UNIVERSITY OF DUBLIN

CS4B1A1

TRINITY COLLEGE

FACULTY OF ENGINEERING & SYSTEMS SCIENCES

DEPARTMENT OF COMPUTER SCIENCE

B.A. (Mod.) Computer Science
Degree Examination

Trinity Term 2000

4BA1 INFORMATION SYSTEMS

Monday, 29th May 2000 Drawing Office 14.00–17.00

Mr. V. Wade and Dr. M. Mac an Airchinnigh

Attempt **five** questions, at least **two** from each section.
Please use separate answer books for each section.
Students may avail of the HANDBOOK OF MATHEMATICS of Computer Science

SECTION A

1. A Library stores many books and maintains transactions relating to book loans. For each book the library maintains the ISBN number (unique for each book, but the same for all copies of that book), title, a list of keywords which indicate the subject matter of a book, publisher name (unique), publisher addresses in different countries (non unique), author number(s) (unique for each author) and author name(s). To uniquely identify each copy of the book in the library, a "library issue number" is assigned (i.e. a number ranging from 1 to number of copies of <u>that</u> book in the library). For each borrowing of a particular copy of a book, the library maintains the reader number of the borrower, his/her address, the date of loan and the return date that the book is due. You may assume that no copy of a book can be borrowed twice in the same day and that a book can have many authors.

   (a) Develop a Functional Dependency Diagram showing the relationships between the entities in the above database. State any assumption you have made which are not inconsistent with the above description.

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(b) Derive a relational scheme for the database which is in Boyce-Codd normal form, indicating primary, foreign keys and any other constraints you deem appropriate.

(c) Write SQL statements to perform the following queries:

(i) List the titles and author names of the books which are out on loan today (29th May 2000).

(ii) Delete all the copies of books published by 'Printec Publishers.'

(iii) List the readers who have books on loan which are about 'puzzles' or 'quizzes' (i.e. have keywords either 'quizzes' or 'puzzles').

(iv) Make a list of all the books, which have either an author called 'Smith' or a current reader (borrower) called 'Smith.'

2.

(a) Compare and contrast integrity constraints, table constraints, and assertions, giving an example of each in SQL. In your answer refer to timing of enforcement of the constraints, possible results of enforcement of constraints and usual applications of such constraints.

(b) What is an Active Database? How can Triggers be used to support an active database? Illustrate your answer with example applications of active databases, which would use triggers.

(c) Suppose we have two relations:

Employee (Name, <u>Employee#</u>, Salary, Department#, Supervisor#)
Department (DepartmentName, <u>Department#</u>, Manager#, TotalSalary)

Note that the TotalSalary is the summation of all the salary for employees in a particular department. In order to keep this attribute correct, every time we insert a new employee into a department, update an employee's salary, move an existing employee from one department into another or delete an employee — the total salary for a department may change.

Using the SQL Trigger operation, suggest an active rule, which keeps TotalSalary consistent when an existing employee is moved from one department to another.

3.

(a) Explain the following terms: ACID properties of transactions, Serializability.

(b) Consider the following possible schedules for transactions T_1, T_2, and T_3 and determine which, if any, of them are serializable indicating the serial schedule where appropriate.

$$S_1 = \{r_1(a), r_1(b), r_3(c), r_1(c), r_2(c), w_1(b), r_1(d), r_2(b), w_2(b), r_2(d), r_3(a), w_1(d), r_3(d), w_3(d), w_3(c)\}$$
$$S_2 = \{r_1(a), r_2(c), r_2(b), r_3(c), r_3(a), r_1(b), r_1(c), w_1(b), r_3(d), w_3(d), w_3(c), w_2(b), r_2(d), r_1(d)w_1(d)\}$$
$$S_3 = \{r_2(c), r_1(a), r_3(c), r_3(a), r_3(d), w_3(d), r_1(b), r_1(c), w_1(b), r_2(b), r_1(d), w_1(d), w_3(c), w_2(b), r_2(d)\}$$

(c) Explain, giving algorithms where appropriate, how pure time-stamping can be used to provide concurrency control in database management systems.

4.

(a) Compare and contrast Object Oriented DBMSs and Relational DBMSs. In your answer refer to data model definition, representation of complex information (e.g. generalization, aggregation), representation of arbitrary relationships between entities, query languages, integration with programming languages, appropriateness for traditional business information systems/engineering or scientific information systems/multimedia information systems, and standardization.

