Multicore Programming: Synchronization:Semaphores

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Topics

1. Synchronization Problems

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Topics

1. Synchronization Problems
2. Semaphore Definition

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Topics

1. Synchronization Problems
2. Semaphore Definition
3. Exploration of Problem Solutions using Semaphores

Reference: The Little Book of Semaphores, Allen Downey Version 2.1.5

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Synchrhonization Constraints: Serialization

Algorithm

Ram:
Eats breakfast
Writes Software module B
Signals Done
Eats Lunch

Algorithm

Laxman:
Eats breakfast
Tests Software module A
Eats Lunch
Receives Signal to Start
Tests Software module B

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Syncrhonization Constraints: Mutual Exclusion

Algorithm

Ram:

Eats breakfast

Signals Begining Modify

Modifies Software module A

Signals Done Modifying

Algorithm

Laxman:

Eats breakfast

Signals Begining Modify

Modifies Software module A

Signals Done Modifying

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Semaphore: Definition

Semaphore is an integer with the following differences:

1. Semaphore is created and initialized to any value.
2. When a thread decrements its value, if it is negative it waits, i.e., it gets blocked.
3. When a thread increments its value, if there are waiting threads, then one thread gets unblocked.

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Serialization Problem:

A writes Software Module A

B tests Software Module A

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Signaling with Semaphores:

Create done(0)

A writes Software Module A
done.signal

done.wait
B tests Software Module A

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Rendezvous:

A writes Software Module A
A tests Software Module B

B writes Software Module B
B tests Software Module A

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Rendezvous: Solution with Semaphores:

Thread 1:
Create doneA(0)
A writes Software Module A
doneA.signal
waitB.signal
A tests Software Module B

Thread 2:
Create doneB(0)
B writes Software Module B
doneB.signal
waitA.signal
B tests Software Module A

Potential Problems?

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Mutual Exclusion:

Thread 1:
count = count++;

Thread 2:
count = count++;

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Mutual Exclusion: Solution with Semaphore

Create update(1)

Thread 1:

```
update.wait()
count = count++;
update.signal()
```

Thread 2:

```
update.wait()
count = count++;
update.signal()
```


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Barrier: Rendezvous With n threads

Thread i:

1. rendezvous
2. critical section

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Barrier: Solution 1 with Semaphores

Thread 1: create b(-n)
Thread i:

1. b.signal
2. b.wait
3. barrier point

Problem ??

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Barrier: Solution 1 with Semaphores

Thread 1: count = 0
create update_count(1)
create b(0)
if (count == n) b.signal
Thread i:

1. update_count.wait
2. count++;
3. update_count.signal
4. if (count == n) b.signal
5. b.wait
6. barrier point

Problem ??

Is there always a problem

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Implement Barrier using Semaphore and OpenMP

1. Implement using “semaphore.h” and openMP “omp.h”.
2. *YOUR SOLUTION HERE.*

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Barrier using semaphores

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

int main(int argc, char **argv){
    sem_t b;
    int count=0;
    sem_init(&b, 1, 0);

