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DESIGN OF THE DIAGNOSTIC ENCYCLOPEDIA WORKSTATION (DEW)

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Abstract—The Diagnostic Encyclopedia Workstation (DEW) contains reference knowledge for diagnostic support in pathology. Illustrations are accessible via a video disc device. DEW can hold more knowledge, pictures and case histories than books, and its information is accessible via several entries. Software for data entry has been written in MUMPS with use of the relational database toolkit AIDA, which is particularly suited for manipulation of free text. The graphical mouse-driven user interface is written in C using MetaWindows.

The DEW contains 85 diagnoses in ovarian pathology, covering all frequent cases and many rarities, illustrated by approximately 3000 pictures, divided among 158 cases.

Diagnostic support   Interactive encyclopedia   Pathology   Reference knowledge

1. INTRODUCTION

This paper focuses on the design and implementation of an electronic encyclopedia, aimed to contain reference knowledge in the field of pathology. Reference knowledge consists of all information available to the pathologist in the diagnosis of a case: it includes the training received, the diagnostic experience gained in practice, books, atlases and the expertise of consulted colleagues. In pathology, decisions are primarily based on visual observations of patient materials. Due to preservation, visual evaluations can be reconsidered by repeated observations. Because of the repeatability of observations, pictures have a lasting value as a carrier of knowledge. Therefore, reference knowledge in pathology has an intrinsically pictorial component.

We introduce a system called Diagnostic Encyclopedia Workstation with acronym DEW, which contains verbal information as well as pictures. Since pathology is a wide-ranging domain, the DEW is, for the time being, restricted to the pathology of the ovary. This part of pathology is quite circumscribed and, compared to most organs, complex enough to be a good representative of pathology in general: the ovary contains several kinds of tissue and its hormonal status changes both monthly and in a lifetime.

This paper describes the considerations underlying the design of the DEW, the design itself and implementation of the DEW. Since the database is read-only the software for data entry and for consultation are developed as separate entities, using for either application the most suitable programming language and tools. Both parts of the application software are described.

2. CONSIDERATIONS UNDERLYING THE DESIGN OF THE DEW

There are several restrictions to the use of books as reference knowledge. Table 1 shows how the requirements for the contents of such a computer system are derived from

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Table 1. Overview of how requirements for contents, hardware, and software are derived from the drawbacks of consulting books as source of reference knowledge

Drawbacks of books	Requirements for contents	Technical /software requirements
pictures per diagnosis usually limited to 1 or 2 in black and white →	large collection of well documented illustrated cases →	large optical storage capacity with fast retrieval
limited differential diagnostic information →	differential diagnosis lists and criteria for differentiation ↘	
many books necessary to cover field of pathology →		large storage capacity on disk and data base system with flexible manipulation of free texts
directed search for information impaired by one-dimensional access →	well structured information and subdivision in separate categories →	flexible retrieval via several entries

the drawbacks, inherent to the consulation of books. A self-explicable user interface is important to promote acceptance of the system by pathologists.

In addition to the requirements mentioned in the table, the system must run on a commonly used PC and accessories of moderate cost in order to compete with the constantly recurring costs of books, necessary to guarantee widespread use.

On the basis of these demands an IBM-AT personal computer was selected, equipped with 640 Kb memory and a 20 Mb Winchester drive. The computer is connected to a video long-disc player (VLP). A video disc can be mounted in the player and contains a maximum of 54000 images on either side, stored in pulse code modulation using one track per picture. Each image on the disc can be addressed by sending simple command codes via a standard RS-232 serial interface. The quality of the images on the disc are comparable with the average illustrations in regular books. The videodisc is used in an increasing number of applications such as archival purposes, education, and diagnostic support [1–3]. Figure 1 shows an overview of the DEW.

3. DESIGN OF THE DEW

Database

The choice of a database system and the design of the database was started with an inventory of the structure of pathology knowledge and the demands for retrieval.

The structure of reference knowledge in pathology can be represented in a hierarchical way: diseases of the ovary are ordered by the WHO, which is reflected in a classification tree [4]. The top node of the tree is the ovary and the leaves of the tree are diagnoses. Between top and leaves are one or more intermediate levels, containing subgroups of diagnoses. The structure of the reference knowledge can be represented by an extension of the classification tree: to each diagnosis there is a description, differential diagnoses, literature references, and well documented cases. The cases are the source of the illustrations per diagnosis. However, this extended tree is not strictly hierarchical since part of the cases, differential diagnoses and literature references will be associated with more than one diagnosis, thus have multiple connections with higher levels in the tree.

