Alexander Brodsky – overview of research publications (Summer 2015)

Overview

A. Decision Guidance (DG) Research Areas: Languages, Algorithms, Tools, Applications

My DG research involves (1) designing DG languages and models based on seamless integration of DG functionality into broadly used languages and tools; (2) developing algorithms for general and special classes of DG problems; (3) developing tools toward a DGMS; and (4) DG applications to manufacturing, power, energy and supply chain, as well as DG applications to package recommender systems.

DG Languages, Formal Semantics, Soundness and Completeness of Reductions: The papers [7,9,14,32,33,39,41, 45,60,61,62,69,72,75,76,77,80,83,84,95,96] deal with languages, models and formal semantics for DG. The key observation is that no single language will suit all DG users because they range from domain–specific users (e.g., business analysts, manufacturing operators, power grid engineers) to database application developers, software developers, as well as operations researchers. For optimization functionality, in particular, it is not practical to teach all these types of users mathematical/constraint programming (MP/CP) and MP/CP modeling languages (such as AMPL, GAMS or OPL), which were originally designed for operations researchers.

Rather, I believe that the best course of action is to seamlessly integrate DG functionality (including optimization, statistical learning and predictive analysis) into languages/formalisms/tools already used by different groups of users, so that their learning curve for using DG functionality will be minimal. Doing this in a seamless fashion, yet utilizing the best available algorithms for each particular problem/task, is obviously a non-trivial challenge.

To understand the idea more concretely, consider the Decision Guidance Query Language (DGQL) [14,61,76,80], which was proposed and developed to enable optimization functionality for DB application developers using SQL and relational DBMS. DGQL provides a query-like abstraction for expressing decision optimization problems so that database programmers would be able to use it without prior experience in MP and, more importantly, to reuse SQL queries already built into existing applications.

As a simple example, assume that we have an optimization problem for strategic sourcing: given a demand (for products and their quantities), decide on how many units of each product should be purchased from each supplier so as to minimize the total purchase cost, while satisfying the demand and availability constraints. To do this in DGQL, a DB programmer needs to write (or reuse) a regular SQL program, i.e., a sequence of SQL views and integrity constraints, as follows. She will need to (1) assume that both information on suppliers (catalogs, prices, volume discounts, availability, etc.) as well as the purchase quantities (of each product from each supplier) are encoded in relational tables and (2) write SQL views that will (a) compute metrics of interest (e.g., cost, time, revenue) and (b) pose DB integrity constraints (e.g., for each product, the column for the demand quantity must be bounded by the column for the total purchased quantity). Beyond this purely SQL code, the user will only need to (1) annotate the relevant columns of input tables as *decision variables* (e.g., the column corresponding to the *purchase quantity* for each product and supplier) and indicate the *objective* (e.g., *minimize cost,* already expressed in one of the SQL views).

The processing of a DGQL query is performed by automatically generating a formal optimization problem (MILP expressed in OPL in our implementation) and solving it using an MILP solver.

The key challenge in this work is to develop formal reduction procedures to standard optimization models so as to utilize the most suitable MP/CP solvers. A formal reduction procedure, in turn, requires the definition of (1) formal optimization semantics for DGQL (based on the set of non-deterministic computations) and then (2) a formal proof that the reduction procedure is *sound* and *complete.* Informally, soundness and completeness mean that the set S1 of possible optimization results, according to the DGQL semantics, contains (*soundness*) and is contained in (*completeness*) the set S2 of results obtained through the reduction and a standard optimization solution.

More generally, my work on DG languages includes seamless integration of DG functionality into various languages in use by different types of users, including by software developers using Java [33,77,83,84,95,96], and database application developers using SQL, XQuery (over XML) and JSONiq (over JSON) [9,11,14,32,39,45,61, 69,72,75,76,92], as well as by domain-specific end-user specialized tools [7,41,60,62]. The DG functionality includes optimization, regression analysis and predictive analysis based on stochastic simulation. The challenges here are similar to the challenges exemplified for DGQL.

