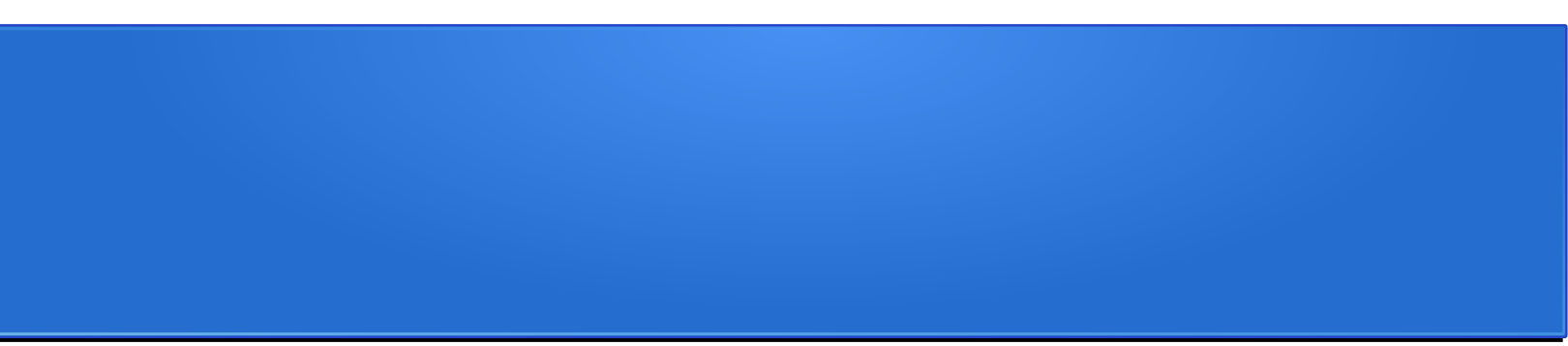


Распараллеливание
итеративных программ:
как работает конструкция
`#pragma omp parallel for`

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План

- Пример 1: Программа для исследования работы директивы `#pragma omp parallel for`
- Исследование способов распределения итераций цикла между потоками
- Пример 2: Реализация конструкции `#pragma omp parallel for` с использованием POSIX API



Пример 1:
Программа для исследования
работы директивы
`#pragma omp parallel for`

Исходный алгоритм

```
[-] #include <omp.h>
    | #include <stdio.h>
[-] int main()
    | {
    |     const int N = 20;
    |
    |     #pragma omp parallel for ordered
    |     for (int i = 0; i < N; i++) {
    |     #pragma omp ordered
    |         printf("iteration# %d executed in thread# %d\n",
    |               i, omp_get_thread_num());
    |     }
    |
    |     return 0;
    | }
```

