Design of Parallel and High-Performance Computing

Fall 2019

Lecture: Scheduling

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Overview

- **DAGs again: An example**
- **Scheduling**
  - Greedy
  - Work stealing
- **Cilk**

- **Background material:**
  - Blumofe, Leiserson:
    [Scheduling Multithreaded Computations by Work Stealing]()
    Journal ACM, 46(5), 1999

Example: Fibonacci Numbers

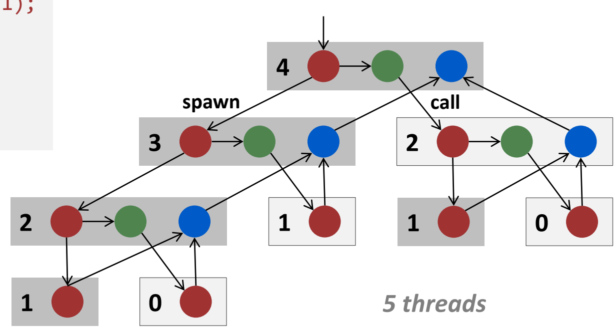
```
int fib (int n) {
  if (n<2) return (n);
  else {
    int x,y;
    x = spawn fib(n-1); // can execute in
                        // parallel with parent
    y = fib(n-2);
    sync;
    return (x+y);
  }
}
```

Stupid way of computing (why?)
But good example

Example: Fibonacci Numbers

```
int fib (int n) {
  if (n<2) return (n);
  else {
    int x,y;
    x = spawn fib(n-1);
    y = fib(n-2);
    sync;
    return (x+y);
  }
}
```

The DAG unfolds dynamically:



Node: **Sequence of instructions without call, spawn, sync, return**
Edge: **Dependency**

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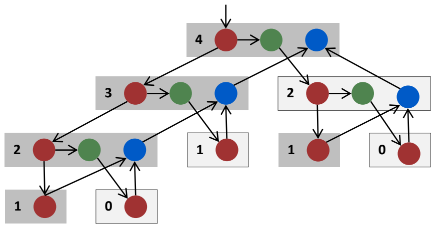
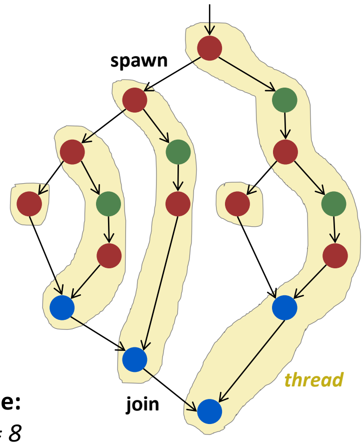
Example: Fibonacci Numbers

Graphs obtained this way are called nested parallel (or fully strict):

- Every thread has one incoming edge (the spawn edge)
- Every join edge from a thread is connected to the parent thread

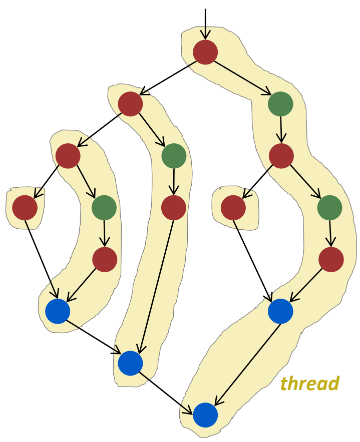




Assuming every node has unit time:

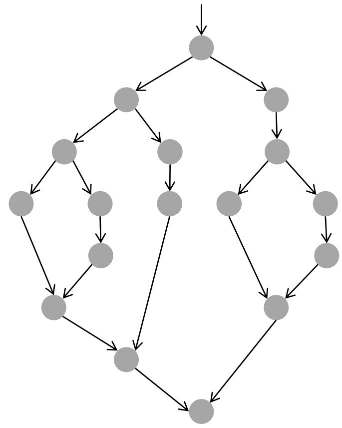
W = 17, D = 8

How to Schedule on p Processors?



