Task Parallelism

Prof. Guido Araujo

Task Parallelism

- Programming model
- Runtime design
- Task stealing
- Runtime performance
- Runtime overhead
- Optimization
  - Task coalescing
  - Dynamic worker deactivation
  - Workload balancing
  - Dependency analysis
- Example

Programming models

- BSC OpenSs
- OpenMP 4.x
  - Intel IOMP
  - GCC GOMP
  - Unicamp MTSP

```
#pragma omp task in(v[i-1]) out(v[i])
fun1(&v[i-1], &v[i])
```

Task Parallelism

The OpenMP 4.0 task programming model

```
for (int i=1, j=1;  i<N;  i++)  {

      #pragma omp task in(v[i-1]) out(v[i])
       fun1(&v[i-1],  &v[i]);

       for (int k=0;  k<i;  k++,  j++)  {

          #pragma omp task in(v[i]) out(u[j])
             fun2(&v[i],   &u[j]);
       }

       fun3( 3 * i );
}
```

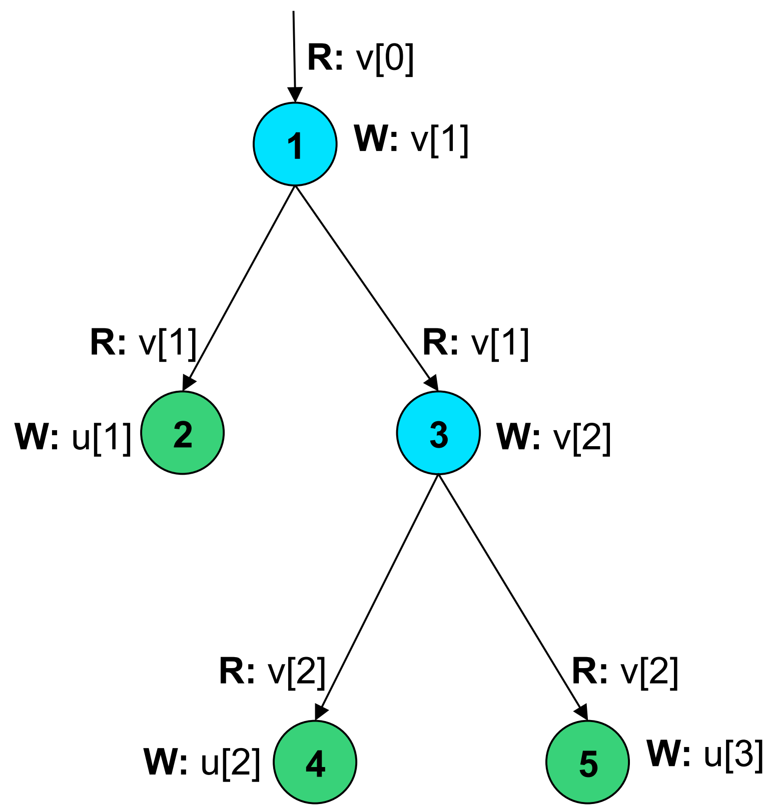
Create a task!

Create a task!

Create NO tasks!

Task Parallelism

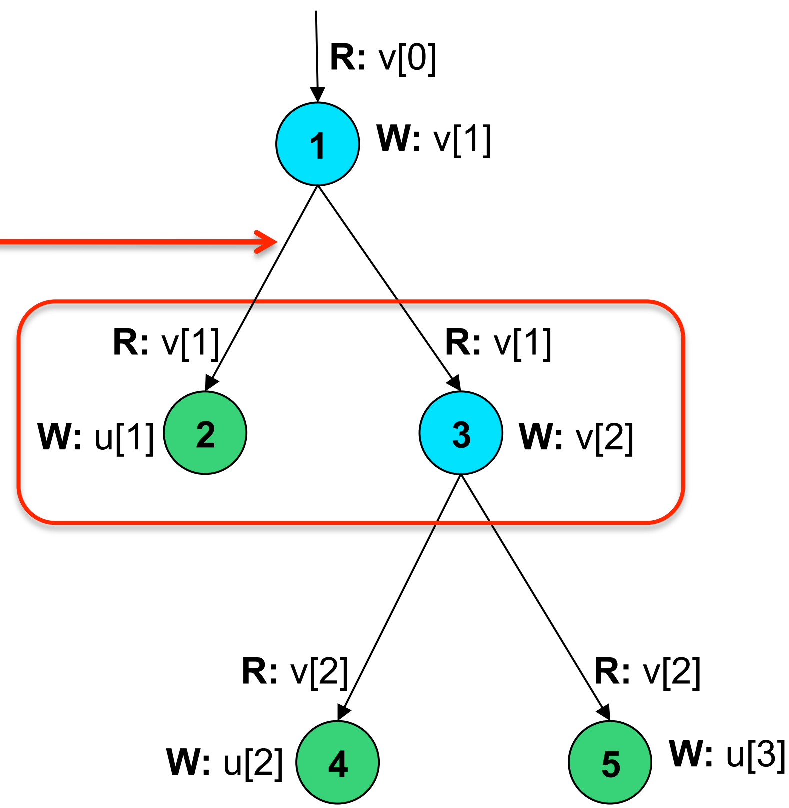
```
for (int i=1, j=1;  i<N;  i++)  {

    #pragma task in(v) out(v)
     fun1(&v[i-1],  &v[i]);

     for (int k=0;  k<i;  k++,  j++)  {

       #pragma task in(v) out(u)
       fun2(&v[i],   &u[j]);
     }

     fun3( 3 * i );
}
```



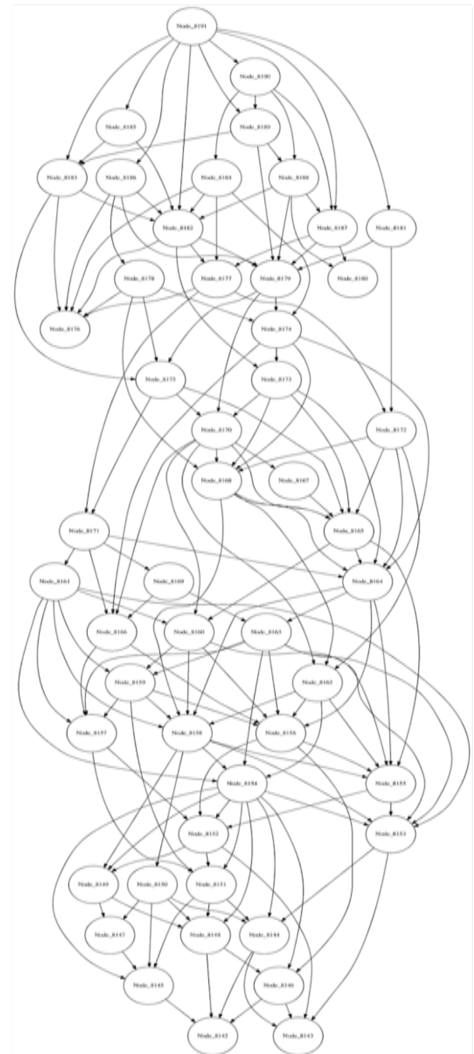
Task Parallelism Advantages

No need to communicate data. Just detect the dependency

Parallelism between interations of different loops



But graphs are not always that simple!



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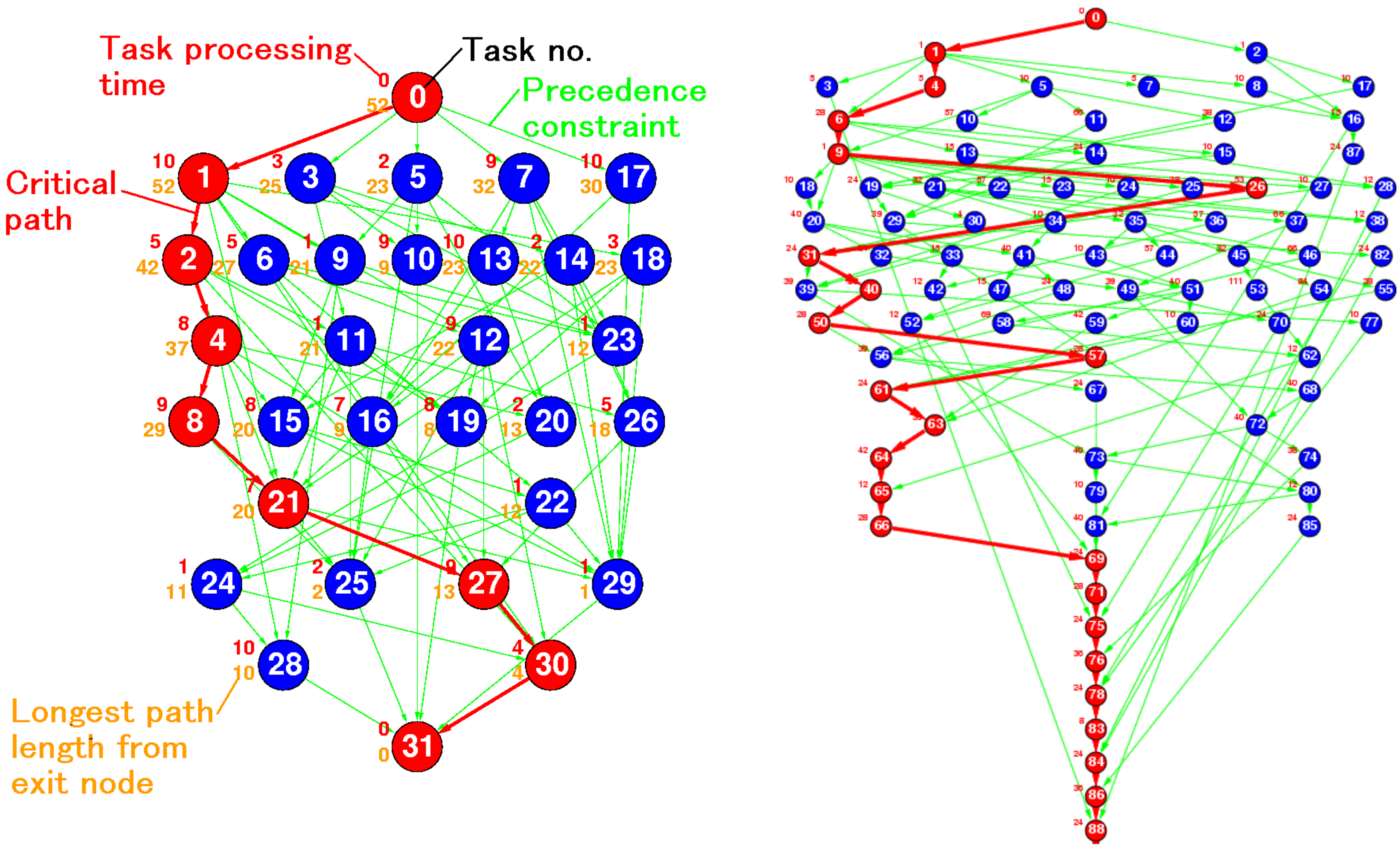

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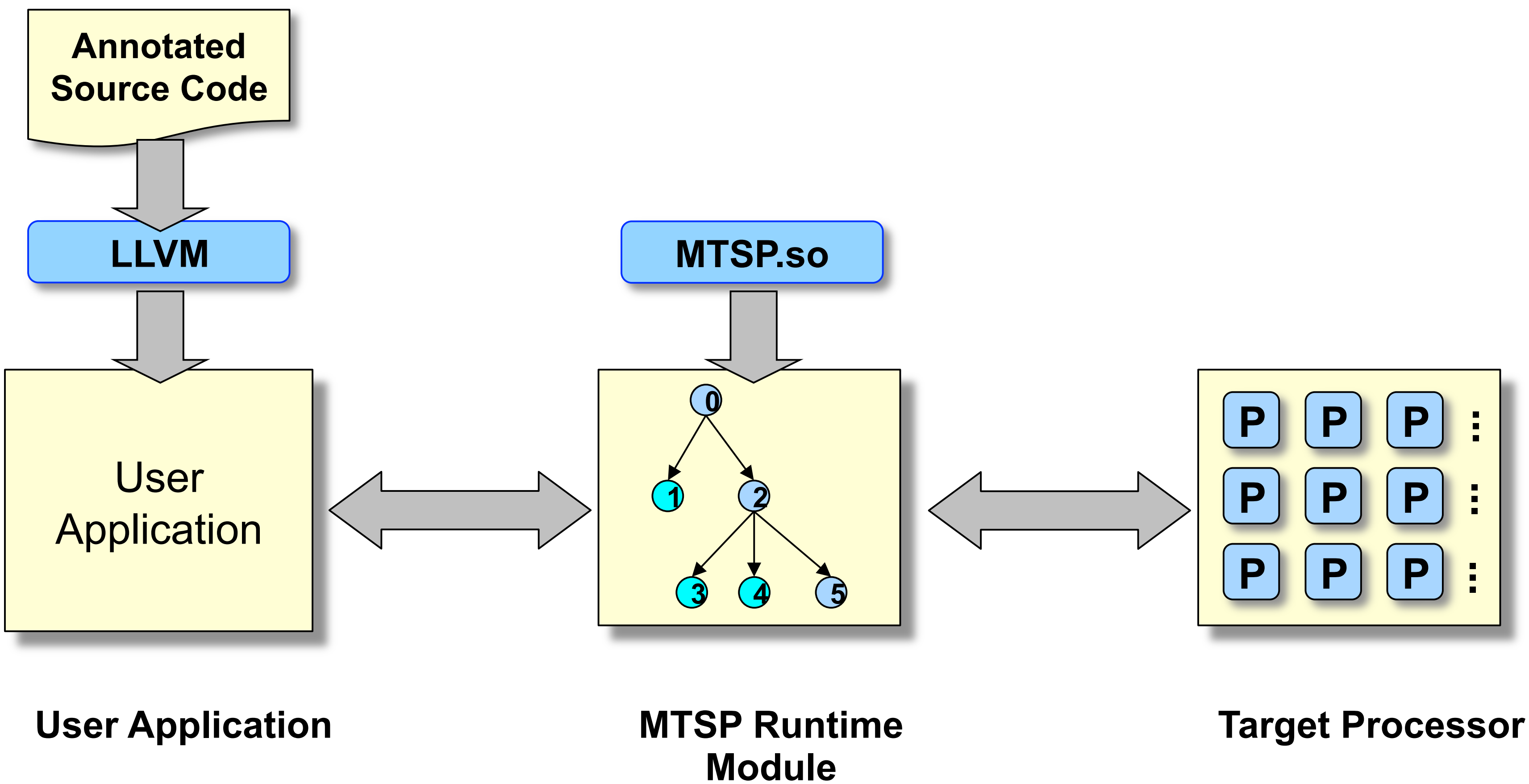
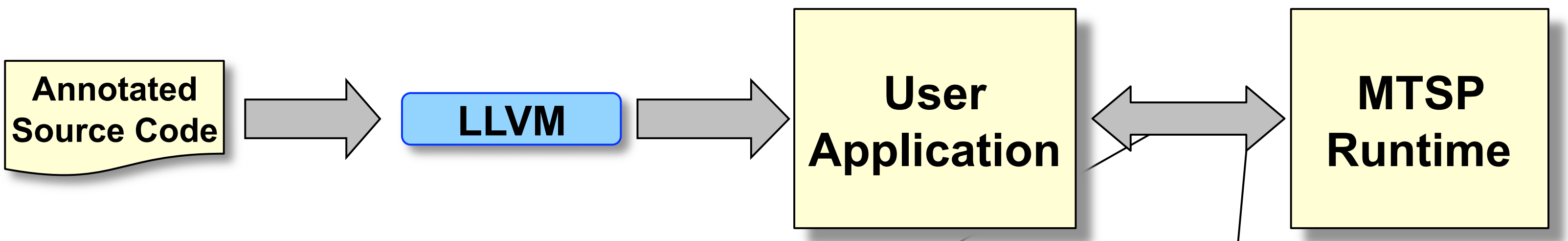
Runtime design

