



**HAL**  
open science

# An Interdisciplinary Framework for Systematic Innovation: A Case Study on Nature-Inspired Imaging Solutions

Nicolas Douard, Ahmed Samet, Denis Cavallucci, George Giakos

► **To cite this version:**

Nicolas Douard, Ahmed Samet, Denis Cavallucci, George Giakos. An Interdisciplinary Framework for Systematic Innovation: A Case Study on Nature-Inspired Imaging Solutions. IEEE International Workshop on Imaging Systems and Techniques (IST) 2024, 14-16 Oct. 2024, Tokyo, Japan, Oct 2024, Tokyo, Japan. 10.1109/IST63414.2024.10759205 . hal-04922407

**HAL Id: hal-04922407**

**<https://hal.science/hal-04922407v1>**

Submitted on 30 Jan 2025

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# An Interdisciplinary Framework for Systematic Innovation: A Case Study on Nature-Inspired Imaging Solutions

Nicolas Douard<sup>1,2\*</sup>, Ahmed Samet<sup>1</sup>, Denis Cavallucci<sup>1</sup>, George Giakos<sup>2</sup>

<sup>1</sup>National Institute of Applied Sciences, University of Strasbourg,  
24 Bd de la Victoire, 67000 Strasbourg, France

<sup>2</sup>Department of Electrical and Computer Engineering, Manhattan University,  
3825 Corlear Ave, New York, NY 10463, USA

\*Corresponding author: nicolas.douard@insa-strasbourg.fr

**Abstract**—This research presents a novel interdisciplinary framework designed to uncover connections across diverse knowledge domains through advanced semantic modeling techniques. A case study focused on nature-inspired imaging solutions illustrates the potential of the framework. Innovation often emerges at the intersection of various scientific fields. However, manually identifying these intersections within the vast scientific literature is impractical. By exploring how biological principles can inspire the development of advanced imaging technologies, such as image sensors for rapid motion tracking, we underscore the critical role of interdisciplinary research in the promotion of technological innovation. Our framework systematically identifies and analyzes cross-domain connections, showcasing the potential of automated bioinspired approaches to drive innovation from the early stages. This research highlights how semantic modeling can bridge gaps between disparate fields, facilitating the discovery of novel insights, and fostering a more integrated approach to academic research. By automating the process of identifying relevant intersections within extensive literature, our framework not only enhances research efficiency, but also broadens the scope for innovative solutions. Ultimately, this work underscores the value of interdisciplinary collaboration and the transformative potential of bioinspired methodologies in the advancement of technology. The findings presented offer an actionable roadmap for leveraging semantic modeling to accelerate the pace of innovation in various domains.

**Index Terms**—bioinspired innovation, imaging technologies, technological innovation, semantic modeling, interdisciplinary research

## I. INTRODUCTION

Innovation often arises at the intersection of diverse knowledge domains, particularly when biological principles inspire engineering solutions [1]. This approach, known as biomimetics or bioinspired design, has led to numerous technological advances by emulating the strategies that have been tested in nature [1]. However, manually uncovering these interdisciplinary links within the vast scientific literature is impractical. This paper focuses on a case study involving nature-inspired imaging solutions, demonstrating the relevance of interdisciplinary connections in driving technological advancements.

Bioinspiration has long been explored by TRIZ (Theory of Inventive Problem Solving) researchers [2], [3], yet they have been unable to achieve real-time automated pairing identification. This limitation highlights the need for more advanced methods to efficiently discover and utilize cross-disciplinary insights, particularly in the rapidly evolving field of biomimetics.

We employ a framework introduced in Douard et al. (2023) [4], [5] using advanced semantic modeling techniques to reveal associations in scientific texts. Unlike simple keyword mapping, our approach captures the nuanced thematic structures of the texts, providing a deeper understanding of cross-domain connections. By distinguishing between monodisciplinary and multidisciplinary texts, we create an optimized corpus that highlights significant interdisciplinary connections, enhancing the accuracy of our models. This framework enhances our ability to discover interdisciplinary insights, thereby fostering innovation.

Our study aims to explore how biological principles can enhance technologies like image sensors for rapid motion tracking. By systematically identifying and analyzing these cross-domain connections, we seek to showcase the potential of interdisciplinary research in uncovering novel solutions to complex challenges. This case study exemplifies how nature-inspired approaches can drive innovation and improve technological capabilities.

## II. METHODOLOGY

### A. Interdisciplinary Model

To effectively identify texts that span multiple disciplines, we propose using a supervised machine learning classifier. This classifier is designed to recognize interdisciplinary documents, even when metadata labels them under just one domain. Accurately identifying such interdisciplinary works is crucial for constructing comprehensive maps of knowledge connections across disciplines.

