Published version:
INFORMS Journal on Computing **10** (1998) 388–389.

Predictions for Web Technologies in Optimization

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In surveying the World Wide Web's potential in operations research and management science, Bhargava and Krishnan [1] often use examples of applications in optimization or mathematical programming. Connections between advances in optimization and in computer science actually go back much further, to the early days of both. Their relationship was surveyed authoritatively by William Orchard-Hays [2], a pioneer in developing computer systems for optimization and also a prolific writer. In a "History of Mathematical Programming Systems" written 20 years ago, he stated:

> One cannot clearly comprehend the development of mathematical programming software without reference to the development of the computing field itself. . . . First, mathematical programming and computing have been contemporary in an almost uniquely exact sense. Their histories parallel each other year by year in a remarkable way. Furthermore, mathematical programming simply could not have developed without computers. Although the converse is obviously not true, still linear programming was one of the important and demanding applications for computers from the outset.

A history of future systems is not so easy to write, however, as a passage on the next page of the same article demonstrates:

> [T]he nature of the computing industry, profession, and technology has by now been determined — all their essential features have existed for perhaps five years. One hopes that some of the more recent developments will be applied more widely and effectively but the technology that now exists is pretty much what will exist, leaving aside a few finishing touches to areas already well developed, such as minicomputers and networks.

Finishing touches indeed! In the "already well developed" areas of "minicomputers and networks" we can see today a faint foreshadowing of the revolution in computing brought about by microprocessors and personal computers, and by the Internet and the World Wide Web. This passage points up a difficulty in all attempts to predict the evolution of technology. One may have a good idea in general terms as to *what* the future holds, yet be far off the mark with respect to timing and scale.

In light of this difficulty, how should we view Bhargava and Krishnan's vision of the future of the Web, at least as it applies to optimization? To the extent that they discuss *what* Web features we are likely to need and use, our confidence would seem to be well justified. They have sensibly focused on technologies that may be obscure right now, but that in fact are either already available or are clearly on the horizon. We cannot be nearly as certain as to which of these technologies will prove to be most successful, however, or as to how many more years of development and testing any one technology will require before it "catches on" and becomes widely used. This uncertainty is in fact a

major contributor to the sense of excitement currently surrounding the development of Web applications in optimization.

Much the same analysis extends to Bhargava and Krishnan's four vignettes (of which two involve optimization explicitly). The vignettes have been carefully chosen to require only those technologies that can be clearly foreseen. We can be confident that people will be acting out these scenarios, even if we can't be quite sure how their actions will be accomplished or when they will become commonplace.

As another example, I recently had occasion to write a more detailed but also more speculative vignette involving the use of the Web in optimization. I present it next, and then comment on what developments would be necessary for its realization.

Another Vignette

The largest company in the trucking industry has only 4% of the market. As a consequence, there are a lot of medium-size trucking companies that maintain a small staff devoted to planning, scheduling, and operations. Larry, a member of such a staff at S&C Trucking, is charged with preparing a bid for a contract to stock approximately 100 Sports Central stores from five regional warehouses. A truck that has been loaded at the warehouse will visit three to eight stores, following routes to be established by the trucking company. Each store must be visited two or three times per week.

Trucking is a low-margin business, so Larry needs as accurate an estimate as possible of the weekly mileage to be traveled by trucks under the contract. Thus, he wants to construct a tentative set of low-cost routes, but the problem is too large to do so by hand with any assurance that the result is near the lowest cost. It seems to Larry that there should exist some kind of optimization program for this purpose, but S&C Trucking has no previous experience with software of that kind.

Larry thus turns first to an online Optimization Guide, where information about many kinds of packages can be searched by listing entries that match specified keywords or by following the branches of a tree of problem types. An hour of searching is sufficient to convince Larry that there exist vehicle routing packages to meet his needs, but he needs more detailed information to be able to choose a package.

In the past, Larry would have proceeded to contact software vendors and to pore over their literature. Instead he now writes out a formulation of the Sports Central vehicle routing problem, using the same general-purpose modeling language that he (and others at S&C) have used for previous cost-minimization studies. He submits this model to a facility at the Optimization Guide Web site that translates and analyzes it, compares the result to a database of available software, and returns a short annotated list of packages that are equipped to deal with it. After some more checking at the Web sites for the listed packages, Larry chooses three that appear the most promising.