When using a strictly hierarchical database redundancy of information is inevitable since multiple connections of a node with higher levels are not allowed in a hierarchical tree [Fig. 2]. The amount of redundancy would be considerable as it involves the cases with multiple diagnoses, many literature references and all differential diagnostic information. The presence of redundancy implies inefficient use of memory and, more important, it is impractical in keeping the database internally consistent during entry and update of information. The use of a relational database eliminates the necessity of redundancy and allows for efficient retrieval of separate entities of information.

As to the size of the database there are eight major groups of diagnoses [4]. Some of these are subdivided, making a total of 25 subgroups of tumor diagnoses encompassing approximately 90 diagnoses, including rarities. In this number each different tumor grade is counted separately. Blaustein [5] recognizes four diagnosis groups in non-tumour pathology of the ovary, covering 62 diagnoses including rarely occurring diseases. When comparing pathology books some variation in these numbers occurs. A basic encyclopedia, excluding non-tumor rarities, will contain 90 tumor diagnoses and 35 non-tumor diagnoses, including a description of the normal ovary. The average amount of text is estimated at three pages per diagnosis and one page per case. With an average of three cases per diagnosis the requirement is 950 pages of text or 2.5 Mbyte of memory with the possibility of extension to other organ systems.

The relational database system AIDA meets all database requirements, summarized in Table 1 [6]. AIDA is a 4GS (fourth generation software) package, written in MUMPS which excellently supports manipulation of free text. Its availability as a toolkit makes the AIDA-MUMPS combination very suitable for construction of the database and the software for the entry and update of information.

The actual database contains six main tables for the storage of information:

(1) The relation DIAGNO holds the diagnosis description, divided among 17 different categories of information as shown in Table 2. Since a text may be shared by more than one diagnosis, a numeric field is present for each category to store a reference to another diagnosis.

(2) The relation CASUS contains information about patient cases. Its contents are also shown in Table 2.

(3) The relation CASIMA has only fields of fixed length. It holds all pictures belonging to a case, sorted by subject of photography, laboratory technique (both character fields) and magnification (numeric field).

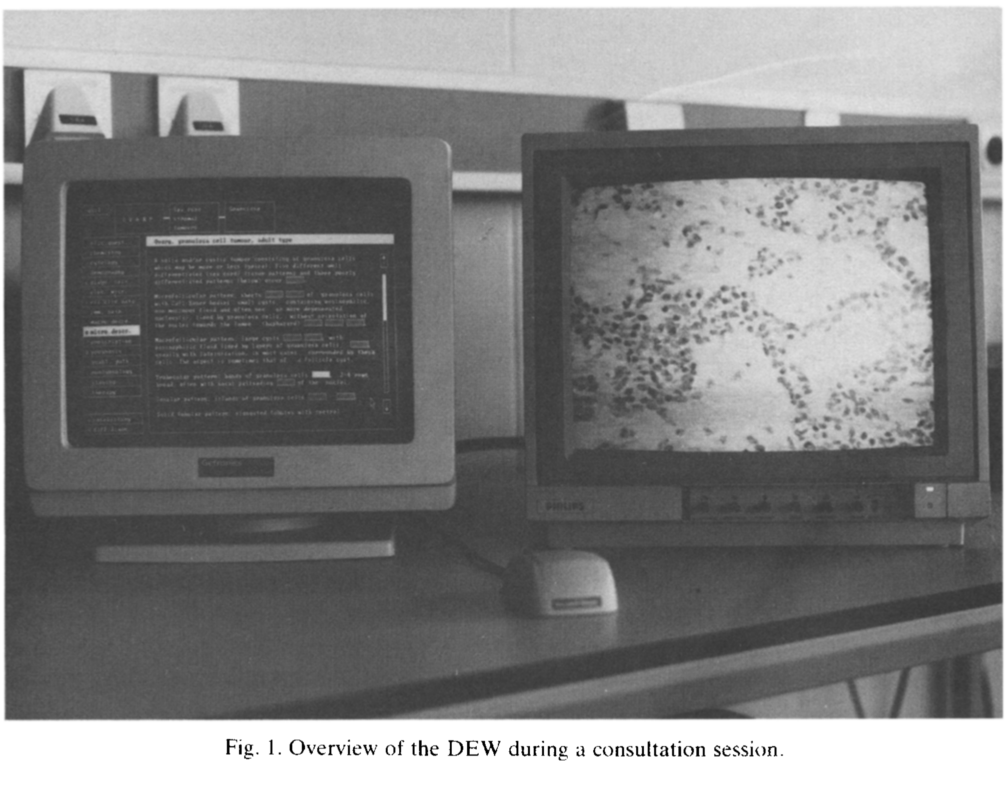

Fig. 1. Overview of the DEW during a consultation session.

