Data Base Research: A Survey

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Abstract

The research activities in the area of data base systems are reviewed. Most of the issues considered by research institutes center around models of information, interactive data manipulation, system aspects, implementation techniques and modelling and analysis. Comparison with industry activities and documented user requirements shows differences of emphasis between research and development. Conclusions are drawn with respect to established and potentially emerging principles in the area of data base design and architecture and with respect to potential future trends in data base research.

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1. INTRODUCTION /49, 192/

The objective of this paper is primarily to provide an overview over past and present research activities in the data base area. This pa-

per does not survey commercially available data base software. Further, information retrieval systems and non-computeroriented aspects of information systems are not addressed. We are well aware of the danger of such limitations and recommend to the reader, who is interested in an introduction to the field, to study in depth some of the commercially available data base systems, such as IMS (A.J. Barnett and J.A. Lightfoot: Information Management System (IMS) - A Users Experience with Evolutionary Development. In Data Base Management Systems (D.A. Jardine editor), North Holland, Amsterdam, 1974) in addition to the literature referenced in this survey.

What is a data base system? This is already a question, which has been and still is subject of debates. We will make our definition with the help of a scheme , which in our experience is widely accepted. It is a simplification of an architecture scheme employed by a major standardization group (ANSI/X3/SPARC) and is very similar to schemes shown in Date's or Wedekind's book. To the authors knowledge, the IMS designer have been the first who implemented, consciously or unconsciously, such a scheme nearly a decade ago.

The scheme is shown in fig. 1 and shows persons, views of information, data mappings, programs and a data flow during retrieval of information. The conceptual view is the central point. It represents the way information is seen by the group responsible for the system aspects of stored, integrated information. This group is usually referred to as the "data base administrator". For a given system installation, a conceptual schema specifies which type of information may exist at the conceptual level. A schema describes, what is legal or "correct" and is therefore similar to a grammar defining the syntax of a language.

The conceptual view is never used directly. It serves as a central reference point for other views of information. For example, the physical or internal view of information reflects the way the information is actually stored in memory. Given the data base in conceptual form, we can construct the corresponding physical form with the help of a mapping, the conceptual to internal mapping (fig. 1 mapping C/I).

The use of conceptual information is through mappings. All of these mappings are in the responsibility of the data base administrator and are specified in a data definition and mapping language. The mappings between conceptual and external views serve a double purpose: (a) to select the subpart of information necessary and sufficient for a spe-

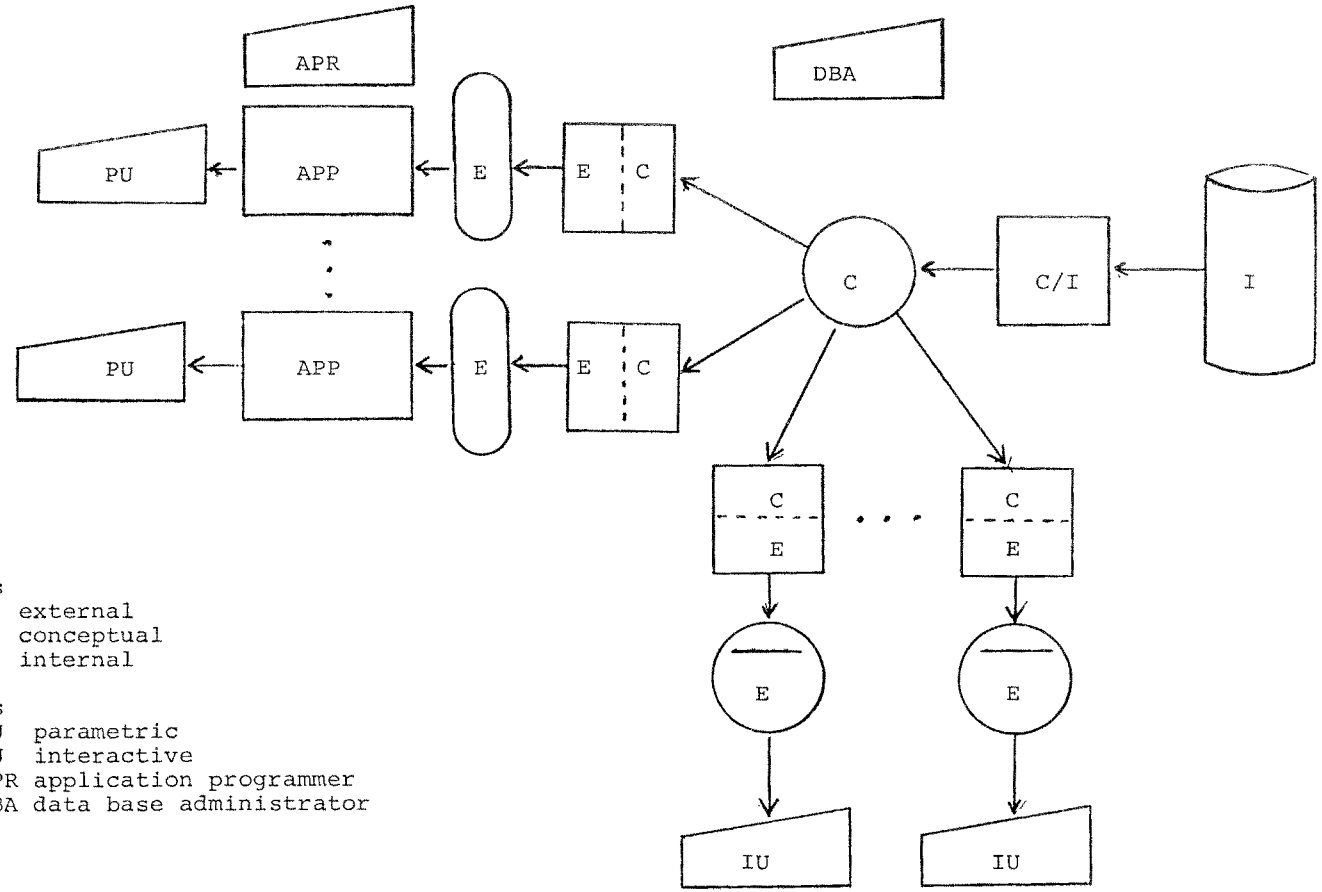


Fig. 1:Structure of a data base system

cific use of the data base and (b) possibly, to transform the selected subview to a view, which is "more natural" for the specific use. Point (a) represents the primary purpose and is of importance for reasons of protection, scheduling, user isolation etc., i.e. essentially for systems aspects.

There are two major end-user groups to consider. First we have the query language user, also called the interactive problem solver and typified by the "non-DP-professional". The query language users view of data is very similar to the conceptual view. He performs data manipulation at a fairly high level without needing help by experts. This is different for the "parametric user", who performs well defined actions with parameters of a simple structure. This user interacts with the system via application programs written by application programmers in some programming language into which a data manipulation language is incorporated as a sublanguage. We talk of a host language - sublanguage relationship. In general, the query data manipulation language is at a higher level than the application programmers data manipulation language.

In practice, large amounts of stored information are extremely unlikely to be used by only one person. It is therefore a requirement to a data base management system that it allows sharing of and concurrent access to the stored information. Concurrency creates a number of problems in connection with system integrity, scheduling, deadlock prevention, recovery, protection, and efficiency in solving all these problems.

While commercially employed systems (like IMS) primarily support applications involving parametric users, research concentrates on support of the interactive problem solver. Correspondingly we find a large number of research activities oriented towards the data model used for the conceptual view and to a single user high level query language system. Sections 2 and 3 are devoted to data models and data manipulation languages to describe this research. In section 4 we will discuss research in the area of system aspects. Section 5 describes contributions of research to implementation techniques such as a storage structures and search algorithms. Section 6 will refer to some of the modelling, measurement and analysis efforts and section 7 will contain conclusions with respect to primary results, recognizable trends and some major problems deserving research.

2. DATA MODELS

The conceptual view has been introduced as the central point of reference in a data base management system. Clearly, such a view should be as close as possible to intuitive notions of information. Proposals for a conceptual view are known as data models. A conceptual data model provides a set of possibilities of how to encode conceptually information which exists in the real world. Of course, the mapping between real world information and conceptual information is not formalized.

Closely connected with the notion of a conceptual data model is that of a conceptual schema. For illustration purposes let us consider an extremely simplified real world situation. We have sets P of professors, S of students, and C of courses. Each of the objects in these sets has a number , which is unique within the set, and a name. Further, we know for every professor which students he advises and which courses are tought by him. A student has exactly one professor as advisor and may attend a number of courses and a course is taught by exactly one professor and attended by a number of students. Fig. 2 shows the information in an attempt to be close to reality without biasing towards any data model.

