Aggregate Update Problem for Multi-clocked Dataflow Languages

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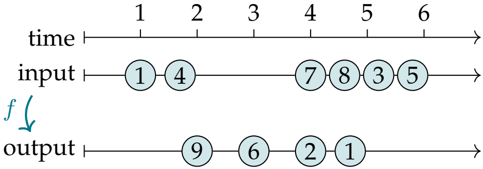
Dataflow Programming

Programming paradigm.

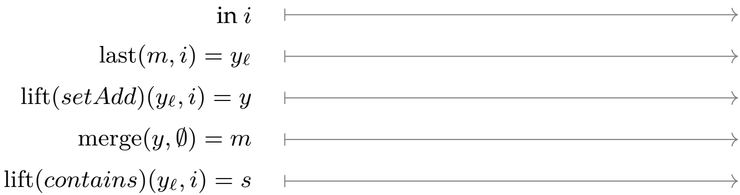
Basic concept: Data streams are combined with operators to generate output streams.

Popular dataflow languages:

- Lustre
- Lucid Synchrone
- SIGNAL
- Esterell
- LabView
- LOLA
- Striver
- TeSSLa



Running Example



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$\text{last}(m, i) = y_\ell$

$\text{lift}(\mathit{setAdd})(y_\ell, i) = y$

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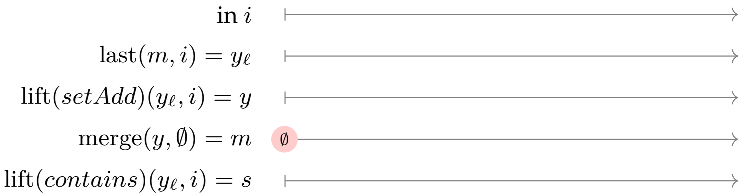

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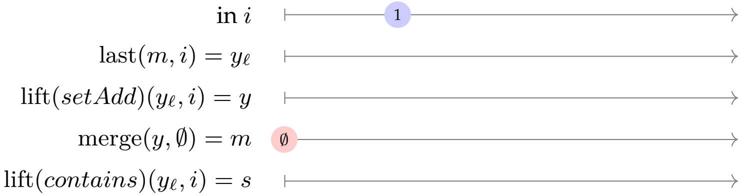

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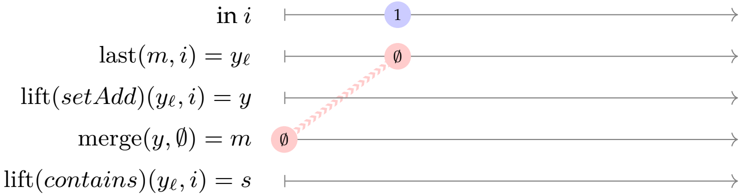

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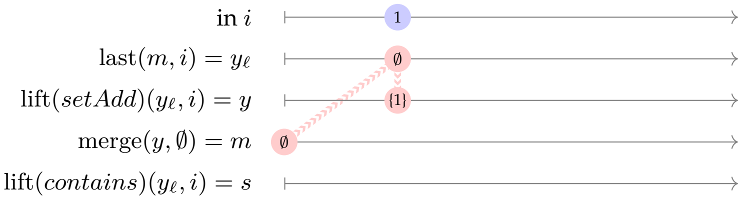

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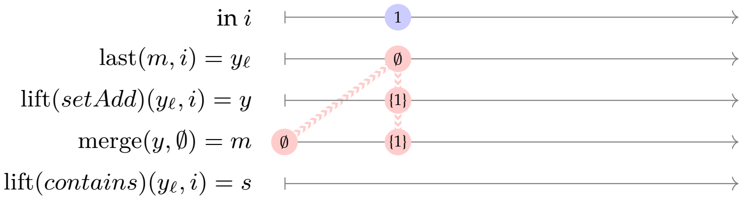

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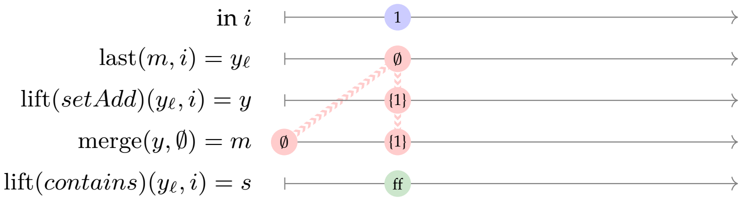

