly (by compiler)
  - explicitly (by options or directives)

```
#pragma intel omp sharable(a)  // C/C++

!dir$ omp sharable(a)          ! Fortran
```

- No single system image
  - No shared file pointers
  - No shared sockets
  - … or any other shared OS resources

Made Sharable by the Compiler

- Routine-local stack variables within the scope of the routine

```
void func(void) {
    int a;
    ...
#pragma omp parallel shared(a)
```

- Call by value parameters inside the scope of the called routine

```
void func(int a) {
    ...
#pragma omp parallel shared(a)
```

Making Fortran Data Sharable

- Fortran COMMON blocks:

```
common /BLK/ a(100)
```

  by directive

```
!dir$ omp sharable (/BLK/)
```

  by compiler option

```
-clomp-sharable-commons
```

- Fortran local SAVE data:

```
real a(100)
save a
```

  by directive

```
!dir$ omp sharable(a)
```

  by compiler option

```
-clomp-sharable-localsaves
```

- Fortran Module variables:

```
module m
real a(100)
```

  by directive

```
!dir$ omp sharable(a)
```

  by compiler option

```
-clomp-sharable-modvars
```

Making Dynamic Data Sharable

- **Fortran: by directive**

```
use omp_lib
real, allocatable :: a(:)
!dir$ omp sharable(a)

allocate a(size)
```

- **C: substitutes for `malloc()`/`free()`**

```
#include <omp.h>
void *ptr;
ptr = kmp_sharable_malloc(size);
ptr = kmp_sharable_realloc(size);
ptr = kmp_sharable_calloc(n,size);
kmp_sharable_free(ptr);
```

Dynamic C++ Data

- `#include <kmp_sharable.h>`
- All objects of a class A become sharable by inheriting from `class kmp_sharable_base`:

```
class A : public kmp_sharable_base {...};
```

- Make a single dynamic object sharable:

```
A *ptr = new (kmp_sharable) A;
```

- Sharable STL containers:

```
vector<int,kmp_sharable_allocator<int> > *ptr =
    new (kmp_sharable) vector<int,
          kmp_sharable_allocator<int> >;
```

Detecting Missing Sharable Specifications

- For static and stack data

  `-cluster-openmp -clomp-sharable-propagation –ipo`

  detects variables which should be sharable at link time:

  ```
  fortcom: Warning: Sharable directive should be
  inserted by user as `!dir$ omp sharable(n)’ in
  file … line …
  ```

- For dynamic data

  use `KMP_DISJOINT_HEAPSIZE=<size>` shell variable to provoke segfaults on non-sharable heap data which is used in a shared way

A Simple Cluster OpenMP Program

```
#include <omp.h>
static int a;
#pragma intel omp sharable(a)

int main()
{
  a = 0;
#pragma omp parallel
  {
#pragma omp critical
    a++;
  }
  printf("%d should equal %d\n",
         omp_get_max_threads(), a);
}
```

