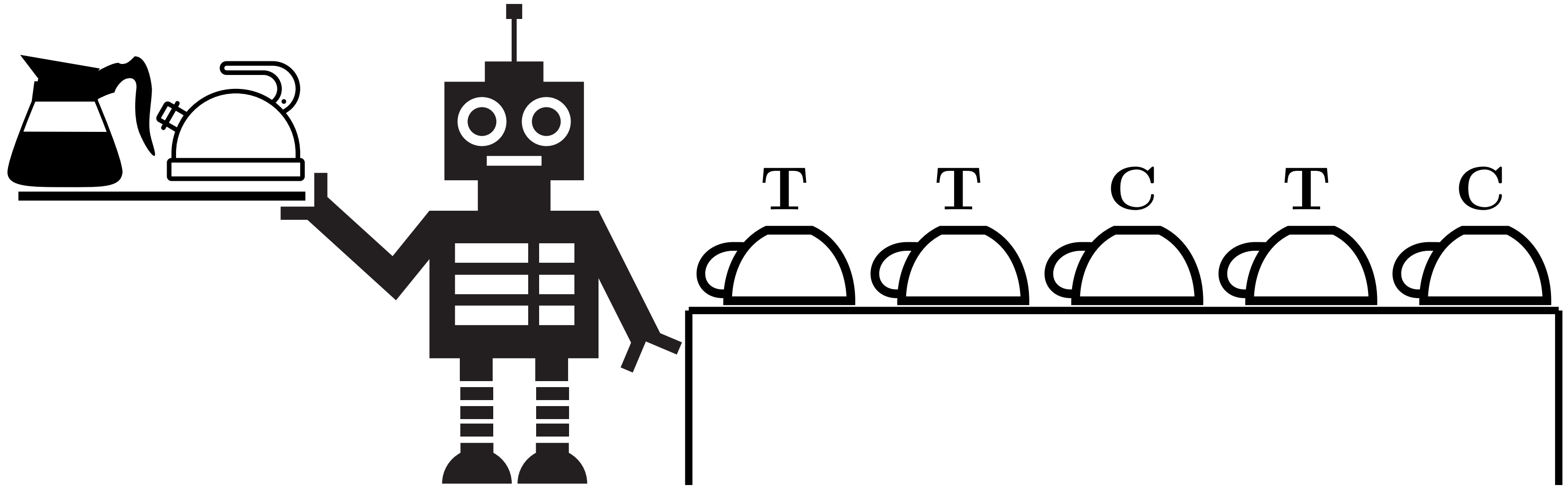
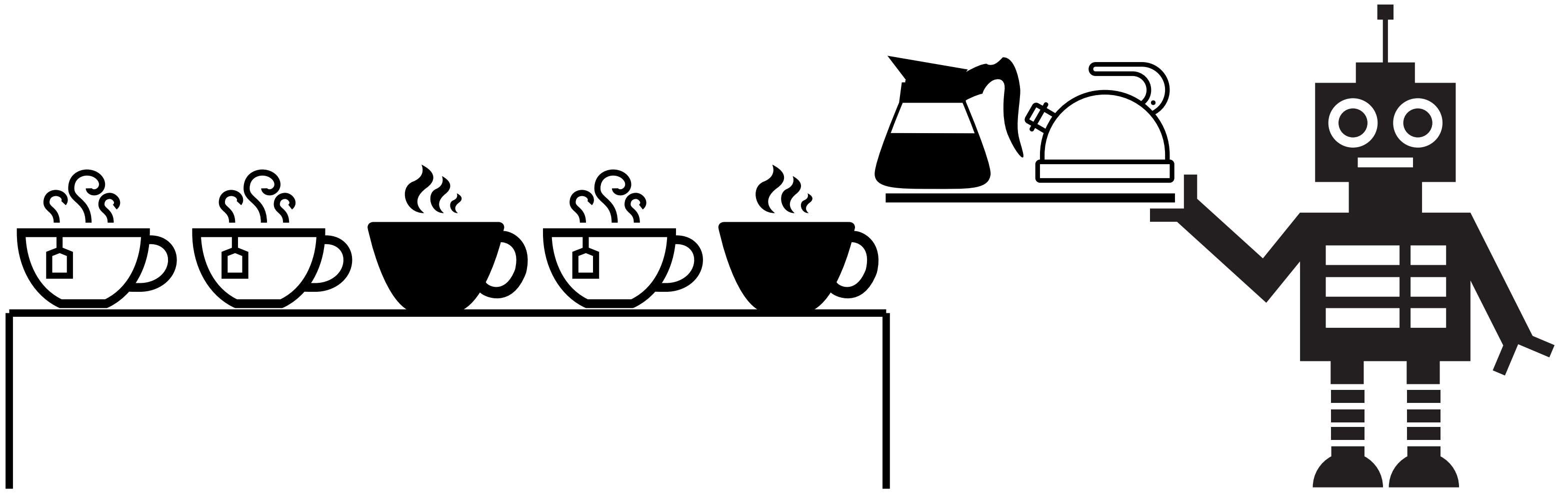
Learning higher-order logic programs through abstraction and invention

