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Different Cycle, Different Assignment: Diversity in Assignment Problems with Multiple Cycles

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Abstract

We present approaches to handle diverse assignments in multi-cycle assignment problems. The goal is to assign a task to different agents in each cycle, such that all possible combinations are made over time. Our method combines the original profit value, that is to be optimized by the assignment problem with an additional assignment preference. By merging both, we steer the optimization towards diverse assignments without large trade-offs in the original profits.

Introduction

In multi-cycle assignment problems with rotational diversity, a set of tasks has to be repeatedly assigned to a set of agents, such that over multiple cycles a high diversity of assignments from tasks to agents is achieved. At the same time, the assignments' profit has to be maximized in each cycle. Due to changing availability of tasks and agents, planning ahead is infeasible: each cycle is an independent assignment problem.

The main motivator for this paper, is Test Case Selection and Assignment (TCSA) for cyber-physical systems, such as industrial robots. TCSA usually occurs in Continuous Integration (CI) processes, where new releases of the robot control software are regularly integrated and released. Typically, CI involves assigning test cases to test agents several times a day. Comprehensive test suites exist, but available time and hardware for their execution are limited. It is, therefore, necessary to select a subset of most critical test cases and distribute them to the available agents, such that the most relevant test cases are executed. This relevance can be different at each cycle, due to discovered failures or changes in the system-under-test. The assignment of tests to agents is constrained by the available time and the compatibility between test and agent. In terms of assignment, the test case priority resembles the profit, the test's runtime corresponds to the task weight, and an agent's available time is its capacity.

The availability of agents is influenced by maintenance, technical faults, or short-term usage in other projects, and the set of test cases changes due to the ongoing development. Therefore, TCSA cannot be solved by a static assignment

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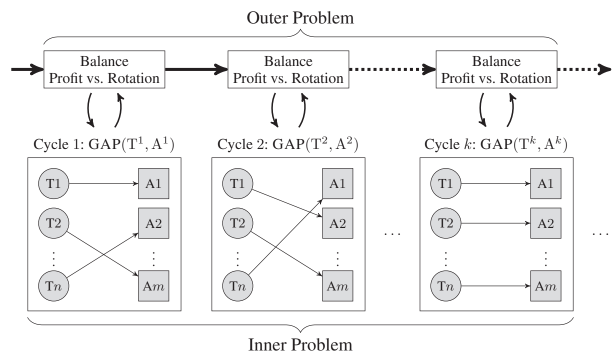

Figure 1: Multi-Cycle Assignment Problem: At each cycle an independent GAP has to be solved.

without the need for frequent updates. Enforcing diverse assignments is thus crucial to avoid repetitive assignments at each cycle, and to have a broad coverage of tasks and agents to increase confidence.

Assignment rotation is found in job rotation scheduling, where it is usually approached by a single static schedule. There, the goal is to find schedules and work assignments for humans to avoid fatigue and boredom (Bhadury and Radovilsky 2006), or to evenly distribute shifts to personnel (Carnahan, Redfern, and Norman 2000; Bard and Purnomo 2005; Ayough, Zandieh, and Farsijani 2012).

We approach the multi-cycle assignment problem as a two-part problem (see Figure 1): Profit maximization and rotation are combined into a single objective value, and then solved as a General Assignment Problem (Pentico 2007). Rotational diversity is maintained with a single execution of the costly assignment model. Our optimization model combines profits and affinities, a metric to describe the state of rotation, into a single optimization criterion. Solving this model incrementally, i.e., at each cycle, allows to control rotational diversity. Experiments show the applicability on a multi-cycle multiple knapsack problem and TCSA.

We chose to formulate rotational diversity as a general assignment problem, as our contribution is steered towards the general rotation mechanism. Nevertheless, the closest problem variant is the group of knapsack problems. One or multiple agents (knapsacks) have to be filled with tasks to maximize the value of the selected tasks. A multi-cycle knapsack variant is presented in (Faaland 1981), where not all, but only the unassigned items are kept for the next cycle.

