

The part of the computational science article that uses bridges as examples contains a marginal error regarding the Széchenyi (note the correct spelling) Chain Bridge in Budapest. That bridge opened for traffic on 20 November 1849. Post and Votta write, “Although the retreating Germans blew it up in 1945, the bridge has since been rebuilt according to its original design.” But that is not really the case.

The Széchenyi Chain Bridge was completely rebuilt from 1913 to 1915 and is essentially the same today as it was right after that reconstruction. During that rebuild, the biggest changes involved significantly strengthening the pillars and replacing the chains with new high-strength steel ones. Each element of the new chain was roughly double the size of the original. Both types of elements were on display for many years in the hallways of the Technical University of Budapest and still may be there. A wonderful history of the bridge (in Hungarian but with many pictures) is available at <http://www.idg.hu/expo/lanc>.

I understand that the points made by Post and Votta do not in any way hinge on the accuracy of this minute detail. Yet it is an opportunity to marvel at the ingenuity of earlier generations of engineers. We owe it to them to get it right.

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Post and Votta reply: The readers who responded to our article have interesting and valid comments, some of which merit further discussion.

Thomas Sheahen makes several points supporting our premise that computational science’s credibility needs improvement. Otherwise, the science cannot inform strategic decisions affecting society. With regard to Sheahen’s specific criticisms, climate models have included clouds since the 1960s.¹

Global warming is a fact. Identifying the causes and predicting future warming are active areas of research. A library search for papers on global warming turned up more than 5000 published since January 2000. The climate-modeling community has recognized that existing models are inadequate and has been working to improve them and to identify and add new effects.² The

Community Climate System Model and Earth System Modeling Framework programs have been formed to coordinate the national and, to some extent, the international efforts in this area. One of us (Post) attended the 9th CCSM Workshop in Santa Fe, New Mexico, in 2004. There it was evident that the models are being improved, software engineering is becoming a key part of the CCSM program, and the verification and validation process is becoming a central part of model development. The international climate-modeling community has a program with a multibillion-dollar annual budget to gather, analyze, and store detailed data for continental, oceanic, atmospheric, and polar weather and climate phenomena.³ The newer models generally confirm what the earlier models identified: the importance of CO₂ emissions in global warming. Other predictions of climate and weather phenomena also are making an impact. For example, predictions of El Niño effects are being used to make agricultural decisions.⁴ Although the models have undergone tremendous progress and continual improvement, immense challenges remain, and work on addressing them continues.

Craig Bolon’s assertion that computational science needs the injection of the project discipline employed by IT organizations like Microsoft is not totally correct. Computational science and engineering will benefit from improved software project-management processes, but not necessarily from the same kinds used in the IT industry. For instance, IT processes emphasize the importance of detailed and prescriptive requirements, but for scientific software such requirements are difficult to develop. Code development for computational science usually involves research to find the best solutions and most accurate models needed for credible answers. It’s also not clear that Microsoft Windows is without problems. Windows XP recently had to be massively rewritten to minimize security vulnerabilities. Windows users now download security patches frequently—sometimes daily.

The paper Rudolf Eigenmann refers to is “The T Experiments: Errors in Scientific Software,” by Les Hatton.⁵ It illustrates the value of “code benchmarking”—comparing the results of many codes for a single problem and determining the reasons for divergent results.

Josip Loncaric expands on two

key points in our paper. The first is that developers and users of scientific and engineering codes need considerable domain knowledge to ensure that their results are as accurate as possible. We think this situation is probably getting worse rather than better. The challenge of developing codes for very complex, massively parallel computers has increased the emphasis on programming skills. As a result, the emerging generation of computational scientists is skilled in code development but much less so in the relevant scientific discipline.

The second point Loncaric highlights is that a model for a natural system—physical, chemical, biological, and so forth—is often much more than the sum of the individual components. For physical systems, Robert Laughlin recently pointed out that much of science today is inherently reductionist.⁶ Present scientific research paradigms emphasize the detailed study of the individual elements that contribute to a complex system’s behavior. High-energy physics, for example, involves the study of fundamental particles at progressively higher accelerator energies. Yet successful models of complex systems, such as low-temperature superconductors, are relatively insensitive to the detailed accuracy of the individual constituent effects. Laughlin stresses that successful models capture the emergent principles that determine the behavior of complex systems. Examples of these emergent principles are conservation laws, the laws of thermodynamics, detailed balance, and preservation of symmetries.

