Zwift: A Programming Framework for High Performance Text Analytics on Compressed Data

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Motivation

• Data management evolution in history.

MySQL
SQL Server
DB2

Data Warehouse
Mining
Complex structures

MapReduce
Hadoop
Spark

Every data, 2.5 quintillion bytes of data created – 90% data in the world today has been created in the last two years alone[1].

• QUESTION:

What if the data are too big that exceed storage capacity?

[1] What is Big Data?
https://www-01.ibm.com/software/data/bigdata/what-is-big-data.html
Motivation

• Challenge 1:
  • SPACE: Large Space Requirement

• Challenge 2:
  • TIME: Long Processing Time

• Observation:
  • Using Hash Table to check redundant content
Motivation

• Our Idea:
  • Text analytics directly on compressed data (TADOC)

Motivation

• How text analytics directly on compressed data (TADOC) recovers data?
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Output:

\[ \text{a b a} \]
Motivation

• How text analytics directly on compressed data (TADOC) recovers data?

Output:

\[
\begin{array}{ccc}
\text{a} & \text{b} & \text{a} \\
\end{array}
\]
Motivation

• How text analytics directly on compressed data (TADOC) recovers data?

Output:

```
|   a |   b |   a |
```

R1: a b
R2: c d
R0: a R2 R2
Motivation

• How text analytics directly on compressed data (TADOC) recovers data?

Output:

```
Output:

a b a a b
```
Motivation

• How text analytics directly on compressed data (TADOC) recovers data?

Output:

Output:

\[ \text{a b a a b c} \]
Motivation

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Output:

\[ \text{Output: a b a a b c a b d a b c a b d} \]
Motivation

• Text analytics directly on compressed data (TADOC), why it is good?
• In format.

Challenge 1: Space

Appear more than once, but only **store** once!

Challenge 2: Time

Appear more than once, but only **compute** once!
What’s more?

Even BETTER!
Motivation

• Text analytics directly on compressed data (TADOC), why it is good?
• In Process:

Some applications do not need to keep the sequence.

In each rule, we may remove sequence info too.

Further saves storage space and computation time.
Outline

• Introduction
  • Motivation & Example
  • Programming Challenges
  • Solution

• Zwift Implementation
  • Language Overview
  • Language Features

• Results
  • Benchmarks
  • Performance
  • Storage Savings & Productivity

• Conclusion

We are here!

Use word count for illustration

Not easy to generalize this technique

A conceptual framework and a high level solution

How we implement our idea

Exhibition of the Zwift from several perspectives
Example

• Word Count

1 Calculation; R0 -> R1, R0 -> R2.

Weight of R0: 1
Local word table in R0: <a,1>
Local rule table in R0:
<R1,1>, <R2, 2>

2 Calculation; R2 -> R1.

Weight of R2: 2
Local word table in R2: <c,1>, <d,1>
Local rule table in R2: <R1, 2>

3 Calculation: (4+1).

Weight of R1: 5
Local word table in R1: <a,1>, <b,1>

4 Results integration.
Example

• Word Count

1. R0 propagates the frequency of R1 (which is 1) to R1, and the frequency of R2 (which is 2) to R2.

   Weight of R0: 1
   Local word table in R0: <a,1>
   Local rule table in R0: <R1,1>, <R2, 2>

2. R2 calculates its weight (which is 2), and propagates the frequency of R1 multiplied by R2’s weight to R1.

   Weight of R2: 2
   Local word table in R2: <c,1>, <d,1>
   Local rule table in R2: <R1, 2>

3. R1 calculates its weight, which is 5 (4+1).

   Weight of R1: 5
   Local word table in R1: <a,1>, <b,1>

4. We integrate the local word table in each node multiplied by its weight as the final result.
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- How to keep file information?
- When to remove sequence information?
Programming Challenges

• Which one is better?

**Problem dimension**

**Implementation dimension**

**Dataset dimension**

CFG relation

Information propagation

Step #

<word, index>

Word table

R0: R1 R1 R2 a

R1: R2 c R2 d

R2: a b

1

1

<a,6>, <b,5>

<c,2>, <d,2>

<a, 2x2 + 1 +1> = <a, 6>

<b, 2x2 + 1> = <b, 5>

<a, 2x2 + 1 +1> = <a, 6>

R0: R1 R1 R2 a

R1: R2 c R2 d

R2: a b

1

1

<a,1>, <b,1>

<word, index>

Word table

CFG relation

Information propagation
Programming Challenges

The best traversal order may depend on input.
Solution

• A conceptual framework, a six-element tuple \((G, V, F, V, D, \wedge)\)
  • A graph \(G\), DAG representation

• \(G\), how to represent it.
Solution

- A conceptual framework, a six-element tuple \((G, V, F, V, D, \wedge)\)
  - A domain of values \(V\), possible values as the outputs

\[
\begin{array}{c}
R0: [R1 a R2 R2] \\
R2: [R1 c R1 d] \\
R1: [a b]
\end{array}
\]

