Forecasting Carbon Emissions in China's Provinces Based on Graph Neural Networks

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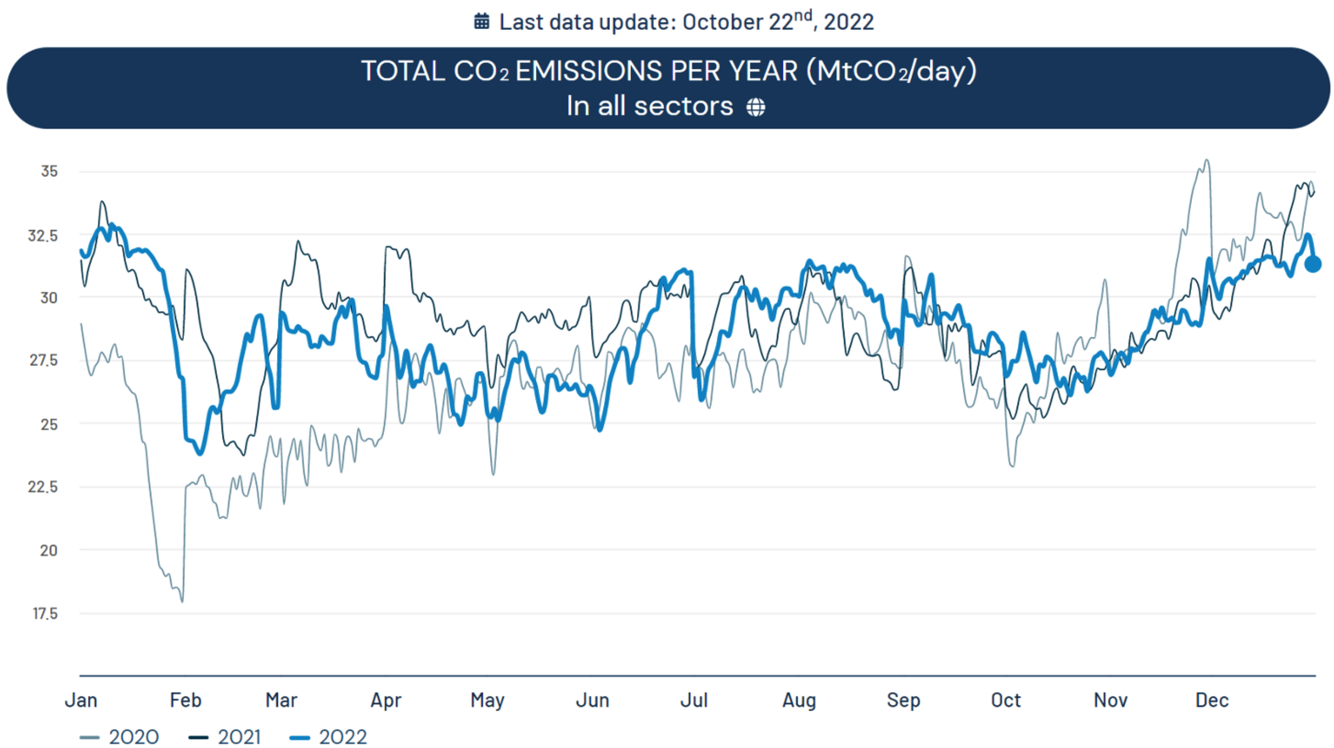

Figure 1: Total Carbon Emissions across Investigated Sectors

ABSTRACT

This is a coursework project submitted to the course *Foundation of Data Science and Analytics*. The project aims to forecast the carbon emissions in China's provinces based on Graph Neural Networks. The project is divided into three parts: data preprocessing, model training, and model evaluation. The data preprocessing part includes data cleaning, data integration, and data visualization. The model training part includes the construction of the graph neural network and the training of the model. The model evaluation part includes the evaluation of the model and the analysis of the results. The project is implemented in Python and the source code is available at here.

KEYWORDS

Emission prediction, Graph Neural Networks, Carbon Emissions, China's Provinces

1 INTRODUCTION

Global warming, far from being a recent phenomenon, can be perceived from another point as a persisting dilemma that continues to impact both anthropogenic development and the natural ecosystem. The primary agent provoking global warming is attributed to the emissions of greenhouse gases. Empirical studies confirm that carbon dioxide holds the dubious distinction of being the most abundant greenhouse gas in the atmosphere, contributing a staggering 72% to global warming.

