# The Name of the Title is Hope

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As data centers become increasingly prevalent, their energy consumption and the consequent carbon emissions have emerged as a global concern. Data centers demand substantial electricity, particularly those supporting complex computations and large-scale data processing tasks, such as social networking services. These services are often numerous independent microservices, offering high flexibility and scalability. This work explores the possibility of deploying the microservices constituting a social network onto bare-metal servers in geo-distributed data centers to minimize carbon emissions as much as possible without impacting Quality of Service (QoS) significantly. Through simulations and real deployment tests, we demonstrated that it is possible to reduce the carbon emssions produced in a year by xx% in exchange of xx% decrease in latency, xx% decrease in throughput, and xx% decrease in availability.

CCS Concepts: • **Computer systems organization** → **Embedded and cyber-physical systems**; • **Software and its engineering** → *General programming languages*; • **Networks** → *Network resources allocation*; • **Applied computing** → **Environmental science**; • **Hardware** → **Environmentally sustainable computing**.

Additional Key Words and Phrases: Carbon Emission, Computer Systems, Cross Datacenter Scheduling, Microservices, Sustainablity

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## 1 INTRODUCTION

In recent years, the digital revolution has dramatically increased the demand for data center services, leading to a surge in energy consumption and associated carbon emissions. Data centers are crucial for storing, managing, and processing vast amounts of data, supporting everything from cloud computing to social networking services. However, they are also among the most energy-intensive facilities, contributing significantly to global carbon emissions. It is estimated that by 2030, the data center industry could account for 8% of global carbon emissions, highlighting the urgent need for sustainable practices within this sector (Cao et al., 2021).

Major technology companies, including Google and Facebook, have recognized the environmental impact of their data centers and committed to achieving carbon neutrality in their operations. These commitments represent a significant shift towards sustainability in the technology sector, focusing on reducing carbon footprints through the adoption of renewable energy sources and more efficient energy management practices. For instance, Google has pledged to operate on carbon-free energy 24/7 by 2030, a commitment that requires innovative approaches to energy management and operational flexibility (Lehnhoff et al., 2021).

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This paper explores the possibility of reducing carbon emissions in data centers without significantly impacting the Quality of Service (QoS). We focus on a social network application sourced from the DeathstarBench Suite, examining how geo-distributed data center deployment strategies can minimize carbon emissions. By leveraging the different energy sources powering these data centers, particularly renewable energy, we aim to assess the potential reductions in carbon emissions achievable under various deployment scenarios. Our work contributes to the broader discourse on sustainable computing, providing insights into how data centers can operate more environmentally friendly while maintaining high levels of service availability and performance.

Our investigation is set against the backdrop of increasing efforts to mitigate the environmental impact of digital infrastructure. As data centers become increasingly pivotal to our digital lives, the imperative to address their environmental footprint grows stronger. By examining the interplay between data center operations and carbon emissions, we hope to offer valuable perspectives on achieving more sustainable data center practices across the industry.

For more insights and related work on carbon-neutral strategies and their implementation in large-scale data centers, refer to the comprehensive surveys by Cao et al. (2021), which discuss both policy instruments and technological methodologies towards carbon neutrality in data centers, highlighting current efforts by industry leaders such as Google and Facebook.

## 2 RELATED WORK

In recent years, researchers have recognized the significant part data centers play in carbon emission and started looking for solutions. A lot of studies prove that it is possible to reduce data center carbon emission by migrating workloads from fossil-fuel-heavy data centers to low-carbon ones that utilize renewable energy [23, 45].

Several researches were carried out aimed at providing a guide to workloads scheduling and orchestration across geo-distributed data centers. One popular direction is to build mathematical models to compute a scheduling recommendation by optimizing metrics in terms of emission and energy consumption [28, 29], while little attention is paid to the QoS. GA-Par measures data transmission latency, but the focus of this framework is application security on the cloud instead of performance metrics with more effects on user experience [44]. Stratus is a graph-based system that uses Voronoi partitions to determine which data centre requests should be routed to [12]. It makes trade-off among latency, carbon emissions and electricity cost when making a scheduling decision. One downside of this work is that the researchers did not use application benchmarks or examine the QoS of real-world applications.

