Work Stealing
in
Multiprogrammed Environments

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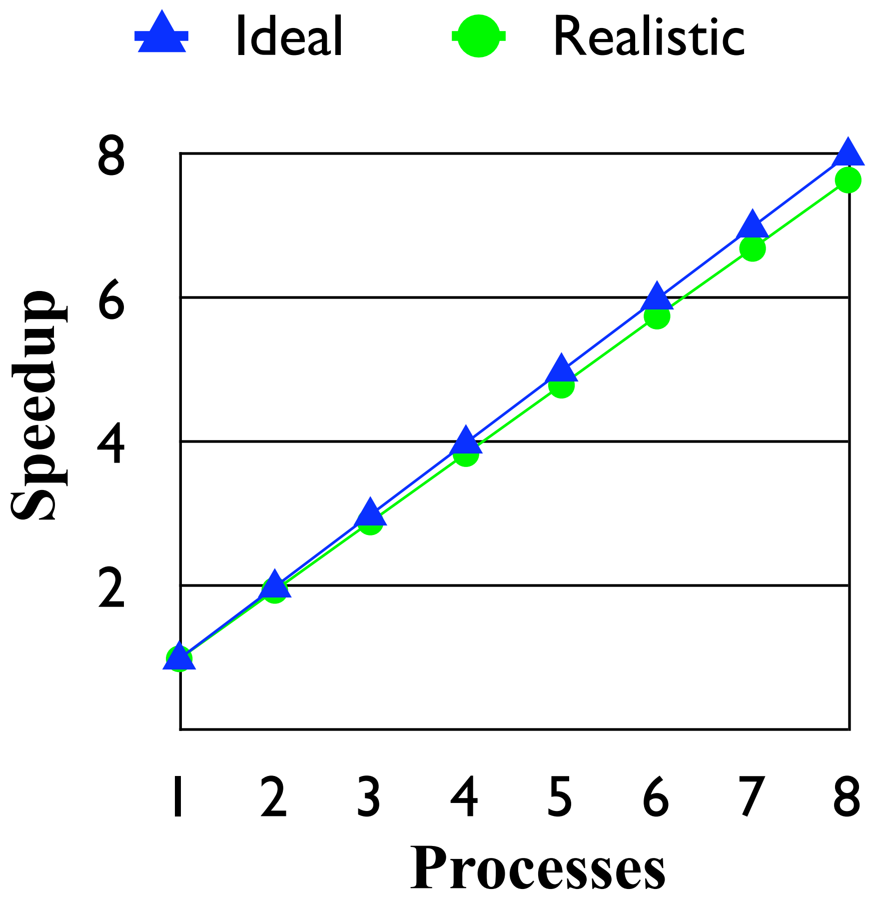
Outline

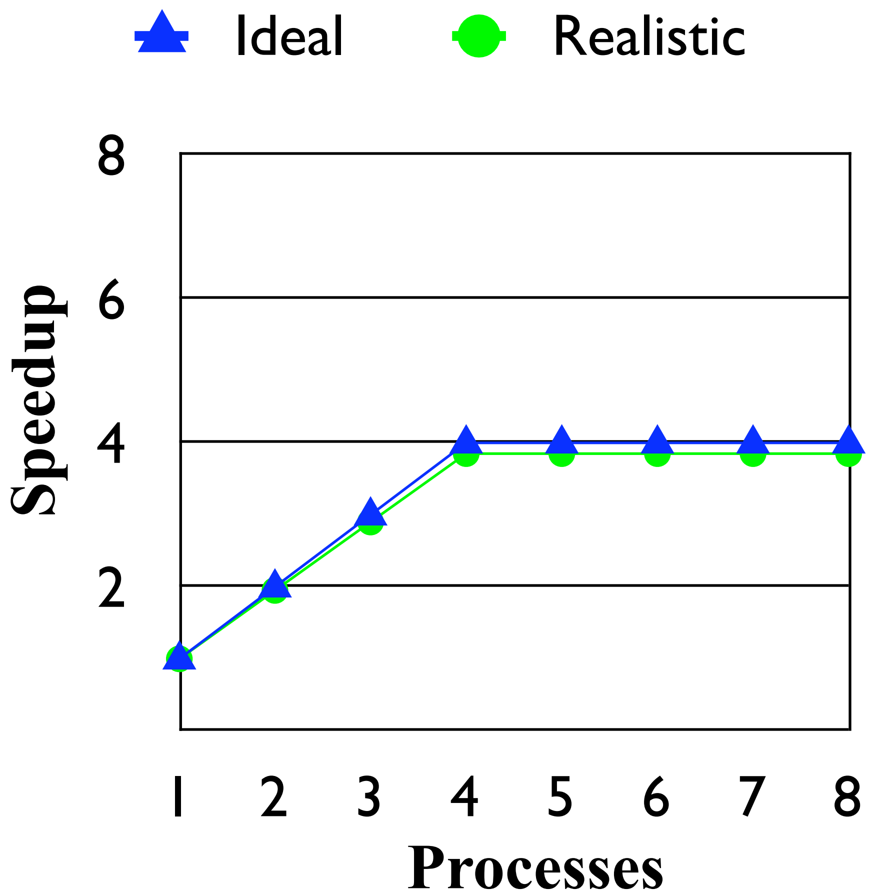
- Motivate the issue
- Describe work-stealing in general
- Explain the new algorithm and the problems along the way
- Demonstrate its effectiveness

Realistic Parallelization

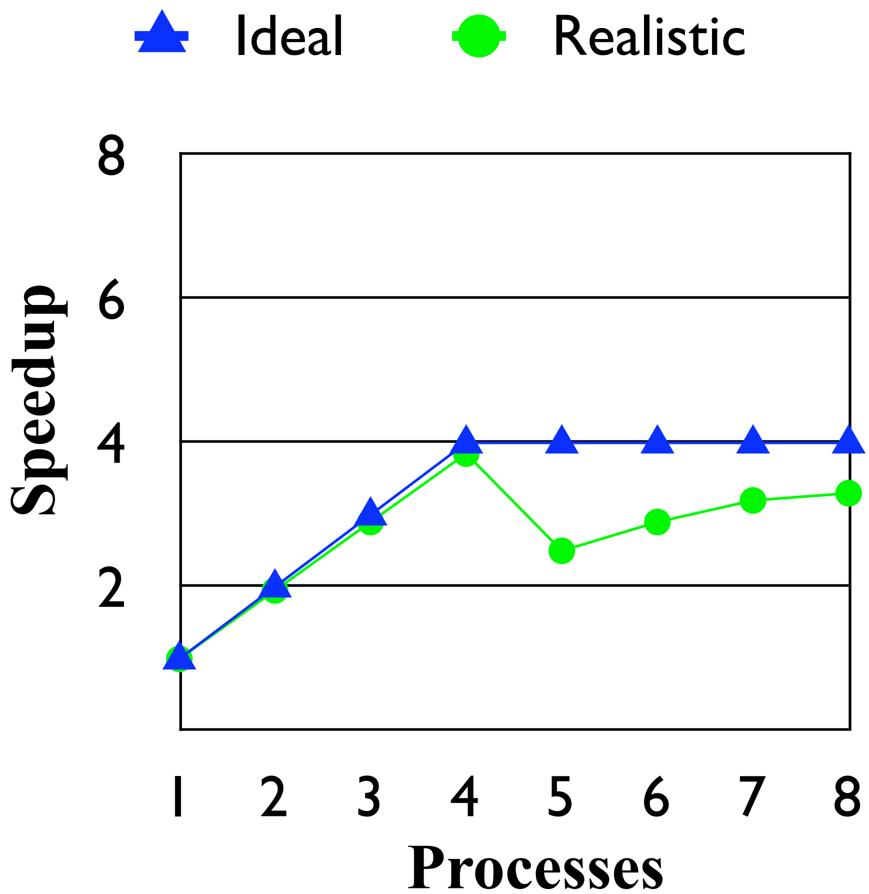


More Realistic Parallelization

Limited number of processors available!

