Verified Time-Aware Stream Processing

Rafael Castro G. Silva

rafaelcgs10@gmail.com

Department of Computer Science
University of Copenhagen

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What is this PhD about?

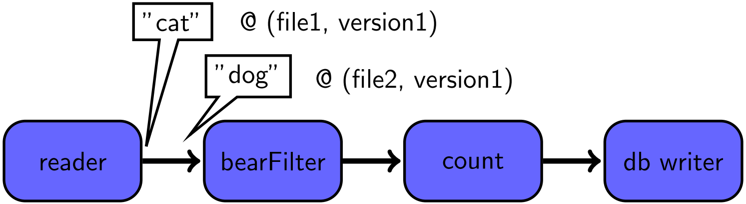
- Distributed Systems
  - Stream processing frameworks
    - Dataflow models
      - Timely Dataflow
- Formal Methods
  - Verification using proof assistants
    - Isabelle proofs
      - Verified and executable code

Contents

- Timely Dataflow
- Progress Tracking
- Verified Progress Tracking
- Verified Timely Dataflow
- Questions, comments and suggestions

Timely Dataflow

Example of a conventional Dataflow



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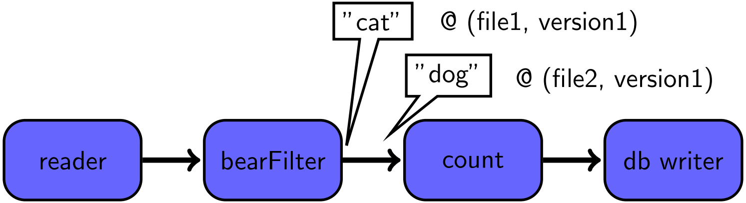

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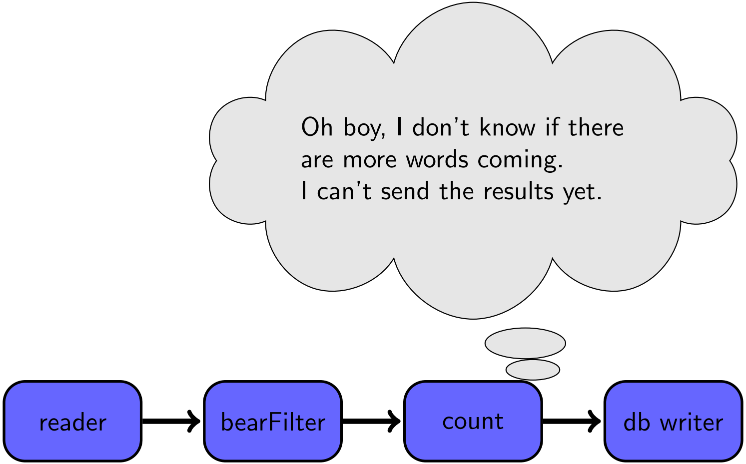

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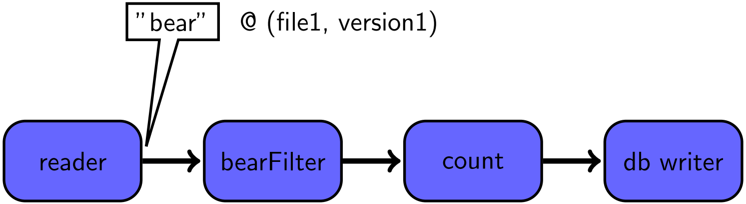

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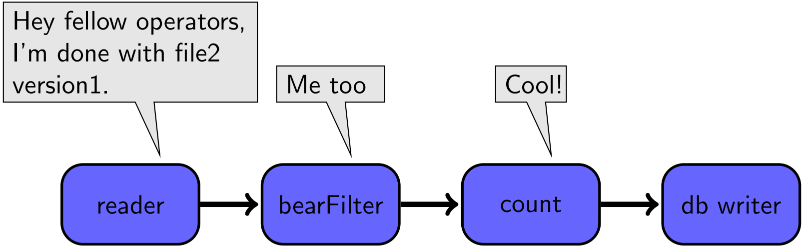

