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Computer Science Technical Section

Newsletter

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Genetic Algorithms, Evolutionary Algorithms and Scatter Search: Changing Tides and Untapped Potentials

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1. Introduction

The recent literature of heuristic optimization procedures abounds with fanfare about "Evolutionary Methods," particularly those that operate by combining solutions (or by "mating" vectors). The preeminent example of such methods is the Genetic Algorithm (GA) approach, which is widely publicized to embody the fundamental mechanisms of biological improvement – with the suggestion that it draws on forces which have shaped our very existence! A quote from the January 16, 1996 issue of the Wall Street Journal is illustrative: "Three billion years of evolution can't be wrong [according to a prominent GA pioneer].... It's the most powerful algorithm there is."

Such claims have undeniably had a wide impact. As pointed out by Reeves (1997), GAs have a following that includes practitioners of many fields, including engineering, biology and psychology, whose members considerably outnumber the practitioners of OR and MS.

Consequently, we may be reasonably prompted to ask whether, underneath the rhetoric, genetic algorithms have the remarkable character

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The INFORMS CSTS Newsletter is published semiannually on April 1st and October 1st by the INFORMS Computer Science Technical Section (CSTS). Manuscripts, news articles, camera-ready advertisement and correspondence should be addressed to the Editor. Manuscripts submitted for publication will be reviewed and should be received by the Editor three months prior to the publication date. Requests for CSTS membership information, orders for back issues of this Newsletter, and address changes should be addressed to:

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Message from the Editors

S. Raghavan, Tom Wiggen

This is our first issue as the new co-editors of the CSTS newsletter. We aim to live up to the standard set by previous editions of this publication and we will be on the lookout for ways to improve the newletter in the future. We want to thank Dick Barr who served as the acting editor for the fall 97 CSTS newsletter, while simultaneously serving as the CSTS Chair. Dick has made it easier for us to ease into the editor's job by letting us reuse the building blocks he created for last fall's issue.

Many thanks especially to Fred Glover for writing this issue's feature article on scatter search in the small amount of lead time we were able to give him.

This newsletter is a suitable place to publicize a research idea or a short note on work in progress, particularly in the areas of design and analysis of algorithms, heuristic search, learning, modeling languages, parallel and distributed processing, simulation, computational logic, visualization and empirical evaluation of algorithms. Other suitable things include book reviews, software evaluations, news about web sites and internet resources, interesting applications, conference announcements and industry news. We need news and newsletter articles from you. If possible, submit items by e-mail or send instructions for downloading them from your web site. The deadline for the next issue will be approximately October 1, 1998. Our goal as editors is to increase the content of this newsletter. We need your help to do this, so we look forward to being inundated by your articles and news items.

This newsletter is created for you and will, whenever possible, be tailored to better meet your needs. We welcome your suggestions, comments and criticisms. We also welcome inquiries from individuals who are interested in joining the Newsletter's editorial board.

Message from the Chair

Richard S. Barr

By the time you are reading this, I hope that the INFORMS Board has approved our application for status change from that of a Section to a Society. All of the feedback so far has been encouraging, due in great measure from the strong and active history of our group. Becoming the INFORMS Computing Society will be both a recognition of CSTS's accomplishments and an opportunity to establish ourselves as the premier organization at the OR-CS interface. Occasionally, societies grow to be as popular as their parent institute and, while we may not achieve this stature, we are certainly in a position to develop in this direction, to the benefit of INFORMS and ourselves.

Thanks to Manuel Laguna and José Luis Gonzalez, our next conference will be held in Cancún, Mexico, in January, 2000. Cancún has beautiful sand, a modern infrastructure, and is close to ancient pyramids and scuba diving on the island of Cozumél. This, our first non-U.S. site, combines what I consider two of the better things in life: a warm, sunny beach and operations research.

As you have probably noticed, this newsletter is fortunate to have not just one, but two, new editors: Tom Wiggen and S. (Raghu) Raghavan. They have created an excellent first issue and are to be thanked and congratulated. Speaking for the CSTS membership, we appreciate their taking on this important, valuable role. I am sure that Raghu and Tom would appreciate your contributions of articles and announcements to future issues.

I have been working with Kluwer Academic Publishers on a substantial CSTS-member discount—at least 50% off of the standard individual subscriber rate—on their computing/AI/OR journals. INFORMS has asked whether the offer could be extended to all of its members. I see this as both a CSTS member benefit and an enticement to join, since one subscription would justify the CSTS membership fee. With two-tiered pricing and greater discounts for our members, this could benefit the entire institute, increase our membership, and even generate a little revenue, if we so desire. Details to follow on these developments.

The past year as CSTS chair has gone by quickly and it has been a rewarding experience, mainly due to our

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CSTS Member Profile: Henry S. Weigel

Henry Weigel is the Special Assistant to the Director of the Office of Energy Markets and End Use of the Energy Information Administration (EIA). He is responsible for technical, administrative, quality control, office procedure automation, and ADP matters. In particular, he is responsible for disseminating information on the internet. He reviews energy-related data, analysis, and forecast publications for technical soundness and clarity.

In the area of forecasting, for example, he wrote an "Options Paper" on obtaining advice from industry and users of EIA forecasts. He subsequently laid the groundwork for a symposium on short-term energy forecasting in November 1991.

As an analyst in EIA he conducted a world oil market analysis that resulted in an Information Memorandum for the Deputy Secretary of Energy. In addition he analyzed energy use on the basis of an international energy market equilibrium model. The results contributed to an EIA Annual Report to Congress. The model requires information on energy resource supplies, foreign electric utilities, foreign refineries, and the international transportation network. To keep it up to date, Mr. Weigel gathers and evaluates data, studies, and reports from the open literature as well as private and Government sources.

Mr. Weigel was formerly the Deputy and Technical Director of the Management Sciences Group at the General Research Corporation, a group of about 170 technical staff members. He directed mathematical model design and development, technical project reviews and trouble-shooting for all projects. He also coordinated the technical steering groups that dealt with such aspects as model design, software development, quality assurance, user interfaces, and database issues. He personally headed up the model design steering group. Additionally, he has designed and developed a number of computer programs.

