

Department of Computer and Information Science

Examination paper for (course code) (course title)

TDT4136 - Introduction to Artificial Intelligence

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If you believe that some information is missing in the formulation of a problem, briefly describe the necessary assumptions you made.

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Date

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(NOTE: All the answers need to be written down into answer sheets, not into the question list.)

TASK 1: Task Environment (10p)

Specify the task environment of the following four agents.

Note 2020: Several students have pointed out that there sometimes exists reasonable alternative answers to questions about agent environments. On future exams these kinds of questions will be discussion questions where you will explain your answers and what assumptions you make.

Possible answers:

Observable: Fully (F) or partially (P).

Agents: Single (S) or Multi (M)

Deterministic: Deterministic (D) or stochastic (S).

Episodic: Episodic (E) or sequential (S)

Static: Static (S), semi (I) or dynamic (D)

Discrete: Discrete (D) or continuous (C)

Agent 1: Deep Blue

Deep Blue is a chess playing agent that played and won against Garry Kasparov in 1997. Consider one game against Garry using a clock.

Agent 2: Roomba

Roomba is a vacuum-cleaning robot that drives around and vacuums the floors in all the rooms of a home.

Agent 3: A Tesla factory paint-robot.

A paint robot on the Tesla factory paints one and one car. The cars are transported by a transport robot to and from the paint robot. The paint robot uses a spray-painting robot arm to paint the cars.

Agent 4: Stats Monkey the robot journalist

Stats Monkey collects box scores and play-by-play data to spit out credible accounts of college baseball games while the games are being played.

Answer to be written down into answer sheet following the given table:

Task Environment	Observable P/F	Agents S/M	Deterministic D/S	Episodic E/S	Static S/D/I	Discrete D/C
Deep Blue	F	M	D	S	I	D
Roomba	P	S	S	S	D	C

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Paint robot	P	M	S	S	S	C
Stats Monkey	P	S	D	S	I	C

TASK 2: Propositional and first-order logic (20p)

- a) (4p) What are the advantages and disadvantages of the propositional logic ? What is the difference between implication and entailment in propositional logic ? (*The answer should be shorter than one page*).

Pros:

- Propositional logic is declarative: Pieces of syntax correspond to facts
- Propositional logic allows partial/disjunctive/negated information
- Propositional logic is compositional

Cons:

- Propositional logic has very limited expressive power.

Implication: $(S \rightarrow Q)$ is true iff $(\neg S \vee Q)$ is true.

Entailment: $(KB \models Q)$ is true iff every interpretation that makes all $(S \in KB)$, makes Q true.

- b) (4p) Convert the following formula to CNF (conjunctive normal form)

$$(A \wedge B) \Rightarrow (\neg A \Leftrightarrow B)$$

$$\neg A \vee \neg B$$

- c) (2p) Multiple choice

The formula $\forall x \exists y P(x,y) \rightarrow \exists q P(q,q)$ would be treated as a validity

1. Under all possible circumstances
2. By an inference engine that implements occurs check as Skolem functions
3. By an inference engine that implements occurs check as Skolem constants
4. Under no possible circumstances

3 (R&N, p.362)

- d) (3p) True or False (*correct answer= 1p; wrong answer= -1/2p; total score will be 0-3p*)

1. Universal Instantiation is built on Skolemization. **F (R&N, p.323)**
2. The Backward Chaining Algorithm can be described as follows:
 - i. Pose the original query as a goal.
 - ii. Find every clause in the knowledge base whose right-hand side unifies with the goal under some substitution.
 - iii. Prove in turn every conjunct on the left-hand sides of each of these clauses, keeping track of the accumulated substitutions. **T (R&N, p.337)**
3. There exists a sentence S in First Order Logic such that S cannot be converted into an inferentially equivalent sentence in Conjunctive Normal Form. **F (R&N, p.345)**

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- e) The statement “Every Russian school boy knows a game”¹ has two interpretations:
 A. There exists a game such that every Russian school boy knows this game.
 B. For each Russian school boy, there exists a game so that the boy knows this game.

