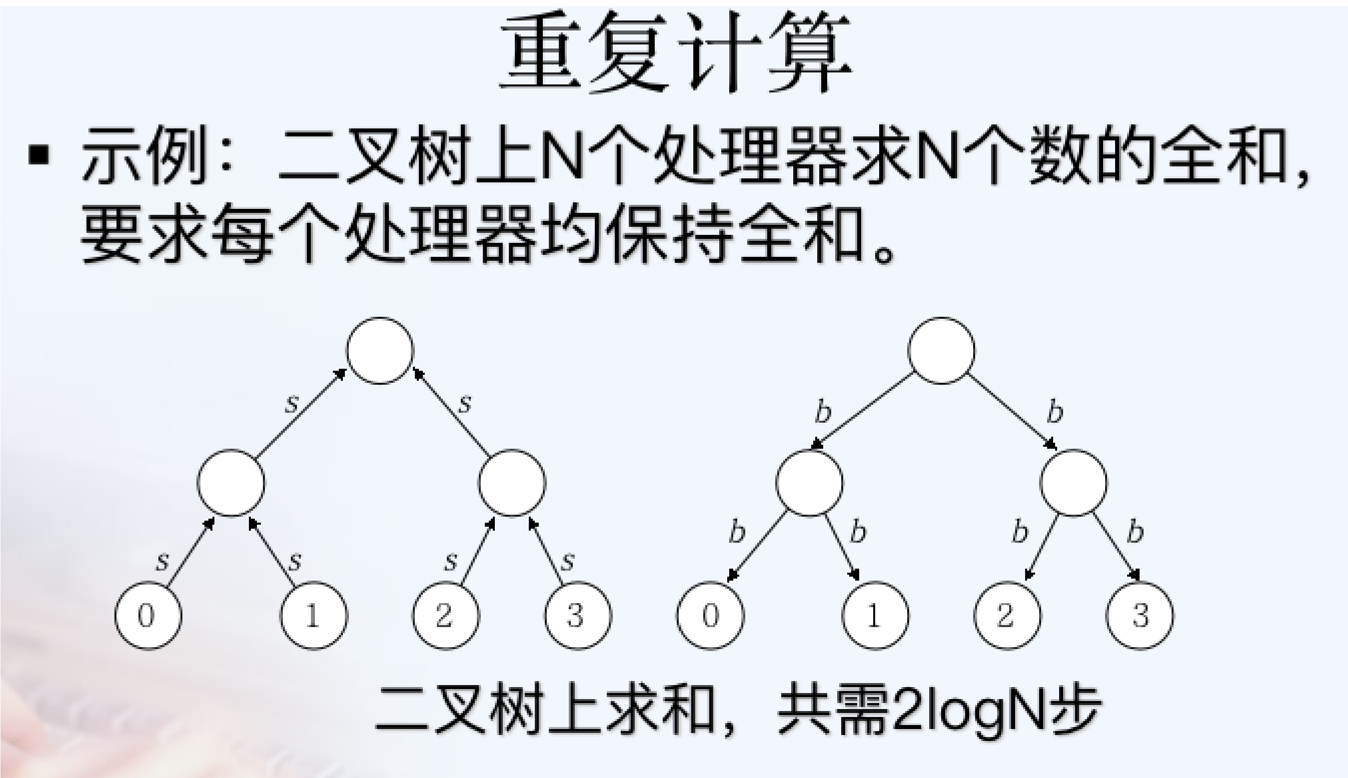
并行程序设计 上机练习一

实验一

题目: 课程主页lec2_PP.ppt的P35-36两种重复计算方式的OpenMP和MPI实现。（任务数可约定为2的幂次方）

二叉树求和

算法流程图:



PCAM分析

划分:
域分解:每个节点均包含一个当前节点权值,均为一个域
功能分解:将任务分成三种,叶子节点,中间节点,根节点
通信:
使用静态的结构化异步通信
对于叶子节点,完成两次通信,第一次向其父节点发送该叶子节点的值,第二次等待父亲节点传回sum
对于中间节点,完成三次通信,第一次所有接受子节点的和,第二次等待其父节点回传sum,第三次通信发送