Since time and resources are in short supply, Larry cannot afford to acquire, install, and test each of the candidate packages. Instead he prepares a scaled-down

benchmark for the problem at hand, using sample data provided by Sports Central. He sends the benchmark to an Optimization Server site that locates the candidates on the Internet, handles all of the details of communicating the problem, and sends back the results. A few experiments with this facility enable Larry to identify a preferred package for solving his problem.

Larry next arranges for more intensive remote use of the vehicle routing component of the selected package. Through another facility of the Optimization Server, he arranges for two weeks' use of up to four simultaneous executions of the package. By applying sophisticated resource allocation software that takes advantage of idle time on thousands of workstations, the Server can provide the desired level of use at a low flat rate. Larry can then experiment with routes for a larger subset of Sports Central's data, using the remote server to find minimum-cost vehicle routes for various scenarios, while analyzing and graphically displaying the results locally. Based on the costs that emerge from these analyses, he is able to put together a realistic and detailed bid.

S&C Trucking's detailed analysis enables it to confidently make the low bid for the contract. Upon being awarded the contract, it purchases and installs the vehicle routing software at its own offices. Larry is now assigned to compute and maintain the actual truck routes to be driven. He does not need to make any significant changes in his mode of operation, however, because the same software that managed his use of the vehicle routing package over the Internet is available to manage its use on S&C's local network.

Analysis

Every action described in this vignette is possible now to some extent. Yet current limitations of the Web require a style of operation that uncomfortably resembles the mainframe conventions of Orchard-Hays' day, such as the submission of jobs and the creation of low-level problem descriptions and generators. In asserting that such a scenario will become commonplace, therefore, I am expressing confidence in a number of predictions.

First, I see the Web supporting fast two-way communication, to an extent that permits evaluation of sophisticated software. Bhargava and Krishnan have described CORBA and other technologies that are likely to supply the technical foundation for this need.

Second, I see a standardization of high-level languages and interfaces for describing specialized problems, so that test problems are easy to set up and to compare across a range of software packages. Bhargava and Krishnan suggest that the XML standard might prove useful for this purpose.

Finally, I see the development of protocols for electronic commerce in distributed computing resources, so that it becomes practical to try out optimization software without acquiring or installing it. DecisionNet is a step in this direction, but there remain thorny

issues of how to allocate and charge for computer use. Charges for computer time would seem to be a throwback that discourages testing and experimentation; on the other hand, it takes only a little knowledge of computational complexity to see that even one user can easily saturate all foreseeable computing resources.

My vignette appears highly speculative at present because it relies on all of these predictions. With each prediction being susceptible to the previously mentioned errors of timing and scale, it seems especially unlikely that all will be fulfilled without any great surprises.

Returning to Orchard-Hays' predictions, the previous quotation does not represent his final thoughts on the matter. In the same article, he went on to suggest that optimization had not become devoid of challenge:

> I realize that we are still too close to the end of the period of development for my statement to stand unchallenged; there are still lingering hopes that things can somehow be different from what they are. I will not push the point further but I would like to suggest that we [are] at the beginning of a new era with even greater challenges. The past twenty-five years have given us an enormous set of capabilities. It has been great fun creating them — in spite of some disappointments — but the time has come to apply them more seriously and expertly to the many critical problems facing the world. No one can foresee how that will come out but the challenge is worth of the best efforts of any generation.

The view expressed in the last two sentences strikes me as having been right on target, and I would not be surprised if it continues to be valid for another 20 years.

References

[1] Hemant K. Bhargava and Ramayya Krishnan, The World Wide Web: Opportunities for Operations Research and Management Science. *INFORMS Journal on Computing* **10** (1998) ???–???.

[2] William Orchard-Hays, History of Mathematical Programming Systems. In *Design and Implementation of Optimization Software,* Harvey J. Greenberg, ed., Sijthoff & Noordhoff (Alphen aan den Rijn, 1978) 1–26.