

# Programming OpenMP

## *Task Dependencies*

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# Improving Tasking Performance: Task dependences

## ■ Task dependences as a way to define task-execution constraints

```
int x = 0;
#pragma omp parallel
#pragma omp single
{
  ● #pragma omp task
  std::cout << x << std::endl;

  #pragma omp taskwait

  ● #pragma omp task
  x++;
}
```

OpenMP 3.1

```
int x = 0;
#pragma omp parallel
#pragma omp single
{
  ● #pragma omp task depend(in: x)
  std::cout << x << std::endl;

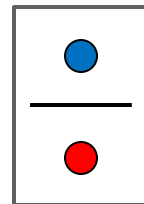
  #pragma omp taskwait

  ● #pragma omp task depend(inout: x)
  x++;
}
```

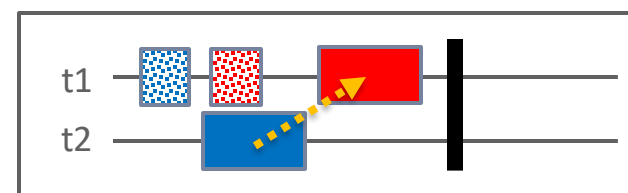
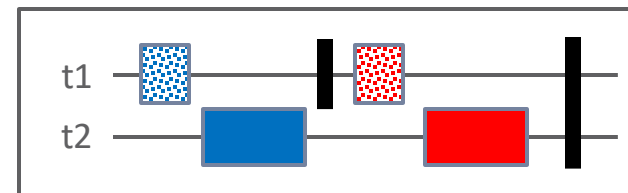
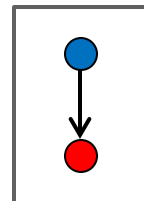
OpenMP 4.0

Task dependences can help us to remove “strong” synchronizations, increasing the look ahead and, frequently, the parallelism!!!!

OpenMP 3.1



OpenMP 4.0



Task's creation time  
 Task's execution time

# *What's in the spec*

# What's in the spec: a bit of history

## OpenMP 4.0

- The `depend` clause was added to the `task` construct

## OpenMP 4.5

- The `depend` clause was added to the target constructs
- Support to `doacross` loops

## OpenMP 5.0

- `lvalue` expressions in the `depend` clause
- New dependency type: `mutexinoutset`
- Iterators were added to the `depend` clause
- The `depend` clause was added to the `taskwait` construct
- Dependable objects

# What's in the spec: syntax depend clause

```
depend([depend-modifier,] dependency-type: list-items)
```

where:

→ `depend-modifier` is used to define iterators

→ `dependency-type` may be: `in`, `out`, `inout`, `mutexinoutset` **and** `depobj`

→ A `list-item` may be:

- C/C++: A lvalue expr or an array section     `depend(in: x, v[i], *p, w[10:10])`
- Fortran: A variable or an array section     `depend(in: x, v(i), w(10:20))`

# What's in the spec: sema depend clause (1)

- A task cannot be executed until all its predecessor tasks are completed
- If a task defines an `in` dependence over a list-item
  - the task will depend on all previously generated sibling tasks that reference that list-item in an `out`, `inout` or `mutexinoutset` dependence
- If a task defines an `out/inout` dependence over list-item
  - the task will depend on all previously generated sibling tasks that reference that list-item in an `in`, `out`, `inout` or `mutexinoutset` dependence
- **TODO:** add semantics for new `inouset` and `mutexinouset`