收到的sum值给所有儿子节点
对于根节点完成两次通信,第一次通信获得所有子节点的和,第二次将计算的sum发送给所有儿子节点
组合:
我们将任务分成三种,因此我们对与每个节点均以自己作为一个组合(不划分)

> - 对于叶子节点在第二次通信时将节点自身值赋为sum
> - 对于根节点,在第二次通信前计算所有子节点传来的数值的和,并加上本身节点值
> - 对于中间节点,在第一次通信以及第二次通信前计算所有子节点传来的数值的和,并加上本身节点值

映射:
将对应的任务分别发送给叶子节点/中间节点/根节点

代码实现:

```
#include <stdio.h>
#include <string.h>
#include <bits/stdc++.h>
#include "mpi.h"
#define GHH(...) printf(__VA_ARGS__)
// #define GHH(...)
// using namespace std;

int main(int argc, char* argv[])
{
    clock_t begin = clock();
    int numprocs, myid, source;
    MPI_Status status;
    int data[10];
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &myid);
    MPI_Comm_size(MPI_COMM_WORLD, &numprocs);

    data[0] = myid;
    GHH("thread %d begin!\n",myid);
    if(myid == 0);
    else if(myid == 1 ){                    //根节点
        MPI_Recv(data+1, 1, MPI_INT, myid*2, myid*2,  //阶段1,收集来自左右子树的和
            MPI_COMM_WORLD, &status);
        GHH("root %d get sum %d from left son %d\n",myid,data[1],myid*2);

        MPI_Recv(data+2, 1, MPI_INT, myid*2+1, myid*2+1,
            MPI_COMM_WORLD, &status);
        GHH("root %d get sum %d from right son %d\n",myid,data[2],myid*2+1);

        data[0]+=data[1]+data[2];

        GHH("root %d send sum %d to left son %d\n",myid,data[0],myid*2);
        MPI_Send(data, 1, MPI_INT, myid*2, myid,    //阶段2,向下广播求和的值
            MPI_COMM_WORLD);

        GHH("root %d send sum %d to right son %d\n",myid,data[0],myid*2+1);
        MPI_Send(data, 1, MPI_INT, myid*2+1, myid,    //阶段2,向下广播求和的值
            MPI_COMM_WORLD);
    }else if (myid >= (numprocs+1)/2){ //叶子结点
        MPI_Send(data, 1, MPI_INT, myid/2, myid,    //阶段1,向上传递自身节点值
            MPI_COMM_WORLD);
        GHH("leaf %d send itself to parent %d\n",myid,myid/2);

        MPI_Recv(data, 1, MPI_INT, myid/2, myid/2,    //阶段2,收到来自根节点的全局和
            MPI_COMM_WORLD, &status);
        GHH("leaf %d get sum %d from parent %d\n",myid,data[0],myid/2);

    }else {                          //中间节点
        MPI_Recv(data+1, 1, MPI_INT, myid*2, myid*2,  //阶段1,收集来自左右子树的和
```