However, it is noteworthy to mention that China ranks as the preeminent emitter of carbon dioxide on a global scale, discharging in excess of 6 billion tonnes of carbon dioxide annually. Hence, addressing this crisis, intrinsically connected to the existential fate of mankind, became a priority for China. As a concrete commitment to this endeavor, President Xi Jinping, in September 2020, proclaimed China's aim to "reach a peak in CO2 emissions by 2030 and accomplish carbon neutrality by 2060". The challenge of achieving carbon neutrality is multifarious, necessitating a holistic approach, encompassing policy, economy, culture, and technology. This paper opts to focus on the forecasting of carbon emissions, a crucial foundational element for strategic decision-making. Proficient predictions furnish invaluable data that bolsters informed decision-making. Conversely, if the prognosis proves inaccurate, ensuing plans may fall into the domain of impracticality.

The stakeholders who stand most directly impacted by these emissions include governments, investors, and researchers. Government bodies, equipped with foresight into future carbon emissions, can effectuate more meaningful change in climate policy, emergency development, and global cooperation. Conversely, researchers and investors, informed by predictive results, can more effectively design mechanisms such as the Emissions Trading System, Carbon Pricing System, and related technologies. Consequently, the act of forecasting carbon emissions carries significant implications for subsequent research.

Since the year 2011, endeavors have been made to utilize logistic equations in order to prognosticate China's carbon emissions. At present, the primary methodologies employed for the prediction of CO2 emissions can be categorized into three principal clusters, specifically, statistical analysis models, non-linear intelligent models, and grey prediction techniques. Statistical models offer ease of application, yet they necessitate the collection of ample historical data before the models can undergo training. Conversely, machine learning frequently outperforms in forecasting relative to conventional statistical methods.

This study implements the Graph Neural Network (GNN) approach, presenting multiple advantages: Firstly, GNNs are capable of effectively modelling spatial and temporal correlations. Secondly, GNNs have the capacity to integrate additional contextual data, such as socio-economic and policy factors. Thirdly, GNNs can yield an interpretable model structure, thus enabling researchers to derive insights into the relationships between various factors and their subsequent impact on carbon emissions.

At this juncture, GNNs have not been extensively explored in the context of predicting carbon emissions. Hence, future research should pivot its focus towards delving into the application of GNNs in carbon emissions forecasting. The unique benefits offered by GNNs should be leveraged to construct models that are both highly accurate and interpretable.

2 DATA DESCRIPTION

Transitioning now to our research endeavor, the initial phase entailed data acquisition from CarbonMonitor CHINA, a repository that chronicles the carbon emission statistics for the past five years. We amassed more than 200 thousand data points spanning from January 1, 2019, to December 31, 2022, systematically segregating the data into 31 distinct states and five sectors respectively.

Subsequently, we performed a rudimentary data analysis, classified according to temporality, sector, and state. A review of the past four years reveals that carbon emissions peaked in the year 2021. Furthermore, a substantial variation in carbon emissions was discerned across different sectors. Additionally, the states of Hebei and Shandong emerged as the leading contributors to the nation's carbon emissions.

2.1 Template Styles

The primary parameter given to the "`acmart`" document class is the *template style* which corresponds to the kind of publication or SIG publishing the work. This parameter is enclosed in square brackets and is a part of the `documentclass` command:

```
\documentclass[STYLE]{acmart}
```

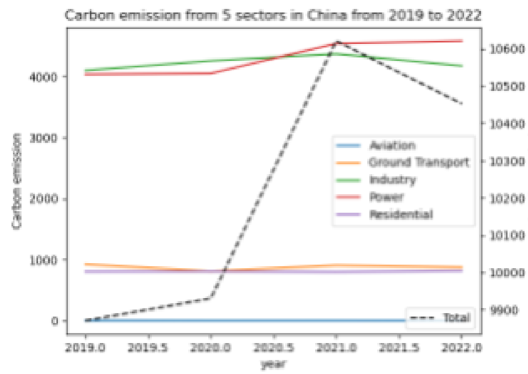

Figure 2: A graphical representation of emissions from five different sectors.

