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Attribute-Based Bloom Filter Tabu Search for the Flexible Flowshop Problem

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Abstract

Abstract. The Flexible Flowshop Scheduling Problem (FFSP) is a generalization of the classic Flowshop Scheduling Problem (FSSP) [3, 9, 10], where instead of single machines, machine groups occupy a manufacturing stage. This problem is often extended with additional constraints, like release times, sequence-dependent setup times, machine eligibility, transfer times, and objective functions alongside makespan, such as lateness, tardiness, the number of tardy jobs [4, 6–8]. These extensions significantly enlarge the search space and the complexity of simulation – decoding of each solution – resulting in increased computational cost per iteration. Tabu search algorithms provide a partial solution to this, by skipping previously explored solutions [5]. However, classical Tabu Search relies on large data structures to create exact solution memory, which consumes large amounts of memory when the search requires large lists. Another limitation of the classical Tabu Search approach is the exact matching as a singular tabu condition, ignoring the underlying patterns present in most permutation-based encodings.

This paper proposes an *Attribute-Based Bloom Filter Tabu Search* framework that extends classical tabu memory by representing both exact-match tabu and similarity-based tabu conditions using Bloom filters [1, 2]. In the proposed approach, tabu decisions are no longer limited to strict solution equality, but are instead expressed as logical compositions of probabilistic membership tests over multiple filters.

The tabu condition is formulated as a flexible logical predicate of the form

$$\mathrm{Tabu}(s) = \mathrm{Exact}(s) \ \vee \ (\mathrm{Attr}_1(s) \wedge \mathrm{Attr}_2(s) \wedge \dots),$$

where Exact(s) denotes membership in an exact-match Bloom filter and $\text{Attr}_i(s)$ denotes membership in an attribute-specific Bloom filter. No restriction is imposed on how exact and attribute-based filters are combined, allowing fine-grained control over intensification and diversification behavior.

For the Flexible Flowshop domain, the considered attributes capture structural properties of schedules such as relative job order patterns, machine assignment structures, setup-time interaction patterns, and due-date-related characteristics. These attributes abstract away representational differences while preserving information that is strongly correlated with search stagnation and cycling.

Computational results on Flexible Flowshop benchmark instances show that the proposed attribute-based tabu mechanism reduces redundant exploration and improves solution quality compared to classical exact-match tabu search, with increasing benefits as problem complexity grows.

The main contribution of this work is a reconceptualization of tabu memory as a composable set of probabilistic filters over solution attributes rather than a monolithic exact-history mechanism. While evaluated on the Flexible Flowshop Scheduling Problem, the approach is generic and applicable to a wide class of combinatorial optimization problems where meaningful structural attributes can be identified.

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