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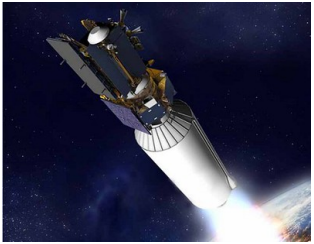
Expressivity of Planning with Horn Description Logic Ontologies

AAAI'22, virtual, 22th February – 1st March, 2022

Planning and Reasoning



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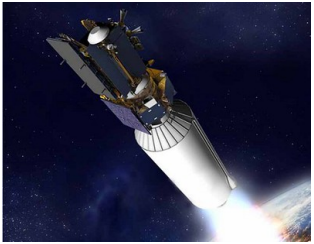

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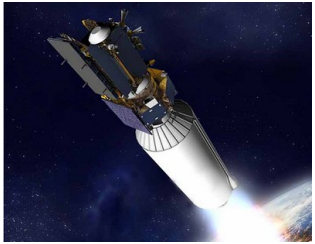

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explicit-input knowledge and action bases (eKABs)
(Calvanese, Montali, Patrizi, and Stawowy 2016)

Planning and Reasoning

Making eKABs more expressive and practical

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Outline

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- Description logics (DLs)
- Planning domain definition language (PDDL)
- Explicit-input knowledge and action bases (eKABs)

Results

- Compilability
- Non-compilability
- Experiments

Description logics (DLs) – A simple example

Description logics: decidable fragments of FOL

$$\text{TBox } \mathcal{T} = \{\ \text{Drone} \sqsubseteq \text{MovingObject},$$
$$\text{Drone} \sqcap \exists \text{near}.\text{MovingObject} \sqsubseteq \text{RiskOfPhysicalDamage},$$
$$\text{Drone} \sqsubseteq \exists \text{controlledBy}.\text{Operator} \sqcup \text{AI}\ \}$$
$$\text{state } s = \{\ \text{Drone}(a),\ \text{Drone}(b),\ \text{near}(a, b)\ \}$$

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Some DLs: DL-Lite, $\mathcal{ELH}_\bot$, Horn-$\mathcal{ALCHOIQ}$, Horn-$\mathcal{SHIQ}$, Horn-$\mathcal{SROIQ}$, $\mathcal{ALCI}$, $\mathcal{SH}$, …

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Conjunctive queries (CQs):

$$s, \mathcal{T} \models \exists x, y.\ \text{RiskOfPhysicalDamage}(x) \wedge \text{RiskOfPhysicalDamage}(y) \wedge \text{near}(x, y)$$

Datalog rewritings for CQs over DLs

Datalog$^{(\neg)}$ rewriting $\mathcal{R}_{\mathcal{T},\mathcal{Q}}$:

$$\mathrm{MovingObject}(x) \leftarrow \mathrm{Drone}(x)$$

$$\mathrm{RiskOfPhysicalDamage}(x) \leftarrow \mathrm{Drone}(x) \land \mathrm{near}(x, y) \land \mathrm{MovingObject}(y)$$

$$\mathrm{Q} \leftarrow \mathrm{RiskOfPhysicalDamage}(x) \land \mathrm{RiskOfPhysicalDamage}(y) \land \mathrm{near}(x, y)$$

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- exist for $\mathcal{ELH}_\bot$ (polynomial), Horn-$\mathcal{SHIQ}$ (exponential), …
- reduce open-world to closed-world reasoning

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(:action Move
  :parameters (?x ?y)
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- closed-world states
- first-order formulas in conditions and action effects
- model checking is decidable
- task: find a plan to reach the goal from the initial state

eKABs

Explicit-input knowledge and action bases (Calvanese, Montali, Patrizi, and Stawowy 2016)

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$$\mathrm{Drone} \sqcap \exists \mathrm{near}.\mathrm{MovingObject} \sqsubseteq \mathrm{RiskOfPhysicalDamage}$$

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(:goal (not (mko (exists (?x ?y) (and
  (RiskOfPhysicalDamage ?x)
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- epistemic minimal-knowledge operator (mko)
- open-world states and conditions, but closed-world effects
- split modeling into static and dynamic part
- complexity of checking entailment of ECQs depends on the TBox

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Compiling eKABs into PDDL

(Calvanese, Montali, Patrizi, and Stawowy 2016):

- compilation of DL-Lite eKABs into PDDL
- key: rewriting (E)CQs into first-order formulas
- however, resulting PDDL exponentially larger
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Here:

- more expressive (Horn-)DLs
- polynomial-size compilation schemes that preserve plan size polynomially (Thiébaux, Hoffmann, and Nebel 2005)
- compilation may take super-polynomial time
- use (polynomial-size) Datalog$^{\neg}$ rewritings of (E)CQs

Main Compilability Result

Theorem

For the class of eKAB instances for which all ECQs are Datalog$^\neg$ rewritable w.r.t. the TBox, there is a compilation scheme into PDDL that preserves plan size exactly.

