A Hybrid Approach to Conjunctive Partial Deduction

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Introduction

Partial evaluation

- $\boxed{\textbf{input}}$ program and part of input data (static data)
- $\boxed{\textbf{output}}$ specialized (residual) program

Partial evaluator

- constructs a finite representation of all possible computations
- extracts resultants from transitions

Optimization comes from

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Input logic program P and a query Q_0

Initialization $S = \{Q_0\}$ $S = \{Q_0, Q_3, Q_4, Q_5\}$ $S = \{Q_0, Q_3, Q_4, Q_5, Q_6\}$

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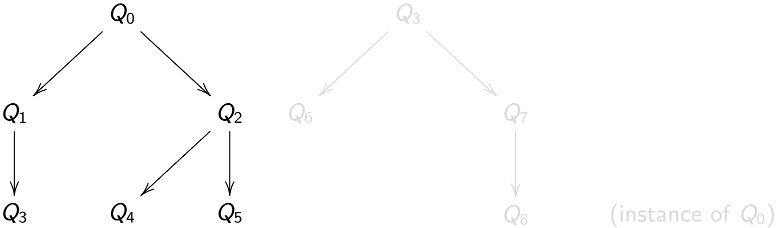

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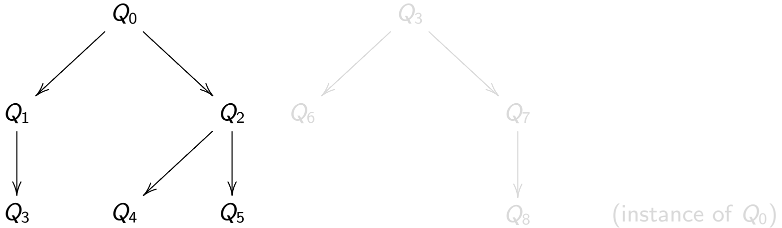

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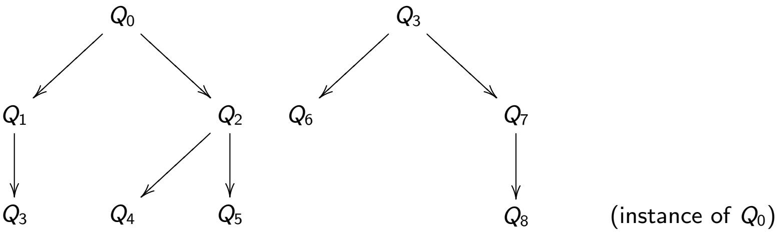

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\begin{tikzcd}
 & Q_0 \arrow[dl] \arrow[dr] & & & Q_3 \arrow[dl] \arrow[dr] & & \\
Q_1 \arrow[d] & & Q_2 \arrow[dl] \arrow[d] & Q_6 & & Q_7 \arrow[d] & \\
Q_3 & Q_4 & Q_5 & & & Q_8 & \text{(instance of } Q_0\text{)}
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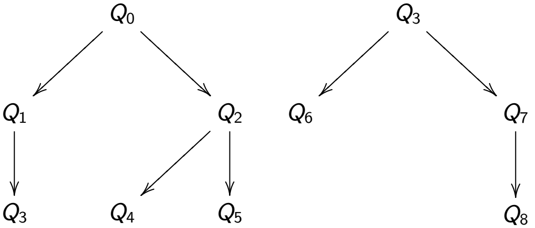

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This work

Original motivation:

- paralelizing partial evaluation?
- run time groundness and sharing information is essential

Current approaches not useful because

- run time information is not available (only PE time info)
- usual operations (instance and splitting) do not preserve groundness and sharing

Our approach:

- **hybrid control issues (combines static analysis and online tests)**
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Lightweight CPD

1. Pre-processing
   - call and success pattern analysis
   - left-termination analysis
   - identification of non-regular predicates
2. Partial evaluation
   - non-leftmost unfolding statically determined
   - only a limited form of splitting (statically determined)
   - no generalization (but might give up)
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   - initially one-step renamed resultants
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Static analyses

Call and success pattern analysis (e.g., [Leuschel and Vidal, LOPSTR'08])