Questions:

1. (2p) Formulate each of these two interpretations in first order logic.

Let $R(x)$: x is a Russian schoolboy, $G(y)$: y is a game, $K(x,y)$: x knows y .

A: $\exists y [G(y) \wedge (\forall x R(x) \Rightarrow K(x,y))]$

B: $\forall x [R(x) \Rightarrow \exists y (G(y) \wedge K(x,y))]$

2. (2p) Convert the formulas into clausal form.

Clausify A (eliminate \exists and replace $A \Rightarrow B$ with $\neg A \vee B$):

A: $\exists y [G(y) \wedge (\forall x R(x) \Rightarrow K(x,y))]$

$\exists y [G(y) \wedge (\forall x \neg R(x) \vee K(x,y))]$

$\exists y [G(y) \wedge (\neg R(x) \vee K(x,y))]$

$G(S1) \wedge (\neg R(x) \vee K(x,S1))]$

P1: $G(s1)$

P2: $\neg R(x) \vee K(x,s1)$

Now we convert B to CNF but we do also its negation as a preparation for the next task which is about resolution refutation

Negate B and clausify (move \neg inwards, using that $\neg \forall x P \equiv \exists x \neg P$ and $\neg \exists x P \equiv \forall x \neg P$ and De Morgan's Laws: $\neg(A \wedge B) \equiv \neg A \vee \neg B$ and $\neg(A \vee B) \equiv \neg A \wedge \neg B$):

$\neg \forall x [R(x) \Rightarrow \exists y (G(y) \wedge K(x,y))]$

$\exists x \neg [R(x) \Rightarrow \exists y (G(y) \wedge K(x,y))]$

$\exists x \neg [\neg R(x) \vee \exists y (G(y) \wedge K(x,y))]$

$\exists x [R(x) \wedge \neg \exists y (G(y) \wedge K(x,y))]$

$\exists x [R(x) \wedge \forall y \neg (G(y) \wedge K(x,y))]$

$\exists x [R(x) \wedge \forall y (\neg G(y) \vee \neg K(x,y))]$

$R(s2) \wedge \forall y (\neg G(y) \vee \neg K(s2,y))$

P3: $R(s2)$

P4: $\neg G(y) \vee \neg K(s2,y)$

3. (3p) Use either a resolution proof or the Tableaux method to show that the logical formulation of interpretation A implies the logical formulation of interpretation B.

Resolution proof (use the clausal forms from task 2e2 or derive them here):

P5: $\neg K(s2,s1)$ (P1,P4). -here you do substitution $y/S1$

¹ The saying “Every Russian schoolboy knows ...” (that you must recapture with the pawn!) is attributed to the Soviet chess Grandmaster David Bronstein who used it to imply how little Western chess players (in the 1950s) understood of the game compared to any Russian. However, Bronstein never met Magnus Carlsen ♚

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P6: $K(s_2, s_1)$ (P3, P2)

P7: $[\]$ (P5, P6). Empty set meaning that NEG B is inconsistent with A, meaning B is implied by A.

TASK 3: Search (20p)

You are going to evaluate search algorithms that can find the shortest indoor walking paths.

Figure 2 illustrates seven rooms and the actual walking distances between them. Table 1 specifies the straight-line distances between room 127D and all the other rooms. The evaluation function $f(n)$ evaluates node n . When we evaluate the algorithms, we start our path search in room 181 and we want to find the shortest path to room 127D, which is our end node.

