

## PUBLISHER

Randolph A. Nanna  
Tel: 301-209-3102  
rnanna@aip.org

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Tel: 301-209-3051  
kmcnaugh@aip.org

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One Physics Ellipse  
College Park, MD 20740-3842  
Tel: 301-209-3051  
Fax: 301-209-0842  
e-mail: tip@aip.org

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# Differential equations

I liked your article (*The Industrial Physicist*, February 2001, pp. 21–23). One would think that every scientist and engineer knows these things, but many do not. This may be because courses on differential equations are often taught by mathematicians whose interests lie elsewhere. In my case, I had to take short courses and also had to teach myself. Maybe there should be more courses on celestial mechanics and dynamic systems.

Just to nitpick, I will mention that even when a differential equation is solvable, exact prediction is often not attainable. The cosine, exponential, and elliptic functions can be computed to arbitrary accuracy, but not in a fixed interval of time. For practical purposes, the (Wintel) PC limits us to 80-bit floating point precision. I have heard of software that offers extended precision, but it has to bypass the fast (now built-in) math co-processor. Unfortunately, scientific computing no longer drives computer hardware design, but somebody should come up with an open-ended math co-processor (and associated compilers to access it) that would work with the Intel central processing units. I understand that Apple has a souped-up math system in a high-end machine, designed in part to keep its niche in image processing (for those fast Fourier transforms and similar wavelet computations), but I don't know the details.

I have recently been adapting Chebyshev approximation to solving ordinary differential

equations (one independent variable). I call this continuous numerical continuation (CNC), as opposed to continuous analytical continuation (CAC), which uses Taylor series. CAC was promoted in the 1960s for satellite orbits by Dwayne Hartwell. It worked well for gravitational forces, but not for drag models. It requires nice recurrence relations for higher derivatives, and not needing these is an advantage of CNC. CAC was also touted by H. T. Davis in his book, *Introduction to Nonlinear Differential and Integral Equations*, which was reprinted by Dover Press in 1962.

CNC needs further development, but I do not have any time to devote to it. I carried it as far as I could in hopes of selling the idea to an orbit-computing agency, but I think the "not invented here" syndrome prevented that. So if you would like a copy of the software (in Fortran 77) and documentation, as far as they go, I would be happy to send them to you via e-mail. It is contained in one Win-zip file, with multiple files inside. Extending the concepts of CNC to partial differential equations, whether boundary value problems or general solution applications, such as Hamilton-Jacobi equations, would be something of a challenge. But it might be far more efficient and accurate than using finite-element methods.

Foster Morrison  
Turtle Hollow Associates, Inc.  
Gaithersburg, Maryland  
Turtle\_Hollow@sigmaxi.org



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[*Author replies*: I agree that even though hardware and numerical methods have improved vastly in the last two decades, we still need to do better. We need to implement more mathematical functions and numerical algorithms and tables. A good example that you mention is math co-processors, sometimes called floating point chips, where the elementary mathematical functions are implemented. Some chip vendors implement special functionality such as the fast Fourier transform, which is used for digital signal processing purposes, for example. The problem is that the potential market for special functionality is much smaller. The general idea is to implement as much as one can find a market for.

An example of special functionality brought to a large market is graphics accelerator boards. These are useful not only to engineers who make differential-equation-based models of physical phenomena, but also to people working with data analysis, computer games, movies, and image pro-

cessing. We can live with the fact that we cannot calculate some systems in real time, but we all want the graphic animations to run at real-world speed. That goal can be achieved because we know what algorithms to use and the market is large enough to make it profitable for the vendors. As the field of computer-based engineering increases, niches that are small today will become large enough to justify the development and production costs.

When it comes to mathematical algorithms and numerical methods, it is a bit different. Again, it has to be profitable to the vendor to implement a new technique. And that happens when the user finds it worthwhile to start using the new tool. Some considerations are learning time and purchase and maintenance costs of the tool versus gained values. To an engineer or applied physicist, such values are increased speed, accuracy, robustness, and applicability.