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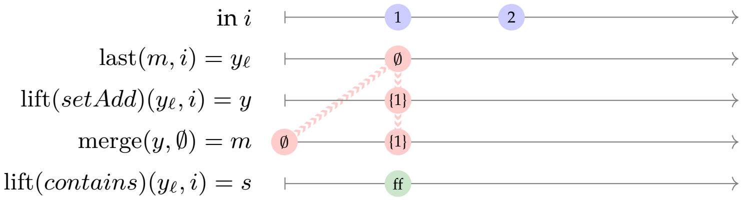

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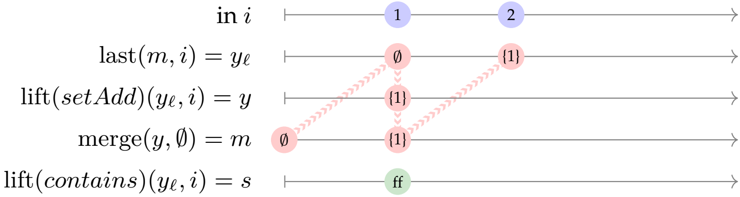

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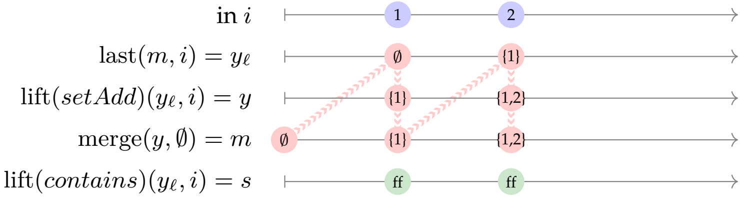

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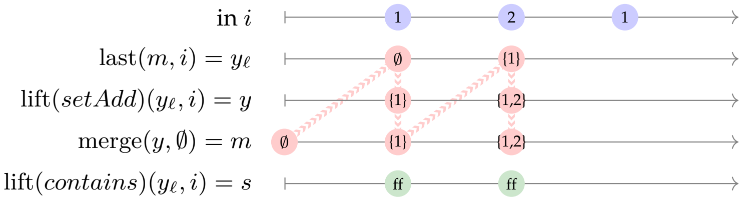

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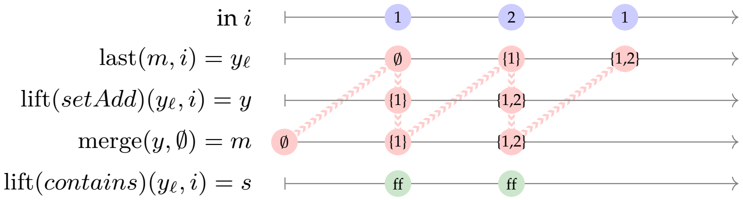
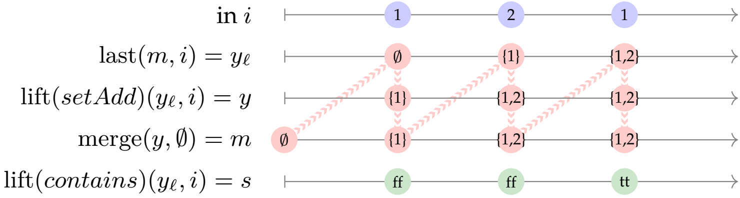

in i
1
2
1
$\mathrm{last}(m, i) = y_\ell$
∅
{1}
{1,2}
$\mathrm{lift}(setAdd)(y_\ell, i) = y$
{1}
{1,2}
$\mathrm{merge}(y, \emptyset) = m$
∅
{1}
{1,2}
$\mathrm{lift}(contains)(y_\ell, i) = s$
ff
ff

Running Example



in i		1	2	1
$\text{last}(m, i) = y_\ell$		∅	{1}	{1,2}
$\text{lift}(setAdd)(y_\ell, i) = y$		{1}	{1,2}	{1,2}
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$\text{lift}(contains)(y_\ell, i) = s$		ff	ff	tt

