Symbolic Execution of Apache Spark Programs

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Abstract

Informationen zu Inhalten der Zusammenfassung entnehmen Sie bitte Kapitel 6.1 des Skripts zur Veranstaltung *Wissenschaftliches Arbeiten und Schreiben für Maschinenbau-Studierende*.

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Contents

1 Introduction

2 Related Work

2.1 Apache Spark

Spark is a data processing framework that was first introduced in 2012 [1]. Similar to other systems, such as MapReduce [2] and Dryad [3], it aims to offer a clean and flexible abstraction to distributed computations on large datasets. However, Spark offers two advantages in comparison to such systems: It makes use of a shared memory abstraction that improves performance by avoiding persisting intermediate sets. It also provides an efficient fault-tolerance mechanism, based on tracking coarse-grained operations, that can recover lost tasks with minimal impact.

The working units in Spark are called *Resilient Distributed Datasets*, better known as RDDs. These units represent an immutable partitioned collection of elements in a distributed memory space. RDDs can only be created through a set of deterministic operations, known as *transformations* (e.g., *map*, *filter* and *join*), that can be applied to both, raw data or other RDDs. Transformations are not evaluated immediately, instead Spark keeps track of all the transformations applied to each RDD in a program so it can optimize their subsequent processing. Additionally, RDDs can be operated to return a value or can be made persistent into storage. These kind of operations are known as *actions* (e.g., *count*, *reduce* and *save*), and they are the ones that trigger the processing of RDDs.

To interact with the RDD abstraction, Spark provides several APIs for different programming languages such as Java, Scala, Python and recently R [4].

```
1  object SparkWordCount{
2    def main(args: Array[String]) {
3      val conf = new SparkConf().setAppName("Spark Example").setMaster("local")
4      val spark = new SparkContext(conf)
5      val wordCount = spark.textFile("input/log.txt", 1)
6        .flatMap(_.split(" "))
7        .map((_,1))
8        .reduceByKey(_+_)
9        .collect()
10       .map(println(_))
11   }
12 }
```

Moreover, repeating the same transformations on the same dataset always yield the same RDD as a result; this property is necessary for the fault-tolerant mechanism.

(Lineage or provenance) Capturing lineage or provenance information for data has long been a research topic in scientific computing and databases, for applications such as explaining results, allowing them to be reproduced by others, and recomputing data if a bug is found in a workflow or if a dataset is lost [1]

(Spark) Spark provides a convenient language-integrated programming interface in the Scala programming language. Spark exposes RDDs through a language-integrated API where each dataset is represented as an object and transformations are invoked using methods on these objects. [1]

(Spark) Iterative algorithms and interactive querying of data sets.

(Version)Be sure to mention the current version of Spark at the moment or the version used for the analysis.

(How operation starts) Programmers start by defining one or more RDDs through transformations on data in stable storage (e.g., map and filter) [1]

(Spark Interface in Scala) Spark provides the RDD abstraction through a language-integrated API in Scala, a statically typed functional programming language for the Java VM. [1]

(First order functions) Users provide arguments to RDD operations like map by passing closures (function literals). Scala represents each closure as a Java object, and these objects can be serialized and loaded on another node to pass the closure across the network. [1]

(Transformations and Actions supported in paper) Table 2: Transformations and actions available on RDDs in Spark. Seq[T] denotes a sequence of elements of type T [1]

(Graph representation) We propose a simple graph-based representation for RDDs that facilitates these goals. (The goal of connecting consecutive RDD operations) [1]

(Concept of narrow dependency. Maybe not useful here but I don't want to forget) First, narrow dependencies allow for pipelined execution on one cluster node, which can compute all the parent partitions. For example, one can apply a map followed by a filter on an element-by-element basis [1]

(Runs under Mesos maybe not necessary) The system runs over the Mesos cluster manager, allowing it to share resources with Hadoop, MPI and other applications [1]

(Mention that Spark has several libraries, machine learning, graph, stream, structured)

(Mention that Spark is now an Apache product but also under Databricks) Cite [5]

Check R. Bose and J. Frew. Lineage retrieval for scientific data processing: a survey and Cheney, L. Chiticariu, andW.-C. Tan. Provenance in databases: Why, how, and where

3 Evaluation

4 Future Work

5 Einrichtung und Erläuterungen

Es wird empfohlen, bei der Installation einer LaTeX-Distribution die Optionen *automatische Updates* bzw. *on the fly-Installation* zu aktivieren. Dies hat den Vorteil, dass bislang nicht installierte Pakete bei Bedarf automatisch nachinstalliert werden.

Um das modifizierte TU-Design zu verwenden, müssen Sie zunächst das offizielle TU-Design installieren. Die dazugehörigen, betriebssystemabhängigen Installationsanleitungen finden Sie unten.
In Ihrem Dokument laden Sie dann das Paket *tustyle*. Standardmäßig ist die Layoutfarbe rot, sie können diese jedoch nach Belieben ändern. Hierzu laden sie das Paket mit der Option Ihrer gewünschten Farbe. Sollte Ihre Farbe noch nicht in der Klasse vorgesehen sein, können Sie diese selbstständig hinzufügen. Orientieren Sie sich hierbei an den Zeilen 144 bis 150 in dem Paket. Um eine neue Farbe zu definieren, benötigen Sie lediglich ihren RGB-Code.

