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Effective Communication: Tips on Technical Writing

When writing technical articles, engineers and researchers should invest the time and energy to write as clearly and efficiently as possible. Sometimes we fail to do that, perhaps because we fall into the fallacy that results speak for themselves or because we feel that we don't have time to read books and articles on technical writing. The impact of a technical article may have as much to do with how well it is presented as with the engineering or scientific significance of the work. A well-written article is easier to understand and easier to remember; the more readers that remember your work, the higher the likelihood it will get cited. This article reviews some basic principles and discusses a few tips (dos and don'ts) about writing technical papers.

CONTEXT

You worked hard on your technical project or idea, and now you have a lot of interesting results that you want to publish because they advance the state of the art, bring in new theoretical insights, improve performance in practice, or even revolutionize the field! No matter how strong the results, you should always strive to present them as clearly as possible. You want your readers to fully grasp your ideas and be able to reproduce them to improve their research or designs. The more you impact your readers, the more they will look forward to reading your future articles. Impact is the key word; as communications professionals will tell you, how well you tell a story is as important as the story itself.

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Thanks to modern tools, it is easier to write today than it was decades ago. With Web search engines and online databases, literature searches can be performed very quickly. Thus, we should always strive to provide a complete and appropriate set of references. Also, in modern software packages, spelling and grammar errors can be corrected easily manually or automatically, somewhat reducing the writer's stress. Soon word processing software will also provide tools for style analysis and recommendation, as well as powerful translation; those will be particularly useful for authors whose native language is not English. However, we are still far from the day of having tools that will write an entire article for us automatically. Thus, we need to pay attention to basic principles of good technical writing.

BASIC PRINCIPLES

What makes for good technical writing? Of course, the answer to that has many facets, and we cannot cover all of them in this article. From the contributions in [1]–[6], it is clear that a good article has the following qualities:

- Technical Accuracy: The process and algorithm descriptions are correct and work as described, the math is correct, and the equations, tables, and figures do not contain typos.
- Conciseness and Clarity: The sentences are short and arguments are clearly presented.
- Good Organization and Structure: Statements come in a logical order, presented data supports arguments and conclusions, graphs are correctly sized and easy to read, and the choice and number of references are appropriate.
- Good English Usage: The text contains no spelling or grammar errors, no misused or pompous words, and no long successions of loose sentences.
- Usefulness: Readers see how to apply the results to their own work.
- Ethicalness: Key previous work is properly cited and comparisons are fair and unbiased. The work contains no plagiarism or self-plagiarism and no misleading statements; all data are truthful.
- Targeted for the Audience.

Different kinds of articles (conference papers, short articles for trade magazines, full papers for scientific journals, etc.) should have different depth-breadth balances, length, and scope. Still, some basic principles apply in all cases. For example, the basic parts of an article include: abstract, introduction, methods, results, conclusions, references, and appendices. The introduction and conclusions should be the sections titled in that manner, whereas methods and results should be presented in a few sections whose titles are appropriate for the content of the article. It is useful for the reader if methods and results are not intermixed. Many readers (like me) will jump to the results section first, and the better the sections are structured and present a complete picture of the main contributions, the

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more the reader will have an incentive to go back and read the methods section.

BEST STEPS

In my view, there is a best sequence of steps for writing a technical article. I usually start with a fresh review of the literature. For each reference, I write a few one-line sentences summarizing the points that are most relevant. I keep that list in a separate document, usually opened in a different desktop window. Then I write a draft outline of the article, with tentative titles for the methods and results sections. For each section, as well as for the introduction, the outline is a set of one-line sentences that summarize the main points to be presented or discussed. Then, I write the introduction and the sections by expanding each line of the outline into one or two paragraphs. I read the entire resulting rough draft and rewrite the introduction and edit the other sections. Finally, I write the conclusion and then the abstract, and then I revise many times to produce a first draft of the entire article. After a few reading and editing passes, I have a draft that can be sent to others for review. Isaac Asimov was able to think of a story, fit it in his head within a given budget for total number of words, and then write the story sequentially from start to finish, ending with a well-structured text that just fit within the budgeted length [7]. He was indeed a rare exception…

A good conclusions section is important. It is your opportunity to clarify for the reader the main contributions of the paper and the most important results. It's where you present the punch lines. Otherwise, readers will make their own conclusions, which will most likely not match your own.

