From a Calculus to an Execution Environment for Stream Processing

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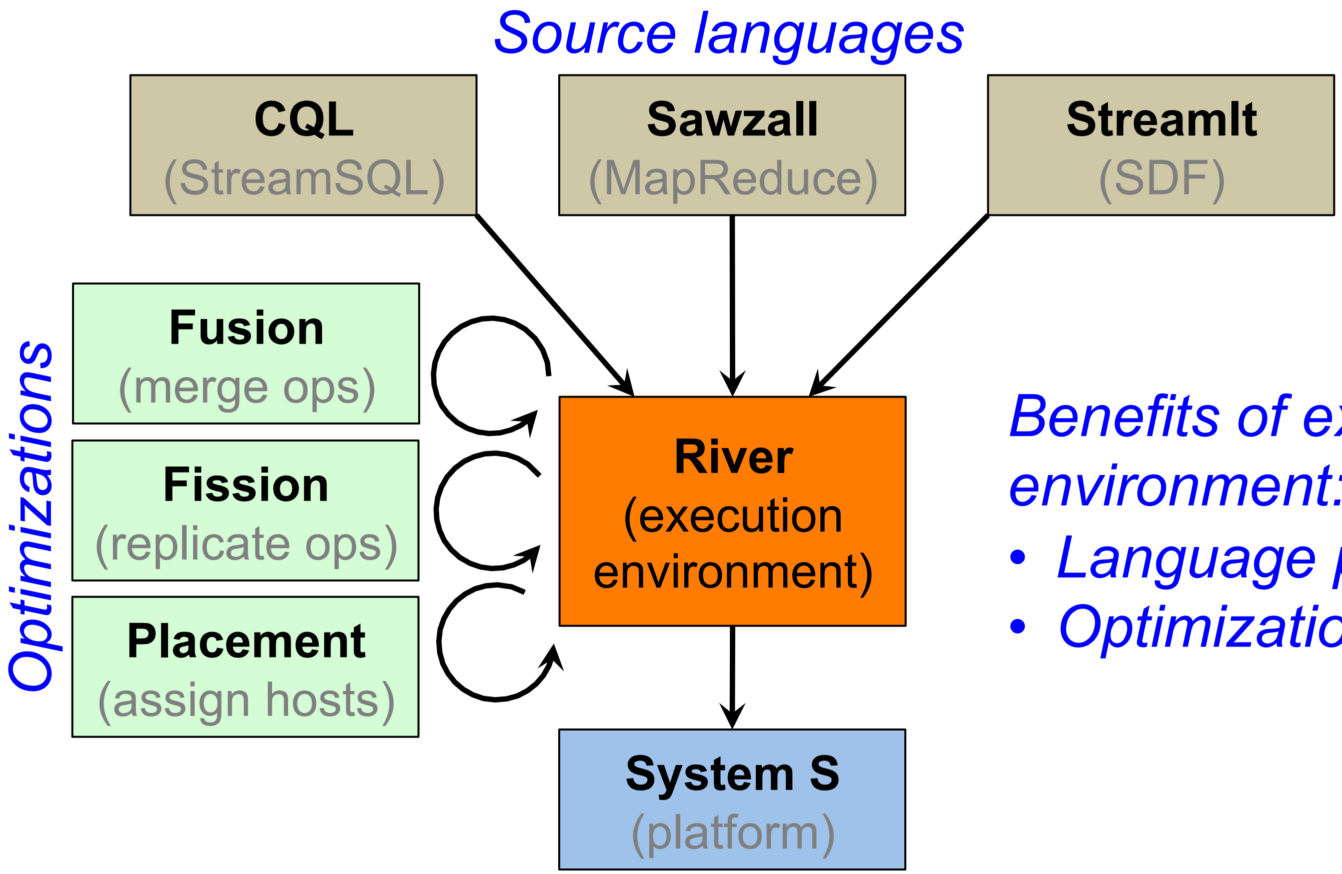
DEBS 2012

… to an Execution Environment



Source languages

CQL
(StreamSQL)

Sawzall
(MapReduce)

StreamIt
(SDF)

Optimizations

Fusion
(merge ops)

Fission
(replicate ops)

Placement
(assign hosts)

River
(execution environment)

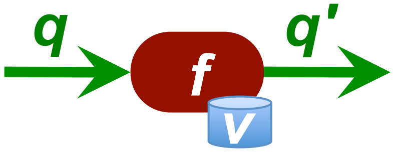
System S
(platform)

Benefits of execution environment:

- *Language portability*
- *Optimization reuse*

From a Calculus …

- Calculus = formal language + semantics
  - Stream calculus, Soulé et al. [ESOP'10]
- Graph language:
  - Stream operators with functions (*F*)
  - Queues (*Q*)
  - Variables (*V*)



- Semantics:
  - Small-step
  - Operational
  - Sequence of "operator firings"

$$F \vdash \langle Q_1, V_1 \rangle \rightarrow_b \langle Q_2, V_2 \rangle \rightarrow_b^* \ldots$$

