Breton, E. J. (1990). Functional representation of technology. Proceedings of the 1st ASIS SIG/CR Classification Research Workshop, 19-28. doi: 10.7152/acro.v1i1.12460

Functional Representation of Technology

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The literature on technology can be viewed as a vast compilation of answers to technical needs or problems. Take the patent literature, for instance: We have over four million inventions designed to satisfy specific technical needs of every type imaginable. Every technical product is intended to answer some need.

On the other hand, here we are in a rapidly changing civilization that is generating technical needs at an ever accelerating rate: needs to protect the environment, to conserve materials, to feed people, to move people, to house people, to create jobs, to support civilization's infrastructure....

The challenge of scientists and engineers is to tap this resource of answers in the literature to to satisfy civilization's evolving needs. This challenge translates into an information retrieval task: matching technical needs with potential answers in the literature. Current classification and querying means have not been optimized to do this.

NEED FOR A BETTER WAY TO REPRESENT TECHNOLOGY

The problem with universally-used subject and keyword querying systems is that you require an inkling of an answer in order to select search terms. You are building on what you already know. Hence the range of possible answers to a problem tends to be restricted by what you already know. This, in turn, tends to reduce the likelihood of coming up with creative solutions.

For example, if a mechanical engineer wanted to find a better way of measuring surface roughness, she or he typically would start a keyword search with terms *gages & surface & roughness or profilometer*. This search probably would not turn up a description of an *ellipsometer*, which is a highly specialized instrument that can be used to measure surface roughness. Thus, in this scenario, options that would be presented for measuring surface roughness would be constrained by the domain of knowledge of the person generating the search terms.

Having wrestled with the problems of subject and keyword searching over my entire 30-year career in industrial research, I have come to the conclusion that a solution to this dilemma lies in classifying technologies by the functions they perform.

FUNCTIONAL REPRESENTATION OF TECHNOLOGY

Function is a good basis for classifying technology because: (1) Every technology has one or more functions — chairs, diapers, computers, battleships, for instance owe their existence to functions they perform, and (2) scientists and engineers, in solving technical problems, define what is needed in terms of functions and attributes. Hence, functional classification of technologies ought to enable technical databases to be much more effective tools for problem solving by establishing a *common language* between people with problems and databases with

ISSN: 2324-9773

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answers.

Functions are combinations of verbs with objects (verb/object predicates in the form of a verb x object matrix are described further on). We can define two types of function to characterize a technology: system functions and component functions. These are illustrated in Figure 1, which is a functional diagram of a food blender. The system function is the overall function of the blender: BLEND INGREDIENTS. This is the use of the blender. This system function is an assembly of three first-level componential functions: CONTAIN INGREDIENTS, DISPERSE INGREDIENTS, and POSITION (blender) COMPONENTS. CONTAIN INGREDIENTS and POSITION COMPONENTS are what might be called root functions. They cannot be factored any further into subcomponents. On the other hand, the DISPERSE INGREDIENTS component is comprised of two subcomponent (second-level) functions: ROTATE IMPELLER and CUT/MIX INGREDIENTS. ROTATE IMPELLER, in turn, is comprised of three other, third-level component functions.

Note that the root functions of the blender are derived from fundamental properties of matter and energy. These are designated by the rectangles in the schematic. They might be thought of as prefunctional, being the building blocks of functions. They are included in functional analyses for a number of reasons. One is to show the relationship of a technology to its scientific building blocks. An understanding of these relationships and the underlying science prepares the mind to better design, use, and maintenance technology. Another reason is to facilitate the process of invention by leading inventors back to basic building blocks for creating new technology. These scientific building blocks are like words, the building blocks of language. You combine scientific building blocks to create functions and attributes just as you combine words to create sentences.