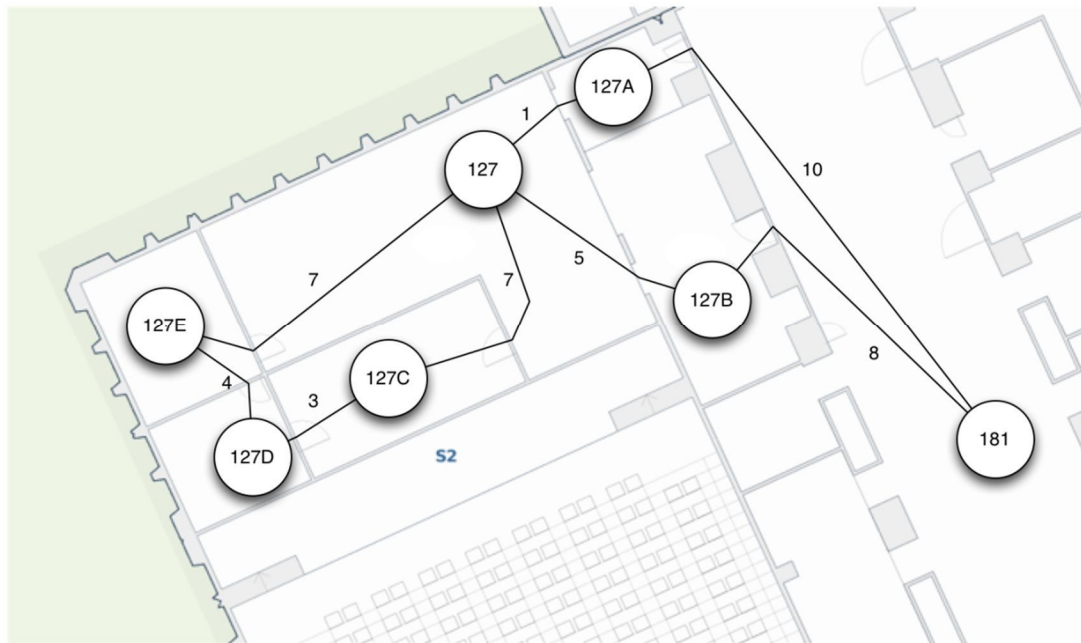


Figure 1: The graph represents the possible walking paths between the seven rooms 127D, 127E, 127C, 127, 127A, 127B and 181. The numbers close to the paths indicate the actual walking distances between the connected rooms.

Table 1: Straight line distance between the rooms and 127D

Room	SLD from 127D
127	7
127A	10
127B	9
127C	3
127E	2
181	14

- a) Greedy best-first search (3p): What is the evaluation function $f(n)$ for greedy best-first search? Write the function and describe the term(s) on the right hand side.

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Answer: $f(n) = h(n)$, $h(n)$ is a heuristic function that estimates how far n is from the goal state, for example SLD for the indoor paths in this task.

- b) A* (3p): What is the evaluation function for A*? Write the function and describe the term(s) on the right hand side.

Answer: $f(n) = g(n) + h(n)$, $h(n)$ is the heuristic, such as SLD, and $g(n)$ is the actual cost of getting to n , for instance the actual distance travelled in this task.

- c) Greedy best first search (3p): For each step in the search, write the evaluation function for the node that is selected for expansion.

Step	Node	$f(n) = g(n)$	Open/Closed
1	181	14	O: 127B (9), 127A (10) C: 181
2	127B	9	O: 127 (7), 127A (10) C: 181, 127B (9)
3	127	7	O: 127E (2), 127C (3), 127A (10) C: 181, 127B (9), 127 (7)
4	127E	2	O: 127D (0), 127C (3), 127A (10) C: 181, 127B (9), 127 (7), 127E (2)
5	127D	0	O: 127C (3), 127A (10) C: 181, 127B (9), 127 (7), 127E (2), 127D (0)

Answer: $f(127B)=9$, $f(127)=7$, $f(127E)=2$, $f(127D)=0$. Total actual distance travelled: 24.

- d) A* (3p): For each step in the search, write the evaluation function including all the terms and their values for the node that is selected for expansion.

