

OpenMP

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Outline

- OpenMP概述
- 编译制导语句
- 运行时库函数
- 环境变量
- 实例

Outline

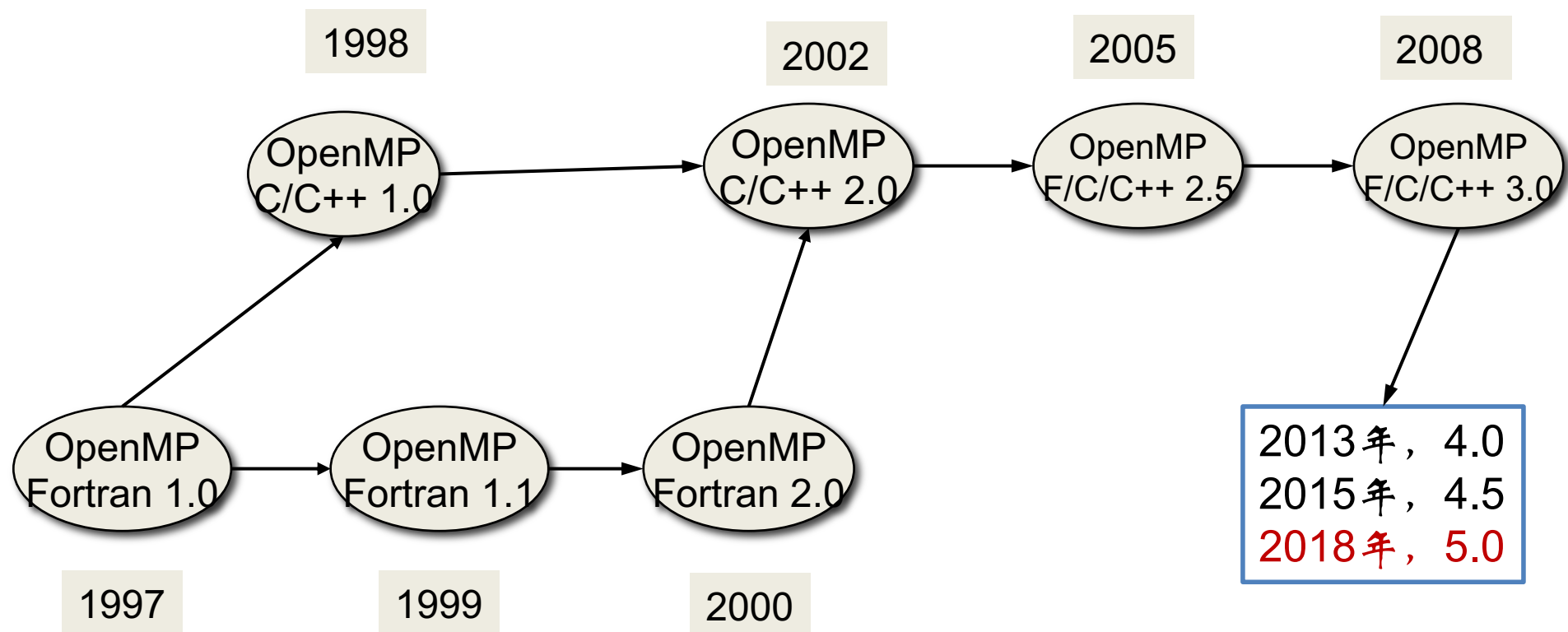
- **OpenMP概述**
- 编译制导语句
- 运行时库函数
- 环境变量
- 实例

