# Dedal: Using Domain Concepts to Index Engineering Design Information

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## Abstract

The goal of Dedal is to facilitate the reuse of engineering design experience by providing an intelligent guide for browsing multimedia design documents.

Based on protocol analysis of design activities, we defined a language to describe the content and the form of technical documents for mechanical design. We use this language to index pages of an Electronic Design Notebook which contains text and graphics material, meeting reports and transcripts of conversations among designers. Index and query representations combine elements of the design language with concepts from a model of the designed artifact. The information retrieval mechanism uses heuristic knowledge from the artifact model to help engineers formulate questions, guide the search for relevant information and refine the existing set of indices. Dedal is a compromise between domain-independent argumentation-based systems and pure model-based systems which assume a complete formalization of all design documents.

We describe an experiment where a subject must design a new shock absorber by modifying a similar design. Toward this end, we indexed on-line documents and videotaped material associated with a shock absorber designed at Stanford's Department of Mechanical Engineering. The subject uses Dedal to access these multimedia documents while solving the problem.

## Introduction

Dedal is part of the Design Reuse Assistant project whose goal is to facilitate the reuse of previous design experience for designing mechanical devices.

In an attempt to capture design information, researchers have investigated ways of acquiring both formal design knowledge (Baudin et al 90) (Gruber & Russell 90) and informal design information using media such as videotapes (Stults 88), audiotapes and text and graphic documentation aids (Lakin et al 89). While complete models of an artifact's design are difficult to acquire, canned-text design information or videotapes of meetings are easy to capture but difficult to retrieve by systems that have no representation of the information *content* (Blair & Maron 85).

Based on protocol analysis of a designer's information seeking behavior, we identified a language to describe the *content* and the *form* (text, table, equation, etc.) of design records such as meeting summaries, pages of an electronic design notebook, technical reports and transcripts of conversations among an expert designer and a novice. The language incorporates elements of a model of the artifact being designed with a vocabulary of topics usually covered by design documents.

Dedal is a system that uses this language to: (1) enable the description of the design record content, (2) help engineers formulate questions, and (3) select appropriate records in answer to a question. We tested the ability of an engineer

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to formulate queries using this language and the ability of Dedal to retrieve records related to the user's questions. Section 2 describes a pilot study to identify the design language. Section 3 presents an overview of Dedal. Section 4 describes empirical results of the usefulness of this indexing scheme by two engineers using Dedal while modifying the design of an automobile shock absorber.

## Language to Describe Design Records

Design records associated with an Engineering device cover prescribed features such as requirements, structure and behavior of the final artifact and elements of design history such as decisions, alternatives considered and rationale for design choices. This information has different *levels of detail* ranging from detailed descriptions of a part to global views of an assembly and can take the form of text, graphics, tables, photos or equations.

Our first task was to define a language to describe these aspects of design documents by observing the information-seeking behavior of a designer solving a problem.

We conducted a pilot study at Stanford's Center for Design Research and NASA Ames to identify the classes of information engineers need to access when they *redesign* an existing mechanical device in response to a requirement change. A redesign task requires an understanding of the original design and triggers questions that cover most aspects of its characteristics and history. For this study we chose a variation of an automobile shock absorber (or damper) developed at Stanford's Department of Mechanical Engineering for Ford Motor Corporation by three designers over a seven month period. The design was documented in the designers' personal notebooks and in three technical reports written at different stages of the design process.

- *Pilot study:* A mechanical designer (*subject*) adapted a damper previously designed for a compact car to a vehicle for multiple terrains. While solving the redesign problem the subject was encouraged to think aloud and ask questions of one of the damper designers (*expert*) who could either answer the questions or act as a quick index into the documentation. We videotaped and transcribed this six-hour session.
- *Questions extraction:* We extracted 80 questions from the verbal protocol that the subject asked during the session.
- *Contextualization:* Each question was reformulated to incorporate contextual elements, such as the subject of the question, that were implied but not explicitly stated in the question.
- *Identification of design topics:* We identified categories that encompassed the extracted questions. These classes are an extension of the classification performed by researchers at Oregon State University (Kuffner & Ullman 90) to find out what kind of information designers are interested in.

We duplicated this study with a NASA designer and found that *both* the questions asked by the designer and the concepts addressed in the design documents could be expressed by combining an element from the topic list presented in Figure 1 with elements from a model of the artifact being designed. The meaning of the vocabulary extracted from our study (Figure 1) is described in a separate paper [Baya et al 92]. The concepts of the topic, level-of-detail and media lists are likely to be addressed in *any* mechanical design document. If instead of *design* our main task was *diagnosis* or *manufacturing*, chances are that this vocabulary would have to be changed to take into account the important features of these domains. The topic, levels of detail, and media lists are generic *task-dependent* concepts whereas the subject-class list refers to concepts that depend on a *particular design*.