Mr. Weigel chaired the popular "Mathematical Programming User-Vendor Interface" sessions, which CSTS sponsored at several consecutive INFORMS meeting. His paper on the Army's Personnel Decision Support System was published in the Decision Support Systems journal. He has also published a paper on multi-commodity network flow modeling in the Naval Research Logistics Quarterly.

Mr. Weigel received a BA in mathematics and physics (with honors) from the University of Wisconsin. He received MA in 1969 from the University of Maryland at College Park with majors in applied mathematics and mathematical analysis. He did graduate work in Operations Research at George Washington University.

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CSTS member profiles are intended to keep us up to date on what our members are doing. Recent issues of the Newsletter profiled persons from academia and industry. The present issue features a representative of civilian government service. Future Newsletters will focus on persons in the military and student members.

Seventh INFORMS Computer Science Technical Section Conference

January 5-7, 2000 Cancún, México

Computer science and operations research share an important part of their history. Their interface is responsible for advances that could not have been achieved in isolation. The first six CSTS conferences witnessed fascinating developments in the computer science/operations research interface. We would like to take this opportunity to invite you to the seventh CSTS conference, which has the goal of bringing together researchers and practitioners in Operations Research, Computer Science, Management Science, Artificial Intelligence, and other related fields.

The advisory committee for the conference consists of:

- ·Bruce Golden (U of Maryland)
- ·Harvey Greenberg (U of Colorado)
- ·Paolo Toth (U of Bologna)
- ·John Hooker (Carnegie Mellon U).

We are currently in the process of selecting a conference hotel as well as forming a program committee, for which we would like to invite CSTS members. Anyone interested in organizing sessions or tutorials should contact either one of us. We hope to continue the tradition of excellence established in previous CSTS conferences and therefore we would like to count with your support and participation.

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Monterey Meeting Report

David Woodruff

The 1998 CSTS meeting in January was attended by 114 registered participants. Monterey, California offered participants a number of interesting sites and dining opportunities. The rain came and went, but didn't really put a damper on our activities. The final accounting has not been conducted, but the meeting had a net profit of a few thousand dollars from an overall budget of about $18,000.

Claude Le Pape's plenary talk on constrained logic programming highlighted an eclectic collection of research presentations. As usual the presentations were well prepared and well attended. Our coffee breaks occupied the hotel restaurant, which afforded people a chance to sit down and conduct converstations while enjoying some coffee, fruit, or other snacks.

The next meeting will be in January of 2000 in Cancun, Mexico. Manuel Laguna of the University of Colorado is the general chair for what promises to be another outstanding CSTS gathering.

News about members

Richard Brooks has moved from the Institute of Communications at California State University Monterey Bay to the Informations Science and Technology Division of the Applied Research Laboratory at Penn State.

Multisensor Fusion: Fundamentals and Applications with Software by R. R. Brooks and S. S. Iyengar was published in January by Prentice Hall PTR. Among other things, it discusses multi-dimensional data structures, meta-heuristics, and reasoning with uncertainty. It is of interest to researchers and suitable for upper division and graduate courses.

Chair's Message: Continued from page 3

volunteers: their many contributions and my enjoyable interactions with them. Thank you for this opportunity. I anticipate that your new chair, Harlan Crowder, with his creative thinking, industrious nature, and keen wit, will be an outstanding and memorable leader of our Computing Society.

New Software Announcements

MProbe 2.0

MProbe is a tool for analyzing mathematical programming models. It has special capabilities for analyzing nonlinear functions to discern their shapes in a region of interest. MProbe is specifically designed to operate on nonlinear functions having many variables. MProbe also estimates the shape of a nonlinearly constrained region (convex? nonconvex?), the objective function effect (global optimum? local optimum only?), and the effectiveness of the constraints.

Version 2.0 retains all of the features of version 1.01:
* a listing of statistics about the model
* simple navigation of the model
* generation of a plain text trace
* a direct link to AMPL
* a windowed interface with a full help system

Especially useful for nonlinear programs:
* analysis of constraint and objective shape
* estimation of function range
* estimation of function "slope" (a multidimensional analog of slope)
* function plotting between any two arbitrary points (which can assist in determining why a solver is stuck at a particular point when a feasible point giving a better function value is known to exist)

And adds a number of useful new features:
* faster 32-bit implementation
* recognition of quadratic functional forms
* Region Workshop: is the region formed by the constraints convex or nonconvex?
* estimates constraint "effectiveness": what fraction of the variable space does each constraint eliminate? Can an equality be satisfied in the specified variable space?
* comments on the objective function shape effect (global optimum possible? local optimum likely?)
* flexible sorting of information about con-

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Integrating Optimization And Simulation:The New OptQuest System

The new OptQuest system for Crystal Ball Pro brings unprecedented intelligence to spreadsheet software for corporate decision-making, and gives a new dimension to optimization and simulation models in business and industry.

Decisioneering, makers of risk-analysis and forecasting software used by 85% of all Fortune 500 companies, introduces OptQuest in its Crystal Ball Pro software, a comprehensive decision optimization package that empowers decision makers to look beyond conventional decision-making approaches and actually pinpoint the optimal choices in uncertain situations.

Representing over 20 years of research in management sciences and operations research, OptQuest incorporates highly developed metaheuristic technologies to track which solutions have worked well in the past, and then recombine and enhance them to produce new, still better solutions.

"Ordinary spreadsheet solvers can find only local solutions - the highest or lowest point within a limited range - when model data is known with certainty," says Decisioneering CEO Eric Weissmann. "They fail, however, in the search for global solutions to real life problems that contain significant amounts of uncertainty.

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The reviews in this section have been provided by the authors of the software. We would welcome an associate editor willing to take on the responsibility of developing this section into an independent, unbiased software review section.

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often attributed to them. Specifically, is there a solid basis for believing that GAs are ideal representatives of solution combination strategies? And more pointedly, for those who are interested in bottom line results, is there perhaps reason to suspect that the GA approaches – although supposedly embracing the essence of "evolution by combination" – may be missing some crucial aspect that can be found in some alternative solution combination approach for optimization problems?

