

SATzilla: Portfolio-based Algorithm Selection for SAT

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Background: It has been widely observed that there is no single “dominant” SAT solver; instead, different solvers perform best on different instances.

Objectives: Rather than following the traditional approach of choosing the best solver for a given class of SAT instances, we aim to make this decision fully automatically, online and on a per-instance basis, with the goal of solving a broad range of SAT instances more efficiently in terms of running time.

Methods: We describe SATzilla, an automated approach for constructing per-instance algorithm portfolios for SAT that use so-called empirical hardness models to choose among their constituent solvers. This approach takes as input a distribution of problem instances and a set of component solvers, and constructs a portfolio optimizing a given objective function (such as mean running time, percent of instances solved, or score in a competition). In this article, we go well beyond earlier versions of SATzilla, by making the portfolio construction scalable and completely automated, and improving it by integrating local search solvers as candidate solvers, by predicting performance score instead of running time, and by using hierarchical hardness models that take into account different types of SAT instances.

Results: The excellent performance of SATzilla was independently verified in the 2007 SAT Competition, where our SATzilla07 solvers won three gold, one silver and one bronze medal. We demonstrate the effectiveness of the new techniques introduced here in extensive experimental results on data sets including instances from the most recent SAT competition.

Conclusions: The effectiveness of the SATzilla approach demonstrated in this article suggests that per-instance automated algorithm selection may also be possible for NP-hard problems other than SAT. We expect this to pave the way for achieving substantial improvements in the state of the art in solving other important problems in AI and beyond.

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1 Introduction

This document describes the revised \LaTeX template used by JAIR starting with volume 83 (2025). The template is based on ACM’s consolidated article template, introduced in 2017, which provides a consistent \LaTeX style for use across ACM publications, and incorporates accessibility and metadata-extraction functionality necessary for future Digital Library endeavors. JAIR adopted this template because 1) our old template was sadly out of date

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and we wanted a reliable, maintained template and 2) the journal is now distributed as part of the ACM library (though JAIR remains an independent, open-access journal published by AI Access Foundation, freely available at <https://jair.org>). Note that much of the functionality described below relates to ACM publications in general, rather than the specific template used by JAIR.

If you are new to publishing with JAIR or ACM, this document provides a guide to the process of preparing your work for publication. If you have published with ACM before, this document provides insight and instruction into more recent changes to the article template.

The “acmart” document class can be used to prepare articles for any ACM publication — conference or journal, and for any stage of publication, from review to final “camera-ready” copy, to the author’s own version, with very few changes to the source.

2 Template Overview

As noted in the introduction, the “acmart” document class can be used to prepare many different kinds of documentation — a double-anonymous initial submission of a full-length technical paper, a two-page SIGGRAPH Emerging Technologies abstract, a “camera-ready” journal article, a SIGCHI Extended Abstract, and more — all by selecting the appropriate *template style* and *template parameters*.

This document will explain the major features of the document class. For further information, the *LaTeX User’s Guide* is available from <https://www.acm.org/publications/proceedings-template>.

There are a number of *template parameters* that modify some part of the applied template style. A complete list of these parameters can be found in the *LaTeX User’s Guide*.

Frequently-used parameters, or combinations of parameters, include:

- `anonymous,review`: Suitable for a “double-anonymous” conference submission. Anonymizes the work and includes line numbers. Use with the `\command` to print the submission’s unique ID on each page of the work.
- `authorversion`: Produces a version of the work suitable for posting by the author.
- `screen`: Produces colored hyperlinks.

This document uses the following string as the first command in the source file:

```
\documentclass[review]{jair}
```

3 Modifications

Modifying the template — including but not limited to: adjusting margins, typeface sizes, line spacing, paragraph and list definitions, and the use of the `\vspace` command to manually adjust the vertical spacing between elements of your work — is not allowed.

Your document will be returned to you for revision if modifications are discovered.

4 Typefaces

The “acmart” document class requires the use of the “Libertine” typeface family. Your \TeX installation should include this set of packages. Please do not substitute other typefaces. The “lmodern” and “ltimes” packages should not be used, as they will override the built-in typeface families.

5 Title Information

The title of your work should use capital letters appropriately - <https://capitalizemytitle.com/> has useful rules for capitalization. Use the `\title` command to define the title of your work. If your work has a subtitle, define it with the `\subtitle` command. Do not insert line breaks in your title.

If your title is lengthy, you must define a short version to be used in the page headers, to prevent overlapping text. The title command has a “short title” parameter:

```
\title[short title]{full title}
```

6 Authors and Affiliations

Each author must be defined separately for accurate metadata identification. As an exception, 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}
```

The `authornote` and `authornotemark` commands allow a note to apply to multiple authors — for example, if the first two authors of an article contributed equally to the work.

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.

7 Rights Information

JAIR articles are freely available, and a copyright notice referencing the Creative Commons CC BY license is included in the template. This copyright notice should be included in all JAIR articles.

8 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**.

9 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*.

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

Table 2. Some Typical Commands

Command	A Number	Comments
<code>\author</code>	100	Author
<code>\table</code>	300	For tables
<code>\table*</code>	400	For wider tables

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.

10 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. We note that JAIR authors are discouraged from using sophisticated mathematical notation in the abstract (especially notation that is difficult to reproduce in vanilla HTML), since the abstract will also be formatted in HTML on the JAIR web site.

10.1 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).

10.2 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:

$$\lim_{n \rightarrow \infty} x = 0 \quad (1)$$

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:

$$\sum_{i=0}^{\infty} x_i = \int_0^{\pi+2} f \quad (2)$$

just to demonstrate L^AT_EX's able handling of numbering.

11 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.

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 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 Citations and Bibliographies

The use of Bib_TE_X 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.

For managing citations, it is recommended to use bibliography files in Bib_TE_X format. You can then either use Bib_TE_X with the ACM-Reference-Format style, or Bib_LA_TE_X with the acmnumeric or acmauthoryear styles, that include support for advanced citation of software artifact from the biblatex-software package, also separately available on CTAN.

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 Bib_TE_X file.

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



Fig. 1. 1907 Franklin Model D roadster. Photograph by Harris & Ewing, Inc. [Public domain], via Wikimedia Commons. (<https://goo.gl/VLCRBB>).

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].

13 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:

```
\begin{acks}
...
\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.