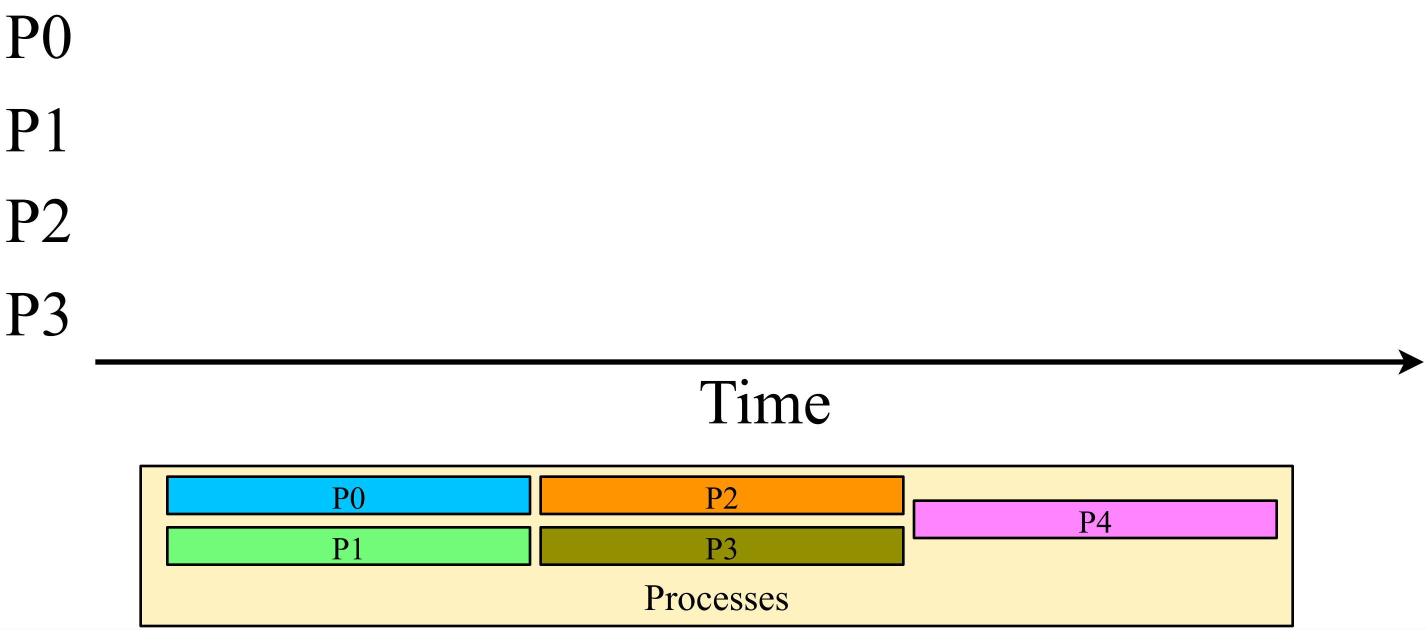


What Actually Happens



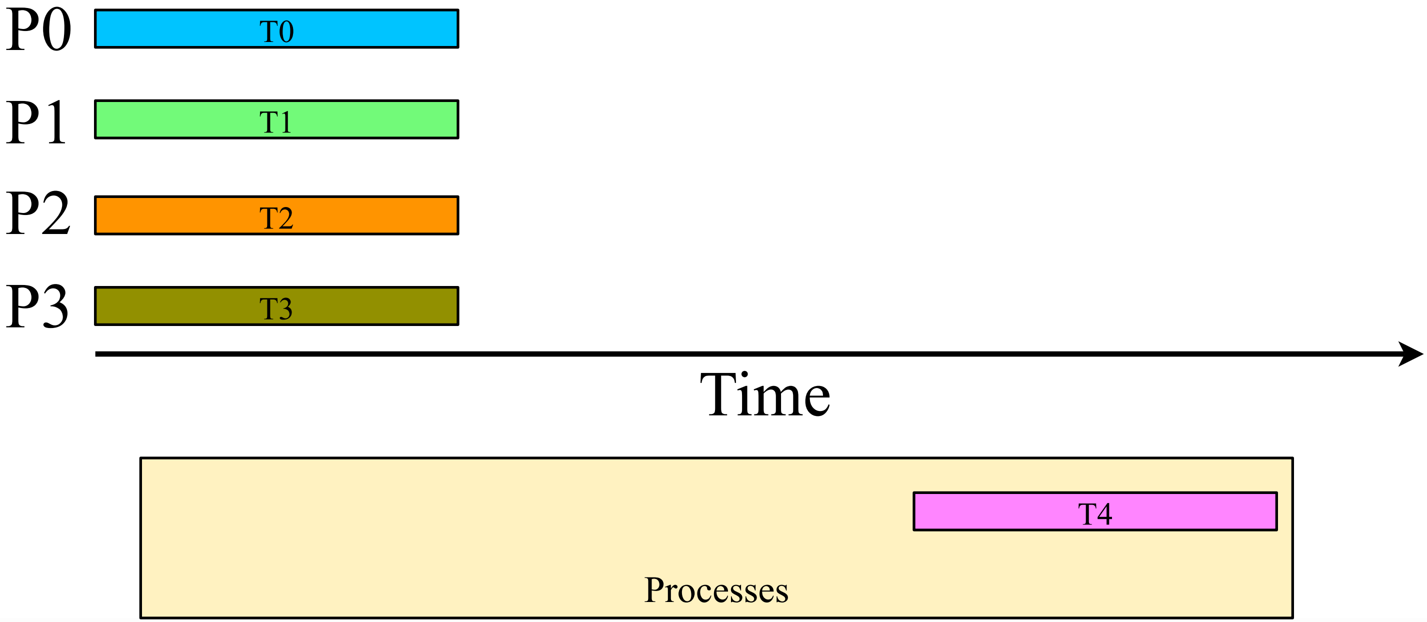
What Actually Happens

- Bad scheduling of the processes causes poor utilization
- Worst Case (5 processes, 4 processors)



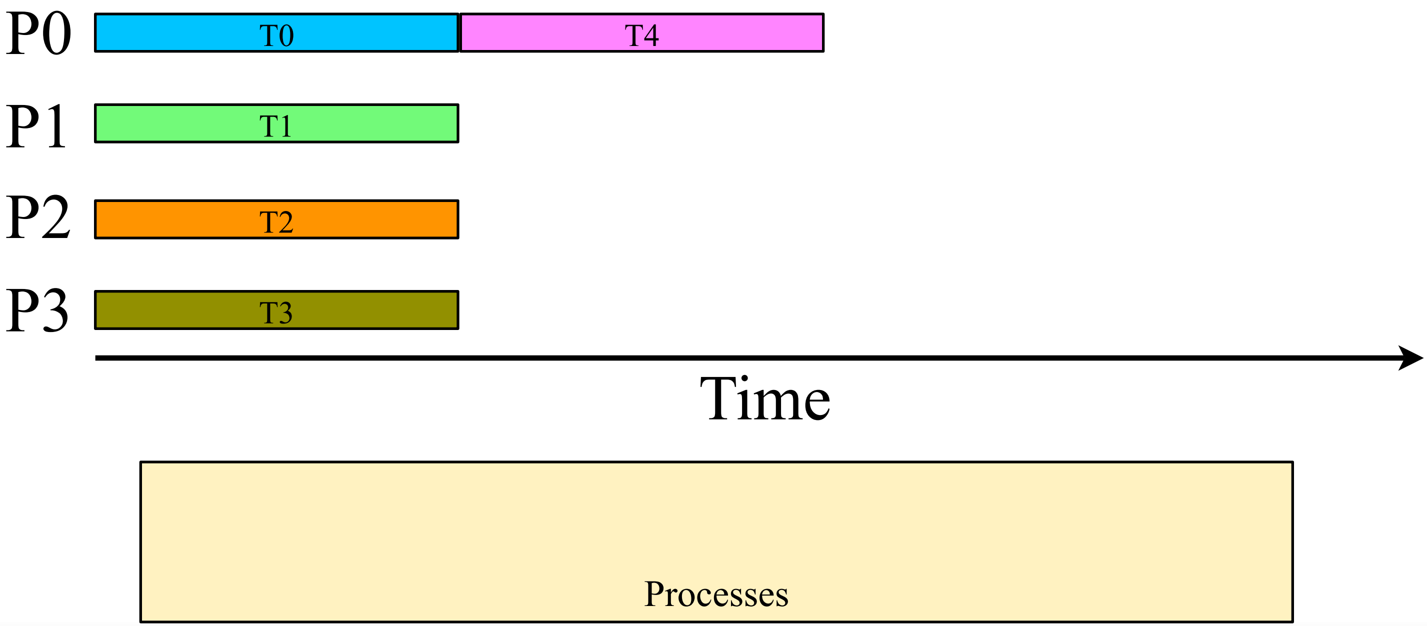
What Actually Happens

- Four processes run simultaneously to completion
- Fifth process waits for resources



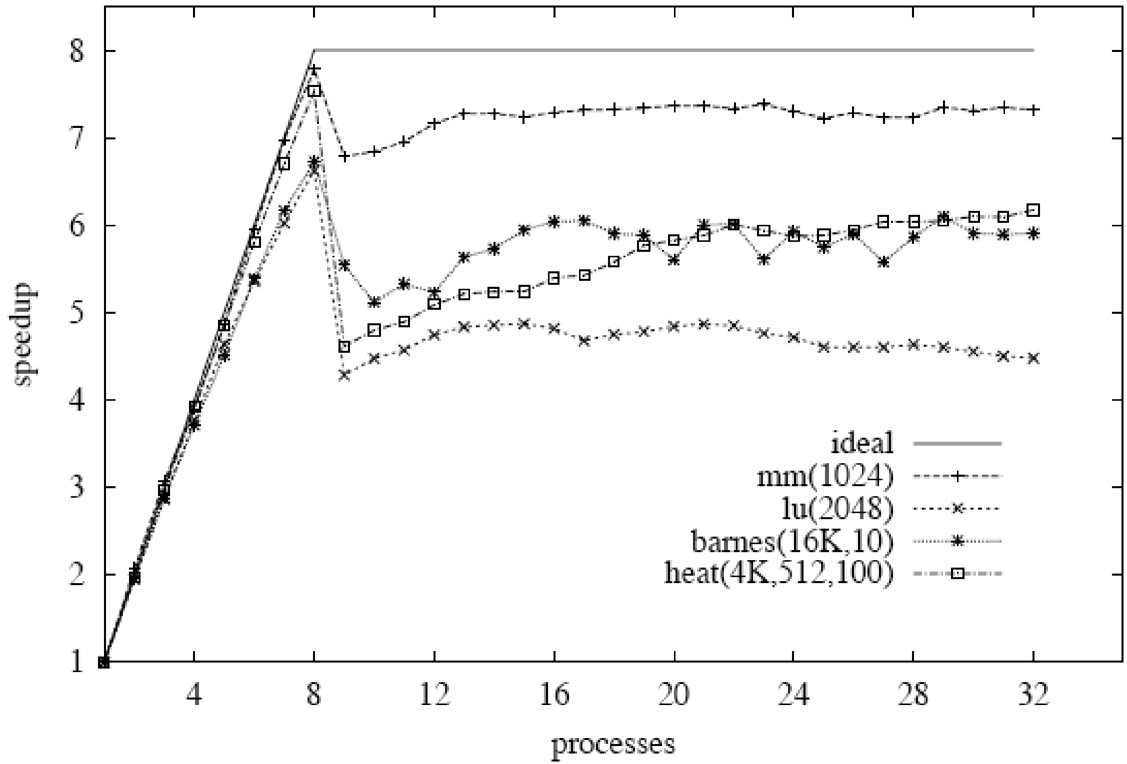
What Actually Happens

- Fifth process runs once one of the other processes completes
- 3 processors have only 50% utilization



