FTDD973: A Multimedia Knowledge–Based System & Methodology for Operator Training & Diagnostics

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Abstract

FTDD973 (973 Fabricator Training, Documentation, and Diagnostics) is an interactive multimedia knowledge based system and methodology for computer–aided training and certification of operators, as well as tool and process diagnostics in IBM's CMOS SGP fabrication line (building 973). FTDD973 is an example of what can be achieved with modern multimedia workstations. Knowledge–based systems, hypertext, hypergraphics, high resolution images, audio, motion video, and animation are technologies that in synergy can be far more useful than each by itself. FTDD973's modular and object–oriented architecture is also an example of how improvements in software engineering are finally making it possible to combine many software modules into one application. FTDD973 is developed in ExperMedia/2; an OS/2 multimedia expert system shell for domain experts.

1) Introduction

Existing mass production approaches to workplace training no longer meet the new international standards for industrial competitiveness. The standards of the "new economy" include quality, variety, customization, convenience, timeliness, and continuous innovation. With multimedia KBS technology application, we can raise the level of manufacturing operator expertise across the board and enhance the operator's job to include more diagnostics. This will pay off in increasing productivity (proficiency across multiple operations), decreased scrap, and reduced reaction time. One of the biggest challenges in semiconductor manufacturing is to cut our "mean time off line" and improve our productivity per person. FTDD973 is directly addressing and benefiting both.

A major departure of our approach from previously reported multimedia systems for semiconductor manufacturing is the seamless integration of training, certification, and on–line documentation with knowledge based diagnostics. In addition, existing multimedia training methodologies usually require large initial course preparation investment and are suitable for relatively stable subject matters. Such applications usually require specialized and often expensive hardware and software. FTDD973 is developed in ExperMedia/2 and resides entirely on hard disk and can be used in stand–alone or network configuration. It provides modular, easy to upgrade, customizable training and diagnostic modules on standard hardware (386PC, 6Meg RAM, 70 Meg HD) and software (OS/2 2.0). ExperMedia/2 is an OS/2 multimedia expert system shell for domain experts. It is based on standard OS/2 features and a set of novel utilities.

1.1) Motivation

The IBM Vermont plant manufactures a wide range of Integrated Circuit (IC) products (RAM, ROM, ASIC, Processors, Logic, EPROM, ...) fabricated on three full scale production lines. The 973 fabricator is one of IBM's advanced CMOS manufacturing lines. It is comprised of over 40 tool groups, 175 processes across 7 different technologies and is serviced by over 200 operators, production technicians (PT), and maintenance technicians (MT). FTDD973 started as a diagnostic assistant for the oxide growth process, one of the major tasks in the Hot Process area (one of the areas currently supported by FTDD973). A closer study of the oxide growth operation in the scope of CIM and IBM's six sigma manufacturing concepts and requirements (zero defect, paperless workplace, improved cost , quality, and turn around time) revealed that the biggest challenge was to reduce "mean time off line" and improve operator productivity. In order to reduce "mean time off line", we needed to put first call diagnostics in the hands of the individuals closest to the process (operators). This cuts down on reaction time because the operator is physically located in the area. On the other hand, to increase operator proficiency across multiple operations and decrease scrap, it is essential to increase operator expertise across the board (efficient training and information dissemination).

Our initial feasibility and requirements analysis, and interviews with manufacturing personnel, revealed that the four major components of the operator's workplace: *training, certification, diagnostics, and documentation* needed to be integrated taking advantage of the multimedia capability of the workstations (PS2), multi–tasking capabilities of the operating system (OS/2) and AI techniques proved successful in our previous diagnostic applications [Hekmatpour91] [Hekmatpour93]. A decision was made to extend FTDD973's architecture and initial intent to provide a complete intelligent and efficient workplace for all aspects of the 973 fabricator operation (Figure 1).

Figure 1. FTDD973's Integrated Workplace Methodology

1.2) Architecture

FTDD973 is developed based on an object–oriented modular knowledge structure, comprised of a collection of interacting and cooperating modules arranged around the control and management knowledge bases (CMKB), as shown in Figure 2. Each module represents an autonomous and self sufficient utility/task. Training modules provide interactive multimedia training for the 973 fabricator tool and process operation, as well as orientation for the area. Diagnostic modules provide interactive tool and process diagnosis. Documentation modules provide on–line hypermedia documents covering all necessary information on tool, process, process parameters, logistics, and various other applications and databases which the operator comes in contact with. Certification modules provide an interactive test, evaluation, and feedback environment. The user profile database includes various information on the manufacturing personnel in each area. For example, it includes employee number, name, department, tools and processes for which they are certified, date certified, level certified (beginner, novice, intermediate, expert), any special expertise, and authority level (system administrator, production technician, maintenance technician, operator, ...). Any module can query the user profile database directly, but the updates and modifications are managed by CMKB or directly via GUI (Graphical User Interface) by authorized personnel (System administrator).

