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A CD-ROM Based Agricultural Information Retrieval System

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Abstract. *An information retrieval system for agricultural extension was developed using CD-ROM technology as the primary medium for information delivery. Object-oriented database techniques were used to organize the information. Conventional retrieval techniques including hypertext, fulltext searching, and relational databases, and decision support programs such as expert systems were integrated into a complete package for accessing information stored on the CD-ROM. A multimedia user interface was developed to provide a variety of capabilities including computer graphics and high-resolution digitized images. Information for the disk was gathered and entered using extension publications which were tagged using an SGML-based document markup language. The fully operational CD-ROM system has been implemented in all 67 county extension offices in Florida.* **Keywords.** *Database, CD-ROM, Information retrieval.*

An information retrieval system has been developed for delivery of extension information in Florida. An efficient method for distribution of this system has been created based on CD-ROM (compact-disk, read only memory) technology. The system uses stand-alone, desktop microcomputers (and more recently, notebook and laptop computers), to deliver large databases. The CD-ROM can hold up to 680 megabytes of digital information. Previously, extension information had to be delivered via terminal access to mainframe computers, with limited phone access in county offices, or through the use of relatively small hard disk drives in microcomputer-based systems. CD-ROM enables large databases comprised of text, graphics, expert systems, and other application programs to be delivered using a sophisticated graphical user interface having quick response time. The system offers an economical and effective way of handling information that is traditionally distributed with printed publications.

The Florida Cooperative Extension Service, part of the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida, has been developing electronic information retrieval systems since 1982, beginning with a project known as FAIRS (Johnson and Beck, 1986). IFAS CD-ROM development has been part of this effort since 1989. Twelve disks have been developed to date (eight disks aof a series and four on special topics). The disks are distributed to all 67 county extension offices in Florida on a regular basis.

This article describes the system architecture and software environment that has been created for the IFAS CD-ROM. In addition, it is important to recognize the social and institutional adjustments needed to adapt to new information technology. The success of the project depended on solving real problems in the institution and providing incentives to extension specialists and county agents to be involved with the project. For example, the computer must enhance, not be a burden to, the traditional publication process. Techniques for organizing, locating, and presenting information through database models, query processing, and multimedia user interfaces must be exploited. These and other institutional changes needed to accommodate electronic information delivery are described in another paper (Jones, 1992).

The following sections describe the content and design of the IFAS CD-ROM. First the types of materials that are available on the IFAS CD-ROM will be summarized. Then the system architecture is presented. This includes a document-processing capability that streamlines the publication process for extension specialists. An object-oriented database design is described which provides the theoretical basis for organizing and integrating information and acts as the database manager for the CD-ROM. An implementation of the multimedia user interface is described which provides hypertext and fulltext searching capabilities, as well as record-oriented searching and integration with expert systems and other application programs. Finally, implementation and evaluation of the system in county extension offices is discussed.

Content of IFAS CD-ROM

The materials on the IFAS CD-ROM are comprised primarily of complete extension handbooks. Currently there are two dozen handbooks on the CD-ROM including the *Master Gardener Notebook*, *Florida Pest Control Guides*, *Energy Handbook*, *Florida Lawn Handbook*, and *Vegetable Handbook*. A single handbook may contain over 100 extension documents, and there are over 2,000 documents on the current CD-ROM. The handbook concept was developed to describe a comprehensive set of documents.

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It is important to obtain a critical mass of documents covering enough information on a particular commodity to be useful to county agents. The database must cover enough topics so that the agent is confident about finding answers to a particular question when consulting the CD-ROM.

Each document consists of text, tables, and figures which may be black and white drawings or color photograph quality (VGA+ resolution). For each document, there is also a WordPerfect (WordPerfect Corp., 1992) file, and a print file formatted for a Hewlett Packard laser printer. Thus each document can be printed on demand. In addition to documents, record-oriented databases can be imported from relational databases. Examples of record-oriented databases include the IFAS Faculty Directory containing a summary of each faculty member which can be searched by name or specialty. The Plant Selector contains records, including color photographs, on over 500 ornamental trees, shrubs, vines, ground covers, and annual plants. Plants can be searched over various characteristics.

