Technical Writing

Writing these editorials was one of my biggest concerns when I considered taking on the role of editor-in-chief of *IEEE Control Systems Magazine* in 2014. Writing is hard, and it is not a skill that comes easily to me. It never has, as I am sure my frustrated high school English teachers could attest.

However, after a lot of hard work and practice, I am finally getting the hang of it. My approach is to rough out ideas on paper (never in front of a computer), mull over the ideas in my head for a while (biking is a good time to do this), and then start typing. Once written, I then print it out and read it over carefully to look for logical and grammatical errors. This last step takes time and dedication, especially for a long document. However, learning to read your own work as carefully as you might read the work of others (thereby avoiding the tendency to mentally fill in logical and structural inconsistencies) is a crucial step in the overall writing process. Online tools (such as https://www.grammarly.com/) are particularly handy for analyzing specific grammar questions.

The next step is to ask someone else to read it, which, because it can expose weaknesses, I often face with some trepidation. There was a time when I would prefer to receive negative feedback from anonymous reviewers rather than engage in frank discussions with someone I know. To avoid similar hesitation, I now require that my students/postdocs exchange paper drafts to proofread each other's work and give detailed feedback. That provides an important opportunity to enhance the current documents and learn how to improve future articles.

There are, of course, many resources to help with the writing process. In fact, there may be too many. Similar to many self-help processes, the key is to find one that works for you and stick with it. For example, there are the traditional sources, that is, *Fowler's Modern English Usage* [1] and Strunk and White's *The Elements of Style* [2]. These

Jonathan How's research group enjoying a lunch BBQ on campus: (front, from left) Lena Downes, Sebastian A. Lopez-Cot, Jesus Tordesillas, and Dong-Ki Kim; (middle, from left) Kaveh Fathian, Saina Rezvani, Aleix Paris i Bordas, Golnaz Habibi, Jonathan How, Brett Lopez, Kris Frey, and Can Pu; (back, from left) Stewart Jamieson, Sharan Raja, Michael Everett, Parker Lusk, and Kasra Khosoussi.

Two teams prepare for a workshop debate on whether "the IEEE International Conference on Robotics and Automation, the IEEE/Robotics Society of Japan International Conference on Intelligent Robots and Systems, and other major robotics conferences cover too broad a range of topics for meaningful discourse." The two teams are (from left) Hadas Kress-Gazit and Jonathan How (for) versus Peter Corke and Chad Jenkins (against). Moderator John Leonard (second from right) discusses the setup with one of the organizers, Lee Clement. (Photo courtesy of Olivier Lamarre.)

are good manuals to review for advice. However, they make for extremely dense reading. The more recent offering by Steven Pinker [3] was created as a "writing guide for the 21st century," and since the style of writing is more accessible than that of the previous manuals, it is a highly recommended alternative. I am also sure that many universities have the equivalent of the Writing and Communication Center at the Massachusetts Institute of Technology, which provides free consultations about any writing or oral-presentation issues. Reading other well-written articles is another method to improve your own writing, so I advise my students to study award-winning papers at top conferences to determine what makes them great.

Numerous renowned authors in the field have also published documents that provide writing advice. For example, in [4], Dimitri Bertsekas gives 10 simple rules for mathematical writing, with highlights such as

1) Organize in segments, write segments linearly, and consider a hierarchical development.
2) Don't underexplain; don't overexplain.
3) Tell them what you will tell them.
4) Consider examples and counterexamples.
5) Use visualization where possible.

Reference [5] provides an extensive report on the topic from a course taught at Stanford in 1987. The report includes a list of 27 "especially important points" in the first six pages. Of those, point 12 (keep the reader in mind) deserves particular attention. It emphasizes the need to motivate the reader on what follows and remind them about what they should know from the document so far. Point 13 is interesting, as it notes that readers will typically skim over formulas when they read the paper for the first time. So, make sure that "your sentences flow smoothly when all but the simplest formulas are replaced by 'blah.'" I also like point 22, as it provides a particularly clear discussion of the use of *which* versus *that*, a rule that is

Jonathan How giving a talk at the Amazon re:MARS 2019 Artificial Intelligence and Machine Learning Conference in Las Vegas, Nevada. (Photo courtesy of Joe Speed.)

often not well understood. In addition to Strunk and White, [5] also recommends [6] as a well-written reference on "footnotes, references, quotations, and such things, done correctly."

John Tsitsiklis [7] provides both a seminar and written notes on writing with mathematical content. Among his many suggestions is a reminder to authors to consider the intended audience and what prior knowledge should (or should not) be assumed. He recommends avoiding long sentences because they tend to lead to grammatical errors. Breaking up sentences also helps impose a linear structure to the arguments, which is essential for technical documents. Tsitsiklis suggests that you pick a preferred terminology (and spelling) and then be consistent throughout the document. Similar to my suggestion above, [8] also recommends that nontrivial revisions be completed on a printout of the document (not directly on the computer). In my experience, many errors are missed when viewed on a computer screen.

Dennis Bernstein's work [9] emphasizes the importance of motivating the reader and including examples. In addition, [10] recommends that, as the research develops, authors try to develop a vision for the paper structure (and possible titles), as that can help focus the work. My advice to students when paper deadlines loom is to rough out the paper introduction to

highlight the state of the art, the perceived gaps, and the possible contributions of this new work. They should then try to complete the research to the point that they have a good understanding of what the final result/key figure will look like (at least in draft form). The process then tends to iterate between finalizing the results and firming up the contributions to ensure that they are consistent and sufficiently exciting. In the meantime, of course, the bulk of the paper gets written to fill in the details.

While all of these resources provide sound guidance on the mechanics, writing well is a skill that for many (myself included) requires a lot of practice. My advice is read over a couple of these references (and refer back to them when there are further questions), and then practice, practice, and practice some more!

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