The MSTP runtime



The CLang OMP Interface



/// Used to create a pool of threads

/// and initiate the system

void kmpc_fork_call(...);

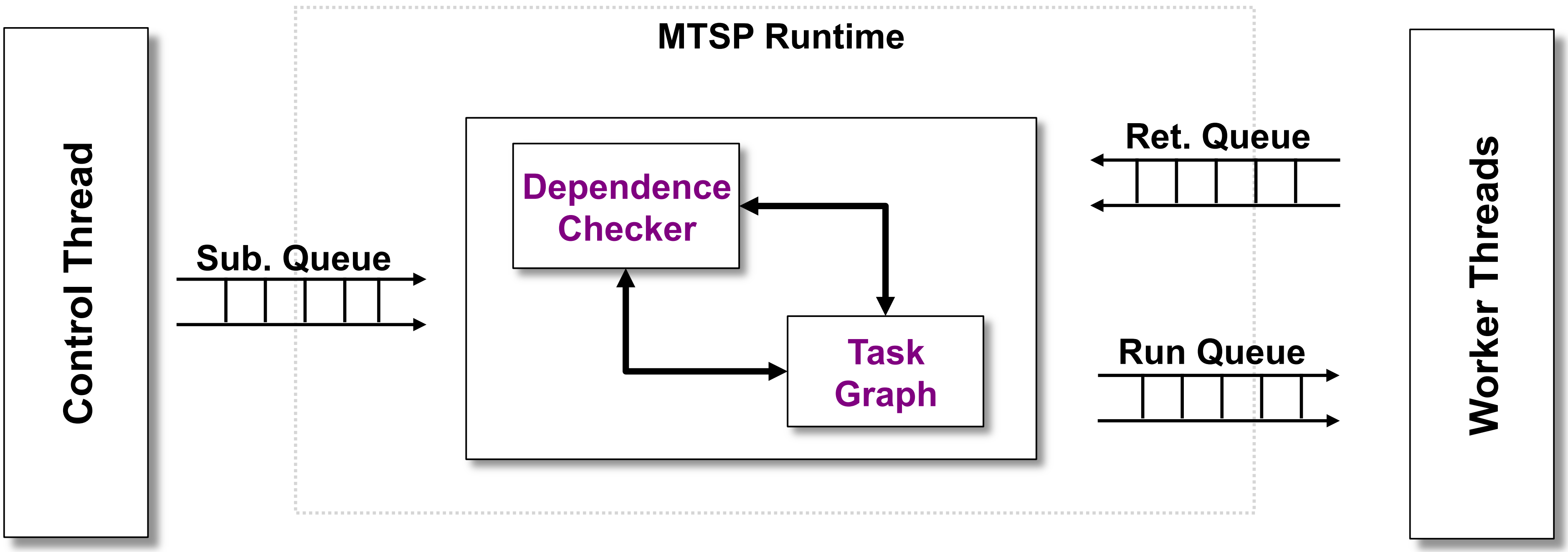
/// Used for task allocation

kmp_task* **kmpc_omp_task_alloc**(...);

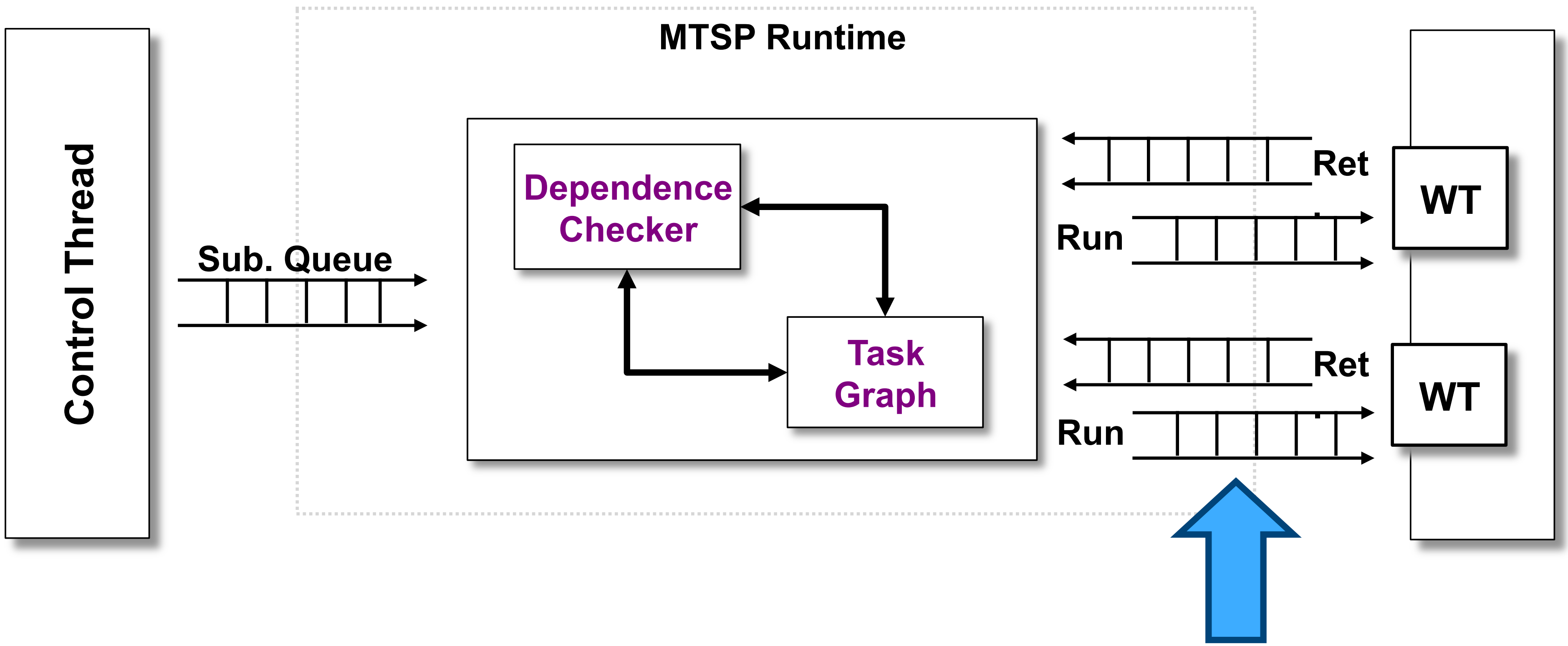
/// Used to add a task to the runtime

***kmp_int32* kmpc_omp_task_with_deps(...);**

MTSP Overview



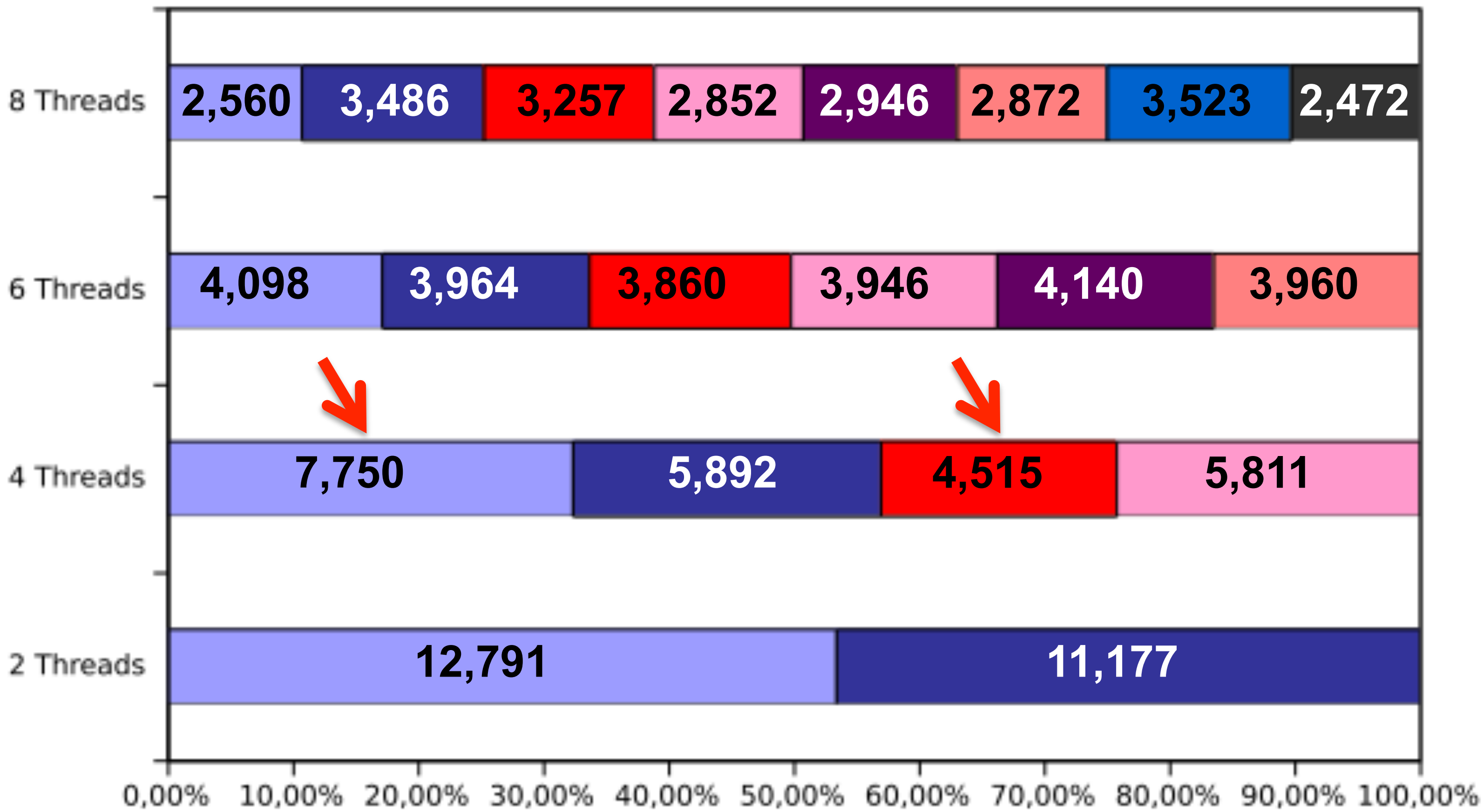
Distributed Queues



Each core has its own run/ret queues.