Accordingly, any information in a design record can be described by several *indexing patterns* of the form: **information-about** topic T **regarding** subject S **with** level of detail L using medium M. T, L and M are selected from the topic, level-of-detail and media lists, respectively, whereas S is one of the following types: feature, component, assembly, requirement. In addition, each indexing pattern contains a pointer to the record and segment corresponding to the starting location of the information (e.g.,. document name and page number or video counter).

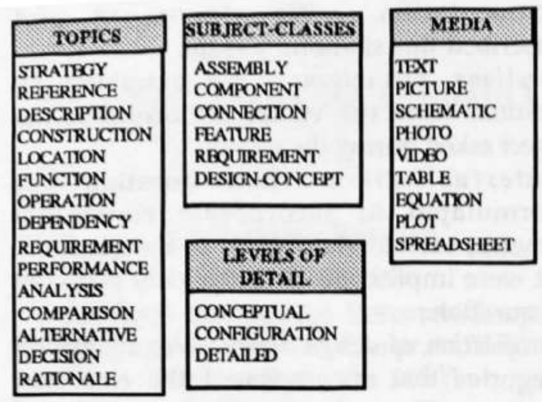


**Figure 1:** Task and Design Dependent Elements of Dedal's Language

For instance, if:*"the solenoid induces a magnetic field generating a force which pushes the lever..."* is a segment of information in the document Report-3344 , it can be described in Dedal by the following indexing patterns:

<information-about topic: **operation,**
regarding subject: **solenoid**
with level-of-detail: **conceptual,**
using medium: **text,**
in record: Report-3344, segment: 12>

<information-about topic: **dependency,**
regarding subject: **magnetic-field of solenoid,**
with level-of-detail: **conceptual,**
using medium **text,**
in record: Report-3344, segment 12>.

Questions in Dedal mirror the structure of the indexing patterns. The format of a question is: **ask-about** *Topic* **regarding** *subject* **with** preferred medium or level of detail. For instance "where is the solenoid?" can be formulated as:

**(q1)** <ask-about topic: **location,** regarding subject: **solenoid** with preferred-medium:**schema**>

## Interacting with Dedal

Engineers at Stanford's Center for Design Research are using an Electronic Design Notebook™[1] (EDN) to capture information such as technical reports, meeting summaries and design notes usually recorded in the designer's paper notebooks. Dedal is an interface to these electronic records. It includes two main components: (1) an indexing component to describe the records, and (2) a retrieval component. These two components interact with a knowledge-base of indexing patterns describing the records.

### Indexing

Indexing with Dedal includes two phases:

In the first phase, a knowledge engineer sits with an expert familiar with the artifact described in the design records. Together they define the device dependent concepts associated with the design and the relations among these concepts. In our tests with indexing the automobile shock absorber we started by focusing on the structure of the prototype produced at the end of the first conceptual design phase. The structure of a device is usually easier to identify than other aspects, such as the geometry of the parts or the description of its behavior. We also included the quantities associated with the attributes of the device, dependency links among these quantities, the main decision points and alternative considered. These concepts and links constitute what we call the device related concept model (DRC model).

In the second phase, an "indexer" describes each record. During this content description phase, the following questions are triggered: What element of the DRC model is the subject of this information segment (subject selection)? What is being said about this subject (topic selection)? At what level of detail? What is the medium used to convey the information? The information can be attached to different levels of the subject hierarchy. For instance, the content of a segment of text detailing the interactions between the parts of a mechanism M can be described by several indexing patterns or "summarized" by saying that this text is about the topic *description* of the subject *mechanism M*.

### Querying

The query module consists of:

• A question formulation component in the form of a graphic interface displaying the DRC

[1] The Electronic Design Notebook is a trademark of performing graphics inc.

components of the mechanical assembly and the generic task dependent vocabulary.

- **A retrieval component** which takes as input a question from the user and matches it to the set of indexing patterns, returning a set of references. The retrieved references are grouped into *answer-sets* of no more than five references. The retrieval component uses a set of heuristics to loosen the match when either no indexing patterns exactly correspond to the current question or the user instructs Dedal to retrieve another answer-set. The retrieval strategy of Dedal can be summarized as follows: given a question of the form <topic, subject, preferred medium, preferred level-of-detail>.