#pragma omp parallel num_threads(3)
  {
    sleep(omp_get_thread_num());
#pragma omp critical
    {
      count++;
    }
    if (count == 3){
      sem_post(&b);
      printf("thread=%d arrived at barrier\n", omp_get_thread_num());
    } else if (count < 3){
      printf("Wating In thread %d\n", omp_get_thread_num());
      sem_wait(&b);
      printf("Awakened thread=%d\n", omp_get_thread_num());
      sem_post(&b);
    }
  }
  return 0;
}
```


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Multicore Programming

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May 3, 2013

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Agenda

1. Introduction to Multithreading
2. About Pthreads
3. Pthreads - An Example
4. Introduction to OpenMP
5. Programming Model
6. OpenMP Example
7. Data Parallelism
8. Task Parallelism
9. Synchronization Issues
10. Explicit Asynchronous/Synchronous Execution
11. Load balancing in Loops

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Introduction to Multithreading

1. Multiple threads exists within the context of a single process.
2. Can share resources such as memory, not applicable with processes.
3. Single-core system: More Context switching time.
4. Multi-core system: Less switching, truly concurrent.

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About Pthreads

1. Standard C library with functions for using threads.
2. Available across different platforms.

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1. Standard C library with functions for using threads.
2. Available across different platforms.

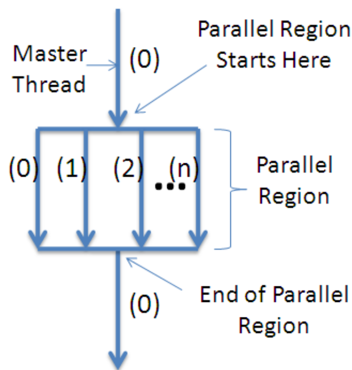

Figure: Creation of Multi-threads

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Example : Vector Addition

In main():

```
pthread_t callThread[numT];

for(i=0; i<numT; i++)
    pthread_create(&callThread[i],NULL, vectAdd,(void*)i);

for(i=0; i<numT; i++)
    pthread_join(&callThread[i], NULL);
```


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Example : Vector Addition

In vectAdd() :

```
start = tid * (N/numT);
end = (tid+1) * (N/numT);

for(i=start; i< end; i++)
    C[i]=  A[i] + B[i];
```

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Compilation :

1. Include pthread.h in the main file

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Compilation :

1. Include pthread.h in the main file
2. Compile program with

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Compilation :

1. Include pthread.h in the main file
2. Compile program with -lpthread

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Compilation :

1. Include pthread.h in the main file
2. Compile program with -lpthread
   - gcc -o test test.c -lpthread

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About OpenMP

1. Abbreviation: **Open** specifications for **Multi-Processing**.
2. API to exhibit *multi-threaded shared memory parallelism*.
3. The API is specified for C/C++ and Fortran
4. Three distinct components. As of version 3.1:
    4.1 Compiler Directives (20)
    4.2 Runtime Library Routines (32)
    4.3 Environment Variables (9)

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OpenMP Programming Model

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

#pragma omp parallel
    {


        //Parallel Region



    }
```

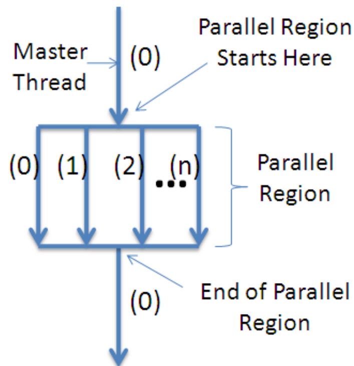

Figure: Creation of Multi-threads

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OpenMP Example

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

int main()
{

#pragma omp parallel num_threads(4)

    {
        printf("Hello! My Thread Id is :: %d\n", omp_get_thread_num());
    }

    return 0;
}
```


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OpenMP Example

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

int main()
{

#pragma omp parallel num_threads(4)

    {
        printf("Hello! My Thread Id is :: %d\n", omp_get_thread_num());
    }

    return 0;
}
```

Compile (GNU C Compiler): gcc -fopenmp hello.c -o hello.out
Run: ./hello.out

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OpenMP Example

Output:
Hello! My Thread Id is :: 0
Hello! My Thread Id is :: 3
Hello! My Thread Id is :: 1
Hello! My Thread Id is :: 2

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Setting the Number of Threads

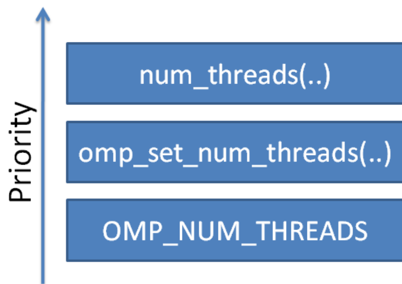

Figure: Ways to Set Threads

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Bigger Data

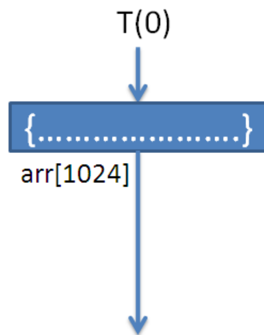

Figure: Single Thread Operation (Sequential)

Will take longer execution time.