Benefits of Calculus: Translation Correctness Proofs

Input Execute Output

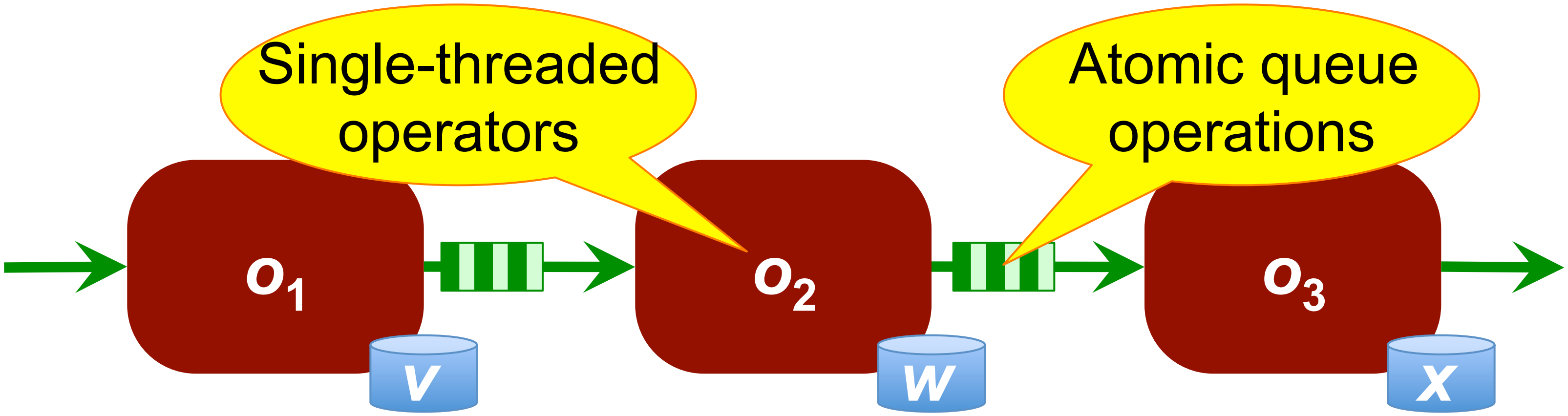
$$\begin{tikzcd}
 & F_s, P_s, I_s \arrow[rr, "\longrightarrow_s^*"] \arrow[dd, "\llbracket \cdot \rrbracket_s^{p,i}"'] & & O_s & \\
\text{Translate} & & & & \text{Translate} \\
 & F_b, P_b, I_b \arrow[rr, "\longrightarrow_b^*"'] & & O_b \arrow[uu, "\llbracket \cdot \rrbracket_s^{o}"'] &
\end{tikzcd}$$

Input Execute Output

From Abstractions to the Real World

Brooklet calculus	River execution environment
Sequence of atomic steps	Operators execute concurrently
Pure functions, state threaded through invocations	Stateful functions, protected with automatic locking
Non-deterministic execution	Restricted execution: bounded queues and back-pressure
Opaque functions	Function implementations
No physical platform, independent from runtime	Abstract representation of platform, e.g. placement
Finite execution	Indefinite execution