Compiling and Running

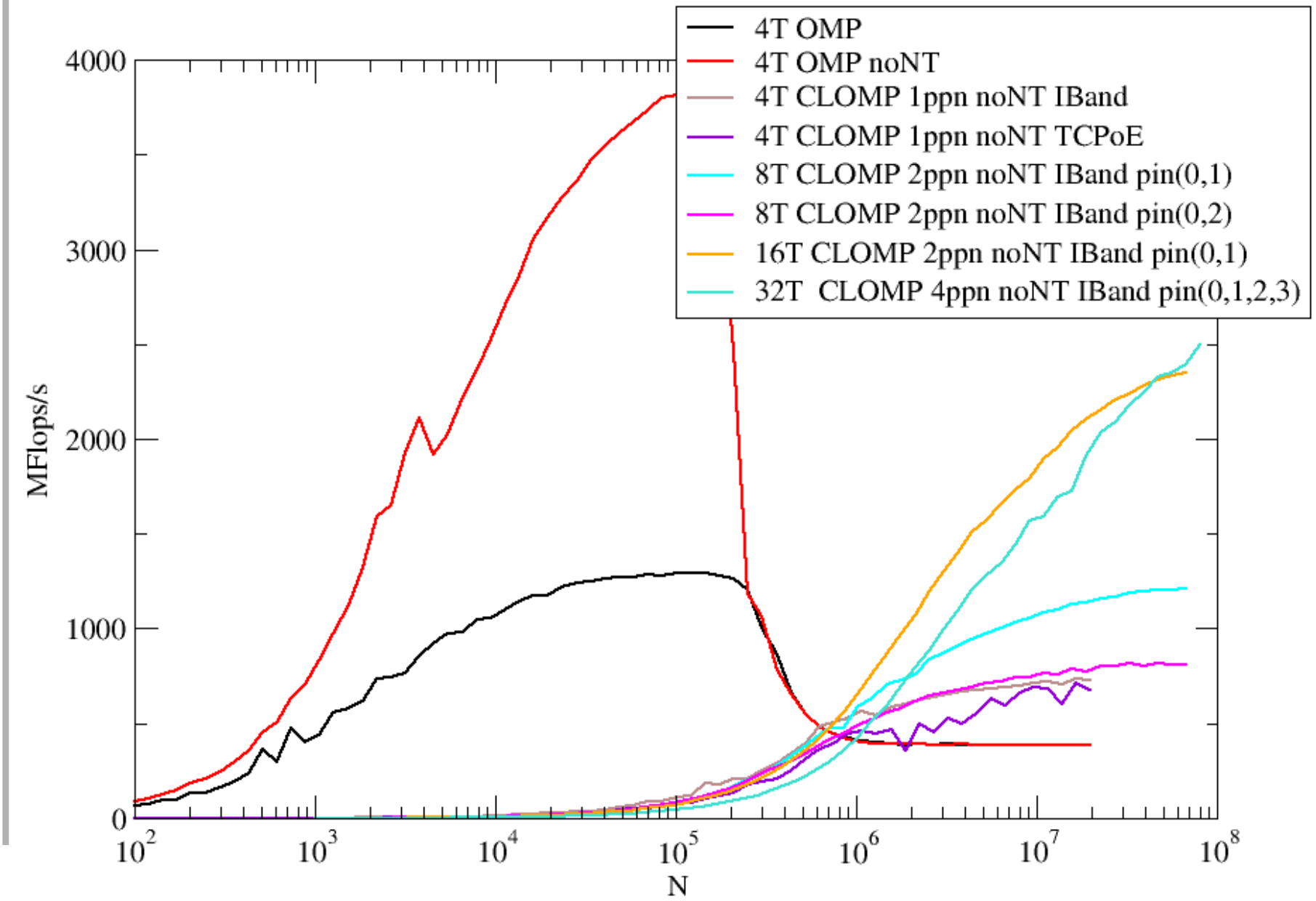
- **Compile:** `icc –cluster-openmp test.c`
- **Write** `kmp_cluster.ini` **file with details on how to run the binary:**

```
--hostfile=./hosts --process_threads=4
--launch=ssh --sharable-heap=200000000
--transport=dapl --adapter=OpenIB-cma
```