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Chunk your Data, Share work among threads

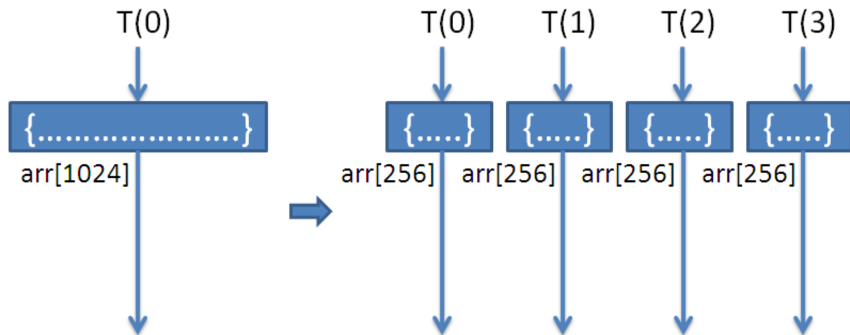

Figure: MultiThread Operation (Parallel)

Will take less execution time.

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OpenMP For directive

```
#pragma omp parallel num_threads(4)
  #pragma omp for
    for(i=0; i<4; i++)
    {
        printf("Iteration %d, ThreadId %d\n", i, omp_get_thread_num());
    }
```


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OpenMP For directive

```
#pragma omp parallel num_threads(4)
  #pragma omp for
    for(i=0; i<4; i++)
    {
        printf("Iteration %d, ThreadId %d\n", i, omp_get_thread_num());
    }
```

Output:

Iteration 0, ThreadId 0

Iteration 2, ThreadId 2

Iteration 3, ThreadId 3

Iteration 1, ThreadId 1

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Shared Data

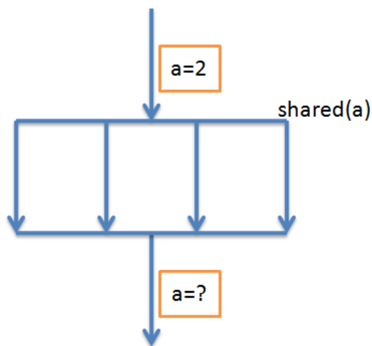

Figure: Globally accessible Data

Simultaneous Write Operations can do hazards.

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Make your Data Private

Creates private copy of variable for each thread.

```
    int a = 2;

#pragma omp parallel private(a)
    {
        printf("Value of a :: %d\n", a);
    }
```

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Make your Data Private

Creates private copy of variable for each thread.

```
    int a = 2;

#pragma omp parallel private(a)
    {
        printf("Value of a :: %d\n", a);
    }
```

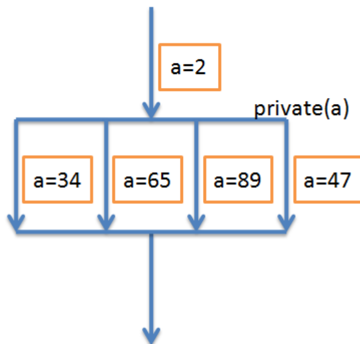

Figure: Private Clause

Problem: Variables uninitialized for each thread

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Firstprivate Clause

Creates private copy of variable for each thread with automatic initialization.

```
    int a = 2;

#pragma omp parallel firstprivate(a)
    {
        printf("Value of a :: %d\n", a);
    }
```

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Firstprivate Clause

Creates private copy of variable for each thread with automatic initialization.

```
int a = 2;

#pragma omp parallel firstprivate(a)
{
    printf("Value of a :: %d\n", a);
}
```