# What's in the spec: depend clause (1)

- A task cannot be executed until all its predecessor tasks are completed

- If a task defines

→ the task will create  
an out or inout

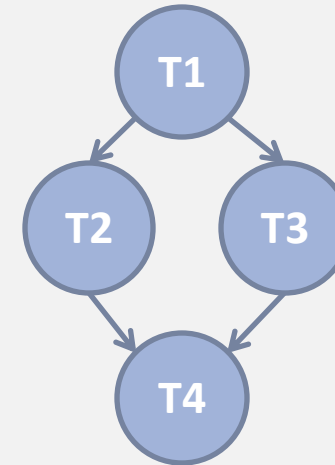
```

int x = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x) //T1
    { ... }

    #pragma omp task depend(in: x) //T2
    { ... }

    #pragma omp task depend(in: x) //T3
    { ... }

    #pragma omp task depend(inout: x) //T4
    { ... }
}
    
```



one of the list items in

- If a task defines

→ the task will create  
an in, inout

one of the list items in



# What's in the spec: depend clause (2)

## ■ New dependency type: mutexinoutset

```

int x = 0, y = 0, res = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(out: res) //T0
    res = 0;

    #pragma omp task depend(out: x) //T1
    long_computation(x);

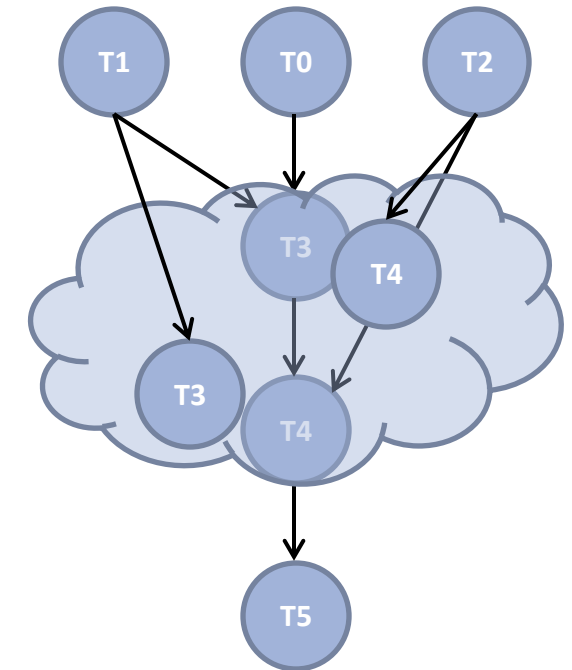
    #pragma omp task depend(out: y) //T2
    short_computation(y);

    #pragma omp task depend(in: x) depend(mutexinoutset/T3/res) //T3
    res += x;

    #pragma omp task depend(in: y) depend(mutexinoutset/T4/res) //T4
    res += y;

    #pragma omp task depend(in: res) //T5
    std::cout << res << std::endl;
}

```



1. *inoutset property*: tasks with a mutexinoutset dependence create a cloud of tasks (an inout set) that synchronizes with previous & posterior tasks that dependent on the same list item
2. *mutex property*: Tasks inside the inout set can be executed in any order but with mutual exclusion

# What's in the spec: depend clause (4)

- Task dependences are defined among **sibling tasks**

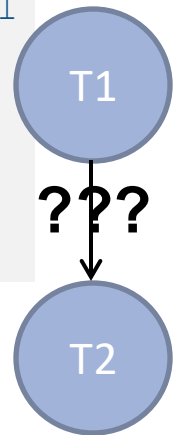
```
//test1.cc
int x = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x) //T1
    {
        #pragma omp task depend(inout: x) //T1.1
        x++;

        #pragma omp taskwait
    }
    #pragma omp task depend(in: x) //T2
    std::cout << x << std::endl;
}
```

- List items used in the depend clauses [...] must indicate **identical** or **disjoint storage**

```
//test2.cc
int a[100] = {0};
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: a[50:99]) //T1
    compute(/* from */ &a[50], /*elems*/ 50);

    #pragma omp task depend(in: a) //T2
    print(/* from */ a, /* elem */ 100);
}
```