OpenMP概述



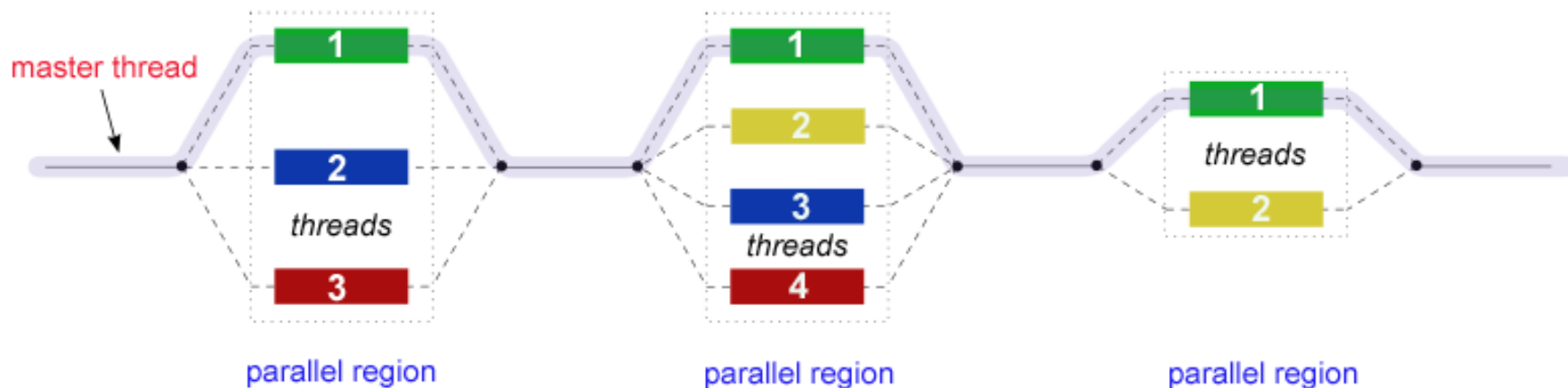
- OpenMP 是一种面向共享内存以及分布式共享内存的多处理器多线程并行编程语言。
- OpenMP 是一种能够被用于显式制导多线程、共享内存并行的应用程序编程接口 (API) 。
- OpenMP 标准诞生于 1997 年，目前其结构审议委员会 (Architecture Review Board, ARB) 已经制定并发布 OpenMP 5.0 版本。
- www.openmp.org

OpenMP 发展历程



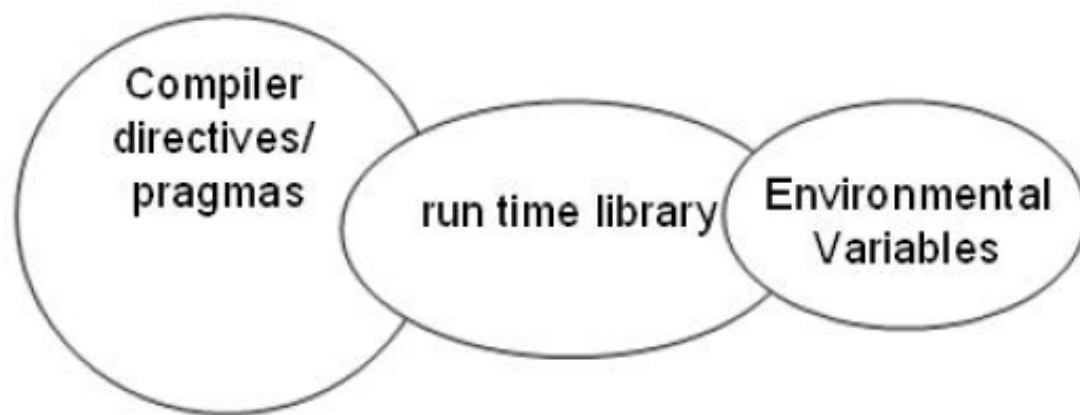
OpenMP编程模型：Fork-Join

- 在开始执行的时候，只有主线程存在。
- 主线程在运行过程中，当遇到需要进行并行计算的时候，**派生 (Fork)** 线程来执行并行任务。
 - 在并行执行的时候，主线程和派生线程共同工作。
- 在并行代码结束执行后，派生线程**退出或者挂起**，不再工作，控制流程回到单独的主线程中 (Join)。



OpenMP 的实现

- 编译制导语句
- 运行时库函数
- 环境变量



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编译制导语句 (Compiler Directive)

- 并行域
- 共享任务
- 同步
- 数据域
 - 数据共享属性子句
 - threadprivate子句
 - 数据拷贝子句

编译制导语句 (Compiler Directive)

- 编译制导语句的含义是在编译器编译程序的时候，会识别特定的注释，而这些特定的注释就包含着 OpenMP 程序的一些语义。
- 在 C/C++ 程序中，用 `#pragma omp parallel` 来标识一段并行程序块。在一个无法识别 OpenMP 语义的普通编译器中，这些特定的注释会被当作普通的注释而被忽略。

```
#pragma omp <directive> [clause[ [,] clause]...]
```

编译制导语句 (Compiler Directive)

将循环拆分到多个线程执行

```
void main()
{
    double Res[1000];

    for(int i=0;i<1000;i++) {
        do_huge_comp(Res[i]);
    }
}
```

