# Lab Class ML:II

By Wednesday, 2015-11-25, solutions for the following exercises have to be submitted: 1, 2, 3, 5a-f, 6a-b.

## Exercise 1 : Hypothesis Space

Explain the following terms as precisely as possible.

(a) Hypothesis space

(b) Version space

(c) Consistent hypothesis

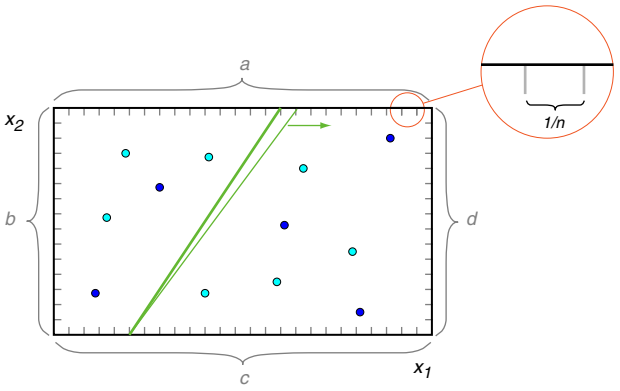
(d) Most general hypothesis

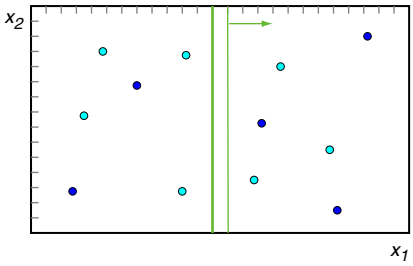
(e) Most specific hypothesis

(g) Target concept

## Exercise 2 : Hypothesis Space

Let $x_1$ and $x_2$ be two attributes for the description of objects; the sizes of their domains are $|X_1|$ and $|X_2|$. An object can belong to class 0 or class 1, illustrated as light and dark dots in the figure. Let the hypothesis space $H$ comprise all discrimination lines that can be drawn in the two-dimensional feature space $X$.




(a) Compute an upper bound for $|H|$, if arbitrary linear hypotheses are allowed (see left figure).

(b) Compute an upper bound for $|H|$, if arbitrary linear hypotheses like $1x_1 + 0x_2 + b$ are allowed (see right figure).

## Exercise 3 : Concept Learning

Given is the following training set $D$, which you have obtained as co-driver by observing your friend:

| | Weekday | Mother-in-the-car | Seen-police | Mood | Time of day | Drunk-alcohol | run-a-red-light |
|---|---|---|---|---|---|---|---|
| 1 | Monday | no | no | easygoing | morning | nothing | yes |
| 2 | Thursday | no | yes | annoyed | evening | something | no |
| 3 | Saturday | yes | no | nervous | lunchtime | nothing | no |
| 4 | Monday | no | no | easygoing | evening | nothing | yes |

Let the set $H$ contain hypotheses that are built from a conjunction of restrictions for attribute-value combinations; e. g. $\langle$*Monday,yes,?,?,?,something*$\rangle$.

(a) Apply the Find-S algorithm for the example sequence 1, 2, 3, 4.

(b) Apply the Candidate-Elimination algorithm for the example sequence 1, 2, 3, 4.

Exercise 4 : Concept Learning (Background)

(a) The Find-S algorithm considers only positive training examples. Explain whether this property can cause the algorithm to return an inconsistent hypothesis. Assume the hypothesis setup from the lecture.

(b) Is the hypothesis constructed by the Find-S algorithm dependent on the example order? Explain your answer.

(c) Which of the two algorithms Find-S and Candidate-Elimination has a stronger inductive bias? Explain your answer.

(d) Explain the terms ”soundness” and ”completeness” in the context of the Candidate-Elimination algorithm.

Exercise 5 : P Concept Learning

Develop a simple Python implementation of the Candidate-Elimination algorithm discussed in the lecture.

