UNIVERSITY OF DUBLIN CS4B1A1

TRINITY COLLEGE

FACULTY OF ENGINEERING & SYSTEMS SCIENCES

DEPARTMENT OF COMPUTER SCIENCE

B.A. (Mod.) Computer Science **Trinity Term 1998**
Degree Examination

4BA1 INFORMATION SYSTEMS

Thursday, 28th May Sports Hall 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) Identify and briefly explain the types of constraints that can occur in a relational database management system.

(b) Suppose a database schema consists of two relations containing information about holiday flights. The first relation, called Aircraft, contains an aircraft's id number (primary key), the aircraft's maximum passenger capacity, its minimum crew number requirement and the maximum distance it can travel with a full passenger list and with a full tank of aviation fuel. The second relation, called Holiday, consists of the name of the destination country, location of the airport (city name), and the id of the aircraft which flies to that holiday destination. As there can be several holiday destinations within a country, a combination of country name and city name is used to identify a destination. Also the aircraft must exist in the database before it can be assigned to a holiday destination.

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Identify and illustrate ALL the circumstances under which a relational database management system would have to check for EACH of the following types of integrity constraint violation: key, entity and referential.

(c) In general, discuss how constraints based on the SEMANTICS of a relational schema can be specified in Relational Database Management Systems. Illustrate your answer using the holiday flights relational schema or an extension of that schema.

2. The Communications of the ACM is a journal, published every month, which contains technical papers in the area of computer science. The publisher of the journal maintains a database concerning each edition of the journal and the technical papers contained in each edition.

The publisher maintains the following information concerning each edition of the journal:

⟨ the title of the edition e.g. 'Database Management';

⟨ the Volume and Edition numbers (which together uniquely identify each edition) e.g., Volume 10, Number 5 identifies a particular year and edition within that year;

⟨ number of pages in the edition; and details about the technical papers published in that edition.

The information maintained about each technical paper consists of

⟨ each paper's author(s),

⟨ the paper title,

⟨ the number of pages in the paper and

⟨ a list of keywords describing the technical area of the paper.

(a) Draw a Functional Dependency diagram for the relations in the above database, stating any assumption you have made.

(b) Specify the SQL statements needed to create the fully normalised tables which can be derived from the functional dependency diagram. Note: ensure you fully specify Primary Keys, Foreign Keys, and any constraints you deem appropriate based on the description above and any enterprise rules you have assumed.

(c) Write SQL queries to perform the following:

(i) Retrieve all the titles of papers published by 'Jones, J'.

(ii) Retrieve titles of the papers authored by 'Wade, V' in the area of 'database' or 'programming'.

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(iii) At the end of the year the publisher decides to publish a 'Special Issue' of papers which were previously published in any of the editions of the journal from Volume 10 and which addressed the technical Issue of 'database' or 'CORBA'. Give the SQL command to retrieve the titles of the papers which would be selected for this special issue.

3.

(a) What are the ACID properties of database transactions and distinguish between the following concurrency control techniques: locking, timestamping and optimistic methods?

(b) Outline two deadlock prevention algroithms which combine locking and basic timestamping and illustrate their operation using an example transaction schedule.

(c) Which concurrency control method would be best suited to a customer banking database which is only used by customers when they are lodging money into, withdrawing money from or checking the balance of their own accounts (i.e., no background transactions being executed by the bank staff themselves)? Give reasons for your answer.

4.

(a) What do the following terms mean in relation to Object Oriented Databases: Inheritance Hierarchy (including single and multiple inheritance), Aggregation Hierarchy, Object Identity?

(b) Define an example Object Oriented Database schema which illustrates Inheritance and Aggregation.

(c) Define a relational schema which represents the same information model but uses a relational schema (i.e., show how inheritance and aggregation might be represented using relational tables).

(d) Explain the relative advantages and disadvantages in using relational database management system to model/store object oriented information.