# What's in the spec: depend clause (5)

- Iterators + deps: a way to define a dynamic number of dependences

```

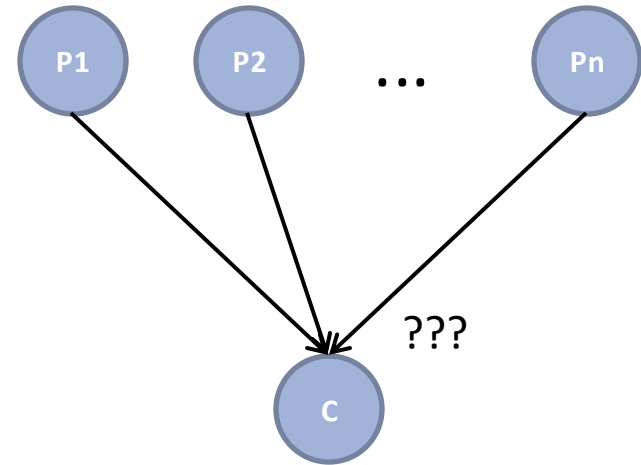
std::list<int> list = ...;
int n = list.size();

#pragma omp parallel
#pragma omp single
{
  for (int i = 0; i < n; ++i)
    #pragma omp task depend(out: list[i]) //Px
    compute_elem(list[i]);

  #pragma omp task depend(iter@0)(j=0:n), in : list[j]) //C
  print_elems(list);
}

```

It seems innocent but it's not:  
`depend(out: list.operator[] (i))`



Equivalent to:  
`depend(in: list[0], list[1], ..., list[n-1])`

# *Philosophy*

# Philosophy: data-flow model

## ■ Task dependences are orthogonal to data-sharings

→ **Dependences** as a way to define a **task-execution constraints**

→ **Data-sharings** as **how the data is captured** to be used inside the task


```
// test1.cc
int x = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x) \
                firstprivate(x) //T1
    x++;

    #pragma omp task depend(in: x) //T2
    std::cout << x << std::endl;
}
```

OK, but it always prints '0' :(

```
// test2.cc
int x = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x) //T1
    x++;

    #pragma omp task depend(in: x) \
                firstprivate(x) //T2
    std::cout << x << std::endl;
}
```



We have a data-race!!

# Philosophy: data-flow model (2)

- Properly combining dependences and data-sharings allow us to define a **task data-flow model**
  - Data that is read in the task → input dependence
  - Data that is written in the task → output dependence
  
- A task data-flow model
  - Enhances the **composability**
  - **Eases the parallelization** of new regions of your code

# Philosophy: data-flow model (3)

```
//test1_v1.cc
int x = 0, y = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x) //T1
    {
        x++;
        y++;    // !!!
    }
    #pragma omp task depend(in: x)    //T2
    std::cout << x << std::endl;

    #pragma omp taskwait
    std::cout << y << std::endl;
}
```

```
//test1_v2.cc
int x = 0, y = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x, y) //T1
    {
        x++;
        y++;
    }
    #pragma omp task depend(in: x)    //T2
    std::cout << x << std::endl;

    #pragma omp task depend(in: y)    //T3
    std::cout << y << std::endl;
}
```

If all tasks are **properly annotated**,  
we only have to worry about the  
dependences & data-sharings of the new task!!!

# *Use case*

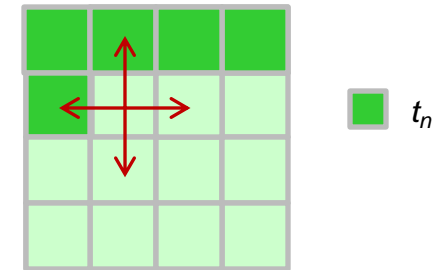


# Use case: intro to Gauss-seidel

```
void serial_gauss_seidel(int tsteps, int size, int (*p)[size]) {  
    for (int t = 0; t < tsteps; ++t) {  
        for (int i = 1; i < size-1; ++i) {  
            for (int j = 1; j < size-1; ++j) {  
                p[i][j] = 0.25 * (p[i][j-1] * // left  
                                p[i][j+1] * // right  
                                p[i-1][j] * // top  
                                p[i+1][j]); // bottom  
            }  
        }  
    }  
}
```

## Access pattern analysis

For a specific  $t, i$  and  $j$



Each cell depends on:

- two cells (north & west) that are computed in the current time step, and
- two cells (south & east) that were computed in the previous time step