To answer such questions, it is illuminating to examine the evolution of GA approaches themselves. Although it is sometimes forgotten, GAs underwent a critical re-examination in the mid 1980s, with an emerging recognition that they harbored significant shortcomings as tools for optimization. (The work of Grefenstette et al., 1985 is often cited as a turning point that spurred this recognition.) Consequently, over the next several years, and continuing into the 1990s, a series of efforts were undertaken to counter these shortcomings. The outcome, not surprisingly, has compelled GA practitioners to negotiate a series of twists and turns in order to hang onto the GA framework – at least in name – while striving to make it applicable for problems it was not originally suited to handle. This is not to imply these efforts have not been worthwhile. By preserving an image that has successfully attracted followers from many disciplines, the GA community has done the valuable service of fostering widespread recognition of the importance of metaheuristic concepts in general.

The following little Trivia Quiz has been put together to give a glimpse of some of the developments that have been adopted as modifications of GAs, and of the presumed origins of these developments. To make things easier, the answers to the quiz – as found in the GA literature – are already indicated parenthetically beside the questions. However, to make the quiz more interesting, you are allowed to know a little secret: these answers are not correct. (The correct ones will be discussed after the quiz. While origins by themselves are of little consequence, the critical changes produced in the nature and application of GAs are of greater significance.)

TRIVIA QUIZ

What Are The Sources Of Each Of The Following Innovations In Solution Combination Methods? (Traditional GA answers are shown in parentheses.)

1. Rules for combining solutions that give richer and more effective combination possibilities than the original GA "one-point crossover" and "two-point crossover" – e.g., as represented by the "uniform" and "Bernoulli" crossovers that allow each child to receive any combination of bits from the strings contributed by the parents. (Ackley (1987), Spears and DeJong (1991).)

2. Use of heuristic methods to improve parent and/or child solutions. (Mühlenbein *et al*. (1988), Ulder *et al*. (1991).)

3. Focusing on the best solutions generated, by maintaining a "rank based" population that consists only of a selected number of top solutions produced, without duplicate representations. (Whitley and Kauth (1988); Whitley (1989).)

4. Providing mechanisms that explicitly operate to join partial solutions, of varying dimension. (Goldberg, Korb and Deb (1989).)

5. Exploiting vector representations that are not restricted to being binary. (Davis (1989), Eschelman and Schafer (1992).)

6. Introducing special cases of linear combinations for operating on continuous vectors. (Davis (1989), Wright (1990), Bäck *et al*. (1991).)

7. Combining more than 2 parents simultaneously to produce children. (Eiben *et al*., (1994), Mühlenbein and Voight (1996).)

8. Introducing strategies that subdivide the population into different groupings, or "islands." (Mühlenbein and Schlierkamp-Voosen (1994).)

Fortunately, it doesn't take a lot of space to itemize the references where these various developments were first introduced, since they come from a single paper published more than a decade before the earliest of those cited above. I will postpone identifying this paper in order to set the stage for discussing the implications of its ideas.

Most of us would feel that the developments listed in the quiz are not particularly outrageous or radical, but rather are entirely natural, at least from the orientation of operations research and management science. (This is not to detract from their importance as milestones in the GA literature.) Consequently, we might be led to guess that they would be readily embraced once they reached the attention of the GA community at large. In fact, the opposite occurred. These modifications of GAs were generally conceived as heresies rather than advances, until their practical merit could no longer be disputed. (Not all GA researchers are happy with some of these developments even today.)

1.1 Themes and Nomenclature

It is amusing in retrospect to trace the process by which empirical demonstration has won out over dogma, and to observe the accompanying phenomenon by which dogma has re-written itself to encompass elements that it previously rejected. For example, to make the introduction of general real-valued and integer-valued vectors palatable, considerable effort has been devoted to arguing that non-binary representations can still be encompassed within binary representations, if the latter are re-expressed appropriately. (This is essential to allow basic GA theory to remain applicable.) However, there has emerged a literature on *deception*, rooted in binary representations, that would seem to put such an effort in a suspicious light. Confirmation of the weakness of binary representations is established by a simple demonstration that such representations can generate "information gaps" for solution combination methods (see, e.g., Glover, 1994). As a consequence, the problems of deception are not surprising.

The initial resistance in GA circles to using heuristic improvement to modify members of the population, and the ultimate gambit that overcame this resistance, are still more intriguing.

From a genetic standpoint, traits acquired by extra-genetic improvement (such as those manufactured in response to the environment, or produced by "training" to achieve better outcomes) can not be inherited and passed to subsequent generations. The incorporation of such acquired traits is the premise of the theory called Lamarckian evolution, which is viewed with some disfavor in respectable scientific circles. GA researchers who wanted to base their approaches on "good genetics" naturally regarded such external tinkering to be inappropriate. Consequently, when heuristic improvement was at last introduced in the late 1980s and found to yield a method superior to the original GAs, there arose a need to justify the result as somehow compatible with earlier GA principles, in order to continue to call this modified approach a genetic algorithm.

The resolution to the problem was finally provided when someone came up with the clever idea of re-interpreting the genetic concept of mutation. By this device, instead of referring to rare random changes, "mutation" was recast (corresponding to the linguistic roots of the word) to refer to any change at all. In a single stroke, the use of heuristic improvement thus became validated as a component of GAs, since it merely constituted a form of mutation.

Similar examples of wordplay can be found in efforts to formulate other GA modifications in a way that will allow them to be perceived as encompassed by the original GA framework. A conspicuous instance occurs in the reference made to "partial solutions" and "building blocks" – notions originally introduced to describe the hyperplane sampling effects of early types of crossover. As realization began to dawn at the end of the 1980s that advantages could be gained by joining components of vectors rather than full vectors, the earlier terminology was given new meaning. As a result, "partial solutions" and "building blocks" are now re-construed (on suitable occasion) to refer to isolated vector components, in contrast to carrying their earlier technical meaning of full dimensional schemata (which were treated only by wholesale and narrowly defined manipulation of indivisible vectors). Thus, the original framework could be portrayed to embrace designs that were beyond it. Even so, the GA approach that is acclaimed for introducing the strategy of working directly with partial rather than full factors, due to Goldberg, Korb and Deb (1989), relies on randomized processes patterned after the early forms of GA crossover. The approach contains no notion of strategically isolating elements of elite solutions or of assembling them by heuristic procedures designed to create high quality outcomes.