Conceptual data models are all more or less based on the notions of set theory. One of the earlier attempts is the Information Algebra of CODASYL /34/. Other models and stimulating ideas are due to Mealy /124/, Feldman and Rovner /74/, and, Ash and Sibley /3/. The most successful model in terms of acceptance and as a stimulus for data base research has been developed by E.F. Codd in a series of papers to which we will devote the next subsection.

2.1. Codd's Relational Model (CRM) /39-41, 43/

In CRM information is a finite set of named relations of assorted degree. A n-ary relation is a finite subset of a cartesian product

$$D1 \times D2 \times \ldots Dn$$

where the Di are potentially infinite sets of "scalar" data values such as numerical values or string values. In other words, a n-ary relation is a set of n-tuples. To any relation, the elements of the

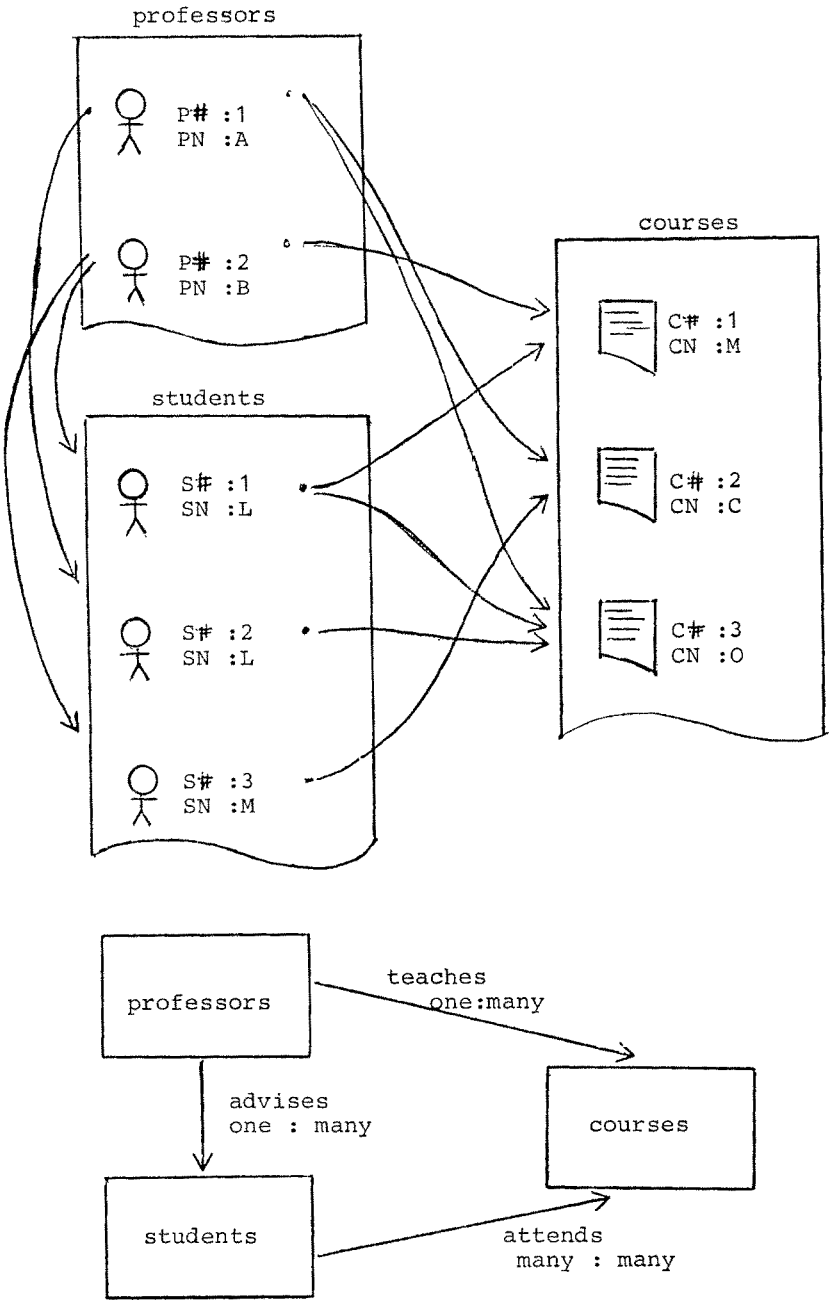


Fig. 2:Example situation and schema

tuples are named with attribute names for ease of reference. A relation is homogeneous, i.e. any two elements of the same relation have the same attribute names associated with them. This allows a tabular listing of a relation as shown in fig. 3, the representation of the example information in CRM.

Some domains within a relation may be keys and/or references. Two distinct tuples in a relation have different values in their key elements. A refernce domain actually is used to refer to some value that is element of another tuple in the same or another relation. For example, P# in P is a key domain, but P# in S is a reference domain which contains only such integer values, which appear as P# in P.

The relations shown in fig. 3 and corresponding to the schema indicated in fig. 4 are all in socalled first normal form. This means, that all elements of a tuple are scalar (and not sets or lists or structural in any other way). This has consequences in the way information can be modeled. Consider the relationship between students and professors. Principally there are at least two ways to store this information:
(a) we can build the set of all students (or their unique numbers) advised by one professor and store this set with the professor tuple or
(b) we store with every student the professor (or his unique number), which advises the student. Case (a) would not be in "first normal form". Fortunately, case (b) is in this form.

The relationships between professors and students or professors and courses are one to many (i.e. <u>one</u> professor advises <u>many</u> students). In these cases we store the converse relation to satisfy normalization. However, the student/course relationship is many to many and therefore requires the introduction of an additional relation, the relation SC. Codd has defined further normalizations, the "second" and "third normal form", which essentially serve to remove some redundancies. The reader is referred to Codd /41/, Date /49/, or Wedekind /192/.

The advantages of CRM are its apparent simplicity and its appeal to those, who are used to "think" in tables, in particular for researchers with a background in the elementary notions of discrete mathematics. Since a relation is a set, set operations like union, intersection, relative complementation etc. can immediately be applied if the relations agree in domain names. More importantly, projection may be

S		
S#	SN	P#
1	L	2
2	L	1
3	M	2

P	
P#	PN
1	A
2	B

C		
C#	CN	P#
1	M	2
2	C	1
3	O	1

SC	
S#	C#
1	1
1	3
2	3
3	2

Fig. 3:Normalized CRM relations

S (S# int, SN char, P# int) key (S#) ref (P# to P.P#)

P (P# int, PN char) key (P#)

C (C# int, CN char, P# int) key (C#) ref (P# to P.P#)

SC (S# int, C# char) key (S# , C#) ref (S# to S.S# , C# to C.C#)

Fig. 4 CRM schema

applied to relations and relations of different structure may be combined using well known methods of composition such as cartesian product or Pierce product, or a generalization called join in Codd's terminology. In a slightly different approach every relation may be viewed as a stored predicate and first order predicate calculus may be applied to define new relations. Codd has investigated both approaches, the "relational algebra" and the "relational calculus" and has shown that they are equivalent /41/.

The relational model has been subject to a number of critical considerations /20, 43/. It is obvious that it does not offer the full range of structures to which we are used within computer science. It has, for example, no equivalent to the hierarchic record organization of COBOL, PL/I, PASCAL or ALGOL68, a structure which is simple, corresponds to intuition and is most frequently used. This is only one important example of a structure violating the "first normal form" condition.

The example of the relationship between students and professors has shown how the schema is affected by constraints. For example, if the one:many constraint of the professor - student relationship is relaxed to a many:many constraint, a completely new relation has to be introduced.

Another consequence of normalization is the fact, that basic information has to be encoded with the help of other information, which is often of no interest to the requestor of the basic information. For example, in order to know the name of the advisor of the student with name "M", the "system" has to learn that this advisor has the professor number 2, since there is no other way to get to his name. This may be considered tolerable, however, more critical situations arise, if we allow a user to see only a subset of domains, which does not contain the key values. For example, a particular user may be allowed to look at every employee's salary and compare it with the employee's manager salary, but for reasons of privacy he is not allowed to look at the man numbers associated with the salaries. There are immediately two problems. First, in order to find a man's manager's salary, the user has to know the man number of this manager, contradicting the privacy constraint. Second, if the man number is projected out it may well happen that two persons with the same salary appear as one tuple in the projection, thus making any statistics on salary distribution in the projection invalid. One can imagine ways around the first prob-

lem though no elegant ways are known to the authors. The second problem is solved in at least some of the experimental systems (like INGRES, SQUARE) by allowing "duplicates in sets". These implementations are actually implementing a homogeneous flat file model as it is described, for example,
by McGee /122/. This model is in turn a special case of the graph model described later in this section. It cannot be claimed that implementations of the homogeneous flat file model find their clean, theoretical foundation in CRM, though some operations, like joins, make sense with both kinds of data structures.