SECTION B

5. Let us consider a farm ($\varphi \in \mathit{FARM}$) to be a collection of fields, $f_i \in \mathit{FIELD}$, each of which contains livestock or crops, or which lies fallow (i.e., is empty). This basic model of a farm φ is given by the space

$$\varphi \in \mathit{FARM} = \mathit{FIELD} \rightarrow \mathcal{P}(\mathit{LIVESTOCK} \cup \mathit{CROPS})$$

subject to certain constraints of which the following is an important one. A field must be homogeneous, that is it can only contain one kind of livestock or one kind of crop. There can be no mixing of either livestock or crops.

(a) Write formal mathematical expressions for each of the following:

i) the merging of two farms φ_1 and φ_2 (as a result of a farmer buying or inheriting a second farm for example);

ii) the determination of all those fields which lie fallow on a given farm φ;

iii) the subdivision of a farm into two disjoint subfarms based on a certain collection of chosen fields S.

(b) For further development of the basic agricultural model a distinction was proposed between the owner of a farm and the workers of a farm (usually called farmers). Owners could be farmers or other individuals, including *legal persons* such as cooperatives, trust funds, etc. We model this by a pair of maps (α, β):

$$\alpha \in \mathit{OWNERS} = \mathit{PERSON} \rightarrow \mathcal{P}'\mathit{FARM}$$
$$\beta \in \mathit{WORKERS} = \mathit{PERSON} \rightarrow \mathcal{P}'\mathit{FARM}$$

where $\mathcal{P}'X$ denotes $\mathcal{P}X \backslash \{\emptyset\}$. Assuming the usual sort of constraints and invariants, write a complete formal specification for the situation where an owner p_1 sells one of the farms φ to one of the workers p_2 on the same farm. Be sure to give a rationale for each decision you make.

(c) Due to an unfortunate outbreak of disease in one of the kinds of livestock (such as the sheep, denoted by l) on one of the farms φ owned by p, all those livestock had to be destroyed ($D[p, \varphi, l]$), and the corresponding fields to be left fallow for one year. Write a complete formal specification for the corresponding state change of the system:

$$(\alpha, \beta) \xrightarrow{D[p, \varphi, l]} (\alpha' \beta')$$

6. Let us consider some models of a computing environment:

$$\alpha \in ENV_0 = VAR \to VAL$$
$$(\tau, \mu) \in ENV_1 = (VAR \to LOC) \times (LOC \to VAL)$$
$$\gamma \in ENV_2 = ZONE \to (VAR \to VAL)$$

where *VAR*, *VAL*, *LOC*, and *ZONE* denote sets of variables, values, locations, and computation zones, respectively. Both ENV_1 and ENV_2 are considered to be elaborations of ENV_0 which is the basic abstract model.

(a) Show how to obtain retrieve functions $ENV_1 \xrightarrow{\Re_1} ENV_0$ and $ENV_2 \xrightarrow{\Re_2} ENV_0$ and indicate any necessary constraints or invariants on the models that you deem necessary.

(b) The semantics of assignment may be tersely represented by the mathematical expressions

$$A_0[x, a]\alpha := \alpha \dagger [x \mapsto a]$$
$$A_1[x, a](\tau, \mu) := (\tau, \mu \dagger [\tau(x) \mapsto a])$$
$$A_2[z, x, a]\gamma := \gamma \dagger [z \mapsto \gamma(z) \dagger [x \mapsto a]]$$

Prove that $A_1[x, a]$ is a correct elaboration of $A_0[x, a]$, subject to appropriate conditions which you will identify.

(c) Let us define a zone z to be an element of the (finite) field $\mathbb{Z}_p$, where p is prime:

$$ZONE = \mathbb{Z}_p$$

Consider a section $ENV_0 \xrightarrow{\Gamma} (ENV_0 \times ZONE)$, $\Gamma(\alpha) = (\alpha, \zeta(\alpha))$, of the (trivial) fibre bundle

$$ZONE \longrightarrow ENV_0 \times ZONE \xrightarrow{\pi} ENV_0$$

where $\zeta\colon ENV_0 \longrightarrow ZONE$ is a distribution function which assigns computing environments to zones. Let $S = \operatorname{rng} \gamma$. Then we may consider an element $\gamma \in ENV_2$ to be formally equivalent to the restricted section $\lhd_S \Gamma = \{\Gamma(\alpha) \mid \alpha \in S\}$. Explain clearly the relationship between the addition of a new fibre $([x \mapsto a], \zeta([x \mapsto a]))$ to the section $\lhd_S \Gamma$ and the fundamental indexed monoid $(ENV_2, \textcircled{\dagger}, \theta)$.