串行代码



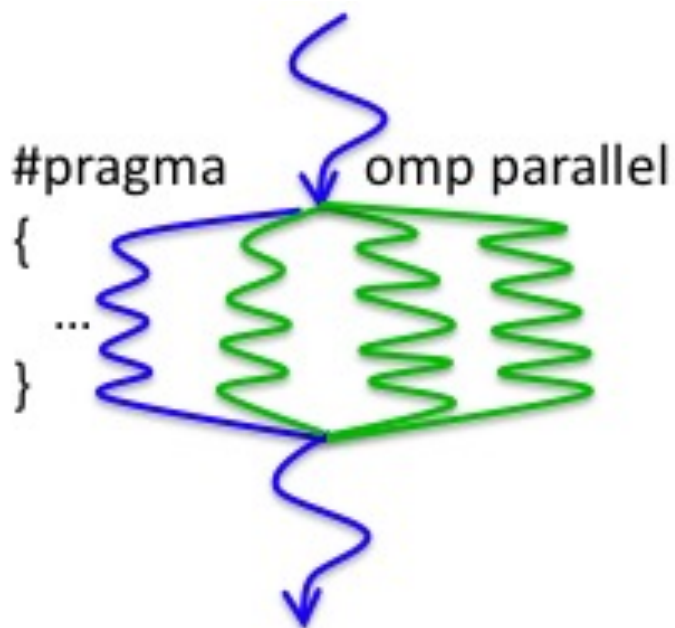
```
#include "omp.h"
void main()
{
    double Res[1000];
    #pragma omp parallel for
    for(int i=0;i<1000;i++) {
        do_huge_comp(Res[i]);
    }
}
```

并行代码

编译制导语句 (Compiler Directive)

- 并行域
- 共享任务
- 同步
- 数据域
 - threadprivate
 - 数据域属性子句

并行域 (parallel region)



并行域

- 并行域中的代码被所有的线程执行
- 具体格式
 - `#pragma omp parallel [clause[[,]clause]...]newline`
 - `clause=`
 - **`if(scalar-expression)`**
 - **`private(list)`**
 - **`firstprivate(list)`**
 - **`default(shared | none)`**
 - **`shared(list)`**
 - **`copyin(list)`**
 - **`reduction(operator: list)`**
 - **`num_threads(integer-expression)`**

并行域示例

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

```
main () {  
    int nthreads, tid;
```

```
/* Fork a team of threads giving them their own copies of variables */  
#pragma omp parallel private(tid) {
```

```
/* Obtain and print thread id */
```

```
tid = omp_get_thread_num();
```

```
printf("Hello World from thread = %d\n", tid);
```

```
/* Only master thread does this */
```

```
if (tid == 0) {
```

```
    nthreads = omp_get_num_threads();
```

```
    printf("Number of threads = %d\n", nthreads);
```

```
}
```

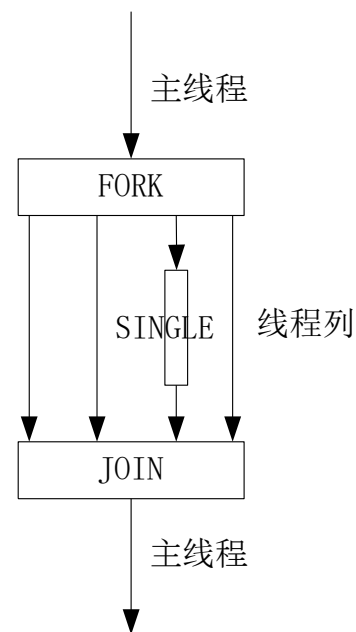
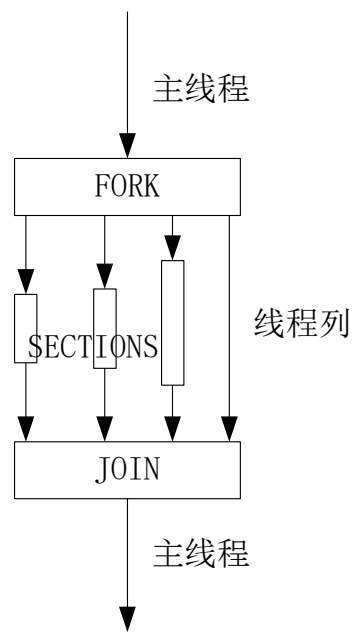
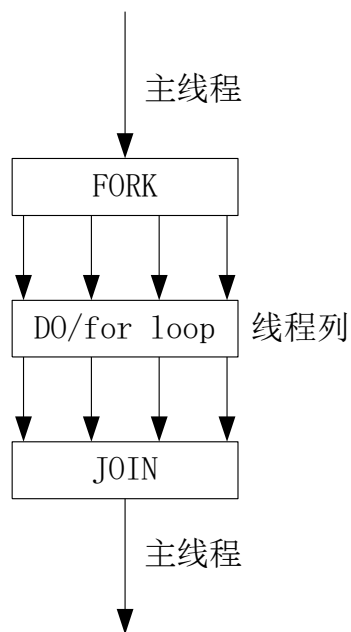
```
} /* All threads join master thread and terminate */  
}
```