Applications programs include the entire software library of 60 programs from the IFAS Software Support office. These include topics such as irrigation system design and models of soil and ground water pollution. In addition, expert systems provide decision making for diagnosis and recommendations. For example, TREES, an expert system for urban forestry, provides advice on selecting species and planting trees in an urban environment (Beck et al., 1993).

Creating, storing, retrieving, and managing this diversity of materials requires a comprehensive, flexible information retrieval system. Not only must this software handle text, but also images, record-oriented databases, expert systems, and application programs, each with specialized requirements. The architecture of the information retrieval software for supporting this broad range of functions is described in the next section.

Information Retrieval System

Hardware and Software Environment

The IFAS CD-ROM information retrieval software is written in C++ and runs under MS-DOS. A custom graphical user interface that runs within 640K bytes of RAM was developed for use in the county offices. Hardware specifications were designed around standard equipment, including an 80286 or 80386 microcomputer, VGA+ graphics, a Hewlett Packard LaserJet printer, and a CD-ROM player. It was desired to keep memory requirements under 640K to support older equipment with limited memory, but this limitation is increasingly difficult to work under. Newer releases of the software require expanded memory managers to go beyond 640K.

C++ is an object-oriented programming language. Object-oriented programming is a new approach to software design (Korson and McGregor, 1990). The strategy on the CD-ROM project is to develop a large software library. When extensions need to be made to the system, the software library can be consulted to find existing code that may be reused or modified slightly to suit a new customized need. Object-oriented programming enables the creation of such a library, emphasizing reuse and permitting modifications without adversely affecting existing code. Commercial-class libraries are available that can be linked into the system. Finally, the modularity of design and features such as encapsulation provide project management advantages which aid the software development team.

Document Processing

A document processing capability is central to the system architecture. The system is designed to enhance the creation, organization, and distribution of printed publications. A document tagging scheme based on SGML (International Standards Organization, 1986) has been implemented to facilitate document processing. Items within a document are tagged. For example, the title and author of a document may be tagged as:

```
<title> Nematode Pests of Perennial Landscape Plants </title>
<author><fn>Robert</fn><mi>A.</mi><ln>Dunn</ln></author>
```

Tags explicitly identify document components such as the title, author, sections, subsections, figures, and tables. Once tagged, the elements of the document may be processed in various ways. One way is to print the document according to a specified style. Different styles for printing the document may be used simply by specifying the style for each component type. Another use of the tags is for mapping the document into a document database for storage and retrieval.

The document-processing software has several components (Beck et al., 1992). The physical tagging is done by authors using a standard word processor (WordPerfect Corp., 1992) which has been adapted to insert tags into the text. Programs called translators convert the document into other forms. One translator converts the word processing file into an SGML-compatible format. Another translator converts the SGML file into a database format. By creating a single document using the word processing tool, multiple uses of the document are possible, ranging from generation of the printed publication, to creation of an information retrieval system.

Object-Oriented Database Management System

The object-oriented database management system (OODBMS) provides the core facility for organizing, storing, and retrieving information. An OODBMS called CANDIDE (Beck et al., 1989) has been designed and implemented based on semantic data modeling principles. All the data on the CD-ROM, including text fragments, menus, tables, figures, illustrations, and photos, are stored as CANDIDE objects. Interconnections among objects provide a high level of integration.

The knowledge representation techniques used in CANDIDE can be viewed in several ways. Mainly, the database can be viewed as a taxonomy of classes and instances. Classes represent generic concepts, and instances represent occurrences of a concept. For example, figure 1 shows a class taxonomy for agricultural chemicals. The taxonomy, known as a generalization taxonomy, shows class/subclass relationships. For example, the class "dimethoate" is a subclass of "insecticide," and that class is a subclass of "pesticide." The instance object "dimethoate 2.67ec" (shown in the small window) is a member of the class "dimethoate." An instance may belong to one or more classes. Objects have attributes with values. For example,