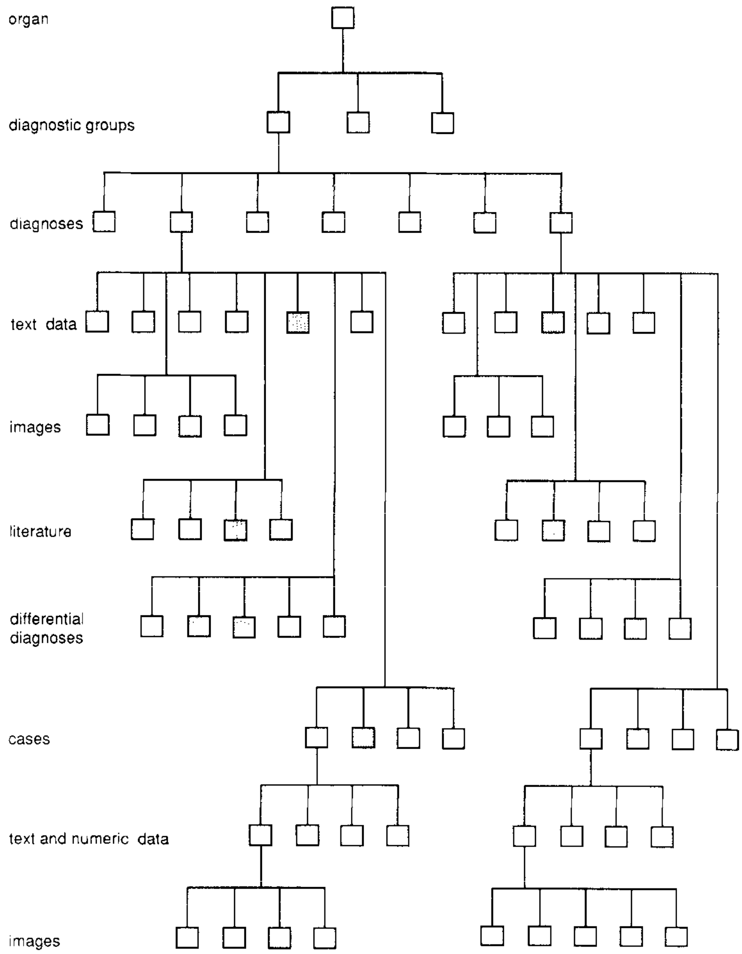

Fig. 2. Structure of pathology information. Places marked by a shaded box indicate multiple occurrence of information.

Table 2. Contents of the relations DIAGNO and CASUS. Text fields are free length fields, whereas character and numeric fields have a fixed length

Relation DIAGNO Field name	Type	Relation CASUS Field name	Type
Diagnosis number	integer	Casus number	integer
Diagnosis name	char	Code of case	char
Demography	text	Diagnosis of case	char
Clinical signs	text	Sex	char
Macroscopic description	text	Age	integer
Macroscopy recipes	text	Start of disease	char
Radiology	text	FIGO stage	char
Laboratory data	text	Macrosc. description	text
Staging	text	Microsc. description	text
Microscopy description	text	Mitoses/25 fields	integer
Electron microscopy	text	DNA index	integer
Immune pathology	text	Volume % epithelium	integer
Cytology	text	Therapy	char
Quantitative pathology	text	Follow-up	char
Quant. pathol. recipes	text	Case history	text
Diagnosis criteria	text		
Therapy	text		
Prognosis	text		
Clinical questions	text		

(4) The relation DIFTXT consists of a free text field which holds differentiating criteria for each pair of morphologically related diagnoses. Since such a text sometimes applies to more than one pair of diagnoses, two numerical fields are added to store a reference.

(5) The relation IMAG contains for each image a numerical field for its address on the video disc and a free text field for a caption.

(6) The relation LITDAT holds all literature references. A character field of fixed length is used to store the name of the first author and a free text field stores the complete reference.

Besides these main relations, which directly store information relevant to the user, the database has several relations for internal use. They represent one-to-many relations. For example, the relation DIACAS links cases to diagnoses: it stores at each diagnosis number the cases belonging to that diagnosis. Similar relations are present to link diagnostic groups with diagnoses and diagnoses with differential diagnoses. In each one-to-many relation, sequence numbers offer the possibility to order the rows in the relation. This is especially desirable for differential diagnoses, which can then be ordered by decreasing relevance. The main structure of the database is shown in Fig. 3(a) and 3(b).