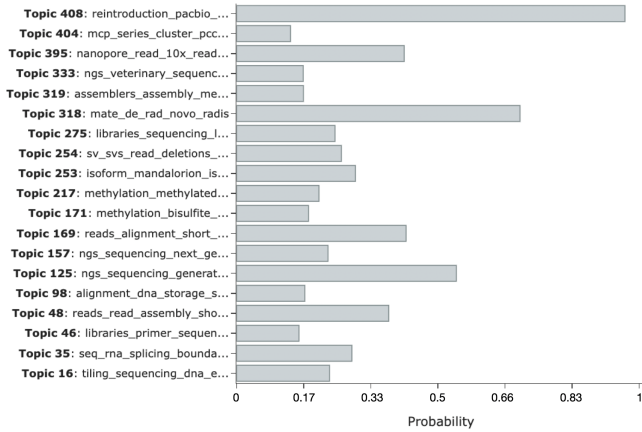


Fig. 1. Article topic distribution example.

A specific corpus of literature is preprocessed to create a target column indicating whether an article belongs to one or multiple *fields of study*.

### B. Interdisciplinary Graph

Starting with an initial set of engineering topics related to a research question, we investigate commonly linked biology topics. Advanced topic modeling techniques such as BERTopic [6] are employed to create a unique set of topics. Each topic is labeled to reflect its association with either engineering or biology.

Article abstracts are semantically evaluated against each topic. This gives, for each article, a probability of belonging to a specific topic, as illustrated in Fig. 1. We associate each article with a primary and a secondary topic, each belonging to either engineering or biology. Subsequently, a graph of topics is created where nodes represent topics and edges represent the frequency of association between topics, derived from the training corpus. We approach this frequency as an interdisciplinary *weight*.

After constructing the interdisciplinary graph, we can visualize the relationships between engineering and biology topics, as illustrated in Fig. 2. This graph depicts a sample of interconnected topics, where each node represents a specific topic, and the edges represent the association frequencies (weights) between the topics. The varying thickness of the edges reflects the varying strengths of these interdisciplinary connections. By analyzing this graphical representation, we can identify the most promising interdisciplinary links that strike a balance between meaningful associations and potential for novel insights.

We observe a broad spectrum of association frequencies (weights) between topics. Extremely low association frequencies (few edges) can be considered noise, while extremely high frequencies may be viewed as non-innovative. Our focus is on identifying the optimal balance within this range.

Figure 3 presents an intertopic distance map, visualizing the relationships between engineering and biology topics extracted

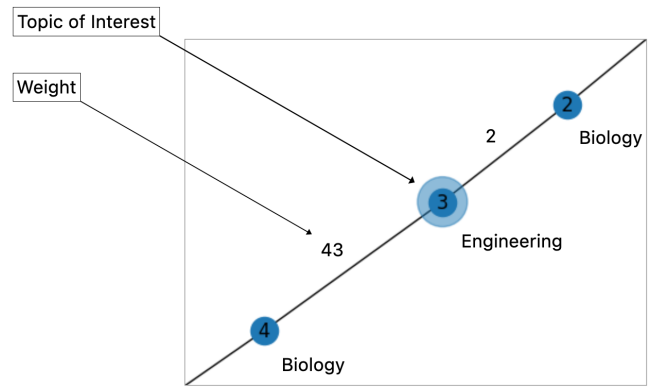


Fig. 2. Topic model illustrative sample.

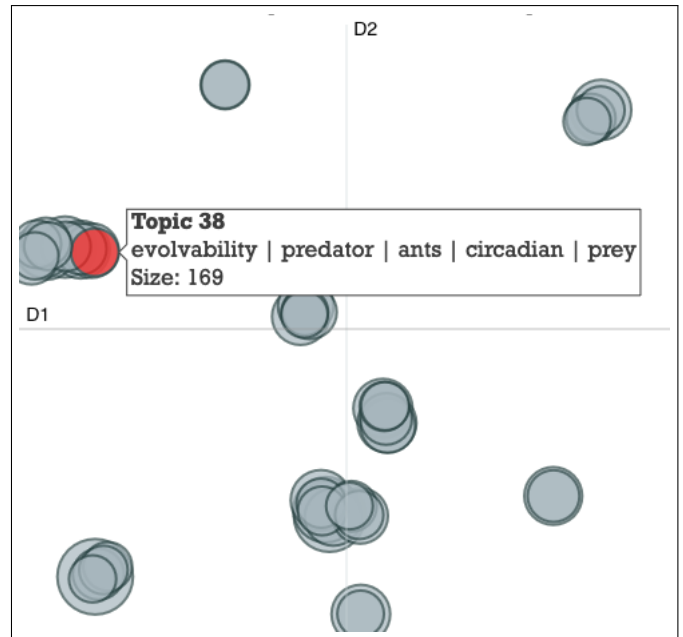


Fig. 3. Intertopic distance map highlighting a specific topic.

