# **Concept Learning**

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State Key Lab of CAD&CG, ZJU 2010-03-11



### **Overview**



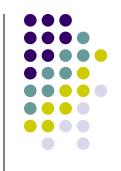
- Learning from examples
- General-to-specific ordering of hypotheses
- Version spaces and candidate elimination algorithm
- Inductive bias

### Introduction



- What is concept learning?
  - Induce Boolean function from a sample of positive/negative training examples.
  - Infer the general definition of some concept, given examples labeled as members or nonmembers of the concept.
- Concept learning in daily life
  - 根据人证物证判断犯罪嫌疑人是否有罪
  - 根据笔试面试决定是否录用
  - And more ...





#### Concept:

days on which my friend Tom enjoys his favorite water sports

#### Task:

 predict the value of "Enjoy Sport" for an arbitrary day based on the values of the other attributes

#### **Training Data**

#### **Attributes**

5	ID	Sky	Temp	Humidi ty	Wind	Water	Foreca st	Enjoy
	1	Sunny	Warm	Normal	Strong	Warm	Same	Yes
	2	Sunny	Warm	High	Strong	Warm	Same	Yes
<b>,</b>	3	Rainy	Cold	High	Strong	Warm	Change	No
	4	Sunny	Warm	High	Strong	Cool	Change	Yes

#### **Example**

# Representing Hypothesis



- Hypothesis h is described as a conjunction of constraints on attributes
- Each constraint can be:
  - A specific value : e.g. Water=Warm
  - A don't care value : e.g. Water=?
  - No value allowed (null hypothesis): e.g. Water=Ø
- Example: hypothesis *h*

```
Sky Temp Humid Wind Water Forecast < Sunny ? Strong ? Same >
```

# A Demo Task – Enjoy Sport



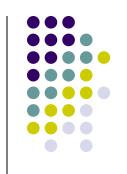
#### Given:

- Instance Space X: Possible days described by the attributes=[Sky, Temp, Humidity, Wind, Water, Forecast]
- Target function c: Enjoy Sport X → {0,1}
- Hypotheses Space H:
  - conjunction of literals e.g. < Sunny ? ? Strong ? Same >
- Training examples D:
  - positive and negative examples of the target function,
     <x1,c(x1)>,..., <xn,c(xn)>

#### Determine:

• A hypothesis h in **H** such that h(x)=c(x) for all x in X.

# The Inductive (归纳) Learning Hypothesis



- Any hypothesis found to approximate the target function well over a sufficiently large set of training examples will also approximate the target function well over other unobserved examples.
- Find the hypothesis that best fits the training data
- 根据已知推断未知,假定已知满足某种规律

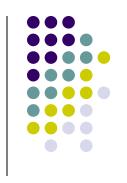
# Number of Instances, Concepts, Hypotheses



- Sky: sunny, cloudy, rainy
- Air Temp: warm, cold
- Humidity: normal, high
- Wind: strong, weak
- Water: warm, cold
- Forecast: same, change

```
#distinct instances: 3*2*2*2*2*2 = 96
#distinct concepts: 2^{96}
#syntactically distinct hypotheses: 5*4*4*4*4*4=5120
#semantically distinct hypotheses: 1+4*3*3*3*3*3=973
```

## **Perspective**



- Concept learning can be formulated as a searching:
  - through a predefined space of potential hypotheses for the hypothesis that best fits the training examples.
- General-to-specific ordering

$$h_j \ge_g h_k \longleftrightarrow (\forall x \in X)[(h_k(x) = 1) \to (h_j(x) = 1)]$$

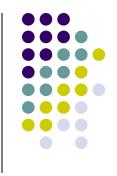
- Example : <Sunny,?,?,?,?,> >= <Sunny,?,?,Strong,?,?>
- Introduce a hierarchy structure into hypotheses space, which leads to efficient searching strategy.





Algorithm	Order	Strategy	N/P	
FIND-S	Specific-to- general	Top-down	Positive	
LIST-THEN- ELIMINATE	General-to- Specific	Bottom-up	Negative	
CANDIDATE- ELIMINATION	Bi-directional	Bi-directional	Both	

### FIND-S



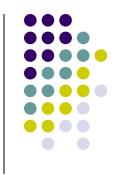
- h0 = <0, 0, 0, 0, 0>
- h1 = <Sunny, Warm, Normal, Strong, Warm, Same>
- h2 = <Sunny, Warm, ?, Strong, Warm, Same>
- h3 = <Sunny, Warm, ?, Strong, Warm, Same>
- h4 = <Sunny, Warm, ?, Strong, ?, ?>

#### Training examples:

- <a></a> < Sunny, Warm, Normal, Strong, Warm, Same>, Enjoy Sport = **Yes**
- 2. <Sunny, Warm, High, Strong, Warm, Same>, Enjoy Sport = Yes
- 3. <Rainy, Cold, High, Strong, Warm, Change>, Enjoy Sport = No
- 4. <Sunny, Warm, High, Strong, Cool, Change>, Enjoy Sport = **Yes**