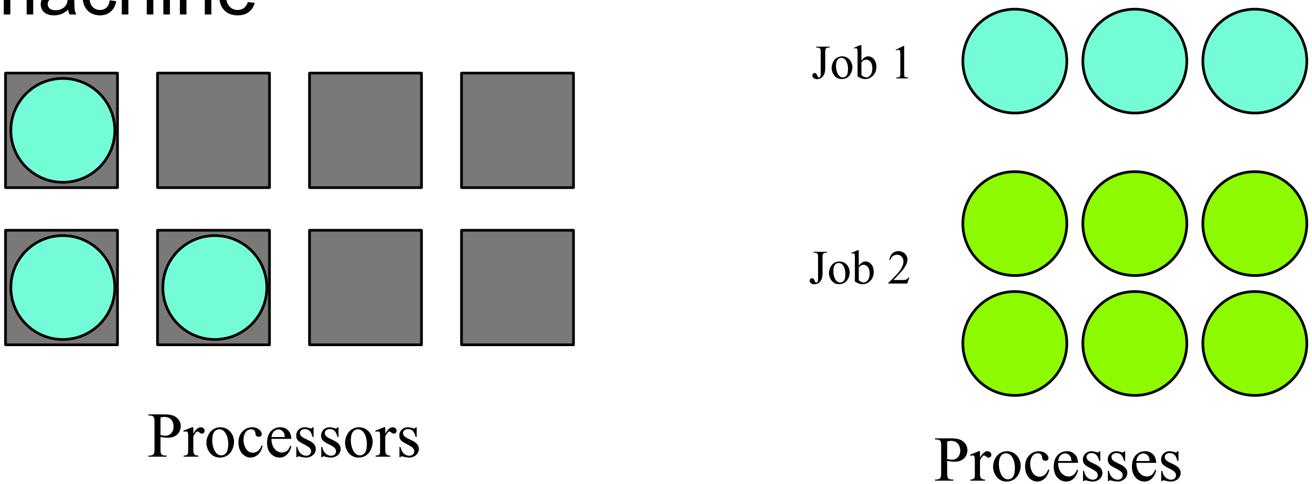
Some Actual Results

- Testbed has 8 processors
- Work is statically partitioned



Other Solutions

- Co-scheduling
  - All processes of a program are scheduled to execute at the same time
  - Gives the appearance of a dedicated machine



Other Solutions

- Process Control
  - Kernel notifies program of current resources
  - Processes are dynamically created or killed based on what is available
  - # processes = # processors

Better Solution

- Work Stealing
  - Dynamically balance the load across processes
  - Maintain utilization even when competing with other programs for resources
  - Handle even worst possible scheduling of processes

Term Definitions

- Process
  - A kernel-scheduled entity; all processes of one program can share memory
- Thread
  - User-level task scheduled by the user-level library

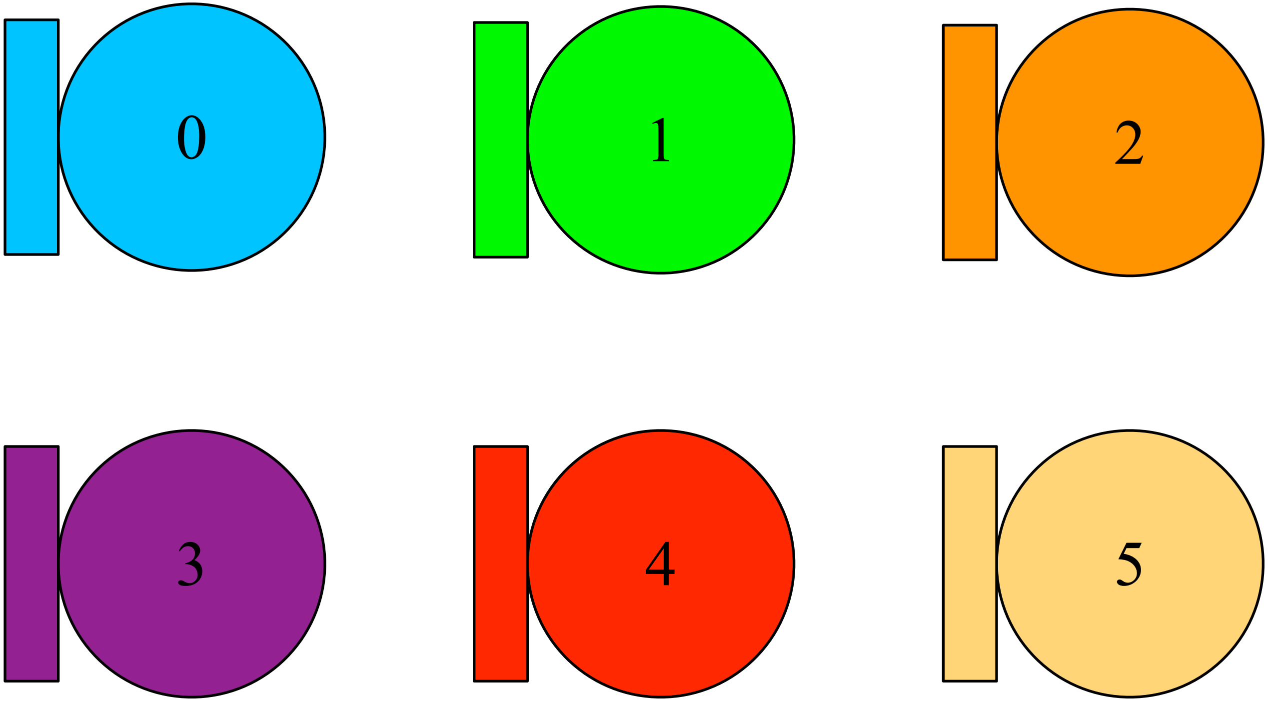
Work-Stealing Algorithm

- Each process maintains a thread deque
  - All threads in this deque are ready to run (not blocking on anything)
- Running threads can unblock other threads, or create new threads
  - New (or newly unblocked) threads are added to the bottom of the deque

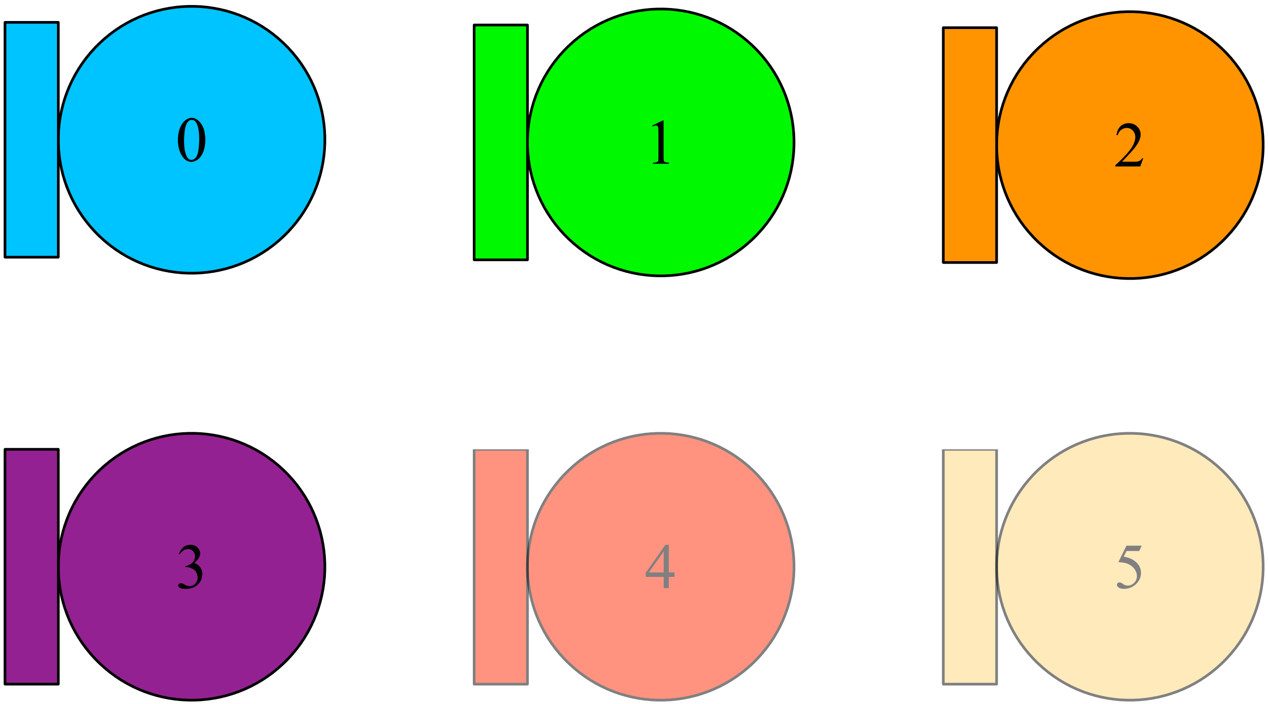
Work-Stealing Algorithm

- When a thread completes execution, the next thread is pulled off the bottom of the deque
- When a process's deque is empty, it will steal work from another process
  - Threads are "stolen" from the top of the other process's deque