2.2. Graph Oriented Data Models

The common idea behind the data models discussed in this section is the implicit or explicit notion of labeled graphs over entities or named binary relations between entities . The origins of the model in computer science goes back to McCarthy's abstract objects (as models of information) which have to conform to an abstract syntax (as the schema to the model). (McCarthy,J.: Towards a Mathematical Science of Computation. Proc. IFIP Congr. 1962, North Holland, Amsterdam, 1963). McCarthy's work has influenced the activities of a group in the IBM Vienna Laboratories to model the interpreter states during execution of programs (Lucas P. and K. Walk: On the formal description of PL/I. Annual Reviews of Automatic Programming 6, 3 (1969)). The data structures in languages like COBOL, PL/I, PASCAL, and ALGOL68 are adaptations and extensions of this model, in general with restrictions as to what may be specified in a schema. "Schema" appears now as a synonym for "declaration" or "abstract syntax". Some of the data models designers refer explicitely to this origin /1, 56/. Practically all commercially available data base systems are based on the graph model.

Within data base research activities the graph model shows up more or less consciously in a number of papers. McGee discusses a graph model in 1968 /121/. The entity set model of the DIAM system designed by Astrahan, Altman, Fehder and Senko is essentially a binary relational model and therefore a graph model /155/. Other well known graph models are those developed in CODASYL activities and generally known as the DBTG model /35, 37, 38/. We find the graph model also in Abrial's "data semantics" /1/ and many other research papers /20, 56, 63, 158/. Schmid and Swenson employed recently some sort of graph model to es-

tablish a connection between relations in CRM and the real world /151/.

Among the earlier data base research activities the DIAM effort deserves special attention /155/. It contributed essentially to the acceptance of a data base system structure as shown in fig. 1. Its data model, the entity set model, had and still has impact on standerdization activities. The DIAM data model has not been defined with the same mathematical rigor as CRM. This is related to the fact, that its designers stressed the closeness of the model to the real world more than pure mathematical formalism. We will not discuss the DIAM model in more detail here since it can be mapped in a straightforward way to the subsequently described graph model and as such find a clean mathematical foundation.

The essential notion of the graph model is that of an abstraction of objects as nodes in a graph. To be consistent with the most frequently used terminology we call such a node an entity. An entity may be anything "that has reality and distinction of being in fact or in thought, e.g. objects, associations, concepts, and events" /34, 155/. Some entities have unique denotations like
5, 7 or 'ABC'. Other types of entities can only be uniquely identified with the help of relationships between entities.

Information in the graph model is stored as a finite set of named finite binary relations between entities. Since entities are nodes in a graph, relations can be represented as directed labeled edges in the graph. To represent unary relations (which are sets of entities) we assume a given node as the entry node to the information and interprete the binary relation between entry node and any other node as a unary relation. For simplicity in drawing a graph we represent edges from the entry node to other nodes by labeling these nodes with the relation name. Fig. 5 and fig. 6 show the graph model representation and schema for our example.

A first advantage of the graph model over CRM is the fact that only binary relations are used. This removes the need to distinguish between the domains via symbolic domain names. More importantly, due to its explicit notion of entities, which is not present in CRM, it is clean and clear in the mathematical sense without the need to deviate from it for "practical" reasons of convenience. Like for CRM, it is possible to develop calculus or algebra oriented languages with the

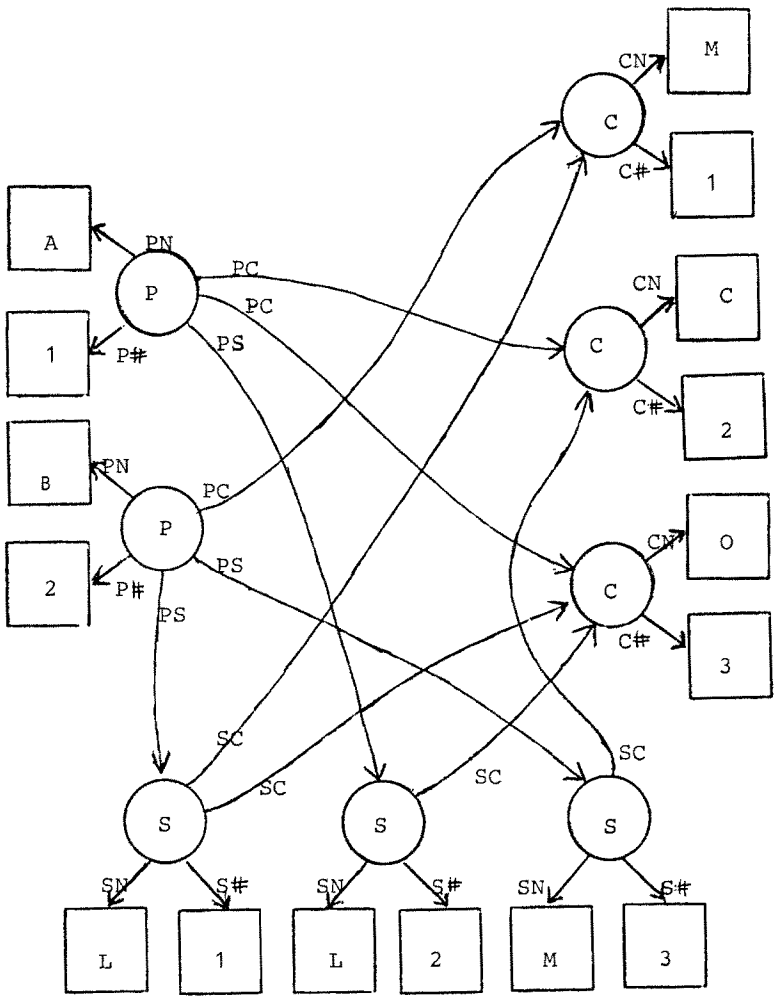
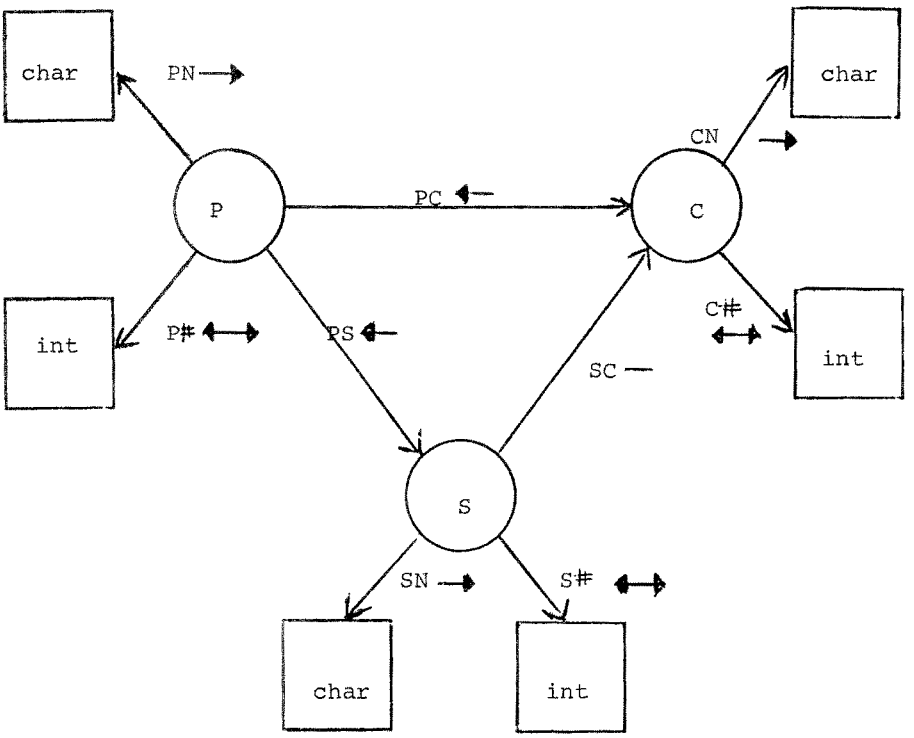


Fig. 5 :Information as a graph



R ⟷ one : one

R ⟶ many : one

R ⟵ one : many

R — many : many

Fig. 6:Schema to the graph model

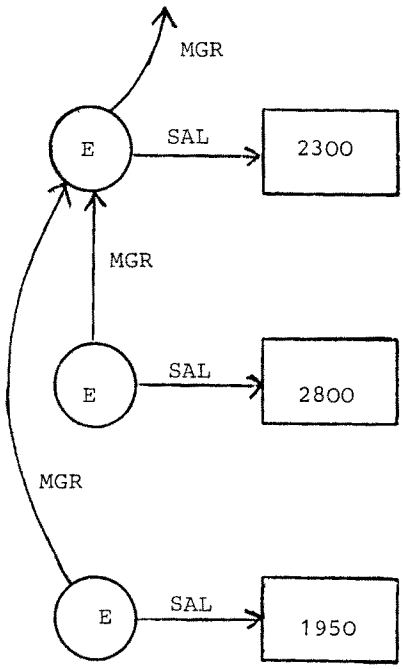


Fig. 7: Subgraph of E, MGR and SAL

same rigor /128/. On the other side it does not provide difficulty to furnish a user with a subview of the data base (i.e. a subgraph) which restricts to the relationships, which may be seen by the user. See fig. 7 for an illustration. Since practically all known structures in computer science can be mapped conveniently to some form of graphs, it does not force us to exclude these structures from our high level data modeling.

