OpenMP Programming

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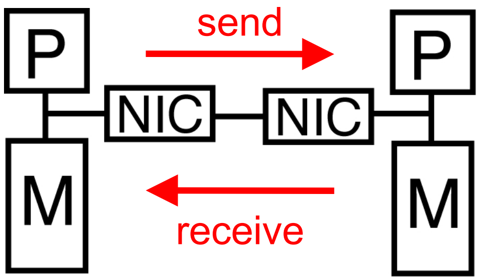
OpenMP

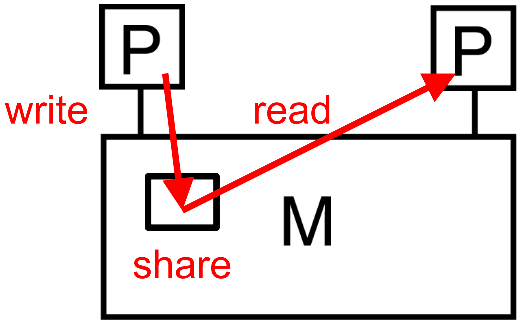
- **Portable application program interface (API) for shared-memory parallel programming based on multi-threading by compiler directives**
- **OpenMP = Open specifications for Multi Processing**
- **OpenMP homepage**

  `www.openmp.org`
- **OpenMP tutorial**

  `www.llnl.gov/computing/tutorials/openMP`
- **Process: an instance of program running**
- **Thread: a sequence of instructions being executed, possibly sharing resources with other threads within a process**



MPI (distributed memory)

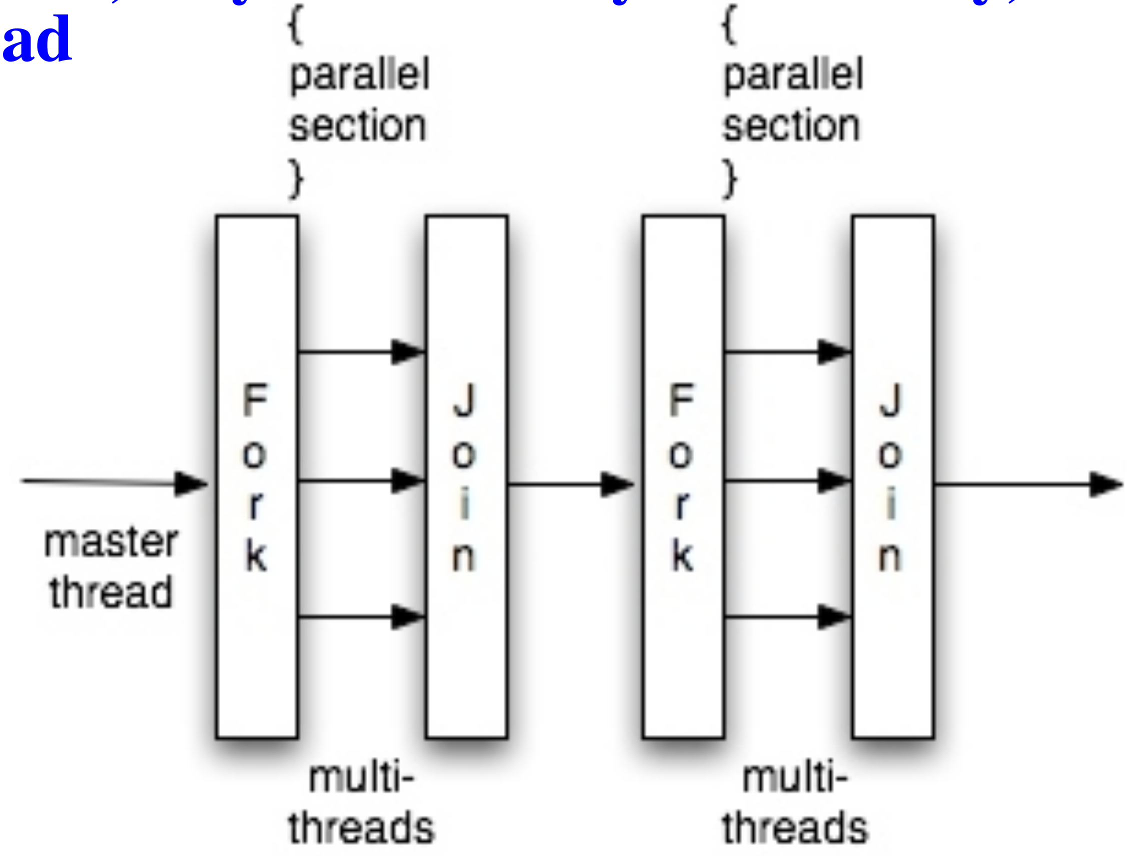


OpenMP (shared memory)