from our topic model. This map embeds topic representations into a 2D space, with node proximity indicating the strength of interdisciplinary connections between topics. Closer nodes represent stronger links, enabling identification of promising interdisciplinary areas for potential innovation.

### III. CASE STUDY: IMAGE SENSORS AND RAPID MOTION TRACKING

Innovative advancements often stem from interdisciplinary research, particularly when biological principles inspire engineering solutions. This case study investigates the application of neuromorphic vision principles to image sensors for rapid motion tracking. By bridging the gap between biology and engineering, we aim to explore how nature-inspired techniques can revolutionize technology.

### A. Research Question

In this case study on neuromorphic vision [7], [8], we address the research question: *How can image sensors track rapid motion without information loss?*

Dynamic vision sensors, also known as neuromorphic sensors, mimic biological event-based processing to achieve efficient and real-time motion tracking. These sensors replicate how biological systems process visual information, focusing on changes in the scene rather than capturing entire frames. This approach offers significant advantages in speed and data efficiency, making them robust solutions for dynamic environments. By detecting and recording only changes in light intensity at the pixel level, dynamic vision sensors provide continuous time resolution, enabling precise and rapid motion detection.

Fig. 4 illustrates the architecture of individual pixels within neuromorphic sensors. It shows how these pixels are structured to detect changes in the visual scene, enabling the sensor to respond quickly to dynamic events. Fig. 5 demonstrates the output of these pixels, presenting an example of neuromorphic pixel events. This figure highlights how the sensor captures and processes discrete changes, represented as spikes, rather than continuous frame data.

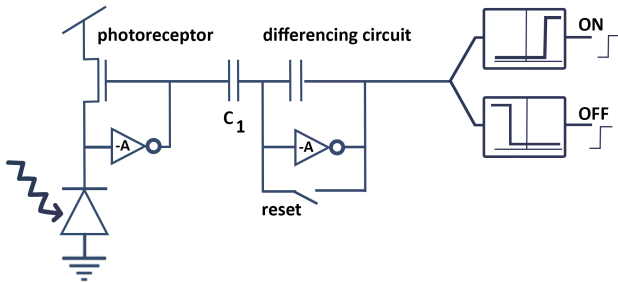


Fig. 4. Neuromorphic sensor pixel architecture.

### B. Dataset

The Semantic Scholar corpus of more than 100,000,000 abstracts [9] spans various disciplines, offering a robust foundation for analysis. However, the metadata labeling each document's primary discipline is imperfect. Articles often relate to multiple fields, making metadata alone inadequate for identifying interdisciplinary works.

Combining textual data with metadata enables predictive model training to generalize beyond primary discipline labels and recognize interdisciplinary patterns in the full text.

### C. Fields of Study

Given the focus on engineering, physics, and biology, the following fields of study are considered, as shown in Table I.

Although the current scope offers an initial point to benchmark the framework, the core methodology is not restricted to any specific discipline, allowing for potential expansion into other domains.

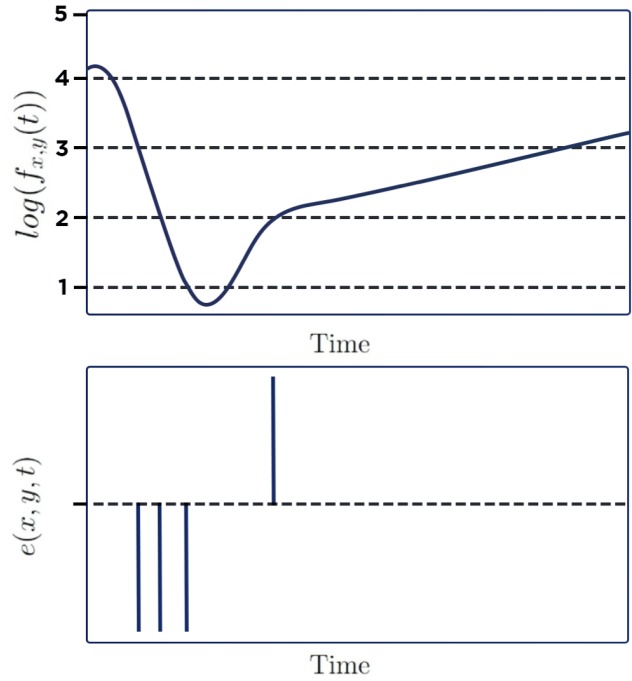


Fig. 5. Example of neuromorphic pixel events.