编译制导语句

- 并行域
- 共享任务
- 同步
- 数据域
 - 数据共享属性子句
 - threadprivate子句
 - 数据拷贝子句

共享任务

- 共享任务结构将它所包含的代码划分给线程组的各成员来执行
 - 并行for循环
 - 并行sections
 - 串行执行



for编译制导语句

- for语句指定紧随它的循环语句必须由线程组并行执行;
- 语句格式
 - `#pragma omp for [clause[[,]clause]...] newline`
 - `[clause]=`
 - `Schedule(type [,chunk])`
 - `ordered`
 - `private (list)`
 - `firstprivate (list)`
 - `lastprivate (list)`
 - `shared (list)`
 - `reduction (operator: list)`
 - `nowait`

for编译制导语句

Thread	0	1	2	3
no chunk *	1-4	5-8	9-12	13-16
chunk = 2	1-2	3-4	5-6	7-8
	9-10	11-12	13-14	15-16

- **schedule (type [,chunk])**

- 描述如何将循环的迭代划分给线程组中的线程

- **chunk**

- 每个线程分配的计算量。

- 如果没有指定chunk大小，迭代会尽可能的平均分配给每个线程

- **type**

- static, 循环被分成大小为 chunk的块，静态分配给线程

- dynamic, 循环被动态划分为大小为chunk的块，动态分配给线程

for 示例

```
#include <omp.h>
#define CHUNKSIZE 100
#define N 1000
```

```
main () {
    int i, chunk;
    float a[N], b[N], c[N];
```

```
    /* Some initializations */
    for (i=0; i < N; i++)
        a[i] = b[i] = i * 1.0;
    chunk = CHUNKSIZE;
```

```
    #pragma omp parallel shared(a,b,c,chunk) private(i)
    {
        #pragma omp for schedule(dynamic,chunk) nowait
        for (i=0; i < N; i++)
            c[i] = a[i] + b[i];
    } /* end of parallel section */
}
```

Sections编译制导语句

- sections编译制导语句指定内部的代码被划分给线程组中的各线程
- 不同的section由不同的线程执行
- Section语句格式:

```
#pragma omp sections [ clause[[,]clause]... ] newline
{
  [#pragma omp section newline]
  ...
  [#pragma omp section newline]
  ...
}
```

Sections 编译制导语句

- clause=
 - private (list)
 - firstprivate (list)
 - lastprivate (list)
 - reduction (operator: list)
 - nowait
- 在sections语句结束处有一个隐含的路障，使用了nowait子句除外

Sections 编译制导语句

```
#include <omp.h>
#define N 1000
main () {
    int i;
    float a[N], b[N], c[N], d[N];
    /* Some initializations */
    for (i=0; i < N; i++)
        a[i] = i * 1.5;
        b[i] = i + 22.35;
    #pragma omp parallel shared(a,b,c,d) private(i) {
        #pragma omp sections nowait {
            #pragma omp section
                for (i=0; i < N; i++)
                    c[i] = a[i] + b[i];
            #pragma omp section
                for (i=0; i < N; i++)
                    d[i] = a[i] * b[i];
        } /* end of sections */
    } /* end of parallel section */
}
```

single编译制导语句

- 指定内部代码只有线程组中的一个线程执行。
- 线程组中没有执行single语句的线程会一直等待代码块的结束，使用nowait子句除外
- 语句格式：
 - `#pragma omp single [clause[[,]clause]...] newline`
 - `clause=`
 - `private(list)`
 - `firstprivate(list)`
 - `nowait`