Rather than continue to chart such steps that have shaped the changing landscape of GAs, we may find it useful to consider an alternative framework for combining solutions – a framework that arose directly from the OR/MS tradition, and that introduced key departures from the original GA prescriptions from the start.

2. Scatter Search and Path Relinking

The solution combination approach that initiated the developments indicated in the Trivia Quiz is called *scatter search* (Glover, 1977), and is closely associated with ideas that also have subsequently become incorporated in tabu search (TS). In the TS setting, scatter search has been extended to yield the method now called *path relinking* (Glover, 1989; Glover and Laguna, 1993).

The fact that scatter search afforded classes of strategies that were not part of the original GA conception, yet were eventually introduced to make GAs perform more effectively, motivates us to ask whether there are other aspects of scatter search and its path relinking generalization that remain beyond the GA framework, and that may be useful for solving optimization problems.

The relevance of this question is increased by recent applications of scatter search and path relinking which have disclosed their promise for solving difficult problems in discrete and nonlinear optimization. A partial listing of such applications is as follows.

Vehicle Routing – Rochat and Taillard (1995); Taillard (1996)
Quadratic Assignment – Cung *et al*. (1996, 1977)
Financial Product Design – Consiglio and Zenios (1996)
Neural Network Training – Kelly, Rangaswamy and Xu (1996)
Job Shop Scheduling – Yamada and Nakano (1996)
Flow Shop Scheduling – Yamada and Reeves (1997)
Graph Drawing – Laguna and Marti (1997)
Linear Ordering – Laguna, Marti and Campos (1997)
Unconstrained Continuous Optimization – Fleurent *et al*. (1996)
Bit Representation – Rana and Whitley (1997)
Optimizing Simulation – Glover, Kelly and Laguna (1996)
Complex System Optimization – Laguna (1997)

The origins of scatter search and path relinking shed light on their character, and reveal that they did not emerge in a vacuum, but were a natural extension of other approaches in the OR/MS tradition. These methods derive their foundations in particular from earlier strategies for combining decision rules and constraints, with the goal of enabling a solution procedure based on the combined elements to yield better solutions than one based only on the original elements.

2.1 Combining Decision Rules

Historically, the antecedent strategies for combining decision rules were introduced in the context of scheduling methods to obtain improved local decision rules for job shop scheduling problems (Glover, 1963). New rules were generated by creating numerically weighted combinations of existing rules, suitably restructured so that their evaluations embodied a common metric.

The approach was motivated by the supposition that information about the relative desirability of alternative choices is captured in different forms by different rules, and that this information can be exploited more effectively when integrated by means of a combination mechanism than when treated by the standard strategy of selecting different rules one at a time, in isolation from each other. In addition, the method departed from the customary approach of stopping upon reaching a local optimum, and instead continued to vary the parameters that determined the combined rules, as a basis for producing additional trial solutions. (This latter strategy also became a fundamental component of tabu search. See, e.g., Glover and Laguna, 1997.)

The decision rules created from such combination strategies produced better empirical outcomes than standard applications of local decision rules, and also proved superior to a "probabilistic learning approach" that selected different rules probabilistically at different junctures, but without the integration effect provided by generating combined rules (Crowston, *et al*., 1963).

2.2 Combining Constraints

The associated procedures for combining constraints likewise employed a mechanism of generating weighted combinations, in this case applied in the setting of integer and nonlinear programming, by introducing nonnegative weights to create new constraint inequalities, called *surrogate constraints* (Glover, 1965). The approach isolated subsets of constraints that were gauged to be most critical, relative to trial solutions based on the surrogate constraints, and produced new weights that reflected the degree to which the component constraints were satisfied or violated.

A principal function of surrogate constraints, in common with the approaches for combining decision rules, was to provide ways to evaluate choices that could be used to generate and modify trial solutions. From this foundation, a variety of heuristic processes evolved that made use of surrogate constraints and their evaluations. Accordingly, these processes led to the complementary strategy of combining solutions, as a *primal* counterpart to the *dual* strategy of combining constraints, which became manifest in scatter search and its path relinking generalization. (The *primal/dual* distinction stems from the fact that surrogate constraint methods give rise to a mathematical duality theory associated with their role as relaxation methods for optimization. E.g., see Greenberg and Pierskalla, 1970, 1973; Glover, 1965, 1975; Karwan and Rardin, 1976, 1979; Freville and Plateau, 1986, 1993.)

3. Elements of Scatter Search and Path Relinking

While there is not enough space in this article to cover scatter search and path relinking in detail, a sketch of their main elements may be useful for understanding their fundamental character and their potential applications.

3.1 Scatter Search

The scatter search process, building on the principles that underlie the surrogate constraint design, is organized to capture information not contained separately in the original vectors, and to take advantage of auxiliary heuristic methods both for selecting the elements to be combined and for generating new vectors.

The original form of scatter search may be sketched as follows.

Scatter Search Procedure

1. Generate a starting set of solution vectors by heuristic processes designed for the problem considered, and designate a subset of the best vectors to be *reference solutions*. (Subsequent iterations of this step, transferring from Step 3 below, incorporate advanced starting solutions and best solutions from previous history as candidates for the reference solutions.)
2. Create new points consisting of linear combinations of subsets of the current reference solutions. The linear combinations are:
(a) chosen to produce points both inside and outside the convex regions spanned by the reference solutions.
(b) modified by generalized rounding processes to yield integer values for integer-constrained vector components.
3. Extract a collection of the best solutions generated in Step 2 to be used as starting points for a new application of the heuristic processes of Step 1. Repeat these steps until reaching a specified iteration limit.

Three particular features of scatter search deserve mention. First, the linear combinations are structured according to the goal of generating weighted centers of selected subregions, allowing for nonconvex combinations that project these centers into regions external to the original reference solutions. (The dispersion patterns created by such centers and their external projections is particularly useful for mixed integer optimization.) Second, the strategies for selecting particular subsets of solutions to combine in Step 2 are designed to make use of clustering, which allows different types of strategic variation by generating new solutions “within clusters” and “across clusters”. Third, the method is organized to use supporting heuristics that are able to start from infeasible solutions, and hence which remove the restriction that solutions selected as starting points for re-applying the heuristic processes must be feasible.

