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It's 1975. I'm a computer nerd wearing bell bottom pants and Dr. Scholl sandals, making my way down a side corridor in the third basement of the Pentagon. I come to an out-of-the-way small office, crammed with desks and terminals and the first minicomputer I'd ever seen. Talking to one of the chief petty officers who are squeezed into the room is a small, slender woman, white hair pulled back into a flawless bun, O-6 braid on her Navy uniform, debating the efficiency of a piece of code with the chief, the light glinting off the charm bracelet on her left wrist.

Wait, what was on her wrist?

That was my introduction to then-CAPT and soon to be Commodore/RADM Grace Murray Hopper. And yes, she wore a charm bracelet that day and often in those days. In uniform. I'm not sure who would have gainsaid her. She was short and slight, but formidable when she chose to be.

When President Obama posthumously awarded RADM Hopper the Presidential Medal of Freedom late in 2016 it was only the latest in decades of honors and recognition bestowed on this seminal figure. The Association of Computing Machinery (ACM) hosts an annual conference on women in computing in her name. She was a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and of the American Association for the Advancement of Science (AAAS), a member of the Franklin Institute,

the Naval Institute, the International Oceanographic Foundation, and more. She was the first individual female recipient of the National Medal of Technology in 1991 and the Navy's Arleigh Burke-class guided missile destroyer USS Hopper was named for her. She died on January 1, 1992, and was buried in Arlington National Cemetery, having retired from military service in 1986 at the age of 79 as the oldest serving officer in uniform.

Many think of Grace Hopper as a pioneer in computing, and she was. But MORS members will remember and be interested to learn that she was first and foremost a mathematician whose career took shape from her work in analytic support to wartime operational decisions. A great deal has been written about her as a computer scientist, and those interested in the evolution of digital computing and software might enjoy Walter Isaacson's excellent book The Innovators (Simon & Schuster 2014). In this article, I'd like to consider some of the themes she often spoke about from the perspective of their applicability to military operations research today.

But first a brief bio. The woman who would later be dubbed Amazing Grace was born in 1906 in New York City. She graduated from Vassar a Phi Beta Kappa and earned a PhD in mathematics from Yale in 1934 with a dissertation on irreducibility criteria—a hint at her future work in decomposition of functions for efficient computation. She returned to Vassar as faculty and was promoted to associate professor in 1941. To the dismay of more than one math major, she demanded that her students describe in correct, cogent written English the nature of problems and their solutions in addition to completing the work in mathematical notation. Bored, she took a partial leave to study advanced mathematical analysis methods with Richard Courant at New York University. MORS members and many engineers will remember Courant as the founder of the finite element method for solving partial differential equations numerically, a topic the two explored at that time.

Dr. Hopper had tried to enlist in the Navy early in WWII but was rejected as being too old and underweight for her height. But she was determined, and in 1943 took a full leave of absence

from Vassar and joined the US Navy Reserve, graduating first in her class from the Navy Reserve Midshipmen's School. Newly commissioned LTJG Hopper was assigned to the Bureau of Ordnance Computation Project at Harvard University, where she joined Howard Aikin as one of the first programmers of the Mark I computer, a general-purpose electromechanical computer that became a key asset in the Manhattan Project. When the war ended she refused a full professorship at Vassar, remaining at Harvard as a research fellow and Naval Reserve officer to work on the Mark II and Mark III computers, where she influenced adoption of basic hardware features such as conditional branching (if/then and goto). She famously was one of the team whose discovery that a moth had shorted an electromechanical relay in the Mark II led to the ubiquitous programming term "bug."

In 1949, Dr. Hopper joined the newly formed Eckert-Mauchly Computer Corporation, where she oversaw programming for the new UNIVAC computer. The first commercially available computer produced in the United States, it was fully digital and included stored program capability, an important innovation that allowed the reuse of subroutines within programs and by multiple programs. Unlike its predecessors, the UNIVAC was optimized for general computational tasks rather than specialized and targeted numerical tasks. To take advantage of this capability, Dr. Hopper argued, it was important that data be identified in terms familiar to users and that processing functions be invoked at a much higher level than the hardware logic gates that would soon emerge via transistors. A stored program computer could, she pointed out, take computer code as an input and translate it into the very detailed steps low-level hardware could execute. Despite facing significant skepticism, she proceeded to produce the first high-level programming language and associated functioning compiler. For the first time, programs could be written in a way that more closely reflected how users thought about their data.