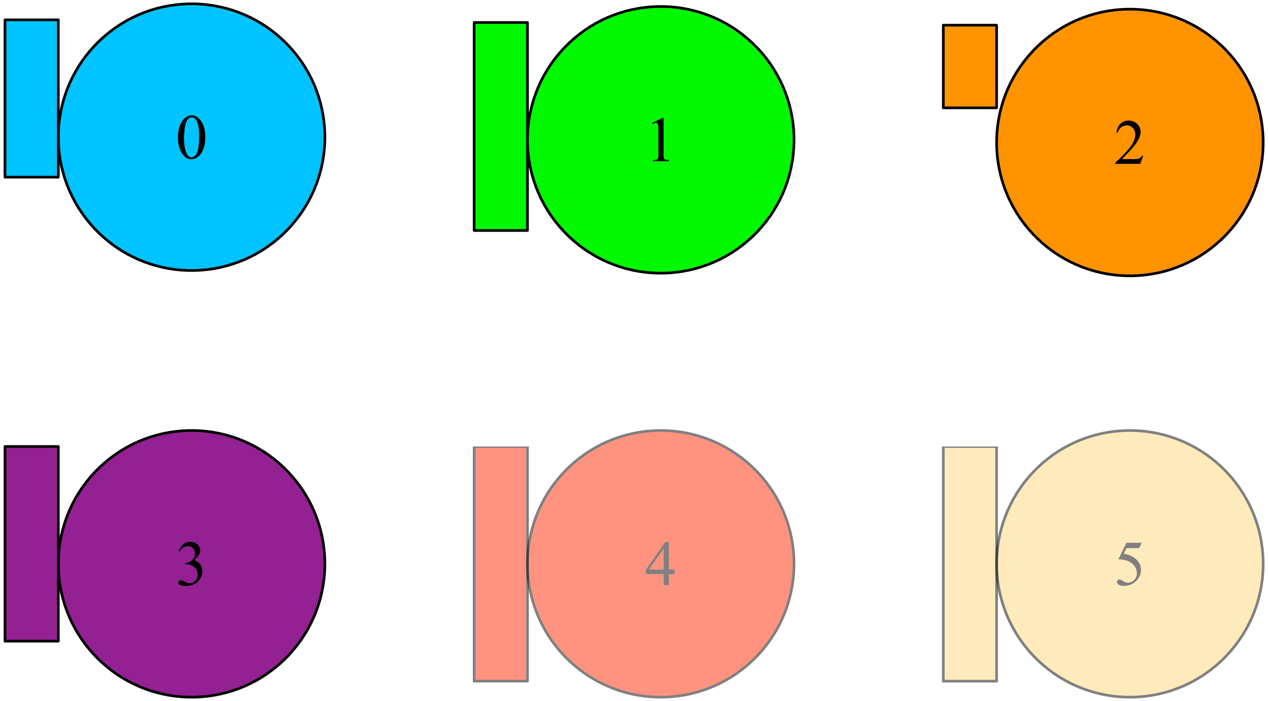
Work-Stealing Algorithm



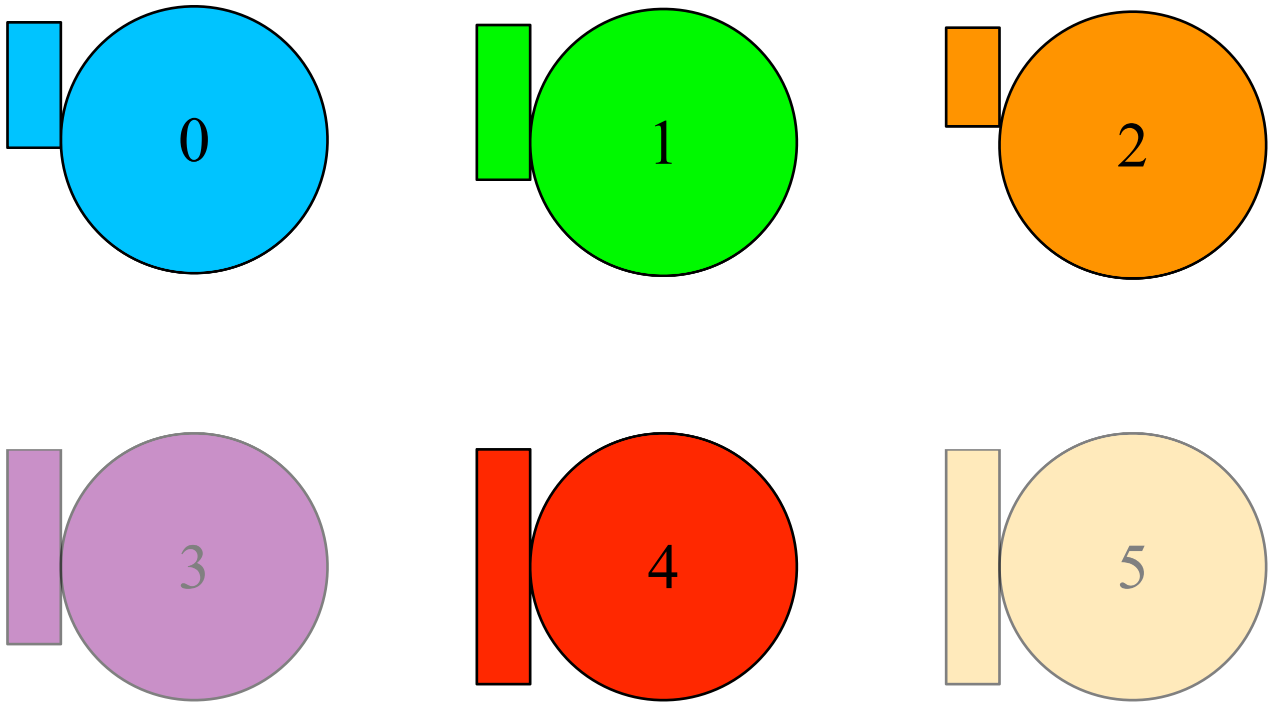
Work-Stealing Algorithm



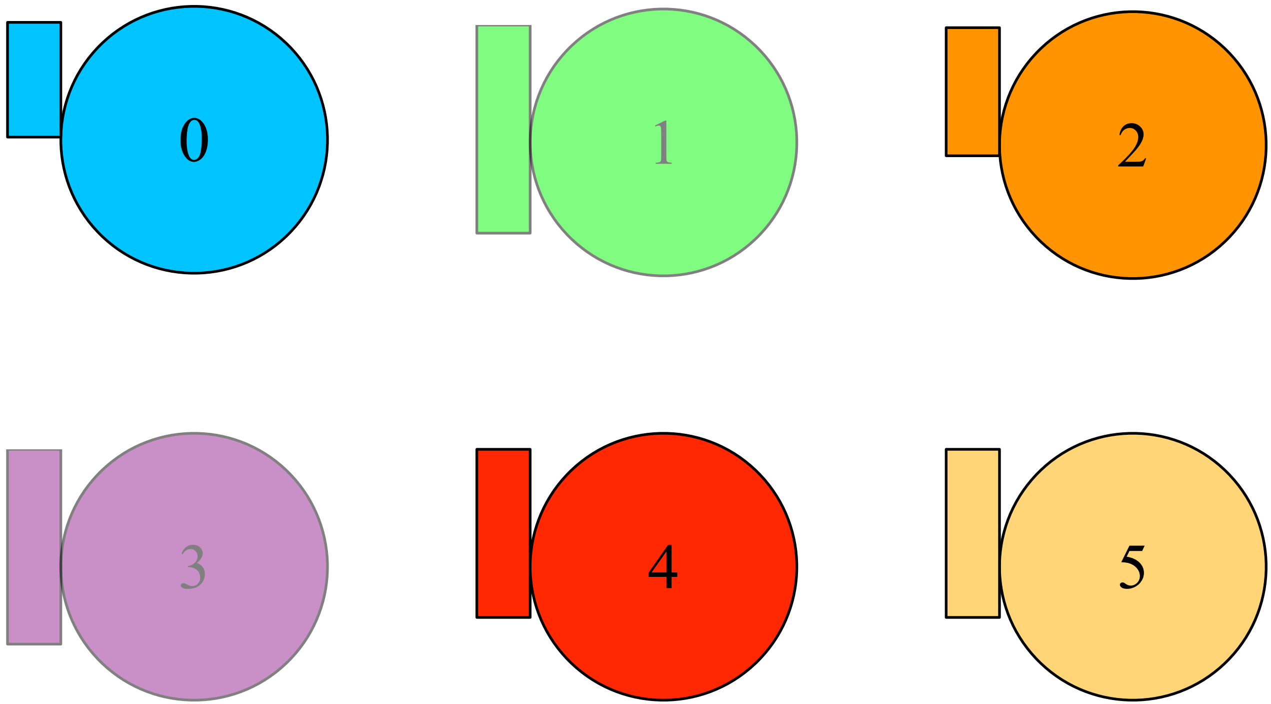
Work-Stealing Algorithm



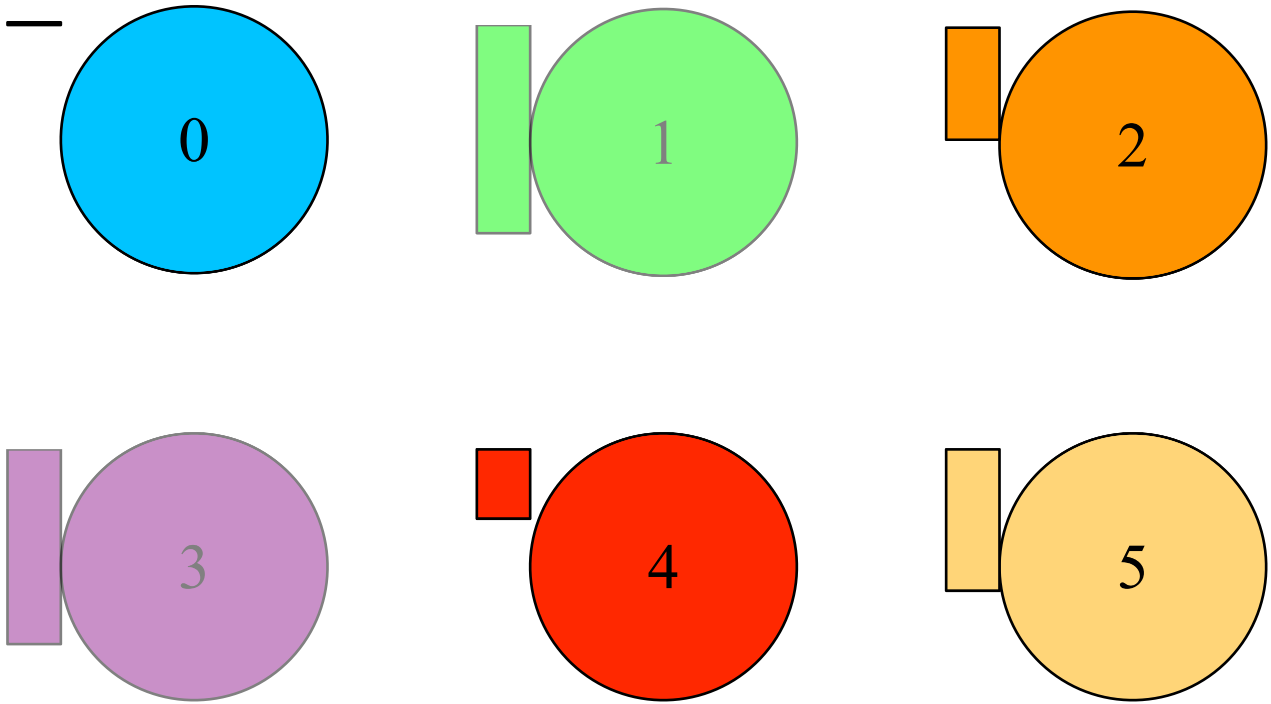
Work-Stealing Algorithm



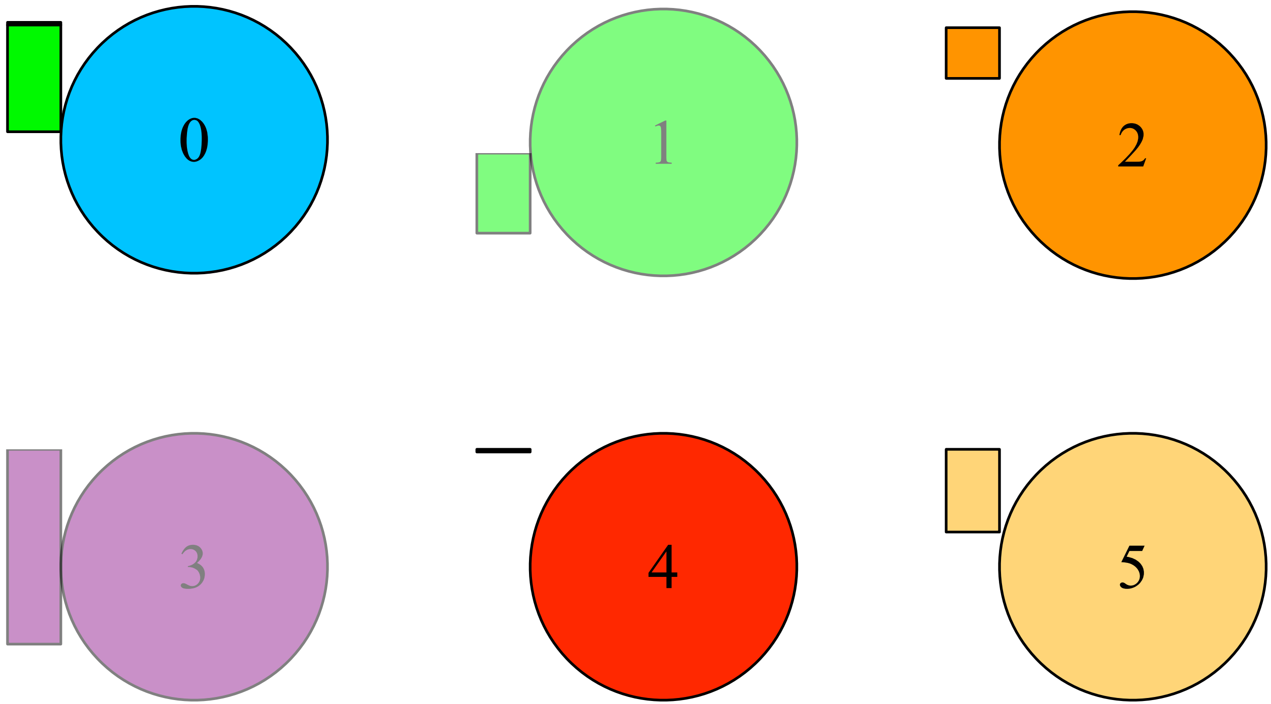
Work-Stealing Algorithm