(a) Hypotheses and examples will be represented as tuples of strings. Use the following functions to generate the minimally and maximally specific hypotheses:

```
def g_0(n):
    return ('?',) * n

def s_0(n):
    return ('T',) * n
```

(b) Implement a function `more_general(h1, h2)` that returns `True` when $h_1 \geq_g h_2$ holds.

(c) Implement a function `min_generalizations(h, x)` that returns all minimal generalizations of hypothesis `h` that are fulfilled by example `x`.

(d) Implement a function `min_specializations(h, domains, x)` for a hypothesis `h` and an example `x`. The argument `domains` is a list of lists, in which the $i$-th sub-list contains the possible values of feature $i$. The function should return all minimal specializations of `h` with respect to `domains` which are not fulfilled by `x`. Example output:

```
>>> min_specializations(h=('?', 'x'),
                        domains=[['a', 'b, 'c'], ['x', 'y']],
                        x=('b', 'x'))
[('a', 'x'), ('c', 'x'), ('?', 'T')]
```

(e) Implement the Candidate-Elimination algorithm from the slides as a Python function with the following signature: `candidate_elimination(examples)`, where `examples` is a list of $(n+1)$-tuples. The first $n$ elements of each tuple should be the feature values, and the last element is the value of the target concept (you may assume that this value is always either `True` or `False`). Your function should return a 2-tuple containing the sets $G$ and $S$. Hint: Use the previously implemented functions where appropriate. Start by computing the domains of the features, and generating $g_0$ and $s_0$ of the correct dimension.

(f) Given is the following set of examples for the target concept EnjoySport:

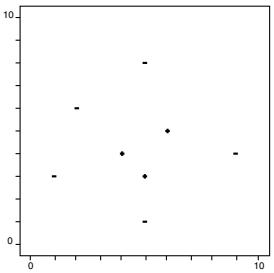
| | Sky | Temp | Humid | Wind | Water | Forecast | EnjoySport |
|---|---|---|---|---|---|---|---|
| 1 | sunny | warm | normal | strong | warm | same | True |
| 2 | sunny | warm | high | strong | warm | same | True |
| 3 | rainy | cold | high | strong | warm | change | False |
| 4 | sunny | warm | high | strong | cool | change | True |

Run your implementation on the examples in the order given above, and report the values of $G$ and $S$ that you obtain.

(g) Produce a visualization of the hypothesis space spanned by $G$ and $S$.

Exercise 6 : Concept Learning

The set of possible examples is given by all points of the x-y plane with integer coordinates from the interval $[1, 10]$. The hypothesis space is given by the set of all rectangles. A rectangle is defined by the points $(x_1, y_1)$ and $(x_2, y_2)$ (bottom left and upper right corner). I. e., hypotheses are functions that assign a point $(x, y)$ to the value 1, if $x_1 \leq x \leq x_2$ and $y_1 \leq y \leq y_2$ hold, with arbitrary, but fixed integer values for $x_1, y_1, x_2, y_2$ from the interval $[1, 10]$. Given the following training set:




| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Point $(x, y)$ | (5,3) | (9,4) | (1,3) | (5,8) | (4,4) | (5,1) | (6,5) | (2,6) |
| Class | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

(a) Use the Candidate-Elimination algorithm to determine the set of the most general hypotheses $G$ and the set of the most specific hypotheses $S$. Specify the hypotheses from $G$ and $S$ as $\langle x_1, y_1, x_2, y_2 \rangle$ and draw them on the chart. Use at least examples 1, 5 and 8.

Consider first how to minimally generalize or specify. An example point can be viewed as a rectangle $\langle x, y, x, y \rangle$.

(b) What happens if an additional example $(1, 8)$ with value 1 is added?

(c) Name a different rule to construct a hypothesis. This rule should have a smaller inductive bias.

(d) P Modify your implementation from Exercise 5 to handle examples and hypotheses given as rectangles. Run Candidate-Elimination on the eight examples given in the table.