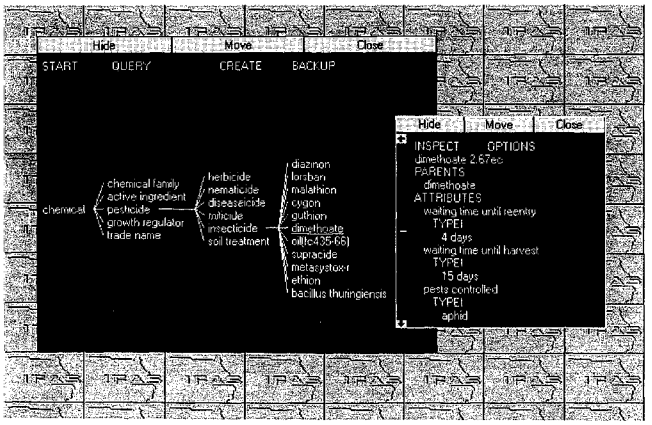

Figure 1–Generalization taxonomy showing some classes in the object-oriented database and an example instance.

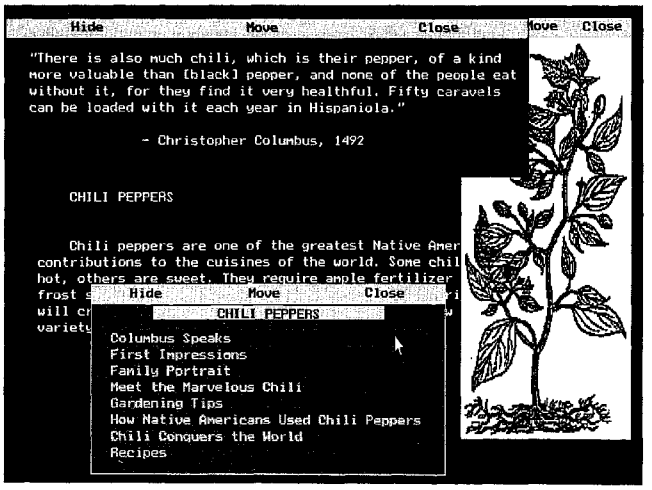

Figure 2–Example of user interface illustrating menus, hypertext, and graphics.

"dimethoate 2.67" has attributes "waiting time until reentry," "waiting time until harvest," and "pests controlled." The attribute values are also objects, thus the attribute can express relationships between objects. For example, there is an object in the database for "aphid" which appears as a value of the "pests controlled" attribute. This gives rise to another view of the database, that of a network structure. Objects are interconnected in an extensive network via attribute and taxonomic relationships.

CANDIDE supports a number of inferencing operations over objects. One of the most important is classification. The system can automatically determine the classes to which a new object belongs. Classification is used as a basis for query processing (Beck et al., 1989). Queries are expressed as new database classes. A query class is classified to determine which instances in the database are members of the class. These instances are returned as the answer to the query.

The advantage of using the OODBMS approach is that it provides a uniform way of representing heterogeneous information from broad domains. This is necessary for describing the diversity of data types present on the CD-ROM. The taxonomic and network data modeling facilities of the OODBMS provide a way to structure the knowledge of many different domains in a single, integrated system. Inferencing operations provide new ways of querying and automatically discovering relationships in the database, an emerging field known as "database mining" (Piatetsky-Shapiro, 1991).

User Interface

The user interface has been designed around a number of requirements. First is the principle of dialogue independence. This is a requirement that the data be completely independent of the user interface. There should be no information in the database controlling how the data are displayed. This enables different interfaces to be generated for displaying the same data in different styles. It also means that changes in the data do not have an influence on the display. Furthermore, it means that the data can be analyzed independently of the interface.

Another requirement is that, to the fullest extent possible, the user interface needs to be generated automatically. Manual generation of hypertext systems, for example, is cost prohibitive for large databases. Yet graphical user interfaces have many highly customized features. It should not be necessary to reinvent these features for each new application. One way to automatically generate the user interface is through mapping specifications. Such specifications describe the styles for displaying information contained in the data objects. Mapping specifications describe how data objects can be converted into a display. Different specifications can be used to produce different styles.

The user interface has been constructed using C++. This provides a class library for generating interface features such as windows, hypertext displays, pop-up menus, and dialogue boxes. Features can be reused and modified as needed for a new application. As the library grows, the range of available features becomes diversified, enabling new customized interfaces to be generated more quickly.

An example of a display illustrating the user interface features available under MS-DOS is shown in figure 2. This display is generated automatically once the data objects are created. Some more specific features of the user interface will now be described.