2.3. The Equivalence of Data Models

It is not at all surprising that the different models are equivalent in the sense that information encoded in the DBTG or DIAM model can be encoded in CRM and vice versa. Moreover, in most cases there is a simple and straightforward way to convert a schema in one model to a corresponding equivalent schema in the other. The question of choice between two different models must be decided on how "convenient" or "natural" processing becomes in the models. This is, however, not only a question of the data model but also a question of the data manipulation language. In the next section we will therefore come back to the question of equivalence.

The question of equivalence of data models has been investigated by Bobrow /17/, Neuhold /134/, Sibley /167/ and McGee /122/. Different models are likely to coexist for a while (at least in the world of researches), even on the same system. This creates a new mapping problem, namely of how to superimpose a model A on a model B, a problem, which creates the need for a "superimposition theory" as it was stated by E.F. Codd /43/. First results in this direction are reported by Frasson /82/.

3. DATA MANIPULATION LANGUAGES

3.1. Low Level Versus High Level Logic

As we can see in fig. 1, data are accessed in external form either via an application program or interactively at a terminal. In the first case, records are typically retrieved one by one and processed sequentially in a programming language. This type of processing is referred to as "low level" or as "one record at a time logic". Typical for the second case of access is the higher level "multiple records at a time

logic". Research activities are primarily oriented towards the higher level logic. It is important to realize that also in the application program case "multiple records at a time logic" is required to specify in advance on which subset of the data the program is going to operate. The system needs this information for scheduling and resource allocation purposes. In effect, the selection of the subspace to a program is a mapping between the conceptual and the external view, which by the nature of its use has to be specified in a high level logic. Even though research projects are primarily oriented towards interactive access to data and even though their implemented systems are modest compared to commercially available systems, their results may very well be of relevance for the type of processing through application programs as it is still more common in todays user installations.

Subsequently some of the data manipulation languages developed by researchers will be referenced. We start with the CRM implementations, then we continue with languages based on other data models. A special subsection is devoted to languages which are characterized by the way in which they are used. Finally we will come back to the equivalence of data models.

3.2. Some CRM Implementations

Table I lists some of the experimental systems, which claim to implement CRM, though for some it would be more correct to claim that they

System	location	remark	reference
IS/I	IBM UK	algebra	Todd
MacAims	MIT	algebra	Goldstein
RDMS	MIT/MULTICS	algebra	Steuert
MORIS	Milano	calculus	Bracchi
SQUARE	IBM Research	mapping	Boyce
SEQUEL	IBM Research	mapping	Chamberlin
INGRES	Berkeley	calculus	Held
ZETA	Toronto	definitional	Mylopoulos
DAMAS	MIT	calculus	Rothnie

Table I. Some relational systems

implement homogeneous flat file. Of the nine systems shown, the first four represent early experiments. SQUARE is a language based on the concept of "mapping", an approach which is somewhere in between relational algebra and relational calculus. It is implemented on top of XRM, a data management supporting n-ary relations or, better, homogeneous flat files /111/. XRM in turn is implemented on top of RAM, a data management, which supports stored binary relations and resembles the graph model /110/. SQUARE has a compact syntax. The query language SEQUEL is derived from it with more English keywords. INGRES stands for a system, which offers QUEL and the graphics oriented CUPID as enduser interfaces /93, 119/. ZETA is a system which is currently being developed at Toronto. It has a data management supporting relations and provides a "syntax directed" definitional tool to let the user implement his high level query language on top of low level primitives. DAMAS is a system specifically used by its implementor to study an optimization aspect of data access.

To give an impression of the different styles of query languages, let us consider the following query:

> What is the name of the advisor of the student, whose name is "M"?

In IS/1, the relational algebra approach, we obtain:

```
( (P * (S; C2 = 'M' )); C1 = C5) % C2
```

This expression is a sequence of a selection (operator = ';'), a cartesian product (operator = '*'), a second selection and a projection (operator = '%'). Ci refers to the value in the i'th domain.

In QUEL, the calculus oriented query language to INGRES, we obtain:

```
RANGE OF PROF IS P
RANGE OF STUD IS S
RETRIEVE INTO R(PROF.PN) WHERE PROF.P# = STUD.P# AND STUD.SN
= 'M'
```

Here the answer is in the result relation R, a unary relation. Clearly PROF and STUD are variables in the predicate calculus sense over which existential quantifications are applied by default.

In SEQUEL, the "mapping" approach, we obtain:

```
SELECT PN FROM P WHERE P.P# IN
SELECT P# FROM S WHERE S.SN = 'M'; ;
```

All of the nine systems represent what might be called first generation research data base systems. This means that their contribution to the solution of data base problems, though already significant as pointed out above, may be increased by follow-on development. At least for the three systems SEQUEL, INGRES, and ZETA we know that such ongoing research is planned. The follow-on system to SEQUEL is called System R.

3.3. Some Non-CRM Systems

As already mentioned, most research activities are using CRM as their data model. In this subsection we will discuss some languages which are using a graph oriented data model.

First there is DIAM with RIL (Representation Independent Language) as its data manipulation language /72/. The DIAM work continues in an effort called DIAM II with FORAL as its query language /157-159/. Senko's FORAL has the interesting property of a graph (or binary relational) model oriented query language for the composition of relations between entities. The example query of the preceding subsection can be formulated in FORAL as follows:

```
P(PN) where for PS SN = 'M';
```

FORAL establishes the connection between professors and students with a single identifier where IS/1 or QUEL need at least one comparison. A recently described system, developed in Nice, implements the graph model on top of IMS and offers a query language with similar advantages /82/. McGee describes a data manipulation language to a conceptual graph model, which is very similar to the DBTG model /123/.

A very interesting research developed system is SIMS /194/ which offers a query language and a data definition language. The data definition language allows to map data given in their internal form and possibly generated on another computer, to a hierarchical conceptual form. This hierarchical form can then be accessed by the query lan-

guage without actually converting the data. SIMS meets with these features objectives, which are missed by most other experimental systems, though SIMS is one of the earlier implementations.

Report generation, i.e. the design of layouts of computer generated reports is a non-trivial problem which to solve with the help of a computer seems natural. Dana and Presser report about an interesting high level language specifically designed for this task /46/.

3.4. User Interface Aspects

In this section we will discuss some data manipulation languages whose designers apply a specific technique with respect to the interface to the user.

A series of research efforts has as its target to embed the query language into a general purpose programming language to combine the data access with powerful computational facilities. Two of these efforts have as their specific research goal to develop and study protection mechanisms /44, 75/. Earley describes a proposal for the inclusion of CRM data structures into an ALGOL like language /59/. Schauer proposes to build an interactive CRM query language in a data base system for the evaluation of measurement data on top of APL /149/.

A question, which is currently still open, is whether the traditional way of defining rigorously a formal language is the best way to attract all end-user groups to the computer. Some researchers believe in the possibility that a freedom in syntax as offered by a natural language, might make the computer more attractive to at least some user groups. Codd proposes such a natural language system, called RENDEZVOUS, which is currently being implemented /42/. TORUS is a natural language system being developed at Toronto. It uses ZETA as its data management /131/. Thompson, Petrick and Kraegeloh report about experimental language systems, which are already implemented /184, 147, 102/. Further references to systems natural language and the linguistic approach can be found in /156/.

The feasibility of the "communication with the computer in natural language" is subject to rather sceptical considerations. In the case of data manipulation languages many of these considerations are not applicable, since the "universe of discourse" is essentially restrict-

ed to the objects and verbs stored in the data base and described in a simply structured data dictionary.

A completely different approach is taken by Zloof, McDonald and Schauer /198, 119, 149/. Their method requires a display device, which is used to display the description of the stored CRM relations in some graphical form. In Zloof's Query By Example the user fills "examples" into free spaces of the relation description. Simple queries can be formulated easily and with a low probability of error. In McDonald's CUPID, the user has to draw a flow diagram like picture (with the help of a menue) which expresses the semantics of the query. Schauer's extended query by example is an extension and modification of Zloof's method. It is natural to use a display device if information is associated with geographic locations. GADS /25/ is such a system in which a user can point to locations or subareas within a displayed map to obtain information related to the graphic entities.

