Incremental Datalog Prototype in Soufflé

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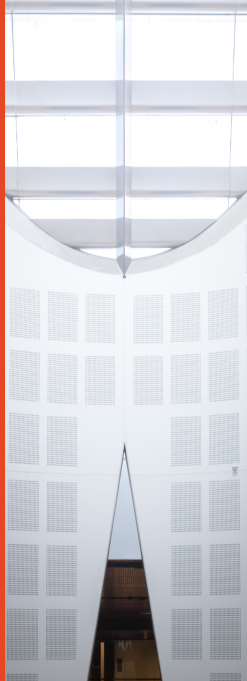
THE UNIVERSITY OF SYDNEY



Introduction

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- Binary disassembly - Grammatech
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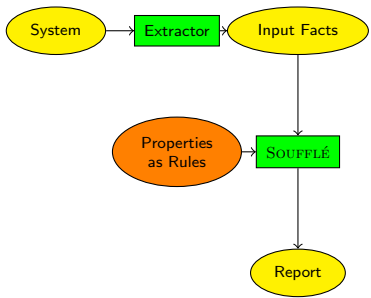
Parallel Datalog engines (e.g. SOUFFLÉ) allow high performance

- Comparable to optimized, hand-crafted tools
- Maintaining ease of use

Soufflé

- System as a set of facts
- System properties as a set of Datalog rules
- Datalog engine (SOUFFLÉ) evaluates rules using facts to check if properties are satisfied



Example - Pointer Analysis

System

```
1  a = new O();
2  b = a;
3
4  a.f = c;
5  d = a.f;
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Input Facts

```
1 alloc(a,l1).
2 assign(b,a).
3
4 store(a,f,c).
5 load(d,a,f).
```

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Output:

- `vpt(a, l1).`
- `vpt(b, l1).`
- `alias(c, d).`
- `...`

Example

Pointer Analysis

```
1  // allocation sites (x = new O())
2  vpt(Var, Obj) :- alloc(Var, Obj).
3
4  // assignments (x = y)
5  vpt(Var, Obj) :- assign(Var, Var2), vpt(Var2, Obj).
6
7  // load-store pairs (v = y.f; p.f = q; y and p alias)
8  vpt(Var, Obj) :- load(Var, Y, F), store(P, F, Q),
9                   vpt(Q, Obj), vpt(P, AliasObj), vpt(Y, AliasObj).
10
11 // generating the alias relation
12 alias(Var1, Var2) :- vpt(Var1, Obj), vpt(Var2, Obj), Var1 != Var2.
```

Incremental Evaluation

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Security analysis can be slow - up to 2 weeks for OpenJDK

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Small change $\rightarrow$ *fast re-run of analysis*

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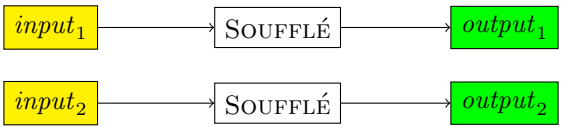

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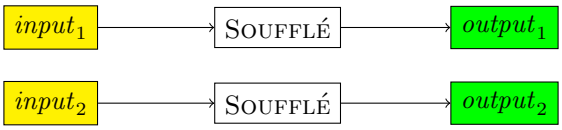

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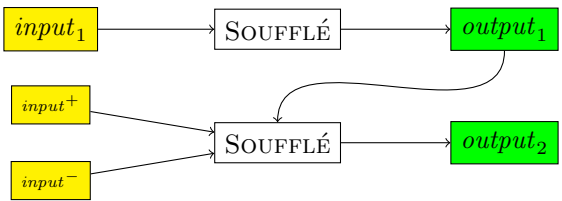

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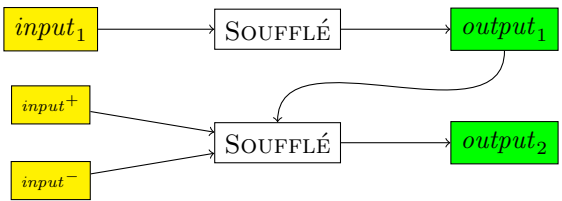

Counting Method

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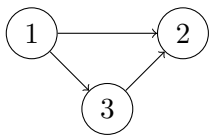
Simpler Example