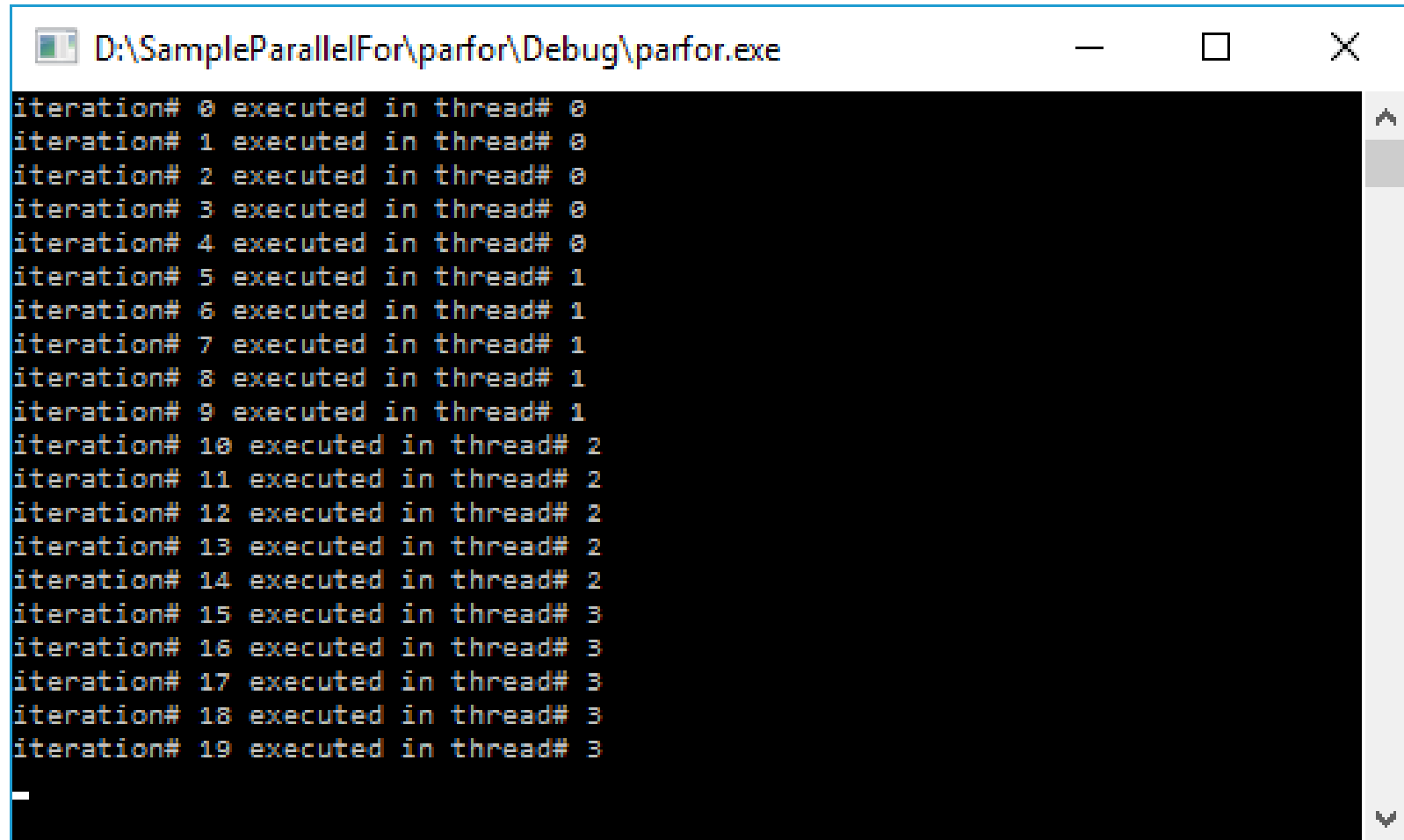
Параметры экспериментов

- Число итераций в цикле N
- Способ распределения итераций по потокам
 - без указания способа распределения
 - `static`
 - `dynamic`
 - `guided`
- размер блока X в опции `schedule`
 - `schedule(static, X)`



Исследование способов распределения итераций цикла между потоками

#pragma omp parallel for (N = 20)



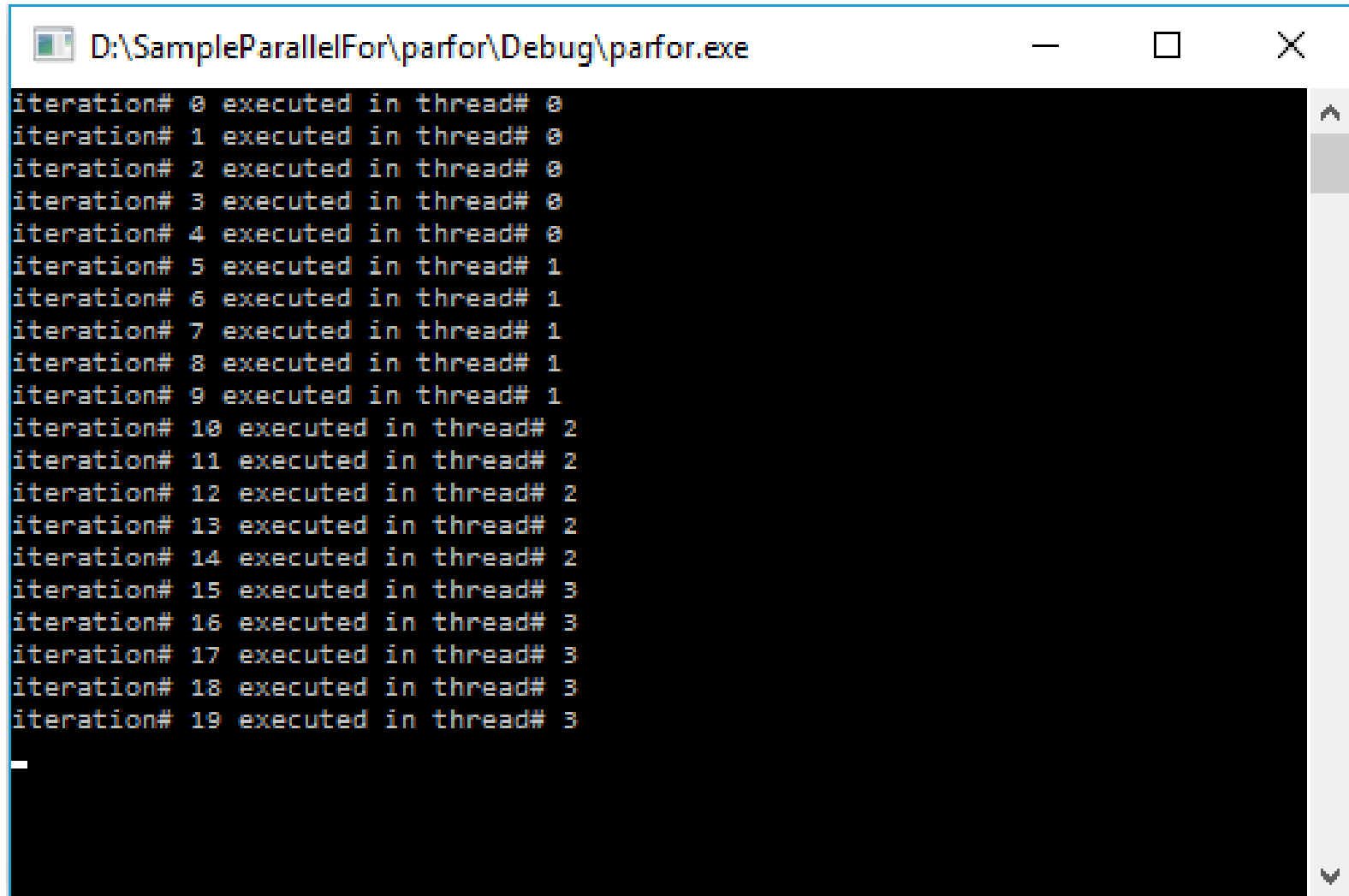
```
D:\SampleParallelFor\parfor\Debug\parfor.exe
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 0
iteration# 3 executed in thread# 0
iteration# 4 executed in thread# 0
iteration# 5 executed in thread# 1
iteration# 6 executed in thread# 1
iteration# 7 executed in thread# 1
iteration# 8 executed in thread# 1
iteration# 9 executed in thread# 1
iteration# 10 executed in thread# 2
iteration# 11 executed in thread# 2
iteration# 12 executed in thread# 2
iteration# 13 executed in thread# 2
iteration# 14 executed in thread# 2
iteration# 15 executed in thread# 3
iteration# 16 executed in thread# 3
iteration# 17 executed in thread# 3
iteration# 18 executed in thread# 3
iteration# 19 executed in thread# 3
```