[IJCAI16]

Initial state:



Final state:



First-order recursive solution [MLJ2015]

```
f(A,B):-f3(A,B),at_end(B).
f(A,B):-f3(A,C),f(C,B).
f3(A,B):-f2(A,C),move_right(C,B).
f2(A,B):-turn_cup_over(A,C),f1(C,B).
f1(A,B):-wants_tea(A),pour_tea(A,B).
f1(A,B):-wants_coffee(A),pour_coffee(A,B).
```

Higher-order solution

```
f(A,B):-until(A,B,at_end,f3).
f3(A,B):-f2(A,C),move_right(C,B).
f2(A,B):-turn_cup_over(A,C),f1(C,B).
f1(A,B):-ifthenelse(A,B,wants_tea,pour_tea,pour_coffee).
```

Abstraction and invention - robot example

Higher-order definition

until(S1,S2,Cond,Do) ← Cond(S1)
until(S1,S2,Cond,Do) ← Do(S1,S3),until(S3,S2).

Abstraction
f(A,B):-until(A,B,at_end,f3).
Invention
f3(A,B):-f2(A,C),move_right(C,B).

HO predicate	Reduction
until	1
ifthenesle	1
map	1
filter	2

Previous Metagol (ECAI14,IJCAI15)

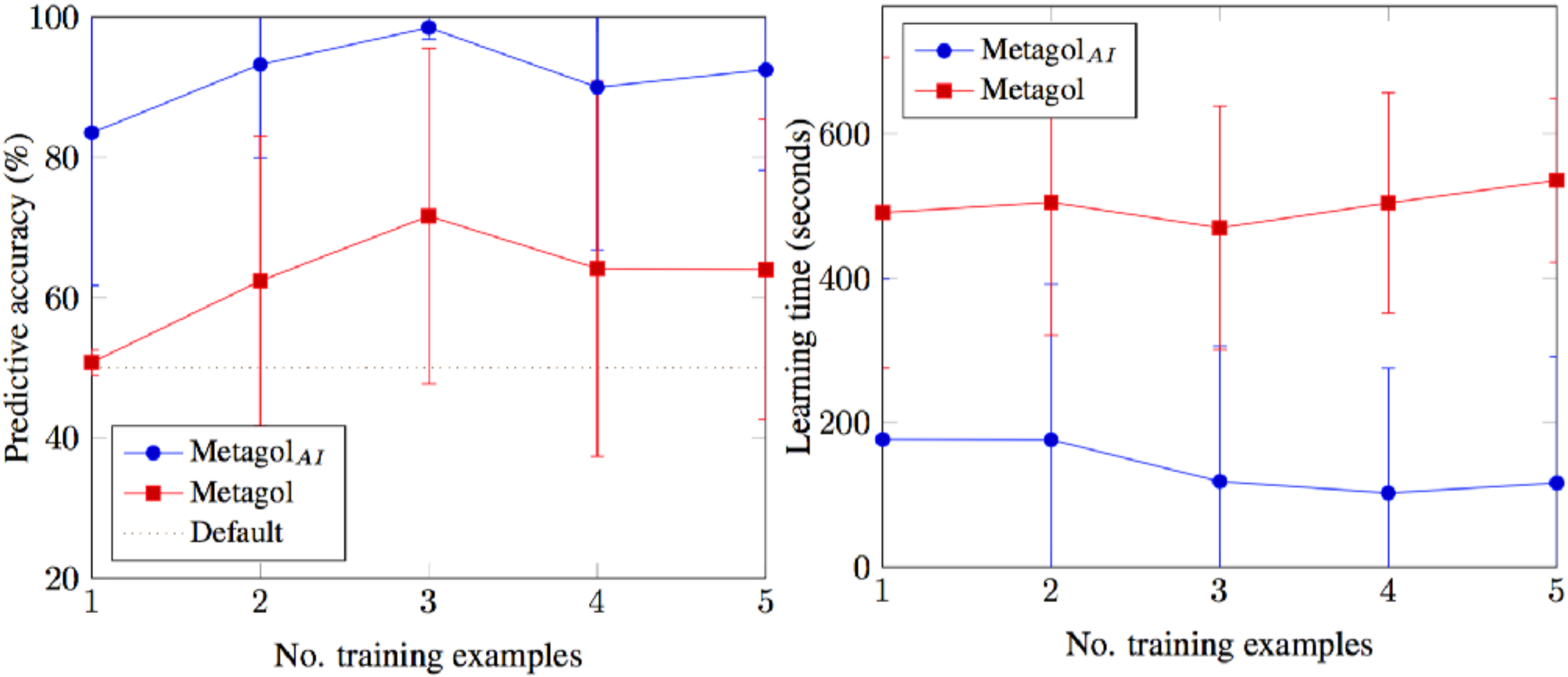
```
prove([],H,H).
prove([Atom|Atoms],H1,H2):-
  prove aux(Atom,H1,H3),
  prove(Atoms,H3,H2).
prove aux(Atom,H1,H2):-
  metarule(Name,Subs,(Atom :- Body)),
  new metasub(H1,sub(Name,Subs)),
  abduce(H1,H3,sub(Name,Subs)),
  prove(Body,H3,H2).
```

New Metagol with interpreted BK

```
prove([],H,H).
prove([Atom|Atoms],H1,H2):-
   prove aux(Atom,H1,H3),
   prove(Atoms,H3,H2).
prove_aux(Atom,H1,H2):-
   background((Atom:-Body)),
   prove(Body,H1,H2).
prove aux(Atom,H1,H2):-
   metarule(Name,Subs,(Atom :- Body)),
   new metasub(H1,sub(Name,Subs)),
   abduce(H1,H3,sub(Name,Subs)),
   prove(Body,H3,H2).
```