single 示例

```
#include <stdio.h>

void work1() {}
void work2() {}

void a12()
{
    #pragma omp parallel
    {
        #pragma omp single
            printf("Beginning work1.\n");

        work1();

        #pragma omp single
            printf("Finishing work1.\n");

        #pragma omp single nowait
            printf("Finished work1 and beginning work2.\n");

        work2();
    }
}
```

parallel for 编译制导语句

- Parallel for 编译制导语句表明一个并行域包含一个独立的for语句
- 语句格式
 - `#pragma omp parallel for [clause...] newline`
 - `clause=`
 - `if (scalar_logical_expression)`
 - `default (shared | none)`
 - `schedule (type [,chunk])`
 - `shared (list)`
 - `private (list)`
 - `firstprivate (list)`
 - `lastprivate (list)`
 - `reduction (operator: list)`
 - `copyin (list)`

parallel for 编译制导语句

```
#include <omp.h>
#define N      1000
#define CHUNKSIZE 100
int main ()
{
    int i, chunk;
    float a[N], b[N], c[N];
    /* Some initializations */
    for (i=0; i < N; i++)
        a[i] = b[i] = i * 1.0;
    chunk = CHUNKSIZE;
    #pragma omp parallel for shared(a,b,c,chunk) private(i) schedule(static,chunk)
        for (i=0; i < n; i++)
            c[i] = a[i] + b[i];
}
```

parallel sections 编译制导语句

- parallel sections 编译制导语句表明一个并行域包含单独的一个 sections 语句
- 语句格式
 - #pragma omp parallel sections [clause...] newline
 - clause=
 - default (shared | none)
 - shared (list)
 - private (list)
 - firstprivate (list)
 - lastprivate (list)
 - reduction (operator: list)
 - copyin (list)
 - ordered

parallel sections 示例

```
void XAXIS();
void YAXIS();
void ZAXIS();

void all()
{
    #pragma omp parallel sections
    {
        #pragma omp section
        XAXIS();

        #pragma omp section
        YAXIS();

        #pragma omp section
        ZAXIS();
    }
}
```

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同步

- master 制导语句
- critical制导语句
- barrier制导语句
- atomic制导语句
- flush制导语句
- ordered制导语句

master 制导语句

- master制导语句指定代码段只有主线程执行
- 语句格式
 - #pragma omp master newline

critical制导语句

- critical制导语句表明域中的代码一次只能执行一个线程
- 其他线程被阻塞在临界区
- 语句格式：
 - #pragma omp critical [name] newline

critical制导语句

```
int dequeue(float *a);
void work(int i, float *a);

void a16(float *x, float *y)
{
    int ix_next, iy_next;

    #pragma omp parallel shared(x, y) private(ix_next, iy_next)
    {
        #pragma omp critical (xaxis)
        ix_next = dequeue(x);
        work(ix_next, x);

        #pragma omp critical (yaxis)
        iy_next = dequeue(y);
        work(iy_next, y);
    }
}
```

barrier制导语句

- barrier制导语句用来同步一个线程组中所有的线程
- 先到达的线程在此阻塞，等待其他线程
- barrier语句最小代码必须是一个结构化的块
- 语句格式
 - #pragma omp barrier newline

atomic制导语句

- atomic制导语句指定特定的存储单元将被原子更新
- 语句格式
 - #pragma omp atomic newline
- atomic使用的格式

```
x binop = expr  
x++  
++x  
x--  
--x
```

x是一个标量

expr是一个不含对x引用的标量表达式，且不被重载

binop是+,*,-,/,&^,|,>>,or<<之一，且不被重载

atomic 示例

```
#include <iostream>
#include <omp.h>
int main()
{
    int sum = 0;
    std::cout << "Before: " << sum << std::endl;
    #pragma omp parallel for
    for (int i = 0; i < 20000; ++i)
    {
        #pragma omp atomic
        sum++;
    }
    std::cout << "After: " << sum << std::endl;
    return 0;
}
```

输出:

Before: 0

After:20000

无atomic, 则输出
结果会不确定。

flush制导语句

- flush制导语句用以标识一个同步点，用以确保所有的线程看到一致的存储器视图
- 语句格式
 - #pragma omp flush (list) newline
- flush将在下面几种情形下隐含运行，nowait子句除外

barrier

critical:进入与退出部分

ordered:进入与退出部分

parallel:退出部分

for:退出部分

sections:退出部分

single:退出部分

ordered制导语句

- ordered制导语句指出其所包含循环的执行按循环次序进行
- 任何时候只能有一个线程执行被ordered所限定部分
- 只能出现在for或者parallel for语句的动态范围中
- 语句格式：
 - #pragma omp ordered newline

ordered 示例

```
void work(int i) {}
void a24_good(int n)
{
    int i;

    #pragma omp for ordered
    for (i=0; i<n; i++) {
        if (i <= 10) {
            #pragma omp ordered
            work(i);
        }

        if (i > 10) {
            #pragma omp ordered
            work(i+1);
        }
    }
}
```


