Outline

- Learning first order concepts: FOIL
- Symbolic combination of inductive and analytical learning: FOCL

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FOIL: Induction of Horn Clauses

[Quinlan, ML Journal, Aug 1990]

Key idea:

- Use greedy search driven by information gain
- For learning collections of function-free horn clauses

see figures from [Quinlan, 1990]

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Selection Measure Used by FOIL

$$Gain(Literal) = T^{++}[log_2 \frac{P1}{P1+N1} - log_2 \frac{P0}{P0+N0}]$$

- P0 = Number of initial positive tuples (before adding Literal)
- N0 = Number of initial negative tuples
- T^{++} = Number of initial positive tuples covered after adding Literal
- P1 = Number of positive tuples after adding Literal
- N1 = Number of negative tuples after adding Literal

Note Gain is just the information contributed by the Literal

$$Gain(Literal) = T^{++}[Inf(T_0) - Inf(T_1)]$$

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FOIL Details

Stopping criterion:

- Simple: when all training data is covered
- MDL: when next best literal requires more bits than the data it explains

Post-pruning:

- Like decision tree learning, post-prune unnecessary literals

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FOIL Summary

Features:

- Learns 1st order rules, adapting methods from decision tree learning
- Can acquire recursive definitions
- Can acquire inexact rules

Non-Features:

- Based on short-sighted greedy search
- Cannot postulate new predicates
- Not incremental

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FOCL: The Problem

Given:

- Training examples of target concept (boolean)
- Approximate domain theory (first order horn clauses)

Determine:

- Target concept (conjunction of first order horn clauses) that fits the data, biased by the domain theory

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FOCL Overview

- **Purpose:** use first order domain theory to guide learning
- **Key idea:**
  - use both analytical and inductive means of generating refinements to target concept
  - use information gain to choose among candidate refinements
- **Applications:** Nynex application, self-customize calendar assistant
- **Reference:** Pazzani and Kibler, "The utility of knowledge in inductive learning," *Machine Learning*, Vol. 9, No. 1, pp. 57-94, June 1992.
- **Related efforts:** Bergadano and Giordano's ML-SMART is similar approach. Inductive component is based on Quinlan's FOIL.

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FOCL

Main idea:

- Use FOIL's method for inductively refining target concept
- Expand Domain Theory to analytically refine target concept
- Choose between the two based on mutual information
- Outperforms inductive FOIL, robust to DT errors

Some limitations:

- Learns boolean concepts. Discrete-valued possible, real-valued difficult.

see figures from [Pazzani and Kibler, 1992]

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Some Terminology for Horn Clauses

A **Rule**:

- P(x,y) :- A(x), B(x,y)

  P(x,y) :- C(x), B(x,y)

A **Horn Clause**: P(x,y) :- C(x), B(x,y)

The **Body** of above clause: C(x), B(x,y)

A **Literal**: B(x,y)

Extensional Definition of predicate P

- P(a,a) = T P(a,b) = F ...

Intensional Definition of predicte P

- P(x,y) :- A(x), B(x,y)

  P(x,y) :- C(x), B(x,y)

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A Target Concept in Chess

King-rook-king illegal board positions:

```
Illegal(r1,f1,r2,f2,r3,f3) :- same-loc(r1,f1,r2,f2)

Illegal(r1,f1,r2,f2,r3,f3) :- same-loc(r1,f1,r3,f3)

Illegal(r1,f1,r2,f2,r3,f3) :- same-loc(r2,f2,r3,f3)

Illegal(r1,f1,r2,f2,r3,f3) :- k-attack-k(r1,f1,r3,f3)

Illegal(r1,f1,r2,f2,r3,f3) :- r-attack-k(r1,f1,r2,f2,r3,f3)
```

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What We Would Like

A single learning method that operates over entire spectrum:

- Given perfect domain theory, generalizes accurately
- Given no domain theory, generalizes like inductive learning
- Degrades gracefully with quality of domain theory
- Learns its own domain theory
- Accomodates noisy data

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Dimensions Along Which Approaches Vary

How domain theory influences hypothesis search

- Defines *initial hypothesis* (KBANN, EITHER)
- Generates *alternative search steps* to inductive method (FOCL)
- *Changes the target criterion* for the final hypothesis (EBNN)

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Dimensions Along Which Approaches Vary II

Representation of domain theory and target function

- Propositional, First order, Neural Nets, etc.
- Boolean, Multi-valued, Real-valued

Sequencing of Analysis and Induction

- Analytical then inductive (KBANN, IOE, IOU)
- Inductive then analytical (Liebowitz)
- Interleaved analytical/inductive (FOCL, EITHER, EBNN)

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