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Biomimetics — Ontology-Enhanced Thesaurus (OET) for biomimetics

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Contents

Page

Foreword

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 266, *Biomimetics*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

A thesaurus is often used to map terms between different knowledge domains. The Knowledge Infrastructure for Biomimetics project was established to fill the gap between biology and technology. The project originally planned to develop a biomimetic thesaurus and an ontology that would complement such a thesaurus in situations where the thesaurus cannot deliver useful search terms because concepts in the two domains are associated with keywords that lack explicit links. Although work on the biomimetic thesaurus has been postponed, Ontology-Enhanced Thesaurus (OET) does not require a thesaurus and can be used as a standalone tool. For more details see 5.2.

OET addresses a portion of this knowledge infrastructure. It is composed of an ontology of biomimetics and an application named Keyword Explorer that provides an interface to the ontology. OET and Keyword Explorer help designers, engineers, and other bio-inspired design (BID) practitioners by mapping technical terms to biological terms that can then be used to search biological texts to identify biological models (see Figure 3). For example, a traditional thesaurus may relate “stain-resistant” to “self-cleaning” or “soil release”. A biomimetic thesaurus or internet keyword search may additionally return “antifouling”. OET can identify organisms that share functions related to “antifouling” but not directly associated with the term.

In Clause 4, after a brief overview of the current state of the art of tools and systems in biomimetics, OET and Keyword Explorer are positioned in the related work. Clause 5 describes OET together with its design rationale. In-depth description on the implemented ontology in OET is Clause 6 and Clause 7. Clause 8 describes accessing and running the Keyword Explorer prototype in order to get feedback from readers.

NOTE A publicly available version of Keyword Explorer and OET is available at http://biomimetics.hozo.jp/OET/demo.html as a web application — it only includes one function (antifouling) but demonstrates the capabilities of the prototype version. The corresponding ontology can be inspected via “Browsing the Biomimetics Ontology” in http://biomimetics.hozo.jp/OET/, but it is not possible to download it. Paid users of this document can download the prototype version.

Biomimetics — Ontology-Enhanced Thesaurus (OET) for biomimetics

1 Scope

This document describes prototypes of the Ontology-Enhanced Thesaurus (OET) and the Keyword Explorer interface to OET. Although their design philosophy is described, this document focuses on their value and how they work.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
data
minimum piece of information that is meaningful for its potential readers or users

Note 1 to entry: In many cases, data is a component of larger entity, a data set or a data base. Data can be text as in research papers, simulation models, algorithms, numbers, pictures, figures, voice and video recordings.

3.2
database
set of almost any digital objects, which can be text, picture, sound, video, etc.

3.3
information retrieval service
set of software that allows users to retrieve information from *databases* (3.2)

Note 1 to entry: Quite often, ontologies or thesauri are incorporated in the information retrieval service.

3.4
index
set of key terms (usually arranged in alphabetical order) with pointers to the original source of each term (includes books, research papers, or other forms of writing)

3.5
metadata
data (3.1) that provides information about other data

Note 1 to entry: The keywords in an index are metadata of the body of the text from which the keywords are extracted.

3.6
ontology
formal, structured, and explicit description of concepts in a domain of discourse and the relations between them in the fields of knowledge management and artificial intelligence

Note 1 to entry: An ontology together with a set of individual instances of classes constitutes a knowledge base.

3.7
taxonomy
orderly classification of things or concepts into groups within a larger system, based on common qualities

3.8
thesaurus
list of words arranged in groups based on similarity of meaning

4 Role of the knowledge infrastructure for biomimetics

4.1 General

In Figure 1, ISO 18457 and ISO 18458 cover the phases from “Analysis” to “Overall evaluation” and ISO 18459 covers the phases from “Project/design of experiment” to “Prototype construction/manufacturing.” The Knowledge Infrastructure for Biomimetics covers “Analysis” and “Analogy/abstraction”, with OET focusing mainly on “Analogy/abstraction”. OET is a product of the Knowledge Infrastructure project and is composed of an ontology and the Keyword Explorer interface.