Waiter results

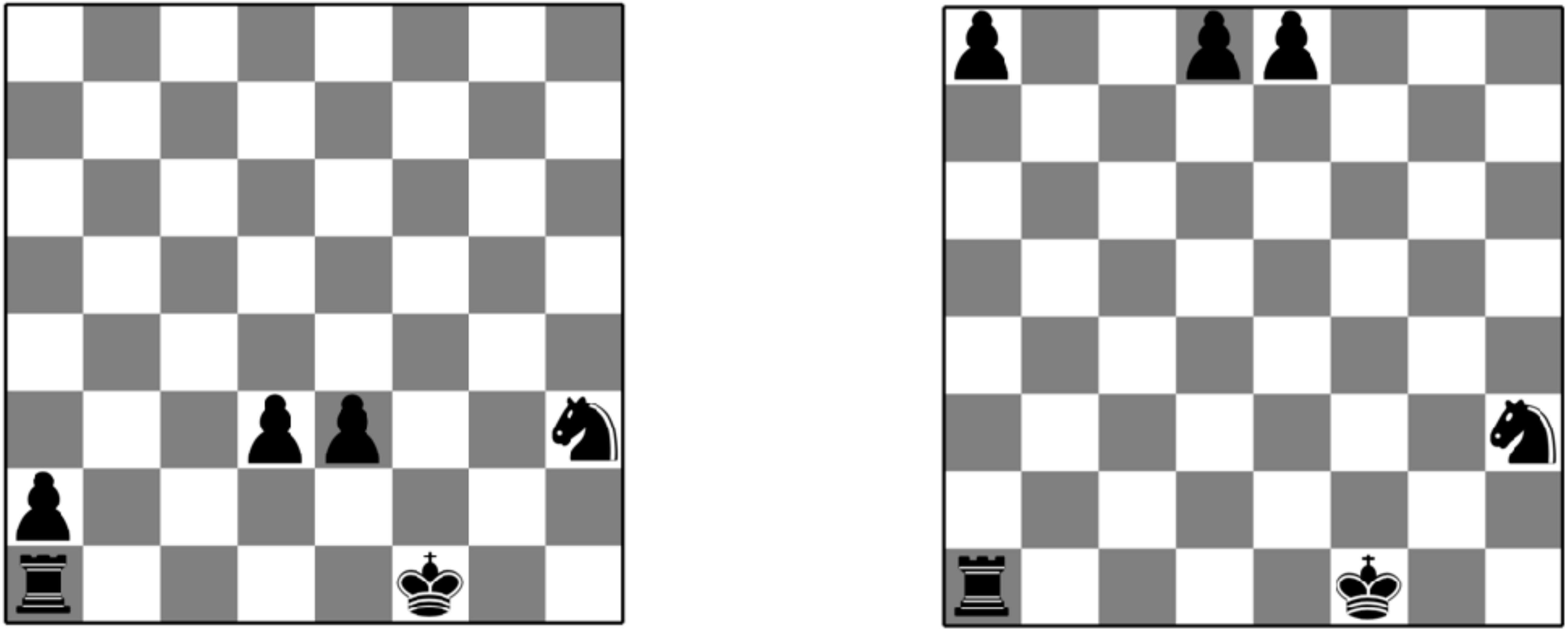
Proposition 1: Sample complexity proportional to program size