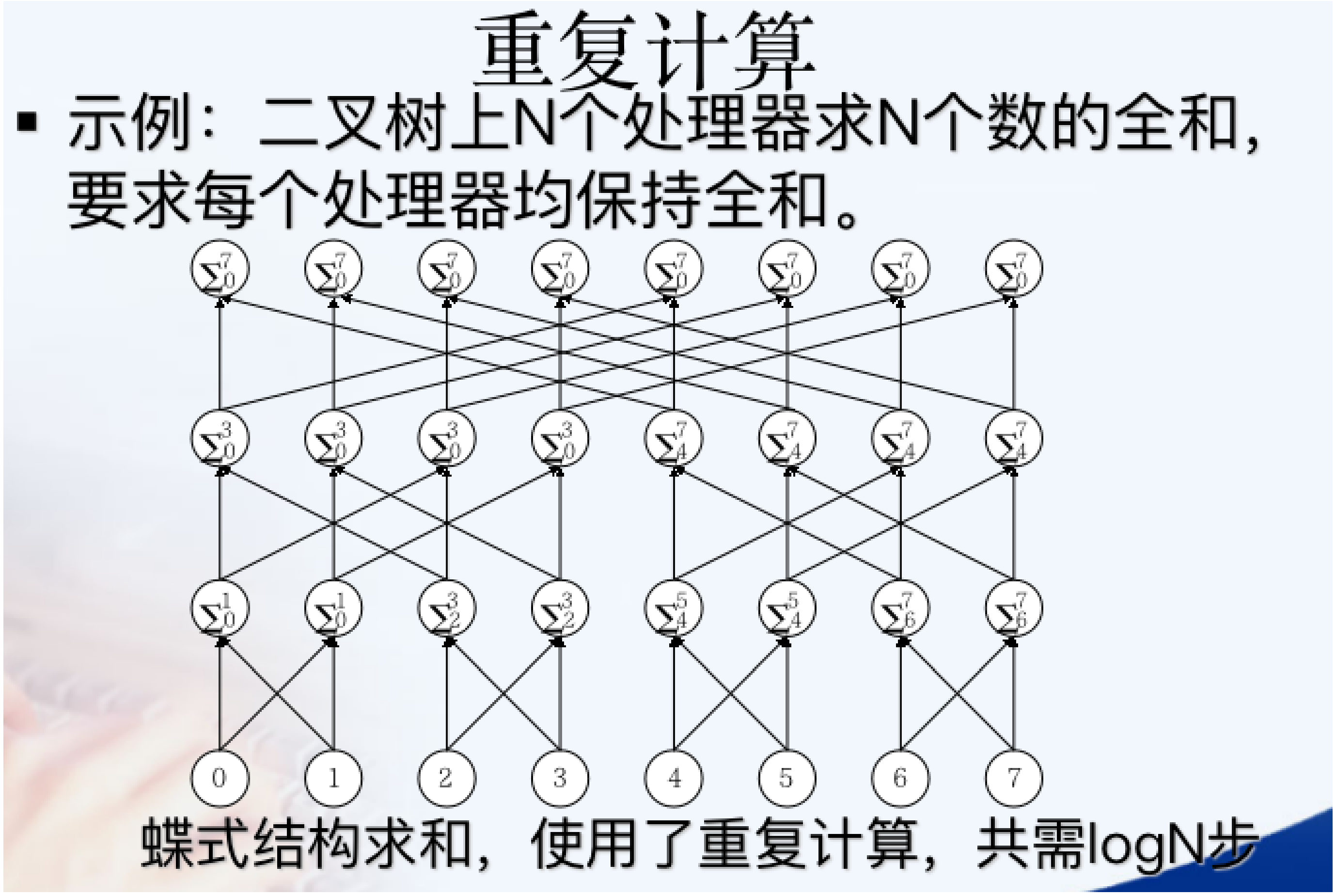
```
            MPI_COMM_WORLD, &status);
        GHH("midnode %d get sum %d from left son %d\n",myid,data[1],myid*2);

        MPI_Recv(data+2, 1, MPI_INT, myid*2+1, myid*2+1,
            MPI_COMM_WORLD, &status);
        GHH("midnode %d get sum %d from right son %d\n",myid,data[2],myid*2+1);

        data[0]+=data[1]+data[2];

        MPI_Send(data, 1, MPI_INT, myid/2, myid,    //向其父亲节点发送该节点左右子树以及自己的
            MPI_COMM_WORLD);
        GHH("midnode %d send itself to parent %d\n",myid,myid/2);

        MPI_Recv(data, 1, MPI_INT, myid/2, myid/2,    //阶段2,向下广播自根节点的全局和
            MPI_COMM_WORLD, &status);
        GHH("midnode %d get sum %d from parent %d\n",myid,data[0],myid/2);

        MPI_Send(data, 1, MPI_INT, myid*2, myid,
            MPI_COMM_WORLD);
        GHH("midnode %d send sum %d to left son %d\n",myid,data[0],myid*2);

        MPI_Send(data, 1, MPI_INT, myid*2+1, myid,
            MPI_COMM_WORLD);
        GHH("midnode %d send sum %d to right son %d\n",myid,data[0],myid*2+1);

    }
    MPI_Finalize();

    clock_t end = clock();
    printf("thread %d sum is %d. Runtime :%lf(ms)\n",myid,data[0],1000.0*(end-begin)/CL(
} /* end main */

// mpic++ -o fun test.cpp -fopenmp > compile.log
// mpirun -n 8 -genv OMP_NUM_THREADS 1 ./fun > out.log
```