DG Algorithms: Many of my publications deal with DG algorithms, including [6,9,11,12,13,14,15,17,18,32,34,39, 40,47,53,55,56,57,59,60,61,68,69,71,72,74,75,76,92,98,117]. One class of algorithms deals with implementing formal reductions procedures, as discussed earlier. Mostly, however, I worked on various specialized algorithms for specific classes of optimization and learning problems. Because these problems have a formulation at a higher level of abstraction, it is often possible to leverage a special problem structure and features to develop better algorithms.

As an example, consider the problem of optimizing a Multistage Production Network (MPN), in which multiple products are produced from input materials/parts through a network of *production cells.* Each production cell has multiple machines working in parallel. For the required demand of the output products, a decision must be made on (1) how much should be produced by each MPN production cell, (2) which machines in each cell should be turned on, and (3) their output quantity. The objective is to minimize the total production cost while satisfying the demand and machines' capacity constraints. Assuming that the cost functions of machines are expressed as piece-wise linear functions, the overall problem can be represented as an MILP. However, the MILP problem is highly combinatorial, having a binary *on/off* variable for each machine (i.e., combinatorial search space is exponential in the number of machines).

To solve this problem more efficiently, in [15,47,57] we proposed the Online Decomposition Algorithm (ODA) which leverages the fact that in MPN-like problems, only a part of the problem is *dynamic* (e.g., the demand for the output product), whereas the rest of the problem is *static* (e.g., the connectivity graph of the *production cells* and the cost functions of the machines). ODA is based on preprocessing. The key idea in preprocessing is to optimize (offline) each production cell for each possible value of the discretized production output range. These preprocessed optimizations are used to approximate each production cell with a continuous function that gives, for a value of production output, the minimal possible cost for operating the production cell.

Then, the online algorithm (ODA) first finds an optimal solution for the approximated problem where production cell models (with binary variables) are replaced with their continuous approximations. This "approximate" solution allows to decompose the original problem, which otherwise is not decomposable. Then, based on the preprocessed information, search heuristics are used to find which machines need to be turned on. This effectively reduces the original exponential search space to a very small space of near-optimal machine configurations. This approach led to improvement of algorithm time complexity and optimality of results by an order

of magnitude (of course, at the expense of preprocessing, which can only be done once for MPN-like problems and then reused).

More generally, I worked on a range of specialized algorithms, including (1) stochastic one-stage optimization where deterministic approximations can be extracted from the original DG formulation [39,53]; (2) regression of multi-dimensional piece-wise linear functions for problems that originate from the DG formulations [17,18,34,56, 68,71,92]; (3) efficient classification algorithms over multivariate time series, leveraging special structure of the target utility function [32,54,60,72]; (4) top-k computation algorithms for simulation-based DG problems [17,69,75]; and (5) efficient probabilistic algorithms for diversifying package recommendations while optimizing their quality [59,62,70,74].

DG Tools, Systems and Applications: The work on tools, systems and applications includes [1,2,3,4,5,6,7,8,10,16,19, 41,42,43,46,48,49,50,51,53,55,58,62,63,65,66,67,70,79,81,85,93,98]. Significant focus was on DG applications and systems in the area of manufacturing [2,3,4,5,7,19,42,49,51,67,79,117], as well as in the area of the energy and power grid [10,31,48,63,65,66,93,116]. Also, I have been working on applications of DG to recommender systems with composite alternatives, such as travel packages, system configuration, and (energy and power) infrastructure investment [1,31,43,46,58,62,70,74,81,118].

