A Unified MapReduce Domain-Specific Language for Distributed and Shared Memory Architectures

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Wyndham Pittsburgh University Center
Introduction

• New challenges for software engineers and developers

• Instead of being faster, computer architectures are more parallel

• Depending on the amount of data to be processed, local memory is not enough and distributed systems become a necessity

• Programming interfaces become prone to excessive complexity
MapReduce abstract model

• 2004 - Google introduced the MapReduce abstract model, based on two operations, *map* and *reduce*, originally from functional programming languages

• Simplicity and scalability for developing software to process large datasets

• Aimed, but **not limited**, to distributed environments
MapReduce job execution flow - Dean and Ghemawat (2004, p. 3)
MapReduce abstract model

“Many different implementations of the MapReduce interface are possible. The right choice depends on the environment. For example, one implementation may be suitable for a small shared-memory machine, another for a large NUMA multi-processor, and yet another for an even larger collection of networked machines”

Dean and Ghemawat (2004, p. 3)
MapReduce implementations

- **2004** - MapReduce original publication
- **2005** - Hadoop
- **2007** - Phoenix
- **2009** - Phoenix Rebirth
- **2010** - Tiled-MapReduce
- **2011** - Phoenix++
MapReduce implementations

- 2004 - MapReduce original publication
- 2005 - Hadoop
- 2007 - Phoenix
- 2009 - Phoenix Rebirth
- 2010 - Tiled-MapReduce
- 2011 - Phoenix++
Hadoop interface components

- Language: Java
- Mapper and Reducer
- Writable
- InputFormatReader
- RecordReader
Phoenix++

- Language: C++
- Efficient key-value storage
  - Modular storage options: Containers
- Effective combiner stage
  - Aggressively call combiner after every map emit
Phoenix++

- Modular storage options
- Specialized *Container* types

<table>
<thead>
<tr>
<th>Key Distribution</th>
<th>Sample applications</th>
<th>Container type</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>:</em></td>
<td>Word Count</td>
<td>variable-size hash table</td>
</tr>
<tr>
<td>*:k</td>
<td>Histogram, Linear Regression, K-means, String Match</td>
<td>array with fixed mapping</td>
</tr>
<tr>
<td>1:1</td>
<td>Matrix Multiplication, PCA</td>
<td>shared array</td>
</tr>
</tbody>
</table>
Performance comparison
Hadoop vs Phoenix++

Experiment of 1 GB word count using Phoenix++ and Hadoop on a multi-core architecture. The y-axis is in a logarithmic scale.
Related work

- Important researches on improving Hadoop for high performance at the single-node level.

- No research was found on building a unified MapReduce programming interface.
Unified MapReduce programming interface

• One single programming interface

• Transformation rules for Hadoop and Phoenix++ programming interfaces

• Shared-memory and distributed state-of-the-art solutions
Unified MapReduce programming interface

- Focus on MapReduce logic
- Abstraction capable of keeping key performance components
- Able to be hereafter extended to comprehend new solutions and architectures (e.g., GPGPUs)
Unified MapReduce programming interface

```plaintext
@Type name(attr_name: attr_type, ...)

@MapReduce<NAME, K_IN , V_IN , K_OUT , V_OUT , K_DIST > {
    @Map(key, value){
        // Map code logic
    }

    @SumReducer
}
```
Unified MapReduce programming interface

@MapReduce<NAME, K_IN , V_IN , K_OUT , V_OUT , K_DIST > { 

... 