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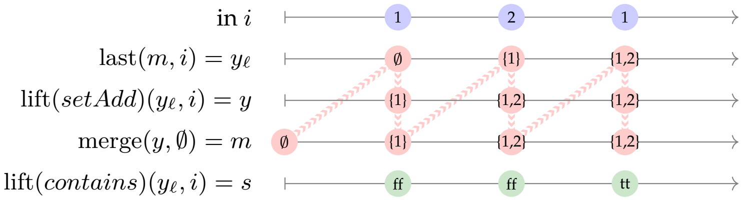
in i — 1, 2, 1
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Evaluation of dataflow languages follows a basic scheme:

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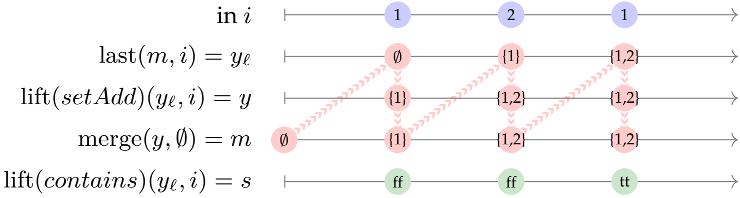

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1
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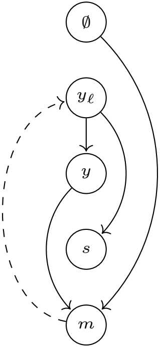
ff
ff
tt

Evaluation of dataflow languages follows a basic scheme:

- Construct dependency graph



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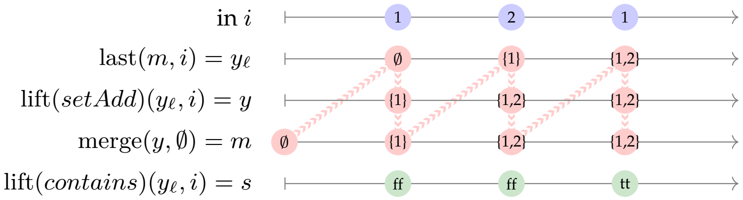
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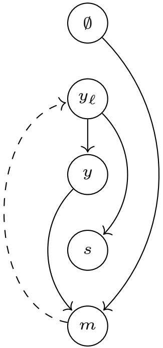
∅
{1}
{1,2}
{1,2}
ff
ff
tt

Evaluation of dataflow languages follows a basic scheme:

- Construct dependency graph
- Find linear ordering of graph



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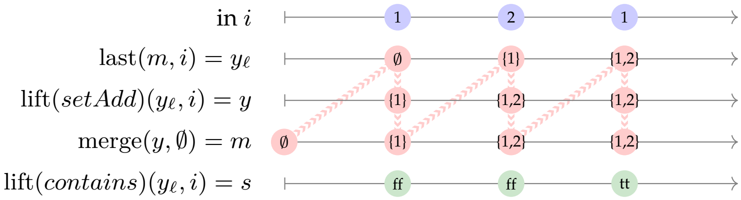
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ff
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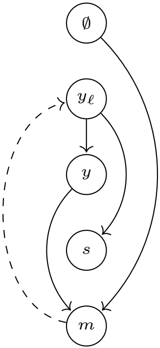
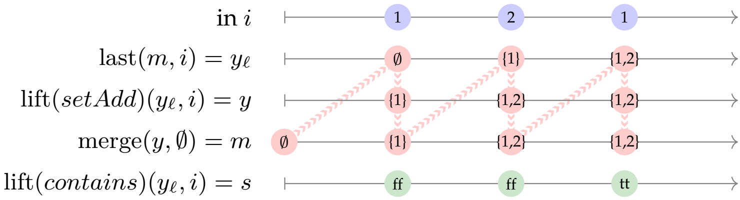
Evaluation of dataflow languages follows a basic scheme:

- Construct dependency graph
- Find linear ordering of graph
- Continuously read inputs and calculate stream values in the given order



Aggregate Update Problem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1
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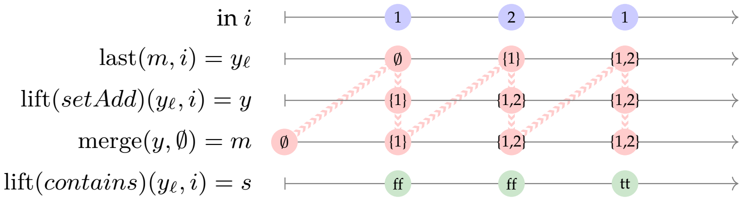
ff
ff
tt

Dataflow languages have immutable semantics: After applying *setAdd* to the events from stream y_ℓ these (old) events may still be accessed.