#pragma omp parallel for (N = 22)

D:\SampleParallelFor\parfor\Debug\parfor.exe

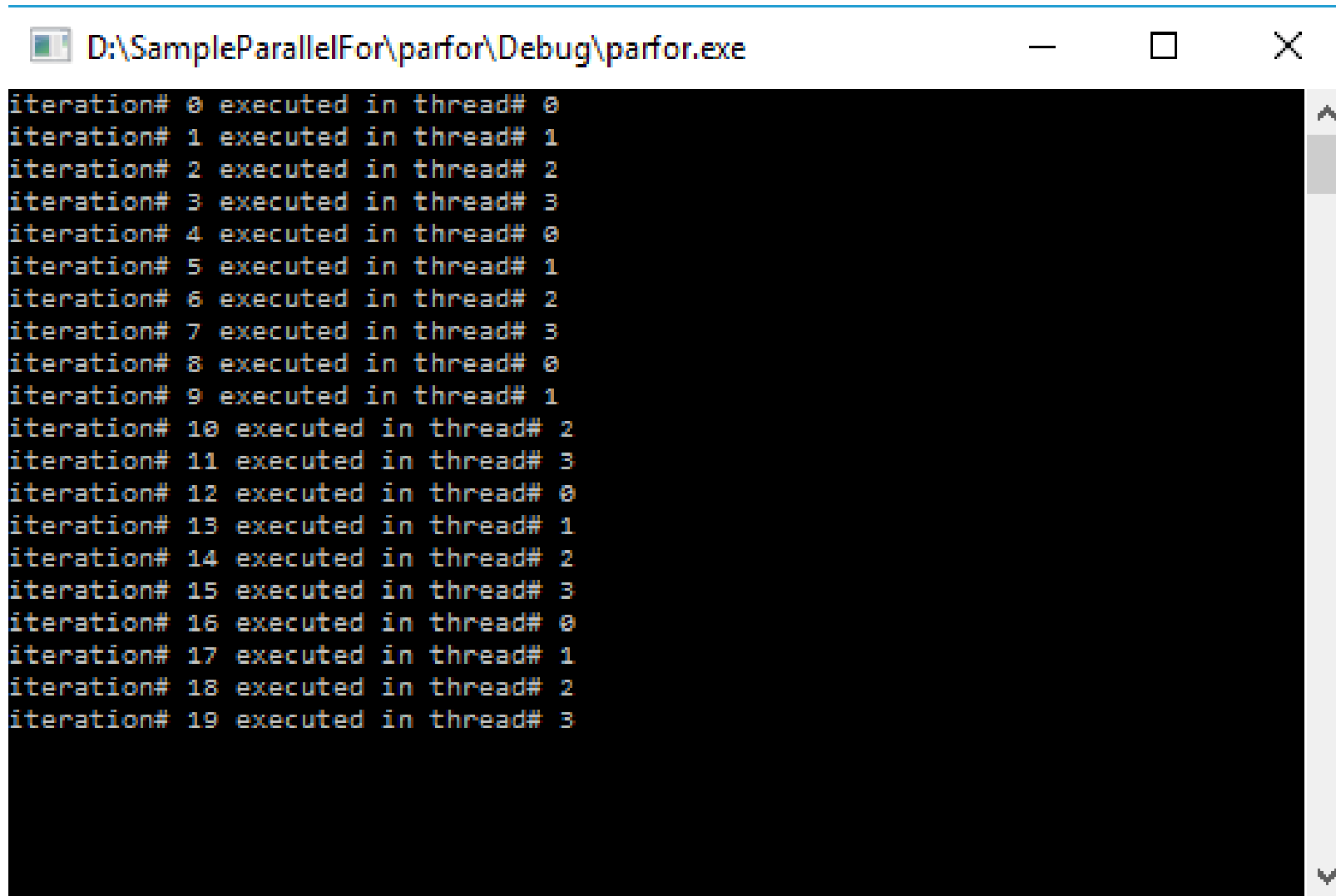
```
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 0
iteration# 3 executed in thread# 0
iteration# 4 executed in thread# 0
iteration# 5 executed in thread# 0
iteration# 6 executed in thread# 1
iteration# 7 executed in thread# 1
iteration# 8 executed in thread# 1
iteration# 9 executed in thread# 1
iteration# 10 executed in thread# 1
iteration# 11 executed in thread# 1
iteration# 12 executed in thread# 2
iteration# 13 executed in thread# 2
iteration# 14 executed in thread# 2
iteration# 15 executed in thread# 2
iteration# 16 executed in thread# 2
iteration# 17 executed in thread# 3
iteration# 18 executed in thread# 3
iteration# 19 executed in thread# 3
iteration# 20 executed in thread# 3
iteration# 21 executed in thread# 3
```


