OpenMP
Application Program Interface

Examples

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Introduction

This collection of programming examples supplements the OpenMP API for Shared Memory Parallelization specifications, and is not part of the formal specifications. It assumes familiarity with the OpenMP specifications, and shares the typographical conventions used in that document.

Note – This first release of the OpenMP Examples reflects the OpenMP Version 4.0 specifications. Additional examples are being developed and will be published in future releases of this document.

The OpenMP API specification provides a model for parallel programming that is portable across shared memory architectures from different vendors. Compilers from numerous vendors support the OpenMP API.

The directives, library routines, and environment variables demonstrated in this document allow users to create and manage parallel programs while permitting portability. The directives extend the C, C++ and Fortran base languages with single program multiple data (SPMD) constructs, tasking constructs, device constructs, worksharing constructs, and synchronization constructs, and they provide support for sharing and privatizing data. The functionality to control the runtime environment is provided by library routines and environment variables. Compilers that support the OpenMP API often include a command line option to the compiler that activates and allows interpretation of all OpenMP directives.

Complete information about the OpenMP API and a list of the compilers that support the OpenMP API can be found at the OpenMP.org web site

http://www.openmp.org
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Examples

The following are examples of the OpenMP API directives, constructs, and routines.

A statement following a directive is compound only when necessary, and a non-compound statement is indented with respect to a directive preceding it.

#### 1 A Simple Parallel Loop

The following example demonstrates how to parallelize a simple loop using the parallel loop construct. The loop iteration variable is private by default, so it is not necessary to specify it explicitly in a `private` clause.

```c
void simple(int n, float *a, float *b)
{
    int i;

    #pragma omp parallel for
    for (i=1; i<n; i++) /* i is private by default */
        b[i] = (a[i] + a[i-1]) / 2.0;
}
```
Example 1.1f

SUBROUTINE SIMPLE(N, A, B)

  INTEGER I, N
  REAL B(N), A(N)

!$OMP PARALLEL DO  !I is private by default
  DO I=2,N
    B(I) = (A(I) + A(I-1)) / 2.0
  ENDDO
!$OMP END PARALLEL DO

END SUBROUTINE SIMPLE
2 The OpenMP Memory Model

In the following example, at Print 1, the value of \( x \) could be either 2 or 5, depending on the timing of the threads, and the implementation of the assignment to \( x \). There are two reasons that the value at Print 1 might not be 5. First, Print 1 might be executed before the assignment to \( x \) is executed. Second, even if Print 1 is executed after the assignment, the value 5 is not guaranteed to be seen by thread 1 because a flush may not have been executed by thread 0 since the assignment.

The barrier after Print 1 contains implicit flushes on all threads, as well as a thread synchronization, so the programmer is guaranteed that the value 5 will be printed by both Print 2 and Print 3.

```
Example 2.1c

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

int main(){
  int x;
  x = 2;
  #pragma omp parallel num_threads(2) shared(x)
  {
      if (omp_get_thread_num() == 0) {
          x = 5;
      } else {
        /* Print 1: the following read of x has a race */
        printf("1: Thread# %d: x = %d\n", omp_get_thread_num(), x);
      }
  }

  #pragma omp barrier

  if (omp_get_thread_num() == 0) {
    /* Print 2 */
    printf("2: Thread# %d: x = %d\n", omp_get_thread_num(), x);
  } else {
    /* Print 3 */
    printf("3: Thread# %d: x = %d\n", omp_get_thread_num(), x);
  }
  return 0;
}  
```
Example 2.1f

The following example demonstrates why synchronization is difficult to perform correctly through variables. The value of flag is undefined in both prints on thread 1 and the value of data is only well-defined in the second print.
Example 2.2c

```c
#include <omp.h>
#include <stdio.h>
int main()
{
    int data;
    int flag=0;
#pragma omp parallel num_threads(2)
{
    if (omp_get_thread_num()==0)
    {
        /* Write to the data buffer that will be
         read by thread */
        data = 42;
        /* Flush data to thread 1 and strictly order
         the write to data
         relative to the write to the flag */
        #pragma omp flush(flag, data)
        /* Set flag to release thread 1 */
        flag = 1;
        /* Flush flag to ensure that thread 1 sees
         the change */
        #pragma omp flush(flag)
    }
    else if(omp_get_thread_num()==1)
    {
        /* Loop until we see the update to the flag */
        #pragma omp flush(flag, data)
        while (flag < 1)
        {
            #pragma omp flush(flag, data)
        }
        /* Values of flag and data are undefined */
        printf("flag=%d data=%d\n", flag, data);
        #pragma omp flush(flag, data)
        /* Values data will be 42, value of flag
        still undefined */
        printf("flag=%d data=%d\n", flag, data);
    }
} return 0;
}```
Example 2.2f

PROGRAM EXAMPLE
  INCLUDE "omp_lib.h" ! or USE OMP_LIB
  INTEGER DATA
  INTEGER FLAG

  FLAG = 0
  !$OMP PARALLEL NUM_THREADS(2)
    IF(OMP_GET_THREAD_NUM() .EQ. 0) THEN
      ! Write to the data buffer that will be read by thread 1
      DATA = 42
      ! Flush DATA to thread 1 and strictly order the write to DATA
      ! relative to the write to the FLAG
      !$OMP FLUSH(FLAG, DATA)
      ! Set FLAG to release thread 1
      FLAG = 1;
      ! Flush FLAG to ensure that thread 1 sees the change */
      !$OMP FLUSH(FLAG)
    ELSE IF(OMP_GET_THREAD_NUM() .EQ. 1) THEN
      ! Loop until we see the update to the FLAG
      !$OMP FLUSH(FLAG, DATA)
      DO WHILE(FLAG .LT. 1)
        !$OMP FLUSH(FLAG, DATA)
      ENDDO
      ! Values of FLAG and DATA are undefined
      PRINT *, 'FLAG=', FLAG, ' DATA=', DATA
      !$OMP FLUSH(FLAG, DATA)
    ENDIF
  !$OMP END PARALLEL
END
Example 2.3c

#include <omp.h>
#include <stdio.h>
int main()
{
    int flag=0;

    #pragma omp parallel num_threads(3)
    {
        if(omp_get_thread_num()==0)
        {
            /* Set flag to release thread 1 */
            #pragma omp atomic update
            flag++;
            /* Flush of flag is implied by the atomic directive */
        }
        else if(omp_get_thread_num()==1)
        {
            /* Loop until we see that flag reaches 1*/
            #pragma omp flush(flag)
            while(flag < 1)
            {
                #pragma omp flush(flag)
            }
            printf("Thread 1 awoken\n");
            /* Set flag to release thread 2 */
            #pragma omp atomic update
            flag++;
            /* Flush of flag is implied by the atomic directive */
        }
        else if(omp_get_thread_num()==2)
        {
            /* Loop until we see that flag reaches 2 */
            #pragma omp flush(flag)
            while(flag < 2)
            {
                #pragma omp flush(flag)
            }
            printf("Thread 2 awoken\n");
        }
    }
    return 0;
}
Example 2.3f

PROGRAM EXAMPLE
INCLUDE "omp_lib.h" ! or USE OMP_LIB
INTEGER FLAG

FLAG = 0
!$OMP PARALLEL NUM_THREADS(3)
  IF(OMP_GET_THREAD_NUM() .EQ. 0) THEN
    ! Set flag to release thread 1
    !$OMP ATOMIC UPDATE
    FLAG = FLAG + 1
    !Flush of FLAG is implied by the atomic directive
  ELSE IF(OMP_GET_THREAD_NUM() .EQ. 1) THEN
    ! Loop until we see that FLAG reaches 1
    !$OMP FLUSH(FLAG, DATA)
    DO WHILE(FLAG .LT. 1)
      !$OMP FLUSH(FLAG, DATA)
    ENDDO
    PRINT *, 'Thread 1 awoken'
    ! Set FLAG to release thread 2
    !$OMP ATOMIC UPDATE
    FLAG = FLAG + 1
    !Flush of FLAG is implied by the atomic directive
  ELSE IF(OMP_GET_THREAD_NUM() .EQ. 2) THEN
    ! Loop until we see that FLAG reaches 2
    !$OMP FLUSH(FLAG, DATA)
    DO WHILE(FLAG .LT. 2)
      !$OMP FLUSH(FLAG, DATA)
    ENDDO
    PRINT *, 'Thread 2 awoken'
  ENDIF
!$OMP END PARALLEL
END
3  Conditional Compilation

C/C++

The following example illustrates the use of conditional compilation using the OpenMP macro \_OPENMP. With OpenMP compilation, the \_OPENMP macro becomes defined.

Example 3.1c

```c
#include <stdio.h>

int main()
{
    #ifdef _OPENMP
        printf("Compiled by an OpenMP-compliant implementation.\n");
    #endif

        return 0;
}
```

Fortran

The following example illustrates the use of the conditional compilation sentinel. With OpenMP compilation, the conditional compilation sentinel !$ is recognized and treated as two spaces. In fixed form source, statements guarded by the sentinel must start after column 6.

Example 3.1f

```fortran
PROGRAM EXAMPLE
C234567890
!$   PRINT *, "Compiled by an OpenMP-compliant implementation."

END PROGRAM EXAMPLE
```

C/C++
4 Internal Control Variables (ICVs)

According to $, an OpenMP implementation must act as if there are ICVs that control the behavior of the program. This example illustrates two ICVs, \texttt{nthreads-var} and \texttt{max-active-levels-var}. The \texttt{nthreads-var} ICV controls the number of threads requested for encountered parallel regions; there is one copy of this ICV per task. The \texttt{max-active-levels-var} ICV controls the maximum number of nested active parallel regions; there is one copy of this ICV for the whole program.

In the following example, the \texttt{nest-var}, \texttt{max-active-levels-var}, \texttt{dyn-var}, and \texttt{nthreads-var} ICVs are modified through calls to the runtime library routines \texttt{omp_set_nested}, \texttt{omp_set_max_active_levels}, \texttt{omp_set_dynamic}, and \texttt{omp_set_num_threads} respectively. These ICVs affect the operation of \texttt{parallel} regions. Each implicit task generated by a \texttt{parallel} region has its own copy of the \texttt{nest-var}, \texttt{dyn-var}, and \texttt{nthreads-var} ICVs.

In the following example, the new value of \texttt{nthreads-var} applies only to the implicit tasks that execute the call to \texttt{omp_set_num_threads}. There is one copy of the \texttt{max-active-levels-var} ICV for the whole program and its value is the same for all tasks. This example assumes that nested parallelism is supported.

The outer \texttt{parallel} region creates a team of two threads; each of the threads will execute one of the two implicit tasks generated by the outer \texttt{parallel} region.

Each implicit task generated by the outer \texttt{parallel} region calls \texttt{omp_set_num_threads(3)}, assigning the value 3 to its respective copy of \texttt{nthreads-var}. Then each implicit task encounters an inner \texttt{parallel} region that creates a team of three threads; each of the threads will execute one of the three implicit tasks generated by that inner \texttt{parallel} region.

Since the outer \texttt{parallel} region is executed by 2 threads, and the inner by 3, there will be a total of 6 implicit tasks generated by the two inner \texttt{parallel} regions.

Each implicit task generated by an inner \texttt{parallel} region will execute the call to \texttt{omp_set_num_threads(4)}, assigning the value 4 to its respective copy of \texttt{nthreads-var}.

The print statement in the outer \texttt{parallel} region is executed by only one of the threads in the team. So it will be executed only once.

The print statement in an inner \texttt{parallel} region is also executed by only one of the threads in the team. Since we have a total of two inner \texttt{parallel} regions, the print statement will be executed twice -- once per inner \texttt{parallel} region.
Example 4.1c

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

int main (void)
{
    omp_set_nested(1);
    omp_set_max_active_levels(8);
    omp_set_dynamic(0);
    omp_set_num_threads(2);
    #pragma omp parallel
    {
        omp_set_num_threads(3);

        #pragma omp parallel
        {
            omp_set_num_threads(4);
            #pragma omp single
            {
                /*
                    * The following should print:
                    * Inner: max_act_lev=8, num_thds=3, max_thds=4
                    * Inner: max_act_lev=8, num_thds=3, max_thds=4
                    */
                printf("Inner: max_act_lev=%d, num_thds=%d, max_thds=%d\n",
                        omp_get_max_active_levels(), omp_get_num_threads(),
                        omp_get_max_threads());
            }
        }

        #pragma omp barrier
        #pragma omp single
        {
            /*
                * The following should print:
                * Outer: max_act_lev=8, num_thds=2, max_thds=3
                */
            printf("Outer: max_act_lev=%d, num_thds=%d, max_thds=%d\n",
                        omp_get_max_active_levels(), omp_get_num_threads(),
                        omp_get_max_threads());
        }
    }
    return 0;
}
```
Example 4.1f

```fortran
program icv
  use omp_lib
  
  call omp_set_nested(.true.)
  call omp_set_max_active_levels(8)
  call omp_set_dynamic(.false.)
  call omp_set_num_threads(2)

  !$omp parallel
    call omp_set_num_threads(3)
  !$omp parallel
    call omp_set_num_threads(4)
  !$omp single
    ! The following should print:
    ! Inner: max_act_lev= 8 , num_thds= 3 , max_thds= 4
    ! Inner: max_act_lev= 8 , num_thds= 3 , max_thds= 4
    print *, "Inner: max_act_lev=" , omp_get_max_active_levels(),
          & " , num_thds=" , omp_get_num_threads(),
          & " , max_thds=" , omp_get_max_threads()
  !$omp end single
  !$omp end parallel

  !$omp barrier
  !$omp single
    ! The following should print:
    ! Outer: max_act_lev= 8 , num_thds= 2 , max_thds= 3
    print *, "Outer: max_act_lev=" , omp_get_max_active_levels(),
          & " , num_thds=" , omp_get_num_threads(),
          & " , max_thds=" , omp_get_max_threads()
  !$omp end single
  !$omp end parallel
end
```
The parallel Construct

The `parallel` construct can be used in coarse-grain parallel programs. In the following example, each thread in the `parallel` region decides what part of the global array `x` to work on, based on the thread number:

```
#include <omp.h>

void subdomain(float *x, int istart, int ipoints)
{
    int i;
    for (i = 0; i < ipoints; i++)
        x[istart+i] = 123.456;
}

void sub(float *x, int npoints)
{
    int iam, nt, ipoints, istart;

    #pragma omp parallel default(shared) private(iam,nt,ipoints,istart)
    {
        iam = omp_get_thread_num();
        nt = omp_get_num_threads();
        ipoints = npoints / nt; /* size of partition */
        istart = iam * ipoints; /* starting array index */
        if (iam == nt-1) /* last thread may do more */
            ipoints = npoints - istart;
        subdomain(x, istart, ipoints);
    }
}

int main()
{
    float array[10000];
    sub(array, 10000);
    return 0;
}
```
Example 5.1f

SUBROUTINE SUBDOMAIN(X, ISTART, IPOINTS)
   INTEGER ISTART, IPOINTS
   REAL X(*)

   INTEGER I

   DO 100 I=1,IPOINTS
      X(ISTART+I) = 123.456
   100      CONTINUE

END SUBROUTINE SUBDOMAIN

SUBROUTINE SUB(X, NPOINTS)
   INCLUDE "omp_lib.h"     ! or USE OMP_LIB

   REAL X(*)
   INTEGER NPOINTS
   INTEGER IAM, NT, IPOINTS, ISTART

   !$OMP PARALLEL DEFAULT(PRIVATE) SHARED(X,NPOINTS)

       IAM = OMP_GET_THREAD_NUM()
       NT = OMP_GET_NUM_THREADS()
       IPOINTS = NPOINTS/NT
       ISTART = IAM * IPOINTS
       IF (IAM .EQ. NT-1) THEN
           IPOINTS = NPOINTS - ISTART
       ENDIF
       CALL SUBDOMAIN(X,ISTART,IPOINTS)

   !$OMP END paralleL

END SUBROUTINE SUB

PROGRAM PAREXAMPLE
   REAL ARRAY(10000)
   CALL SUB(ARRAY, 10000)
END PROGRAM PAREXAMPLE
6 Controlling the Number of Threads on Multiple Nesting Levels

The following examples demonstrate how to use the `OMP_NUM_THREADS` environment variable to control the number of threads on multiple nesting levels:

C/C++

Example 6.1c

```c
#include <stdio.h>
#include <omp.h>
int main (void)
{
    omp_set_nested(1);
   omp_set_dynamic(0);
#pragma omp parallel
{
    #pragma omp parallel
    {
        #pragma omp single
        {
            /*
             * If OMP_NUM_THREADS=2,3 was set, the following should print:
             * Inner: num_thds=3
             * Inner: num_thds=3
             *
             * If nesting is not supported, the following should print:
             * Inner: num_thds=1
             * Inner: num_thds=1
             */
            printf("Inner: num_thds=%d\n", omp_get_num_threads());
        }
    }
#pragma omp barrier
   omp_set_nested(0);
#pragma omp parallel
{
    #pragma omp single
    {
        /*
         * Even if OMP_NUM_THREADS=2,3 was set, the following should print, because nesting is disabled:
         * Inner: num_thds=1
         * Inner: num_thds=1
         */
        printf("Inner: num_thds=%d\n", omp_get_num_threads());
    }
}
```
Example 6.1f

```c
#include <stdio.h>

int main() {
    // Barrier
    #pragma omp barrier
    #pragma omp single
    {
        /*
        * If OMP_NUM_THREADS=2,3 was set, the following should print:
        * Outer: num_thds=2
        */
        printf("Outer: num_thds=%d\n", omp_get_num_threads());
    }
    return 0;
```

```fortran
program icv
    use omp_lib
    call omp_set_nested(.true.)
    call omp_set_dynamic(.false.)
    !$omp parallel
    !$omp parallel
    !$omp single
    ! If OMP_NUM_THREADS=2,3 was set, the following should print:
    ! Inner: num_thds= 3
    ! Inner: num_thds= 3
    ! If nesting is not supported, the following should print:
    ! Inner: num_thds= 1
    ! Inner: num_thds= 1
    print *, "Inner: num_thds=" , omp_get_num_threads()
    !$omp end single
    !$omp end parallel
    !$omp barrier
    call omp_set_nested(.false.)
    !$omp parallel
    !$omp single
    ! Even if OMP_NUM_THREADS=2,3 was set, the following should print, 
    ! because nesting is disabled:
    ! Inner: num_thds= 1
    ! Inner: num_thds= 1
    print *, "Inner: num_thds=" , omp_get_num_threads()
    !$omp end single
    !$omp end parallel
    !$omp barrier
    !$omp single
    ! If OMP_NUM_THREADS=2,3 was set, the following should print: 
    ! Outer: num_thds= 2
    print *, "Outer: num_thds=" , omp_get_num_threads()
    !$omp end single
    !$omp end parallel
```
end
Interaction Between the `num_threads` Clause and `omp_set_dynamic`

The following example demonstrates the `num_threads` clause and the effect of the `omp_set_dynamic` routine on it.

The call to the `omp_set_dynamic` routine with argument 0 in C/C++, or `.FALSE.` in Fortran, disables the dynamic adjustment of the number of threads in OpenMP implementations that support it. In this case, 10 threads are provided. Note that in case of an error the OpenMP implementation is free to abort the program or to supply any number of threads available.

---

Example 7.1c

```c
#include <omp.h>
int main()
{
  omp_set_dynamic(0);
  #pragma omp parallel num_threads(10)
  {
    /* do work here */
  }
  return 0;
}
```

---

Example 7.1f

```fortran
PROGRAM EXAMPLE
  INCLUDE "omp_lib.h" ! or USE OMP_LIB
  CALL OMP_SET_DYNAMIC(.FALSE.)
  !$OMP PARALLEl NUM_THREADS(10)
    ! do work here
  !$OMP END PARALLEL
END PROGRAM EXAMPLE
```
The call to the `omp_set_dynamic` routine with a non-zero argument in C/C++, or `.TRUE.` in Fortran, allows the OpenMP implementation to choose any number of threads between 1 and 10.

### Example 7.2c

```c
#include <omp.h>
int main()
{
  omp_set_dynamic(1);
  #pragma omp parallel num_threads(10)
  {
    /* do work here */
  }
  return 0;
}
```

### Example 7.2f

```fortran
PROGRAM EXAMPLE
  INCLUDE "omp_lib.h" ! or USE OMP_LIB
  CALL OMP_SET_DYNAMIC(.TRUE.)
  !$OMP PARALLEL NUM_THREADS(10)
    ! do work here
  !$OMP END PARALLEL
END PROGRAM EXAMPLE
```

It is good practice to set the `dyn-var` ICV explicitly by calling the `omp_set_dynamic` routine, as its default setting is implementation defined.
8 The proc_bind Clause

The following examples demonstrate how to use the proc_bind clause to control the thread binding for a team of threads in a parallel region. The machine architecture is depicted in the figure below. It consists of two sockets, each equipped with a quad-core processor and configured to execute two hardware threads simultaneously on each core. These examples assume a contiguous core numbering starting from 0, such that the hardware threads 0,1 form the first physical core.

The following equivalent place list declarations consist of eight places (which we designate as p0 to p7):

```
OMP_PLACES="{0,1},{2,3},{4,5},{6,7},{8,9},{10,11},{12,13},{14,15}"
```

or

```
OMP_PLACES="{0:2}:8:2"
```

Spread Affinity Policy

The following example shows the result of the spread affinity policy on the partition list when the number of threads is less than or equal to the number of places in the parent's place partition, for the machine architecture depicted above. Note that the threads are bound to the first place of each subpartition.
Example 8.1c

```c
void work();
void main()
{
    #pragma omp parallel proc_bind(spread) num_threads(4)
    {
        work();
    }
}
```

Example 8.1f

```fortran
PROGRAM EXAMPLE
 !$OMP PARALLEL PROC_BIND(SPREAD) NUM_THREADS(4)
 CALL WORK()
 !$OMP END PARALLEL
 END PROGRAM EXAMPLE
```

It is unspecified on which place the master thread is initially started. If the master thread is initially started on p0, the following placement of threads will be applied in the parallel region:

- thread 0 executes on p0 with the place partition p0,p1
- thread 1 executes on p2 with the place partition p2,p3
- thread 2 executes on p4 with the place partition p4,p5
- thread 3 executes on p6 with the place partition p6,p7

If the master thread would initially be started on p2, the placement of threads and distribution of the place partition would be as follows:

- thread 0 executes on p2 with the place partition p2,p3
- thread 1 executes on p4 with the place partition p4,p5
- thread 2 executes on p6 with the place partition p6,p7
- thread 3 executes on p0 with the place partition p0,p1

The following example illustrates the `spread` thread affinity policy when the number of threads is greater than the number of places in the parent’s place partition.
Let $T$ be the number of threads in the team, and $P$ be the number of places in the parent’s place partition. The first $T/P$ threads of the team (including the master thread) execute on the parent’s place. The next $T/P$ threads execute on the next place in the place partition, and so on, with wrap around.

**Example 8.2c**

```c
void work();
void foo()
{
    #pragma omp parallel num_threads(16) proc_bind(spread)
    {
        work();
    }
}
```

**Example 8.2f**

```fortran
subroutine foo
    !$omp parallel num_threads(16) proc_bind(spread)
    call work()
    !$omp end parallel
end subroutine
```

It is unspecified on which place the master thread is initially started. If the master thread is initially started on $p_0$, the following placement of threads will be applied in the parallel region:

- threads 0,1 execute on $p_0$ with the place partition $p_0$
- threads 2,3 execute on $p_1$ with the place partition $p_1$
- threads 4,5 execute on $p_2$ with the place partition $p_2$
- threads 6,7 execute on $p_3$ with the place partition $p_3$
- threads 8,9 execute on $p_4$ with the place partition $p_4$
- threads 10,11 execute on $p_5$ with the place partition $p_5$
- threads 12,13 execute on $p_6$ with the place partition $p_6$
- threads 14,15 execute on $p_7$ with the place partition $p_7$
If the master thread would initially be started on p2, the placement of threads and distribution of the place partition would be as follows:

- threads 0, 1 execute on p2 with the place partition p2
- threads 2, 3 execute on p3 with the place partition p3
- threads 4, 5 execute on p4 with the place partition p4
- threads 6, 7 execute on p5 with the place partition p5
- threads 8, 9 execute on p6 with the place partition p6
- threads 10, 11 execute on p7 with the place partition p7
- threads 12, 13 execute on p0 with the place partition p0
- threads 14, 15 execute on p1 with the place partition p1

**Close Affinity Policy**

The following example shows the result of the `close` affinity policy on the partition list when the number of threads is less than or equal to the number of places in parent's place partition, for the machine architecture depicted above. The place partition is not changed by the `close` policy.

```
C/C++

ework();
void main()
{
  #pragma omp parallel proc_bind(close) num_threads(4)
  {
    work();
  }
}
```

```
Fortran

Example 8.3f

PROGRAM EXAMPLE
  !$OMP PARALLEL PROC_BIND(CLOSE) NUM_THREADS(4)
  CALL WORK()
  !$OMP END PARALLEL
END PROGRAM EXAMPLE
```

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It is unspecified on which place the master thread is initially started. If the master thread is initially started on p0, the following placement of threads will be applied in the parallel region:

- thread 0 executes on p0 with the place partition p0-p7
- thread 1 executes on p1 with the place partition p0-p7
- thread 2 executes on p2 with the place partition p0-p7
- thread 3 executes on p3 with the place partition p0-p7

If the master thread would initially be started on p2, the placement of threads and distribution of the place partition would be as follows:

- thread 0 executes on p2 with the place partition p0-p7
- thread 1 executes on p3 with the place partition p0-p7
- thread 2 executes on p4 with the place partition p0-p7
- thread 3 executes on p5 with the place partition p0-p7

The following example illustrates the close thread affinity policy when the number of threads is greater than the number of places in the parent's place partition.

Let T be the number of threads in the team, and P be the number of places in the parent's place partition. The first T/P threads of the team (including the master thread) execute on the parent’s place. The next T/P threads execute on the next place in the place partition, and so on, with wrap around. The place partition is not changed by the close policy.