In sum, scatter search is founded on the following premises.

(P1) Useful information about the form (or location) of optimal solutions is typically contained in a suitably diverse collection of elite solutions.

(P2) When solutions are combined as a strategy for exploiting such information, it is important to provide for combinations that can extrapolate beyond the regions spanned by the solutions considered, and further to incorporate heuristic processes to map combined solutions into new points. (This serves to provide both diversity and quality.)

(P3) Taking account of multiple solutions simultaneously, as a foundation for creating combinations, enhances the opportunity to exploit information contained in the union of elite solutions.

The fact that the heuristic processes of scatter search are not restricted to a single uniform design, but represent a varied collection of procedures, affords additional strategic possibilities. Implications of such features will be elaborated later.

3.2 Path Relinking

From a spatial orientation, the process of generating linear combinations of a set of reference solutions may be characterized as generating paths between and beyond these solutions, where solutions on such paths also serve as sources for generating additional paths. This leads to a broader conception of the meaning of creating *combinations* of solutions. By natural extension, such combinations may be conceived to arise by generating paths between and beyond selected solutions in neighborhood space, rather than in Euclidean space (Glover 1989, 1994; Glover and Laguna, 1993).

This conception is reinforced by the fact that a path between solutions in a neighborhood space will generally yield new solutions that share a significant subset of attributes contained in the parent solutions, in varying "mixes" according to the path selected and the location on the path that determines the solution currently considered. The character of such paths is easily specified by reference to solution attributes that are added, dropped or otherwise modified by the moves executed in neighborhood space. Examples of such attributes include edges and nodes of a graph, sequence positions in a schedule, vectors contained in linear programming basic solutions, and values of variables and functions of variables.

To generate the desired paths, it is only necessary to select moves that perform the following role: upon starting from an *initiating solution*, the moves must progressively introduce attributes contributed by a *guiding solution* (or reduce the distance between attributes of the initiating and guiding solutions). The roles of the initiating and guiding solutions are interchangeable, each solution can also be induced to move simultaneously toward the other as a way of generating combinations.

Variants of path relinking that use constructive and destructive neighborhoods, called *vocabulary building* approaches, produce strategic combinations of partial solutions (or "solution fragments") as well as of complete solutions. The organization of vocabulary building permits the goal for combining the solution components to be expressed as an optimization model in a number of contexts, with the added advantage of allowing exact methods to be used to generate the moves (Glover, 1992; Glover and Laguna, 1993). By this means, it becomes possible to produce optimal linkages of the components. (Quite recently, a variant of this strategy has been introduced in the GA setting by Aggarwal, Orlin and Tai (1997), and applied to weighted clique problems by Balas and Niehaus (1998).)

The incorporation of attributes from elite parents in partially or fully constructed solutions was foreshadowed by another aspect of scatter search, embodied in an accompanying proposal to assign preferred values to subsets of *consistent* and *strongly determined* variables. The theme is to isolate assignments that frequently or influentially occur in high quality solutions, and then to introduce compatible subsets of these assignments into other solutions that are generated or amended by heuristic procedures. (Such a process implicitly relies on a simple form of frequency based memory to identify and exploit variables that qualify as consistent, and thereby provides a further bridge to associated tabu search ideas.) This strategy of building solutions from fragments of others, as a supplementary mechanism for combining solutions, is refined in the vocabulary building process by iteratively assembling and disassembling the fragments, with the ultimate goal of creating and assembling fragments that produce elite solutions.

Multiparent path generation possibilities emerge in path relinking by considering the combined attributes provided by a set of guiding solutions, where these attributes are weighted to determine which moves are given higher priority. The generation of such paths in neighborhood space characteristically "relinks" previous points in ways not achieved in the previous search history, hence giving the approach its name.

Neighborhoods for these processes may differ from those used in other phases of search. For example, they may be chosen to *tunnel through* infeasible regions that may be avoided by other neighborhoods. Such possibilities arise because feasible guiding points can be coordinated to assure that the process will re-enter the feasible region, with out danger of becoming "lost." The ability of neighborhood structures to capture contextual features additionally provides a foundation for incorporating domain-specific knowledge about different classes of problems, thus enabling path relinking to exploit such knowledge directly.

4. Conclusion

Due to the limitations of brevity, this article of course only scratches the surface of strategies for solution combination methods that are provided by the scatter search and path relinking frameworks. (Additional considerations, such as associated intensification and diversification processes, and the design of accompanying "improvement methods," are examined more fully in Glover, 1997.)

However, a key observation deserves to be stressed. The literature often contrasts evolutionary methods – especially those based on combining solutions – with "local search" methods, and notably with the types of adaptive memory strategies incorporated in tabu search. Yet as already noted, the foundations of scatter search and tabu search strongly overlap, and moreover path relinking was initiated as a strategy to be applied with the guidance of tabu search. By means of these connections, a wide range of strategic possibilities exist for implementing scatter search and path relinking methods.

Very little computational investigation of these methods has been done until quite recently, and a great deal remains to be learned about the most effective implementations for various classes of problems. The highly promising outcomes of the studies cited in Section 2 suggest that these approaches may offer a useful potential for more advanced applications.

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Minutes of CSTS Business Meeting, INFORMS Dallas October 1997

Bjarni Kristjansson/Secretary/Treasurer

Dick Barr, President of CSTS, opened the CSTS business meeting promptly at 6:15pm, on October 27.

San Diego Minutes

The minutes from the San Diego meeting, written by Matt Saltzman, were approved unanimously.

Elections

Two Board vacancies need to be filled in the upcoming spring elections - nominations needed.

1998 CSTS Meeting

Place: Monterey California
Time: January 7-9, 1998
Sign-up forms at http://www.gsm.ucdavis.edu/~woodruff/csts.html
Preliminary preparations close to final stage
Approximately 100 talks planned
Two receptions planned(more info needed).