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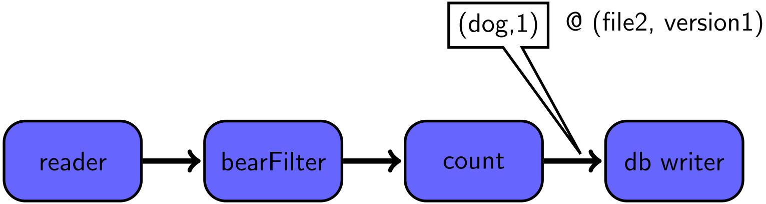

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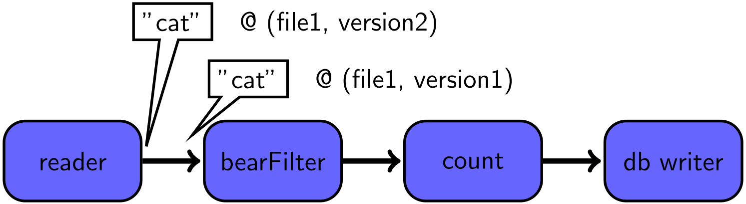

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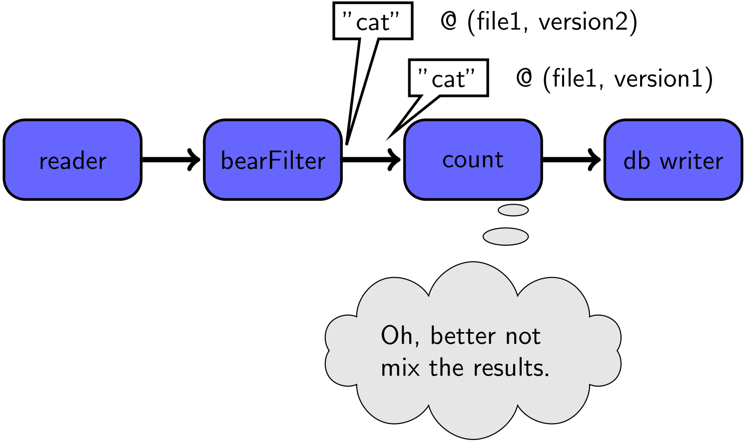

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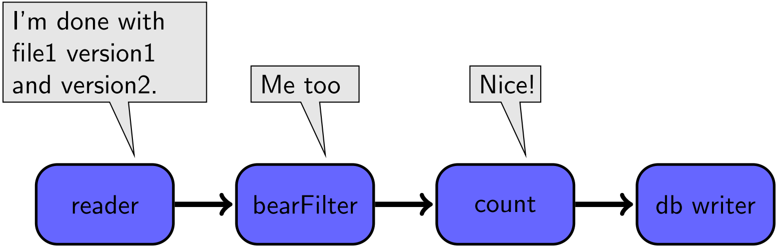

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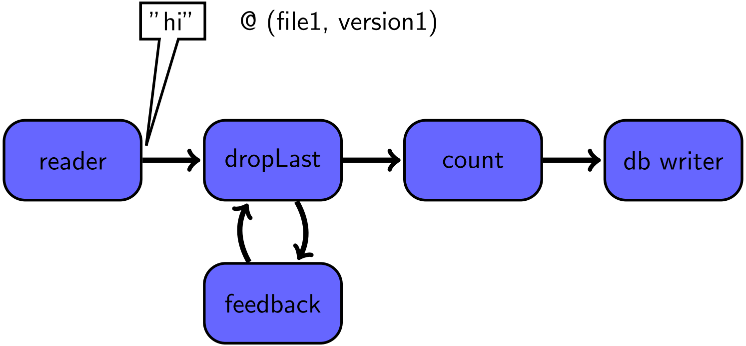