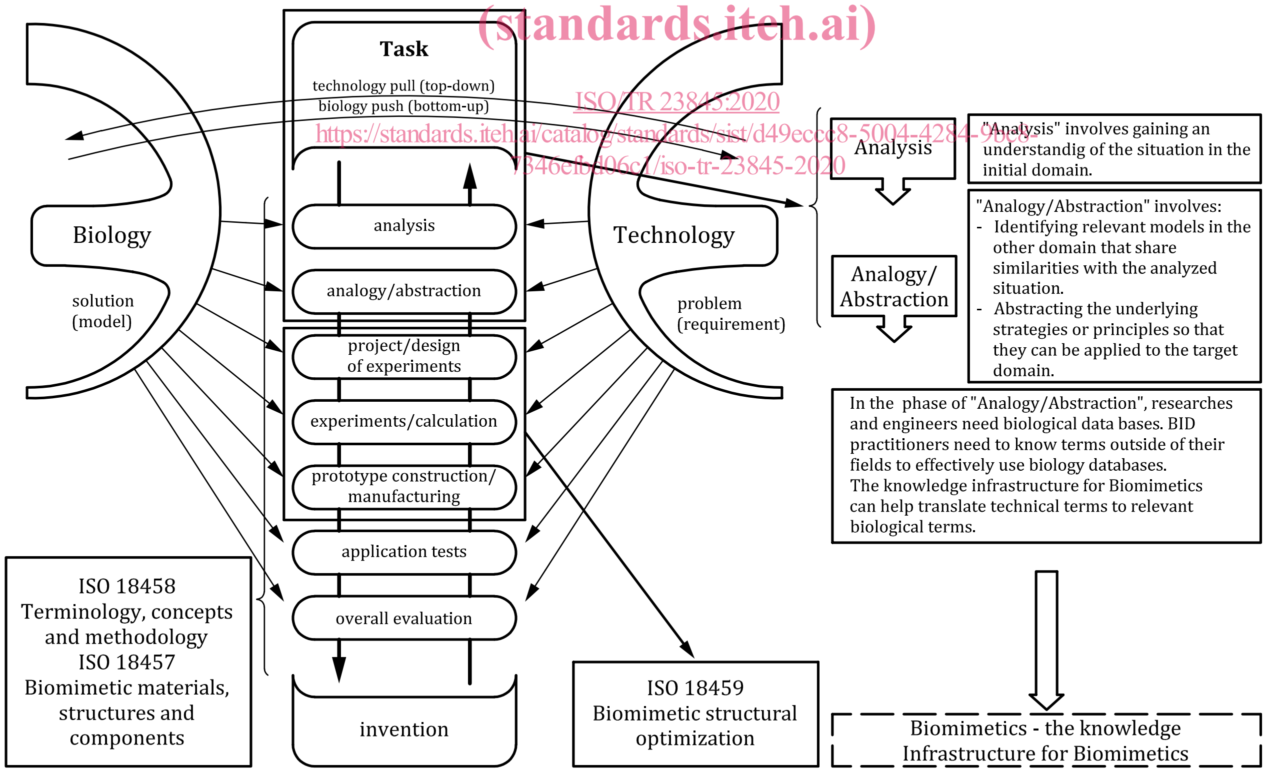

Figure 1 — Simplified flow chart of a biomimetic development process (adapted from ISO 18458)

4.2 Related work in the framework of the design processes of BID

There are quite a few methods/tools for supporting innovative design based on biomimetics or bio-inspired design (BID). They are classified according to two dimensions (see Table 1). The rows are the phase of the targeted design process ("Analysis" and "Analogy/abstraction") based on Wanieck's analysis[1]. The columns are based on a qualitative assessment of the degree of guidance the tools provide practitioners searching for BID solutions (low to high).

Table 1 — Classification of existing methods/tools

	High guidance	**Low guidance**
Analysis phase	SAPPhIRE DANE Biomimetic Ontology	BioTRIZ E2B thesaurus
Analogy/abstraction phases	SAPPhIRE DANE Biomimetic Ontology OET	iSEE AskNature

Chakrabarti[2] developed the SAPPhIRE system for automated analogical search of relevant ideas based on a generic model for representing causality in natural and artificial systems. It helps develop novel, analogical ideas for solving design problems using inspiration from both natural and technological domains.

Goel's system, named DANE (Design Analogy to Nature Engine)[3][4], facilitates analogical reasoning to help practitioners find and understand biological systems relevant to the design context. Practitioners can build structured representations of biological and technical systems using the Structure-Behavior-Function (SBF) ontology to model the systems, extract relevant principles, and build a library for the BID community. The current focus is on automatically extracting the SBF models directly from biological texts[5]. The plan is to incorporate augmented intelligence such that DANE becomes a collaboration partner in the design process.

Hollermann[6] developed a biomimetic methodology and tool for supporting creativity in product innovation based on a general concept including a detailed guideline. It supports the identification of biological models through the iSEE (iterative semantic examination) process.

BioTRIZ[7][8][9] is an extension of the TRIZ methodology to better support BID. TRIZ was developed through an analysis of successful patents[10] and has shown that it can solve problems in a wide range of topics, ranging from engineering through architecture to management. BioTRIZ consists of a set of tools, rules, and techniques to help identify possible solutions in biology.