CSTS 2000

Possible sites/hosts discussed:

- Harvey Greenberg - Denver
- Manuel Laguna – Cancun, Mexico
- Bill Stewart – Williamsburg

After lively discussion about weather statistics and travel budgets Cancun was chosen by unanimous vote.

CSTS Prize

The committee chair is Anna Nagurney, and committee members are Panos Pardalos, John Tsitsiklis, and Hanif Sherali. The prize is advertised in the INFORMS newsletter, in addition to OR/MS and NET. Dick Barr's suggestion, to increase the reward money from $500 to $1000, was unanimously approved by the attending members.

- Nominations will be accepted until February 15, 1998
- Four copies of each nomination letter are required
- Winner will be announced at the May meeting in Montreal

Journal On Computing

Bruce Golden reported that the Journal is running smoothly, with a strong, stable Editorial Board, an excellent printer and a sound financial position. We have a good relationship with Cadmus and the INFORMS Board. Four hundred and fifty pages were published in 1997. The expenses continue to be quite low. The Journal has a basic website and there are plans for further enhancement of the site. The next issue will be published soon. Karla Hoffman discussed electronic publications - possibly using the Journal as a test site.

In addition:

- Journal circulation needs increasing
- The number of Institutional Sponsors has remained near 20 for the last few years
- The JOC is now abstracted in IAOR, ISI and Computer Abstracts
- Members are encouraged to submit papers for publication a.s.a.p. – the backlog is smaller than previously noted
- Writers are needed for a cluster of articles on Intelligent Data Analyzes, Data Mining and Data Visualization
- Suggestions for feature articles are welcome.

Recent Issues

- Winter 1997: Cluster on Integer Programming
- Spring 1997: Stochastic Programming Survey
- Summer 1997: Feature Article on Genetic Algorithms
- Fall 1997: Cluster on Applications of OR to Manufacturing
- Winter 1998: Cluster on Telecommunications

Feature Article Search

- Computational Integer Programming
- World Wide Web
- Intelligent Data Analysis
  - Blend of statistics, computer science, pattern recognition and machine learning
  - Data mining is one small example
  - Massive (and messy) data sets
  - Data visualization

Status Change

We are applying and expect to have an answer from INFORMS by Montreal regarding changing CSTS from a section to a society. It is hoped that the application will be approved and will be voted on by the membership in the spring.

Name Change

The following names were offered as our new Society name, along with results of a straw vote.

5 INFORMS Computer Science Technical Society (CSTS)

Continued on page 16

Business Meeting: Continued from page 15

0 INFORMS Computer Science Society (CSS)
0 INFORMS Computer Society (CS)
0 INFORMS Computing Science Society (CSS)
4 INFORMS Society on Computing (SC)
11 INFORMS Computing Society (CS)
0 CATS

Newsletter
Presently, a search is underway for an editor for the INFORMS newsletter. Two names have been forwarded Tom Wiggen, University of North Dakota, and S. Raghavan, U S WEST. Members are asked to send their suggestions to Dick Barr at barr@seas.smu.edu.

Liaisons
Persons who can act as liaisons with other societies are needed to increase connectivity between various groups. A detailed description of what qualifications are required for such a job are listed on the INFORMS website.

Focus Group
Dick Barr attended an INFORMS focus group that centered on topics such as "What are your problems in OR?" It was run by Lou Kringer, a former advertising executive and MIT OR graduate who is working on increasing public awareness of and name recognition for the field and INFORMS.

Attendance
The meeting was well-attended, however, many left without signing the roster, which showed: Dick Barr, John Chinneck, Joe Creegan, Harlan Crowder, Katrin Daly, David Gay, Mary Gonglon, Bruce Golden, Don Hi, Karla Hoffman, Jim Kelly, Bjarni Kristjansson, Manuel Laguna, Leon Lasdon, Ken McAloon, Anna Nagurney, Asim Roy, Nick Schinidas, Sanjay Saigal, Carol Tretkoff, Kevin Wood and Leslie-Ann Yarrow.

Meeting adjourned at 7pm.

MProbe 2.0 : Continued from page 6

straints and variables
* window and menu enhancements

For further information, or to download a demonstration copy of MProbe, visit the web page at **http://www.sce.carleton.ca/faculty/chinneck/mprobe.html**

Journal on Computing: Contents

Vol. 10, No. 1

The Application of OR to Telecommunications
"A Cutting Plane Algorithm for Multicommodity Survivable Network Design Problems", M. Stoer, G. Dahl
"A Dual Ascent Procedure with Valid Inequalities for Designing Hierarchial Network Topologies", S. Mitra, I. Murthy
"A Virtual Clustering Approach for Routing Problems in Telecommunications Networks", M. Bartolacci, S. Wu
"Interconnecting LANs and FDDI Backbone Using Transparent Bridges: A Model and Solution Algorithms", J. Park, F. Kaefer
Contributed Research Articles
"An Efficient Algorithm for a Class of Two-Resource Problems", L. Lei, R. Armstrong, S. Gu
"Sparse Matrix Methods for Interior Point Linear Programming", E. Rothberg,, B. Hendrickson
"Complexity of Simulation Models: A Graph Theoretic Approach", E. Yucesan, L. Schruben
"Distributed State Space Generation of Discrete-State Stochastic Models", G. Ciardo, J. Gluckman, D. Nicol
"On the Application of Explanation-Based Learning to Acquire control Knowledge for Branch and Bound Algorithms", M. Realff, G. Stephanopoulos
"Numerical Methods for Fitting and Simulating Autoregressive-to-Anything Processes", M. Cario, B. Nelson