---

**Example 8.4c**

```c/c++
void work();
void foo()
{
    #pragma omp parallel num_threads(16) proc_bind(close)
    {
        work();
    }
}
```

---

**Example 8.4f**

```fortran
subroutine foo
!$omp parallel num_threads(16) proc_bind(close)
    call work()
```
It is unspecified on which place the master thread is initially started. If the master thread is initially running on p0, the following placement of threads will be applied in the parallel region:

- threads 0,1 execute on p0 with the place partition p0-p7
- threads 2,3 execute on p1 with the place partition p0-p7
- threads 4,5 execute on p2 with the place partition p0-p7
- threads 6,7 execute on p3 with the place partition p0-p7
- threads 8,9 execute on p4 with the place partition p0-p7
- threads 10,11 execute on p5 with the place partition p0-p7
- threads 12,13 execute on p6 with the place partition p0-p7
- threads 14,15 execute on p7 with the place partition p0-p7

If the master thread would initially be started on p2, the placement of threads and distribution of the place partition would be as follows:

- threads 0,1 execute on p2 with the place partition p0-p7
- threads 2,3 execute on p3 with the place partition p0-p7
- threads 4,5 execute on p4 with the place partition p0-p7
- threads 6,7 execute on p5 with the place partition p0-p7
- threads 8,9 execute on p6 with the place partition p0-p7
- threads 10,11 execute on p7 with the place partition p0-p7
- threads 12,13 execute on p0 with the place partition p0-p7
- threads 14,15 execute on p1 with the place partition p0-p7
Master Affinity Policy

The following example shows the result of the master affinity policy on the partition list for the machine architecture depicted above. The place partition is not changed by the master policy.

\begin{example}{8.5c}
\begin{verbatim}
void work();
void main()
{
#pragma omp parallel proc_bind(master) num_threads(4)
{
    work();
}
}
\end{verbatim}
\end{example}

\begin{example}{8.5f}
\begin{verbatim}
PROGRAM EXAMPLE
 !$OMP PARALLEL PROC_BIND(MASTER) NUM_THREADS(4)
 CALL WORK()
 !$OMP END PARALLEL
 END PROGRAM EXAMPLE
\end{verbatim}
\end{example}

It is unspecified on which place the master thread is initially started. If the master thread is initially running on p0, the following placement of threads will be applied in the parallel region:

- threads 0-3 execute on p0 with the place partition p0-p7

If the master thread would initially be started on p2, the placement of threads and distribution of the place partition would be as follows:

- threads 0-3 execute on p2 with the place partition p0-p7
Fortran Restrictions on the do Construct

If an end do directive follows a do-construct in which several DO statements share a DO termination statement, then a do directive can only be specified for the outermost of these DO statements. The following example contains correct usages of loop constructs:

**Example 9.1f**

```fortran
SUBROUTINE WORK(I, J)
INTEGER I, J
END SUBROUTINE WORK

SUBROUTINE DO_GOOD()
INTEGER I, J
REAL A(1000)
DO 100 I = 1,10
  !$OMP DO
  DO 100 J = 1,10
  CALL WORK(I,J)
100 CONTINUE ! !$OMP ENDDO implied here

  !$OMP DO
  DO 200 J = 1,10
  A(I) = I + 1
200      !$OMP ENDDO

  !$OMP DO
  DO 300 I = 1,10
     DO 300 J = 1,10
     CALL WORK(I,J)
300 CONTINUE
  !$OMP ENDDO
END SUBROUTINE DO_GOOD
```

The following example is non-conforming because the matching do directive for the end do does not precede the outermost loop:

**Example 9.2f**

```fortran
SUBROUTINE WORK(I, J)
INTEGER I, J
END SUBROUTINE WORK

SUBROUTINE DO_WRONG
INTEGER I, J
END SUBROUTINE DO_WRONG
```
DO 100 I = 1,10
!$OMP   DO
   DO 100 J = 1,10
      CALL WORK(I,J)
   100 CONTINUE
!$OMP END DO
END SUBROUTINE DO_WRONG
**Fortran Private Loop Iteration Variables**

In general loop iteration variables will be private, when used in the *do-loop* of a *do* and *parallel do* construct or in sequential loops in a *parallel* construct (see $ and $). In the following example of a sequential loop in a *parallel* construct the loop iteration variable *I* will be private.

*Example 10.1f*

```fortran
SUBROUTINE PLOOP_1(A,N)
INCLUDE "omp_lib.h"      ! or USE OMP_LIB

REAL A(*)
INTEGER I, MYOFFSET, N

!$OMP PARALLEL PRIVATE(MYOFFSET)
MYOFFSET = OMP_GET_THREAD_NUM()*N
DO I = 1, N
   A(MYOFFSET+I) = FLOAT(I)
ENDDO
!$OMP END PARALLEL

END SUBROUTINE PLOOP_1
```

In exceptional cases, loop iteration variables can be made shared, as in the following example:

*Example 10.2f*

```fortran
SUBROUTINE PLOOP_2(A,B,N,I1,I2)
REAL A(*), B(*)
INTEGER I1, I2, N

!$OMP PARALLEL SHARED(A,B,I1,I2)
!$OMP SECTIONS
!$OMP SECTION
   DO I1 = I1, N
      IF (A(I1).NE.0.0) EXIT
   ENDDO
!$OMP SECTION
   DO I2 = I2, N
      IF (B(I2).NE.0.0) EXIT
   ENDDO
!$OMP END SECTIONS
!$OMP SINGLE
   IF (I1.LE.N) PRINT *, 'ITEMS IN A UP TO ', I1, 'ARE ALL ZERO.'
   IF (I2.LE.N) PRINT *, 'ITEMS IN B UP TO ', I2, 'ARE ALL ZERO.'
!$OMP END SINGLE
```

!$OMP END PARALLEL

END SUBROUTINE PLOOP_2

Note however that the use of shared loop iteration variables can easily lead to race conditions.
11 The `nowait` clause

If there are multiple independent loops within a parallel region, you can use the `nowait` clause to avoid the implied barrier at the end of the loop construct, as follows:

**Example 11.1c**

```c
#include <math.h>

void nowait_example(int n, int m, float *a, float *b, float *y, float *z)
{
    int i;
    #pragma omp parallel
    {
        #pragma omp for nowait
        for (i=1; i<n; i++)
            b[i] = (a[i] + a[i-1]) / 2.0;

        #pragma omp for nowait
        for (i=0; i<m; i++)
            y[i] = sqrt(z[i]);
    }
}
```

**Example 11.1f**

```fortran
SUBROUTINE NOWAIT_EXAMPLE(N, M, A, B, Y, Z)
    INTEGER N, M
    REAL A(*), B(*), Y(*), Z(*)
    INTEGER I

    !$OMP PARALLEL

    !$OMP DO
        DO I=2,N
            B(I) = (A(I) + A(I-1)) / 2.0
        ENDDO
    !$OMP END DO NOWAIT

    !$OMP DO
        DO I=1,M
```

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In the following example, static scheduling distributes the same logical iteration numbers to the threads that execute the three loop regions. This allows the `nowait` clause to be used, even though there is a data dependence between the loops. The dependence is satisfied as long the same thread executes the same logical iteration numbers in each loop.

Note that the iteration count of the loops must be the same. The example satisfies this requirement, since the iteration space of the first two loops is from 0 to n-1 (from 1 to N in the Fortran version), while the iteration space of the last loop is from 1 to n (2 to N+1 in the Fortran version).

### Example 11.2c

```c
#include <math.h>
void nowait_example2(int n, float *a, float *b, float *c, float *y, float *z) {
    int i;
    #pragma omp parallel
    {
        #pragma omp for schedule(static) nowait
        for (i=0; i<n; i++)
            c[i] = (a[i] + b[i]) / 2.0f;
        #pragma omp for schedule(static) nowait
        for (i=0; i<n; i++)
            z[i] = sqrtf(c[i]);
        #pragma omp for schedule(static) nowait
        for (i=1; i<=n; i++)
            y[i] = z[i-1] + a[i];
    }
}
```

### Example 11.2f

```fortran
SUBROUTINE NOWAIT_EXAMPLE2(N, A, B, C, Y, Z)
INTEGER N
REAL A(*), B(*), C(*), Y(*), Z(*)
INTEGER I
 !$OMP PARALLEL
 !$OMP DO SCHEDULE(STATIC)
  Y(I) = SQRT(Z(I))
 ENDDO
 !$OMP END DO NOWAIT
 !$OMP END PARALLEL

END SUBROUTINE NOWAIT_EXAMPLE
```

In the following example, static scheduling distributes the same logical iteration numbers to the threads that execute the three loop regions. This allows the `nowait` clause to be used, even though there is a data dependence between the loops. The dependence is satisfied as long the same thread executes the same logical iteration numbers in each loop.

Note that the iteration count of the loops must be the same. The example satisfies this requirement, since the iteration space of the first two loops is from 0 to n-1 (from 1 to N in the Fortran version), while the iteration space of the last loop is from 1 to n (2 to N+1 in the Fortran version).
DO I=1,N
    C(I) = (A(I) + B(I)) / 2.0
ENDDO
!$OMP END DO NOWAIT
!$OMP DO SCHEDULE(STATIC)
    DO I=1,N
        Z(I) = SQRT(C(I))
    ENDDO
!$OMP END DO NOWAIT
!$OMP DO SCHEDULE(STATIC)
    DO I=2,N+1
        Y(I) = Z(I-1) + A(I)
    ENDDO
!$OMP END DO NOWAIT
!$OMP END PARALLEL
    END SUBROUTINE NOWAIT_EXAMPLE2
The collapse clause

In the following example, the $k$ and $j$ loops are associated with the loop construct. So the iterations of the $k$ and $j$ loops are collapsed into one loop with a larger iteration space, and that loop is then divided among the threads in the current team. Since the $i$ loop is not associated with the loop construct, it is not collapsed, and the $i$ loop is executed sequentially in its entirety in every iteration of the collapsed $k$ and $j$ loop.

C/C++

The variable $j$ can be omitted from the private clause when the collapse clause is used since it is implicitly private. However, if the collapse clause is omitted then $j$ will be shared if it is omitted from the private clause. In either case, $k$ is implicitly private and could be omitted from the private clause.

Example 12.1c

```c
void bar(float *a, int i, int j, int k);
int kl, ku, ks, jl, ju, js, il, iu, is;
void sub(float *a)
{
    int i, j, k;
    #pragma omp for collapse(2) private(i, k, j)
    for (k=kl; k<=ku; k+=ks)
        for (j=jl; j<=ju; j+=js)
            for (i=il; i<=iu; i+=is)
                bar(a, i, j, k);
}
```

C/C++

Fortran

Example 12.1f

```fortran
subroutine sub(a)
real a(*)
intrinsic kl, ku, ks, jl, ju, js, il, iu, is
common /csub/ kl, ku, ks, jl, ju, js, il, iu, is
integer i, j, k
!$omp do collapse(2) private(i, j, k)
    do k = kl, ku, ks
        do j = jl, ju, js
            do i = il, iu, is
                call bar(a, i, j, k)
            enddo
        enddo
    enddo
enddo
```

12 The collapse clause

In the following example, the $k$ and $j$ loops are associated with the loop construct. So the iterations of the $k$ and $j$ loops are collapsed into one loop with a larger iteration space, and that loop is then divided among the threads in the current team. Since the $i$ loop is not associated with the loop construct, it is not collapsed, and the $i$ loop is executed sequentially in its entirety in every iteration of the collapsed $k$ and $j$ loop.

C/C++

The variable $j$ can be omitted from the private clause when the collapse clause is used since it is implicitly private. However, if the collapse clause is omitted then $j$ will be shared if it is omitted from the private clause. In either case, $k$ is implicitly private and could be omitted from the private clause.

Example 12.1c

```c
void bar(float *a, int i, int j, int k);
int kl, ku, ks, jl, ju, js, il, iu, is;
void sub(float *a)
{
    int i, j, k;
    #pragma omp for collapse(2) private(i, k, j)
    for (k=kl; k<=ku; k+=ks)
        for (j=jl; j<=ju; j+=js)
            for (i=il; i<=iu; i+=is)
                bar(a, i, j, k);
}
```

C/C++

Fortran

Example 12.1f

```fortran
subroutine sub(a)
real a(*)
intrinsic kl, ku, ks, jl, ju, js, il, iu, is
common /csub/ kl, ku, ks, jl, ju, js, il, iu, is
integer i, j, k
!$omp do collapse(2) private(i, j, k)
    do k = kl, ku, ks
        do j = jl, ju, js
            do i = il, iu, is
                call bar(a, i, j, k)
            enddo
        enddo
    enddo
enddo
```
In the next example, the \( k \) and \( j \) loops are associated with the loop construct. So the iterations of the \( k \) and \( j \) loops are collapsed into one loop with a larger iteration space, and that loop is then divided among the threads in the current team.

The sequential execution of the iterations in the \( k \) and \( j \) loops determines the order of the iterations in the collapsed iteration space. This implies that in the sequentially last iteration of the collapsed iteration space, \( k \) will have the value 2 and \( j \) will have the value 3. Since \texttt{klast} and \texttt{jlast} are \texttt{lastprivate}, their values are assigned by the sequentially last iteration of the collapsed \( k \) and \( j \) loop. This example prints: 2 3.
Example 12.2c

```
#include <stdio.h>
void test()
{
    int j, k, jlast, klast;
    #pragma omp parallel
    {
        #pragma omp for collapse(2) lastprivate(jlast, klast)
        for (k=1; k<=2; k++)
        {
            jlast=j;
            klast=k;
        }
        #pragma omp single
        printf("%d %d\n", klast, jlast);
    }
}
```

Example 12.2f

```
program test
!$omp parallel
!$omp do private(j,k) collapse(2) lastprivate(jlast, klast)
  do k = 1,2
    do j = 1,3
      jlast=j
      klast=k
    enddo
  enddo
!$omp end do
!$omp single
  print *, klast, jlast
!$omp end single
!$omp end parallel
end program test
```

The next example illustrates the interaction of the `collapse` and `ordered` clauses.
In the example, the loop construct has both a `collapse` clause and an `ordered` clause. The `collapse` clause causes the iterations of the \( k \) and \( j \) loops to be collapsed into one loop with a larger iteration space, and that loop is divided among the threads in the current team. An `ordered` clause is added to the loop construct, because an ordered region binds to the loop region arising from the loop construct.

According to $\$, a thread must not execute more than one ordered region that binds to the same loop region. So the `collapse` clause is required for the example to be conforming. With the `collapse` clause, the iterations of the \( k \) and \( j \) loops are collapsed into one loop, and therefore only one ordered region will bind to the collapsed \( k \) and \( j \) loop. Without the `collapse` clause, there would be two ordered regions that bind to each iteration of the \( k \) loop (one arising from the first iteration of the \( j \) loop, and the other arising from the second iteration of the \( j \) loop).

The code prints

```
0 1 1
0 1 2
0 2 1
1 2 2
1 3 1
1 3 2
```

---

**Example 12.3c**

```c
#include <omp.h>
#include <stdio.h>
void work(int a, int j, int k);
void sub()
{
    int j, k, a;
    #pragma omp parallel num_threads(2)
    {
        #pragma omp for collapse(2) ordered private(j,k) schedule(static,3)
        for (k=1; k<=3; k++)
            for (j=1; j<=2; j++)
            {
                #pragma omp ordered
                printf("%d %d %d\n", omp_get_thread_num(), k, j);
                /* end ordered */
                work(a,j,k);
            }
    }
}
```

---
Example 12.3f

```fortran
program test
  include 'omp_lib.h'
  !$omp parallel num_threads(2)
  !$omp do collapse(2) ordered private(j,k) schedule(static,3)
    do k = 1,3
      do j = 1,2
        !$omp ordered
        print *, omp_get_thread_num(), k, j
        !$omp end ordered
        call work(a,j,k)
        enddo
      enddo
  !$omp end do
  !$omp end parallel
end program test
```
13 The parallel sections Construct

In the following example routines XAXIS, YAXIS, and ZAXIS can be executed concurrently. The first section directive is optional. Note that all section directives need to appear in the parallel sections construct.

C/C++

Example 13.1c

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

void sect_example()
{
    #pragma omp parallel sections
    {
        #pragma omp section
        XAXIS();
        #pragma omp section
        YAXIS();
        #pragma omp section
        ZAXIS();
    }
}
```

C/C++

Example 13.1f

```fortran
SUBROUTINE SECT_EXAMPLE()
!$OMP PARALLEL SECTIONS
!$OMP SECTION
    CALL XAXIS()
!$OMP SECTION
    CALL YAXIS()
!$OMP SECTION
    CALL ZAXIS()
!$OMP END PARALLEL SECTIONS
END SUBROUTINE SECT_EXAMPLE
```

Fortran
The \texttt{firstprivate} Clause and the \texttt{sections} Construct

In the following example of the \texttt{sections} construct the \texttt{firstprivate} clause is used to initialize the private copy of \texttt{section\_count} of each thread. The problem is that the \texttt{section} constructs modify \texttt{section\_count}, which breaks the independence of the \texttt{section} constructs. When different threads execute each section, both sections will print the value 1. When the same thread executes the two sections, one section will print the value 1 and the other will print the value 2. Since the order of execution of the two sections in this case is unspecified, it is unspecified which section prints which value.

\begin{example}
\begin{verbatim}
#include <omp.h>
#include <stdio.h>
#define NT 4
int main( ) {
    int section_count = 0;
    omp_set_dynamic(0);
    omp_set_num_threads(NT);
    #pragma omp parallel
    #pragma omp sections firstprivate( section_count )
    {
        #pragma omp section
        {
            section_count++;
            /* may print the number one or two */
            printf( "section\_count \%d\n", section_count );
        }
        #pragma omp section
        {
            section_count++;
            /* may print the number one or two */
            printf( "section\_count \%d\n", section_count );
        }
    }
    return 1;
}
\end{verbatim}
\end{example}
Example 14.1f

program section
    use omp_lib
    integer :: section_count = 0
    integer, parameter :: NT = 4
    call omp_set_dynamic(.false.)
    call omp_set_num_threads(NT)
    !$omp parallel
    !$omp sections firstprivate ( section_count )
    !$omp section
        section_count = section_count + 1
        ! may print the number one or two
        print *, 'section_count', section_count
    !$omp section
        section_count = section_count + 1
        ! may print the number one or two
        print *, 'section_count', section_count
    !$omp end sections
    !$omp end parallel
end program section
15 The single Construct

The following example demonstrates the single construct. In the example, only one thread prints each of the progress messages. All other threads will skip the single region and stop at the barrier at the end of the single construct until all threads in the team have reached the barrier. If other threads can proceed without waiting for the thread executing the single region, a nowait clause can be specified, as is done in the third single construct in this example. The user must not make any assumptions as to which thread will execute a single region.

Example 15.1c

```c
#include <stdio.h>

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

void single_example()
{
    #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();
    }
}
```

Example 15.1f

```fortran
SUBROUTINE WORK1()
END SUBROUTINE WORK1

SUBROUTINE WORK2()
```
END SUBROUTINE WORK2

PROGRAM SINGLE_EXAMPLE
$OMP PARALLEL

$OMP SINGLE
    print *, "Beginning work1."
$OMP END SINGLE

    CALL WORK1()

$OMP SINGLE
    print *, "Finishing work1."
$OMP END SINGLE

$OMP SINGLE
    print *, "Finished work1 and beginning work2."
$OMP END SINGLE NOWAIT

    CALL WORK2()

$OMP END PARALLEL

END PROGRAM SINGLE_EXAMPLE
16 Tasking Constructs

The following example shows how to traverse a tree-like structure using explicit tasks. Note that the `traverse` function should be called from within a parallel region for the different specified tasks to be executed in parallel. Also note that the tasks will be executed in no specified order because there are no synchronization directives. Thus, assuming that the traversal will be done in post order, as in the sequential code, is wrong.

---

**Example 16.1c**

```c/c++
struct node {
    struct node *left;
    struct node *right;
};
extern void process(struct node *);
void traverse( struct node *p ) {
    if (p->left) 
        #pragma omp task // p is firstprivate by default
        traverse(p->left);
    if (p->right) 
        #pragma omp task // p is firstprivate by default
        traverse(p->right);
    process(p);
}
```

---

**Example 16.1f**

```fortran
RECURSIVE SUBROUTINE traverse ( P )
    TYPE Node
        TYPE(Node), POINTER :: left, right
    END TYPE Node
    TYPE(Node) :: P
    IF (associated(P%left)) THEN
        !$OMP TASK // P is firstprivate by default
        call traverse(P%left)
        !$OMP END TASK
    ENDIF
    IF (associated(P%right)) THEN
        !$OMP TASK // P is firstprivate by default
        call traverse(P%right)
        !$OMP END TASK
```
In the next example, we force a postorder traversal of the tree by adding a `taskwait` directive. Now, we can safely assume that the left and right sons have been executed before we process the current node.

**Example 16.2c**

```c
struct node {
    struct node *left;
    struct node *right;
};
extern void process(struct node *);
void postorder_traverse( struct node *p ) {
    if (p->left)
        #pragma omp task // p is firstprivate by default
        postorder_traverse(p->left);
    if (p->right)
        #pragma omp task // p is firstprivate by default
        postorder_traverse(p->right);
    #pragma omp taskwait
    process(p);
}
```

**Example 16.2f**

```fortran
RECURSIVE SUBROUTINE traverse ( P )
    TYPE Node
        TYPE(Node), POINTER :: left, right
    END TYPE Node
    TYPE(Node) :: P
    IF (associated(P%left)) THEN
        !$OMP TASK // P is firstprivate by default
        call traverse(P%left)
        !$OMP END TASK
    ENDIF
    IF (associated(P%right)) THEN
        !$OMP TASK // P is firstprivate by default
        call traverse(P%right)
        !$OMP END TASK
    ENDIF
    !$OMP TASKWAIT
END SUBROUTINE
```

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The following example demonstrates how to use the **task** construct to process elements of a linked list in parallel. The thread executing the **single** region generates all of the explicit tasks, which are then executed by the threads in the current team. The pointer `p` is **firstprivate** by default on the **task** construct so it is not necessary to specify it in a **firstprivate** clause.

**Example 16.3c**

```c
typedef struct node node;
struct node {
  int data;
  node * next;
};

void process(node * p)
{
  /* do work here */
}

void increment_list_items(node * head)
{
  #pragma omp parallel
  {
    #pragma omp single
    {
      node * p = head;
      while (p) {
        #pragma omp task
        // p is firstprivate by default
        process(p);
        p = p->next;
      }
    }
  }
}
```

**Example 16.3f**

```fortran
MODULE LIST
  TYPE NODE
    INTEGER :: PAYLOAD
    TYPE (NODE), POINTER :: NEXT
```
END TYPE NODE
CONTAINS
SUBROUTINE PROCESS(p)
  TYPE (NODE), POINTER :: P
  ! do work here
END SUBROUTINE
SUBROUTINE INCREMENT_LIST_ITEMS (HEAD)
  TYPE (NODE), POINTER :: HEAD
  TYPE (NODE), POINTER :: P
  !$OMP PARALLEL PRIVATE(P)
  !$OMP SINGLE
    P => HEAD
    DO
      !$OMP TASK
        ! P is firstprivate by default
        CALL PROCESS(P)
      !$OMP END TASK
      P => P%NEXT
      IF ( .NOT. ASSOCIATED (P) ) EXIT
    END DO
  !$OMP END SINGLE
  !$OMP END PARALLEL
END SUBROUTINE
END MODULE

The \texttt{fib()} function should be called from within a \texttt{parallel} region for the different specified tasks to be executed in parallel. Also, only one thread of the \texttt{parallel} region should call \texttt{fib()} unless multiple concurrent Fibonacci computations are desired.

\textbf{Example 16.4c}

\begin{verbatim}
int fib(int n) {
    int i, j;
    if (n<2)
      return n;
    else {
      #pragma omp task shared(i)
      i=fib(n-1);
      #pragma omp task shared(j)
      j=fib(n-2);
      #pragma omp taskwait
      return i+j;
    }
}
\end{verbatim}
Fortran

Example 16.4f

RECURSIVE INTEGER FUNCTION fib(n) RESULT(res)
INTEGER n, i, j
IF ( n .LT. 2) THEN
res = n
ELSE
!$OMP TASK SHARED(i)
i = fib( n-1 )
!$OMP END TASK
!$OMP TASK SHARED(j)
j = fib( n-2 )
!$OMP END TASK
!$OMP TASKWAIT
res = i+j
END IF
END FUNCTION

Fortran

Note: There are more efficient algorithms for computing Fibonacci numbers. This classic recursion algorithm is for illustrative purposes.

The following example demonstrates a way to generate a large number of tasks with one thread and execute them with the threads in the team. While generating these tasks, the implementation may reach its limit on unassigned tasks. If it does, the implementation is allowed to cause the thread executing the task generating loop to suspend its task at the task scheduling point in the task directive, and start executing unassigned tasks. Once the number of unassigned tasks is sufficiently low, the thread may resume execution of the task generating loop.

C/C++

Example 16.5c

#define LARGE_NUMBER 10000000
double item[LARGE_NUMBER];
extern void process(double);

int main() {
#pragma omp parallel
{
#pragma omp single
{
#pragma omp task    // i is firstprivate, item is shared
process(item[i]);
}
}
Example 16.5f

real*8 item(10000000)
integer i

!$omp parallel
!$omp single ! loop iteration variable i is private
   do i=1,10000000
!$omp task
! i is firstprivate, item is shared
   call process(item(i))
!$omp end task
end do
!$omp end single
!$omp end parallel
end

The following example is the same as the previous one, except that the tasks are generated in an untied task. While generating the tasks, the implementation may reach its limit on unassigned tasks. If it does, the implementation is allowed to cause the thread executing the task generating loop to suspend its task at the task scheduling point in the task directive, and start executing unassigned tasks. If that thread begins execution of a task that takes a long time to complete, the other threads may complete all the other tasks before it is finished.

In this case, since the loop is in an untied task, any other thread is eligible to resume the task generating loop. In the previous examples, the other threads would be forced to idle until the generating thread finishes its long task, since the task generating loop was in a tied task.

Example 16.6c

#define LARGE_NUMBER 10000000
double item[LARGE_NUMBER];
extern void process(double);
int main() {
#pragma omp parallel
{
   #pragma omp single
   {
}}
Example 16.6f