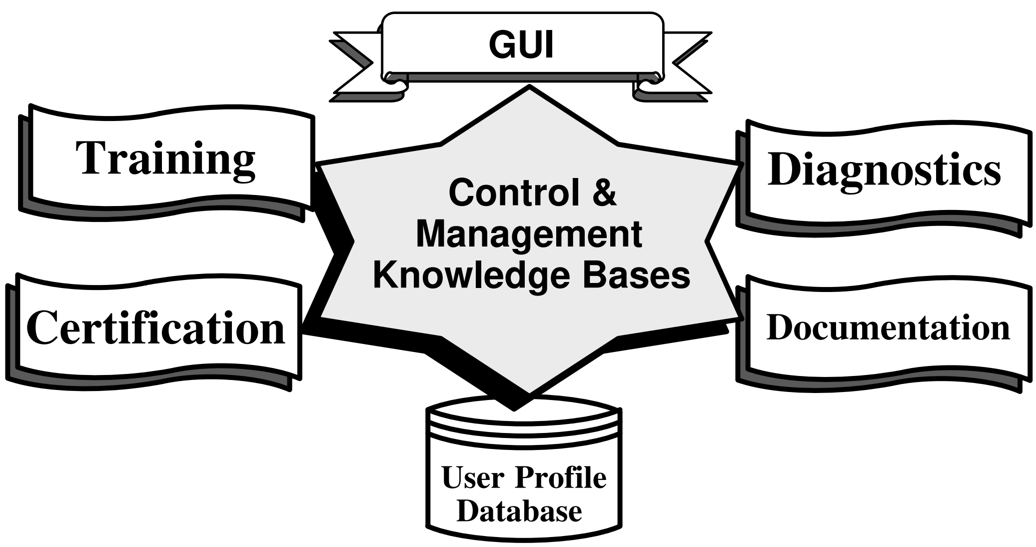

Figure 2. FTDD973's Architecture

1.3) System Hierarchy

Knowledge bases and multimedia utilities are hierarchically organized according to the expert's mental model (how the expert conceptualizes the diagnostic task hierarchy and its relationship to training, certification, and documentations). FTDD973 currently consists of 10 diagnostic knowledge bases, 3 hypertext documents, 45 Multimedia/Hypermedia training documents, and 60 manufacturing procedure documents (Figure 3).

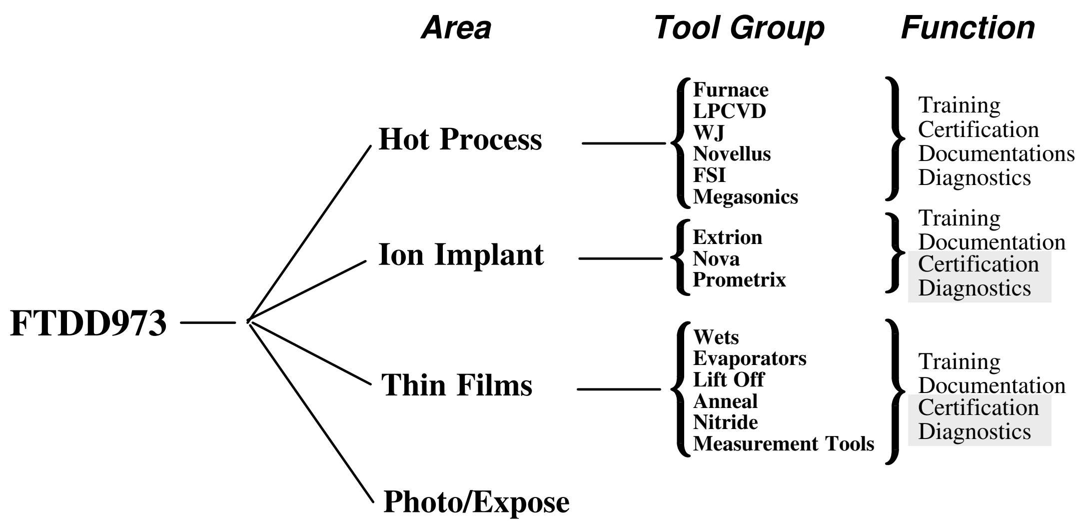

Figure 3. FTDD973 System Hierarchy

2) Interactive Multimedia–Based Training and Education

Traditional Computer Based Training (CBT) and computer–assisted instruction (CAI) teach a subject by offering corrective feedback based on a large, pre–stored set of problems, solutions and associated remedial advice. The most noticeable problem with CBT and CAI is the amount of time it takes to produce effective courseware as all possibilities need to be anticipated in advance by the author. Some Intelligent Tutoring Systems (ITS) have addressed this problem by providing an environment where problems are generated automatically. Such "generative" systems need only be given general teaching strategies and they could produce a large number of interactions without all of them being explicitly programmed in advanced. However, most of these systems lack a clear representation of the knowledge that they are teaching. In such systems there is a mismatch between the program's internal process and those of the trainee's cognitive processes. The trainee using CBT or ITS is usually denied any chance of using his/her initiative in guiding the learning process. The CBT and CAI strategy is "learning by being told". However, research has shown that "learning by discovery" and "learning–by–doing" is in many cases a more effective strategy [Kass91] [Yazdani88]. The main goal in our training methodology has been to reduce intimidation and to put the trainee in control of learning, where it belongs. Instead of sitting in a classroom listening to an instructor, or following an operator on the manufacturing floor (who is usually fighting fires and the last thing on his/her mind is training), the trainees work individually on computers that combine text, high resolution color images, graphics, audio, animation, and motion video. This environment is characterized by student sequencing through course material in a self–paced manner, while being monitored by the system. The goals in developing FTDD973's training methodology can be summarized as:

- *Shorten the training process.*
- *Improve the training quality.*
- *Provide consistent training across the board.*
- *Produce modular and portable training courseware. Since IBM is a member of the Interactive Multimedia Association (IMA), we have adapted the general principle of the IMA's practices for Multimedia Portability [IMA1] which is also known as MIL–STD–1379D Appendix D (for portable courseware).*
- *Effectively deliver and monitor the training objectives.*
- *Enable domain experts to easily develop and modify multimedia training courseware by providing them with architecture, methodology, and necessary tools and techniques.*

2.1) Why Multimedia Training

The IBM Vermont plant manufactures a wide range of Integrated Circuit (IC) products (RAM, ROM, ASIC, Processors, Logic, EPROM, ...) fabricated on three full scale production lines (different technologies). The 973 fabricator is one of IBM's advanced CMOS manufacturing lines. It is serviced by several hundred operators, production technicians (PT), and maintenance technicians (MT). Currently, a multitude of methods are used for educating and assisting the manufacturing personnel. These methods include informal, unstructured training sessions, printed "in–house" manuals, sit–down classroom courses, and walk–thru orientations, to name a few. On the other hand, in our manufacturing environment, the student population grows with every group of new employees (temporary or permanent). This student group is large and decentralized. They cannot all be released from the manufacturing line simultaneously to take a standard training course.

A majority of the process engineers, process technicians, and senior operators interviewed at the IBM Vermont plant, emphasized the fact that their major concern was the heterogeneous work environment they had to deal with. In addition, it was emphasized that the current training and certification methodology was inefficient and time consuming due to usual operator turn around and frequent changes in the process and tools. In most cases the operators are trained by current operators and process technicians who have their own styles and biases. In addition, most of the information required for their regular activities are textual documents (softcopy or hardcopy).

Interactive multimedia training and certification offers consistent presentation of the subject matter, on a flexible 24 hour per day seven day a week schedule. While, admittedly, the use of interactive multimedia training and certification will never totally replace conventional methods of instruction, our experience has shown tremendous benefits in quality and the overall cost of training. The subject matter delivered to the employee is guaranteed consistent when such a methodology is used. We avoid the "Monday Morning Syndrome" when some of the subject matter presented by a line technician to new hires might be a little sketchy or missing altogether. Using such an on–line computer–based training methodology also eliminates the back–level problem. Currently, using printed documents, we're never sure if the line operator is using the most current revision or whether an operator's training had covered the latest version of process or tool upgrades. By making the information available "on–line", and integrating training, certification, diagnostics, and documentation, we have better control over what information is being used and what is needed to be disseminated.

Most importantly, interactive multimedia training works. This technology goes beyond the point of being user–friendly to being what Sullivan [Sullivan 91] calls USER–SEDUCTIVE. People like to use this technology. This has been shown in numerous studies and we see it everyday from our contacts with existing and new users here at the Vermont manufacturing plant. Thus, to use the words of Ben Franklin: "You tell me and I forget, You teach me and I remember, You involve me and I learn." We can certainly involve our operators through the use of interactive multimedia training and certification and take one step closer to being a Six Sigma, World–Class semiconductor manufacturing.

2.2) Multi–level Student Model (Beginner, Novice, Intermediate, Expert)

Training and certification methodologies implemented in manufacturing enterprises are usually based on a single and simple student model. Regardless of the familiarity or lack of familiarity of the students with the business process and equipment, all go through the same training and certification process. In addition, the certification procedure is usually conducted orally in a walk–thru show and tell fashion and is subject to the trainer's judgment and biases. A new hire, who has never worked in the semiconductor manufacturing environment, is given the same training material as an operator who has many years of experience in semiconductor manufacturing and has been transferred to this new assignment from another line. In addition, there is no formal methodology for increasing the responsibility of an operator as the training proceeds. To address this problem, we developed a new multi–level student model. This new model advances the student rank as the training progresses and as the student improves his/her certification test score.

Expert PTs, MTs and operators were interviewed to identify efficient methodologies for training the manufacturing personnel in their area. In other words, how should we present and manage the training material to students of varying background and expertise? Four levels were identified; *Beginner, Novice, Intermediate*, and *Expert* (Figure 4). An operator rated as a *Beginner*, would require the most assistance and step by step guidance, Whereas an *Expert* would only need to be able to locate the information rapidly and efficiently as the need arises. A user is assigned an initial level by the area PT. The user advances to the next level (increasing responsibility and access to information) as he/she passes the certification procedure for that level. As the user level is advanced, the detailed procedural information is reduced, but the conceptual and deep knowledge of the process and the tool is made available. A *Novice* student knows the steps involved in the operation, an *Intermediate* student should know the cardinality and temporal relationship and importance of the steps. An *Expert* user would also understand the taxonomy of the process steps and tasks.