Contents of the database and the video disc

At present 85 tumor diagnoses with 158 cases have been entered in the database. These diagnoses belong to four major diagnosis groups of ovarian pathology: common epithelial tumors, sex cord stromal tumors, lipid cell tumors and germ cell tumors. The diagnosis descriptions are primarily based on textbooks and publications in journals [4, 5, 7–11]. Consultation of the descriptions is facilitated by the fact that they are uniformly organized: the items of information in each category are described in a fixed order, which is shared by all texts of that category. For each diagnosis a differential diagnosis (DD)-list has been made on the basis of a search through the literature for morphologically similar diagnoses. In addition, tables are constructed with differentiating features for each pair of morphologically related diagnoses.

As to the cases, a few diagnoses are not illustrated by a case because of their rarity such as malignant serous adenofibroma and polyembryoma. Part of the cases serve to illustrate more than one diagnosis, implying a higher average of cases per diagnosis than 85/158. The illustrations belonging to the cases total approximately 3000. For the acquisition of macroscopic pictures an archive search was done, which was successful for only a minority of the diagnoses. The majority of the histologic slides have been especially cut from available paraffin material to obtain an optimal basis for photography. Standard histologic stains available for each case are Hematoxilin-Eosin and PAS. Dependent on the diagnosis involved and available material, additional stains are also available: PAS-diastase, astrablue, Gomori, Giemsa, Grimelius and fat. The objective magnifications include 1.25×, 2.5×, 10×, 25×, 100× and 160×, with an additional magnification of 4× at the level of a color slide ($24 \times 36\ mm^2$). Some electron microscopic, immunomicroscopic and cytologic slides are included. The availability of techniques and magnifications varies per case.

User interface for data entry

The software for data entry and update is written in MUMPS from which AIDA routines are called to perform database operations.

The user interface contains 30 different input screens. Numerical and fixed length character fields are combined in one screen insofar they belong to one relation. All free text fields have their own input screen. Screens can be bypassed, allowing for direct input of available information. Figure 4 shows the input screen for the microscopy description.

The entered data is checked by AIDA with respect to its type: text, character or numeric. More specific validation is performed by the application input program, which

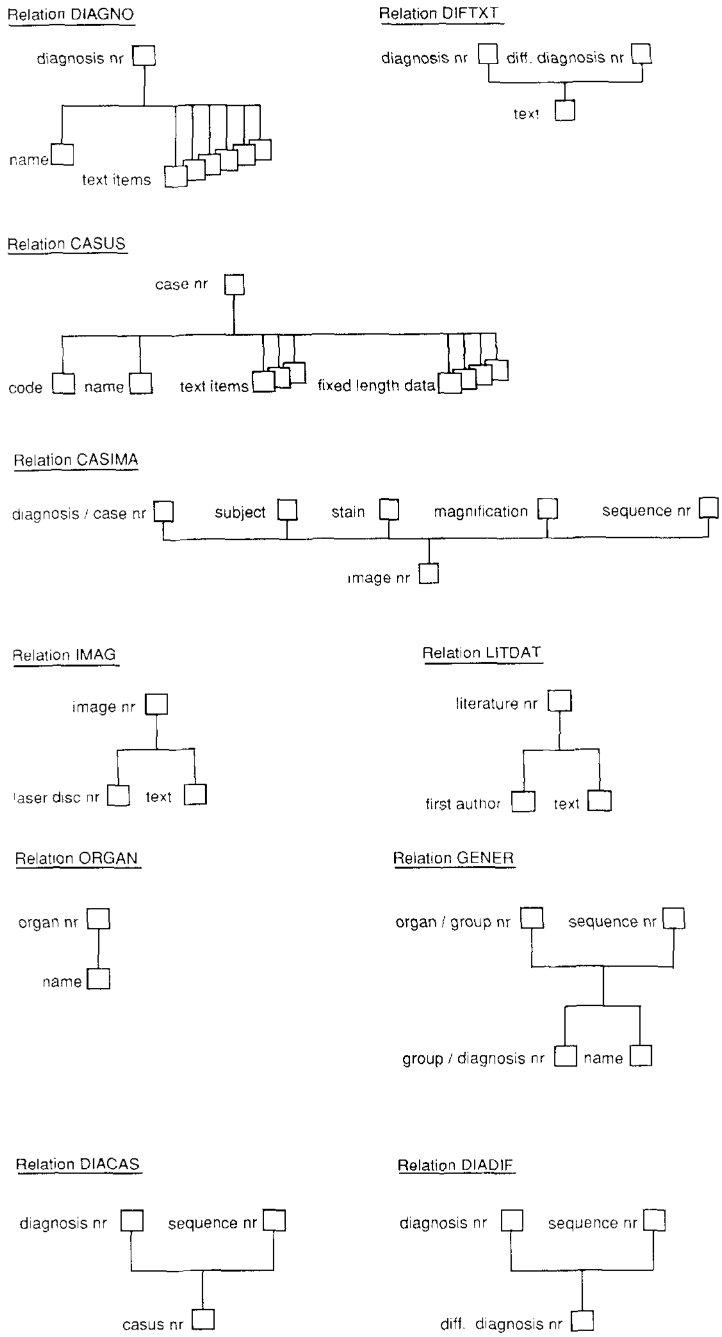

Fig. 3. Structure of the database. The connections between the relations are clearly visible by the presence of common fields.

tests the validity of values entered for items such as age and DNA index. When names are changed or information is deleted, the input program takes care of database consistency.