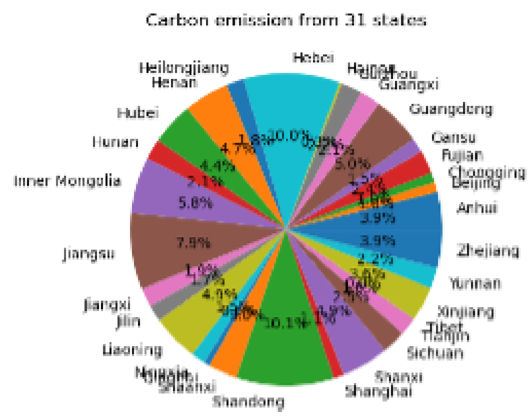

Figure 3: A graphical representation of emissions from 31 different states.

Journals use one of three template styles. All but three ACM journals use the `acmsmall` template style:

- `acmsmall`: The default journal template style.
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Frequently-used parameters, or combinations of parameters, include:

- `anonymous,review`: Suitable for a "double-blind" conference submission. Anonymizes the work and includes line numbers. Use with the `\acmSubmissionID` command to print the submission's unique ID on each page of the work.
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3 MODIFICATIONS

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```
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6 AUTHORS AND AFFILIATIONS

Each author must be defined separately for accurate metadata identification. Multiple authors may share one affiliation. Authors' names should not be abbreviated; use full first names wherever possible. Include authors' e-mail addresses whenever possible.

Grouping authors' names or e-mail addresses, or providing an "e-mail alias," as shown below, is not acceptable:

```
\author{Brooke Aster, David Mehldau}
\email{dave,judy,steve@university.edu}
\email{firstname.lastname@phillips.org}
```

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If your author list is lengthy, you must define a shortened version of the list of authors to be used in the page headers, to prevent overlapping text. The following command should be placed just after the last `\author{}` definition:

```
\renewcommand{\shortauthors}{McCartney, et al.}
```

Omitting this command will force the use of a concatenated list of all of the authors' names, which may result in overlapping text in the page headers.

The article template's documentation, available at https://www.acm.org/publications/proceedings-template, has a complete explanation of these commands and tips for their effective use.

Note that authors' addresses are mandatory for journal articles.

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The ACM Reference Format text is required for all articles over one page in length, and is optional for one-page articles (abstracts).

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Two elements of the "acmart" document class provide powerful taxonomic tools for you to help readers find your work in an online search.

The ACM Computing Classification System — https://www.acm.org/publications/class-2012 — is a set of classifiers and concepts that describe the computing discipline. Authors can select entries from this classification system, via https://dl.acm.org/ccs/ccs.cfm, and generate the commands to be included in the LaTeX source.

User-defined keywords are a comma-separated list of words and phrases of the authors' choosing, providing a more flexible way of describing the research being presented.

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9 SECTIONING COMMANDS

Your work should use standard LaTeX sectioning commands: `section`, `subsection`, `subsubsection`, and `paragraph`. They should be numbered; do not remove the numbering from the commands.

Simulating a sectioning command by setting the first word or words of a paragraph in boldface or italicized text is **not allowed.**

Table 1: Frequency of Special Characters

Non-English or Math	Frequency	Comments
Ø	1 in 1,000	For Swedish names
π	1 in 5	Common in math
\$	4 in 5	Used in business
Ψ_1^2	1 in 40,000	Unexplained usage

10 TABLES

The “acmart” document class includes the “booktabs” package — https://ctan.org/pkg/booktabs — for preparing high-quality tables.

Table captions are placed *above* the table.

Because tables cannot be split across pages, the best placement for them is typically the top of the page nearest their initial cite. To ensure this proper “floating” placement of tables, use the environment **table** to enclose the table’s contents and the table caption. The contents of the table itself must go in the **tabular** environment, to be aligned properly in rows and columns, with the desired horizontal and vertical rules. Again, detailed instructions on **tabular** material are found in the *LaTeX User’s Guide*.

Immediately following this sentence is the point at which Table 1 is included in the input file; compare the placement of the table here with the table in the printed output of this document.

To set a wider table, which takes up the whole width of the page’s live area, use the environment **table*** to enclose the table’s contents and the table caption. As with a single-column table, this wide table will “float” to a location deemed more desirable. Immediately following this sentence is the point at which Table 2 is included in the input file; again, it is instructive to compare the placement of the table here with the table in the printed output of this document.