@Reduce(key, values){
    double product = 1 
    
    for(int i=0; i < length(values); i++)
        product *= values [ i ]

    emit(key, product)
    
} 
}
# Transformation process

<table>
<thead>
<tr>
<th>Stage</th>
<th>Elements</th>
</tr>
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<tbody>
<tr>
<td>First</td>
<td>imports/includes</td>
</tr>
<tr>
<td>Second</td>
<td>@MapReduce @Map @Reduce @Type global variables</td>
</tr>
<tr>
<td>Third</td>
<td>unsolved keywords</td>
</tr>
<tr>
<td>Fourth</td>
<td>variable types</td>
</tr>
<tr>
<td>Fifth</td>
<td>functions</td>
</tr>
</tbody>
</table>
Unified interface - Histogram

@type pixel(r: ushort, g: ushort, b: ushort)

@MapReduce<HistogramMR, long, pixel, int, ulonglong, "*:768">

@Map(key, p)

emit(p.b, 1)
emit(p.g+256, 1)
emit(p.r+512, 1)

@SumReducer
public class HistogramMR {

    public static class Map extends Mapper<LongWritable, Pixel, IntWritable, LongWritable> {

        private final static LongWritable one = new LongWritable(1);

        @Override
        public void map(LongWritable key, Pixel p, Context context)
            throws IOException, InterruptedException {

            context.write(new IntWritable(p.getR()), one);
            context.write(new IntWritable(p.getG() + 256), one);
            context.write(new IntWritable(p.getB() + 512), one);
        }
    }
}
class HistogramMR : public MapReduceSort<
  HistogramMR, pixel,
  intptr_t, uint64_t,
  array_container<intptr_t, uint64_t, sum_combiner, 768>
{

  public:

  void map(data_type const& value, map_container& out) const {

    emit_intermediate(out, value.b, 1);
    emit_intermediate(out, value.g+256, 1);
    emit_intermediate(out, value.r+512, 1);

  }

}
Unified interface - *WordCount*

```java
@MapReduce<WordCountMR, long, text, string, int>

@Map(key, value)

toupper(value)

tokenize(value)

emit(token, 1)

@SumReducer
```
public class WordCountMR {

    public static class Map extends Mapper<LongWritable, Text, Text, IntWritable> {

        private final static IntWritable one = new IntWritable(1);
        private Text word = new Text();

        @Override
        public void map(LongWritable key, Text value, Context context)
        throws IOException, InterruptedException {
            String line = value.toString();
            StringTokenizer tokenizer = new StringTokenizer(line);
            while (tokenizer.hasMoreTokens()) {
                word.set(tokenizer.nextToken());
                context.write(word, one);
            }
        }
    }
}
Phoenix++ interface - WordCount

- C++ includes ± 6 lines
- MapReduce blocks ± 25 lines
- Custom split ± 24 lines
- Custom types - C++ struct ± 34 lines
- TOTAL 89 lines
Mean execution time in seconds for original and generated Hadoop code (30 executions)
Performance evaluation - Phoenix++

Mean execution time in seconds for original and generated Phoenix++ code (30 executions)
SLOCCCount

- Source Lines of Code counting
- Effort estimate based on COCOMO model
SLOC count and reduction

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<th>Hadoop</th>
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SLOC reduction for the interface version with curly braces
Hone
Appuswamy et al.
Azwraith
Phoenix
Phoenix 2
Tiled-MapReduce

Introduction                Background                Related Work                Unified Interface            Evaluation

Performance on shared-memory
Abstraction
Conclusions

• MapReduce implementations for lower level architectures, particularly, lose MapReduce's originally aimed abstraction.

• Through a comprehensive set of transformation rules it is possible to effectively cover the components of Phoenix++ and Hadoop’s programming interfaces.
Conclusions

- Performance evaluation shows less than 3% of variance from original and generated versions for all sample applications

- A SLOC and effort reduction from 41.84% and up to 96.48% is achieved
Conclusions

- Code written with the proposed unified interface can be reused for addressing different architectures

- Phoenix++ provides some optimizations for NUMA architectures, which are not supported by the transformation rules
Future work

• The effective construction of the compiler and code generator based on the proposed transformation rules

• The extension of transformation rules for compatibility with MapReduce solutions for different architectures (e.g., GPGPUs)
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