Towards Distributed Computation of Answer Sets

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Answer Set Programming

- The ASP (Answer Set Programming) language is a logic sublanguage born in 2000 for Knowledge Representation, it is based on the stable model semantics;
- Two-phases solving procedure: *grounding* and *solving*;
- *grounding* phase can generate huge programs, which exceeds the resources amount of a single machine.

To overcome these limitations, this paper proposes three distributed tools to handle the *grounding* and/or the *solving* phase in a system with distributed resources:
- mASPreduce;
- STRASP (STRAtified ASP);
- DASC (Distributed Answer Set Coloring).
The Graph Coloring Algorithm

Rule Dependancy Graph (RDG)

1. $p(a)$.  
2. $q(b)$.  
3. $r(a) ::= p(a), \neg q(b)$.
4. $r(c) ::= \neg r(a)$.

![Graph Coloring Algorithm Diagram]
The Graph Coloring Algorithm

Operators

Definition (Nondeterministic operator)

Given the RDG $\Gamma$ and the partial coloring $C$ of $\Gamma$, $\circ \in \{\oplus, \ominus\}$, we define $D^\circ_\Gamma : C \rightarrow C$ as

- $D^\oplus_\Gamma(C) = (C_\oplus \cup \{r\}, C_\ominus)$ for some $r \in S(\Gamma, C) \setminus (C_\oplus \cup C_\ominus)$
- $D^\ominus_\Gamma(C) = (C_\oplus, C_\ominus \cup \{r\})$ for some $r \in S(\Gamma, C) \setminus (C_\oplus \cup C_\ominus)$

Definition (Propagation operators)

- $P_\Gamma(C) = C \sqcup (S(\Gamma, C) \cap \overline{B}(\Gamma, C), S(\Gamma, C) \cup B(\Gamma, C))$
- $T_\Gamma(C) = (C_\oplus \cup (S(\Gamma, C) \setminus C_\ominus), C_\ominus)$
- $V_\Gamma(C) = (C_\oplus, \Pi \setminus T^*_\Gamma(C))$
The Graph Coloring Algorithm
Solving procedure

Theorem (Operational answer set characterization)
Let $\Gamma$ RDG and $C$ total coloring of $\Gamma$. $C$ is an admissible coloring of $\Gamma$ iff there exists a sequence $(C^i)_{0 \leq i \leq n}$ such that:
- $C^0 = (PV)_{\Gamma}^*((\emptyset, \emptyset))$;
- $C^{i+1} = (PV)_{\Gamma}^*(D^\circ_{\Gamma}(C^i))$ for some $\circ \in \{\oplus, \ominus\}$ and $0 \leq i < n$;
- $C^n = C$.
From $C^n$ a stable model is deduced.
the mASPreduce solver

- developed by Federico Igne;
- it deals with the pure solving phase only, it is an implementation of the Graph Coloring Algorithm;
- based on MapReduce paradigm;
- written in Scala with the Apache Spark framework;
- RDG encoded via the GraphX module of Spark;
- non-deterministic and propagation operations implemented as map/reduce routines;
- fix point operators implemented with Pregel.
STRASP

developed by Pietro Totis;
written in Scala with the Apache Spark framework;
Dependency graph encoded via the GraphX module of Spark;
this tool can be used as
  - a grounder for non-definite programs, which speed up the total computation by calculating the maximal stratified subprograms;
  - a complete solver for definitive/stratified programs;

two levels of parallelization during grounding:
  - Component level parallelism;
  - Rule level parallelism.
Towards Distributed Computation of Answer Sets

DASC

- developed by Marco De Bortoli;
- it deals with the pure solving phase;
- low level implementation of the Graph Coloring Algorithm;
- written in C++ with the Boost library:
  - RDG implemented via Parallel Boost Graph Library;
  - communication implemented via MPI library;
- custom redistribution algorithm;
- design choices w.r.t. mASPreduce:
  - modified version of RDG, in which we also have a node for each atom;
  - different strategy for propagation implementation, which improve network traffic.
## Experimental results

### DASC

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<thead>
<tr>
<th>inst</th>
<th>Distr</th>
<th>1 cp unit</th>
<th>2 cp units</th>
<th>3 cp units</th>
<th>4 cp units</th>
<th>5 cp units</th>
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<tr>
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<td>NR</td>
<td>1.226</td>
<td>1.393</td>
<td>1.115</td>
<td>1.232</td>
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<tr>
<td>5</td>
<td>RR</td>
<td>1.83</td>
<td>6.23</td>
<td>6.18</td>
<td>6.26</td>
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<tr>
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<td>NR</td>
<td>6.118</td>
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<td>20.765</td>
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<tr>
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<td>71.09</td>
<td>81.55</td>
<td>69.76</td>
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<td>83.60</td>
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<td>185.46</td>
<td>195.41</td>
<td>182.33</td>
<td>191.27</td>
</tr>
</tbody>
</table>
## Experimental results

### mASPreduce

<table>
<thead>
<tr>
<th>inst</th>
<th>1 cp unit</th>
<th>2 cp units</th>
<th>3 cp units</th>
<th>4 cp units</th>
<th>5 cp units</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>56.330 (0.003)</td>
<td>42.190 (0.010)</td>
<td>40.160 (0.011)</td>
<td>41.177 (0.013)</td>
<td>35.405 (0.014)</td>
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<tr>
<td>3</td>
<td>95.697 (0.048)</td>
<td>64.315 (0.14)</td>
<td>61.767 (0.151)</td>
<td>62.845 (0.16)</td>
<td>54.144 (0.172)</td>
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<tr>
<td>4</td>
<td>150.82 (0.36)</td>
<td>88.043 (1.11)</td>
<td>89.145 (1.393)</td>
<td>89.695 (1.115)</td>
<td>78.178 (1.232)</td>
</tr>
<tr>
<td>5</td>
<td>error (1.83)</td>
<td>error (6.118)</td>
<td>error (6.18)</td>
<td>error (6.226)</td>
<td>error (5.256)</td>
</tr>
<tr>
<td>6</td>
<td>stopped (7.03)</td>
<td>stopped (22.513)</td>
<td>stopped (20.765)</td>
<td>stopped (20.881)</td>
<td>stopped (18.511)</td>
</tr>
<tr>
<td>7</td>
<td>stopped (21.99)</td>
<td>stopped (71.07)</td>
<td>stopped (81.55)</td>
<td>stopped (66.43)</td>
<td>stopped (65.83)</td>
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<td>stopped (58.90)</td>
<td>stopped (185.46)</td>
<td>stopped (185.45)</td>
<td>stopped (182.33)</td>
<td>stopped (191.27)</td>
</tr>
</tbody>
</table>
Experimental results

STRASP

Figure: Comparison between Clingo (left) and our Spark approach to stratified programs (right)
Conclusion and Future Work

- DASC performance shows that lowering the level of implementation pays off, yet we are still far from the state-of-the-art Clingo performance: heuristics implementation would help in that sense;

- Clingo and STRASP have similar trends, diverging only by a constant factor; unfortunately this constant is too large. Anyway, we expected far better results by lowering the implementation level and by adding the Single Rule Level Parallelism.
Thanks for your attention