Vincent[11] is developing a Biomimetics Ontology focusing on the trade-off as a central concept to bridge the gap between biology and problem-solving in technology. The concept of the trade-off is defined using the method of the TRIZ Contradiction Matrix. The ontology can identify trade-offs, suggest biological analogues, and uncover principles for BID.

AskNature[12] is a comprehensive database of several kinds of useful BID resources. It consists of four primary types of interconnected information: (1) biological strategies, (2) inspired ideas related to BID, (3) resources for learning/teaching BID, and (4) collections of themed clusters curated by the users. Although it provides useful information for practitioners, these types of databases require constant updating as new information becomes available and rely on the practitioner to drive the search process.

The work of Nagel[13] and Cheong[14] building on research by Stone and Shu's labs[15][16] helps fill the gap between functional terms used in engineering and biology. They employ the functional basis[17] which is widely accepted as a standardized representation of engineering product functionality in USA. They built the Engineering-to-Biology (E2B) thesaurus[18] for translating engineering function and flow terms into meaningful biological functional terms to help address the terminology issues engineers face when working between the two domains, and assist in problem definition, inspiration searching, biological functional modelling, and analogy formulation. Their work is different from OET in two respects. Their thesaurus only deals with function/flow terms, whereas OET covers organisms, features, and living environments, as well as functions. Moreover, they mainly provide biological functional terms for information retrieval, while the Keyword Explorer provides candidate organisms as possible solutions based on OET's association-based inference.

OET provides practitioners with a simple way of identifying potentially relevant organisms for future research, in comparison to SAPPhIRE and DANE that are based on models, and the Biomimetic Ontology that is based on trade-offs.

4.3 Positioning of OET in the context of the BID design process

As biomimetics is a cross-disciplinary endeavour, it is crucial for all relevant disciplines to exchange their accumulated knowledge and ideas. Each discipline has developed its unique set of concepts and words that often have different meanings and usages. Without a proper translation mechanism, communication among the disciplines will be hindered.

At a high level, practitioners of biomimetics doing "technology pull" often follow four steps[1]:

1. Analysis: gain a deep understanding of the technical problem to be solved or situation to be improved, which may involve functional analysis and abstraction as well as reformulating the challenge to simplify the second step;
2. Analogy: identify relevant biological species, phenomena, or models that share similarities to the technical challenge but suggest new ideas;
3. Abstraction: examine the relationship of the biological models to various aspects of the original technology challenge to identify underlying strategies and principles which will aid in transfer of the ideas;
4. Application: find an implementable solution to the original challenge.

In the case of "biology push", the analysis step relates to the biological phenomenon or model. The analogy step involves finding technical situations that share common drivers, while the abstraction and application steps are similar to those in "technology pull."

Access to biological databases is crucial, but these databases are organized using biological terms. Therefore, translation of the technical terms into biological terms is required.

OET has been primarily developed for practitioners but could also be valuable to biologists.

5 How Keyword Explorer works

5.1 General

Keyword Explorer is an application program running on OET that explores concepts defined in OET where each concept is used as a keyword to retrieve relevant information. The exploration mechanism is association-based. See Figure 2 where rectangles denote concepts and links denote associations (relations) defined in OET. When a user inputs "antifouling", Keyword Explore traverses the concepts in OET like a person does association-based inference.

EXAMPLE "When it gets dirty, if it automatically cleans itself (*self-cleaning*), it would work for antifouling, to self-clean, *washing out* the dirt would be also effective. To do so, *covering its surface with water* would work well. Oh, it reminds me of *hydrophilic* property which in turn reminds me of *water repellence*. *Rose petals* are well-known as their *hydrophilic* property which is opposite to *water repellence*. Rose petals realize those two properties by their *double structure* of microscopic protrusions covered with a hydrophobic waxy material which is also found on *lotus leaves*. To find something *antifouling*, would be effective to investigate organisms *living in the mud*. Ummm, *earthworms* live in the mud and their surface looks clean".

In such a way, users would be able to reach rose petal, lotus leaf, earthworm, and other organisms, some of which could be useful. They can find papers about them and would be able to find more detailed information as well as experts on the related topics.

To enable such association-based inference, different types of concepts are required. Antifouling and self-cleaning are **functions** (the role played within the larger system); washing out and covering with water are **behaviours** (how a function is manifested); water repellent and hydrophilic are **properties** (inherent characteristics of the organism); rose petal, lotus leaf and earthworms are **organisms**; and living in the mud is related to **living environment**. Furthermore, self-cleaning is a sub-function of the antifouling function, while washing out and covering with water enable self-cleaning, which suggests function-decomposition plays an important role in facilitating associative inference.