编译制导语句

- 并行域
- 共享任务
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 - 数据共享属性子句
 - `threadprivate`子句
 - 数据拷贝子句

数据共享属性子句

- 变量作用域范围
- 数据域属性子句
 - private子句
 - shared子句
 - default子句
 - firstprivate子句
 - lastprivate子句
 - reduction子句

private子句

- private子句表示它列出的变量对于每个线程是局部的。
- 语句格式
 - private(list)

private()

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

```
int main()
```

```
{
```

```
    int i, x = 100;
```

```
    #pragma omp parallel for private(x)
```

```
    for (i=0; i<8; i++)
```

```
    {
```

```
        x += i;
```

```
        printf("x = %d\n", x);
```

```
    }
```

```
    printf("global x = %d\n", x);
```

```
    return 1;
```

```
}
```

4线程

x = 0

x = 1

x = 2

x = 5

x = 6

x = 13

x = 4

x = 9

global x = 100

shared子句

- shared子句表示它所列出的变量被线程组中所有的线程共享
- 所有线程都能对它进行读写访问
- 语句格式
 - shared (list)

default子句

- default子句让用户自行规定在一个并行域的静态范围中所定义的变量的缺省作用范围
- 语句格式
 - default (shared | none)

firstprivate子句

- firstprivate子句是private子句的超集
- 对变量做原子初始化
- 语句格式：
 - firstprivate (list)

firstprivate()

4线程

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

```
int main()
```

```
{
```

```
    int i, x = 100;
```

```
    #pragma omp parallel for firstprivate(x)
```

```
    for (i=0; i<8; i++)
```

```
    {
```

```
        x += i;
```

```
        printf("x = %d\n", x);
```

```
    }
```

```
    printf("global x = %d\n", x);
```

```
    return 1;
```

```
}
```

x = 100

x = 101

x = 102

x = 105

x = 106

x = 113

x = 104

x = 109

global x = 100

lastprivate子句

- lastprivate子句是private子句的超集
- 将变量从最后的循环迭代或段复制给原始的变量
- 语句格式
 - lastprivate (list)

lastprivate()

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

```
int main()
{
    int i, x = 100;
    #pragma omp parallel for firstprivate(x) lastprivate(x)
    for (i=0; i<8; i++)
    {
        x += i;
        printf("x = %d\n", x);
    }
    printf("global x = %d\n", x);
    return 1;
}
```

4线程:

x = 100

x = 101

x = 102

x = 105

x = 106

x = 113

x = 104

x = 109

global x = 113

reduction子句

- reduction子句使用指定的操作对其列表中出现
的变量进行规约
- 初始时，每个线程都保留一份私有拷贝
- 在结构尾部根据指定的操作对线程中的相应变量
进行规约，并更新该变量的全局值
- 语句格式
 - reduction (operator: list)

reduction 子句

```
#include <omp.h>
int main ()
{
    int i, n, chunk;
    float a[100], b[100], result;
    /* Some initializations */
    n = 100;
    chunk = 10;
    result = 0.0;
    for (i=0; i < n; i++)
    {
        a[i] = i * 1.0;
        b[i] = i * 2.0;
    }
    #pragma omp parallel for default(shared) private(i)\
        schedule(static,chunk) reduction(+:result)
    for (i=0; i < n; i++)
        result = result + (a[i] * b[i]);
    printf("Final result= %f\n",result);
}
```

threadprivate编译制导语句

- threadprivate语句使一个全局文件作用域的变量在并行域内变成每个线程私有
- 每个线程对该变量复制一份私有拷贝
- 语句格式:
 - #pragma omp threadprivate (list) newline

threadprivate编译制导语句

```
#include <omp.h>
int counter = 0;
#pragma omp threadprivate(counter)
void inc_counter(){counter++;}

int main(int argc, char * argv[]){
    int i;
    #pragma omp parallel private (i)
    {
        for(i=0; i<1000; i++)
            inc_counter();
        printf("counter=%d\n",counter);
    }
    printf("counter=%d\n",counter);
}
```