An example of a DGMS-based application is the DG Manufacturing Process Analysis and Optimization system, which was prototyped as part of the Mason project for NIST (for which I serve as a PI). The tool's GUI is captured in Figure 2 in the Appendix. In the tool, the left pane corresponds to the DGMS Knowledge Base (KB). It contains atomic performance models for components of automobile manufacturing processes, such as uncoiling (aluminum coils), cutting, die-press and internal reinforcement and welding. It also contains composite performance models, such as Tesla Prep Process, Tesla Assembly Process and Tesla Whole Process. Composite models like these are graphically constructed by a process engineer, using the middle pane of the tool, by dragging, dropping and connecting components from the KB. The right pane presents the data elements (values of parameters, control variables, metrics, constraints, etc.) associated with a selected model.

Against a selected performance model (atomic or composite), domain-specific users can ask analysis and optimization questions. For example, a process engineer can instantiate a temporal demand of production and ask the system to optimize the process over a time period. The optimization query will return a fully-instantiated process model, in which all the control variables (settings of machine, load distribution, etc.) will be instantiated to satisfy all of the model constraints (including demand satisfaction) while minimizing the selected metric (e.g., total cost of production). The deterministic optimization is performed by the tool by analysis of the composite performance model, automatically generating an MILP problem formulation in OPL, solving it by an MILP solver (IBM CPLEX). The stochastic optimization variant of the problem is performed by the tool through a specialized algorithm based on deterministic approximations.

B. Earlier Research: Constraint Databases, Constraints for Databases and Secure Information Systems

My earlier research focused on Constraint Databases (CDB) [22,25,26,27,28,29,36,37,38, 102,103,104,105,106,107,109,110], and constraints for databases and secure information systems [20,21,23,24,29,35,44,64,73,78,82,86,88,89,90,91,99, 100,101,108]. My PhD work focused on constraint inference and termination in logic programming [23,111,112,113,131].

Constraints provide a flexible and uniform way to conceptually represent diverse data, including capturing spatio-temporal behavior, complex modeling requirements, and partial and incomplete information. They have been used in a wide variety of application domains. Constraint databases integrate data captured by constraints in databases. My work in constraint databases included CCUBE [25,102], the first object-oriented constraint database system, enabled by results on constraint indexing and filtering [22,104,109,110], algorithms for constraint algebra operators [25,26,36,37,102,103,104,106,109], and algorithms for CDB query optimization [26,37,106,109]. A commercial reimplementation of CCUBE (by AdaptiveTrade Inc.) was also used as the engine behind the commercialized Adaptive Enterprise Optimization (AEO) Server and Studio, and a number of AEO-based solutions deployed in Fortune 500 companies.

The work on constraints for secure information systems [20,21,24,64,73,78,82,86,88,89,90,91,99] focused mainly on the problem of *inference channels,* which occur when information disclosed to users combined with known constraints (logical and probabilistic) may lead to inference of unauthorized information. I also worked on the problem of distributed integrity constraint management, and the related problem on how global DB constraints can be optimally decomposed among DB sites as to minimize communication needed to verify the global constraints [35,100,101].

Publications

Refereed Journal Articles:

1. [J-2015-MB] Mengash*, Hanan; Brodsky, Alexander: *A Group Package Recommender Based on Learning Group Preferences, Multi-Criteria Decision Optimization, and Voting.* European Journal on Decision Processes, Springer, July, 2015. {JIF: NA}

2. [J-2015-MKB] Menasce, Daniel A.; Krishnamoorthy*, Mohan; Brodsky, Alexander: *Autonomic Smart Manufacturing,* Journal of Decision Systems, Taylor and Francis publishers, June 2015, pp. 1-19. {JIF: {2012: 0.618, 2013: 0.463, 2014: 0.683}}

3. [J-2015-SKSBL] Shin, S.J.; Kim, D.B.; Shao*, G.; Brodsky, A.; Lechevalier, D.: *Developing a Decision Support System for Improving Sustainability Performance of Manufacturing Processes,* J. of Intelligent Manufacturing, 1-20. 2015. {JIF: {2013: 1.66, 2014: 2.029}}