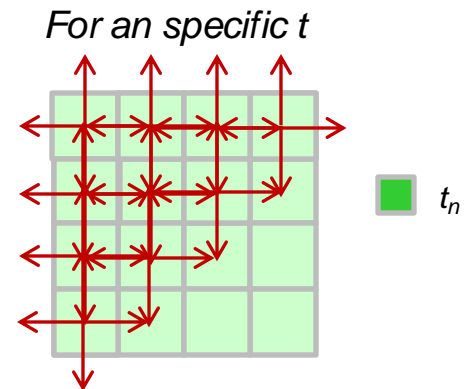
# Use case: Gauss-seidel (2)

```

void serial_gauss_seidel(int tsteps, int size, int (*p)[size]) {
    for (int t = 0; t < tsteps; ++t) {
        for (int i = 1; i < size-1; ++i) {
            for (int j = 1; j < size-1; ++j) {
                p[i][j] = 0.25 * (p[i][j-1] * // left
                                p[i][j+1] * // right
                                p[i-1][j] * // top
                                p[i+1][j]); // bottom
            }
        }
    }
}

```

## 1<sup>st</sup> parallelization strategy



We can exploit the wavefront to obtain parallelism!!

# Use case : Gauss-seidel (3)

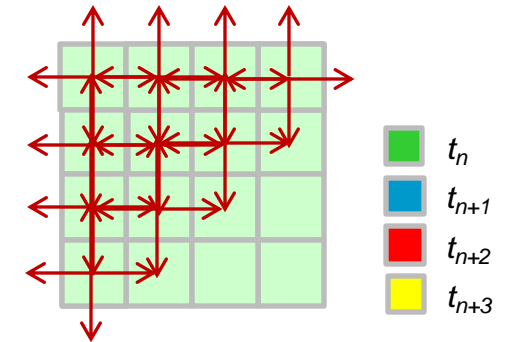
```
void gauss_seidel(int tsteps, int size, int TS, int (*p)[size]) {
    int NB = size / TS;
    #pragma omp parallel
    for (int t = 0; t < tsteps; ++t) {
        // First NB diagonals
        for (int diag = 0; diag < NB; ++diag) {
            #pragma omp for
            for (int d = 0; d <= diag; ++d) {
                int ii = d;
                int jj = diag - d;
                for (int i = 1+ii*TS; i < ((ii+1)*TS); ++i)
                    for (int j = 1+jj*TS; j < ((jj+1)*TS); ++j)
                        p[i][j] = 0.25 * (p[i][j-1] * p[i][j+1] *
                                           p[i-1][j] * p[i+1][j]);
            }
        }
        // Lasts NB diagonals
        for (int diag = NB-1; diag >= 0; --diag) {
            // Similar code to the previous loop
        }
    }
}
```

# Use case : Gauss-seidel (4)

```
void serial_gauss_seidel(int tsteps, int size, int (*p)[size]) {
    for (int t = 0; t < tsteps; ++t) {
        for (int i = 1; i < size-1; ++i) {
            for (int j = 1; j < size-1; ++j) {
                p[i][j] = 0.25 * (p[i][j-1] * // left
                                p[i][j+1] * // right
                                p[i-1][j] * // top
                                p[i+1][j]); // bottom
            }
        }
    }
}
```

## 2<sup>nd</sup> parallelization strategy

multiple time iterations



We can exploit the wavefront  
of multiple time steps to obtain MORE  
parallelism!!