Evaluating Workload

Problem: Load Balancing



SparseLu -n 64 -m 64

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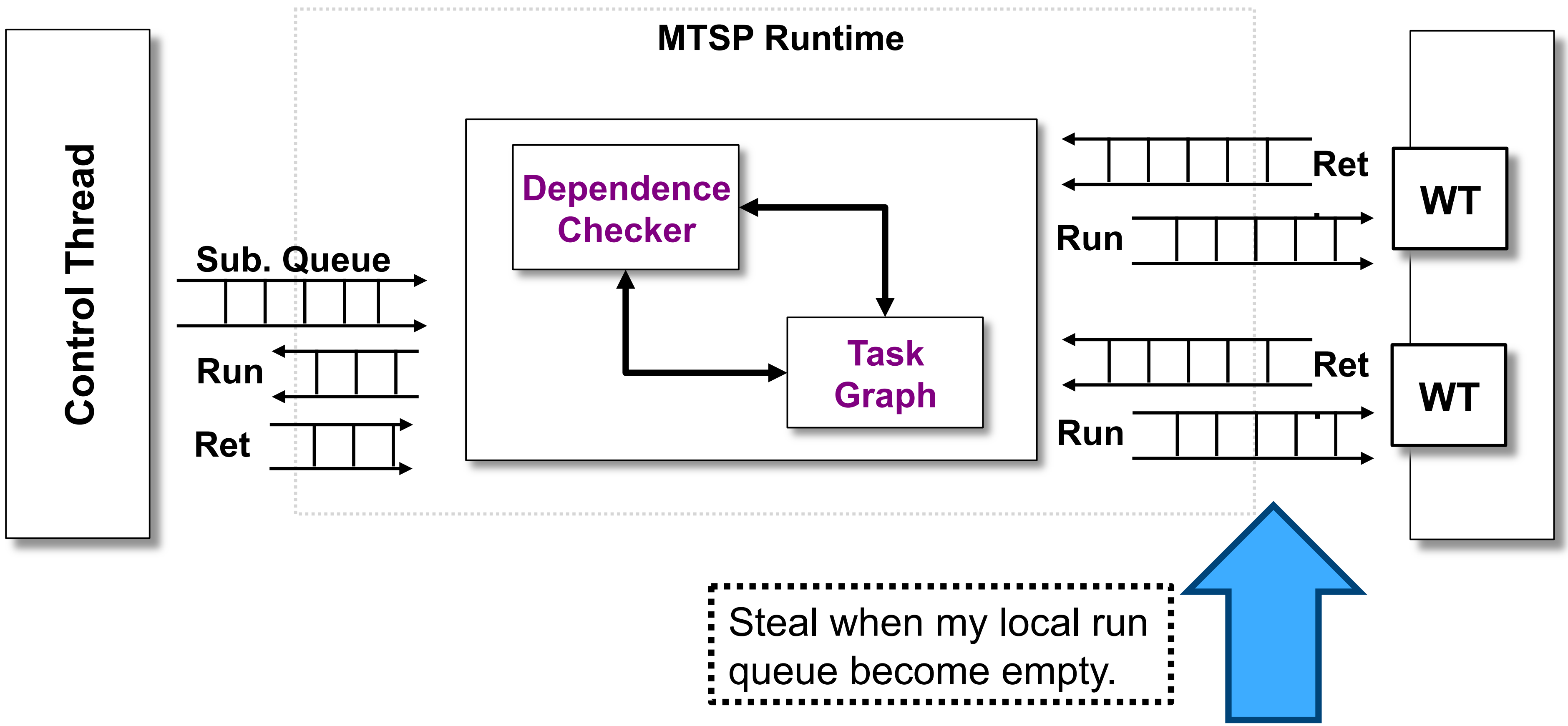
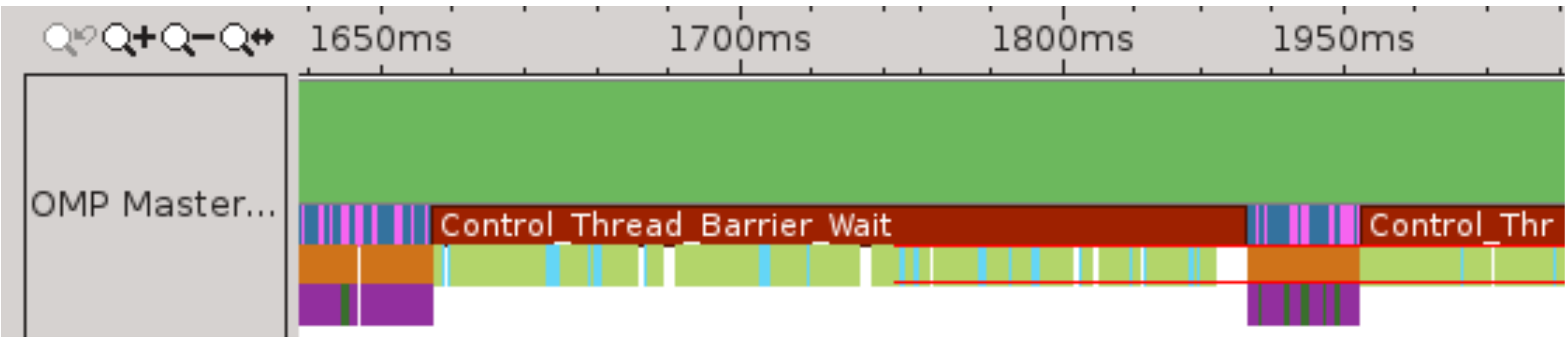
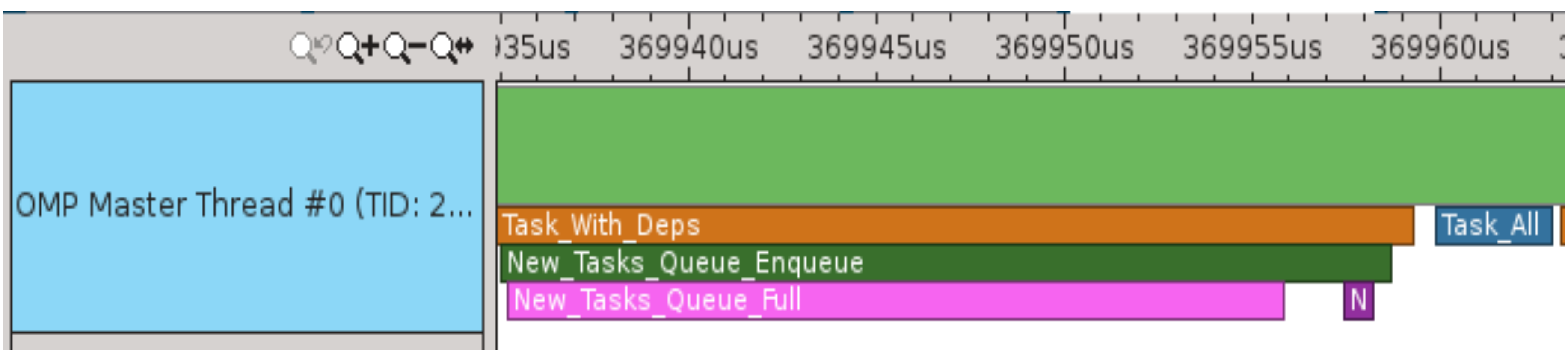
Work Stealing among Worker Threads



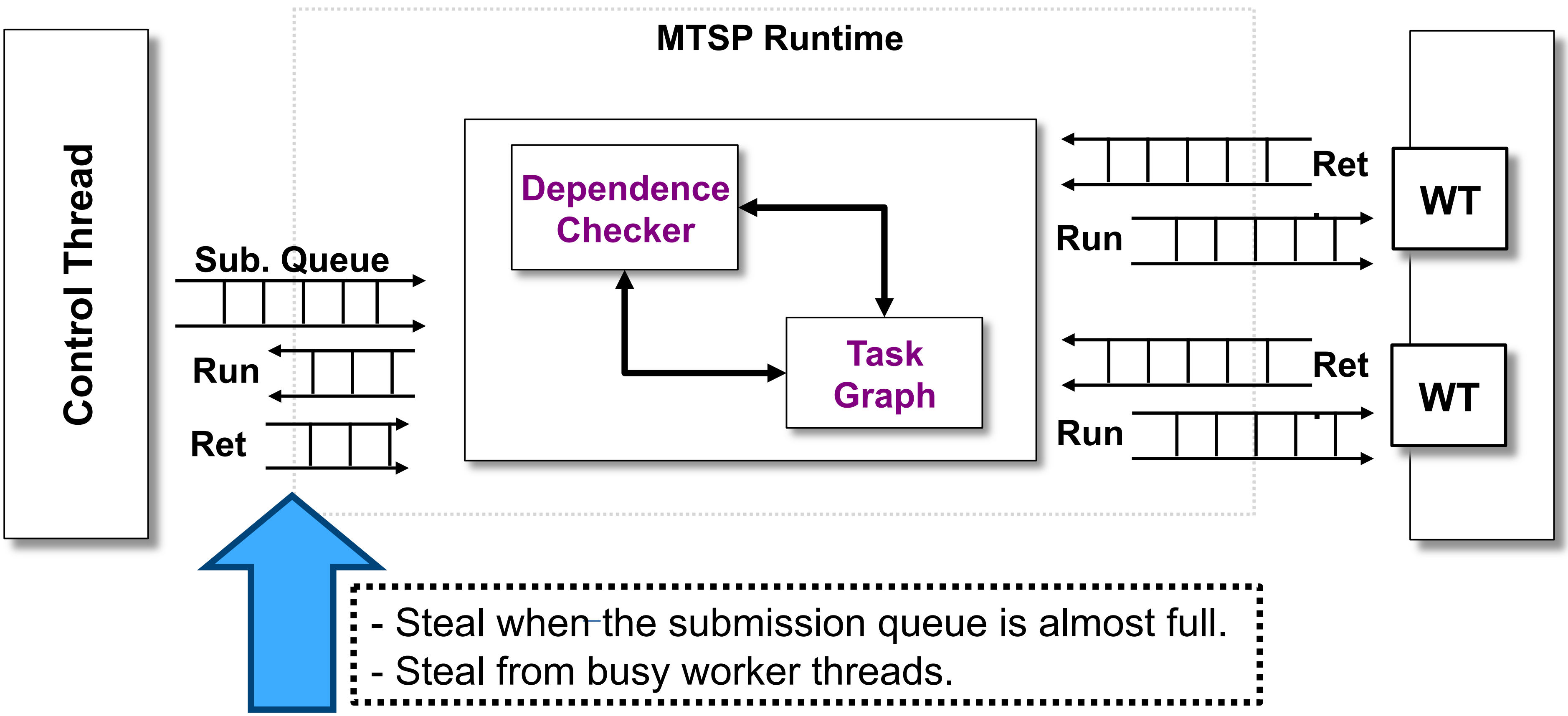
Control thread waiting

Solution: Work Stealing to control thread



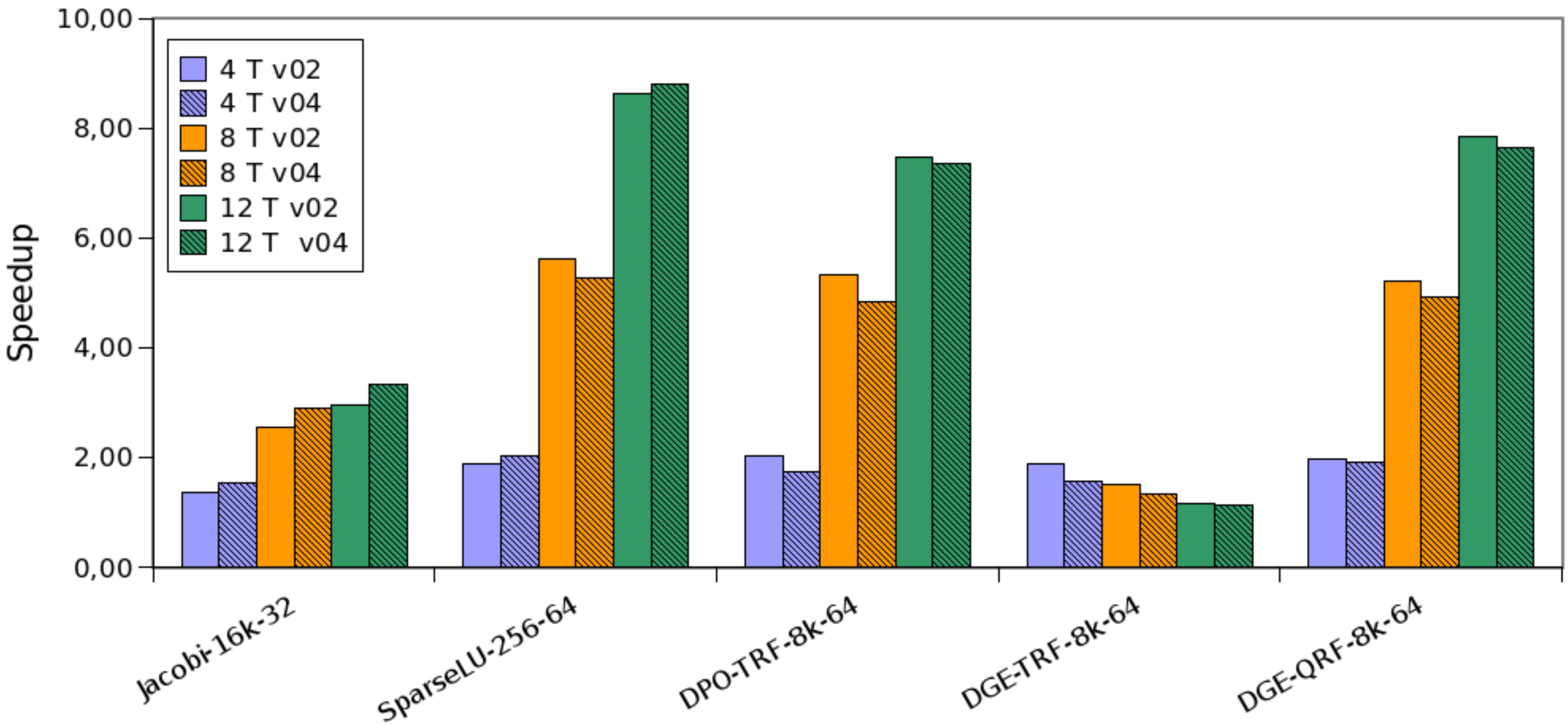


Work Stealing for the Control Thread



- Steal when the submission queue is almost full.
- Steal from busy worker threads.

Control Thread Stealing



Take away: for a larger number of threads performance improves!

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Efficient Task Execution

Efficient Task Execution

Manager Cost	= 1 second
Task Size	= 1.5 seconds

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1 Worker Thread

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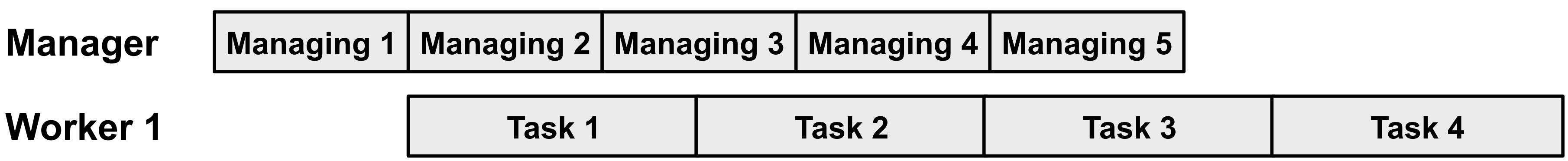
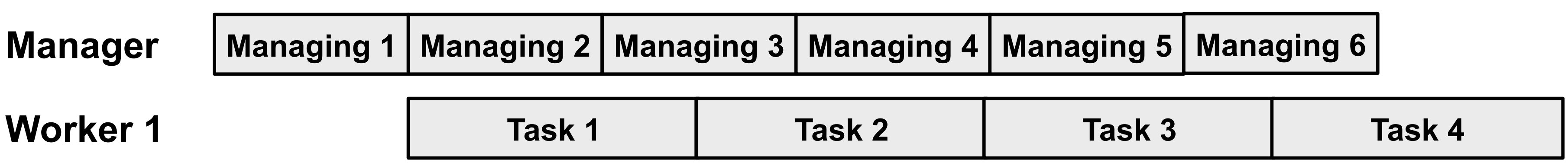


Efficient Task Execution

Manager Cost = 1 second

Task Size = 1.5 seconds

1 Worker Thread



One task is dispatched every 1 second.