Vol. 10, No. 2

Combinatorial Optimization:
"On the Performance of Heuristics on Finite and Infinite Fractal Instances of the Euclidean Traveling Salesman Problem", G. Norman and P. Moscato
"Solving the Orienteering Problem through Branch-and-Cut", M. Fischetti, J. Gonzalez, and P. Toth
"Approximating Shortest Paths in Large-scale Networks with an Application to Intelligent Transportation Systems", Y-L. Chou, E. Romeijin, and R. Smith
"An Exact Solution Approach Based on Shortest-Paths for p-hub Median Problems", A. T. Ernst and M. Krishnamoorthy
"Using Variable Redefinition for Computing Lower Bounds for Minimum Spanning and Steiner Trees with Hop Constraints", L. Gouveia
Contributed Research Articles:
"Variance Reduction and Objective Function Evaluation in Stochastic Linear Programs", J. Higle
"On Formal Semantics and Analysis of Typed Modeling Languages: An Analysis of Ascend", H. Bhargava, R. Krishnan, and P. Piela
"Feature Selection via Mathematical Programming", P. Bradley, O. Mangasarian, W. Street
"Operator Splitting Methods for Monotone Affine Variational Inequalities, with a Parallel Application to Optimal Control", J. Eckstein and M. Ferris
"Strategies for Creating Advanced Bases for Large-scale Linear Programming Problems", G. Mitra and I. Maros

Book Reviews

Conditional Monte Carlo: Gradient Estimation and Optimization Applications
Michael FU, University of Maryland & Jian-Qiang HU, Boston University

This book deals with various gradient estimation techniques of perturbation analysis based on the use of conditional expectation. Gradient estimation is the goal, and conditioning is the unifying theme. In the setting of discrete-event stochastic simulation — to which this work is primarily addressed — the latter is often referred to as conditional Monte Carlo, albeit the usual context is variance reduction and not gradient estimation. Gradient estimation research based on these ideas has reached a point of maturity where some attempt to tie together the many various developments is warranted. The authors present a very general framework for deriving gradient estimators based on this technique. Furthermore, they illustrate the practical purview of the technique by presenting applications to queueing and inventory, and also to more "exotic" application areas such as financial derivatives pricing and statistical quality control.

The contents of the book are divided into two parts. The first part deals with most of the theory, whereas the second part describes the various application areas. Chapter 1 is an introduction to the gradient estimation problem for stochastic discrete-event systems. The authors describe some key ideas in perturbation analysis, introduce the basic tools for establishing unbiasedness and strong consistency, and provide a preview of the contents contained in the following chapters. The next three chapters contain most of the theory. Chapter 2 describes the ideas of conditional Monte Carlo for gradient estimation through three extended examples. Chapter 3 applies the conditioning ideas to stochastic gradient estimation in the generalized semi-Markov process (GSMP) framework by deriving the general estimators for timing parameters and structural parameters, and proving their theoretical properties. Chapter 4, demonstrates the generality of the framework by relating it to various other related results in the literature.

The second part contains various application areas. Chapter 5 serves as an introduction to this part by providing a capsule view of Chapters 2, 3, and 4, in

Continued on page 18

Annotated Bibliographies in Combinatorial Optimization
Edited by Mauro DELL'AMICO, Università di Modena, Francesco MAFFIOLI, Politecnico di Milano, Silvano MARTELLO, Università di Bologna

This book presents annotated bibliographies on important topics within the field of combinatorial optimization. However, the book offers much more than a pure bibliography as each chapter provides a concise, comprehensive and fully up-to-date survey of that area. The 24 chapters, all by leading experts, cover both method and application oriented subjects. In addition there are many sections on available software and an initial chapter reviewing the most influential texts of the last decade.

With more than 2800 annotated references this book provides:

- An indispensable resource for more experienced researchers
- An ideal starting point for researchers who need to become familiar with some particular application or theory
- A practical guide for teachers guiding thesis work

The predecessor to this book, *Combinatorial*

Continued on page 18

Local Search in Combinatorial Optimization
Edited by Emile Aarts and Jan Karel Lenstra, Eindhoven University of Technology

In the past three decades local search has grown from a simple heuristic idea into a mature field of research in combinatorial optimization. Local search is quite often the method of choice for solving NP-hard problems as it provides a robust approach for obtaining high quality solutions to problems of realistic size (which are fairly large) in a reasonable amount of time. This book collects the substantial theoretical and empirical knowledge in this field, with contributions by leading authorities in various aspects of local search.

Chapter 1 reviews the basic issues in local search. Chapters 2 and 3 discuss theoretical results on the

Continued on page 19

FU & HU: Continued from page 17

largely non-technical terms and by presenting some basics of stochastic gradient-based optimization via simulation. Chapter 6 presents many examples in the area of queueing, which has been the primary area of application for perturbation analysis. Chapter 7 describes some results in inventory systems. Finally, Chapter 8 contains more recent examples of applications in other promising areas: maintenance; financial modeling, and in particular, the problem of option pricing; and statistical quality control.

In summary, this monograph brings together many of the interesting developments in perturbation analysis based on conditioning under a more unified framework, and illustrates the diversity of applications to which these techniques can be applied.

Publisher Information

March 1997 by Kluwer Academic Publishers, Boston, ISBN 0-7923-9873-4, 416 pages.

OptQuest : Continued from page 6

OptQuest delivers the optimization and risk analysis necessary for accurate and confident decision-making."

Applications for OptQuest in Crystal Ball Pro include, but are not limited to: determining a mix of investments that will maximize returns while limiting risk given uncertain performance of specific investments; setting product prices that will maximize revenue given uncertain demand at specific prices; managing inventory costs given uncertain demand for product; selecting R&D projects for maximizing ROI given uncertain product demand, average selling price, market penetration and competition.

Further information about OptQuest can be found by clicking on the "OptQuest button" on the Internet URL: http://www.optquest.com/~optinfo/

DELL'AMICO et al: Continued from page 17

Optimization: Annotated Bibliographies (edited by M. O'hEigeartaigh, J. K. Lenstra and A. H. G. Rinooy Kan, 1985), quickly became a standard reference for researchers in the field. This new book adopts the same style and is an essential tool for all researchers who wish to keep abreast of the developments in the subject over recent years. The chapters and contributors are as follows.