Always use midrule to separate table header rows from data rows, and use it only for this purpose. This enables assistive technologies to recognise table headers and support their users in navigating tables more easily.

11 MATH EQUATIONS

You may want to display math equations in three distinct styles: inline, numbered or non-numbered display. Each of the three are discussed in the next sections.

11.1 Inline (In-text) Equations

A formula that appears in the running text is called an inline or in-text formula. It is produced by the **math** environment, which can be invoked with the usual `\begin . . . \end` construction or with the short form `$ . . . $`. You can use any of the symbols and structures, from α to ω, available in LaTeX [24]; this section will simply show a few examples of in-text equations in context. Notice how this equation: $\lim_{n\rightarrow \infty} x = 0$, set here in in-line math style, looks slightly different when set in display style. (See next section).

11.2 Display Equations

A numbered display equation—one set off by vertical space from the text and centered horizontally—is produced by the **equation** environment. An unnumbered display equation is produced by the **displaymath** environment.

Again, in either environment, you can use any of the symbols and structures available in LaTeX; this section will just give a couple of examples of display equations in context. First, consider the equation, shown as an inline equation above:

$$\lim_{n\rightarrow \infty} x = 0 \tag{1}$$

Notice how it is formatted somewhat differently in the **displaymath** environment. Now, we’ll enter an unnumbered equation:

$$\sum_{i=0}^{\infty} x + 1$$

and follow it with another numbered equation:

$$\sum_{i=0}^{\infty} x_i = \int_{0}^{\pi+2} f \tag{2}$$

just to demonstrate LaTeX’s able handling of numbering.

12 FIGURES

The “`figure`” environment should be used for figures. One or more images can be placed within a figure. If your figure contains third-party material, you must clearly identify it as such, as shown in the example below.

Figure 4: 1907 Franklin Model D roadster. Photograph by Harris & Ewing, Inc. [Public domain], via Wikimedia Commons. (https://goo.gl/VLCRBB).

Your figures should contain a caption which describes the figure to the reader.

Figure captions are placed *below* the figure.

Every figure should also have a figure description unless it is purely decorative. These descriptions convey what’s in the image to someone who cannot see it. They are also used by search engine crawlers for indexing images, and when images cannot be loaded.

A figure description must be unformatted plain text less than 2000 characters long (including spaces). **Figure descriptions should**

Table 2: Some Typical Commands

Command	A Number	Comments
`\author`	100	Author
`\table`	300	For tables
`\table*`	400	For wider tables

not repeat the figure caption – their purpose is to capture important information that is not already provided in the caption or the main text of the paper. For figures that convey important and complex new information, a short text description may not be adequate. More complex alternative descriptions can be placed in an appendix and referenced in a short figure description. For example, provide a data table capturing the information in a bar chart, or a structured list representing a graph. For additional information regarding how best to write figure descriptions and why doing this is so important, please see https://www.acm.org/publications/taps/describing-figures/.

12.1 The "Teaser Figure"

A "teaser figure" is an image, or set of images in one figure, that are placed after all author and affiliation information, and before the body of the article, spanning the page. If you wish to have such a figure in your article, place the command immediately before the `\maketitle` command:

```
\begin{teaserfigure}
  \includegraphics[width=\textwidth]{sampleteaser}
  \caption{figure caption}
  \Description{figure description}
\end{teaserfigure}
```

13 EXPERIMENT

In this section, we present the experiment of these three models, AGCRN, MLP and FC-LSTM.

13.1 Evaluation Metrics

To compare the model performance, we implement MAE, MAPE and RMSE to measure these three models.

MAE: MAE measures the average absolute difference between the predicted and actual carbon emissions. It evaluates the model's ability to make accurate predictions.

$$MAE(y, \hat{y}) = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i|$$

MAPE: MAPE measures the average absolute percentage difference between the predicted and actual carbon emissions. It is used to evaluate the accuracy of the model's predictions relative to the actual values.

$$MAPE(y, \hat{y}) = \frac{1}{n}\sum_{i=1}^{n} \frac{||y_i - \hat{y}_i||}{||y_i||}$$

Table 3: Parameter settings

Parameter/Setting	Value
Tp	1d
Tr	10d
Loss function	L2Loss
Optimizer	Adam
Percentage of training data	70%
Percentage of validation data	15%
Percentage of test data	15%
Epochs	100
Number of runs	1

Table 4: Average performance comparison of different approaches.