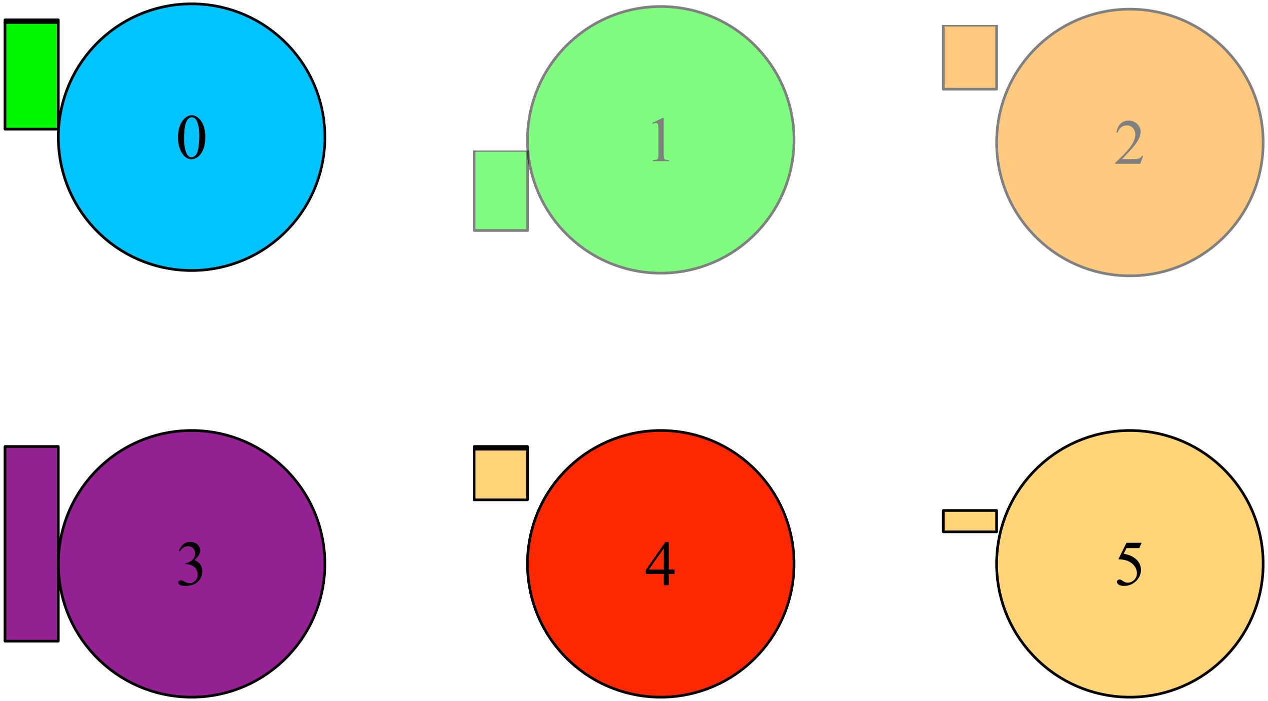
Work-Stealing Algorithm



Work-Stealing Algorithm



Work-Stealing Algorithm

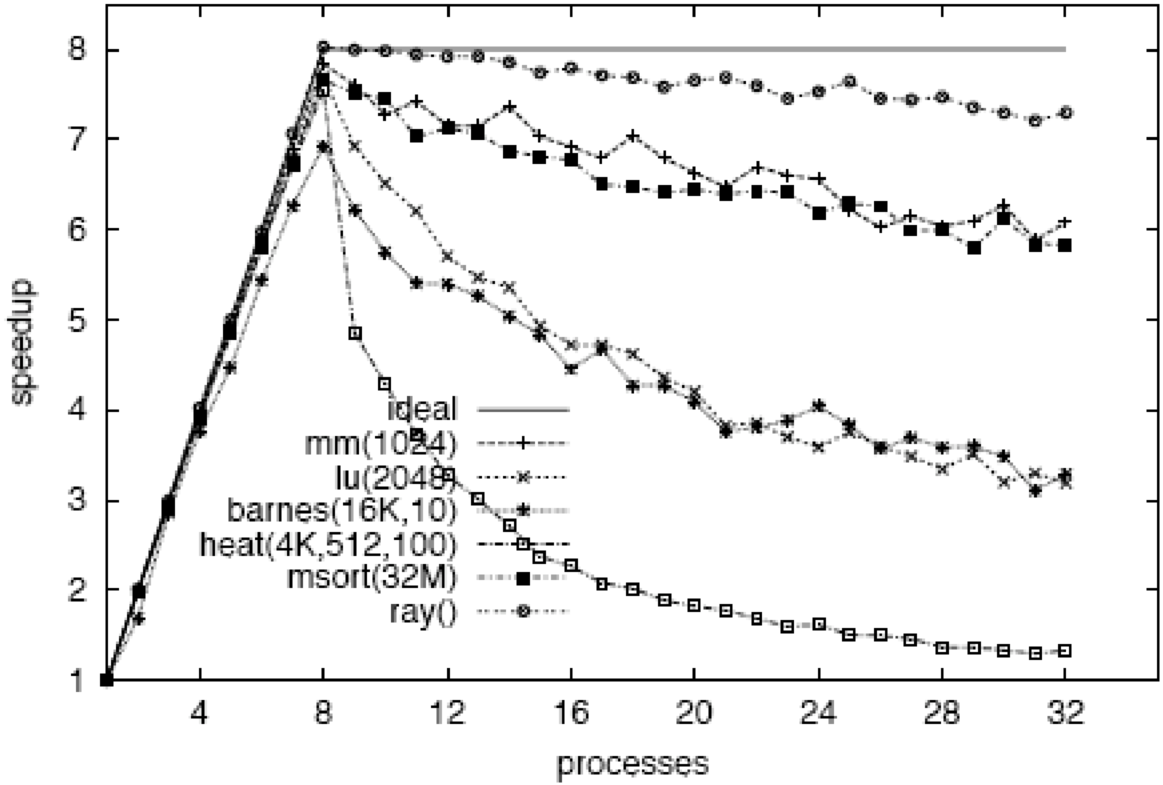


Implementation

- Difficult issues
  - Synchronization between processes
  - Prevent bad kernel scheduling from deteriorating performance

Implementation - Synchronization

1. Protect the deques with spinlocks