8线程:

[illegible]

threadprivate编译制导语句

```
int alpha[10], beta[10], i;//eg3  
#pragma omp threadprivate(alpha)  
int main ()  
{  
    /* First parallel region */  
    #pragma omp parallel private(i,beta)  
    for (i=0; i < 10; i++)  
        alpha[i] = beta[i] = i;  
    /* Second parallel region */  
    #pragma omp parallel  
        printf("alpha[3]= %d and beta[3]=%d\n",alpha[3],beta[3]);  
}
```

private和threadprivate 区别

	PRIVATE	THREADPRIVATE
数据类型	变量	变量
位置	在域的开始或共享任务单元	在块或整个文件区域的例程的定义上
持久性	否	是
扩充性	只是词法的- 除非作为子程序的参数而传递	动态的
初始化	使用 FIRSTPRIVATE	使用 COPYIN

copyin子句

- copyin子句用来为线程组中所有线程的threadprivate变量赋相同的值
- 主线程该变量的值作为初始值
- 语句格式
 - copyin(list)

copyin 示例

```
#include <omp.h>
int global=0;
#pragma omp threadprivate(global)
int main(int argc, char * argv[])
{
    global=1000;
    #pragma omp parallel copyin(global)
    {
        printf("global=%d\n",global);
        global=omp_get_thread_num();
    }
    printf("global=%d\n",global);
    printf("parallel again\n");
    #pragma omp parallel
        printf("global=%d\n",global);
}
```

```
global=1000
global=1000
global=1000
global=1000
global=1000
global=1000
global=1000
global=1000
global=0
parallel again
global=0
global=2
global=1
global=4
global=3
global=5
global=6
global=7
```

copyprivate 子句

- copyprivate子句提供了一种机制用一个私有变量将一个值从一个线程广播到执行同一并行区域的其他线程。

- 语句格式:

copyprivate(list)

- copyprivate子句可以关联single构造，在single构造的barrier到达之前就完成了广播工作。

copyprivate 子句

```
int counter = 0;
#pragma omp threadprivate(counter)
int increment_counter()
{
    counter++;
    return(counter);
}
```

```
#pragma omp parallel
```

```
{
    int count;
    #pragma omp single copyprivate(counter)
    {
        counter = 50;
    }
    count = increment_counter();
    printf("ThreadId: %ld, count = %ld\n", omp_get_thread_num(), count);
}
```

ThreadId: 2, count = 51

ThreadId: 0, count = 51

ThreadId: 3, count = 51

ThreadId: 1, count = 51

ThreadId: 2, count = 1

ThreadId: 1, count = 1

ThreadId: 0, count = 51

ThreadId: 3, count = 1

Outline

- OpenMP概述
- 编译制导语句
- 运行时库函数
- 环境变量
- 实例

运行库例程与环境变量

- 运行库例程

- OpenMP标准定义了一个应用编程接口来调用库中的多种函数
- 对于C/C++，在程序开头需要引用文件“omp.h”

- 环境变量

- OMP_SCHEDULE：线程调度类型，只能用到for, parallel for中
- OMP_NUM_THREADS：定义执行中最大的线程数
- OMP_DYNAMIC：通过设定变量值TRUE或FALSE,来确定是否动态设定并行域执行的线程数
- OMP_NESTED：确定是否可以并行嵌套