运行结果展示

```
thread 0 begin!
thread 2 begin!
thread 3 begin!
thread 7 begin!
leaf 7 send itself to parent 3
thread 1 begin!
root 1 get sum 11 from left son 2
root 1 get sum 16 from right son 3
midnode 2 get sum 4 from left son 4
midnode 2 get sum 5 from right son 5
midnode 2 send itself to parent 1
midnode 2 get sum 28 from parent 1
midnode 2 send sum 28 to left son 4
midnode 2 send sum 28 to right son 5
midnode 3 get sum 6 from left son 6
midnode 3 get sum 7 from right son 7
midnode 3 send itself to parent 1
midnode 3 get sum 28 from parent 1
midnode 3 send sum 28 to left son 6
midnode 3 send sum 28 to right son 7
thread 4 begin!
leaf 4 send itself to parent 2
leaf 4 get sum 28 from parent 2
thread 5 begin!
leaf 5 send itself to parent 2
leaf 5 get sum 28 from parent 2
thread 6 begin!
leaf 6 send itself to parent 3
leaf 6 get sum 28 from parent 3
root 1 send sum 28 to left son 2
root 1 send sum 28 to right son 3
leaf 7 get sum 28 from parent 3
thread 0 sum is 0. Runtime :70.020000(ms)
thread 7 sum is 28. Runtime :77.778000(ms)
thread 2 sum is 28. Runtime :63.924000(ms)
thread 3 sum is 28. Runtime :67.978000(ms)
thread 4 sum is 28. Runtime :75.195000(ms)
thread 5 sum is 28. Runtime :70.540000(ms)
thread 6 sum is 28. Runtime :59.505000(ms)
thread 1 sum is 28. Runtime :68.156000(ms)
```

蝶式求和

算法流程图



PCAM分析

划分:

域分解:每个计算节点均等价,因此每个计算节点本身就是一个划分

功能分解:每个计算节点均等价,因此每个计算节点功能一致,仅有一个划分

通信:

使用动态的非结构化同步通信

使用同步的方式,记录当前节点id为i(从0到n-1),第k轮将节点i给id为$i \oplus 2^k$($\oplus$表示异或)的节点发送当前节点sum

组合:

由于任务只有一种,因此我们仅需要叙述每个节点对应的步骤:

> - 首先使用同步的通信方式,所有节点按轮完成其对应的数据传输任务(保证数据一致性)
> - 对于第k轮将节点i给id为$i \oplus 2^k$($\oplus$表示异或)的节点发送当前节点sum
> - 保证每个节点均接受到该轮传输的对应sum_{old}之后,更新本身节点值$sum = sum + sum_{old}$

映射:

将上述组合后的任务分发至所有节点即可

代码实现

```cpp
#include <stdio.h>
#include <string.h>
#include <bits/stdc++.h>
#include "mpi.h"
int main(int argc, char* argv[])
{
    clock_t begin = clock();
    int numprocs, myid, source;
    MPI_Status status;
    int data[10];
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &myid);
    MPI_Comm_size(MPI_COMM_WORLD, &numprocs);
    data[0]=myid+1;
    for(int i = 1; i < numprocs ; i<<=1){
        MPI_Send(data,1,MPI_INT,myid^i,myid^i,MPI_COMM_WORLD);
        MPI_Recv(data+1,1,MPI_INT,myid^i,myid,MPI_COMM_WORLD,&status);
        data[0] += data[1];
    }
    MPI_Finalize();
    clock_t end = clock();
    printf("thread %d sum is %d. Runrime:%lf(ms)\n",myid,data[0],1000.0*(end-begin)/CLO
} /* end main */

// mpic++ -o fun test.cpp -fopenmp > compile.log
// mpirun -n 8 -genv OMP_NUM_THREADS 1 ./fun > out.log
```