The question, wether one user-interface oriented approach is more successful than another cannot be answered by abstract reasoning. Investigations are under way, which employ the methods of experimental psychology to find unbiased answers to the posed question /143, 183/. One of the reported experiments seems to indicate that questions of syntax (or more generally of the form as opposed to the contents) are of a slight significance for the unskilled while questions of semantics are significant independent of the users skill /143/.

3.5. Data Model Equivalence

As pointed out earlier, and illustrated by examples, we know that different data models are (or "can be made") equivalent with respect to corresponding schemata. Subsequently we will briefly indicate that equivalence can easily be extended to the equivalence of the query languages. To this end we introduce informally two query languages, one (CRM) for CRM and the other (GRAPH) for the graph model. Both languages are very similar to SEQUEL. In CRM we deal with relation names, attribute names and variables. A variable is denoted by a relation name followed by a period followed by an attribute name.

Example

S relation name
SN attribute name
S.SN variable

In GRAPH we deal with sets (unary relations) and relations (binary relations). A set denotation is a set name or a set name followed by a period followed by a relation denotation. A relation denotation is a relation name or a relation name followed by a period followed by a relation denotation. A set denotation may also be used as a variable with the obvious meaning that the variable "runs" over all elements of the set.

Example

S, S.SC, S.SC.CN sets (or variables)
PS, PS.SC, PS.SC.CN relations

It should be noted that GRAPH is recursive in the definition of sets while CRM is bound to two levels.

The period is in both languages used as the operator for functional composition from left to right.

A query is of the form:

SELECT list1 FROM list2 WHERE predicate;

In CRM list1 is a list of attribute names, list2 is a list of relation names, and the predicate is over variables which can be built starting with the relations in list2.

In GRAPH list1 is a list of relation denotations, list2 is a list of set denotations and the predicate is over set denotations which can be built with the help of relations starting with the sets in list2.

In both languages the use of subscripts may be necessary to avoid ambiguity. The subsequent examples are such that ambiguity does not arise.

Query 1

Name of the professor, who advises student M.

CRM:

```
SELECT PN FROM P,S WHERE P.P# = S.P# and  S.SN = 'M';
```

GRAPH

```
SELECT PN FROM P WHERE P.PS.SN = 'M'
```

This simple query illustrates already the essential difference between the two data models. CRM normalization requires that some logical relationship between entities are encoded with the help of unique porperties of these entities while in the graph model these relationships may be used directly. Therefore, CRM has to make a comparison where GRAPH simply uses functional composition as we do in natural language. This will become even more apparent in the next query.

Query 2

Names of courses attended by students which are advised by 'B'.

CRM:

```
SELECT CN FROM P, S, C, SC WHERE P.PN = 'B' and  P.P# = S.P#
and  S.S# = SC.S# and SC.C# = C.C#;
```

GRAPH:

```
SELECT PS.SC.CN FROM P WHERE P.PN = 'B';
```

The brevity and elegance of the GRAPH form compared to the CRM form should, however, not be used to conclude an essential superiority of the graph model over CRM. In fact, it is possible to extend the CRM language with a macro processor which accepts as definitions relations between entities in terms of their CRM encodings. This macro processor can then accept GRAPH queries and convert these queries into CRM queries in a simple straight forward algorithm. With other words, we can implement the GRAPH language on top of a CRM implementation such that the user has all the advantages of the graph model. The differences

of the languages and their underlying models appear on a level which is primarily of a syntactical nature since they can be transformed away with the help of syntax macros. Issues of one data model versus the other are of little practical relevance given the right sort of implementation. Many other questions like those discussed in subsequent sections deserve and are in the process of receiving more attention.

4. SYSTEM PROBLEMS

4.1. Introduction

The major problems in a data base system like IMS are connected with concurrent access to data shared by many users, with application program management and scheduling, with system enforced data integrity, with locking and recovery or error isolation, with data independence and last, but not least, with high enough transaction rates and short enough response times to make the whole system attractive for the user.

The implementation of such a system, even for experimental purposes, may turn out to be quite costly in time and manpower. It is therefore natural that only few research projects aim at a large portion of the full set of data base management system functions. Among the systems mentioned in section 3, DIAM in its original conception was at least very ambitious with respect to data independence and supported storage structures. System R, the follow-on activity to SEQUEL, though being experimental, plans to provide solutions in nearly all of the problem areas mentioned above.

The fact that researchers so far have not developed full size operational data base systems does not mean that they have ignored problems outside data models and high level query languages. In subsequent sections we will reference a considerable number of relevant papers in the area of data independence and data integrity and recovery in connection with multi-user systems. In addition, the reader will find references to research in the area of security and authorization in the attached bibliography.

4.2. Data Independence /175/

A data base system supports data independence to the extent in which it allows transformations of the internal or conceptual forms of data without affecting (a maximum of) existing programs in the sense that non-affected programs, which run correctly before the transformations, run also correctly after the transformations. Hence, data independence is in effect the independence of programs with respect to data transformations. This makes clear that data independence is not the automatic consequence of the selection of a certain conceptual data model as it is sometimes claimed.

We distinguish between internal and conceptual data independence. The need for internal data independence, i.e. independence of application programs with respect to changes of the internal form of the data, while the conceputal form stays invariant, is a consequence of the widely recognized fact that there is no absolutely best internal data organization /182/. The performance of an application program depends heavily on how many of its access paths are directly implemented (for example via links or inverted files or other storage structures; see section 5). Every such direct implementation means redundancy in storing, i.e. requires additional update activities. The data base administrator will attempt to optimize the internal organization for a given mix of application programs. Since the mix changes with time, there will be a need to adapt the internal data organization.

The need for conceptual data independence arises due to additions of new types of information, or more generally, changes in the conceptual schema. In general, at least some of the existing application programs are affected, while still a large part may remain unaffected. Consider, for example, the addition of a domain to a CRM conceptual data base. There should be no need to alter programs, which only read data, since the old model is a subview (projection) of the new model. This may already be different for programs which update information, since there may be a dependency between the changed domains and the new domain. Certainly, at least some of the programs which insert new elements into relations are affected, since otherwise the new information cannot be entered. Other changes in the conceptual model, for example, relaxing the many to one constraint of a binary relation to a many to many constraint, may even affect read only programs, if these programs are designed such, that they rely on the old many to one constraint.

Support of conceptual data independence requires that the system is capable of determing for each of its application programs, whether it is affected or not. This involves a very complex decision problem, which is not solvable in general. It is therefore necessary to restrict the data mapping languages such that the decision problem remains solvable. This requires a type of theory, which has not been extensively applied /exceptions appear, in other contexts, in 53 and 65/.

Support of internal data independence requires the following:

1. A data definition and mapping language, which specifies the internal form to every conceptual form allowed by the schema. The degree of data independence to a given conceptual schema is the set of different mappings supported for the conceptual schema.

2. To any given application program the system must be capable of recognizing the predefined access paths in the internal schema, which meet "optimally" the program's needs, and exploit these access paths during execution of the program. This process has been called reduction of the external access to the internal access. A system without this optimizing reduction may be "logically" data independent but practically serves no purpose . In other words, what is necessary is a data independence which results in performance gains for the user.

Almost all of the experimental query language implementations described in section 3 support data independence to a limited degree in the following way: When a user (in his "data base administration role") introduces a new relation he may specify which attributes should be inverted. However, a query is formulated independently of whether there exist inversions or not. During execution of a query the system exploits the advantages offered by inversions and maintains the inversions without any burden on the user except unavoidable storage and time overhead /175/.

A more comprehensive approach to data independence starts with the development of a flexible data definition and mapping language. Taylor, and with a slightly modified motivation, Smith have developed such languages for a data model very close to the DBTG model /179,

169/. As pointed out earlier, SIMS has also such a language, which enables it to operate on given data without converting these data as a whole /194/. The importance of the possibility to access data by means of a description and without converting the data as a whole is illustrated by the existence of data collections, which to convert to a standard form is more expensive than rewriting all the application programs operating on these date /166/.

The evaluation of a data definition and mapping language in a full size data base management system is a very complex task. This fact has probably given impetus to experiments with such languages in the area of data translation, which has also a justification in its own right. Data translation is the conversion of data, which have been created and processed in one system, to a data organization which allows processing in another system. The orientation of these projects combines practical orientation with experimental evaluation of the power of mapping languages, while the projects still remain small enough to be conducted in less than a large group.