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Answer:

Step	Node	$g(n)$	$h(n)$	$f(n)$	Frontier/Expanded
1	181	0	14	14	F: 127B (17), 127A (20) E: 181
2	127B	8	9	17	F: 127A (20), 127 (20) E: 181, 127B What if 127 is explored first (look at 3, alt, which will take one extra step to go to 3)
3	127A	10	10	20	F: 127 (18) 127 (20) , E: 181, 127B, 127A
3, alt	127	13	7	20	F: 127A (20), 127E (22), 127C (23) E: 181 , 127B, 127 (20) Ends up at 3.
4	127	11	7	18	F: 127E (20), 127C (21) E: 181, 127B, 127A, 127
5	127E	18	2	20	F: 127C (21), 127D (22), E: 181, 127B, 127A, 127, 127E
6	127C	18	3	21	F: 127D (20), 127D (22) , E: 181, 127B, 127A, 127, 127E, 127C (21),
7	127D	20	0	20	F: E: 181, 127B, 127A, 127, 127E, 127C (21), 127D (20)

- e) Admissible heuristics (4p): Explain what an admissible heuristics is in one sentence only. Give two examples of admissible heuristics for the 8-puzzle where the objective is to slide tiles horizontally or vertically into the open space until the goal state is reached.

Answer: An admissible heuristic is one that never overestimates the cost to reach the goal.

Two admissible heuristics for the 8-puzzle:

1. Number of misplaced tiles and
2. The sum of the distances that of the tiles from their goal position.

- f) Optimality of A* for graph search (1p): Must the heuristics be both admissible and consistent in order for the Russel and Norvig version of A* to be optimal when applied to graph search? Alternatives: Yes or No.

Answer: yes

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- g) Search algorithms (3p): Which of the search algorithms 1) A*, 2) genetic algorithms, 3) minimax, 4) constraint propagation should be chosen for the following search problems:
1. Search for a schedule of flights that has some restrictions.
 2. Search for best action in backgammon.
 3. Find the best design of a car.
 4. Find the shortest route for a self-diving car.

Answer:

Task	Answer
A	4 (constraint propagation)
B	3 (minimax)
C	2 (genetic algorithms)
D	1 (A*)

TASK 4: Constraint satisfaction (20p)

Figure 2 shows the water regions in Norway, which there are eleven of, and these are Finnmark (F), Troms (T), Norland (N), Sør-Trøndelag (ST), Møre og Romsdal (MR), Østfold (Ø), Sogn of Fjordane (SF), Hordaland (H), Buskerud (B), Rogaland (R) and Vest-Agder (VA).

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

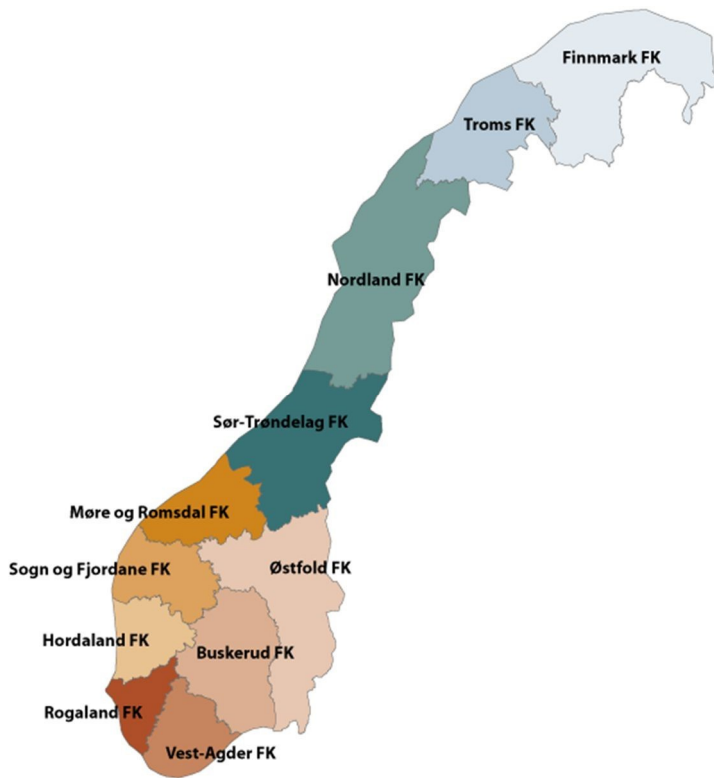


Figure 2: Water regions of Norway.