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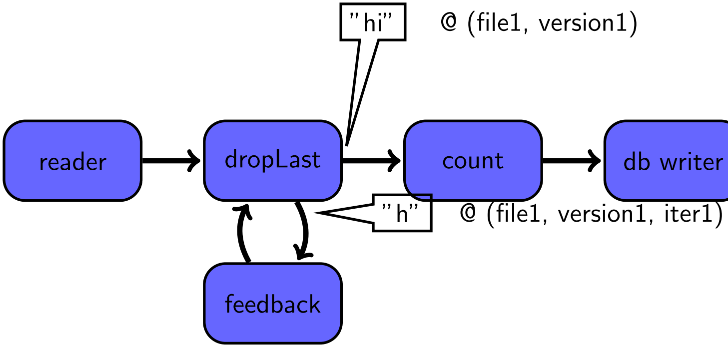

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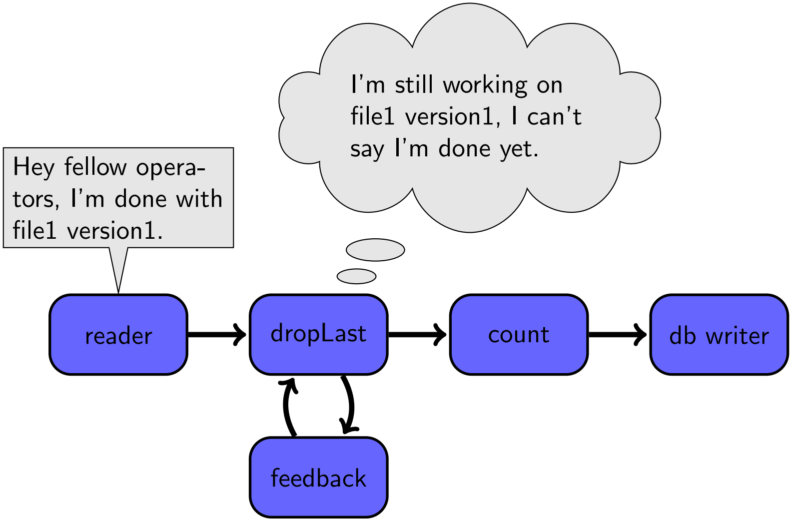

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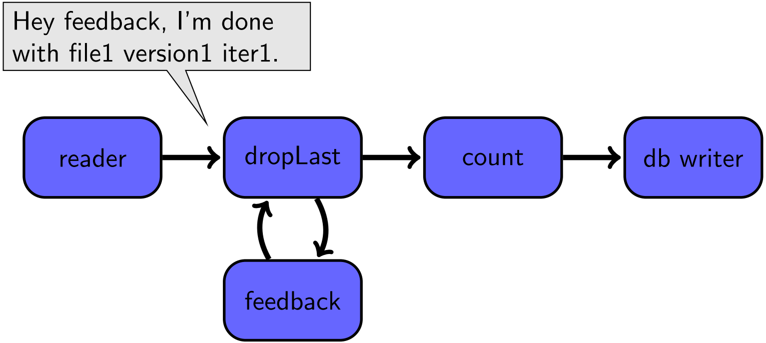

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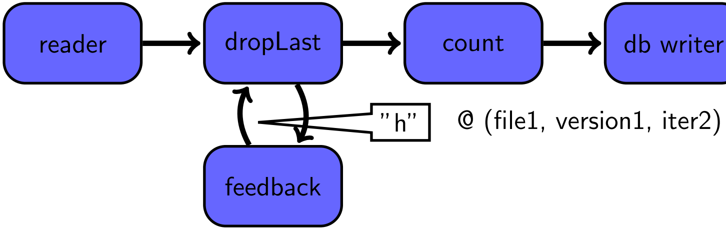