- `./a.out`

Latency Galore: Vector Triad (Woodcrest 3GHz)

```
A(:) = B(:)+C(:)*D(:)
```

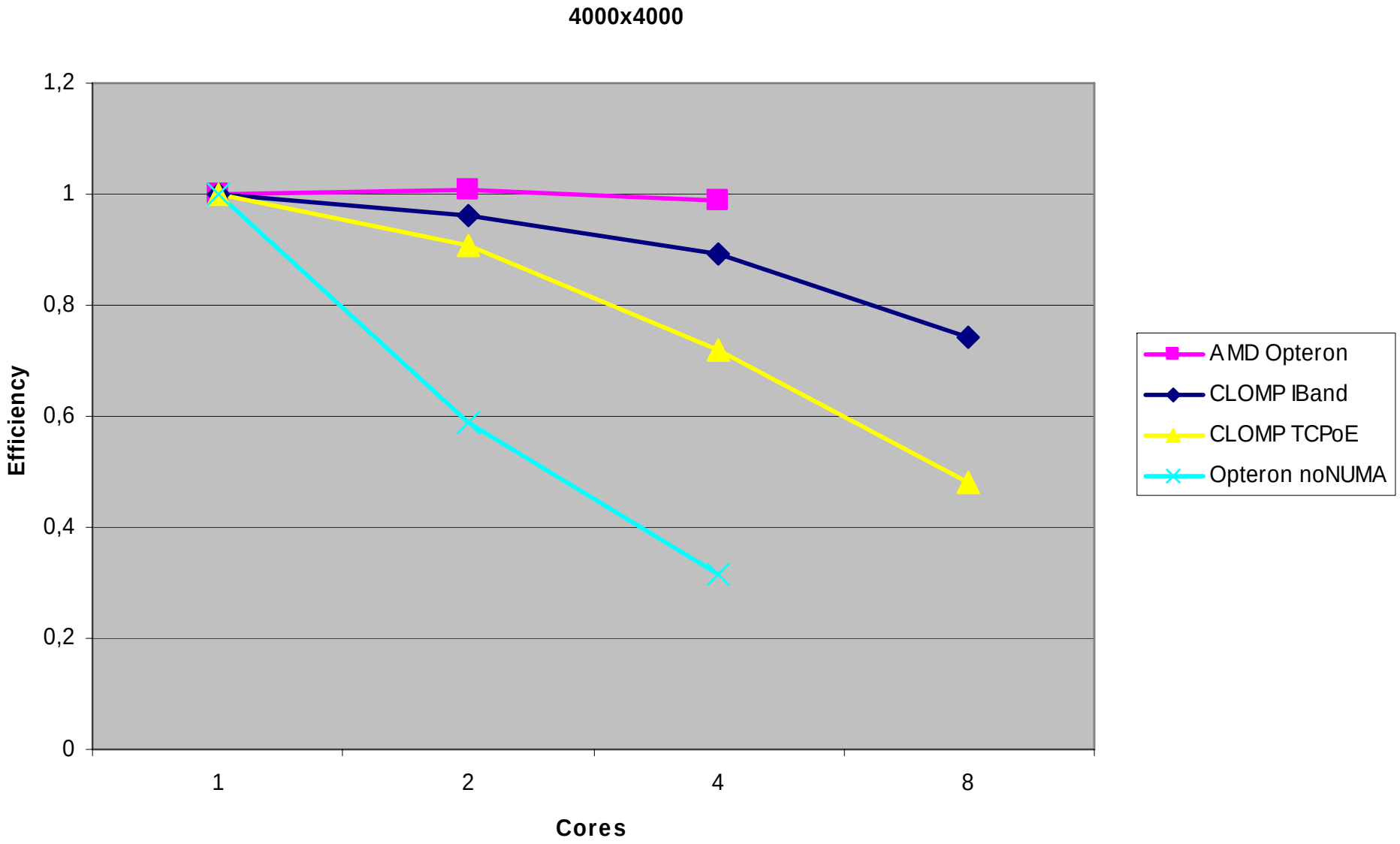


Heat Conduction Example

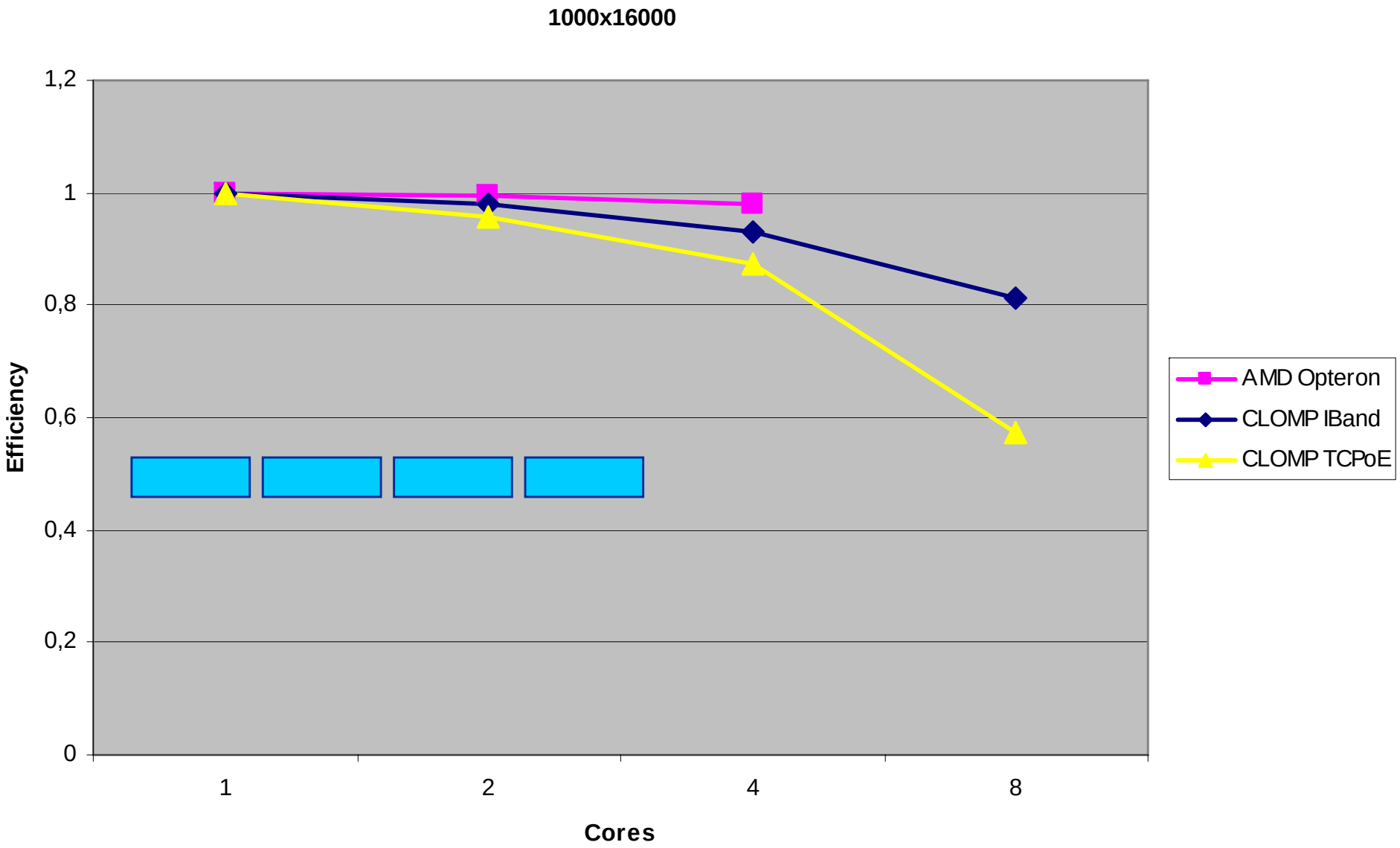
- Simple 2D finite difference solver for heat conduction equation

```
!$OMP parallel do private(dphi,i) reduction(max:dphimax)
schedule(static)
      do k=1,kmax-1
         do i=1,imax-1
            dphi=(phi(i+1,k,t0)+phi(i-1,k,t0)- &
                     2.0_8*phi(i,k,t0))*dy2i &
                 +(phi(i,k+1,t0)+phi(i,k-1,t0)- &
                     2.0_8*phi(i,k,t0))*dx2i
            dphi=dphi*dt
            dphimax=max(dphimax,abs(dphi))
            phi(i,k,t1)=phi(i,k,t0)+dphi
         enddo
      enddo
!$OMP end parallel do
```