Concurrent Execution
Case 1: No Shared State

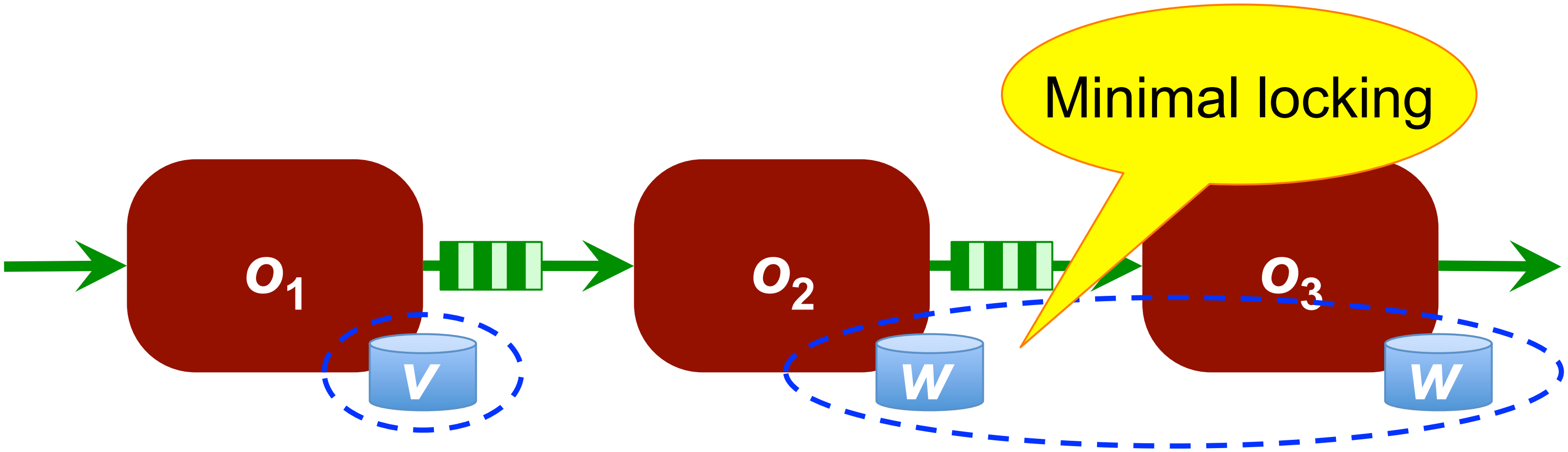


Single-threaded operators

Atomic queue operations

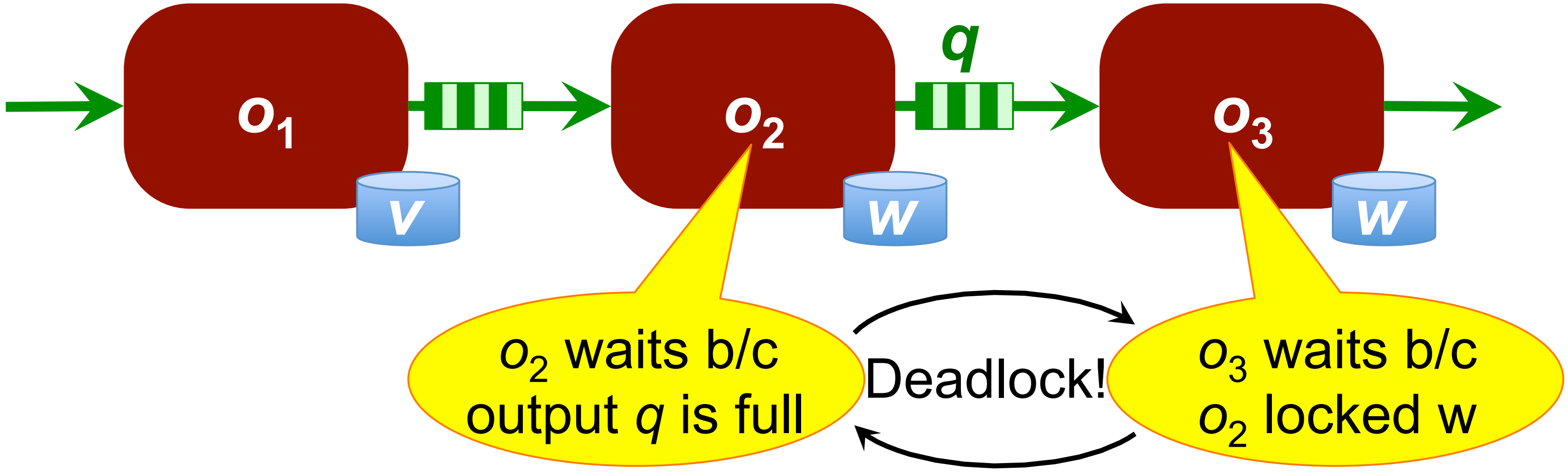
- Brooklet operators fire one at a time
- River operators fire concurrently
- For both, data must be available

Concurrent Execution
Case 2: With Shared State



- Locks form equivalence classes over shared variables
- Every shared variable is protected by one lock
- Shared variables in the same class protected by same lock
- Locks acquired/released in standard order

