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Improving the Normalization of Weight Rules in Answer Set Programs

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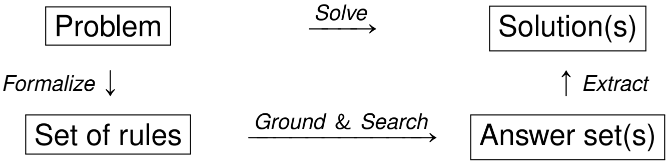
Background

- Answer set programming (ASP) features a rule-based syntax subject to answer-set semantics.



Different Types of Rules

We consider propositional answer set programs containing:

- Normal rules:

  $a \leftarrow b,\ c,\ \text{not}\, d,\ \text{not}\, e$

- Cardinality rules:

  $a \leftarrow 3 \leqslant \{b,\ c,\ d,\ \text{not}\, e,\ \text{not}\, f\}$

- Weight rules:

  $a \leftarrow 6 \leqslant [b = 2, c = 4, d = 3, e = 3, f = 1, g = 4]$

Objectives:

- Rewrite weight rules using normal rules
- Complement back-ends lacking weight rule support
- Improve efficiency of nogood recording

Example of Normalization

$$a \leftarrow 3 \leqslant \{b,\ c,\ d,\ \mathrm{not}\ e,\ \mathrm{not}\ f\}$$

$$\longmapsto$$

$$a \leftarrow b, c, d.$$
$$a \leftarrow b, c, \mathrm{not}\ e.$$
$$a \leftarrow b, c, \mathrm{not}\ f.$$
$$a \leftarrow b, d, \mathrm{not}\ e.$$
$$a \leftarrow b, d, \mathrm{not}\ f.$$
$$a \leftarrow b, \mathrm{not}\ e, \mathrm{not}\ f.$$
$$a \leftarrow c, d, \mathrm{not}\ e.$$
$$a \leftarrow c, d, \mathrm{not}\ f.$$
$$a \leftarrow c, \mathrm{not}\ e, \mathrm{not}\ f.$$
$$a \leftarrow d, \mathrm{not}\ e, \mathrm{not}\ f.$$

Related Work

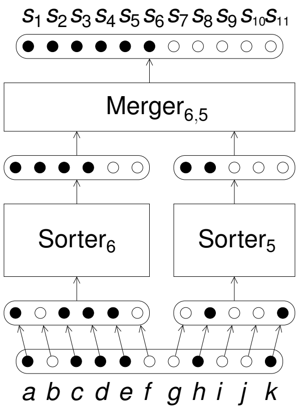
- Eén and Sörensson, JSAT'06
  - Translation of Pseudo-Boolean to sorting networks to SAT
- Bailleux, Boufkhad, and Roussel, SAT'09
  - Polynomial Watchdog translation using tares
- Codish, Fekete, Fuhs, and Schneider-Kamp, TACAS'11
  - Optimal base problem and algorithm(s)
- Bomanson and Janhunen, LPNMR'13
  - Merging and sorting for normalizing cardinality rules

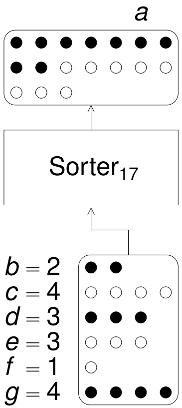
Outline

1. Primitives: Merging and Sorting Programs
2. Arithmetics Behind the Translation
3. Encoding the Summation
4. Enhancements
5. Experiments
6. Conclusions

1. Primitives: Merging and Sorting Programs

- We illustrate normalization designs using circuits
- Merging and sorting circuits have normal rule encodings
- Weight rules can be normalized using these primitives





2. Arithmetics Behind the Translation

- Suppose we have a weight rule of the form

$$\begin{aligned} a \leftarrow 31 \leqslant \langle b = 13, c = 7, d = 1, e = 11, f = 19, \\ g = 19, h = 10, \mathrm{not}\, i = 13, \mathrm{not}\, j = 6, \\ \mathrm{not}\, k = 13, \mathrm{not}\, l = 3, \mathrm{not}\, m = 4\rangle \end{aligned}$$

- ... and an answer set $M = \{a, c, d, e, i, k, \ldots\}$

- Summing the weights of satisfied body literals gives

$$7 + 1 + 11 + 6 + 3 + 4 = 32$$

- Question: How to do this with circuits?