4. [J-2014-KSSB] Kim, Duck Bong; Shin, Jeungjun; Shao*, Guodong; Brodsky, Alexander: *A Decision Guidance Framework for Sustainability Performance Analysis of Manufacturing Processes,* Journal of Intelligent Manufacturing, 1-17, 2014. {JIF: {2013: 1.66, 2014: 2.029}}

5. [J-2014-SBSK] Shao*, Guodong; Brodsky, Alexander; Shin, Seungjun; Kim, Duck Bong: *Decision Guidance Methodology for Sustainable Manufacturing Using Process Analytics Formalism,* Journal of Intelligent Manufacturing (JIM), 1-18, 2014. {JIF: {2013: 1.66, 2014: 2.029}}

6. [J-2014-FBS] Farley*, S., Brodsky, A., Sherry, L.: *Flight rescheduling decisions for minimizing passenger trip delays,* J. Intelligent Decision Technologies, v. 8, issue 1, pp. 35-44, IOS Press, 2014. {JIF: {2013:0.64, 2014:0.32}}

7. [J-2014-BSR] Brodsky, A., Shao*, G., Riddick, F.: *Process Analytics Formalism for Decision Guidance in Sustainable Manufacturing.* Journal of Intelligent Manufacturing, 1-20, 2014. {JIF: {2013: 1.66, 2014: 2.029}}

8. [J-2014-ABBG] Al-Nory*, M., Brodsky, A., Bozkaya, B., Graves, S.C.: *Desalination Supply Chain Decision Analysis and Optimization*, J. Desalination, Elsevier, June 2014, 144-157. [JIF: 3.954] {JIF: {2013: 3.953, 2014: 4.529}}

9. [J-2013-NBL] Ngan*, C.K., Brodsky, A., & Lin, J.: *Multi-Event Decision Making over Multivariate Time Series*, International Journal of Information and Decision Sciences, Special Issue on Collaborative Decision Support Systems, Volume 5, Issue 3, August 2013. {JIF: {2014: 0.727}}

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12. [J-2012-LBL] Luo*, Juan; Brodsky, Alexander; Li, Yuan; *An EM-based Ensemble Learning Algorithm on Piecewise Surface Regression Problem,* International Journal of Applied Mathematics and Statistics, 2012, issue 4, pp. 59—74 {JIF: {2013: 1.221, 2014: 0.391}}

13. [J-2012-SCCBB] Shortle, John F; Chen, Chun-Hung; Crain, Ben; Brodsky, Alexander; Brod, Daniel; *Optimal splitting for rare-event simulation,* IIE Transactions, issue 5 (Operations Engineering & Analysis), volume 44, pp. 352—367, Taylor and Francis publishers. {JIF: {2013: 1.397, 2014: 1.553}}

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15. [J-2012-EBG] Egge*, Nathan; Brodsky, Alexander; Griva, Igor: *Distributed Manufacturing Networks: Optimization via Preprocessing in Decision Guidance Query Language*, International Journal of Decision Support System Technology (IJDSST), Vol. 4, Issue 3 (2012) pp. 25—42, IGI Global. {JIF: {2013: 0.125, 2014: 0.188}}

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19. [J-2011-SKBE] Shao*, Guodong; Kibira, Deogratias; Brodsky, Alexander; Egge, Nathan: *Decision Support for Sustainable Manufacturing Using Decision Guidance Query Language*, International Journal of Sustainable Engineering, Vol. 4, Issue 3 (2011) pp. 251—265, Taylor & Francis. {JIF: {2013: 0.721, 2014: 0.594}}

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22. [J-1999-BLLM] Brodsky, Alexander; Lassez, Catherine; Lassez, Jean-Louis; Maher, M.J.: *Separability of Polyhedra for Optimal Filtering of Spatial and Constraint Data*, Journal of Automated Reasoning, Vol. 23, Issue 1 (1999) pp. 83—104, Springer. {JIF: {2013: 1.661, 2014: 1.58}}

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32. [B-2012-NBL] Ngan*, Chun-Kit; Brodsky, Alexander; Lin, Jessica: *An Event-based Service Framework for Learning, Querying, and Monitoring Multivariate Time Series*, Enterprise Information Systems (Revised Selected papers from ICEIS-2011), Springer Lecture Notes in Business Information Processing, Vol. 102 (2012) pp. 208—223, Springer-Verlag.