```
real*8 item(10000000)
!$omp parallel
!$omp single
!$omp task untied
   ! loop iteration variable i is private
   do i=1,10000000
!$omp task ! i is firstprivate, item is shared
   call process(item(i))
!$omp end task
   end do
!$omp end task
!$omp end single
!$omp end parallel
```

The following two examples demonstrate how the scheduling rules illustrated in $ affect the usage of threadprivate variables in tasks. A threadprivate variable can be modified by another task that is executed by the same thread. Thus, the value of a threadprivate variable cannot be assumed to be unchanged across a task scheduling point. In untied tasks, task scheduling points may be added in any place by the implementation.

A task switch may occur at a task scheduling point. A single thread may execute both of the task regions that modify tp. The parts of these task regions in which tp is modified may be executed in any order so the resulting value of var can be either 1 or 2.

Example 16.7c

```
int tp;
#pragma omp threadprivate(tp)
```
int var;
void work()
{
  #pragma omp task
  {
    /* do work here */
    #pragma omp task
    {
      tp = 1;
      /* do work here */
    }
    /* no modification of tp */
    var = tp; //value of tp can be 1 or 2
    tp = 2;
  }
}

Fortran

Example 16.7f

module example
  integer tp
  !$omp threadprivate(tp)
  integer var
  contains
  subroutine work
    use globals
    !$omp task
    ! do work here
    !$omp task
      tp = 1
      ! do work here
    !$omp task
      ! no modification of tp
    !$omp end task
    var = tp    ! value of var can be 1 or 2
    !$omp end task
    tp = 2
    !$omp end task
  end subroutine
end module

Fortran

In this example, scheduling constraints prohibit a thread in the team from executing a new task that modifies tp while another such task region tied to the same thread is suspended. Therefore, the value written will persist across the task scheduling point.
Example 16.8c

```c
int tp;
#pragma omp threadprivate(tp)
int var;
void work()
{
    #pragma omp parallel
    {
        /* do work here */
        #pragma omp task
        {
            tp++;
            /* do work here */
        }
        /* do work here but don't modify tp */
    }
    var = tp;  // Value does not change after write above
}
```

Example 16.8f

```fortran
module example
  integer tp
  !$omp threadprivate(tp)
  integer var
  contains
  subroutine work
    !$omp parallel
    ! do work here
    !$omp task
    tp = tp + 1
    ! do work here
    !$omp task
    ! do work here but don't modify tp
    !$omp end task
    var = tp  ! Value does not change after write above
  !$omp end task
  !$omp end parallel
end subroutine
end module
```
The following two examples demonstrate how the scheduling rules illustrated in $ affect the usage of locks and critical sections in tasks. If a lock is held across a task scheduling point, no attempt should be made to acquire the same lock in any code that may be interleaved. Otherwise, a deadlock is possible.

In the example below, suppose the thread executing task 1 defers task 2. When it encounters the task scheduling point at task 3, it could suspend task 1 and begin task 2 which will result in a deadlock when it tries to enter critical region 1.

---

**Example 16.9c**

C/C++

```c
void work()
{
    #pragma omp task
    { //Task 1
        #pragma omp task
        { //Task 2
            #pragma omp critical //Critical region 1
            /*do work here */
        }
    }
    #pragma omp critical //Critical Region 2
    {
        /*do work here */
    }
}
```

---

**Example 16.9f**

Fortran

```fortran
module example
contains
  subroutine work
    !$omp task
    ! Task 1
    !$omp task
    ! Task 2
    !$omp critical
    ! Critical region 1
    ! do work here
    !$omp end critical
    !$omp end task
    !$omp critical
    ! Critical region 2
```

! Capture data for the following task
!$omp task
   !Task 3
   ! do work here
!$omp end task
!$omp end critical
!$omp end task
   end subroutine
end module
In the following example, `lock` is held across a task scheduling point. However, according to the scheduling restrictions, the executing thread can't begin executing one of the non-descendant tasks that also acquires `lock` before the task region is complete. Therefore, no deadlock is possible.

### Example 16.10c

```c/c++
#include <omp.h>
void work() {
  omp_lock_t lock;
  omp_init_lock(&lock);
  #pragma omp parallel
  {
    int i;
    #pragma omp for
    for (i = 0; i < 100; i++) {
      #pragma omp task
      {
        // lock is shared by default in the task
        omp_set_lock(&lock);
        // Capture data for the following task
        #pragma omp task
        // Task Scheduling Point 1
        { /* do work here */ }
        omp_unset_lock(&lock);
      }
    }
    omp_destroy_lock(&lock);
  }
}
```

### Example 16.10f

```fortran
module example
  include 'omp_lib.h'
  integer (kind=omp_lock_kind) lock
  integer i
contains
  subroutine work
    call omp_init_lock(lock)
    !$omp parallel
    !$omp do
    do i=1,100
      !$omp task
        ! Outer task
  ```
The following examples illustrate the use of the **mergeable** clause in the **task** construct. In this first example, the **task** construct has been annotated with the **mergeable** clause. The addition of this clause allows the implementation to reuse the data environment (including the ICVs) of the parent task for the task inside **foo** if the task is included or undeferred. Thus, the result of the execution may differ depending on whether the task is merged or not. Therefore the **mergeable** clause needs to be used with caution. In this example, the use of the **mergeable** clause is safe. As \( x \) is a shared variable the outcome does not depend on whether or not the task is merged (that is, the task will always increment the same variable and will always compute the same value for \( x \)).

---

**Example 16.11c**

```c
#include <stdio.h>
void foo ( )
{
    int x = 2;
    #pragma omp task shared(x) mergeable
    {
        x++;
    }
    #pragma omp taskwait
    printf("%d\n",x);  // prints 3
}
```

---

**Example 16.11f**

```fortran
subroutine foo()
    integer :: x
```

---
This second example shows an incorrect use of the `mergeable` clause. In this example, the created task will access different instances of the variable `x` if the task is not merged, as `x` is `firstprivate`, but it will access the same variable `x` if the task is merged. As a result, the behavior of the program is unspecified and it can print two different values for `x` depending on the decisions taken by the implementation.
The following example shows the use of the `final` clause and the `omp_in_final` API call in a recursive binary search program. To reduce overhead, once a certain depth of recursion is reached the program uses the `final` clause to create only included tasks, which allow additional optimizations.

The use of the `omp_in_final` API call allows programmers to optimize their code by specifying which parts of the program are not necessary when a task can create only included tasks (that is, the code is inside a `final` task). In this example, the use of a different state variable is not necessary so once the program reaches the part of the computation that is finalized and copying from the parent state to the new state is eliminated. The allocation of `new_state` in the stack could also be avoided but it would make this example less clear. The `final` clause is most effective when used in conjunction with the `mergeable` clause since all tasks created in a `final` task region are included tasks that can be merged if the `mergeable` clause is present.

---

**Example 16.13c**

```c
#include <string.h>
#include <omp.h>
#define LIMIT 3 /* arbitrary limit on recursion depth */
void check_solution(char *);
void bin_search (int pos, int n, char *state) {
  if ( pos == n ) {
    check_solution(state);
    return;
  }
  #pragma omp task final( pos > LIMIT ) mergeable
  {
    char new_state[n];
    if (!omp_in_final() ) {
      memcpy(new_state, state, pos );
      state = new_state;
    }
    state[pos] = 0;
    bin_search(pos+1, n, state );
  }
  #pragma omp task final( pos > LIMIT ) mergeable
  {
    char new_state[n];
    if (!omp_in_final() ) {
      memcpy(new_state, state, pos );
      state = new_state;
    }
    state[pos] = 1;
    bin_search(pos+1, n, state );
  }
  #pragma omp taskwait
```
Example 16.13f

```fortran
recursive subroutine bin_search(pos, n, state)
    use omp_lib
    integer :: pos, n
    character, pointer :: state(:)
    character, target, dimension(n) :: new_state1, new_state2
    integer, parameter :: LIMIT = 3
    if (pos .eq. n) then
        call check_solution(state)
        return
    endif
    !$omp task final(pos > LIMIT) mergeable
    if (.not. omp_in_final()) then
        new_state1(1:pos) = state(1:pos)
        state => new_state1
    endif
    state(pos+1) = 'z'
    call bin_search(pos+1, n, state)
    !$omp end task
    !$omp task final(pos > LIMIT) mergeable
    if (.not. omp_in_final()) then
        new_state2(1:pos) = state(1:pos)
        state => new_state2
    endif
    state(pos+1) = 'y'
    call bin_search(pos+1, n, state)
    !$omp end task
    !$omp taskwait
end subroutine
```

The following example illustrates the difference between the `if` and the `final` clauses. The `if` clause has a local effect. In the first nest of tasks, the one that has the `if` clause will be undeferred but the task nested inside that task will not be affected by the `if` clause and will be created as usual. Alternatively, the `final` clause affects all `task` constructs in the `final` task region but not the `final` task itself. In the second nest of tasks, the nested tasks will be created as included tasks. Note also that the conditions for the `if` and `final` clauses are usually the opposite.
void foo ( )
{
    int i;
    #pragma omp task if(0)  // This task is undeferred
    {
        #pragma omp task     // This task is a regular task
        for (i = 0; i < 3; i++) {
            #pragma omp task     // This task is a regular task
            bar();
        }
    }
    #pragma omp task final(1) // This task is a regular task
    {
        #pragma omp task     // This task is included
        for (i = 0; i < 3; i++) {
            #pragma omp task     // This task is also included
            bar();
        }
    }
}
**Example 16.14f**

```fortran
subroutine foo()
  integer i
  !$omp task if(.FALSE.) ! This task is undeferred
  !$omp task             ! This task is a regular task
  do i = 1, 3
    !$omp task             ! This task is a regular task
    call bar()
    !$omp end task
  enddo
  !$omp end task
  !$omp end task
  !$omp task final(.TRUE.) ! This task is a regular task
  !$omp task             ! This task is included
  do i = 1, 3
    !$omp task             ! This task is also included
    call bar()
    !$omp end task
  enddo
  !$omp end task
  !$omp end task
end subroutine
```

**Task Dependences**

**Flow Dependence**

In this example we show a simple flow dependence expressed using the `depend` clause on the `task` construct.

**Example 16.15c**

```c
#include <stdio.h>
int main()
{
  int x = 1;
  #pragma omp parallel
  #pragma omp single
  {
    #pragma omp task shared(x) depend(out: x)
    x = 2;
  }
```
The program will always print "x = 2", because the depend clauses enforce the ordering of the tasks. If the depend clauses had been omitted, then the tasks could execute in any order and the program and the program would have a race condition.

**Anti-dependence**

In this example we show an anti-dependence expressed using the depend clause on the task construct.

**Example 16.16c**

```c
#include <stdio.h>
int main()
{
    int x = 1;
    #pragma omp parallel
    #pragma omp single
    {
        #pragma omp task shared(x) depend(in: x)
        printf("x = %d\n", x);
    }
    return 0;
}
```
Example 16.16f

```fortran
program example
    integer :: x
    x = 1
    !$omp parallel
    !$omp single
    !$omp task shared(x) depend(in: x)
    print*, "x = ", x
    !$omp end task
    !$omp task shared(x) depend(out: x)
    x = 2
    !$omp end task
    !$omp end single
    !$omp end parallel
end program
```

The program will always print "x = 1", because the `depend` clauses enforce the ordering of the tasks. If the `depend` clauses had been omitted, then the tasks could execute in any order and the program would have a race condition.

Output Dependence

In this example we show an output dependence expressed using the `depend` clause on the `task` construct.

```
#include <stdio.h>
int main()
{
    int x;
    #pragma omp parallel
    #pragma omp single
    {
        #pragma omp task shared(x) depend(out: x)
```
Example 16.17f

```
program example
  integer :: x
  !$omp parallel
  !$omp single
  !$omp task shared(x) depend(out: x)
    x = 1
  !$omp end task
  !$omp task shared(x) depend(out: x)
    x = 2
  !$omp end task
  !$omp taskwait
  print*, "x = ", x
  !$omp end single
  !$omp end parallel
end program
```

The program will always print "x = 2", because the depend clauses enforce the ordering of the tasks. If the depend clauses had been omitted, then the tasks could execute in any order and the program would have a race condition.

**Concurrent Execution with Dependences**

In this example we show potentially concurrent execution of tasks using multiple flow dependences expressed using the depend clause on the task construct.

**Example 16.18c**

```
#include <stdio.h>
int main()
{
  int x = 1;
```
#pragma omp parallel
#pragma omp single
{
    #pragma omp task shared(x) depend(out: x)
    x = 2;
    #pragma omp task shared(x) depend(in: x)
    printf("x + 1 = %d. ", x+1);
    #pragma omp task shared(x) depend(in: x)
    printf("x + 2 = %d\n", x+2);
}
return 0;

Example 16.18f

program example
    integer :: x
    x = 1
    !$omp parallel
    !$omp single
    !$omp task shared(x) depend(out: x)
    x = 2
    !$omp end task
    !$omp task shared(x) depend(in: x)
    print*, "x + 1 = ", x+1, "."
    !$omp end task
    !$omp task shared(x) depend(in: x)
    print*, "x + 2 = ", x+2, "."
    !$omp end task
    !$omp end single
    !$omp end parallel
end program

The last two tasks are dependent on the first task. However there is no dependence between the last two tasks, which may execute in any order (or concurrently if more than one thread is available). Thus, the possible outputs are "x + 1 = 3. x + 2 = 4. " and "x + 2 = 4. x + 1 = 3. ". If the depend clauses had been omitted, then all of the tasks could execute in any order and the program would have a race condition.
Matrix multiplication

This example shows a task-based blocked matrix multiplication. Matrices are of NxN elements, and the multiplication is implemented using blocks of BSxBS elements.

Example 16.19c

```c
// Assume BS divides N perfectly
void matmul_depend(int N, int BS, float A[N][N], float B[N][N], float C[N][N] )
{
    int i, j, k, ii, jj, kk;
    for (i = 0; i < N; i+=BS) {
        for (j = 0; j < N; j+=BS) {
            for (k = 0; k < N; k+=BS) {
                #pragma omp task depend ( in: A[i:BS][k:BS], B[k:BS][j:BS] )
                depend ( inout: C[i:BS][j:BS] )
                for (ii = i; ii < i+BS; ii++ )
                    for (jj = j; jj < j+BS; jj++ )
                        for (kk = k; kk < k+BS; kk++ )
            }
        }
    }
}
```
Example 16.19f

! Assume BS divides N perfectly
subroutine matmul_depend (N, BS, A, B, C)
  integer :: N, BS, BM
  real, dimension(N, N) :: A, B, C
  integer :: i, j, k, ii, jj, kk
  BM = BS -1
  do i = 1, N, BS
    do j = 1, N, BS
      do k = 1, N, BS
        !$omp task depend (in: A(i:i+BM, k:k+BM), B(k:k+BM, j:j+BM)) &
        !$omp depend (inout: C(i:i+BM, j:j+BM))
        do ii = i, i+BS
          do jj = j, j+BS
            do kk = k, k+BS
              C(jj,ii) = C(jj,ii) + A(kk,ii) * B(jj,kk)
            end do
          end do
        end do
      end do
    end do
  end do
end subroutine
17 The taskgroup Construct

In this example, tasks are grouped and synchronized using the taskgroup construct.

Initially, one task (the task executing the start_background_work() call) is created in the parallel region, and later a parallel tree traversal is started (the task executing the root of the recursive compute_tree() calls). While synchronizing tasks at the end of each tree traversal, using the taskgroup construct ensures that the formerly started background task does not participate in the synchronization, and is left free to execute in parallel. This is opposed to the behaviour of the taskwait construct, which would include the background tasks in the synchronization.

Example 17.1c

```c
extern void start_background_work(void);
extern void check_step(void);
extern void print_results(void);
struct tree_node
{
    struct tree_node *left;
    struct tree_node *right;
};
typedef struct tree_node* tree_type;
extern void init_tree(tree_type);
define max_steps 100
void compute_something(tree_type tree)
{
    // some computation
}
void compute_tree(tree_type tree)
{
    if (tree->left)
    {
        #pragma omp task
        compute_tree(tree->left);
    }
    if (tree->right)
    {
        #pragma omp task
        compute_tree(tree->right);
    }
    #pragma omp task
    compute_something(tree);
}
int main()
{
    int i;
```
tree_type tree;
init_tree(tree);
#pragma omp parallel
#pragma omp single
{
#pragma omp task
    start_background_work();
    for (i = 0; i < max_steps; i++)
    {
#pragma omp taskgroup

#pragma omp task
    compute_tree(tree);
}  // wait on tree traversal in this step
check_step();
}
} // only now is background work required to be complete
print_results();

C/C++

module tree_type_mod
    integer, parameter :: max_steps=100
    type tree_type
        type(tree_type), pointer :: left, right
    end type
    contains
        subroutine compute_something(tree)
            type(tree_type), pointer :: tree
            ! some computation
        end subroutine
        recursive subroutine compute_tree(tree)
            type(tree_type), pointer :: tree
            if (associated(tree%left)) then
            !$omp task
                call compute_tree(tree%left)
            !$omp end task
            endif
            if (associated(tree%right)) then
            !$omp task
                call compute_tree(tree%right)
            !$omp end task
            endif
            !$omp task
                call compute_something(tree)
            !$omp end task
        end subroutine
Example 17.1f
end module
program main
  use tree_type_mod
  type(tree_type), pointer :: tree
  call init_tree(tree);
!$omp parallel
!$omp single
!$omp task
    call start_background_work()
!$omp end task
    do i=1, max_steps
      !$omp taskgroup
      !$omp task
        call compute_tree(tree)
      !$omp end task
      !$omp end taskgroup  ! wait on tree traversal in this step
      call check_step()
    enddo
!$omp end single
!$omp end parallel   ! only now is background work required to be complete
  call print_results()
end program
The taskyield Directive

The following example illustrates the use of the taskyield directive. The tasks in the example compute something useful and then do some computation that must be done in a critical region. By using taskyield when a task cannot get access to the critical region the implementation can suspend the current task and schedule some other task that can do something useful.

Example 18.1c

```c
#include <omp.h>

void something_useful ( void );
void something_critical ( void );
void foo ( omp_lock_t * lock, int n )
{
    int i;

    for ( i = 0; i < n; i++ )
        #pragma omp task
           { something_useful();
            while ( !omp_test_lock(lock) )
                #pragma omp taskyield
                something_critical();
            omp_unset_lock(lock);
       }
}
```

Example 18.1f

```fortran
subroutine foo ( lock, n )
    use omp_lib
    integer (kind=omp_lock_kind) :: lock
    integer n
    integer i

    do i = 1, n
        !$omp task
            call something_useful()
        do while ( .not. omp_test_lock(lock) )
```
!$omp taskyield
end do
   call something_critical()
   call omp_unset_lock(lock)
   !$omp end task
end do

end subroutine
The workshare Construct

The following are examples of the workshare construct.

In the following example, workshare spreads work across the threads executing the parallel region, and there is a barrier after the last statement. Implementations must enforce Fortran execution rules inside of the workshare block.

Example 19.1f

```fortran
SUBROUTINE WSHARE1(AA, BB, CC, DD, EE, FF, N)
    INTEGER N
    REAL AA(N,N), BB(N,N), CC(N,N), DD(N,N), EE(N,N), FF(N,N)
    !$OMP PARALLEL
    !$OMP WORKSHARE
        AA = BB
        CC = DD
        EE = FF
    !$OMP END WORKSHARE
    !$OMP END PARALLEL
END SUBROUTINE WSHARE1
```

In the following example, the barrier at the end of the first workshare region is eliminated with a nowait clause. Threads doing \( CC = DD \) immediately begin work on \( EE = FF \) when they are done with \( CC = DD \).

Example 19.2f

```fortran
SUBROUTINE WSHARE2(AA, BB, CC, DD, EE, FF, N)
    INTEGER N
    REAL AA(N,N), BB(N,N), CC(N,N)
    REAL DD(N,N), EE(N,N), FF(N,N)
    !$OMP PARALLEL
    !$OMP WORKSHARE
        AA = BB
        CC = DD
    !$OMP END WORKSHARE NOWAIT
    !$OMP WORKSHARE
        EE = FF
    !$OMP END WORKSHARE
    !$OMP END PARALLEL
END SUBROUTINE WSHARE2
```
The following example shows the use of an `atomic` directive inside a `workshare` construct. The computation of `SUM(AA)` is workshared, but the update to `R` is atomic.

**Example 19.3f**

```fortran
SUBROUTINE WSHARE3(AA, BB, CC, DD, N)
INTEGER N
REAL AA(N,N), BB(N,N), CC(N,N), DD(N,N)
REAL R
R=0
!$OMP PARALLEL
!$OMP WORKSHARE
   AA = BB
!$OMP ATOMIC UPDATE
   R = R + SUM(AA)
   CC = DD
!$OMP END WORKSHARE
!$OMP END PARALLEL
END SUBROUTINE WSHARE3
```

Fortran `WHERE` and `FORALL` statements are *compound statements*, made up of a *control* part and a *statement* part. When `workshare` is applied to one of these compound statements, both the control and the statement parts are workshared. The following example shows the use of a `WHERE` statement in a `workshare` construct.

Each task gets worked on in order by the threads:

- `AA = BB` then
- `CC = DD` then
- `EE .ne. 0` then
- `FF = 1 / EE` then
- `GG = HH`

**Example 19.4f**

```fortran
SUBROUTINE WSHARE4(AA, BB, CC, DD, EE, FF, GG, HH, N)
INTEGER N
REAL AA(N,N), BB(N,N), CC(N,N)
REAL DD(N,N), EE(N,N), FF(N,N)
REAL GG(N,N), HH(N,N)

!$OMP PARALLEL
!$OMP WORKSHARE
   AA = BB
   CC = DD
   WHERE (EE .ne. 0) FF = 1 / EE
   GG = HH
!$OMP END WORKSHARE
!$OMP END PARALLEL
END SUBROUTINE WSHARE4
```
In the following example, an assignment to a shared scalar variable is performed by one thread in a workshare while all other threads in the team wait.

Example 19.5f

```fortran
SUBROUTINE WSHARE5(AA, BB, CC, DD, N)
INTEGER N
REAL AA(N,N), BB(N,N), CC(N,N), DD(N,N)
INTEGER SHR
!
$OMP PARALLEL SHARED(SHR)
$OMP WORKSHARE
    AA = BB
    SHR = 1
    CC = DD * SHR
$OMP END WORKSHARE
$OMP END PARALLEL

END SUBROUTINE WSHARE5
```

The following example contains an assignment to a private scalar variable, which is performed by one thread in a workshare while all other threads wait. It is non-conforming because the private scalar variable is undefined after the assignment statement.

Example 19.6f

```fortran
SUBROUTINE WSHARE6_WRONG(AA, BB, CC, DD, N)
INTEGER N
REAL AA(N,N), BB(N,N), CC(N,N), DD(N,N)
INTEGER PRI
!
$OMP PARALLEL PRIVATE(PRI)
$OMP WORKSHARE
    AA = BB
    PRI = 1
    CC = DD * PRI
$OMP END WORKSHARE
$OMP END PARALLEL

END SUBROUTINE WSHARE6_WRONG
```
Fortran execution rules must be enforced inside a workshare construct. In the following example, the same result is produced in the following program fragment regardless of whether the code is executed sequentially or inside an OpenMP program with multiple threads:

**Example 19.7f**

```fortran
SUBROUTINE WSHARE7(AA, BB, CC, N)
INTEGER N
REAL AA(N), BB(N), CC(N)
!
$OMP PARALLEL
$OMP WORKSHARE
AA(1:50) = BB(11:60)
CC(11:20) = AA(1:10)
$OMP END WORKSHARE
$OMP END PARALLEL
!
END SUBROUTINE WSHARE7
```

```fortran
!
```

---

Fortran
20 The master Construct

The following example demonstrates the master construct. In the example, the master keeps track of how many iterations have been executed and prints out a progress report. The other threads skip the master region without waiting.

Example 20.1c

```
#include <stdio.h>

extern float average(float, float, float);

void master_example( float* x, float* xold, int n, float tol )
{
    int c, i, toobig;
    float error, y;
    c = 0;
    #pragma omp parallel
    {
        do{
            #pragma omp for private(i)
            for( i = 1; i < n-1; ++i ){
                xold[i] = x[i];
            }
            #pragma omp single
            {
                toobig = 0;
            }
            #pragma omp for private(i,y,error) reduction(+:toobig)
            for( i = 1; i < n-1; ++i ){
                y = x[i];
                x[i] = average( xold[i-1], x[i], xold[i+1] );
                error = y - x[i];
                if( error > tol || error < -tol ) ++toobig;
            }
            #pragma omp master
            {
                ++c;
                printf( "iteration %d, toobig=%d\n", c, toobig );
            }
        }while( toobig > 0 );
    }
}
```
Example 20.1f

SUBROUTINE MASTER_EXAMPLE( X, XOLD, N, TOL )
REAL X(*), XOLD(*), TOL
INTEGER N
INTEGER C, I, TOOBIG
REAL ERROR, Y, AVERAGE
EXTERNAL AVERAGE
C = 0
TOOBIG = 1
!$OMP PARALLEL
   DO WHILE( TOOBIG > 0 )
     !$OMP DO PRIVATE(I)
       DO I = 2, N-1
         XOLD(I) = X(I)
       ENDDO
     !$OMP SINGLE
       TOOBIG = 0
     !$OMP END SINGLE
     !$OMP DO PRIVATE(I,Y,ERROR), REDUCTION(+:TOOBIG)
       DO I = 2, N-1
         Y = X(I)
         X(I) = AVERAGE( XOLD(I-1), X(I), XOLD(I+1) )
         ERROR = Y-X(I)
         IF( ERROR > TOL .OR. ERROR < -TOL ) TOOBIG = TOOBIG+1
       ENDDO
     !$OMP MASTER
       C = C + 1
       PRINT *, 'Iteration ', C, 'TOOBIG=', TOOBIG
     !$OMP END MASTER
   ENDDO
!$OMP END PARALLEL
END SUBROUTINE MASTER_EXAMPLE
21 The critical Construct

The following example includes several critical constructs. The example illustrates a queuing model in which a task is dequeued and worked on. To guard against multiple threads dequeuing the same task, the dequeuing operation must be in a critical region. Because the two queues in this example are independent, they are protected by critical constructs with different names, xaxis and yaxis.

C/C++

Example 21.1c

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

void critical_example(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);
    }
}
```

Fortran

Example 21.1f

```fortran
SUBROUTINE CRITICAL_EXAMPLE(X, Y)
    REAL X(*), Y(*)
    INTEGER IX_NEXT, IY_NEXT

!$OMP PARALLEL SHARED(X, Y) PRIVATE(IX_NEXT, IY_NEXT)

!$OMP CRITICAL(XAXIS)
    CALL DEQUEUE(IX_NEXT, X)
!$OMP END CRITICAL(XAXIS)
```

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CALL WORK(IX_NEXT, X)

 !$OMP CRITICAL(YAXIS)
 CALL DEQUEUE(IY_NEXT,Y)
 !$OMP END CRITICAL(YAXIS)
 CALL WORK(IY_NEXT, Y)

 !$OMP END PARALLEL

 END SUBROUTINE CRITICAL_EXAMPLE

------------------------- Fortran


Worksharing Constructs Inside a critical Construct

The following example demonstrates using a worksharing construct inside a critical construct. This example is conforming because the worksharing single region is not closely nested inside the critical region. A single thread executes the one and only section in the sections region, and executes the critical region. The same thread encounters the nested parallel region, creates a new team of threads, and becomes the master of the new team. One of the threads in the new team enters the single region and increments \( i \) by 1. At the end of this example \( i \) is equal to 2.