- for each predicate p/n, we get a set of patterns $p/n : in \mapsto out$
- e.g., $\mathtt{append}/3 : \{1, 2\} \mapsto \{1, 2, 3\}$

```
append([ ], Y, Y).
append([X|R], Y, [X|S]) :- append(R, Y, S).
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Left-termination analysis

- determines if p/n terminates for call pattern *in* with Prolog's leftmost selection strategy
- e.g., $\mathtt{append}/3$ left-terminates for call pattern $\{1\}$
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Strongly regular programs

Extends B-stratifiable programs [Hruza and Stepánek, TPLP 2004]:

- first, the call graph of the program is built
- predicate p/n is strongly regular if there is no

$$p(t_1, \ldots, t_n) \leftarrow body$$

  such that *body* contains two atoms in the same SCC as p/n
- a logic program is strongly regular if all predicates are

Property: SRP cannot produce infinitely growing conjunctions at PE time

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Example (strongly regular)

$\mathtt{applast}(\mathtt{L}, \mathtt{X}, \mathtt{Last}) :- \mathtt{append}(\mathtt{L}, [\mathtt{X}], \mathtt{LX}), \mathtt{last}(\mathtt{Last}, \mathtt{LX}).$
$\mathtt{last}(\mathtt{X}, [\mathtt{X}]).$
$\mathtt{last}(\mathtt{X}, [\mathtt{H}|\mathtt{T}]) :- \mathtt{last}(\mathtt{X}, \mathtt{T}).$
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- 3 SCCs: $\{\mathtt{applast}/3\}$, $\{\mathtt{append}/3\}$ and $\{\mathtt{last}/2\}$
- no clause violates the strongly regular condition

Example (not strongly regular)

$\mathtt{flipflip}(\mathtt{XT}, \mathtt{YT}) :- \mathtt{flip}(\mathtt{XT}, \mathtt{TT}), \mathtt{flip}(\mathtt{TT}, \mathtt{YT}).$
$\mathtt{flip}(\mathtt{leaf}(\mathtt{X}), \mathtt{leaf}(\mathtt{X})).$
$\mathtt{flip}(\mathtt{tree}(\mathtt{L}, \mathtt{I}, \mathtt{R}), \mathtt{tree}(\mathtt{FR}, \mathtt{I}, \mathtt{FL})) :- \mathtt{flip}(\mathtt{L}, \mathtt{FL}), \mathtt{flip}(\mathtt{R}, \mathtt{FR}).$

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Partial evaluation: global level

Global state:

$$\langle\langle\{qs_1,\ldots,qs_n\},\ gs\rangle\rangle$$

where

- $\{qs_1,\ldots,qs_n\}$ is a set of queries (with call patterns)
- gs is the set of already partially evaluated queries

Initial global state: $\langle\langle\{qs\},\emptyset\rangle\rangle$

Transition system

$$\text{(restart)}\quad \frac{\nexists qs' \in gs.\ qs_i \trianglerighteq qs',\ \ i \in \{1,\ldots,n\}}{\langle\langle\{qs_1,\ldots,qs_n\},\ gs\rangle\rangle \to \langle qs_i, [\,], \{qs_i\} \cup gs\rangle}$$

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Definition (unfoldable atom)

- it doesn't embed any previous call
- leftmost atom or left-terminating for the associated call pattern

  (to ensure correctness w.r.t. finite failures, instead of requiring weakly fair SLD trees [De Schreye et al, JLP 99])

For instance, given the query $\mathrm{p(a), q(X)}$ and the program

$$\begin{array}{l}\mathrm{p(b).}\\ \mathrm{q(X) :- q(X).}\end{array}$$

the derivation $\mathrm{p(a)}, \underline{\mathrm{q(X)}} \leadsto \mathrm{p(a), q(X)}$ is not weakly fair (thus $\mathrm{pq(X) :- pq(X).}$ is not a legal resultant)

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Splitting

Definition (independent splitting)

Given a query qs, we have that qs_1, qs_2, qs_3 is an independent splitting if

- $qs = qs_1, qs_2, qs_3$
- qs_1 and qs_2 do not share variables (according to call patterns)

For instance, given the query

$$qs = \mathrm{append}(\mathrm{X}, \mathrm{Y}, \mathrm{L}_1), \mathrm{append}(\mathrm{X}, \mathrm{Z}, \mathrm{L}_2), \mathrm{append}(\mathrm{L}_1, \mathrm{L}_2, \mathrm{R})$$

the independent splitting of qs returns

$$\begin{array}{rcl} qs_1 & = & \mathrm{append}(\mathrm{X}, \mathrm{Y}, \mathrm{L}_1) \\ qs_2 & = & \mathrm{append}(\mathrm{X}, \mathrm{Z}, \mathrm{L}_2) \\ qs_3 & = & \mathrm{append}(\mathrm{L}_1, \mathrm{L}_2, \mathrm{R}) \end{array}$$

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Partial evaluation: local level

(variant) $$\frac{\exists qs' \in ls.\ qs \approx qs'}{\langle qs, ls, gs\rangle \stackrel{v}{\Rightarrow} \langle \diamond, ls, gs\rangle}$$

(independent splitting) $$\frac{\text{i-split}(qs) = \langle qs_1, qs_2, qs_3\rangle}{\langle qs, ls, gs\rangle \stackrel{i}{\Rightarrow} \langle\langle\{qs_1, qs_2, qs_3\},\ gs\rangle\rangle}$$

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1. Pre-processing
   - call and success pattern analysis
   - left-termination analysis
   - identification of non-regular predicates
2. Partial evaluation
   - non-leftmost unfolding statically determined
   - only a limited form of splitting (statically determined)
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A prototype has been implemented ($\approx$ 1000 lines, SWI Prolog)

(left-termination and SRP analysis still missing)

http://kaz.dsic.upv.es/lite.html

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residual	0	29	1	34	15	47	23	10

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New hybrid framework for CPD (correctness not difficult)

Well suited to preserve run time information (groundness and sharing)

Good candidate to develop a paralelizing partial evaluator

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- add (run time) variable sharing information
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