Column Generation (CG)

- A set of columns, $a \in \mathcal{A} \subset \mathbb{R}^m$, $c_a \in \mathbb{R}$, $b \in \mathbb{R}^m$
- **Large-scale** primal and dual problems:

(P)
$$\max \sum_{a \in \mathcal{A}} c_a x_a$$
$$\sum_{a \in \mathcal{A}} a\, x_a \leq b$$
$$x_a \geq 0 \qquad a \in \mathcal{A}$$

(D)
$$\min \pi b$$
$$\pi a \geq c_a \qquad a \in \mathcal{A}$$
$$\pi \geq 0$$

- $\mathcal{A}$ too large, impossible (or impractical) to solve at once

Column Generation

Guy Desaulniers,Jacques Desrosiers,Marius M. Solomon

Column Generation:

Column Generation Guy Desaulniers,Jacques Desrosiers,Marius M. Solomon,2006-03-20 Column Generation is an insightful overview of the state of the art in integer programming column generation and its many applications The volume begins with A Primer in Column Generation which outlines the theory and ideas necessary to solve large scale practical problems illustrated with a variety of examples Other chapters follow this introduction on Shortest Path Problems with Resource Constraints Vehicle Routing Problem with Time Window Branch and Price Heuristics Cutting Stock Problems each dealing with methodological aspects of the field Three chapters deal with transportation applications Large scale Models in the Airline Industry Robust Inventory Ship Routing by Column Generation and Ship Scheduling with Recurring Visits and Visit Separation Requirements Production is the focus of another three chapters Combining Column Generation and Lagrangian Relaxation Dantzig Wolfe Decomposition for Job Shop Scheduling and Applying Column Generation to Machine Scheduling The final chapter by Fran ois Vanderbeck Implementing Mixed Integer Column Generation reviews how to set up the Dantzig Wolfe reformulation adapt standard MIP techniques to the column generation context branching preprocessing primal heuristics and deal with specific column generation issues initialization stabilization column management strategies

Column Generation Guy Desaulniers,Jacques Desrosiers,Marius M. Solomon,2008-11-01 Column Generation is an insightful overview of the state of the art in integer programming column generation and its many applications The volume begins with A Primer in Column Generation which outlines the theory and ideas necessary to solve large scale practical problems illustrated with a variety of examples Other chapters follow this introduction on Shortest Path Problems with Resource Constraints Vehicle Routing Problem with Time Window Branch and Price Heuristics Cutting Stock Problems each dealing with methodological aspects of the field Three chapters deal with transportation applications Large scale Models in the Airline Industry Robust Inventory Ship Routing by Column Generation and Ship Scheduling with Recurring Visits and Visit Separation Requirements Production is the focus of another three chapters Combining Column Generation and Lagrangian Relaxation Dantzig Wolfe Decomposition for Job Shop Scheduling and Applying Column Generation to Machine Scheduling The final chapter by Fran ois Vanderbeck Implementing Mixed Integer Column Generation reviews how to set up the Dantzig Wolfe reformulation adapt standard MIP techniques to the column generation context branching preprocessing primal heuristics and deal with specific column generation issues initialization stabilization column management strategies

A Column-Generation and Branch-and-Cut Approach to the Bandwidth-Packing Problem , *Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems* Jean-Charles Régin,Michel Rueher,2004-04-07 This book constitutes the refereed proceedings of the First International Conference on Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems CPAIOR 2004 held in Nice France in April 2004 The 23 revised full papers and 7 revised short papers presented together with an invited talk were carefully