Fulltext Searching

Fulltext searching is the most widely used technique for accessing text databases on CD-ROM. In fulltext searching, documents can be retrieved which contain a particular word or combination of words or phrases specified by the user. Every word appearing in every document is initially scanned and placed into an index during a pre-processing phase. Once the index, which is keyed by word, has been created, it can be used to quickly identify every document containing a particular word. Fulltext searching is attractive, since the indexing phase is essentially automatic, and thus there is not much expense involved in setting up a text database for fulltext searching.

The fulltext searching function can be used to search a particular handbook. Here is an example query entered for fulltext search:

mole cricket AND control

Once the query is entered, the fulltext searching engine finds all occurrences of document fragments containing the terms "mole cricket" and "control". Upon completion of the search, a list of documents is displayed. Next to each document title is a number which indicates the number of times the words in the query appeared in the document (number of "hits"). The documents are sorted in descending order of number of hits. Presumably the document at the top of the list is most relevant to the user's request since it contains the most hits. The user can select any document for inspection. The document is then displayed in a window with the hit words highlighted.

The fulltext searching function on the IFAS CD-ROM was designed to be an integral part of the information retrieval system. One of its features includes complete integration with hypertext. The document retrieved during fulltext searching is a hypertext document, the format of which is described below.

There are a number of known problems with fulltext searching. The retrieved documents may be impertinent to the user's needs. The search may be imprecise in that documents contained in the database that are relevant to the user's needs are not located. Various attempts have been made to improve fulltext searching, such as use of a thesaurus. But the main problem with fulltext searching is that it is based on string matching rather than concept matching. Research is underway in using OODBMS to give a richer representation of word meaning, and ultimately improve searching through concept matching (Beck and Watson, 1992).

Hypertext

Fulltext searching can be used to get into the neighborhood of the relevant part of the database, and then hypertext is used to search locally within the neighborhood.

Hypertext systems have recently gained popularity through commercial products such as Hypercard (Apple Computer, Inc., 1992), KnowledgePro (Knowledge Garden, 1992), and Toolbook (Asymetrix Corp., 1992). However, the concept of hypertext was first introduced in the 1940s (Bush, 1945). Videotex systems, which were available commercially around 1980, can be considered an earlier form of hypertext and have been used to build several agricultural information systems (Ellison, 1987; Radimer, 1986; Johnson and Beck, 1986). Few large-scale agricultural information systems have been built using hypertext because of the time and expense involved, but the advent of tools for automating the generation of hypertext systems can be expected to lower the cost.

The hypertext data model is based on a network of interconnecting nodes and links. Each node represents a concept, and each link connects two related concepts. Users browse through a hypertext network by jumping from one concept to the next along connecting links. Each node can contain not only text, but graphic information, programs, sound, or any other form of media, giving rise to the notion of hypermedia. Hypertext systems are considered "non-linear text" in that the user can select any path through the information. This is in contrast to "linear text", such as a book which is read from page to page in a linear sequence.

The structure of a document can be directly mapped to a hypertext system. A document consists of components and references. Components include the title, author, sections, subsections, tables, and figures. References connect specific points in the document to other related documents. Thus, a single document can be decomposed into a number of hypertext nodes, where each node contains a small piece (chunk) of the document. Component relationships and references are implemented using hypertext links. Since the structure of a document is also captured by database objects in the OODBMS, there is a direct mapping from data objects to hypertext displays.

Hypertext functions are provided on the IFAS CD-ROM through generalized links. Links appear on the screen in a variety of formats. For example, a word or phrase occurring in a text display may be highlighted to indicate a link to related information. The user can activate this link by selecting it with the mouse or keyboard. When the link is activated, the related information is displayed on the screen. Links can also appear as menu items, as highlighted buttons, and as regions of an image. When used in images, specific points in the image, such as a state within a map of the United States or the wings on a picture of an insect, can be selected. Generalized links thus contain two components: a display component which signals the existence of the link to the user (highlighted text, buttons, etc.) and an action to be performed if the link is activated. The action is a reference to the related information. With these simple features, a wide variety of functions can be implemented since the action part of the link can be virtually anything. The IFAS CD-ROM can be considered as one huge hypertext database with thousands of nodes and links.