TABLE I  
FIELDS OF STUDY

Field	Focus
Medicine	Various medical research areas
Computer Science	Computing and software engineering
Chemistry	Chemical processes and materials
Physics	Physical principles and theories
Mathematics	Mathematical models and algorithms
Engineering	Engineering principles and applications
Biology	Biological processes and organisms
Materials Science	Study of material properties

## IV. RESULTS

1) *Engineering node representations:* Several key engineering principles, outlined below, have been identified through semantic similarity with the research question.

- Image segmentation techniques
- Object tracking in video
- Sensor-based localization and tracking
- Image restoration and enhancement techniques
- Visual odometry in autonomous mobile robots
- Scatter imaging in computed tomography

### A. Biology node representations

In the analysis, biological principles with potential engineering applications were identified and are listed below in relative order of significance. The biological labels shown in Table II are ranked from highest to lowest importance, derived from the topic model's weights.

TABLE II  
BIOLOGICAL INSPIRATIONS

No.	Biological Inspiration
1	Animal locomotion and spinal coordination
2	Echolocation in Marine Animals and Bats
3	Visual processing in the V1 cortex of monkeys
4	Emotion recognition in speech and facial expressions
5	Cardiac bidomain propagation and arrhythmias
6	Gene selection for cancer classification using microarray data
7	Malaria parasite nuclei segmentation in blood images
8	Infectious Disease Outbreak

### B. Proposed biology articles

Table III shows the relevant biology articles identified. The selection of these articles is based on their relevance to the biological concepts listed in Table II.

TABLE III  
SUMMARY OF RESEARCH ARTICLES

Details
Audet, J. et al. <i>Control of fore- and hindlimb movements and their coordination during quadrupedal locomotion across speeds in adult spinal cats</i> Journal of Neurotrauma, 2022 [10]
Debusschere, E. et al. <i>Eavesdropping in the wild: what are porpoises and bats up to</i> 2018 [11]
Zhang, H. et al. <i>Predicting perceptual suppression from local field potential in visual cortex</i> 2009 IEEE EMBC, 2009 [12]

### C. Proposed bioinspired solutions

The proposed bioinspired solutions draw inspiration from various biological phenomena, offering an innovative approach that closely aligns with the principles underpinning dynamic vision sensors. These biologically inspired solutions and their corresponding engineering principles are summarized in Table IV.

TABLE IV  
BIOLOGICAL INSPIRATIONS AND ENGINEERING PRINCIPLES

Biological Inspiration	Engineering Principle
Spinalized Cats	Multiple Sensor Modules
Echolocation in Animals	Dynamic Adaptive Triggering
Generalized Flash Suppression	Selective Attention Mechanism

- **Decentralized Sensor Modules:** Inspired by spinalized cats, the design incorporates multiple sensor modules to independently track movement aspects (speed, direction, angle). These sensors communicate with a central processor to integrate data, similar to neuromorphic sensors that compile event data for a coherent image, potentially ensuring robust detection and minimal information loss (see Fig. 5).
- **Dynamic Triggering Mechanism:** Inspired by echolocation, this solution involves adaptive triggering for image capture, activating only upon detecting predefined motion

patterns. This mirrors the selective event activation in neuromorphic sensors, potentially optimizing processing power and storage by focusing on significant events.

- **Selective Attention Mechanism:** Drawing from generalized flash suppression, this mechanism adjusts the sensor's focus and sampling rate based on motion relevance. Neuromorphic sensors prioritize significant changes similarly, potentially enhancing important movement capture while suppressing less relevant data, thus improving efficiency.

### D. Discussion

This preliminary study underscores the potential of the proposed bioinspiration architecture to identify interdisciplinary connections and foster innovation. More research is needed to address limitations and explore future directions. Specifically, while the current framework enables the derivation of a graph of interconnected concepts from the literature, further methodological refinement is required to define and evaluate the relevance of associations to help drive innovation.

Interdisciplinary weights require an additional layer of abstraction. Very rare associations may be noise, while very common ones could be trivial. Modeling where and how to set the threshold to promote meaningful and actionable ideas and potentially accelerate innovation is essential to move this research forward.