One task is consumed every 1.5 seconds.

No Worker Thread is Idle

Efficient Task Execution

Manager Cost	= 1 second
Task Size	= 1.5 seconds

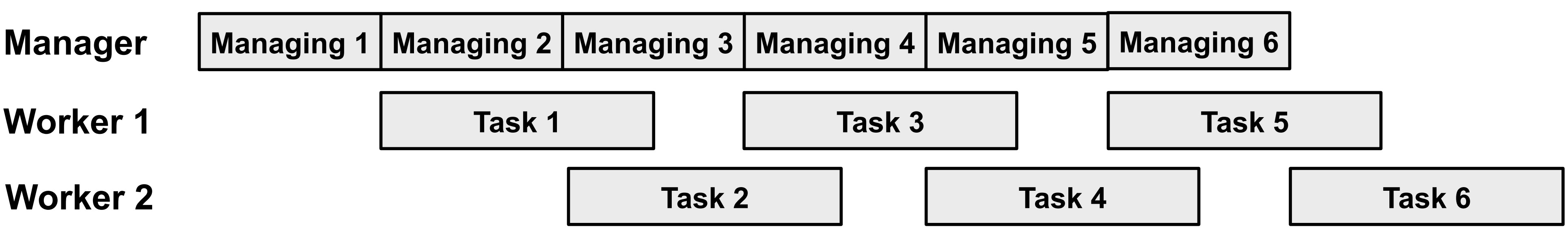
2 Worker Threads

Efficient Task Execution

Manager Cost = 1 second

Task Size = 1.5 seconds

2 Worker Threads



Two tasks are dispatched every 2 seconds.

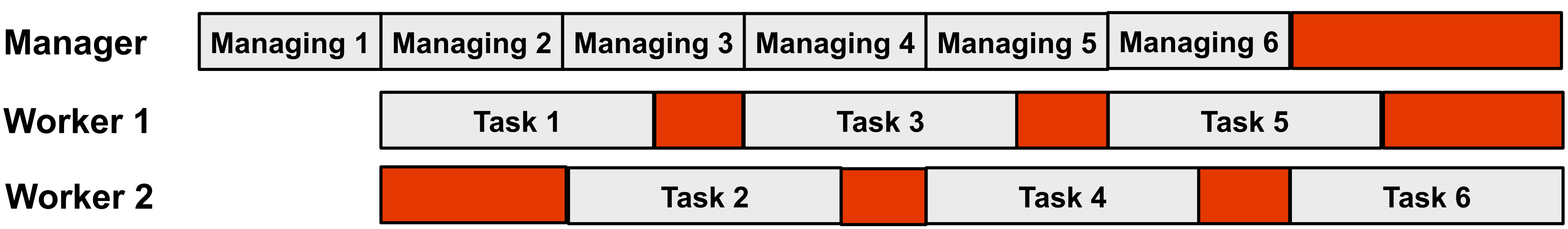
One task isconsumed every 1.0 seconds.

Efficient Task Execution

Manager Cost = 1 second

Task Size = 1.5 seconds

2 Worker Threads



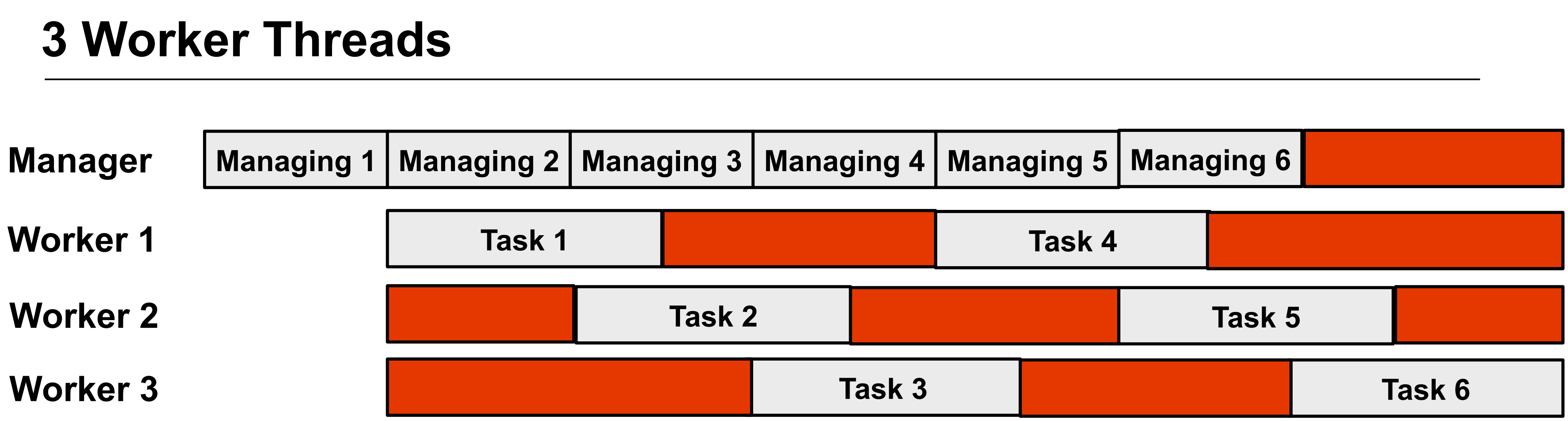
Two tasks are dispatched every 2 seconds.

Two tasks are consumed every 1.5 seconds.

Efficient Task Execution

Manager Cost = 1 second

Task Size = 1.5 seconds



Efficient Task Execution

Manager Cost = **0.5 second**

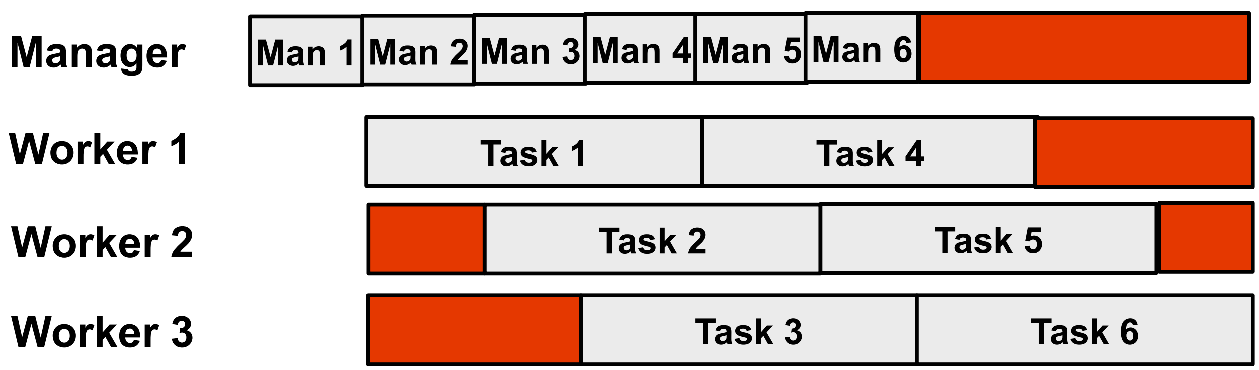
Task Size = 1.5 seconds

Efficient Task Execution

Manager Cost = **0.5 second**

Task Size = 1.5 seconds

3 Worker Threads



Efficient Task Execution

Rationale:

Task management throughput remained constant.

Task consumption throughput increased

Should activate only the needed number of workers

The Implementation

- **Task Size** → TSize
- **Runtime Cost** → RCost
- **Max Number of Workers** → ?

The Implementation

- **Task Size** ⟶ **TSize**
- **Runtime Cost** ⟶ **RCost**
- **Max Number of Workers** ⟶ **?**

The maximum number of workers for a given *TSize* and *RCost* is:

$$MaxWorkers = \frac{TSize}{RCost}$$

That is, the maximum number of tasks the runtime can dispatch during the execution of another task.

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Runtime overhead

Task Data	SparseLU (-64)			
Task ID	402830	402860	4028a0	4028e0
Task cycles	246287	429212	382085	649154
Runtime cycles	9896	19457	25522	33167
#Tasks	64	1024	1024	21856

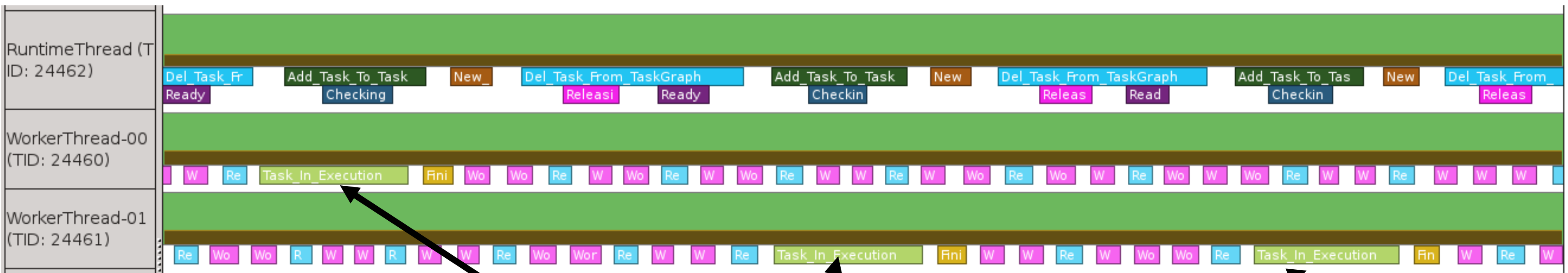
Large tasks

Task Data	Jacobi (-32)			
Task ID	401ab0	401ea0	403040	403170
Task cycles	35736	100728	1682	6742
Runtime cycles	497	637	15234	38907
#Tasks	512	1024	4096	4096

Small tasks with many dependences

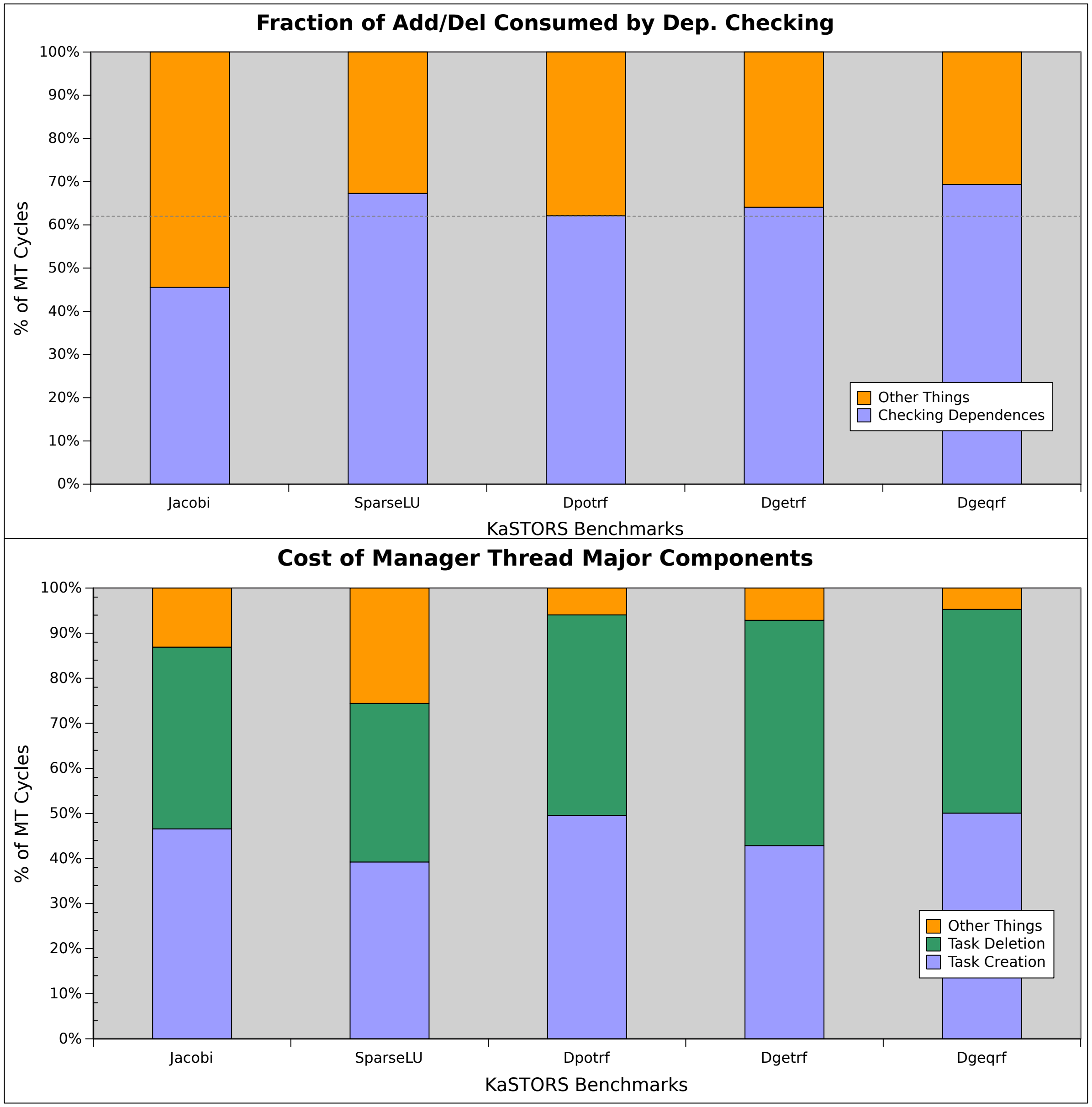
Profiling the MTSP Runtime

What are the major sources of overhead?