**Example 22.1c**

```c
void critical_work()
{
    int i = 1;
    #pragma omp parallel sections
    {
        #pragma omp section
        {
            #pragma omp critical (name)
            {
                #pragma omp parallel
                {
                    #pragma omp single
                    {
                        i++;
                    }
                }
            }
        }
    }
}
```

**Example 22.1f**

```fortran
SUBROUTINE CRITICAL_WORK()

    INTEGER I
    I = 1
```

C/C++
!$OMP  PARALLEL SECTIONS
!$OMP    SECTION
!$OMP     CRITICAL (NAME)
!$OMP      PARALLEL
!$OMP       SINGLE
          I = I + 1
!$OMP       END SINGLE
!$OMP      END PARALLEL
!$OMP    END CRITICAL (NAME)
!$OMP  END PARALLEL SECTIONS
    END SUBROUTINE CRITICAL_WORK
23 Binding of barrier Regions

The binding rules call for a barrier region to bind to the closest enclosing parallel region.

In the following example, the call from the main program to sub2 is conforming because the barrier region (in sub3) binds to the parallel region in sub2. The call from the main program to sub1 is conforming because the barrier region binds to the parallel region in subroutine sub2.

The call from the main program to sub3 is conforming because the barrier region binds to the implicit inactive parallel region enclosing the sequential part. Also note that the barrier region in sub3 when called from sub2 only synchronizes the team of threads in the enclosing parallel region and not all the threads created in sub1.
**Example 23.1c**

```c/c++

void work(int n) {}    

void sub3(int n)    
{    
    work(n);    
    #pragma omp barrier    
    work(n);    
}    

void sub2(int k)    
{    
    #pragma omp parallel shared(k)    
    sub3(k);    
}    

void sub1(int n)    
{    
    int i;    
    #pragma omp parallel private(i) shared(n)    
    {    
        #pragma omp for    
        for (i=0; i<n; i++)    
            sub2(i);    
    }    
}    

int main()    
{    
    sub1(2);    
    sub2(2);    
    sub3(2);    
    return 0;    
}
```

**Example 23.1f**

```fortran

SUBROUTINE WORK(N)    
    INTEGER N    
END SUBROUTINE WORK

SUBROUTINE SUB3(N)    
    INTEGER N    
    CALL WORK(N)    
!$OMP BARRIER    
    CALL WORK(N)
```
END SUBROUTINE SUB3

SUBROUTINE SUB2(K)
INTEGER K
!$OMP PARALLEL SHARED(K)
   CALL SUB3(K)
!$OMP END PARALLEL
END SUBROUTINE SUB2

SUBROUTINE SUB1(N)
INTEGER N
   INTEGER I
!$OMP PARALLEL PRIVATE(I) SHARED(N)
!$OMP DO
   DO I = 1, N
      CALL SUB2(I)
   END DO
!$OMP END PARALLEL
END SUBROUTINE SUB1

PROGRAM EXAMPLE
   CALL SUB1(2)
   CALL SUB2(2)
   CALL SUB3(2)
END PROGRAM EXAMPLE
The atomic Construct

The following example avoids race conditions (simultaneous updates of an element of $x$ by multiple threads) by using the atomic construct.

The advantage of using the atomic construct in this example is that it allows updates of two different elements of $x$ to occur in parallel. If a critical construct were used instead, then all updates to elements of $x$ would be executed serially (though not in any guaranteed order).

Note that the atomic directive applies only to the statement immediately following it. As a result, elements of $y$ are not updated atomically in this example.

C/C++

Example 24.1c

```c
float work1(int i)
{
    return 1.0 * i;
}

float work2(int i)
{
    return 2.0 * i;
}

void atomic_example(float *x, float *y, int *index, int n)
{
    int i;

    #pragma omp parallel for shared(x, y, index, n)
    for (i=0; i<n; i++) {
        #pragma omp atomic update
        x[index[i]] += work1(i);
        y[i] += work2(i);
    }
}

int main()
{
    float x[1000];
    float y[10000];
    int index[10000];
    int i;

    for (i = 0; i < 10000; i++) {
        index[i] = i % 1000;
        y[i]=0.0;
    }
```
for (i = 0; i < 1000; i++)
    x[i] = 0.0;
atomic_example(x, y, index, 10000);
return 0;

C/C++

Fortran

Example 24.1f

REAL FUNCTION WORK1(I)
   INTEGER I
   WORK1 = 1.0 * I
   RETURN
END FUNCTION WORK1

REAL FUNCTION WORK2(I)
   INTEGER I
   WORK2 = 2.0 * I
   RETURN
END FUNCTION WORK2

SUBROUTINE SUB(X, Y, INDEX, N)
   REAL X(*), Y(*)
   INTEGER INDEX(*), N

   INTEGER I

   !$OMP PARALLEL DO SHARED(X, Y, INDEX, N)
   DO I=1,N
       !$OMP ATOMIC UPDATE
       X(INDEX(I)) = X(INDEX(I)) + WORK1(I)
       Y(I) = Y(I) + WORK2(I)
   ENDDO

   END SUBROUTINE SUB

PROGRAM ATOMIC_EXAMPLE
   REAL X(1000), Y(10000)
   INTEGER INDEX(10000)

   INTEGER I

   DO I=1,10000
       INDEX(I) = MOD(I, 1000) + 1
       Y(I) = 0.0
   ENDDO

   DO I = 1,1000
       X(I) = 0.0
   ENDDO
CALL SUB(X, Y, INDEX, 10000)

END PROGRAM ATOMIC_EXAMPLE

The following example illustrates the read and write clauses for the atomic directive. These clauses ensure that the given variable is read or written, respectively, as a whole. Otherwise, some other thread might read or write part of the variable while the current thread was reading or writing another part of the variable. Note that most hardware provides atomic reads and writes for some set of properly aligned variables of specific sizes, but not necessarily for all the variable types supported by the OpenMP API.

Example 24.2c

```c
int atomic_read(const int *p)
{
    int value;
    /* Guarantee that the entire value of *p is read atomically. No part of * *p can change during the read operation. */
    #pragma omp atomic read
    value = *p;
    return value;
}

void atomic_write(int *p, int value)
{
    /* Guarantee that value is stored atomically into *p. No part of *p can change * until after the entire write operation is completed. */
    #pragma omp atomic write
    *p = value;
}  
```

Example 24.2f

```fortran
function atomic_read(p)
    integer :: atomic_read
    integer, intent(in) :: p
    ! Guarantee that the entire value of p is read atomically. No part of ! p can change during the read operation.
```
OpenMP Examples

Fortran

The following example illustrates the capture clause for the atomic directive. In this case the value of a variable is captured, and then the variable is incremented. These operations occur atomically. This particular example could be implemented using the fetch-and-add instruction available on many kinds of hardware. The example also shows a way to implement a spin lock using the capture and read clauses.

C/C++

Example 24.3c

```c
int fetch_and_add(int *p)
{
    /* Atomically read the value of *p and then increment it. The previous value is returned. This can be used to implement a simple lock as shown below. */
    int old;
    #pragma omp atomic capture
    { old = *p; (*p)++; }
    return old;
}

/*
 * Use fetch_and_add to implement a lock
 */
struct locktype {
    int ticketnumber;
    int turn;
};
void do_locked_work(struct locktype *lock)
{
    int atomic_read(const int *p);
    void work();

    // Obtain the lock
    int myturn = fetch_and_add(&lock->ticketnumber);
```
while (atomic_read(&lock->turn) != myturn)
;
// Do some work. The flush is needed to ensure visibility of
// variables not involved in atomic directives

#pragma omp flush
     work();
#pragma omp flush
     // Release the lock
     fetch_and_add(&lock->turn);
}

Example 24.3f

function fetch_and_add(p)
    integer:: fetch_and_add
    integer, intent(inout) :: p

! Atomically read the value of p and then increment it. The previous value is
! returned. This can be used to implement a simple lock as shown below.
!$omp atomic capture
    fetch_and_add = p
    p = p + 1
!$omp end atomic
end function fetch_and_add

! Use fetch_and_add to implement a lock
module m
interface
    function fetch_and_add(p)
        integer :: fetch_and_add
        integer, intent(inout) :: p
    end function

    function atomic_read(p)
        integer :: atomic_read
        integer, intent(in) :: p
    end function
end interface

type locktype
    integer ticketnumber
    integer turn
end type
contains
subroutine do_locked_work(lock)
type(locktype), intent(inout) :: lock
integer myturn
integer junk
!
myturn = fetch_and_add(lock%ticketnumber)
do while (atomic_read(lock%turn) .ne. myturn)
continue
dendo
! Do some work. The flush is needed to ensure visibility of variables
! not involved in atomic directives
!$omp flush
  call work
!$omp flush
! Release the lock
  junk = fetch_and_add(lock%turn)
end subroutine
end module
25 Restrictions on the atomic Construct

The following non-conforming examples illustrate the restrictions on the atomic construct.

C/C++

Example 25.1c

```c
void atomic_wrong ()
{
    union {int n; float x;} u;

#pragma omp parallel
{
    #pragma omp atomic update
    u.n++;  
    #pragma omp atomic update
    u.x += 1.0;

    /* Incorrect because the atomic constructs reference the same location  
       through incompatible types */
}
}
```

Fortran

Example 25.1f

```fortran
SUBROUTINE ATOMIC_WRONG()
    INTEGER:: I
    REAL:: R
    EQUIVALENCE(I,R)

!$OMP PARALLEL
!$OMP ATOMIC UPDATE
    I = I + 1
!$OMP ATOMIC UPDATE
    R = R + 1.0
! incorrect because I and R reference the same location
! but have different types
!$OMP END PARALLEL
END SUBROUTINE ATOMIC_WRONG
```
Example 25.2c

```c
void atomic_wrong2 ()
{
    int x;
    int *i;
    float   *r;

    i = &x;
    r = (float *)&x;

#pragma omp parallel
{
    #pragma omp atomic update
    *i += 1;

    #pragma omp atomic update
    *r += 1.0;

    /* Incorrect because the atomic constructs reference the same location
       through incompatible types */

}
}
```
The following example is non-conforming because \( I \) and \( R \) reference the same location but have different types.

**Example 25.2f**

```fortran
SUBROUTINE SUB()
    COMMON /BLK/ R
    REAL R

    !$OMP ATOMIC UPDATE
    R = R + 1.0
    END SUBROUTINE SUB

SUBROUTINE ATOMIC_WRONG2()
    COMMON /BLK/ I
    INTEGER I

    !$OMP PARALLEL
    !$OMP ATOMIC UPDATE
    I = I + 1
    CALL SUB()
    !$OMP END PARALLEL
    END SUBROUTINE ATOMIC_WRONG2
```

Although the following example might work on some implementations, this is also non-conforming:

**Example 25.3f**

```fortran
SUBROUTINE ATOMIC_WRONG3
    INTEGER:: I
    REAL:: R
    EQUIVALENCE(I,R)

    !$OMP PARALLEL
    !$OMP ATOMIC UPDATE
    I = I + 1
    ! incorrect because I and R reference the same location
    ! but have different types
    !$OMP END PARALLEL

    !$OMP PARALLEL
    !$OMP ATOMIC UPDATE
    R = R + 1.0
    ! incorrect because I and R reference the same location
    ! but have different types
    !$OMP END PARALLEL
```
END SUBROUTINE ATOMIC_WRONG3

Fortran
26 The **flush** Construct without a List

The following example distinguishes the shared variables affected by a **flush** construct with no list from the shared objects that are not affected:

---

**Example 26.1c**

```c
int x, *p = &x;

void f1(int *q)
{
    *q = 1;
    #pragma omp flush
    /* x, p, and *q are flushed */
    /* because they are shared and accessible */
    /* q is not flushed because it is not shared. */
}

void f2(int *q)
{
    #pragma omp barrier
    *q = 2;
    #pragma omp barrier
    /* a barrier implies a flush */
    /* x, p, and *q are flushed */
    /* because they are shared and accessible */
    /* q is not flushed because it is not shared. */
}

int g(int n)
{
    int i = 1, j, sum = 0;
    *p = 1;
    #pragma omp parallel reduction(+: sum) num_threads(10)
    {
        f1(&j);
        /* i, n and sum were not flushed */
        /* because they were not accessible in f1 */
        /* j was flushed because it was accessible */
        sum += j;
        f2(&j);
        /* i, n, and sum were not flushed */
        /* because they were not accessible in f2 */
        /* j was flushed because it was accessible */
```
int main()
{
    int result = g(7);
    return result;
}
!$OMP PARALLEL REDUCTION(+: SUM) NUM_THREADS(10)
   CALL F1(J)
     ! I, N and SUM were not flushed
     ! because they were not accessible in F1
     ! J was flushed because it was accessible
     SUM = SUM + J
   CALL F2(J)
     ! I, N, and SUM were not flushed
     ! because they were not accessible in f2
     ! J was flushed because it was accessible
     SUM = SUM + I + J + P + N
!$OMP END PARALLEL

G = SUM
END FUNCTION G

PROGRAM FLUSH_NOLIST
  COMMON /DATA/ X, P
  INTEGER, TARGET :: X
  INTEGER, POINTER :: P
  INTEGER RESULT, G

  P => X
  RESULT = G(7)
  PRINT *, RESULT
END PROGRAM FLUSH_NOLIST
27 Placement of flush, barrier, taskwait and taskyield Directives

The following example is non-conforming, because the flush, barrier, taskwait, and taskyield directives are stand-alone directives and cannot be the immediate substatement of an if statement.

```c
Example 27.1c

void standalone_wrong()
{
    int a = 1;

    if (a != 0)
        #pragma omp flush(a)
        /* incorrect as flush cannot be immediate substatement
           of if statement */

    if (a != 0)
        #pragma omp barrier
        /* incorrect as barrier cannot be immediate substatement
           of if statement */

    if (a != 0)
        #pragma omp taskyield
        /* incorrect as taskyield cannot be immediate substatement of if statement */

    if (a != 0)
        #pragma omp taskwait
        /* incorrect as taskwait cannot be immediate substatement
           of if statement */
}
```

The following example is non-conforming, because the flush, barrier, taskwait, and taskyield directives are stand-alone directives and cannot be the action statement of an if statement or a labeled branch target.
Example 27.1f

SUBROUTINE STANDALONE_WRONG()
   INTEGER  A
   A = 1
   ! the FLUSH directive must not be the action statement
   ! in an IF statement
   IF (A .NE. 0) !$OMP FLUSH(A)

   ! the BARRIER directive must not be the action statement
   ! in an IF statement
   IF (A .NE. 0) !$OMP BARRIER

   ! the TASKWAIT directive must not be the action statement
   ! in an IF statement
   IF (A .NE. 0) !$OMP TASKWAIT

   ! the TASKYIELD directive must not be the action statement
   ! in an IF statement
   IF (A .NE. 0) !$OMP TASKYIELD

   GOTO 100

   ! the FLUSH directive must not be a labeled branch target
   ! statement
   100 !$OMP FLUSH(A)
   GOTO 200

   ! the BARRIER directive must not be a labeled branch target
   ! statement
   200 !$OMP BARRIER
   GOTO 300

   ! the TASKWAIT directive must not be a labeled branch target
   ! statement
   300 !$OMP TASKWAIT
   GOTO 400

   ! the TASKYIELD directive must not be a labeled branch target
   ! statement
   400 !$OMP TASKYIELD

END SUBROUTINE

The following version of the above example is conforming because the \texttt{flush}, \texttt{barrier}, \texttt{taskwait}, and \texttt{taskyield} directives are enclosed in a compound statement.
Example 27.2c

```c
void standalone_ok()
{
    int a = 1;

    #pragma omp parallel
    {
        if (a != 0) {
            #pragma omp flush(a)
        }
        if (a != 0) {
            #pragma omp barrier
        }
        if (a != 0) {
            #pragma omp taskwait
        }
        if (a != 0) {
            #pragma omp taskyield
        }
    }
}
```

The following example is conforming because the `flush`, `barrier`, `taskwait`, and `taskyield` directives are enclosed in an `if` construct or follow the labeled branch target.

Example 27.2f

```fortran
SUBROUTINE STANDALONE_OK()
    INTEGER A
    A = 1
    IF (A .NE. 0) THEN
        !$OMP FLUSH(A)
    ENDIF
    IF (A .NE. 0) THEN
        !$OMP BARRIER
    ENDIF
    IF (A .NE. 0) THEN
        !$OMP TASKWAIT
    ENDIF
    IF (A .NE. 0) THEN
        !$OMP TASKYIELD
    ENDIF
    GOTO 100
100 CONTINUE
```
$OMP FLUSH(A)
GOTO 200
200 CONTINUE
$OMP BARRIER
GOTO 300
300 CONTINUE
$OMP TASKWAIT
GOTO 400
400 CONTINUE
$OMP TASKYIELD
END SUBROUTINE
28 The ordered Clause and the ordered Construct

Ordered constructs are useful for sequentially ordering the output from work that is done in parallel. The following program prints out the indices in sequential order:

Example 28.1c

```c
#include <stdio.h>

void work(int k)
{
    #pragma omp ordered
    printf(" %d\n", k);
}

void ordered_example(int lb, int ub, int stride)
{
    int i;

    #pragma omp parallel for ordered schedule(dynamic)
    for (i=lb; i<ub; i+=stride)
        work(i);
}

int main()
{
    ordered_example(0, 100, 5);
    return 0;
}
```

Example 28.1f

```fortran
SUBROUTINE WORK(K)
    INTEGER K

    !$OMP ORDERED
    WRITE(*,*) K
    !$OMP END ORDERED

END SUBROUTINE WORK
```
SUBROUTINE SUB(LB, UB, STRIDE)
  INTEGER LB, UB, STRIDE
  INTEGER I

  !$OMP PARALLEL DO ORDERED SCHEDULE(DYNAMIC)
    DO I=LB,UB,STRIDE
      CALL WORK(I)
      END DO
  !$OMP END PARALLEL DO

END SUBROUTINE SUB

PROGRAM ORDERED_EXAMPLE
  CALL SUB(1,100,5)
END PROGRAM ORDERED_EXAMPLE

It is possible to have multiple ordered constructs within a loop region with the ordered clause specified. The first example is non-conforming because all iterations execute two ordered regions. An iteration of a loop must not execute more than one ordered region:
Example 28.2c

```c
void work(int i) {}

void ordered_wrong(int n)
{
  int i;
  #pragma omp for ordered
  for (i=0; i<n; i++) {
    /* incorrect because an iteration may not execute more than one
    ordered region */
    #pragma omp ordered
    work(i);
    #pragma omp ordered
    work(i+1);
  }
}
```

Example 28.2f

```fortran
SUBROUTINE WORK(I)
  INTEGER I
END SUBROUTINE WORK

SUBROUTINE ORDERED_WRONG(N)
  INTEGER N
  INTEGER I
  !$OMP   DO ORDERED
  DO I = 1, N
    !$omp ordered
    CALL WORK(I)
    !$omp ordered
    CALL WORK(I+1)
  !$OMP   END ORDERED
END DO
END SUBROUTINE ORDERED_WRONG
```

The following is a conforming example with more than one `ordered` construct. Each iteration will execute only one `ordered` region:
Example 28.3c

```c
void work(int i) {}  
void ordered_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);  
  }  
}  
}  
```

Example 28.3f

```fortran
SUBROUTINE ORDERED_GOOD(N)  
INTEGER N  
!
OMP   DO ORDERED  
DO I = 1,N  
IF (I <= 10) THEN  
!OMP       ORDERED  
CALL WORK(I)  
!OMP       END ORDERED  
ENDIF  

IF (I > 10) THEN  
!OMP       ORDERED  
CALL WORK(I+1)  
!OMP       END ORDERED  
ENDDO  
END SUBROUTINE ORDERED_GOOD  
```
The following example shows how the `cancel` directive can be used to terminate an OpenMP region. Although the `cancel` construct terminates the OpenMP worksharing region, programmers must still track the exception through the pointer `ex` and issue a cancellation for the `parallel` region if an exception has been raised. The master thread checks the exception pointer to make sure that the exception is properly handled in the sequential part. If cancellation of the `parallel` region has been requested, some threads might have executed `phase_1()`. However, it is guaranteed that none of the threads executed `phase_2()`.

```c++
void example() {
    std::exception *ex = NULL;
    #pragma omp parallel shared(ex)
    {
        #pragma omp for
        for (int i = 0; i < N; i++) {
            // no 'if' that prevents compiler optimizations
            try {
                causes_an_exception();
            } catch (const std::exception *e) {
                // still must remember exception for later handling
                #pragma omp atomic write
                ex = e;
                // cancel worksharing construct
            }
            #pragma omp cancel for
        }
        // if an exception has been raised, cancel parallel region
        if (ex) {
            #pragma omp cancel parallel
        }
        phase_1();
        #pragma omp barrier
        phase_2();
    }
    // continue here if an exception has been thrown in the worksharing loop
    if (ex) {
        // handle exception stored in ex
    }
}
```
Example 29.1f

The following example illustrates the use of the `cancel` construct in error handling. If there is an error condition from the `allocate` statement, the cancellation is activated. The encountering thread sets the shared variable `err` and other threads of the binding thread set proceed to the end of the worksharing construct after the cancellation has been activated.

```fortran
subroutine example(n, dim)
    integer, intent(in) :: n, dim(n)
    integer :: i, s, err
    real, allocatable :: B(:)
    err = 0
    !$omp parallel shared(err)
    ! ...
    !$omp do private(s, B)
    do i=1, n
        !$omp cancellation point
        allocate(B(dim(i)), stat=s)
        if (s .gt. 0) then
            !$omp atomic write
            err = s
        !$omp cancel do
        endif
        ! ...
        ! deallocate private array B
        if (allocated(B)) then
            deallocate(B)
        endif
    enddo
    !$omp end parallel
end subroutine
```

Example 29.2c

The following example shows how to cancel a parallel search on a binary tree as soon as the search value has been detected. The code creates a task to descend into the child nodes of the current tree node. If the search value has been found, the code remembers the tree node with the found value through an `atomic` write to the result variable and then cancels execution of all search tasks. The function `search_tree_parallel` groups all search tasks into a single task group to control the effect of the `cancel` directive. The `level` argument is used to create undeferred tasks after the first ten levels of the tree.
binary_tree_t *search_tree(binary_tree_t *tree, int value, int level) {
    binary_tree_t *found = NULL;
    if (tree) {
        if (tree->value == value) {
            found = tree;
        }
        else {
#pragma omp task shared(found) if(level < 10)
            {
                binary_tree_t *found_left = NULL;
                found_left = search_tree(tree->left, value, level + 1);
                if (found_left) {
                    #pragma omp atomic write
                    found = found_left;
                    #pragma omp cancel taskgroup
                }
            }
#pragma omp task shared(found) if(level < 10)
            {
                binary_tree_t *found_right = NULL;
                found_right = search_tree(tree->right, value, level + 1);
                if (found_right) {
                    #pragma omp atomic write
                    found = found_right;
                    #pragma omp cancel taskgroup
                }
            }
#pragma omp taskwait
        }
    }
    return found;
}

binary_tree_t *search_tree_parallel(binary_tree_t *tree, int value) {
    binary_tree_t *found = NULL;
    #pragma omp parallel shared(found, tree, value)
    {
        #pragma omp master
        {
            #pragma omp taskgroup
            {
                found = search_tree(tree, value, 0);
            }
        }
    }
    return found;
}
Example 29.2f

The following is the equivalent parallel search example in Fortran.

```fortran
module parallel_search
    type binary_tree
        integer :: value
        type(binary_tree), pointer :: right
        type(binary_tree), pointer :: left
    end type
!
contains
recursive subroutine search_tree(tree, value, level, found)
    type(binary_tree), intent(in), pointer :: tree
    integer, intent(in) :: value, level
    type(binary_tree), pointer :: found
    type(binary_tree), pointer :: found_left => NULL(), found_right => NULL()
    !
    if (.not. associated(found)) then
        allocate(found)
    endif
    !
    if (associated(tree)) then
        if (tree%value .eq. value) then
            found = tree
        else
            !$omp task shared(found) if(level<10)
            call search_tree(tree%left, value, level+1, found_left)
            if (associated(found_left)) then
                !$omp atomic write
                found = found_left
            !
            !$omp cancel taskgroup
            endif
            !$omp end task
            !
            !$omp task shared(found) if(level<10)
            call search_tree(tree%right, value, level+1, found_right)
            if (associated(found_right)) then
                !$omp atomic write
                found = found_right
            !
            !$omp cancel taskgroup
            endif
            !$omp end task
            !
            !$omp taskwait
            endif
    endif
end subroutine
```
subroutine search_tree_parallel(tree, value, found)
    type(binary_tree), intent(in), pointer :: tree
    integer, intent(in) :: value
    type(binary_tree), pointer :: found
!
    if (associated(found)) then
        allocate(found)
    endif
!$omp parallel shared(found, tree, value)
!$omp master
!$omp taskgroup
    call search_tree(tree, value, 0, found)
!$omp end taskgroup
!$omp end master
!$omp end parallel
end subroutine
!
end module parallel_search
30 The threadprivate Directive

The following examples demonstrate how to use the threadprivate directive to give each thread a separate counter.