Summing in Mixed-Radix Bases

- Using the mixed-radix base $B = 3, 2, \infty$:

	6	3	1
$c = 7$	•		•
$d = 1$			•
$e = 11$	•	•	••
not $j = 6$	•		
not $l = 3$		•	
not $m = 4$		•	•
$\Sigma = 32$	•••	•••	•••••
$\Sigma = 32$	•••	••••	••
$\Sigma = 32$	•••••		••
$bound = 31$	•••••		•

- Eén and Sörensson, JSAT'06

Simplifying Bound Checking with Tares

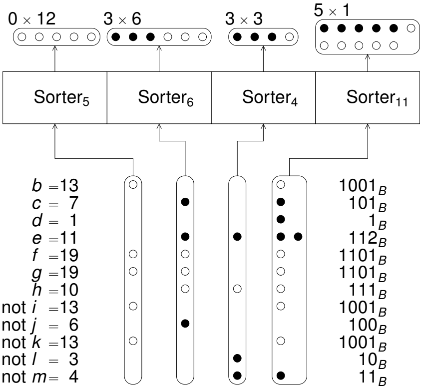
- Using the mixed-radix base $B = 3, 2, \infty$ and tare $t = 5$:

	6	3	1
$\Sigma = 32$	●●●	●●●	●●●●●
$t = \;\; 5$		●	●●
$\Sigma + t = 37$	●●●	●●●●	●●●●●●●
$\Sigma + t = 37$	●●●	●●●●●●	$\ast$
$\Sigma + t = 37$	●●●●●●	$\ast$	$\ast$
$bound + t = 36$	●●●●●●		

- Lexicographical comparison becomes trivial
- It suffices to know the most significant digit of the sum
- Bailleux, Boufkhad, and Roussel, SAT'09

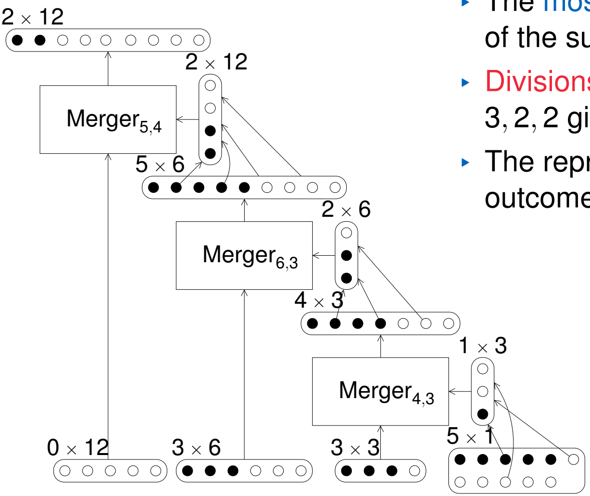
Digit-wise Summing

Normalization of $a \leftarrow 31 \leqslant [b = 13, c = 7, \ldots, \text{not } m = 4]$



Base $B = 3, 2, 2, \infty$ and answer set $M = \{a, c, d, e, i, k, \ldots\}$

Carry Propagation



- The most significant digit of the sum is computed
- Divisions by base radices 3, 2, 2 give carries
- The representation of the outcome becomes unique

4. Enhancements

- Several aspects of the translation can be adjusted
- Choices can be made between
  - types of mergers
  - mixed-radix bases
  - input arrangement in merge-sorting
- These choices affect translation size directly and through impacts on shared structure