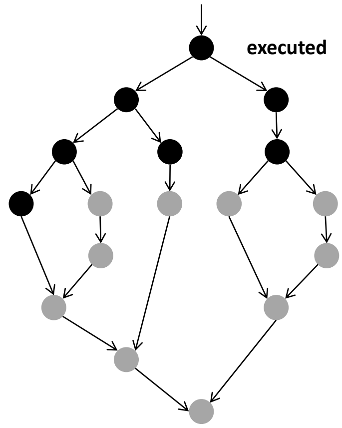
Greedy Scheduler

- *Idea:* Do as much as possible in every step



Greedy Scheduler

- *Idea:* Do as much as possible in every step
- *Definition:* A node is ready if all predecessors have been executed



Greedy Scheduler

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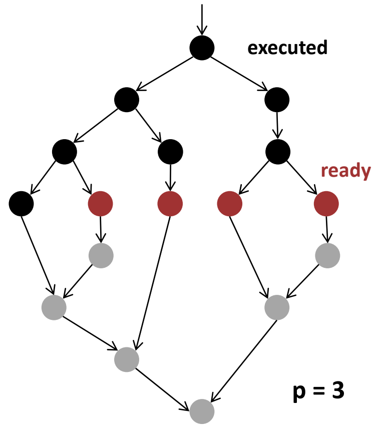
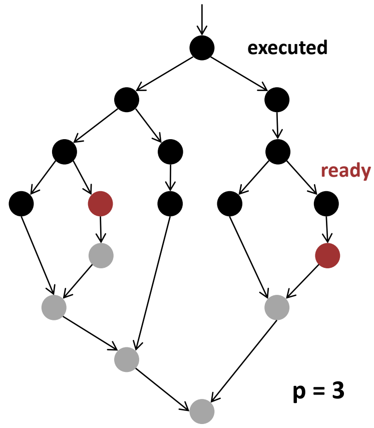
- Complete step:
  - ≥ p nodes are ready
  - run any p



Greedy Scheduler

- *Idea:* Do as much as possible in every step
- *Definition:* A node is ready if all predecessors have been executed
- Complete step:
  - ≥ p nodes are ready
  - run any p
- Incomplete step:
  - < p nodes ready
  - run all
- How good is this theoretically?
  (blackboard)



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Greedy Scheduler: Sketch

Maintain thread pool of live threads, each is ready or not

- **Initial: Root thread in thread pool, all processors idle**
- **At the beginning of each step each processor is idle or has a thread T to work on**
- **If idle**
  - *Get ready thread from pool*
- **If has thread T**
  - Case 0: T has another instruction to execute
    execute it
  - Case 1: thread T spawns thread S
    return T to pool, continue with S
  - Case 2: T stalls
    return T to pool, then idle
  - Case 3: T dies
    if parent of T has no living children, continue with the parent, otherwise idle

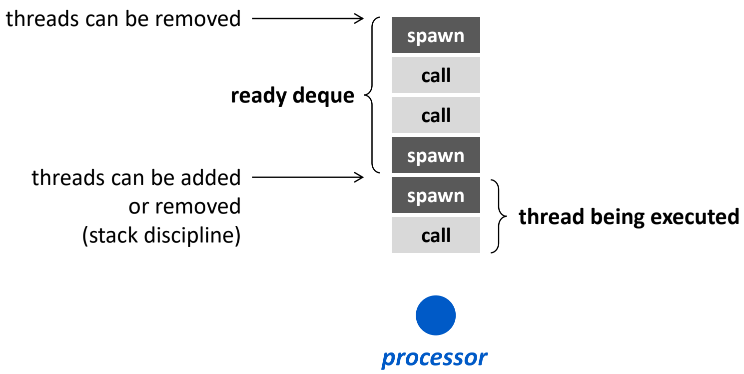
Greedy Scheduler: Problems

- **Centralized**
- **Overhead**

- **Work stealing scheduler:**
  - thread pool distributed
  - all processors do only useful work and operate locally as long as there is work to do
  - Good asymptotic behavior, good practical behavior
  - Implemented in Cilk runtime system