Data retrieval

Once put together an encyclopedia system is read-only. As already pointed out, this enables conversion of the database into a format, which is suitable for an optimal combination of retrieval and user interface for consultation. The creation of the contents of a database relation into an ASCII file is a standard MUMPS feature. A C-program

```
               Microscopy  Description

     which may be more or less typical. Five different
  3. well differentiated (sex cord) tissue patterns█_
     and three poorly differentiated patterns (below)_
     occur [B2345].___________________________________

     Microfollicular pattern: sheets [B2347] [B2348]__
     of granulosa cells with Call-Exner bodies: small_
     cysts, containing eosinophilic, non-mucinous_____
     fluid and________________________________________


     Ref: ___
```

Fig. 4. Input screen for the microscopic description. When a text is shared by more than one diagnosis, it is entered only once and can be referenced by means of the reference field at the bottom. The image numbers will later appear as sensefields.

then converts the ASCII files into a binary, C-readible format. The C-database is created only once. Hence, the conversion need not be carried out in runtime.

The retrieval program is written in C and allows for separate retrieval of categories of diagnostic information, differential diagnosis lists and criteria, cases, images, and literature references. The response time is optimized by using a binary search strategy and by keeping a part of the database in central memory. The contents of this part are based on the anticipation of the information, which the user is likely to ask for next. Therefore, the classification tree resides in central memory permanently. As soon as a diagnosis is selected, all information about the diagnosis, its list of cases and its DD-list are also kept in central memory. Apart from the system itself this information requires approximately 15 kbyte. Keeping the differential diagnoses, which are relevant for the diagnosis under discussion, in memory would also require an average of 90 kbyte. These memory requirements can at present easily be met and do not form a limitation in the optimization of the response time. However, retrieval of a picture involves the response time of both the system and the video disc player. The response time of a Philips VLP 835 is specified in Fig. 5. As the majority of jumps occur within one diagnosis, the response time will rarely exceed 1 s which is considered the maximum for convenience. The Sony LDP 1500 P is somewhat faster. The performance of the players as described above reflects the state of commercially available equipment in 1986. At present (1989), both Sony and Philips produce players with faster response times.

4. CONSULTATION

In an encyclopedia system the presentation of data is of more than usual importance. The design of the user interface is based on an analysis of the items of information, which

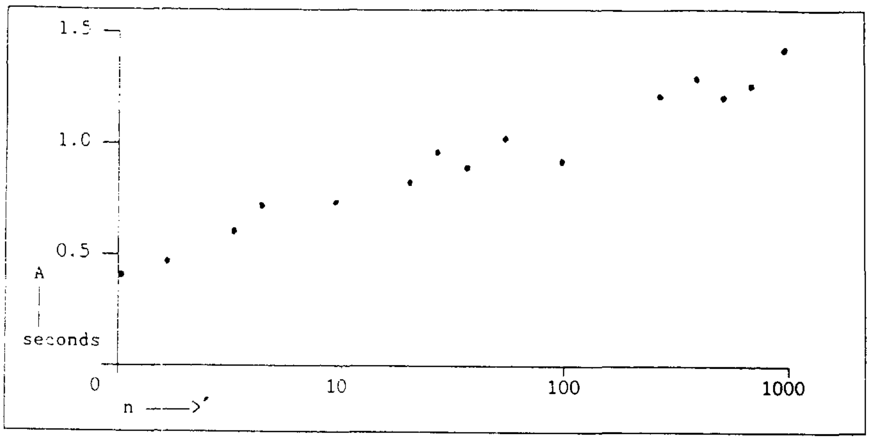

Fig. 5. Response time of the video disc player, Philips VLP 835, showing the time needed to come up with a picture at a distance of n positions.

necessarily need to be specified by the user for the system to respond, and how this information can be most easily specified by the user.

