Scheduling Multithreaded Computations by Work stealing

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Overview

- Introduction to the thematics of Multi Processing
- Goal of the presentation
- Work Sharing
- Premises for work stealing
- Steps towards the development of the work stealing Algorithm
- Analysing the algorithm
- Comparison of the algorithms Work Sharing and Work Stealing
- Improvements
- Implementation

Introduction to the thematics of Multi Processing

- Multiprocessor systems have been around for some time
- Single processors can only increase their speed according to Moore’s law
- At some point there is a limit of the processor speeds
- Single processors are more expensive than multiprocessors for same processing power
- Uniprocessors are easier to handle from a software perspective

Software on Multiprocessing systems

- Design issues:
  - Additional functionality
  - High requirements to the operating system to hide the multiprocessing system
  - Communication Overhead
  - Multiprocessor scheduling is a NP complete problem
  - Therefore a good simulation of the problem is the bins packing problem

Constraints of Multi Processing

- Factors limiting processing power
  - Temperature
  - Communication Speeds
  - Power consumption
  - Software

Goal

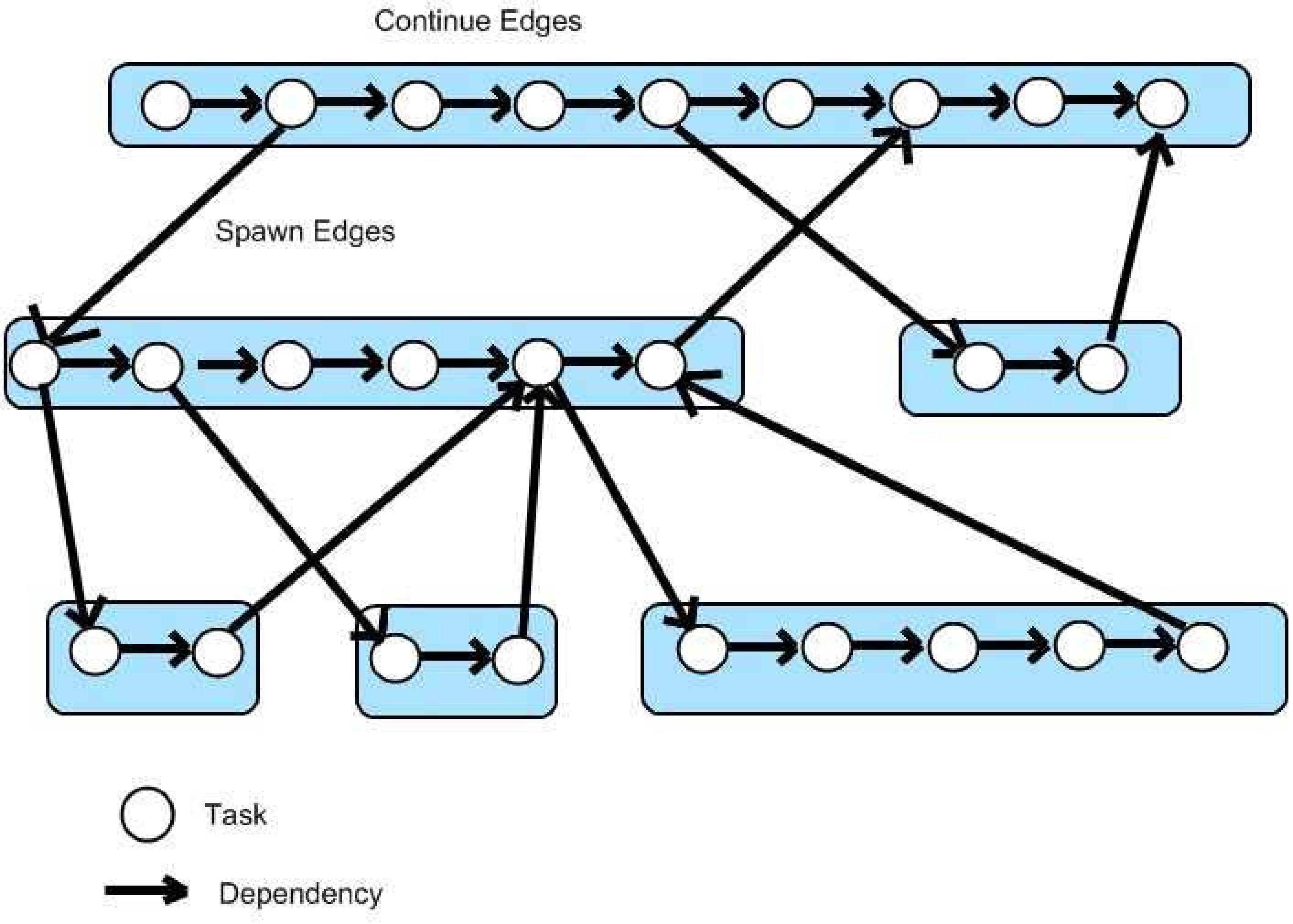
- Comparing the known alternatives of
  - Work stealing
  - Work sharing
- Proving that Work Stealing requires less communication than Work Sharing
  - Work Sharing Communications : $\Theta (T_1 S_{Max})$
  - T_1 : Minimum execution time for one processor
  - S_{Max} : Size in Bytes of the largest activation frame