运行结果展示

```
guanhuhao — pp11@node2: ~/mpi_share/workspa
thread 1 sum is 36. Runrime:80.298000(ms)
thread 2 sum is 36. Runrime:86.631000(ms)
thread 3 sum is 36. Runrime:88.769000(ms)
thread 4 sum is 36. Runrime:78.395000(ms)
thread 5 sum is 36. Runrime:96.854000(ms)
thread 6 sum is 36. Runrime:92.882000(ms)
thread 7 sum is 36. Runrime:82.535000(ms)
thread 0 sum is 36. Runrime:79.863000(ms)
```

实验二

题目

前期练习作业题目中的相关程序实现（ex-21-1/2/3 中有要求向量化/并行化的程序实习）。

作业1.3.1

题面:

3. 向量化以下循环。如果不能，请说明原因。

```
(1) for I = 1 to N do
        S:A(I) = B(I) + C(I+1);
        T:C(I) = A(I)* D(I);
    end for


    S:A(1,N) = B(I:N) + C(2:N+1);
    T:C(1:N) = A(1:N) * D(1:N);


(2) for I = 1 to N do
        S:A(I) = A(I-1) + 1
    end for
```

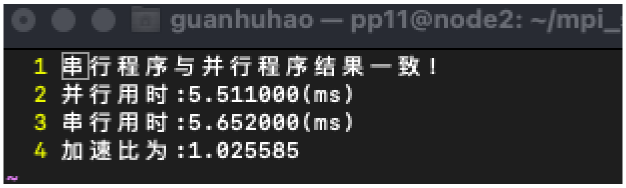
> 存在依赖$S\delta^f S$方向向量为(1)因此不能并行化

代码实现:

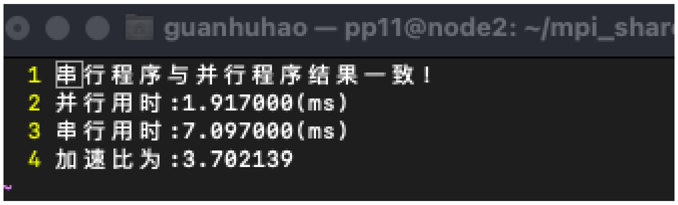
```cpp
#include <bits/stdc++.h>
#include "mpi.h"
using namespace std;
const int n = 1000000;
int a[n+10],b[n+10],c[n+10],d[n+10];
int aa[n+10],bb[n+10],cc[n+10],dd[n+10];
void chuan(){
    clock_t begin = clock();
    for(int i =1;i<=n;i++){
        aa[i]=bb[i]+cc[i+1];
    }
    for(int i=1;i<=n;i++){
        cc[i]=aa[i]*dd[i];
    }
    clock_t end = clock();
    printf("串行用时:%5lf(ms)\n",1000.0*(end-begin)/CLOCKS_PER_SEC);
}
void check(){
    for(int i=1;i<=n;i++){
        if(aa[i]!=a[i]||cc[i]!=c[i]) cout<<"error!"<<endl;
    }
}
int main(int argc, char* argv[])
{

    for(int i=0;i<n+5;i++){
        a[i]=aa[i]=rand()%100;
        b[i]=bb[i]=rand()%100;
        c[i]=cc[i]=rand()%100;
        d[i]=dd[i]=rand()%100;

    }
    chuan();

    clock_t begin = clock();
    #pragma omp parallel for
    for(int i =1;i<=n;i++){
        a[i]=b[i]+c[i+1];
    }
    #pragma omp parallel for
    for(int i=1;i<=n;i++){
        c[i]=a[i]*d[i];
    }
    clock_t end = clock();
    printf("并行用时:%5lf(ms)\n",1000.0*(end-begin)/CLOCKS_PER_SEC);

    check();
} /* end main */
```