Such a multi–level student model reduces the danger of operators getting involved in potentially dangerous or destructive tasks which they may not have had adequate training and preparation for. In fact, a large percentage of "wafer scrap and reworks" is traced back to inaccurate or incomplete processing. In the previous operator training methodology, once an operator was certified, that operator could have been assigned to process products, although he/she may not have had any training in process or tool trouble–shooting. In most cases, ignoring initial signs of problems, or not being able to respond to problems quickly, could be very costly and result in the shut down of a tool or a process. On the other hand, in some situations, initiatives taken by operators who have not been adequately trained and informed of their responsibilities could result in scrap, rework, damaged tools (e.g. broken furnace tube) or an out of spec process. In our multi–level methodology, CMKB keeps track of the user level and last certification date, then decides what tasks could be performed by the operator, and what new training or certification is required at each stage.

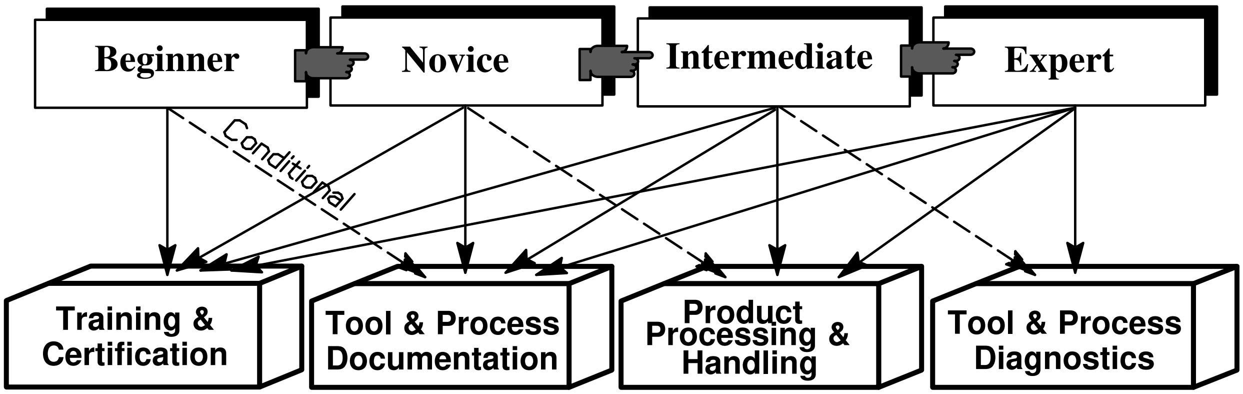

Figure 4. Multi–level Training and Certification Model

2.2.1) User Profile Management

User name, department, passwords, user level, process and tools certified for, certification dates, authorities, and specialized expertise are maintained in the user profile database for each user. User level is identified and assigned to the global environment variable USER_LEVEL by FTDD973 at logon time, but may be changed at anytime during the session (e.g. after the operator takes a certification test). Global access to training, documentation, logistics, and diagnostics is controlled by FTDD973, whereas local access to specific sections of training modules or on–line documents are controlled via local environment variables which are maintained by the corresponding module. The value of these local environment variables determines which sections of a module can be accessed by a user and which sections should be hidden.

2.3) Active vs. Passive Training Modules

Active training modules provide interactive step by step guidance and monitor user responses and adjust/react accordingly. These modules usually cover the more complex scenarios, where the system serves as an active participant in the process, analyzes user responses and formulates a corresponding action based on the response and the overall goal. Active training modules could ask trainees to perform specific tasks, examine tool components, review process procedures or make specific tool/process/product measurements before continuing to the next step. These modules are very similar to FTDD973's diagnostic modules and are implemented as CATs (an acyclic directed decision graph). Active training modules are usually used for beginner and novice training, where the user needs step by step guidance, monitoring, and feedback.

Passive training modules can also provide step by step instructions and procedures, but they neither enforce it, nor monitor the progress. Such modules are suitable for intermediate and expert users who may not require step by step control and guidance. Whenever multimedia and hypermedia modules are accessed directly, they provide passive training, whereas if these are presented via diagnostic knowledge bases or the CMKB, then active training is performed.

2.4) Partitioning of Multimedia Modules into Logical Pages

Coordinating text, graphics, and images in a multimedia environment is very important in effective presentation and management of the subject matter [Hekmatpour92][Feiner90]. Some researchers have investigated the automatic generation of coordinated multimedia [Feiner91]. Our methodology is based on a pre–defined presentation scenario and is implemented in one of the pre–defined templates. Multimedia modules are partitioned into "logical pages" (Figure 5 & 6). A logical page (Figure 5) consists of a set of images (still, video, animation, graphics)) and all their associated description (text and audio). In other words, a logical page is the pre–defined collection of all related information (text, graphics, images, audio instruction, animation, video clips) which the trainee should/could review when studying the subject matter covered in that page. The appearance, format, and access to logical pages are fixed and consistent throughout the system. Logical pages are related to each other via hypertext and hypergraphic links.