(b) The diagram in Fig. 1 below depicts a class hierarchy for an Object Oriented Database Schema.

Based on the object oriented inheritance class hierarchy in Fig. 1, define an equivalent relational model in Boyce-Codd normal form. Comment on the complexity of processing a query to calculate all the salaried student wages from the relational model.

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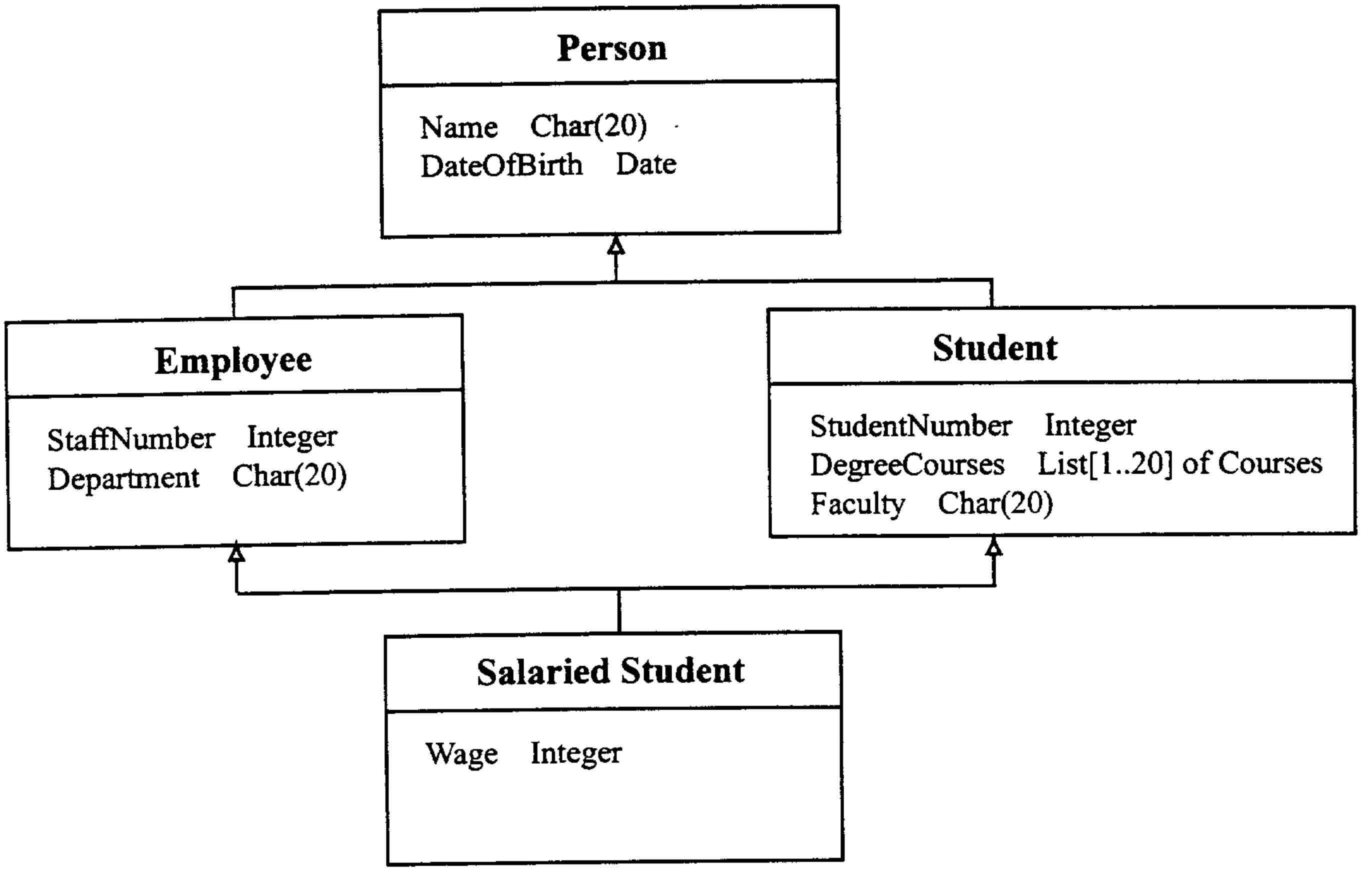