Method	MAE	MAPE	RMSE
AGCRN	0.0151	2.7%	0.0263
MLP	0.0699	8.8%	0.1010
FC-LSTM	0.5447	412.7%	0.4984

RMSE: RMSE is the square root of the MSE and is used to measure the standard deviation of the errors made by the model.

$$RMSE(y, \hat{y}) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

13.2 Simulation Results

In the simulation section, the parameter settings are listed in Table. 3, we split the datasets into 70% training data, 15% validation data and 15% test data.

In Table. 4, we exhibit the average performance comparison of different approaches. As you can see, the AGCRN performs the best in the three methods. MAE is 0.0151, MAPE is 2.7% and RMSE is 0.0263.

The AGCRN model outperformed the MLP and FC-LSTM models in our experiment, primarily due to its ability to capture the complex spatiotemporal dependencies of carbon emissions. The graph-based convolutional neural network structure of the AGCRN model enables it to extract features from the spatial and temporal domains simultaneously, resulting in more accurate predictions. In contrast, the MLP and FC-LSTM models are traditional machine learning models that rely on linear regression and LSTM networks, respectively, to forecast carbon emissions.

13.3 Performance Evaluation

In the experiment, we also visualize the prediction result and evaluate the performance, as shown in Fig. 5 and Fig. 6.

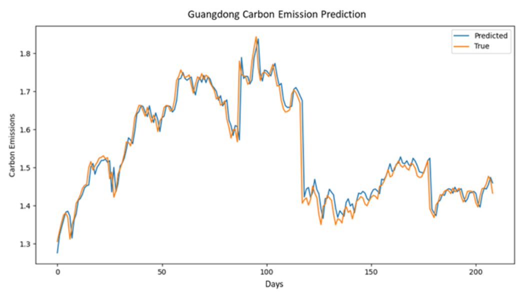

Figure 5: AGCRN.

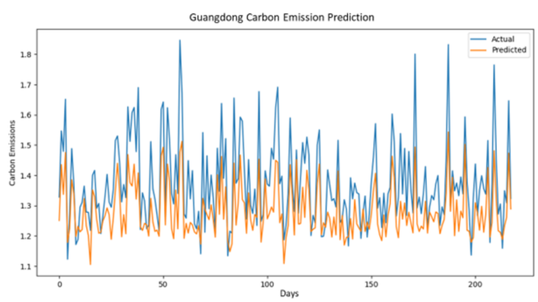

Figure 6: MLP.

From these two pictures of Guangdong carbon emission prediction, we can apparently find that the AGCRN has better prediction results than MLP, which further proves that the AGCRN method is more suitable for carbon emission prediction.

In conclusion, the AGCRN model's superior performance in predicting carbon emissions can be attributed to its unique graph-based convolutional neural network structure, which allows it to capture the intricate spatiotemporal dependencies of carbon emissions. This study's findings offer valuable insights into the development of more accurate and effective models for predicting carbon emissions, which can inform policymakers and stakeholders in their efforts to reduce carbon emissions and mitigate climate change.

14 CONCLUSION AND FUTURE WORK

In this course project, we presented three models, AGCRN, MLP, and FC-LSTM, for predicting the daily carbon emissions of 31 Chinese provinces using historical data from January 1st, 2019 to December 31st, 2022. Our results demonstrated that the AGCRN model outperformed the MLP and FC-LSTM models, indicating its robustness in predicting carbon emissions accurately.

The findings of this project offer a new approach to enhance the precision of carbon emission prediction. The AGCRN model's superior performance can be attributed to its ability to capture the complex spatial and temporal dependencies of carbon emissions. Our study provides valuable insights into the development of more accurate and effective models for predicting carbon emissions, which can inform policymakers and stakeholders in their efforts to reduce carbon emissions and mitigate climate change.

Future work: This project model can help carbon market stakeholders grasp the future trend of the carbon market more accurately and provide a reference for policymakers and investors in decision-making. However, the quality and availability of the carbon emission data are low, which makes it hard to improve the accuracy rapidly.

In future work, we can consider more factors to improve the accuracy of carbon emission prediction such as weather, seasonality, and economic conditions. What's more, it is necessary to improve the computational complexity.

