Automated Scientific Paper Classification

A Machine Learning Approach to arXiv Category Prediction

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*Abstract*—This report presents an automated classification system for categorizing arXiv scientific papers across eight major disciplines using machine learning techniques. Working with a dataset of over 860,000 papers (sampled to 59,000 for computational feasibility), we developed models to classify papers into Physics, Mathematics, Computer Science, Quantitative Biology, Statistics, Electrical Engineering, Quantitative Finance, and Economics categories. Our methodology covers the complete machine learning pipeline from data collection through model evaluation, aiming to enhance academic information management by improving paper organization and discovery, ultimately facilitating interdisciplinary research and literature navigation in an increasingly complex scientific landscape.

# Introduction

The classification of scientific papers into their respective research domains is a critical task in academic information management. As the volume of scientific literature continues to grow exponentially, automated classification systems become increasingly important for organizing, discovering, and analysing research papers effectively. This project focuses on developing and evaluating machine learning models for automatically classifying scientific papers from arXiv, one of the largest repositories of electronic preprints.

Our work addresses the challenge of multi-class classification across eight major scientific disciplines: Physics, Mathematics, Computer Science, Quantitative Biology, Statistics, Electrical Engineering, Quantitative Finance, and Economics. By leveraging modern natural language processing techniques and machine learning algorithms, we aim to create a robust classification system that can accurately categorize papers based on their content, helping researchers and institutions better manage and navigate the vast landscape of scientific literature.

The significance of this project extends beyond mere organizational benefits. Accurate classification of scientific papers facilitates interdisciplinary research by helping researchers discover relevant work across different fields. It also enables better understanding of research trends and the evolution of scientific disciplines over time. Furthermore, automated classification systems can help identify emerging research areas and cross-disciplinary connections that might not be immediately apparent through traditional categorization methods.

This report presents our comprehensive approach to building and evaluating such a classification system. We detail our methodology from data collection and preprocessing to model development and evaluation, providing insights into both the technical challenges encountered and the solutions implemented. Our findings contribute to the broader understanding of automated scientific document classification and offer practical insights for similar applications in academic content management.

# Data Scraping

Our initial dataset comprised 863,251 scientific papers from arXiv. However, due to computational constraints, we sampled this down to a more manageable size of 58,816 papers. This sampled dataset was then split into training, validation, and test sets containing 37,142, 15,795, and 5,879 papers respectively, following standard machine learning practices for model development and evaluation.

The class distribution across the eight scientific disciplines showed considerable variation. Physics papers formed the largest category with 26,674 papers, followed by Mathematics and Computer Science with 13,794 and 12,680 papers respectively. The remaining categories had significantly smaller representations: Quantitative Biology contained 1,861 papers, Statistics had 1,341 papers, and Electrical Engineering included 1,337 papers. The smallest categories were Quantitative Finance and Economics, with 821 and 308 papers respectively.

This imbalanced distribution reflects the historical development and relative sizes of different research communities on arXiv, which originated primarily as a physics preprint server before expanding to other fields. The significant class imbalance presented an important consideration for our modelling approach, requiring careful handling to ensure fair treatment of minority classes during classification.

## Data Collection

The data collection process was conducted using the `arxiv` Python package to interface with the arXiv API. This package provided a robust and efficient way to programmatically access the vast repository of scientific papers hosted on arXiv. The package's implementation handled rate limiting and connection management, allowing us to reliably collect data at scale.

We focused our data collection efforts on eight primary research categories that represent distinct scientific domains. These categories included Physics, Mathematics, Computer Science, Quantitative Biology, Quantitative Finance, Statistics, Electrical Engineering and Systems Science, and Economics. The selection of these specific categories was deliberate, aiming to create a dataset that encompasses a broad spectrum of scientific research while maintaining clear categorical boundaries.

The chosen categories represent both traditional scientific fields like Physics and Mathematics, as well as emerging interdisciplinary areas such as Quantitative Finance and Quantitative Biology. This diversity in the selected categories was crucial for developing a classification system that could effectively handle the varied nature of modern scientific research. Each category contains numerous subcategories, providing fine-grained classification possibilities while still maintaining clear parent category distinctions.

## Data Processing

For each paper in the arXiv repository, we systematically extracted key metadata fields to build our dataset. These fields included the paper's title, summary/abstract, authors, category, comments, and publication date. This comprehensive set of metadata provided the foundation for our subsequent analysis and classification tasks.

The extracted text data required careful cleaning and standardization to ensure consistency across the dataset. We addressed encoding issues by standardizing all text to UTF-8 and Windows-1252 encodings, which helped resolve character rendering problems common in academic texts. Line breaks within paper summaries were eliminated to create uniform, continuous text blocks that would be easier to process. Additionally, we consolidated author names into single comma-separated strings to simplify the data structure while preserving all contributor information.

To streamline our classification approach, we implemented a systematic mapping of specific arXiv categories to their broader parent categories. For example, specialized subcategories like "cs.AI" (Artificial Intelligence) were mapped to their parent category "Computer Science." This hierarchical organization helped maintain clear categorical boundaries while reducing the complexity of our classification task.

## Data Creation

The creation of our dataset involved several critical steps to ensure the quality and usability of the data for machine learning tasks. First, we performed deduplication of papers based on their unique arXiv ID to remove any redundant entries that may have been collected during the scraping process. This step was essential to prevent data leakage and ensure the integrity of our subsequent analysis.