**Example 30.1c**

```c/c++
int counter = 0;
#pragma omp threadprivate(counter)

int increment_counter()
{
    counter++;
    return(counter);
}
```

**Example 30.1f**

```fortran
INTEGER FUNCTION INCREMENT_COUNTER()
COMMON/INC_COMMON/COUNTER
!$OMP THREADPRIVATE(/INC_COMMON/)
COUNTER = COUNTER +1
INCREMENT_COUNTER = COUNTER
RETURN
END FUNCTION INCREMENT_COUNTER
```

**Example 30.2c**

```c/c++
int increment_counter_2()
{
    static int counter = 0;
    #pragma omp threadprivate(counter)
    counter++;
    return(counter);
}
```
The following example demonstrates unspecified behavior for the initialization of a `threadprivate` variable. A `threadprivate` variable is initialized once at an unspecified point before its first reference. Because `a` is constructed using the value of `x` (which is modified by the statement `x++`), the value of `a.val` at the start of the `parallel` region could be either 1 or 2. This problem is avoided for `b`, which uses an auxiliary `const` variable and a copy-constructor.

**Example 30.3c**

```c++
class T {
    public:
        int val;
        T (int);
        T (const T&);
    };

T :: T (int v){
    val = v;
}

T :: T (const T& t) {
    val = t.val;
}

void g(T a, T b){
    a.val += b.val;
}

int x = 1;
T a(x);
const T b_aux(x); /* Capture value of x = 1 */
T b(b_aux);
#pragma omp threadprivate(a, b)

void f(int n) {
    x++;
    #pragma omp parallel for
    /* In each thread:
     * a is constructed from x (with value 1 or 2?)
     * b is copy-constructed from b_aux
     */

    for (int i=0; i<n; i++) {
        g(a, b); /* Value of a is unspecified. */
    }
}
```
The following examples show non-conforming uses and correct uses of the `threadprivate` directive.

The following example is non-conforming because the common block is not declared local to the subroutine that refers to it:

**Example 30.2f**

```fortran
MODULE INC_MODULE
    COMMON /T/ A
END MODULE INC_MODULE

SUBROUTINE INC_MODULE_WRONG()
    USE INC_MODULE
    !$OMP THREADPRIVATE(/T/)
    !non-conforming because /T/ not declared in INC_MODULE_WRONG
END SUBROUTINE INC_MODULE_WRONG
```

The following example is also non-conforming because the common block is not declared local to the subroutine that refers to it:

**Example 30.3f**

```fortran
SUBROUTINE INC_WRONG()
    COMMON /T/ A
    !$OMP THREADPRIVATE(/T/)
    CONTAINS
        SUBROUTINE INC_WRONG_SUB()
            !$OMP PARALLEL COPYIN(/T/)
            !non-conforming because /T/ not declared in INC_WRONG_SUB
            !$OMP END PARALLEL
        END SUBROUTINE INC_WRONG_SUB
    END SUBROUTINE INC_WRONG
```
The following example is a correct rewrite of the previous example:

Example 30.4f

```
SUBROUTINE INC_GOOD()
COMMON /T/ A
!$OMP THREADPRIVATE(/T/)
CONTAINS
   SUBROUTINE INC_GOOD_SUB()
   COMMON /T/ A
   !$OMP THREADPRIVATE(/T/)
   !$OMP PARALLEL COPYIN(/T/)
   !$OMP END PARALLEL
END SUBROUTINE INC_GOOD_SUB
END SUBROUTINE INC_GOOD
```

The following is an example of the use of `threadprivate` for local variables:

Example 30.5f

```
PROGRAM INC_GOOD2
   INTEGER, ALLOCATABLE, SAVE :: A(:)
   INTEGER, POINTER, SAVE :: PTR
   INTEGER, SAVE :: I
   INTEGER, TARGET :: TARG
   LOGICAL :: FIRSTIN = .TRUE.
   !$OMP THREADPRIVATE(A, I, PTR)
   ALLOCATE (A(3))
   A = (/1,2,3/)
   PTR => TARG
   I = 5
   !$OMP PARALLEL COPYIN(I, PTR)
   !$OMP CRITICAL
   IF (FIRSTIN) THEN
      TARG = 4           ! Update target of ptr
      I = I + 10
      IF (ALLOCATED(A)) A = A + 10
      FIRSTIN = .FALSE.
   END IF
   IF (ALLOCATED(A)) THEN
      PRINT *, 'a = ', A
   ELSE
```
The above program, if executed by two threads, will print one of the following two sets of output:

```
  a = 11 12 13
  ptr = 4
  i = 15

  A is not allocated
  ptr = 4
  i = 5

  or

  A is not allocated
  ptr = 4
  i = 15

  a = 1 2 3
  ptr = 4
  i = 5
```

The following is an example of the use of `threadprivate` for module variables:

**Example 30.6f**

```
MODULE INC_MODULE_GOOD3
  REAL, POINTER :: WORK(:)
  SAVE WORK
  !$OMP THREADPRIVATE(WORK)
END MODULE INC_MODULE_GOOD3

SUBROUTINE SUB1(N)
  USE INC_MODULE_GOOD3
  !$OMP PARALLEL PRIVATE(THE_SUM)
  ALLOCATE(WORK(N))
END SUBROUTINE SUB1
```
CALL SUB2(THE_SUM)
WRITE(*,*)THE_SUM
!$OMP END PARALLEL
END SUBROUTINE SUB1

SUBROUTINE SUB2(THE_SUM)
USE INC_MODULE_GOOD3
WORK(:) = 10
THE_SUM=SUM(WORK)
END SUBROUTINE SUB2

END PROGRAM INC_GOOD3

The following example illustrates initialization of threadprivate variables for class-type T. t1 is default constructed, t2 is constructed taking a constructor accepting one argument of integer type, t3 is copy constructed with argument f():

Example 30.4c

static T t1;
#pragma omp threadprivate(t1)
static T t2(23);
#pragma omp threadprivate(t2)
static T t3 = f();
#pragma omp threadprivate(t3)

The following example illustrates the use of threadprivate for static class members. The threadprivate directive for a static class member must be placed inside the class definition.

Example 30.5c

class T {
public:
  static int i;
#pragma omp threadprivate(i)
};
31

Parallel Random Access Iterator Loop

The following example shows a parallel random access iterator loop.

Example 31.1c

```c++
#include <vector>
void iterator_example()
{
    std::vector<int> vec(23);
    std::vector<int>::iterator it;
    #pragma omp parallel for default(none) shared(vec)
    for (it = vec.begin(); it < vec.end(); it++)
    {
        // do work with *it //
    }
}
```

```c++
```
Fortran Restrictions on shared and private Clauses with Common Blocks

When a named common block is specified in a private, firstprivate, or lastprivate clause of a construct, none of its members may be declared in another data-sharing attribute clause on that construct. The following examples illustrate this point.

The following example is conforming:

Example 32.1f

```fortran
SUBROUTINE COMMON_GOOD()
    COMMON /C/ X,Y
    REAL X, Y

    !$OMP PARALLEL PRIVATE (/C/)
    ! do work here
    !$OMP END PARALLEL
    !$OMP PARALLEL SHARED (X,Y)
    ! do work here
    !$OMP END PARALLEL
    END SUBROUTINE COMMON_GOOD
```

The following example is also conforming:

Example 32.2f

```fortran
SUBROUTINE COMMON_GOOD2()
    COMMON /C/ X,Y
    REAL X, Y
    INTEGER I

    !$OMP PARALLEL
    !$OMP DO PRIVATE(/C/)
    DO I=1,1000
        ! do work here
    ENDDO
    !$OMP END DO
    !$OMP DO PRIVATE(X)
    DO I=1,1000
        ! do work here
    ENDDO
    !$OMP END PARALLEL
    END SUBROUTINE COMMON_GOOD2
```
The following example is conforming:

Example 32.3f

```fortran
SUBROUTINE COMMON_GOOD3()
  COMMON /C/ X,Y
  !$OMP PARALLEL PRIVATE (/C/)
    ! do work here
  !$OMP END PARALLEL
  !$OMP PARALLEL SHARED (/C/)
    ! do work here
  !$OMP END PARALLEL
END SUBROUTINE COMMON_GOOD3
```

The following example is non-conforming because x is a constituent element of c:

Example 32.4f

```fortran
SUBROUTINE COMMON_WRONG()
  COMMON /C/ X,Y
  ! Incorrect because X is a constituent element of C
  !$OMP PARALLEL PRIVATE(/C/), SHARED(X)
    ! do work here
  !$OMP END PARALLEL
END SUBROUTINE COMMON_WRONG
```

The following example is non-conforming because a common block may not be declared both shared and private:

Example 32.5f

```fortran
SUBROUTINE COMMON_WRONG2()
  COMMON /C/ X,Y
  ! Incorrect: common block C cannot be declared both shared and private
  !$OMP PARALLEL PRIVATE (/C/), SHARED(/C/)
    ! do work here
  !$OMP END PARALLEL
END SUBROUTINE COMMON_WRONG2
```
The `default(none)` Clause

The following example distinguishes the variables that are affected by the `default(none)` clause from those that are not.

**Example 33.1c**

```c
#include <omp.h>
int x, y, z[1000];
#pragma omp threadprivate(x)

void default_none(int a) {
    const int c = 1;
    int i = 0;

    #pragma omp parallel default(none) private(a) shared(z)
    {
        int j = omp_get_num_threads();
        /* O.K. - j is declared within parallel region */
        a = z[j]; /* O.K. - a is listed in private clause */
        /* - z is listed in shared clause */
        x = c; /* O.K. - x is threadprivate */
        /* - c has const-qualified type */
        z[i] = y; /* Error - cannot reference i or y here */

        #pragma omp for firstprivate(y)
        /* Error - Cannot reference y in the firstprivate clause */
        for (i=0; i<10 ; i++) {
            z[i] = i; /* O.K. - i is the loop iteration variable */
        }

        z[i] = y; /* Error - cannot reference i or y here */
    }
}
```

**Example 33.1f**

```fortran
SUBROUTINE DEFAULT_NONE(A)
INCLUDE "omp_lib.h" ! or USE OMP_LIB

INTEGER A
```
INTEGER X, Y, Z(1000)
COMMON/BLOCKX/X
COMMON/BLOCKY/Y
COMMON/BLOCKZ/Z
 !$OMP THREADPRIVATE(/BLOCKX/)

INTEGER I, J
i = 1

 !$OMP PARALLEL DEFAULT(NONE) PRIVATE(A) SHARED(Z) PRIVATE(J)
J = OMP_GET_NUM_THREADS();
   ! O.K.  - J is listed in PRIVATE clause
A = Z(J) ! O.K.  - A is listed in PRIVATE clause
   !     - Z is listed in SHARED clause
X = 1    ! O.K.  - X is THREADPRIVATE
Z(I) = Y ! Error - cannot reference I or Y here

 !$OMP DO firstprivate(y)
   ! Error - Cannot reference y in the firstprivate clause
DO I = 1,10
   Z(I) = I ! O.K.  - I is the loop iteration variable
END DO

Z(I) = Y    ! Error - cannot reference I or Y here
 !$OMP END PARALLEL
END SUBROUTINE DEFAULT_NONE

---

Fortran
Race Conditions Caused by Implied Copies of Shared Variables in Fortran

The following example contains a race condition, because the shared variable, which is an array section, is passed as an actual argument to a routine that has an assumed-size array as its dummy argument. The subroutine call passing an array section argument may cause the compiler to copy the argument into a temporary location prior to the call and copy from the temporary location into the original variable when the subroutine returns. This copying would cause races in the parallel region.

Example 34.1f

```fortran
SUBROUTINE SHARED_RACE

  INCLUDE "omp_lib.h" ! or USE OMP_LIB

  REAL A(20)
  INTEGER MYTHREAD

  !$OMP PARALLEL SHARED(A) PRIVATE(MYTHREAD)

  MYTHREAD = OMP_GET_THREAD_NUM()
  IF (MYTHREAD .EQ. 0) THEN
    CALL SUB(A(1:10)) ! compiler may introduce writes to A(6:10)
  ELSE
    A(6:10) = 12
  ENDIF

  !$OMP END PARALLEL

END SUBROUTINE SHARED_RACE

SUBROUTINE SUB(X)

  REAL X(*)
  X(1:5) = 4

END SUBROUTINE SUB
```
35 The private Clause

In the following example, the values of original list items \( i \) and \( j \) are retained on exit from the parallel region, while the private list items \( i \) and \( j \) are modified within the parallel construct.

---

**C/C++ Example 35.1c**

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

int main()
{
    int i, j;
    int *ptr_i, *ptr_j;

    i = 1;
    j = 2;

    ptr_i = &i;
    ptr_j = &j;

    #pragma omp parallel private(i) firstprivate(j)
    {
        i = 3;
        j = j + 2;
    
        assert (*ptr_i == 1 && *ptr_j == 2);
    }

    assert(i == 1 && j == 2);

    return 0;
}
```

---

**Fortran Example 35.1f**

```fortran
PROGRAM PRIV_EXAMPLE
    INTEGER I, J

    I = 1
    J = 2

    !$OMP PARALLEL PRIVATE(I) FIRSTPRIVATE(J)
```

---
In the following example, all uses of the variable \( a \) within the loop construct in the routine \( f \) refer to a private list item \( a \), while it is unspecified whether references to \( a \) in the routine \( g \) are to a private list item or the original list item.

Example 35.2c

```c
int a;

void g(int k) {
    a = k; /* Accessed in the region but outside of the construct; therefore unspecified whether original or private list item is modified. */
}

void f(int n) {
    int a = 0;

    #pragma omp parallel for private(a)
    for (int i=1; i<n; i++) {
        a = i;
        g(a*2); /* Private copy of "a" */
    }
}
```

Example 35.2f

```fortran
MODULE PRIV_EXAMPLE2
    REAL A
    CONTAINS

    SUBROUTINE G(K)
        REAL K
        A = K    ! Accessed in the region but outside of the construct; therefore unspecified whether original or private list item is modified.
    END SUBROUTINE G
END MODULE PRIV_EXAMPLE2
```
The following example demonstrates that a list item that appears in a `private` clause in a `parallel` construct may also appear in a `private` clause in an enclosed worksharing construct, which results in an additional private copy.
Example 35.3c

```c
#include <assert.h>
void priv_example3()
{
    int i, a;

    #pragma omp parallel private(a)
    {
        a = 1;
        #pragma omp parallel for private(a)
        for (i=0; i<10; i++)
        {
            a = 2;
        }
        assert(a == 1);
    }
}
```

Example 35.3f

```fortran
SUBROUTINE PRIV_EXAMPLE3()
    INTEGER I, A
    !$OMP PARALLEL PRIVATE(A)
        A = 1
    !$OMP PARALLEL DO PRIVATE(A)
        DO I = 1, 10
            A = 2
        END DO
    !$OMP END PARALLEL DO
    PRINT *, A ! Outer A still has value 1
    !$OMP END PARALLEL
END SUBROUTINE PRIV_EXAMPLE3
```
36 Fortran Restrictions on Storage Association with the `private` Clause

The following non-conforming examples illustrate the implications of the `private` clause rules with regard to storage association.

**Example 36.1f**

```fortran
SUBROUTINE SUB()
    COMMON /BLOCK/ X
    PRINT *,X          ! X is undefined
END SUBROUTINE SUB

PROGRAM PRIV_RESTRICT
    COMMON /BLOCK/ X
    X = 1.0
    !$OMP PARALLEL PRIVATE (X)
    X = 2.0
    CALL SUB()
    !$OMP END PARALLEL
END PROGRAM PRIV_RESTRICT
```

**Example 36.2f**

```fortran
PROGRAM PRIV_RESTRICT2
    COMMON /BLOCK2/ X
    X = 1.0
    !$OMP PARALLEL PRIVATE (X)
    X = 2.0
    CALL SUB()
    !$OMP END PARALLEL

CONTAINS

    SUBROUTINE SUB()
        COMMON /BLOCK2/ Y
        PRINT *,X              ! X is undefined
        PRINT *,Y              ! Y is undefined
    END SUBROUTINE SUB

    END PROGRAM PRIV_RESTRICT2
```
Example 36.3f

```fortran
PROGRAM PRIV_RESTRICT3
EQUIVALENCE (X,Y)
X = 1.0

!$OMP PARALLEL PRIVATE(X)
  PRINT *,Y                  ! Y is undefined
  Y = 10
  PRINT *,X                  ! X is undefined
!$OMP END PARALLEL
END PROGRAM PRIV_RESTRICT3
```

Example 36.4f

```fortran
PROGRAM PRIV_RESTRICT4
INTEGER I, J
INTEGER A(100), B(100)
EQUIVALENCE (A(51), B(1))

!$OMP PARALLEL DO DEFAULT(PRIVATE) PRIVATE(I,J) LASTPRIVATE(A)
  DO I=1,100
    DO J=1,100
      B(J) = J - 1
    ENDDO
    DO J=1,100
      A(J) = J   ! B becomes undefined at this point
    ENDDO
    DO J=1,50
      B(J) = B(J) + 1  ! B is undefined
                       ! A becomes undefined at this point
    ENDDO
  ENDDO
!$OMP END PARALLEL DO       ! The LASTPRIVATE write for A has
                           ! undefined results
  PRINT *, B                  ! B is undefined since the LASTPRIVATE
                           ! write of A was not defined
END PROGRAM PRIV_RESTRICT4
```
Example 36.5f

SUBROUTINE SUB1(X)
    DIMENSION X(10)

    ! This use of X does not conform to the
    ! specification. It would be legal Fortran 90,
    ! but the OpenMP private directive allows the
    ! compiler to break the sequence association that
    ! A had with the rest of the common block.

    FORALL (I = 1:10) X(I) = I
END SUBROUTINE SUB1

PROGRAM PRIV_RESTRICT5
    COMMON /BLOCK5/ A

    DIMENSION B(10)
    EQUIVALENCE (A,B(1))

    ! the common block has to be at least 10 words
    A = 0

    !$OMP PARALLEL PRIVATE(/BLOCK5/)
    ! Without the private clause,
    ! we would be passing a member of a sequence
    ! that is at least ten elements long.
    ! With the private clause, A may no longer be
    ! sequence-associated.

    CALL SUB1(A)
    !$OMP MASTER
    PRINT *, A
    !$OMP END MASTER

    !$OMP END PARALLEL
END PROGRAM PRIV_RESTRICT5

Fortran
C/C++ Arrays in a firstprivate Clause

The following example illustrates the size and value of list items of array or pointer type in a `firstprivate` clause. The size of new list items is based on the type of the corresponding original list item, as determined by the base language.

In this example:

- The type of `A` is array of two arrays of two ints.
- The type of `B` is adjusted to pointer to array of `n` ints, because it is a function parameter.
- The type of `C` is adjusted to pointer to int, because it is a function parameter.
- The type of `D` is array of two arrays of two ints.
- The type of `E` is array of `n` arrays of `n` ints.

Note that `B` and `E` involve variable length array types.

The new items of array type are initialized as if each integer element of the original array is assigned to the corresponding element of the new array. Those of pointer type are initialized as if by assignment from the original item to the new item.
Example 37.1c

```c
#include <assert.h>

int A[2][2] = {1, 2, 3, 4};

void f(int n, int B[n][n], int C[])
{
    int D[2][2] = {1, 2, 3, 4};
    int E[n][n];

    assert(n >= 2);
    E[1][1] = 4;

    #pragma omp parallel firstprivate(B, C, D, E)
    {
        assert(sizeof(B) == sizeof(int (*)[n]));
        assert(sizeof(C) == sizeof(int*));
        assert(sizeof(D) == 4 * sizeof(int));
        assert(sizeof(E) == n * n * sizeof(int));

        /* Private B and C have values of original B and C. */
        assert(&B[1][1] == &A[1][1]);
        assert(&C[3] == &A[1][1]);
        assert(D[1][1] == 4);
        assert(E[1][1] == 4);
    }
}

int main()
{
    f(2, A, A[0]);
    return 0;
}
```

C/C++
The lastprivate Clause

Correct execution sometimes depends on the value that the last iteration of a loop assigns to a variable. Such programs must list all such variables in a lastprivate clause so that the values of the variables are the same as when the loop is executed sequentially.

C/C++

Example 38.1c

```c
void lastpriv (int n, float *a, float *b)
{
    int i;

    #pragma omp parallel
    {
        #pragma omp for lastprivate(i)
        for (i=0; i<n-1; i++)
            a[i] = b[i] + b[i+1];
    }

    a[i]=b[i];      /* i == n-1 here */
}
```

Fortran

Example 38.1f

```fortran
SUBROUTINE LASTPRIV(N, A, B)
    INTEGER N
    REAL A(*), B(*)
    INTEGER I

    !$OMP PARALLEL
    !$OMP DO LASTPRIVATE(I)
    DO I=1,N-1
        A(I) = B(I) + B(I+1)
    ENDDO

    !$OMP END PARALLEL
    A(I) = B(I)      ! I has the value of N here

END SUBROUTINE LASTPRIV
```
39 The reduction Clause

The following example demonstrates the reduction clause; note that some reductions can be expressed in the loop in several ways, as shown for the max and min reductions below:

C/C++

Example 39.1c

#include <math.h>
void reduction1(float *x, int *y, int n)
{
    int i, b, c;
    float a, d;
    a = 0.0;
    b = 0;
    c = y[0];
    d = x[0];
    #pragma omp parallel for private(i) shared(x, y, n) \ 
        reduction(+:a) reduction(^:b) \ 
        reduction(min:c) reduction(max:d)
    for (i=0; i<n; i++) {
        a += x[i];
        b ^= y[i];
        if (c > y[i]) c = y[i];
        d = fmaxf(d, x[i]);
    }
}

C/C++

Fortran

Example 39.1f

SUBROUTINE REDUCTION1(A, B, C, D, X, Y, N)
    REAL :: X(*), A, D
    INTEGER :: Y(*), N, B, C
    INTEGER :: I
    A = 0
    B = 0
    C = Y(1)
    D = X(1)
    !$OMP PARALLEL DO PRIVATE(I) SHARED(X, Y, N) REDUCTION(+:A) &
    !$OMP& REDUCTION(IEOR:B) REDUCTION(MIN:C) REDUCTION(MAX:D)
    DO I=1,N
        A = A + X(I)
        B = Ieor(B, Y(I))
    }
C = MIN(C, Y(I))
    IF (D < X(I)) D = X(I)
END DO

END SUBROUTINE REDUCTION1

A common implementation of the preceding example is to treat it as if it had been written as follows:

Example 39.2c

```
#include <limits.h>
#include <math.h>

void reduction2(float *x, int *y, int n)
{
    int i, b, b_p, c, c_p;
    float a, a_p, d, d_p;
    a = 0.0f;
    b = 0;
    c = y[0];
    d = x[0];
    #pragma omp parallel shared(a, b, c, d, x, y, n) \ 
        private(a_p, b_p, c_p, d_p)
    {
        a_p = 0.0f;
        b_p = 0;
        c_p = INT_MAX;
        d_p = -HUGE_VALF;
        #pragma omp for private(i)
        for (i=0; i<n; i++) {
            a_p += x[i];
            b_p ^= y[i];
            if (c_p > y[i]) c_p = y[i];
            d_p = fmaxf(d_p, x[i]);
        }
        #pragma omp critical
        {
            a += a_p;
            b ^= b_p;
            if (c > c_p) c = c_p;
            d = fmaxf(d, d_p);
        }
    }
}
```
Example 39.2f

```fortran
SUBROUTINE REDUCTION2(A, B, C, D, X, Y, N)
REAL :: X(*), A, D
INTEGER :: Y(*), N, B, C
REAL :: A_P, D_P
INTEGER :: I, B_P, C_P
A = 0
B = 0
C = Y(1)
D = X(1)
!$OMP PARALLEL SHARED(X, Y, A, B, C, D, N) &
!$OMP PRIVATE(A_P, B_P, C_P, D_P)
A_P = 0.0
B_P = 0
C_P = HUGE(C_P)
D_P = -HUGE(D_P)
!$OMP DO PRIVATE(I)
DO I=1,N
A_P = A_P + X(I)
B_P = IEOR(B_P, Y(I))
C_P = MIN(C_P, Y(I))
IF (D_P < X(I)) D_P = X(I)
END DO
!$OMP CRITICAL
A = A + A_P
B = IEOR(B, B_P)
C = MIN(C, C_P)
D = MAX(D, D_P)
!$OMP END CRITICAL
!$OMP END PARALLEL
END SUBROUTINE REDUCTION2
```

The following program is non-conforming because the reduction is on the intrinsic procedure name `MAX` but that name has been redefined to be the variable named `MAX`.

Example 39.3f

```fortran
PROGRAM REDUCTION_WRONG
MAX = HUGE(0)
M = 0

!$OMP PARALLEL DO REDUCTION(MAX: M)
! MAX is no longer the intrinsic so this is non-conforming
DO I = 1, 100
CALL SUB(M, I)
END DO
```

```fortran
SUBROUTINE SUB(M, I)
M = M + 1
END SUBROUTINE SUB
```
END DO

END PROGRAM REDUCTION_WRONG

SUBROUTINE SUB(M, I)
    M = MAX(M, I)
END SUBROUTINE SUB

The following conforming program performs the reduction using the *intrinsic procedure name* MAX even though the intrinsic MAX has been renamed to REN.

**Example 39.4f**

```fortran
MODULE M
    INTRINSIC MAX
END MODULE M

PROGRAM REDUCTION3
    USE M, REN => MAX
    N = 0
    !$OMP PARALLEL DO REDUCTION(REN: N)     ! still does MAX
    DO I = 1, 100
        N = MAX(N, I)
    END DO
    END PROGRAM REDUCTION3
```

The following conforming program performs the reduction using intrinsic procedure name MAX even though the intrinsic MAX has been renamed to MIN.

**Example 39.5f**

```fortran
MODULE MOD
    INTRINSIC MAX, MIN
END MODULE MOD

PROGRAM REDUCTION4
    USE MOD, MIN=>MAX, MAX=>MIN
    REAL :: R
    R = -HUGE(0.0)
    !$OMP PARALLEL DO REDUCTION(MIN: R)     ! still does MAX
    DO I = 1, 1000
        R = MIN(R, SIN(REAL(I)))
    END DO
    PRINT *, R
END PROGRAM REDUCTION4
```
The following example is non-conforming because the initialization \((a = 0)\) of the original list item \(a\) is not synchronized with the update of \(a\) as a result of the reduction computation in the \texttt{for} loop. Therefore, the example may print an incorrect value for \(a\).

To avoid this problem, the initialization of the original list item \(a\) should complete before any update of \(a\) as a result of the \texttt{reduction} clause. This can be achieved by adding an explicit barrier after the assignment \(a = 0\), or by enclosing the assignment \(a = 0\) in a \texttt{single} directive (which has an implied barrier), or by initializing \(a\) before the start of the \texttt{parallel} region.

---

**Example 39.3c**

```c
#include <stdio.h>

int main (void)
{
    int a, i;

    #pragma omp parallel shared(a) private(i)
    {
        #pragma omp master
        a = 0;

        // To avoid race conditions, add a barrier here.