15 CITATIONS AND BIBLIOGRAPHIES

The use of BibTeX for the preparation and formatting of one's references is strongly recommended. Authors' names should be complete — use full first names ("Donald E. Knuth") not initials ("D. E. Knuth") — and the salient identifying features of a reference should be included: title, year, volume, number, pages, article DOI, etc.

The bibliography is included in your source document with these two commands, placed just before the `\end{document}` command:

```
\bibliographystyle{ACM-Reference-Format}
\bibliography{bibfile}
```

where "`bibfile`" is the name, without the "`.bib`" suffix, of the BibTeX file.

Citations and references are numbered by default. A small number of ACM publications have citations and references formatted in the "author year" style; for these exceptions, please include this command in the **preamble** (before the command "`\begin{document}`") of your LaTeX source:

```
\citestyle{acmauthoryear}
```

Some examples. A paginated journal article [2], an enumerated journal article [10], a reference to an entire issue [9], a monograph (whole book) [23], a monograph/whole book in a series (see 2a in spec. document) [17], a divisible-book such as an anthology or compilation [12] followed by the same example, however we only output the series if the volume number is given [13] (so Editor00a's series should NOT be present since it has no vol. no.), a chapter in a divisible book [35], a chapter in a divisible book in a series [11], a multi-volume work as book [22], a couple of articles in a proceedings (of a conference, symposium, workshop for example) (paginated proceedings article) [3, 15], a proceedings article with all possible elements [34], an example of an enumerated proceedings article [14], an informally published work [16], a couple of preprints [6, 7], a doctoral dissertation [8], a master's thesis: [4], an online document / world wide web resource [1, 28, 36], a video game (Case 1) [27] and (Case 2) [26] and [25] and (Case 3) a patent [33], work accepted for publication [30], 'YYYYb'-test for prolific author [31] and [32]. Other cites might contain 'duplicate' DOI and URLs (some SIAM articles) [21]. Boris / Barbara Beeton: multi-volume works as books [19] and [18]. A couple of citations with DOIs: [20, 21]. Online citations: [36–38]. Artifacts: [29] and [5].

16 ACKNOWLEDGMENTS

Identification of funding sources and other support, and thanks to individuals and groups that assisted in the research and the preparation of the work should be included in an acknowledgment section, which is placed just before the reference section in your document.

This section has a special environment:

```
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...
\end{acks}
```

so that the information contained therein can be more easily collected during the article metadata extraction phase, and to ensure consistency in the spelling of the section heading.

Authors should not prepare this section as a numbered or unnumbered `\section`; please use the "`acks`" environment.

17 APPENDICES

If your work needs an appendix, add it before the "`\end{document}`" command at the conclusion of your source document.

Start the appendix with the "`appendix`" command:

```
\appendix
```

and note that in the appendix, sections are lettered, not numbered. This document has two appendices, demonstrating the section and subsection identification method.

18 MULTI-LANGUAGE PAPERS

Papers may be written in languages other than English or include titles, subtitles, keywords and abstracts in different languages (as a rule, a paper in a language other than English should include an English title and an English abstract). Use `language=...` for every language used in the paper. The last language indicated is the main language of the paper. For example, a French paper with additional titles and abstracts in English and German may start with the following command

```
\documentclass[sigconf, language=english, language=german,
                language=french]{acmart}
```

The title, subtitle, keywords and abstract will be typeset in the main language of the paper. The commands `\translatedXXX`, `XXX` begin title, subtitle and keywords, can be used to set these elements in the other languages. The environment `translatedabstract` is used to set the translation of the abstract. These commands and environment have a mandatory first argument: the language of the second argument. See `sample-sigconf-i13n.tex` file for examples of their usage.

19 SIGCHI EXTENDED ABSTRACTS

The "`sigchi-a`" template style (available only in LaTeX and not in Word) produces a landscape-orientation formatted article, with a wide left margin. Three environments are available for use with the "`sigchi-a`" template style, and produce formatted output in the margin:

- `sidebar`: Place formatted text in the margin.
- `marginfigure`: Place a figure in the margin.
- `margintable`: Place a table in the margin.

ACKNOWLEDGMENTS

To Robert, for the bagels and explaining CMYK and color spaces.