Ramirez et al. have built a compiler, which generates conversion programs from data descriptions /142/. This work makes use of the mentioned data definition and mapping language developed by D. P. Smith . Similarly, Taylor's language is used in another major activity at the University of Michigan / Merten, Fry, 126/. This work is continuing with increased functions being built into the currently runnning prototypes. The underlying data models in both projects are DBTG oriented. The usefulness of CRM as internal form of data during translation has been investigated by Navathe and Merten /133/ with a negative result. Liu and Heller have used contextfree grammars as data descriptions at the record level /108/. Housel, Lum and Shu have developed a language DEFINE (mapping to a hierarchical structure) for data definition and a language CONVERT (mapping between hierarchical structures) for translation definition and plan to implement these languages in a prototype /95, 165/. Again their model of data is that of a graph, which, for the purpose of translation, is decomposed into hierarchies. In a network of computers, such as the ARPA net, data conversion is of particular importance. Su and Lam, and also Schneider and Desautels describe an approach to data translation specifically oriented towards this use /177, 153/.

4.3. Data Integrity and Recovery in Multi User Systems

Though the problems, which exist with respect to data integrity and recovery are also present in single user systems, they are enormously increased in a system with many concurrent users. In fact, without multi-user support, traditional means under user responsibility may be adequate for dealing with these problems. In a multi-user system the system has by necessity to take over some of the responsibility for the solution.

The notion of data integrity is closely connected with the notion of consistency and the schema. A schema may be viewed as a collection of assertions about the data base contents which stay invariant during processing. These assertions are also called consistency rules. Such rules may state that information is in a certain sense complete (for example, whenever something is known about a person, then its mannumber, name, address and birthdate are known). A more complex rule may require that a person cannot be its own ancestor, or, that the sum of different expenses in a department may not exceed the budget allocated to the department. A data base supports data integrity to the extent in which it allows a user to specify consistency rules, which are subsequently enforced by the system.

A straightforward approach to specifying such rules could consist of the following.

1. Provide the user with a general language like predicate calculus or a query language to specify assertions.

2. Whenever the data base has been modified, the system checks, whether the assertions still hold.

This approach, proposed for example in /1,78/ and recently also in /66/ has to be considered with caution. First, it is for a general language undecidable whether the assertions are in themselves consistent. Second, it has to be carefully defined when the consistency of a data base is checked, since a user must in general perform a number of modifications to a data base before a consistent state is again transformed into a consistent state. Third, checking of a set of complex consistency rules may require access to a large portion of a data base, which can range from hours for small data bases to several weeks for larger data bases in processing time.

The first problem can be solved only, if the language in which the consistency rules are expressed, is simple enough so that the consistency of the rules remains decidable. Practical systems, like IMS, certainly satisfy this criterion.

The second problem has been recognized and has lead to the introduction of the notion of a transaction /65, 66/. A transaction is a sequence of transformations of the data base by one user, which are supposed to transform a consistent state into a consistent state. Beginning and end of a transaction are under user control. Now consistency checking can take place whenever a transaction is complete.

The third problem is in some way connected to the first one. Given a consistency rule, the system must be capable of determing, how costly its checking during data base transformations will be. The variation of costs of checking a consistency rule may be illustrated with an example: Given a father relation, a consistency rule may state that the subgraph containing only edges labeled with father is cycle free. Checking this rule requires an algorithm that is in execution time proportional to n**3, where n is the number of objects participating in the father relation. If the stored information contains in addition for every person the birthdate, the rule that the birthdate of the father precedes the birthdate of the son, serves the same purpose as the previous cycle rule. This rule can, however, easily and efficiently be verfied for every data base change. In most situations "system enforced integrity" makes only sense, if the time needed for the enforcement is bound by a linear function of the time necessary to perform processing without integrity assurance. A compiled approach like the assurance of integrity constraints by query modification, as proposed by Stonebrecker /176/, may help since it allows comparative analysis of the queries with and without constraints. Of course, such an analysis does not have to be at the source level.

The problem of integrity is increased with concurrent access by more than one user. The system has, in addition, to ensure that the users do not interfere with each other during update operations. To this end the system must provide a facility which gives a user exclusive access to a part of the data base for a limited time. Basic mechanisms for granting exclusive access to a user are well known from operating systems under the names of locking or semaphores.

The situation is analyzed in a technical report by Eswaran et al

/65/. A complication of locking in data base systems, also explained in /65/, is the need to lock objects, which may not yet exist, from being created /30/. There are an infinite number of objects which may potentially be created (though the set of created objects is always finite). Such locks may be described by predicates with an infinite extension. Performance requirements dictate that it can be decided for two such predicates whether they overlap. This imposes restrictions on the formulation of predicates to be handled by the system /65/.

Locking has as consequence the danger of deadlocks. As in operating systems there are essentially two ways to deal with deadlocks. The first, proposed for example by Everest /67/ is preclaiming. With preclaiming of resources the system can schedule the user's transactions such that no deadlock appears. The second solution is preemption, i.e. taking away resources from one process to give the resources to the other process. The preempted process has then to be positioned back to a state in which it did not hold the resources. This is possible with the help of journals and checkpoint files, i.e. data sets which record the internal state of a process during its execution /83/. This method is discussed by Chamberlin et al /29/. It should be noted that these files are required in most systems for recovery purpose.

Recovery is necessary whenever it is impossible for a transaction to terminate normally. The cause for this may be a deadlock, a logical error in the user's program (a zerodivide exception or a consistency check failure, for example), a hardware failure, or the failure of a transaction which has directly or indirectly (via the data base) delivered input to the transaction. The first objective of recovery is the isolation of a failure, such that an error does not propagate in the data base. A second objective is to restart all transactions which have been affected by a failure without being the cause such that they continue execution as if no failure had appeared. This is to a large extent possible. Recovery algorithms have been described by Genton /83/, Davies /50/, Bjork /15/, Edelberg /62/ and Sayani /148/. The basis for much of this work has been laid by recovery in operating systems such as MULTICS /81/.

All solutions to the integrity and recovery problems must of course avoid placing an unnecessary burden on the user. The most that should be expected from an application programmer is to inform the system of the beginning and the end of transactions. The interactive problem

solver should not be required to know about transactions. He should, as far as the query language is concerned, be able to act as if he were the only user of the system.

As with data independence, the problems discussed in this section are at the beginning to be understood. There is certainly significant room for improvement over proposed and existing solutions, in particular, in providing the functions with improved performance.

5. STORAGE STRUCTURES AND SEARCH ALGORITHMS

Data independence as discussed in the preceding section derives its value (a) from the existence of storage organization techniques which reduce the sometimes enormous search time required otherwise and (b) from the existence of algorithms which allow to utilize the storage structures without binding the programs to these structures. The next two subsections are devoted to these two topics.

5.1. Storage Structures

One of the frequently employed techniques is the acceleration of a search with one parameter with the help of an inverted file. If the inverted file is repeatedly inverted we obtain an hierarchical index organization described by Bayer and McCreight and known as 'B-Tree'. B-Trees allow a logarithmic search time for retrieval, update and insert /9/. Lum introduced multi-attribute indexes which allow quicker answers to queries of higher complexity /112/. Finkel and Bentley describe an extension of binary trees to quad trees supporting logarithmic searches with two parameters /77/. Haerder describes methods of address list compressions ('bit lists') to reduce the storage costs of indices in certain cases /90/.

Another method of reducing search time is hashing. Hashing has been extensively studied in connection with its application to data management /113, 115/. Ghosh and Lum have recently shown that under their assumptions, 'hashing by division' is in general best /85/.

Of course, there are a number of additional, essentially basic techniques applied to data organization such as links between or the splitting of records. These methods may be combined in various modifi-

cations. Storage structures have been extensively studied in the past and are well described in textbooks and surveys /54, 99, 100, 118, 120, 135, 160/. The problem remains to offer this richness of structures to programs without binding the programs to specific structures, i.e. to offer the structures with data independence. In the case in which the program does not know the internal organization, it is the system's responsibility to utilize the storage structures optimally. Attempts to solve this problem are discussed in the next subsection.

5.2. The Reduction Problem

Reduction is the problem of reducing external accesses to internal access, where the relationship between internal and external representations are given by mappings of these forms to a conceptual form (fig. 1). Reduction is something like an "optimization" with the primary objective to reduce the number of accesses to secondary storage during execution of a query or an application program. The term "optimization" should not evoke unrealistic expectations; the problem is too complex and is loaded with similar problems as optimization in a compiler.