```
1 hop2(X, Y) :- edge(X, Y).
2 hop2(X, Z) :- edge(X, Y), edge(Y, Z).
```

$\texttt{edge}(1,2), \texttt{edge}(1,3), \texttt{edge}(3,2)$



Counting Method

All Derivations

$$\texttt{hop2}(1,2) \texttt{ :- } \texttt{edge}(1,2)$$
$$\texttt{hop2}(1,3) \texttt{ :- } \texttt{edge}(1,3)$$
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$$\texttt{hop2}(1,2) \texttt{ :- } \texttt{edge}(1,3), \texttt{edge}(3,2)$$

Relations are multisets instead of sets

$$\texttt{hop2} = \{(1,2) \times 2, (1,3) \times 1, (3,2) \times 1\}$$

Counting Method

Deleting a tuple

$$\Delta \texttt{edge} = \{(1, 2) \times -1\}$$

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1  Δhop2(X, Y) :- Δedge(X, Y).
2  Δhop2(X, Z) :- Δedge(X, Y), edge(Y, Z).
3  Δhop2(X, Z) :- edge^ν(X, Y), Δedge(Y, Z). // edge^ν = edge + Δedge
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```

From rule 1: $\Delta\texttt{hop2}(1,2)^{-1}$:- $\Delta\texttt{edge}(1,2)^{-1}$

$$\Delta\texttt{hop2} = \{(1,2) \times -1\}$$
$$\implies \texttt{hop2} = \{(1,2) \times 1, (1,3) \times 1, (3,2) \times 1\}$$

Problems with Recursion

Transitive Closure

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How many times is `path(a,a)` *derived?*
How many times to decrement count when deleting?

Extending to Recursive Datalog

An additional dimension to the counting
Maintain counts *per iteration* of Datalog evaluation

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$$\text{Iteration}_2 : \{\texttt{path}(a,a)^{2,1}, \texttt{path}(b,b)^{2,1}\}$$

$\texttt{path}(a,a)$ derived:

- Once in iteration 1
- Once in iteration 2

Unrolling the Recursion

Storing per-iteration counts is like unrolling the recursion

```
1 path(X, Y)_1 :- edge(X, Y).
2 path(X, Y)_2 :- edge(X, Y1), edge(Y1, Y).
3 path(X, Y)_3 :- edge(X, Y1), edge(Y1, Y2), edge(Y2, Y).
4 path(X, Y)_4 :- edge(X, Y1), edge(Y1, Y2), edge(Y2, Y3), edge(Y3, Y).
5 ...
```

Our Implementation

Our Ideas

Motivation

Integrate counting inside semi-naïve

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Maintaining the Δ version of the relation

1. Maintaining Δ explicitly - requires extra indexes and rules (new evaluation strategy)
2. Simulating Δ with extra counts - requires more storage per tuple

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E.g. $\texttt{path}(a, a)^3 \iff \texttt{path}(a, a)$ was last updated in epoch 3

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Simulating Δ

Epoch value = *current* epoch $\iff$ tuple is in Δ

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How do we know if an updated tuple is *actually* new?

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Reverse Path

```
1 path(X, Y) :- edge(X, Y).
2 path(X, Z) :- edge(X, Y), path(Y, Z).
3 reversepath(X, Y) :- path(Y, X).
```

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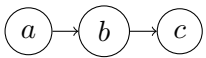

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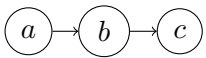

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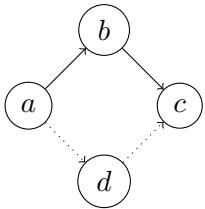

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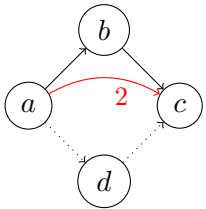

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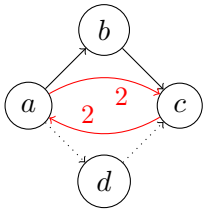

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Challenges

$\Delta\texttt{reversepath}(c, a)^{3,1} \implies \texttt{reversepath}(c, a)^{3,2}$

But actually

The only derivation is:

```
reversepath(c,a) :- path(a,c).
```

Prototype in Soufflé

Implemented in the Soufflé Datalog compiler

- Per-iteration count
- Simulating Δ relations with epoch

```
y = x; a.f = x; y = a.f;

---------------
vpt
x       y       @iteration      @epoch  @count
===============
x       l1      1       0       1
y       l1      2       0       2
a       l2      1       0       1
===============
alias
x       y       @iteration      @epoch  @count
===============
x       y       3       0       1
y       x       3       0       1
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Incremental is invoked.
Enter command >
```

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Enter command > remove assign("y","x")
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x       l1      1       0       1
y       l1      2       -1      1
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Super early prototype:

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0.3 sec	0.5 sec	18 sec

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0.3 sec	0.5 sec	18 sec

Incremental update: removing edge$(499, 500)$

Soufflé (no inc.)	Soufflé (inc.)	DDlog (Differential Dataflow)
-	0.2 sec	14 sec

Outlook

- We propose some new ideas for incremental evaluation of recursive Datalog by counting, with promising preliminary results
- We need to resolve the `reversepath` issue
- We need to extend to negations and aggregates