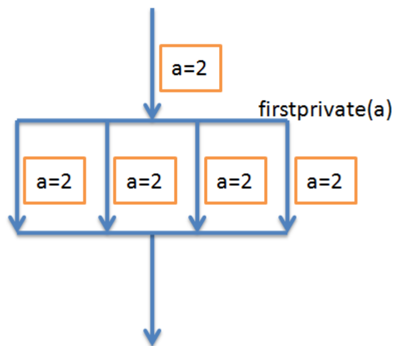

Figure: Firstprivate Clause

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Lastprivate Clause

Private + Copy back value from last loop iteration to the original variable.

```
    int i = 0,a = 2;

#pragma omp parallel firstprivate(a) lastprivate(a)
#pragma omp for
        for(i=0; i<4; i++)
        {
            a += omp_get_thread_num();
        }

        printf("Value of a :: %d\n", a);
```

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Lastprivate Clause

Private + Copy back value from last loop iteration to the original variable.

```
    int i = 0,a = 2;

#pragma omp parallel firstprivate(a)  lastprivate(a)
#pragma omp for
        for(i=0; i<4; i++)
        {
            a += omp_get_thread_num();
        }

        printf("Value of a :: %d\n", a);
```

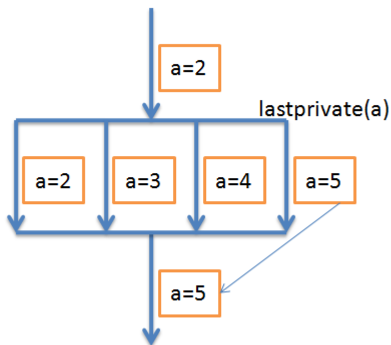

Figure: Lastprivate Clause

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Reduction Clause

1. A private copy for each list variable is created for each thread.
2. Reduction variable is applied to all private copies of the shared variable.
3. Final result is written to the global shared variable.

```
int i, sum=0;
int a[2] = {1,1}, b[2] = {2,2};

#pragma omp parallel reduction(+:sum) num_threads(2)
#pragma omp for
    for(i=0; i<2; i++)
    {
        sum = a[i]+b[i];
    }

    printf("Sum :: %d\n", sum);
```

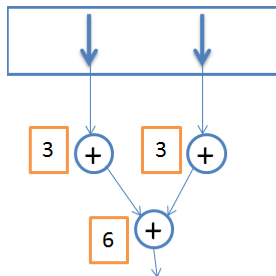

Figure: Reduction Clause

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Master Directive

Code is to be executed by only Master thread.

```
int a[4], i=0;

#pragma omp parallel
{
    // Computation
    #pragma omp for
    for (i = 0; i < 4; i++)
    {
        a[i] = i * i;
    }

    // Print Results
    #pragma omp master
    {
        for (i = 0; i < 4; i++)
            printf("a[%d] = %d\n", i, a[i]);
    }
}
```


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Master Directive

Code is to be executed by only Master thread.

```
int a[4], i=0;

#pragma omp parallel
{
    // Computation
    #pragma omp for
    for (i = 0; i < 4; i++)
    {
        a[i] = i * i;
    }

    // Print Results
    #pragma omp master
    {
        for (i = 0; i < 4; i++)
            printf("a[%d] = %d\n", i, a[i]);
    }
}
```

Output:

a[0] = 0

a[1] = 1

a[2] = 4

a[3] = 9

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Single Directive

Code is to be executed by only one thread in the team.

```
int a[4], i=0;

#pragma omp parallel
{
    // Computation
    #pragma omp for
    for (i = 0; i < 4; i++)
    {
        a[i] = i * i;
    }

    // Print Results
    #pragma omp single
    {
        for (i = 0; i < 4; i++)
            printf("a[%d] = %d\n", i, a[i]);
    }
}
```