Work Sharing

- General Idea is a Global queue
- There are other papers that propose a distributed shared work queue
- Each processor requests a Thread to work on from this central queue
- If the thread is stalled it is returned to the central queue

Premises on Threads

- Life of a thread:
  - Spawn
  - Stalls
  - Dies
- DAG
- Fully Strict
- Example for a Uniprocessor execution


Continue Edges
Spawn Edges
Task
Dependency

Premises on Threads (2)

- Heavyweight threads
  - Activation Frame
  - The frame hold all values
  - No global storage
- A parent with Children remains alive
- Activation Depth S_1= Minimal Amount of space possible
  - Total size of all frames of the execution
- S_P Linear expansion of space for a P – Processor execution schedule

Terminology

- T_P : Time used by a P – processor execution schedule
- $T_{infinity}$: Time of computation for an infinite amount of processors
- $T_P >= T_{infinite}$
- Work : The number of tasks in the computation
- T_1 : The minimum time for a Uniprocessor
- $T_P >= T_1 / P$

Steps twards the comparison

- The Greedy Scheduling Algorithm
- The Busy Leaves Algorithm
- Randomized work – stealing algorithm
- Refining using the atomic access model and recycling

The Greedy Scheduling Algorithm

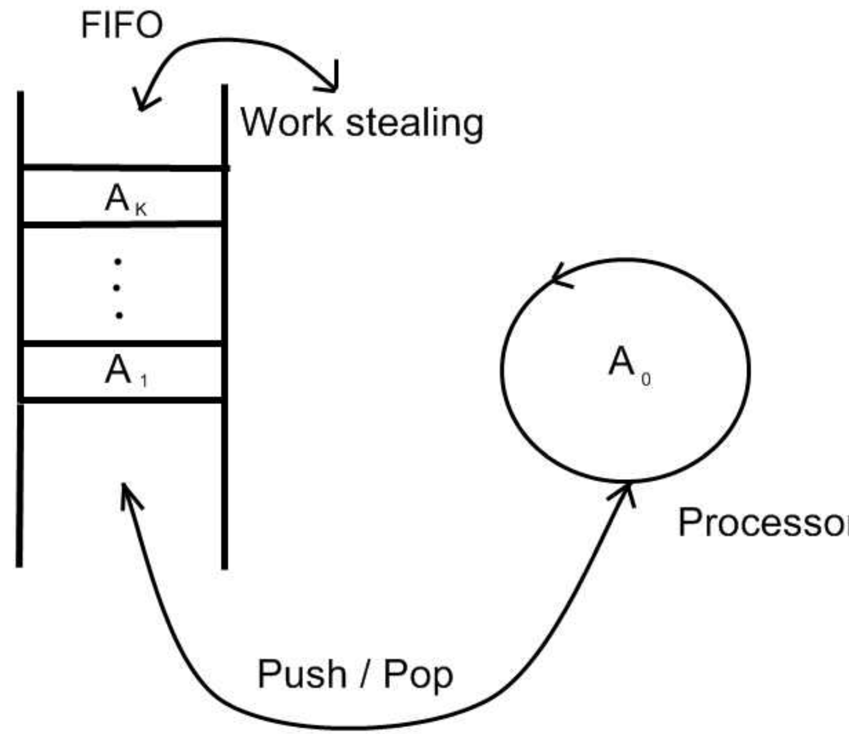
- Linear Speed up
- If P tasks are ready P execute
- If less are ready all execute