A user who wishes to access a particular item of information about a diagnosis in a diagnostic encyclopedia must provide four different kinds of actions. The first concerns the specification of a diagnosis to the system. As organs, diagnostic groups and diagnoses cannot be displayed on one screen simultaneously, the specification of a diagnosis requires a sequence of interactions: the specification of an organ (at present only one), a major diagnostic group, possibly a number of subgroups and finally a diagnosis. At the level of a diagnosis the amount of available information is too large to be displayed on one screen, so the information has to be subdivided into a number of categories, one of which is displayed by default, while the others are optional. The second type of interaction concerns the specification of one of these categories. Action type three allows the user to switch back to diagnosis selection again and the last type of interaction is the possibility to quit the session.

For specifying these choices to the system, there are two possibilities: active (user-entry by typing) or passive (selection from a list of presented possibilities). The obvious choice is passive entry since this is both convenient and it avoids the problem that nomenclature in pathology comprises many synonyms and different spellings. The presentation of possible choices has the additional advantage that the user is informed about what organs and diagnoses are available and how they are classified. All optional items should be on a fixed position of the screen with an indication as to whether or not they are available. This facilitates becoming acquainted with the system.

In our opinion a graphical, mouse-driven interface, supporting windows is most suited for construction of the user interface. Therefore, the consultation software is written in the "C" language and the graphics toolkit "MetaWindows". The user interface is based on windows, which are used for display of information as well as selection of information with a mouse. The action to be taken upon a mouse click depends on its position in the active window. Actions include selection of diagnoses, scrolling of text in a window, selection of pictures, and display of information of another category. Based on user selection the user interface activates the retrieval program and displays the requested information on the text screen or the video monitor. For evaluation purposes, the system continually logs the choices of the user.

After starting the system, the user interface presents the major diagnosis groups of ovarian tumors. All names are displayed in boxes (see Fig. 6). The selection of a diagnosis group with the mouse elicits the display of a subsequent screen showing the subdivision of the selected group. This is repeated until a diagnosis is selected. A few remarks need be made with respect to the specification of diagnoses. Each time a subgroup is selected, it is added to a row at the top of the screen, representing the choices made so far. In this way the user can always see the path, that leads to the current position in the classification tree. In addition, all diagnosis groups are recognizable as a group by the presence of three small vertical lines at the bottom of their box. These lines indicate the presence of a further subdivision. Finally, information is not only available on diagnoses, but also on groups. The availability of group information helps the user to make the next selection, but requires that the user specifies to the system whether he or she wants information with respect to the selected group or the next screen with the subdivision of that group. As a consequence, two choices are possible at each box, representing a diagnosis group. When the cursor is in the left 2/3 of the box, it has its usual "arrow" shape and a click with the mouse will then result in the display of the subdivision of the selected group on the subsequent screen. In the remaining right section of the box the cursor changes to an "I", representing that a click with the mouse will now result in the display of information on the group as a whole.

As soon as a diagnosis has been selected, the system enters the diagnosis information mode. As to the screenlayout (Fig. 7), information about the selected diagnosis is displayed in a window at the right-hand side of the screen with the diagnosis name in the header. Initially, the microscopy description of a diagnosis is displayed by default.

Optional information items are shown at the left of the screen. These items can be selected with the mouse, which causes the corresponding text to be displayed in the right window. A dot in front of the item name indicates that information on that item is available. As to the diagnosis text, a vertical scrollbar at the right indicates the portion of text, which is displayed. The two arrow boxes at the top and bottom of the scrollbar are used to scroll the text up and down. In diagnosis texts, small boxes may be visible with three different styles of shading. These boxes act as sense fields, which allow the user to retrieve pictures, glossary information or literature references by clicking on them. Pictorial information "behind" the sense fields appears on the video monitor, whereas glossary information and literature references are displayed in a toggle window on the text monitor. Each sense field applies to the remark in the text, which directly precedes the box.

In addition to information on the selected diagnosis, the optional items include information with respect to cases and differential diagnoses. When selecting "cases" the user is offered a list of available cases. Selection of a case from the list elicits the display of a screen with a case history at the top and a list of pictures below, sorted by subject of photography, stain and magnification. The pictures are accessible via sense fields. The differential diagnoses are also presented as a list. When selecting one of them the user is offered a table, which shows both the common and different characteristics of the current diagnosis and the selected alternative (Fig. 8). When it happens that the alternative diagnosis is considered to be more likely than the current diagnosis, the user can click with the mouse on the name of the alternative diagnosis, which then becomes the current diagnosis. In this way a direct switch can be made to a diagnosis with a morphologically similar picture.