Aggregate Update Problem



$\text{in } i$		1	2	1
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$\text{lift}(\mathit{setAdd})(y_\ell, i) = y$		{1}	{1,2}	{1,2}
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⇒ During evaluation every data structure must be copied before it is modified.

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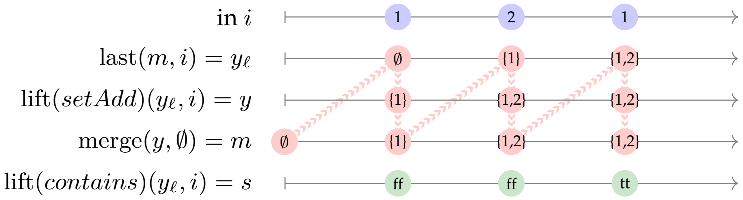

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Dataflow languages have immutable semantics: After applying *setAdd* to the events from stream y_ℓ these (old) events may still be accessed.

⇒ During evaluation every data structure must be copied before it is modified.

But: In the concrete example the data structure fronm y_ℓ could be updated in-place iff stream s is calculated before y.

Aggregate Update Problem

The problem of finding the maximum number of data structures in a program that can be modified in-place is called **Aggregate Update Problem**.

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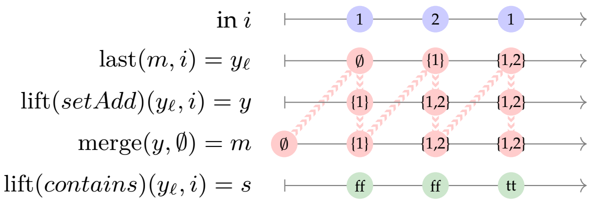
Our approach:

1. Finding the optimal translation order, s.t. as many data structures as possible can be modified in place.
2. Using **mutable** data structures for those that can be updated in place and **persistent** data structures for the other ones.

The optimization algorithm for TeSSLa

1. Classification of the edges in the usage graph:
Read, Write, Pass, Last edges

Example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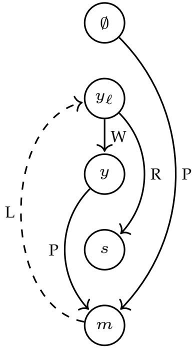

The optimization algorithm for TeSSLa

2. Finding potentially aliasing variables

We call streams a and b potential aliases ($a \simeq b$), if we cannot prove them to be aliasing safe.

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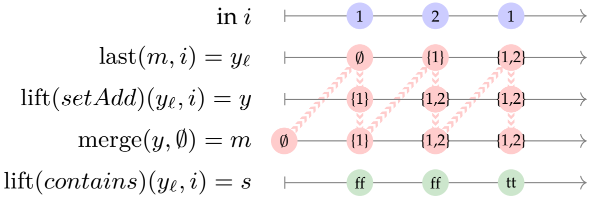

in i		1	2	1
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$\text{lift}(\mathit{setAdd})(y_\ell, i) = y$		{1}	{1,2}	{1,2}
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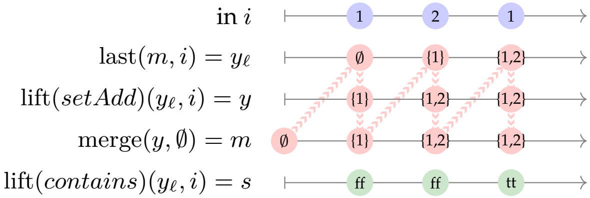

in i: 1, 2, 1

$\mathrm{last}(m, i) = y_\ell$: ∅, {1}, {1,2}

$\mathrm{lift}(setAdd)(y_\ell, i) = y$: {1}, {1,2}, {1,2}

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- $y_\ell \not\simeq m$: y_ℓ and m cannot have the same event at the same time