REPRESENTATION OF ATTRIBUTES OF TECHNOLOGY

Once one has targeted a means for performing a needed function, attention then is focused upon attributes. How well is the function performed? Or what are the features associated with the function that enhance its utility or value? For instance, once one has concluded that they need a food blender, they decide which one to buy on the basis of attributes. Typically, attributes influencing the selection of food blenders by consumers are cost, convenience, and appearance. Laboratories likely would base the selection of a blender upon performance and durability.

CLASSIFICATION OF INDUSTRIAL PRODUCTS

With the goal of classifying the universe of technology, I classified 3,000 industrial products by their uses. Descriptions of them were obtained from new-product news releases that appeared in 140 technical journals covering most fields of technology. (This work was sponsored by the Thomas Publishing Company.)

Industrial product literature is a good representation of the universe of technology because technology is proliferated via commercial products and services. Products and their distribution networks are the vehicle for transferring technology from the laboratory to general use. New-product literature is a good sampling of industrial products because over 95% of "new" products are really slight modifications of existing products. In fact, seldom did we come across truly new

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products.

I ended up with two types of product: those used for their functions and those used for their properties (weight, strength, conductivity, etc.). This distinction appears in the functional analysis of a food blender depicted in Figure 1.

FUNCTIONAL CATEGORIES

Products used for their functions were represented by sentences with the following components:

Subjects = names of products.

Verbs = functions of products.

Objects = what products act on.

Modifiers = attributes of products.

Verbs of sentences representing those products used for their functions could be grouped under one of six generic categories:

MAKE	Products used to alter the state of being of something, i.e., tools, processes, generators, etc. GENERATE, MANUFACTURE, REPAIR, CREATE, CUT, MIX ...
CONTROL	Products used to control the use or operation of something. REGULATE, CALIBRATE ...
ASCERTAIN	Products used to determine the state, location, content, or some parameter of something, i.e., rulers, scales, analyzers, monitors, etc. MEASURE, CHECK, ANALYZE, DISPLAY ...
PROTECT	Products used to maintain the integrity of something, i.e., packages, locks, gloves, etc. PACKAGE, MAINTAIN ...
HOLD	Products used to maintain the location, position, or shape of something, i.e., tanks, brackets, shelves, chairs, etc., STORE, CONTAIN, POSITION ...
MOVE	Products used to alter the location of something, i.e., conveyor belts, trucks, power transmission equipment, telephones, water pipes, etc. TRANSMIT, DISTRIBUTE, DISSEMINATE, CONVEY ...

Objects that these verbs acted on were placed in three generic categories:

MATTER	This represents all forms of matter in the universe: manufactured products, biological matter — anything made up of solids, liquids, or gases.
ENERGY	This represents all forms of energy in the universe: thermal, mechanical, electromagnetic ...
INFORMATION	This represents all forms of information processed by humans.

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FUNCTION CLASSIFICATION MATRIX

These verb and object categories can be represented by the matrix shown in Figure 2. The six verb categories are represented by columns A through F. Objects are represented by rows. An intersection of a row and a column at a cell in the matrix defines a predicate. In practice, cells are doorways to higher-resolution definitions of these verb/object predicates (functions). In a succession of user-computer interactions, they would lead to a much smaller set of subjects (products) that more precisely satisfy the user's need. This is illustrated further on by a sample interaction from a proposed system.

The verb/object predicates for the MATTER row are easy to visualize: We MAKE computers; we CONTROL traffic with stop lights; we MEASURE weight with scales; we PROTECT bread with wrappers; we HOLD (store) books on shelves; we MOVE books in trucks. Likewise we can visualize verb/object predicates for the ENERGY row: GENERATE electricity; CONTROL heat; MEASURE temperature; PROTECT heat loss with insulation; STORE energy in electrical capacitors; TRANSMIT electricity with extension cords. We do not have examples of verb/object predicates for all forms of energy: For example, in the current analysis we did not encounter means for storing electromagnetic radiation.

CLASSIFICATION OF INFORMATION

In classifying information-related products, I ended up with products that were either "inputs to human thinking" or products related to doing something to information in some way.