reviewed and selected from 56 submissions Methodological and foundational issues from AI OR and algorithmics are presented as well as applications to the solution of combinatorial optimization problems in various fields via constraint programming **New Methods Using Column Generation** Frank B. Parng,2009 *Column Generation for the Cutting Stock Problem* Marvin Caspar,2021-08-31 Seminar paper from the year 2020 in the subject Business economics Operations Research grade 1 3 University of Kaiserslautern language English abstract The Cutting Stock Problem CSP appears when a material has to be cut into smaller pieces and occurs in many branches of industry On the one hand the CSP belongs to the earliest studied problems through methods of Operational Research and on the other to the most intensively studied problems in combinatorial optimization In the one dimensional Cutting Stock Problem 1DCSP there are typically identical pieces of a single standard length called rolls that need to be cut into smaller pieces lengthwise Examples where the cutting process is performed in one single dimension can be found in the steel industry and the paper industry The two dimensional CSP 2DCSP is classified into cutting of regular and irregular shapes and is often found in clothing and shoe leather industries A real world application of a three dimensional CSP 3DCSP lies in the production of mattresses where rubber blocks are cut into different types of orthogonal rectangular prisms Methods of finding an optimal solution exist for the 1DCSP Often in large problem instances the required time for finding an optimal solution proliferates and heuristics may turn out to be the more sensible option in this case Nowadays there are countless different ways to find acceptable solutions in a fast manner of time among others the column generation approach which is the central component of the present work This work is organized as follows In Chapter 2 a brief overview of different formulations for the CSP is given Furthermore some known extensions of the classic CSP are presented e g raw material that consists of various sizes at the same time CSP has many relatives the closest is the Bin Packing Problem BPP where items are packed into bins as efficiently as possible The third chapter shows the column generation technique for solving the CSP and provides the connection between a solution for the relaxed problem and an integer solution In Chapter 4 different test instances of the CSP are compared using a column generation implementation solved in three different MIP solvers The conclusion is provided in Chapter 5

Branch-and-price: Column Generation for Solving Huge Integer Programs Cynthia Barnhart,1996 **Searching for Optimal Integer Solutions to Set Partitioning Problems Using Column Generation** David Bredstrom,Kurt Jornsten,M. Rönnqvist,2007 We describe a new approach to produce integer feasible columns to a set partitioning problem directly in solving the linear programming LP relaxation using column generation Traditionally column generation is aimed to solve the LP relaxation as quick as possible without any concern of the integer properties of the columns formed In our approach we aim to generate the columns forming the optimal integer solution while simultaneously solving the LP relaxation By this we can remove column generation in the branch and bound search The basis is a subgradient technique applied to a Lagrangian dual formulation of the set partitioning problem extended with an additional surrogate constraint This extra

constraint is not relaxed and is used to better control the subgradient evaluations The column generation is then directed via the multipliers to construct columns that form feasible integer solutions Computational experiments show that we can generate the optimal integer columns in a large set of well known test problems as compared to both standard and stabilized column generation and simultaneously keep the number of columns smaller than standard column generation **A Column Generation Algorithm to Schedule Identical Parallel Machines** B. Vizvári,R. Demir,1994 **A Column Generation Algorithm for Two-dimensional Cutting Stock Problems** Somkanae Nunvititpongse,1994 **Column Generation Techniques for Pickup and Delivery Problems** Marc Sol,1994 Staff Scheduling and Rostering ,2004 Column Generation Methods for Quadratic Mixed Binary Programming Enrico Bettiol,2019 Non linear programming problems There are several solution methods in literature for these problems which are however not always efficient in general in particular for large scale problems Decomposition strategies such as Column Generation have been developed in order to substitute the original problem with a sequence of more tractable ones One of the most known of these techniques is Dantzig Wolfe Decomposition it has been developed for linear problems and it consists in solving a sequence of subproblems called respectively master and pricing programs which leads to the optimum This method can be extended to convex non linear problems and a classic example of this which can be seen also as a generalization of the Frank Wolfe algorithm is Simplicial Decomposition SD In this thesis we discuss decomposition algorithms for solving quadratic optimization problems In particular we start with quadratic convex problems both continuous and mixed binary Then we tackle the more general class of binary quadratically constrained quadratic problems In the first part we concentrate on SD based methods for continuous convex quadratic programming We introduce new features in the algorithms for both the master and the pricing problems of the decomposition and provide results for a wide set of instances showing that our algorithm is really efficient if compared to the state of the art solver Cplex This first work is accepted for publication in the journal Computational Optimization and Applications We then extend the SD based algorithm to mixed binary convex quadratic problems we embed the continuous algorithm in a branch and bound scheme that makes us able to exploit some properties of our framework In this context again we obtain results which show that in some sets of instances this algorithm is still more efficient than Cplex even with a very simple branch and bound algorithm This work is in preparation for submission to a journal In the second part of the thesis we deal with a more general class of problems that is quadratically constrained quadratic problems where the constraints can be quadratic and both the objective function and the constraints can be non convex For this class of problems we extend the formulation to the matrix space of the products of variables we study an algorithm based on Dantzig Wolfe Decomposition that exploits a relaxation on the Boolean Quadric Polytope BQP which is strictly contained in the Completely Positive cone and hence in the cone of positive semi definite PSD matrices This is a constructive algorithm to solve the BQP relaxation of a binary problem an dwe obtain promising results for the root node bound for some quadratic problems We