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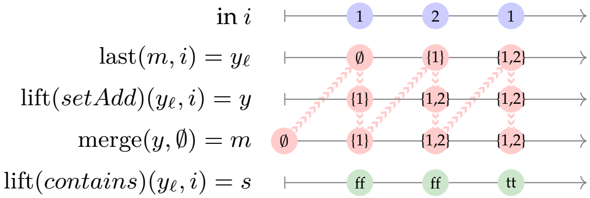

in i
last$(m, i) = y_\ell$
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2
1
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{1,2}
∅
{1}
{1,2}
{1,2}
ff
ff
tt

- $y_\ell \not\simeq m$: y_ℓ and m cannot have the same event at the same time
- $y \simeq m$: y and m may have the same event at the same time

The optimization algorithm for TeSSLa

3. Criteria for mutable variables

A stream s may be implemented with mutable data structures ($s \in M_\varphi$), if none of the following patterns matches

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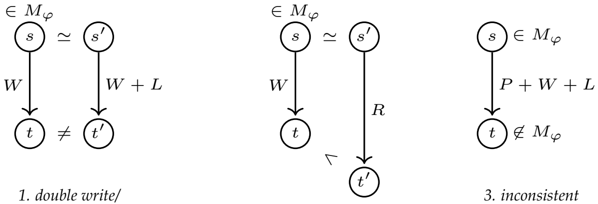

1. double write/ reproduction

2. read after write

3. inconsistent mutability

The optimization algorithm for TeSSLa

4. Algorithm for determination of the maximum set of mutable variables

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- Find variable families which can be all mutable or all persistent (rule 3).

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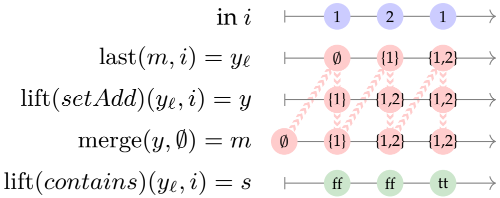

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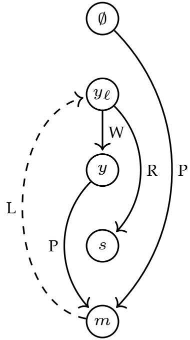
ff
ff
tt

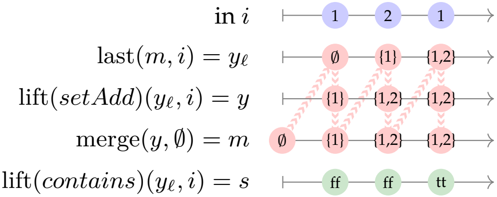


The optimization algorithm for TeSSLa

4. Algorithm for determination of the maximum set of mutable variables

- Find variable families which can be all mutable or all persistent (rule 3).

Example:



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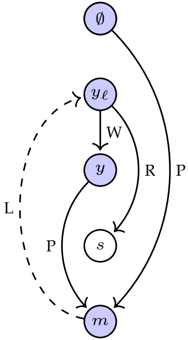
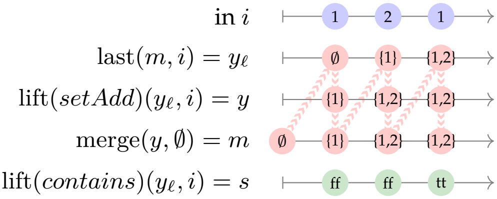


The optimization algorithm for TeSSLa

4. Algorithm for determination of the maximum set of mutable variables

- Climb up from Write nodes and search for aliases.

Example:



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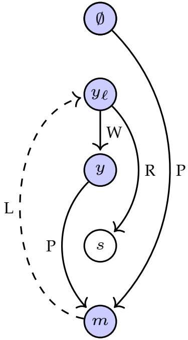
$\text{merge}(y, \emptyset) = m$	∅	{1}	{1,2}	{1,2}
$\text{lift}(\mathit{contains})(y_\ell, i) = s$		ff	ff	tt

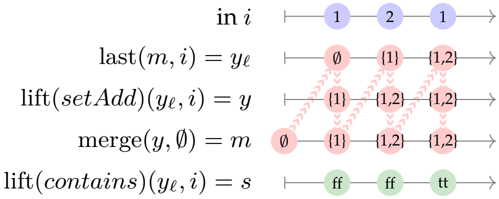


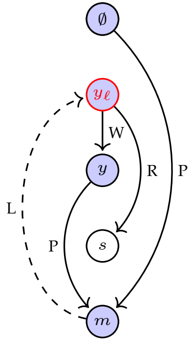
The optimization algorithm for TeSSLa

4. Algorithm for determination of the maximum set of mutable variables

- Climb up from Write nodes and search for aliases.