A well-written abstract is also important; unlike the conclusion, the abstract has to first quickly position the problem, then say a few words about the methods and finally mention the key results. A common mistake is including in the abstract formulas, citations, and acronyms. Abstracts are published separately, and thus acronyms and citations become meaningless. Plus, such separately published abstracts are usually in databases that support only regular text, and hence formulas cannot be correctly rendered.

Figures, diagrams, and tables should always be used in the text, because they can convey quantitative information more effectively and take much less space than a verbose description. "A picture is worth a thousand words," so we should be careful to present them well. Reference [3] presents basic guidelines on good illustrations, whereas [8] is a bible on the subject.

ONE OF THE MOST IMPORTANT ASPECTS OF GOOD COMMUNICATION IS PAYING ATTENTION TO YOUR AUDIENCE.

THE AUDIENCE

One of the most important aspects of good communication is paying attention to your audience, and this applies to writing. You should write for your reader, not for yourself. The more you think as the reader, the easier it will be to figure out ways to convey your points as clearly as possible.

Your readers usually cluster into four main groups: 1) reviewers, who have a keen eye to find fallacies in your arguments; 2) subject experts, who want to skip the introduction and quickly jump into the main contributions; 3) nonexperts, who work on related subjects and selected your paper as a step for broadening their knowledge; and 4) those who don't know much about the subject, but stumbled on your paper and got curious enough to read it. Except for tutorial papers, usually your main target is the expert reader (groups 1 and 2). Even then you should not miss opportunities to reach other readers (groups 3 and 4) for a broader impact.

In broadening the reach of the article, the introduction, abstract, and conclusions play a key role. Thus, to write them effectively, one good tip is to take a good break after finishing the methods and the results sections before you start working on expanding the introduction outline into paragraphs. The first paragraph of the introduction is very important: focus it on the main problem, so the reader immediately sees what the paper is about. For example, if you are writing a paper on wavelet image compression, instead of starting the introduction with "The recent decade has seen a widespread adoption of wavelet image compression techniques," you can use the same 13-word space to start with "Encoding images with wavelets leads to higher compression ratios and fewer visual artifacts." Your reader may take the first form as saying "I'm writing about wavelets because they're a hot topic," and the second as saying "wavelets are useful for your work in image compression; they address issues you care about." In addition, at the end of that sentence you should include citations to one or a few key articles in the area that clearly demonstrate the stated advantages.

The introduction and abstract should draw the reader's interest; for that, it helps to focus mostly on a broader set of readers, such as those in groups 3 and 4. The methods and results sections should address mostly readers in groups 1 and 2, and the conclusion should be targeted to all groups.

THE TIMING

It is important to pace your article appropriately. The introduction has to sell the importance of the problem, your idea, and your results to entice the reader to keep reading. It will most efficiently do so if it is as clear and short as possible. For example, if you are writing a four-page conference article and the abstract and introduction take most of the first page, you went too far. We have commonly seen journal manuscripts on wavelet image denoising, for example, where a basic description of wavelets and its key properties (introduction plus a background section) may not end until

halfway through the manuscript. It's more efficient to just state clearly the main definitions and key background results, with appropriate references, to quickly set the context and save space for the forthcoming sections that describe the novel contributions.

Also important is spending enough space on the results section. Many articles make the mistake of spending too much space on the methods sections, thus discussing the results sometimes with just a statement like "It is clear from Table 1 that our proposed method is a significant improvement over others," to which the reader reaction is likely to be "Huh?" What does "significant" mean? Is the improvement worth the effort of considering this new idea? Does it come with penalties in other relevant metrics? Sometimes a small improvement can be a big deal in practice, as long as it's correctly positioned. I'll happily take a 5% reduction in operation costs for a datacenter, for example, but I won't bother with a new image encoding algorithm that improves compression ratio by 10% at the expense of a 2x increase in computation.

The following two sections review some dos and don'ts of good technical writing. The tips are my top picks from [1]–[6] (whose reading I highly recommend) plus some other ideas.

COMMON ERRORS

The most common error in writing, especially technical writing, is not wearing the reader's hat. For every new statement or illustration we introduce, we should always think as a critical reader and read it back to see if it conveys the message we want. That way, we can anticipate questions and rewrite appropriately. The "Common Errors" sidebar shows a representative list compiled from [1]–[6].