Task Size → <u>2,000 Add & Mul</u>

MTSP Overhead Split

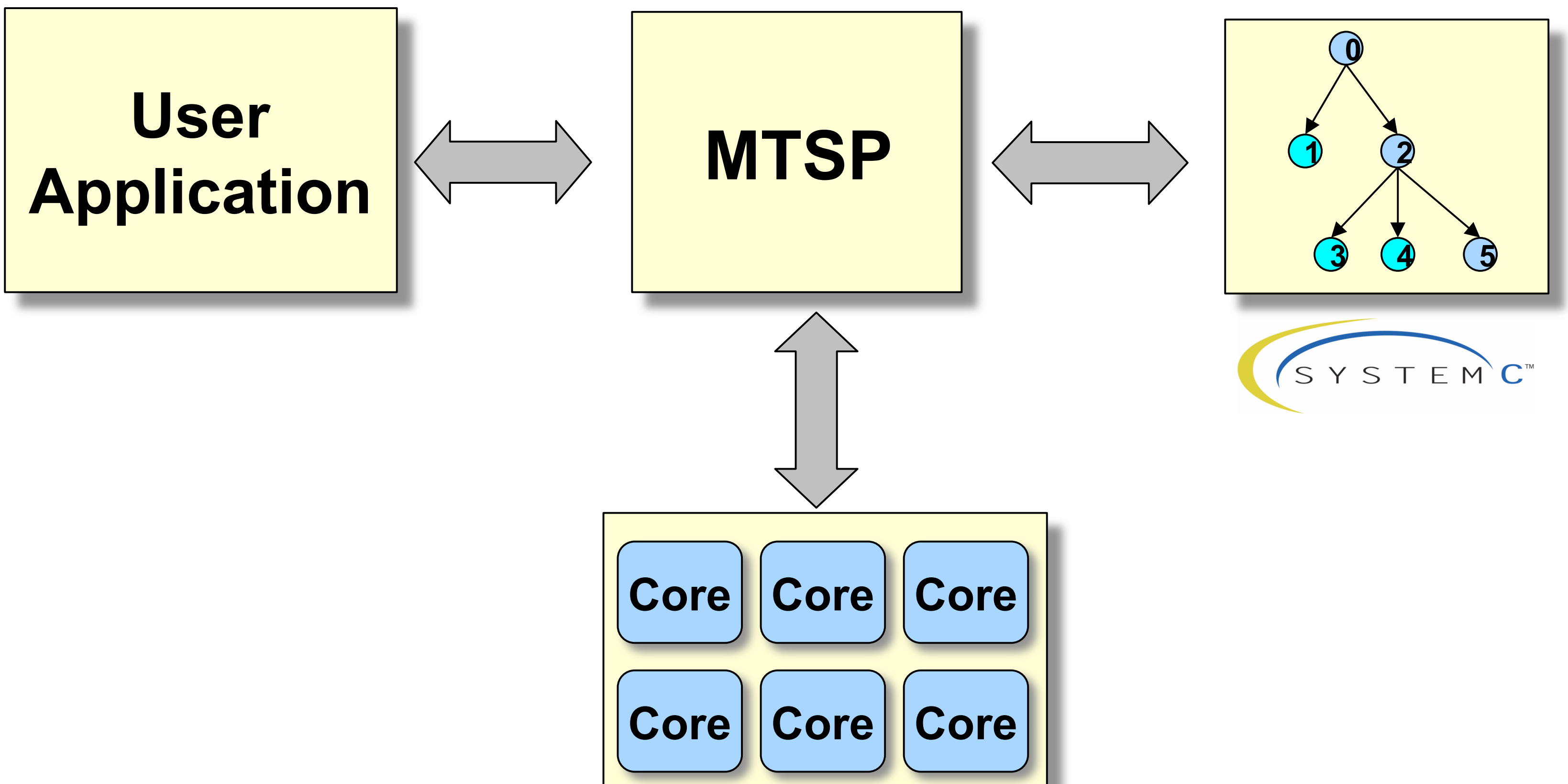


Need to reduce the runtime overhead!

What if we use hardware support?

Solution: Hardware-enabled task management

Task Graph Accelerator (TGA)



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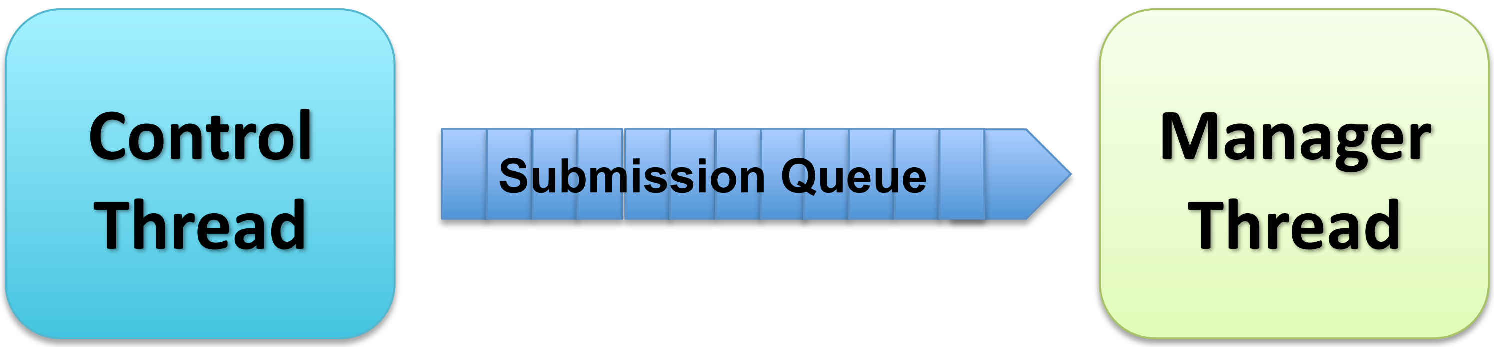
Task Coalescing

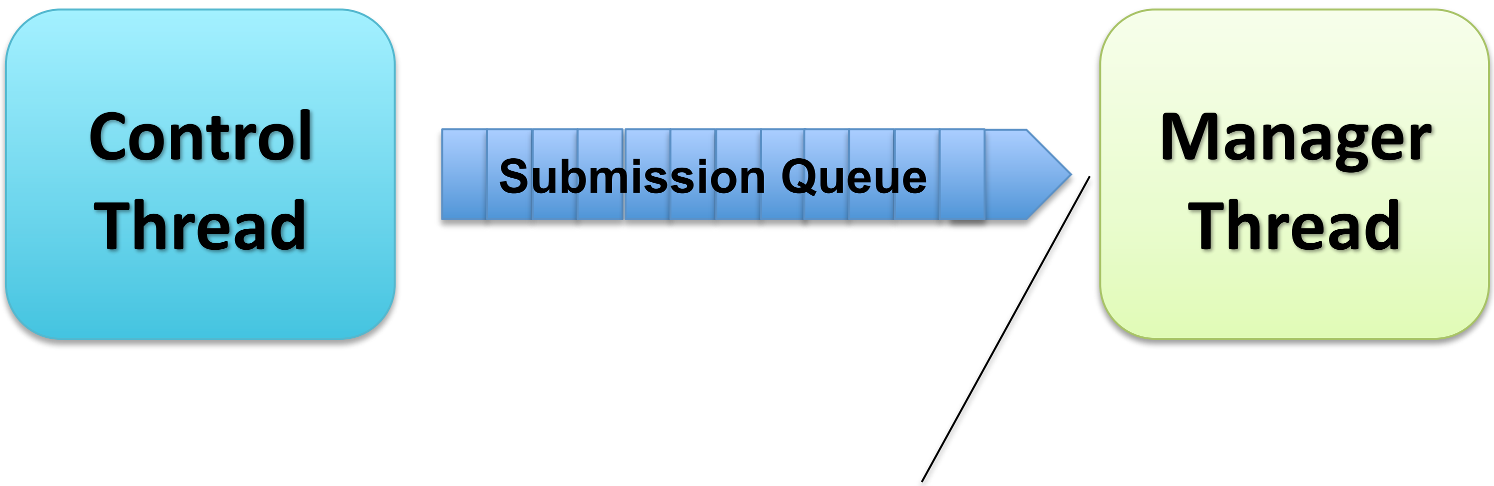
- What is it?
  - Group together subsequent tasks from the submission queue.

- Why do it?
  - Reduce the average time spent with task management.

Task Coalescing



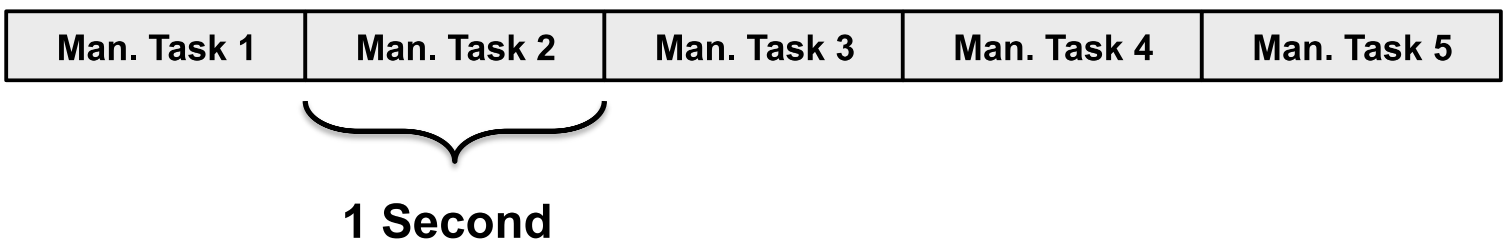
Task Coalescing




```
while (current_task() == prev_task())
      concatenate_tasks();
```

Task Coalescing

Manager Thread



Individual task management.

Task Coalescing

Manager Thread

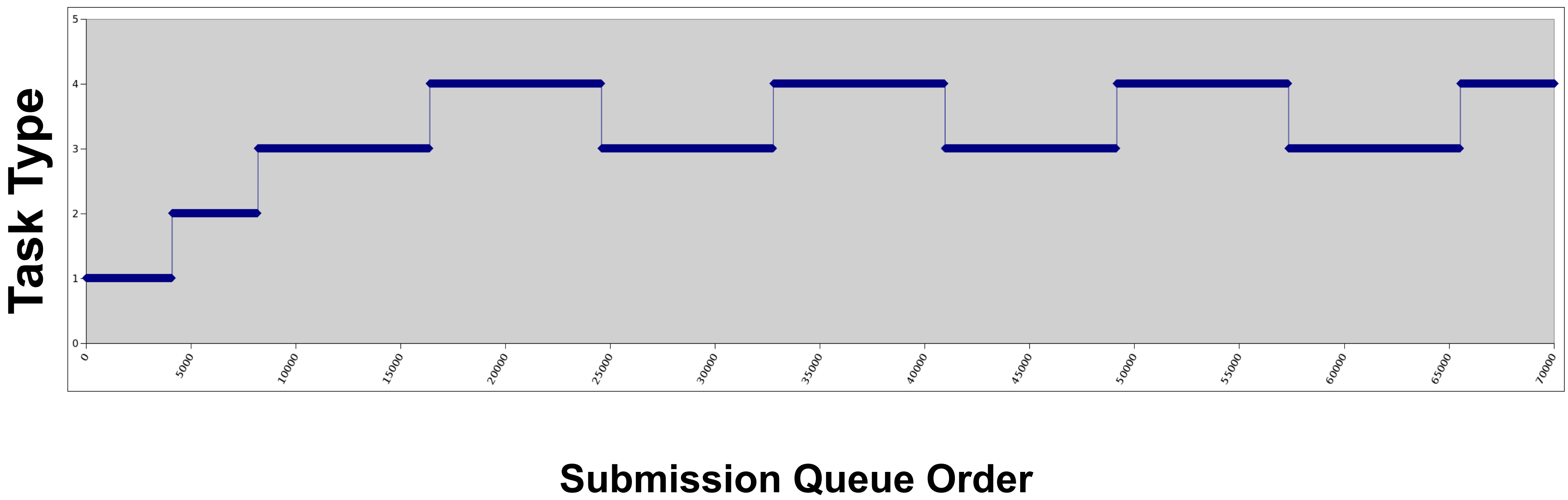
Task 1 & 2	**Task 3 & 4**	**Task 5 & 6**	**Task 7 & 8**	**Task 9 & 10**

1 Second...

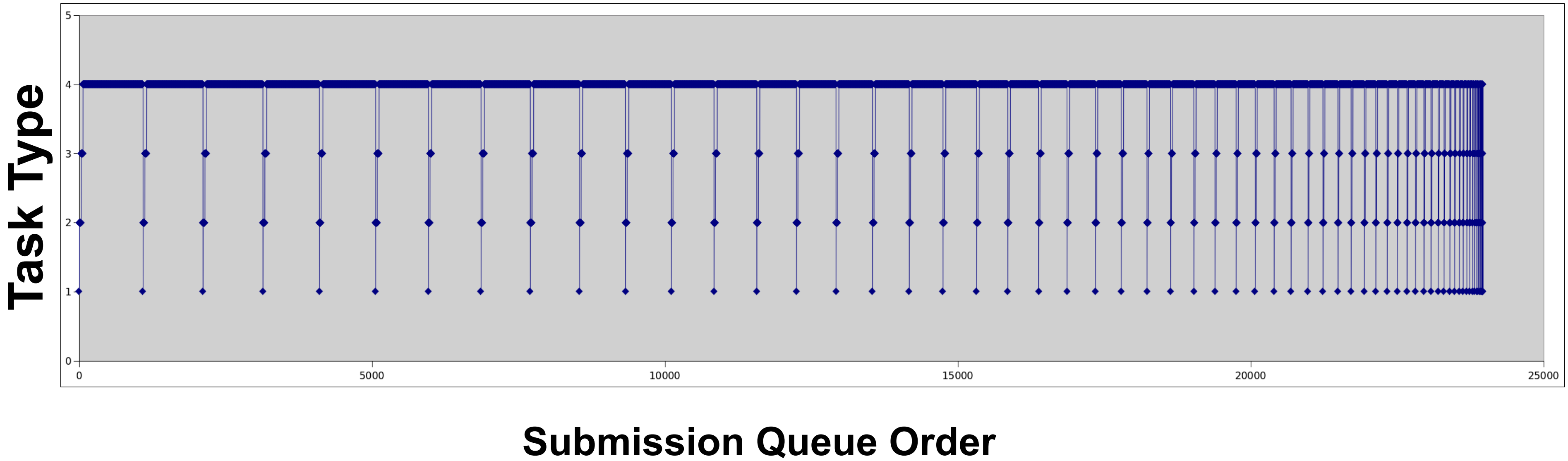
but 2 Tasks

Coalesced task management.