Figure 1: Class Hierarchy for an Object Oriented Database Schema

SECTION B

5. In a certain confederation of islands in the North Atlantic the local air transport network (*ATN*) was modelled as a map α from the islands (*ISLES*) to sets of aircraft types (*AIRCRAFT*):

$$\alpha \in ATN = ISLES \rightarrow \mathcal{P}AIRCRAFT$$

where $\alpha(x) = \{a, b, c\}$ denotes "the isle x has three types of aircraft: a, b, c." In a further elaboration of the model, the numbers of aircraft of each type owned by each island were recorded:

$$\beta \in ATN_1 = ISLES \rightarrow (AIRCRAFT \rightarrow \mathbb{N})$$

where $\beta(x) = [a \mapsto 4, b \mapsto 2, c \mapsto 7]$ denotes "the isle x has 4 aircraft of type a, 2 aircraft of type b and 7 aircraft of type c." Finally, by modelling the capacity of each aircraft one expected to be able to measure traffic between the islands:

$$\kappa \in CAPACITY = AIRCRAFT \rightarrow \mathbb{N}$$

where $\kappa(a) = 12$ denotes "the capacity of aircraft type a is a maximum of 12 adult passengers." All models were subject to the usual well-formedness constraints (invariants).

(a) Give the complete formal specification for each of the following operations:

(i) the addition of a new aircraft of type d to the fleet on isle x;

(ii) the removal of aircraft of type d out of service on isle x;

(iii) the update of the state of the aircraft network α to reflect the fact that isles x and y together with their aircraft fleets were completely destroyed (accidentally?) in a nuclear explosion.

(b) In the elaboration ATN_1, the specification of the addition of a new aircraft of type d to the fleet on isle x was given by

$$Ent_1 : ISLES \times AIRCRAFT \longrightarrow (ATN_1 \longrightarrow ATN_1)$$
$$Ent_1[x, d]\beta := \beta \dagger [x \mapsto \beta(x) \oplus [d \mapsto 1]]$$

Prove that this is a correct elaboration of the $Ent[x, d]$ operation of part (a). You may assume that the retrieval map is $\Re = \mathcal{I} \rightarrow \mathsf{dom}$, and that $((\mathcal{I} \rightarrow \mathsf{dom})\beta)(x) = \mathsf{dom}\,\beta(x)$.

(c) Write a specification to determine the total capacity of the fleet on isle x. [Hint: Consider the map join operator $\bowtie$ which takes two maps μ and ν with common domain and forms the join $\mu \bowtie \nu := [x \mapsto \langle \mu(x), \nu(x) \rangle \mid x \in \mathsf{dom}\,\mu \cap \mathsf{dom}\,\nu]$. You may also assume the existence of a sequence constructor Seq which extracts from a map a sequence of its range elements.]

6. In the usual mapping model of doctor-patient relations, $\kappa \in CLINIC = X \to \mathcal{P}Y$, we associate with each doctor $x \in \mathsf{dom}\,\kappa$, a set of her/his patients $S \in \mathcal{P}Y$.

(a) For each of the following mathematical expressions give at least one appropriate English language interpretation. For each expression indicate any validity conditions which you consider necessary.

(i) $\kappa(x)$,
(ii) $\kappa \sqcup [x \mapsto \emptyset]$,
(iii) $\kappa \circledcup [x \mapsto S]$ where $S = \{y_1, y_2, \ldots, y_n\}$, and
(iv) $\kappa \dagger [x \mapsto \lhd[S]\kappa(x)]$ where $S = \{y_1, y_2, \ldots, y_n\}$.

(b) An alternative mapping model of doctor-patient relations is obtained by considering the relation from the patient's perspective, $\rho \in Y \to X$, where we consider a patient y to have a doctor x. Taking the inverse image, ρ^{-1}, leads to a fibering of the space of patients.

(i) Under what condition(s) can we take a section through the fibers? With the use of a suitable small example demonstrate formally the properties of a section.
(ii) What practical interpretation might you give to such a section?