Chapters and Contributors

1. Selected Books in and around Combinatorial Optimization (F. Maffioli, S. Martello)
2. Hardness of Approximation (V. Kann, A. Panconesi)
3. Polyhedral Combinatorics (K. Aardal, R. Weismantel)
4. Branch-and-Cut Algorithms (A. Caprara, M. Fischetti)
5. Matroids and Submodular Functions (A. Frank)
6. Perfect, Ideal and Balanced Matrices (M. Conforti, G. Cornuéjols, A. Kapoor, K. Vuskovic)
7. Advances in Linear Optimization (C. Roos, T. Terlaky)
8. Decompoistion and Column Generation (F. Soumis)
9. Stochastic Integer Programming (L. Stougie, M. H. van der Vlerk)
10. Randomized Algorithms (M. Goemans, D. Karger, J. Kleinberg)
11. Local Search (E. Aarts, M. Verhoeven)
12. Sequencing and Scheduling (J. A. Hoogeveen, J. K. Lenstra, S. L. Van de Velde)
13. The Traveling Salesman Problem (M. Jünger, G. Reinelt, G. Rinaldi)
14. Vehicle Routing (G. Laporte)
15. Max-Cut Problem (M. Laurent)
16. Location Problems (M. Labbé, F. Louveaux)
17. Flows and Paths (R. K. Ahuja)
18. Network Design (A. Balakrishnan, T. L. Magnanti, P. Mirchandani)
19. Network Connectivity (S. Raghavan, T. L. Magnanti)
20. Linear Assignment (M. Dell'Amico, S. Martello)
21. Quadratic and Three-Dimensional Assignments (R. E. Burkhard, E. Çela)
22. Cutting and Packing (H. Dyckhoff, G. Scheithauer, J. Terno)
23. Set Covering Problem (S. Ceria, P. Nobili, A. Sassano)
24. Combinatorial Topics in VLSI Design (R. H. Mohring, D. Wagner)
25. Computational Molecular Biology (M. Vingron, H.-P.Lenhof, P. Mutzel)

Publisher Information

1997 by John Wiley & Sons Ltd, ISBN 0-471-96574-X, 500 pages.

Upcoming Meetings

IPCO Houston '98 (Sixth International Conference on Integer Programming and Combinatorial Optimization), Rice University, Houston, Texas, June 22 - 24, 1998. Organizers: Andrew Boyd (Chair), Texas A&M University, Roger Z. Rios, Texas A&M University. [URL=http://www.hpc.uh.edu/~ipco98/]

INFORMS Israel 1998, June 28-July 1, 1998. General Chairs: Jacob Hornik, Tel Aviv University, Recanati Graduate School of Management, Ramat Aviv 69978, Israel and Ben Lev, School of Management, University of Michigan, 4901 Evergreen Road, Dearborn, MI 48128-1491. The theme of the conference is Management Science and Operations Research in an Emerging Region. [URL=http://www.informs.org/Conf/TelAviv98/]

International Conference on Operations Research, Zurich Switzerland, Aug 31 - Sep 3, 1998. Conference Chairman : H.-J. Lüthi [URL=http://www.or98.ethz.ch]

INFORMS Fall 1998 Meeting, Seattle WA, October 25-28, 1998. General Co-Chairs: Albert Maimon, Boeing Computer Services, P.O. Box 24346, MS 7A TH, Seattle WA 98124-0346 and Marisa Altschul, Boeing Information & Support Systems, P.O. Box 3707, MS 7H-73, Seattle WA 98124. The aim of this conference is to present a program covering the wide spectrum of OR/MS technical topics, while lending a certain emphasis to the quantitative tools and frameworks for analysis that will be needed to successfully address the complexities associated with the globalization of public- and private-sector organizations. [URL=http://www.math.org/informs98.shtml]

INFORMS Spring 1999 Meeting, Cincinnati OH, May 2-5,1999. General Chair: David Rogers (david.rogers@uc.edu), University of Cincinnati, Cincinnati OH 45221-0130.

INFORMS Fall 1999 Meeting, Philadelphia PA, Nov 7-10, 1999.

INFORMS/CSTS 7th Biennial Conference, Cancun Mexico, January 2000. General Chair: Manuel Laguna.

INFORMS Spring 2000 Meeting, San Francisco CA.

INFORMS/KORS, Seoul, South Korea, Summer 2000.

Aarts & Lenstra: Continued from page 17

complexity of local search and on its performance for well structured neighborhoods. Chapters 4 through 7 deal with the four principal strategies: simulated annealing, tabu search, genetic algorithms, and neural networks. Chapters 8 through 13 decribe the state of the art in applying local search to the traveling salesman problem, vehicle routing, machine scheduling, VLSI layout, and coding design.

In summary this book provides a truly remarkable, and unique, collection of work, and is invaluable for researchers, students and practitioners in this area.

The individual chapters are as follows:

1. Introduction (E. H. L. Aarts, J. K. Lenstra)
2. Computational complexity (M. Yannakakis)
3. Local improvement on discrete structures (C. Tovey)
4. Simulated annealing (E. H. L. Aarts, J. H. M. Korst, P. J. M. van Laarhoven)
5. Tabu search (A. Hertz, E. Taillard, D. de Werra)
6. Genetic algorithms (H. Muehlenbein)
7. Artificial neural networks (C. Peterson, B. Söderberg)
8. The traveling salesman problem: a case study (D. S. Johnson, L. A. McGeoch)
9. Vehicle routing: modern heuristics (M. Gendreau, G. Laporte, J.-Y. Potvin)
10. Vehicle routing: handling edge exchanges (G. A. P. Kindervater, M. W. P. Savelsbergh)
11. Machine scheduling (E. J. Anderson, C. A. Glass, C. N. Potts)
12. VLSI layout synthesis (E. H. L. Aarts, P. J. M. van Laarhoven, C. L. Liu, P. Pan)

13 Code design (I. S. Honkala, P. R. J. Östergard)

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April 1997 by John Wiley & Sons, Chichester, England. ISBN 0-471-94822-5, 528 pages.

Journal on Computing Report

Bruce Golden, Editor-in-Chief

The INFORMS Journal on Computing completed another successful year with the Fall 1997 issue, which included a cluster of articles on the application of OR to manufacturing. The first issue of 1998 appeared in late March. It contains a cluster of articles on telecommunications. The second issue will contain a cluster on combinatorial optimization and the third issue will explore the interconnections between integer programming and constraint logic programming. The final issue of 1998 is expected to include a feature article on the World Wide Web.

We encourage all CSTS members to subscribe and support the JOC, and to share ideas with the editorial board.

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