Example:


in i
1 2 1
$\text{last}(m, i) = y_\ell$
∅ {1} {1,2}
$\text{lift}(\mathit{setAdd})(y_\ell, i) = y$
{1} {1,2} {1,2}
$\text{merge}(y, \emptyset) = m$
∅ {1} {1,2} {1,2}
$\text{lift}(\mathit{contains})(y_\ell, i) = s$
ff ff tt

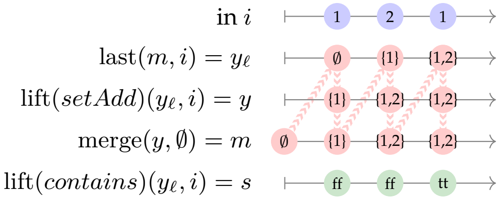


The optimization algorithm for TeSSLa

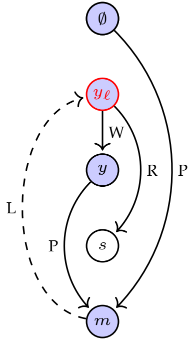
4. Algorithm for determination of the maximum set of mutable variables

- Make variable family persistent if rule 1 (double write/replicate) is breached.

Example:



in i: 1, 2, 1
$\text{last}(m, i) = y_\ell$: ∅, {1}, {1,2}
$\text{lift}(setAdd)(y_\ell, i) = y$: {1}, {1,2}, {1,2}
$\text{merge}(y, \emptyset) = m$: ∅, {1}, {1,2}, {1,2}
$\text{lift}(contains)(y_\ell, i) = s$: ff, ff, tt

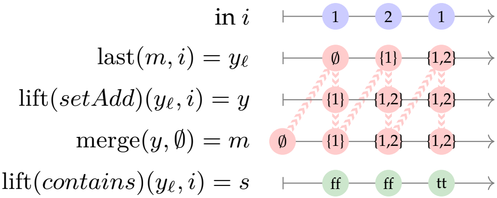


The optimization algorithm for TeSSLa

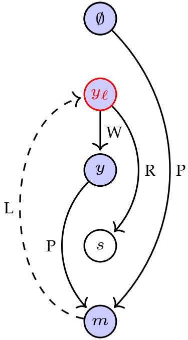
4. Algorithm for determination of the maximum set of mutable variables

- Include edges for Read-Before-Write dependencies (rule 2) in usage graph.

Example:



in i
1
2
1
$\mathrm{last}(m, i) = y_\ell$
∅
{1}
{1,2}
$\mathrm{lift}(setAdd)(y_\ell, i) = y$
{1}
{1,2}
{1,2}
$\mathrm{merge}(y, \emptyset) = m$
∅
{1}
{1,2}
{1,2}
$\mathrm{lift}(contains)(y_\ell, i) = s$
ff
ff
tt

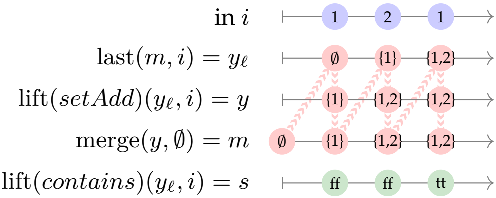


The optimization algorithm for TeSSLa

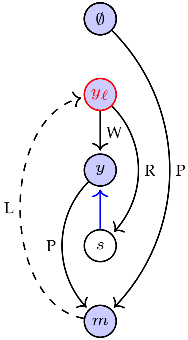
4. Algorithm for determination of the maximum set of mutable variables

- Include edges for Read-Before-Write dependencies (rule 2) in usage graph.