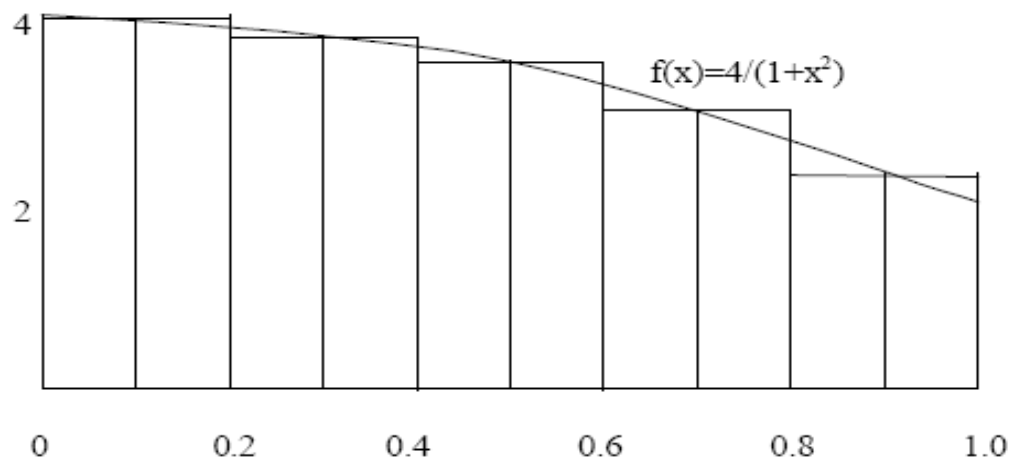
Outline

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OpenMP 计算实例

- 矩形法则的数值积分方法估算Pi的值

$$Pi = \int_0^1 \frac{4}{1+x^2} dx \approx \frac{1}{N} \sum_{i=1}^N f\left(\frac{i}{N} - \frac{1}{2N}\right) = \frac{1}{N} \sum_{i=1}^N f\left(\frac{i-0.5}{N}\right)$$



OpenMP 计算实例

// 串行代码

```
static long num_steps = 1000000;
double step;
void main ()
{   int i;
    double x, pi, sum = 0.0;
    step = 1.0/(double) num_steps;
    for (i=0;i< num_steps; i++){
        x = (i+0.5)*step;
        sum = sum + 4.0/(1.0+x*x);
    }
    pi = step * sum;
}
```

//使用并行域并行化的程序

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

```
static long num_steps = 100000;
```

```
double step;
```

```
#define NUM_THREADS 2
```

```
void main ()
```

```
{  int i;
```

```
    double x, pi, sum[NUM_THREADS];
```

```
    step = 1.0/(double) num_steps;
```

```
    omp_set_num_threads(NUM_THREADS); //
```

```
#pragma omp parallel
```

```
{
```

```
    double x;
```

```
    int id;
```

```
    id = omp_get_thread_num();
```

```
    for (i=id, sum[id]=0.0; i< num_steps; i=i+NUM_THREADS){//
```

```
        x = (i+0.5)*step;
```

```
        sum[id] += 4.0/(1.0+x*x);
```

```
    }
```

```
}
```

```
for(i=0, pi=0.0; i<NUM_THREADS; i++)
```

```
    pi += sum[i] * step;
```

```
}
```

//使用共享任务结构并行化的程序

```
#include <omp.h>
static long num_steps = 100000;
double step;
#define NUM_THREADS 2
void main ()
{
    int i;
    double x, pi, sum[NUM_THREADS];
    step = 1.0/(double) num_steps;
    omp_set_num_threads(NUM_THREADS) ;//*****
    #pragma omp parallel //*****
    {
        double x;
        int id;
        id = omp_get_thread_num();
        sum[id] = 0; /**
        #pragma omp for//*****
        for (i=0;i< num_steps; i++){
            x = (i+0.5)*step;
            sum[id] += 4.0/(1.0+x*x);
        }
    }
    for(i=0, pi=0.0;i<NUM_THREADS;i++)pi += sum[i] * step;
}
```

//使用private子句和critical部分并行化的程序

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

```
static long num_steps = 100000;
```

```
double step;
```

```
#define NUM_THREADS 2
```

```
void main ()
```

```
{
```

```
    int i;
```

```
    double x, sum, pi=0.0;
```

```
    step = 1.0/(double) num_steps;
```

```
    omp_set_num_threads(NUM_THREADS)
```

```
    #pragma omp parallel private (x, sum)
```

```
    {
```

```
        id = omp_get_thread_num();
```

```
        for (i=id,sum=0.0;i< num_steps;i=i+NUM_THREADS){
```

```
            x = (i+0.5)*step;
```

```
            sum += 4.0/(1.0+x*x);
```

```
        }
```

```
        #pragma omp critical
```

```
            pi += sum
```

```
    }
```

```
}
```

//使用并行归约得出的并行程序

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

```
static long num_steps = 100000;
```

```
double step;
```

```
#define NUM_THREADS 2
```

```
void main ()
```

```
{ int i;
```

```
double x, pi, sum = 0.0;
```

```
step = 1.0/(double) num_steps;
```

```
omp_set_num_threads(NUM_THREADS)
```

```
#pragma omp parallel for reduction(+:sum) private(x)
```

```
for (i=0;i<num_steps; i++){
```

```
    x = (i+0.5)*step;
```

```
    sum = sum + 4.0/(1.0+x*x);
```

```
}
```

```
pi = step * sum;
```

```
}
```