33. [B-2012-BAN] Brodsky, Alexander; Al-Nory*, Malak; Nash, Hadon: *SC-CoJava: A Service Composition Language to Unify Simulation and Optimization of Supply Chains*, Springer Lecture Notes in Business Information Processing, Modeling for Decision Support in Network-Based Services, Vol. 42 (2012) pp. 118—142.

34. [B-2011-LB] Luo*, Juan; Brodsky, Alexander: *Piecewise Surface Regression Modeling in Intelligent Decision Guidance System*, Springer Smart Innovation, Systems and Technologies series, Intelligent Decision Technologies (revised from IDT-2011) pp. 223—235.

35. [B-2005-BKV] Brodsky, Alexander; Kerschberg, Larry; Varas*, Samuel: *Optimal Constraint Decomposition for Distributed Databases*, Advances in Computer Science – ASIAN 2004 – Higher-Level Decision Making (2005), pp. 3205—3206, Springer LNCS.

36. [B-1997-BSCE] Brodsky, Alexander; Segal*, Victor; Chen*, Jia; Exarkhopoulo*, Pavel: *The CCUBE Constraint Object-Oriented Database System*, in Constraints and Databases,

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40. [C-2015-KBM] Krishnamoorthy*, Mohan; Brodsky, Alexander; Menasce, Daniel: *Optimization Stochastic Temporal Manufacturing Processes with Inventories: An Efficient Heuristic Algorithm Based on Deterministic Approximations,* Proceedings INFORMS Computer Society Conference (ICS 2015), January 2015. {AR: NA}

41. [C-2015-MBK] McDowall*, John; Brodsky, Alexander; Kerschberg, Larry: A Formal Model for Optimization Dynamic Service Composition, Proceedings INFORMS Computer Society Conference (ICS 2015), January 2015. {AR: NA}

42. [C-2014-BKMSR] Brodsky, Alexander; Krishnamoorthy*, Mohan; Menasce, Daniel; Shao, Guodong*; Rachuri, Sudarsan: *Toward Smart Manufacturing Using Decision Analytics.* Proceedings of IEEE Big Data Conference, Special Session on Smart Manufacturing, October 2014. {AR: {2013: 17%, 2014: 18.5%}, AR-special-session: NA}

43. [C-2014-MB] Mengash*, Hanan; Brodsky, Alexander: *DG-GPR: A Decision-Guided Group Package Recommender With Hybrid Condorcet-Instant Runoff Voting.* Proceedings of IFIP WG 8.3 DSS 2.0 Conference, Supporting Decision Making With New Technologies, June 2014. {AR: NA}

44. [C-2014-VBA] Vemasani*, Preetham; Brodsky, Alexander; Ammann, Paul: *Generating Test Data to Distinguish Conjunctive Queries with Equalities.* Proceedings of IEEE Conference on Software Testing/ Verification and Validation Workshops (ICSTW), March 2014. {AR: NA}

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53. [C-2012-FBS] Farley*, Susan; Brodsky, Alexander; Sherry, Lance: *Flight Rescheduling Decisions for Robust Passenger Itineraries*, Proceedings of the IFIP WG8.3 DSS Conference: Fusing Decision Support Systems Into the Fabric of the Context (2012) IOS Press Inc. {AR:NA}

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55. [C-2012-HB] Haberlin*, Richard; Brodsky, Alexander: *Battle Management System (BMS): An Optimization for Military Decision Makers*, Proceedings of the 28th IEEE International Conference on Data Engineering Workshops (ICDEW 2012), Decision Guidance and Support

Systems, pp. 78—81, IEEE. {AR: {2013: 44%, 2012: NA}}

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