运行结果展示

当OMP_NUM_THREADS 设置为2时运行截图如下:



当OMP_NUM_THREADS 设置为4时运行截图如下:



当OMP_NUM_THREADS 设置为8时运行截图如下:

因此我们可以得出,需要设置合适的OMP_NUM_THREADS才能发挥并行的优势

作业3.3.2

题面

(2) 尝试向量化/并行化此循环。

```
for i = 1 to 100 do // 循环 2 N 是常量
    for j = 1 to 100 do
        S2:B[j] = A[j, N]; // 语句 S2
        doall k = 1 to 100 do
            S3:A[j+1, k] = B[j] + C[j, k]; // 语句 S3
        enddoall // loop-k
        S4:Y[i+j] = A[j+1, N]; // 语句 S4
    endfor // loop-j
endfor // loop-i

doall i = 1 to 100 do
    S1:X[i] = Y[i] + 10; // 语句 S1
enddoall
```

代码实现

```
#include <bits/stdc++.h>
#include "mpi.h"
using namespace std;
const int n = 100;
int a[n+10][n+10],b[n+10],c[n+10][n+10],d[n+10];
int aa[n+10][n+10],bb[n+10],cc[n+10][n+10],dd[n+10];
int y[n*2+10],x[n*2+10];
int yy[n*2+10],xx[n*2+10];
double chuan(){          //串行程序计算
    clock_t begin = clock();
    for(int i =1;i<=n;i++){
        xx[i]=yy[i]+10;
        for(int j =1;j<=n;j++){
            bb[j]=aa[j][n];
            for(int k=1;k<=n;k++){
                aa[j+1][k]=bb[j]+cc[j][k];
            }
            yy[i+j]=aa[j+1][n];
        }
    }
    clock_t end = clock();
    // printf("串行用时:%5lf(ms)\n",1000.0*(end-begin)/CLOCKS_PER_SEC);
    return 1000.0*(end-begin)/CLOCKS_PER_SEC;
}
bool check(){           //检查是否与串行程序相同
    for(int i=1;i<=n;i++){
        for(int j =1;j<=n;j++)
            if(aa[i][j]!=a[i][j]||cc[i][j]!=c[i][j]) {
                cout<<"error!"<<endl;
                return false;
            }
        if(b[i]!=bb[i]||d[i]!=dd[i]||x[i]!=xx[i]||y[i]!=yy[i]) {
            cout<<"error"<<endl;
            return false;
        }
    }
    return true;
}
void randData(){        //生成随机数据
    for(int i=0;i<n+5;i++){
        for(int j =0;j<n+5;j++) {
            a[i][j]=aa[i][j]=rand()%100;
            c[i][j]=cc[i][j]=rand()%100;
        }
        b[i]=bb[i]=rand()%100;
        d[i]=dd[i]=rand()%100;
        x[i]=xx[i]=rand()%100;
        y[i]=yy[i]=rand()%100;
    }
}
```

```c
int main(int argc, char* argv[])
{
    randData();      //生成随机数据

    double time_seq = chuan();

    clock_t begin = clock();
    for(int i =1;i<=n;i++){
        for(int j = 1;j<=n;j++){
            b[j]=a[j][n];
            // #pragma omp parallel for
            for(int k =1;k<=n;k++){
                a[j+1][k]=b[j]+c[j][k];
            }
            y[i+j] = a[j+1][n];
        }
    }

    #pragma omp parallel for
    for(int i=1;i<=n;i++){
        x[i]=y[i]+10;
    }
    clock_t end = clock();

    if(check()) printf("串行程序与并行程序结果一致!\n");
    double time_pra = 1000.0*(end-begin)/CLOCKS_PER_SEC;
    printf("并行用时:%5lf(ms)\n",time_pra);
    printf("串行用时:%5lf(ms)\n",time_seq);
    printf("加速比为:%lf\n",time_seq/time_pra);

} /* end main */
```