        #pragma omp for reduction(+:a)
        for (i = 0; i < 10; i++) {
            a += i;
        }

        #pragma omp single
        printf ("Sum is %d\n", a);
    }
}
```

---

**Example 39.6f**

```fortran
INTEGER A, I

!$OMP PARALLEL SHARED(A) PRIVATE(I)

!$OMP MASTER
A = 0
```

---
To avoid race conditions, add a barrier here.

```fortran
!$OMP END MASTER

!$OMP DO REDUCTION(+:A)
    DO I = 0, 9
        A = A + I
    END DO

!$OMP SINGLE
    PRINT *, "Sum is ", A
!$OMP END SINGLE

!$OMP END PARALLEL
END
```
## The \texttt{copyin} Clause

The \texttt{copyin} clause is used to initialize threadprivate data upon entry to a \texttt{parallel} region. The value of the threadprivate variable in the master thread is copied to the threadprivate variable of each other team member.

\begin{Verbatim}
Example 40.1c

#include <stdlib.h>

float* work;
int size;
float tol;

#pragma omp threadprivate(work,size,tol)

void build()
{
    int i;
    work = (float*)malloc( sizeof(float)*size );
    for( i = 0; i < size; ++i ) work[i] = tol;
}

void copyin_example( float t, int n )
{
    tol = t;
    size = n;
    #pragma omp parallel copyin(tol,size)
    {
        build();
    }
}
\end{Verbatim}

\begin{Verbatim}
Example 40.1f

MODULE M
REAL, POINTER, SAVE :: WORK(:)
INTEGER :: SIZE
REAL :: TOL
!$OMP THREADPRIVATE(WORK,SIZE,TOL)
END MODULE M
\end{Verbatim}
SUBROUTINE COPYIN_EXAMPLE( T, N )
USE M
REAL :: T
INTEGER :: N
TOL = T
SIZE = N
!$OMP PARALLEL COPYIN(TOL,SIZE)
CALL BUILD
!$OMP END PARALLEL
END SUBROUTINE COPYIN_EXAMPLE

SUBROUTINE BUILD
USE M
ALLOCATE(WORK(SIZE))
WORK = TOL
END SUBROUTINE BUILD
The **copyprivate** Clause

The **copyprivate** clause can be used to broadcast values acquired by a single thread directly to all instances of the private variables in the other threads. In this example, if the routine is called from the sequential part, its behavior is not affected by the presence of the directives. If it is called from a **parallel** region, then the actual arguments with which **a** and **b** are associated must be private.

The thread that executes the structured block associated with the **single** construct broadcasts the values of the private variables **a**, **b**, **x**, and **y** from its implicit task's data environment to the data environments of the other implicit tasks in the thread team. The broadcast completes before any of the threads have left the barrier at the end of the construct.

### Example 41.1c

```c
#include <stdio.h>
float x, y;
#pragma omp threadprivate(x, y)
void init(float a, float b ) {
    #pragma omp single copyprivate(a,b,x,y)
    {
        scanf("%f %f %f %f", &a, &b, &x, &y);
    }
}
```

### Example 41.1f

```fortran
SUBROUTINE INIT(A,B)
REAL A, B
COMMON /XY/ X,Y
!$OMP THREADPRIVATE (/XY/)
!$OMP SINGLE
    READ (11) A,B,X,Y
!$OMP END SINGLE COPYPRIVATE (A,B,/XY/)
END SUBROUTINE INIT
```
In this example, assume that the input must be performed by the master thread. Since the `master` construct does not support the `copyprivate` clause, it cannot broadcast the input value that is read. However, `copyprivate` is used to broadcast an address where the input value is stored.

**Example 41.2c**

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

float read_next() {
    float * tmp;
    float return_val;

    #pragma omp single copyprivate(tmp)
    {
        tmp = (float *) malloc(sizeof(float));
    }  /* copies the pointer only */

    #pragma omp master
    {
        scanf("%f", tmp);
    }

    #pragma omp barrier
    return_val = *tmp;
    #pragma omp barrier
    #pragma omp single nowait
    {
        free(tmp);
    }

    return return_val;
}
```

**Example 41.2f**

```fortran
REAL FUNCTION READ_NEXT()
REAL, POINTER :: TMP

!$OMP   SINGLE
ALLOCATE (TMP)
!$OMP END SINGLE COPYPRIVATE (TMP)  ! copies the pointer only
```
Suppose that the number of lock variables required within a parallel region cannot easily be determined prior to entering it. The copyprivate clause can be used to provide access to shared lock variables that are allocated within that parallel region.

Example 41.3c

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

omp_lock_t *new_lock()
{
    omp_lock_t *lock_ptr;

    #pragma omp single copyprivate(lock_ptr)
    {
        lock_ptr = (omp_lock_t *) malloc(sizeof(omp_lock_t));
        omp_init_lock(lock_ptr);
    }

    return lock_ptr;
}
```

Example 41.3f

```fortran
FUNCTION NEW_LOCK()
USE OMP_LIB       ! or INCLUDE "omp_lib.h"
    INTEGER(OMP_LOCK_KIND), POINTER :: NEW_LOCK

!$OMP   SINGLE
```
ALLOCATE(NEW_LOCK)
CALL OMP_INIT_LOCK(NEW_LOCK)
 !$OMP END SINGLE COPYPRIVATE(NEW_LOCK)
END FUNCTION NEW_LOCK

Note that the effect of the copyprivate clause on a variable with the allocatable attribute is different than on a variable with the pointer attribute. The value of \texttt{A} is copied (as if by intrinsic assignment) and the pointer \texttt{B} is copied (as if by pointer assignment) to the corresponding list items in the other implicit tasks belonging to the parallel region.

\textit{Example 41.4f}

SUBROUTINE S(N)
INTEGER N

REAL, DIMENSION(:,), ALLOCATABLE :: A
REAL, DIMENSION(:,), POINTER :: B

ALLOCATE (A(N))
 !$OMP SINGLE
 ALLOCATE (B(N))
 READ (11) A,B
 !$OMP END SINGLE COPYPRIVATE(A,B)
 ! Variable \texttt{A} is private and is
 ! assigned the same value in each thread
 ! Variable \texttt{B} is shared

 !$OMP BARRIER
 !$OMP SINGLE
 DEALLOCATE (B)
 !$OMP END SINGLE NOWAIT
END SUBROUTINE S

---

Fortran
42  Nested Loop Constructs

The following example of loop construct nesting is conforming because the inner and outer loop regions bind to different parallel regions:

**Example 42.1c**

```c
void work(int i, int j) {}  
void good_nesting(int n)  
{  
   int i, j;  
   #pragma omp parallel default(shared)  
   {  
      #pragma omp for  
      for (i=0; i<n; i++)  
      #pragma omp parallel shared(i, n)  
      {  
         #pragma omp for  
         for (j=0; j < n; j++)  
         work(i, j);  
      }  
   }  
}
```

**Example 42.1f**

```fortran
SUBROUTINE WORK(I, J)  
INTEGER I, J  
END SUBROUTINE WORK

SUBROUTINE GOOD_NESTING(N)  
INTEGER N  
INTEGER I  
!$OMP PARALLEL DEFAULT(SHARED)  
!$OMP DO  
DO I = 1, N  
!$OMP PARALLEL SHARED(I,N)  
!$OMP DO  
DO J = 1, N  
CALL WORK(I,J)
```
END DO
!$OMP END PARALLEL
END DO
!$OMP END PARALLEL
END SUBROUTINE GOOD_NESTING
The following variation of the preceding example is also conforming:

**Example 42.2c**

```c
void work(int i, int j) {}

void work1(int i, int n)
{
    int j;
    #pragma omp parallel default(shared)
    {
        #pragma omp for
        for (j=0; j<n; j++)
            work(i, j);
    }
}

void good_nesting2(int n)
{
    int i;
    #pragma omp parallel default(shared)
    {
        #pragma omp for
        for (i=0; i<n; i++)
            work1(i, n);
    }
}
```

**Example 42.2f**

```fortran
SUBROUTINE WORK(I, J)
INTEGER I, J
END SUBROUTINE WORK

SUBROUTINE WORK1(I, N)
INTEGER J
!$OMP PARALLEL DEFAULT(SHARED)
!$OMP DO
    DO J = 1, N
        CALL WORK(I,J)
    END DO
!$OMP END PARALLEL
END SUBROUTINE WORK1
```
SUBROUTINE GOOD_NESTING2(N)
INTEGER N
!$OMP PARALLEL DEFAULT(SHARED)
!$OMP DO
   DO I = 1, N
      CALL WORK1(I, N)
   END DO
!$OMP END PARALLEL
END SUBROUTINE GOOD_NESTING2
43  Restrictions on Nesting of Regions

The examples in this section illustrate the region nesting rules.

The following example is non-conforming because the inner and outer loop regions are closely nested:

Example 43.1c

```
void work(int i, int j) {}
void wrong1(int n)
{
    #pragma omp parallel default(shared)
    {
        int i, j;
        #pragma omp for
        for (i=0; i<n; i++) {
            /* incorrect nesting of loop regions */
            #pragma omp for
            for (j=0; j<n; j++)
                work(i, j);
        }
    }
}
```

Example 43.1f

```
SUBROUTINE WORK(I, J)
INTEGER I, J
END SUBROUTINE WORK
SUBROUTINE WRONG1(N)
INTEGER N
    INTEGER I,J
!$OMP PARALLEL DEFAULT(SHARED)
!$OMP DO
    DO I = 1, N
!$OMP DO   ! incorrect nesting of loop regions
        DO J = 1, N
            CALL WORK(I,J)
        END DO
    END DO
!$OMP END PARALLEL
```
END SUBROUTINE WRONG1

The following orphaned version of the preceding example is also non-conforming:

Example 43.2c

void work(int i, int j) {}
void work1(int i, int n)
{
  int j;
  /* incorrect nesting of loop regions */
  #pragma omp for
  for (j=0; j<n; j++)
    work(i, j);
}

void wrong2(int n)
{
  #pragma omp parallel default(shared)
  {
    int i;
    #pragma omp for
    for (i=0; i<n; i++)
      work1(i, n);
  }
}

Example 43.2f

SUBROUTINE WORK1(I,N)
  INTEGER I, N
  INTEGER J
  !$OMP DO ! incorrect nesting of loop regions
  DO J = 1, N
    CALL WORK(I,J)
  END DO
END SUBROUTINE WORK1
SUBROUTINE WRONG1(N)
  INTEGER N
  INTEGER I
  !$OMP PARALLEL DEFAULT(SHARED)
  !$OMP DO
    DO I = 1, N
      CALL WORK1(I,N)
    END DO
  !$OMP END PARALLEL
The following example is non-conforming because the loop and `single` regions are closely nested:

**Example 43.3c**

```c
void work(int i, int j) {}
void wrong3(int n)
{
    #pragma omp parallel default(shared)
    {
        int i;
        #pragma omp for
        for (i=0; i<n; i++) {
            /* incorrect nesting of regions */
            #pragma omp single
            work(i, 0);
        }
    }
}
```

**Example 43.3f**

```fortran
SUBROUTINE WRONG3(N)
INTEGER N

INTEGER I
!$OMP PARALLEL DEFAULT(SHARED)
!$OMP DO
    DO I = 1, N
    !$OMP SINGLE ! incorrect nesting of regions
        CALL WORK(I, 1)
    !$OMP END SINGLE
    END DO
!$OMP END PARALLEL
END SUBROUTINE WRONG3
```

The following example is non-conforming because a `barrier` region cannot be closely nested inside a loop region:
Example 43.4c

```c
void work(int i, int j) {}
void wrong4(int n) {
    #pragma omp parallel default(shared)
    {
        int i;
        #pragma omp for
        for (i=0; i<n; i++) {
            work(i, 0);
            /* incorrect nesting of barrier region in a loop region */
            #pragma omp barrier
            work(i, 1);
        }
    }
}
```

Example 43.4f

```fortran
SUBROUTINE WRONG4(N)
  INTEGER N

  INTEGER I
  !$OMP PARALLEL DEFAULT(SHARED)
  !$OMP DO
  DO I = 1, N
    CALL WORK(I, 1)
  ! incorrect nesting of barrier region in a loop region
  !$OMP BARRIER
  CALL WORK(I, 2)
  END DO
  !$OMP END PARALLEL
END SUBROUTINE WRONG4
```

The following example is non-conforming because the `barrier` region cannot be closely nested inside the `critical` region. If this were permitted, it would result in deadlock due to the fact that only one thread at a time can enter the `critical` region:


**Example 43.5c**

void work(int i, int j) {}
void wrong5(int n)
{
  #pragma omp parallel
  {
    #pragma omp critical
    {
      work(n, 0);
      /* incorrect nesting of barrier region in a critical region */
      #pragma omp barrier
      work(n, 1);
    }
  }
}

**Example 43.5f**

```fortran
SUBROUTINE WRONG5(N)
  INTEGER N
!$OMP   PARALLEL DEFAULT(SHARED)
!$OMP     CRITICAL
CALL WORK(N,1)
! incorrect nesting of barrier region in a critical region
!$OMP   BARRIER
CALL WORK(N,2)
!$OMP     END CRITICAL
!$OMP   END PARALLEL
END SUBROUTINE WRONG5
```

The following example is non-conforming because the **barrier** region cannot be closely nested inside the **single** region. If this were permitted, it would result in deadlock due to the fact that only one thread executes the **single** region:

**Example 43.6c**

void work(int i, int j) {}
void wrong6(int n)
{
  #pragma omp parallel
OpenMP Examples

Example 43.6f

```c
#include <omp.h>

C/C++

{ 
    #pragma omp single
    { 
        work(n, 0);
        /* incorrect nesting of barrier region in a single region */
        #pragma omp barrier
        work(n, 1);
    }
}
```

Fortran

```fortran
SUBROUTINE WRONG6(N)
    INTEGER N

    !$OMP PARALLEL DEFAULT(SHARED)
    !$OMP SINGLE
        CALL WORK(N,1)
    !$OMP BARRIER
        CALL WORK(N,2)
    !$OMP END SINGLE
    !$OMP END PARALLEL
END SUBROUTINE WRONG6
```

Fortran
The `omp_set_dynamic` and `omp_set_num_threads` Routines

Some programs rely on a fixed, prespecified number of threads to execute correctly. Because the default setting for the dynamic adjustment of the number of threads is implementation defined, such programs can choose to turn off the dynamic threads capability and set the number of threads explicitly to ensure portability. The following example shows how to do this using `omp_set_dynamic`, and `omp_set_num_threads`.

In this example, the program executes correctly only if it is executed by 16 threads. If the implementation is not capable of supporting 16 threads, the behavior of this example is implementation defined. Note that the number of threads executing a parallel region remains constant during the region, regardless of the dynamic threads setting. The dynamic threads mechanism determines the number of threads to use at the start of the parallel region and keeps it constant for the duration of the region.

```
Example 44.1c

#include <omp.h>
#include <stdlib.h>

void do_by_16(float *x, int iam, int ipoints) {} 

void dynthreads(float *x, int npoints)
{
  int iam, ipoints;

  omp_set_dynamic(0);
  omp_set_num_threads(16);

  #pragma omp parallel shared(x, npoints) private(iam, ipoints)
  {
    if (omp_get_num_threads() != 16)
      abort();

    iam = omp_get_thread_num();
    ipoints = npoints/16;
    do_by_16(x, iam, ipoints);
  }
}
```
Example 44.1f

```fortran
SUBROUTINE DO_BY_16(X, IAM, IPOINTS)
    REAL X(*)
    INTEGER IAM, IPOINTS
END SUBROUTINE DO_BY_16

SUBROUTINE DYNTHREADS(X, NPOINTS)

    INCLUDE "omp_lib.h" ! or USE OMP_LIB

    INTEGER NPOINTS
    REAL X(NPOINTS)
    INTEGER IAM, IPOINTS

    CALL OMP_SET_DYNAMIC(.FALSE.)
    CALL OMP_SET_NUM_THREADS(16)

    !$OMP PARALLEL SHARED(X,NPOINTS) PRIVATE(IAM, IPOINTS)

        IF (OMP_GET_NUM_THREADS() .NE. 16) THEN
            STOP
        ENDIF

        IAM = OMP_GET_THREAD_NUM()
        IPOINTS = NPOINTS/16
        CALL DO_BY_16(X,IAM,IPOINTS)

    !$OMP END PARALLEL

END SUBROUTINE DYNTHREADS
```
45 The `omp_get_num_threads` Routine

In the following example, the `omp_get_num_threads` call returns 1 in the sequential part of the code, so `np` will always be equal to 1. To determine the number of threads that will be deployed for the `parallel` region, the call should be inside the `parallel` region.

```
#include <omp.h>
void work(int i);

void incorrect()
{
    int np, i;

    np = omp_get_num_threads(); /* misplaced */

    #pragma omp parallel for schedule(static)
    for (i=0; i < np; i++)
        work(i);
}
```

```
SUBROUTINE WORK(I)
  INTEGER I
  I = I + 1
END SUBROUTINE WORK

SUBROUTINE INCORRECT()
  INCLUDE "omp_lib.h" ! or USE OMP_LIB
  INTEGER I, NP

  NP = OMP_GET_NUM_THREADS() ! misplaced: will return 1
  !$OMP PARALLEL DO SCHEDULE(STATIC)
  DO I = 0, NP-1
      CALL WORK(I)
  ENDDO
  !$OMP END PARALLEL DO
END SUBROUTINE INCORRECT
```
The following example shows how to rewrite this program without including a query for the number of threads:

---

**Example 45.2c**

```c
#include <omp.h>
void work(int i);

void correct()
{
    int i;

    #pragma omp parallel private(i)
    {
        i = omp_get_thread_num();
        work(i);
    }
}
```

---

**Example 45.2f**

```fortran
SUBROUTINE WORK(I)
    INTEGER I
    I = I + 1
END SUBROUTINE WORK

SUBROUTINE CORRECT()
    INCLUDE "omp_lib.h" ! or USE OMP_LIB
    INTEGER I

!$OMP PARALLEL PRIVATE(I)
    I = OMP_GET_THREAD_NUM()
    CALL WORK(I)
!$OMP END PARALLEL

END SUBROUTINE CORRECT
```
The \texttt{omp_init_lock} Routine

The following example demonstrates how to initialize an array of locks in a \texttt{parallel} region by using \texttt{omp_init_lock}.

\texttt{C/C++}

\begin{verbatim}
#include <omp.h>
omp_lock_t *new_locks()
{
    int i;
    omp_lock_t *lock = new omp_lock_t[1000];

    #pragma omp parallel for private(i)
    for (i=0; i<1000; i++)
        omp_init_lock(&lock[i]);

    return lock;
}
\end{verbatim}

\texttt{Fortran}

\begin{verbatim}
FUNCTION NEW_LOCKS()
    USE OMP_LIB        ! or INCLUDE "omp_lib.h"
    INTEGER(OMP_LOCK_KIND), DIMENSION(1000) :: NEW_LOCKS

    INTEGER I

    !$OMP PARALLEL DO PRIVATE(I)
        DO I=1,1000
            CALL OMP_INIT_LOCK(NEW_LOCKS(I))
        END DO
    !$OMP END PARALLEL DO

END FUNCTION NEW_LOCKS
\end{verbatim}
Ownership of Locks

Ownership of locks has changed since OpenMP 2.5. In OpenMP 2.5, locks are owned by threads; so a lock released by the `omp_unset_lock` routine must be owned by the same thread executing the routine. With OpenMP 3.0, locks are owned by task regions; so a lock released by the `omp_unset_lock` routine in a task region must be owned by the same task region.

This change in ownership requires extra care when using locks. The following program is conforming in OpenMP 2.5 because the thread that releases the lock `lck` in the parallel region is the same thread that acquired the lock in the sequential part of the program (master thread of parallel region and the initial thread are the same). However, it is not conforming in OpenMP 3.0 and 3.1, because the task region that releases the lock `lck` is different from the task region that acquires the lock.

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

int main()
{
    int x;
    omp_lock_t lck;

    omp_init_lock (&lck);
    omp_set_lock (&lck);
    x = 0;

    #pragma omp parallel shared (x)
    {
        #pragma omp master
        {
            x = x + 1;
            omp_unset_lock (&lck);
        }

        /* Some more stuff. */
    }
    omp_destroy_lock (&lck);
    return 0;
}
```
Example 47.1f

```fortran
program lock
use omp_lib
integer :: x
integer (kind=omp_lock_kind) :: lck

call omp_init_lock (lck)
call omp_set_lock (lck)
x = 0

!$omp parallel shared (x)
!$omp master
  x = x + 1
  call omp_unset_lock(lck)
!$omp end master

! Some more stuff.
!$omp end parallel

call omp_destroy_lock(lck)
end
```
Simple Lock Routines

In the following example, the lock routines cause the threads to be idle while waiting for entry to the first critical section, but to do other work while waiting for entry to the second. The `omp_set_lock` function blocks, but the `omp_test_lock` function does not, allowing the work in `skip` to be done.

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

void skip(int i) {}
void work(int i) {}

int main() {
    omp_lock_t lck;
    int id;
    omp_init_lock(&lck);

    #pragma omp parallel shared(lck) private(id)
    {
        id = omp_get_thread_num();

        omp_set_lock(&lck);
        /* only one thread at a time can execute this printf */
        printf("My thread id is %d.\n", id);
        omp_unset_lock(&lck);

        while (! omp_test_lock(&lck)) {
            skip(id); /* we do not yet have the lock,
             so we must do something else */
        }

        work(id); /* we now have the lock
             and can do the work */

        omp_unset_lock(&lck);
    }
    omp_destroy_lock(&lck);
    return 0;
}
```

Note that the argument to the lock routines should have type `omp_lock_t`, and that there is no need to flush it.

Example 48.1c
Note that there is no need to flush the lock variable.

*Example 48.1f*

```fortran
SUBROUTINE SKIP(ID)
END SUBROUTINE SKIP

SUBROUTINE WORK(ID)
END SUBROUTINE WORK

PROGRAM SIMPLELOCK

  INCLUDE "omp_lib.h"     ! or USE OMP_LIB

  INTEGER(OMP_LOCK_KIND) LCK
  INTEGER ID

  CALL OMP_INIT_LOCK(LCK)

  !$OMP PARALLEL SHARED(LCK) PRIVATE(ID)
    ID = OMP_GET_THREAD_NUM()
    CALL OMP_SET_LOCK(LCK)
    PRINT *, 'My thread id is ', ID
    CALL OMP_UNSET_LOCK(LCK)
  !$OMP END PARALLEL

  DO WHILE (.NOT. OMP_TEST_LOCK(LCK))
    CALL SKIP(ID)     ! We do not yet have the lock
      ! so we must do something else
    END DO

  CALL WORK(ID)       ! We now have the lock
      ! and can do the work

  CALL OMP_UNSET_LOCK( LCK )

END PROGRAM SIMPLELOCK
```
Nestable Lock Routines

The following example demonstrates how a nestable lock can be used to synchronize updates both to a whole structure and to one of its members.

Example 49.1c

```c
#include <omp.h>
typedef struct {
    int a,b;
    omp_nest_lock_t lck; } pair;

int work1();
int work2();
int work3();
void incr_a(pair *p, int a)
{
    /* Called only from incr_pair, no need to lock. */
    p->a += a;
}
void incr_b(pair *p, int b)
{
    /* Called both from incr_pair and elsewhere, */
    /* so need a nestable lock. */
    omp_set_nest_lock(&p->lck);
    p->b += b;
    omp_unset_nest_lock(&p->lck);
}
void incr_pair(pair *p, int a, int b)
{
    omp_set_nest_lock(&p->lck);
    incr_a(p, a);
    incr_b(p, b);
    omp_unset_nest_lock(&p->lck);
}
void nestlock(pair *p)
{
    #pragma omp parallel sections
    {
        #pragma omp section
        incr_pair(p, work1(), work2());
        #pragma omp section
        incr_b(p, work3());
    }
}
```
Example 49.1f

MODULE DATA
    USE OMP_LIB, ONLY: OMP_NEST_LOCK_KIND
    TYPE LOCKED_PAIR
        INTEGER A
        INTEGER B
        INTEGER (OMP_NEST_LOCK_KIND) LCK
    END TYPE
END MODULE DATA

SUBROUTINE INCR_A(P, A)
    ! called only from INCR_PAIR, no need to lock
    USE DATA
    TYPE(LOCKED_PAIR) :: P
    INTEGER A
    P%A = P%A + A
END SUBROUTINE INCR_A

SUBROUTINE INCR_B(P, B)
    ! called from both INCR_PAIR and elsewhere,
    ! so we need a nestable lock
    USE OMP_LIB       ! or INCLUDE "omp_lib.h"
    USE DATA
    TYPE(LOCKED_PAIR) :: P
    INTEGER B
    CALL OMP_SET_NEST_LOCK(P%LCK)
    P%B = P%B + B
    CALL OMP_UNSET_NEST_LOCK(P%LCK)
END SUBROUTINE INCR_B

SUBROUTINE INCR_PAIR(P, A, B)
    USE OMP_LIB       ! or INCLUDE "omp_lib.h"
    USE DATA
    TYPE(LOCKED_PAIR) :: P
    INTEGER A
    INTEGER B

    CALL OMP_SET_NEST_LOCK(P%LCK)
    CALL INCR_A(P, A)
    CALL INCR_B(P, B)
    CALL OMP_UNSET_NEST_LOCK(P%LCK)
END SUBROUTINE INCR_PAIR

SUBROUTINE NESTLOCK(P)
    USE OMP_LIB       ! or INCLUDE "omp_lib.h"
    USE DATA
    TYPE(LOCKED_PAIR) :: P
    INTEGER WORK1, WORK2, WORK3
    EXTERNAL WORK1, WORK2, WORK3
!$OMP  PARALLEL SECTIONS

!$OMP  SECTION
    CALL INCRPAIR(P, WORK1(), WORK2())
!$OMP  SECTION
    CALL INCR_B(P, WORK3())
!$OMP  END PARALLEL SECTIONS

END SUBROUTINE NESTLOCK
target Construct

target Construct on parallel Construct

This following example shows how the `target` construct offloads a code region to a target device. The variables `p`, `v1`, `v2`, and `N` are implicitly mapped to the target device.

C/C++

Example 50.1c

```c
extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(int N)
{
  int i;
  float p[N], v1[N], v2[N];
  init(v1, v2, N);
  #pragma omp target
  #pragma omp parallel for private(i)
  for (i=0; i<N; i++)
    p[i] = v1[i] * v2[i];
  output(p, N);
}
```

Fortran

Example 50.1f

```fortran
subroutine vec_mult(N)
  integer ::  i,N
  real    ::  p(N), v1(N), v2(N)
  call init(v1, v2, N)
  !$omp target
  !$omp parallel do
  do i=1,N
    p(i) = v1(i) * v2(i)
  end do
  !$omp end target
  call output(p, N)
end subroutine
```
target Construct with map Clause

This following example shows how the target construct offloads a code region to a target device. The variables \( p, v1, v2 \), are explicitly mapped to the the target device using the map clause. The variable \( N \) is implicitly mapped to the target device.