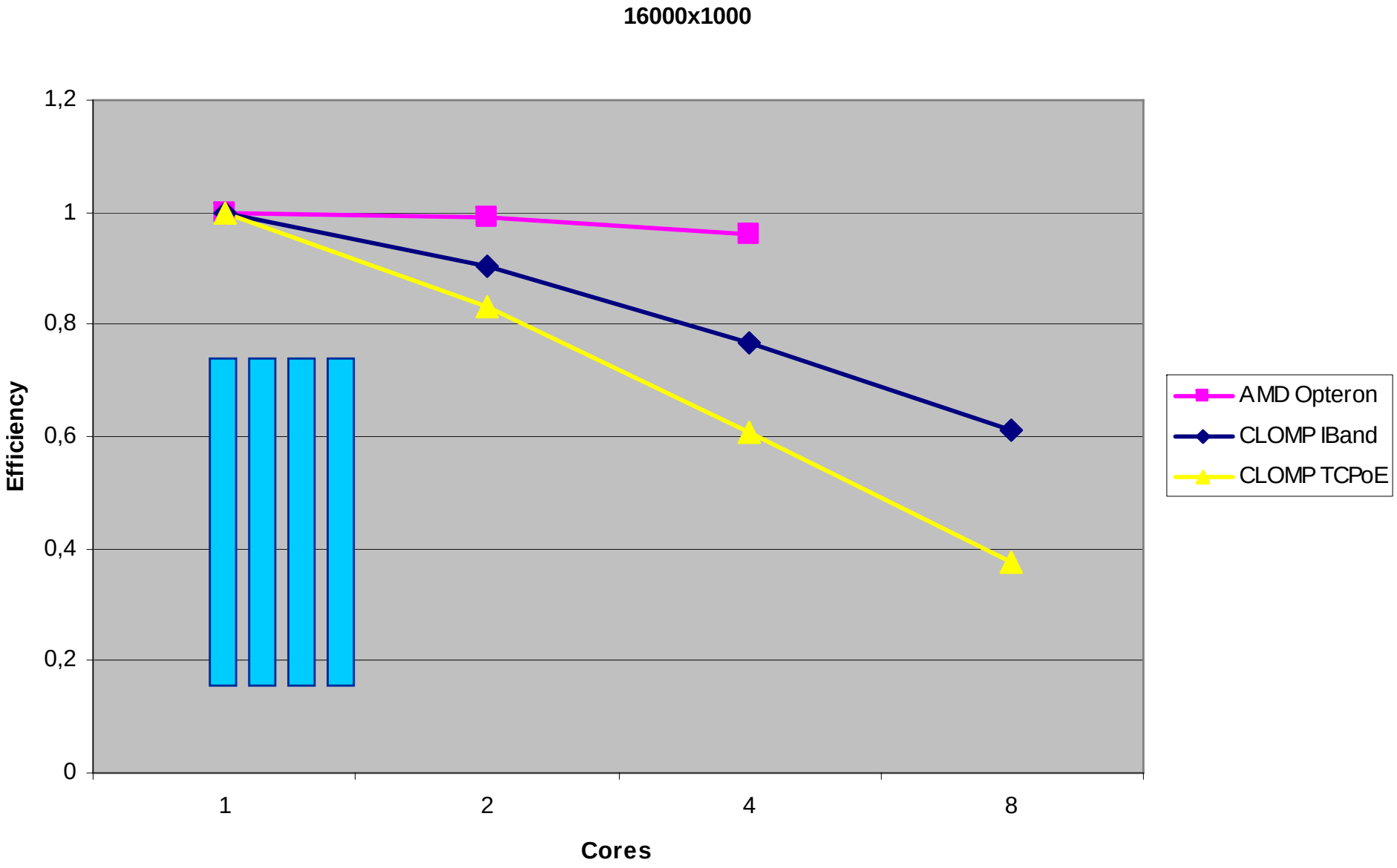
Communication vs Computation
4000x4000 Grid



