The curmudgeon's column

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Recently I gave each of my five kids a copy of a book that I had been delighted to read, *The Curmudgeon's Guide to Getting Ahead* by Charles Murray. I identified with the curmudgeon, hence the title of this column. Murray's book had its origins in postings the author made on the internal website of the American Enterprise Institute where he works, with tips for entry-level staff and interns such as:

- Excise the word "like" from your spoken English.
- Don't suck up, meaning don't flatter your supervisors.
- Stop "reaching out" and "sharing."
- Rid yourself of piercings, tattoos, and weird hair colors.
- Make strong language count.

As a father I thought all of this was good, solid advice.

With the curmudgeon in mind, I have a few comments to make about our lives as researchers, pushing the leading edge of technology in our industries. Herding a small group of developer cats at Z-Terra, I have to point them to research areas in the pasture where the grass is not so trampled by the research groups of large companies with larger budgets and lots of smart people working on fashionable topics. In small companies, it helps to be a contrarian, to develop novel algorithms in areas overlooked by large research groups or the academic groups funded by them.

A few years ago, I read a book by Peter Thiel, *Zero to One*. Thiel starts the book with a question he always asks people he interviews for a job: "What important truth do very few people agree with you on?" It is a contrarian question that is related to the title of his book. He argues that while incremental innovations — making existing things better — is going from 1 to *n*, inventing new technology is going from 0 to 1. That made me think what my answer to his question would be, and one possible result is smart migrations versus full-waveform inversion (FWI) and reverse time migration (RTM).

While a large number of researchers in our industry have joined the stampede on FWI and RTM, high-end imaging tools requiring more and more computer resources, fewer have followed John Sherwood's work on improving beam migration and beam tomography. I believe the combination of fast beam migration (FBM) and beam tomography can lead to high-resolution velocity models similar to those obtained using FWI, but 100 to 1000 times faster. At the same time, the algorithm is very stable, unlike FWI, which easily falls into local minima. A while back, I attended a local Geophysical Society of Houston (GSH) presentation where John Sherwood was showing examples of beam tomography results. One of the results was a velocity model after beam tomography where the velocity update was different inside a river channel, somewhere between 1000 and 2000 m deep. I was blown away by that resolution, never before did I see the results of a tomography update that had so much detail. I came back to the office convinced we had to work on this technology.

In my classification, beam migrations are a subset of smart migrations, a class of algorithms that uses information in the prestack input data to guide the migration operator, in contrast with brute force migrations (or dumb migrations) such as Kirchhoff and RTM that make the assumption that every point in the subsurface is a diffractor, do not use the stack information available, and make no a priori assumptions about the migrated image structure. Some hybrid algorithms that use the dips from the stack to constrain the aperture do not fit neatly in my classification, but the helicopter view still stands. One early and successful commercial implementation of a smart migration class algorithm is FBM developed by John Sherwood at Applied Geophysical Services. The speed of FBM is achieved in two steps:

1) A factor of 5 to 10 in speedup is achieved using beam forming, or beam decomposition of the input data, where the number of input data is reduced by a factor of 5 to 10.
2) A factor of 10 to 100 in speedup is obtained by spreading each input trace or beam over a beam instead of a full aperture volume.

Beam tomography works by combining standard tomography with beam migration. The industry-standard reflection tomography performed in the postmigrated domain has many advantages over standard tomography performed on prestack data. In general, postmigrated events are much easier to pick, the data volume is more manageable, and the whole process is more robust. The procedure converts common-image gather residual picks to velocity changes using 3D tomographic back projection. In tomographic migration velocity analysis, fans of rays are used to back project residual velocities to the places where the velocities errors originated. The state-of-the-art tomography in the early to mid 2000s was based on single value updates, from each (x,y,z) point in the image, a single value for the residual velocity (or time delay) was used to update the velocity along all offset and azimuth rays. The state-of-the-art tomography in the mid to late 2000s was based on event picking in offset gathers, and generating residual velocity updates from each (x,y,z) point in the image, resulting in a vector of velocity residual values function of offset dV(h) used to update the velocity. Because you have 50 to 100 bins in an offset gather, the number of independent velocity values for each (x,y,z) point

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is in the order of 50 to 100. The state of the art today is to separate the input data by several main azimuths (typically five to 10), migrate them separately, and update the velocity model using several azimuths and all offsets dV(h;a). Six azimuths multiplied by 60 offsets generates 360 independent values for the velocity update. In beam tomography, about 10,000 source-receiver pairs contribute to the velocity update for each (x,y,z) point in the subsurface. That will be the state of the art in the industry five to 10 years from now.

The faster imaging software allows for more iterations of velocity model building (100 to 500 iterations, instead of the current seven to 10), which enables the processing team to enhance the seismic resolution and imaging of complex geologic structures and allows for deeper data penetration, steeper dip, and subsalt structure imaging. Improved velocity models in combination with wave-equation imaging provide much greater resolution and accuracy than what can be accomplished today with standard imaging technology. While not yet mainstream, this technology represents a fundamental advance and is a necessary building block in any seismic processing system that uses wave-equation methods for imaging ultra-deep land and water, complex geologic structures that are the focus of modern oil-and-gas exploration. TLE