In spite of its flexibility and usefulness for handling and integrating large databases, hypertext has a number of serious problems and is generally inadequate as a model for organizing information. These problems are caused by a lack of formality. A hypertext link can mean virtually anything, and ad hoc relationships between any two points in the system can be manually created by system developers. The user must manually browse the hypertext network by making selections from lists of available links. It is often unclear to the user what these links are for, and thus it is difficult to make a selection properly. Hypertext does not support any automatic query facilities. All operations involving creating and searching a hypertext system are done manually. Consequently, the cost of constructing and maintaining a large hypertext database can be prohibitive. The OODBMS solves many of these problems by providing a formal database structure, with well-defined semantics. In the IFAS CD-ROM, the hypertext facility is only a projection from the underlying OODBMS. With this approach, users can have more advanced features, such as concept-based query processing, not available in general hypertext systems. Also, the hypertext system can be generated automatically.

Relational Databases

In addition to fulltext searching and hypertext, a complete information system must also support record-oriented data or relational databases (Codd, 1970). A relational database is composed of tables. Columns of the table represent attributes, and each row of the table is a record describing a particular data entry. Many agricultural databases either already exist or are more suitable to be stored in a record format such as dBase (Borland International, 1992). Several dBase-format databases have

already been integrated into the IFAS CD-ROM. Once integrated into the environment, particular records can be retrieved in a number of fashions. For example, a hypertext link might connect a document with a record describing the document's author. Record-oriented databases can also be searched automatically to find records which satisfy a particular query.

The Plant Selector database is illustrated in figure 3, which shows a sample query, and a list of plants which match this query. The user creates a query by making selections from the query window. The user can select various attributes of interest and specify values to be associated with those attributes. Only records matching the specified attribute and values combinations are retrieved.

Data records are directly converted to object form for storage in the OODBMS. Objects are more general than records, thus a record can be represented by an object. Traditionally, relational databases have been applied to relatively narrow domains such as record-keeping systems in which only a few dozen relational tables comprised the entire database. Object-oriented databases have all the advantages of relational databases plus the ability to handle very large domains of information as is needed in an information retrieval system.

Expert Systems

Expert system capabilities have been added to the CD-ROM through integration with CLIPS (Giarratano, 1991). CLIPS is an expert system shell written in C. Since the source code is available for CLIPS, it can be compiled and linked directly into the CD-ROM software environment. Run-time versions of CLIPS can be distributed without royalties. Unfortunately, CLIPS does not provide a graphical user interface, so the user interface for the CD-ROM is used to develop interfaces for expert systems. This means that the hypertext and images display capabilities of the CD-ROM can be used to provide help and other functions for expert systems.

Additional functionality is achieved by using the OODBMS to store rules and data associated with the expert system. The rule base can be segmented into categories which can be stored as classes within CANDIDE. This is advantageous when the rule base becomes large. During execution, the rule taxonomies in CANDIDE are pruned to identify rules to activate. These are passed to CLIPS for processing by the CLIPS inferencing engine. Results (facts from CLIPS) are returned for display or other processing through the user interface.

The TREES expert system on urban forestry has been developed using this environment (Beck et al., 1993). This expert system helps users to select trees for planting at a particular site, and provides supplementary planting instructions. Facilities for asking questions about the site were developed using the graphical user interface, including displaying photos to illustrate site characteristics. The OODBMS was used to store both a taxonomy of site characteristics (including questions to ask and rules associated with these characteristics), and a taxonomy of trees organized under various characteristics. The expert system uses rules to determine which tree characteristics are desirable for a particular site, based on the user's answers to questions. Then a search of the database is made to find trees having these characteristics.

Other Environments

Currently the IFAS CD-ROM is available under MS-DOS and runs on generic DOS-based hardware platforms. With the possible exception of the Hewlett Packard laser printer (all printed output must be formatted for that printer), all the components of the hardware and software environment are standard and easily obtained. This hardware configuration also matches the equipment available in all Florida county extension offices.

It is desirable to port this system to other hardware and software environments. A project currently underway addresses the issues of running the IFAS CD-ROM database management and retrieval software on multiple platforms. C++ is highly portable, but the user interface is not portable since different platforms have different protocols for controlling graphical user interfaces. A commercial product (XVT Software Inc., 1993) is being used to port the software environment to other platforms, including Microsoft Windows, Apple Macintosh, and UNIX-based workstations, by providing a generic graphical user interface.