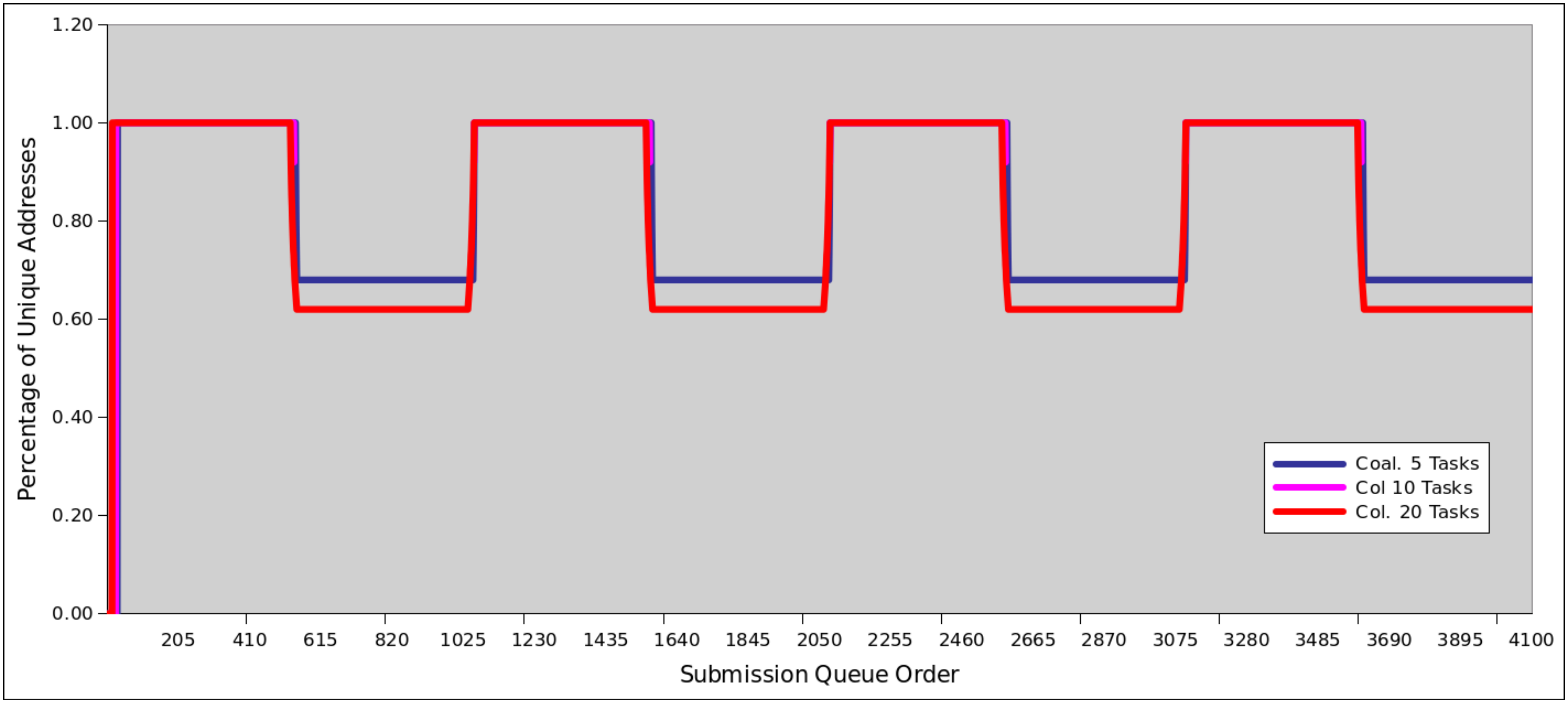
Task Submission Pattern (Jacobi)



Task Submission Pattern (SparseLU)



Parameter Sharing Among Tasks



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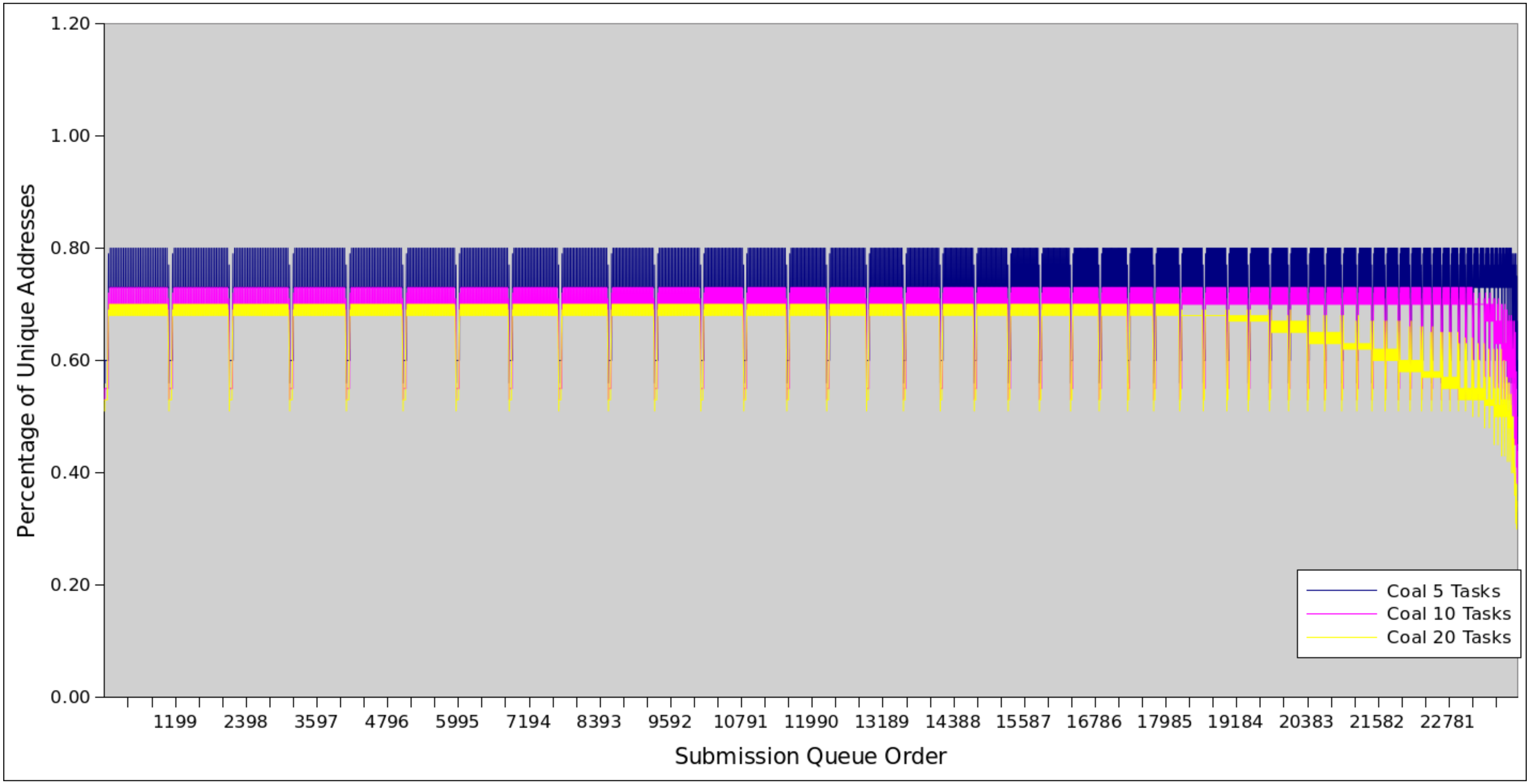

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The Idea

Manager Cost	= 1 second	← **Difficult to improve!**
Task Size	= 1.5 seconds	← **Cannot control.**

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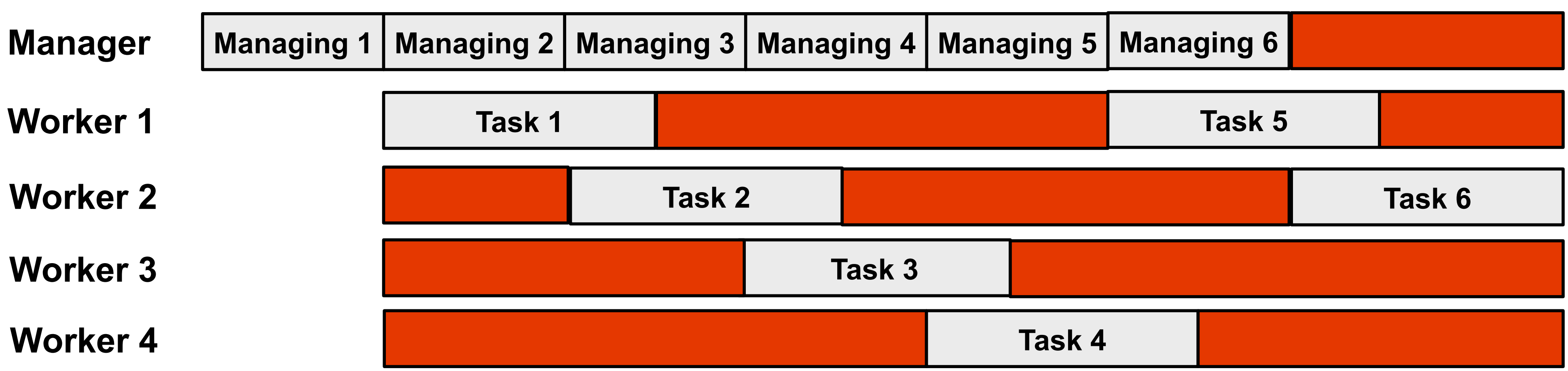

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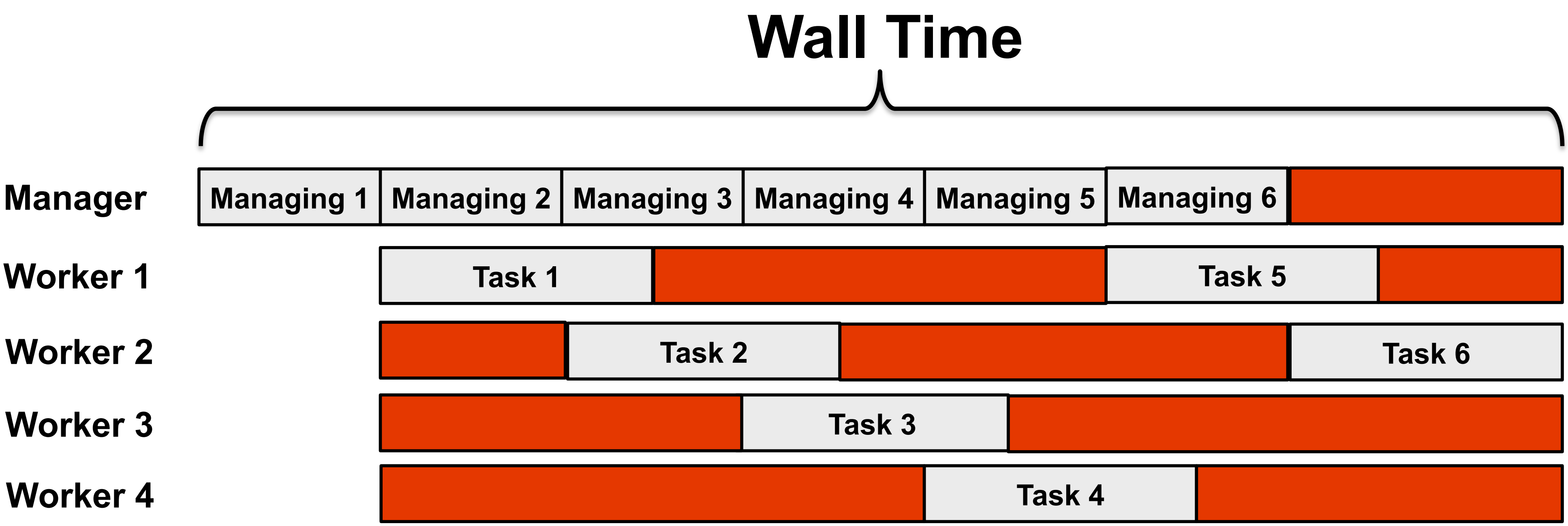

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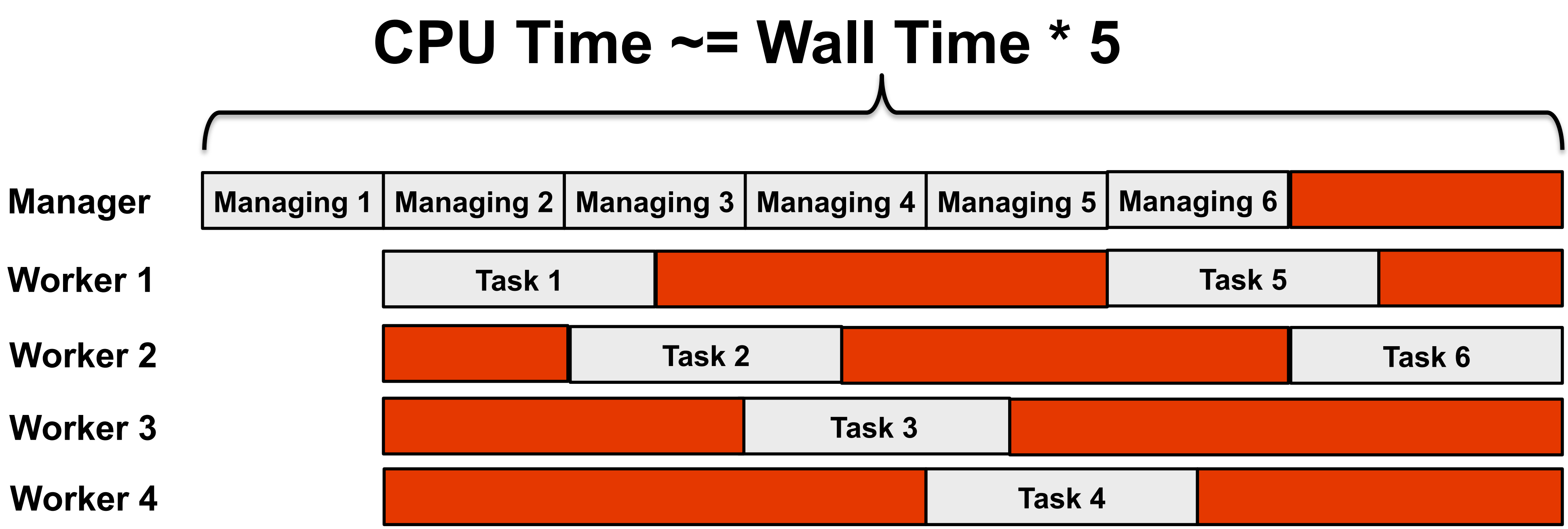