There are also a few studies about the impacts of cross-datacenter scheduling on QoS. A group of researchers evaluated the performance of microservices using metrics of CPU usage and 99%-ile latency in the situation where some microservices of the applications are migrated to remote data centers when the local done does not have enough resources. They utilized three open-sourced microservice benchmarks of the DeathStarBench, SocialNetwork, MediaService, and HotelReservation for the experiment. What microservices of the applications should be migrated to a remote data center in order to mitigate the performance reduce is demonstrated in the work as well [38].

## 3 TEMPLATE OVERVIEW

As noted in the introduction, the "`acmart`" document class can be used to prepare many different kinds of documentation — a dual-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.

### 3.1 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}
```

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

- `acmsmall`: The default journal template style.
- `acmlarge`: Used by JOCCH and TAP.
- `acmtog`: Used by TOG.

The majority of conference proceedings documentation will use the `acmconf` template style.

- `acmconf`: The default proceedings template style.
- `sigchi`: Used for SIGCHI conference articles.
- `sigchi-a`: Used for SIGCHI "Extended Abstract" articles.
- `sigplan`: Used for SIGPLAN conference articles.

### 3.2 Template Parameters

In addition to specifying the *template style* to be used in formatting your work, there are a number of *template parameters* which 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 "dual-anonymous" 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.
- `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[acmlarge]{acmart}
```

## 4 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.**

## 5 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.

## 6 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}
```

## 7 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}
```

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.

## 8 RIGHTS INFORMATION

Authors of any work published by ACM will need to complete a rights form. Depending on the kind of work, and the rights management choice made by the author, this may be copyright transfer, permission, license, or an OA (open access) agreement.

Regardless of the rights management choice, the author will receive a copy of the completed rights form once it has been submitted. This form contains LaTeX commands that must be copied into the source document. When the document source is compiled, these commands and their parameters add formatted text to several areas of the final document:

- the "ACM Reference Format" text on the first page.
- the "rights management" text on the first page.
- the conference information in the page header(s).

Rights information is unique to the work; if you are preparing several works for an event, make sure to use the correct set of commands with each of the works.

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

## 9 CCS CONCEPTS AND USER-DEFINED KEYWORDS

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

Table 1. Frequency of Special Characters

| Non-English or Math | Frequency | Comments |
|---|---|---|
| Ø | 1 in 1,000 | For Swedish names |
| $\pi$ | 1 in 5 | Common in math |
| \$ | 4 in 5 | Used in business |
| $\Psi_1^2$ | 1 in 40,000 | Unexplained usage |

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.

CCS concepts and user-defined keywords are required for for all articles over two pages in length, and are optional for one- and two-page articles (or abstracts).

## 10 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.**

## 11 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.

## 12 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.

Table 2. Some Typical Commands

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

### 12.1 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 $\alpha$ to $\omega$, available in LaTeX [26]; this section will simply show a few examples of in-text equations in context. Notice how this equation: $\lim_{n\to\infty} x = 0$, set here in in-line math style, looks slightly different when set in display style. (See next section).

### 12.2 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:

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

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.

## 13 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

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

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/.

## 13.1 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}
```

## 14 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 [9], an enumerated journal article [10], a reference to an entire issue [8], a monograph (whole book) [25], a monograph/whole book in a series (see 2a in spec. document) [18], a divisible-book such as an anthology or compilation [13] followed by the same example, however we only output the series if the volume number is given [14] (so Editor00a's series should NOT be present since it has no vol. no.), a chapter in a divisible book [40], a chapter in a divisible book in a series [11], a multi-volume work as book [24], a couple of articles in a proceedings (of a conference, symposium, workshop for example) (paginated proceedings article) [2, 16], a proceedings article with all possible elements [39], an example of an enumerated proceedings article [15], an informally published work [17], a couple of preprints [5, 6], a doctoral dissertation [7], a master's thesis: [3], an online document / world wide web resource [1, 32, 41], a video game (Case 1) [31] and (Case 2) [30] and [27] and (Case 3) a patent [37], work accepted for publication [34], 'YYYYb'-test for prolific author [35] and [36]. Other cites might contain 'duplicate' DOI and URLs (some SIAM articles) [22]. Boris / Barbara Beeton: multi-volume works as books [20] and [19]. A couple of citations with DOIs: [21, 22]. Online citations: [41–43]. Artifacts: [33] and [4].

## 15 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.

## 16 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.

## 17 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.

## 18 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

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# 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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