Adjust Profits to Address Rotation

The main idea to maintain rotational diversity is to manipulate the values contributing to the objective of the inner assignment problem. This adjustment steers the optimization process towards an assignment which is balancing profit maximization and making diverse assignments. The adjustment is made according to a strategy and the state of the available resources, that is tasks and agents available in the current cycle, and their affinities.

The affinity, that is, the preferences between tasks and agents to be assigned to each other, is determined by counting the number of cycles since this assignment was made last, starting from 1 at the first cycle or the last assignment. If a task and agent are incompatible, the affinity is always 0. At cycle k, the affinity increases for tasks which have not been assigned to available agents in the previous cycle $k-1$.

Strategies

To combine profits and affinities into a single value for the inner assignment problem, we present five strategies.

Strategy 1: Objective Switch (OS/γ)

The Objective Switch strategy maintains rotational diversity by monitoring the affinity pressure, and, if it reaches a threshold, switching from profit to affinity values.

The threshold is a fixed, user-defined configuration parameter, and selected according to the desired trade-off between maximized profits and high rotational diversity.

Strategy 2: Product Combination (PC)

The Product Combination strategy is the product of a task's priority and affinity. This strategy does not require additional configuration, but it does not actively react on the overall state of rotational diversity, too. Still, high affinity values can strongly influence the profits and put an emphasis on tasks with missing rotation.

Strategy 3: Weighted Partial Profits (WPP)

The Weighted Partial Profits (WPP) strategy is based on a weighted sum method to calculate the task values. A task- and cycle-specific weight parameter λ_j^k balances the influence of each objective on the final task value. λ_j^k is self-adaptive and depends on the ratio between the ideal and the actual affinities, similar to the affinity pressure.

Strategy 4: Fixed Objective: Profit (FOP)

Each task value equals the static profit value.

Strategy 5: Fixed Objective: Affinity (FOA)

Each task value equals the affinity value. FOP and FOA are the two most extreme approaches, because each of them completely ignores the other goal, albeit profits or affinities. FOP and FOA serve as baselines to evaluate the trade-offs made by the other strategies.

Experimental Evaluation

We consider two sets of problems: a) a multi-cycle variant (MCMKP) of the multiple knapsack problem (MKP) and b) test case selection and assignment (TCSA). MKP is chosen as a known problem to evaluate the trade-offs between profit maximization and rotational diversity.

TCSA, as our motivating application, is a real-world case study to evaluate the practical interest of our approach. A test suite has to be distributed among a number of test agents. The test case selection has to select those tests with the highest priorities, given by an upstream process at each cycle, and to ensure a rotation of tests between agents, such that a test is frequently executed on all compatible agents.

For TCSA, our preliminary results show, that all strategies, except the rotation-unaware baseline FOP, are able to maintain rotational diversity at a similar level. This includes both the full rotations of tasks, and the average number of rotations per task. The profits earned from the assignments are close to the FOP baseline in the smallest scenario, but decrease with a higher number of tests, except for PC, which is able to balance profit maximization and rotation better than the other strategies. For PC, the profit trade-off is always less than 10 %, in average even less than 4 % in comparison to the purely profit-oriented FOP.

Conclusion

Considering rotation and achieving rotational diversity is possible with a marginal profit trade-off. Of the presented strategies, both product combination and objective switch strategy are able to achieve rotational diversity, depending on the problem setting and the characteristics of agents and tasks. The former always combines profits and affinities by their product, whereas the latter focuses either on profits or affinities based on an affinity pressure threshold.

The combination of profits and affinities into a single task value showed to be an efficient approach for balancing profits and rotation. Especially in settings where it is not possible or desired to run an extended multi-objective optimization, our approach to split the problem is a feasible alternative, that still allows making use of problem-specific, single-objective solvers for the inner problem.

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