Dr. Hopper's technical vision regularly preceded hardware capabilities but was prescient. She wanted COBOL, the common business oriented language whose definition was urged by the Department of Defense (DoD) and to which she contributed, to be something like the Sequential Query Language (SQL) for relational databases and R for statistical modeling later became. That is, she felt that the tools we use for analytic computing should allow us to model problems at a high conceptual level, agnostic with regard to the actual hardware they would run on.

Although she retired from the Naval Reserve in 1966, the Navy recalled her to active duty at the age of 60 to deal with an accelerating proliferation of hardware, software, and programming languages, even at that early date, and the resulting problems associated with it: staff training, interoperability, maintainability, and more, problems that operations researchers/systems analysts (ORSAs) are called upon to address even today, albeit in different systems.

And so, in 1975 my division chief inside the Army Command and Control Center sent me down the corridor to fetch CAPT Hopper, who had graciously agreed to be the first speaker in a new monthly brownbag series for the technical staff. The amiable, approachable tone of her discussion with the chief petty officer continued during our walk back, right up to the point where we entered the more secure area that contained our meeting room.

It was there that the guard requested she sign in and include her social security number. And it was there that she became CAPT Hopper in full force, making it clear that a recent law forbade collection of SSNs except under limited conditions that did not apply here. Turning to me she said, “You have 30 seconds to solve this or I’m going back to get some work done.”

Yikes. I got my lowly GS-9 self to a phone, called my division chief and he came down to walk her past the bemused guard. And that was my first real opportunity to consider data privacy, collection, and the uses to which it might be put.

Over lunch CAPT Hopper charmed and instructed. She had deep skill at taking a problem, translating it to mathematical or technical terms, translating those into computation steps, and then summarizing the outcomes at the original problem level. But she also knew how to get and keep a less technical audience’s attention. And so, she started her talk by pulling a wire from her tote bag. A little less than 12 inches long (11.3 more or less), it gleamed as she held it up. “This,” she announced, “is a nanosecond.”

Ah, the famous Hopper nanosecond. I lost mine, handed to us that day, during a later household move, alas. But I never lost the lesson she was teaching. She had adopted the nanosecond wire, or sometimes stick, to represent the distance an unimpeded electromagnetic signal can travel in that amount of time after attempting to explain satellite communications to a senior leader. Signals cannot go faster and in the face of resistance, interference, etc., might go slower.

The point? That computation—and communications and more—although progressing rapidly, was inherently limited. It requires resources that are inherently finite. We might get newer, faster hardware and more interesting languages, more powerful subroutine (later component) software libraries, graphical user interfaces. But always, always, we had to solve problems under the constraints of finite time, hardware capacity, limited decimal precision, and more. And therefore we would always face the question of what to capture and analyze, and what to leave out.

So, in the first five minutes of her arrival at our center, Grace Hopper introduced me, my division chief, and a bemused guard to data privacy issues, then called our division’s attention to the matter of constraints in computation. As we munched sandwiches, she had one more overarching theme that resonates, sometimes openly, often subtly, in issues of the *Phalanx* and at MORS conferences today. She asked us what the purpose of our work was.

Hmmmmm …… what WAS the purpose of my work? I knew what tasks were on my list for the week: code to write, debug, and document. I knew my code was part of the World Wide Military Command and Control System (WWMCCS) under development. But I realized at that moment that neither I nor most of my colleagues really understood what problem we were solving for the end user and why that problem mattered. And therefore we didn’t really know if our code was a step in solving it. Only later, when I implemented one of the first TCP/IP communications protocol stacks in Silicon Valley and pondered why an inefficient distributed packet network might be exactly the right way to ensure military communications in the event of a strategic nuclear strike, did I begin to understand the need that WWMCCS attempted to address.