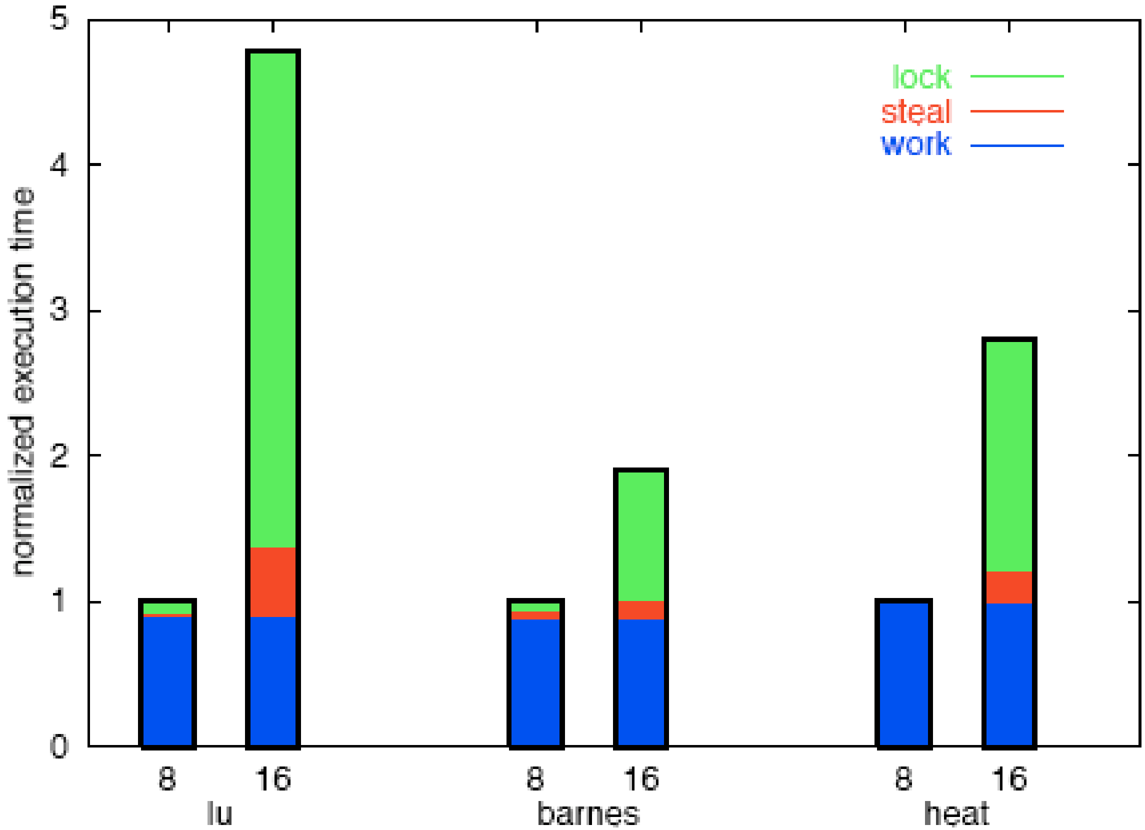


Implementation - Synchronization

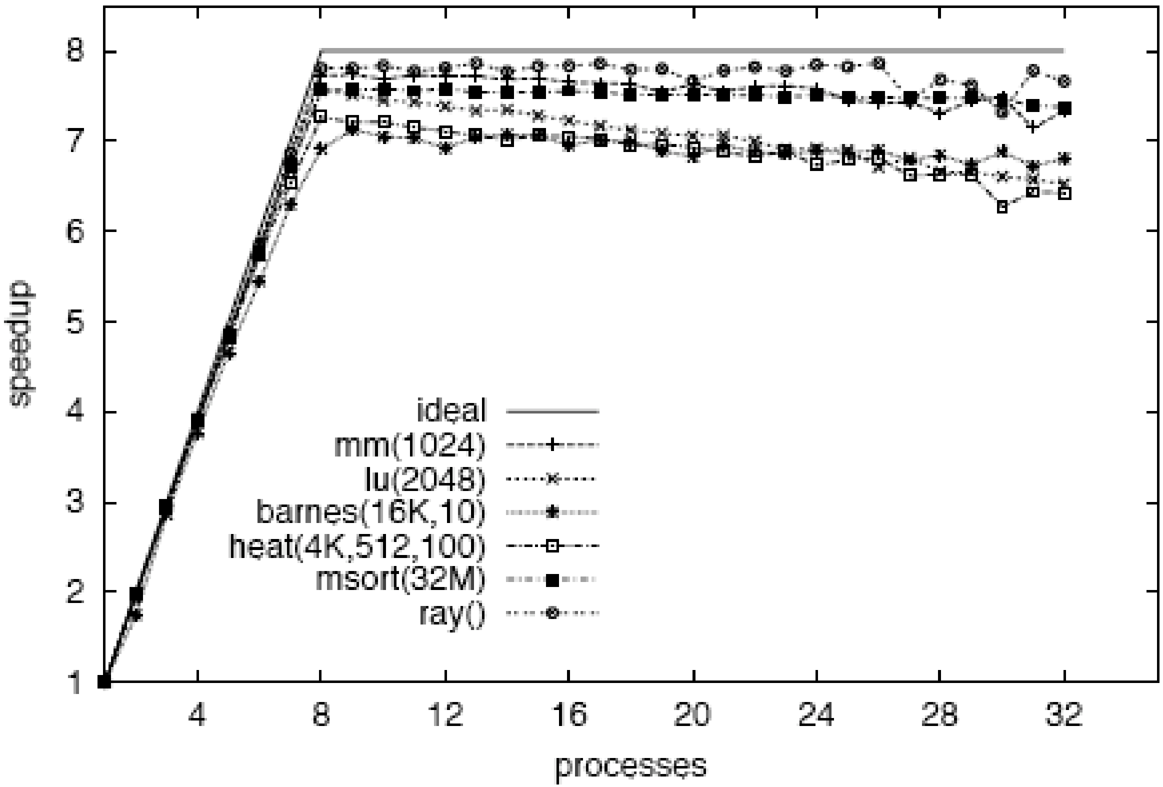
1. Protect the deques with spinlocks
   - One process could be preempted by the kernel while it has a lock
   - A second process attempting to get that lock will spin on it until the first process resumes and frees the lock