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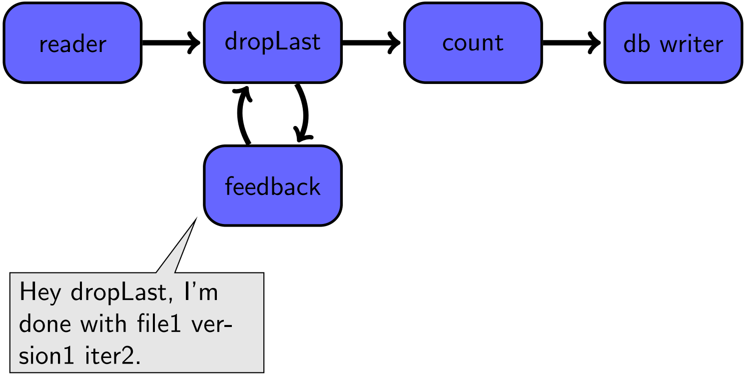

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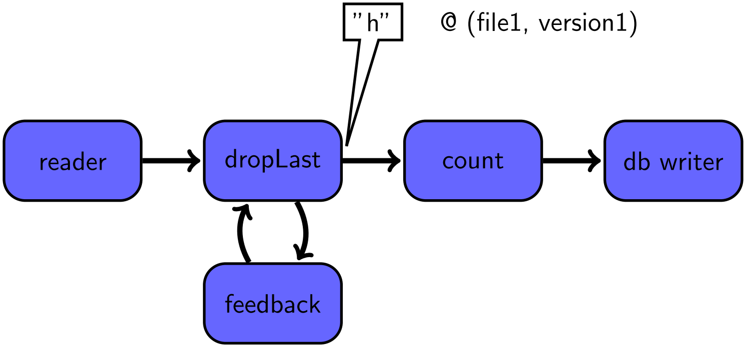

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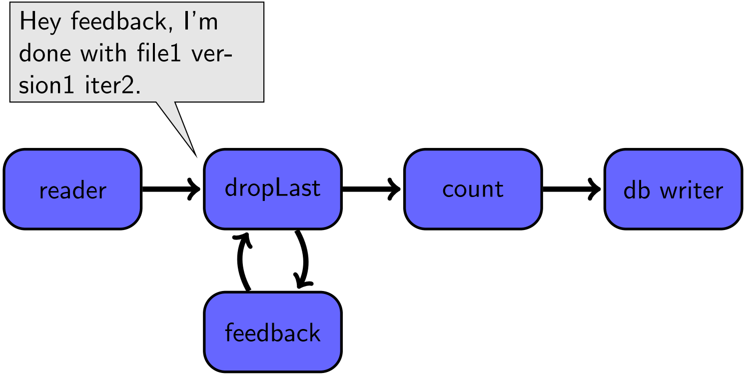

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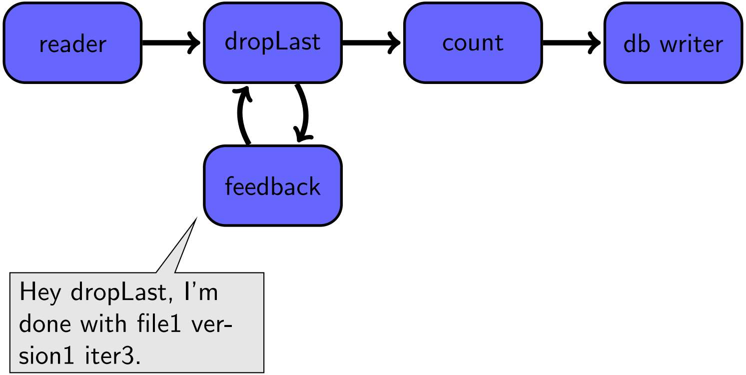
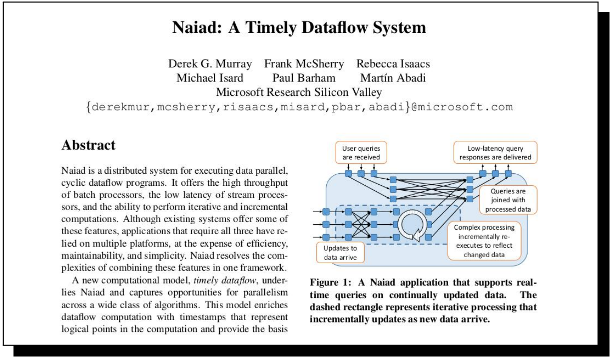