Since a computational simulation is only a model of nature, not nature itself, there is no assurance that a collection of highly accurate individual components will capture the emergent effects. Yet most computational simulations implicitly assume that if each component is accurate, the whole code will be accurate. Nature includes all of the emergent phenomena, but a computational model may not. This perspective underscores the importance of validation of the integrated code and of individual models.

Denes Marton takes us to task for possibly misspelling Széchenyi, Széchényi, or Szechenyi. Unfortunately, non-Hungarian speakers like us can find all three spellings for the bridge in various sources. We relied on the advice of a Hungarian colleague, who has admitted, on further inquiry, that Széchenyi is likely correct.

All the English-language accounts we could find mentioned the original bridge construction in the 1840s and the reconstruction after World War II. We don't doubt Marton's additional historical elements about the reconstruction in 1913–1915, but we couldn't find an English account of them.

References

1. R. T. Wetherald, S. Manabe, *Science* **37**, 1485 (1980); **45**, 1397 (1988).
2. See, for example, the website of the Program for Climate Model Diagnosis and Intercomparison at http://www.pcmdi.llnl.gov/ipcc/about_ipcc.php.
3. See, for example, <http://weather.gov/organization.php>, <http://seaboard.ndbc.noaa.gov>, and <http://www.wmo.ch>.
4. For more information, see <http://www.dynapred.com> and http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina.
5. L. Hatton, *IEEE Comput. Sci. Eng.* **4**(2), 27 (1997).
6. R. B. Laughlin, *A Different Universe: Reinventing Physics from the Bottom Down*, Basic Books, New York (2005).

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Comments on the Culture of the Force

One of Frank Wilczek's main themes in "Whence the Force of $F = ma$? I: Culture Shock" (PHYSICS TODAY, October 2004, page 11) appears to be that although the force is, in Wilczek's words, "vaguely defined," it "continues to flourish" because the microscopic details it conceals are not really relevant for the scale of the phenomena it serves to describe. Further, it "survives the competition" because "it is much easier to work with." To this second point one might add that nothing succeeds like success. Let me explain.

The concept of force had been under attack much before the comments of Peter Tait and Bertrand Russell. Even some of Isaac Newton's immediate successors, most notably Joseph-Louis Lagrange and Jean Le Rond d'Alembert, were critical of the concept. D'Alembert regarded it as "useless to mechanics" and said that it "ought therefore to be banished from it."¹ However, the use of New-

ton's idea that force is a primary, nonderived concept, which was pursued steadfastly by Leonhard Euler,¹ led to the greatest successes in continuum mechanics in the two centuries immediately following publication of Newton's *Principia*. That period culminated in the 1820s in Augustin-Louis Cauchy's stress principle,¹ which unified the seemingly disparate fields of fluid mechanics and elasticity. This approach, commonly attributed to Newton rather than to Euler or Cauchy, is chosen over its main competitor, the variational formulation of Lagrange, to be

taught in a typical fluid mechanics course. The stress has also been given a microscopic interpretation in kinetic theory and in more general statistical mechanics.

Wilczek mentions some assumptions about forces. Newton regarded mechanics as "the science of motions that result from any forces whatever."¹ Thus, he did not exclude contact forces, the dominating concept in continuum mechanics. Nor did he demand that all forces be central, which has particular relevance to the derivation of the angular momentum principle.

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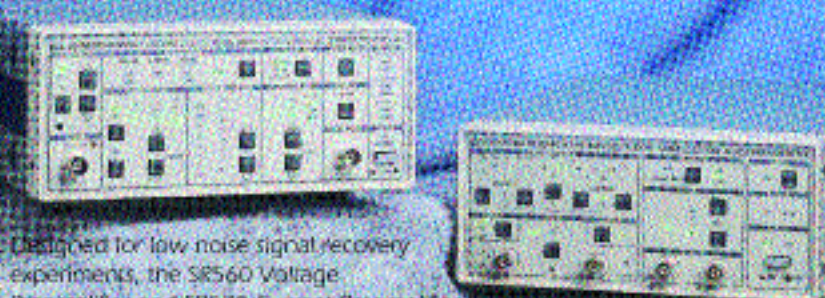
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