1. Find candidate indexing patterns.
2. Order the indexing patterns retrieved by preferred medium and level of detail.
3. Get feedback from the user on the relevance of the answers. If a relevant reference is retrieved using a heuristic, the question asked by the system is turned into a new index.

Dedal currently uses fourteen **retrieval heuristics** to find related answers to a question. For instance: segments described by concepts like *<decision for lever material>* and *<alternative for lever material>* are likely to be located in nearby regions of the documentation. Another heuristic is "look-for-superpart": if *A* is a part of a mechanism B, information about: *<location of A >* is likely to be found in a picture describing mechanism *B*. Other heuristics reason about the dependencies among the quantities describing the device. For instance: if a question is about *rationale* for the value of quantity Q1, and Q1 depends on Q2, then look for a segment of information describing the *rationale* for the value of Q2.

If the question **q1** (page 3) about the **location** of the **solenoid** is posed to Dedal and if no indexing pattern matches this description, Dedal will activate the retrieval heuristics. In this example, given that *solenoid* is a part of the *force generating mechanism*, the application of the "look-for-superpart" heuristic will retrieve the pattern Ip1 which reference a record showing a picture of this mechanism:

**Ip1:** <topic: **description**
subject: **force-generation-mechanism**
level-of-detail: configuration
medium: schema
reference: (record:damper-transcribed-data-subject-one, segment: 2)>

The reference associated with this pattern is the transcription of a conversation between one of the original damper designers and an engineer asking questions about this design. The reference has two parts, the record name and an EDN page where the relevant information segment is located. If a reference in an answer set is on-line, the user can select it and go directly to the page using the hypertext facility associated with the EDN environment.

- **The index refinement component:** Each time Dedal uses the inference mechanism to find a reference, the user has the option to validate the retrieved reference. Dedal then creates a new index: The topic and the subjects associated with this new index are from the current question, the reference of this new index is the validated reference. The next time the same query is asked to the system, this new index will be retrieved as an exact match in the fist answer set. In our example, If the indexing pattern Ip1 is validated by the user, Dedal will create a new pattern Ip2:

**Ip2:** <topic: **location**
subject: **solenoid**
level-of-detail: configuration,
medium : schema,
reference:(record:damper-transcribed-data-subject-one,, segment: 2)>

Next time the same question is asked, Dedal will retrieve Ip2 as an exact match without calling the retrieval heuristics. In our current version the new descriptions created by the system are stored in a file associated with a particular user and redesign session.

## Empirical Results

We conducted an experiment to evaluate the ability of an engineer to describe design records using our language, the ability of a user to formulate questions to the system, and the retrieval performance of Dedal. Among the questions extracted from the damper redesign protocol, we selected 47 questions whose answers were available in the design records. We asked the mechanical engineer (the subject) who was involved in the redesign pilot study to formulate and submit these questions to Dedal. The goal for Dedal was to reproduce the "intelligent retrieval behavior of the expert" during the redesign study. The answers retrieved by the system were then rated by the subject and by the expert. We considered two classes of ratings: relevant and irrelevant.

**Indexing the Damper Design Records:**
Most damper design documents were captured in the Electronic Design Notebook, except for a videotape showing the operation and testing of the original prototype. One of the experts who designed the damper indexed the design records. The expert defined a "first draft" of a damper model and then refined it while indexing the design records by adding a new subject when no suitable concept could be found in the DRC model. After each indexing session, the expert and a knowledge engineer reviewed the new concepts added during the session and decided how to incorporate them in the damper model.

An average of 4 minutes was needed to index an EDN page of the damper requirement report. The time was less for the appendix pages which were mainly articles and manufacturing catalogue information. Indexing the videotape transcription of the conversation among designers required about 2 minutes per EDN page. It should be noted that the information in the records was familiar to the expert.

**Ability to formulate questions in Dedal:**
Of the 47 questions asked, only 7 had to be reformulated because the user was unsure of which subject to select. This was the case for the extracted question "What did they (the designers) do to limit the heat dissipation coming from the solenoid?" This was first translated to "What is the isolation of the solenoid?" but isolation was not in the model. The user then switched to "What is the material of the solenoid shaft?" and the system was then able to retrieve a set of references.