Timely Dataflow


Naiad: A Timely Dataflow System

Derek G. Murray Frank McSherry Rebecca Isaacs
Michael Isard Paul Barham Martín Abadi
Microsoft Research Silicon Valley
{derekmur,mcsherry,risaacs,misard,pbar,abadi}@microsoft.com

Abstract

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A new computational model, *timely dataflow*, underlies Naiad and captures opportunities for parallelism across a wide class of algorithms. This model enriches dataflow computation with timestamps that represent logical points in the computation and provide the basis

Figure 1: A Naiad application that supports real-time queries on continually updated data. The dashed rectangle represents iterative processing that incrementally updates as new data arrive.

- Iterative computation (cycles)
- Reports on the presence of data instead of the absence
- Two implementations: C# (Naiad) and Rust

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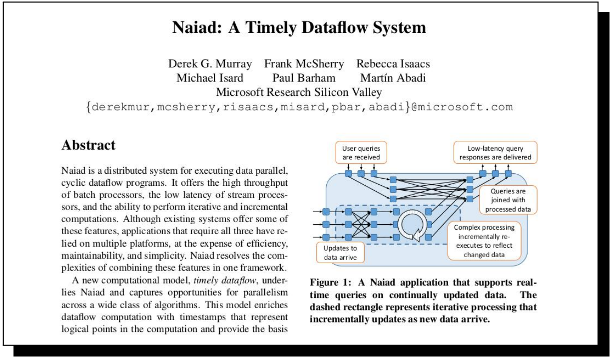

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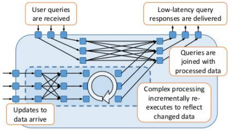

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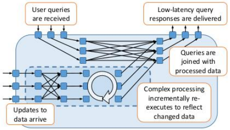

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Progress Tracking

Progress Tracking Protocollllll

- Two core components: Local Propagation and Distributed Exchange
  - Local: localy compute the frontiers
    - *A frontier is a lower bound on the timestamps that may appear at the operator instance inputs*
  - Exchange the timestamps between workers
- For every worker and for every location of the graph a conservative approximation of which timestamps may still arrive (a.ka. frontier)

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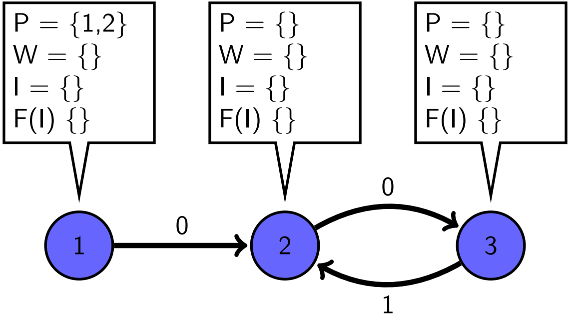

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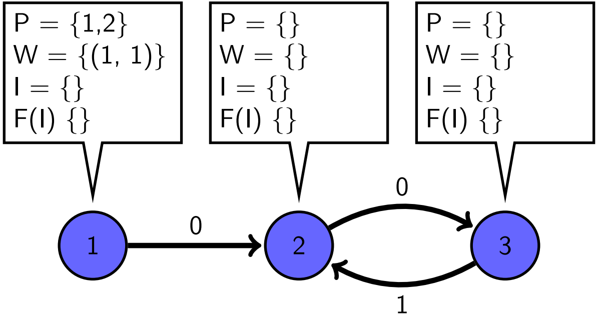

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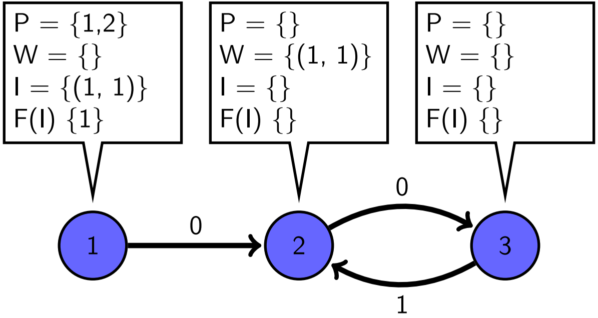