#pragma omp parallel for schedule(static) (N = 20)



```
D:\SampleParallelFor\parfor\Debug\parfor.exe
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 0
iteration# 3 executed in thread# 0
iteration# 4 executed in thread# 0
iteration# 5 executed in thread# 1
iteration# 6 executed in thread# 1
iteration# 7 executed in thread# 1
iteration# 8 executed in thread# 1
iteration# 9 executed in thread# 1
iteration# 10 executed in thread# 2
iteration# 11 executed in thread# 2
iteration# 12 executed in thread# 2
iteration# 13 executed in thread# 2
iteration# 14 executed in thread# 2
iteration# 15 executed in thread# 3
iteration# 16 executed in thread# 3
iteration# 17 executed in thread# 3
iteration# 18 executed in thread# 3
iteration# 19 executed in thread# 3
```

#pragma omp parallel for schedule(static,1) (N = 20)



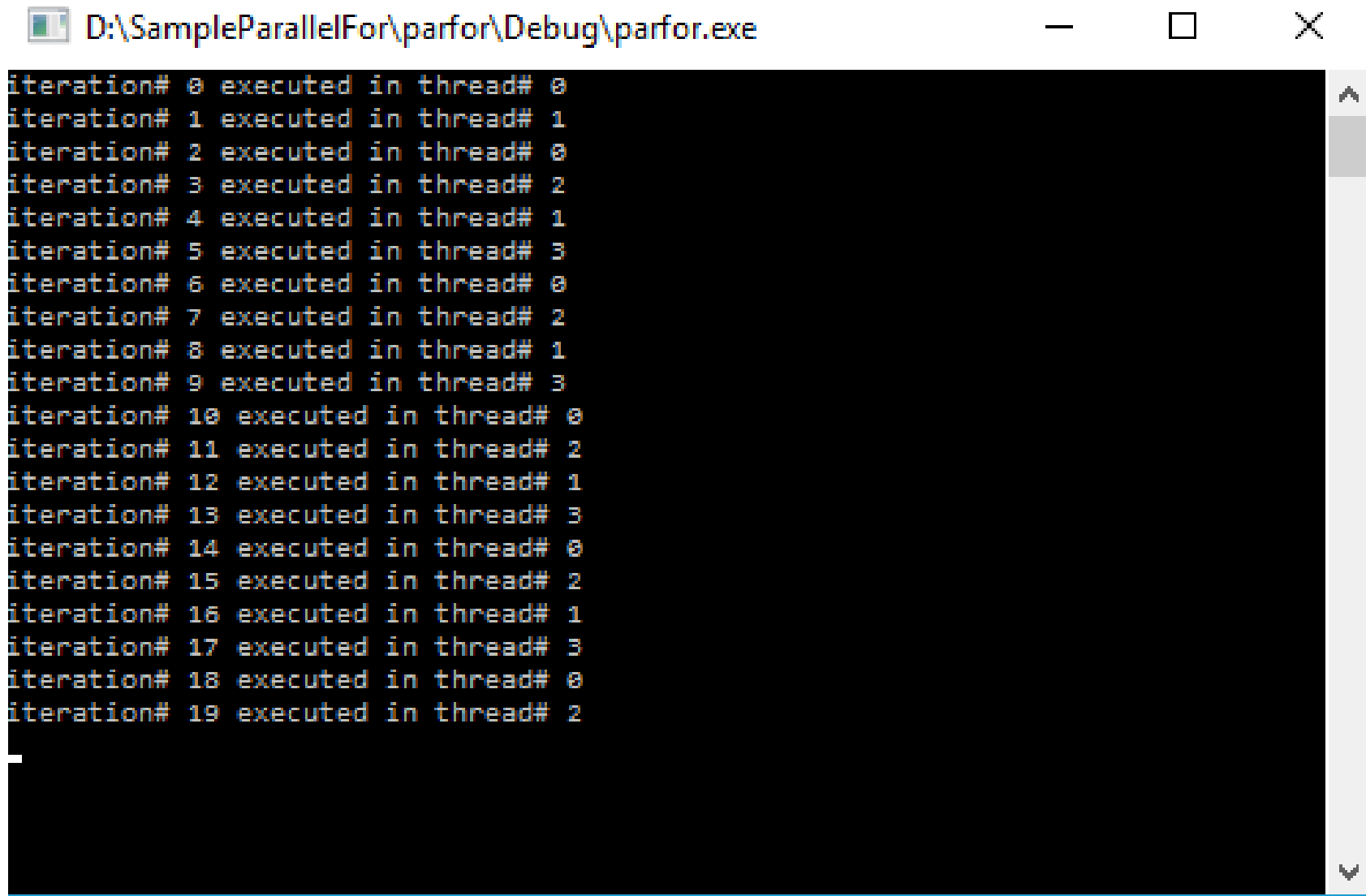
```
D:\SampleParallelFor\parfor\Debug\parfor.exe  
iteration# 0 executed in thread# 0  
iteration# 1 executed in thread# 1  
iteration# 2 executed in thread# 2  
iteration# 3 executed in thread# 3  
iteration# 4 executed in thread# 0  
iteration# 5 executed in thread# 1  
iteration# 6 executed in thread# 2  
iteration# 7 executed in thread# 3  
iteration# 8 executed in thread# 0  
iteration# 9 executed in thread# 1  
iteration# 10 executed in thread# 2  
iteration# 11 executed in thread# 3  
iteration# 12 executed in thread# 0  
iteration# 13 executed in thread# 1  
iteration# 14 executed in thread# 2  
iteration# 15 executed in thread# 3  
iteration# 16 executed in thread# 0  
iteration# 17 executed in thread# 1  
iteration# 18 executed in thread# 2  
iteration# 19 executed in thread# 3
```