The Busy Leaves Algorithm

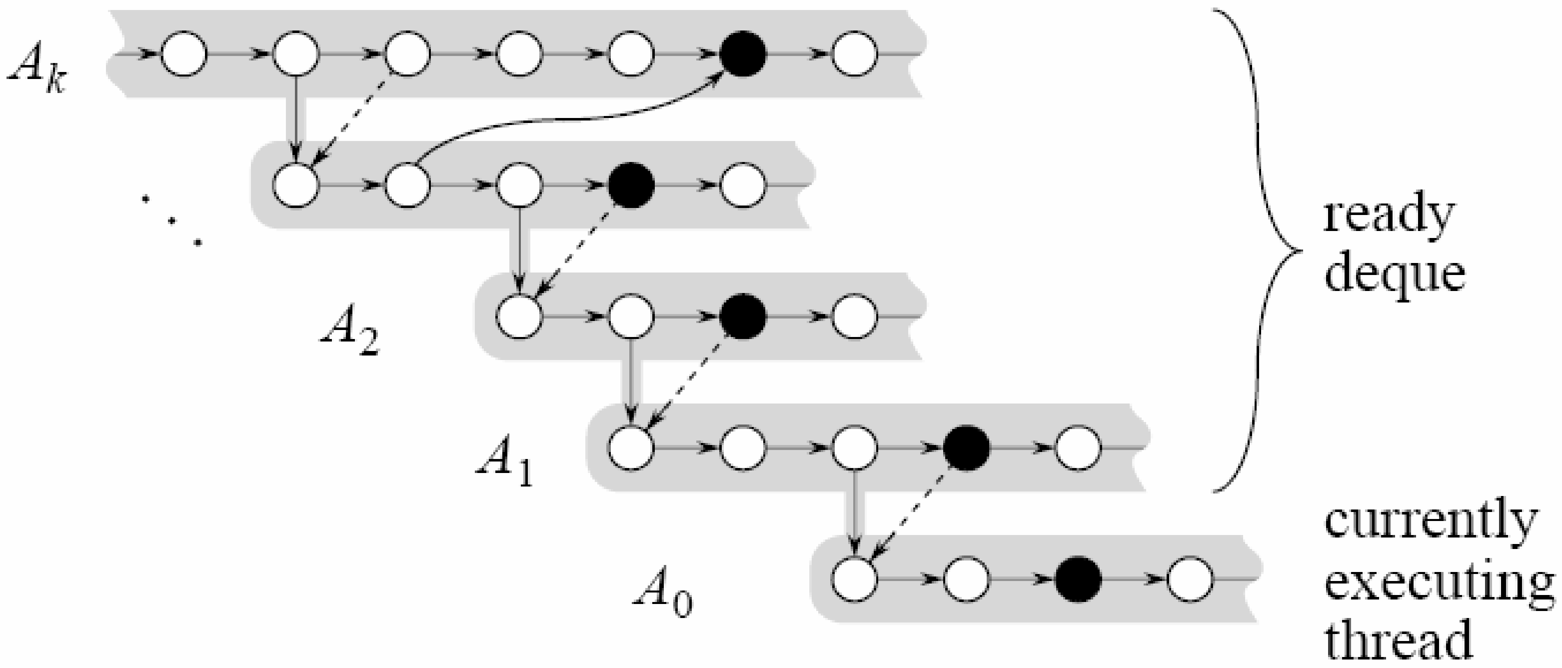
- No contending for access to thread pool
- Unit access to the pool
- Average available Prallelism: $T_1 / T_{infinity}$
- Good for small scale systems
- No scaling to large scale systems
- Operation:
  1. A spawns B, Then B is executed
  2. If A stalls, return A to the thread pool
  3. If A dies, Parent is executed. Else other thread in pool
- $S_P <= S_1 * P$