Sound familiar? Have any of you, dear readers, found yourself knee deep in a simulation, or building a model, tweaking this and verifying that, only to stop and ask whether this whole effort was actually addressing the end user’s real problem? Have you ever gone off to rapidly implement what the user asked for without stopping to ensure that it would address the user’s actual need? Perhaps not. The Military Operations Research Society (MORS) is home to serious professionals, disciplined, and with deep domain knowledge. I say that without any irony or sarcasm. Many MORS members are ORSAs with deep skill, not only in modeling and simulation, wargaming, cost and risk analysis, but also in formal decision analysis methods designed to avoid such mistakes.

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But I confess I have done so, and more than once during a career of more than 40 years, especially when I forget the lessons my bell-bottom clad younger self was offered by a true expert.

If you haven't read the transcript of RADM Hopper's 52nd MORS Banquet Address, published in the June 1985 issue of *Phalanx* and available in the online archive of back issues, I urge you to do so. (See http://www.mors.org/Publications/*Phalanx*/*Phalanx*-Past-Issues.) You will, I hope, be charmed as I was by her gentle sense of humor, her clarity of vision, and her concern for the future of analytics and computation across DOD.

To close, here are a few of her points that seem to me to be particularly cogent for us in today's era of big, heterogeneous data, massively parallel cloud-based distributed computation facilities, software-intensive weapons systems, and military analysis that must take into account the operational impact of social media, cyberattacks, and other civilian capabilities.

1. The importance of understanding the problem. Identifying the right problem to solve is crucial to useful analysis. So is casting that problem in terms that are meaningful to the client's domain. Only then can we be sure our technical work actual contributes to an operational solution.
2. The importance of tools and data at the right level of granularity for the task at hand. Ubiquitous data is not necessarily useful data for a given purpose. More subtly, data collected in one place for one purpose may or may not fuse well with data collected for another purpose or at another level of detail. I'm a machine learning expert. Give me data and I'll find patterns in it. But will the patterns I find describe the features that are actually most relevant to the problem at hand? That depends entirely on what has been collected, what has been omitted, and with what detail. It also depends on the learning method I choose. Deep learning methods address this somewhat but do not remove the challenge, which exists in the analyses most ORSAs are called upon to perform as well.
3. The importance of total flow of information. Here RADM Hopper is speaking not only of networking and data fusion, although she was ahead of her time in addressing that, but the flow from user description of a problem through to analysis and the flow of analytic results back to the user in appropriate forms that address the real problem motivating the analytics.
4. User accessibility, know-how, and hands-on involvement. In 1984, RADM Hopper was speaking of hardware and software that users themselves could acquire. But it is not much of a stretch to point out that, as many MORS members already know, a model or simulation with an interface allowing the decision maker to explore "what if" scenarios can contribute deeply to better, more informed decisions.
5. Reuse. In 1984, RADM Hopper urged design and coding of systems to allow their easy modification and reuse. Again, it is not too much of a stretch to regularly ask ourselves just how reusable our current models and analyses are and how we could design and implement them to become more so—or whether that would not be prudent. If not, why not?

Dr. Grace Murray Hopper, later RADM Hopper, stood little more than 5 feet tall and weighed 105 pounds when she tried to join the Navy. She probably weighed the same when I met her in 1975. But she was a heavyweight, towering as a mathematical analyst and a pioneer in the use of computing to inform and enhance military operations. We are fortunate she chose to serve and can learn from her still today.

About the Author

Dr. Robin Burk began her career on the software side. She joined the faculty at the US Military Academy at West Point after the attacks of 9/11, where she taught in multiple departments and helped to set up the Center of Excellence for the emerging new analytic discipline of network science. After focusing a basic research grant program at the Defense Threat Reduction Agency she spent several years as chief scientist for Decision Analytics at Battelle. Today she consults through Analytic Decisions2 LLC and is working on a book addressing how to prevent collapse of the complex, interdependent systems we rely upon each day.