A First-Order Interpreter for Knowledge-based Golog based on Exact Progression and Limited Reasoning

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Current Golog Interpreters

- Based on closed world assumption (CWA), dynamic CWA, or domain closure assumption (DCA)
- Query evaluation based on regression, with decreasing efficiency as the length of action sequences grows
- Online, offline or a combination
    - search operator for guarding successful execution
    - planning operator for improving efficiency

Proper$^+$ Knowledge Bases [Lakemeyer and Levesque, 02]

Definition

A first-order KB equivalent to a possibly infinite set of clauses

Example

$\forall x.x \neq y \supset \neg on(x, y) \vee \neg clear(y)$, $\forall x.\neg on(x, x)$
$\forall x, y, z.y \neq z \supset \neg on(x, y) \vee \neg on(x, z)$
$\forall x.x \neq A \wedge x \neq D \supset clear(x)$

[Liu, Lakemeyer & Levesque, 04]

proposed a logic of limited belief $\mathcal{SL}$ and showed $\mathcal{SL}$-based reasoning with proper$^+$ KBs is decidable.

[Liu & Lakemeyer, 09]

showed for local-effect actions and proper$^+$ KBs, progression is not only first-order definable but also efficiently computable.

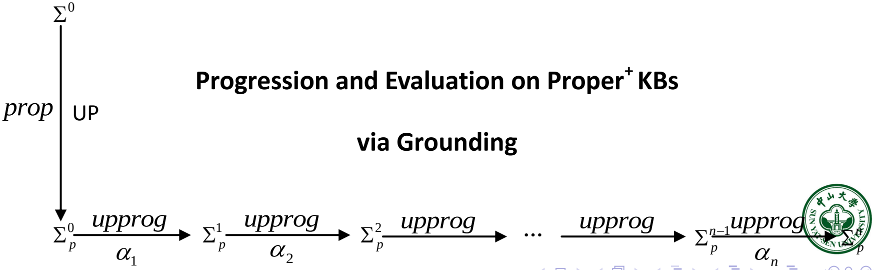
Our Contribution

An interpreter based on exact progression and limited reasoning

- Handle first-order incomplete information in the form of proper^{+} KBs
- Implemented progression and limited reasoning by grounding based on unique name assumption
- The search operator returns a conditional plan
- The planning operator calls a modern planner when local complete information is available

Implementing Progression and Evaluation by Grounding

- We first implemented algorithms by Liu, Lakemeyer and Levesque, but the implementations were not efficient
- We considered implementation via grounding, but there are infinitely many individuals
- The trick is to use an appropriate number of them as representatives of those not mentioned by the KB



Initial Grounding

☞ It should be a finite representation of infinitely many clauses.

Proper$^+$ Blocks World

$\forall x. x \neq y \supset \neg on(x, y) \vee \neg clear(y)$, $\forall x. x \neq A \wedge x \neq B \supset clear(x)$

☞ The width of the proper$^+$KB above is 2, so we intrduce 2 representatives, u_1 and u_2.

Grounding (brute-force)

$\neg on(A, B) \vee \neg clear(B),\ \neg on(A, u_1) \vee \neg clear(u_1),$
$\neg on(A, u_2) \vee \neg clear(u_2), \neg on(B, A) \vee \neg clear(A),$
$\neg on(B, u_1) \vee \neg clear(u_1), \neg on(B, u_2) \vee \neg clear(u_2) \ldots$
$clear(u_1), clear(u_2)$

Extended Grounding

☞ It should be extended to describe new individuals explicitly too.

Original KB with u_1 and u_2 as representatives

$\neg on(u_1, u_2)$, $\neg on(u_1, A)$, $\neg on(u_1, B)$,
$\neg on(A, u_1)$, $\neg on(B, u_1)$,
$clear(u_1)$, $\neg on(u_1, u_1)$, $\ldots$

☞ When an action mentions a new individual c_1, we add the following to the original KB:

Extension with new individual c_1

$\neg on(c_1, u_2)$, $\neg on(u_1, c_1)$, $\neg on(c_1, A)$, $\neg on(c_1, B)$,
$\neg on(A, c_1)$, $\neg on(B, c_1)$,
$clear(c_1)$, $\neg on(c_1, c_1)$, $\ldots$

Progression wrt Local-Effect Actions

Local-Effect Actions

only change the truth value of fluent atoms with arguments mentioned by the actions

Influenced Atoms of $\alpha = move(B, A, c_1)$

$on(B, A, s), on(A, c_1, s), clear(A, s), clear(c_1, s)$

Progression of a ground KB

1. extend the ground KB if needed
2. add successor state axioms instantiated wrt influenced atoms
3. forget the influenced atoms via resolution

Theorem

Progression here is equivalent to that in [Liu & Lakemeyer, 09].