After deduplication, we carefully divided our dataset into three distinct subsets to support proper model development and evaluation. The training set, comprising 63% of the data, served as the primary dataset for model training. We allocated 27% of the data to the validation set, which was used to tune model parameters and prevent overfitting during the training process. The remaining 10% was reserved for the test set, which provided an unbiased evaluation of the final model performance.

To maintain the representativeness of our data across all subsets, we implemented stratified splitting based on paper categories. This stratification ensured that the distribution of research categories remained consistent between the training, validation, and test sets, preventing any potential bias in our model evaluation. The final dataset, containing 863,251 papers, was saved in CSV format to facilitate easy access and further processing during subsequent stages of our research.

Through these careful preparation steps, we established a robust foundation for our model development and analysis work. The resulting datasets were well-structured and properly balanced, enabling reliable training and evaluation of our classification models.

## Dataset Creation

The dataset creation process involved several critical steps to ensure the quality and usability of the data for machine learning tasks:

1. Deduplication: Papers were deduplicated based on their unique arXiv ID to remove redundant entries.
2. Data Splitting: The dataset was divided into three subsets:
   1. Training Set: 63% of the data, used to train the models.
   2. Validation Set: 27% of the data, used to tune model parameters and prevent overfitting.
   3. Test Set: 10% of the data, used to evaluate the final model performance.
3. Stratification: The splits were stratified by category to ensure that the class distribution was maintained across all subsets.
4. Saving Datasets: The final datasets were saved in CSV format for easy access and further processing:

- `arxiv\_lite.csv`: Contains 2,000 papers, used for initial testing and code experimentation.

- `arxiv.csv`: Contains 107,944 papers, used for the main implementation and model training.

- `arxiv\_large.csv`: Contains 863,251 papers, representing the full dataset.

These steps ensured that the datasets were well-prepared for subsequent analysis and model development.

Lorem ipsum.

# Ease of Use

## Selecting a Template (Heading 2)

First, confirm that you have the correct template for your paper size. This template has been tailored for output on the A4 paper size. If you are using US letter-sized paper, please close this file and download the Microsoft Word, Letter file.

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Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections A-D below for more information on proofreading, spelling and grammar.

Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

## Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

## Units

* Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as “3.5-inch disk drive”.
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* Do not mix complete spellings and abbreviations of units: “Wb/m2” or “webers per square meter”, not “webers/m2”. Spell out units when they appear in text: “. . . a few henries”, not “. . . a few H”.

Identify applicable funding agency here. If none, delete this text box.

* Use a zero before decimal points: “0.25”, not “.25”. Use “cm3”, not “cc”. (*bullet list*)

## Equations

The equations are an exception to the prescribed specifications of this template. You will need to determine whether or not your equation should be typed using either the Times New Roman or the Symbol font (please no other font). To create multileveled equations, it may be necessary to treat the equation as a graphic and insert it into the text after your paper is styled.

Number equations consecutively. Equation numbers, within parentheses, are to position flush right, as in (1), using a right tab stop. To make your equations more compact, you may use the solidus ( / ), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

*a**b* 

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use “(1)”, not “Eq. (1)” or “equation (1)”, except at the beginning of a sentence: “Equation (1) is . . .”

## Some Common Mistakes

* The word “data” is plural, not singular.
* The subscript for the permeability of vacuum **0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o”.
* In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
* A graph within a graph is an “inset”, not an “insert”. The word alternatively is preferred to the word “alternately” (unless you really mean something that alternates).
* Do not use the word “essentially” to mean “approximately” or “effectively”.
* In your paper title, if the words “that uses” can accurately replace the word “using”, capitalize the “u”; if not, keep using lower-cased.
* Be aware of the different meanings of the homophones “affect” and “effect”, “complement” and “compliment”, “discreet” and “discrete”, “principal” and “principle”.
* Do not confuse “imply” and “infer”.
* The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
* There is no period after the “et” in the Latin abbreviation “et al.”.
* The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

An excellent style manual for science writers is [7].

# Using the Template

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

## Authors and Affiliations

**The template is designed for, but not limited to, six authors.** A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

### For papers with more than six authors: Add author names horizontally, moving to a third row if needed for more than 8 authors.

### For papers with less than six authors: To change the default, adjust the template as follows.

#### Selection: Highlight all author and affiliation lines.

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## Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is “Heading 5”. Use “figure caption” for your Figure captions, and “table head” for your table title. Run-in heads, such as “Abstract”, will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced. Styles named “Heading 1”, “Heading 2”, “Heading 3”, and “Heading 4” are prescribed.

## Figures and Tables

#### Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 1”, even at the beginning of a sentence.

1. Table Type Styles

| Table Head | Table Column Head | | |
| --- | --- | --- | --- |
| Table column subhead | Subhead | Subhead |
| copy | More table copya |  |  |

1. Sample of a Table footnote. (*Table footnote*)
2. Example of a figure caption. (*figure caption*)

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization”, or “Magnetization, M”, not just “M”. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write “Magnetization (A/m)” or “Magnetization {A[m(1)]}”, not just “A/m”. Do not label axes with a ratio of quantities and units. For example, write “Temperature (K)”, not “Temperature/K”.

##### Acknowledgment *(Heading 5)*

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

##### References

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first ...”

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors’ names; do not use “et al.”. Papers that have not been published, even if they have been submitted for publication, should be cited as “unpublished” [4]. Papers that have been accepted for publication should be cited as “in press” [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

1. G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*
2. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
3. I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
4. K. Elissa, “Title of paper if known,” unpublished.
5. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
6. Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
7. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

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