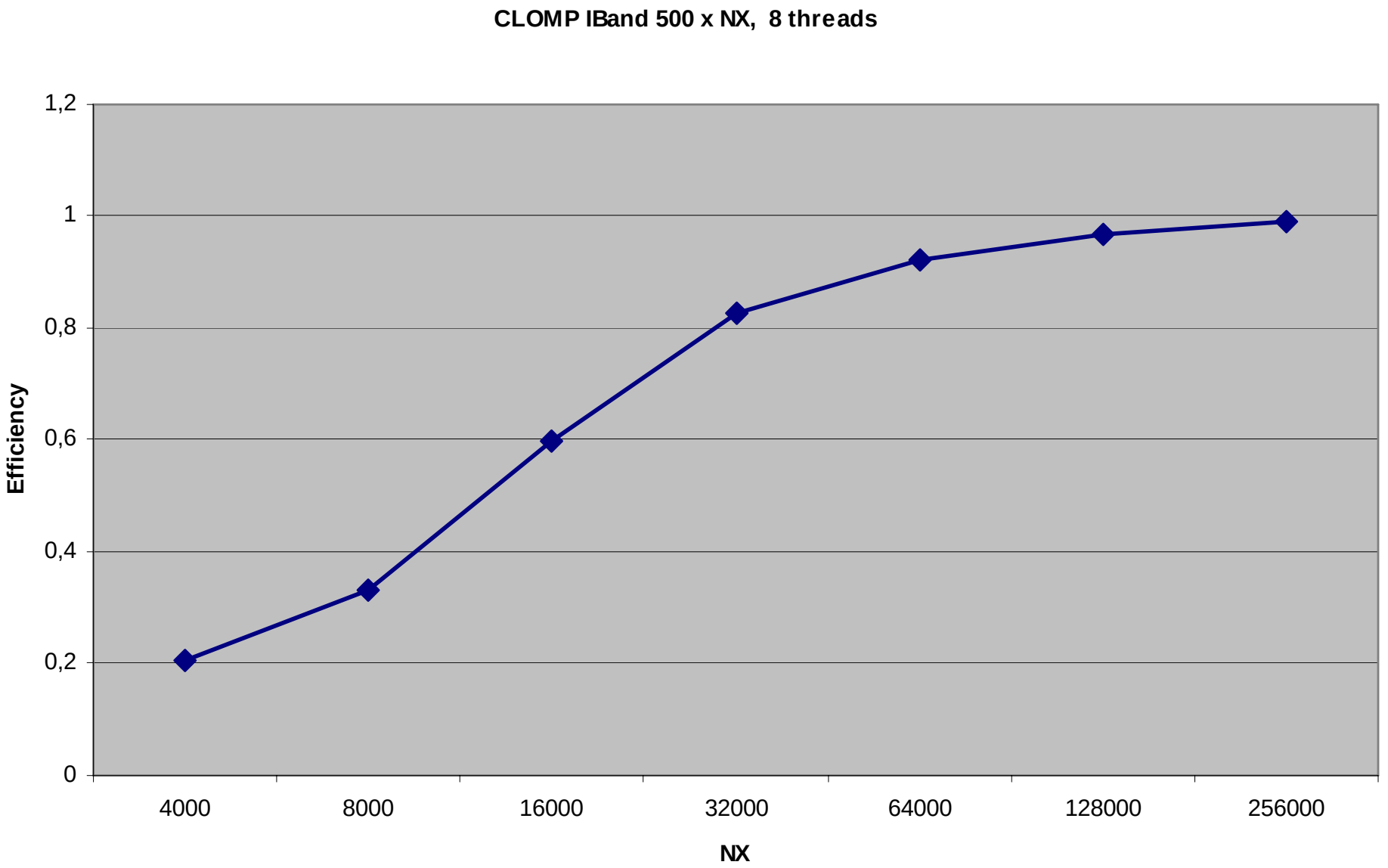
Communication vs. Computation
Favourable Case



Communication vs. Computation
Unfavourable Case



Communication vs. Computation
Good Problem Sizes



Application: Lattice Boltzmann Method

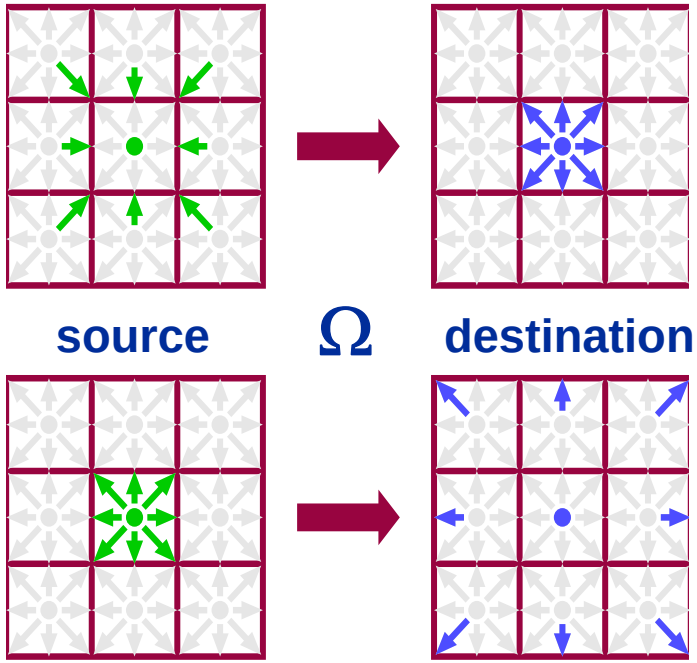
Numerical Method for Simulation of Fluids

Stream-Collide (Pull-Method)