Restricted Execution
Bounded Queues



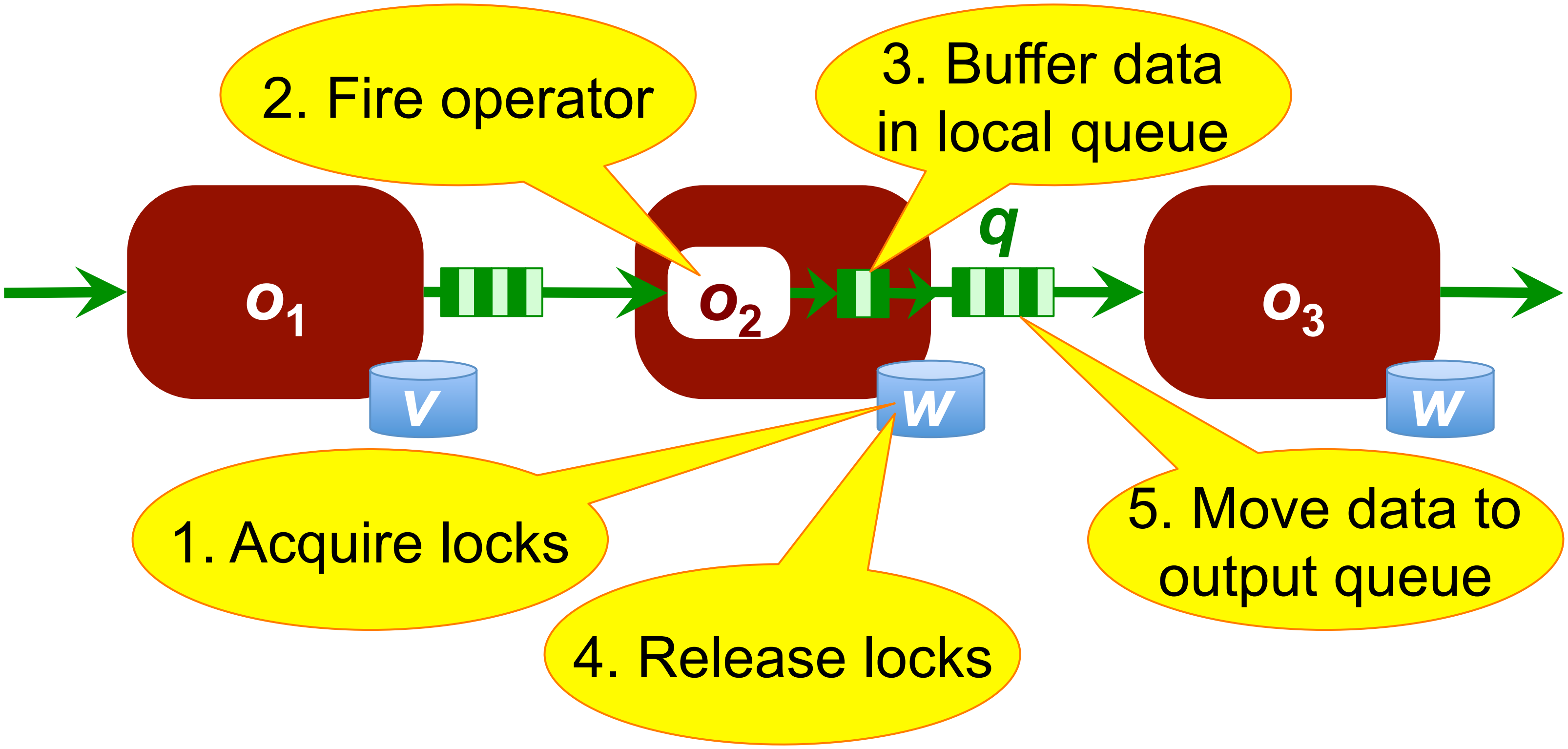
o_2 waits b/c output q is full

Deadlock!

o_3 waits b/c o_2 locked w

- Naïve approach:
  block when output queue is full

Restricted Execution
Safe Back-Pressure



- Our approach: only block on output queue when not holding locks on variables

Applications of an Execution Environment

- Easier to develop source languages
  - Implementation language
  - Language modules
  - Operator templates
- Possible to reuse optimizations
  - Annotations provide additional information between source and intermediate language

Function Implementations and Translations

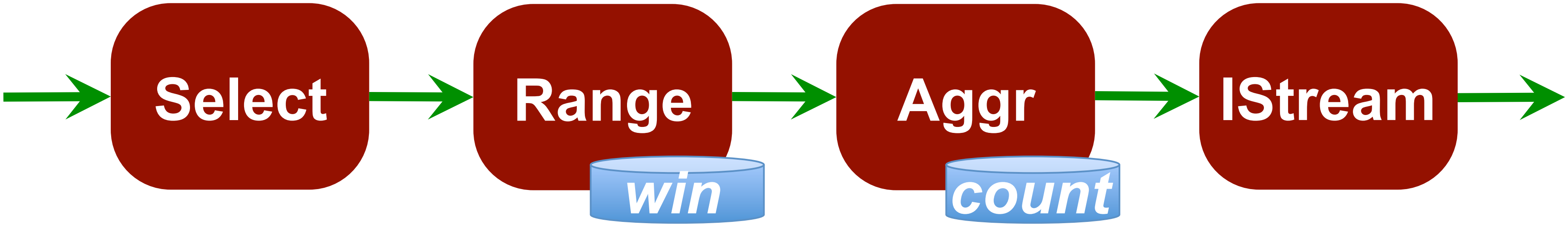
```
logs : {origin : string; target : string} stream;
hits : {origin : string; count : int} stream =
   select istream(origin, count(origin))
      from logs[range 300]
      where origin != target
```

Pre-existing operator templates

```
Bag.filter (fun x -> #expr)
```

Expose operators, communication, and state

```
Bag.filter (fun x ->
   origin != target)
```