- \(V\), what do we want to get from \(G\)?
Solution

• A conceptual framework, a six-element tuple \((G, V, F, V, D, \wedge)\)
  • A domain of values \(F\), possible values to be propagated

\[
\begin{array}{c|c|c|c|c}
R0 & R1 & a & R2 & R2 \\
\hline
1 & 2 & & & \\
\hline
R2 & R1 & c & R1 & d \\
\hline
2 & & & & \\
\hline
R1 & a & b & & \\
\end{array}
\]

• \(F\), what to propagate?
Solution

• A conceptual framework, a six-element tuple \((G, V, F, V, D, \land)\)
  • A meet operator \(V\), how to transform values

\[ R0: \quad \begin{array}{c}
\text{Calculation; R0} \rightarrow \text{R1, R0} \rightarrow \text{R2.}
\end{array} \]

\[ R1: \quad \begin{array}{c}
\text{Calculation: (4+1).}
\end{array} \]

\[ R2: \quad \begin{array}{ccc}
\text{Calculation; R2} \rightarrow \text{R1.}
\end{array} \]

\[ \land \]
Solution

• A conceptual framework, a six-element tuple \((G, V, F, V, D, \wedge)\)
  • A direction of the value flow \(D\)
Solution

- A conceptual framework, a six-element tuple \((G, V, F, V, D, \land)\)
  - A gleaning operator \(\land\), final stage of the analytics

\[ \begin{align*}
R0: & \quad R1 \quad \color{red}{a} \quad R2 \quad R2 \\
R1: & \quad \color{red}{a} \quad b \\
R2: & \quad R1 \quad c \quad R1 \quad \color{red}{d} \\
\end{align*} \]

- \(\land\), the last step, how to generate results?

Results integration.
Solution

• High-level algorithm for TADOC:

1. **Loading**: Load the grammar, build G (or its variants), and initialize the data structures local to each node or global to the algorithm.

2. **Propagation**: Propagate information with the meet operator $\lor$ while traversing G in direction D.

3. **Gleaning**: Glean information through the gleaning operator $\land$ and output the final results.
Contribution

• How to generalize the idea of TADOC
• Zwift, the first programming framework for TADOC
  • The Zwift Language
  • A compiler and runtime
  • A utility library
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The Zwift Language

• The Conceptual Framework (G, V, F, V,D, ∧)
  • A graph G.
  • A domain of values V.
  • A domain of values F.
  • A meet operator V.
  • A direction of the value flow D.
  • A gleaning operator ∧.

Zwift DSL template.

01 ELEMENT = LETTER/WORD/SENTENCE
02 USING_FILE = true/false
03 NodeStructure = {
04 //data structures in each node
05 }
06 Init = {
07 //initializations for each node in ZwiftDAG
08 }
09 Direction = FORWARD/BACKWARD/DEPTHFIRST
10 Action = {
11 //actions taken at each node during a traversal
12 }
13 Result = {
14 // result structure
15 }
16 FinalStage = {
17 // final operations to produce the results
18 }
Language Features

• Edge Merging
  • Edge merging merges multiple edges between two nodes into one, and the weight of the edge may be used to indicate the number of original edges in the Zwift code.

• Node Coarsening
  • Node coarsening reduces the size of the graph, and at the same time, reduces the number of substrings spanning across nodes.

• Two-Level Bit Vector
  • Level Two contains a number of N-bit vectors (where N is a configurable parameter). Level One contains a pointer array and a level-1 bit vector.
Language Features

• Coarse-Grained Parallelism
  • The parallelism is at the data level. The coarse-grained method also simplifies the conversion from sequential code to parallel and distributed versions of the code.

• Version Selection
  • Zwift allows programmers to easily run the different versions on some representative inputs.

• Double Compression
  • Double compression performs further compression (e.g., using Gzip) of the compressed results from Sequitur.
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Benchmarks

• Six benchmarks
  • Word Count, Inverted Index, Sequence Count, Ranked Inverted Index, Sort, Term Vector

• Five datasets
  • 580 MB ~ 300 GB

• Two platforms
  • Single node
  • Spark cluster (10 nodes on Amazon EC2)
Benchmarks

(a) Manual-direct (baseline)

(b) Manual-gzip

(c) Manual-opt

(d) Zwift
Performance

• Execution time benefits of speedup over *manual-direct*.
  • Zwift yields 2X speedup, on average, over *manual-direct*.
  • Zwift and *manual-opt* show similar performance, which indicates that Zwift successfully unleashes most power of TADOC.
Storage Savings

Zwift reduces storage usage by **90.8%**, even more than *manual-gzip* does.
Productivity

On average, the Zwift code is 84.3% shorter than the equivalent C++ code.
Conclusion

• Zwift is an effective framework for TADOC.
  • It reduces storage usage by 90.8%
  • It reduces execution time by 41.0%
• Zwift significantly improves programming productivity.
Thanks!

• Any questions?