Query Evaluation

- We perform unit propagation over a ground KB
- For clause evaluation
  - $\texttt{eval}(\phi(d_1, \ldots, d_n)) \rightarrow \texttt{eval}(\phi(u_1, \ldots, u_n))$, for $d_1, \ldots, d_n$ not mentioned by KB and $u_1, \ldots, u_n$ as representatives
  - check if $\phi(u_1, \ldots, u_n)$ is subsumed by a clause in the KB
- Others are reduced to clause evaluation recursively, e.g.
  - $\texttt{eval}(\eta \vee \psi) \longrightarrow \texttt{eval}(\eta)$ or $\texttt{eval}(\psi)$ returns true
  - $\texttt{eval}(\exists x \psi) \longrightarrow \texttt{eval}(\psi(x/d))$ returns true for some d in a particular finite domain

Theorem

Evaluation here is equivalent to that in [Liu et al., 04] at $\mathcal{B}_0$ level.

An Interpreter

Implemented in Prolog

- with evaluation and progression implemented in C

Search Operator $\Sigma(\delta)$

- Looking ahead to ensure that nondeterministic choices are resolved to guarantee the successful completion of δ
- Sensing actions allowed in δ and a conditional plan is returned
- Automatically branching wrt sensing results, not relying on special branching actions specified by the programmer

Planning Operator $\Upsilon(\tau, \delta)$

- Based on the work of [Baier, Fritz & McIlraith, 07]
- τ explicitly specifies the domain of all related individuals
- Local complete information: for any $P(\vec{c})$ related to δ, $P(\vec{c}) \in KB$ or $\neg P(\vec{c}) \in KB$
- No sensing actions are allowed in δ
- Calling a modern planner to return a sequence of actions, improving efficiency and ensuring soundness and completeness
- A planner can be called multiple times efficiently because progression maintains the current KB

Experimental Results for Wumpus World (8×8, 3000)

Prob	Gold	IMP	Reward	Moves	Time	Calls
10%	1412	695	437	33	0.670	16
15%	890	917	275	22	0.430	11
20%	567	1171	175	14	0.254	7
30%	263	1581	82	6	0.112	3
40%	182	1924	58	3	0.064	2

An Example Program Execution in the Blocks World

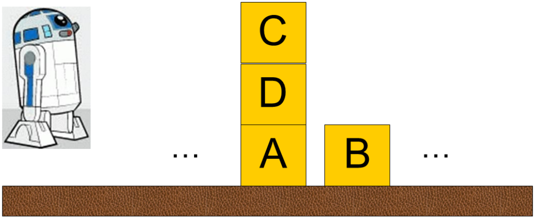
Proper$^+$ Initial KB

$\forall x.x \neq A \wedge x \neq B \wedge x \neq C \wedge x \neq D \supset clear(x)$,
$\forall x, y.x \neq y \supset \neg on(x, y) \vee \neg clear(y)$, $\quad \forall x.\neg on(x, x)$,
$\forall x, y.x \neq y \supset \neg on(x, y) \vee \neg on(y, x), \ldots$

very little knowledge about the exact configuration

Actions: $move(x, y, z), sense\_clear(x), sense\_on(x, y)$

Goal: make clear a list of blocks: A, B, C, D



Conclusions

- Implemented a Golog interpreter based on exact progression of first-order incomplete information
- Implemented limited reasoning, no CWA, DCWA or DCA, but only unique name assumption and DCWA on knowledge
- Implemented progression and evaluation via grounding with theoretical foundation
- A planning problem is generated dynamically each time the planner is called during a single execution task
- Search operator returns a conditional plan not relying on special branching actions

Future Work

- Implement limited reasoning at the $\mathcal{B}_1$ level