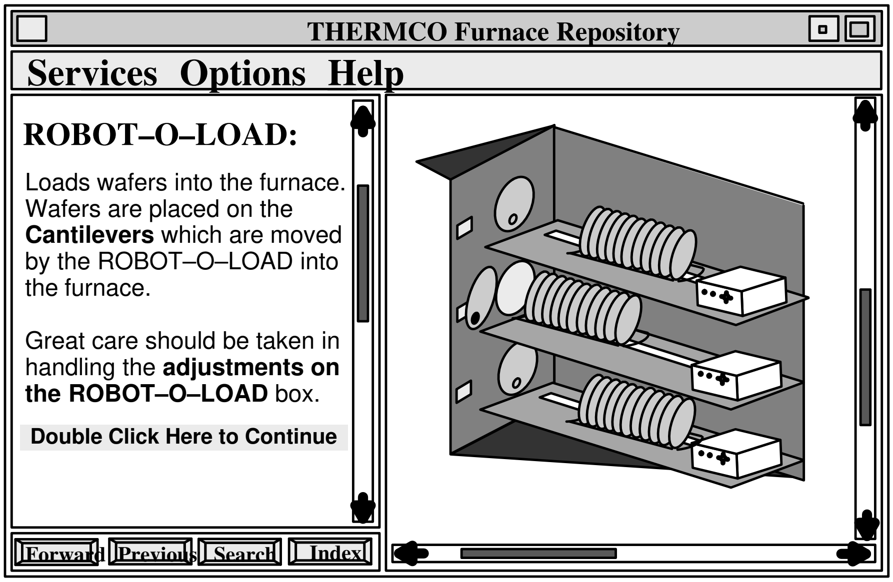

Figure 5. An Example of Multimedia Logical Page

2.5) Logical Page Templates

To accommodate various situations and to maintain consistency among modules, a set of "Logical Page Templates" are defined (Figure 6) and adhered to throughout FTDD973. These templates provide consistent facilities for embedding various multimedia and hypermedia utilities and functions in applications. The logical page templates facilitate sharing of multimedia courseware between the areas covered by FTDD973 and between other systems planned for other manufacturing lines. In addition, multimedia documents can be shared among projects, maintaining a consistent user interaction and presentation. For example, the "safety and hazardous material handling" multimedia training document developed in Ion Implantation area can be easily used by other areas within the 973 fabricator.