Let's elaborate on a common example. In many articles on image compression, we find tables such as Table 1.

Assuming that PSNR had been defined (as peak-signal to noise ratio), the table still has several problems. First, it doesn't state that the numbers are measured in decibels (dB). Second, it uses three decimals for dB figures, which has no practical value—meaningful improvements should be of the order of at least 0.5 dB or so, and thus one decimal is enough. Third, it uses just two test images! Although "lena" and "barbara" are widely available, they are not of good quality and should in fact be avoided (encoding "lena" was fine in the mid 1980s, not today). Standard image data sets containing at least a couple dozen images do exist and should be used. A fourth and subtle point is that in the baseline JPEG algorithm the parameters are set for best subjective visual quality, not for best PSNR performance. Thus, for a meaningful PSNR comparison, the JPEG parameters should be modified (in particular, the quantization weight matrix should be removed). A good idea would be to replace that table by one with a single column, reporting only PSNR improvements for the improved algorithm, to save the reader from mental calculations. Plus, I would add a final row with the average improvement over the set.

[TABLE 1] A BAD EXAMPLE.

	PSNR FOR EACH COMPRESSION SYSTEM		
IMAGE	JPEG	MY SIMPLE ALGORITHM	MY IMPROVED ALGORITHM
LENA	38.377	38.345	39.276
BARBARA	39.221	39.293	40.154

BEST PRACTICES

We discussed some key ideas in the section on basic principles, but let me stress one of my favorite rules of writing. In the introduction of William Strunk's *The Elements of Style* [1], E.B. White highlights "Rule Seventeen. Omit needless words! Omit needless words! Omit needless words!" That got stuck in my mind as "Cut! Cut! Cut!" The best way to apply that rule is to keep rereading the article with questions in mind such as "Did I overstate my arguments?," "Can I make this point in a more concise and direct manner?," "Is this figure really necessary?," "Is this word really needed?," and so forth. That

COMMON ERRORS

- DON'T overstate your points and conclusions.
- DON'T forget to mention competing results and other clearly related approaches found in the literature.
- DON'T "forget" to discuss the shortcomings of your ideas; readers will eventually find them out, and it's better to hear them from you.
- DON'T rush in writing the introduction, abstract, and conclusions.
- DON'T say that your great idea A is much better than your naïve idea B; position A with respect to existing literature.
- DON'T be confused about the meaning of words (it's versus its, affect versus effect, since versus because, which versus that, principal versus principle, etc.)
- DON'T use illustrations with text that are too small to read; reducing figures to illegible size is NOT a good way to gain space.
- DON'T overexplain background ideas, concepts, or equations that can be replaced by good citations.
- DON'T assume your reader is an expert and knows all acronyms.
- DON'T end an abstract by saying "performance will be discussed;" use instead a punch line: "Our method improves A by X %."
- AVOID qualifiers such as very, intense, little, etc; use quantitative arguments instead.
- AVOID pompous writing (say use, not utilize; end, not terminate; find out, not ascertain; need, not necessity); simple is better.
- AVOID cliché terms such as synergy, paradigm, proactive, top notch, world class, etc.

BEST PRACTICES

- DO plan ahead; write and revise a good outline before you start writing paragraphs.
- DO write the methods and results sections before expanding the introduction outline and writing the abstract and conclusions.
- DO use figures and illustrations, but as few as possible, so each can be large enough to be read without difficulty.
- DO focus on results, not on methods; e.g., instead of saying "We use machine learning techniques to study ways to improve A," say "We get an X % reduction in error using machine-learning technique Z."
- DO follow the composition rules in [1]–[6].
- DO spend extra time at the end to refine the introduction, abstract, and conclusions.
- DO use the active voice; it strengthens actions and thus the argument. For example, instead of saying "the input signal is processed by the preconditioning filter A," say "filter A removes high-frequency noise from the input signal;" this eliminates the redundant "is processed" and adds the reason for filtering.
- DO revise and edit; cut, cut, cut!
- DO use spelling and grammar checking.
- DO spend time to make your illustrations visually pleasing.
- DO use a direct, factual tone; breezy or opinionated descriptions are distracting.
- DO break long sections into subsections; subsection titles should be brief and draw attention to key points.
- DO use the conclusions section to emphasize the main contributions of your research; don't include a summary of what was described in the methods section.
- DO use certain terms with care; say "to optimize performance" or "to maximize usefulness" only if the system does indeed maximize an appropriate metric.
- At many stages during the writing process, take a break, "step out of the paper," and think like a reader. Reread what you wrote with a critical eye to find parts that are unclear, unjustified, or not stressed well enough.

takes time, and we should budget for it; as Blaise Pascal once said in a letter to a friend, "I have made this letter longer than usual, only because I have not had the time to make it shorter." A compilation of other good suggestions from [1]–[6], plus some other tips, are shown in the "Best Practices" sidebar.