The Idea

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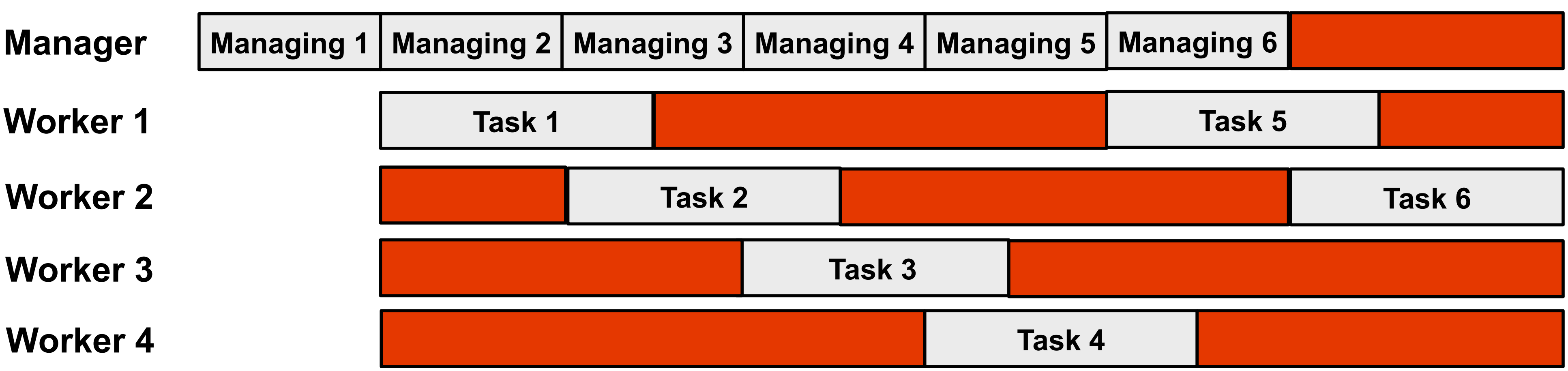
Can we reduce CPU Time without degrading Wall Time?



The Implementation

- Always use a small number of threads!

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- Programs have phases...

The Implementation

- ~~Always use a small number of threads!~~
- Programs have phases...
- Dynamically compute the instantaneous maximum number of workers supported!

Remembering

- **Task Size** → **TSize**
- **Runtime Cost** → **RCost**
- **Max Number of Workers** → **?**

The maximum number of workers for a given *TSize* and *RCost* is:

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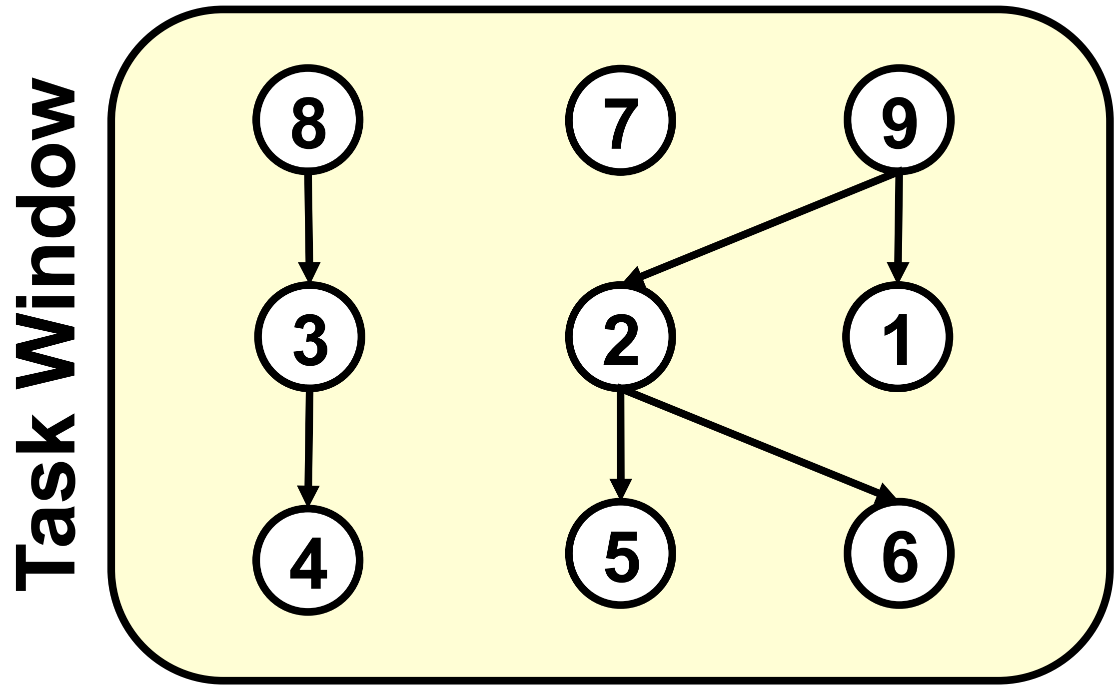
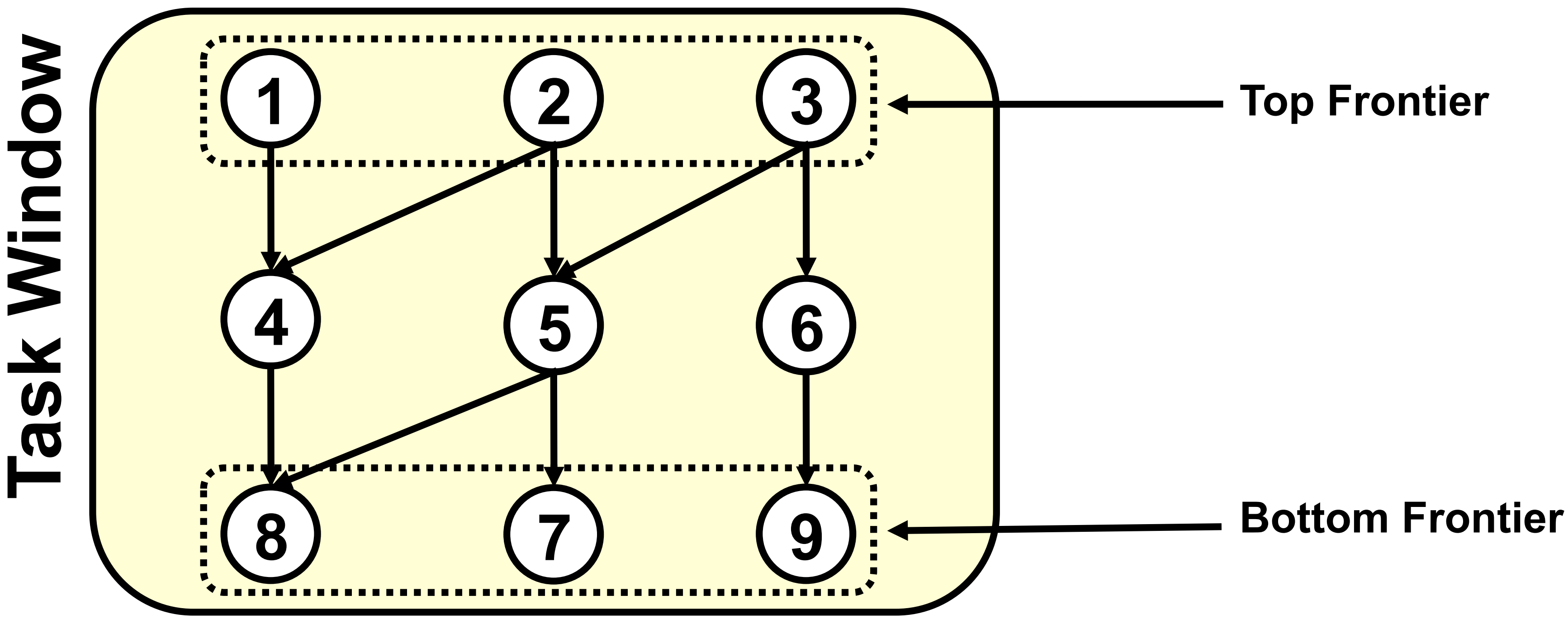


Which node should execute first? 7, 8 or 9?

Critical Path Prediction and QoS



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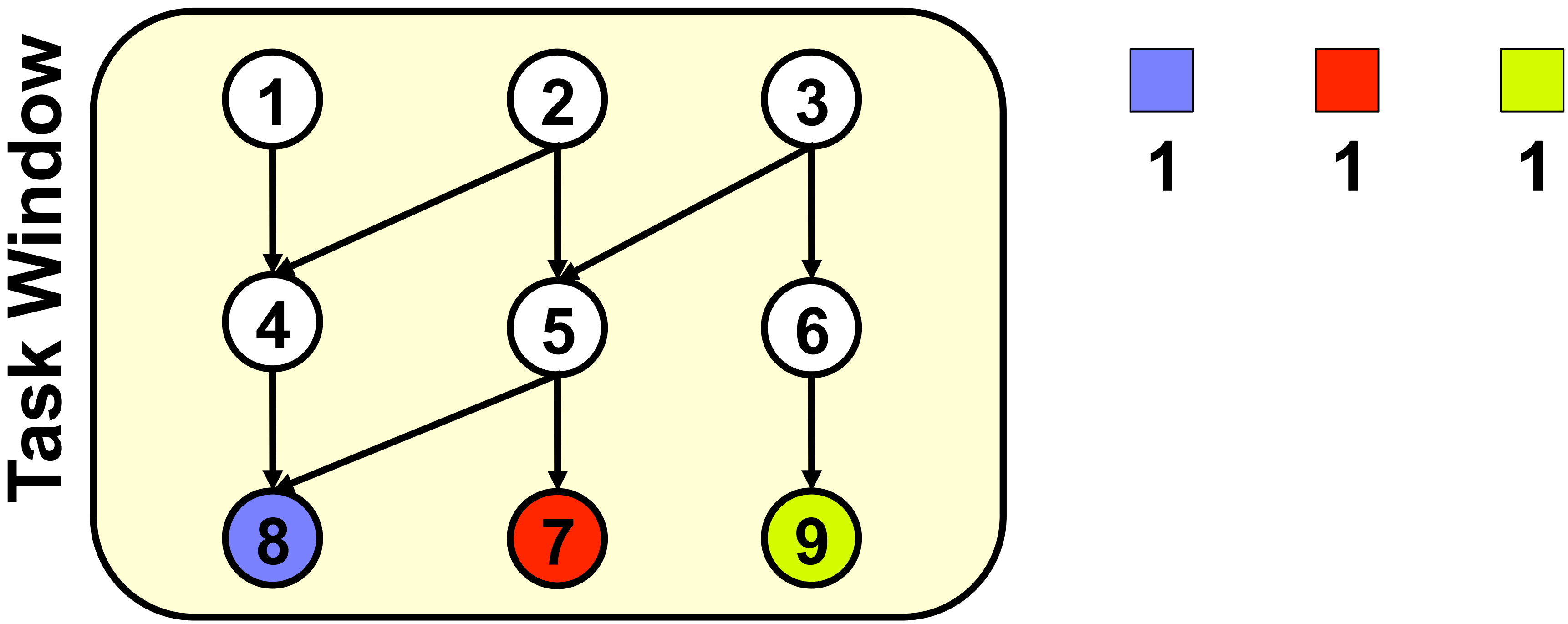

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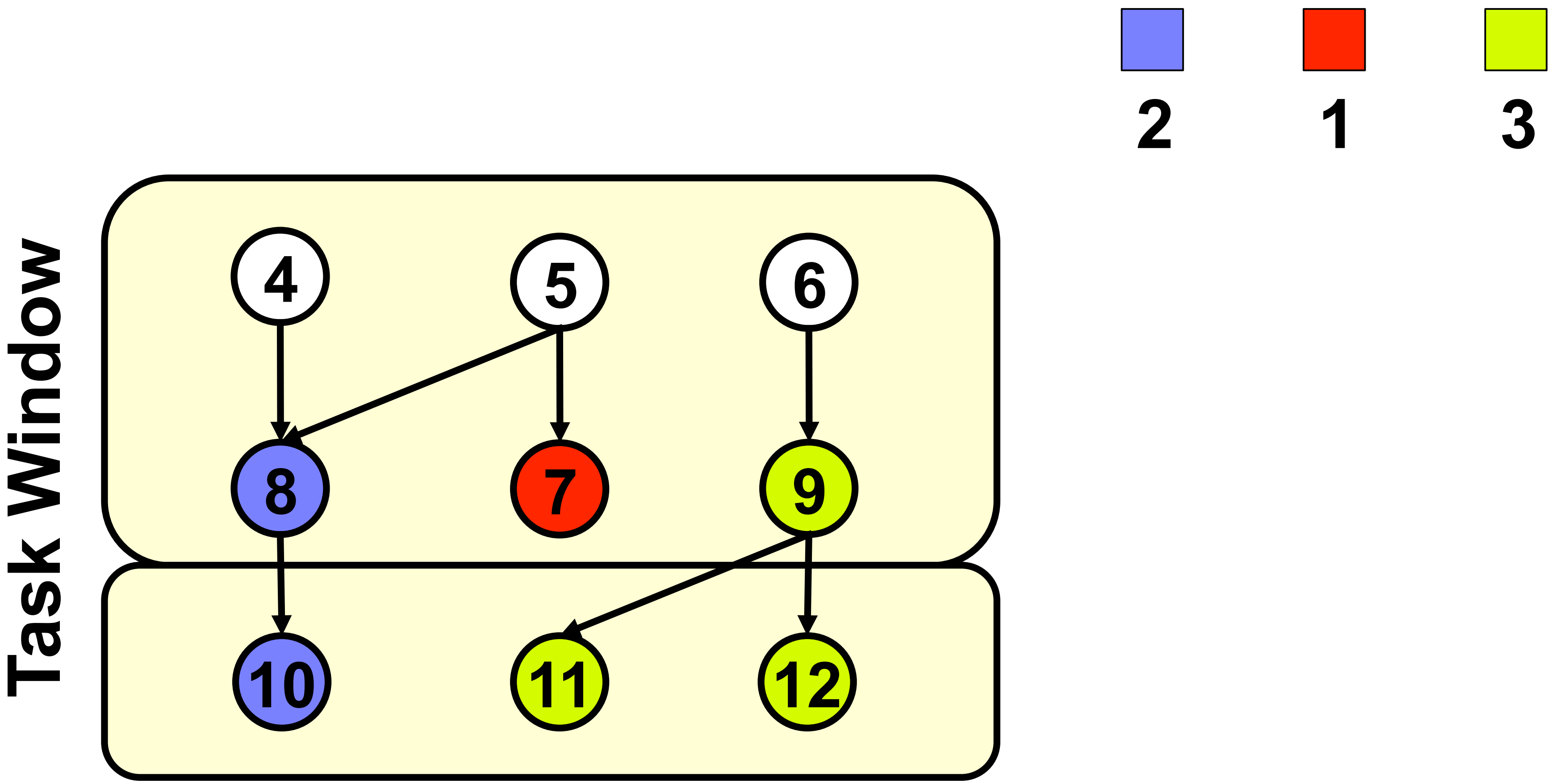