Implementation - Synchronization

1. Protect the deques with spinlocks



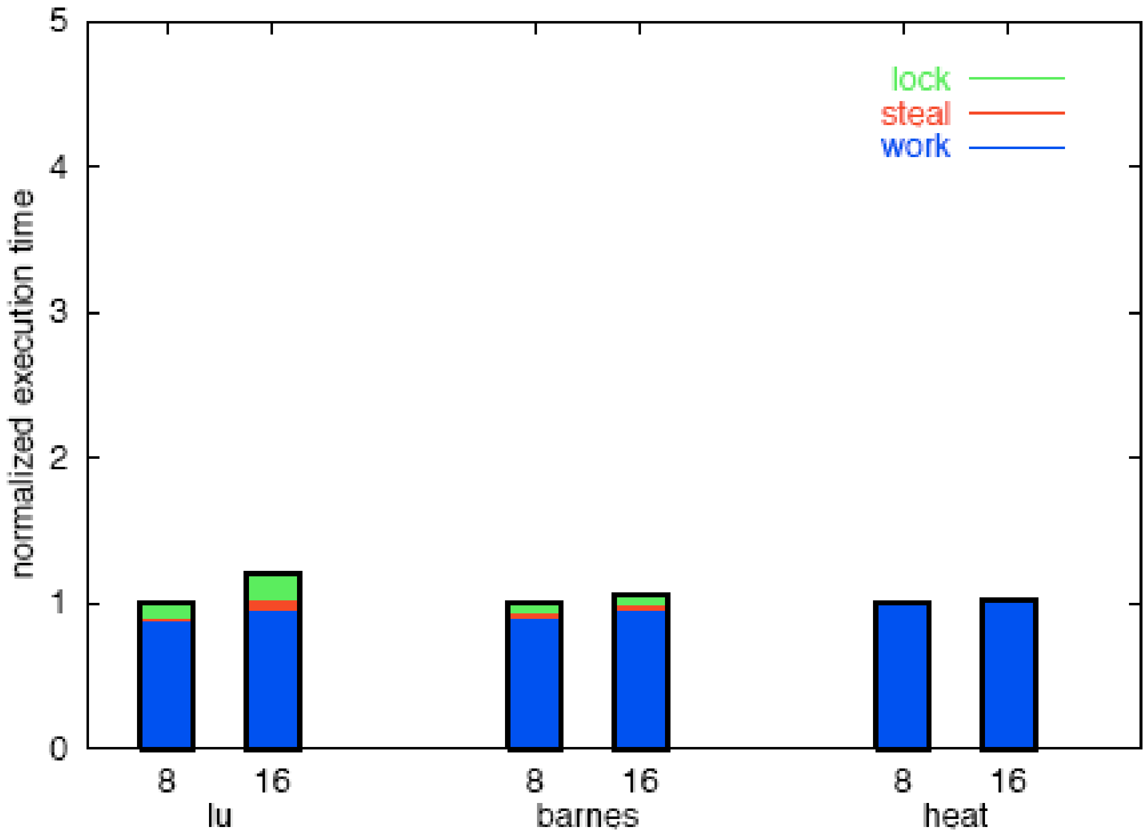
2. Protect deques with blocking locks



2. Protect deques with blocking locks

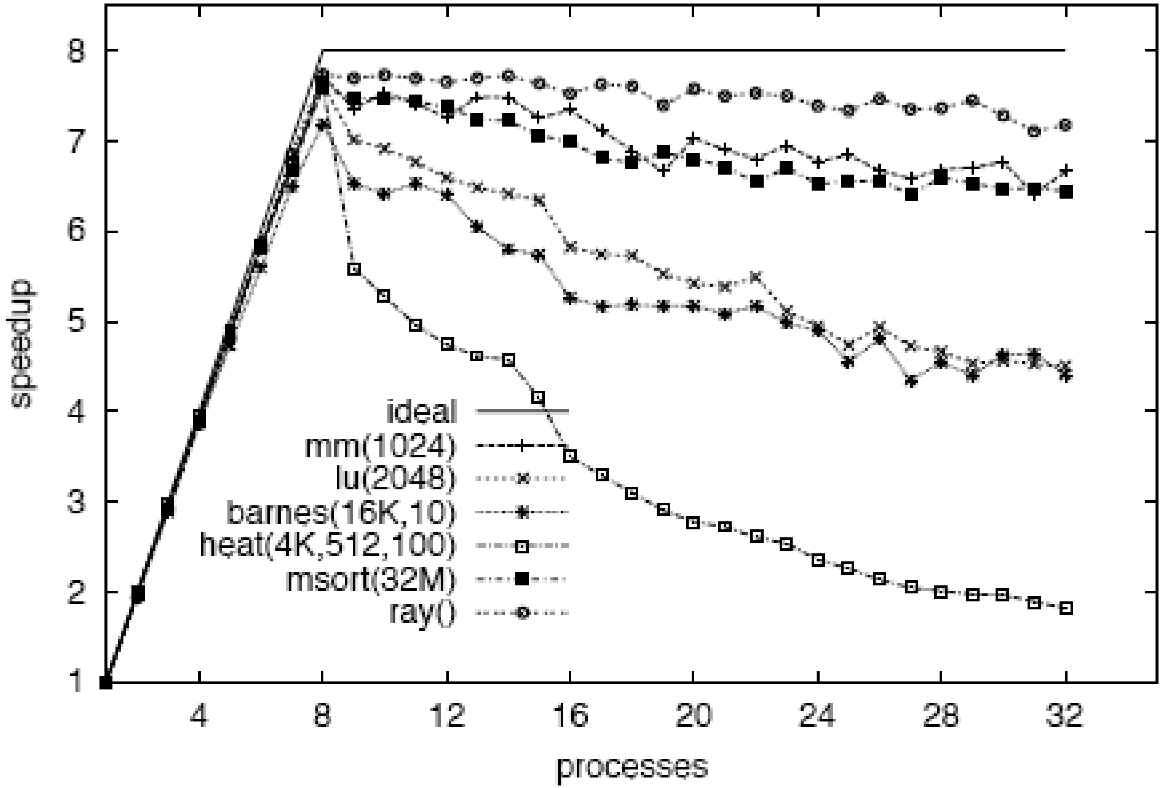
- One process gets preempted while it has the lock
- Second process attempts to get the lock, blocks, yielding the processor
- First process resumes execution and releases the lock then eventually is preempted
- Second process can now obtain the lock

2. Protect deques with blocking locks



Implementation - Synchronization

3. Use atomic operations to operate on the deques and avoid locks altogether



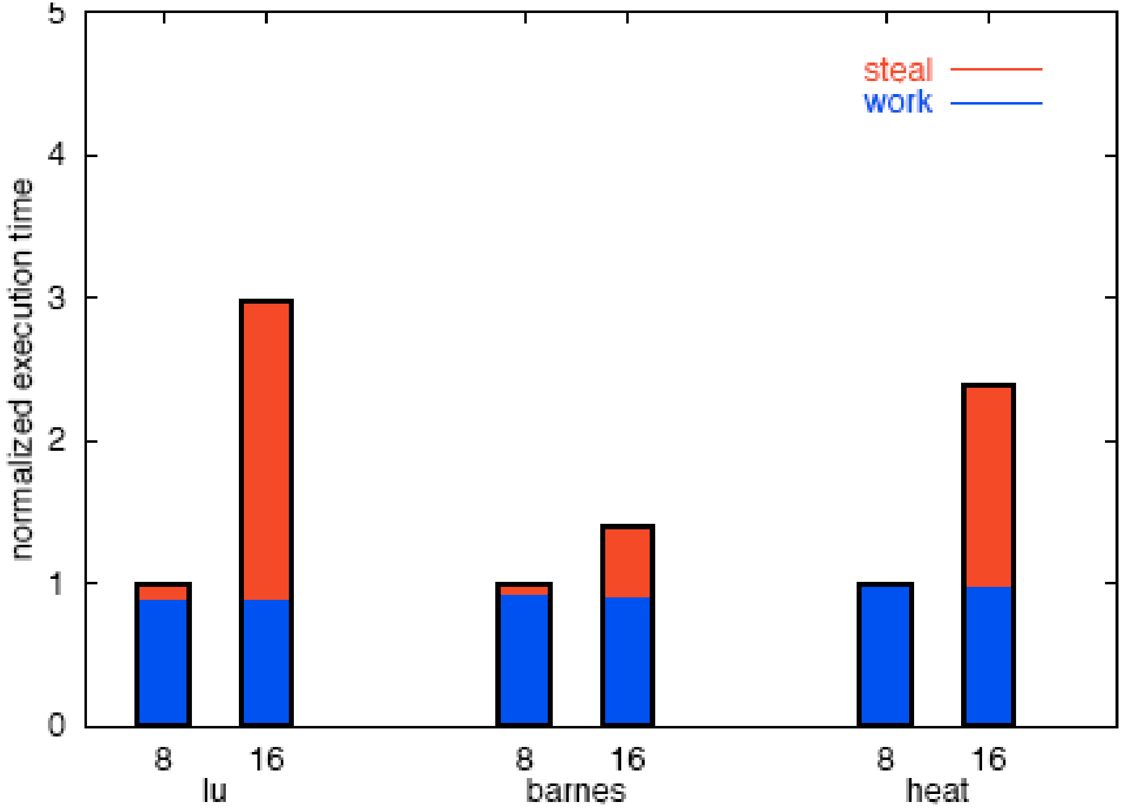
Implementation - Synchronization

3. Use atomic operations to operate on the deques and avoid locks altogether

- Running processes empty all deques
- Only runnable thread is on a process that has been preempted
- Running processes continuously make failed stealing attempts
- Eventually, the preempted process runs and threads are unblocked