CONCLUSIONS

The impact of a technical article usually depends as much on how well it is written as on its technical contributions. The main aspect of good technical writing is doing it for the reader: you write what you believe the reader wants to hear, not just what you want to say. Careful planning, good structuring, and concise and clear presentation of ideas and illustrations are common marks of good articles. Close attention to the points discussed here can help you improve the impact of your next article. Your readers will thank you for that.

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REFERENCES

[1] W. Strunk and E.B. White, *The Elements of Style,* 3rd ed. New York: McMillan, 1979.

[2] G. Blake and R.W. Bly, *The Elements of Technical Writing.* New York: McMillan, 1993.

[3] J. Zobel, *Writing for Computer Science*. New York: Springer, 1997.

[4] D.R. Morgan, "Dos and don'ts of technical writing," *IEEE Potentials,* vol. 24, pp. 22–25, Aug.–Sept. 2005.

[5] M.M. Pierson and B.L. Pierson, "Beginnings and endings: Keys to better engineering technical writing," *IEEE Trans. Prof. Commun.,* vol. 40, pp. 299–304, Dec. 1997.

[6] IEEE Author Digital Toolbox [Online]. Available: http://www.ieee.org/web/publications/authors/transjnl/index.html

[7] I. Asimov, *Gold*. New York: Harper Collins, 1995, pt. 3, "Revisions."

[8] E.R. Tufte, *The Visual Display of Quantitative Information.* Cheshire, CT: Graphics Press, 1993. SP

exploratory DSP continued from page 128

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REFERENCES

[1] E. Bresch, J. Nielsen, K. Nayak, and S. Narayanan, "Synchronized and noise-robust audio recordings during realtime magnetic resonance imaging scans," *J. Acoust. Soc. Amer.*, vol. 120, no. 4, pp. 1791–1794, Oct. 2006.

[2] S. Narayanan, K.S. Nayak, S. Lee, A. Sethy, and D. Byrd, "An approach to real-time magnetic resonance imaging for speech production," *J. Acoust. Soc. Amer.*, vol. 115, no. 5, pp. 1771–1776, 2004.

[3] J.I. Jackson, C.H. Meyer, D.G. Nishimura, and A. Macovski, "Selection of a convolution function for Fourier inversion using gridding," *IEEE Trans. Med. Imaging*, vol. 10, no. 3, pp. 473–478, Sept. 1991.

[4] T. McInerney and D. Terzopoulos, "Deformable models in medical image analysis: A survey," *Medical Image Anal.*, vol. 1, no. 2, pp. 91–108, 1996.

[5] M. Lustig, D. Donoho, J. Santos, and J. Pauly, "Compressed sensing MRI," *IEEE Signal Processing Mag.*, 2008, submitted for publication.

[6] Y. Kim, J. Nielsen, S. Narayanan, and K. Nayak, "Edge detection using sub-sampled k-space data: application to upper airway MRI," in *Proc. 15th Annu. Meeting Int. Society Magnetic Resononace in Medicine*, Berlin, May 2007, p. 3458.

[7] S. Lee, E. Bresch, and S. Narayanan, "An exploratory study of emotional speech production using functional data analysis techniques," in *Proc. 7th Int. Seminar Speech Production*, Ubatuba, Brazil, Dec. 2006, pp. 11–17.

[8] C.P. Browman and L. Goldstein, "Articulatory phonology: An overview," *Phonetica*, vol. 49, no. 3-4, pp. 155–180, 1992.

[9] S. Tobin, D. Byrd, E. Bresch, and S. Narayanan, "Syllable structure effects on velum-oral coordination evaluated with real-time MRI," *J. Acoust. Soc. Amer.*, vol. 119, no. 5, p. 3302, May 2006. SP