#pragma omp parallel for schedule(static,2) (N = 20)

D:\SampleParallelFor\parfor\Debug\parfor.exe

```
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 1
iteration# 3 executed in thread# 1
iteration# 4 executed in thread# 2
iteration# 5 executed in thread# 2
iteration# 6 executed in thread# 3
iteration# 7 executed in thread# 3
iteration# 8 executed in thread# 0
iteration# 9 executed in thread# 0
iteration# 10 executed in thread# 1
iteration# 11 executed in thread# 1
iteration# 12 executed in thread# 2
iteration# 13 executed in thread# 2
iteration# 14 executed in thread# 3
iteration# 15 executed in thread# 3
iteration# 16 executed in thread# 0
iteration# 17 executed in thread# 0
iteration# 18 executed in thread# 1
iteration# 19 executed in thread# 1
```

#pragma omp parallel for schedule(dynamic) (N = 20)



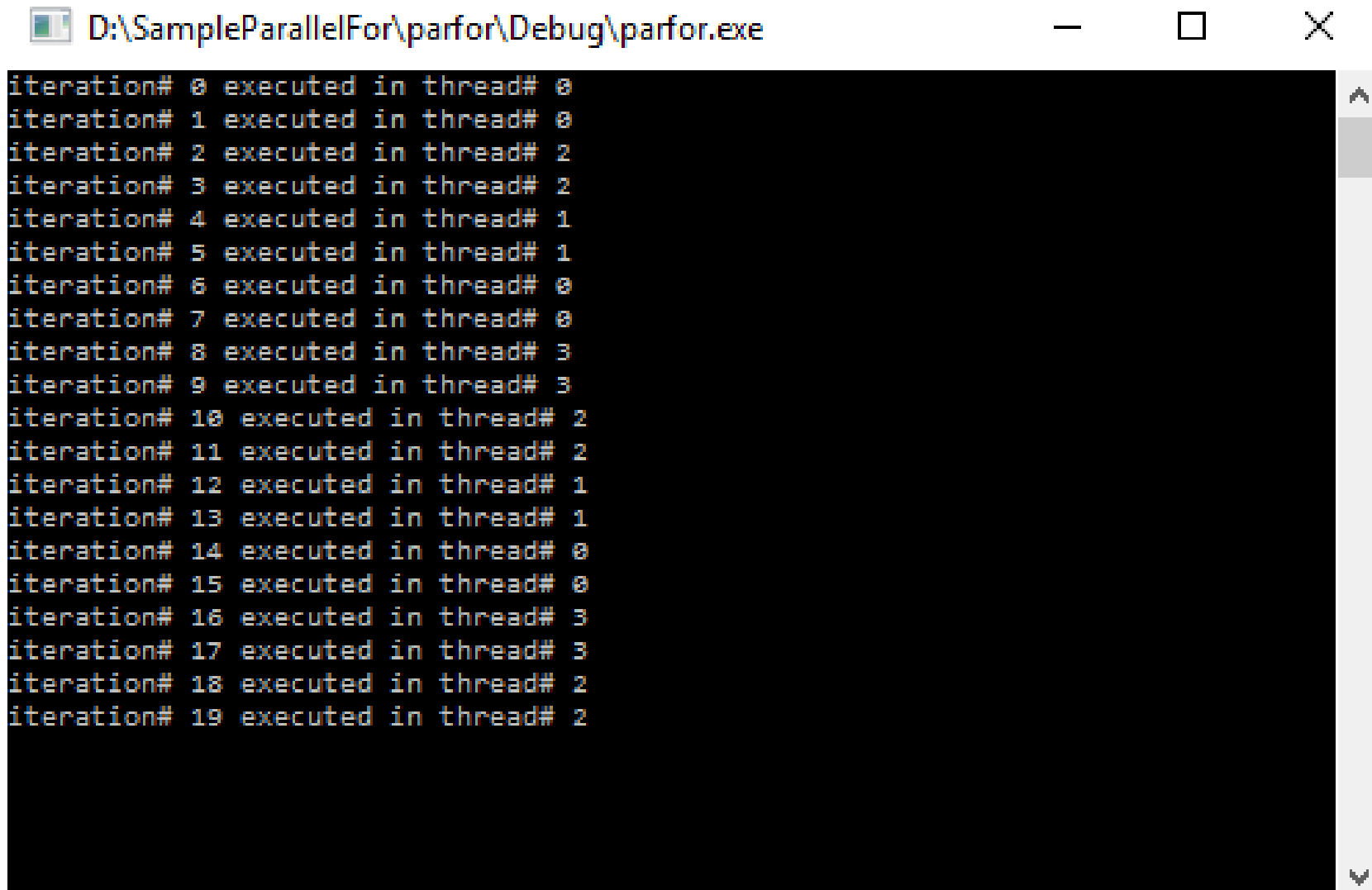
```
D:\SampleParallelFor\parfor\Debug\parfor.exe  
iteration# 0 executed in thread# 0  
iteration# 1 executed in thread# 1  
iteration# 2 executed in thread# 0  
iteration# 3 executed in thread# 2  
iteration# 4 executed in thread# 1  
iteration# 5 executed in thread# 3  
iteration# 6 executed in thread# 0  
iteration# 7 executed in thread# 2  
iteration# 8 executed in thread# 1  
iteration# 9 executed in thread# 3  
iteration# 10 executed in thread# 0  
iteration# 11 executed in thread# 2  
iteration# 12 executed in thread# 1  
iteration# 13 executed in thread# 3  
iteration# 14 executed in thread# 0  
iteration# 15 executed in thread# 2  
iteration# 16 executed in thread# 1  
iteration# 17 executed in thread# 3  
iteration# 18 executed in thread# 0  
iteration# 19 executed in thread# 2
```

#pragma omp parallel for
schedule(dynamic,1) (N = 20)

D:\SampleParallelFor\parfor\Debug\parfor.exe

```
iteration# 0 executed in thread# 0  
iteration# 1 executed in thread# 1  
iteration# 2 executed in thread# 0  
iteration# 3 executed in thread# 2  
iteration# 4 executed in thread# 3  
iteration# 5 executed in thread# 1  
iteration# 6 executed in thread# 0  
iteration# 7 executed in thread# 2  
iteration# 8 executed in thread# 3  
iteration# 9 executed in thread# 1  
iteration# 10 executed in thread# 0  
iteration# 11 executed in thread# 2  
iteration# 12 executed in thread# 3  
iteration# 13 executed in thread# 1  
iteration# 14 executed in thread# 0  
iteration# 15 executed in thread# 2  
iteration# 16 executed in thread# 3  
iteration# 17 executed in thread# 1  
iteration# 18 executed in thread# 0  
iteration# 19 executed in thread# 2
```

#pragma omp parallel for schedule(dynamic,2) (N = 20)



The screenshot shows a Windows command prompt window titled "D:\SampleParallelFor\parfor\Debug\parfor.exe". The window contains the following output:

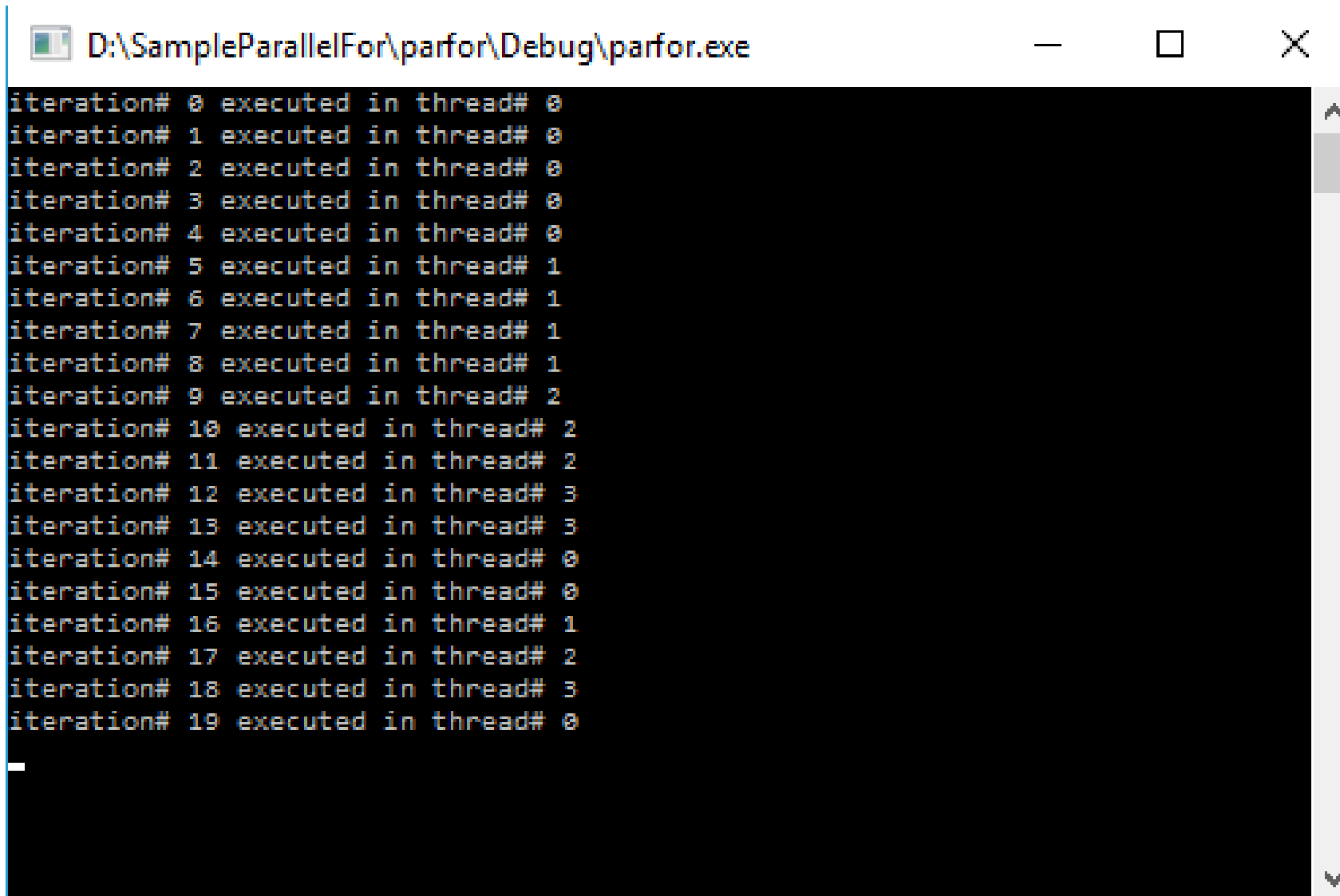
```
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 2
iteration# 3 executed in thread# 2
iteration# 4 executed in thread# 1
iteration# 5 executed in thread# 1
iteration# 6 executed in thread# 0
iteration# 7 executed in thread# 0
iteration# 8 executed in thread# 3
iteration# 9 executed in thread# 3
iteration# 10 executed in thread# 2
iteration# 11 executed in thread# 2
iteration# 12 executed in thread# 1
iteration# 13 executed in thread# 1
iteration# 14 executed in thread# 0
iteration# 15 executed in thread# 0
iteration# 16 executed in thread# 3
iteration# 17 executed in thread# 3
iteration# 18 executed in thread# 2
iteration# 19 executed in thread# 2
```

#pragma omp parallel for schedule(guided) (N = 20)

D:\SampleParallelFor\parfor\Debug\parfor.exe

```
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 0
iteration# 3 executed in thread# 0
iteration# 4 executed in thread# 0
iteration# 5 executed in thread# 1
iteration# 6 executed in thread# 1
iteration# 7 executed in thread# 1
iteration# 8 executed in thread# 1
iteration# 9 executed in thread# 2
iteration# 10 executed in thread# 2
iteration# 11 executed in thread# 2
iteration# 12 executed in thread# 3
iteration# 13 executed in thread# 3
iteration# 14 executed in thread# 0
iteration# 15 executed in thread# 0
iteration# 16 executed in thread# 1
iteration# 17 executed in thread# 2
iteration# 18 executed in thread# 3
iteration# 19 executed in thread# 0
```

