Heterogeneous
Parallel
Programming

Lecture 4.1

Parallel Computation Patterns

Reduction

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Objective

- To learn the parallel reduction pattern
  - An important class of parallel computation
  - Work efficiency analysis
  - Resource efficiency analysis

Partition and Summarize

- A commonly used strategy for processing large input data sets
  - There is no required order of processing elements in a data set (associative and commutative)
  - Partition the data set into smaller chunks
  - Have each thread to process a chunk
  - Use a reduction tree to summarize the results from each chunk into the final answer
- Google and Hadoop MapReduce frameworks support this strategy
- We will focus on the reduction tree step for now.

Reduction enables other techniques.

- Reduction is also needed to clean up after some commonly used parallelizing transformations

- Privatization
  - Multiple threads write into an output location
  - Replicate the output location so that each thread has a private output location
  - Use a reduction tree to combine the values of private locations into the original output location

What is a reduction computation?

- Summarize a set of input values into one value using a “reduction operation”
  - Max
  - Min
  - Sum
  - Product
- Often with user defined reduction operation function as long as the operation
  - Is associative and commutative
  - Has a well-defined identity value (e.g., 0 for sum)

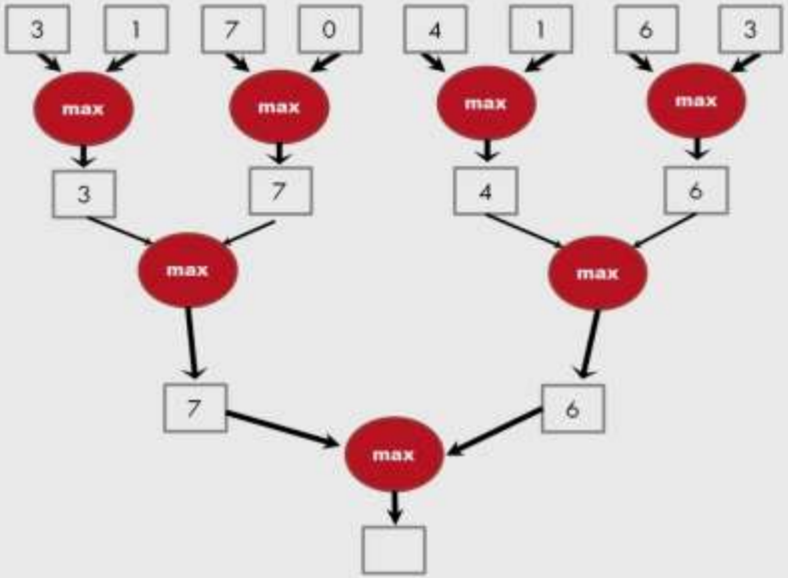
An example of “collective operation

An Efficient Sequential Reduction O(N)

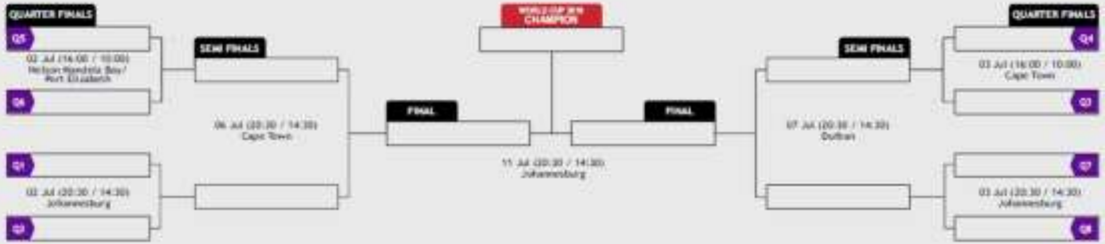
- Initialize the result as an identity value for the reduction operation
  - Smallest possible value for max reduction
  - Largest possible value for min reduction
  - 0 for sum reduction
  - 1 for product reduction

- Iterate through the input and perform the reduction operation between the result value and the current input value
  - N reduction operations performed for N input values

A parallel reduction tree algorithm performs N-1 Operations in log(N) steps



A tournament is a reduction tree with "max" operation



A Quick Analysis

- For N input values, the reduction tree performs
  - (1/2)N + (1/4)N + (1/8)N + … (1)N = (1- (1/N))N = N-1 operations
  - In Log (N) steps – 1,000,000 input values take 20 steps
    - Assuming that we have enough execution resources
  - Average Parallelism (N-1)/Log(N))
    - For N = 1,000,000, average parallelism is 50,000
    - However, peak resource requirement is 500,000!
    - This is not resource efficient.
- This is a work-efficient parallel algorithm
  - The amount of work done is comparable to sequential
  - Many parallel algorithms are not work efficient

To learn more, read
Section 6.1