Select

Range

win

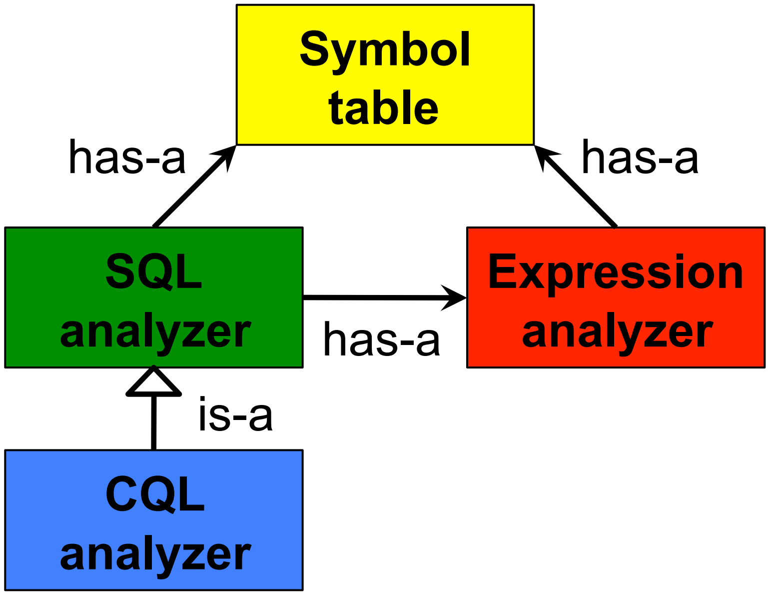
Aggr

count

IStream

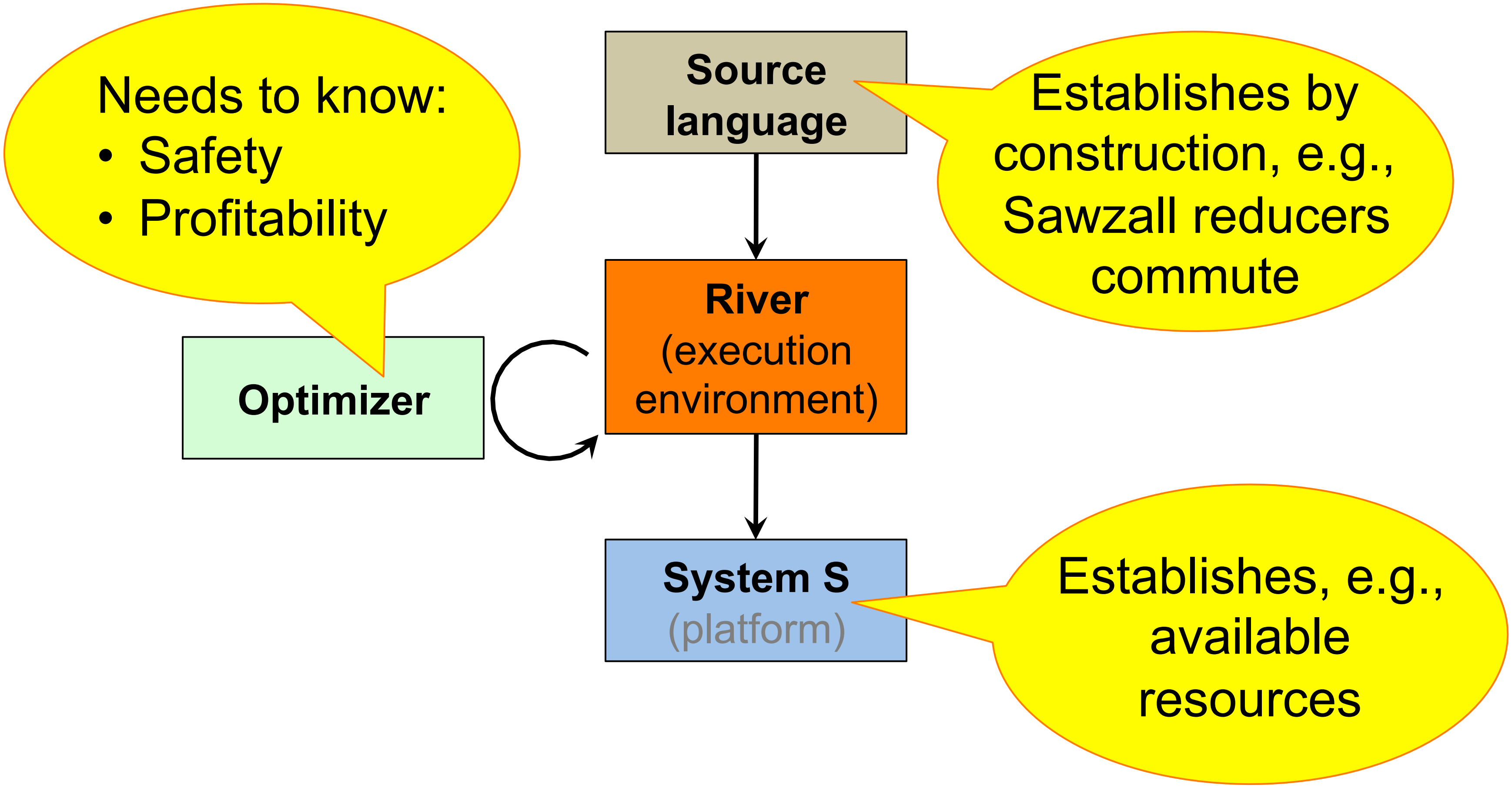
Translation Support: Pluggable Compiler Modules

```
select istream(*)
   from quotes[now], history
   where quotes.ask<=history.low
      and quotes.ticker=history.ticker
```



CQL = SQL + Streaming + Expressions

Optimization Support: Extensible Annotations



Needs to know:
- Safety
- Profitability

Source language

Establishes by construction, e.g., Sawzall reducers commute

Optimizer

River (execution environment)

System S (platform)

Establishes, e.g., available resources

Optimization Support: Current Annotations

Annotation	Description	Optimization
@Fuse(ID)	Fuse operators with same ID in the same process	Fusion
@Parallel()	Perform fission on an operator	Fission
@Commutative()	An operator’s function is commutative	Fission
@Keys($k_1,\ldots,k_n$)	An operator’s state is partitionable by fields $k_1,\ldots,k_n$	Fission
@Group(ID)	Place operators with same ID on the same machine	Placement