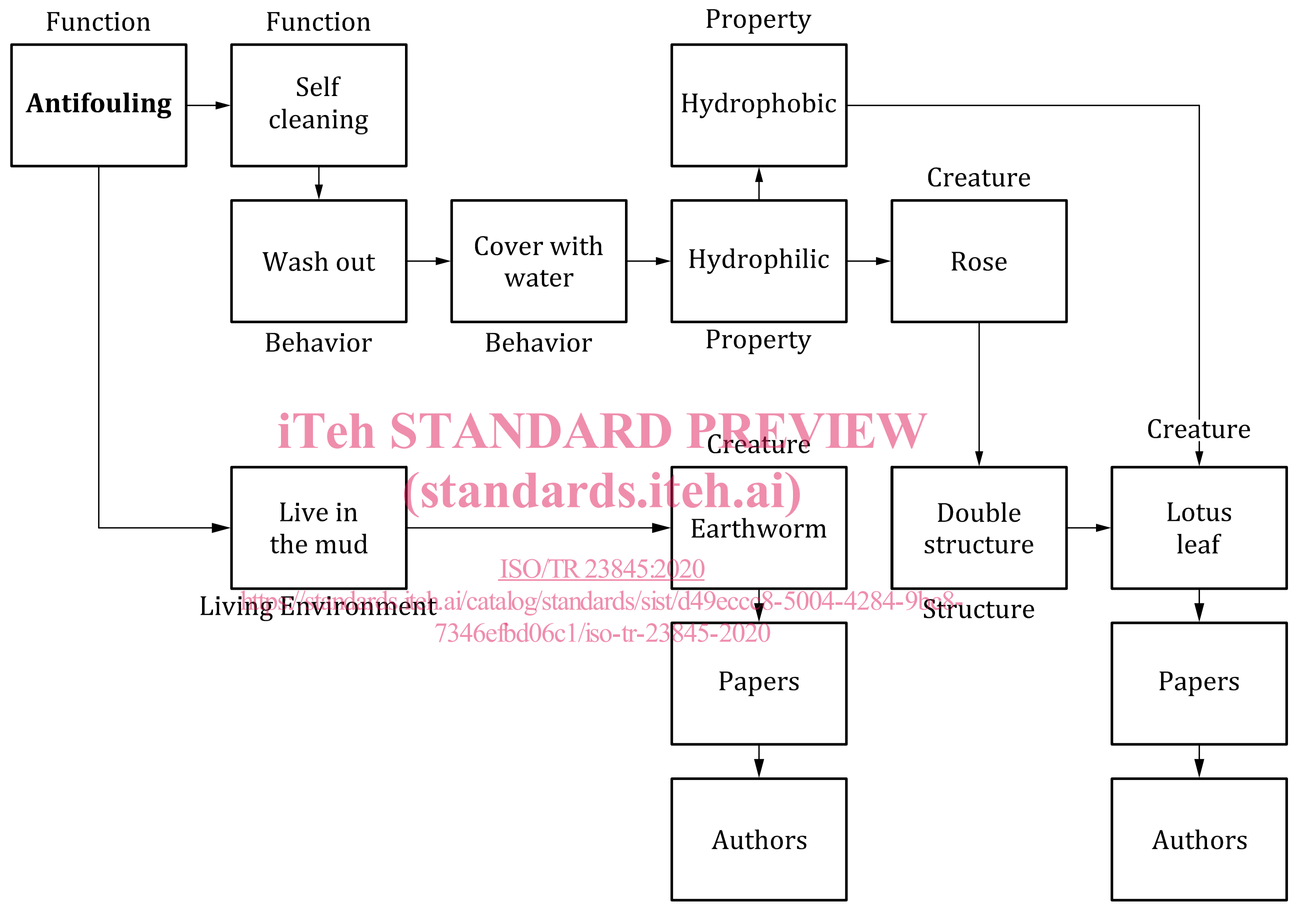

Figure 2 — Association-based inference by Keyword explorer

Ontologies play a key part in the knowledge infrastructure — Figure 3 shows how the ontologies in OET fill the gap between engineering and biology. The two vertical ovals represent conventional thesauri in the engineering and biology domains. Although each thesaurus works well in the respective domain, they would be inadequate for biomimetics which spans these two domains. Although biomimetic thesauri have been created, they have limitations as described in 6.4. Ontologies can enhance the utility of conventional thesauri by bridging conceptual gaps between engineering and biology domains.