Randomized work – stealing algorithm

- Each processor maintains a Thread deque
- Maintains the busy leaves properties
- Actions
  1. If Thread A enables Thread B, A is placed in the ready queue
  2. If A spawns B, B is executed
  3. If A dies, no Threads -> work stealing from random processor



Randomized work – stealing algorithm



The atomic access model and recycling

- Balls and Bins Game
- P - Balls
- P - Bins
- M is the number of the Requests
- Balls are tossed randomly into bins
- Rules:
    1. Random balls from reservoir into Bins
    2. Removes one ball from each Bin

The atomic access model and recycling

- Game ends after
  - M ball tosses
  - All Balls have been returned to the reservoir
- Ball symbolizes a steal request
- Interest: Total delay time
  - Remains rather small

Balls and Bins Game Results

- Expected total delay = The number of Requests
- Start with analysing 1 ball
- Either it is delayed or it is not delayed at every of the m throws
- Does not matter what ball is removed from the bin first
- Then we assume that all the balls are equal
- The total delay is the sum of P delays of balls

Analysing time and communication cost

- An accounting argument was used
- Each round P dollars are available
- These dollars are then distributed among three bins:
  - Wait
  - Steal
  - Work
- The execution finishes when as many tokens are in the work bin as there are tasks
  - At the end there are task tokens in the work bin

Analysing time and communication cost

- Number of calculated dollars in the steal bucket:
  - P times the longest Path of the DAG
- Number of calculated waits:
  - Is at most the number of dollars in the steal bucket
- The total communication for work stealing:
  - The number of steal attempts times the amount of information S_{Max} -> $O(P * T_{infinity} * S_{Max})$
  - Since in linear Speedup systems we assume $P = O(T_1 / T_{infinity})$
- Result for the communication : $O(T_1 S_{Max})$

Comparison of the algorithm to other methods

- Work sharing
  - Work Sharing Communications : $\Theta (T_1 S_{Max})$
- Work stealing
  - $O(T_1 S_{Max})$
  - Since $P << T_1 / T_{infinity}$ we expect much better results

Improvements

- No guarantee that processors can run out of space
- Working with strict not fully strict graphs
- Possibly even non strictness

Implementations

- Cilk
  - C implementation for Multiprocessors of Work stealing
- Achievments:
  - Chessprogramms that have won awards

Danke für die Aufmeksamkeit

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Presented by Dayton Bishop

Ressources

1. Robert D. Blumofe and Charles E. Leiserson. Space-efficient scheduling of multithreaded computations. In *Proceedings of the Twenty Fifth Annual ACM Symposium on Theory of Computing*, pages 362–371, San Diego, California, May 1993.

Proof(1)

1. Delay D
2. Delay of one ball by another
3. Probability of for a delay
4. Proving Inequality

$$D = \sum_{r=1}^{P} \delta_r \ . \tag{1}$$

$$\delta = \sum_{i=1}^{m} \sum_{r=2}^{P} x_{ir} \ . \tag{2}$$

$$\Pr\left\{ \bigwedge_{(i,r)\in S} (x_{ir} = 1) \right\} \le P^{-|S|} \ . \tag{3}$$

$$\Pr\left\{ x_{ir} = 1 \,\middle|\, \bigwedge_{(i',r')\in S'} (x_{ir} = 1) \right\} \le 1/P \ , \tag{4}$$

$$\begin{aligned} D &= \sum_{r=1}^{P} \max\{2em_r, \lg P + \lg(1/\epsilon)\} \\ &= \Theta(M + P\lg P + P\lg(1/\epsilon)) \ , \end{aligned}$$