# Use case : Gauss-seidel (5)

```

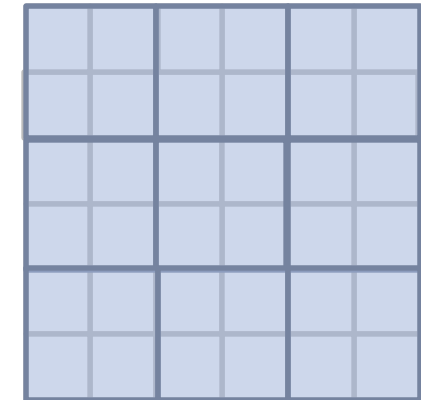
void gauss_seidel(int tsteps, int size, int TS, int (*p)[size]) {
    int NB = size / TS;

    #pragma omp parallel
    #pragma omp single
    for (int t = 0; t < tsteps; ++t)
        for (int ii=1; ii < size-1; ii+=TS)
            for (int jj=1; jj < size-1; jj+=TS) {
                #pragma omp task depend(inout: p[ii:TS][jj:TS])
                depend(in: p[ii-TS:TS][jj:TS], p[ii+TS:TS][jj:TS],
                    p[ii:TS][jj-TS:TS], p[ii:TS][jj:TS])

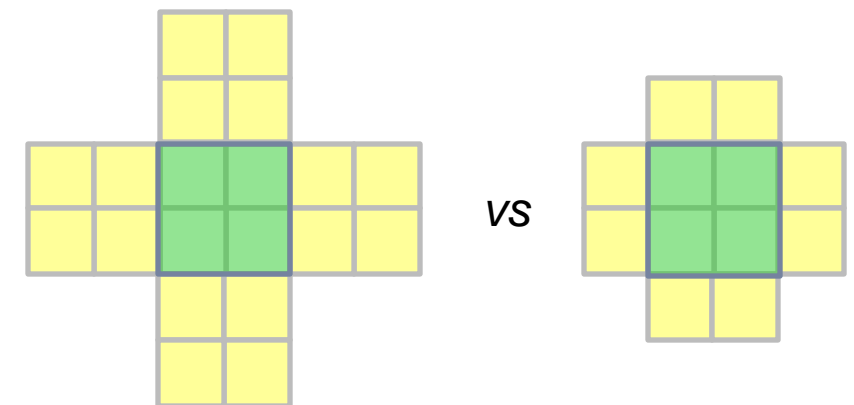
                {
                    for (int i=ii; i<(1+ii)*TS; ++i)
                        for (int j=jj; j<(1+jj)*TS; ++j)
                            p[i][j] = 0.25 * (p[i][j-1] * p[i][j+1] *
                                p[i-1][j] * p[i+1][j]);
                }
            }
    }
}

```

inner matrix region



Q: Why do the input dependences depend on the whole block rather than just a column/row?



