Information-Centric Dataflow

Re-Imagining Reactive Distributed Computing

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Distributed Computing
Many Different Types of Interactions

- Message passing
- Remote Method Invocation
- Dataset synchronization
- Key-value store

Compute First Networking: Distributed Computing meets ICN

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Dataflow
Structured Distributed Data Processing

Input source -> f1 -> f2 -> f3 -> Accumulated result

Immutable Data Object
Dataflow

Structured Distributed Data Processing

Received asynchronously at f1
Dataflow
Structured Distributed Data Processing

Triggering Computation at f1,
Consumed by f1
Dataflow

Structured Distributed Data Processing

- input source
- f1
- f2
- f3
- accumulated result

Newly produced result object
Dataflow

Structured Distributed Data Processing

input source → f1 → f2 → f3 → accumulated result

Triggering computation at f2, consumed at f2
Dataflow
Structured Distributed Data Processing

- **input source**
- **f1**
- **f2**
- **f3**
- **accumulated result**
- **Newly produced result object**
Dataflow

Structured Distributed Data Processing

input source

f1

f2

f3

Newly produced result object

accumulated result
Dataflow

Structured Distributed Data Processing
Dataflow
Poster Child Example: word-count

text-to-lines -> lines-to-words -> word-count -> collect-results

text file

some lines

lines-to-words #1

words

count-words #1

word occurences

collect-results

words

lines-to-words #2

some lines

count-words #2

word-occurrences

a: 42
the: 39
tree: 27
house: 13
dog: 4
Dataflow Concepts

Batch & Stream Processing

• Data objects as asynchronous events

• Stream processing: each data object processed independently (unbounded)

• Batch processing: grouping of data objects (bounded)
Dataflow Concepts

Windowing

• Slicing data sets for processing as a group (aggregation)

• One data item can be assign to more than one group

• Directing data to specific consumers
Dataflow Concepts

Timing

• Elastic data processing
• Asynchronous sourcing
• Unpredictable transport and processing delays
• Ideally: processing matches production rate

• Task of a Dataflow system: adjust processing graph to production rate and "real-time requirements"
Dataflow
Mainstream Implementations

- Apache BEAM
  - Unified programming model for data processing pipelines
- Dataflow runners
  - Execution environments for Dataflow applications
- Apache Flink, Samza, Spark
- Google Cloud Dataflow
Dataflow

Transport and Back Pressure

- Example: Apache Flink
- Connections connect task managers, not tasks
- Need to regulate upstream processing rates
Problem Statement

Overlays, Pipes, Address Mappings, Orchestration

- Overlays do not match the inherent logic of processing immutable data objects
  - Data is locked into connections
  - Connections are virtual channels between IP hosts
  - Orchestrator required to track resources, maintain mappings of task relationships to connections between hosts
- Elastic Dataflow requires agile function instantiation, flow graph updates etc.
- Performance is a function of upstream data rates, network throughput, processing speed
  - Limited visibility into root causes of performance problems at orchestrator
IceFlow

Information-Centric Dataflow
IceFlow
Information-Centric Dataflow

/infrastr1/a

/word-count/count-words/1

/infrastr1/b

/infrastr1/c

/infrastr1/d

/infrastructure/infrastr1/c

/infrastr1/e

/infrastr1/f

/infrastr1/g

/infrastr1/h

/word-count/text-to-lines/

/word-count/lines-to-words/1

/word-count/count-words/1
IceFlow
Information-Centric Dataflow
IceFlow Concepts

- Just Names
  - For infrastructure
  - And for actors
- Computation results as Named Data Objects
  - Usual ICN properties...
- Asynchronous data production
  - Consumer has to know when data is available
- Flow control
  - Some coupling between consumers and producers
- Garbage collection
  - Producers may be resource-constrained
  - Cannot keep data forever
**IceFlow Operation**

**Dataset Synchronization**

- Producers produce data under a known prefix
  - Consumers subscribe to prefix
  - And learn update new input data
- Ideally: one prefix for whole application ("word-count")
  - Everyone could learn about all data in the app context
  - For practical reasons: need indirection
  - One prefix per consumer group
IceFlow
Windows and Result Sharing

• Need more flexibility to re-use computation results in different contexts
  • Group data objects in windows
  • Group windows under per-consumer name prefixes

![Diagram showing data flow and structure in IceFlow](image-url)
IceFlow

Dataflow data and configuration

• Need additional shared information
  • Static application flowgraph
  • Actual current dynamic flowgraph
• Also: loose coupling between consumers and producers
  • Consumers reports: what windows have been processed
  • So that producer can advance
• Result: share namespace with Dataflow data and configuration info
  • Some config info represented in CRDTs (like in CFN)
IceFlow

Resource Management

• IceFlow can be smarter than receiver-driven AIMD
  • No need to fetch data that cannot be processed at throughput speed
  • "Receive Window"
• Producers should not overrun consumers
  • Output queue occupancy...
  • When consistently full: trigger scale-out

![Diagram of IceFlow resource management]
IceFlow
Insights So Far

- Today’s Dataflow systems are powering many data science applications
- Overlay approach
  - Usual address mapping and virtual circuit issues
  - Limited data sharing
  - Centralized orchestration
- Real opportunity for redesigning distributed data processing with ICN
  - Elegant name-based approach: no mappings, no resolution – just data
  - Direct sharing of computation results
  - Potentially better visibility into network performance
- Dataset synchronization in principle the right approach
  - NDN Psync performance not great in experiments (NFD)
  - Also requires multicast forwarding strategy
- Additional mechanisms needed
  - Name-based routing (NLSR should be fine)
  - Failure recovery