A metamodel complementing the interdisciplinary weights could be calibrated using a set of known cases. Possibly, multicriteria thresholds could be defined so that key concepts associated with known cases are identified. The threshold could be raised until the signal for known cases starts to appear, enabling the filtering out of noisy components. Alternatively, subsets of the graph could be approached as patterns, allowing different forms of association to be classified. Unsupervised clustering could be employed to organically segment patterns. A smaller set of well-known patterns could then be manually labeled or benchmarked against known cases. Addressing these challenges can help improve the framework and bridge the gaps between diverse knowledge domains.

## V. CONCLUSION

This study puts into practice a novel interdisciplinary framework that systematically identified connections between biology and engineering through semantic modeling. Applying this to a case study on nature-inspired imaging solutions underscored how bridging these domains can drive technological innovation. The bioinspired designs proposed for enhancing the rapid motion tracking capabilities of image sensors, inspired by phenomena like animal locomotion and echolocation, offer promising avenues for optimizing performance while minimizing information loss. While further investigation is merited, this work highlighted the potential benefits of leveraging interdisciplinary connections and bioinspired methodologies to spur innovation in imaging and other fields.

## REFERENCES

- [1] Bar-Cohen, Yoseph, Kenneth Meijer, Juan C Moreno, Hans Savelberg, Robert G Dennis, Hugh Herr, Robert Szema, Luke P Lee, Multifunctional Materials, Sia Nemat-Nasser, Syrus C. Nemat-Nasser, Thomas A. Plaisted, Anthony Starr, Alireza Vakil, Amirkhizi Defense, Attack Strategies, Mechanisms In Biology, Julian F V Vincent, Justin Carlson, Shail Ghaey, Sean Moran, Cam Anh Tran, David L Kaplan, S.I. Humayun, James Weiland, Gianluca Lazzi and Keyoor Gosalia. "Biomimetics : Biologically Inspired Technologies." (2011).
- [2] Vincent, Julian F. V. and Darrell L. Mann. "Systematic technology transfer from biology to engineering." *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* 360 (2002): 159 - 173.
- [3] Vincent, Julian F. V., Olga Bogatyreva, Anja-Karina Pahl, Nikolay Bogatyrev and Adrian Bowyer. "Putting Biology into TRIZ: A Database of Biological Effects." *Creativity and Innovation Management* 14 (2005): 66-72.
- [4] Douard, Nicolas, Ahmed Samet, George C. Giakos and Denis Cavallucci. "Navigating the Knowledge Network: How Inter-Domain Information Pairing and Generative AI Can Enable Rapid Problem-Solving." *TFC* (2023).
- [5] Nicolas Douard, Ahmed Samet, George C. Giakos, and Denis Cavallucci. Bridging two different domains to pair their inherent problem-solution text contents: Applications to quantum sensing and biology. *TFC* (2022).
- [6] Grootendorst, Maarten R.. "BERTopic: Neural topic modeling with a class-based TF-IDF procedure." *ArXiv abs/2203.05794* (2022).
- [7] Lichtsteiner, Patrick, Christoph Posch and Tobi Delbrück. "A 128 × 128 120 dB 15 μs Latency Asynchronous Temporal Contrast Vision Sensor." *IEEE Journal of Solid-State Circuits* 43 (2008): 566-576.
- [8] Nowak, Martin, Anthony Beninati, Nicolas Douard and George C. Giakos. "Polarimetric dynamic vision sensor p(DVS) principles." *IEEE Instrumentation & Measurement Magazine* 23 (2020): 18-23.
- [9] Lo, Kyle, Lucy Lu Wang, Mark Neumann, Rodney Michael Kinney and Daniel S. Weld. "S2ORC: The Semantic Scholar Open Research Corpus." *Annual Meeting of the Association for Computational Linguistics* (2020).
- [10] Audet, Johannie, Jonathan Harnie, Charly G. Lecomte, Stephen Mari, Angèle N. Merlet, Boris I. Prilutsky, Ilya A. Rybak and Alain Frigon. "Control of fore- and hindlimb movements and their coordination during quadrupedal locomotion across speeds in adult spinal cats." *Journal of neurotrauma* (2022).
- [11] Debusschere, Elisabeth, Jolien Goossens, Jan Reubens, Jonas Mortelmans, Klaas Deneudt and Francisco Hernandez. "Eavesdropping in the wild: what are porpoises and bats up to." (2018).
- [12] Zhang, Hongmiao, Nikos K. Logothetis and Hualou Liang. "Predicting perceptual suppression from local field potential in visual cortex." *2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (2009): 6802-6805.