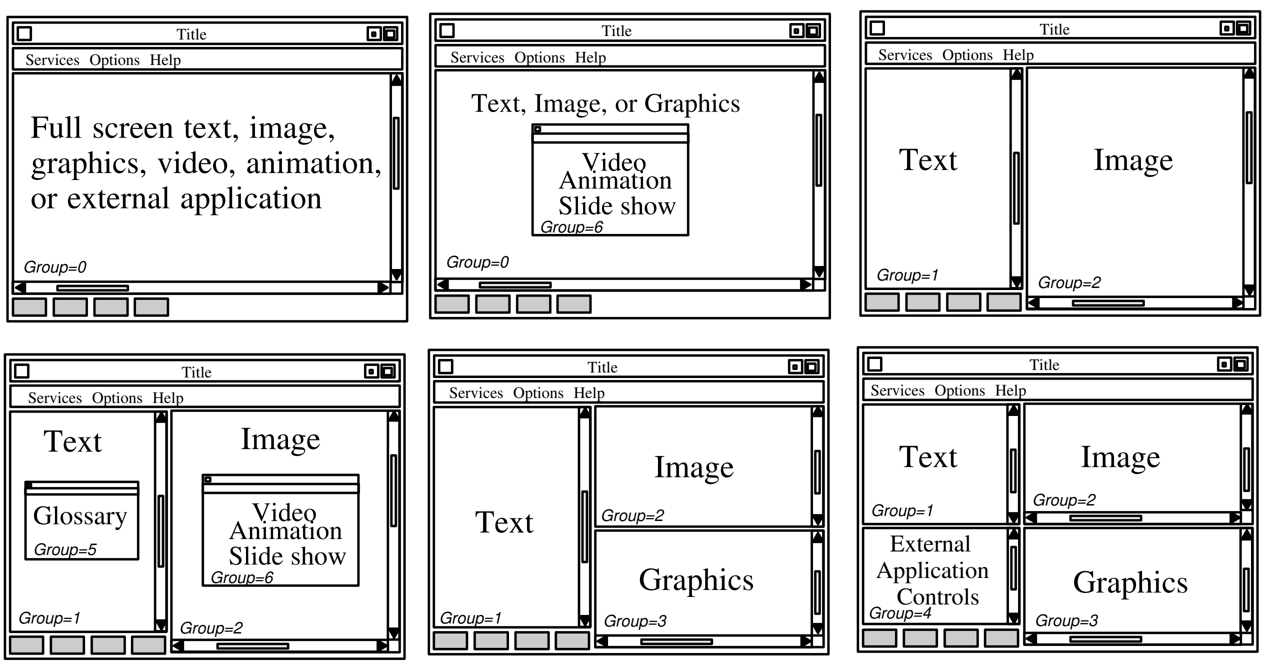

Figure 6. A Partial List of Multimedia Logical Page Templates

2.6) Customizing the Logical Page

In addition to a variety of logical page templates, most of the major attributes of a logical page can be customized. For example, page background color, highlight color, page size and position, partition ratios, text style and font size, pull down menus and menu items, system menu items, push buttons, vertical and horizontal scrolls, min/max icons and window titles. Some of these are controlled via the tagging language used to define the logical page templates (e.g. *:font facename=Courier size=13x8.*) and some are controlled by utilities provided by ExperMedia/2.

3) Hypermedia Documentation

3.1) Area and Tool Orientation

The first time a user logs in, he/she is presented with an introduction to the system and a tutorial on hypermedia and multimedia. Once the user has finished reviewing the introduction, he/she is then presented with the list of orientations to be reviewed. These introduce the user to functions performed in the area, the tools, terminologies, documents, computer systems, data collection procedures and the overall view of how all the pieces fit together in that area, as well as how the area fits into the overall semiconductor manufacturing process in general and that specific fabrication line (i.e. 973 fabricator) in particular. Orientation modules utilize hypertext, hypegraphic, audio, motion video, and animation. On average, it takes new operators about 2 hours to review all orientations for their area. Most of the systems developed so far do not enforce any time limitations but they keep track of documents reviewed and time spent on each. An operator may review a document as many times as necessary and return to document at any time.

3.2) Hypergraphic Repository

Manuals (maintenance, diagnostic, and operation) are usually comprised of textual descriptions, pictures of components and schematic diagrams. The quality of these pictures (black & white) is often not good. In some cases these documents are outdated or the pictures don't match the component on the tool (either due to local or vendor upgrades). Technicians and operators complain about having to go back and forth between several manuals to get all the information about a component. In addition, they complain that such manuals are hard to comprehend and are boring. To address this dilemma, we have developed hypergraphic repositories. The repositories utilize hypertext and hypergraphic to provide an efficient and interesting media for presenting various operation and technical information about tools and processes. Coordinated text and graphics has proved valuable in training and explanation–based systems [Feiner91][Maybury91]. The user can query the repository based on component name, operation, component location or function. The repositories utilize the capabilities of hypertext (i.e. links, table of contents, topic and keyword search and margin notes) as well as hypergraphic. Hypergraphic allows the user to obtain specific type of information about a component by clicking on the component to bring up its hot–spot pop–up menu. Then he/she may review the component's textual description (name, symbol, function, part #), view a close–up picture, listen to any associated audio instruction or description, or view an animation or video by selecting the appropriate hot–spot function (Figure 6). Hot–spots can be linked to any other part of the repository (text, images, graphics) or external applications such as audio, animation, motion video, diagnostic modules, certification, or other multimedia documents (Figure 7). Hypergraphic capability also allows navigation into composite components (black boxes). For example, a user can click on a panel door to open the panel and get a view of what is inside. The user may then click on a component inside the panel to get a close–up view, or open up a complex component to review its sub–components.