(a) Predictive accuracies

(b) Learning times

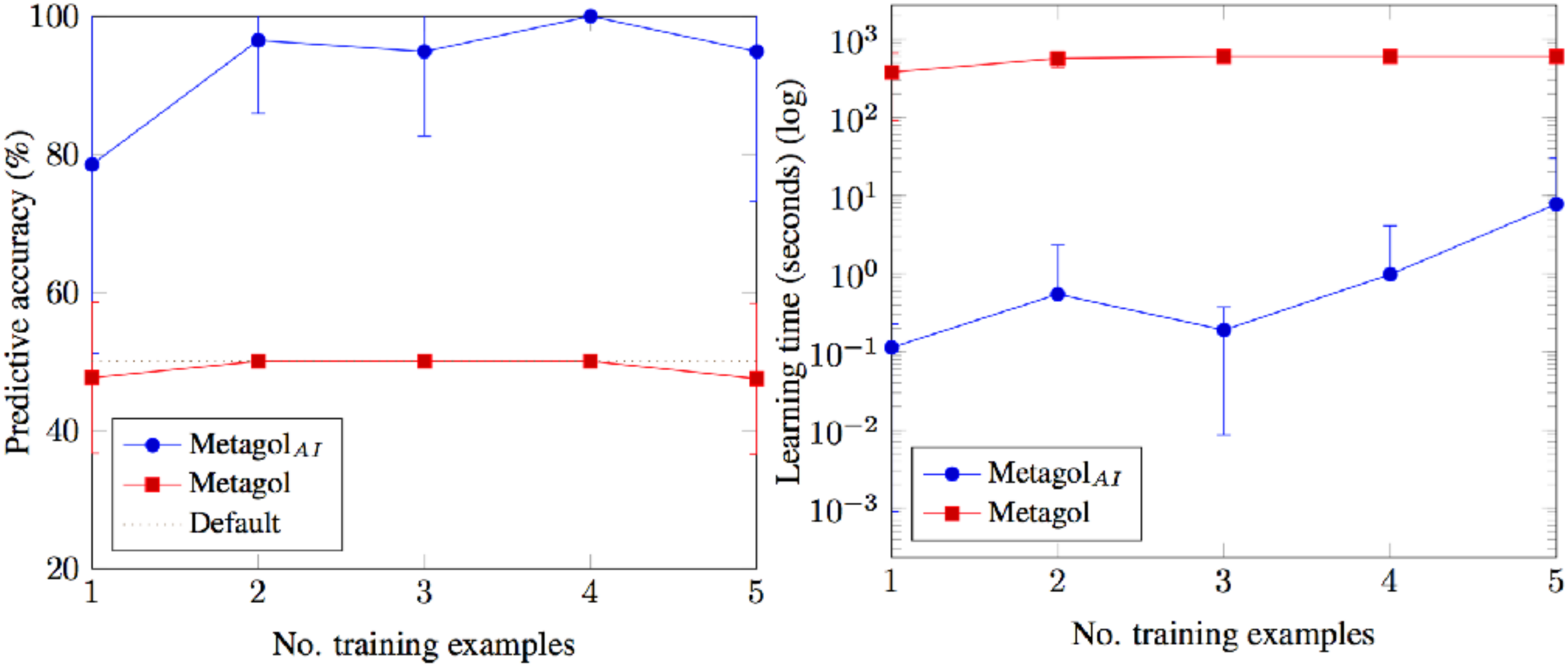
Chess experiment



(a) Initial state

(b) Final state

Chess results



(a) Predictive accuracies

(b) Learning times

Programming example 1

Input	**Output**
[[i,j,c,a,i],[2,0,1,6]]	[[i,j,c,a],[2,0,1]]
[[1,1],[a,a],[x,x]]	[[1],[a],[x]]
[[1,2,3,4,5],[1,2,3,4,5]]	[[1,2,3,4],[1,2,3,4]]
[[1,2],[1,2,3],[1,2,3,4],[1,2,3,4,5]]	[[1],[1,2],[1,2,3],[1,2,3,4]]

***f3* = droplast**

```
f(A,B):-map(A,B,f3).
f3(A,B):-f2(A,C),f1(C,B).
f2(A,B):-f1(A,C),tail(C,B).
f1(A,B):-reduceback(A,B,concat).
```

***f1* = reverse**

Programming example 2

Input	**Output**
[[i,j,c,a,i],[2,0,1,6]]	[[i,j,c,a]]
[[1,1],[a,a],[x,x]]	[[1],[a]]
[[1,2,3,4,5],[1,2,3,4,5]]	[[1,2,3,4]]
[[1,2],[1,2,3],[1,2,3,4],[1,2,3,4,5]]	[[1],[1,2],[1,2,3]]

```
f(A,B):-f4(A,C),f3(C,B).
f4(A,B):-map(A,B,f3).
f3(A,B):-f2(A,C),f1(C,B).
f2(A,B):-f1(A,C),tail(C,B).
f1(A,B):-reduceback(A,B,concat).
```

***f4* = droplasts**

Conclusions

- General method of introducing higher-order constructs such as while, until, ifthenelse, map
- Leads to reduction in program size
- Sample complexity reduction and search space reduction

Future work

- Invent the higher-order abstractions
- Applications in planning, vision and NLP

Bibliography

https://github.com/metagol

- A. Cropper, S.H. Muggleton. Learning efficient logical robot strategies involving composable objects. IJCAI 2015.
- S.H. Muggleton, D. Lin, A. Tamaddoni-Nezhad. Meta-interpretive learning of higher-order dyadic datalog: Predicate invention revisited. Machine Learning, 2015.
- D. Lin, E. Dechter, K. Ellis, J.B. Tenenbaum, S.H. Muggleton. Bias reformulation for one-shot function induction. ECAI 2014.