You are going to color the map. Unlike the artist that has colored the map of figure 2, you can use three colors only (red, green and blue), but no neighboring regions can have the same color. To solve this problem, you have to use your knowledge of constraint satisfaction. You will use the full constraint graph for b, and the reduced constraint graph for d and e. The reduced constraint graph only includes the regions south of Møre og Romsdal (that is we are not including Møre and Romsdal in the reduced constraint graph).

- a) Constraint satisfaction problems (3p): Specify 1) the variables, 2) the domain and 3) give at least three examples of constraints.

Answer:

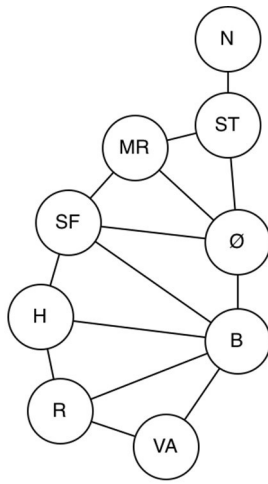
Variables: F, T, N, ST, MR, Ø, SF, H, B, R and VA.

Domain: red, green, blue.

Constraints: No neighboring region should have the same color. $F \neq T$, $T \neq N$, $N \neq ST$.

- b) Graph (3p): Draw the full constraint graph illustrating the water regions of Norway. Use the abbreviations in your graph: F, T, N and so on.

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c) Description (3p): Which of the following terms describe the domain and the constraints of the specified problem?

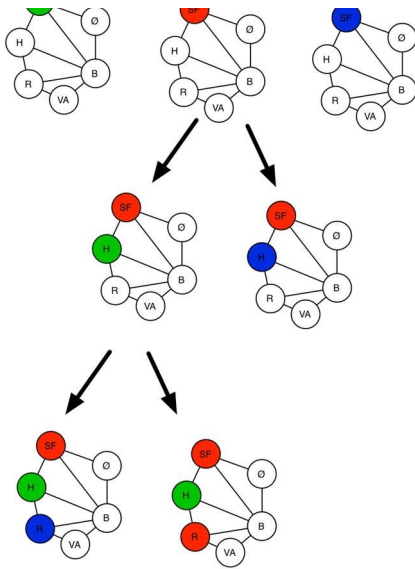
1. Discrete domain,
2. Continuous domain,
3. Finite domain,
4. Infinite domain,
5. Linear constraints
6. Nonlinear constraints,
7. Unary constraints,
8. Binary constraints,
9. N-ary constraints.

<i>Answer:</i>
a. Discrete domain
c. Finite Domain
h. Binary constraints

d) Backtracking search (4p): Illustrate the first three levels of the search tree of backtracking search using the constraint graph. Each node in the tree should list all the assignments made by that point in the search. Use the reduced constraint graph. You should assign values to nodes in the following order: SF , H , R , VA , \emptyset .

Answer: From book: The term backtracking search is used for a depth-first search that chooses values for one variable at a time and backtracks when a variable has no legal values left to assign.

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- e) Forward checking (4p): Illustrate forward checking with a table. Each variable should have a column in the table, showing the remaining domain for that variable at each point in the search (represented by rows). Show three steps. Use the reduced constraint graph.

Answer:

From Book: One of the simplest forms of inference is called forward checking. Whenever a variable X is assigned, the forward-checking process establishes arc consistency for it: for each unassigned variable V that is connected to X by a constraint, delete from V 's domain any value that is inconsistent with the value chosen for X .