compare our results with those obtained by the Semi definite relaxation of the ad hocsolver BiqCrunch We also show that for linearly constrained quadratic problems our relaxation can provide the integer optimum under certain assumptions We further study block decomposed matrices and provide results on the so called BQP completion problem these results are connected to those of PSD and CPP matrices We show that given a BQP matrix with some unspecified elements it can be completed to a full BQP matrix under some assumptions on the positions of the specified elements This result is related to optimization problems We propose a BQP relaxation based on the block structure of the problem We prove that it provides a lower bound for the previously introduced relaxation and that in some cases the two formulations are equivalent We also conjecture that the equivalence result holds if and only if its so called specification graph is chordal We provide computational results which show the improvement in the performance of the block based relaxation with respect to the unstructured relaxation and which support our conjecture This work is in preparation for submission to a journal

Column Generation in Integer Programming with Applications in Multicriteria Optimization Jørgen Tind,Matthias Ehrgott,University of Auckland. Department of Engineering Science,2007 **Integer Programming Column Generation Strategies for the Cutting Stock Problem and Its Variants** Nancy Perrot,2005 Cette th se traite du probl me de d coupe uni dimentionnel et de ses variantes Une revue compr hensive des diff rentes formulations et approches de r solution associ es y est compl t e par des r sultats sur les relations th oriques d quivalence ou de dominance qui existent entre ces formulations et des comparaisons sur des questions pratiques telles que la sym trie dans la repr sentation des solutions et les sch mas de branchement qu elles induisent La th se se poursuit par la comparaison num rique de strat gies d impl mentation pour une approche de branch and price avec des r sultats en mati re d initialisation de stabilisation de strat gie de branchements et sur l obtention de solutions primales Ces strat gies sont ensuite utilis es pour r soudre des probl mes industriels La th se montre aussi comment le sous probl me de sac dos avec co t fixe peut tre r solu exactement et efficacement *Principles and Practice of Constraint Programming* ,1999 **Operations Research** Wayne L. Winston,1987 *Application of Column Generation Techniques to Shopment Planning* Mokhtar Sadek Bazaraa,Georgia Institute of Technology. School of Industrial and Systems Engineering. Project no. E-24-Z38,Georgia Institute of Technology. School of Mathematics. Project G-37-624,2003 **An All-integer Column Generation Methodology for Set Partitioning Problems** Elina Rönnberg,Torbjörn Larsson,2008 **Column Generation for Bi-Objective Integer Linear Programs** Boadu Mensah Sarpong,2013 Multi objective optimization deals with finding solutions to problems for which several objectives or criteria are considered Unlike in single objective optimization the optimal value of a multi objective problem is a set of points called the non dominated set Lowerand upper bounds of a multi objective problem can also be described using sets For most practical problems the variables considered in multi objective optimization represent non fractionable items and thus we talk of multi objective integer programs In order to obtain good lower and upper bounds that can be used in the

design of exact methods some problems are usually formulated with an exponential number of decision variables and these problems are solved by column generation The work of this thesis seeks to contribute to the study of the use of column generation in multi objective integer linear programming We do this by studying a bi objective vehicle routing problem which may be seen as a generalization of several other vehicle routing problems We propose mathematical formulations for this problem and also find ways to quickly compute lower bounds by column generation Since the subproblems solved when computing lower bounds have similar structures we propose intelligent ways of treating some of these subproblems simultaneously rather than independently

Decoding **Column Generation**: Revealing the Captivating Potential of Verbal Expression

In a time characterized by interconnectedness and an insatiable thirst for knowledge, the captivating potential of verbal expression has emerged as a formidable force. Its power to evoke sentiments, stimulate introspection, and incite profound transformations is genuinely awe-inspiring. Within the pages of "**Column Generation**," a mesmerizing literary creation penned with a celebrated wordsmith, readers embark on an enlightening odyssey, unraveling the intricate significance of language and its enduring effect on our lives. In this appraisal, we shall explore the book is central themes, evaluate its distinctive writing style, and gauge its pervasive influence on the hearts and minds of its readership.

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