Beispiel: \usepackage[blue]{tustyle} lädt das Paket *tustyle* mit der Farbe *blau*

Sollten Sie die offiziellen TU-Klassen verwenden, können Sie die Layoutfarbe als Option der Dokumentenklasse übergeben. Die möglichen Farben entnehmen Sie bitte der Handbuch des Corporate Designs.

Beispiel: \documentclass[accentcolor=tud9c]{tudreport} lädt die Dokumentenklasse tudreport mit dem Farbe 9c (weinrot, Farbe dieses Dokuments)

5.1 Einrichtung unter Windows

5.1.1 Setup

Zu Beginn wird für den Start folgendes Setup vorgeschlagen:

- LaTeX-Distribution: MiKTeX [Zugriff: 13.12.2014]
- LaTeX-Editor: TeXstudio [Zugriff: 13.12.2014]
- Literaturverwaltung (optional): Endnote/Citavi [Zugriff: 13.12.2014] mit TU-Lizenz der ULB oder das kostenfreie JabRef [Zugriff: 13.12.2014]
- PDF-Reader (optional): Sumatra PDF [Zugriff: 13.12.2014] (Adobe Reader verhindert den Kompiliervorgang bei geöffnetem PDF-Dokument)

Es gibt eine Vielzahl kostenloser und kostenpflichtiger LaTeX Distributionen (Auswahl [Zugriff: 13.12.2014]) und Editoren (Übersicht [Zugriff: 13.12.2014]) mit unterschiedlichem Funktionsumfang, mit denen persönliche Vorlieben erfüllt werden können. Aus Gründen der Einfachheit und Reproduzierbarkeit beziehen sich Hilfestellungen sowie Tipps und Tricks dieser Einrichtungshilfe allerdings auf oben genanntes Setup. Die Installation der genannten Komponenten ist unproblematisch und sollte mit den jeweiligen Installationsprogrammen durchgeführt werden können.

Für eine problemlose Kompilierung unter Windows 7 wird empfohlen, die Miktexversion für 32 Bit zu verwenden.

5.1.2 Installation der TU-Design-Vorlage für LaTeX

Die Vorlage für Abschlussarbeiten greift für die Umsetzung des Corporate Designs der TU Darmstadt auf die TUD-Design LaTeX Vorlage [Zugriff: 13.12.2014] zurück, welche von der Stabstelle Kommunikation und Medien genehmigt wurde. Diese hält die Vorgaben des Corporate Design Handbuchs (CDH) recht strikt ein (strikter als viele Fachgebiete dies bei den jeweils eigenen Word-Vorlagen tun), weshalb manche Anpassungen an Institutsvorgaben u.U. nur schwer umsetzbar sind, da sie gegen das CDH verstoßen.
Die notwendigen Pakete für die Verwendung der Vorlage für Abschlussarbeiten sind

- das TUD-Design [Zugriff: 13.12.2014]
- die TUD- Fonts [Zugriff: 13.12.2014]

Hinweis: die TUD-Design Thesis Klasse, welche ebenfalls zum Download bereit steht, wird nicht benötigt.

Installation

Für die Installation der TUD-Design Vorlage unter der MiKTeX Distribution unter Windows 7 kann folgende überarbeitete Anleitung verwendet werden. Sie basiert auf der Installationsanleitung auf den Seiten der TUD-Design Vorlage [Zugriff: 13.12.2014].

Hinweis: Für die Installation werden Administrator-Rechte benötigt

1. Entpacken der beiden Zip-Dateien (fonts und tuddesign) und anschließend aus den beiden Ordnern einen machen (ineinander kopieren und Verzeichnisse überschreiben)

2. Öffnen der Eingabeaufforderung mit Administratorrechten: Start » Programme » Zubehör, dann Rechtsklick auf Eingabeaufforderung » „Als Administrator ausführen“

3. Mit `cd <Pfad>` in das Verzeichnis wechseln, in dem der in 1 angelegte Ordner `texmf` liegt. Falls der texmf-Ordner auf einem anderen Laufwerk als Cliegt, muss beim Verzeichniswechsel der Parameter `/d` angegeben werden:
   Beispiel:
   texmf-Ordner liegt unter `E:\Test`
   Befehl: `cd /d E:\Test`

4. Löschen des Ordners `texmf\fonts\map\dvipdfm` inklusive seines Inhalts mit folgendem Befehl
   `rmdir /Q /S "C:\Users\Benutzername\TU-Design\texmf\fonts\map\dvipdfm"`

5. Kopieren der Unterverzeichnisse von texmf in den Ordner `\%PROGRAMFILES%\tuddesign\` mit folgendem Befehl:
   `xcopy texmf "%PROGRAMFILES%\tuddesign" /E /I`
   Falls der xcopy Befehl fehlschlägt, liegen keine Administratorrechte vor (keine Schreibrechte für Programme-Ordner)

6. Dannach folgenden Befehl ausführen:
   `mo_admin`
   Zum Reiter Roots wechseln, den *add*-Knopf drücken und das Verzeichnis `\%PROGRAMFILES%\tuddesign` auswählen. (Unterordner tuddesign im Standard-Programmverzeichnis der Windows-Partition - i.d.R. auf `C:\`)
   Dann auf *OK* klicken.