14 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.

Acknowledgments

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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 Sagie. 2007. Deciding equivalences 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. Statecharts 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. *TeX: 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://www.tug.org/instmemb.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

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Morbi malesuada, quam in pulvinar varius, metus nunc fermentum urna, id sollicitudin purus odio sit amet enim. Aliquam ullamcorper eu ipsum vel mollis. Curabitur quis dictum nisl. Phasellus vel semper risus, et lacinia dolor. Integer ultricies commodo sem nec semper.

A.2 Part Two

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B Online Resources

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Nam interdum magna at lectus dignissim, ac dignissim lorem rhoncus. Maecenas eu arcu ac neque placerat aliquam. Nunc pulvinar massa et mattis lacinia.

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- (1) All claims investigated in this work are clearly stated. [yes/partially/no]
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- (3) Limitations or technical assumptions are stated clearly and explicitly. [yes/partially/no]
- (4) Conceptual outlines and/or pseudo-code descriptions of the AI methods introduced in this work are provided, and important implementation details are discussed. [yes/partially/no/NA]
- (5) Motivation is provided for all design choices, including algorithms, implementation choices, parameters, data sets and experimental protocols beyond metrics. [yes/partially/no]

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Does this paper make theoretical contributions? [yes/no]

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- (5) The use of mathematical notation and formalism serves the purpose of enhancing clarity and precision; gratuitous use of mathematical formalism (i.e., use that does not enhance clarity or precision) is avoided. [yes/partially/no]
- (6) Appropriate citations are given for all non-trivial theoretical tools and techniques. [yes/partially/no]

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Does this paper include computational experiments? [yes/no]

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- (1) All source code required for conducting experiments is included in an online appendix or will be made publicly available upon publication of the paper. The online appendix follows best practices for source code readability and documentation as well as for long-term accessibility. [yes/partially/no]
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- (4) Raw, unaggregated data from all experiments is included in an online appendix or will be made publicly available upon publication of the paper. The online appendix follows best practices for long-term accessibility. [yes/partially/no]
- (5) The unaggregated data comes with a license that allows free usage for reproducibility purposes. [yes/partially/no]
- (6) The unaggregated data comes with a license that allows free usage for research purposes in general. [yes/partially/no]
- (7) If an algorithm depends on randomness, then the method used for generating random numbers and for setting seeds is described in a way sufficient to allow replication of results. [yes/partially/no/NA]
- (8) The execution environment for experiments, the computing infrastructure (hardware and software) used for running them, is described, including GPU/CPU makes and models; amount of memory (cache and RAM); make and version of operating system; names and versions of relevant software libraries and frameworks. [yes/partially/no]
- (9) The evaluation metrics used in experiments are clearly explained and their choice is explicitly motivated. [yes/partially/no]
- (10) The number of algorithm runs used to compute each result is reported. [yes/no]
- (11) Reported results have not been “cherry-picked” by silently ignoring unsuccessful or unsatisfactory experiments. [yes/partially/no]
- (12) Analysis of results goes beyond single-dimensional summaries of performance (e.g., average, median) to include measures of variation, confidence, or other distributional information. [yes/no]
- (13) All (hyper-) parameter settings for the algorithms/methods used in experiments have been reported, along with the rationale or method for determining them. [yes/partially/no/NA]
- (14) The number and range of (hyper-) parameter settings explored prior to conducting final experiments have been indicated, along with the effort spent on (hyper-) parameter optimisation. [yes/partially/no/NA]
- (15) Appropriately chosen statistical hypothesis tests are used to establish statistical significance in the presence of noise effects. [yes/partially/no/NA]

Articles using data sets:

Does this work rely on one or more data sets (possibly obtained from a benchmark generator or similar software artifact)? [yes/no]

If yes, please complete the list below.

- (1) All newly introduced data sets are included in an online appendix or will be made publicly available upon publication of the paper. The online appendix follows best practices for long-term accessibility with a license that allows free usage for research purposes. [yes/partially/no/NA]
- (2) The newly introduced data set comes with a license that allows free usage for reproducibility purposes. [yes/partially/no]
- (3) The newly introduced data set comes with a license that allows free usage for research purposes in general. [yes/partially/no]

- (4) All data sets drawn from the literature or other public sources (potentially including authors' own previously published work) are accompanied by appropriate citations. [yes/no/NA]
- (5) All data sets drawn from the existing literature (potentially including authors' own previously published work) are publicly available. [yes/partially/no/NA]
- (6) All new data sets and data sets that are not publicly available are described in detail, including relevant statistics, the data collection process and annotation process if relevant. [yes/partially/no/NA]
- (7) All methods used for preprocessing, augmenting, batching or splitting data sets (e.g., in the context of hold-out or cross-validation) are described in detail. [yes/partially/no/NA]

Explanations on any of the answers above (optional):

[Text here; please keep this brief.]

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