7. A monoid $(H, \otimes, 1)$ is said to act on a monoid $(K, \oplus, 0)$ by endomorphisms if

$$\begin{aligned} (h_1 \otimes h_2)k &= h_1(h_2 k) \\ 1k &= k \end{aligned}$$

and for every $h \in H$ the map $k \mapsto hk$ of K is an endomorphism. For the product set $M = K \times H$ define a binary composition by

$$(k_1, h_1)(k_2, h_2) = (k_1(h_1 k_2), h_1 h_2)$$

Then M is called the semi-direct product of $(H, \otimes, 1)$ and $(K, \oplus, 0)$ with respect to the above composition.

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(a) Let $(X \rightarrow Y, \dagger, \theta)$ denote an arbitrary monoid of maps with binary operator override. Show that restriction with respect to a set $S \subseteq X$ is an endomorphism of $(X \rightarrow Y, \dagger, \theta)$. **[Hint:** Use the fact that $\mu \dagger \nu = \lhd [\mathsf{dom}\, \nu]\mu \sqcup \nu$.]

(b) Show that restriction and removal operators form monoids which are isomorphic to the monoids $(\mathcal{P}X, \cap, X)$ and $(\mathcal{P}X, \cup, \emptyset)$, respectively, and which act on $(X \rightarrow Y, \dagger, \theta)$. What does it mean to say that restriction operators are the *duals* of removal operators?

(c) Form the semi-direct product of H and K, where H is the monoid of restriction endomorphisms which acts on the monoid of sections of a fibre bundle, $K = (SECTION, \otimes, \emptyset)$, where

$$\Gamma_1, \Gamma_2 \in SECTION = \mathcal{P}(E \times Z)$$

and, with the aid of an appropriate diagram, give a suitable interpretation to the composition

$$(\Gamma_1, S)(\Gamma_2, T)$$

8. Let Σ be an alphabet $\{a_1, a_2, \ldots, a_n\}$, and $\bar{\Sigma}$ be the corresponding alphabet of formal inverse letters $\{\bar{a}_1, \bar{a}_2, \ldots, \bar{a}_n\}$. Define the free group over the alphabet Σ, denoted $FG(\Sigma)$, to be $((\Sigma \cup \bar{\Sigma})^*, \cdot, 1)$ where words are written in their reduced form, i.e., occurrences of $a_j \bar{a}_j$ are replaced by 1. Let us now consider the structure $(((\Sigma \cup \bar{\Sigma})^*)^2, \cdot, (1, 1))$ where concatenation on pairs (s, t) and (u, v) is given by

$$(s, t)(u, v) = (s\bar{t}, v\bar{u})$$

Pairs (u, v) and (s, t) are said to be equivalent, written $(u, v) \sim (s, t)$, if they reduce to the same word $u\bar{v} = s\bar{t}$ in $FG(\Sigma)$.

(a) Verify that this law of composition covers

i) the law of concatenation for the free monoid $(\Sigma^*, \cdot, 1)$ by computing the concatenation of two words $u \mapsto (u, 1)$ and $v \mapsto (v, 1)$.

ii) the law of concatenation for the monoid of "positive" difference lists $((\Sigma^*)^2, \cdot, (1, 1))$, where $(us, s)(vt, t) = (uvts, ts)$.

(b) Show how to obtain the monoid of "negative" difference lists. **[Hint:** Consider the function $\zeta : (x, y) \mapsto (y, x)$.]

(c) Extend the Σ^* morphism len from the free monoid to the structure $(((\Sigma \cup \bar{\Sigma})^*)^2, \cdot, (1, 1))$ and show that it has the properties of a logarithm.