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- use derived predicates to include Datalog$^\neg$ rules in PDDL 2.2:

$$\mathrm{RiskOfPhysicalDamage}(x) \leftarrow \mathrm{Drone}(x) \wedge \mathrm{near}(x, y) \wedge \mathrm{MovingObject}(y)$$

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- (plus some technicalities, optimizations)
- size of PDDL depends on size of Datalog¬ rewritings
- immediately applicable to existing Datalog¬ rewritings for DLs
- [new polynomial-size Datalog¬ rewriting for Horn-$\mathcal{ALCHOIQ}$]

Polynomial-size Datalog$^{\neg}$ rewriting for Horn-$\mathcal{ALCHOIQ}$

Combined rewriting for Horn-$\mathcal{ALCHOIQ}$: (Carral, Dragoste, and Krötzsch 2018)

- exponential Datalog program using types $C(x) \to R(x, t_D) \wedge D(t_D)$
- complex filtration phase "check whether $F_{q,\sigma}$ is a rooted directed forest"

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Transform into polynomial rule set:

- represent types using Datalog^S set terms (Ortiz, Rudolph, and Šimkus 2010)

$$\mathrm{concept}(C, X) \rightarrow \mathrm{role}(r, X, \{D\}) \wedge \mathrm{concept}(D, \{D\})$$

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- encode filtration into stratified Datalog$^{S,\neg}$

$$\mathrm{edge}(i, j, V_1, \ldots, V_k) \to \mathrm{reach}(i, j, V_1, \ldots, V_k)$$
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- translate set terms back into Datalog$^\neg$ using bit vectors

Non-compilability

(Thiébaux, Hoffmann, and Nebel 2005)

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Unless ExpTime$^{\text{NP}}$ = ExpTime*, there is no polynomial-size compilation scheme from Horn-$\mathcal{SROIQ}$ eKABs to PDDL preserving plan size polynomially.*

- based on 2ExpTime-hardness proof for CQ entailment in Horn-$\mathcal{SROIQ}$
- Horn-$\mathcal{SROIQ}$ eKABs (non-uniformly) simulate universal 2ExpTime Turing machine
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- [similar results for $\mathcal{SH}$, $\mathcal{ALCI}$ eKABs]

Experiments

- implementation of compilation scheme using practical but exponential Datalog$^\neg$ rewriting for Horn-$\mathcal{SHIQ}$ (Clipper) (Eiter, Ortiz, Šimkus, Tran, and Xiao 2012)

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- comparison with (Calvanese, Montali, Patrizi, and Stawowy 2016; Borgwardt, Hoffmann, Kovtunova, and Steinmetz 2021)
- platform: Intel Core i5-4590 CPU @3.30GHz, 8GB memory, 600s timeout

Results

Domain	#	# solved Cal16	# solved Bor21	# solved Horn	planning time Cal16	planning time Bor21	planning time Horn
Cats	20	14	20	20	63.46	0.13	0.03
Elevator	20	20	20	20	0.36	0.30	0.03
Robot	20	4	12	20	15.05	10.10	0.11
TaskAssign	20	3	20	20	0.81	0.12	0.06
TPSA	15	14	5	15	2.01	2.42	0.30
VTA	15	15	13	15	23.06	371.56	16.91
VTA-Roles	15	15	5	15	2.25	11.61	1.36
$\sum$	125	85	95	125	19.99	77.33	3.59
Drones	24			20			101.42
Queens	30			15			21.66
RobotConj	56			56			8.14
$\sum$	110			91			30.87

- our method (“Horn”) solves all DL-Lite instances very fast
- feasible also for more expressive TBoxes
- compilation itself also much faster on average

Summary

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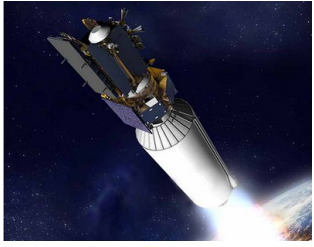

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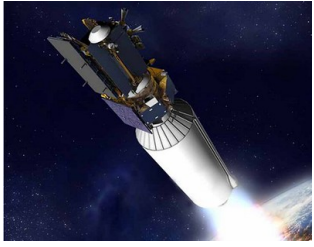

Thank you!

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