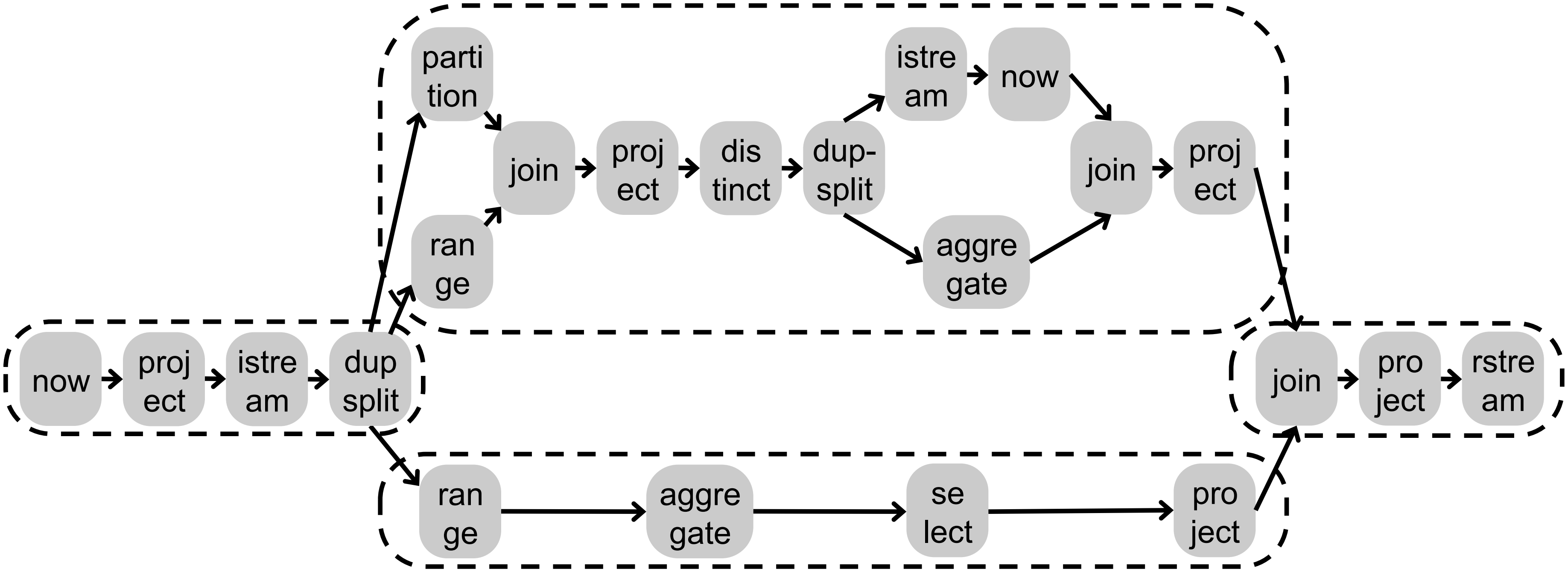
Evaluation

- Four benchmark applications
  - CQL linear road
  - StreamIt FM radio
  - Sawzall web log analyzer (batch)
  - CQL web log analyzer (continuous)

- Three optimizations
  - Placement
  - Fission
  - Fusion

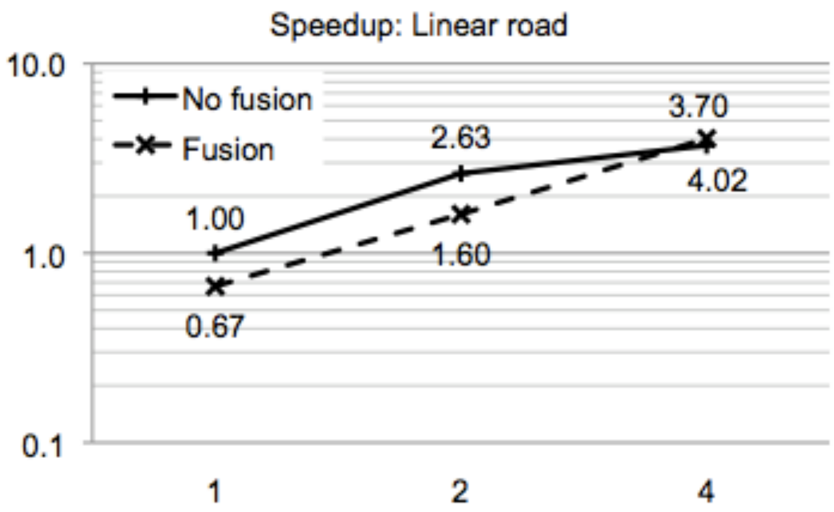
Distributed Linear Road

(simplified version from Arasu/Babu/Widom [VLDBJ'06])