运行结果展示

```
guanhuhao — pp11@node2: ~/mpi_
串行程序与并行程序结果一致!
并行用时:5.358000(ms)
串行用时:6.580000(ms)
加速比为:1.228070
```

作业3.5.1

题面

五、 分析以下 3 个循环中存在的依赖关系；分别通过循环交换、分布和逆转等多种方法来尝试向量化和/或并行化变换：

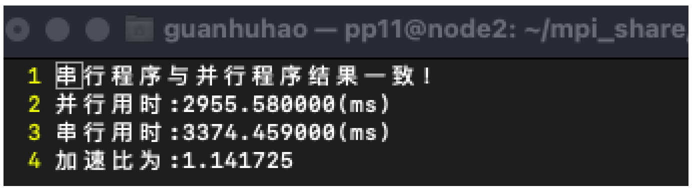
```
for i = 1 to 100 do //循环 1
    S:A[i] = A[i] + B[i-1];
    T:B[i] = C[i-1] * 2 ;
    U:C[i] = 1 / B[i] ;
    V:D[i] = C[i] * C[i] ;
endfor
```

代码实现:

```cpp
#include <bits/stdc++.h>
#include "mpi.h"
using namespace std;
const int n = 1000000;
const int mod = 1e4;
int a[n+10],b[n+10],c[n+10],d[n+10];
int aa[n+10],bb[n+10],cc[n+10],dd[n+10];
double chuan(){               //串行程序计算
    clock_t begin = clock();
    for(int i=1;i<=n;i++){
        aa[i]=aa[i]+bb[i-1];
        bb[i]=cc[i-1]*2%mod+1;
        cc[i]=int(1/bb[i]);
        dd[i]=cc[i]*cc[i]%mod+1;
    }
    clock_t end = clock();
    // printf("串行用时:%5lf(ms)\n",1000.0*(end-begin)/CLOCKS_PER_SEC);
    return 1000.0*(end-begin)/CLOCKS_PER_SEC;
}
bool check(){
    for(int i=1;i<=n;i++){
        if(aa[i]!=a[i]||cc[i]!=c[i]||bb[i]!=b[i]||dd[i]!=d[i]) {
            cout<<"error!"<<endl;
            return false;
        }
    }
    return true;
}
void randData(){               //生成随机数据
    for(int i=0;i<n+5;i++){
        a[i]=aa[i]=rand()%100;
        b[i]=bb[i]=rand()%100;
        c[i]=cc[i]=rand()%100;
        d[i]=dd[i]=rand()%100;
    }
}
int main(int argc, char* argv[])
{
    randData();          //生成随机数据

    double time_seq = chuan();  //串行程序计算

    clock_t begin = clock();
    for(int i =1;i<=n;i++){
        b[i]=c[i-1]*2%mod+1;
        c[i]=int(1/b[i]);
    }
    #pragma omp parallel for
    for(int i=1;i<=n;i++){
        a[i]=a[i]+b[i-1];
```

```
            d[i]=c[i]*c[i]%mod+1;
        }
        clock_t end = clock();

        if(check()) printf("串行程序与并行程序结果一致!\n");
        double time_pra = 1000.0*(end-begin)/CLOCKS_PER_SEC;
        printf("并行用时:%5lf(ms)\n",time_pra);
        printf("串行用时:%5lf(ms)\n",time_seq);
        printf("加速比为:%lf\n",time_seq/time_pra);

} /* end main */
```

运行结果展示



由于该算法比较简单,在数据规模较小时无论怎么设置

3.5.2

题面

作业

3 新的广播MyBcastMPI实现。基本思路：

（1）将MPI进程按所在节点划分子通讯域N；

（2）可以将各子通讯域的首进程（编号为0）再组成一个子通讯域H；

（3）由广播的root进程将消息发给原来最大通讯域中的0号进程h，再由h在H通讯域中广播（MPI_Bcast），各首进程然后在各自子通讯域N中再行广播（MPI_Bcast）。

4 用MPI_Send和MPI_Recv来模拟实现诸如MPI_Alltoall, MPI_Allgather功能并与标准MPI实现做简要性能对比