Implementation - Synchronization

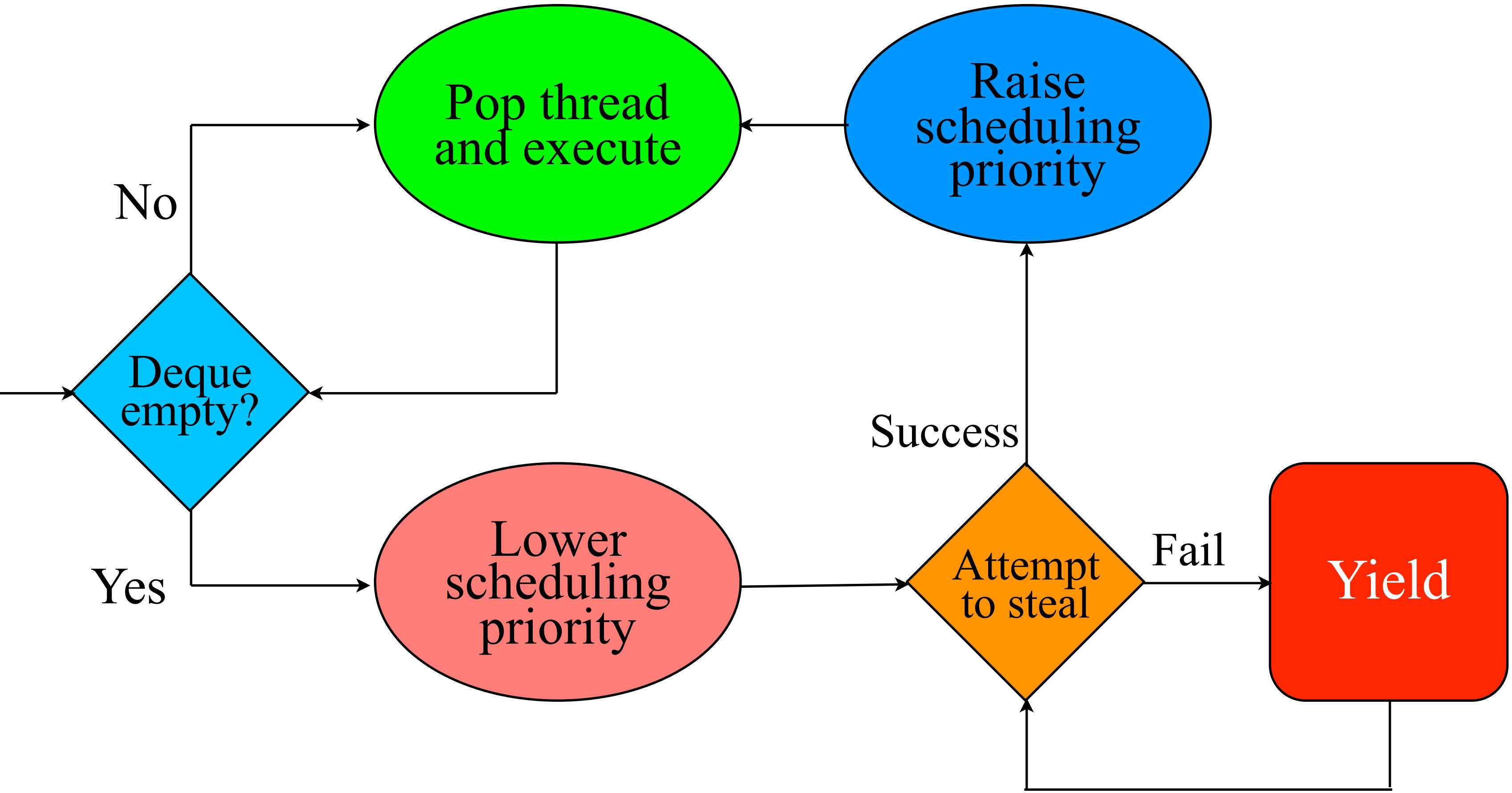
3. Use atomic operations to operate on the deques and avoid locks altogether



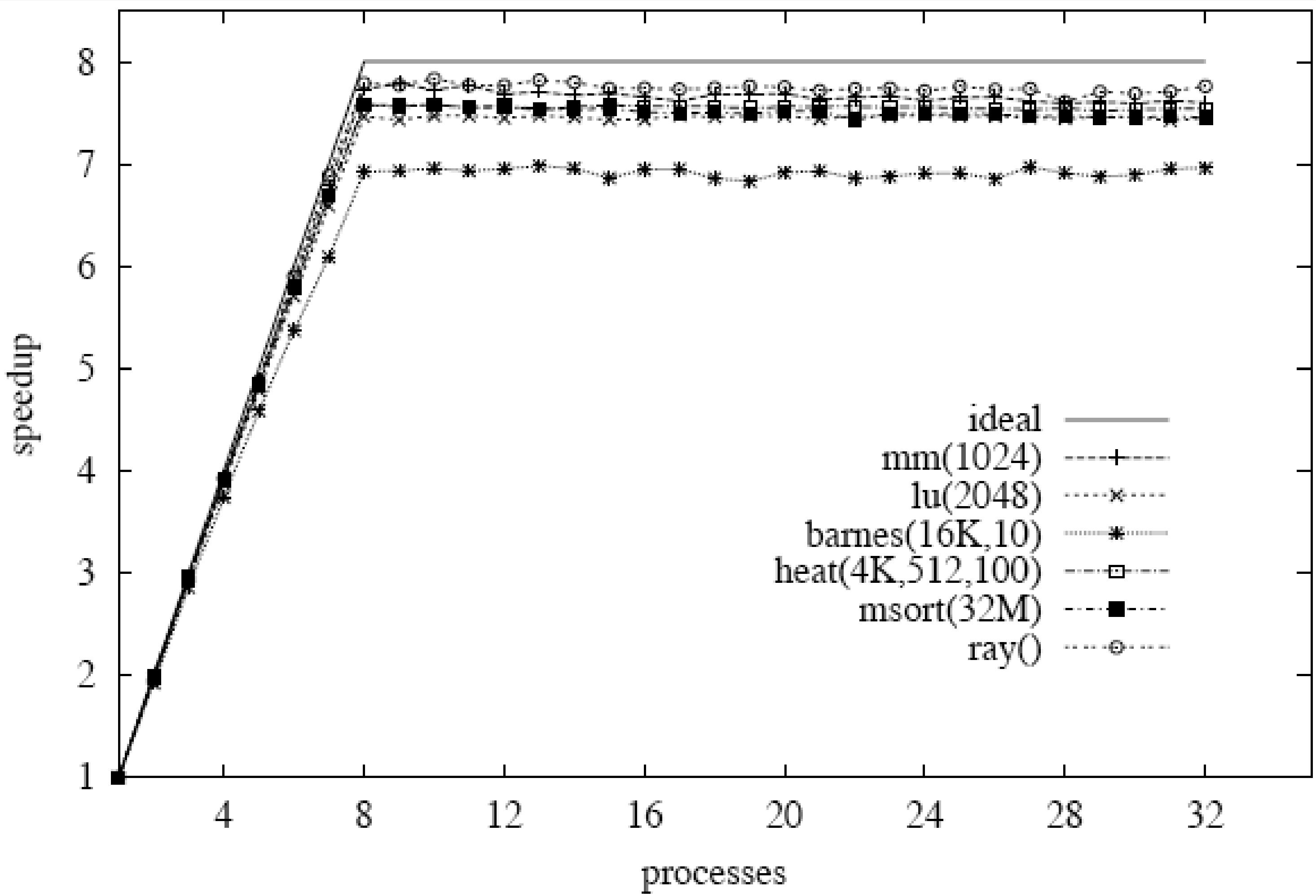
Implementation - Scheduling

- Prevent processes from wasting resources spinning on failed steal attempts
  - Use the system calls to help the kernel schedule processes more conveniently
  - priocntl
    - Change the priority level of this process
  - yield
    - Voluntarily release the processor

Implementation - Scheduling



Final Results



Conclusions

- This work-stealing algorithm proves to be effective and efficient
  - Performs as well as static partitioning in a dedicated environment
  - Far outperforms static solutions in non-dedicated multi-programming environments
  - User-level implementation with no kernel support required

Questions?