REFERENCES

[1] Rafal Ablamowicz and Bertfried Fauser. 2007. *CLIFFORD: a Maple 11 Package for Clifford Algebra Computations, version 11*. Retrieved February 28, 2008 from http://math.tntech.edu/rafal/cliff11/index.html

[2] Patricia S. Abril and Robert Plant. 2007. The patent holder's dilemma: Buy, sell, or troll? *Commun. ACM* 50, 1 (Jan. 2007), 36–44. https://doi.org/10.1145/1188913.1188915

[3] Sten Andler. 1979. Predicate Path expressions. In *Proceedings of the 6th. ACM SIGACT-SIGPLAN symposium on Principles of Programming Languages (POPL '79)*. ACM Press, New York, NY, 226–236. https://doi.org/10.1145/567752.567774

[4] David A. Anisi. 2003. *Optimal Motion Control of a Ground Vehicle*. Master's thesis. Royal Institute of Technology (KTH), Stockholm, Sweden.

[5] Sam Anzaroot and Andrew McCallum. 2013. *UMass Citation Field Extraction Dataset*. Retrieved May 27, 2019 from http://www.iesl.cs.umass.edu/data/data-umasscitationfield

[6] Sam Anzaroot, Alexandre Passos, David Belanger, and Andrew McCallum. 2014. Learning Soft Linear Constraints with Application to Citation Field Extraction. arXiv:1403.1349

[7] Lutz Bornmann, K. Brad Wray, and Robin Haunschild. 2019. Citation concept analysis (CCA)—A new form of citation analysis revealing the usefulness of concepts for other researchers illustrated by two exemplary case studies including classic books by Thomas S. Kuhn and Karl R. Popper. arXiv:1905.12410 [cs.DL]

[8] Kenneth L. Clarkson. 1985. *Algorithms for Closest-Point Problems (Computational Geometry)*. Ph. D. Dissertation. Stanford University, Palo Alto, CA. UMI Order Number: AAT 8506171.

[9] Jacques Cohen (Ed.). 1996. Special issue: Digital Libraries. *Commun. ACM* 39, 11 (Nov. 1996).

[10] Sarah Cohen, Werner Nutt, and Yehoshua Sagic. 2007. Deciding equivalances among conjunctive aggregate queries. *J. ACM* 54, 2, Article 5 (April 2007), 50 pages. https://doi.org/10.1145/1219092.1219093

[11] Bruce P. Douglass, David Harel, and Mark B. Trakhtenbrot. 1998. Statecarts in use: structured analysis and object-orientation. In *Lectures on Embedded Systems*, Grzegorz Rozenberg and Frits W. Vaandrager (Eds.). Lecture Notes in Computer Science, Vol. 1494. Springer-Verlag, London, 368–394. https://doi.org/10.1007/3-540-65193-4_29

[12] Ian Editor (Ed.). 2007. *The title of book one* (1st. ed.). The name of the series one, Vol. 9. University of Chicago Press, Chicago. https://doi.org/10.1007/3-540-09237-4

[13] Ian Editor (Ed.). 2008. *The title of book two* (2nd. ed.). University of Chicago Press, Chicago, Chapter 100. https://doi.org/10.1007/3-540-09237-4

[14] Matthew Van Gundy, Davide Balzarotti, and Giovanni Vigna. 2007. Catch me, if you can: Evading network signatures with web-based polymorphic worms. In *Proceedings of the first USENIX workshop on Offensive Technologies (WOOT '07)*. USENIX Association, Berkley, CA, Article 7, 9 pages.

[15] Torben Hagerup, Kurt Mehlhorn, and J. Ian Munro. 1993. Maintaining Discrete Probability Distributions Optimally. In *Proceedings of the 20th International Colloquium on Automata, Languages and Programming (Lecture Notes in Computer Science, Vol. 700)*. Springer-Verlag, Berlin, 253–264.

[16] David Harel. 1978. *LOGICS of Programs: AXIOMATICS and DESCRIPTIVE POWER*. MIT Research Lab Technical Report TR-200. Massachusetts Institute of Technology, Cambridge, MA.

[17] David Harel. 1979. *First-Order Dynamic Logic*. Lecture Notes in Computer Science, Vol. 68. Springer-Verlag, New York, NY. https://doi.org/10.1007/3-540-09237-4

[18] Lars Hörmander. 1985. *The analysis of linear partial differential operators. III*. Grundlehren der Mathematischen Wissenschaften [Fundamental Principles of Mathematical Sciences], Vol. 275. Springer-Verlag, Berlin, Germany. viii+525 pages. Pseudodifferential operators.