The last is important because we all know that it is burdensome to use different

software tools and then export and import results from one system to another. It also makes it hard for us to exchange models and results with our colleagues. In the past, differential-equation-solving software developers specialized heavily. Some produced software that could solve only one specific equation. Often, the computer program was used only in one short project. The reason was that there were no alternatives—the hardware was so slow that one had to use all the simplifications, special model features, and tricks to get any results at all. Thus, the market was too small to motivate mass production, or even to justify the cost of producing user manuals and documentation.

Nowadays, we can build a software tool that can be used for a wide variety of physics applications. We can even make software that allows the building of complex models that take into account physics in different fields—such as structural dynamics, heat transfer, acoustics, and electromagnetics—at the same time. In the real

world, none of these phenomena occur purely; rather they affect each other, sometimes to a large extent. The user can thereby build one multiphysics model that gives him or her a much more accurate prediction of the real-world system's behavior.

Your idea of an open-ended math co-processor applies to such software too. We who produce such general multiphysics software should make it open-ended so that our users can add their own codes for special features of the problem at hand.

We currently use the finite-element method to discretize space because it is convenient for nonrectangular space domains. It is not the best method in rectangular domains, where finite-difference methods are superior. But person-time is more expensive than machine time, so many users are willing to spend a little execution time—maybe an hour or even a day or two—to save an hour of modeling. Our plan for the future is not only to provide an open-ended platform, but to include the more popular special functionalities as part of the standard solver core as they emerge.

Svante Littmarck

Comsol, Inc.

Burlington, Massachusetts

svante@comsol.com]

## Nobel Prizes

I wish to add my two cents worth to your article "Nobel Prizes Honor Innovations in Electronics" (December 2000, pp. 8–11). Although innovations in semiconductor devices were seldom the work of a single individual, I acknowledge the vigorous pursuit and the patents generated by Kilby and Noyce, and I stand in strong support of this award. However, in the period from 1956 to 1958, virtually everyone capable of fabricating silicon transistors attempted to fabricate some kind of multiple-transistor structure. At the Raytheon Research Division, we beat out both Texas Instruments and Transitron in the fabrication of Device No. 15, a 5-W, 1,000 °C power transistor for the Signal Corps. Warren Erricson was assigned the task of building a four-transistor bridge circuit, which he did. Contrary to the opinion of my good

friend Marshall Nathan, which is given in your article, although the yield of these transistors was very low, suggesting the improbability of such circuits, the yield in certain portions of each slice was 100%, making such circuits attainable. Raytheon, however, only patented devices in manufacturing, and as a consequence, the Texas Instruments patent portfolio has been extensive, while Raytheon's is nonexistent.

I also disagree with my good friend Nick Holonyak about Bob Hall's invention of the GaAs semiconductor laser. If any one of the three teams deserved being called the first in the invention of the semiconductor laser, Bob Rediker and his group at Lincoln Laboratory receive my accolades. These people discovered the luminous efficiency of GaAs p-n junctions, publicized their work in *Lincoln Laboratory Quarterly Reports*, verbally communicated their findings to everyone in the field, and handed out recipes for making GaAs LEDs. If one may judge by published or verbal statements, it was not until the seminal paper delivered by the Lincoln Laboratory people at the Device Conference in June 1963 in Durham, New Hampshire, that the researchers from General Electric and IBM jumped into the act.

I also strongly support Herb Kroemer's award (one of three sharing the Nobel Prize in Physics). I would, however, like to point out two slightly incorrect statements. When Kroemer delivered his heterojunction paper to the Device Conference in 1957, he was employed at the RCA Research Division, but the paper described work he had initiated in his thesis at Goettingen University. This paper described increasing the bandgap of the emitter to improve emitter efficiency, rather than narrowing the bandgap of the base, which would have added complications to the collector junction.

Jerome M. Lavine

Sudbury, Massachusetts

lavine@world.std.com

In the article "Physics and Entrepreneurship" (February 2001, p. 35), the second paragraph should read "...creating a high-tech culture in northeast Ohio..." 