7. In der Konsole folgendes eingeben:
   `initexmf --admin --update-fndb`

8. Anschließend Folgendes eingeben
   `initexmf --edit-config-file=updmap`

9. Folgende Zeilen in die sich öffnende Datei einfügen und speichern:

Map 5ch.map
Map 5fp.map
Map 5sf.map

10. Abschließend diesen Befehl ausführen
`initexmf --mkmaps`

Bibliography

[1] Zaharia, M. et al. “Resilient distributed datasets: A fault-tolerant abstraction for in-memory cluster computing”. In: *NSDI’12 Proceedings of the 9th USENIX conference on Networked Systems Design and Implementation* (2012), pp. 2–2. ISSN: 00221112. DOI: 10.1111/j.1095-8649.2005.00662.x. arXiv: EECS-2011-82.

[2] Dean, J. and Ghemawat, S. “MapReduce: Simplied Data Processing on Large Clusters”. In: *Proceedings of 6th Symposium on Operating Systems Design and Implementation* (2004), pp. 137–149. ISSN: 00010782. DOI: 10.1145/1327452.1327492. arXiv: 10.1.1.163.5292.

[3] Isard, M. et al. “Dryad: Distributed Data-Parallel Programs from Sequential Building Blocks”. In: *ACM SIGOPS Operating Systems Review* (2007), pp. 59–72. ISSN: 01635980. DOI: 10.1145/1272998.1273005.

[4] Venkataraman, S. et al. “SparkR: Scaling R Programs with Spark”. In: *Sigmod* (2016), p. 4. ISSN: 07308078. DOI: 10.1145/1235. arXiv: arXiv:1508.06655v1.

[5] *Apache Spark™ - Lightning-Fast Cluster Computing*. URL: http://spark.apache.org/ (visited on 2017).

6 Declaration of Academic Integrity

Thesis Statement pursuant to § 22 paragraph 7 of APB TU Darmstadt

I herewith formally declare that I have written the submitted thesis independently. I did not use any outside support except for the quoted literature and other sources mentioned in the paper. I clearly marked and separately listed all of the literature and all of the other sources which I employed when producing this academic work, either literally or in content. This thesis has not been handed in or published before in the same or similar form.

In the submitted thesis the written copies and the electronic version are identical in content.

Date: Signature:

List of Figures

List of Tables

Glossary

API	Application Programming Interface
RDD	Resilient Distributed Dataset

List of Symbols

Notation	Description
ε	Dehnung
E	Elastizitätsmodul
φ	Winkel
σ	Spannung
T	Temperatur

A Anhang

A.1 Ein Anhang

Hier gibt es etwas zu sagen oder auch nicht.

A.1.1 Teil eines Anhangs

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

A.1.2 Noch ein Teil eines Anhangs

- First item in a list
- Second item in a list
- Third item in a list
- Fourth item in a list
- Fifth item in a list

A.2 Noch ein Anhang

Hier gibt es etwas zu sagen oder auch nicht.

A.2.1 Teil des weiteren Anhangs

1. First item in a list
2. Second item in a list
3. Third item in a list
4. Fourth item in a list
5. Fifth item in a list

A.2.2 Noch ein Teil des weiteren Anhangs

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$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{i=n} x_i = \frac{x_1 + x_2 + \ldots + x_n}{n} \tag{A.1}$$

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$$\int_0^\infty e^{-\mathrm{ax}^2}\mathrm{d}x = \frac{1}{2}\sqrt{\int_{-\infty}^{\infty} e^{-\mathrm{ax}^2}\mathrm{d}x \cdot \int_{-\infty}^{\infty} e^{-\mathrm{ay}^2}\mathrm{d}y} = \frac{1}{2}\sqrt{\frac{\pi}{\alpha}} \tag{A.2}$$

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original

language. There is no need for special content, but the length of words should match the language.

$$\sum_{k=0}^{\infty} a_0 g^k = \lim_{n\to\infty} \sum_{k=0}^{n} a_0 q^k = \lim_{n\to\infty} a_0 \frac{1-q^{n+1}}{1-q} = \frac{a_0}{1-q} \tag{A.3}$$

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-p \pm \sqrt{p^2 - 4q}}{2} \tag{A.4}$$

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$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} = \frac{1}{c^2} \frac{\partial^2 \Phi}{\partial t^2} \tag{A.5}$$

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.