Products in the latter category were represented by intersections of the INFORMATION row with columns (A through F) in the matrix in Figure 2. For example, we GENERATE (make) information; in data transmission, we CONTROL the flow of information; we ASCERTAIN what is in a database with information retrieval software; we PROTECT information; we STORE (hold) information; we DISTRIBUTE (move) information (Copiers are means for distributing information, for instance).

Products that are "inputs to human thinking" are building blocks of information just as properties of matter and energy are building blocks of hardware. I am proposing to classify both of these building-block categories under the generic heading INHERENT PROPERTIES.

Information has usefulness only within the context of the meanings given to the words or symbols used to convey the information. I am viewing these meanings as inherent properties of words and symbols. The inherent property of a group of words is the meaning of the group. The inherent properties (meanings) of words and groups of words are the input or building blocks of human thinking. For example, the building blocks of the thoughts expressed in this paragraph are the inherent meanings of the words and sentences used to write it.

Classification of information-related products is tricky because their functions are not as obvious as the other two categories of objects. Let me illustrate the problem with classification of a magnetic disk for PCs:

If the disk were a hypertext discription of sewage treatment, it would be placed in the INHERENT-PROPERTY category because the description is an input to human thinking. On the

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other hand, if it were word-processing software like Word Perfect, it would be placed in the MAKE (generate) category because word-processing programs are tools for generating information. Or, if it were a blank disk, it would be placed in the HOLD (store) category.

INHERENT-PROPERTY MATRIX

The INHERENT-PROPERTY category for matter, energy, and information was incorporated into Figure 2 as a one-dimensional matrix adjacent to the verb/object matrix. The two matrices were combined in the manner illustrated because they share the same rows.

Forms of matter and energy that are building blocks of functions, as illustrated in Figure 1, would be classified in cell 1 (e.g., properties of plastic) and cell 2 (e.g., properties of electrical energy) of the matrix, respectively. Information that was input to human thinking would be put in cell 3 (e.g., instruction manuals).

One might view this inherent property matrix as a rudimentary classification system for applied science. It will probably evolve into a greatly expanded matrix.

CLASSIFICATION OF ATTRIBUTES

Attributes represent qualities of a product. Attributes associated with the 3,000 products were grouped under one of the following quality categories:

1. BETTER INHERENT PROPERTIES
2. BETTER PERFORMANCE of a product's function
3. LOWER MAINTENANCE
4. MORE DURABILITY
5. SAFER to use
6. MORE CONVENIENT to use
7. LOWER ENVIRONMENTAL HARM
8. BETTER APPEARANCE
9. LOWER COST (initial or operational)

In finding better ways of doing things, engineers look for attributes in the above quality categories. Hence writers of news releases emphasize the comparative adjectives in this list. (Whether they are accurate or not is another matter; that's up to the buyers to resolve.)

CLASSIFICATION OF A BLENDER

To illustrate the use of the functional classification scheme, consider how a laboratory technician seeking means to blend clay with hydrochloric acid would use the scheme to find what he or she needed.

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Starting with the matrix in Figure 2, one would select the MAKE/MATTER (A1) cell because the function of the blender is to make something. Food and any liquid that it would be blended with are forms of matter. In blending, one starts with matter in separate states (food and liquid) and then transforms them into a homogeneous state. Thus, blend is a subset of the make (change) function — It could not be a subset of control, measure, protect, move, store, or position.

Selection of the A1 cell would pull up a menu with these choices:

(a) 1 *Construction* 2 *Fabrication and General Manufacturing*,
3 *Specialized Manufacturing*, 4 *Processing Matter*

Blending is processing matter. It could not be anything else. Selecting *Processing of Matter* would pull up the menu:

(b) 1 *Mix/Blend*, 2 *Separate*, 3 *Change Temperature*,
4 *React*, 5 *Purify*

Select *Mix/Blend* to further increase resolution of the MAKE column.