Example:



in i
1
2
1
$\text{last}(m, i) = y_\ell$
∅
{1}
{1,2}
$\text{lift}(setAdd)(y_\ell, i) = y$
{1}
{1,2}
{1,2}
$\text{merge}(y, \emptyset) = m$
∅
{1}
{1,2}
{1,2}
$\text{lift}(contains)(y_\ell, i) = s$
ff
ff
tt

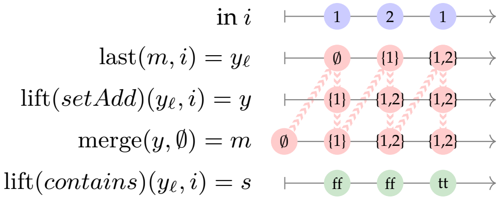


The optimization algorithm for TeSSLa

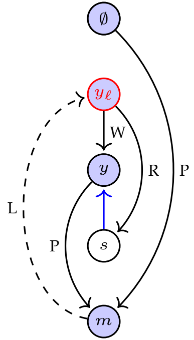
4. Algorithm for determination of the maximum set of mutable variables

- Find optimal translation order of usage graph (NP-complete).

Example:



in i
1
2
1
$\text{last}(m, i) = y_\ell$
∅
{1}
{1,2}
$\text{lift}(setAdd)(y_\ell, i) = y$
{1}
{1,2}
{1,2}
$\text{merge}(y, \emptyset) = m$
∅
{1}
{1,2}
{1,2}
$\text{lift}(contains)(y_\ell, i) = s$
ff
ff
tt

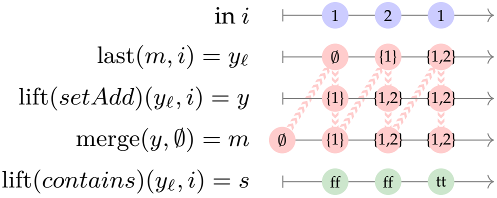


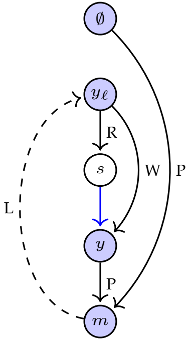
The optimization algorithm for TeSSLa

4. Algorithm for determination of the maximum set of mutable variables

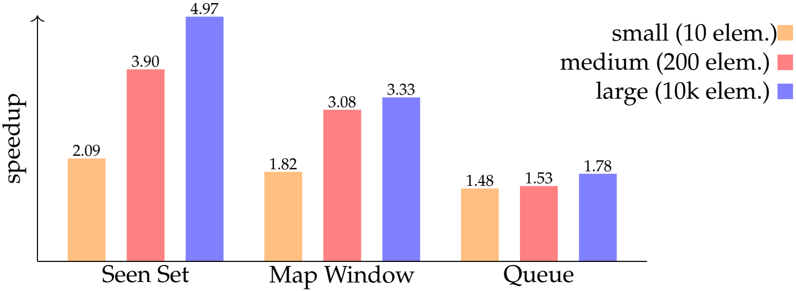
- Find optimal translation order of usage graph (NP-complete).

Example:


in i
1
2
1
$\text{last}(m, i) = y_\ell$
∅
{1}
{1,2}
$\text{lift}(\mathit{setAdd})(y_\ell, i) = y$
{1}
{1,2}
{1,2}
$\text{merge}(y, \emptyset) = m$
∅
{1}
{1,2}
{1,2}
$\text{lift}(\mathit{contains})(y_\ell, i) = s$
ff
ff
tt



Evaluation of the approach: Synthetic examples



Speedups compared to the non-optimized (fully persistent) implementation (10^9 input events).

Evaluation of the approach: Real-World examples

Specification	**Optimized**	**Non-optimized**	**Speedup**
DBTimeCons.	171 s	216 s	1.3
DBAccessCons.(full)	233 s	> 1 h	> 15.5
DBAccessCons.(33 %)	59.2 s	127 s	2.1
PeakDetection	7.56 s	14.0 s	1.9
SpectrumCalc.	1.04 s	2.07 s	2.0

Conclusion

- Dataflow languages can be evaluated by iteratively calculating stream events in the correct order.
- The Aggregate Update Problem deals with the question which data-structures can be updated in place.
- We presented a solution for finding the perfect ordering to maximize in place updates.
- The evaluation showed significant speedups.

Contact information

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