#pragma omp parallel for schedule(guided,1) (N = 20)



```
D:\SampleParallelFor\parfor\Debug\parfor.exe  
iteration# 0 executed in thread# 0  
iteration# 1 executed in thread# 0  
iteration# 2 executed in thread# 0  
iteration# 3 executed in thread# 0  
iteration# 4 executed in thread# 0  
iteration# 5 executed in thread# 1  
iteration# 6 executed in thread# 1  
iteration# 7 executed in thread# 1  
iteration# 8 executed in thread# 1  
iteration# 9 executed in thread# 2  
iteration# 10 executed in thread# 2  
iteration# 11 executed in thread# 2  
iteration# 12 executed in thread# 3  
iteration# 13 executed in thread# 3  
iteration# 14 executed in thread# 0  
iteration# 15 executed in thread# 0  
iteration# 16 executed in thread# 1  
iteration# 17 executed in thread# 2  
iteration# 18 executed in thread# 3  
iteration# 19 executed in thread# 0
```


#pragma omp parallel for schedule(guided,2) (N = 20)

D:\SampleParallelFor\parfor\Debug\parfor.exe



```
iteration# 0 executed in thread# 0
iteration# 1 executed in thread# 0
iteration# 2 executed in thread# 0
iteration# 3 executed in thread# 0
iteration# 4 executed in thread# 0
iteration# 5 executed in thread# 2
iteration# 6 executed in thread# 2
iteration# 7 executed in thread# 2
iteration# 8 executed in thread# 2
iteration# 9 executed in thread# 1
iteration# 10 executed in thread# 1
iteration# 11 executed in thread# 1
iteration# 12 executed in thread# 3
iteration# 13 executed in thread# 3
iteration# 14 executed in thread# 0
iteration# 15 executed in thread# 0
iteration# 16 executed in thread# 2
iteration# 17 executed in thread# 2
iteration# 18 executed in thread# 1
iteration# 19 executed in thread# 1
```



Пример 2: Реализация конструкции `#pragma omp parallel for` с использованием POSIX API

Замыкание

Функция первого класса, в теле которой присутствуют ссылки на переменные, объявленные вне тела этой функции в окружающем коде и не являющиеся её параметрами.

В языке C не поддерживаются замыкания, конструкция `#pragma parallel for` – аналог замыкания

```
int i=0;
parallel_for( {i<N},{i++},{
    printf("iteration# %d executed in thread# %d\n",
        i, omp_get_thread_num());
}
)
```

Метод реализации на С

- 1) объявить обычную функцию, соответствующую замыканию
- 2) создать экземпляр структуры, с полями-ссылками на свободные переменные замыкания
- 3) настроить поля-ссылки на свободные переменные в экземпляре структуры (2) в контексте вызова функции, имитирующей замыкание
- 4) передать в вызове функции (1) экземпляр структуры (2)

Код реализации на C. Случай `schedule(static,1)` 1/5

```
#include <stdio.h>
#include <omp.h>
#include <malloc.h>
#include <pthread.h>
#include <assert.h>
#include <unistd.h>
```

```
const int N = 20;
int X = 10;
```

Код реализации на C. Случай `schedule(static,1)` 2/5

```
struct closure {
    int thread_num;
    int num_threads;
    int X;
};

void* parallel_for_call_back(void*arg)
{
    closure* cls = (closure*)arg;

    for (int i = cls->thread_num; i<N; i += cls->num_threads) {
        printf("iteration# %d executed in thread# %d private X=%d\n",
            i, cls->thread_num, cls->X);
    }
    return 0;
}
```

Код реализации на C. Случай schedule(static,1) 3/5

```
int main()
{
////////////////////////////////////
#pragma omp parallel for schedule(static,1) firstprivate(X)
    for (int i = 0; i < N; i++) {
        printf("iteration# %d executed in thread# %d private X=%d\n",
            i, omp_get_thread_num(), X);
    }
////////////////////////////////////
}
```

Код реализации на С. Случай `schedule(static,1)` 4/5

```
int num_threads = sysconf(_SC_NPROCESSORS_ONLN);

closure* closures;
pthread_t* h_threads;

closures = (closure*)malloc(sizeof(closure)*num_threads);
h_threads = (pthread_t*)malloc(sizeof(pthread_t)*num_threads);

for (int i = 1; i < num_threads; i++) {
    closures[i].thread_num = i;
    closures[i].num_threads = num_threads;
    closures[i].X = X;

    int rc = pthread_create(
        &h_threads[i], NULL, parallel_for_call_back, &closures[i]);
    assert(0 == rc);
}
```


Код реализации на С. Случай `schedule(static,1)` 5/5

```

closures[0].thread_num = 0;
closures[0].num_threads = num_threads;
closures[0].X = X;

parallel_for_call_back(&closures[0]);

for (int i = 1; i < num_threads; i++) {
    int rc = pthread_join(h_threads[i], NULL);
    assert(0 == rc);
}

free(closures);
free(h_threads);

```