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Single Directive

Code is to be executed by only one thread in the team.

```
int a[4], i=0;

#pragma omp parallel
{
    // Computation
    #pragma omp for
    for (i = 0; i < 4; i++)
    {
        a[i] = i * i;
    }

    // Print Results
    #pragma omp single
    {
        for (i = 0; i < 4; i++)
            printf("a[%d] = %d\n", i, a[i]);
    }
}
```

Output:
$a[0] = 0$
$a[1] = 1$
$a[2] = 4$
$a[3] = 9$

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Independent tasks

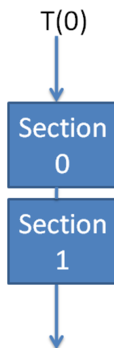

Figure: Single Thread Operation (Sequential)

Will take Longer Execution Time.

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Independent Tasks can run in parallel

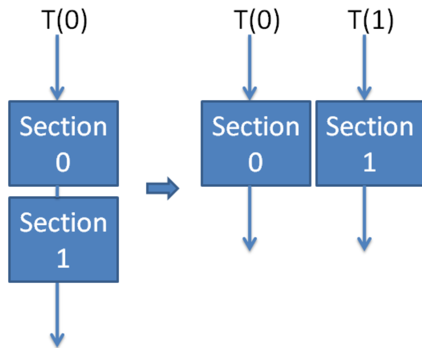

Figure: MultiThread Operation (Parallel)

Will take Less Execution Time.

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OpenMP Sections Directive

```
#pragma omp parallel sections num_threads(2)
    {

#pragma omp section
        {
            printf("A. My ThreadId :: %d\n", omp_get_thread_num());
        }
#pragma omp section
        {
            printf("B. My ThreadId :: %d\n", omp_get_thread_num());
        }

    }
```

Output:
A. My ThreadId :: 0
B. My ThreadId :: 1

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Synchronization Issues

What will be the output.. ??

```
    int max = 11;
    int a[2] = {22,33};
    int tid = 0;

#pragma omp parallel
    {
        tid = omp_get_thread_num();

        if(a[tid] > max)
            max = a[tid];
    }

    printf("Value of Max :: %d\n", max);
```


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Synchronization Issues

What will be the output.. ??

```
int max = 11;
int a[2] = {22,33};
int tid = 0;

#pragma omp parallel
{
    tid = omp_get_thread_num();

    if(a[tid] > max)
        max = a[tid];
}

printf("Value of Max :: %d\n", max);
```

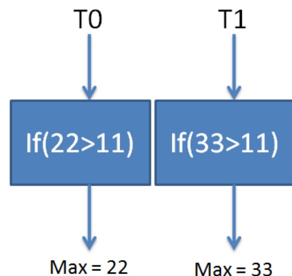

Figure: Race Condition

Output:
Value of Max :: 33 **OR** Value of Max :: 22

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Use Critical Directive

```
    int max = 11;
    int a[2] = {22,33};
    int tid = 0;

#pragma omp parallel
    {

#pragma omp critical
        {
            tid = omp_get_thread_num();
            if(a[tid] > max)
                max = a[tid];
        }

    }

    printf("Value of Max :: %d\n", max);
```


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Use Critical Directive

```
    int max = 11;
    int a[2] = {22,33};
    int tid = 0;

#pragma omp parallel
    {

#pragma omp critical
        {
            tid = omp_get_thread_num();
            if(a[tid] > max)
                max = a[tid];
        }

    }

    printf("Value of Max :: %d\n", max);
```

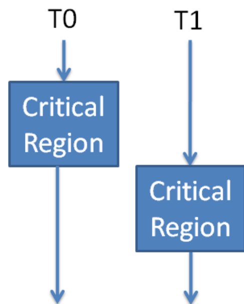

Figure: Critical Region

Output: Value of Max :: 33

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Synchronization Issue

What will be the output.. ??

```
#pragma omp parallel
{
    #pragma omp for // Computation 1
    for (i = 0; i < 4; i++)
        a[i] = i * i;

    #pragma omp master //Print Intermediate Results.
        for (i = 0; i < 4; i++)
            printf("Partial a[%d] = %d\n", i, a[i]);

    #pragma omp for //Computation 2
    for (i = 0; i < 4; i++)
        a[i] += i;
}

for (i = 0; i < 4; i++)
    printf("Final a[%d] = %d\n", i, a[i]);
```