**Retrieval Performance**
The subject asked 47 questions. Dedal returned a relevant answer in the first answer set for 37 of those questions. For 6 questions the subject had to ask for more information to find a good answer, and for 4 questions the expert could find a better answer in the design records than the ones retrieved by Dedal. Table 1 summarizes these results.

| | subject | expert |
|---|---|---|
| relevant-1st-answer-set | 37 | 36 |
| relevant-other-answer-sets | 6 | 7 |
| relevant-answer-not-retrieved | 4 | 4 |
| rated questions | 47 | 47 |
| %-of-question-answered | .91 | .91 |

**Table 1:** Retrieval Performance

The percent of relevant answers in each answer set was estimated to be 71% by the expert and only 62% by the subject for the same questions and the same references retrieved. Reasons why irrelevant references were retrieved include: incorrect question formulation, bad information description, overgeneralization of the retrieval heuristics. In some cases irrelevant references referred to relevant information previously retrieved and therefore were no anymore interesting to the user.

Although the numbers reported in Table 1 are the same for the subject and the expert, it is interesting to note that in many cases the expert and the subject disagreed on which references were relevant. The main source for this difference in appreciation is related to the "context" dependence attached to the notion of *relevant* answers (Graesser 85). This means that the relevance of the answers retrieved depends on other contextual elements than the ones included in the question formulation. Additional contextual elements that could come into play are: the previous questions asked and the problem goal (in the context of a redesign problem, high level goals could be identified).

## Conclusion

Our system uses a model of the artifact being designed and of the design process to describe the content and the form of design information and to formulate queries to the system. More experimentation is needed to evaluate Dedal. However, our preliminary results tend to show that: (1) The analysis of the designer's information-seeking behavior is a relevant way of identifying a vocabulary to describe design documents, (2) using these descriptions to index design records lead to good information retrieval performance, and (3) a user has been able to use our language to formulate queries about the original damper design in the context of a redesign task.

This type of conceptual indexing is performed interactively with a human. This raises questions about *who* should index the records, what his level of expertise should be, and *when* indexing should take place. It is interesting to note that indexing time can be broken into three time segments: a time T1 to understand the information in the record, T2 to select the proper concepts to describe the information and T3 to create the index in Dedal. If indexing is performed by a user familiar with the records and shortly after they have been generated T1 will be minimized. If indexing is performed by a knowledge engineer familiar with modeling techniques T2 might be shortened. We are currently investigating these questions

We are considering two ways to alleviate the index acquisition burden. The first is to integrate the indexing phase with the design process to help designers *generate* the design documentation as in (Russell 89). The second is to investigate further the use of incremental *question-based* indexing techniques (Mabogunje 90) where the questions asked by a designer are used to create new indices. This is facilitated by our assumption that the query language and the information description language can use the same vocabulary and have similar representations.

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## References

Baudin, C.; Sivard, C.; Zweben, M., 1990. Recovering rationale for design changes: A knowledge-based approach. In Proceedings of IEEE, Los Angeles, CA.

Baya, V.; Gevins, J.; C. Baudin C.; Mabogunje, A.;, Leifer, L., 1992. An Experimental Study of Design Information Reuse. In Proceedings of the 4th International Conference on Design Theory and Methodology.

Blair, D. C.; Maron, M. E., 1985. An Evaluation of Retrieval Effectiveness for a Full-Test Document-Retrieval System. Communications of the ACM Volume 28, Number 3.

Conklin, J.; Begeman, M.L., 1988. gIBIS: A Hypertext Tool for Exploratory Policy Discussion. ACM-0-89791-282-9/88/0140.

Graesser, A.; Black, J., 1985. The Psychology of Questions. Lawrence Elrlbaum associates.

Gruber, T.; Russell, D., 1990. Design knowledge and design rationale: A framework for representation, capture, and use. KSL internal report.

Kuffner, T. Ullman, D., 1990. The information requests of mechanical design engineers. In Proceedings of Design Theory and Methodology. DPRG 90-1.

Lakin F.; Wambaugh J.; Leifer L.; Cannon D.; and Sivard C., 1989. The Electronic Design Notebook: Performing Medium and Processing Medium. THE VISUAL COMPUTER, *International Journal of Computer Graphics* 5: 214-226.

Mabogunje, A. 1990. A conceptual framework for the development of a question based design methodology. Center for Design Research Technical Report (19900209).

Russell, D.M., 1988. IDE: The Instructional Design Environment, in: J.Psotka, J., D. Massey, & S. Mutter (Eds), *Intelligent Tutoring Systems: Lessons Learned*. Hillsdale, NJ: L. Erlbaum Associates.

Stults, R., 1988. Experimental Uses of Videotapes to Support Design Activities. Xerox PARC Technical Report SS1-89-19.