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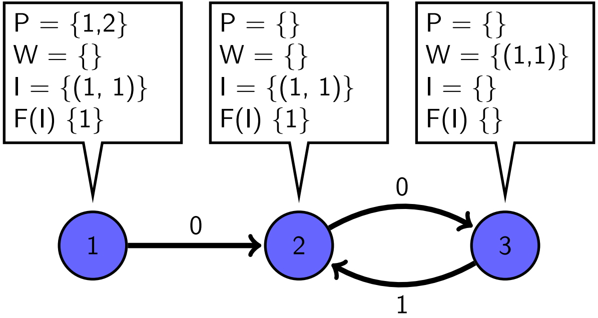

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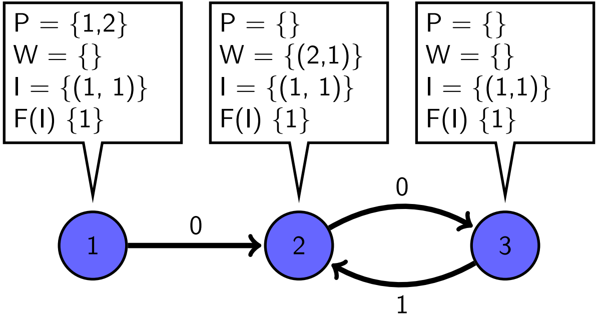

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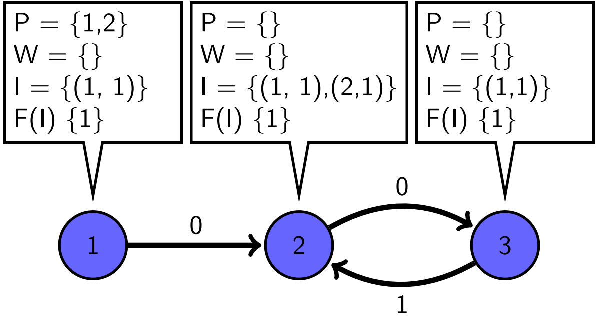

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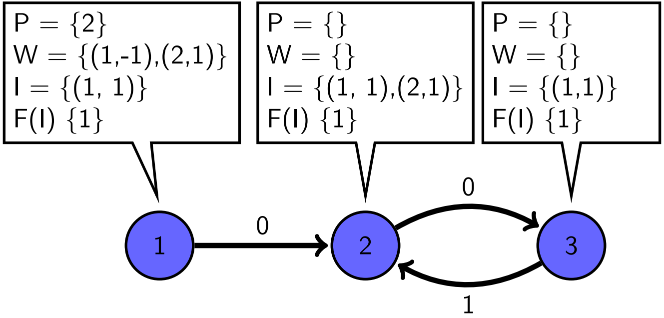

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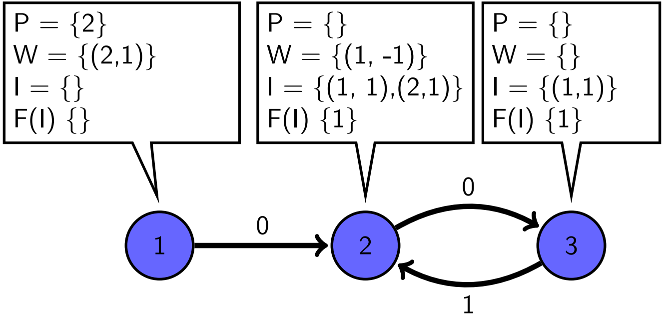