[19] Lars Hörmander. 1985. *The analysis of linear partial differential operators. IV*. Grundlehren der Mathematischen Wissenschaften [Fundamental Principles of Mathematical Sciences], Vol. 275. Springer-Verlag, Berlin, Germany. vii+352 pages. Fourier integral operators.

[20] IEEE 2004. IEEE TCSC Executive Committee. In *Proceedings of the IEEE International Conference on Web Services (ICWS '04)*. IEEE Computer Society, Washington, DC, USA, 21–22. https://doi.org/10.1109/ICWS.2004.64

[21] Markus Kirschmer and John Voight. 2010. Algorithmic Enumeration of Ideal Classes for Quaternion Orders. *SIAM J. Comput.* 39, 5 (Jan. 2010), 1714–1747. https://doi.org/10.1137/080734467

[22] Donald E. Knuth. 1997. *The Art of Computer Programming, Vol. 1: Fundamental Algorithms (3rd. ed.)*. Addison Wesley Longman Publishing Co., Inc.

[23] David Kosiur. 2001. *Understanding Policy-Based Networking* (2nd. ed.). Wiley, New York, NY.

[24] Leslie Lamport. 1986. *LaTeX: A Document Preparation System*. Addison-Wesley, Reading, MA.

[25] Newton Lee. 2005. Interview with Bill Kinder: January 13, 2005. Video. *Comput. Entertain.* 3, 1, Article 4 (Jan.-March 2005). https://doi.org/10.1145/1057270.1057278
[26] Dave Novak. 2003. Solder man. Video. In *ACM SIGGRAPH 2003 Video Review on Animation theater Program: Part I - Vol. 145 (July 27–27, 2003)*. ACM Press, New York, NY, 4. https://doi.org/99.9999/woot07-S422 http://video.google.com/videoplay?docid=6528042696351994555
[27] Barack Obama. 2008. A more perfect union. Video. Retrieved March 21, 2008 from http://video.google.com/videoplay?docid=6528042696351994555
[28] Poker-Edge.Com. 2006. Stats and Analysis. Retrieved June 7, 2006 from http://www.poker-edge.com/stats.php
[29] R Core Team. 2019. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/
[30] Bernard Rous. 2008. The Enabling of Digital Libraries. *Digital Libraries* 12, 3, Article 5 (July 2008). To appear.
[31] Mehdi Saeedi, Morteza Saheb Zamani, and Mehdi Sedighi. 2010. A library-based synthesis methodology for reversible logic. *Microelectron. J.* 41, 4 (April 2010), 185–194.
[32] Mehdi Saeedi, Morteza Saheb Zamani, Mehdi Sedighi, and Zahra Sasanian. 2010. Synthesis of Reversible Circuit Using Cycle-Based Approach. *J. Emerg. Technol. Comput. Syst.* 6, 4 (Dec. 2010).
[33] Joseph Scientist. 2009. The fountain of youth. Patent No. 12345, Filed July 1st., 2008, Issued Aug. 9th., 2009.
[34] Stan W. Smith. 2010. An experiment in bibliographic mark-up: Parsing metadata for XML export. In *Proceedings of the 3rd. annual workshop on Librarians and Computers (LAC '10, Vol. 3)*, Reginald N. Smythe and Alexander Noble (Eds.). Paparazzi Press, Milan Italy, 422–431. https://doi.org/99.9999/woot07-S422
[35] Asad Z. Spector. 1990. Achieving application requirements. In *Distributed Systems* (2nd. ed.), Sape Mullender (Ed.). ACM Press, New York, NY, 19–33. https://doi.org/10.1145/90417.90738
[36] Harry Thornburg. 2001. *Introduction to Bayesian Statistics*. Retrieved March 2, 2005 from http://ccrma.stanford.edu/~jos/bayes/bayes.html
[37] TUG 2017. *Institutional members of the TeX Users Group*. Retrieved May 27, 2017 from http://wwtug.org/instmem.html
[38] Boris Veytsman. 2017. *acmart—Class for typesetting publications of ACM*. Retrieved May 27, 2017 from http://www.ctan.org/pkg/acmart

A RESEARCH METHODS

A.1 Part One

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A.2 Part Two

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B ONLINE RESOURCES

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Received 20 February 2007; revised 12 March 2009; accepted 5 June 2009