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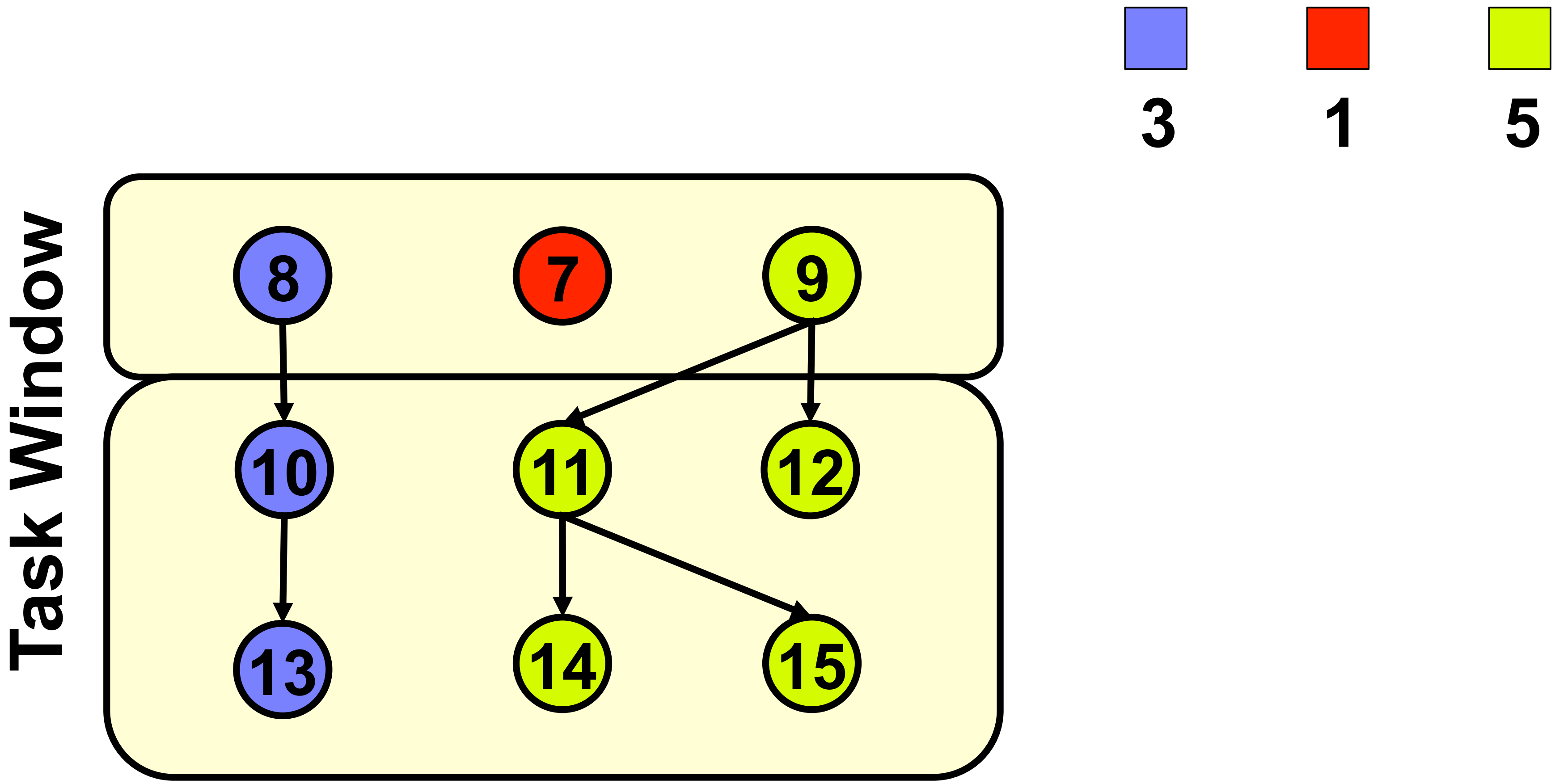

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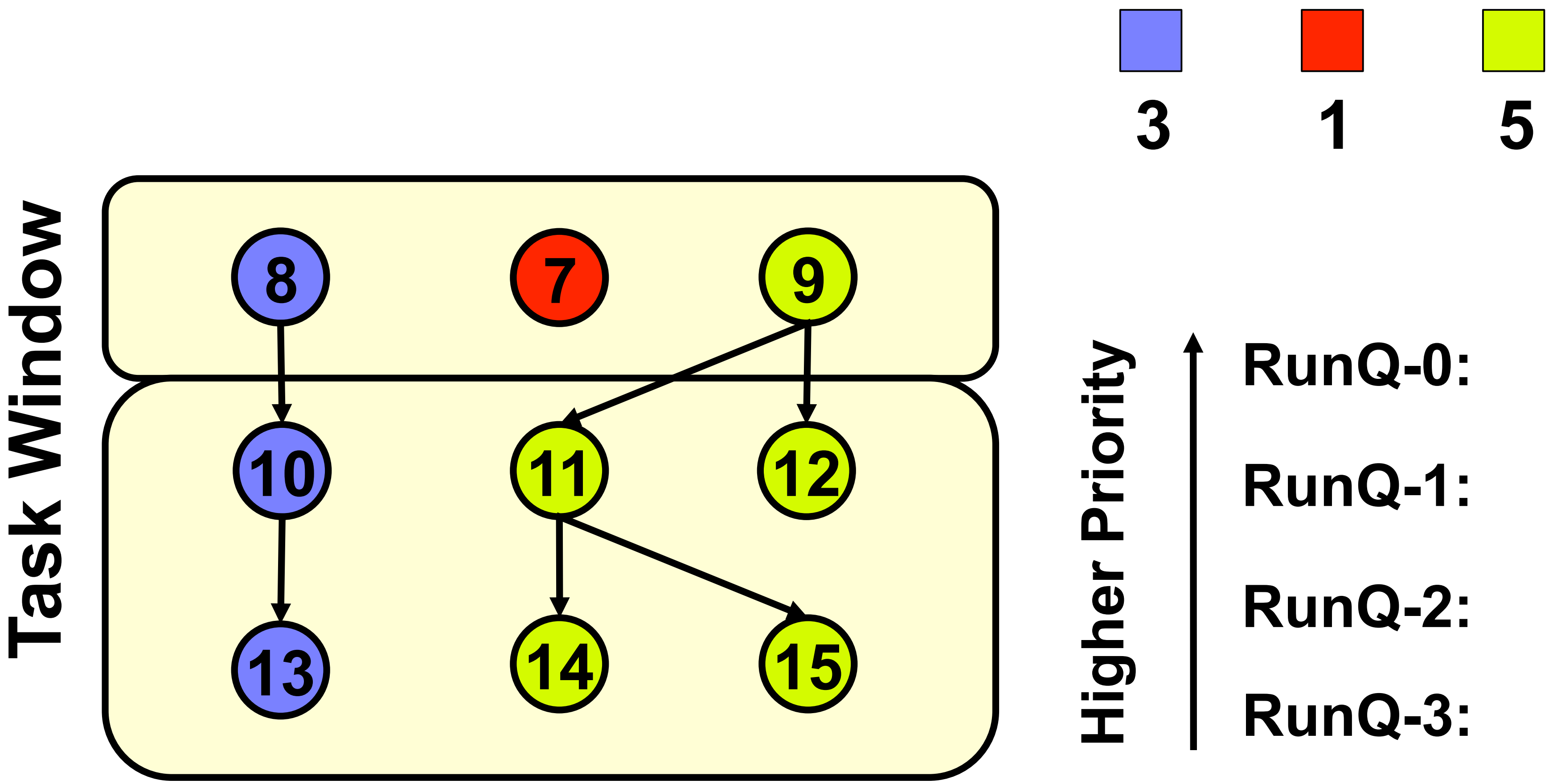

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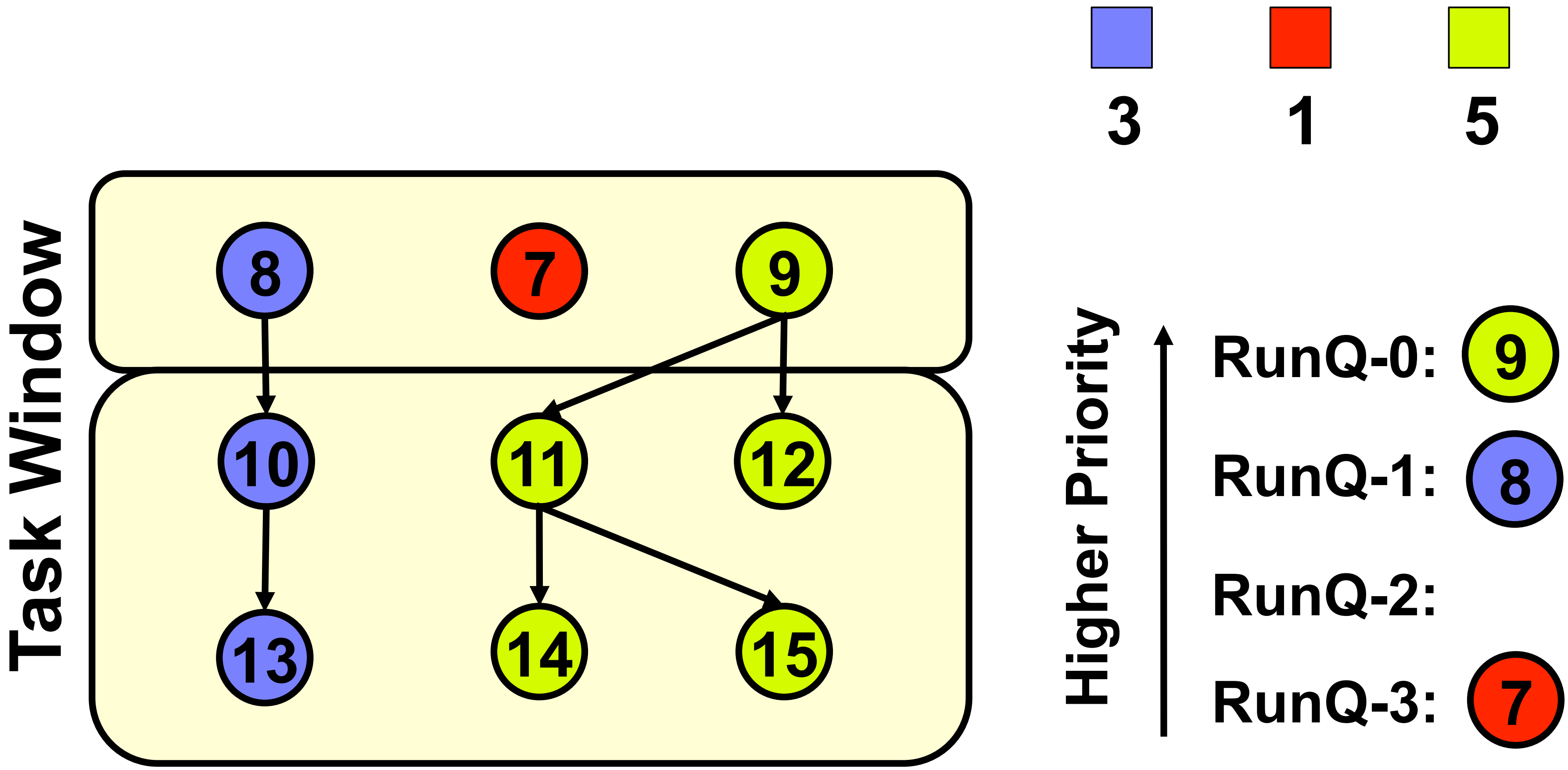

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Programming Support

```
#pragma omp parallel for check
for (i=0; i < N; i++) {
   a[i] = fun(&a[i]);
}
```

What if fun writes to a[i+1] ?!

- Programmers make mistakes
- Have to support loop-carried detection
- New check clause to OMP
- IWOMP 2014

Support Correctness

```
for (i=0; i < N; i++) {
   #pragma omp task in(u[i]) out(v[i]) check
   fun(&u[i], &v[i]);
}
```

What if fun writes to u[i] ?!

- We intend to do the same for tasks
- Use escape analysis techniques

Support Performance

```
for (i=0; i < N; i++) {
  #pragma omp task in(u[i]) out(v[i]) check
  fun(&u[i], &v[i]);
}
```

- Does it pay off?
  - Runtime should estimate the speed-up
  - Evaluate task duration, runtime overhead and # worker threads
  - Develop heuristics to give hints to the programmer
  - It could latter be used for automatic annotation

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