Variations in the objectives of optimization are connected with the handling of intermediate expressions over data sets. Consider, for example, the expression

(A op1 B) op2 (C op3 D)

where A, B, C, D are large relations and op1 to op3 are operators in the relational algebra. A straightforward evaluation might construct two intermediate relations AB = A op1 B, and CD = C op3 D and then evaluate AB op2 CD. Such an algorithm requires in additon to enormous amounts of secondary storage accesses also an enormous amount of auxiliary storage, which may by far exceed the storage occupied by the underlying relations A, B, C, and D. On the other hand, there are drastic improvements in the evaluation of some queries if during their evaluation at least some temporary inversions can be built. Most of the research in this area is primarily oriented towards the interactive use of a data base of modest size and consequently assumes that auxiliary data sets (i.e. indices) can be built temporarily for one query execution.

One of the earliest comprehensive investigations into this problem is due to Palermo /140/. Palermo claims that for the investigated type of queries no tuple has to be accessed more than once. This is achieved by building indices and restricting the domains of variables in calculus expressions and applying a "least growth principle" for the sequence of operations. A reduction algorithm applicable to the DIAM system is described by Astrahan, Ghosh and Senko /5, 84/ . Greenfeld and Rothnie look at the problem of handling quantification in calculus expressions efficiently /89, 147/. Another implemented version of a reduction algorithm is described by Astrahan and Chamberlin /6/. Their problem consists of primarily taking advantage of inversions, but their algorithm involves also the construction of intermediary lists (indexes) by merging of inversions.

A paper related to the reduction problem is due to Wong/Chiang. They assume that each query is a boolean expression over elementary queries. In this case the data base can be organized according to the elementary queries and reduction becomes essentially the problem of putting a boolian expression into some standard form /195/.

CPU usage has not received much attention, perhaps under the assumption that CPU time is not the bottleneck in the system. This assumption is, however, not always valid. To reduce CPU time, less dynamic and less interpretive search stategies are required, which can be compiled into a CPU efficient search module or access module per application. As mentioned earlier, the compiler approach has been taken or proposed by several researchers primarily, however, for other reasons than efficiency /Mehl, Fernandez, Conway, also Taylor in 125, 75, 44 and 180/.

It should be clear that the reduction problem is very complex. Every algorithm described above has to make a number of assumptions with respect to system structure, which are not generally valid. This has to be so, as long as there is no generally respected data base architecture. Questions, which potentially deserve more attention in future research are the recognition of constraints in storage requirements and CPU time in addition to "minimizing" secondary storage accesses.

6. MODELLING AND ANALYSIS

Research in the area of modeling and analysis has as its objective to

learn about existing systems by analyzing their behaviour and to develop simple probabilistic models for the components of a data base management system. Such models may help to predict the influence of changes in a system or system design. Thus the designer of a data base management system and even more, the data base administrator should have primary interest in these research activities.

The need for modeling of data management system and data base systems has been recognized early by Senko and his colleagues and lead to the development of an analysis tool called FOREM and a follow-on tool called PHASE II /154, 138/. Haerder has recently performed a comparative analysis of current indexing techniques using these tools /91/. FOREM and PHASE II are useful to evaluate storage organizations, but limited with respect to overall data base system simulation. Nakamura et al. report about a data base simulation model which they have constructed with the help of a conventional simulation package /132/. Their model is a fairly detailed, event driven simulator of the processes in a data base management system. These processes are so complex that questions of simulation performance may become critical. A possible way out may be the development of comprehensive data base system simulating tools. A step in this direction is proposed by Reiter /144/.

Data base systems have also been objects of analytical modeling activities though they are clearly too complex to be analytically treatable as a whole. Analytical studies restrict themselves therefore to well defined parts of the system. FOREM is an example of a deterministic, analytical tool for the analysis of storage structures. The methods proposed by Cardenas in /22/, Yao in /196/ and Wedekind in /193/ are also essentially deterministic.

To mention is also the analytically tractable queueing model of the DL/I component of IMS developed by Lavenberg and Shedler /103/. Though they allow for "rather general" distributions, their model is at a gross level. For example, it does not explicitly represent the physical storage organization and total I/O is represented by a single server queue. Extensions of the model are, however, likely to make simulation necessary.

Perhaps the most frequently investigated question is the selection of indices to a flat file. Authors, who have contributed to research on this problem under varying assumptions are Lum and Ling /114/, Palermo

/139/, Stonebraker /174/, King /98/, Cardenas /23/, Schkolnick /150/, Yue and Wong /197/ and Farley and Stewart /71/. Shneiderman has investigated the question of index size at different levels /164/.

Data may be allocated to or destributed over a variety of categories: first, data have to be allocated within a storage hierarchy in an attempt to balance between costs and access time, second, data have to be assigned to physical devices to minimize contention given their position in the hierarchy, third, in case of a network (like the ARPA net), data have to be assigned to nodes in the network to improve accessibility and reduce line costs. Lum et al. as well as Buzen and Chen have considered the problem of allocating data within a storage hierarchy, given statistical information on the usage of the data sets /116, 21/. Lum et al. specify a total cost function to an allocation and an algorithm which finds the allocation to a minimal cost. Buzen and Chen's model takes in addition queueing effects at the hierarchy levels into consideration. Their algorithm's target is to minimize response time under given storage constraints.

The second problem, minimizing disk arm contention by suitably distributing data sets over a number of disk drives given their usage statistics, has been considered by Chandra and Wong and recently also by Easton and Wong /31, 60/. There is no best algorithmic solution, but heuristic approaches are given and some bounds for the optimality are derived.

Casey and Chang have considered the third problem of allocating data within a simplified network of computers to reduce line costs /26, 27, 32/. Chang has extended Casey's linear cost functions to a more general function. Both specify algorithms, which attempt to minimize line costs.

With the analysis work reported so far, at least one question remains open: what are the characteristic input data? Or, with other words, how is the workload of a data base system statistically characterized? Nakamura et al. in their simulation raise the further question of the validity of their model. Answers to such questions can only be found by actually observing operational systems and collecting statistics. Rodriguez and Hildebrand describe how relevant data ranging from a log of the user's messages, over a trace of the application program calls (to the data base system) to a trace of physical disk address references can be collected in operational systems /145/. Lewis and Shedler

derive from such observations that the interarrival times between transactions can be satisfactorily modeled by a non-stationary Poisson process (i.e. a Poisson process with a time dependent rate) /107/.

In a semi-empirical approach, Ghosh and Tuel, and also Easton, determine the parameters of a theoretically established model to make the model fit to empirical data /86, 61/. Ghosh and Tuel model certain interactions in a data base system by linear relationships and determine the coefficients by comparison with measurements, which are also used to validate the model. Easton has proposed to use an extension of the independent reference model for the sequence of references of application programs to blocks on secondary storage and again has validated this model by comparison with the behaviour of a large data base system.

It is clear that the objective to obtain representative models and validated workload characterizations has not yet been convincingly met. The reasons for this are connected with the current state of the art of data base research in general, which will be summarized in the next section. However, it is also clear that research on modeling and analysis of data base systems as described in this section has made significant progress, and that its continuation is extremely important from a practical point of view.

7. SUMMARY AND CONCLUSIONS

Before we try to summarize the research activities of the past, at least two major factors have to be considered:

Data base systems are in their objectives of a complexity that is in our opinion by far greater than the complexity of programming language implementations or operating systems. Consider alone the goals of data integrity and data independence. In conventional systems, the integrity remains the responsibility of the user, in a data base system the system has to take over a large part of this responsibility. In a conventional system, a user's program may be device independent due to implementation of equivalent storage structures on different devices. The goal in a data base system requires that the user's program is not only independent of different storage on the same (or another) device, but also that the system takes advantage of current structures during

access where restructuring is under control of the user in his data base administrator role.

The area of data base systems research is new. Major activities started only a few years ago. Understanding the real problems takes a large amount of time; demonstrating the viability of a solution requires expensive prototype implementation efforts. Before such large implementations are performed, the risk of failure has to be reduced by prior assessment. This justifies that a fair amount of research was spent in clarification. For example, it is sometimes held against the researchers that they are engaged in a "religious war" around data models. The question, which data model is taken, is certainly important and of a similar nature as the question, which programming language should be supported. However, data base researchers are now discussing the problem of different models with a changed attitude: it is not so much the question of selecting between two models but more the question of how one model can be represented on top of the other.

A number of promising activities have been started and will continue, which design and evaluate the man-machine interface for the interactive problem solver. In another branch of research, investigations into the system aspects have reached a level that prototype efforts are justified and now under way.

Data translation, driven by data description and mapping languages, continues to be investigated with increased power of the languages. With respect to storage structures there is already more available than can be intelligently handled by data base management systems. Research probably has to put more emphasis on how these structures can be efficiently utilized.

Modeling systems in a way that significant help results for the data base administrator is in its beginning. It will take some time, before the research which has already been conducted and has to be continued is combined into a useful set of tools for the system designer or administrator.