OpenMP Programming Model

Fork-join parallelism

- **Fork:** master thread spawns a team of threads as needed
- **Join:** when the team of threads complete the statements in the parallel section, they terminate synchronously, leaving only the master thread



- OpenMP threads communicate by sharing variables

See Grama’03, Chap. 7

OpenMP Example: omp_example.c

```
#include <stdio.h>
#include <omp.h>
void main () {
  int nthreads,tid;
  nthreads = omp_get_num_threads();
  printf("Sequential section: # of threads = %d\n",nthreads);
  /* Fork multi-threads with own copies of variable */
  #pragma omp parallel private(tid)
  {
    /* Obtain & print thread id */
    tid = omp_get_thread_num();
    printf("Parallel section: Hello world from thread %d\n",tid);
    /* Only master thread does this */
    if (tid == 0) {
      nthreads = omp_get_num_threads();
      printf("Parallel section: # of threads = %d\n",nthreads);}
  } /* All created threads terminate */
}
```

Get the number of threads

Each threads gets a private variable

Get my thread ID: 0, 1, ...

parallel section

- Obtain the number of threads & my thread ID
- By default, all variables are shared unless selectively changing storage attributes using private clauses

OpenMP Example: omp_example.c

- **Compilation on hpc-login3.usc.edu**

```
source /usr/usc/openmpi/default/setup.sh
```

(if bash)

```
gcc -o omp_example omp_example.c -fopenmp
```

- **PBS script**

```
#!/bin/bash
#PBS -l nodes=1:ppn=2
#PBS -l walltime=00:00:59
#PBS -o omp_example.out
#PBS -j oe
#PBS -N omp_example
OMP_NUM_THREADS=2
WORK_HOME=/home/rcf-proj2/an2/anakano
cd $WORK_HOME
./omp_example
```

Set the # of threads using environment parameter

- **Output**

```
Sequential section: # of threads = 1
Parallel section: Hello world from thread 1
Parallel section: Hello world from thread 0
Parallel section: # of threads = 2
```

Setting the Number of Threads

```
#include <stdio.h>
#include <omp.h>

void main () {
  int nthreads,tid;
  omp_set_num_threads(2);
  nthreads = omp_get_num_threads();
  printf("Sequential section: # of threads = %d\n",nthreads);
  /* Fork multi-threads with own copies of variable */
  #pragma omp parallel private(tid)
  {
    /* Obtain & print thread id */
    tid = omp_get_thread_num();
    printf("Parallel section: Hello world from thread %d\n",tid);
    /* Only master thread does this */
    if (tid == 0) {
      nthreads = omp_get_num_threads();
      printf("Parallel section: # of threads = %d\n",nthreads);
    }
  } /* All created threads terminate */
}
```

- **Setting the number of threads to be used in parallel sections within the program (no need to set OMP_NUM_THREADS); see `omp_example_set.c`**

OpenMP Programming Model

- **OpenMP is typically used to parallelize (big) loops**
- **Use synchronization mechanisms to avoid race conditions (i.e., the result changes for different thread schedules)**
- **Critical section: only one thread at a time can enter**

```
#pragma omp parallel
{
  ...
  #pragma omp critical
  {
    ...
  }
   ...
}
```

