FINAL

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

EXAMINATIONS 2018

MSc in Computing Science
for Internal Students of the Imperial College of Science, Technology and Medicine

PAPER M1

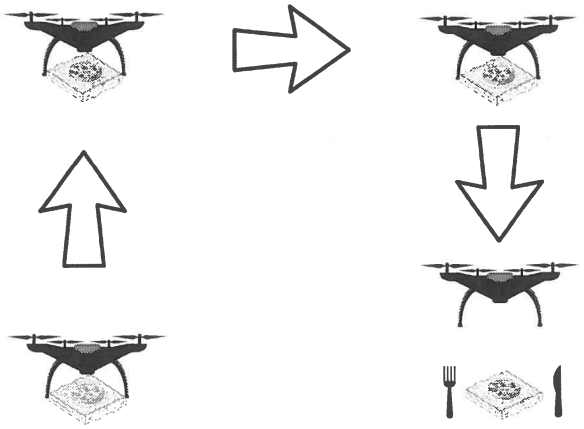
(517+518) PROGRAM DESIGN AND LOGIC

Thursday 3rd May 2018, 10:00
Duration: 120 minutes

Answer THREE questions

Paper contains 4 questions
Calculators not required

Section A (Use a separate answer book for this Section)



1 Consider the following description of a drone-based pizza delivery service:

- A drone has a location (lat, lon, alt) where *lat* and *lon* are floating point numbers indicating latitude and longitude coordinates in decimal degrees, and *alt* is a floating point number denoting the altitude of the drone in metres.
- Drones share a common *cruising altitude*, initially set to 100 metres.
- Pizzas have a weight (in grams). Pizzas are initially in an *uncooked* state but may be *cooked* in an oven. Cooking reduces the weight of a pizza by 15%.
- A drone may be *loaded* with a single pizza with a weight of up to 500g.
- A drone can *fly to* a target location. As illustrated in the diagram above, to do this the drone must *ascend* (i.e. increase its altitude) until it reaches the cruising altitude, *move laterally* (maintaining altitude) until its latitude and longitude match those of the target location, and then *descend* (i.e. decrease its altitude) until it has reached the target location.
- A drone may *release* a pizza to drop it off at the target location.

a Write C++ class declarations (i.e. no function bodies) to support the above.

b Write a test function where:

- A Margherita pizza of weight 512 grams is prepared.
- The pizza is cooked and then loaded onto a drone at location (51.4988, -0.1749, 0).
- The drone flies to location (51.5010, -0.1919, 31.5), where it releases the pizza.
- The cruising altitude for drones is set to 80 metres.
- The drone returns to location (51.4988, -0.1749, 0).

c Write function bodies for your classes.

The three parts carry, respectively, 40%, 25%, and 35% of the marks.

2 Consider the following scenario related to the typesetting of leaflets:

- A leaflet has an integer identifier (ID) and is made up of any number of text elements of 2 kinds: headings and paragraphs. Both elements have a string of text, which end in a line break when printed. Headings are prefixed by a number, which increases from one heading to the next, followed by a dot and a space (e.g. 1. Introduction, 2. Solution, etc.). Paragraphs start with 2 spaces and end with an additional line break.
- A leaflet has an assigned sheet of paper that the text elements can be printed on. A (different) sheet can be assigned to a leaflet at any time. Sheets have a width and height (in number of characters).
- To typeset a leaflet text elements are created and added to the leaflet in the desired order. As leaflets are supposed to be short, adding an element that would make a leaflet exceed 1000 characters must not be permitted. A leaflet can be printed based on the dimensions of the assigned sheet of paper and all text must be properly wrapped to not exceed the width of the sheet (borders and indentation do not need to be considered). Also, if the height of the sheet is exceeded, a warning message must be displayed.
- You may assume the availability of the following template class:

```
template <typename T> class list {
 public:
  list(); //constructor that creates an empty list
  void push_back(const T& item); //adds item to the end
  list<T>::const_iterator begin(); //returns constant iterator
  list<T>::const_iterator end(); } //returns constant iterator
```

a Draw a UML class diagram to describe the above.

b Write C++ class declarations to support the above.

c Write a test function as follows:

- Create a leaflet with an ID 1. Create two sheets: a small sheet (with a width of 50 and a height of 50 characters) and a tiny sheet (with a width of 20 and height of 40 characters).
- Create and add the following text elements to the leaflet in the given order: A heading with the text "Importance of Bees", a paragraph with the text "Bees are important because...", another heading with the text "Threats to Bees", and a paragraph with the text "Significant threats...".
- Assign the small sheet to the leaflet and print it. Assign the tiny sheet to the leaflet and print it again.

d Write the bodies of the functions from part (b). You might want to use the functions: `string to_string(int)` to convert numbers to strings, `string::insert(int, char*)` to insert a character at a position, and `int line_breaks(string)` to return the number of line breaks in a string.