# Use case : Gauss-seidel (5)

```

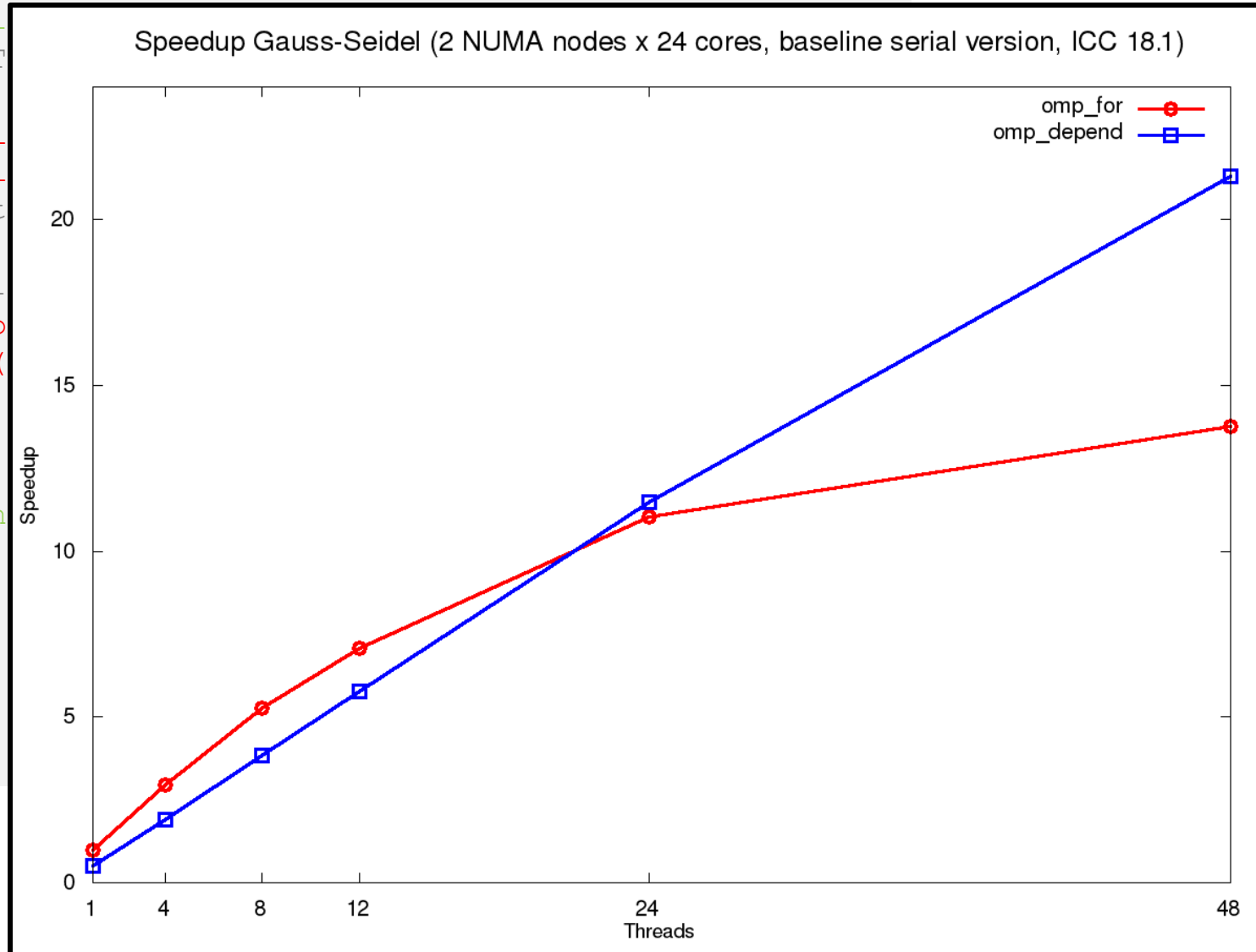
void gauss_seidel(int
int NB = size / T

#pragma omp paral
#pragma omp singl
for (int t = 0; t
for (int ii=1;
for (int jj=1
#pragma omp
depend(

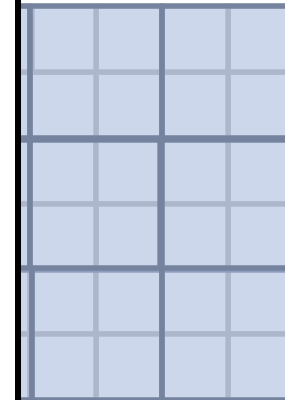
{
for (int
for (in
p[i]

}
}
}

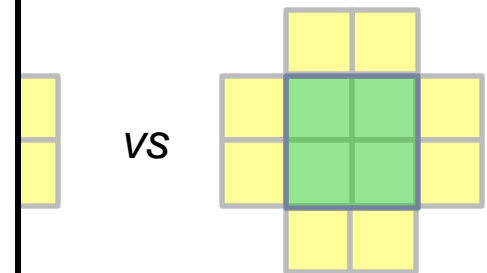
```



matrix region



the input dependences  
the whole block rather  
than a column/row?



# *OpenMP 5.0: (even) more advanced features*

# Advanced features: deps on taskwait

## ■ Adding dependences to the `taskwait` construct

→ Using a `taskwait` construct to explicitly wait for some predecessor tasks

→ Syntactic sugar!

```
int x = 0, y = 0;
#pragma omp parallel
#pragma omp single
{
    #pragma omp task depend(inout: x) //T1
    x++;

    #pragma omp task depend(in: y) //T2
    std::cout << y << std::endl;

    #pragma omp taskwait depend(in: x)

    std::cout << x << std::endl;
}
```