<i>Domain</i>	<i>SF</i>	<i>Ø</i>	<i>H</i>	<i>B</i>	<i>R</i>	<i>VA</i>
<i>Initial</i>	<i>R G B</i>	<i>R G B</i>	<i>R G B</i>	<i>R G B</i>	<i>R G B</i>	<i>R G B</i>
<i>After SF=red</i>	<i>R</i>	<i>G B</i>	<i>G B</i>	<i>G B</i>	<i>R G B</i>	<i>R G B</i>
<i>After H=green</i>	<i>R</i>	<i>G B</i>	<i>G</i>	<i>B</i>	<i>R B</i>	<i>R G B</i>

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<i>After R=blue</i>	<i>R</i>	<i>G B</i>	<i>G</i>	<i>-</i>	<i>B</i>	<i>R G</i>
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- f) Heuristics (3p): Of the three heuristics minimum-remaining-values (MRV), degree (D) and least-constraining-value (LCV):
- Which heuristic should be used to choose which region to color next?
 - Which heuristic should be used to decide the order to examine values?

Answer:

From Book:

- a) The **minimum-remaining-values** (MRV) heuristic chooses the variable with the fewest "legal" values.

The MRV heuristic doesn't help at all in choosing the first region to color. In this case, the **degree heuristic** comes in handy. It attempts to reduce the branching factor on future choices by selecting the variable that is involved in the largest number of constraints on other unassigned variables.

- b) Once a variable has been selected, the algorithm must decide on the order in which to examine its values. For this, the **least constraining-value** heuristic can be effective in some cases. It prefers the value that rules out the fewest choices for the neighboring variables in the constraint graph.

Answer to be written down into answer sheet following the given table:

Task	Answer
a.	MRV, D
b.	LCV

TASK 5: Planning (10p)

- a) Characterizing planning (5p): How can a planning (problem) be characterized? Name two situations when planning is useful. (*The answer should be shorter than one page*).

Answer:

Planning is a way of problem solving that focuses on the effects of actions. It is in some ways similar to search however search is focused on sequences of actions that move between atomic state representations, while planning is focused on actions that move between factored state representations.

Situations when planning is useful:

- when addressing a new situation
- when tasks are complex
- when the environment imposes high risk/cost

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- when collaborating with others

b) Plan representation (5p): Explain how a plan can be represented? Give an example of withdrawing cash from an ATM in either STRIPS or PDDL. (*The answer should be shorter than one page.*)

A plan can be represented as:

- States: First-order predicates over objects describing a point in the search space of an application
- Actions:
 - Name: identifier of the action
 - Precondition: conjunction of literals describing whether the action can be taken
 - Effects: conjunction(s) describing the change
- Goals: A conjunction of literals

There are different languages that can be used, we discussed STRIPS and PDDL: buying a Christmas tree:

STRIPS:

Action (withdraw(cash),

PRECOND: At(ATM) \wedge Sells(ATM, cash, person) \wedge hasMoneyOnAccount (person)

DELETE-LIST: hasMoneyOnAccount (person)

ADD-LIST: have (cash))

PDDL:

Action (withdraw(cash),

PRECOND: At(ATM) \wedge Sells(ATM, cash, person) \wedge hasMoneyOnAccount (person)

EFFECT: -hasMoneyOnAccount (person) \wedge have (cash))

NB! - hasMoneyOnAccount(person) is the negation

There are also other ways to represent planning such as Situational Calculus.

TASK 6: Natural Language Processing (20p)

a) (6p) True or False (*correct answer= 1p; wrong answer= -1/2p; total score will be 0-6p*)

- Sentiment analysis is a text classification application.

T (R&N, p.865)

- The purpose of smoothing is to avoid dramatic effects of low-frequency counts.

T (R&N, p.863)

- The bag of words model can be seen as a simple language model.

T (R&N, p.866)

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- ‘Freeze’, ‘halt’, ‘cease’ and ‘finish’ are examples of stop words.
F (NLP lecture, slide 67)
- The task of Information Retrieval is to return the answer to a user query.
F (R&N, p.867)
- Information Extraction systems are often based on templates
T (R&N, p.874)

b) (2p) What are the main features of human languages that make parsing of these different from the parsing of programming languages?