The four parts carry, respectively, 25%, 40%, 10%, and 25% of the marks.

Section B *(Use a separate answer book for this Section)*

Note: All natural deduction proofs must be presented clearly, with wff numbering, where appropriate, indentations, and explanations. Marks will be deducted for unclear and poorly presented proofs. When using natural deduction, unless otherwise stated, you may use any of the primitive and derived rules, but not equivalences, unless they are proved by natural deduction, themselves.

3 Consider the following sentences of logic

T1 $\forall X\,(p(X) \rightarrow q(X) \vee r(X))$
T2 $\forall X\,(r(X) \rightarrow s(X))$
T3 $\neg \exists X\,(q(X) \wedge t(X))$
T4 $\forall X\,(m(X) \rightarrow t(X))$
T5 $\forall X\,(\neg m(X) \rightarrow s(X))$

a Show by natural deduction and also using any equivalences you wish (without additional proof) that
T1, T2, T3, T4, T5 $\vdash \forall X\,(p(X) \rightarrow s(X))$.

b Show that $T3 \equiv \forall X\,(q(X) \rightarrow \neg t(X))$.
Give the Conjunctive Normal Form (CNF) of *T3*.
Reminder: A wff is in CNF if it is of the form: $W_1 \wedge W_2 \wedge \ldots \wedge W_n$, $n \geq 1$, *and each* W_i *is a disjunction of literals.*

c Prove by resolution that
T3, T4, T5 $\vdash q(a) \rightarrow s(a)$.
Explain every step of preparing the sentences for resolution and then the actual resolution proof itself. This proof must be constructed independently of part a.

d Let *S* represent *T1, T2, T3, T4, T5*. Given that:

i) $S \vdash \forall X\,(p(X) \rightarrow s(X))$ from part (a), and
ii) *T3, T4, T5* $\vdash q(a) \rightarrow s(a)$ from part (b),

one of the following holds.

$S \vdash p(a) \wedge q(a) \rightarrow s(a)$
$S \vdash p(a) \vee q(a) \rightarrow s(a)$
$S \vdash \neg s(a) \rightarrow \neg p(a) \vee \neg q(a)$

Which one holds? Give a brief explanation of why it holds using only (i) and (ii), and any rules of inference and any equivalences you wish.

Parts a, b, c, d carry 30%, 15%, 40%, 15% of the marks, respectively.

4 Formalise in predicate logic the sentences (i)-(v), below, that concern types of bank savings accounts. Use only the predicates listed below and the infix predicates $=$, $<$, $>$, $\leq$, $\geq$ if required. Ensure that you present your formulas clearly, using brackets to correctly identify the scope of quantifiers and disambiguate where necessary.

account(ID, B, T)	*to mean bank B offers an account of type T (for example childSave, savings, etc), and the account has an issue identifier, ID (for example issue1).*
regulated(ID, B)	*to mean account with issue identifier ID in bank B is regulated.*
account_min(ID, B, M)	*to mean account with issue identifier ID can be opened in bank B with a minimum amount of M.*
account_max(ID, B, M)	*to mean account with issue identifier ID can be opened in bank B with a maximum amount of M.*
account_int(ID, B, I)	*to mean account with issue identifier ID in bank B has interest rate I.*
inflation(Inf)	*to mean the rate of inflation is Inf.*
compscheme (ID, B)	*to mean account with issue identifier ID in bank B is subject to the savings compensation scheme.*
dissolved(B)	*to mean bank B is dissolved.*
account_cus(ID, B, CusID, Bal)	*to mean customer identified by CusID has an account with issue identifier ID in bank B with balance Bal.*
compensate(B, CusID, ID, V)	*to mean bank B compensates customer identified by CusID amount V for their account with issue identifier ID.*

i) All savings accounts in the bank called SuperMoney (sm) are regulated.

ii) childSave (cs) and teenSave (ts) are types of bank savings accounts, in any banks that offer them. There are other savings accounts in some banks.

iii) All banks offering a savings account have their own minimum amount the account can be opened with, and some, in addition, have a maximum amount the account can be opened with.

iv) No matter what the rate of inflation is, no regulated savings account has an interest rate higher than inflation. But there are unregulated saving accounts with interest rate higher than inflation.

v) Regulated savings accounts are subject to the savings compensation scheme. Any savings account subject to this scheme will have all of its balance or £85,000, whichever is the smaller, compensated by the bank to the customer, if the bank is dissolved.

Part (i) carries 10%, parts (ii), (iii), (iv) carry 20%, and part (v) carries 30% of the marks.