Work Stealing Scheduler

- **Each processor maintains a "ready deque:" deque of threads ready for execution; bottom is manipulated as a stack**



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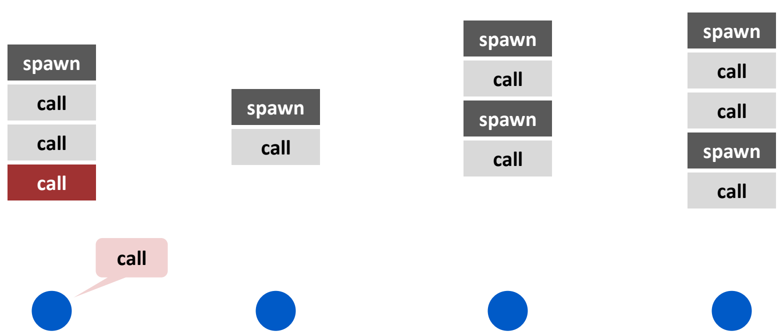

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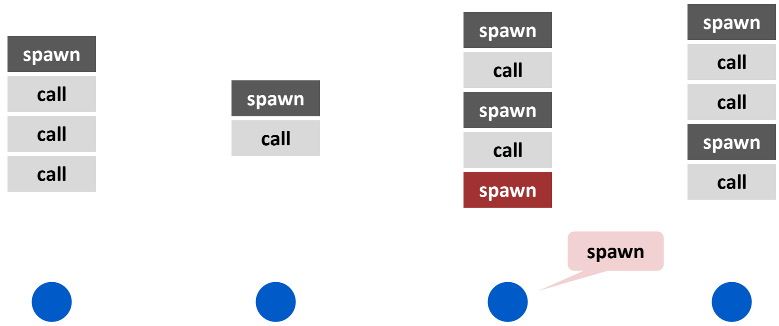

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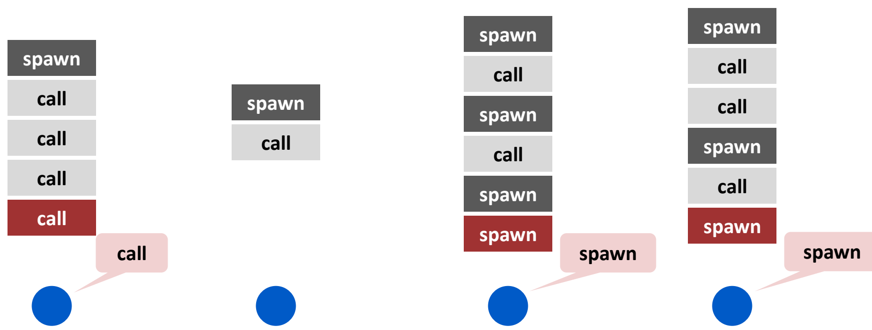

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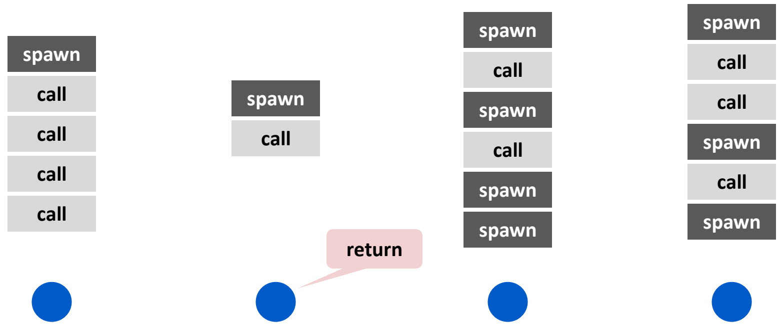