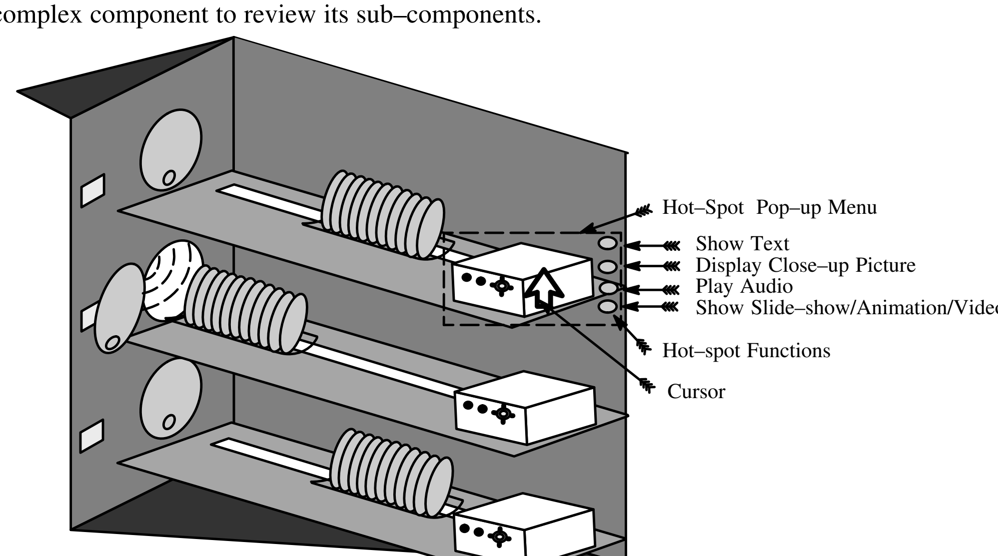

Figure 7. Hypergraphic Hot–spot and Hot–spot Functions

Such repositories have proven to be very useful and are frequently used by *Beginner* and *Novice* operators and technicians during training. It is an efficient, effective, and safe medium for providing orientation on complex semiconductor manufacturing tools without exposing the trainee to hazardous materials, heat, radiation, or poisonous gases. It enables learning by discovery and navigation without being watched by or bothering the trainer. It also eliminates the need for shutting down a tool to show the internal components to trainees. It has allowed the trainees to perform what–if simulations and investigate the internal structure of the tools at their own pace. In addition, the repository serves as a central place for documenting upgrades, component changes, and alternatives for a component.

4) Certification

The certification process is interactive and cooperative and is geared towards process and tool operator certification in general, and semiconductor manufacturing operator certification in particular. The certification procedures test the trainee's progress, track his/her performance and help the trainee to concentrate on the problem area. The feedback and tracking was developed in response to the concerns with the existing certification and training procedures which lacked a meaningful and unintimidating feedback mechanism. In addition, to reduce intimidation, enhance learning and increase the trainee involvement, we expanded the certification beyond a simple pass or fail. Certification modules can be considered an extension of the training by providing meaningful feedback, suggesting topics to be reviewed, and providing general comments as well constructive criticism.

A new user needs a password and a valid IBM employee serial number to take a certification test. New users are assigned USER_LEVEL="Beginner", unless a different level is assigned to them by the PT or MT responsible for the area. Once a trainee has reviewed all the required materials and procedures for his/her area, tool group, and level, he/she will be given an on–line certification test. The test is usually comprised of about 20–50 questions (multiple choice and True/False) which may be answered in any order. The trainee can review an up–to–the –point status summary which shows the user responses to questions and whether a question has not been visited yet (Not Answered) or no answer has been selected for it yet (skip). Once the test is turned in, the CMKB evaluates the responses and generates a report. For each question answered incorrectly, the system lists topics, documents, or training modules to be reviewed.

5) Knowledge–Based Diagnosis

CIM (Computer–Integrated Manufacturing) is viewed as an emerging technology in the domain of manufacturing. The concept of CIM is that the whole performs better than the sum of individuals [Vail88]. In order to make the system run smoothly with minimum delay (continuous flow manufacturing), it is necessary to have a diagnostic system for discovering any cause of a system failure. It is desirable that this diagnostic system is capable of performing its task as fast as possible, since the duration of the system's breakdown is very closely related to productivity and cost. Therefore, there is a need for intelligent diagnostic systems. Diagnosis is also recognized as one of the major tasks in CIM [Alexander89]. Furthermore, in AI and expert systems, diagnosis has been given more attention in recent years, including trouble–shooting in electronic circuits [de Kleer87] and medical diagnosis [Gordon85][Jamieson90].

There have been a variety of approaches taken by various researchers in an attempt to understand methods for creating intelligent diagnostic systems. These range from shallow reasoning using compiled rules [Shortliffe76] to model–based ("deep") systems that reason by exploiting causal, structural, and functional relationships [de Kleer87]. Some acknowledge combining shallow and deep knowledge [Smith89][Sticklen87]. It is hypothesized by some [Gomez81] that the use of "deep" representations of entities to be diagnosed is superior to using empirical knowledge about associations between malfunctioning parts of an entity and symptoms. The rationale is that one cannot exhaustively catalog all such associations; without such a catalog, a heuristic–based diagnostic system becomes brittle and fails when presented with a case that it does not understand. On the other hand, deep knowledge representation is based on models that are difficult to construct–especially models that exhibit the technological intent of the designer. Further, it is unlikely that models will mirror the failure behavior of entities of any complexity, particularly with regard to providing information about multiple perspectives [Bourne91]. Moreover, models are likely to be domain–specific and only some fraction of knowledge will be transferable from one diagnostic system's knowledge base to another. It is also recognized that rule–based systems become increasingly difficult to understand and maintain, as the number of rules grow. While a reasonable rule–based expert system shell can assist a domain expert in formulating cause–and–effect rules, a collection of such rules typically will not function as an expert system, except for the most simple cases. To overcome these limitations, some expert system shells allow the encoding of strategic and object–level knowledge as meta–rules. This however requires extensive knowledge of the programming paradigm and the development environment. Another class of tools provide search algorithm for a flat problem–space representation. Although the problem representation is simplified, the search complexity for a problem of solution length L, and search space branching factor of B, has the worst–case complexity $O(B^L)$. Given the above arguments, what is the solution?

Bourne et al. [Bourne91] suggest that it is actually more fruitful in certain domains to concentrate on constructing models of belief organization for diagnosis than on models of physical entities. The concept of belief potentially has a wider scope than explicitly defined knowledge [Rapaport86]. Bourne et al. propose a method of organization of beliefs about diagnostic problems that provides explicit belief organization with implicit organization of knowledge about physical device characteristics, functionality, and behavior. The method is claimed to provide reasoning about belief among alternatives, is extensible, and can be easily scaled up to large problems. Further, it is asserted that belief manipulation coupled with information about fault history, and symptoms is sufficient to secure good diagnostic results.