Threads wait their turn — only one at a time executes the critical section

Example: Calculating π

- **Numerical integration**

$$\int_0^1 \frac{4}{1+x^2}\,dx = \pi$$

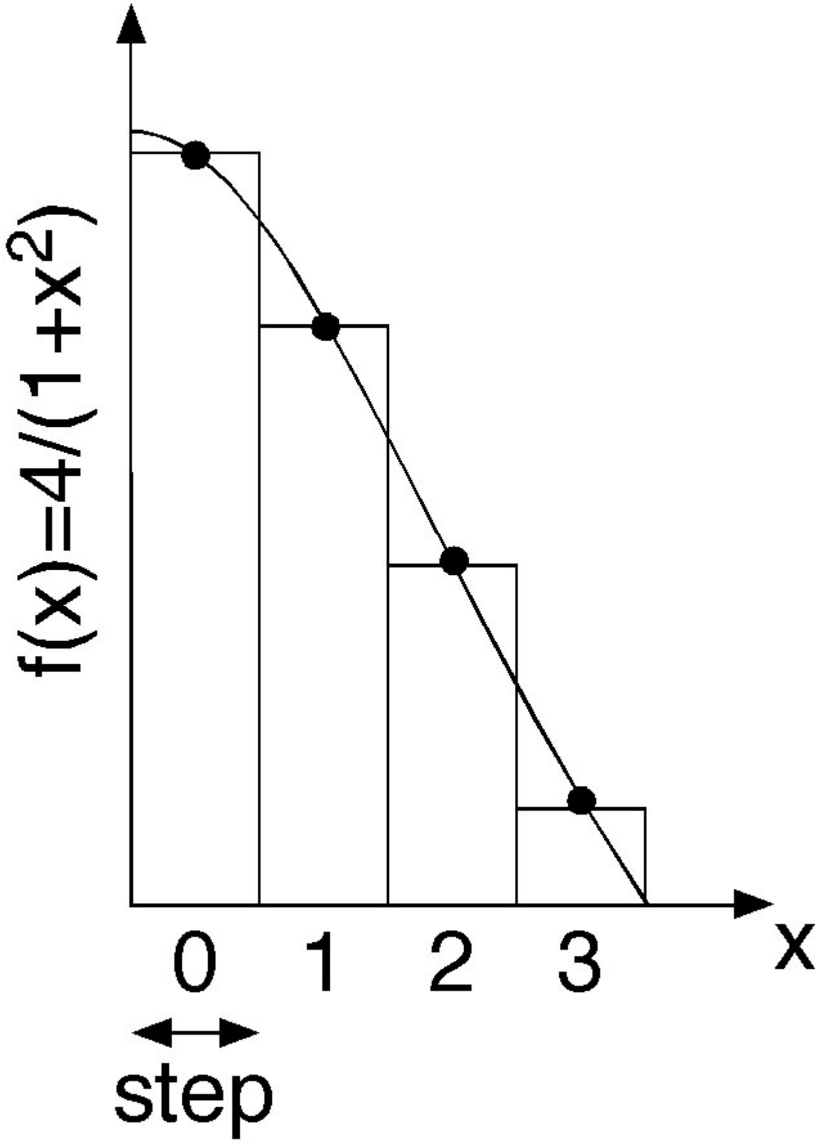
- **Discretization:**

Δ = 1/*N*: **`step = 1/NBIN`**

***x**$_i$* **= (*i*+0.5)Δ (*i* = 0,…,*N*-1)**

$$\sum_{i=0}^{N-1} \frac{4}{1+x_i^2}\Delta \cong \pi$$

```
#include <stdio.h>
#define NBIN 100000
void main() {
  int i; double step,x,sum=0.0,pi;
  step = 1.0/NBIN;
  for (i=0; i<NBIN; i++) {
    x = (i+0.5)*step;
    sum += 4.0/(1.0+x*x);}
  pi = sum*step;
  printf( “PI = %f\n” ,pi);
}
```



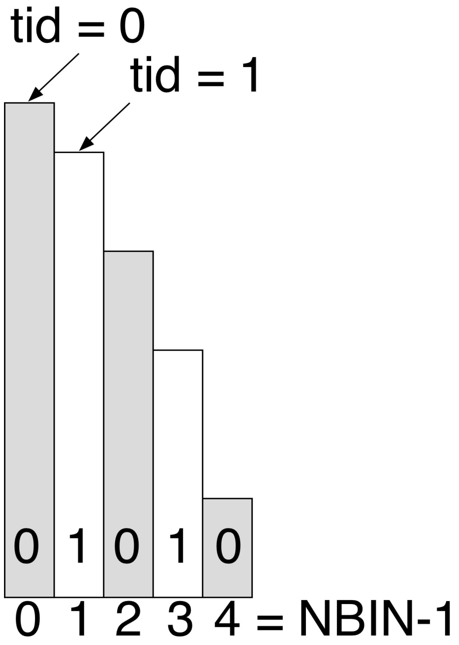
OpenMP Program: `omp_pi_critical.c`

```
#include <stdio.h>
#include <omp.h>
#define NBIN 100000
void main() {
  double step,sum=0.0,pi;
  step = 1.0/NBIN;
  # pragma omp parallel
  {
    int nthreads,tid,i;
    double x;
    nthreads = omp_get_num_threads();
    tid = omp_get_thread_num();
    for (i=tid; i<NBIN; i+=nthreads) {
      x = (i+0.5)*step;
      #pragma omp critical
      sum += 4.0/(1.0+x*x);
    }
  }
  pi = sum*step;
  printf("PI = %f\n",pi);
}
```

Shared variables

Private (local) variables

This has to be atomic



Thread-private variables: Either declare private or define within a parallel section

Avoid Critical Section: omp_pi.c

Data privatization

```
#include <stdio.h>
#include <omp.h>
#define NBIN 100000
#define MAX_THREADS 8
void main() {
  int nthreads,tid;
  double step,sum[MAX_THREADS]={0.0},pi=0.0;
  step = 1.0/NBIN;
  #pragma omp parallel private(tid)
  {
    int i;
    double x;
    nthreads = omp_get_num_threads();
    tid = omp_get_thread_num();
    for (i=tid; i<NBIN; i+=nthreads) {
      x = (i+0.5)*step;
      sum[tid] += 4.0/(1.0+x*x);
    }
  }
  for(tid=0; tid<nthreads; tid++) pi += sum[tid]*step;
  printf("PI = %f\n",pi);
}
```

Array of partial sums for multi-threads

Private accumulator

Inter-thread reduction