Compacting Boolean Formulae for Inference in PLP

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Hard Problems

• Boolean Formulae are used:
  – Satisfiability (SAT solvers)
  – Formal Verification
  – Scheduling

• Knowledge Compilation
  – Compile Boolean Formulae
Knowledge Compilation

- Compilation Languages
  - NNF, DNF, CNF, ...
  - sd-DNNF, ROBBD, SDD, ...
- Properties
  - Decomposability (Conjuncts do not share variables)
  - Determinism (Disjuncts are logically disjoint)
  - Smoothness (Disjuncts mention the same set of variables)
  - Ordering (Decision variables appear in the same order)
- Polytime Operations
- Polytime Transformations
Compiling Boolean Formulae

- Usually NP hard or worse!
  - ROBDDs
  - $F = (X_1 \land X_2) \lor (X_3 \land X_4) \lor (X_5 \land X_6) \lor (X_7 \land X_8)$
  - $X_1, X_3, X_5, X_7, X_2, X_4, X_6, X_8$
Compiling Boolean Formulae

• Usually NP hard or worse!
  – ROBDDs
  – \( F=(X_1 \land X_2) \lor (X_3 \land X_4) \lor (X_5 \land X_6) \lor (X_7 \land X_8) \)
  – \( X_1, X_3, X_5, X_7, X_2, X_4, X_6, X_8 \rightarrow X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8 \)
Motivation

- We use Boolean Formulae
  - To represent models
  - We use ROBBDs and sd-DNNFs for compilation
  - Probabilistic Logic Programs often Intractable
• Probabilistic Logic Programming Language
  – Extends Prolog with probabilities
    0.6::e(a, b).  0.7::e(c, d).
    0.2::e(e, f).  0.3::e(a, d).
    0.4::e(d, f).  0.8::e(b, c).
    0.4::e(d, e).
    p(X, Y) :- e(X, Y).
    p(X, Y) :- e(X, X1), p(X1, Y).
ProbLog

- Probabilistic Logic Programming Language
  - Extends Prolog with probabilities
    - 0.6::e(a, b). 0.7::e(c, d).
    - 0.2::e(e, f). 0.3::e(a, d).
    - 0.4::e(d, f). 0.8::e(b, c).
    - 0.4::e(d, e).
    - p(X, Y) :- e(X, Y).
    - p(X, Y) :- e(X, X1), p(X1, Y).
  - Defines a Probabilistic Distribution
    \[
    P(L^d) = \prod_{f_i \in L^d} p_i \cdot \prod_{f_i \in L \setminus L^d} (1 - p_i)
    \]
ProbLog

- **Probabilistic Logic Programming Language**
  - Extends Prolog with probabilities
    
    \[
    \begin{align*}
    0.6 & \cdot e(a, b) & 0.7 & \cdot e(c, d) \\
    0.2 & \cdot e(e, f) & 0.3 & \cdot e(a, d) \\
    0.4 & \cdot e(d, f) & 0.8 & \cdot e(b, c) \\
    0.4 & \cdot e(d, e) & \\
    p(X, Y) & :- e(X, Y) \\
    p(X, Y) & :- e(X, X1), p(X1, Y)
    \end{align*}
    \]

  - Defines a Probabilistic Distribution
    \[
    P(L^d) \equiv \prod_{f_i \in L^d} p_i \cdot \prod_{f_i \in L \setminus L^d} (1 - p_i)
    \]

- **Queries**
  - Marginal and Conditional
AND-OR Tree

- Intermediate Structure used for BF representation

0.6::e(a, b). 0.7::e(c, d).
0.2::e(e, f). 0.3::e(a, d).
0.4::e(d, f). 0.8::e(b, c).
0.4::e(d, e).

p(X, Y) :- e(X, Y).
p(X, Y) :- e(X, X1), p(X1, Y).

?- problog_exact(p(a, f), P).
AND-OR Tree

- Intermediate Structure used for BF representation
  - AND nodes
  - OR nodes
  - Terminal nodes (probabilistic facts)
  - Cyclic Structure & General Negation
Compacting Boolean Formulae

- Perform Polytime pattern detections
- Perform linear pattern compactions
  - Simplify the Boolean Formulae
    - Reduces the number of operations
  - Reduce the number of binary variables
    - Reduces the search space for Compilation
Detect Patterns

• Single Variable  \[ O(N_{or} \cdot (\log(N_{or}) + \log(N_{and}))) \]  Compaction
Detect Patterns

- Single Branch I $O(N_{or} \cdot \log(N_{or}) + \log(N_{and}))$ Compaction
Detect Patterns

- Compacting
Detect Patterns

- **AND-Cluster** $\mathcal{O}(N_{\text{and}}^2 \cdot N_{\text{term}})$

**Compaction**

\[ p_t = \prod_{C_i \in Ch'_A} p_i \]
Detect Patterns

- Compacting
Detect Patterns

- **OR-Cluster I** $O(N_{or}^2 \cdot N_{term})$

\[
p_t = \left( \prod_{i=1}^{n} \left( (p_i \cdot (1-p_i) + p_i) \cdot (1-p_i) + p_i \right) \right) + \ldots + p_n
\]

**Compaction**
Detect Patterns

- Compaction
Detect Patterns

- **Single Variable** $O(N_{or} \cdot (\log(N_{or}) + \log(N_{and})))$

  ![Diagram of Single Variable]

- **Compaction**

  ![Diagram of Compaction]

- **Compaction**

  ![Diagram of Compaction with annotations]

  

  1. $p(a, f) \quad \text{AND} \quad \{\text{and}(e(a, b), e(b, c), e(c, d)); 0.336\}$
  2. $p(d, f) \quad \text{AND} \quad \{\text{or}(e(d, f), \text{and}(e(d, e), e(e, f)); 0.448\}$
  3. $p(a, d) \quad \{0.3\}$

  ![Diagram of Compaction with annotations and new patterns]
Detect Patterns

- OR-Cluster II (*not supported*)

\[ p_t = \left( \ldots \left( p_1 \cdot (1 - p_2) + p_2 \right) \cdot (1 - p_3) + p_3 \right) \ldots + p_n \]
Detect Patterns

- **Single Branch II** \(O\left(N_{or} \cdot (\log(N_{or}) + \log(N_{and}))\right)\)  

- **Minimal Proof** \(O\left(N_{or} \cdot (\log(N_{or}) + \log(N_{and}) + N_{term})\right)\)  

**Compaction**
Experiments

- 2 PLP Systems: *MetaProbLog* and *ProbLog 2*
- 2 Compilation Languages: *ROBDDs*, *sd-DNNFs*
- 3 Different Compaction Settings: *Prior*, *Post*, *Both*
- 7 Benchmark sets: *Alzheimer*, *Balls*, *Dictionary*, *Grid*, *Les Miserables*, *Smokers*, *WebKB*
- Total of 738 *ProbLog* programs
Results

Relative Number of Programs per Compaction Setting for Knowledge Compilation

- **Prior**: Better programs
- **Post**: Better programs
- **Both**: Same programs

5%
Results - MetaProbLog
Results ProbLog 2
Experiments - Timeouts

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## Experiments – ProbLog 2 - Times

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Conclusion

- Compaction of 6 out 7 Patterns
- Performance Gain in most cases
- Implementation in Prolog (Future work)
- Test on other fields (Future work)
Questions

Thank You