At all times, the top of the screen shows the path that takes the user to the current diagnosis. When the user selects one of the boxes from this path, the system switches back to diagnosis selection mode. As a consequence, it is not necessary to start the new

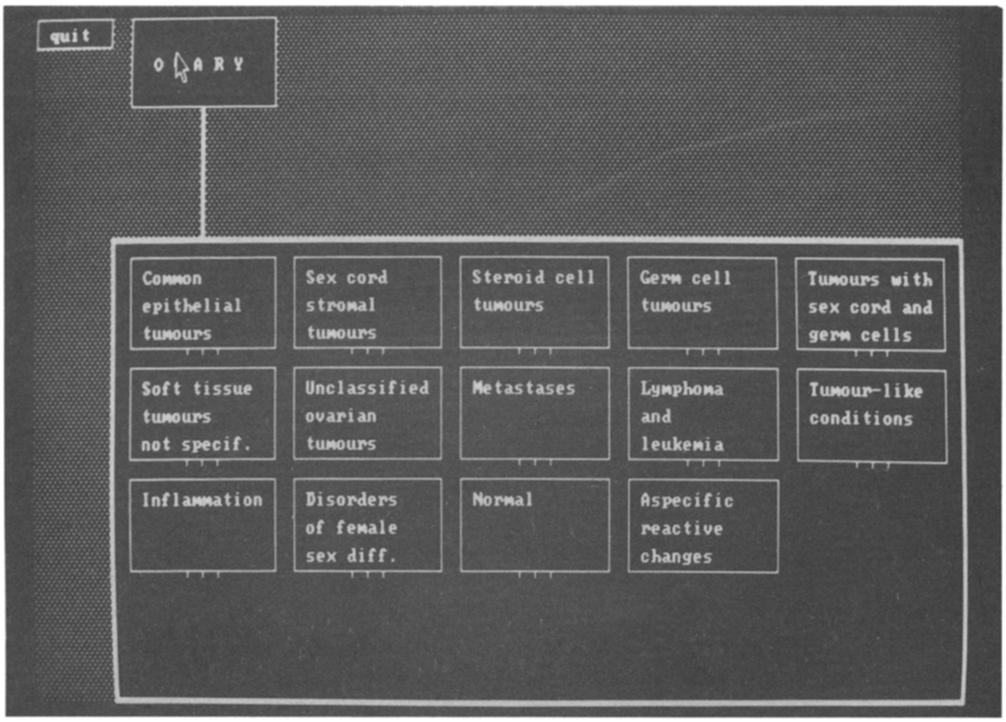

Fig. 6. First screen of the runtime version: the ovary and its major diagnosis groups of tumor pathology. The cursor has the shape of an arrow, i.e. a click will result in the display of a screen with the subdivision of "sex cord stromal tumors".

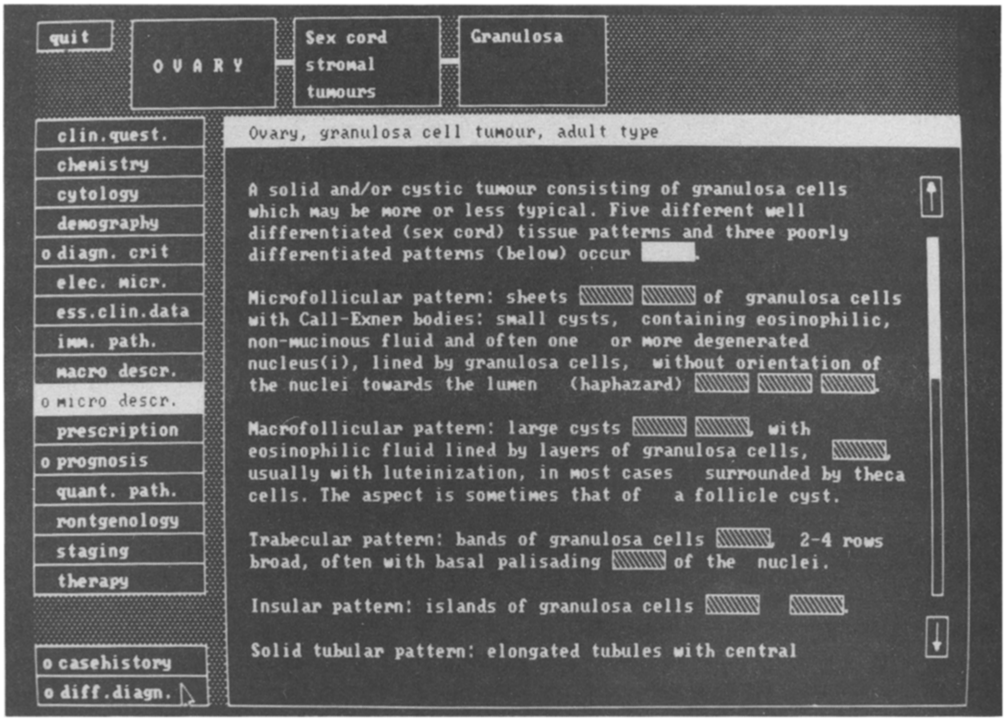

Fig. 7. Screen layout at diagnosis level.