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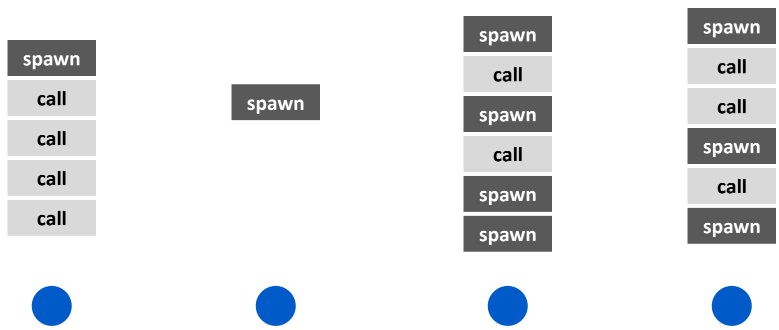

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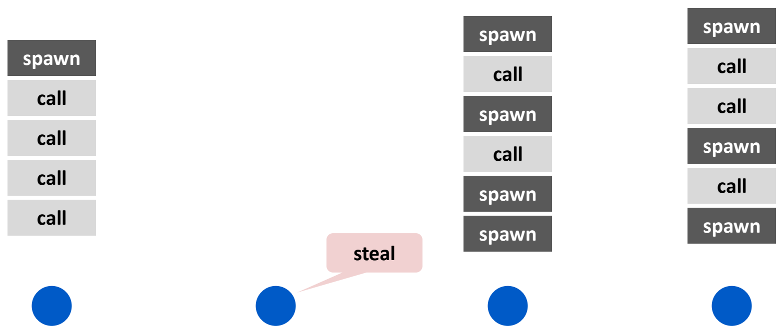

- Steal from the top of a randomly selected processor

Work Stealing Scheduler

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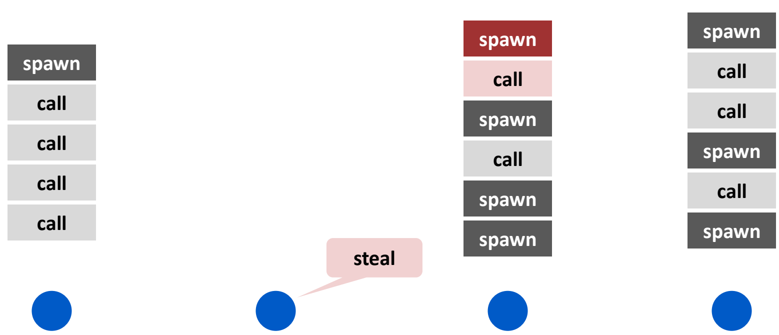

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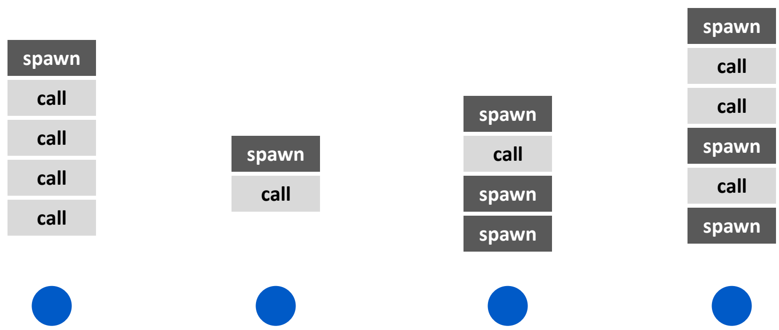

Work Stealing Scheduler: Sketch

Each processor maintains a ready deque, bottom treated as stack

- **Initial: Root thread in deque of a random processor**
- **Deque not empty:**
  - Processor takes thread T from bottom and starts working
  - T spawns S: Put T on stack, continue with S
  - T stalls: Take next thread from stack
  - T dies: Take next thread from stack
  - If T enables a stalled thread S, S is put on the stack of T’s processor
- **Deque empty:**
  - Steal thread from the top of a random (uniformly) processor’s deque
- **Theoretical performance?** *(blackboard)*

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Cilk

- Extension of C/C++
- Compiler and runtime system
- Developed at MIT, now distributed by Intel
- Cilk home at Intel