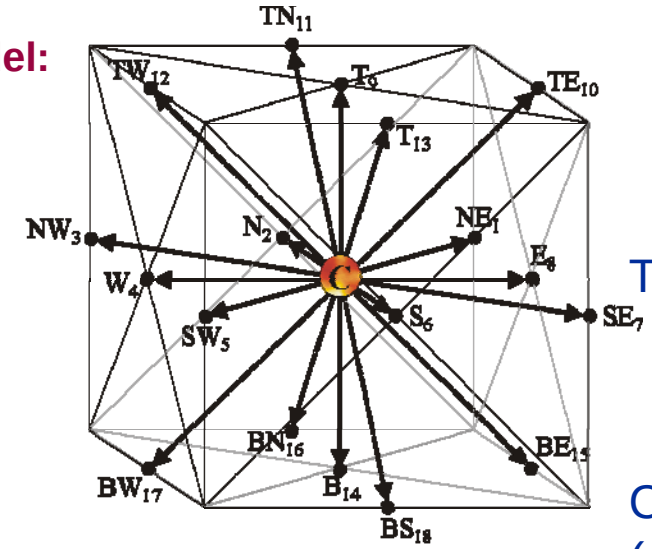
Get the distributions from the neighboring cells in the source array and store the relaxated values to one cell in the destination array

Collide-Stream (Push-Method)

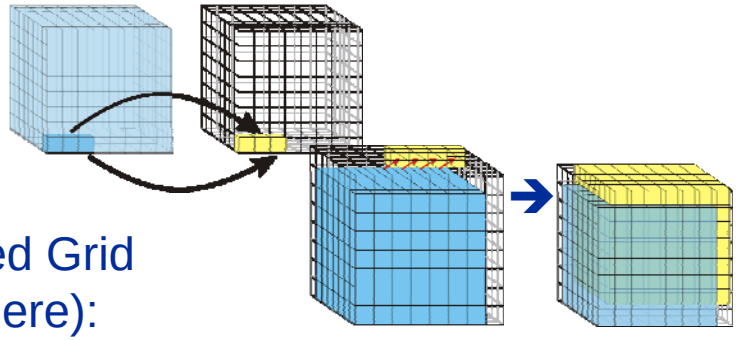
Take the distributions from one cell in the source array and store the relaxated values to the neighboring cells in the destination array



D3Q19 model:



Two Grids:



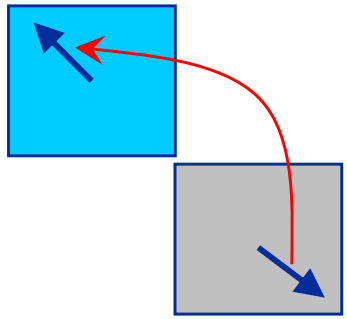
Compressed Grid (not used here):