#### Report the *most specific* hypothesis

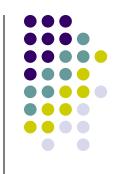
### LIST-THEN-ELIMINATE



<Rainy, Cold, High, Strong, Warm, Change>, Enjoy Sport = **No** 

Report the *most general* hypothesis

### **CANDIDATE-ELIMINATION (1)**



**S2**: {<Sunny, Warm, ?, Strong, Warm, Same>}

**G0, G1, G2**: {<?, ?, ?, ?, ?, ?>}

#### Training examples:

- <Sunny, Warm, Normal, Strong, Warm, Same>, Enjoy Sport = **Yes**
- <Sunny, Warm, High, Strong, Warm, Same>, Enjoy Sport = **Yes**

遇到正例与Find-s方法类似

### **CANDIDATE-ELIMINATION (2)**



S2,S3: {<Sunny, Warm, ?, Strong, Warm, Same>}

#### Training examples:

3. <Rainy, Cold, High, Strong, Warm, Change>, Enjoy Sport = *No* 

遇到反例与List-then-eliminate方法类似

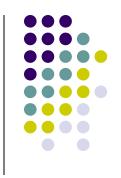
### **CANDIDATE-ELIMINATION (3)**

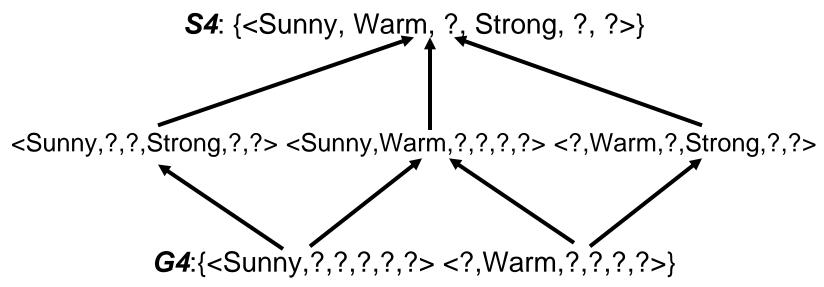


#### Training examples:

4. <Sunny, Warm, High, Strong, Cool, Change>, Enjoy Sport = **Yes** 







Report the *version space* – all possible hypotheses

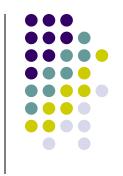
<Sunny,Warm,Normal,Strong,Cool,Change>
 <Rainy,Cold,Normal,Light,Warm,Same>
 <Sunny,Warm,Normal,Light,Warm,Same>
 <Sunny,Cold,Normal,strong,Warm,Same>

### Remarks



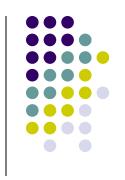
- Convergence Condition
  - Noise Free (No Errors)
  - The target concept **DOES** exist in the searching hypotheses space *H*
- What Training Example Should the Learner Request Next?
  - Satisfy half the hypotheses in the current version space
  - Fastest Convergence, Least Sample Needed, Best Uncertainty Elimination
- How Can Partially Learned Concepts Be Used?
  - Absolutely Accept <Sunny,Warm,Normal,Strong,Cool,Change>
  - Absolutely Deny <Rainy,Cold,Normal,Light,Warm,Same>
  - Pending
    - <Sunny,Warm,Normal,Light,Warm,Same>
    - <Sunny,Cold,Normal,Strong,Warm,Same>

# Inductive Bias (归纳的偏差)



- Bias Vs. Unbiase
- The Futility (无用性) of Bias-Free Learning
  - Too large searching space
  - The convergence is impossible
  - Rational inference is impossible
- Inductive bias of CANDIDATE-ELIMINATION algorithm
  - The target concept c is contained in the given hypothesis space
     H.
  - Inductive System == Deductive System + Inductive Bias

### **Summary**



- Concept learning can be cast as Searching through predefined hypotheses space.
- The general-to-specific partial ordering of hypotheses leads to efficient searching strategy, such as CANDIDATE-ELIMINATION algorithm.
- A practical concept learning methods must employ inductive bias. Otherwise, they can only classify the observed training examples.
- Version spaces and the CANDIDATE-ELIMINATION algorithm provide a useful *conceptual framework* for studying concept learning. However, their correctness rely on the noise-free training examples and the ability of provided hypotheses space to express the unknown target concepts.

# EnjoySport revisit



#### Given:

- Instances X: Possible days, each described by the attributes
  - Sky (Sunny, Cloudy, and Rainy)
  - Temp (Warm and Cold)
  - Humidity (Normal and High)

设想编程调试时候的情景

- Wind (Strong and Weak)
- Water (Warm and Cool)
- Forecast (Same and Change)
- Hypotheses H: Each hypothesis is described by a conjunction of constraints. These constraints may be "?" (any value), "0" (no value), or a specific value.

#### Determine:

• A hypothesis h in **H** such that h(x) = c(x) for all x in **X**.



# Thank you