(c) 1 *Mix*
(Mixing without loss of identity of components.),
2 *Blend*
(Intimate mixing with loss of visual identity of components. Includes mixing soluble liquids.)
(These definitions would either be included on the menu or displayed upon pressing a "hot key.")

Select *Blend* to increase resolution of the MATTER row.

(d) 1 *Solids in Solids*, 2 *Solids in Liquids*, 3 *Liquids in Liquids*
4 *Gases in Liquids*, 5 *Solids in Gases*, 6 *Liquids in Gases*,
7 *Combination of Solids, Liquids and Gases*

Up to this point, we have selected a set of means for blending that could satisfy this basic function needed. Select *Solids in Liquids* to display attributes to enable the technician to pinpoint a blender to do the job.

(e) 1 *Industrial Use*, 2 *Commercial Use (food handling)*,
3 *Laboratory Use*, 4 *Home Use*

Select *Laboratory Use* to obtain subcategories of these attributes.

(f) 1 *Low Cost*, 2 *Convenience*, 3 *Durability*

Select *Durability* to obtain subcategories of durability.

(g) 1 *Ruggedness*, 2 *Chemical Resistance*, 3*Abrasion Resistance*

Select *Chemical Resistance* to obtain a means for blending that should resist attack by hydrochloric acid. This selection would pull up a screen listing the blender models plus their manufacturers that featured chemical-resistant blenders.

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In a full implementation of the proposed system, selection of one of the products would result in a description of this product plus the option of having literature sent to the technician. These menu selections prompted the technician to precisely define a technical need in terms the database could recognize. Such a querying process (enabled by functional and attribute classification) should be broadly applicable to technical problem solving.

FUNCTIONAL CLASSIFICATION IN PERSPECTIVE

This description of functional indexing is simply a flash picture of an ongoing process of developing intelligent databases for technical problem solving. A necessary first step towards achieving this objective is developing a mechanism for representing technical knowledge.

Functional indexing, as described above, is aimed at doing this. Functional indexing is not new. One of the classification systems used by the U.S. Patent Office is based upon functions. However, it is designed to enable a patent examiner to start with an answer (the patent application) and determine if the answer (prior art) already exists. On the other hand, the proposed functional classification system is designed to enable an engineer to start with a problem and determine if an answer exists.

Whether the proposed functional classification system can be developed to be applicable to the universe of technology remains to be seen. By being applicable, I mean being over 99% successful in fitting technologies into the classification system.

The need to create the INHERENT PROPERTIES classification for industrial products shown in Figure 2 has led me into working on a classification system for the science used to create technology.

The classification system in its present stage of development can be tuned to directly match user needs with answers in a database. (Tuning, however, could entail a substantial effort depending upon the database.) However, it cannot match needs with inferred answers.

For example, Thomas Edison in developing an oxidation-resistant filament for electric light bulbs would not have retrieved vacuum from a search on *prevent oxidation*. Instead, he would have retrieved oxidation-resistant coatings, coatings whose primary functions are to prevent oxidation. Vacuum would not be retrieved because, per se, it is not a function. Retrieving vacuum would have required the inference: "Vacuum reduces the concentration of oxygen; therefore vacuum should reduce oxidation because oxidation is decreased by a decrease in oxygen concentration."

Developing the capability of making such inferences will be a goal of future work.

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Figure 1: Functional Analysis of Food Blender