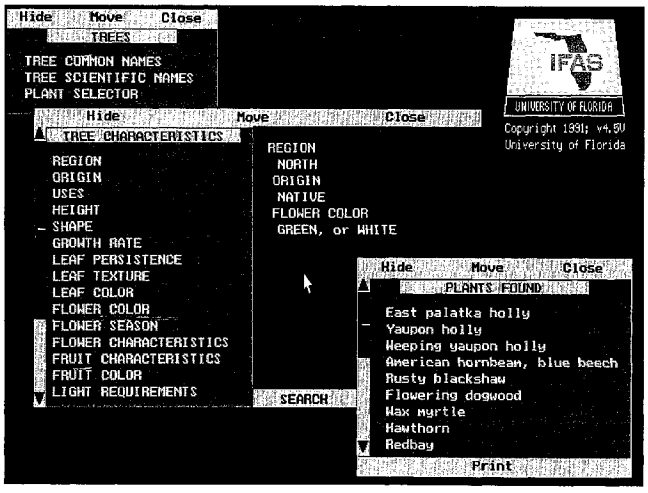

Figure 3–The Plant Selector record-oriented database.

Distribution and Evaluation

The IFAS CD-ROM is distributed on a regular basis to each of 67 county extension offices in Florida. Most of these counties have an 80386 MS-DOS computer with VGA+ graphics capability, a 100 megabytes hard disk system, and a CD-ROM player. Twelve counties have the same capabilities, but with only an 80286-based computer.

The CD-ROM, including installation software, is mailed to each office whenever a new release is available.

In 1989, when the first disks were released to the counties, an advisory group consisting of one agent from each of 10 counties was assembled to provide guidance to the CD-ROM developers and assist in adapting the new technology. In order to provide a critical mass of new materials, it was determined to focus on ornamental horticulture. Thus the advisory group was selected from counties where this material was most needed, primarily urban areas where agents received many calls about

gardening. Furthermore, these areas were active in the Master Gardener program.

In order to document the impact of the CD-ROM when it was first introduced, each of the 10 agents on the advisory board provided a letter summarizing their experience with the new disk. All 10 letters indicated a favorable reaction to the CD-ROM. Many detailed suggestions were also provided. The comments provided in these letters are summarized as follows:

- **User interface.** Users had little difficulty adapting to the new windows-style interface. Although there were some problems, such as using the mouse, these were overcome as the users gained more experience. Graphic devices such as the scroll bar, font size, and color, needed minor adjustments. One unusual finding was that users did not make use of the window manipulation functions for hiding, moving, closing, or reexposing windows.
- **Technical aspects.** Although the software runs within 640K of memory, this is a major constraint. There is a limit to the number of functions that can be run at once with that amount of memory. Another technical problem involved the fulltext searching function. Currently it does not provide a global search. That is, users cannot search over every document on the disk at once, but only those within the currently selected handbook. A new fulltext searching function is being designed to solve this problem.
- **Information content.** The Plant Selector program received the most favorable comments. Users also requested more images and more databases in general. These will eventually be obtained as the CD-ROM expands.

As of this writing, the CD-ROM has been in use over three years. The latest version (Disc 8) of the disk was distributed to over 300 sites. Feedback obtained by talking with county agents indicates that the CD-ROM is being used on a regular basis. One of the most active user groups for the IFAS CD-ROM has been the master gardeners. The CD-ROM is used to provide training as well as an information resource for answering questions. Because of the interest shown by county agents, there has been a significant increase in interest from extension specialists wanting to put their materials on the CD-ROM. This interest coupled with improvements in the publication handling procedures in IFAS has helped to gain acceptance for the CD-ROM.

Conclusions

An electronic database of extension information has been developed which is based on CD-ROM technology. This CD-ROM is distributed regularly to all 67 county extension offices in Florida. The information retrieval software uses object-oriented database technology to integrate hypertext, fulltext searching, relational databases, and expert systems. A graphical user interface is supported.

Future research will continue to enhance the capabilities of object-oriented databases. In particular, object matching and machine learning techniques will eventually provide the capability for more precise queries, and automatic evolution and organization of the database.

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