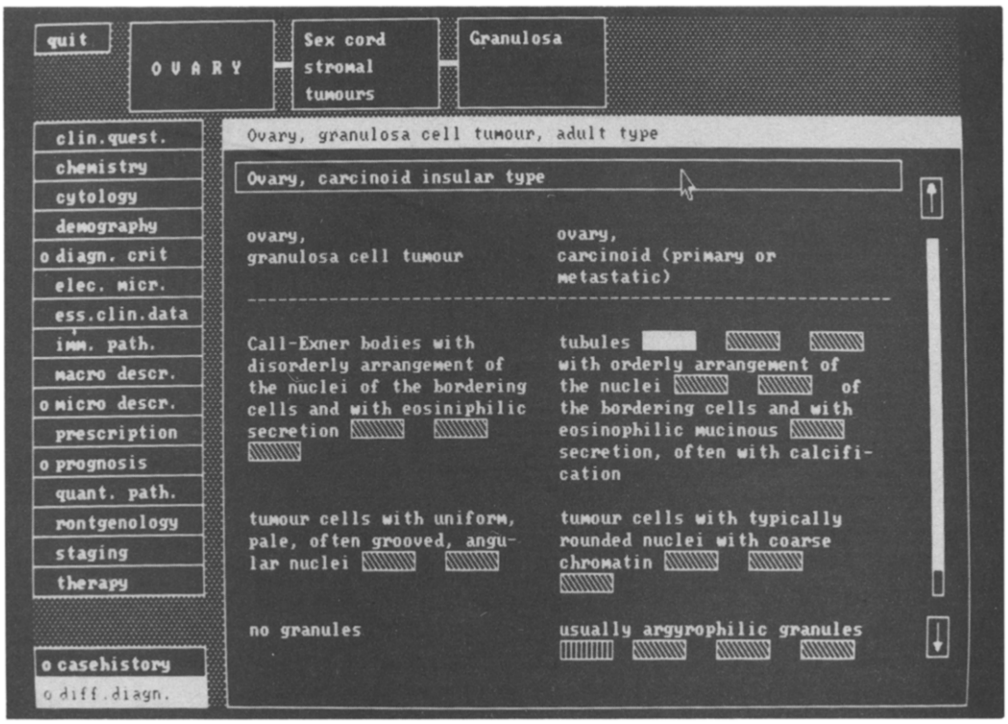

Fig. 8. Differential diagnosis between an adult granulosa cell tumor (current diagnosis) and a carcinoid (alternative) diagnosis. Carcinoid becomes the current diagnosis when the user clicks on its name (arrow).

selection at the top node "Ovary": any group in the path can be selected. At the upper left corner of the screen is a small field, which is used to quit the session with the system.

5. CONCLUSION

It can be concluded that a digital encyclopedia workstation for pathology can be implemented on a PC to offer diagnostic support by integrating access to a verbal database and a videodisc. As to its contents, the DEW offers all characteristics of books and in addition: documented case histories, lists with differential diagnoses and criteria to differentiate among them. The pictures per case include several relevant stains and magnifications. Where possible, macroscopic and electron microscopic pictures are included. The illustrations are available for the cases as well as the diagnosis descriptions.

Information with respect to diagnoses, items of information within a diagnosis, cases, differential diagnoses, pictures and literature references can be separately retrieved. The information is accessible by means of a mouse-driven interface.

The stage of development of the DEW permits clinical evaluation of the diagnostic support offered by the DEW versus books.

SUMMARY

The Diagnostic Encyclopedia Workstation (DEW) contains verbal and pictorial reference knowledge to serve diagnostic decision making in the field of ovarian pathology. Based on an analysis of the structure of pathology knowledge a relational database system was developed to hold the textual information. A video disc is used for the pictorial part of the database. Compared with the common source of reference knowledge, i.e. books, DEW has the following advantages: it can hold more verbal knowledge, pictures and case histories, and its information is accessible via several entries. Software for data entry has been written in the language MUMPS with use of the relational database toolkit AIDA, which is particularly suited for manipulation of free text. The software for consultation was developed as a separate entity, based on an analysis of the most efficient way for the user to access the information in the database. This part is written in C using MetaWindows, which allowed for the development of a graphical mouse-driven user interface.

At present, the DEW contains 85 diagnoses in ovarian pathology, covering all frequent cases and many rarities. The diagnoses are illustrated by approximately 3000 pictures, divided among 158 cases.

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