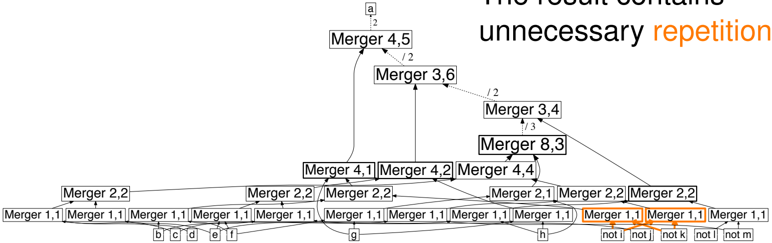
Mixed-Radix Base Selection

- Eén and Sörensson, JSAT'06
  - Enumerating bases consiting of primes < 20
- Bailleux, Boufkhad, and Roussel, SAT'09
  - Using binary bases
- Codish, Fekete, Fuhs, and Schneider-Kamp, TACAS'11
  - Searching optimal bases with sophisticated algorithms
- Our approach:
  - Radices are selected from least to most significant
  - Prime numbers are considered as candidates
  - Effects on translation size are heuristically estimated
  - The most promising prime is chosen

repeat

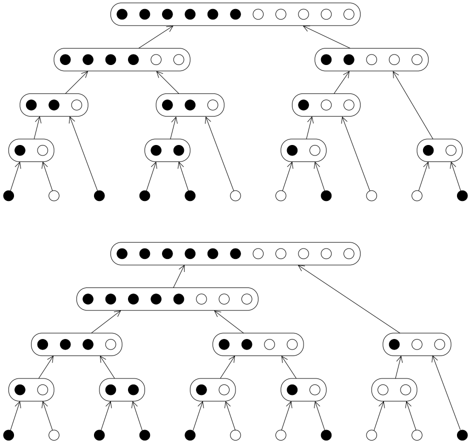
Implementation without Structure Sharing

- Normalization of $a \leftarrow 31 \leqslant [b = 13, c = 7, \ldots, \text{not}\, m = 4]$



- Sorters are implemented via merge-sorting
- The result contains unnecessary repetition

Restructuring Merge-Sorters

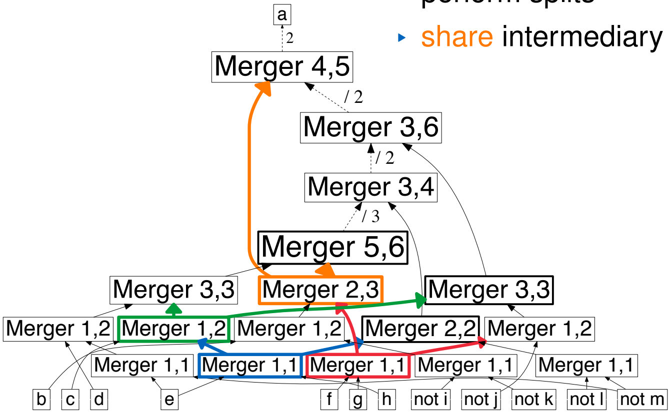


- Input can be arranged and divided freely
- Different choices lead to different structure
- With the right choices, shared input between sorters leads to common structure

Structure Sharing Result

We use a greedy algorithm to:

- perform splits
- share intermediary results



5. Experiments

- The translation is implemented in LP2NORMAL2 with configurable choices of bases and sharing
- For selected benchmarks, the proposed translation improves on the runtime of CLASP

		Mixed		Binary		
Benchmark	Native	Shared	Independent	Shared	Independent	SWC
Bayes-Find	202	**30**	164	246	165	1,721
Bayes-Prove	1,391	**492**	1,316	631	890	2,587
Markov-Find	2,426	2,770	**1,845**	2,682	2,966	5,224
Markov-Prove	**2,251**	3,294	3,428	3,255	3,229	5,402
Fastfood	**10,277**	12,843	14,156	13,756	13,479	17,867
Inc-Scheduling	**257**	1,340	1,330	1,481	1,581	
Nomystery	4,907	4,236	**3,332**	4,290	3,512	4,739
Summary	**21,715**	25,009	25,576	26,345	25,827	

6. Conclusions

We propose new ways to normalize weight rules, incorporating:

- Mixed-radix bases for concise representation of weights
- Tares for simplified bound checking
- Efficient primitives for digit-wise operations

Contributions:

- Structure sharing algorithm
- Base selection heuristic
- Generalization of cardinality translations for weight rules
- Selective and automated configuration of mergers