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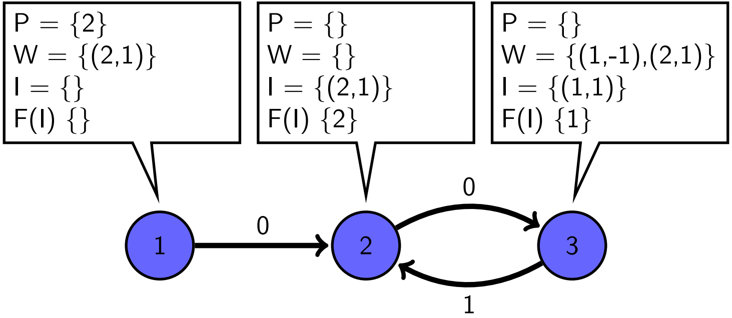

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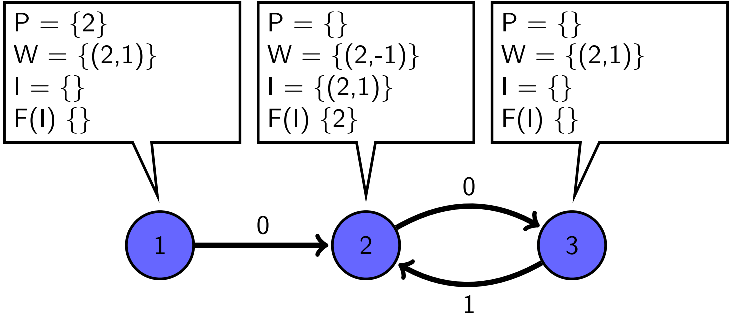

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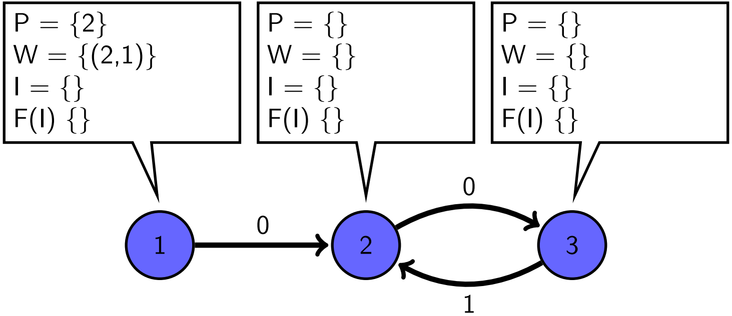


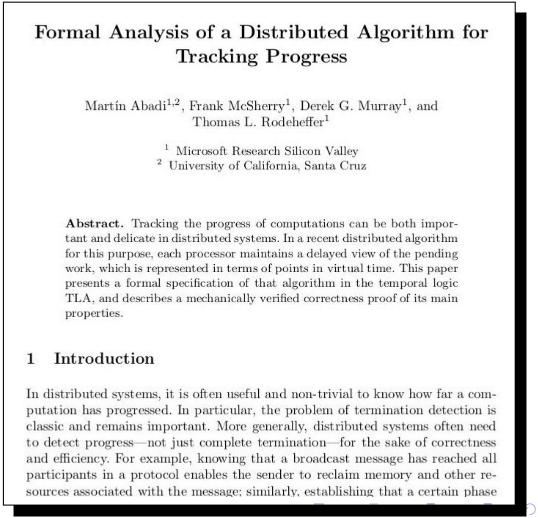
Verified Progress Tracking

Abadi et al.'s exchange protocol

- Exchange Protocol Verification:
  - Presented by Abadi et al. in TLA+

Distribute Safety

If a timestamp is vacant in one worker (now), then that timestamp and any lesser it is vacant for the global system state (now and forever)



Formal Analysis of a Distributed Algorithm for Tracking Progress

Martín Abadi[1,2], Frank McSherry[1], Derek G. Murray[1], and Thomas L. Rodeheffer[1]

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Abstract. Tracking the progress of computations can be both important and delicate in distributed systems. In a recent distributed algorithm for this purpose, each processor maintains a delayed view of the pending work, which is represented in terms of points in virtual time. This paper presents a formal specification of that algorithm in the temporal logic TLA, and describes a mechanically verified correctness proof of its main properties.