Ambiguity and redundancy (NLP lecture, slide 5)

Other differences relate to that humans languages are constantly **evolving** and (to some extent) that they exhibit higher level of **context dependency**

c) (2p) Sentiment analysis of Twitter messages (tweets) faces several challenges. Give examples of at least four problems that need to be addressed.

There are a whole range of challenges, for example:

Word meaning can be domain dependent; modifiers (e.g., negation) can change or reverse the meaning; figurative language can change the meaning (sarcasm, irony, humour); the very restricted length of the messages; brevity, idiomatic language, non-conventional grammar, spelling errors, hashtags, etc. make processing more difficult - as well as the same issues as in Task6b; references to other tweeters and tweets; links and pictures; mixing of languages; and so on (NLP lecture, slide 48)

d) (4p) The documents in a collection that were returned respectively not returned by an Information Retrieval system in response to a given query were analysed for relevance and shown to be distributed as follows:

	Returned	Not returned
Relevant	60	40
Not relevant	20	180

1. What was the system's precision?

0.75 [(relevant returned) / (all returned) = $60 / (60+20) = 3/4$] (R&N, p.869)

2. What was the system's recall?

0.60 [(relevant returned) / (all relevant) = $60 / (60+40) = 3/5$] (R&N, p.869)

3. What is F_1 score?

A way to combine precision and recall; their harmonic mean: $2PR/(P+R)$ (R&N, p.869)

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4. Calculate the F_1 score of the system.

$$\mathbf{0.67} \quad [2PR/(P+R) = 2*(3/4)*(3/5) / (3/4+3/5) = (18/20) / (27/20) = 2/3]$$

(R&N, p.869)

e) (6p) Suppose you have access to the following knowledge sources:

- Dictionaries of basic word forms (lemmas) for English and Norwegian,
- Morphological inflection rules for the same two languages,
- A large set of English e-mails already classified as spam,
- A large set of Norwegian e-mails already classified as spam,
- A large set of English e-mails already classified as not being spam,
- A large set of Norwegian e-mails already classified as not being spam,
- A huge set of unclassified e-mails written in a wide range of human languages, and
- A stream of incoming messages, each of the length of no more than one sentence.

Describe how you would go about building a system which would analyze each incoming message and produce one of the following outputs:

1. The message is not written in a human language.
2. The message is written in a human language which is neither English nor Norwegian.
3. The message is written in English and is spam.
4. The message is written in Norwegian and is spam.
5. The message is written in English and is not spam.
6. The message is written in Norwegian and is not spam.

You do not need to produce a complete solution, but rather sketch the steps that would have to be taken.

Several solutions are possible. We could, for example, view it as a **language modelling and classification** problem, and do the following:

1. Preprocess the words in the classified and unclassified e-mails, for example by
 - a. removing punctuation
 - b. converting all upper case characters to lower case
2. Further analyse / normalise the words in the pre-classified e-mails:
 - a. Apply the inflection rules to each word
 - b. Map each word to its basic form (lemma) in the dictionaries
3. Create five language models (e.g., bag of words or bigrams) from all the words:
 - a. English spam
 - b. English non-spam
 - c. Norwegian spam
 - d. Norwegian non-spam
 - e. Human language
4. Analyse an incoming message to see which language model it fits closest to
 - a. by either using statistical information from the language models, or
 - b. by applying a machine learning-based classifier trained on the data.

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Alternatively, we could address it as an **information retrieval** task (potentially after doing the same preprocessing and word-level analysis as in steps 1 and 2 in the solution above) and then:

1. Treat each incoming message as a query to the documents (the analysed emails)
2. Retrieve the top N (e.g., 100) documents closest matching that query.
3. Assign the class to the query which the majority of the documents belong to.
4. (If the query matches several classes, more documents can be retrieved.)

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