(c) Let us assume that $\rho \in Y \to X$ is always surjective, i.e., is subject to the invariant that $\mathsf{rng}\,\rho = X$. In these circumstances ρ may be regarded as a projection from Y to X. With the aid of a suitable diagram of fibers illustrate the distinction between the universal image $\forall_\rho S$ and the existential image $\exists_\rho S$ where $S \subseteq Y$ is a set of patients and

$$\forall_\rho S := \{x \mid \text{for all } y, \text{if } \rho(y) = x, \text{then } y \in S\}$$
$$\exists_\rho S := \{x \mid \text{there exists a } y \text{ with } \rho(y) = x \text{ and } y \in S\}$$

Give a formal specification of the discharge of a set of patients S and show how the invariant is preserved for the resulting map $\rho' \in Y' \to X'$ by making explicit use of the universal image.

7.

(a) Let us consider the usual factorial function $f\colon \mathbb{N} \to \mathbb{N}$ which is defined recursively by

$$f(1) = 1$$
$$f(n) = n \times f(n-1), \quad n > 1$$

Construct the corresponding tail-recursive form $g\colon \mathbb{N} \to (\mathbb{N} \to \mathbb{N})$, paying particular attention to the connection equation.

(b) The Fibonacci numbers $1, 1, 2, 3, 5, 8, \ldots$ are defined recursively by

$$F_1 = 1$$
$$F_2 = 1$$
$$F_n = F_{n-1} + F_{n-2}, \quad n > 2$$

Construct the corresponding tail-recursive form. [Hint: One usually begins by considering the product $G_n = \langle F_n, F_{n-1} \rangle$ and finding a recursion on G_n.]

(c) The $\Sigma^\star$-morphisms ψ from the free monoid over an alphabet $\Sigma = \{a_1, a_2, \dots, a_n\}$, denoted $(\Sigma^\star, \cdot, 1)$, into a monoid $(M, +, e)$ have corresponding tail-recursive forms ψ_w, $w \in \Sigma^\star$, where

$$\begin{aligned}
\psi_{uv}(m) &= \psi_v \psi_u(m) \\
\psi_{av}(m) &= \psi_v(m + F(a)) \\
\psi_1(m) &= m
\end{aligned}$$

with the connection $\psi_w(m) = m + \psi(w)$, $\psi(w) = \psi_w(e)$ and $F\colon \Sigma \longrightarrow M$. Show that ψ_w has the closed form:

$$\begin{aligned}
\psi_w(m) &= m + {}^{+}/ \circ F^\star w \\
\psi_1(m) &= m
\end{aligned}$$

8. Let $(M, \otimes, u)$ denote a monoid with an inner law of composition, $\otimes$, and identity element u. A monoid $(M, \oplus, v)$ is said to be isomorphic to $(M, \otimes, u)$ if there is a bijective map $f\colon M \longrightarrow M$ which preserves structure, i.e.,

$$\begin{aligned}
f(m \otimes n) &= f(m) \oplus f(n) \\
f(u) &= v
\end{aligned}$$

We call $(M, \oplus, v)$ the dual of $(M, \otimes, u)$, and vice versa.

(a) The model of a spelling-checker dictionary $\delta \in \mathit{DICT} = \mathcal{P}\mathit{WORD}$ exhibits something of the basic mathematical structures which underpin all model-theoretic formal methods. For example, the 'enter a new word' operation corresponds to the inner law of composition, $\cup$, of the monoid of sets $(\mathcal{P}\mathit{WORD}, \cup, \emptyset)$. Find an appropriate bijective map $f\colon \mathcal{P}\mathit{WORD} \longrightarrow \mathcal{P}\mathit{WORD}$ which constructs the dual monoid and give a suitable practical interpretation of its inner law.

(b) In the elaboration of a spelling-checker dictionary, $\mathit{DICT}_1 = \mathit{WORD} \to \mathcal{P}\mathit{DEF}$ there are at least two binary operators, override ($\dagger$), and relational union ($\circledcup$), which give rise to monoids of maps. Demonstrate with the aid of a suitable example that one of these monoids is more general than the other in interpretative power. In what manner are the two monoids related?

(c) Removal ($⩤[S]$) and Restriction $\lhd[S]$ operators on the monoid of maps with override as inner law are monoid endomorphisms. Let A and B denote the sets of all removal and restriction operators, respectively. Find suitable inners laws of composition for A and B and demonstrate that the corresponding monoids are duals of each other.