1 Introduction

In distributed systems, it is often useful and non-trivial to know how far a computation has progressed. In particular, the problem of termination detection is classic and remains important. More generally, distributed systems often need to detect progress—not just complete termination—for the sake of correctness and efficiency. For example, knowing that a broadcast message has reached all participants in a protocol enables the sender to reclaim memory and other resources associated with the message; similarly, establishing that a certain phase

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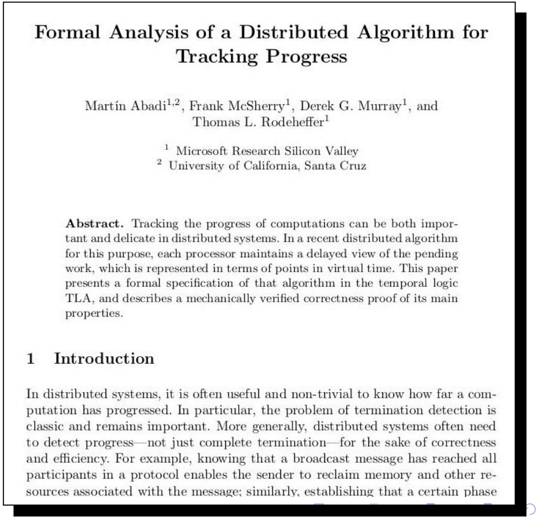

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Verified Progress Tracking for Timely Dataflow

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  - Refined version
  - Same safety property
- Local Propagation Verification

Local Safety

If all worklists neither contain timestamp t nor smaller timestamps, then all locations know whether they may encounter t in the future.

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2012 ACM Subject Classification Security and privacy → Logic and verification; Computing methodologies → Distributed algorithms; Software and its engineering → Data flow languages

Keywords and phrases safety, distributed systems, timely dataflow, Isabelle/HOL

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Related Version Extended report that provides proof sketches and further formalization details.
Full Version: https://www.github.com/matthias-brun/progress-tracking-formalization/raw/main/rep.pdf [9]

Supplementary Material *Software (Isabelle Formalization)*: https://www.isa-afp.org/entries/Progress_Tracking.html

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General goal

Contribute to an ongoing formalization effort using the Isabelle proof assistant towards the first formally verified system for the analysis of big data.

Specific goals

1. Termination of the propagation protocol
2. Executable Progress Tracking Protocol
3. Data plane
4. Scopes
5. DSL
6. Experiments

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Termination of the propagation protocol

- *propagate* is a relation between two system configurations and also parameterized by location and a timestamp:
  - Propagating the timestamp *t* in location *loc* the configuration *c1* turns into *c2*
- We aim to show that it's impossible cannot propagate forever
- We've already managed to show that for a fixed timestamp it cannot be propagate forever

Executable Progress Tracking Protocol

- The propagation protocol is already executable (Sara Decova's master thesis)
- The Exchange protocol also should be made executable
  - Prove that the functions are consistent with the relational counterparties

Data plane

- Nodes must be real operators: they execute user defined functions over the data
- Edges must be channels: they are streams with push and pull API
  - Must exchange data between different workers
- Low level operator constructors (define operators for any amount of inputs and outputs)
- A set of generally useful built-in operators: filter, filter partition, count, aggregate, etc
- The Safety properties again!
  - Use safety to show properties of operators and dataflows
    - Ex: show that *count* doesn't mix the results of different (comparable) timestamps
- Executable from the start

Scopes

- Hierarchal dataflows: an operator can also be a sub-dataflow inside of a dataflow
- This is designed as scopes
  - An additional timestamp dimension
- Another propagation (upwards and downwards)
- The Safety properties once again!

DSL

- Writting dataflow programs in Isabelle is quite inconvenient
- A suitable domain-specific language (DSL)

Experiments

1. How faithful is the verified model to the Rust implementation?
2. Are there any bugs in the Rust implementation not present in the verified code?
3. How does the performance of the verified code compares to the Rust implementation?

Questions, comments and suggestions