Towards Distributed Computation of Answer Sets

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June 21 2019, CILC

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), not q(b).
4  r(c) :- not r(a).
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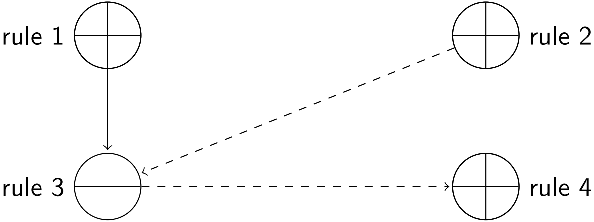

The Graph Coloring Algorithm

Operators

Definition (Nondeterministic operator)

Given the RDG Γ and the partial coloring $\mathcal{C}$ of Γ, $\circ \in \{\oplus, \ominus\}$, we define $\mathcal{D}_\Gamma^\circ : \mathbb{C} \to \mathbb{C}$ as

- $\mathcal{D}_\Gamma^\oplus(\mathcal{C}) = (\mathcal{C}_\oplus \cup \{r\}, \mathcal{C}_\ominus)$ for some $r \in S(\Gamma, \mathcal{C}) \backslash (\mathcal{C}_\oplus \cup C_\ominus)$
- $\mathcal{D}_\Gamma^\ominus(\mathcal{C}) = (\mathcal{C}_\oplus, \mathcal{C}_\ominus \cup \{r\})$ for some $r \in S(\Gamma, \mathcal{C}) \backslash (\mathcal{C}_\oplus \cup C_\ominus)$

Definition (Propagation operators)

$$\mathcal{P}_\Gamma(\mathcal{C}) = \mathcal{C} \sqcup (S(\Gamma, \mathcal{C}) \cap \overline{B}(\Gamma, \mathcal{C}), \overline{S}(\Gamma, \mathcal{C}) \cup B(\Gamma, \mathcal{C}))$$

$$\mathcal{T}_\Gamma(\mathcal{C}) = (\mathcal{C}_\oplus \cup (S(\Gamma, \mathcal{C}) \backslash \mathcal{C}_\ominus), \mathcal{C}_\ominus)$$

$$\mathcal{V}_\Gamma(\mathcal{C}) = (\mathcal{C}_\oplus, \Pi \backslash \mathcal{T}_\Gamma^*(C))$$

The Graph Coloring Algorithm

Solving procedure

Theorem (Operational answer set characterization)

Let Γ RDG and $\mathcal{C}$ total coloring of Γ.
$\mathcal{C}$ is an admissible coloring of Γ iff there exists a sequence $(\mathcal{C}^i)_{0\leq i\leq n}$ such that:

- $\mathcal{C}^0 = (\mathcal{PV})^*_\Gamma((\emptyset,\emptyset))$;
- $\mathcal{C}^{i+1} = (\mathcal{PV})^*_\Gamma(\mathcal{D}^\circ_\Gamma(\mathcal{C}^i))$ for some $\circ \in \{\oplus,\ominus\}$ and $0 \leq i < n$;
- $\mathcal{C}^n = C$.

From $\mathcal{C}^n$ 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.

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

inst	Distr	1 cp unit	2 cp units	3 cp units	4 cp units	5 cp units
2	RR	0.003	0.013	0.015	0.015	0.017
	RD	NR	0.010	0.011	0.013	0.014
3	RR	0.048	0.14	0.19	0.16	0.19
	RD	NR	0.184	0.151	0.166	0.172
4	RR	0.36	1.11	1.42	1.36	1.33
	RD	NR	1.226	1.393	1.115	1.232
5	RR	1.83	6.23	6.18	6.26	5.98
	RD	NR	6.118	6.401	6.226	5.256
6	RR	7.03	22.84	23.86	33.60	24.21
	RD	NR	22.513	20.765	20.881	18.511
7	RR	21.99	71.09	81.55	69.76	65.83
	RD	NR	71.07	83.60	66.43	68.20
8	RR	58.90	188.85	185.45	212.69	220.73
	RD	NR	185.46	195.41	182.33	191.27

Experimental results

mASPreduce

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

Experimental results

STRASP

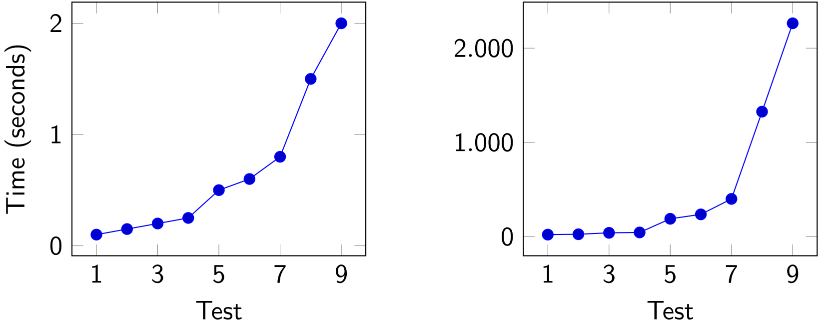

Figure: Comparison between Clingo (left) and our Spark approach to stratified programs (right)

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