

Hybrid Abductive Inductive Learning

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Motivation

CF-Induction

- abduction as a special case of induction

Progol5

- exploits (simple) form of abduction
- single atom**: e.g. $B = \{p:-q(0),q(1)\}$ $e = p$ $H = \{q(0),q(1)\}$
- incomplete**: e.g. $B = \{p:-q(0),q(x)\}$ $e = p$ $H = \{q(0)\}$

HAIL: Hybrid Abductive Inductive Learning...

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Semantics

- A **Kernel Set** of Horn theory B and Horn clause e is a Horn theory

$$K = \left\{ \begin{array}{l} a_1 :- d_{1,1}, \dots, d_{1,m(1)} \\ \vdots \\ a_n :- d_{n,1}, \dots, d_{n,m(n)} \end{array} \right\}$$

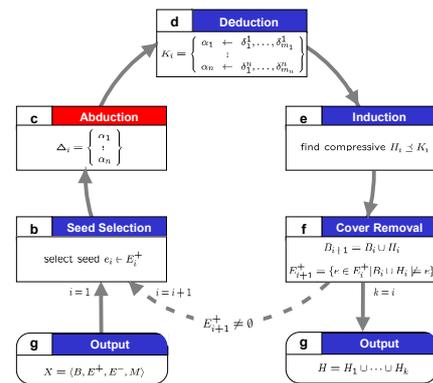
where (for some Skolemising substitution σ)

$$B \wedge a_1 \wedge \dots \wedge a_n \models e \sigma \text{ and } B \wedge \neg e \sigma \models d_{1,1} \wedge \dots \wedge d_{n,m(n)}$$

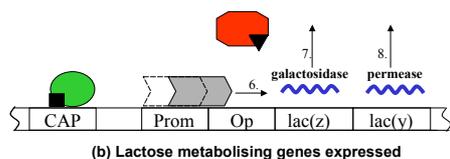
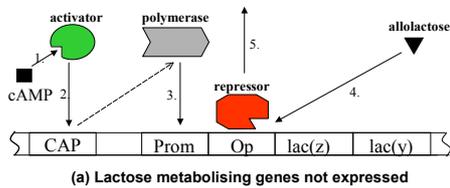
- A Horn theory H is derivable by **Kernel Set Subsumption** from B and e iff H subsumes a Kernel Set of B and e

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Proof Procedure



Example: Lac Operon (E.Coli)



Example: Inputs

```

M {
  :-observable(metabolism/2)?
  :-modeh(*,conc(+sugar,#))?
  :-modeh(*,sugar(#))?
  :-modeb(*,saccharide(+,#))?
}

B {
  metabolism(ESColi,lac):-produce(perm),produce(gala).
  produce(Enzyme):-codes(Gene,Enzyme),express(Gene).
  express(lac(_)):-produce(allo),produce(cAMP).
  produce(allo):-conc(lac,hi).
  produce(cAMP):-conc(glu,lo).
  codes(lac(z),gala).      codes(lac(y),perm).
  saccharide(glu,mono).   saccharide(lac,di).
  :-conc(X,lo),conc(X,hi).
}

E+ { metabolism(eColi,lac).
}

E- { :-metabolism(eColi,glu).
}
  
```

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Example: Transform

T {

`metabolism(ESColi,lac):-produce(perm),produce(gala).`

`produce(Enzyme):-codes(Gene,Enzyme),express(Gene).`

`express(lac(_)):-produce(allo),produce(cAMP).`

`produce(allo):-conc(lac,hi).`

`produce(cAMP):-conc(glu,lo).`

`codes(lac(z),gala). codes(lac(y),perm).`

`saccharide(glu,mono). saccharide(lac,di).`

`conc'(X,Y):-sugar(X).`

G {

`metabolism(ESColi,lac).`

IC {

`% :-conc(X,lo),conc(X,hi).`

`% :-metabolism(ESColi,glu).`

`:-not(conc'(X,Y)),conc(X,Y).`

A {

`conc/2, sugar/1`

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Example: Abduce (KM)

G →

`?+metabolism(ESColi,lac)`

`? produce(perm),produce(gala)`

`? codes(G,perm),expr(G),prod(gala)`

`? express(lac(y),produce(gala)`

`? produce(allo),produce(cAMP),produce(gala)`

`? conc(lac,hi),produce(cAMP),produce(gala)`

`?-not(sugar(lac))`

`?+sugar(lac)`

`?-[]`

Δ {

`conc(lac,hi)`

`sugar(lac)`

`conc(glu,lo)`

`sugar(glu)`

`? produce(cAMP),produce(gala)`

`? conc(glu,lo),produce(gala)`

`?- not(sugar(glu))`

`?+ sugar(glu)`

`?- []`

`? produce(gala)`

`? codes(G,gala),expr(G)`

`? express(lac(z))`

`? produce(allo),produce(cAMP)`

`? conc(lac,hi),produce(cAMP)`

`? produce(cAMP)`

`? conc(glu,lo)`

`? []`

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Example: Deduce (BS)

K = {

`conc(lac,hi) :- saccharide(lac,di).`

`sugar(lac).`

`conc(glu,lo) :- saccharide(glu,mono).`

`sugar(glu).`

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Example: Induce (LS)

H = {

`conc(X,hi) :- saccharide(X,di).`

`sugar(lac).`

`conc(X,lo) :- saccharide(X,mono).`

`sugar(glu).`

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Advantages

Non-rigid Types

- `sugar(lactose)`, `sugar(glucose)`
- but, even if both are added to background ...

Multiple Atoms

- `concentration(lactose,hi)`, `concentration(glucose,lo)`
- but, even if one is added to background ...

(Bounded) Completeness

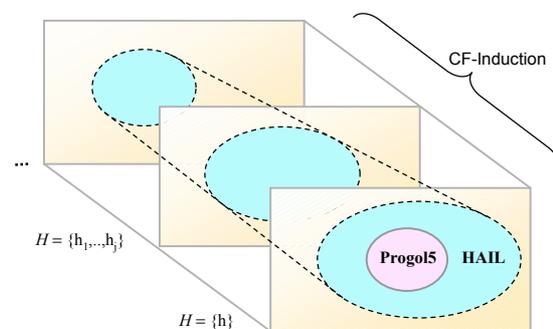
- `concentration(lactose,hi)`
- cannot be computed by Progol5

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Comparison



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