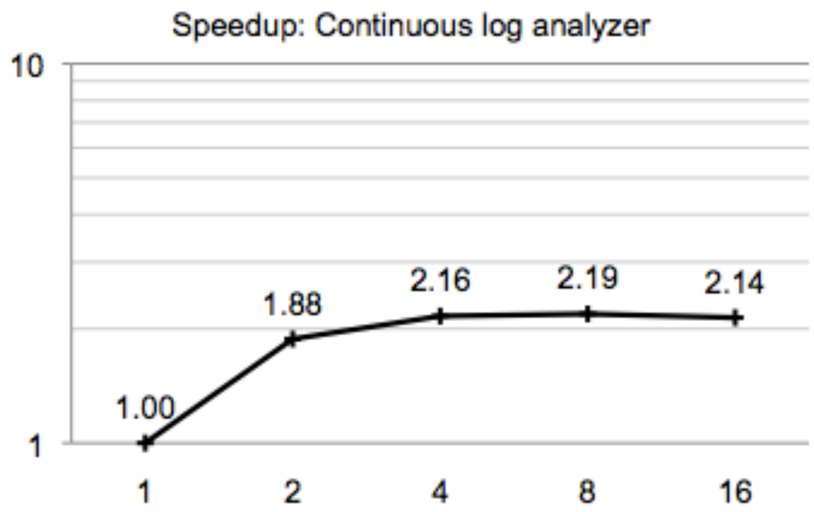


First distributed CQL implementation

CQL: Placement, Fusion, Fission

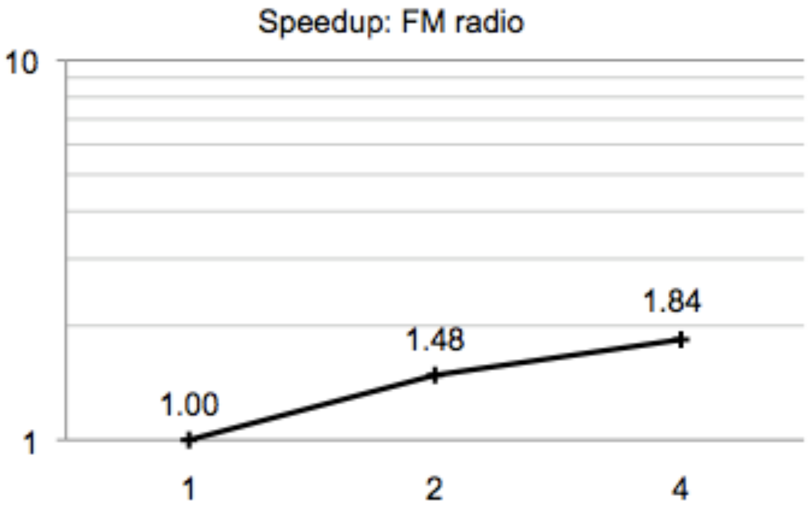


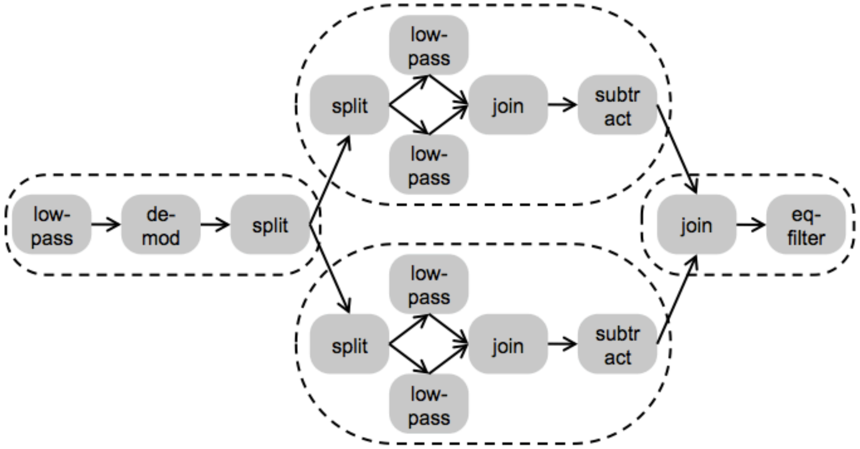
- *Placement + Fusion*
  → 4x speedup on 4 machines