LBMKernel
Code Structure for Collide-Stream Step

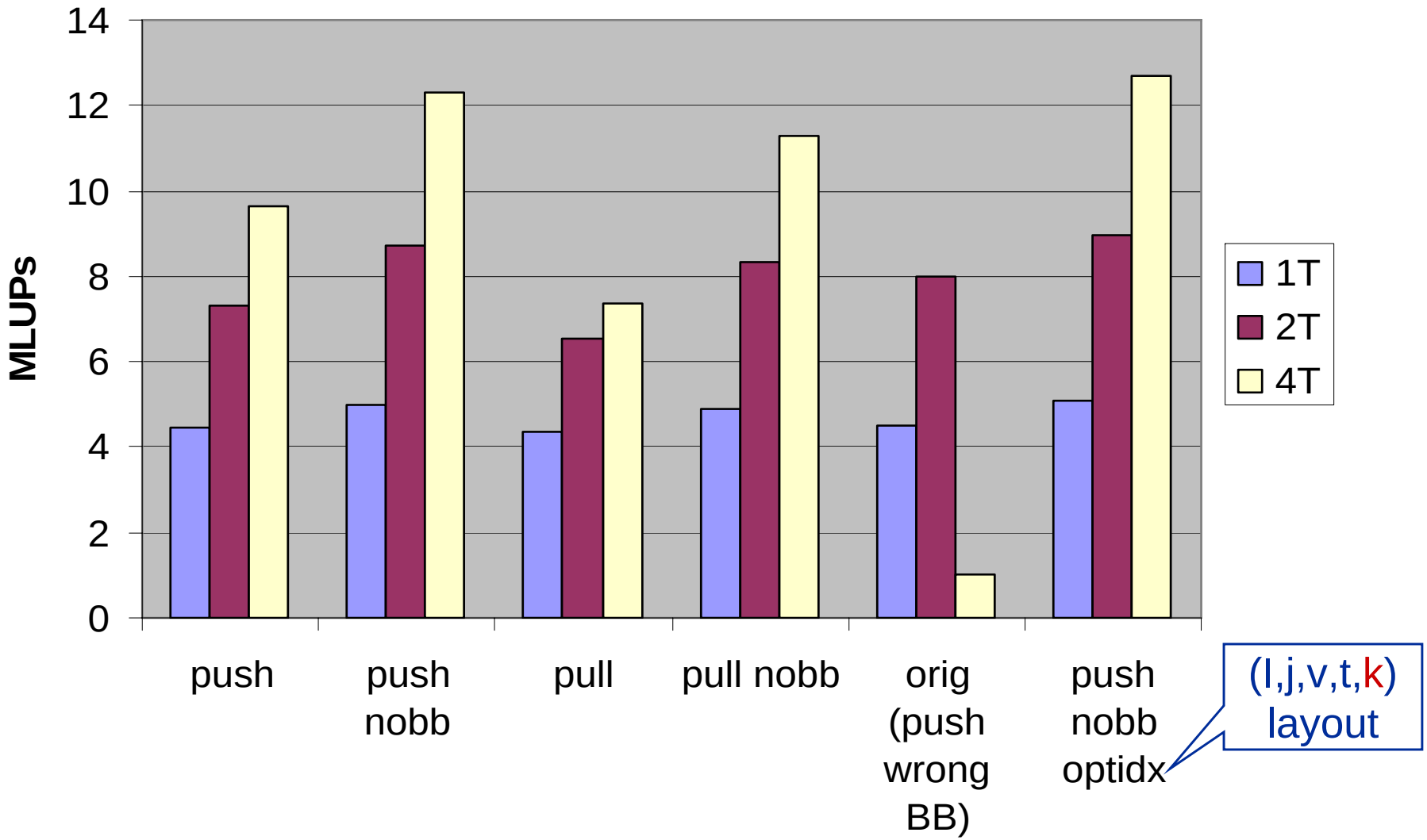
```
double precision
    f(0:xMax+1,0:yMax+1,0:zMax+1,0:18,0:1)
!$OMP PARALLEL DO
do z=1,zMax
   do y=1,yMax
      do x=1,xMax
         if( fluidcell(x,y,z) ) then
            LOAD f(x,y,z, 0:18,t)
            ...Relaxation (complex computations)...
            SAVE f(x  ,y  ,z  , 0,t+1)
            SAVE f(x+1,y+1,z  , 1,t+1)
            SAVE f(x  ,y+1,z  , 2,t+1)
            SAVE f(x-1,y+1,z  , 3,t+1)
            …
            SAVE f(x  ,y-1,z-1,18,t+1)
         endif
      enddo
   enddo
enddo
```

LBMKernel

- Scalability beyond 2 nodes was very bad with standard code
- proper choice of geometry (long thin channel) can restore scalability
  - not a general solution
- **Solution:** bounceback (boundary) routine was not properly optimized for local access
  - on ccNUMA, this is a negligible effect for small obstacle density (n^2)
  - on CLOMP, it is devastating
- Still: indexing has significant impact on performance
  - "push" vs. "pull" algorithm
  - parallelized dimension should be the outermost one to minimize false sharing: (i,j,v,t,k) better than (l,j,k,v,t)
- Might profit from ghost layers, but is this still OpenMP???



Influence of Bounceback and Push vs. Pull for 128x64x128 and (i,j,k,v,t) layout



Cluster OpenMP
Wrap-Up

- Interesting model, fun to play with
- Crucial to get the right IB setup
- Benefits
  - Improved memory bandwidth
  - Inexpensive hardware
- Drawbacks
  - Huge latency penalties
  - Communication vs. Computation
  - Large memory footprint

- “Minimalistic” MPI?

Hands-On

- `qsub –l nodes=2:dgrid,walltime=01:00:00 –I –X`
- `module load compiler/intel-10.0`
- `cd CLOMP/exa1`
- `cp $PBS_NODEFILE hosts`
- `echo “--process_threads=1 --launch=ssh \`
  `--hostfile=hosts” > kmp_cluster.ini`

- **Then either:**

  `ifort -cluster-openmp f_ex1.f`
  or
  `icc –cluster-openmp c_ex1.c`
- `./a.out`
  `a=  2. It should be  2.`