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Synchronization Issue

Expected Output:
Partial a[0] = 0
Partial a[1] = 1
Partial a[2] = 4
Partial a[3] = 9
Final a[0] = 0
Final a[1] = 2
Final a[2] = 6
Final a[3] = 12

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Synchronization Issue

Expected Output:
Partial a[0] = 0
Partial a[1] = 1
Partial a[2] = 4
Partial a[3] = 9
Final a[0] = 0
Final a[1] = 2
Final a[2] = 6
Final a[3] = 12

Actual Output:
Partial a[0] = 0
Partial a[1] = 2
Partial a[2] = 6
Partial a[3] = 12
Final a[0] = 0
Final a[1] = 2
Final a[2] = 6
Final a[3] = 12

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Explicit Synchronous Execution

Use OpenMP Barrier Directive:

```
#pragma omp parallel
{
    #pragma omp for // Computation 1
    for (i = 0; i < 4; i++)
        a[i] = i * i;

    #pragma omp master //Print Intermediate Results.
        for (i = 0; i < 4; i++)
            printf("Partial a[%d] = %d\n", i, a[i]);

    #pragma omp barrier

    #pragma omp for //Computation 2
    for (i = 0; i < 4; i++)
        a[i] += i;
}

for (i = 0; i < 4; i++)
    printf("Final a[%d] = %d\n", i, a[i]);
```

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Explicit Synchronous Execution

Expected Output:
Partial a[0] = 0
Partial a[1] = 1
Partial a[2] = 4
Partial a[3] = 9
Final a[0] = 0
Final a[1] = 2
Final a[2] = 6
Final a[3] = 12

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Explicit Synchronous Execution

Expected Output:
Partial a[0] = 0
Partial a[1] = 1
Partial a[2] = 4
Partial a[3] = 9
Final a[0] = 0
Final a[1] = 2
Final a[2] = 6
Final a[3] = 12

Actual Output:
Partial a[0] = 0
Partial a[1] = 1
Partial a[2] = 4
Partial a[3] = 9
Final a[0] = 0
Final a[1] = 2
Final a[2] = 6
Final a[3] = 12

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Explicit Asynchronous Execution

Is someone sitting Ideal.. ??

```
#pragma omp parallel private(i)
 {
```

```
#pragma omp for
      for(i=0; i<N; i++)
          a[i] += b[i];
```

```
#pragma omp for
      for(i=0; i<N; i++)
          c[i] += d[i];
```

```
 }
```

Independent Calculations

Figure: Two Independent Parallel Regions

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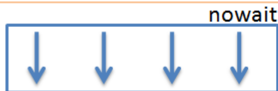
Explicit Asynchronous Execution

Can execute asynchronously.

```
#pragma omp parallel private(i)
{
```

```
#pragma omp for nowait
    for(i=0; i<N; i++)
        a[i] += b[i];
```




```
#pragma omp for nowait
    for(i=0; i<N; i++)
        c[i] += d[i];
```

```
}
```

Figure: Use "nowait"

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Load balancing in Loops

1. Division of loop iterations among the threads in the team.
2. By default, schedule is implementation dependent.
3. Use OpenMP schedule clause with for construct.

schedule (static [, chunk]): Static load balancing by iterations.

```
#pragma omp parallel for schedule(static)
#pragma omp parallel for schedule(static, 2)
```

schedule (dynamic [, chunk]): Dynamic load balancing.

```
#pragma omp parallel for schedule(dynamic)
#pragma omp parallel for schedule(dynamic, 2)
```

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Thank You

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