5.1) Knowledge Base Architecture

Our knowledge–base architecture is an extension of the Bourne et al. proposal whereby, the expert's knowledge about the behavior of the environment is represented as a Behavioral Hierarchy Knowledge Base (BHKB). Next, a number of knowledge bases representing the expert's knowledge about the physical and structural hierarchy of the environment, called Structural Hierarchy Knowledge Base (SHKB) are attached to each terminal node of BHKB. Finally, the expert's knowledge about the association between symptoms and the causes and the functional characteristics of the environment are represented as branches of the SHKB, implemented as Condition Action Trees (CAT), as shown in Figure 8. Representation of knowledge as a hierarchy of CATs, rather than rules, has a three fold advantage. First of all, system performance and incremental expansion is improved, by eliminating the rule–base maintenance and rule interference. Secondly, decomposing the problem into functional CATs provides access to intermediate states, thereby reducing the search space [Minsky63][Newell62]. Thirdly, such a knowledge representation based on the cause–and–effect networks of association is consistent with the experts mental model of the environment and the reasoning process. Overall, the development and maintenance effort, as well as the predictability of the system behavior, independent of the amount of knowledge added into the system, is improved.

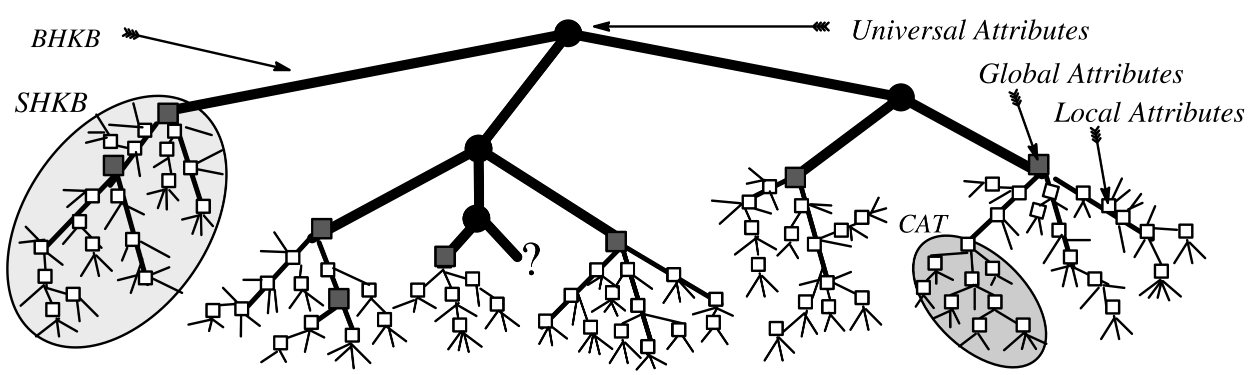

Figure 8. Hierarchical Diagnostic Knowledge Representation

Diagnostic flowcharts are generated for problems according to our knowledge engineering methodology and guidelines. Each flowchart is mapped to a knowledge base, implemented as a CAT. Each node in a CAT may have one or many possible branches associated with it. Each node has three explicit attributes assigned to it. Node strength (*NS*) represents the expert's belief that the node would be the proper diagnosis (option, symptom) for the parent node ($\sum NS = 1$, for all children of a node). Node cost (*NC*) represents the relative cost (dollar, time, man–power, resources) of performing, testing, and/or verifying the conditions/tests/actions described at the node ($0 \leq NC \leq 1$). And finally node rank (*NR*), which reflects the most natural, useful, and meaningful ordering of all nodes in a group, when presenting them to the user (*NR*=1,2, ... ,99). To assure the independence and self sufficiency of each knowledge base, a set of universal attributes, common to all knowledge modules are dynamically loaded at the root node of the BHKB. These include tool id, directories, libraries, maintenance personnel, application support personnel, user preferences and system configurations. Universal attributes are available to all knowledge modules, CATs, menus, screens, and windows throughout the session. Attributes specific to a CAT (global) are loaded when it is put on the agenda and are therefore available to all services and diagnostic modules called by this module, as long as the module is active. Global attributes are updated whenever a CAT is added to or deleted from the agenda. Local attributes are valid as long as the node to which they are assigned is active.

6) Summary and Future Plans

Although FTDD973 is only a few months into its operation, its impact on the training and certification business practices are very encouraging. The preliminary results show that a technical and dynamic environment such as 973 fabricator that involves a great amounts of specification and procedure is conductive to multimedia and hypermedia technology. In addition, intelligent management and control of the training, certification, and diagnostics has proved to be very productive and have been highly praised. We view the current FTDD973 as an opportunity for further introduction of ICAT and VET technology into the manufacturing workplace. We are currently investigating use of VR for tool diagnosis, as well as 3D SEM display for defect analysis and classification.

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