```c
extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(int N)
{
    int i;
    float p[N], v1[N], v2[N];
    init(v1, v2, N);
    #pragma omp target map(v1, v2, p)
    #pragma omp parallel for
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
}
```

```fortran
subroutine vec_mult(N)
    integer :: i,N
    real    :: p(N), v1(N), v2(N)
    call init(v1, v2, N)
    !$omp target map(v1,v2,p)
    !$omp parallel do
    do i=1,N
        p(i) = v1(i) * v2(i)
    end do
    !$omp end target
    call output(p, N)
end subroutine
```
**map Clause With to/from map-types**

The following example shows how the [target](https://www.openmp.org) construct offloads a code region to a target device. In the map clause, the to and from map-types define the mapping between the original (host) data and the target (device) data. The to map-type specifies that the data will only be read on the device, and the from map-type specifies that the data will only be written to on the device. By specifying a guaranteed access on the device, data transfers can be reduced for the target region.

The to map-type indicates that at the start of the target region the variables v1 and v2 are initialized with the values of the corresponding variables on the host device, and at the end of the target region the variables v1 and v2 are not assigned to their corresponding variables on the host device.

The from map-type indicates that at the start of the target region the variable p is not initialized with the value of the corresponding variable on the host device, and at the end of the target region the variable p is assigned to the corresponding variable on the host device.

```
C/C++
Example 50.3c

extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(int N)
{
    int i;
    float p[N], v1[N], v2[N];
    init(v1, v2, N);
    #pragma omp target map(to: v1, v2) map(from: p)
    #pragma omp parallel for
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
}
```

```
C/C++
```

```
Fortran
Example 50.3f

The to and from map-types allow programmers to optimize data motion. Since data for the v arrays are not returned, and data for the p array are not transferred to the device, only one-half of the data is moved, compared to the default behavior of an implicit mapping.
```
subroutine vec_mult(N)
    integer :: i, N
    real :: p(N), v1(N), v2(N)
    call init(v1, v2, N)
    !$omp target map(to: v1,v2) map(from: p)
    !$omp parallel do
    do i=1,N
        p(i) = v1(i) * v2(i)
    end do
    !$omp end target
    call output(p, N)
end subroutine

map Clause with Array Sections

The following example shows how the target construct offloads a code region to a target device. In the map clause, map-types are used to optimize the mapping of variables to the target device. Because variables p, v1 and v2 are pointers, array section notation must be used to map the arrays. The notation :N is equivalent to 0:N.

Example 50.4c

extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target map(to: v1[0:N], v2[:N]) map(from: p[0:N])
    #pragma omp parallel for
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
}
Example 50.4f

In C, the length of the pointed-to array must be specified. In Fortran the extent of the array is known and the length need not be specified. A section of the array can be specified with the usual Fortran syntax, as shown in the following example. The value 1 is assumed for the lower bound for array section v2(:N).

```fortran
module mults
contains
subroutine vec_mult(p,v1,v2,N)
  real,pointer,dimension(:) :: p, v1, v2
  integer :: N,i
  call init(v1, v2, N)
  !$omp target map(to: v1(1:N), v2(:N)) map(from: p(1:N))
  !$omp parallel do
  do i=1,N
    p(i) = v1(i) * v2(i)
  end do
  !$omp end target
end subroutine
end module
```

A more realistic situation in which an assumed-size array is passed to vec_mult requires that the length of the arrays be specified, because the compiler does not know the size of the storage. A section of the array must be specified with the usual Fortran syntax, as shown in the following example. The value 1 is assumed for the lower bound for array section v2(:N).

```fortran
module mults
contains
subroutine vec_mult(p,v1,v2,N)
  real,dimension(*) :: p, v1, v2
  integer :: N,i
  call init(v1, v2, N)
  !$omp target map(to: v1(1:N), v2(:N)) map(from: p(1:N))
  !$omp parallel do
  do i=1,N
    p(i) = v1(i) * v2(i)
  end do
  !$omp end target
end subroutine
end module
```
**target Construct with if Clause**

The following example shows how the `target` construct offloads a code region to a target device.

The *if* clause on the `target` construct indicates that if the variable \( N \) is smaller than a given threshold, then the `target` region will be executed by the host device.

The *if* clause on the `parallel` construct indicates that if the variable \( N \) is smaller than a second threshold then the `parallel` region is inactive.

---

**Example 50.5c**

```c
#define THRESHOLD1 1000000
#define THRESHOLD2 1000
extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target if(N>THRESHOLD1) map(to: v1[0:N], v2[:N])
        map(from: p[0:N])
    #pragma omp parallel for if(N>THRESHOLD2)
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
}
```

**Example 50.5f**

```fortran
module params
integer,parameter :: THRESHOLD1=1000000, THRESHHOLD2=1000
end module
subroutine vec_mult(p, v1, v2, N)
use params
real    ::  p(N), v1(N), v2(N)
integer ::  i
call init(v1, v2, N)
!$omp target if(N>THRESHOLD1) map(to: v1, v2 ) map(from: p)
    !$omp parallel do if(N>THRESHOLD2)
    do i=1,N
        p(i) = v1(i) * v2(i)
    end do
    !$omp end target
```
call output(p, N)
end subroutine
target data Construct

Simple target data Construct

This example shows how the `target data` construct maps variables to a device data environment. The `target data` construct creates a new device data environment and maps the variables `v1`, `v2`, and `p` to the new device data environment. The `target` construct enclosed in the `target data` region creates a new device data environment, which inherits the variables `v1`, `v2`, and `p` from the enclosing device data environment. The variable `N` is mapped into the new device data environment from the encountering task's data environment.

C/C++

```c
extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target data map(to: v1[0:N], v2[:N]) map(from: p[0:N])
    {
        #pragma omp target
        #pragma omp parallel for
        for (i=0; i<N; i++)
            p[i] = v1[i] * v2[i];
    }
    output(p, N);
}
```

Fortran

```fortran
Example 51.1f

The Fortran code passes a reference and specifies the extent of the arrays in the declaration. No length information is necessary in the map clause, as is required with C/C++ pointers.
```
target data Region Enclosing Multiple target Regions

The following examples show how the target data construct maps variables to a device data environment of a target region. The target data construct creates a device data environment and encloses target regions, which have their own device data environments. The device data environment of the target data region is inherited by the device data environment of an enclosed target region. The target data construct is used to create variables that will persist throughout the target data region.

In the following example the variables v1 and v2 are mapped at each target construct. Instead of mapping the variable p twice, once at each target construct, p is mapped once by the target data construct.

Example 51.2c

```c/c++
extern void init(float*, float*, int);
extern void init_again(float*, float*, int);
extern void output(float*, int);
void vec_mult(float *p, float *v1, float *v2, int N) {
  int i;
  init(v1, v2, N);
  #pragma omp target data map(from: p[0:N])
  {
    #pragma omp target map(to: v1[:N], v2[:N])
    #pragma omp parallel for
    for (i=0; i<N; i++)
```

```fortran
subroutine vec_mult(p, v1, v2, N)
  real ::  p(N), v1(N), v2(N)
  integer ::  i
  call init(v1, v2, N)
  !$omp target data map(to: v1, v2) map(from: p)
  !$omp target
  !$omp parallel do
  do i=1,N
    p(i) = v1(i) * v2(i)
  end do
  !$omp end target
  !$omp end target data
  call output(p, N)
end subroutine
```
\[
p[i] = v1[i] \times v2[i];
\]
init_again(v1, v2, N);
#pragma omp target map(to: v1[:N], v2[:N])
#pragma omp parallel for
for (i=0; i<N; i++)
    \[
p[i] = p[i] + (v1[i] \times v2[i]);
\]
}\noutput(p, N);

\[
C/C++
\]

\[
\text{Fortran}
\]

Example 51.2f

The Fortran code uses reference and specifies the extent of the \( p, v1 \) and \( v2 \) arrays. No length information is necessary in the \text{map} clause, as is required with C/C++ pointers. The arrays \( v1 \) and \( v2 \) are mapped at each \text{target} construct. Instead of mapping the array \( p \) twice, once at each \text{target} construct, \( p \) is mapped once by the \text{target data} construct.

\[
\text{Fortran}
\]

\[
\text{C/C++}
\]

In the following example, the variable \( \text{tmp} \) defaults to \text{tofrom} map-type and is mapped at each \text{target} construct. The array \( Q \) is mapped once at the enclosing \text{target data} region instead of at each \text{target} construct.
#include <math.h>
void gramSchmidt(restrict float Q[][COLS], const int rows, const int cols)
{
    #pragma omp target data map(Q[0:rows][0:cols])
    for(int k=0; k < cols; k++)
    {
        double tmp = 0.0;
        #pragma omp target
        #pragma omp parallel for reduction(+:tmp)
        for(int i=0; i < rows; i++)
            tmp += (Q[i][k] * Q[i][k]);
        tmp = 1/sqrt(tmp);
        #pragma omp target
        #pragma omp parallel for
        for(int i=0; i < rows; i++)
            Q[i][k] *= tmp;
    }
}

Example 51.3f

In the following example the arrays v1 and v2 are mapped at each target construct. Instead of mapping the array Q twice at each target construct, Q is mapped once by the target data construct. Note, the tmp variable is implicitly remapped for each target region, mapping the value from the device to the host at the end of the first target region, and from the host to the device for the second target region.

subroutine gramSchmidt(Q,rows,cols)
    integer        ::   rows,cols,  i,k
    double precision :: Q(rows,cols), tmp
    !$omp target data map(Q)
    do k=1,cols
        tmp = 0.0d0
        !$omp target
        !$omp parallel do reduction(+:tmp)
        do i=1,rows
            tmp = tmp + (Q(i,k) * Q(i,k))
        end do
        !$omp end target
    tmp = 1.0d0/sqrt(tmp)
    !$omp target
    !$omp parallel do
    do i=1,rows
        Q(i,k) = Q(i,k)*tmp
    enddo
    !$omp end target
target data Construct with Orphaned Call

The following two examples show how the target data construct maps variables to a device data environment. The target data construct's device data environment encloses the target construct's device data environment in the function vec_mult().

When the type of the variable appearing in an array section is pointer, the pointer variable and the storage location of the corresponding array section are mapped to the device data environment. The pointer variable is treated as if it had appeared in a map clause with a map-type of alloc. The array section's storage location is mapped according to the map-type in the map clause (the default map-type is tofrom).

The target construct's device data environment inherits the storage locations of the array sections v1[0:N], v2[:n], and p0[0:N] from the enclosing target data construct's device data environment. Neither initialization nor assignment is performed for the array sections in the new device data environment.

The pointer variables p1, v3, and v4 are mapped into the target construct's device data environment with an implicit map-type of alloc and they are assigned the address of the storage location associated with their corresponding array sections. Note that the following pairs of array section storage locations are equivalent (p0[:N], p1[:N]), (v1[:N], v3[:N]), and (v2[:N], v4[:N]).

C/C++

Example 51.3c

```c
void vec_mult(float*, float*, float*, int);
extern void init(float*, float*, int);
extern void output(float*, int);
void foo(float *p0, float *v1, float *v2, int N)
{
    init(v1, v2, N);
    #pragma omp target data map(to: v1[0:N], v2[:n]) map(from: p0[0:N])
    {
        vec_mult(p0, v1, v2, N);
    }
    output(p0, N);
}
void vec_mult(float *p1, float *v3, float *v4, int N)
{
```

Fortran

```fortran
end do
!$omp end target data
end subroutine
```
Example 51.4f

The Fortran code maps the pointers and storage in an identical manner (same extent, but uses indices from 1 to N).

The `target` construct's device data environment inherits the storage locations of the arrays `v1`, `v2` and `p0` from the enclosing `target data` constructs's device data environment. However, in Fortran the associated data of the pointer is known, and the shape is not required.

The pointer variables `p1`, `v3`, and `v4` are mapped into the `target` construct's device data environment with an implicit map-type of `alloc` and they are assigned the address of the storage location associated with their corresponding array sections. Note that the following pair of array storage locations are equivalent `(p0, p1)`, `(v1, v3)`, and `(v2, v4).

```fortran
module mults
contains
  subroutine foo(p0,v1,v2,N)
    real,pointer,dimension(:) :: p0, v1, v2
    integer                   :: N,i
    call init(v1, v2, N)
    !$omp target data map(to: v1, v2) map(from: p0)
    call vec_mult(p0,v1,v2,N)
    !$omp end target data
    call output(p0, N)
  end subroutine

  subroutine vec_mult(p1,v3,v4,N)
    real,pointer,dimension(:) :: p1, v3, v4
    integer                   :: N,i
    !$omp target map(to: v3, v4) map(from: p1)
    !$omp parallel do
    do i=1,N
      p1(i) = v3(i) * v4(i)
    end do
    !$omp end target
  end subroutine
end module
```
Example 51.4c

In the following example, the variables \( p_1, v_3, \) and \( v_4 \) are references to the pointer variables \( p_0, v_1, \) and \( v_2 \) respectively. The `target` construct's device data environment inherits the pointer variables \( p_0, v_1, \) and \( v_2 \) from the enclosing `target data` construct's device data environment. Thus, \( p_1, v_3, \) and \( v_4 \) are already present in the device data environment.

```c
void vec_mult(float* &, float* &, float* &, int &);
extern void init(float*, float*, int);
extern void output(float*, int);
void foo(float *p0, float *v1, float *v2, int N)
{
    init(v1, v2, N);
    #pragma omp target data map(to: v1[0:N], v2[:N]) map(from: p0[0:N])
    {
        vec_mult(p0, v1, v2, N);
    }
    output(p0, N);
}
void vec_mult(float* &p1, float* &v3, float* &v4, int &N)
{
    int i;
    #pragma omp target map(to: v3[0:N], v4[:N]) map(from: p1[0:N])
    #pragma omp parallel for
    for (i=0; i<N; i++)
        p1[i] = v3[i] * v4[i];
}
```

Example 51.5f

In the following example, the usual Fortran approach is used for dynamic memory. The \( p_0, v_1, v_2 \) arrays are allocated in the main program and passed as references from one routine to another. In `vec_mult`, \( p_1, v_3 \) and \( v_4 \) are references to the \( p_0, v_1, \) and \( v_2 \) arrays, respectively. The `target` construct's device data environment inherits the arrays \( p_0, v_1, \) and \( v_2 \) from the enclosing `target data` construct's device data environment. Thus, \( p_1, v_3, \) and \( v_4 \) are already present in the device data environment.

```fortran
module my_mult
contains
subroutine foo(p0,v1,v2,N)
```
real,dimension(:) :: p0, v1, v2
integer :: N,i

call init(v1, v2, N)
!$omp target data map(to: v1, v2) map(from: p0)
call vec_mult(p0,v1,v2,N)
!$omp end target data
call output(p0, N)
end subroutine

subroutine vec_mult(p1,v3,v4,N)
real,dimension(:) :: p1, v3, v4
integer :: N,i

!$omp target map(to: v3, v4) map(from: p1)
!$omp parallel do
do i=1,N
  p1(i) = v3(i) * v4(i)
end do
!$omp end target
end subroutine

end module

program main
use my_mult
integer, parameter :: N=1024
real,allocatable, dimension(:) :: p, v1, v2
allocate( p(N), v1(N), v2(N) )
call foo(p,v1,v2,N)
end program

--- Fortran ---

target data Construct With if Clause

The following two examples show how the target data construct maps variables to a device data environment.

In the following example, the if clause on the target data construct indicates that if the variable N is smaller than a given threshold, then the target data construct will not create a device data environment.

The target constructs enclosed in the target data region must also use an if clause on the same condition, otherwise the pointer variable p is implicitly mapped with a map-type of tofrom, but the storage location for the array section p[0:N] will not be mapped in the device data environments of the target constructs.

--- C/C++ ---

Example 51.5c

#define THRESHOLD 1000000
extern void init(float*, float*, int);
extern void init_again(float*, float*, int);
extern void output(float*, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target data if(N>THRESHOLD) map(from: p[0:N])
    {
        #pragma omp target if (N>THRESHOLD) map(to: v1[:N], v2[:N])
        #pragma omp parallel for
        for (i=0; i<N; i++)
            p[i] = v1[i] * v2[i];
        init_again(v1, v2, N);
        #pragma omp target if (N>THRESHOLD) map(to: v1[:N], v2[:N])
        #pragma omp parallel for
        for (i=0; i<N; i++)
            p[i] = p[i] + (v1[i] * v2[i]);
    }
    output(p, N);
}

Module: params
integer,parameter :: THRESHOLD=1000000
end module

Example 51.6f

The if clauses work the same way for the following Fortran code. The target constructs enclosed in the target data region should also use an if clause with the same condition, so that the target data region and the target region are either both created for the device, or are both ignored.

module params
integer,parameter :: THRESHOLD=1000000
end module

subroutine vec_mult(p, v1, v2, N)
    use params
    real ::  p(N), v1(N), v2(N)
    integer ::  i
    call init(v1, v2, N)
!$omp target data if(N>THRESHOLD) map(from: p)
!$omp target if(N>THRESHOLD) map(to: v1, v2)
!$omp parallel do
    do i=1,N
        p(i) = v1(i) * v2(i)
    end do
!$omp end target
    call init_again(v1, v2, N)
!$omp target if(N>THRESHOLD) map(to: v1, v2)
!$omp parallel do

do i=1,N
    p(i) = p(i) + v1(i) * v2(i)
end do
!$omp end target
!$omp end target data
call output(p, N)
end subroutine

In the following example, when the \texttt{if} clause conditional expression on the \texttt{target} construct evaluates to \texttt{false}, the target region will execute on the host device. However, the \texttt{target data} construct created an enclosing device data environment that mapped \texttt{p[0:N]} to a device data environment on the default device. At the end of the \texttt{target data} region the array section \texttt{p[0:N]} will be assigned from the device data environment to the corresponding variable in the data environment of the task that encountered the \texttt{target data} construct, resulting in undefined values in \texttt{p[0:N]}.

\textbf{Example 51.6c}

\begin{verbatim}
#define THRESHOLD 1000000
extern void init(float*, float*, int);
extern void output(float*, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target data map(from: p[0:N])
    {
        #pragma omp target if (N>THRESHOLD) map(to: v1[:N], v2[:N])
        #pragma omp parallel for
        for (i=0; i<N; i++)
            p[i] = v1[i] * v2[i];
    } /* UNDEFINED behavior if N<=THRESHOLD */
    output(p, N);
}
\end{verbatim}

\textbf{C/C++}

\textbf{Example 51.7f}

The \texttt{if} clauses work the same way for the following Fortran code. When the \texttt{if} clause conditional expression on the \texttt{target} construct evaluates to \texttt{false}, the \texttt{target} region will execute on the host device. However, the \texttt{target data} construct created an enclosing device data environment that mapped the \texttt{p} array (and \texttt{v1} and \texttt{v2}) to a device data environment on the default target device. At the end of the \texttt{target data} region
the p array will be assigned from the device data environment to the corresponding variable in the data environment of the task that encountered the target data construct, resulting in undefined values in p.

module params
integer, parameter :: THRESHOLD=1000000
end module

subroutine vec_mult(p, v1, v2, N)
    use params
    real :: p(N), v1(N), v2(N)
    integer :: i
    call init(v1, v2, N)
    !$omp target data map(from: p)
    !$omp target if(N>THRESHOLD) map(to: v1, v2)
    !$omp parallel do
    do i=1,N
        p(i) = v1(i) * v2(i)
    end do
    !$omp end target
    !$omp end target data
    call output(p, N)  !*** UNDEFINED behavior if N<=THRESHOLD
end subroutine

Fortran
target update Construct

Simple target data and target update Constructs

The following example shows how the target update construct updates variables in a device data environment.

The target data construct maps array sections $v1[:N]$ and $v2[:N]$ (arrays $v1$ and $v2$ in the Fortran code) into a device data environment.

The task executing on the host device encounters the first target region and waits for the completion of the region.

After the execution of the first target region, the task executing on the host device then assigns new values to $v1[:N]$ and $v2[:N]$ ($v1$ and $v2$ arrays in Fortran code) in the task's data environment by calling the function `init_again()`.

The target update construct assigns the new values of $v1$ and $v2$ from the task's data environment to the corresponding mapped array sections in the device data environment of the target data construct.

The task executing on the host device then encounters the second target region and waits for the completion of the region.

The second target region uses the updated values of $v1[:N]$ and $v2[:N]$.

Example 52.1c

```c
extern void init(float *, float *, int);
extern void init_again(float *, float *, int);
extern void output(float *, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target data map(to: v1[:N], v2[:N]) map(from: p[0:N])
    {
        #pragma omp target
        #pragma omp parallel for
        for (i=0; i<N; i++)
```
Example 52.1f

```fortran
subroutine vec_mult(p, v1, v2, N)
    real :: p(N), v1(N), v2(N)
    integer :: i
    call init(v1, v2, N)
    !$omp target data map(to: v1, v2) map(from: p)
    !$omp target
    !$omp parallel do
        do i=1,N
            p(i) = v1(i) * v2(i)
        end do
    !$omp end target
    call init_again(v1, v2, N)
    !$omp target update to(v1, v2)
    !$omp target
    !$omp parallel do
        do i=1,N
            p(i) = p(i) + v1(i) * v2(i)
        end do
    !$omp end target
    !$omp end target data
    call output(p, N)
end subroutine
```

```c++
    p[i] = v1[i] * v2[i];
    init_again(v1, v2, N);
    #pragma omp target update to(v1[:N], v2[:N])
    #pragma omp target
    #pragma omp parallel for
    for (i=0; i<N; i++)
        p[i] = p[i] + (v1[i] * v2[i]);
    }
    output(p, N);
```

```fortran
Example 52.1f
```
**target update Construct With if Clause**

The following example shows how the **target update** construct updates variables in a device data environment.

The **target data** construct maps array sections v1[:N] and v2[:N] (arrays v1 and v2 in the Fortran code) into a device data environment. In between the two **target** regions, the task executing on the host device conditionally assigns new values to v1 and v2 in the task's data environment. The function `maybe_init_again()` returns true if new data is written.

When the conditional expression (the return value of `maybe_init_again()`) in the **if** clause is **true**, the **target update** construct assigns the new values of v1 and v2 from the task's data environment to the corresponding mapped array sections in the **target data** construct's device data environment.

---

### C/C++

#### Example 52.2c

```c
extern void init(float *, float *, int);
extern int maybe_init_again(float *, int);
extern void output(float *, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target data map(to: v1[:N], v2[:N]) map(from: p[0:N])
    {
        int changed;
        #pragma omp target
        #pragma omp parallel for
        for (i=0; i<N; i++)
            p[i] = v1[i] * v2[i];
        changed = maybe_init_again(v1, N);
        #pragma omp target update if (changed) to(v1[:N])
        changed = maybe_init_again(v2, N);
        #pragma omp target update if (changed) to(v2[:N])
        #pragma omp target
        #pragma omp parallel for
        for (i=0; i<N; i++)
            p[i] = p[i] + (v1[i] * v2[i]);
    }
    output(p, N);
}
```
Example 52.2f

```fortran
subroutine vec_mult(p, v1, v2, N)
    interface
        logical function maybe_init_again (v1, N)
        real :: v1(N)
        integer :: N
        end function
    end interface
    real ::  p(N), v1(N), v2(N)
    integer ::  i
    logical :: changed
    call init(v1, v2, N)
    !$omp target data map(to: v1, v2) map(from: p)
    !$omp parallel do
      do i=1, N
        p(i) = v1(i) * v2(i)
      end do
    !$omp end target
    changed = maybe_init_again(v1, N)
    !$omp target if(changed) update to(v1(:N))
    changed = maybe_init_again(v2, N)
    !$omp target if(changed) update to(v2(:N))
    !$omp target
    !$omp parallel do
      do i=1, N
        p(i) = p(i) + v1(i) * v2(i)
      end do
    !$omp end target
    !$omp target data
    !$omp end target
    call output(p, N)
end subroutine
```
The following example shows how the `declare target` directive is used to indicate that the corresponding call inside a `target` region is to a `fib` function that can execute on the default target device.

A version of the function is also available on the host device. When the `if` clause conditional expression on the `target` construct evaluates to `false`, the `target` region (thus `fib`) will execute on the host device.

For C/C++ codes the declaration of the function `fib` appears between the `declare target` and `end declare target` directives.