- *Fission*
  → 2x speedup on 16 machines
- *Insufficient work per operator*

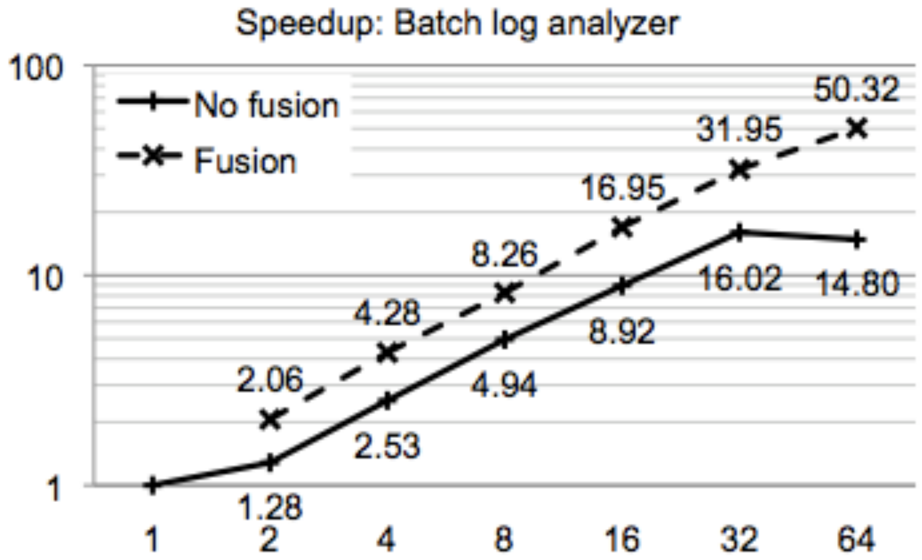
StreamIt: Placement





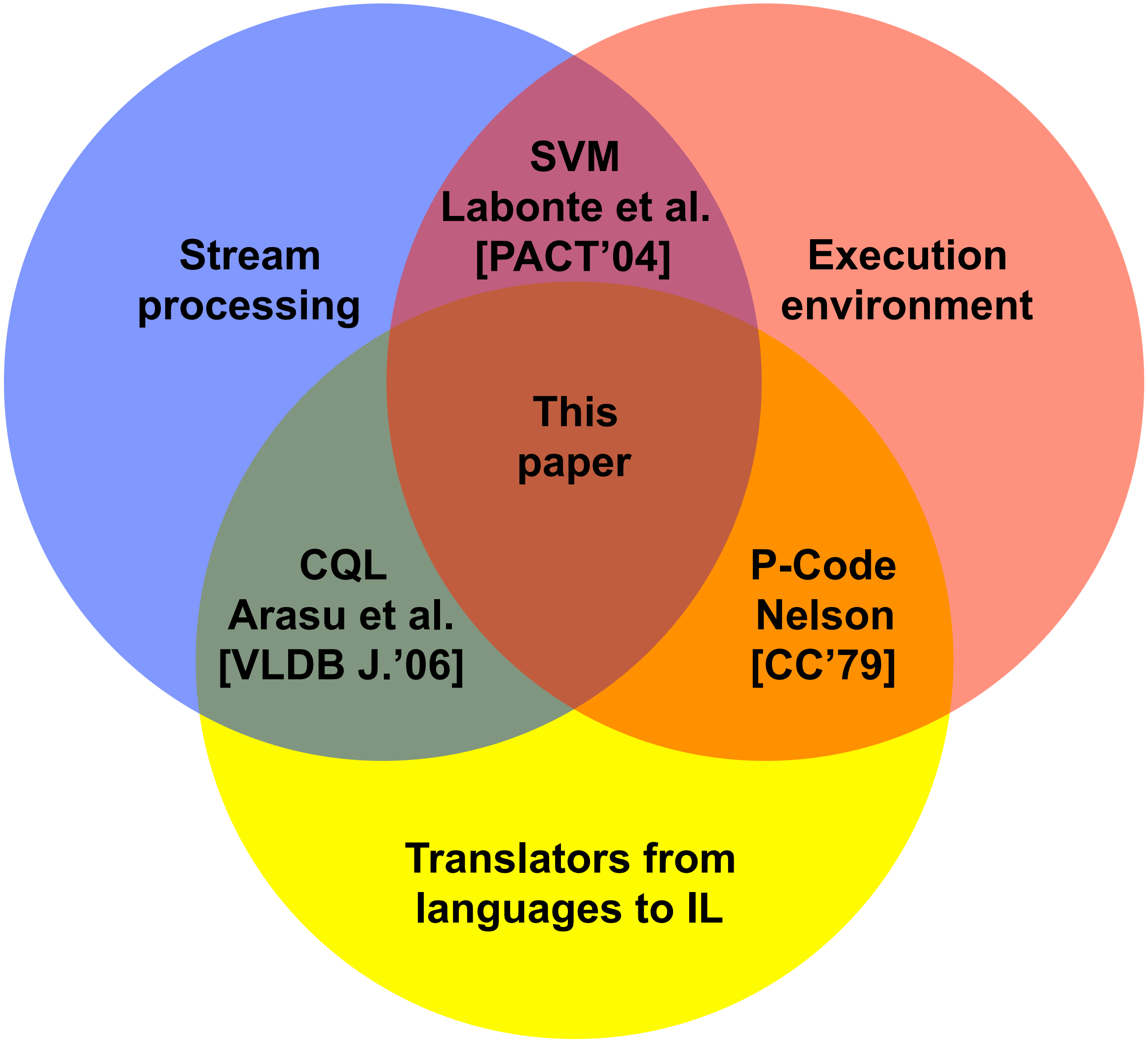
- *Optimization reuse → 1.8x speedup on 4 machines*

Sawzall (MapReduce on River)
Fission + Fusion



- *Same fission optimizer for Sawzall as for CQL*
- *8.92x speedup on 16 machines, 14.80x on 64 cores*
- *With fusion, 50.32x on 64 cores*

Related Work



Stream processing

SVM
Labonte et al.
[PACT'04]

Execution environment

This paper

CQL
Arasu et al.
[VLDB J.'06]

P-Code
Nelson
[CC'79]

Translators from languages to IL

Conclusions

- River, execution environment for streaming
- Semantics specified by formal calculus
  - Brooklet, Soulé et al. [ESOP'10]
- 3 source languages, 3 optimizations
  - First distributed CQL
  - Language compiler module reuse
  - Optimization enabled by annotations
- Encourages innovation in stream processing
- http://www.cs.nyu.edu/brooklet/