Comparing the obtained results with industry activities we may see first a difference of emphasis. Systems like IMS are primarily designed for and employed by parametric users while research systems are primarily designed for the interactive problem solver. With the current state of art, it is likely that research changes priority some-

what in favour of the parametric user. The modeling and analysis work described in section 6 is already now primarily oriented towards running, productive systems.

Conclusions

With the wealth of research existing, it becomes meaningful to ask: what are among all these results the major achievements? Are there any trends recognizable with respect to a change of research direction? What are currently the major problems? While we are trying to answer these questions, we are well aware that the reader may wholeheartedly disagree.

Major results

1. Model Development for Data Independence

One of the primary achievements of past research is the agreement on a type of data base system structure, which is shown in fig. 1. In particular, this means that we have to deal with at least three levels of information (conceptual, internal, external) that users assume different roles (parametric, problem solving, application programming, and data base administrating) and finally that the user in his data base administrator function has control over storage structures to tune the performance of his installation.

2. Multiple Records at a Time Logic

Due to the orientation of research to the interactive problem solver, high level multiple record at a time logic has been developed exceeding in power and flexibility the features offered in many commercially available systems. In particular the notions of views and predicate locks are of similar importance to the parametric use of data bases as to the problem solving use.

3. Storage Structures

Storage structures like the B-trees or to say it more generally "what can be found in Knuth vol. 3, chapter 6" or other textbooks represent important results and are basic to future research activities.

Recognizable Trends

1. Data Model Coexistence

After years of controversies, it is increasingly realized that different models have their justification even within the same system. The coexistence of different models in one system is called the superimposition problem and likely to find more attention in the future.

2. Integration of the DBMS into the OS

Past research has made apparent that many of the problems in the area of scheduling, resource management and recovery, i.e. classic operating system functions, cannot be solved outside the data base management system. Increased experience in this area has already lead to systems, which in much respect contain operating system functions. It can be expected that further research makes the need of integrated solutions to operating, time sharing and data base management systems even more apparent.

3. Data Dictionary/Directory

With the current merge of operating system and data base management system arises a large number of places where descriptive information about data and programs is stored in the system. A trend is recognizable to combine these different types of descriptions into a central data dictionary, thereby ensuring more consistency among the descriptive data and generally offering a simpler interface to the user for maintaining the descriptive information.

Major problems

1. Performance

Performance in the sense of throughput and transaction rate constitutes currently the major problem. It is generally felt that current systems do not offer the level of achievable performance, though this can only be proved by better performing alternatives. In particular, that CPU time may constitute a bottleneck has not been recognized in the past and research is necessary in this area.

2. Integrity, Data Independence, Recovery

It is necessary to provide more possiblities of specifying system enforceable integrity rules and data representations, which can be handled by the system with efficiency. The emphasis here is on more functions and efficiency (to provide these functions ignoring efficiency is trivial) so that the users installation as a whole has benefit. Similarly techniques which allow rapid recovery from failures are extremely desirable and lacking.

3. Concurrency

The problems of concurrency (deadlock prevention, scheduling) again in connection with efficiency, have not been solved in a satisfactory way. These problems increase in multiprocessing systems and with data bases, which are distributed on a network of computers.

4. Design Tools

In todays systems, and even more so in future systems, the user has to make a number of decisions like: how to model the conceptual information, or how to select hardware and physical representation. With the current state of the art, he is not given much information, which helps in making these decisions. Some of the research reported in section 6 is certainly relevant for the development of such tools.

5. Data Reorganization

In a dynamic system with addition, deletion and update of stored information it is inevitable to physically reorganize the data from time to time. The reason is a type of physical disorder like storage fragmentation, which does not affect the logical order, but degrades performance and storage utilization. To reestablish physical order, it is, in general, necessary to dump and reload significant parts of the data base as a whole, which is therfore not available during this process for normal use. For large data bases, which are used around the clock, the interruption may become too long to be tolerable. (The time range is from hours to weeks for a reorganization). A solution to the reorganization problem is necessary which avoids interruption.

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8. BIBLIOGRAPHY

The subsequent list of references contains the basis for this status report. It is hoped that it is also of value as a reference to recent research results. Where present, the annotations are intended to help the reader in selecting literature. They should not be considered as critical reviews, which can be found elsewhere. Subsection I contains alphebetically ordered lists of cross references in numbers referring to entries in subsection II, which is a partially annotated list of references, ordered according to first author.

8.1. Cross References

Privacy

Recovery

Resource Allocation and Scheduling

Search Algorithms

Storage Structures

Surveys and Textbooks

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Trends are:
1. The evolution of a tripartite data description (conceptual, internal, external) as used by ANSI/X3/SPARC.
2. The current debate data structured model (graph, network) vs relational model contributes to the understanding of the nature of data. 3. The introduction of new hardware to support data base algorithms.

9. Bayer, R., and McCreight, E. Organization and Maintenance of Large Ordered Indexes. Acta Informatica 1, 173 - 189 (1972).
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10. Bayer, R. Symmetric Binary B-trees, Data Structure and Maintenance Algorithms. Acta Informatica 1, 290 - 306 (1972).
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data bases for interactive design (W. M. Cleemput and J. G. Linders, editors), Waterloo, Canada, September 15-16, 1975, available from ACM. See also Schauer /149/.

14. Biller, H., and Neuhold, E. J. Formal View on Schema-Subschema Correspondence. Information Processing 74, Proc. of IFIP Congress, North Holland, Amsterdam, 1974.

15. Bjork, L. A. Recovery Scenario for a DB/DC System. 1973 ACM National Conf. Proc., 142-146 (1973).
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A detailed description of a low level query language accessing a relational data base.

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The paper describes an experimental system implemented in LISP. It contains a brief but excellent discussion of the EDMS (hierarchy or network) approach vs. Codd's relational approach.

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SQUARE is a syntatically terse, set oriented, high level query language based on the so-called "concept of mapping". See also Chamberlin/Boyce for "SEQUEL".

19. Bracchi, G., Fedeli, A., and Paolini, P. A Relational Data Base Management System. Laboratorio di Calcolatori, Instituto di Elettrotecnica, Politechnica di Milano, Internal Report No. 72-5, 1972.
MORIS is a Codd relational system with a calculus oriented manipulation language. The users view (external schema) may include hierarchical structures (i.e. unnormalized data).

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A program is described, which may be used to estimate total storage costs and average access time given the data organization and device related specifications.

23. Cardenas, A. F. Analysis and Performance of Inverted Data Base Structures. CACM 18, 253 - 263, 1975.
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24. Cardenas, A. F., and Sagamang, J. P. Modeling and Analysis of Data Base Organization: The Doubly Chained Tree Structure. Inform. Systems 1, 57 -67, 1975.

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The author gives an exact and a heuristic solution to the problem of allocating data sets within a network of computers, given the costs of storing at and transmission between nodes.

27. Casey, R. G. Design of Tree Networks for Distributed Data. AFIPS NCC 1973 Proc. vol. 42, 251 - 257, 1973.

28. Chamberlin, D. D., and Boyce, R. F. SEQUEL - a Structured English Query Language. ACM SIGFIDET Workshop 1974, ACM, New York, 1974.
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The authors propose to use deadlock-detection and backout of processes in case of deadlocks. Their algorithm avoids indefinite delays of a process.

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The authors specify a heuristic algorithm to allocate data sets to disk drives such that the probability of simultaneous access of one disk drive is minimized. The worst case performance of the algorithm is analyzed. See also Easton/Wong.

32. Chang, S.K. Data Base Decomposition in a Hierarchic Computer System. ACM SIGMOD 1975 Int. Conf. on Mgmt. of Data, San Jose,

1975.
The author has extended Casey's results by allowing a non-linear cost function.

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A treatment of the hierarchy allocation problem taking queuing effects into considerations. See also Buzen/Chen.

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36. CODASYL Programming Language Committee. DBLTG proposal, February 1973.
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37. CODASYL Data description Language Committee. Data Description Language. Journal of Development, June 1973.
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38. CODASYL Systems Committee. Feature Analysis of Generalized Data Base Management Systems. Technical Report, May 1971. Available from ACM.
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Calculus. 1971. ACM SIGFIDET Workshop, ACM, New York, 1971.

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50. Davies, C. T. Recovery Semantics for a DB/DC System. 1973 ACM Natl. Conf. Proc., 136 - 141, 1973.
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56. Doerrscheidt, A. Das Konzept des Objektbeschreibungsbaumes als Grundstruktur eines graphenorientierten Datenbankmodells. Lecture notes in computer science 26, 532 - 541, Springer Verlag, Berlin, 1975.
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The basic features of query by example are illustrated. The user's perception of data processing in this query language is that of manipulating tables in a graphically pre-established frame of reference consisting of table skeletons, into which the user fills information.