```c++
#pragma omp declare target
extern void fib(int N);
#pragma omp end declare target
#define THRESHOLD 1000000
void fib_wrapper(int n)
{
    #pragma omp target if(n > THRESHOLD)
    {
        fib(n);
    }
}
```

The Fortran `fib` subroutine contains a `declare target` declaration to indicate to the compiler to create an device executable version of the procedure. The subroutine name has not been included on the `declare target` directive and is, therefore, implicitly assumed.
The program uses the `module_fib` module, which presents an explicit interface to the compiler with the `declare target` declarations for processing the `fib` call.

```fortran
module module_fib
contains
  subroutine fib(N)
    integer :: N
    !$omp declare target
    !...
    end subroutine
  end subroutine
end module
module params
  integer :: THRESHOLD=1000000
end module
program my_fib
use params
use module_fib
!$omp target if( N > THRESHOLD )
call fib(N)
!$omp end target
end program
```

The next Fortran example shows the use of an external subroutine. Without an explicit interface (through module use or an interface block) the `declare target` declarations within an external subroutine are unknown to the main program unit; therefore, a `declare target` must be provided within the program scope for the compiler to determine that a target binary should be available.

**Example 53.2f**

```fortran
program my_fib
  integer :: N = 8
  !$omp declare target(fib)
  !$omp target
  call fib(N)
  !$omp end target
end program
subroutine fib(N)
  integer :: N
  !$omp declare target
  print*,"hello from fib"
  !...
end subroutine
```

Fortran
**declare target Construct for Class Type**

The following example shows how the `declare target` and `end declare target` directives are used to enclose the declaration of a variable `varY` with a class type `typeY`. The member function `typeY::foo()` cannot be accessed on a target device because its declaration did not appear between `declare target` and `end declare target` directives.

```c/c++
Example 53.2c

```struct typeX
{
  int a;
}

class typeY
{
  int foo() { return a^0x01;}
  int a;
}
```

```c/c++
#pragma omp declare target
struct typeX varX;  // ok

class typeY varY;  // ok if varY.foo() not called on target device
#pragma omp end declare target

void foo()
{
    #pragma omp target
    {
        varX.a = 100;  // ok
        varY.foo();    // error foo() is not available on a target device
    }
}
```

**declare target and end declare target for Variables**

The following examples show how the `declare target` and `end declare target` directives are used to indicate that global variables are mapped to the implicit device data environment of each target device.

In the following example, the declarations of the variables `p`, `v1`, and `v2` appear between `declare target` and `end declare target` directives indicating that the variables are mapped to the implicit device data environment of each target device. The
The `target update` directive is then used to manage the consistency of the variables `p`, `v1`, and `v2` between the data environment of the encountering host device task and the implicit device data environment of the default target device.

---

**Example 53.3c**

```c++
#define N 1000
#pragma omp declare target
float p[N], v1[N], v2[N];
#pragma omp end declare target
extern void init(float *, float *, int);
extern void output(float *, int);
void vec_mult()
{
  int i;
  init(v1, v2, N);
  #pragma omp target update to(v1, v2)
  #pragma omp target
  #pragma omp parallel for
  for (i=0; i<N; i++)
    p[i] = v1[i] * v2[i];
  #pragma omp target update from(p)
  output(p, N);
}
```

---

**Example 53.3f**

The Fortran version of the above C code uses a different syntax. Fortran modules use a list syntax on the `declare target` directive to declare mapped variables.

```fortran
module my_arrays
!$omp declare target (N, p, v1, v2)
integer, parameter :: N=1000
real :: p(N), v1(N), v2(N)
end module
subroutine vec_mult()
use my_arrays
integer :: i
call init(v1, v2, N);
!$omp target update to(v1, v2)
!$omp target
!$omp parallel do
do i = 1,N
  p(i) = v1(i) * v2(i)
end do
```

end do
!$omp end target
!$omp target update from (p)
call output(p, N)
end subroutine

The following example also indicates that the function \texttt{Pfun()} is available on the target device, as well as the variable \texttt{Q}, which is mapped to the implicit device data environment of each target device. The \texttt{target update} directive is then used to manage the consistency of the variable \texttt{Q} between the data environment of the encountering host device task and the implicit device data environment of the default target device.

In the following example, the function and variable declarations appear between the \texttt{declare target} and \texttt{end declare target} directives.

\textit{Example 53.4c}

\begin{verbatim}
#define N 10000
#pragma omp declare target
float Q[N][N];
float Pfun(const int i, const int k)
{ return Q[i][k] * Q[k][i]; }
#pragma omp end declare target
float accum(int k)
{
    float tmp = 0.0;
    #pragma omp target update to(Q)
    #pragma omp target
    #pragma omp parallel for reduction(+:tmp)
    for(int i=0; i < N; i++)
    {
        tmp += Pfun(i,k);
        return tmp;
    }
}\end{verbatim}

\textit{Example 53.4f}

The Fortran version of the above C code uses a different syntax. In Fortran modules a list syntax on the \texttt{declare target} directive is used to declare mapped variables and procedures. The \texttt{N} and \texttt{Q} variables are declared as a comma separated list. When the \texttt{declare target} directive is used to declare just the procedure, the procedure name need not be listed -- it is implicitly assumed, as illustrated in the \texttt{Pfun()} function.
module my_global_array  
 !$omp declare target (N,Q)  
 integer, parameter :: N=10  
 real :: Q(N,N)  
 contains  
 function Pfun(i,k)  
 !$omp declare target  
 real :: Pfun  
 integer,intent(in) :: i,k  
 Pfun=Q(i,k) * Q(k,i)  
 end function  
 end module  
 function accum(k) result(tmp)  
 use my_global_array  
 real :: tmp  
 integer :: i, k  
 tmp = 0.0e0  
 !$omp target  
 !$omp parallel do reduction(+:tmp)  
 do i=1,N  
 tmp = tmp + Pfun(k,i)  
 end do  
 !$omp end target  
 end function

```

```

```

declare target and end declare target with declare simd

The following example shows how the declare target and end declare target directives are used to indicate that a function is available on a target device. The declare simd directive indicates that there is a SIMD version of the function P() that is available on the target device as well as one that is available on the host device.

```

Example 53.5c

```

```
```
Example 53.5f

The Fortran version of the above C code uses a different syntax. Fortran modules use a list syntax of the `Declare target` declaration for the mapping. Here the $N$ and $Q$ variables are declared in the list form as a comma separated list. The function declaration does not use a list and implicitly assumes the function name. In this Fortran example row and column indices are reversed relative to the C/C++ example, as is usual for codes optimized for memory access.
do i=1,N
  tmp1 = 0.0e0
  !$omp simd reduction(+:tmp1)
  do k = 1,M
    tmp1 = tmp1 + P(k,i)
    end do
    tmp = tmp + tmp1
  end do
  !$omp end target
end function
teams Constructs

target and teams Constructs with
omp_get_num_teams and omp_get_team_num
Routines

The following example shows how the target and teams constructs are used to create a league of thread teams that execute a region. The teams construct creates a league of at most two teams where the master thread of each team executes the teams region.

The omp_get_num_teams routine returns the number of teams executing in a teams region. The omp_get_team_num routine returns the team number, which is an integer between 0 and one less than the value returned by omp_get_num_teams. The following example manually distributes a loop across two teams.

Example 54.1c

```c
#include <stdlib.h>
#include <omp.h>
float dotprod(float B[], float C[], int N)
{
    float sum0 = 0.0;
    float sum1 = 0.0;
    #pragma omp target map(to: B[:N], C[:N])
    #pragma omp teams num_teams(2)
    {
        int i;
        if (omp_get_num_teams() != 2)
            abort();
        if (omp_get_team_num() == 0)
        {
            #pragma omp parallel for reduction(+:sum0)
            for (i=0; i<N/2; i++)
                sum0 += B[i] * C[i];
        }
        else if (omp_get_team_num() == 1)
        {
            #pragma omp parallel for reduction(+:sum1)
            for (i=N/2; i<N; i++)
                sum1 += B[i] * C[i];
        }
    }
}```
Example 54.1f

Fortran

The following example shows how the target, teams, and distribute constructs are used to execute a loop nest in a target region. The teams construct creates a league and the master thread of each team executes the teams region. The distribute construct schedules the subsequent loop iterations across the master threads of each team.
The number of teams in the league is less than or equal to the variable `num_blocks`. Each team in the league has a number of threads less than or equal to the variable `block_threads`. The iterations in the outer loop are distributed among the master threads of each team.

When a team's master thread encounters the parallel loop construct before the inner loop, the other threads in its team are activated. The team executes the `parallel` region and then workshares the execution of the loop.

Each master thread executing the `teams` region has a private copy of the variable `sum` that is created by the `reduction` clause on the `teams` construct. The master thread and all threads in its team have a private copy of the variable `sum` that is created by the `reduction` clause on the parallel loop construct. The second private `sum` is reduced into the master thread's private copy of `sum` created by the `teams` construct. At the end of the `teams` region, each master thread's private copy of `sum` is reduced into the final `sum` that is implicitly mapped into the `target` region.

---

**Example 54.2c**

```c
float dotprod(float B[], float C[], int N, int block_size,
             int num_teams, int block_threads)
{
    float sum = 0;
    int i, i0;
    #pragma omp target map(to: B[0:N], C[0:N])
    #pragma omp teams num_teams(num_teams) thread_limit(block_threads) |
    reduction(+:sum)
    #pragma omp distribute
    for (i0=0; i0<N; i0 += block_size)
        #pragma omp parallel for reduction(+:sum)
        for (i=i0; i< min(i0+block_size,N); i++)
            sum += B[i] * C[i];
    return sum;
}
```

---

**Example 54.2f**

```fortran
function dotprod(B,C,N, block_size, num_teams, block_threads) result(sum)
implicit none
    real :: B(N), C(N), sum
    integer :: N, block_size, num_teams, block_threads, i, i0
    sum = 0.0e0
    !$omp target map(to: B, C)
```

target teams, and Distribute Parallel Loop Constructs

The following example shows how the target teams and distribute parallel loop constructs are used to execute a target region. The target teams construct creates a league of teams where the master thread of each team executes the teams region. The distribute parallel loop construct schedules the loop iterations across the master threads of each team and then across the threads of each team.
target teams and Distribute Parallel Loop Constructs with Scheduling Clauses

The following example shows how the target teams and distribute parallel loop constructs are used to execute a target region. The teams construct creates a league of at most eight teams where the master thread of each team executes the teams region. The number of threads in each team is less than or equal to 16.

The distribute parallel loop construct schedules the subsequent loop iterations across the master threads of each team and then across the threads of each team.

The dist_schedule clause on the distribute parallel loop construct indicates that loop iterations are distributed to the master thread of each team in chunks of 1024 iterations.

The schedule clause indicates that the 1024 iterations distributed to a master thread are then assigned to the threads in its associated team in chunks of 64 iterations.
target teams and distribute simd
Constructs

The following example shows how the target teams and distribute simd constructs are used to execute a loop in a target region. The target teams construct creates a league of teams where the master thread of each team executes the teams region.

The distribute simd construct schedules the loop iterations across the master thread of each team and then uses SIMD parallelism to execute the iterations.
**Example 54.5c**

C/C++

```c
extern void init(float *, float *, int);
extern void output(float *, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    #pragma omp target teams map(to: v1[0:N], v2[:N]) map(from: p[0:N])
    #pragma omp distribute simd
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
}
```

Fortran

```fortran
subroutine vec_mult(p, v1, v2, N)
    real    ::  p(N), v1(N), v2(N)
    integer ::  i
    call init(v1, v2, N)
    !$omp target teams map(to: v1, v2) map(from: p)
    !$omp distribute simd
    do i=1,N
        p(i) = v1(i) * v2(i)
    end do
    !$omp end target teams
    call output(p, N)
end subroutine
```

**target teams and Distribute Parallel Loop SIMD Constructs**

The following example shows how the `target teams` and the distribute parallel loop SIMD constructs are used to execute a loop in a `target teams` region. The `target teams` construct creates a league of teams where the master thread of each team executes the `teams` region.
The distribute parallel loop SIMD construct schedules the loop iterations across the master thread of each team and then across the threads of each team where each thread uses SIMD parallelism.

**Example 54.6c**

```c++
extern void init(float *, float *, int);
extern void output(float *, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
  int i;
  init(v1, v2, N);
  #pragma omp target teams map(to: v1[0:N], v2[:N]) map(from: p[0:N])
  #pragma omp distribute parallel for simd
  for (i=0; i<N; i++)
    p[i] = v1[i] * v2[i];
  output(p, N);
}
```

**Example 54.6f**

```fortran
subroutine vec_mult(p, v1, v2, N)
  real    ::  p(N), v1(N), v2(N)
  integer ::  i
  call init(v1, v2, N)
  !$omp target teams map(to: v1, v2) map(from: p)
  !$omp distribute parallel do simd
  do i=1,N
    p(i) = v1(i) * v2(i)
  end do
  !$omp end target teams
  call output(p, N)
end subroutine
```
Asynchronous Execution of a target Region Using Tasks

The following example shows how the task and target constructs are used to execute multiple target regions asynchronously. The task that encounters the task construct generates an explicit task that contains a target region. The thread executing the explicit task encounters a task scheduling point while waiting for the execution of the target region to complete, allowing the thread to switch back to the execution of the encountering task or one of the previously generated explicit tasks.

**Example 55.1c**

```c/c++
#pragma omp declare target
float F(float);
#pragma omp end declare target
#define N 1000000000
#define CHUNKSZ 1000000
void init(float *, int);
float Z[N];
void pipedF()
{
    int C, i;
    init(Z, N);
    for (C=0; C<N; C+=CHUNKSZ)
    {
        #pragma omp task
        #pragma omp target map(Z[C:CHUNKSZ])
        #pragma omp parallel for
        for (i=0; i<CHUNKSZ; i++)
            Z[i] = F(Z[i]);
    }
    #pragma omp taskwait
}
```

**Example 55.1f**

The Fortran version has an interface block that contains the declare target. An identical statement exists in the function declaration (not shown here).

```fortran
module parameters
```
integer, parameter :: N=1000000000, CHUNKSZ=1000000
end module

subroutine pipedF()
use parameters, ONLY: N, CHUNKSZ
integer :: C, i
real :: z(N)

interface
  function F(z)
    !$omp declare target
    real, intent(IN) :: z
    real :: F
  end function F
end interface

call init(z,N)

do C=1,N,CHUNKSZ
  !$omp task
  !$omp target map(z(C:C+CHUNKSZ-1))
  !$omp parallel do
    do i=C,C+CHUNKSZ-1
      z(i) = F(z(i))
    end do
  !$omp end task
  !$omp end target
end do
print*, z

end subroutine pipedF

Fortran

The following example shows how the task and target constructs are used to execute multiple target regions asynchronously. The task dependence ensures that the storage is allocated and initialized on the device before it is accessed.

C/C++

Example 55.2c

#include <stdlib.h>
extern void init(float *, float *, int);
extern void output(float *, int);
void vec_mult(float *p, float *v1, float *v2, int N, int dev) {
  int i;
  init(p, N);
  #pragma omp task depend(out: v1, v2)
  #pragma omp target device(dev) map(v1, v2)
```c
{
    // check whether on device dev
    if (omp_is_initial_device())
        abort();
    v1 = malloc(N*sizeof(float));
    v2 = malloc(N*sizeof(float));
    init(v1,v2);
}
foo(); // execute other work asychronously
#pragma omp task depend(in: v1, v2)
#pragma omp target device(dev) map(to: v1, v2) map(from: p[0:N])
{
    // check whether on device dev
    if (omp_is_initial_device())
        abort();
    #pragma omp parallel for
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
    free(v1);
    free(v2);
}
```

```fortran
Example 55.2f

The Fortran example uses allocatable arrays for dynamic memory on the device.

```fortran
subroutine mult(p, N, idev)
    use omp_lib, ONLY: omp_is_initial_device
    real :: p(N)
    real,allocatable :: v1(:), v2(:)
    integer :: i, idev
    !$omp declare target (init)
    !!
    !$omp task depend(out: v1,v2)
    !$omp target device(idev) map(v1,v2)
    if( omp_is_initial_device() ) &
        stop "not executing on target device"
    allocate(v1(N), v2(N))
    call init(v1,v2,N)
    !$omp end target
    !$omp end task
    !!
    call foo() ! execute other work asychronously
    !!
    !$omp task depend(in: v1,v2)
    !$omp target device(idev) map(to: v1,v2) map(from: p)
```
if( omp_is_initial_device() ) &
    stop "not executing on target device"
!$omp parallel do
    do i = 1,N
        p(i) = v1(i) * v2(i)
    end do
deallocate(v1,v2)
!!
!$omp end target
!$omp end task
!!
call output(p, N)
!!
end subroutine
56 Array Sections in Device Constructs

The following examples show the usage of array sections in map clauses on target and target data constructs.

This example shows the invalid usage of two separate sections of the same array inside of a target construct.

```c
Example 56.1c

void foo ()
{
    int A[30];
    #pragma omp target data map( A[0:4] )
    {
        /* Cannot map distinct parts of the same array */
        #pragma omp target map( A[7:20] )
        {
            A[2] = 0;
        }
    }
}
```

```fortran
Example 56.1f

subroutine foo()
    integer :: A(30)
    A = 1
    !$omp target data map( A(1:4) )
    ! Cannot map distinct parts of the same array
    !$omp target map( A(8:27) )
    A(3) = 0
    !$omp end target map
    !$omp end target data
end subroutine
```

This example shows the invalid usage of two separate sections of the same array inside of a target construct.
Example 56.2c

```c
void foo ()
{
    int A[30], *p;
    #pragma omp target data map( A[0:4] )
    {
        p = &A[0];
        /* invalid because p[3] and A[3] are the same
         * location on the host but the array section
         * specified via p[... ] is not a subset of A[0:4] */
        #pragma omp target map( p[3:20] )
        {
            A[2] = 0;
            p[8] = 0;
        }
    }
}
```

Example 56.2f

```fortran
subroutine foo()
    integer,target :: A(30)
    integer,pointer :: p(:)
    A=1
    !$omp target data map( A(1:4) )
    p=>A
    ! invalid because p(4) and A(4) are the same
    ! location on the host but the array section
    ! specified via p(...) is not a subset of A(1:4)
    !$omp target map( p(4:23) )
    A(3) = 0
    p(9) = 0
    !$omp end target
    !$omp end target data
end subroutine
```

This example shows the valid usage of two separate sections of the same array inside of a `target` construct.
Example 56.3c

```c
void foo ()
{
    int A[30], *p;
    #pragma omp target data map( A[0:4] )
    {
        p = &A[0];
        #pragma omp target map( p[7:20] )
        {
            A[2] = 0;
            p[8] = 0;
        }
    }
}
```

Example 56.3f

```fortran
subroutine foo()
    integer,target :: A(30)
    integer,pointer :: p(:)
    !$omp target data map( A(1:4) )
    p=>A
    !$omp target map( p(8:27) )
    A(3) = 0
    p(9) = 0
    !$omp end target map
    !$omp end target data
end subroutine
```

This example shows the valid usage of a wholly contained array section of an already mapped array section inside of a `target` construct.

Example 56.4c

```c
void foo ()
{
    int A[30];
    #pragma omp target data map( A[0:10] )
    {
        p = &A[0];
        #pragma omp target map( p[3:7] )
```
{ 
    A[2] = 0;
    p[8] = 0;
    A[8] = 1;
}
}

C/C++

Fortran

Example 56.4f

subroutine foo()

integer,target :: A(30)
integer,pointer :: p(:)

!$omp target data map( A(1:10) )
    p=>A
!$omp target map( p(4:10) )
    A(3) = 0
    p(9) = 0
    A(9) = 1
!$omp end target
!$omp end target data
end subroutine

Fortran
57 Device Routines

omp_is_initial_device Routine

The following example shows how the omp_is_initial_device runtime library routine can be used to query if a code is executing on the initial host device or on a target device. The example then sets the number of threads in the parallel region based on where the code is executing.

```
#include <stdio.h>
#include <omp.h>
#pragma omp declare target
void vec_mult(float *p, float *v1, float *v2, int N);
extern float *p, *v1, *v2;
extern int N;
#pragma omp end declare target
extern void init_vars(float *, float *, int);
extern void output(float *, int);
void foo()
{
    N = init_vars(&p, &v1, &v2);
    #pragma omp target device(42) map(p[:N], v1[:N], v2[:N])
    {
        vec_mult(p, v1, v2, N);
    }
    output(p, N);
}
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    int nthreads = omp_is_initial_device() ? 8 : 1024;
    if (!omp_is_initial_device())
    {
        printf("1024 threads on target device\n");
        nthreads = 1024;
    }
    else
    {
        printf("8 threads on initial device\n");
        nthreads = 8;
    }
    #pragma omp parallel for private(i) num_threads(nthreads);
```
for (i=0; i<N; i++)
    p[i] = v1[i] * v2[i];

Example 57.1f

module params
    integer,parameter :: N=1024
end module params

module vmult
    contains
    subroutine vec_mult(p, v1, v2, N)
        use omp_lib, ONLY : omp_is_initial_device
        !$omp declare target
        real    :: p(N), v1(N), v2(N)
        integer :: i, nthreads, N
        if (.not. omp_is_initial_device()) then
            print*, "1024 threads on target device"
            nthreads = 1024
        else
            print*, "8 threads on initial device"
            nthreads = 8
        endif
        !$omp parallel do private(i) num_threads(nthreads)
        do i = 1,N
            p(i) = v1(i) * v2(i)
        end do
    end subroutine vec_mult
end module vmult

program prog_vec_mult
    use params
    use vmult
    real :: p(N), v1(N), v2(N)
    call init(v1,v2,N)
    !$omp target device(42) map(p, v1, v2)
    call vec_mult(p, v1, v2, N)
    !$omp end target
    call output(p, N)
end program
**omp_get_num_devices Routine**

The following example shows how the `omp_get_num_devices` runtime library routine can be used to determine the number of devices.

### Example 57.2c

```c
#include <omp.h>
extern void init(float *, float *, int);
extern void output(float *, int);
void vec_mult(float *p, float *v1, float *v2, int N)
{
    int i;
    init(v1, v2, N);
    int ndev = omp_get_num_devices();
    int do_offload = (ndev>0 && N>1000000);
    #pragma omp target if(do_offload) map(to: v1[0:N], v2[:N]) map(from: p[0:N])
    #pragma omp parallel for if(N>1000) private(i)
    for (i=0; i<N; i++)
        p[i] = v1[i] * v2[i];
    output(p, N);
}
```

### Example 57.2f

```fortran
subroutine vec_mult(p, v1, v2, N)
use omp_lib, ONLY : omp_get_num_devices
real    :: p(N), v1(N), v2(N)
integer :: N, i, ndev
logical :: do_offload
call init(v1, v2, N)
ndev = omp_get_num_devices()
do_offload = (ndev>0) .and. (N>1000000)
!$omp target if(do_offload) map(to: v1, v2) map(from: p)
!$omp parallel do if(N>1000)
do i=1,N
    p(i) = v1(i) * v2(i)
end do
!$omp end target
call output(p, N)
end subroutine
```
omp_set_default_device and omp_get_default_device Routines

The following example shows how the `omp_set_default_device` and `omp_get_default_device` runtime library routines can be used to set the default device and determine the default device respectively.

```c
C/C++
Example 57.3c

#include <omp.h>
#include <stdio.h>
void foo(void)
{
    int default_device = omp_get_default_device();
    printf("Default device = %d\n", default_device);
    omp_set_default_device(default_device+1);
    if (omp_get_default_device() != default_device+1)
        printf("Default device is still = %d\n", default_device);
}
```

```fortran
Fortran
Example 57.3f

program foo
use omp_lib, ONLY : omp_get_default_device, omp_set_default_device
integer :: old_default_device, new_default_device
old_default_device = omp_get_default_device()
print*, "Default device = ", old_default_device
new_default_device = old_default_device + 1
call omp_set_default_device(new_default_device)
if (omp_get_default_device() == old_default_device) &
    print*, "Default device is STILL = ", old_default_device
end program
```

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58 Fortran ASSOCIATE Construct

Example 58.1f

This is an invalid example of specifying an associate name on a data-sharing attribute clause. The constraint in the Data Sharing Attribute Rules section in the OpenMP 4.0 API Specifications states that an associate name preserves the association with the selector established at the ASSOCIATE statement. The associate name b is associated with the shared variable a. With the predetermined data-sharing attribute rule, the associate name b is not allowed to be specified on the private clause.

```fortran
program example
    real :: a, c
    associate (b => a)
    !$omp parallel private(b, c) ! invalid to privatize b
    c = 2.0*b
    !$omp end parallel
    end associate
end program
```

Example 58.2f

In this example, within the parallel construct, the association name thread_id is associated with the private copy of i. The print statement should output the unique thread number.

```fortran
program example
    use omp_lib
    integer  i
    !$omp parallel private(i)
    i = omp_get_thread_num()
    associate(thread_id => i)
        print *, thread_id ! print private i value
    end associate
    !$omp end parallel
end program
```
Example 58.3f

This example illustrates the effect of specifying a selector name on a data-sharing attribute clause. The associate name `u` is associated with `v` and the variable `v` is specified on the `private` clause of the `parallel` construct. The construct association is established prior to the `parallel` region. The association between `u` and the original `v` is retained (see the Data Sharing Attribute Rules section in the OpenMP 4.0 API Specifications). Inside the `parallel` region, `v` has the value of -1 and `u` has the value of the original `v`.

```fortran
program example
    integer :: v
    v = 15
associate(u => v)
!$omp parallel private(v)
    v = -1
    print *, v        ! private v=-1
    print *, u        ! original v=15
!$omp end parallel
end associate
end program
```

Fortran