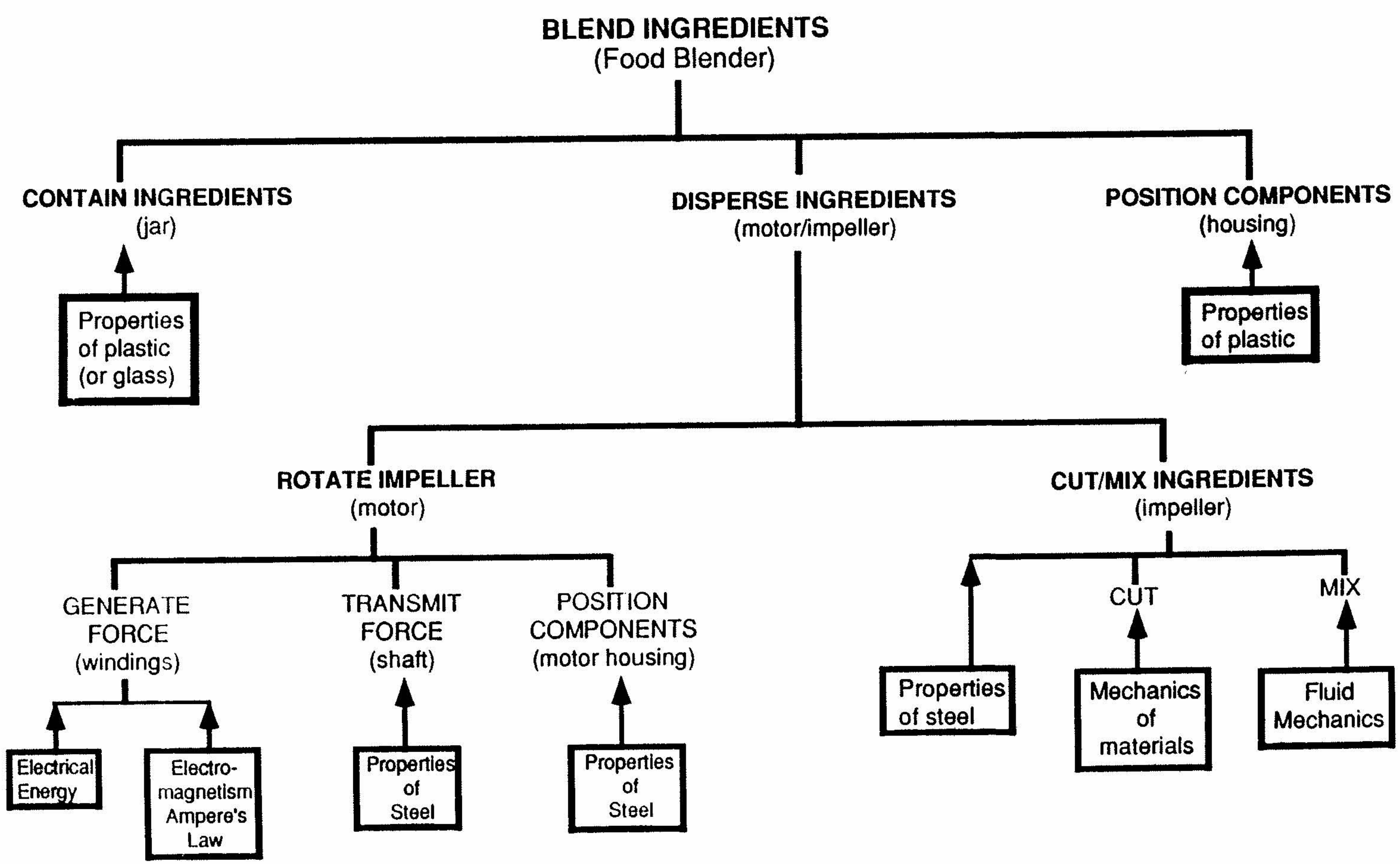

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FIGURE 2: Matrices for Classifying Technology

OBJECT	INHERENT PROPERTY	A MAKE, GENERATE, REPAIR	B CONTROL REGULATE CALIBRATE	C ASCERTAIN, MEASURE, CHECK	D PROTECT PACKAGE MAINTAIN	E HOLD STORE CONTAIN	F MOVE TRANSMIT, DISTRIBUTE
1. MATTER Inanimate Biological	1	A1	B1	C1	D1	E1	F1
2. ENERGY Mechanical Heat Electrical Electromagnetic Nuclear	2	A2	B2	C2	D2	E2	F2
3. INFORMATION	3	A3	B3	C3	D3	E3	F3

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